Role of land surface states in simulation and prediction of monsoons in CFSv2

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Predictability from Land

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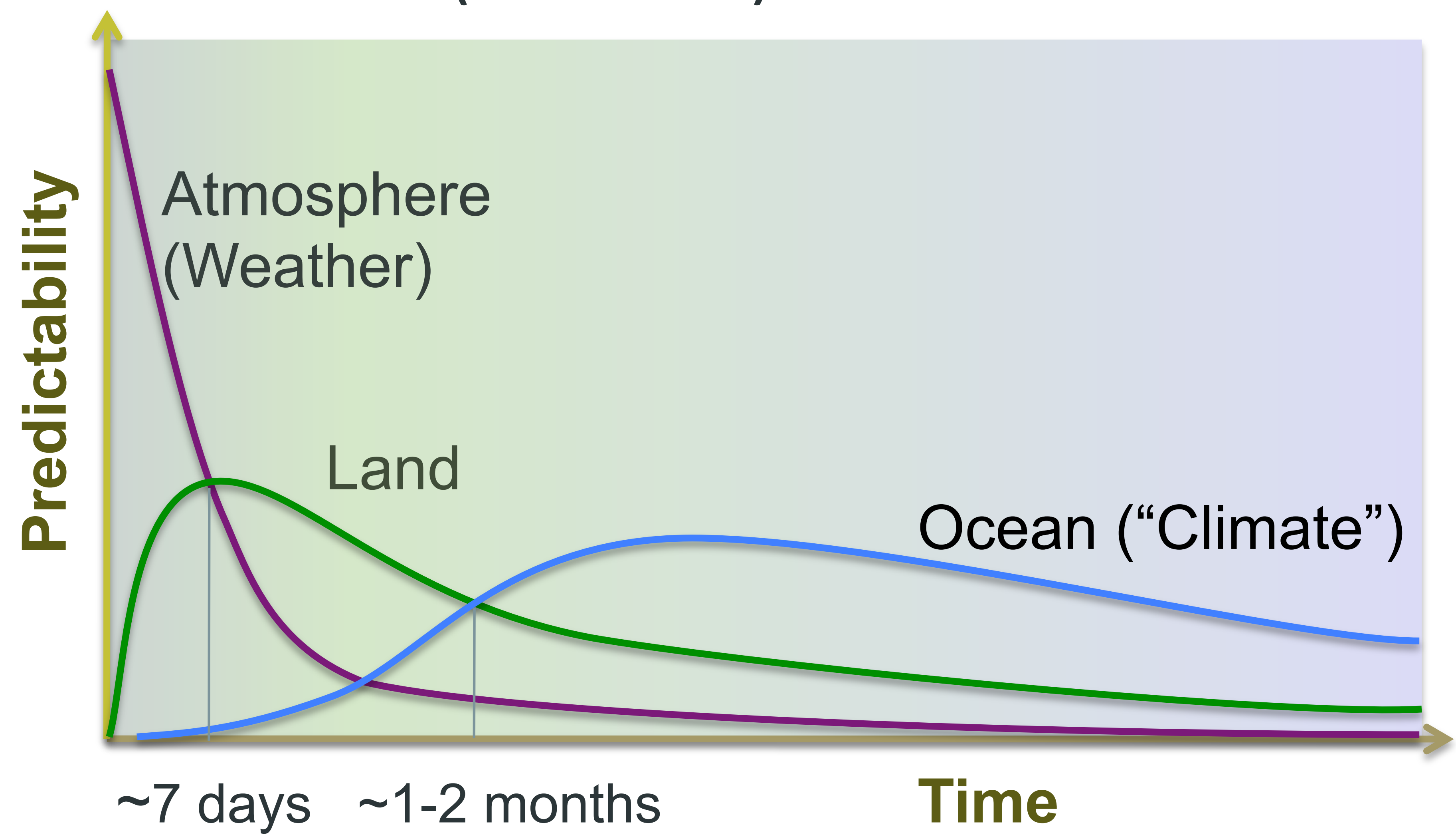

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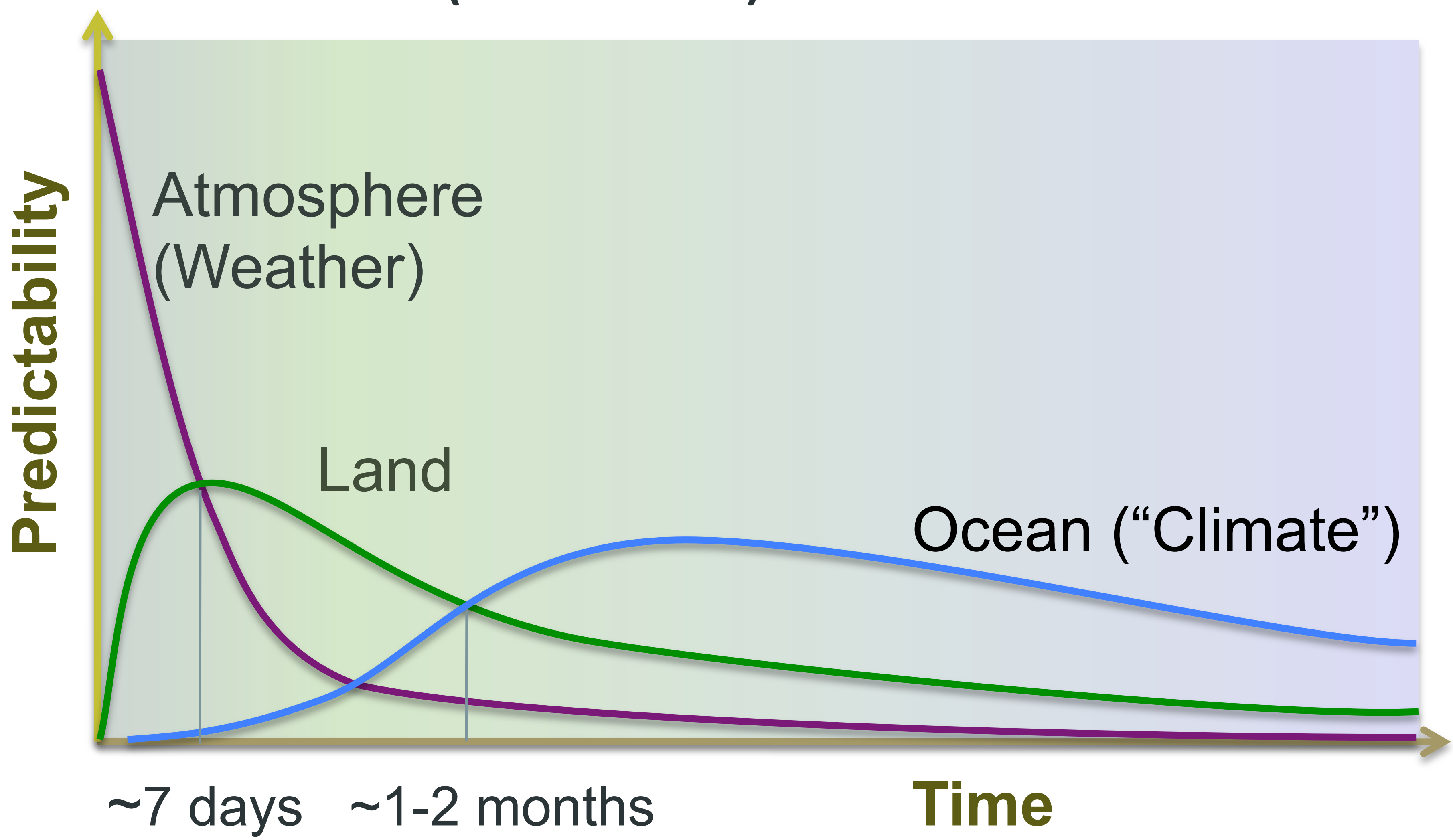

