Soil Moisture as a Harbinger of Increased Forecast Reliability at Subseasonal Time Scales

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w/ Siegfried Schubert, Anthony DeAngelis, Andrea Molod, Sarith Mahanama

What role does soil moisture initialization play in a subseasonal (3-4 week lead) forecast?

There are two ways of addressing soil moisture impacts on forecast skill:

1. Perform multiple forecast experiments, some with soil moisture effects disabled (a la GLACE-2).

The Second Phase of the Global Land–Atmosphere Coupling Experiment: Soil Moisture Contributions to Subseasonal Forecast Skill

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Difficulties:

- ❑ Provides the “what” but not the “why”
- ❑ Expensive to re-run with each new version

2. Understand the soil-moisture-related behavior of the complex seasonal forecast system by reducing it to the basics.

Can we develop a simple representation (one that we can readily understand) of the complex system and use that to quantify soil moisture impacts on forecast skill?

Answer: Yes, as illustrated in this talk!

Simply put:

The simple representation will capture only that part of the full system that extracts forecast skill from soil moisture conditions.

So, any actual skill we get with the simple representation will reflect a lower bound for the skill obtained from soil moisture in the full system.

The simple representation will also help us understand numerous otherwise impenetrable facets of the full forecast system.

Underlying motivation:
To maximize the benefits of initializing soil moisture in forecasts, it helps to understand how soil moisture contributes to forecast skill.

Water balance equation:

Soil profile water holding capacity

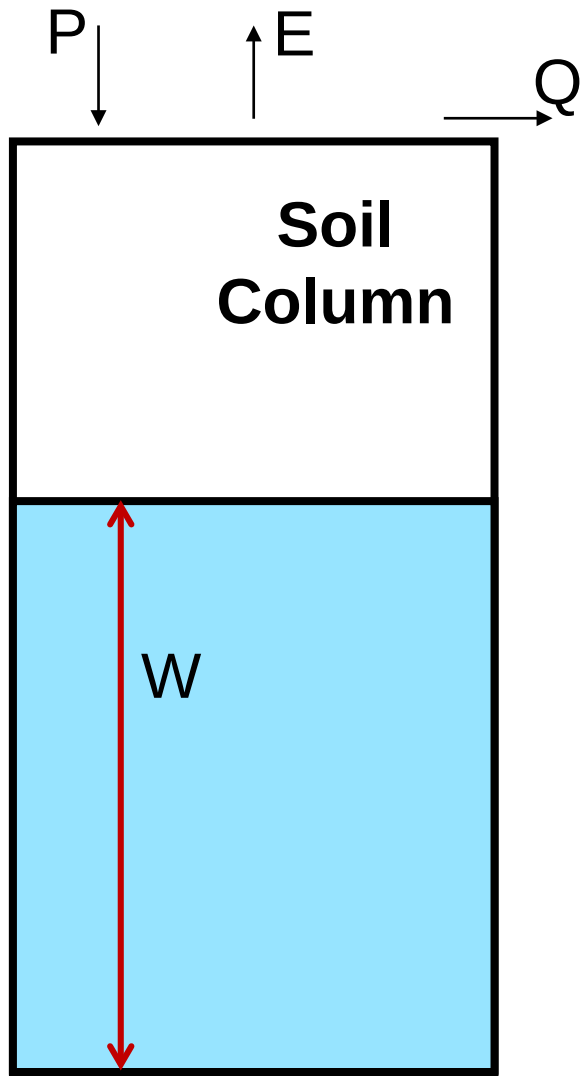
Precipitation

Evapotranspiration

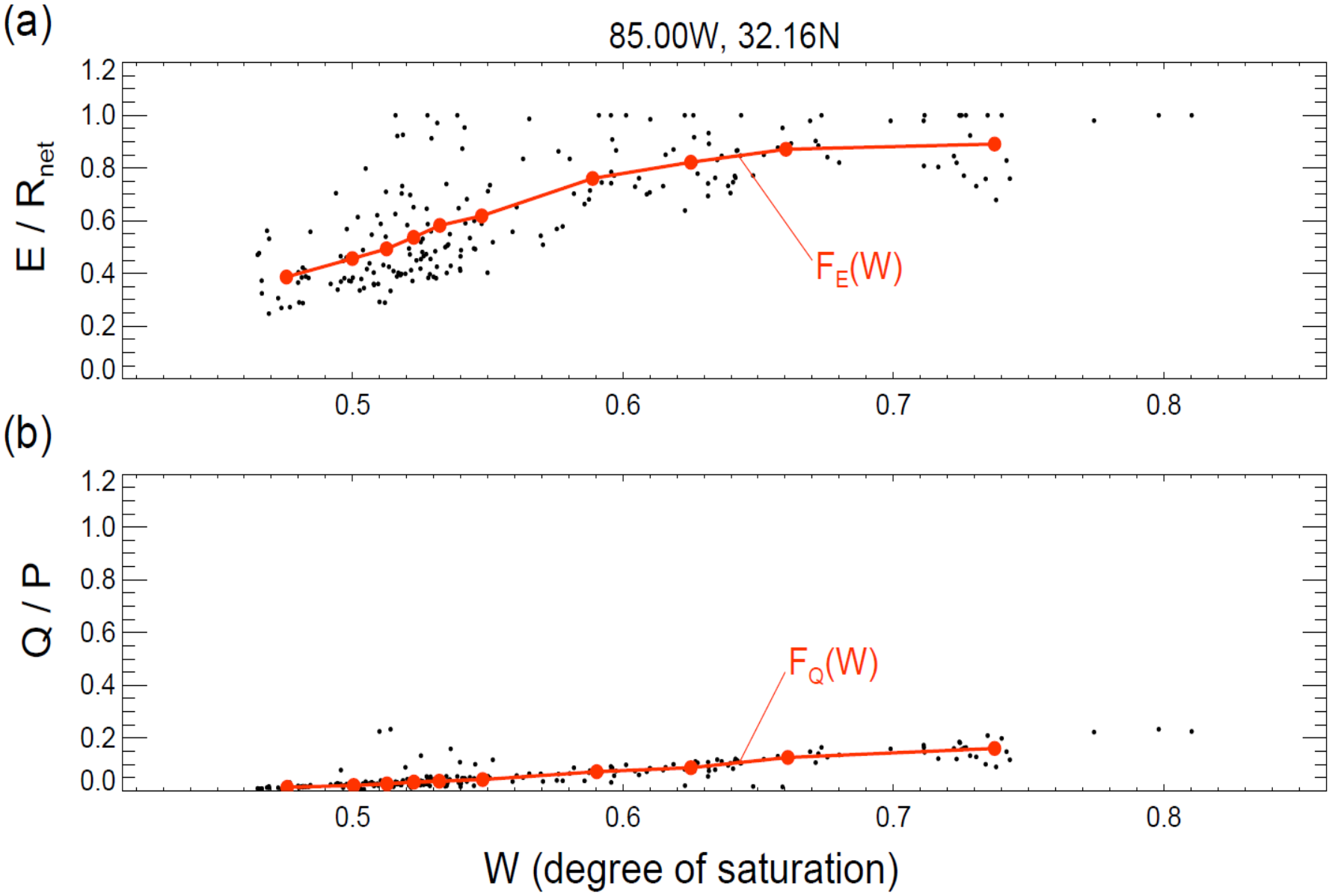
$$C\,W_{n+1} = C\,W_n + P_n - E_n - Q_n,$$

Soil moisture at start of day n (degree of saturation)

