https://ntrs.nasa.gov/search.jsp?R=20200001940 2020-05-24T04:15:05+00:00Z

# Contribution of Land Surface States to Sub-seasonal Predictability

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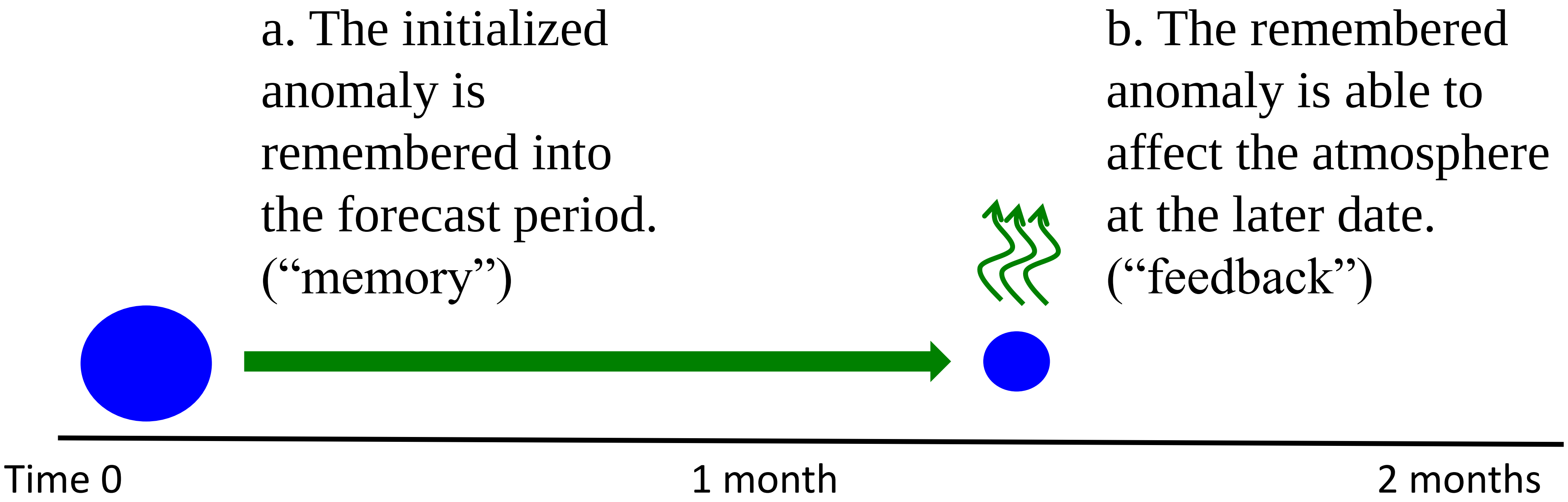
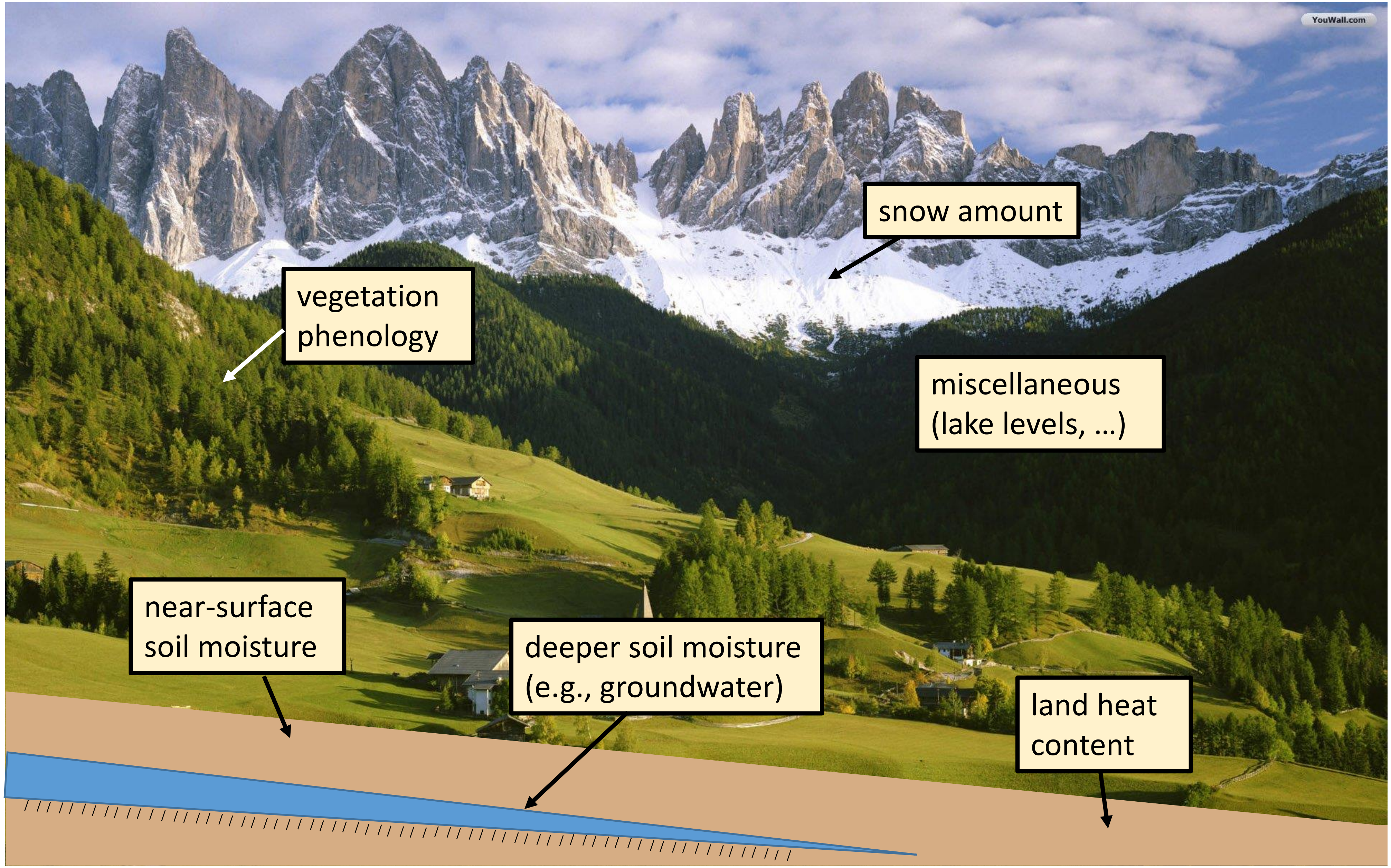
# Theoretical Underpinning

An initialized land state can affect a forecast if the following two things happen:

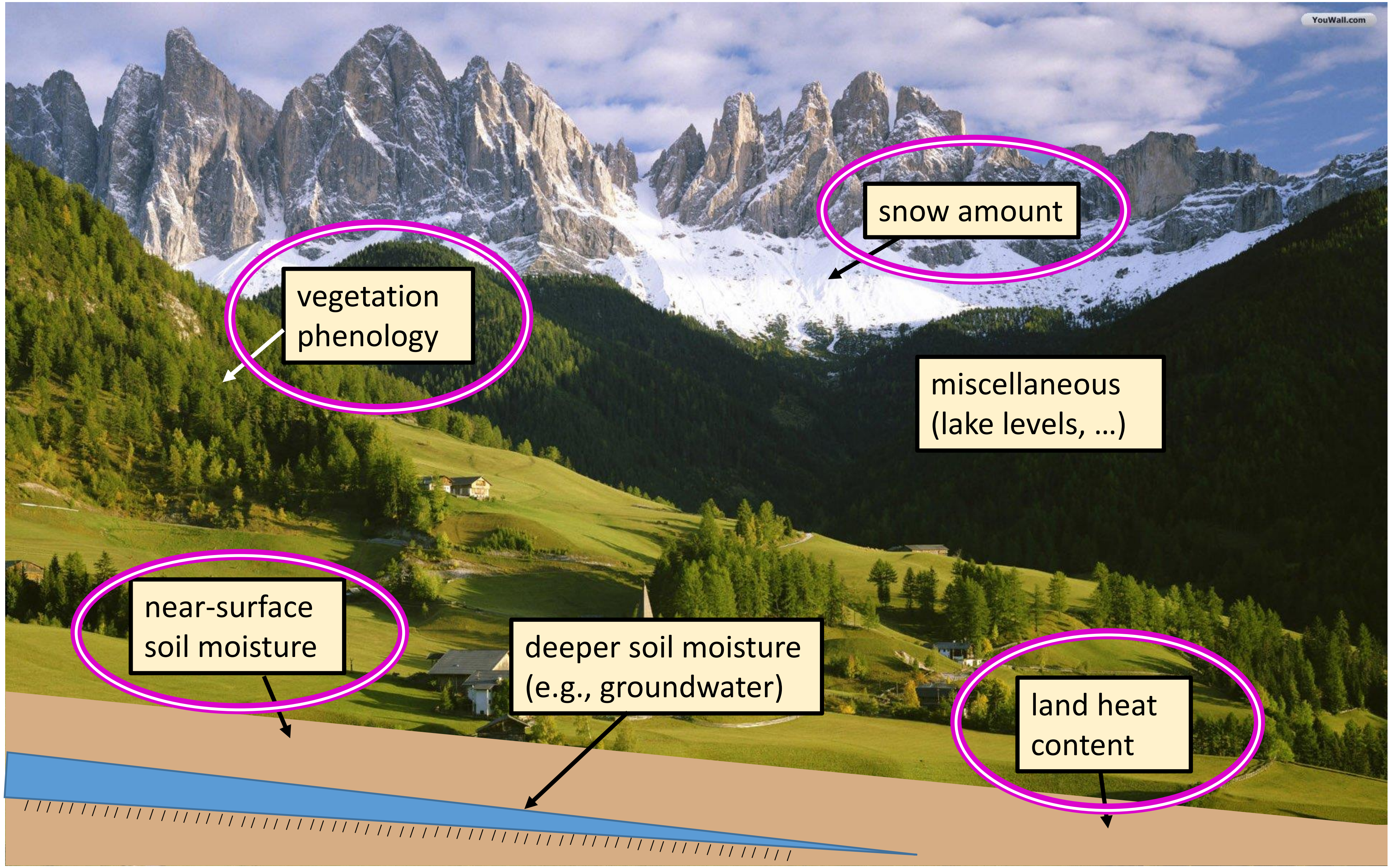


# Which land states might have usable memory?




(Image stolen from internet!)

# For which land states has an impact of initialization on forecasts been demonstrated?

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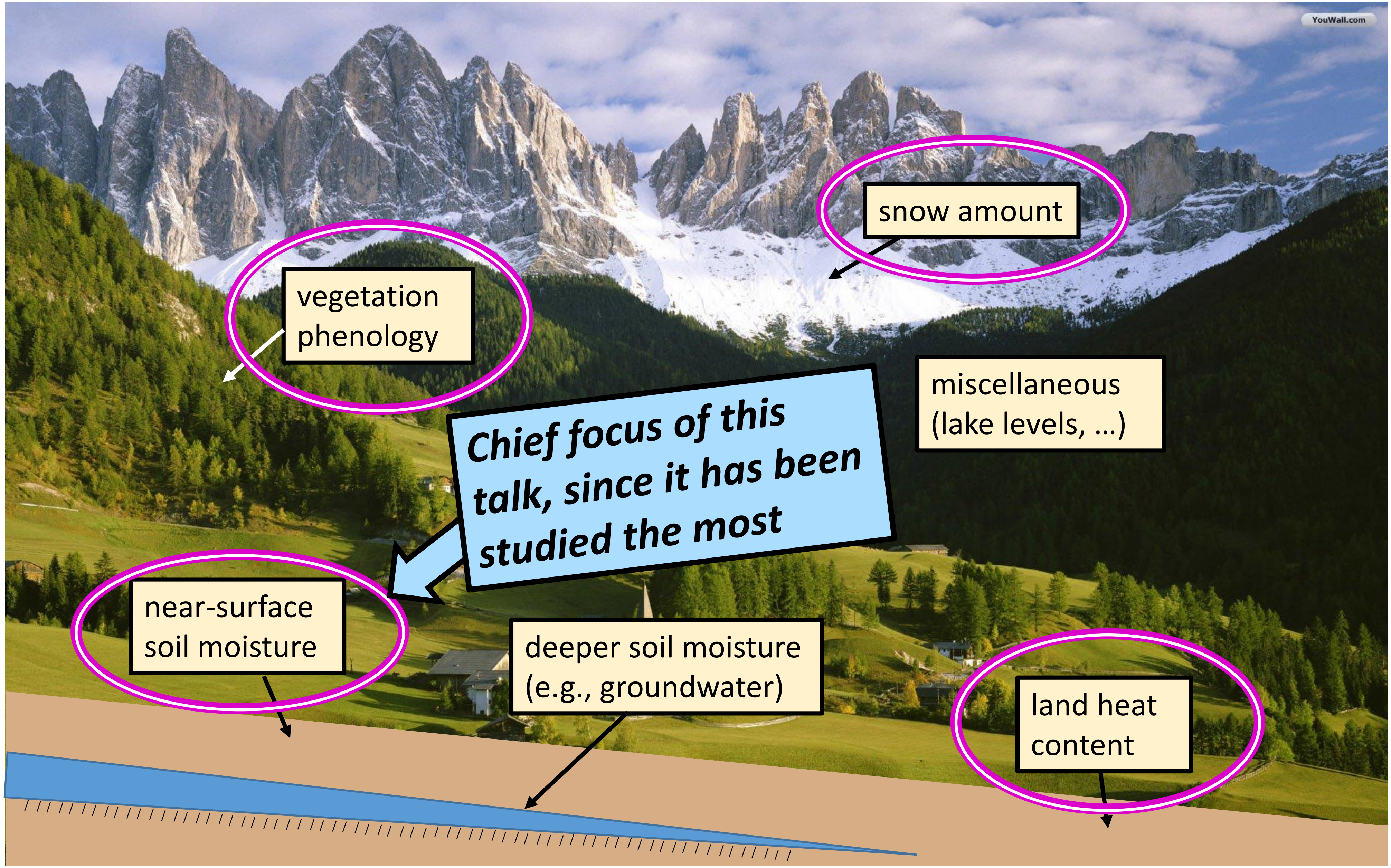
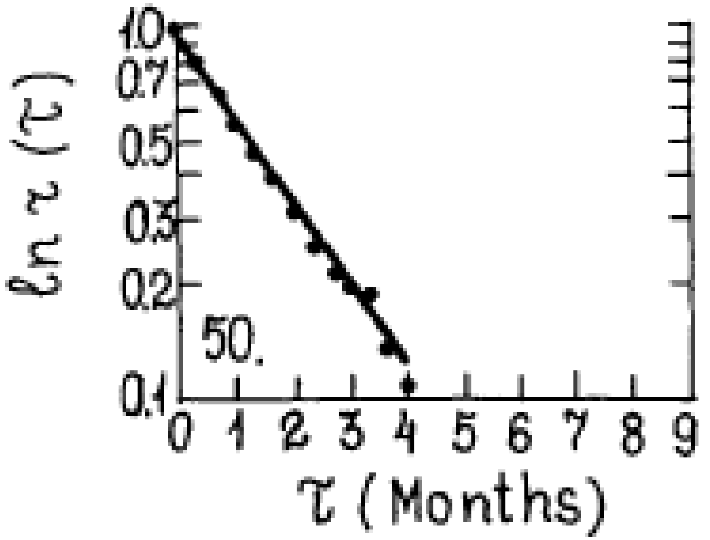


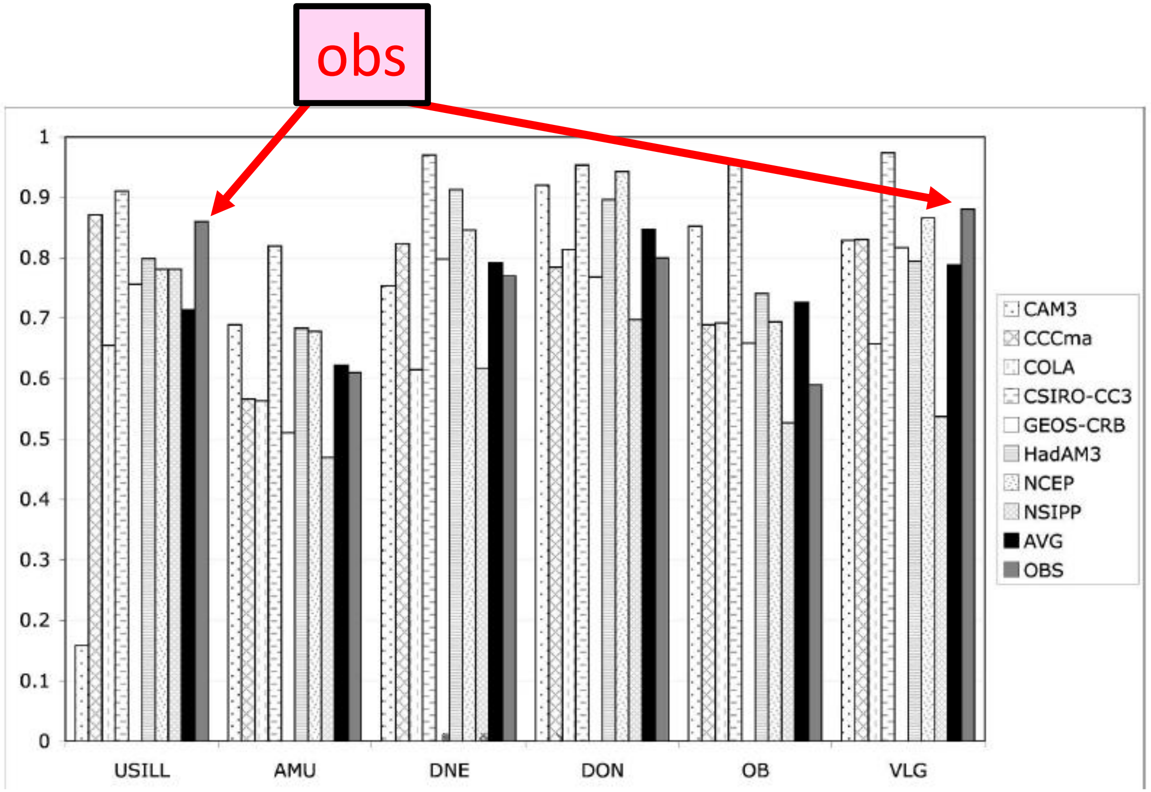

(Image stolen from internet!)

Soil moisture memory is well-established; estimated time-scales range from weeks to months.