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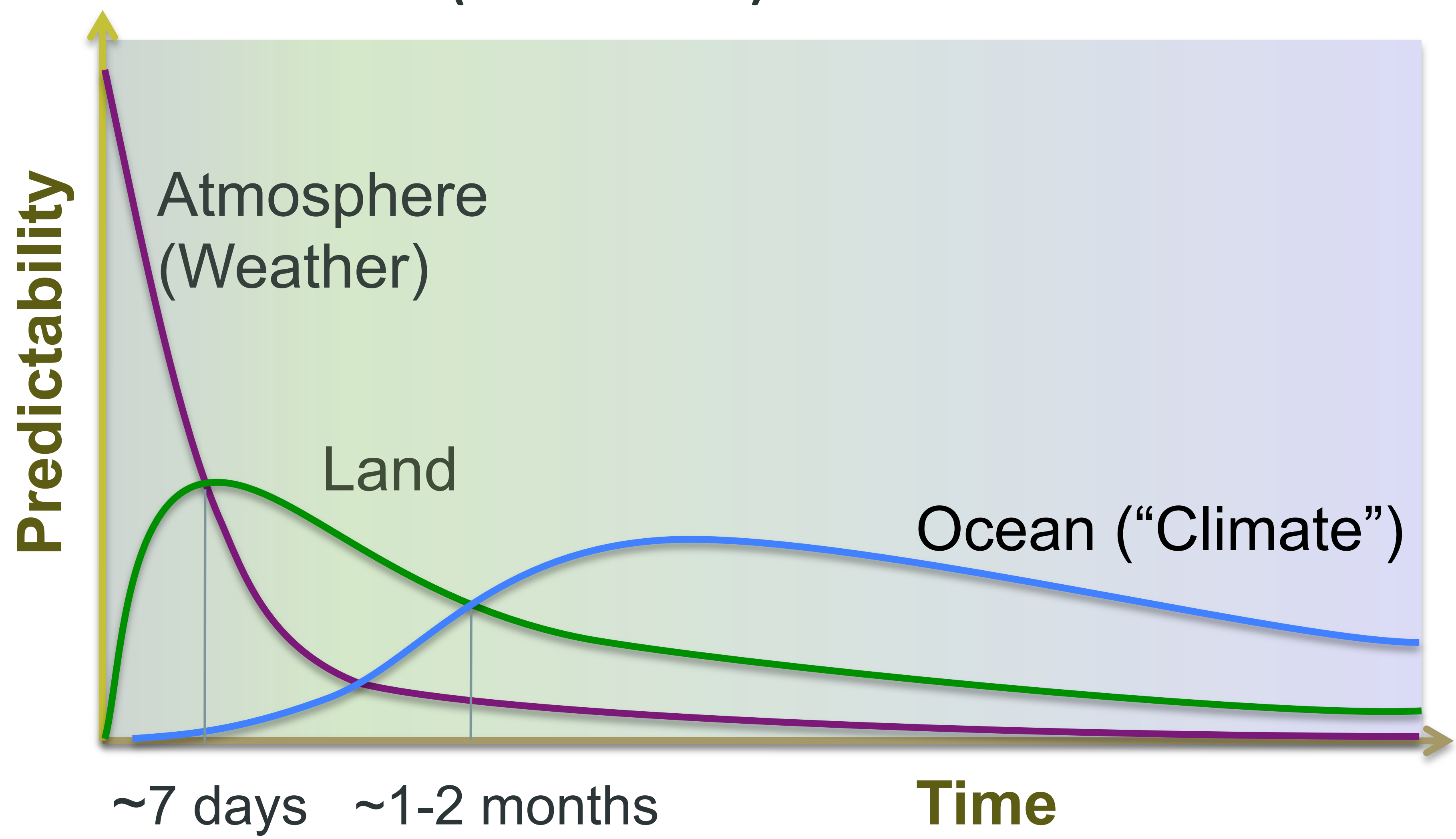

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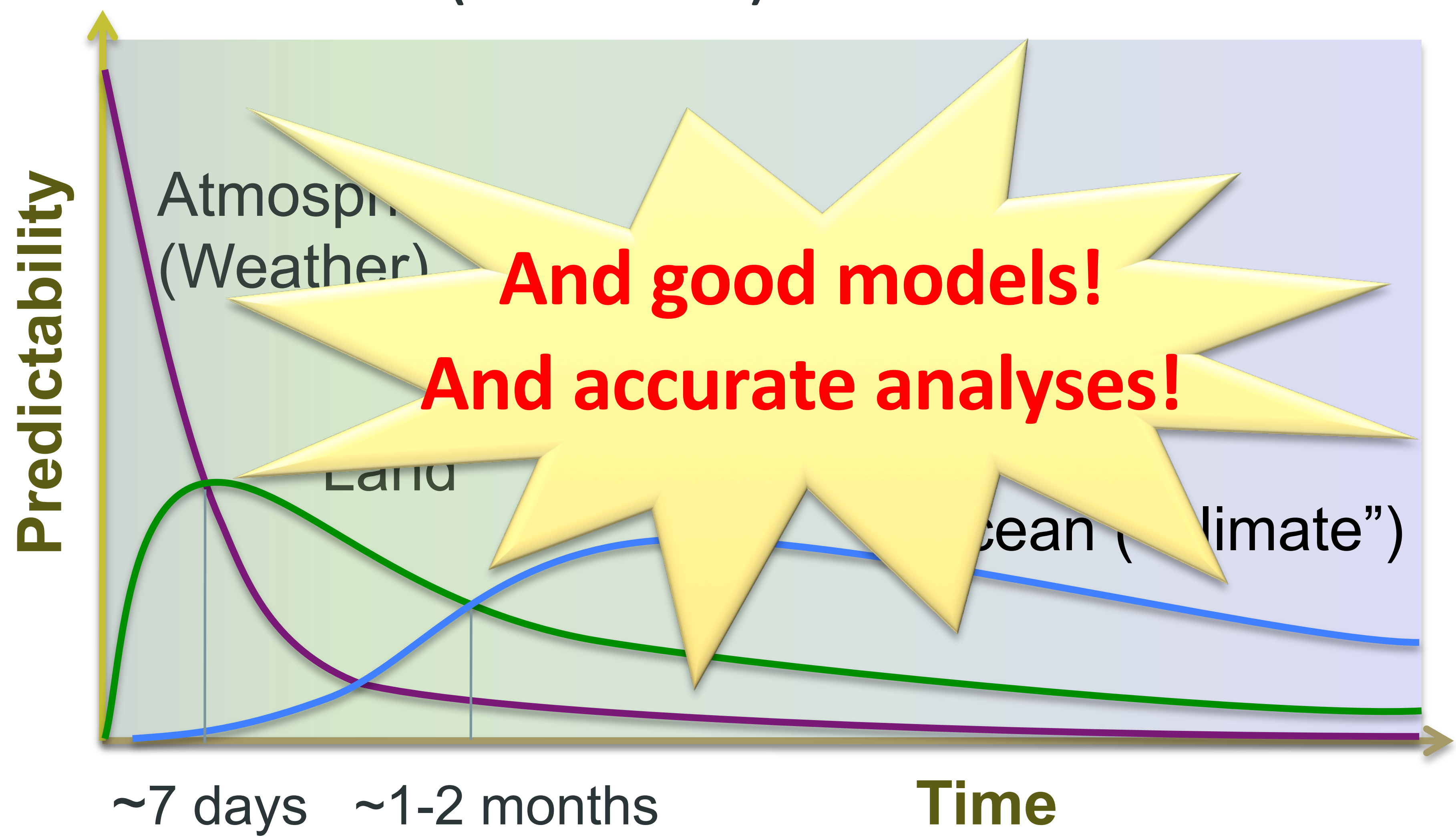