Total runoff

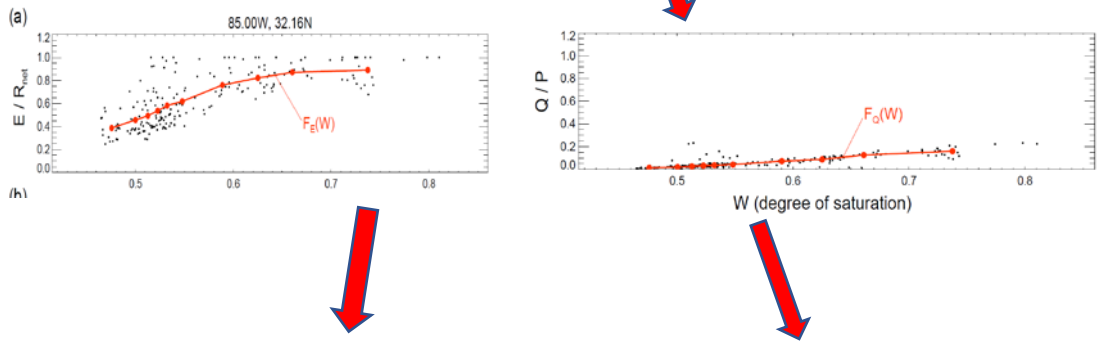


We can fit relationships (using MERRA-2) between W and both E and Q:



Replace

$$C\,W_{n+1} = C\,W_n + P_n - E_n - Q_n$$



with

$$C\,W_{n+1} = C\,W_n + P_n - F_E(W_n)\,R_{net\text{-}n} - F_Q(W_n)\,P_n$$

Replace

$$C\,W_{n+1} = C\,W_n + P_n - E_n - Q_n$$

with

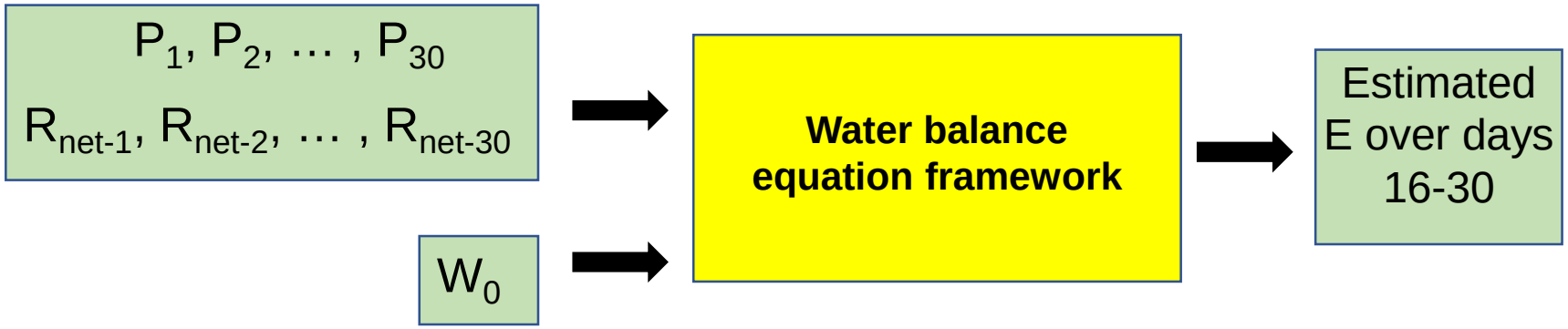
Forcing from atmosphere

$$C\,W_{n+1} = C\,W_n + P_n - F_E(W_n)\,R_{net\text{-}n} - F_Q(W_n)\,P_n$$

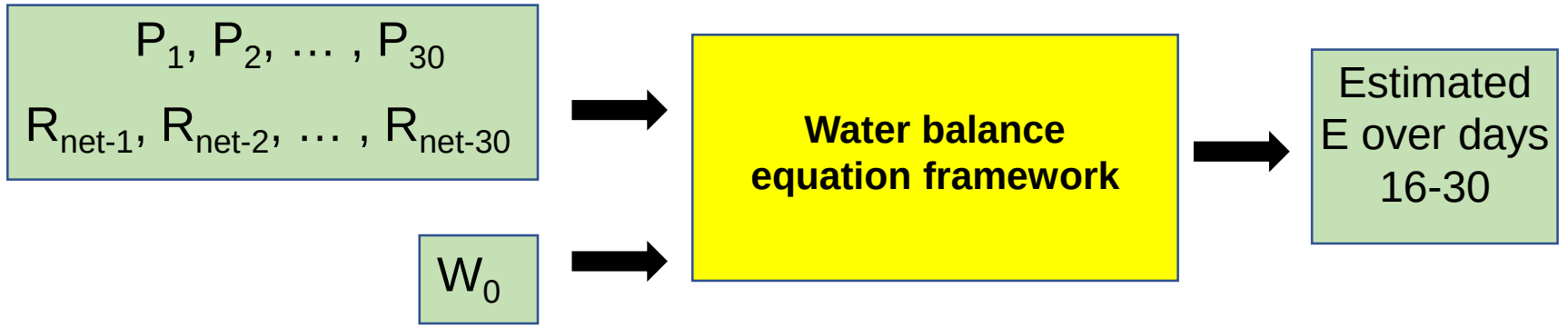
Prescribed boundary condition

Predetermined from MERRA-2
(independent time period)

Basic approach:

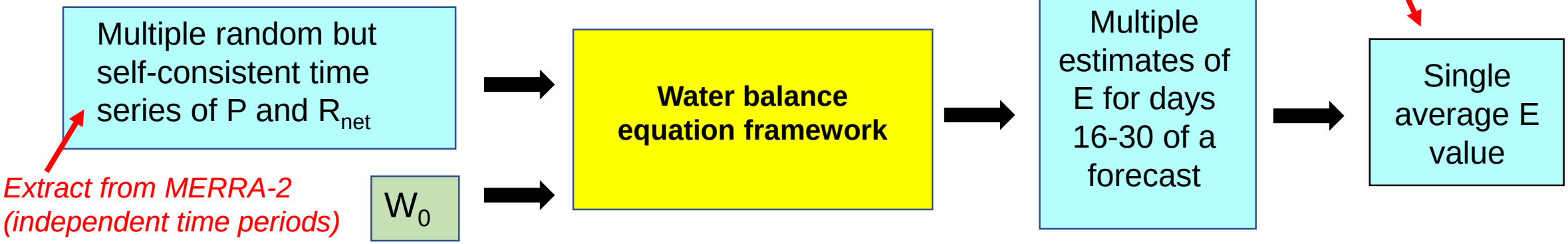


Basic approach:



Approximation for subseasonal (days 16-30) prediction :

For a given location and time of year, this average E value effectively varies only with W_0.



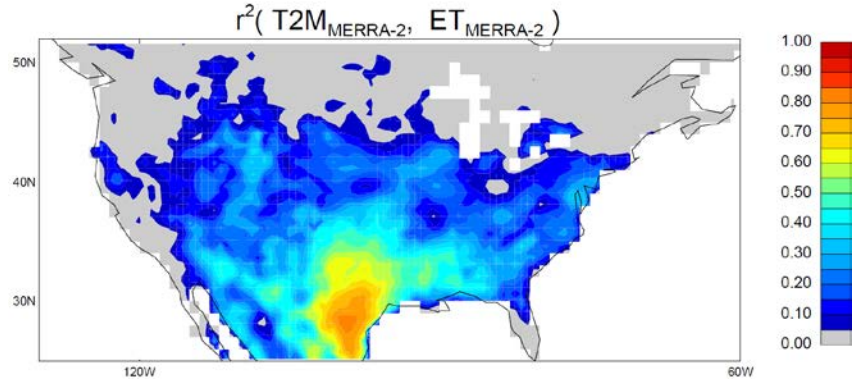
Some details have been glossed over in the interest of time, but…

We can use this simple framework to translate an initial soil moisture into an estimate of evapotranspiration at subseasonal time scales – *an estimate not dependent on forecasted meteorology*.