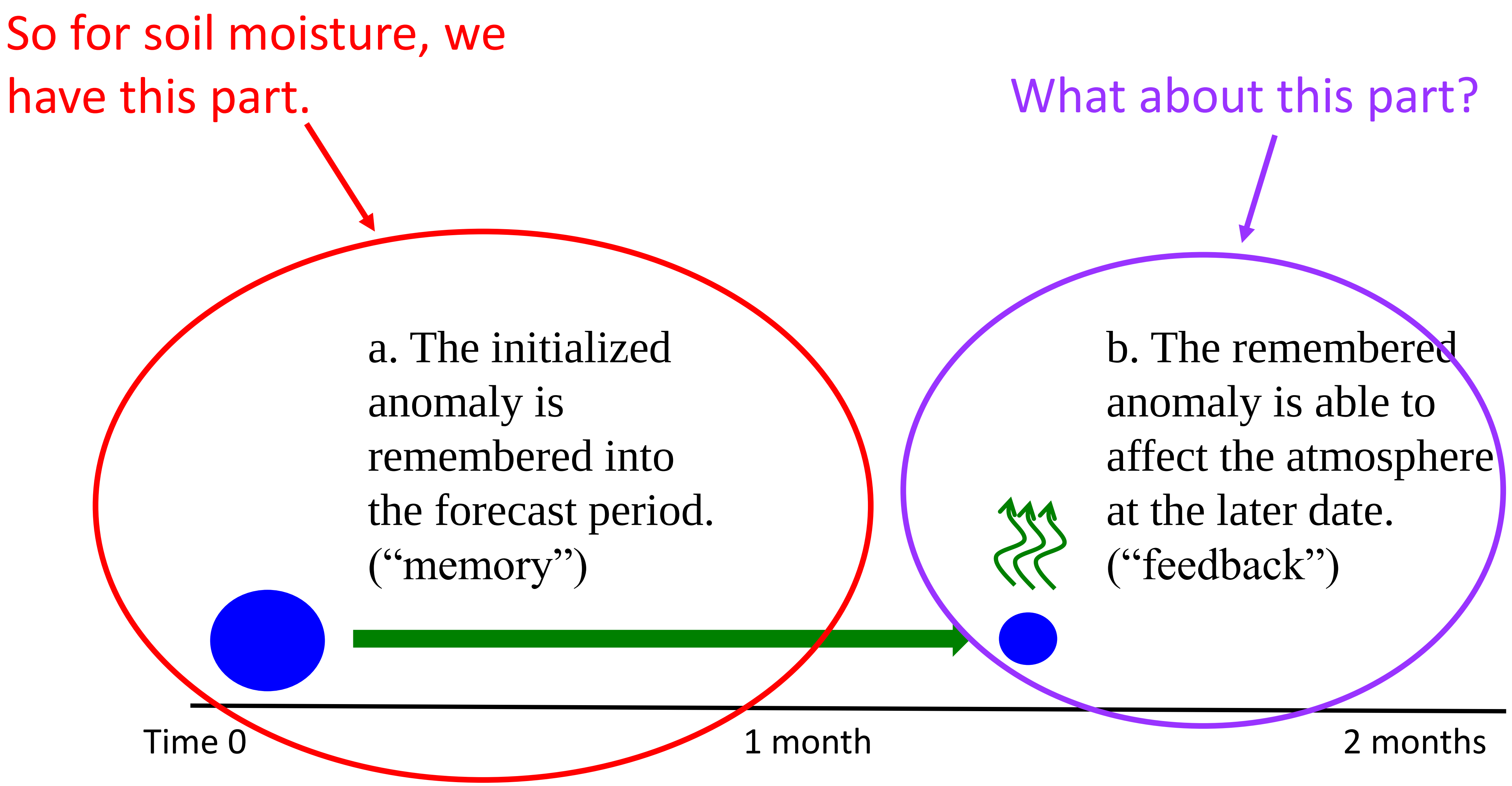

"empirical autocorrelation function"

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




~1-month-lagged autocorrelations of soil moisture (boreal summer)

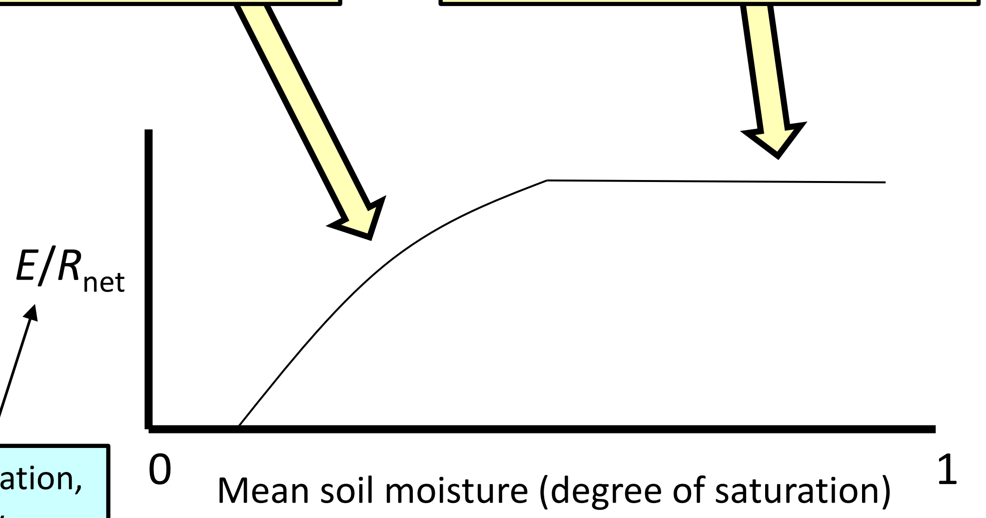
Seneviratne et al., J. Hydromet., 7, 1090-1112, 2006


So for soil moisture, we have this part.
What about this part?
a. The initialized anomaly is remembered into the forecast period. (“memory”)
b. The remembered anomaly is able to affect the atmosphere at the later date. (“feedback”)
Time 0
1 month
2 months

# Conventional wisdom regarding control of soil moisture on evapotranspiration (and thereby on climate, forecasts)

For drier conditions, evapotranspiration varies with soil moisture

For wetter conditions, evapotranspiration largely independent of soil moisture




Evapotranspiration, normalized by incoming energy

Relevant observations are rare, but where they exist, they support this idea….

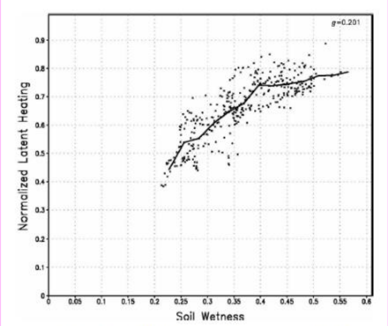


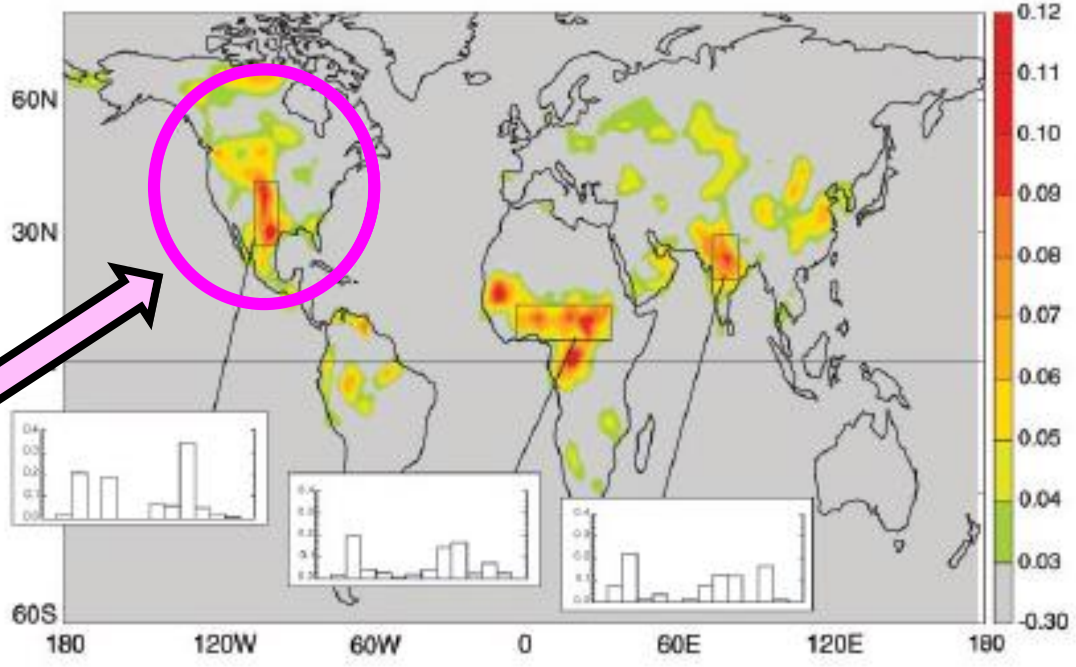

FIG. 8. As in Fig. 3 but for observed average over ARM Extended Facility sites.

Dirmeyer *et al.*, *J. Hydromet.*, 7, 1177–1198, 2006

Because of this relationship, the connection between soil moisture and the atmosphere (through the former's effect on evapotranspiration) is strongest in the <u>transition zones</u> between dry and wet areas.

Shown here: results from the multi-model GLACE experiment. Indicated is where soil moisture variability helps guide short-term boreal summer rainfall variability.

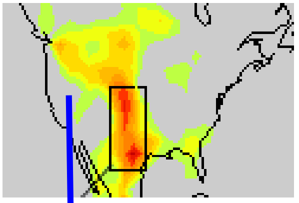
Why are the transition areas important? See next slide, which focuses on North America…

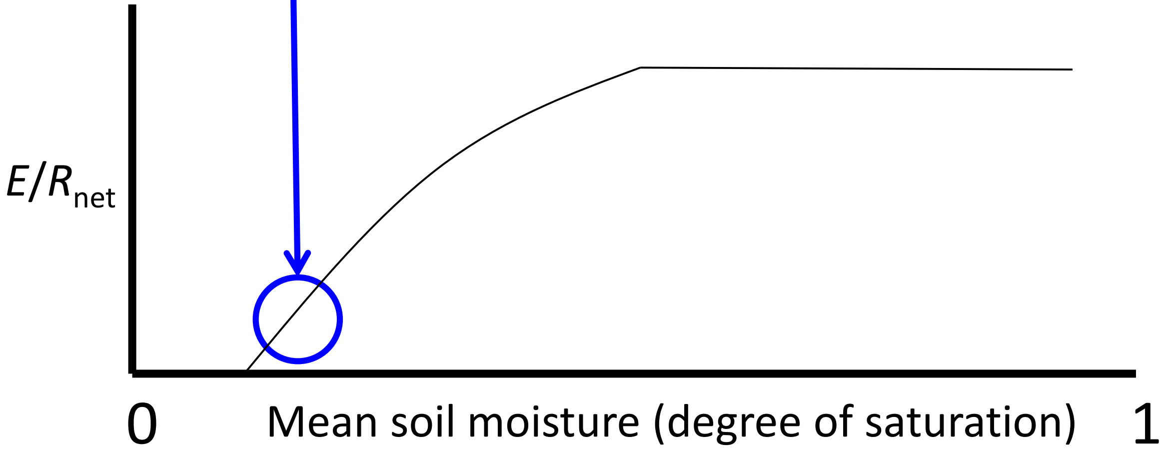



Koster *et al.*, *Science*, 305, 1138–1140, 2004

# Explanation for why soil moisture feedback on the atmosphere is strongest in transition zones

When it is really dry, *E* is too small (and varies too little) to have an effect.





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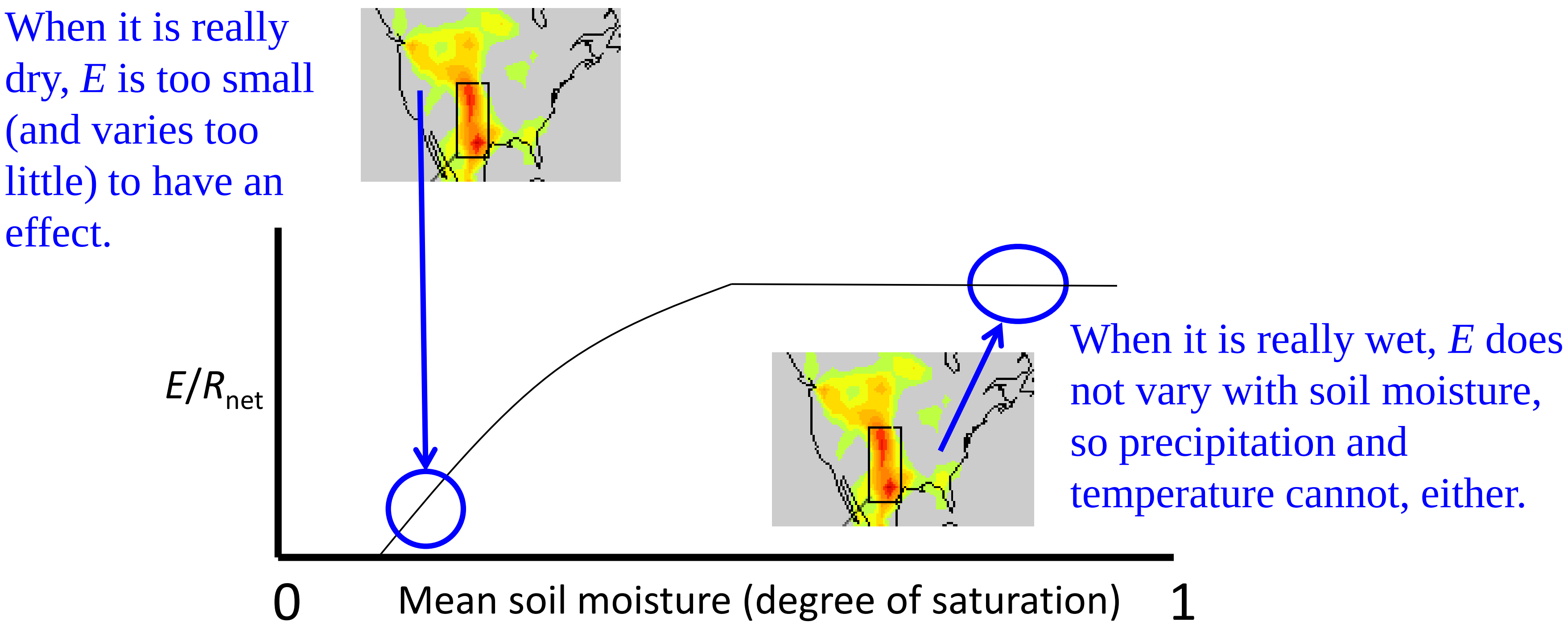

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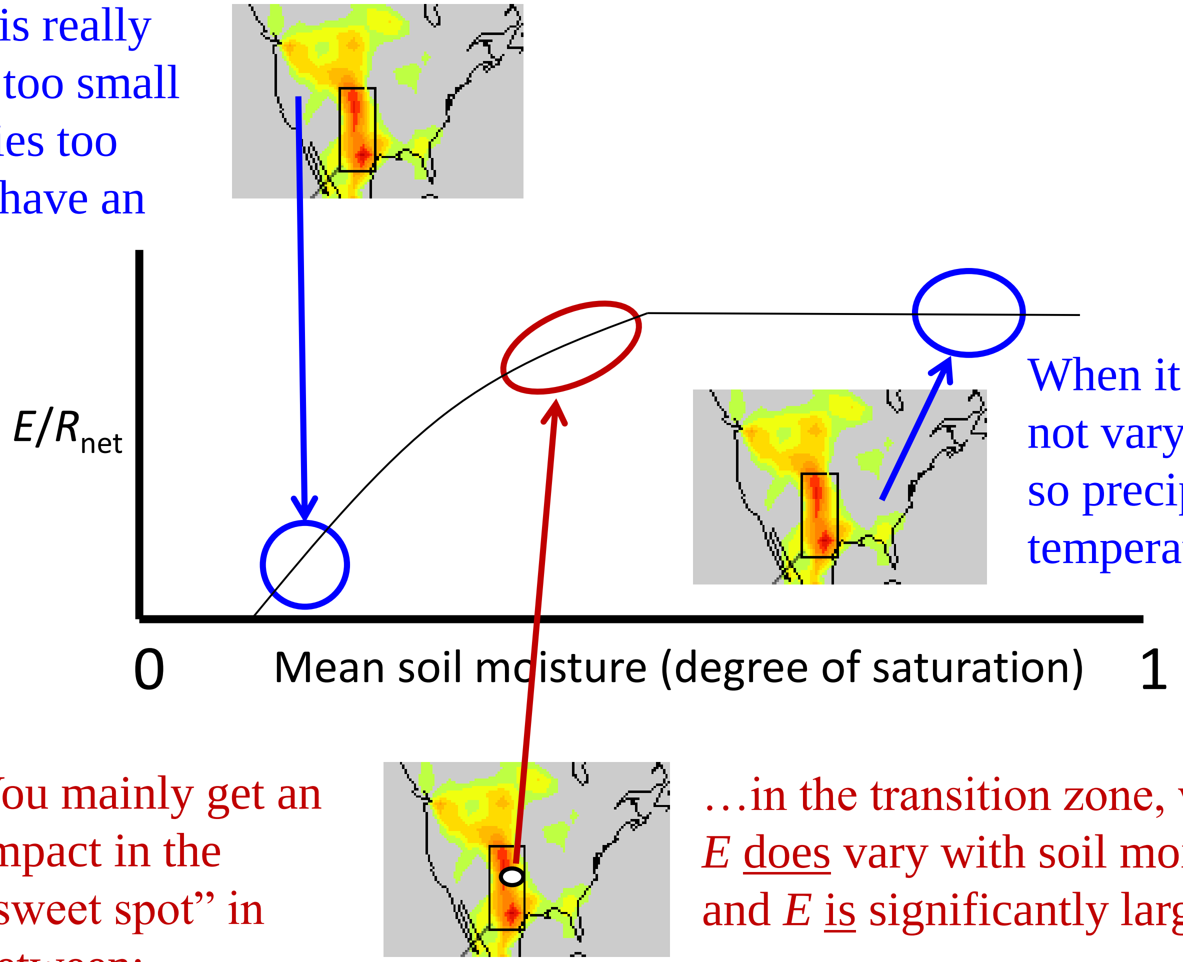
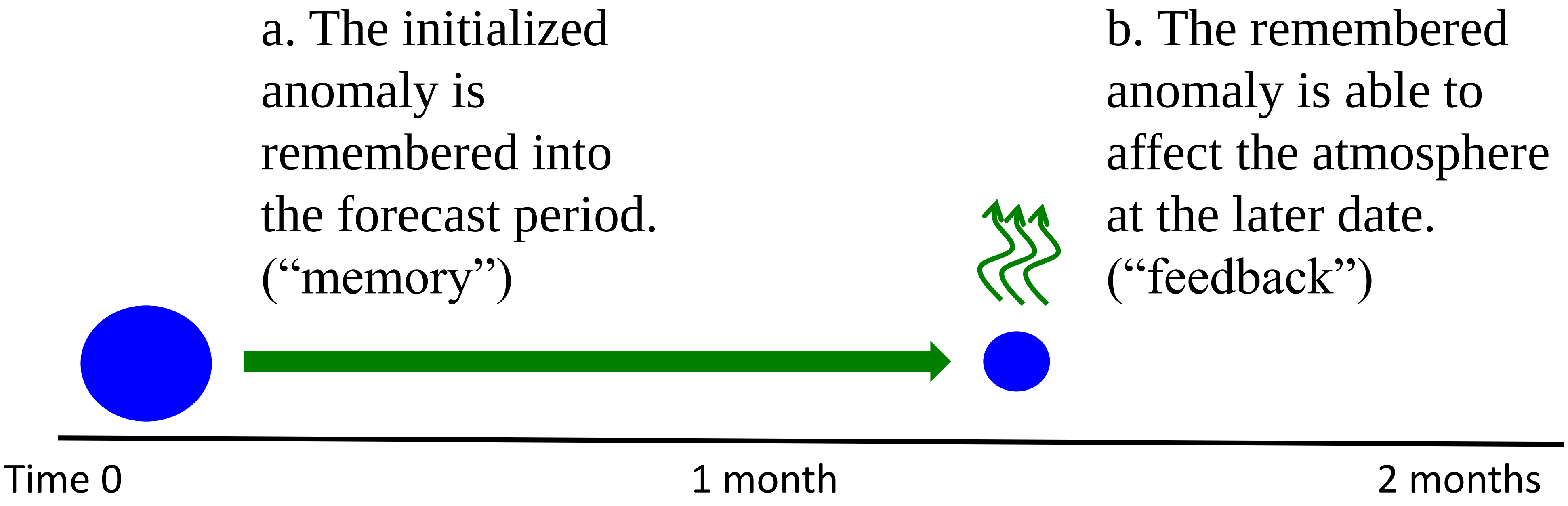



When it is really wet, *E* does not vary with soil moisture, so precipitation and temperature cannot, either.

You mainly get an impact in the "sweet spot" in between:

…in the transition zone, where *E* does vary with soil moisture and *E* is significantly large.

## So, for soil moisture, we seem to have both of these parts, at least in some areas.

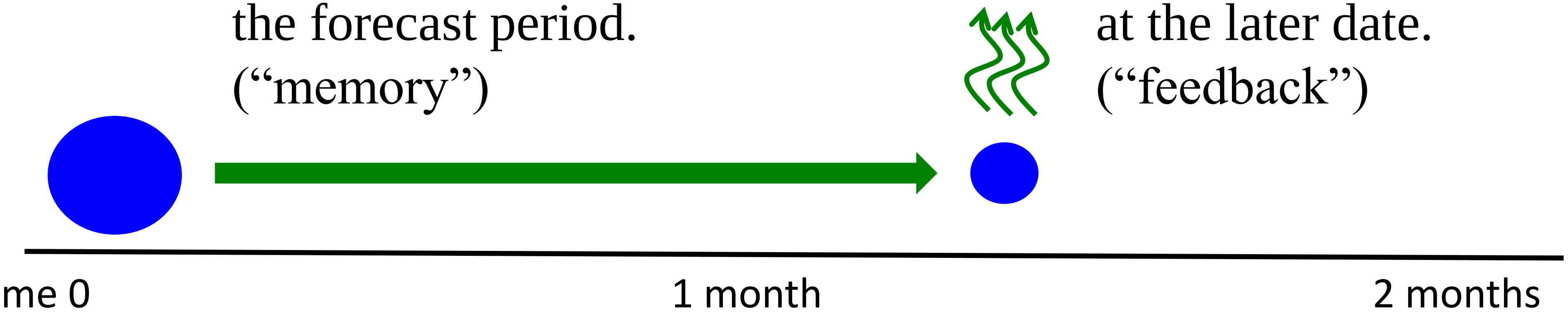


So, for soil moisture, we seem to have both of these parts, at least in some areas.