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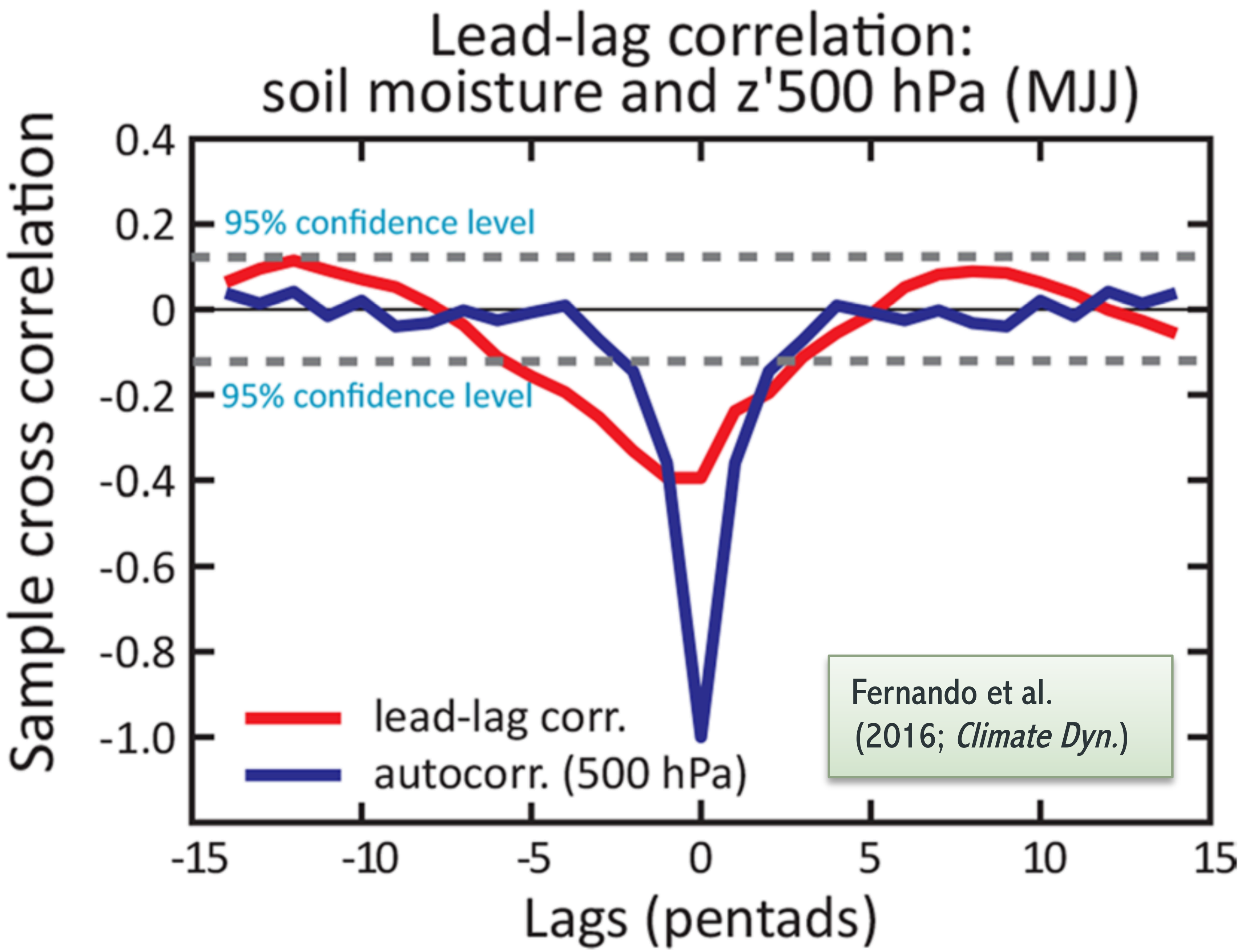
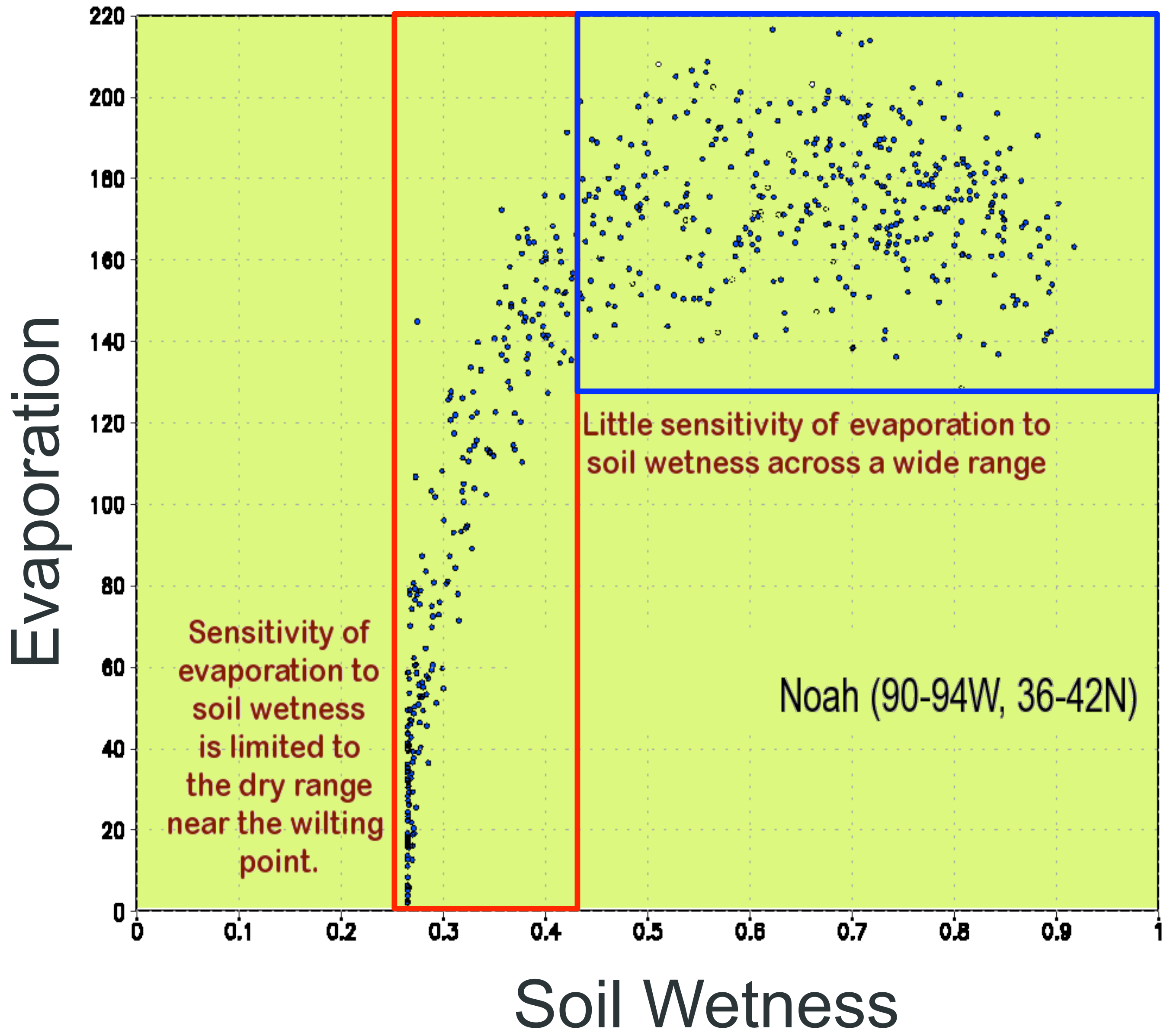


Soil Moisture Controls on Evaporation

- 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).



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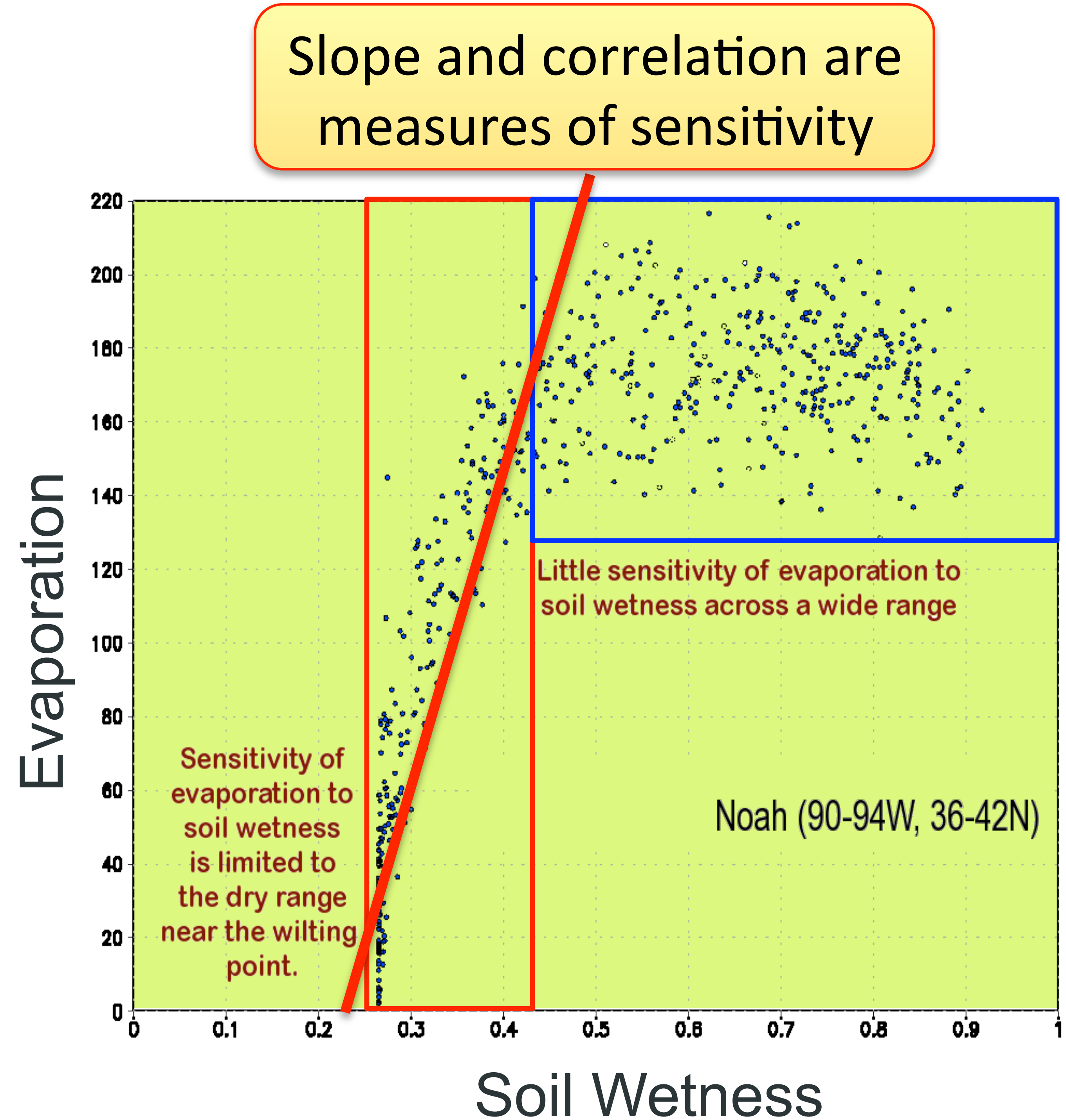