Note also that evapotranspiration and air temperature (T2M) are strongly linked:

Higher E ⇨ More evaporative cooling of system ⇨ Lower T2M

Under the assumption that
ΔT2M (days 16-30) ~ ΔE (days 16-30),
we can also use the framework to translate an initial soil moisture into an estimate of T2M at subseasonal time scales.



Big question: How well does the simple approach work?

Related questions:

1) Does it capture the control of soil moisture over E and T2M in a full subseasonal forecast system?

2) If so, does it reveal useful insights into the forecast system?

Seasonal forecasting system examined: GMAO's GEOS S2S Version 2.

Forecast focus: Continental US

Years examined: 1999-2015

Source of W_0 values: MERRA-2

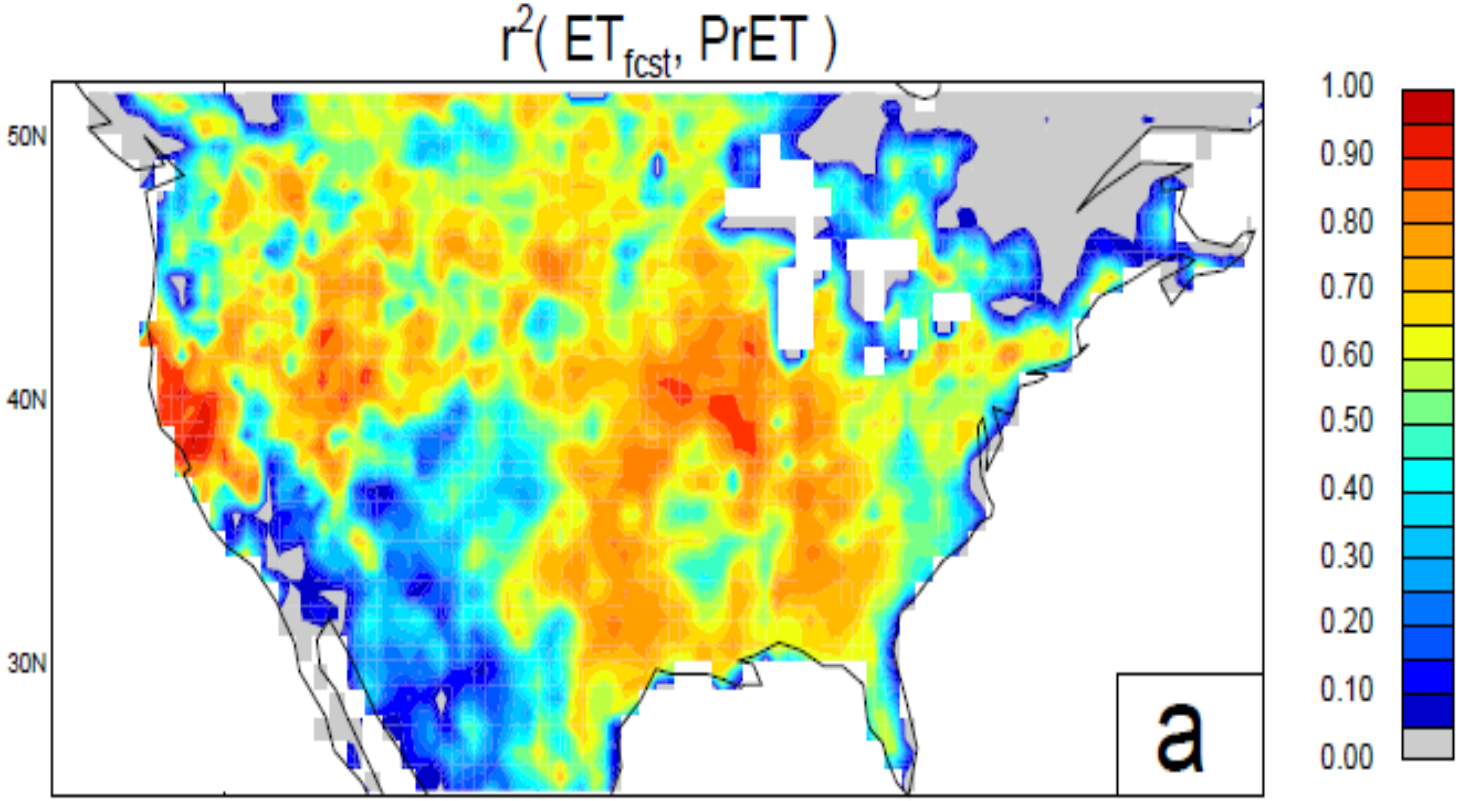
Source of $F_E(W)$ and $F_Q(W)$ relationships: MERRA-2 (independent time period).

Validation data for T2M: CPC station-based observations

For forecasts initialized June 5, June 20, July 5, July 20, August 4, and August 19, analyze E and T2M (air temperature) on days 16-30 of the forecast.

The GEOS S2S system provides estimates of ET on days 16-30 of a forecast, as does the above simple mathematical treatment. How well do the estimates agree?

Quite well, across much of the US!



Implication: Initial soil moisture largely determines the E produced by the S2S system on days 16-30 of a forecast.

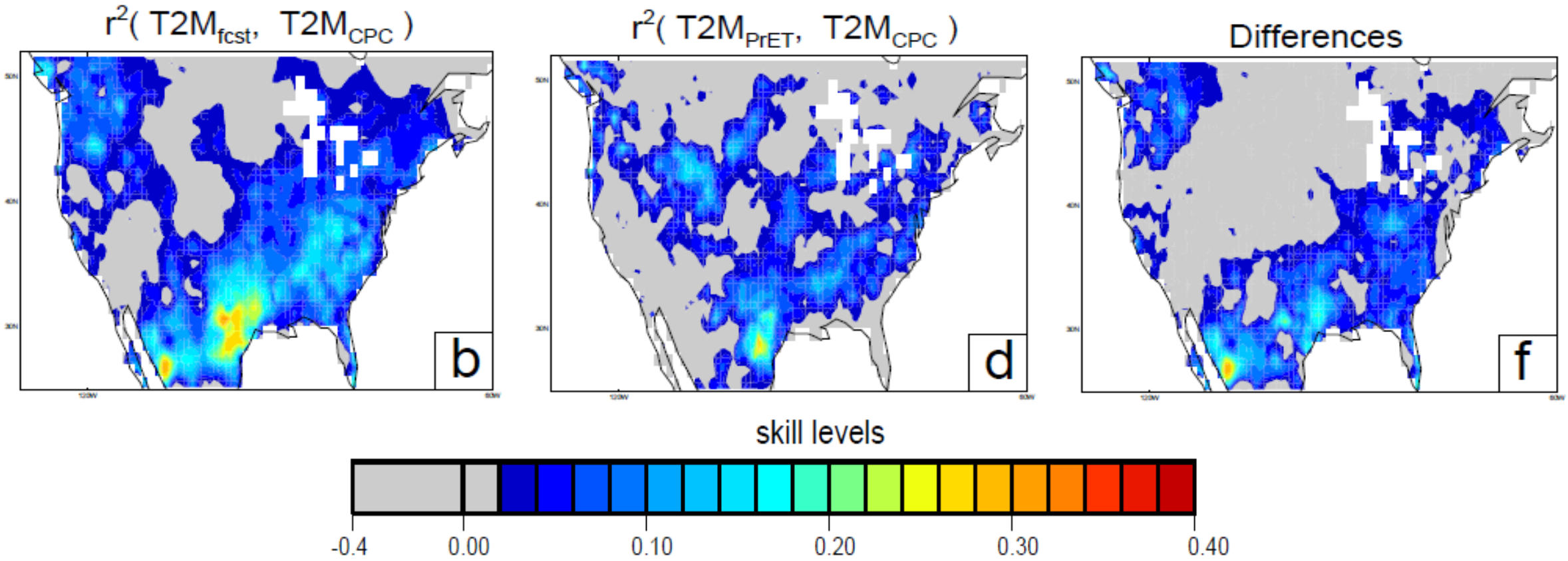
Yes, but what about the contribution of soil moisture initialization to actual forecast skill (i.e., against observations)?