**Does accurate soil moisture initialization actually lead to increased forecast skill?**

…mbered into
the forecast period.
(“memory”)

…bered
anomaly is able to affect the atmosphere at the later date.
(“feedback”)



# Estimations of forecast skill associated with soil moisture initialization

**GLACE-2: The second phase of the Global Land-Atmosphere Coupling Experiment**
(an international, multi-institution project)

Koster *et al.*, *J. Hydromet.*, 12, 804-822, 2011

Gist of experiment:

1. Perform two sets of forecast simulations:
   (i) with accurate soil moisture initial conditions (ICs)
   (ii) without accurate soil moisture ICs

2. Compare forecasted *P*, *T* to obs.

3. Compute soil moisture contribution to forecast skill:

Skill from simulations w/ accurate land ICs − Skill from simulations w/o accurate land ICs = Skill due to land ICs

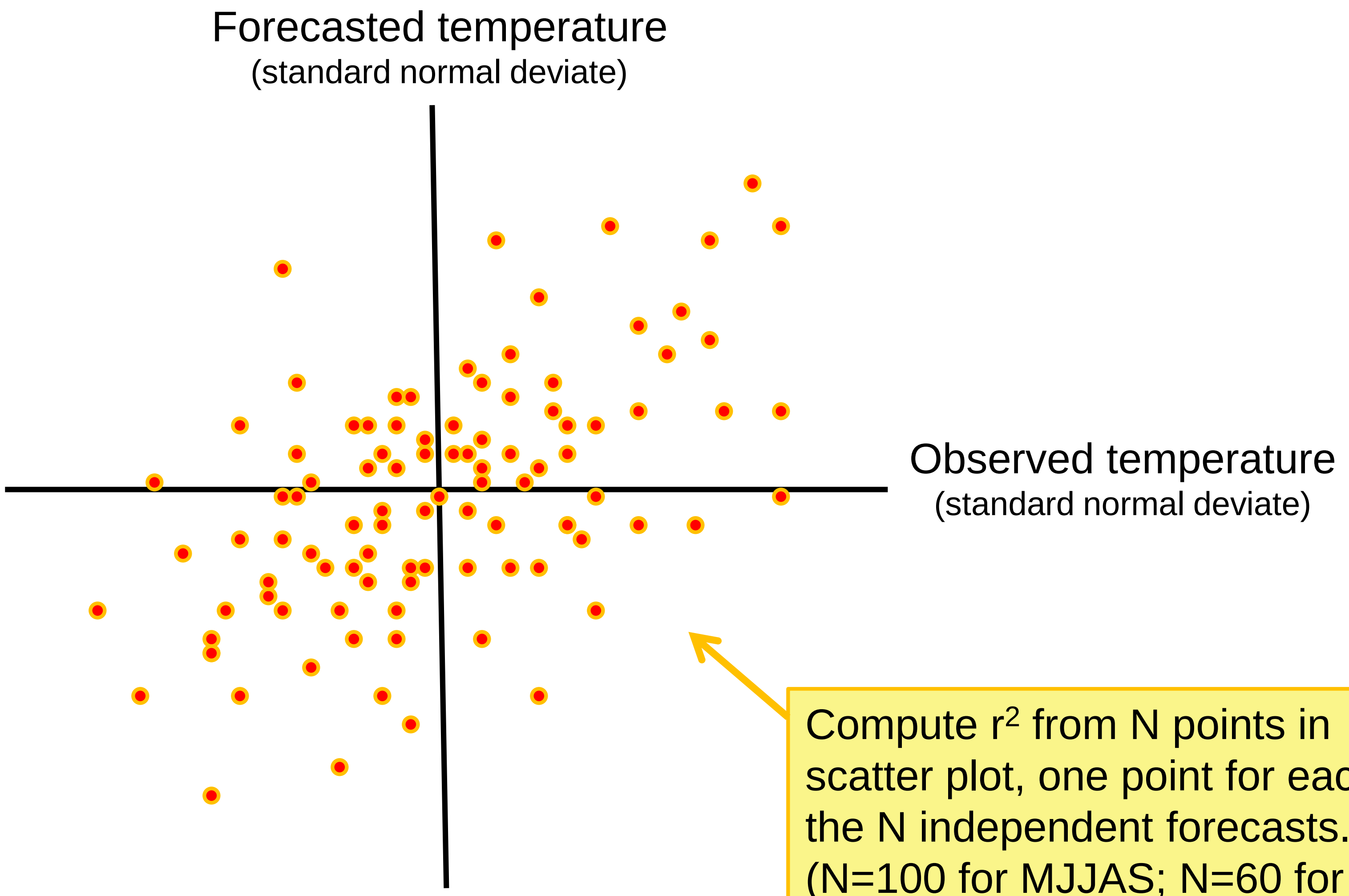
# Baseline: 100 Forecast Start Dates

| | 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.

## Skill measure: $r^2$ when regressed against observations




Compute $r^2$ from N points in scatter plot, one point for each of the N independent forecasts. (N=100 for MJJAS; N=60 for JJA)

- We focus here on multi-model “consensus” view of skill.
- We focus here on JJA, the period when N.H. evaporation is strongest.
- We focus here on the U.S., for which:
  - -- models show strong inherent predictability associated with land initialization (GLACE-1!)
  - -- observations are reliable over the forecast period

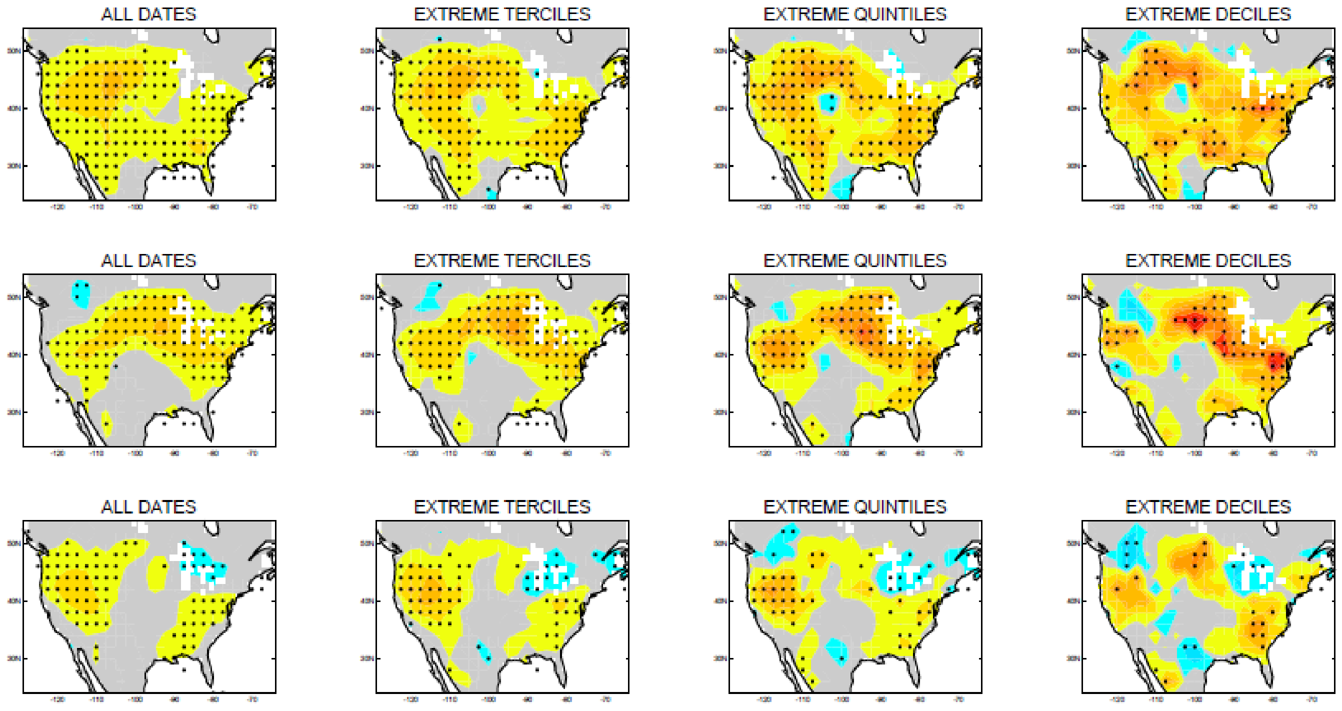
# **Temperature forecasts**: Increase in skill due to land initialization (JJA)
## (conditioned on strength of local initial soil moisture anomaly)

**all points** | **Extreme terciles** | **Extreme quintiles** | **Extreme deciles**

**16-30 days**

**31-45 days**

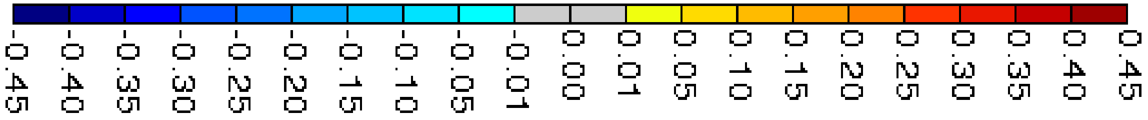
**46-60 days**




Dates for conditioning vary w/location

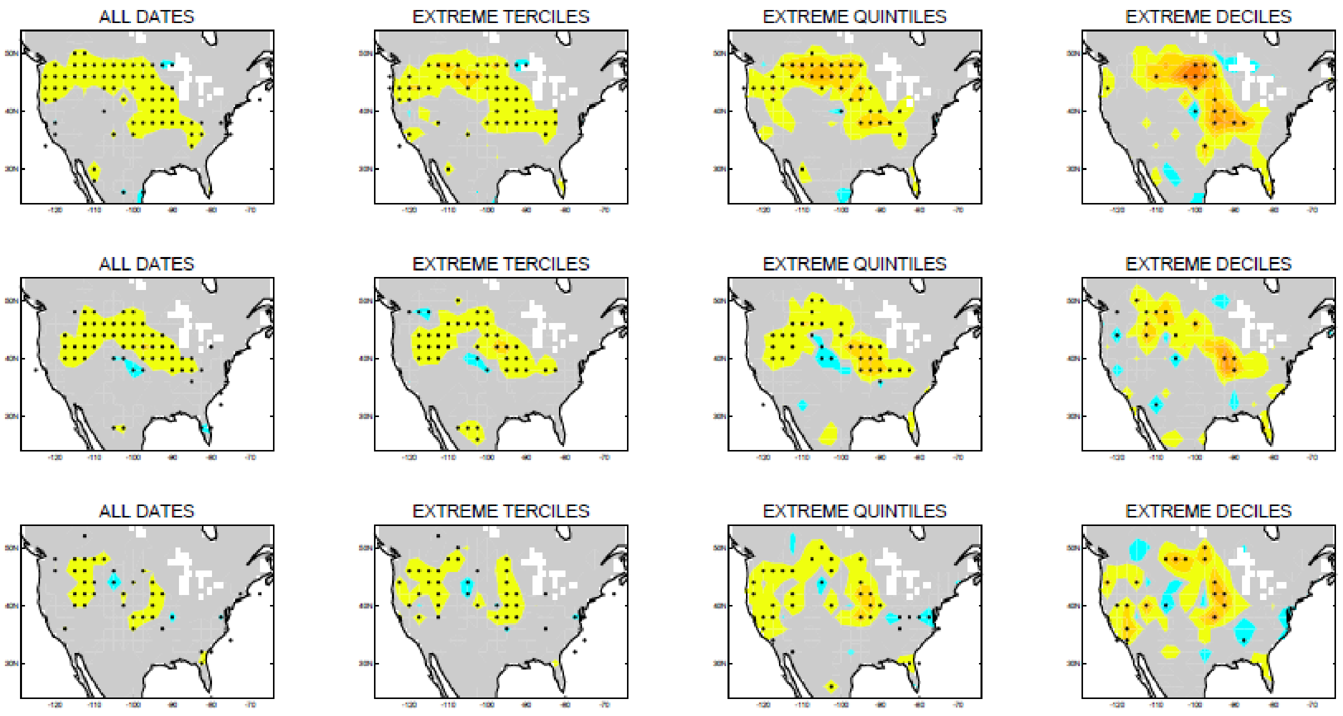
"Weaker" models are averaged in with "stronger" ones.

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



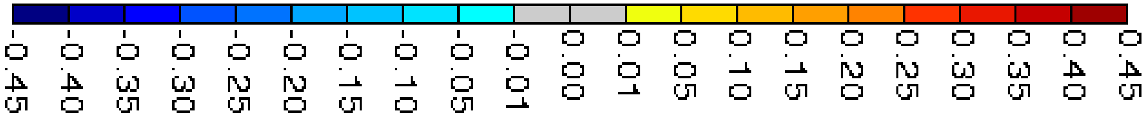
# Precipitation forecasts: Increase in skill due to land initialization (JJA)
## (conditioned on strength of local initial soil moisture anomaly)

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




Dates for conditioning vary w/location

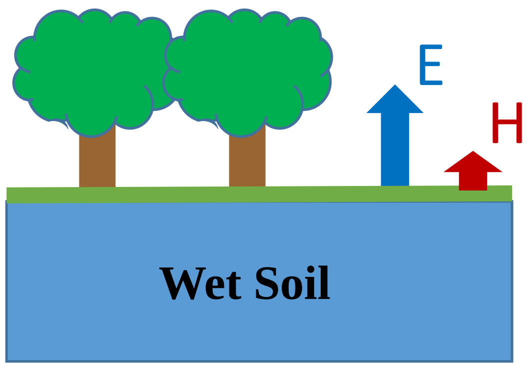
Forecast skill: $r^2$ with land ICs vs $r^2$ w/o land ICs




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

# Local vs. Remote Soil Moisture Impacts on the Atmosphere

1. Consider local effects.




For example:

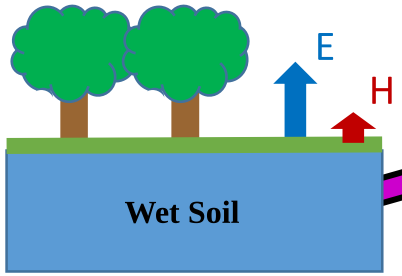
Wet soil ⇨ higher evap., lower sensible heat flux

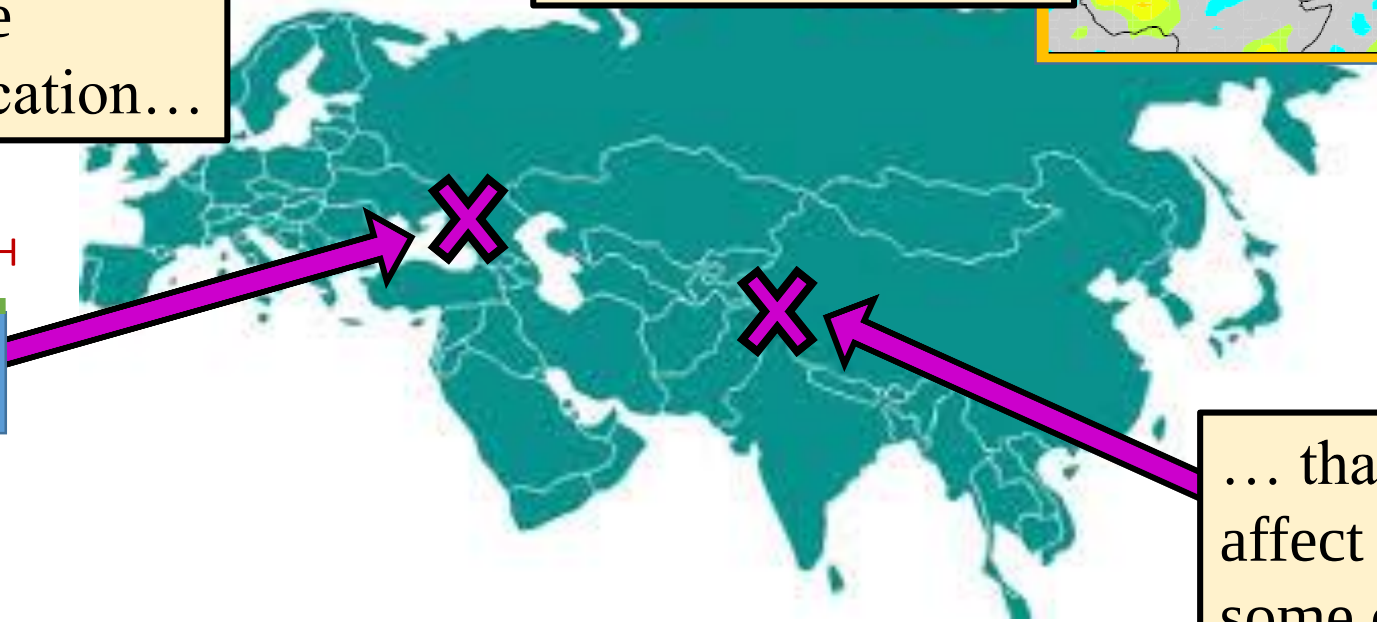
*This can affect* *<u>local</u>* *air temperature:*
⇨ more evaporative cooling
⇨ lower air temperature

*It can also affect* local *precipitation:*
⇨ boundary layer modification
⇨ conditions more conducive
(or perhaps less conducive)
to onset of moist convection

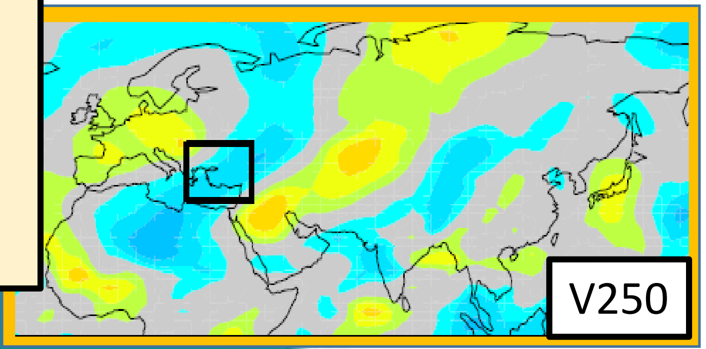
# 2. Now consider potential remote effects:

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.