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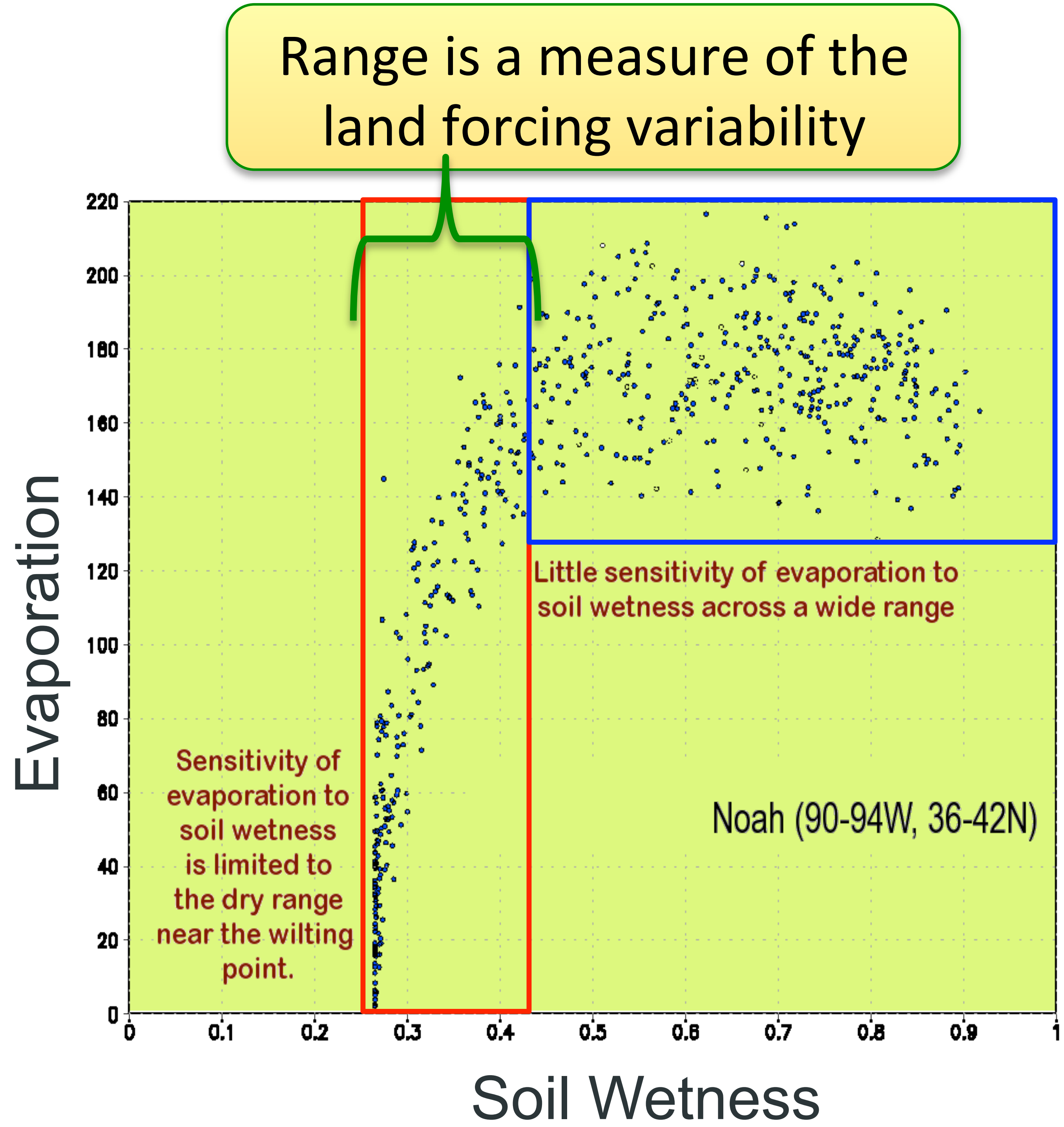

Climate Feedbacks: Three Ingredients

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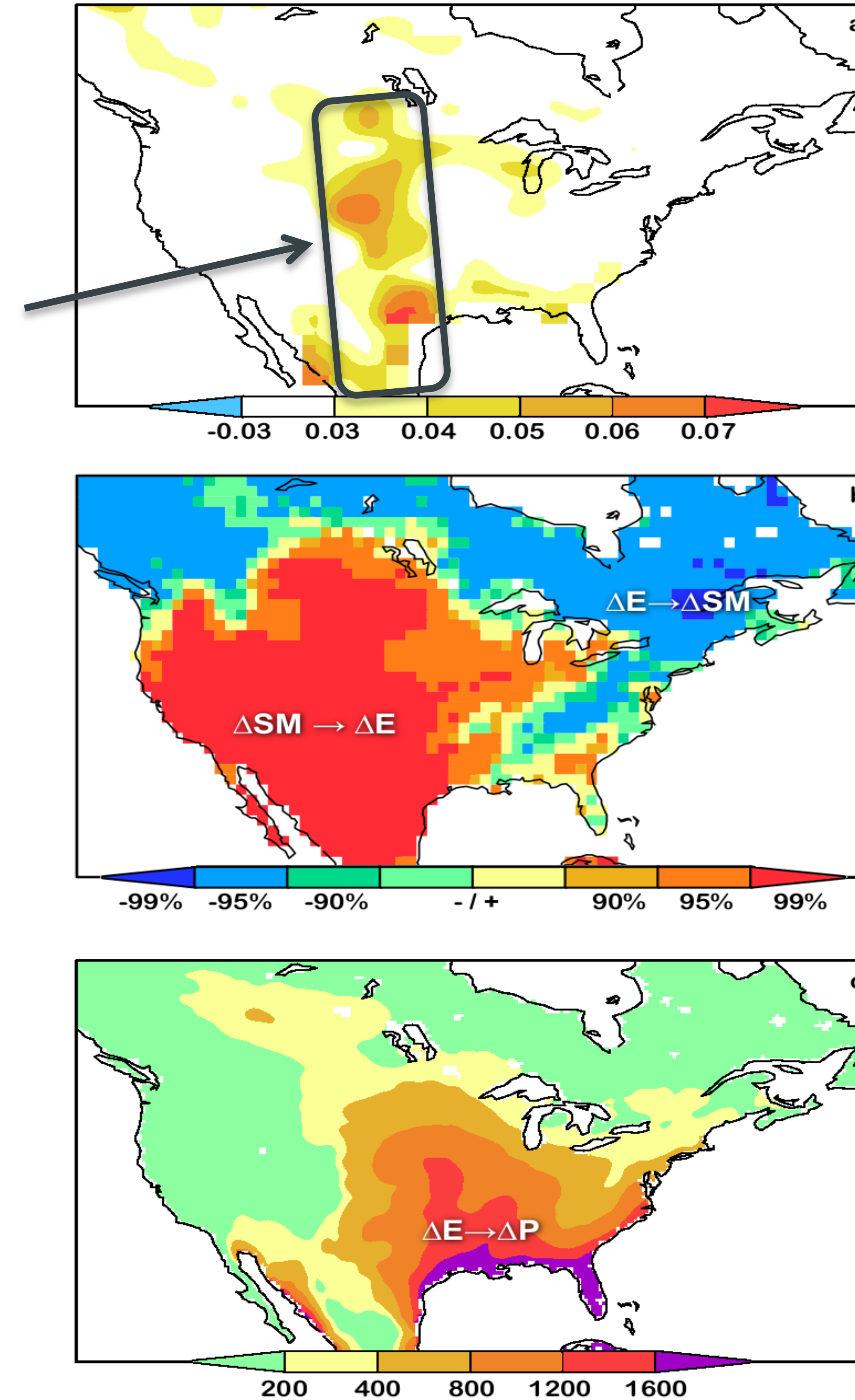