No fully independent, direct observations of E are available.

We do, however, have direct measurements of T2M.

Skill of full GEOS S2S system in predicting observed T2M on days 16-30
Observations: CPC data

Skill of simple mathematical framework in predicting observed T2M on days 16-30
Observations: CPC data



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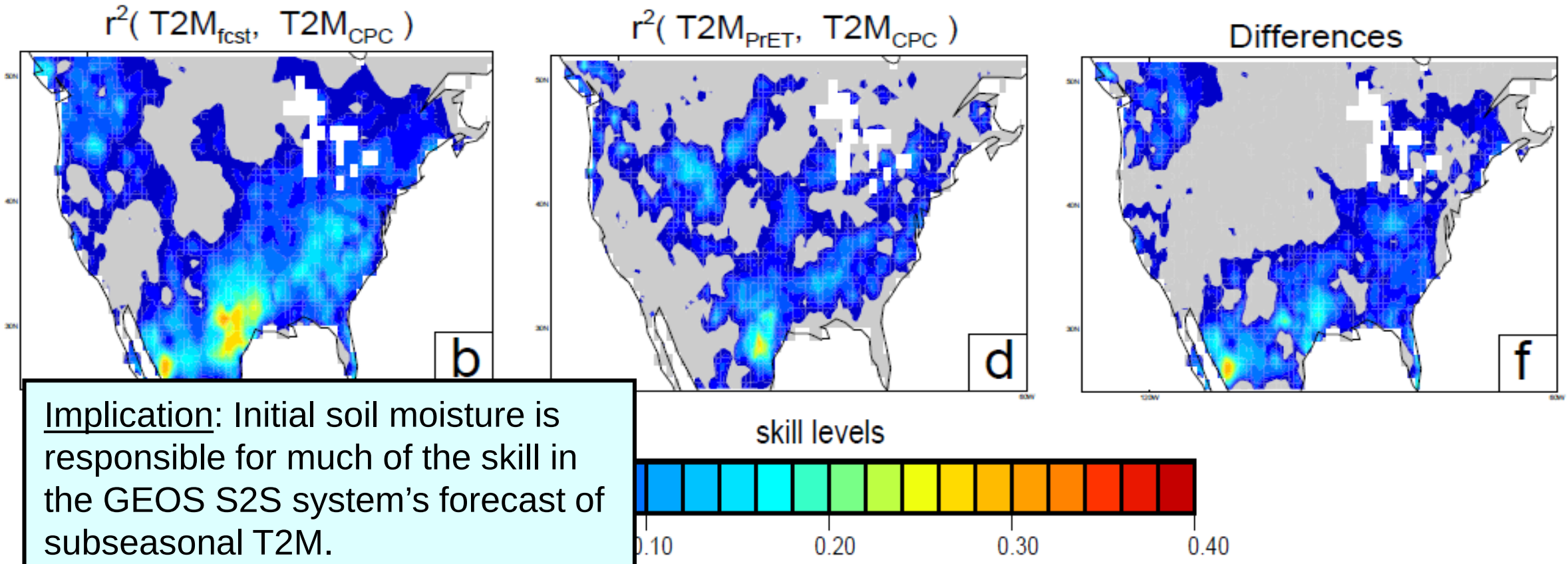
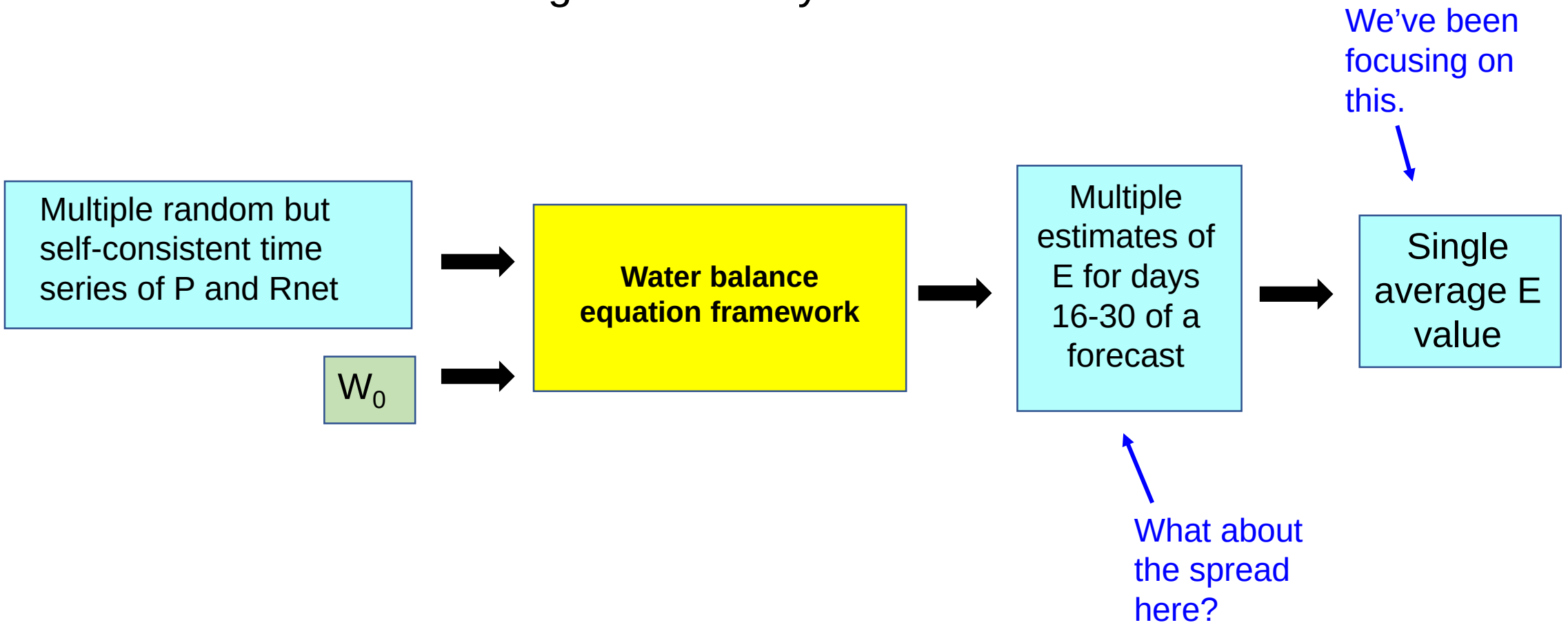