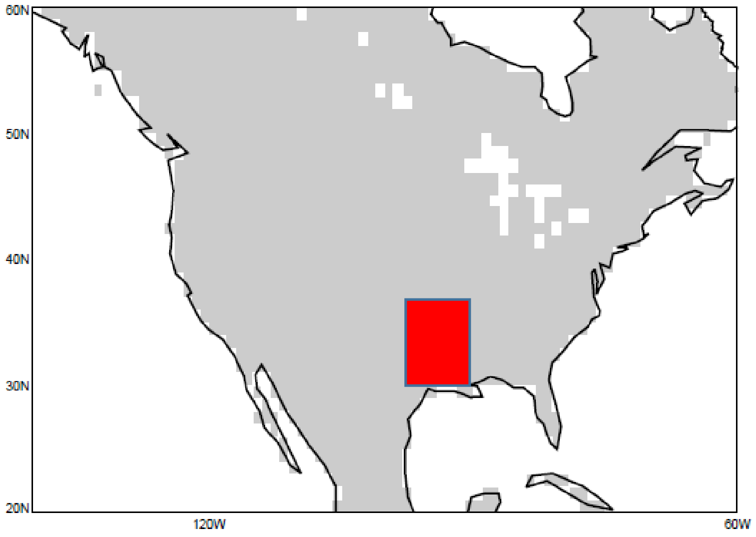
## Experimental Design

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

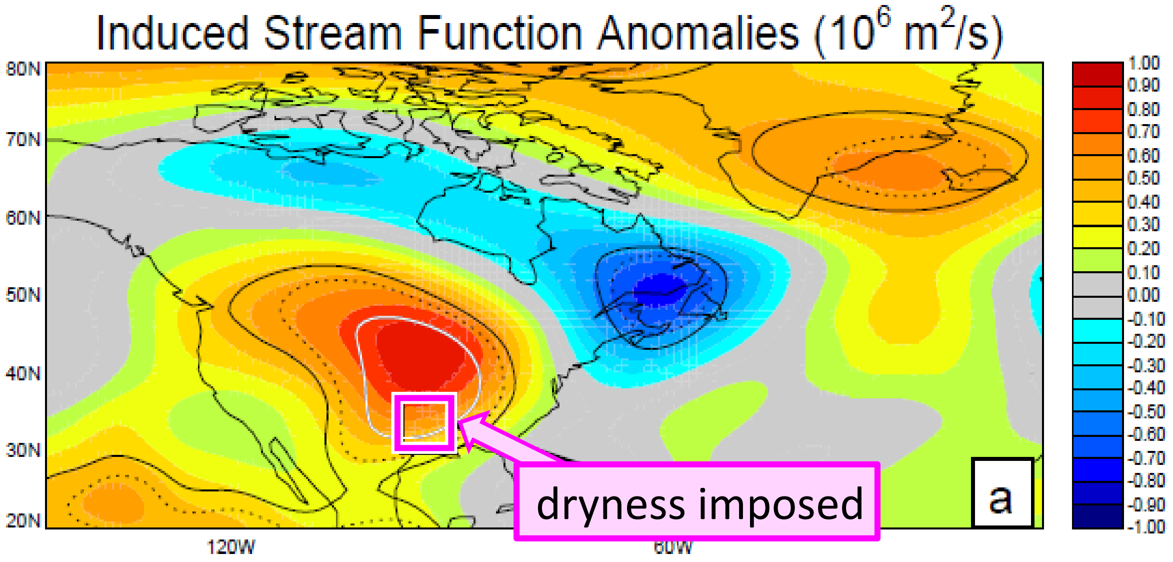
Experiment: Same as control, except:

(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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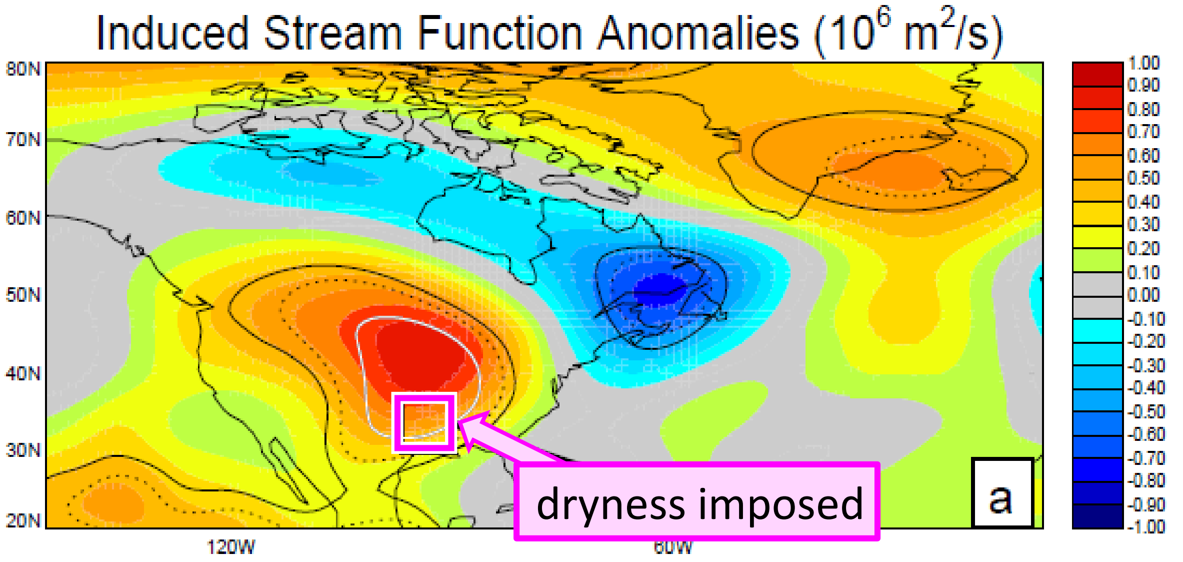
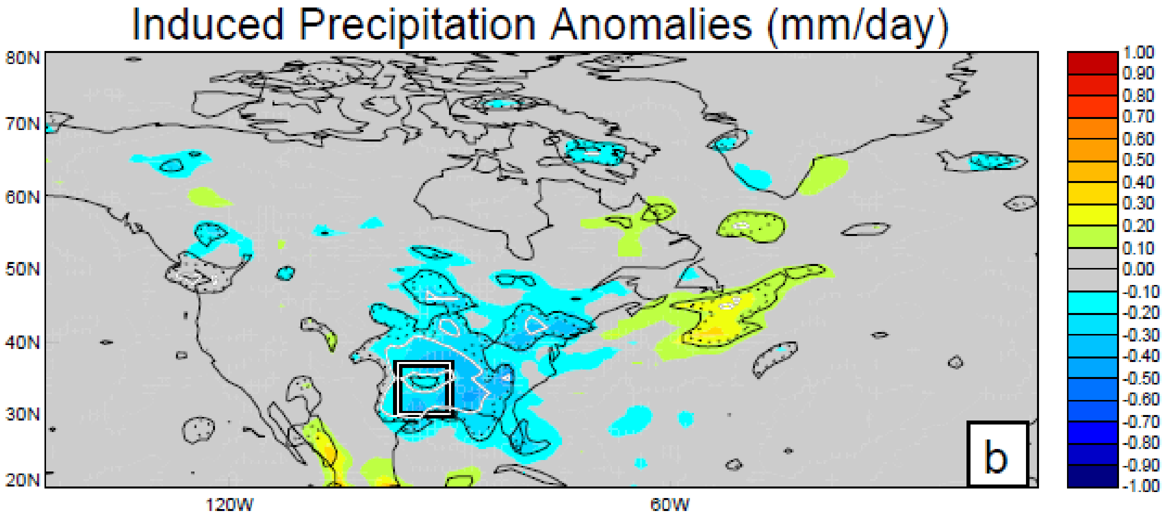
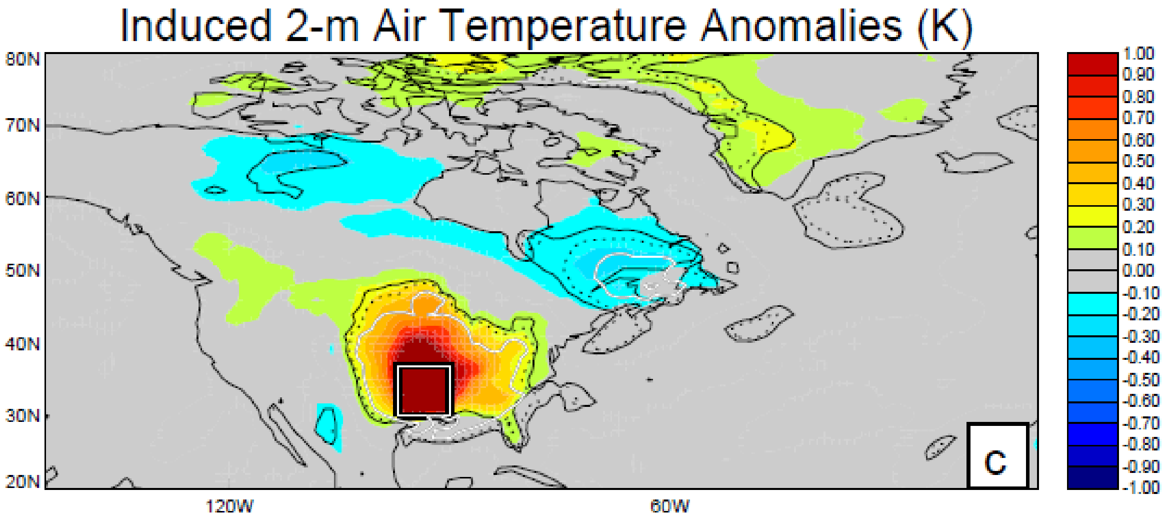
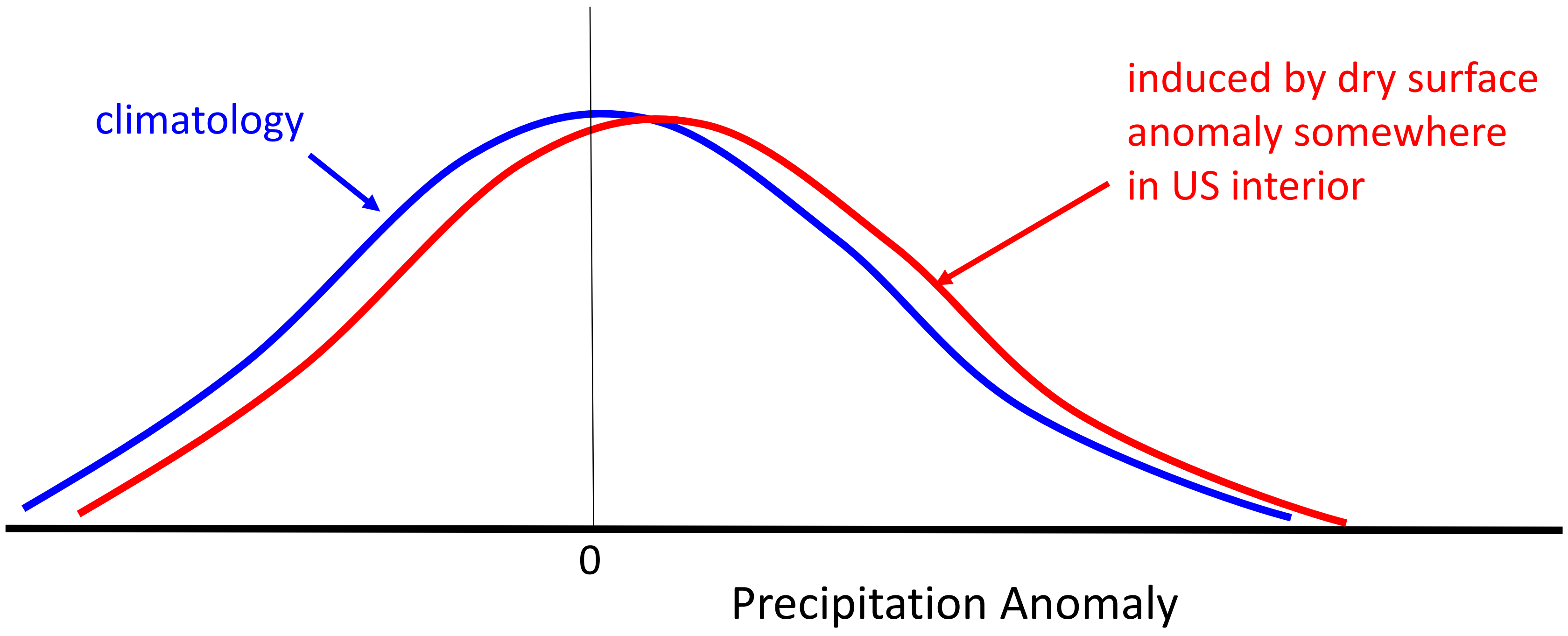


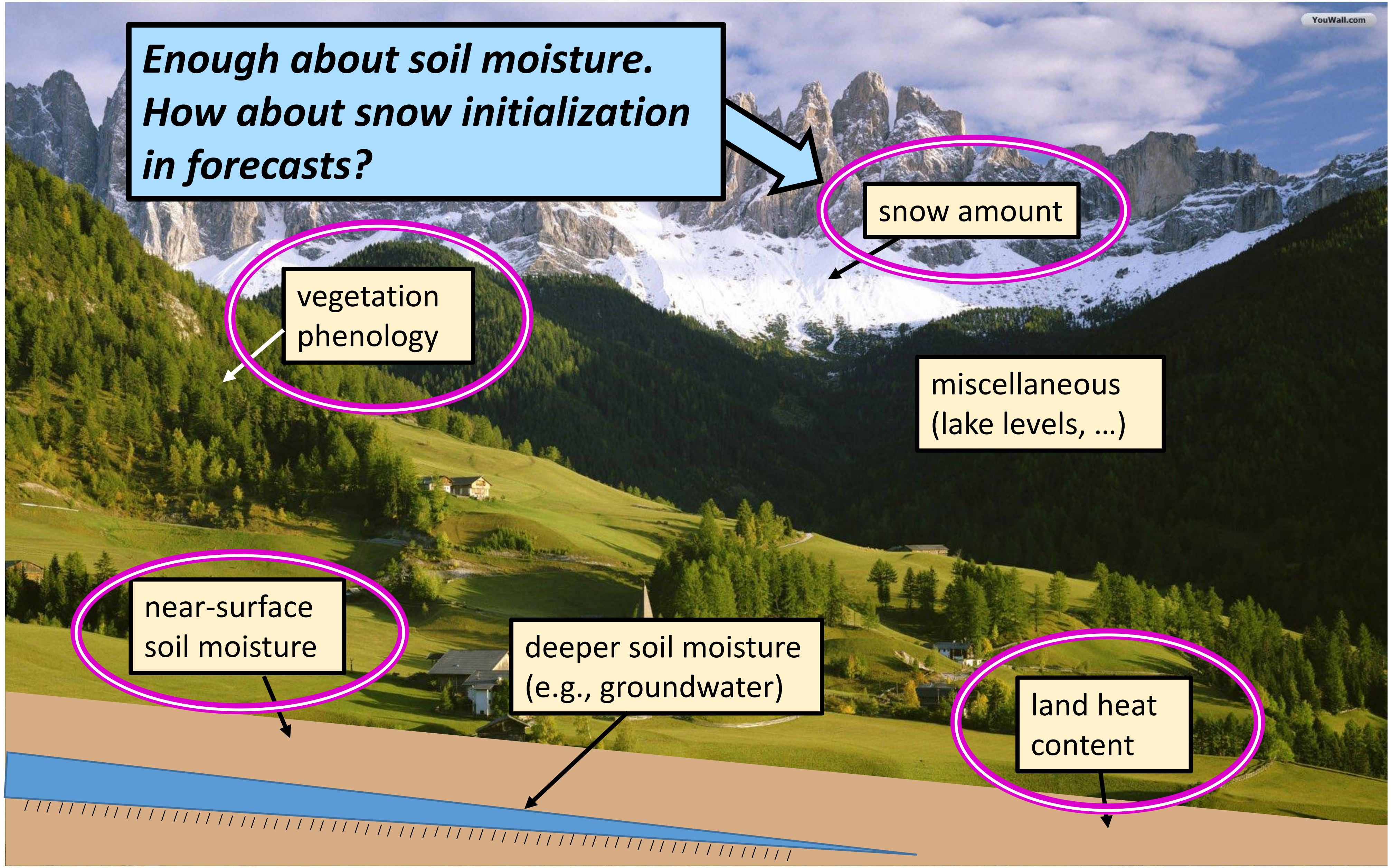




… that does lead to remote, wavelike patterns in T2M and precipitation anomalies.

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.






(Image stolen from internet!)

Jaison Thomas and Aaron Berg performed two sets of forecasts initialized on April 1 for each year in 1986-2005:

1) With realistic April 1 initializations of snow water equivalent, frozen soil moisture, and liquid soil moisture.
2) Without these realistic initializations.

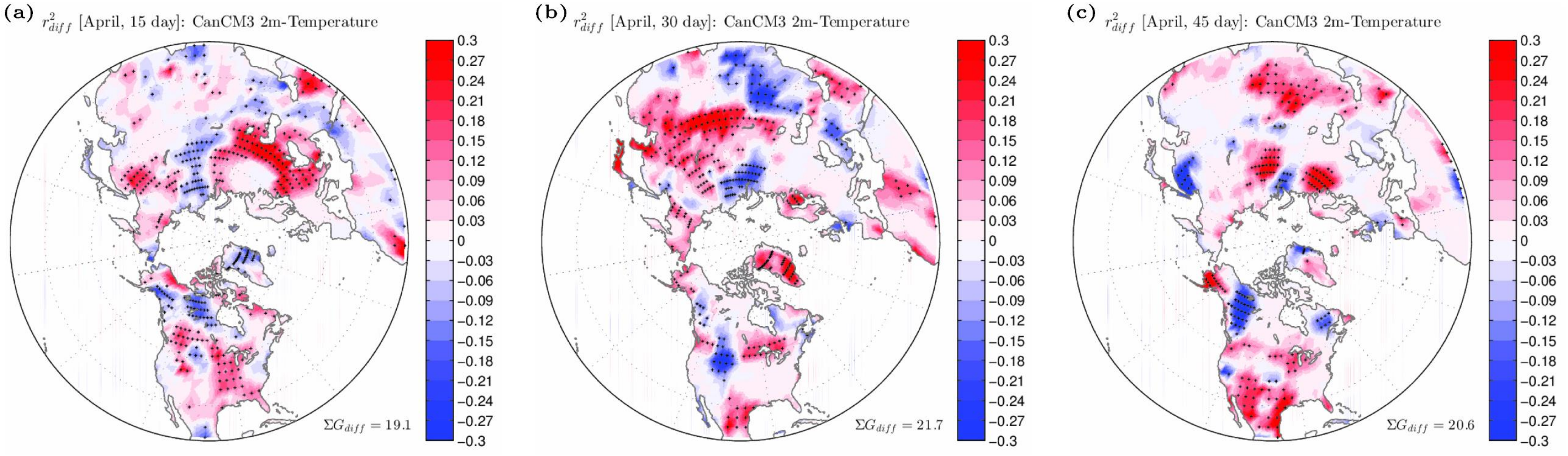
Forecasted 15-day-average 2m temperatures were compared to observations (reanalysis).

As before,

Skill ($r^2$) from simulations w/ accurate land ICs − Skill ($r^2$) from simulations w/o accurate land ICs = Skill due to land ICs

# Snow and soil water contributions to skill:

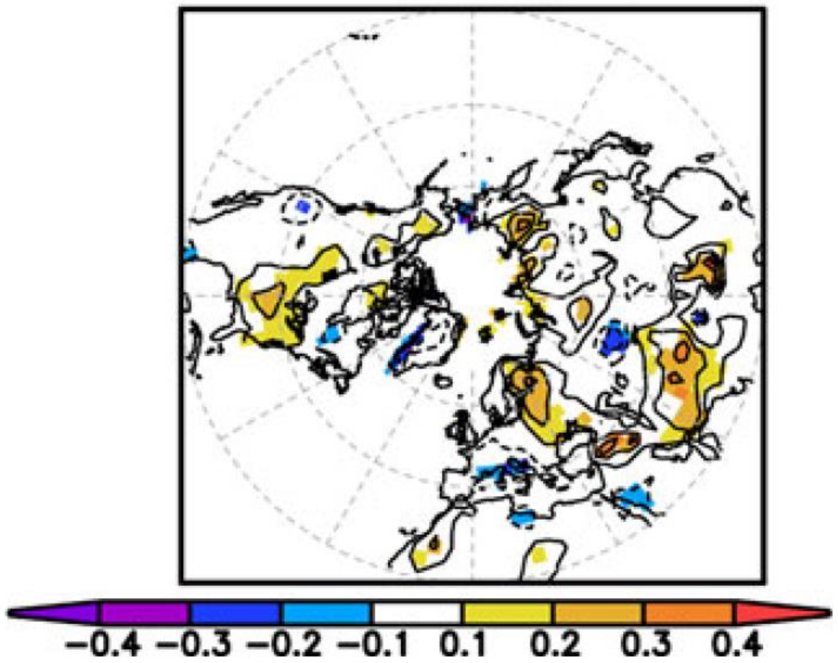
$r^2$ differences (15-day lead) | $r^2$ differences (30-day lead) | $r^2$ differences (45-day lead)




Ambadan et al., Climate Dynamics, 47, 49-65, 2016

Another study: Peings et al. (Clim. Dyn., 37, 985-1004, 2011) performed an analysis evaluating the contribution of snow initialization to temperature and pressure forecast skill.

Increase in anomaly correlation coefficient due to snow initialization:
**2-m air temperature**




Snow initialization led to improvements in the 2-m temperature skill, mostly in the first 2 months following the March 1 initialization. The initialization had little impact on the large scale circulation, however, as indicated by predicted sea level pressure patterns.

(With thanks to Herve Douville, Meteo-France)

Lin et al. (GRL, 43, doi:10.1002/2016GL070966) examined the additional forecast skill achievable through the use of remote sensing in the initialization process.