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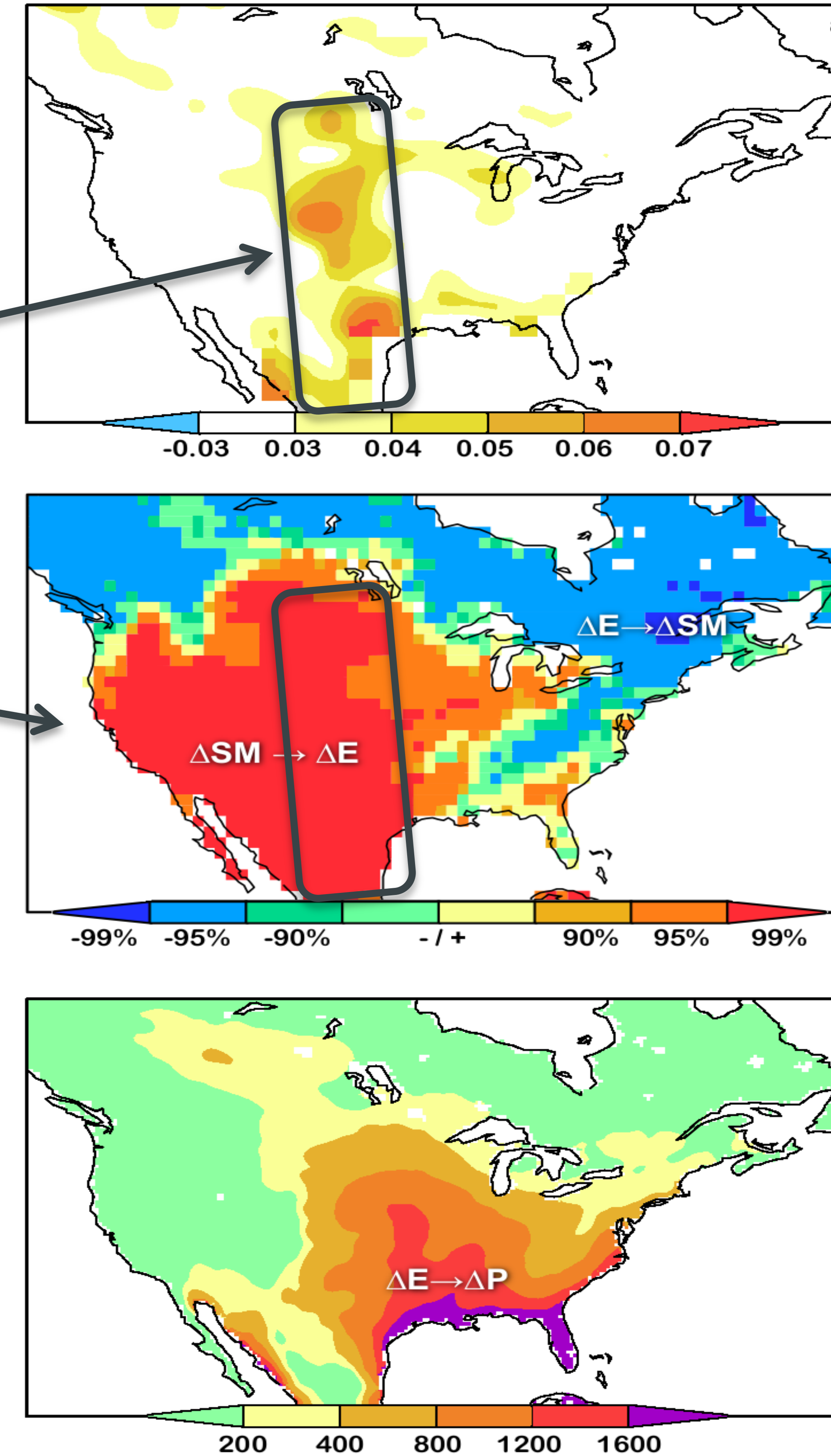
Feedback path: Terrestrial leg



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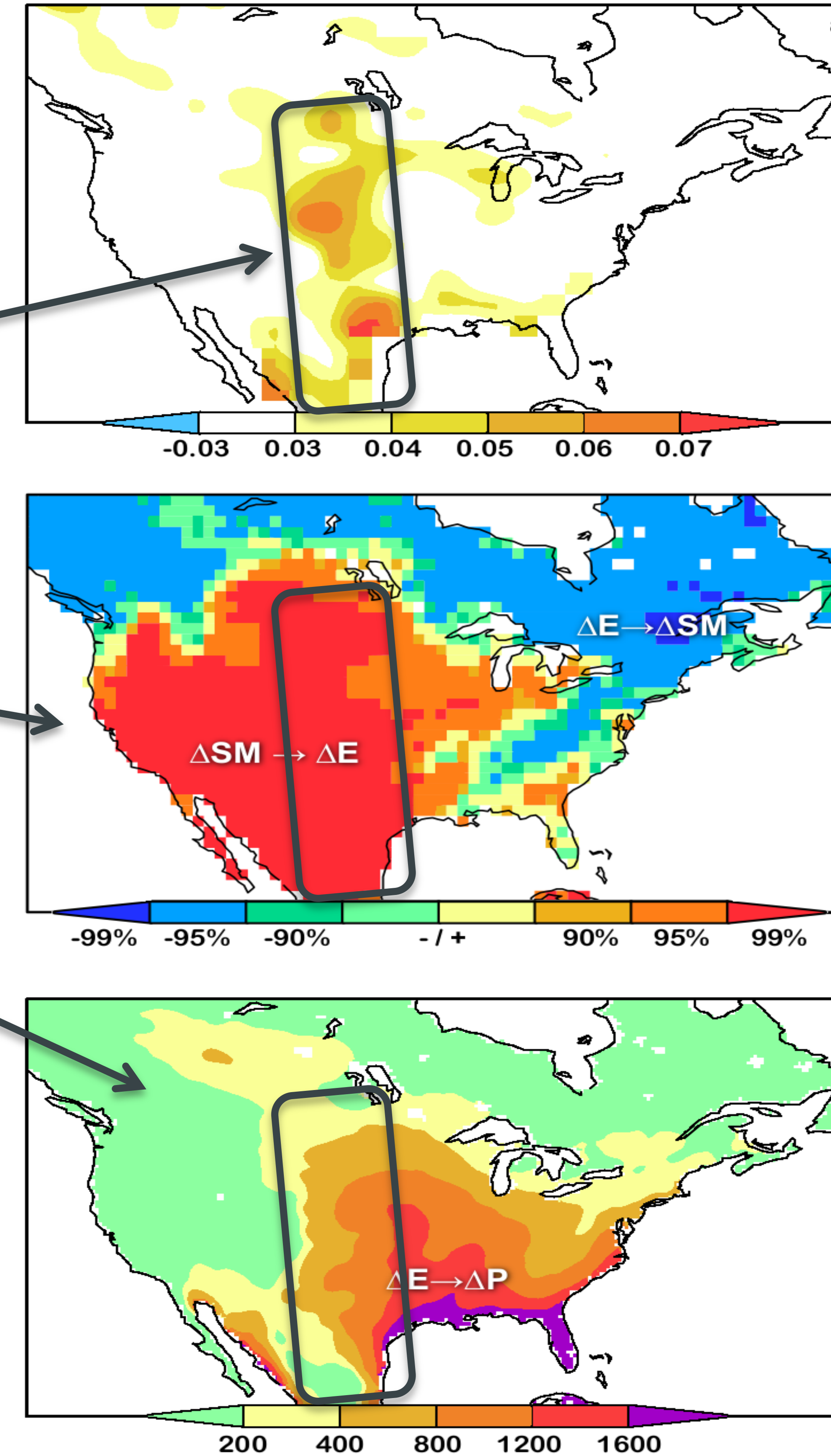
- High CAPE [from the North American Regional Reanalysis, J/kg]