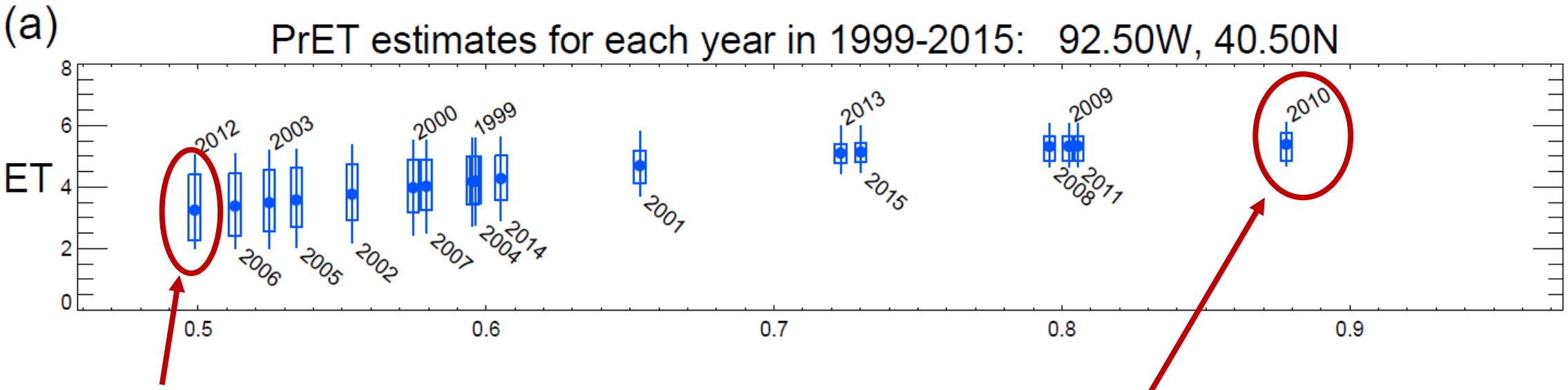
Implication: Initial soil moisture is responsible for much of the skill in the GEOS S2S system's forecast of subseasonal T2M.

Beyond demonstrating the overall importance of soil moisture for forecasts, the simple representation can also address *forecast uncertainty.*

Another facet of forecasting: Uncertainty



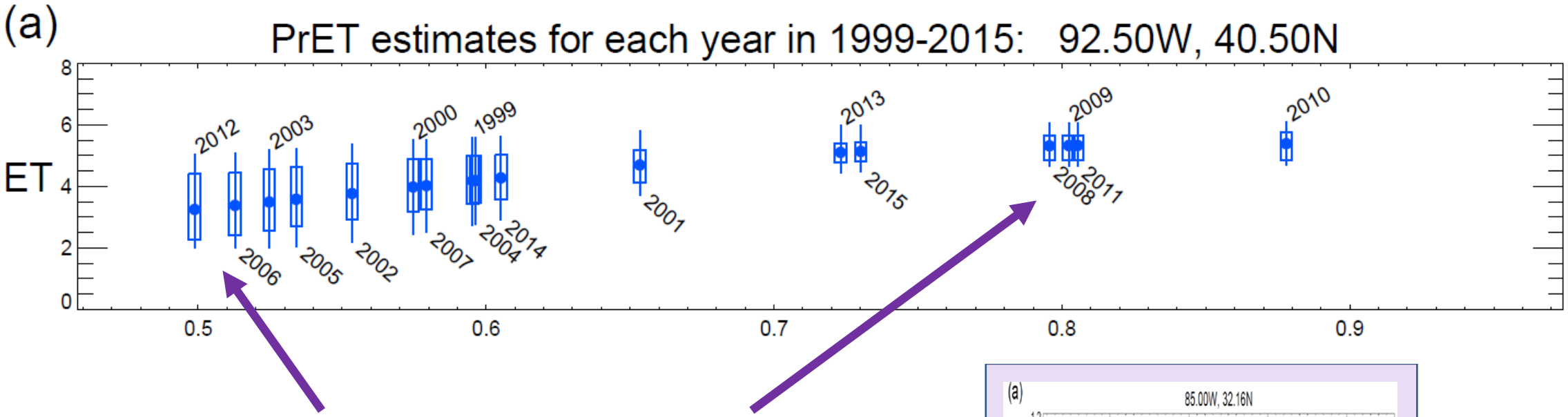
Using values of July 5 W_0 from different years, we get different means and ranges of "forecasted" E at subseasonal time scale (July 20-Aug. 3):



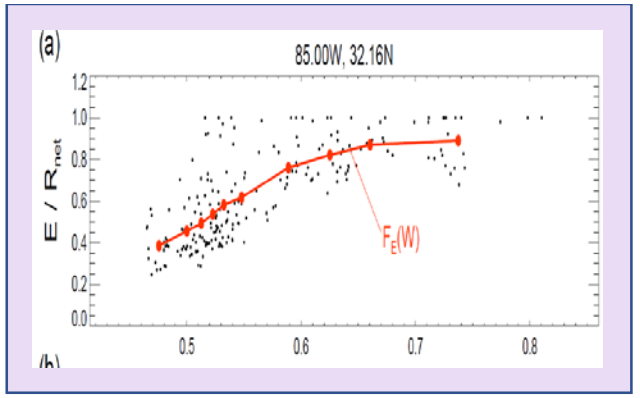
Estimated mean and range for 2012 subseasonal forecast, based on W for July 5, 2012

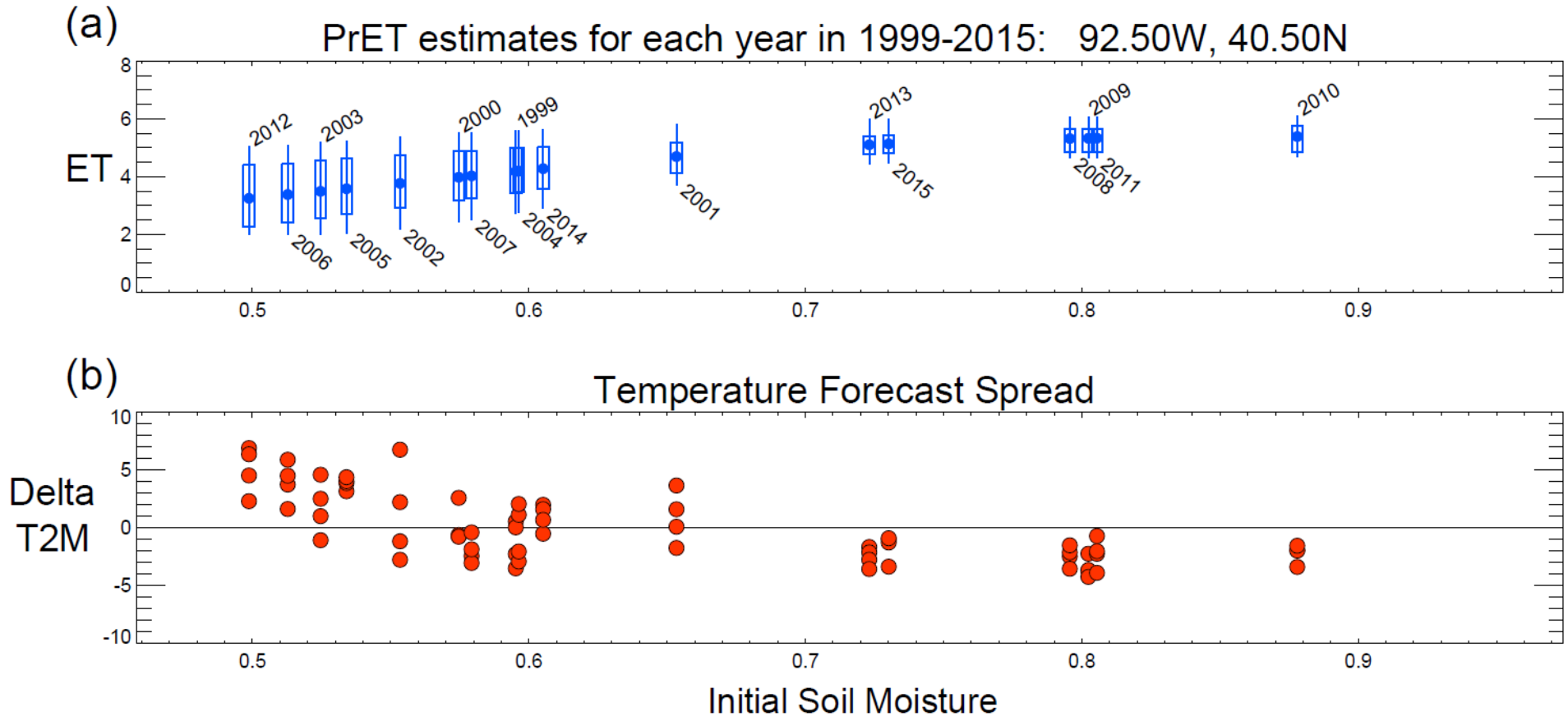
Note smaller range for 2010 subseasonal forecast
⇨ implies reduced uncertainty!