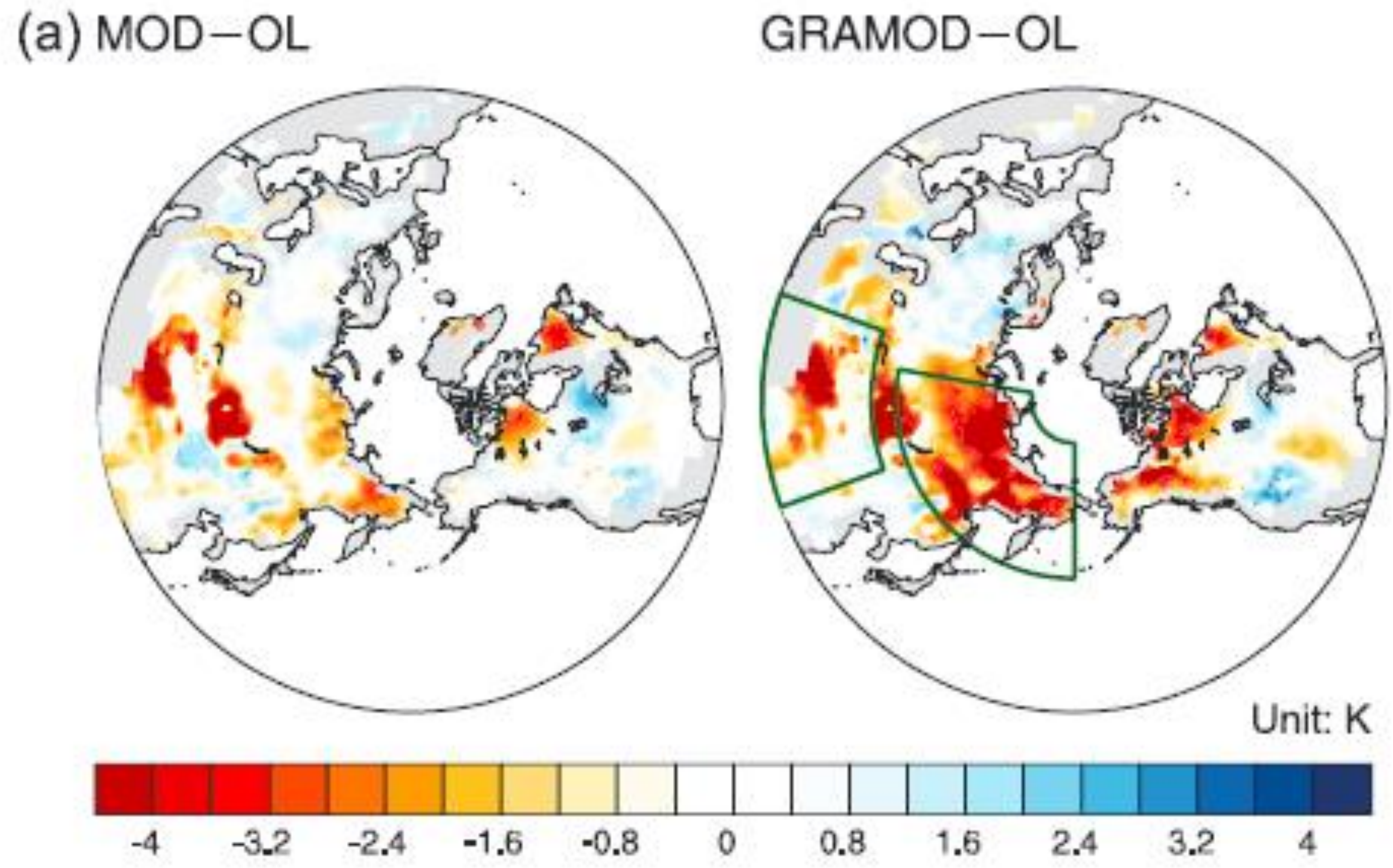


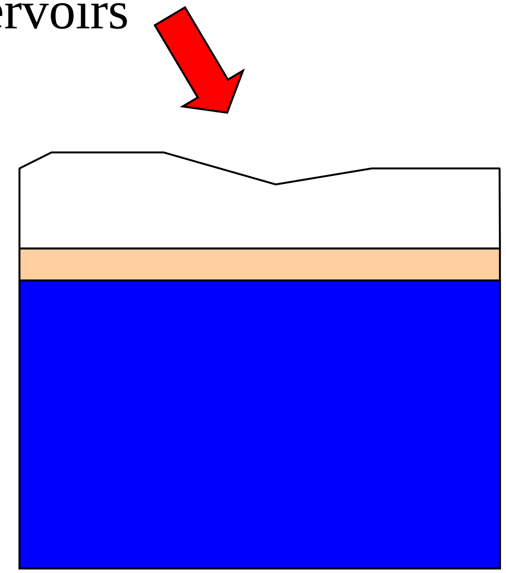

**Figure 2.** The temperature prediction cumulative RMSE (cRMSE) difference between DA and OL. (a) Absolute value difference (K); (b) Percentage difference (%). Figures 2a (left) and 2b (left) (Figures 2a (right) and 2b (right)) show the difference between MOD (GRAMOD) and OL. The forecasts are initialized on 1 March. Negative values indicate reduced prediction errors and improved temperature predictions after using snow DA-constrained land initializations. The green boxes encompass two regions of interest for a further analysis in section 3.3.

Streamflow forecasting via snow and/or soil moisture initialization is also a subseasonal-to-seasonal forecast topic.

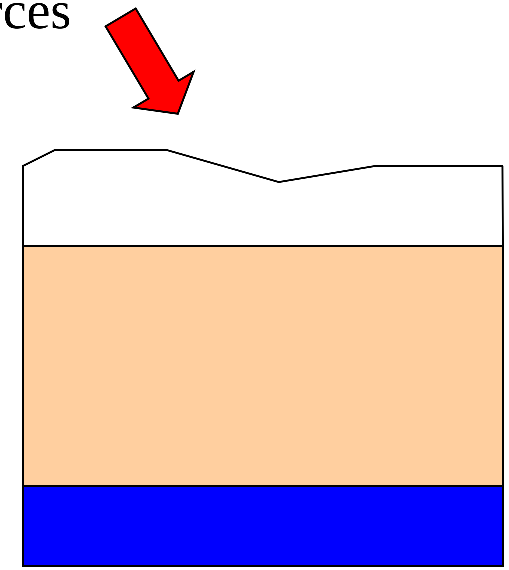
Obvious: Larger snowpack ⇨ Increased streamflow during snowmelt season.

Less obvious: Impact of soil moisture…

Snow (or rainfall) over wet soil: most of the meltwater runs off into streams, reservoirs



Snow (or rainfall) over dry soil: most of the meltwater infiltrates the soil and is lost to water resources



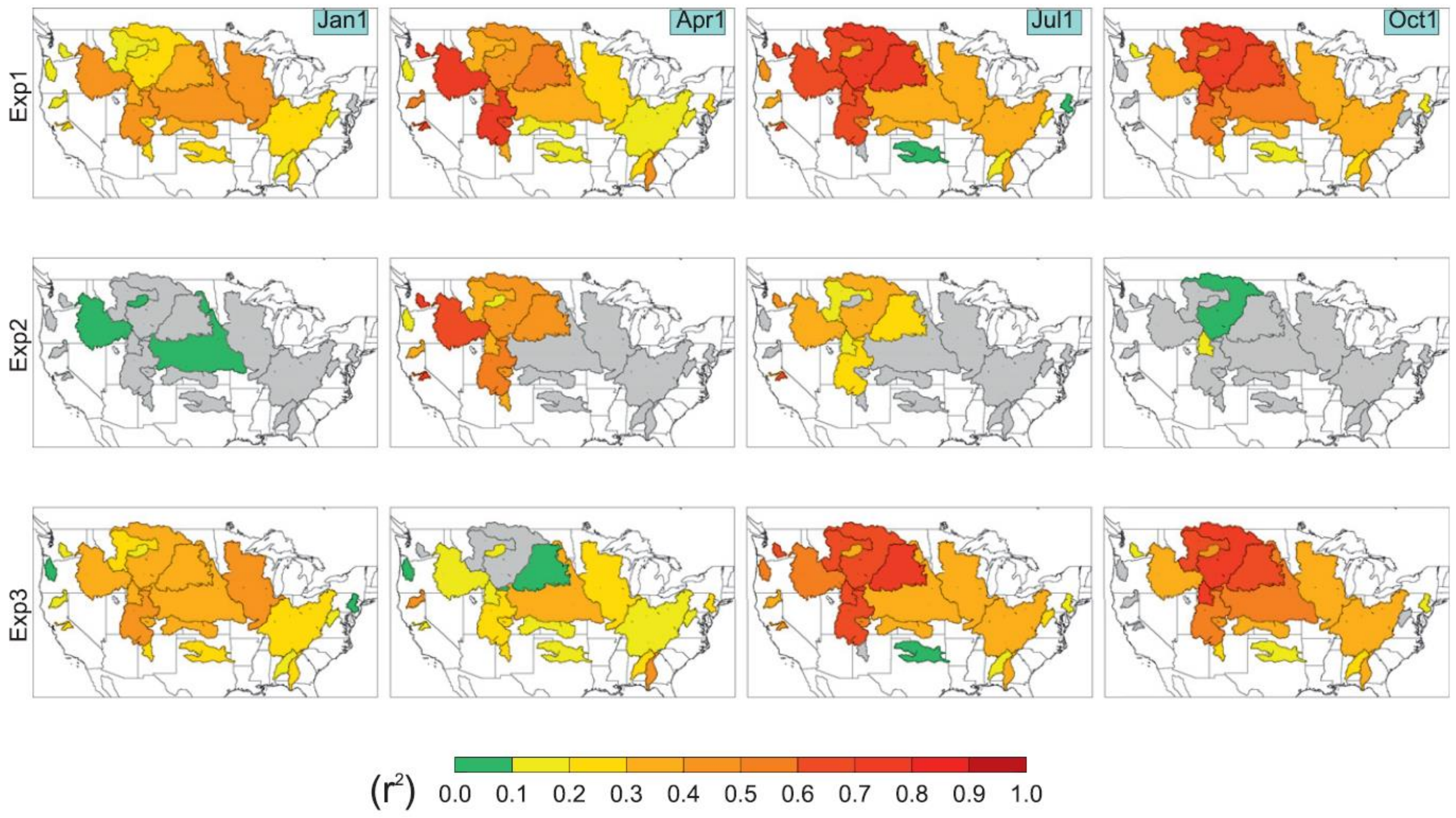
Knowledge of winter snow, soil moisture ⇨ streamflow forecast skill

# Performed experiments; estimated contribution to 3-month streamflow forecast skill from snow and soil moisture ICs:

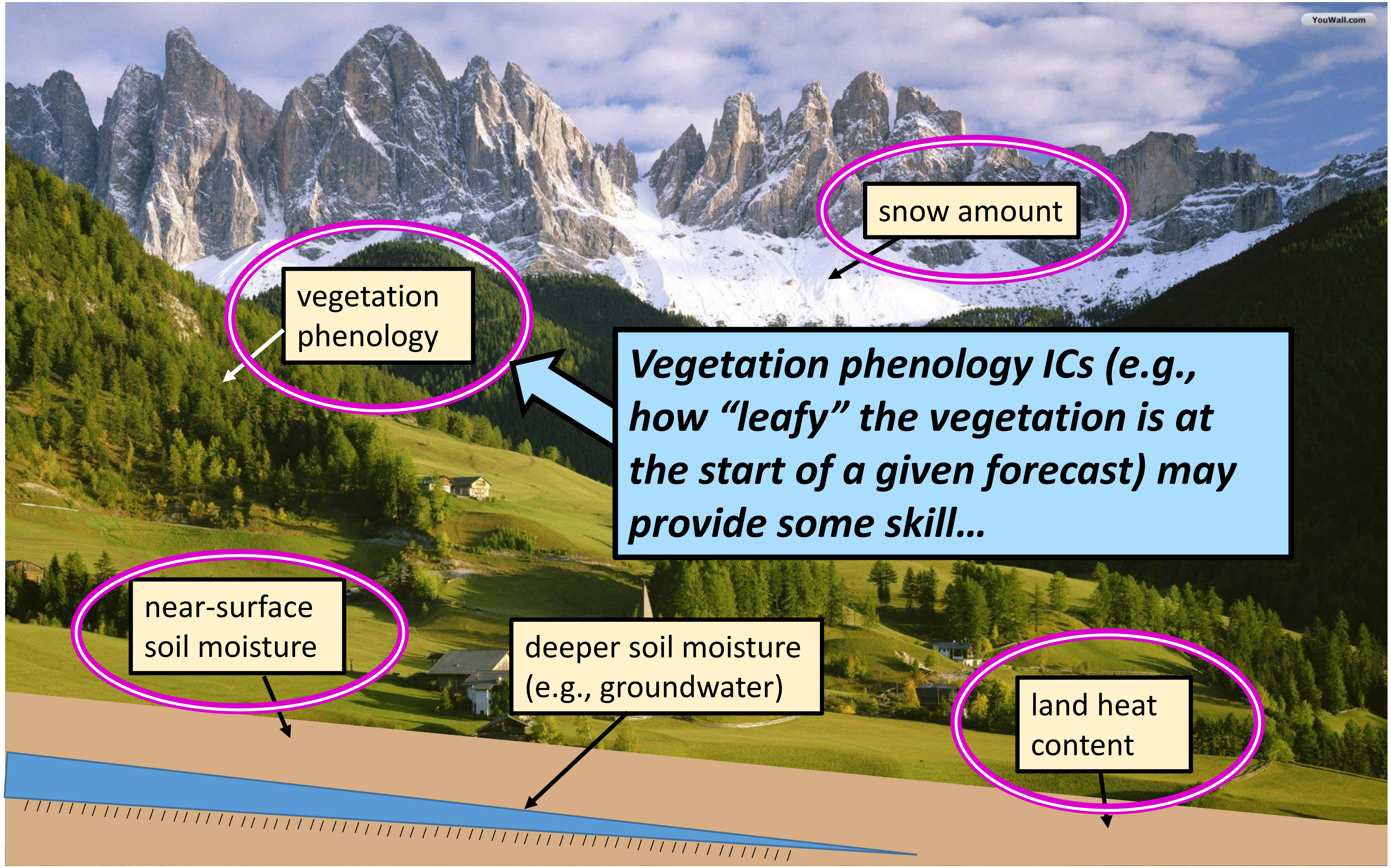
**From both snow and soil moisture ICs**

**From snow ICs**

**From soil moisture ICs**



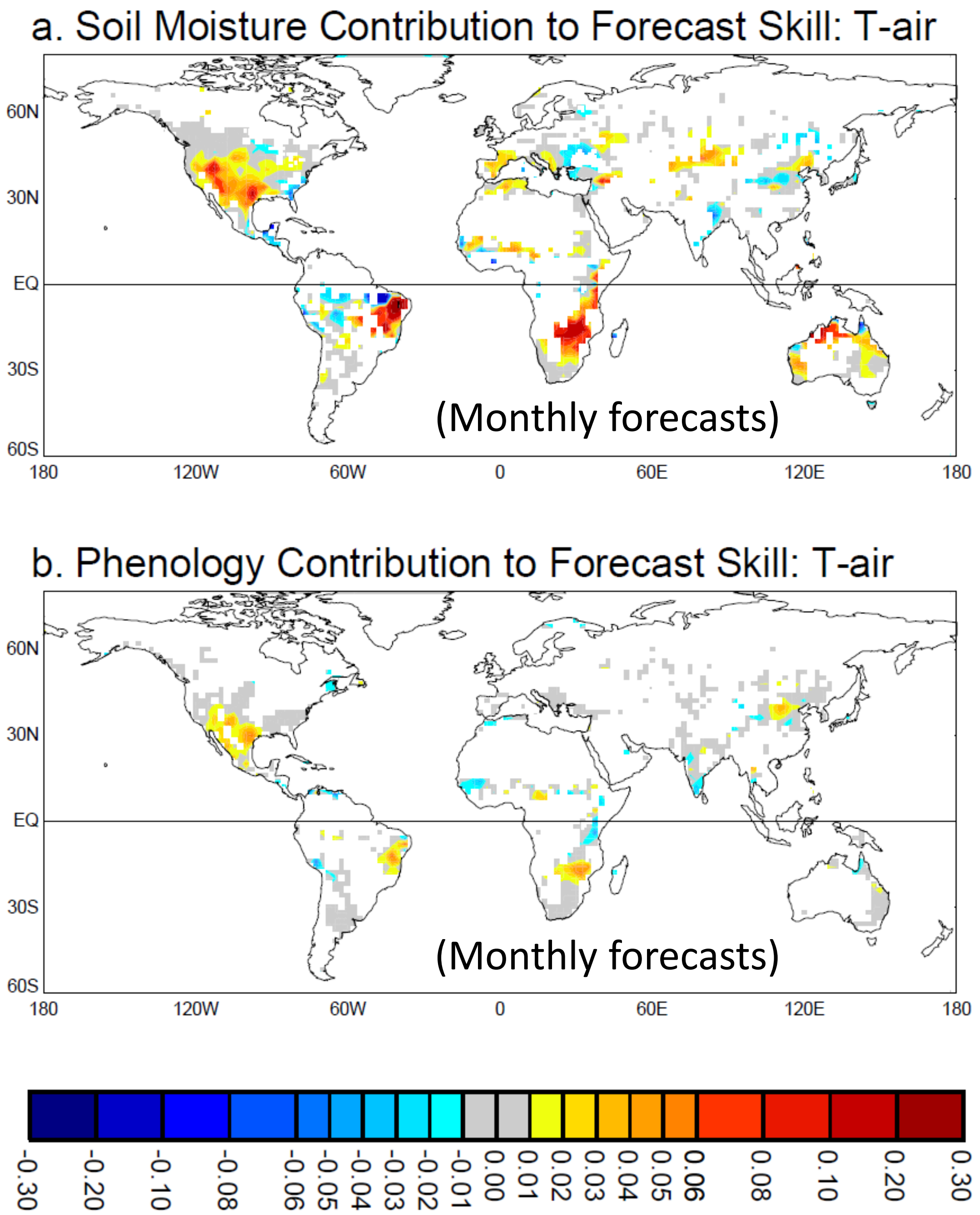

Mahanama et al., J. Hydromet., 13,189-203, 2012




(Image stolen from internet!)

Vegetation state. An experiment similar to GLACE-2, but focusing on the impacts of initialized vegetation state on monthly forecast skill (using a land model with dynamic phenology) was recently performed. In fact, the effects of both soil moisture and vegetation initialization were quantified with the same framework and compared side-by-side.