$$\Delta P \Rightarrow \Delta SM \rightarrow \Delta E \rightarrow \Delta P$$

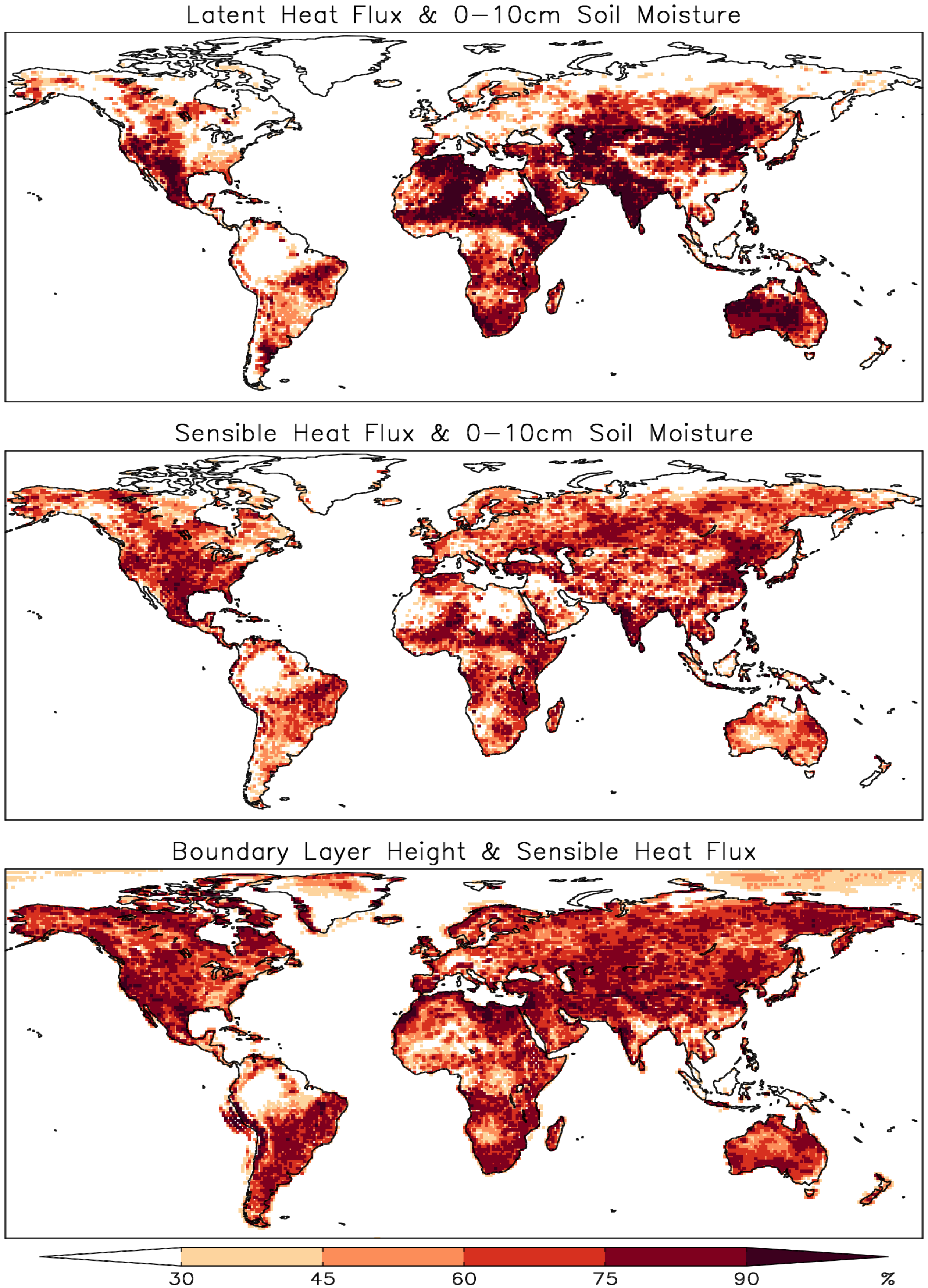
Feedback path: Terrestrial leg ($\Delta SM \rightarrow \Delta E$) Atmospheric leg ($\Delta E \rightarrow \Delta P$)



Sensitivity to Land States

- There is **tremendous sensitivity to soil moisture variations** by surface latent (top) and sensible (middle) heat fluxes in CFS.

Dirmeyer and Halder (2016; *Wea. Forecasting*, in revision).



Explained variance (%) between differences in one day forecasts (June 1) of indicated variables when the only differences in initial conditions are the land states (initial atmosphere and ocean are identical).

Sensitivity to Land States

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- This **sensitivity propagates into the atmosphere**, e.g., PBL height and sensible heat flux (bottom).

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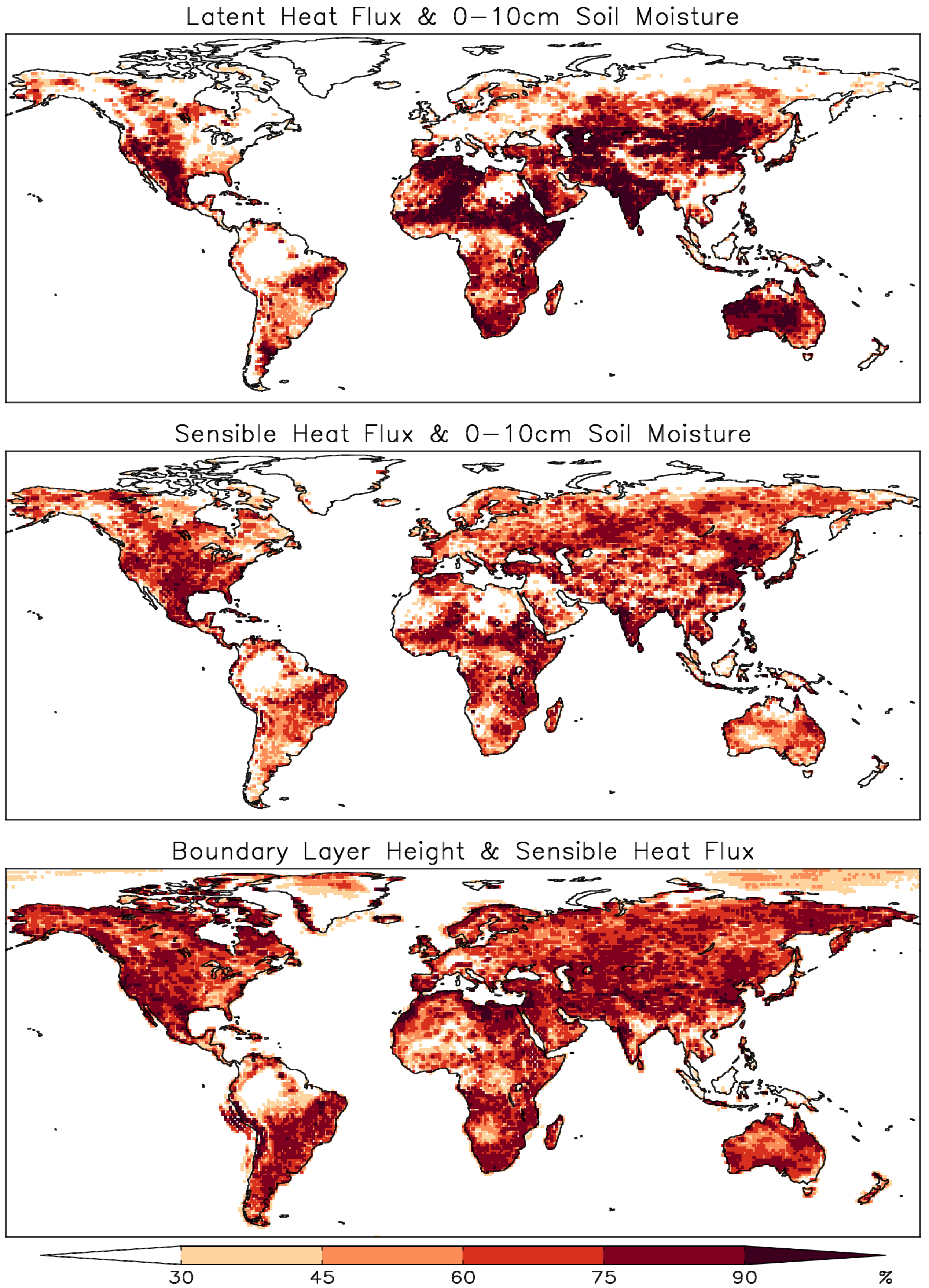