Using values of July 5 W_0 from different years, we get different means and ranges of "forecasted" E at subseasonal time scale (July 20-Aug. 3):



Differences in spread found to be a direct result of nonlinear ET-vs-W relationship.





Differences in spread are generally consistent with ensemble spread of S2S T2M forecasts

⇨ ***The S2S system is more confident of its T2M prediction when soil moisture starts out wet***.

Summary

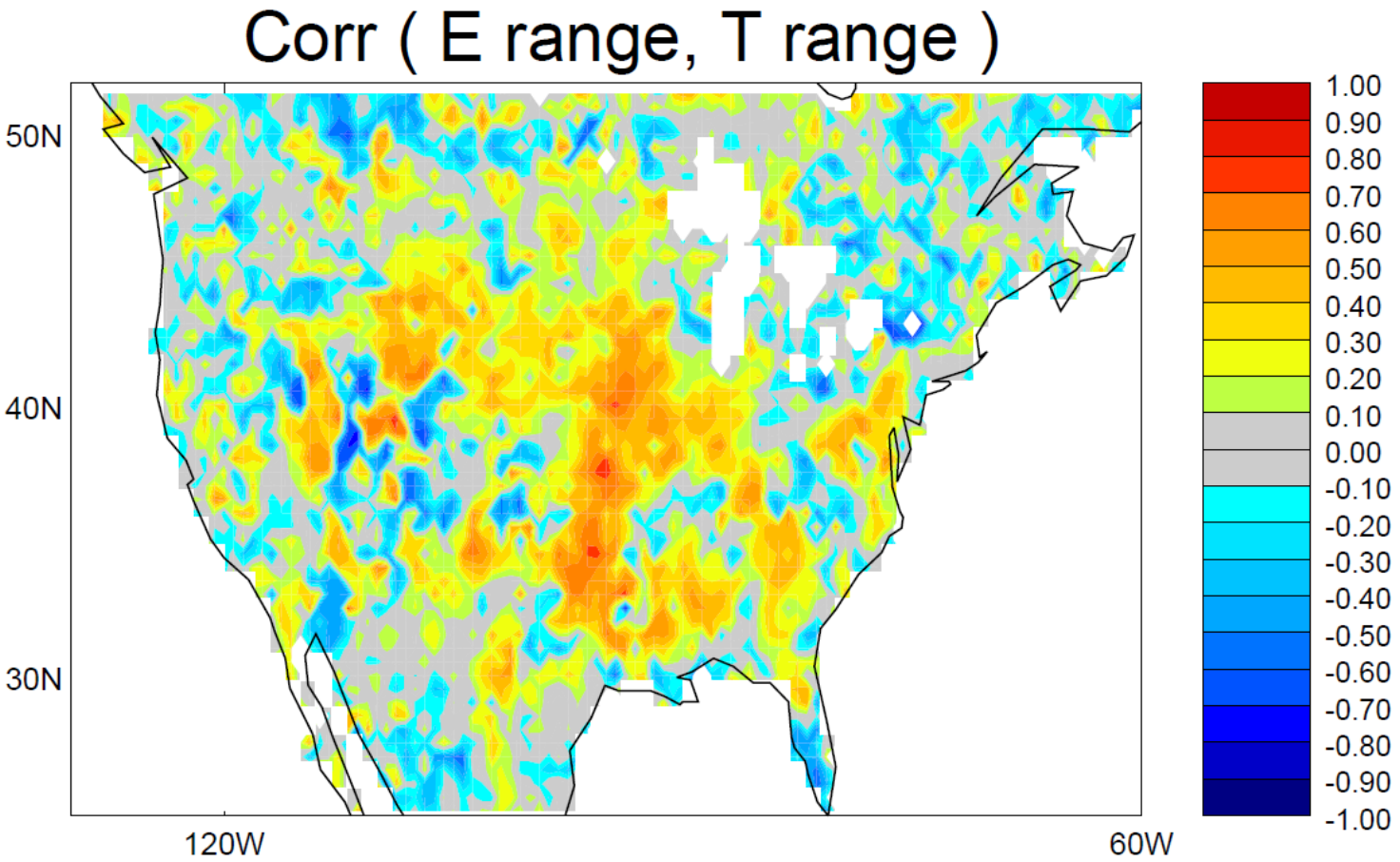
A simple framework based on the soil column water balance is developed and used to analyze the behavior of the full GEOS S2S Version 2 forecast system.

Our findings indicate:

- The 16-30 day evapotranspiration rate forecasted by the S2S system is very largely determined by the initial soil moisture, W_0.
- The 16-30 day T2M forecasted by the system is largely determined by W_0, though other factors (advected winds, rainfall regime, cloudiness, etc.) also contribute.
- W_0 accordingly contributes significantly to T2M forecast skill.
- The simple framework offers the tantalizing prospect of pre-assigning confidence levels to individual E and T2M subseasonal forecasts.

} New science made possible!