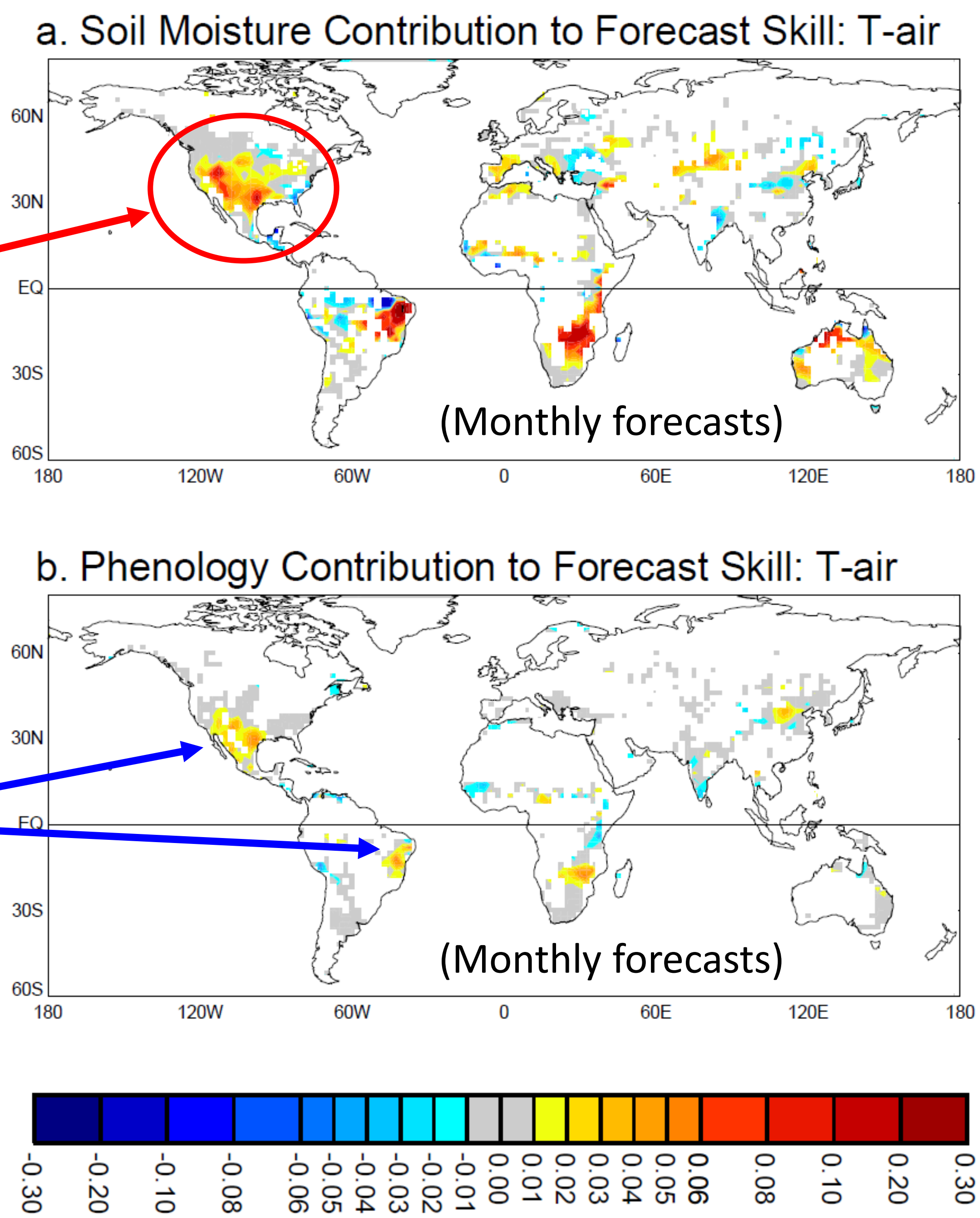
Skill ($r^2$) from simulations w/ accurate land ICs – Skill ($r^2$) from simulations w/o accurate land ICs = Skill due to land ICs

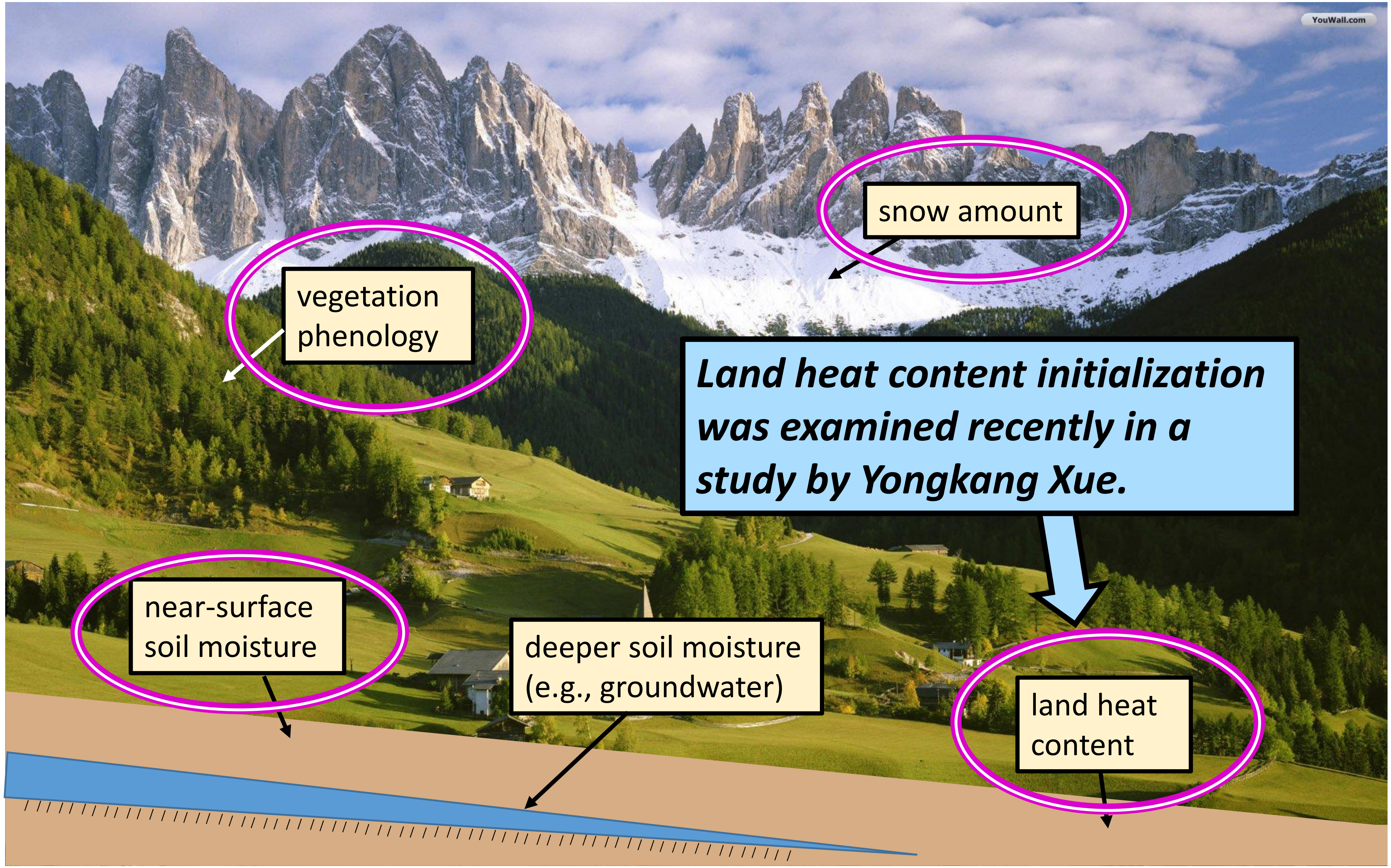



Koster and Walker, J. Hydromet., 16, 1456-1465, 2015

Note: some differences between this pattern (for single model) and that for multi-model GLACE-2 results

Many indications of positive impact, but with magnitudes smaller than that for soil moisture

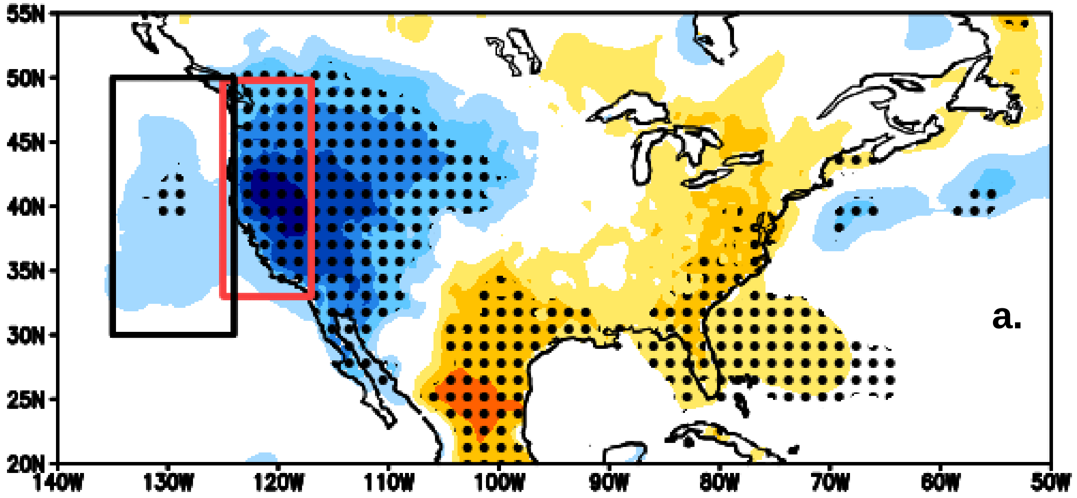




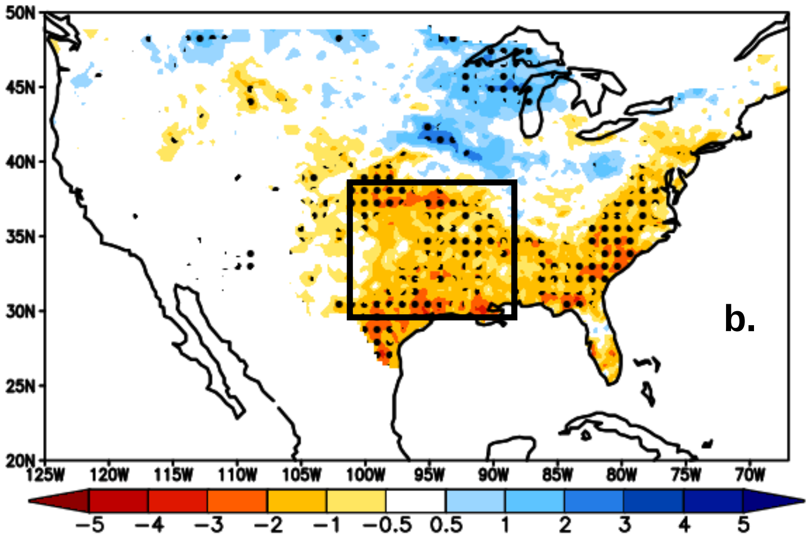

(Image stolen from internet!)

# Observed differences between 9 coldest years and 9 warmest years (based on N.W. U.S. & S. E. Canada LST)

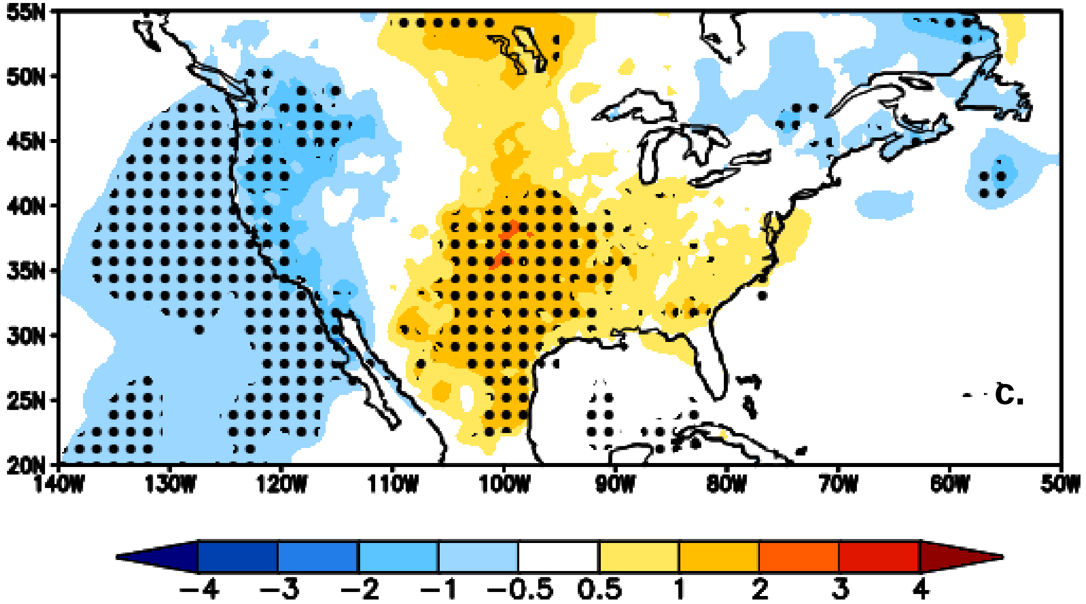
May Observed LST and **SST**




**June Observed Precipitation**




June Observed LST and SST



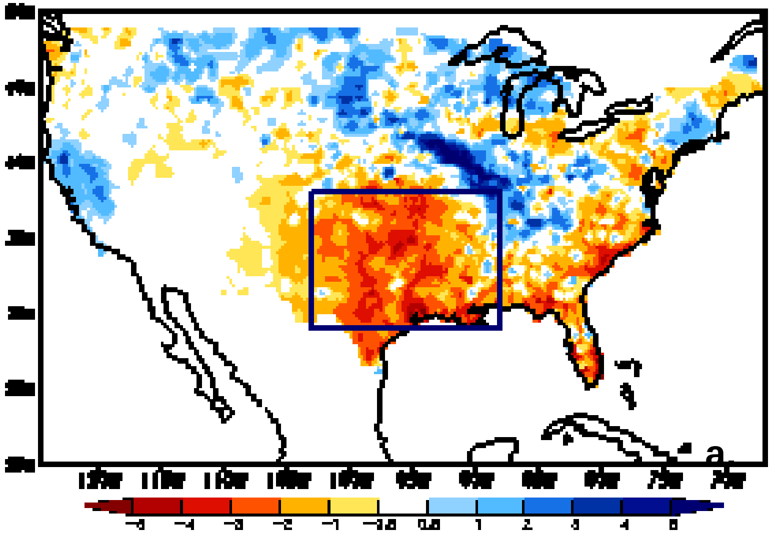

1) LST: land surface temperature

2) The dotted areas denote statistical significance less than α=0.1 level of t-test values.

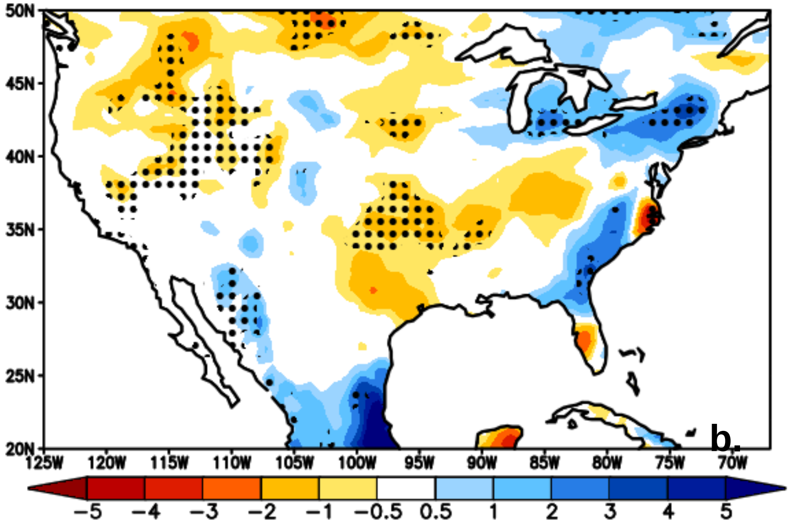
Xue et al., 2012 (JGR), 2016 (ERL)

# Observed/WRF-NMM simulated anomaly/difference of 2011 June Precipitation (mm day$^{-1}$)

## Observed



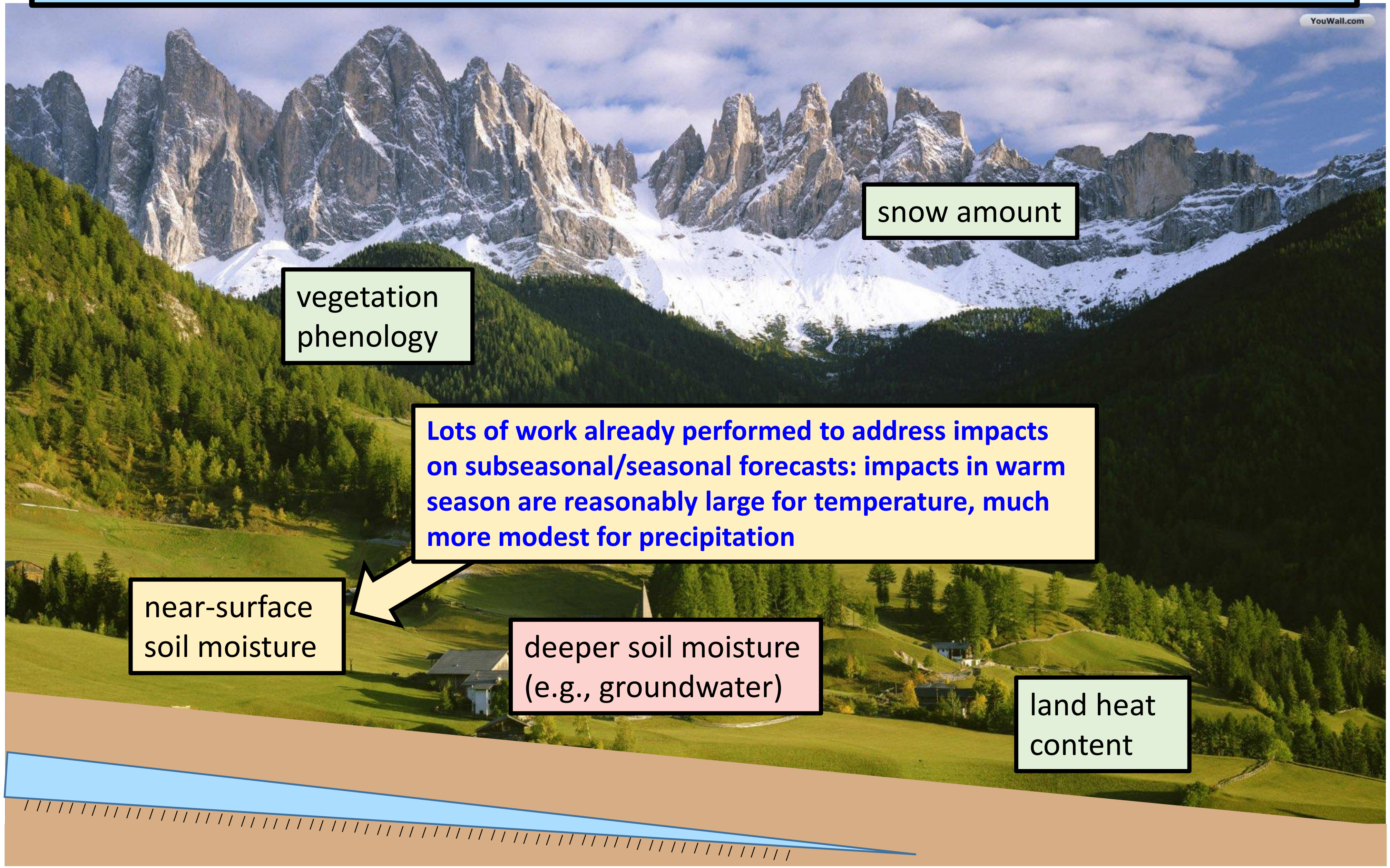

## SUBT Effect




SUBT: Subsurface temperature.
The dotted areas denote statistical significance at the α=0.01 level of t-test values.

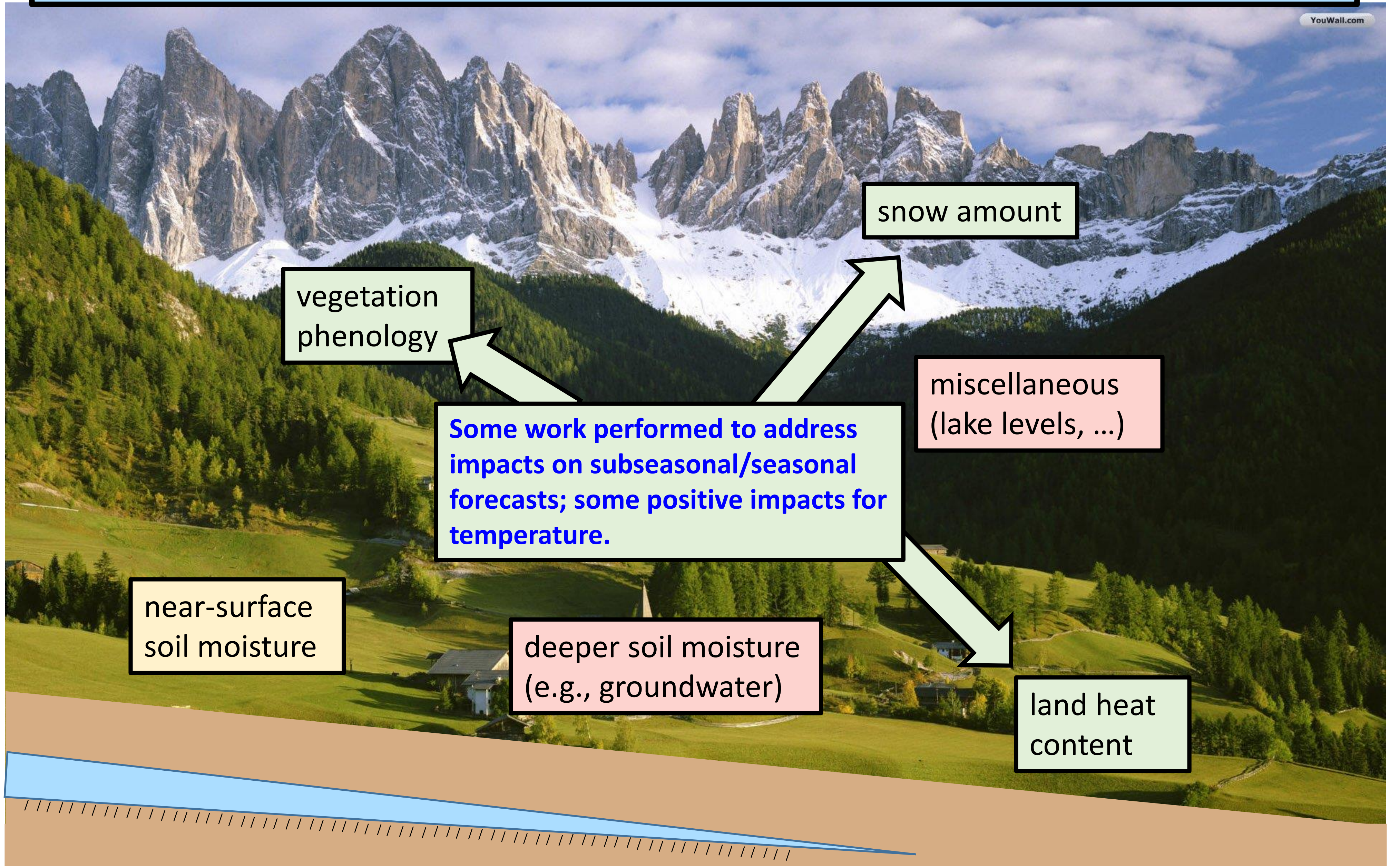
Xue et al., Env. Res. Lett., 11, 044018, 2016.