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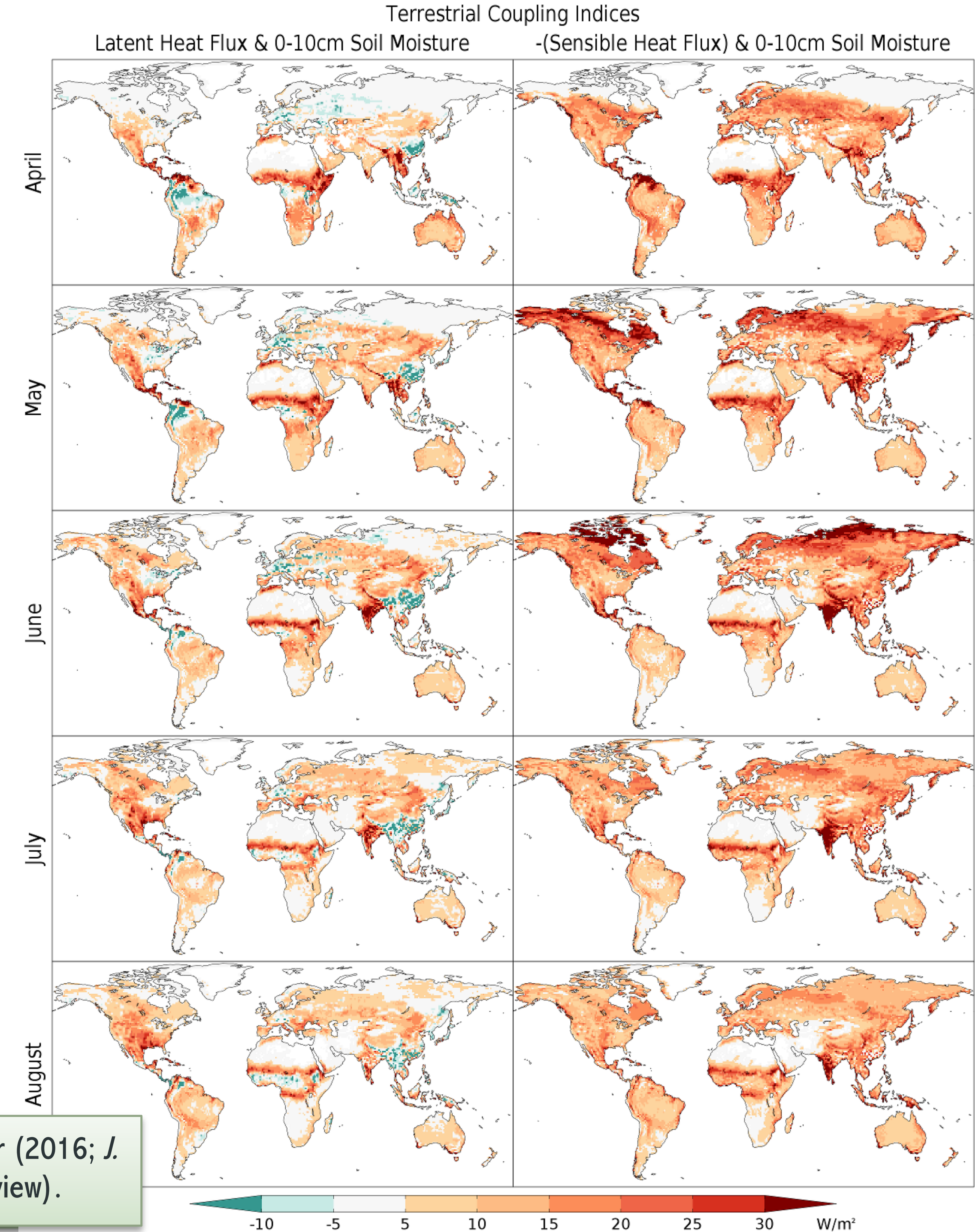
Terrestrial Leg

- For a surface flux Φ, coupling to soil wetness W we define a coupling index:

$$I_\Phi = \frac{d\Phi}{dW}\sigma_W = r(\Phi, W)\sigma_\Phi$$

- W → LHF (ET) on left;
  W → –SHF on right
- "Hot spots" evident in water cycle.
- SHF is a driver for boundary layer growth, triggering convection.
  - Also follows the snowmelt front north in late spring



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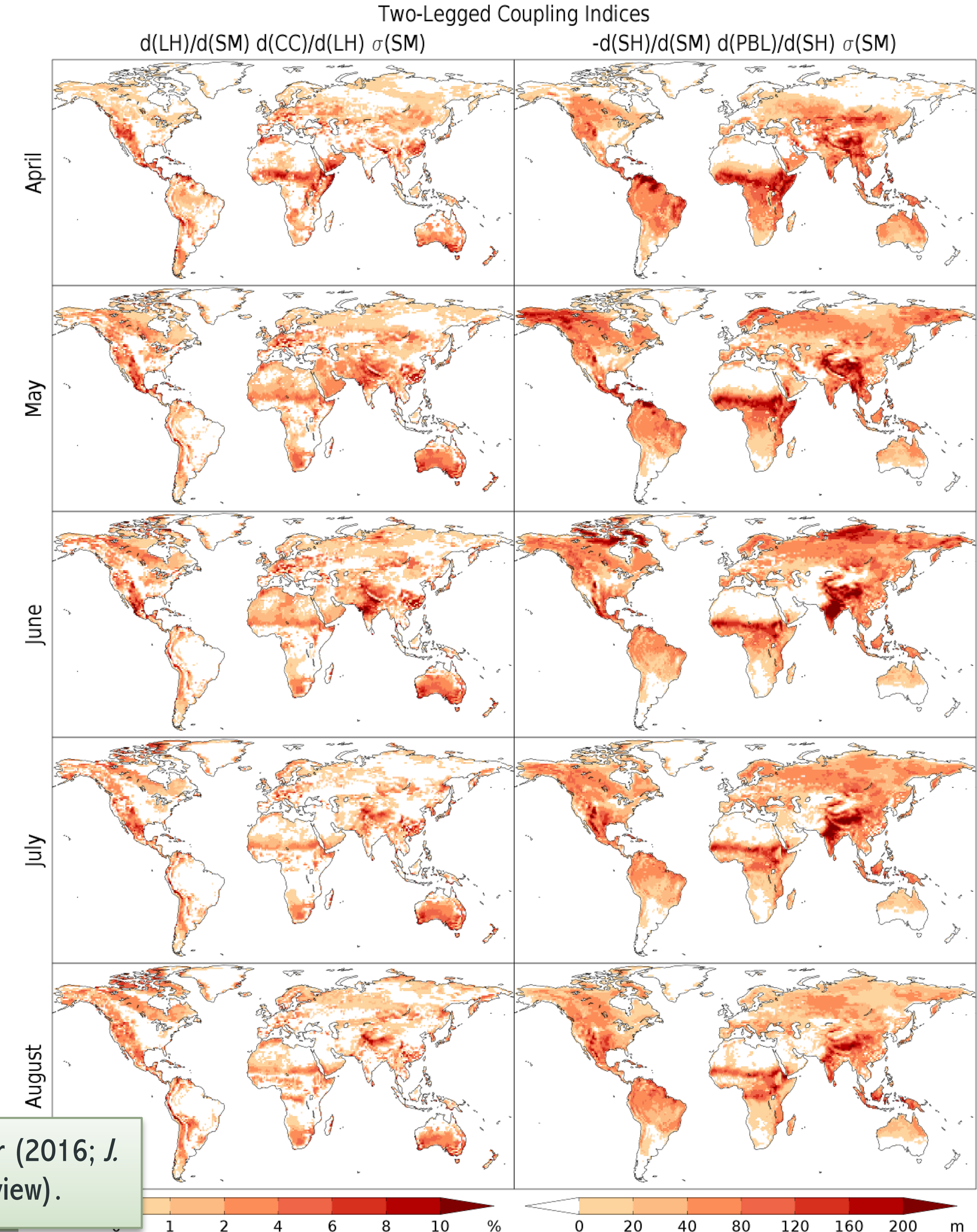
+ Atmospheric Leg

- Follow the chains:

$$\frac{d[LH]}{dW}\frac{d[Cloud\,Cover]}{d[LH]}\sigma_W$$

$$\frac{d[SH]}{dW}\frac{d[PBL\,Depth]}{d[SH]}\sigma_W$$

- Now the linkage is all the way from soil moisture to the direct controls on precipitation
- Great Plains coupling disappears!