Extra slides

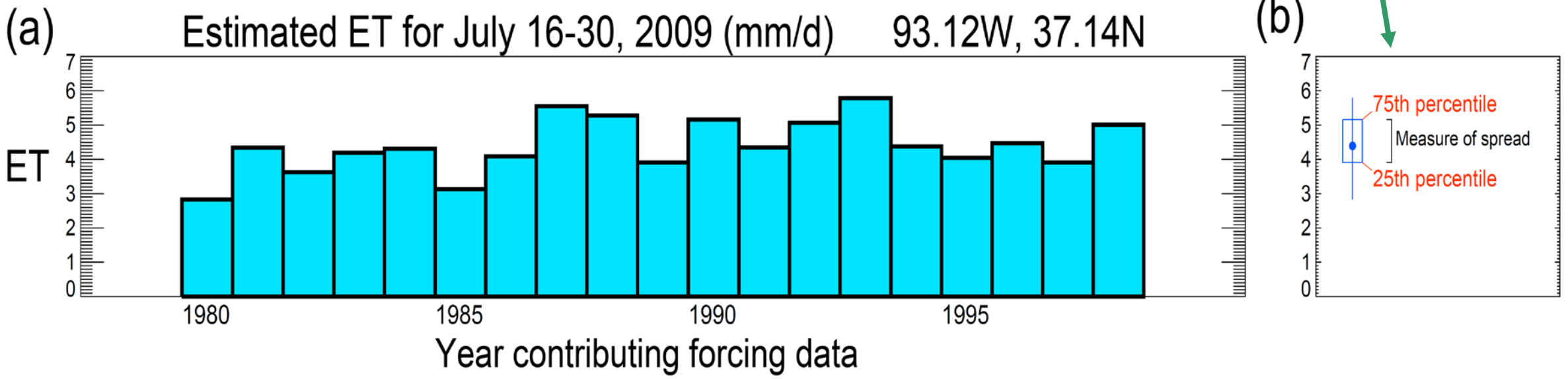

Corr (E range, T range)
50N
40N
30N
120W
60W
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
-0.60
-0.70
-0.80
-0.90
-1.00

Sample calculation: Start with soil moisture on July 1 of 2009. Use "random" P and R_{net} forcing extracted from MERRA-2 (independent time period).

Get 19 estimates of E for July 16-30, 2009

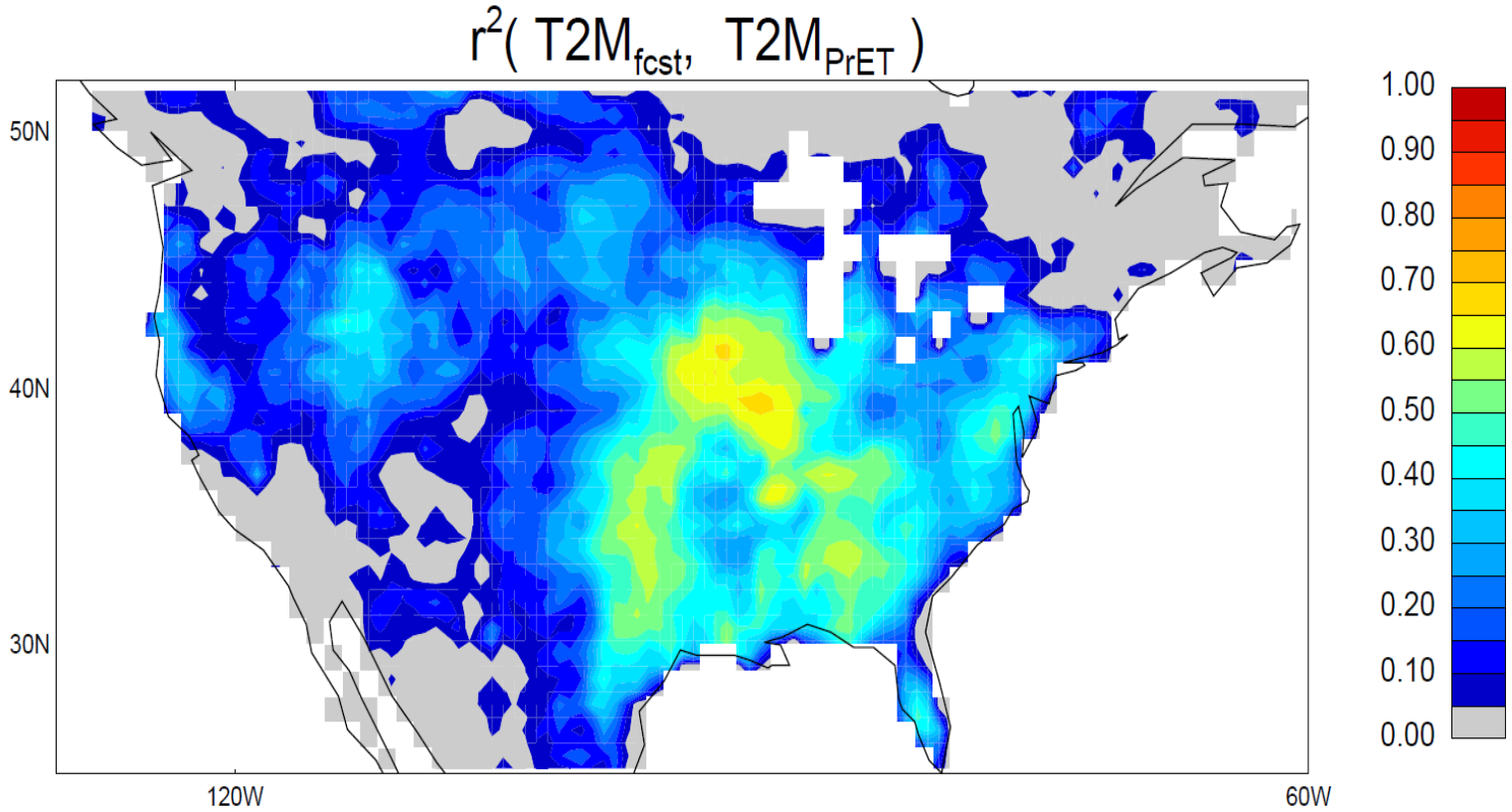
Characterize all these histogram bars…

…with a single box-and-whisker plot.



Estimates of ΔT2M (days 16-30) also agree (to a certain extent) with the T2M forecasted with the full GEOS S2S system.

Reasonably large r^2 values across much of CONUS.



Implication: Initial soil moisture largely determines the T2M produced by the S2S system on days 16-30 of a forecast.

Skill of full GEOS S2S system in predicting "observed" T2M on days 16-30
"Observations": MERRA-2

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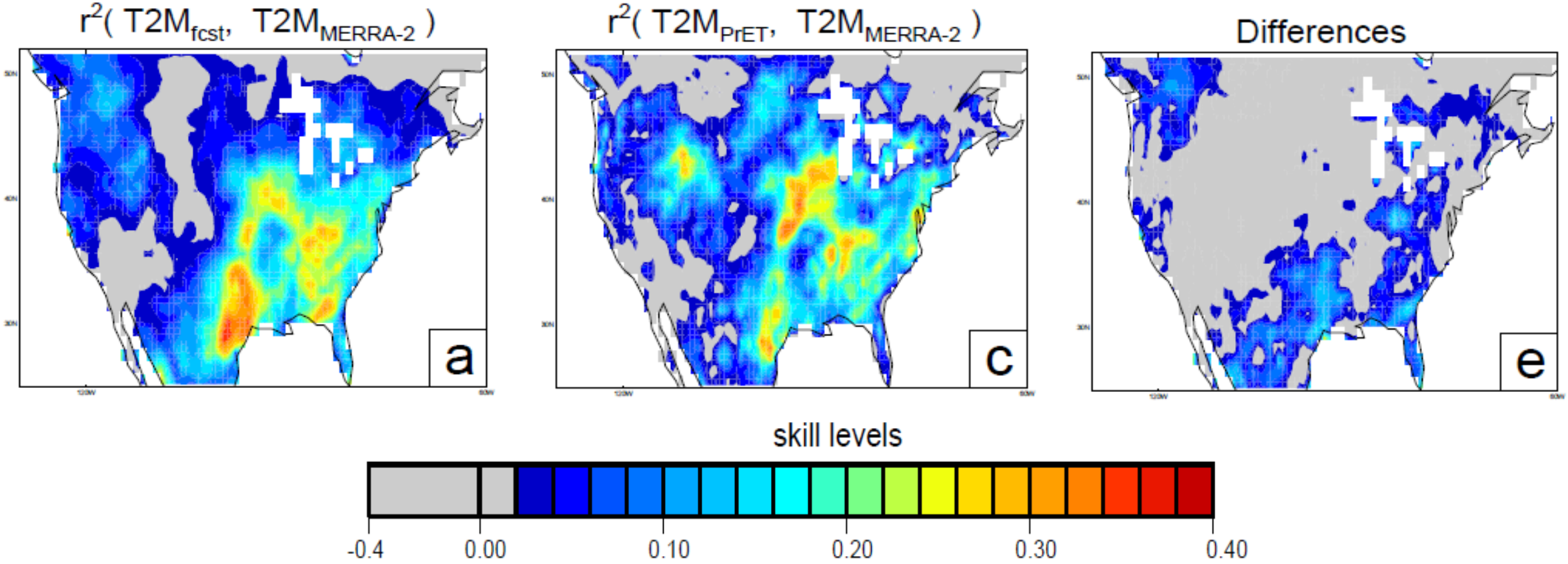