# *Before we mention some ongoing challenges, here's a brief summary*




(Image stolen from internet!)

## *So, before we discuss some ongoing challenges, here's a brief summary*

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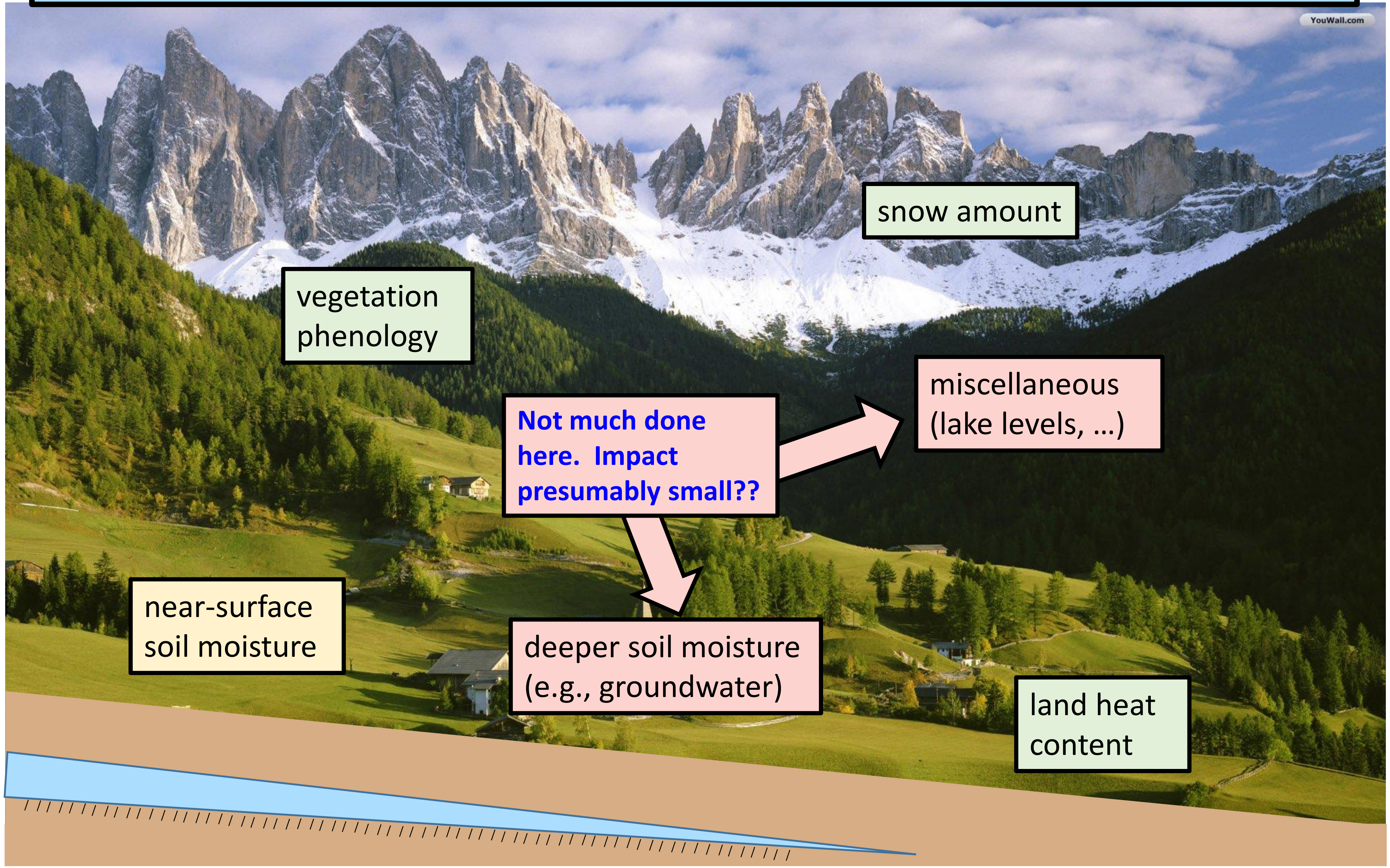
## *So, before we discuss some ongoing challenges, here's a brief summary*




(Image stolen from internet!)

# Some current challenges

- Quantifying the skill contributions further, with a large complement of models (soil moisture analyses relatively mature, but not other variables)
- More thorough theoretical analysis of memory and feedback mechanisms; characterizing “nature’s” land-atmosphere coupling strength.
- Inclusion of additional variables into operational forecast systems (e.g., phenology)
- Taking advantage of the potential for conditional forecasts
- Need for better data for initialization: optimizing use of limited measurement resources to maximize impact on forecast skill, and tapping into as-yet-unused data sources

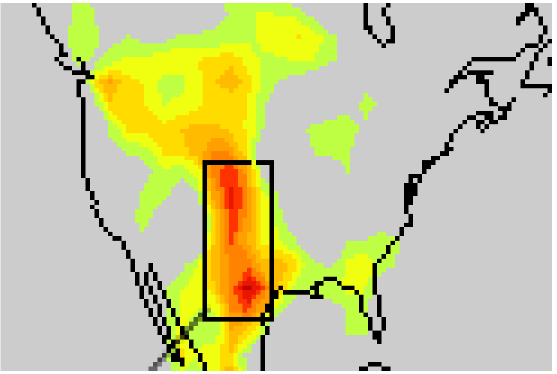
Thank you.

Questions?

# Extra Slides

# Note the contradiction between diagnosed coupling strength locations (from earlier) and locations where skill appears:

## Coupling strength



Reasons for the discrepancy are somewhat unclear but may be related to:

-- different set of models, with different biases (different transition zones)

-- spatial differences in memory

-- ability to produce a feedback loop ("coupled mode") in the forecast system

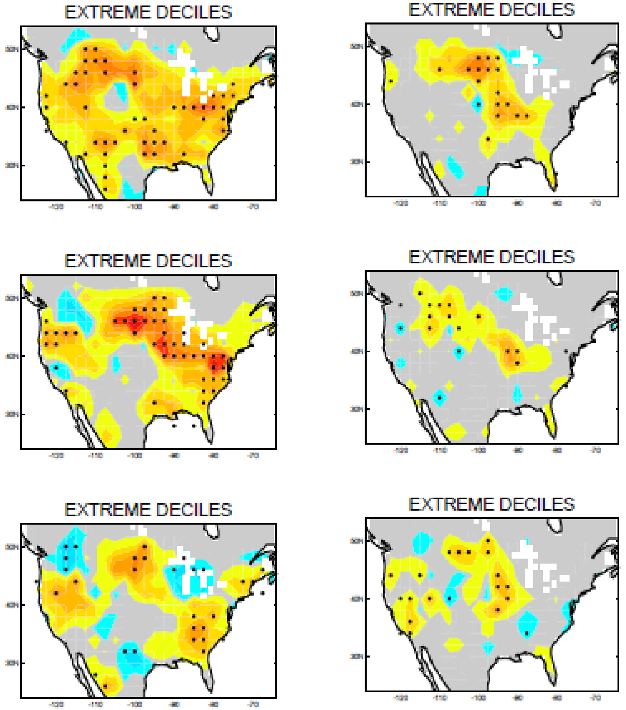
## Skill levels (extreme deciles)

**temperature** | **precipitation**

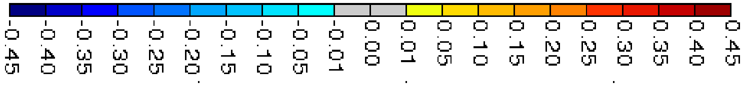
**16-30 days**

**31-45 days**

**46-60 days**




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



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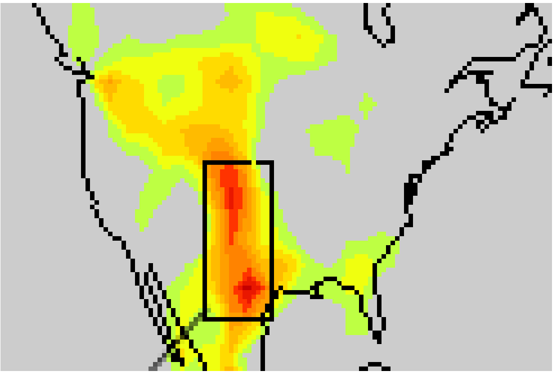
**Coupling strength**



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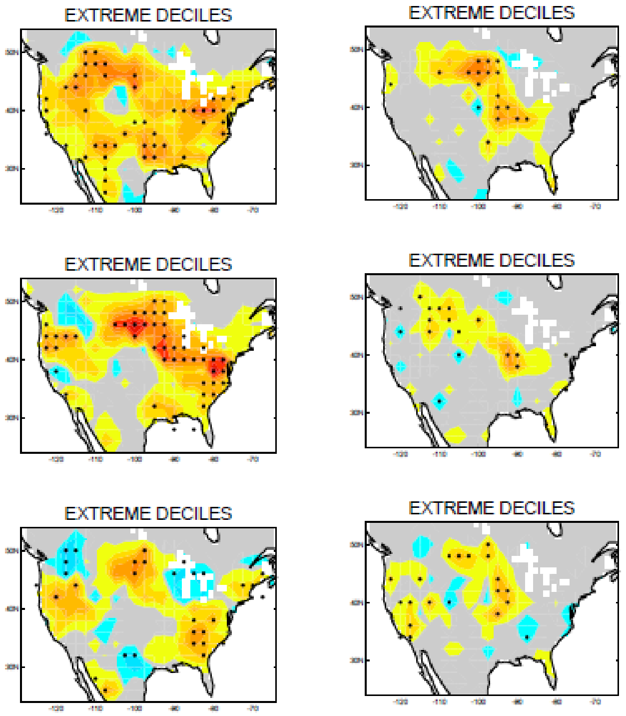


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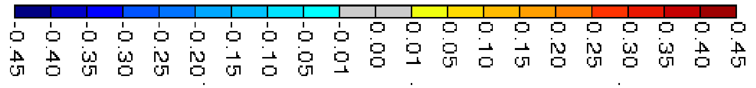
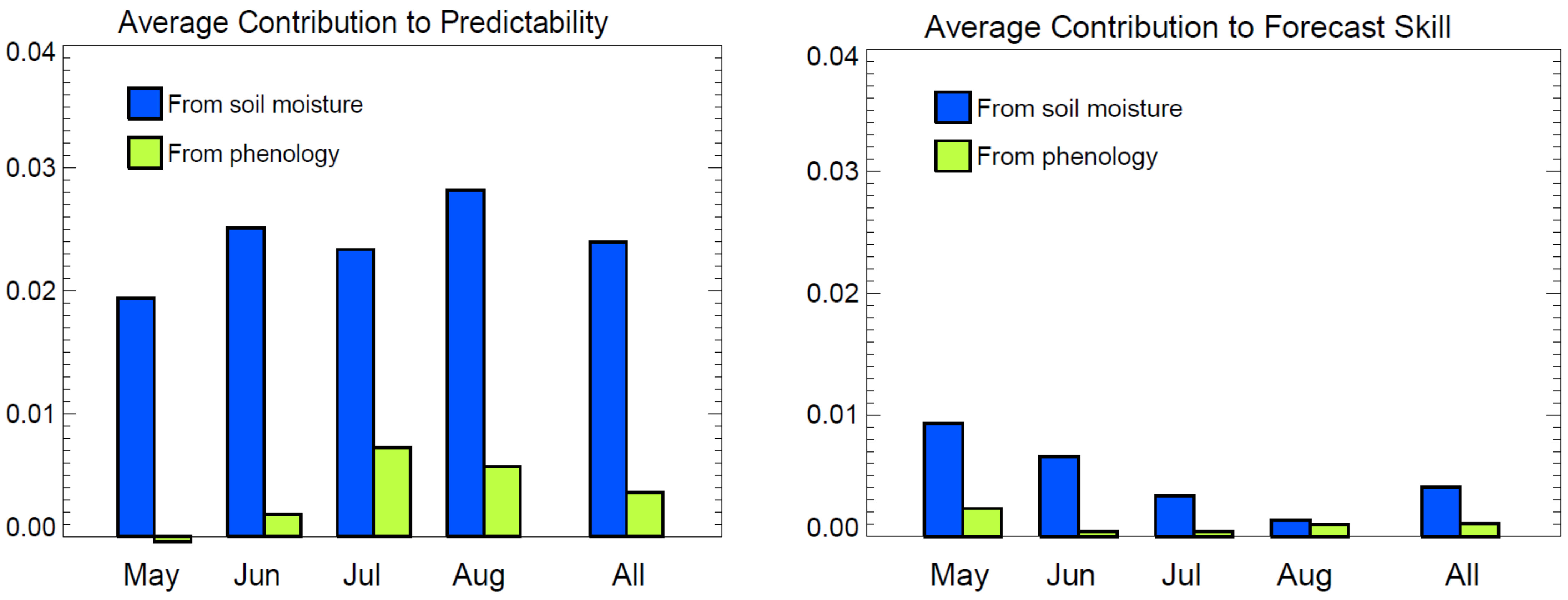



Reasons for the discrepancy are somewhat unclear but may be related to:

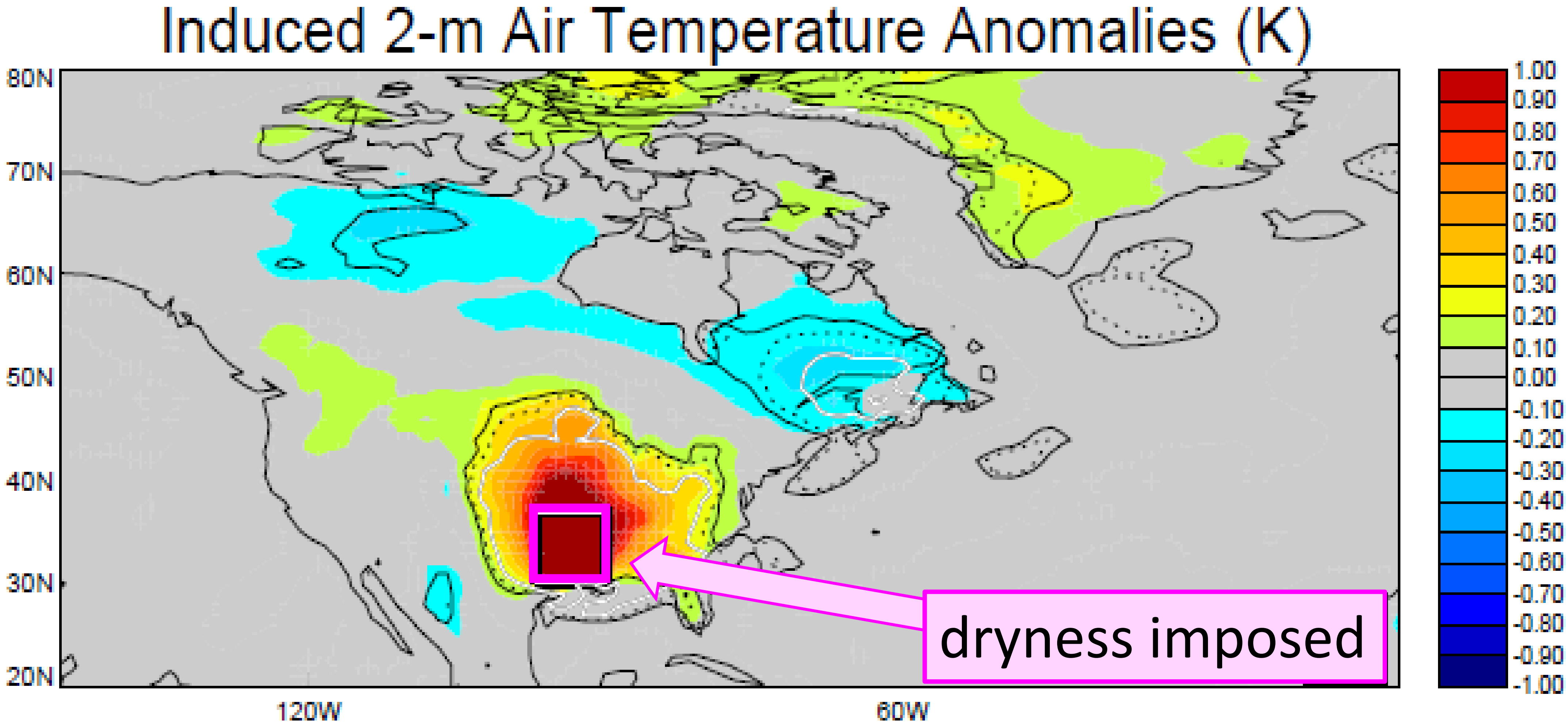
- -- different set of models, with different biases (different transition zones)
- -- spatial differences in memory
- -- ability to produce a feedback loop ("coupled mode") in the forecast system

perhaps not the primary reason, but scientifically exciting – worth a quick look!

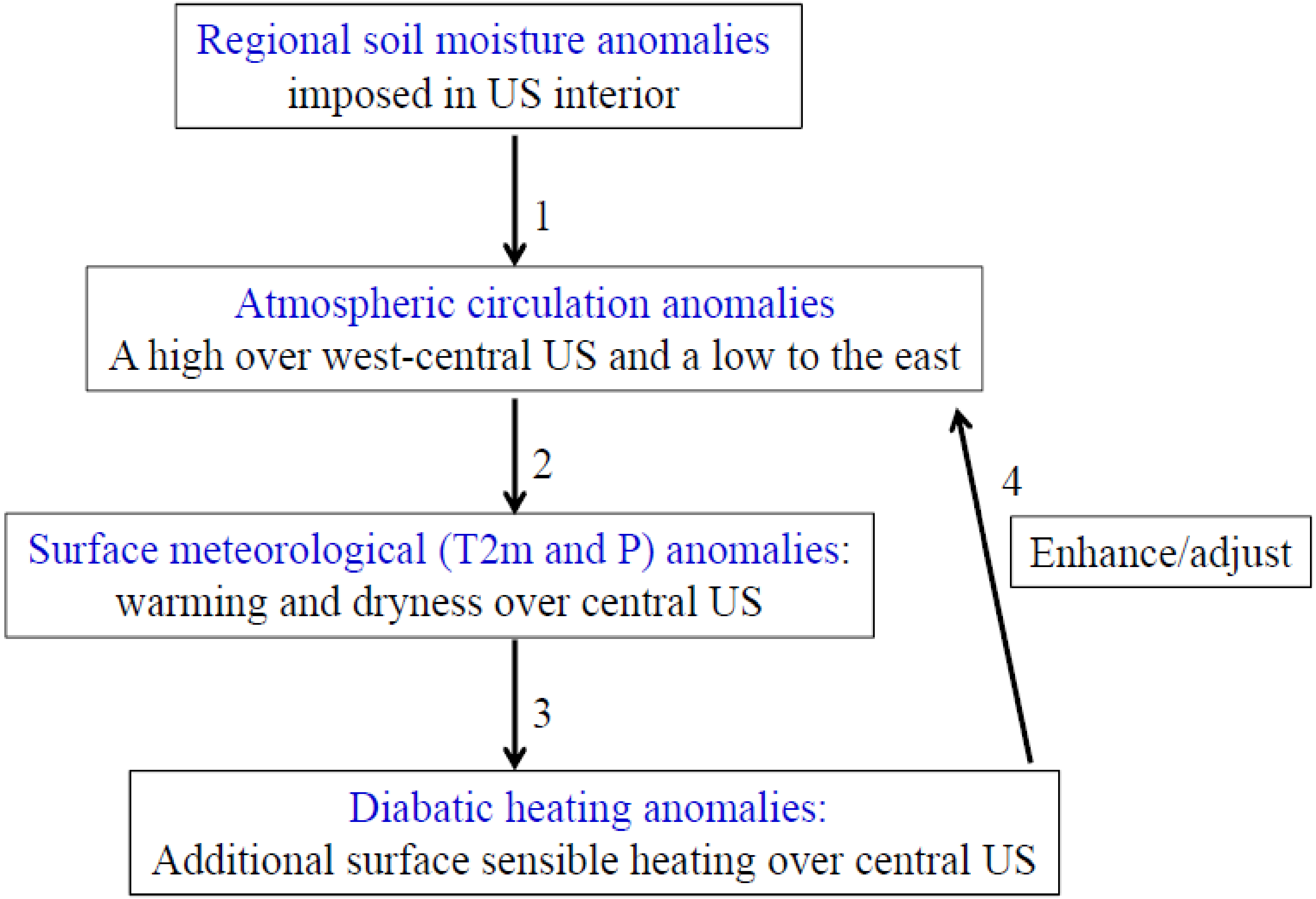
# Global averages of contributions over areas with adequate rain gauge density

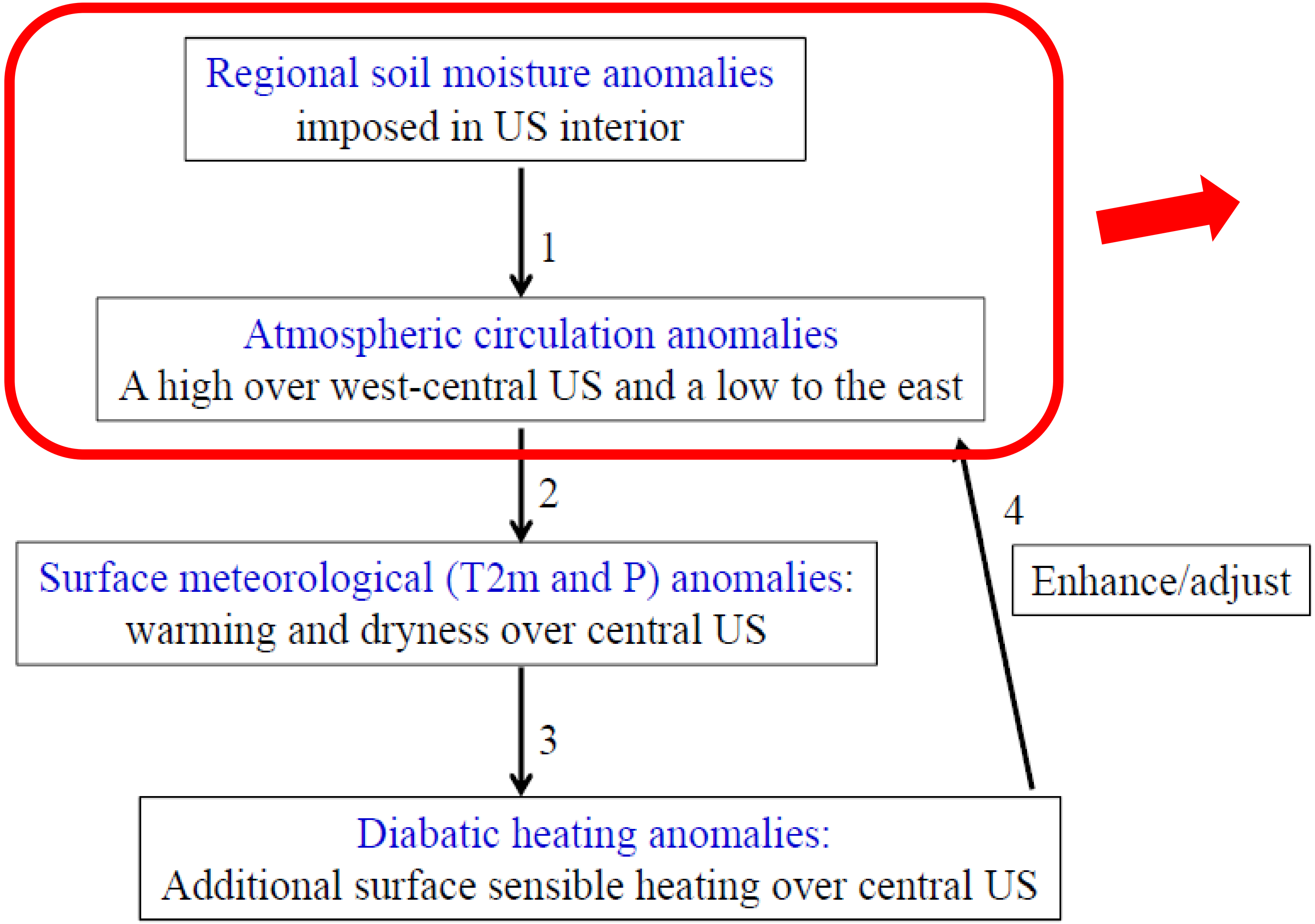


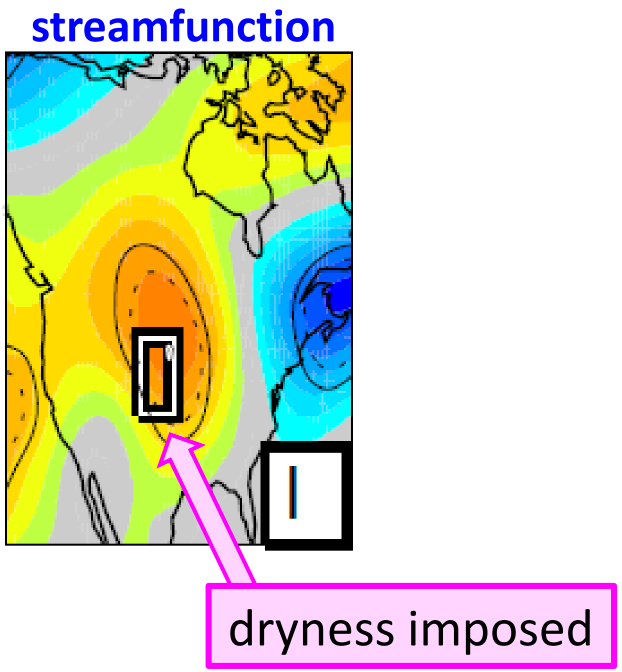

1-month air temperature forecasts

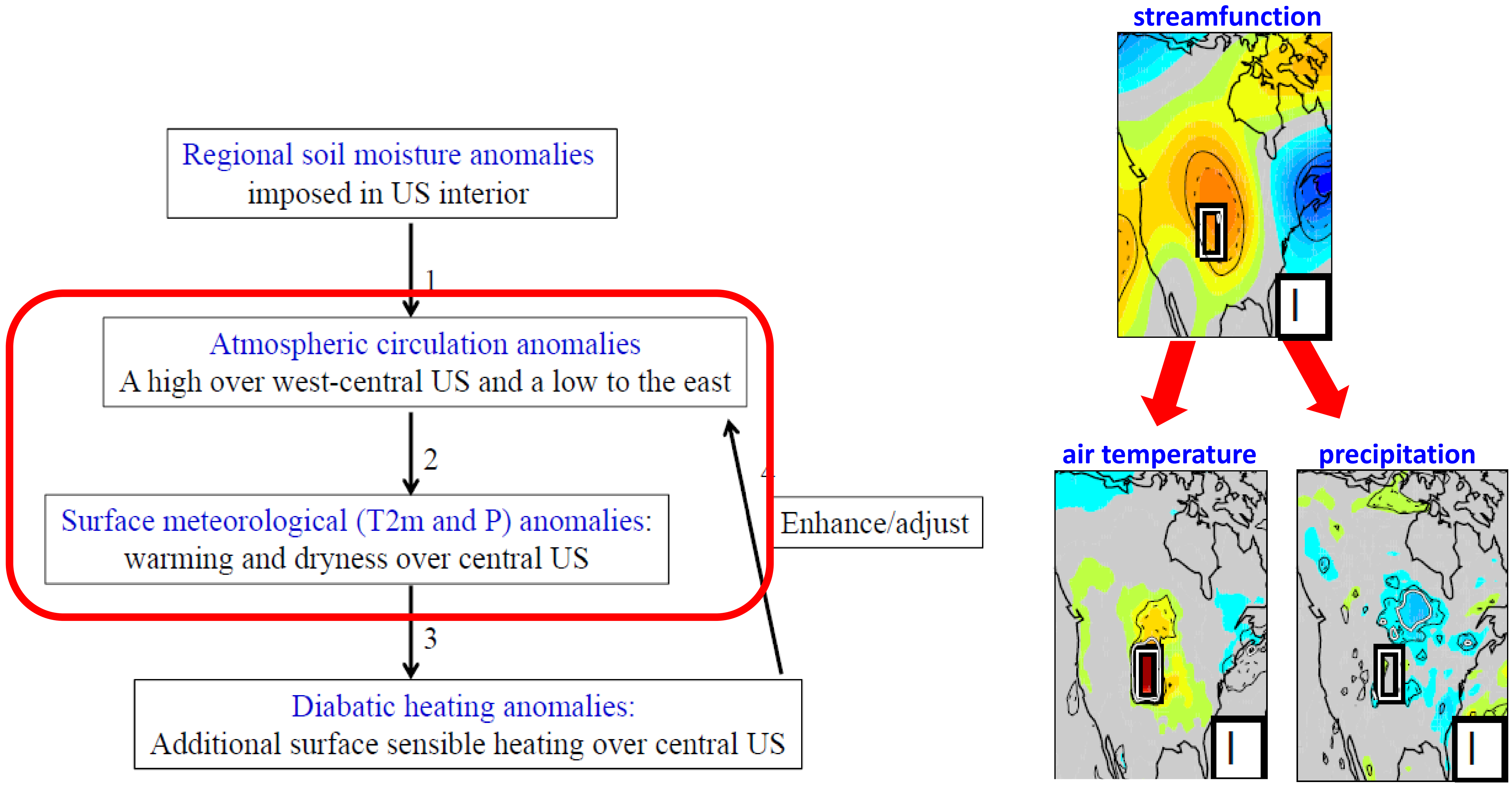

Induced 2-m Air Temperature Anomalies (K)
80N
70N
60N
50N
40N
30N
20N
120W
60W
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
-0.60
-0.70
-0.80
-0.90
-1.00
dryness imposed

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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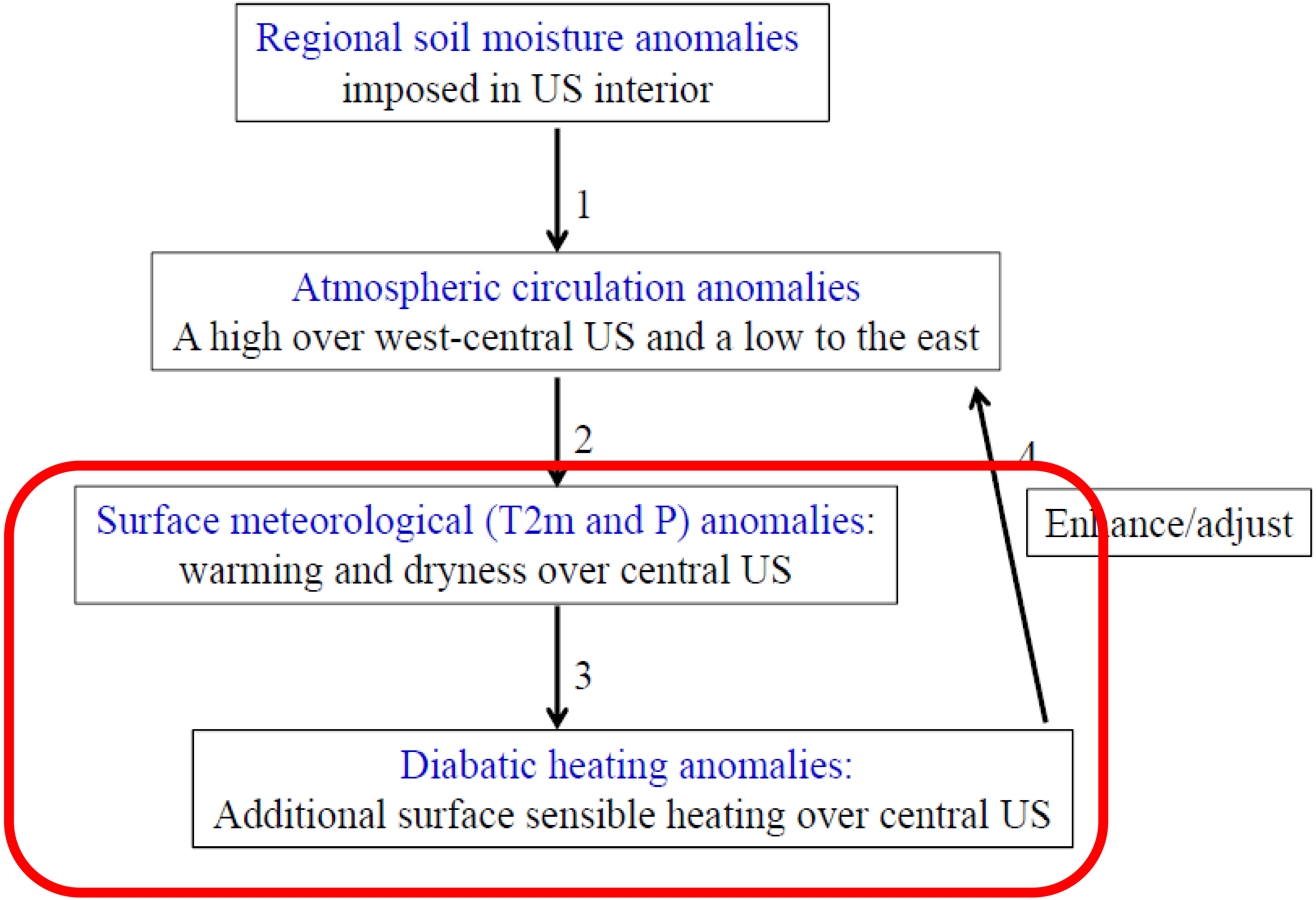
Enhance/adjust
streamfunction
air temperature
precipitation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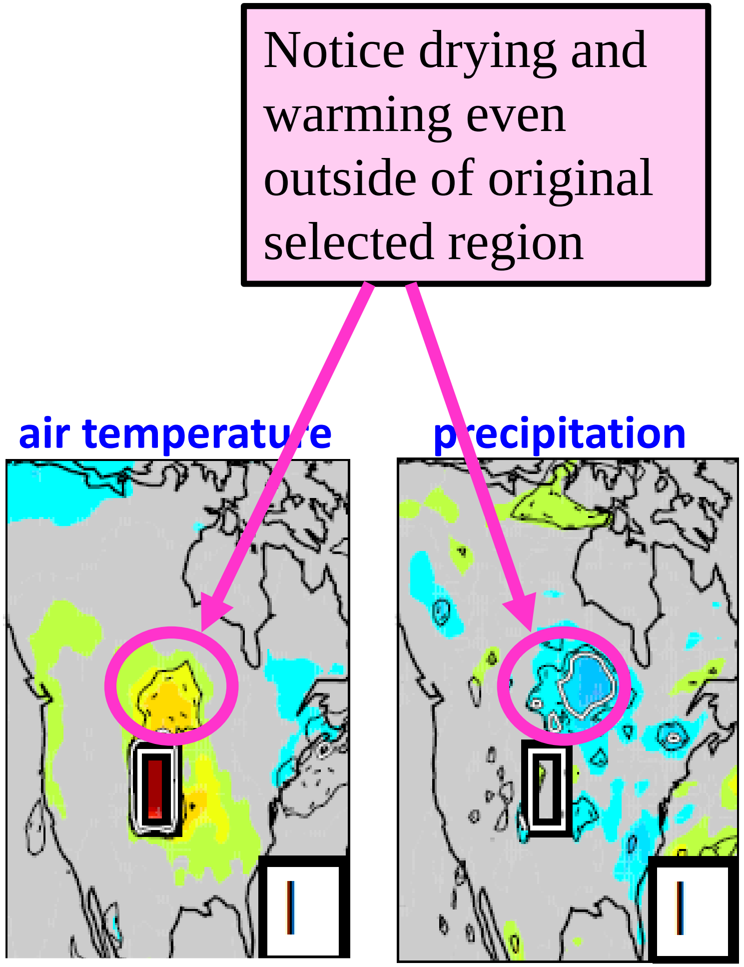
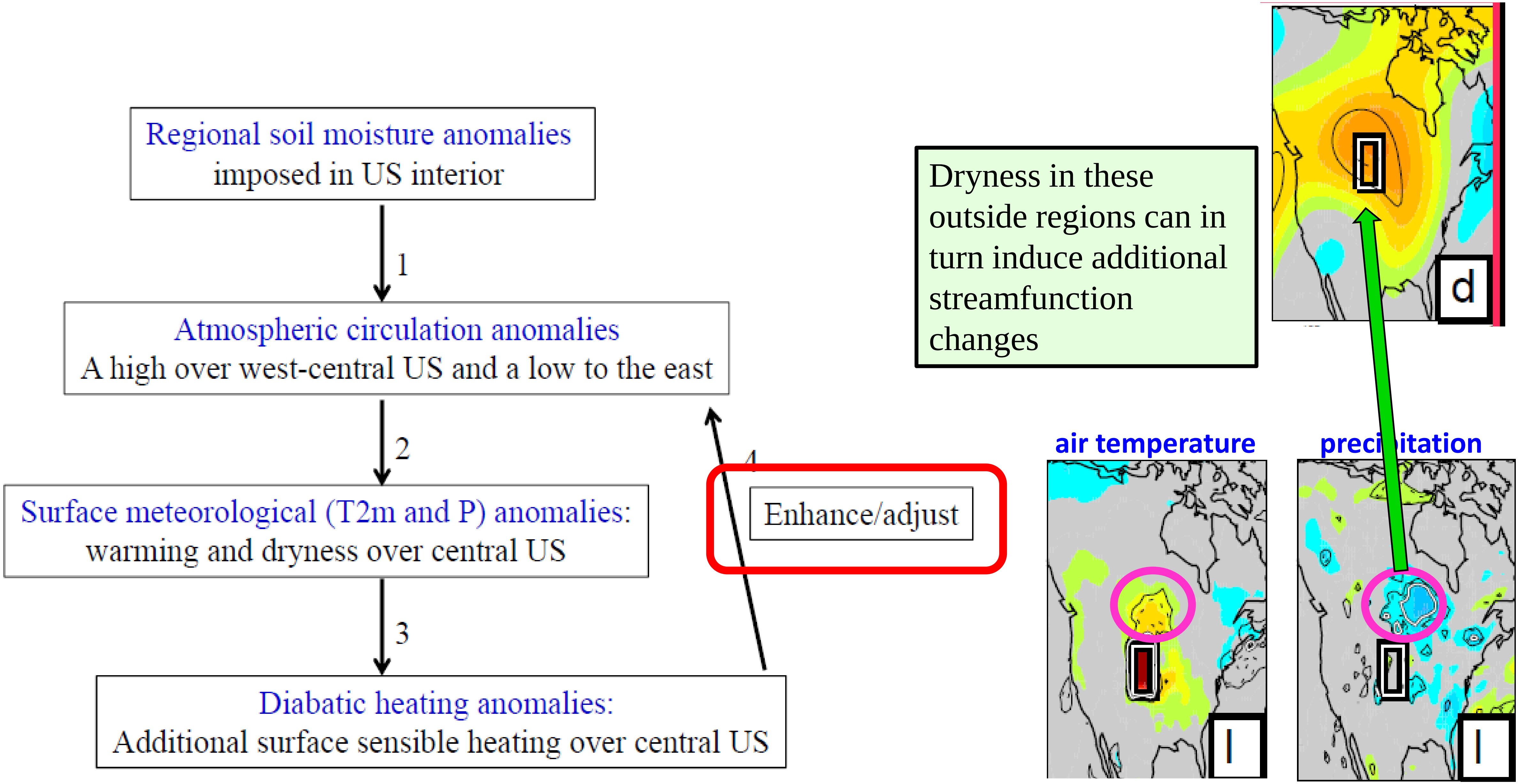

Notice drying and warming even outside of original selected region
air temperature
precipitation



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