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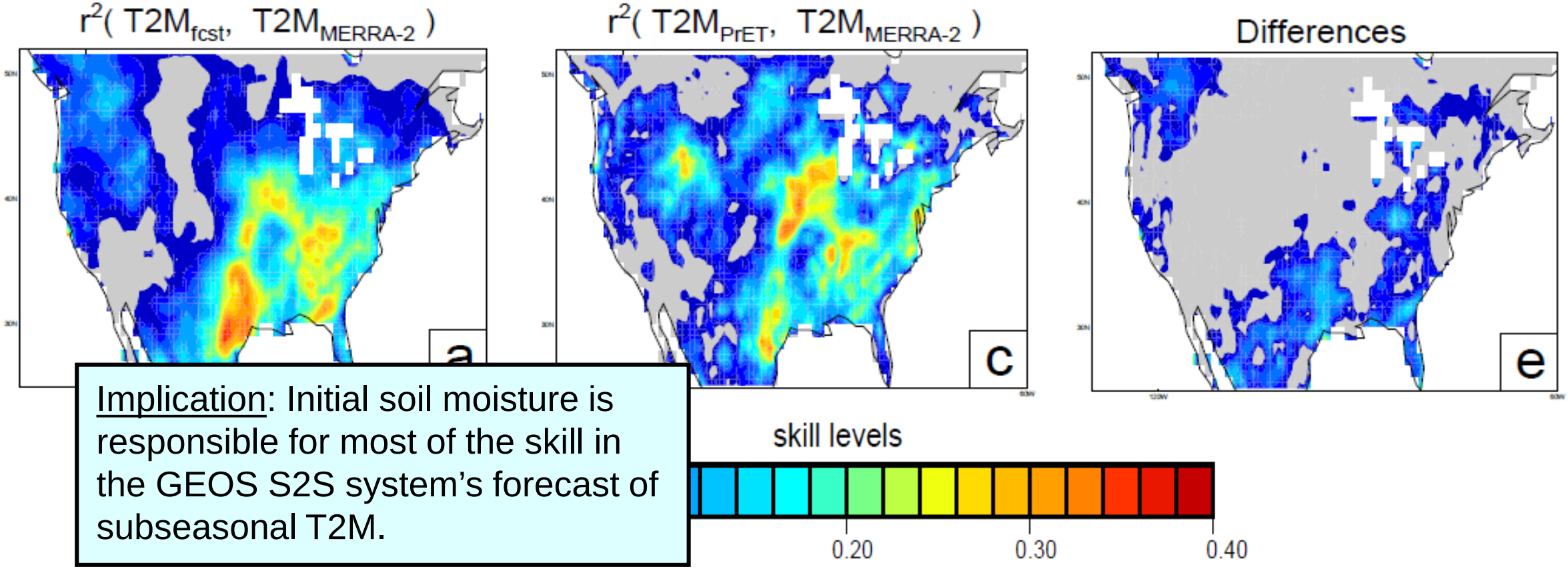


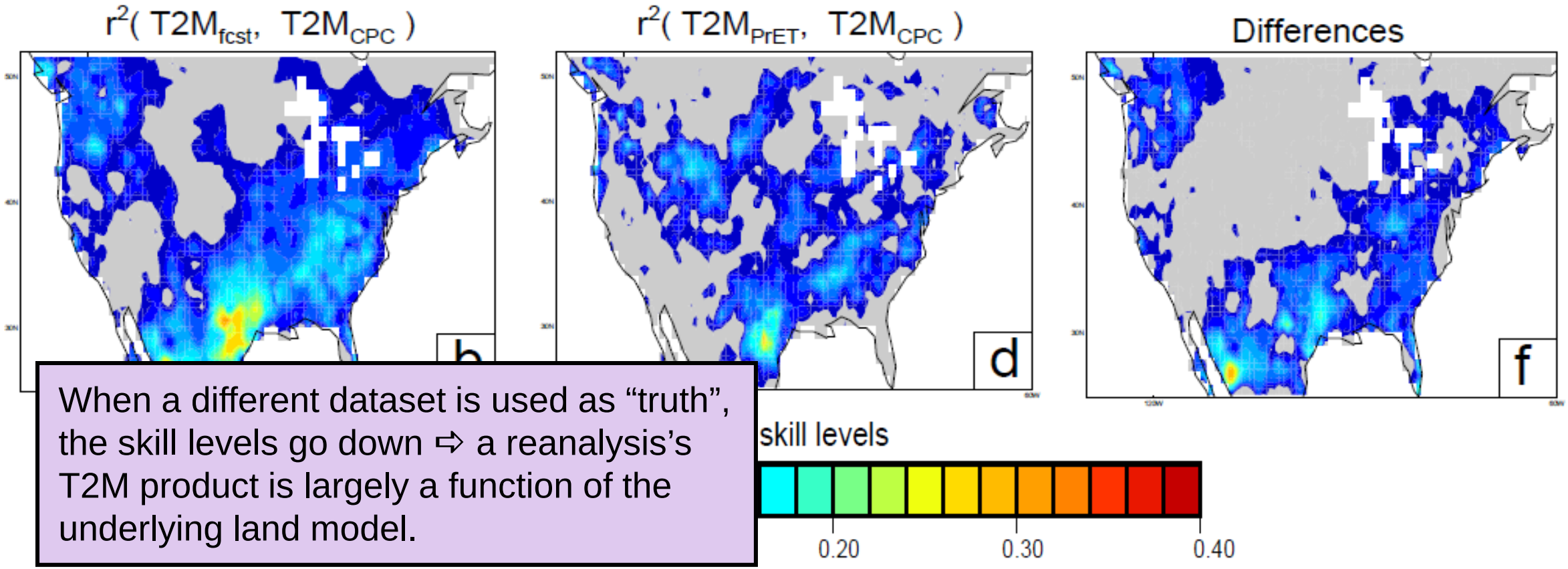
Implication: Initial soil moisture is responsible for most of the skill in the GEOS S2S system's forecast of subseasonal T2M.

Skill of full GEOS S2S system in predicting observed T2M on days 16-30
Observations: CPC data

Skill of simple mathematical framework in predicting observed T2M on days 16-30
Observations: CPC data

CAVEAT!

(Note different observations)



When a different dataset is used as "truth", the skill levels go down ⇨ a reanalysis's T2M product is largely a function of the underlying land model.