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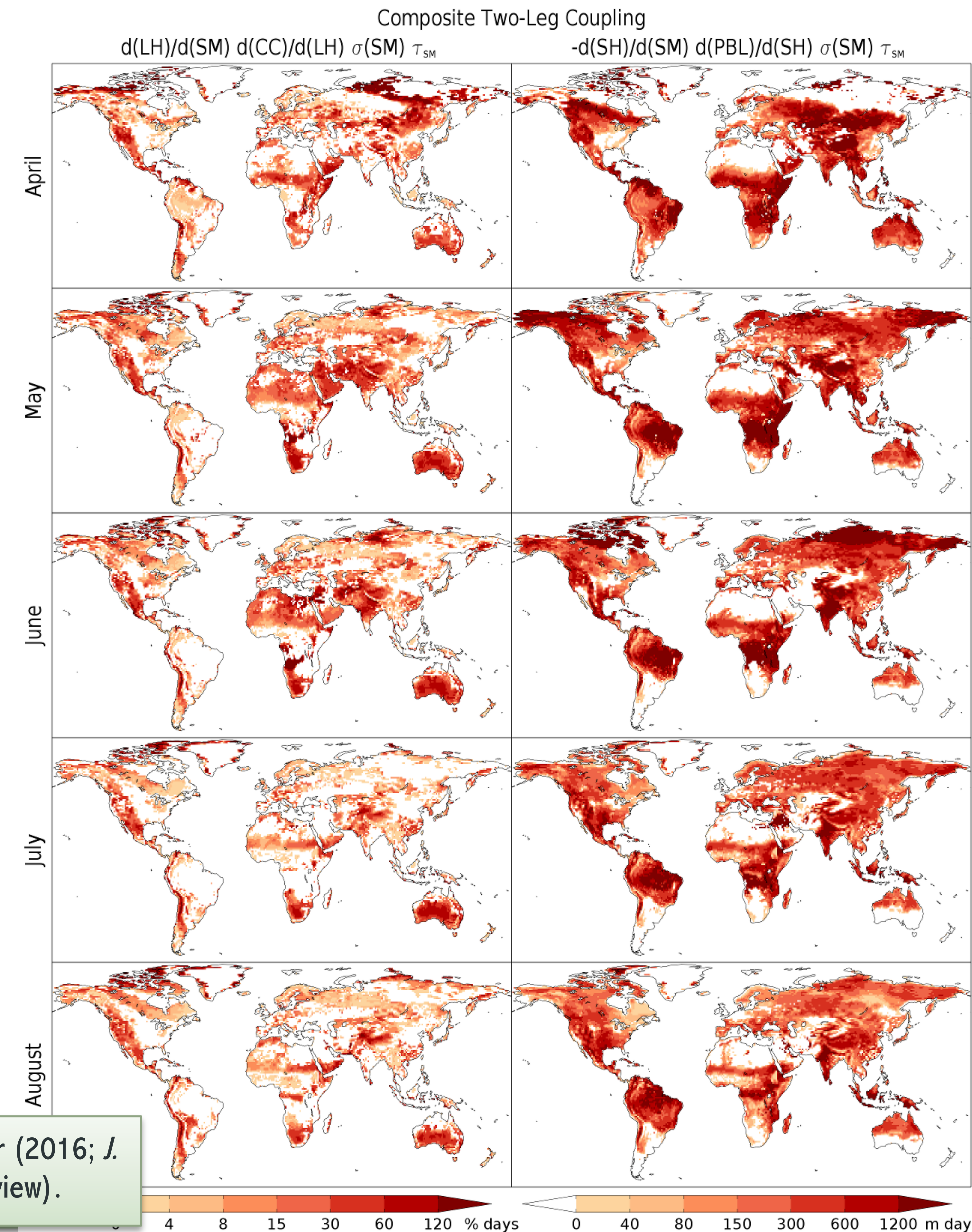
+ Memory

$$\frac{d[LH]}{dW}\frac{d[Cloud\,Cover]}{d[LH]}\sigma_W \tau_W$$

$$\frac{d[SH]}{dW}\frac{d[PBL\,Depth]}{d[SH]}\sigma_W \tau_W$$

- Multiply be e-folding time of soil moisture lagged auto-correlation.
- In CFSv2 not much change except emphasizes high latitudes (frozen ground, weak net radiation).



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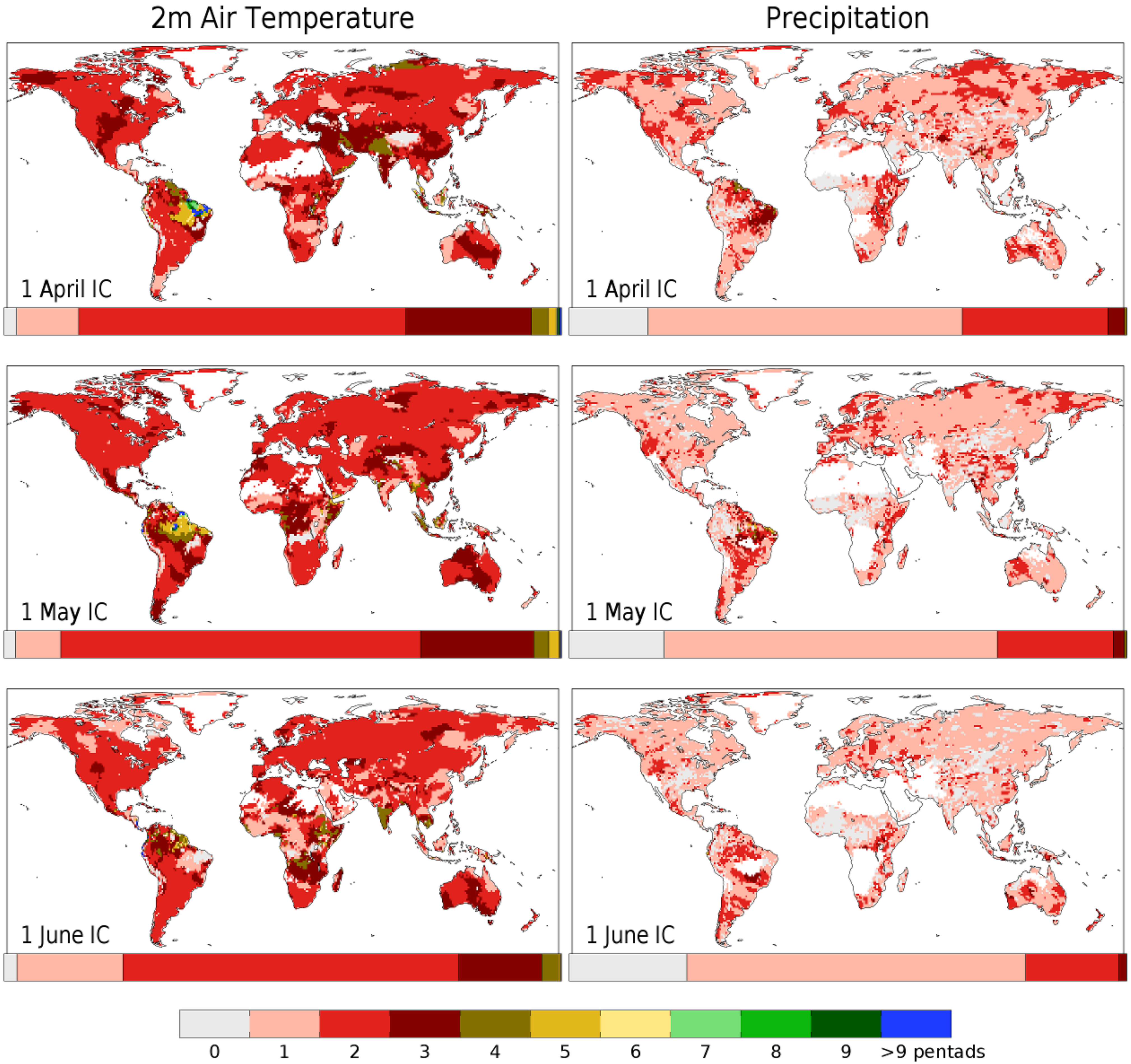
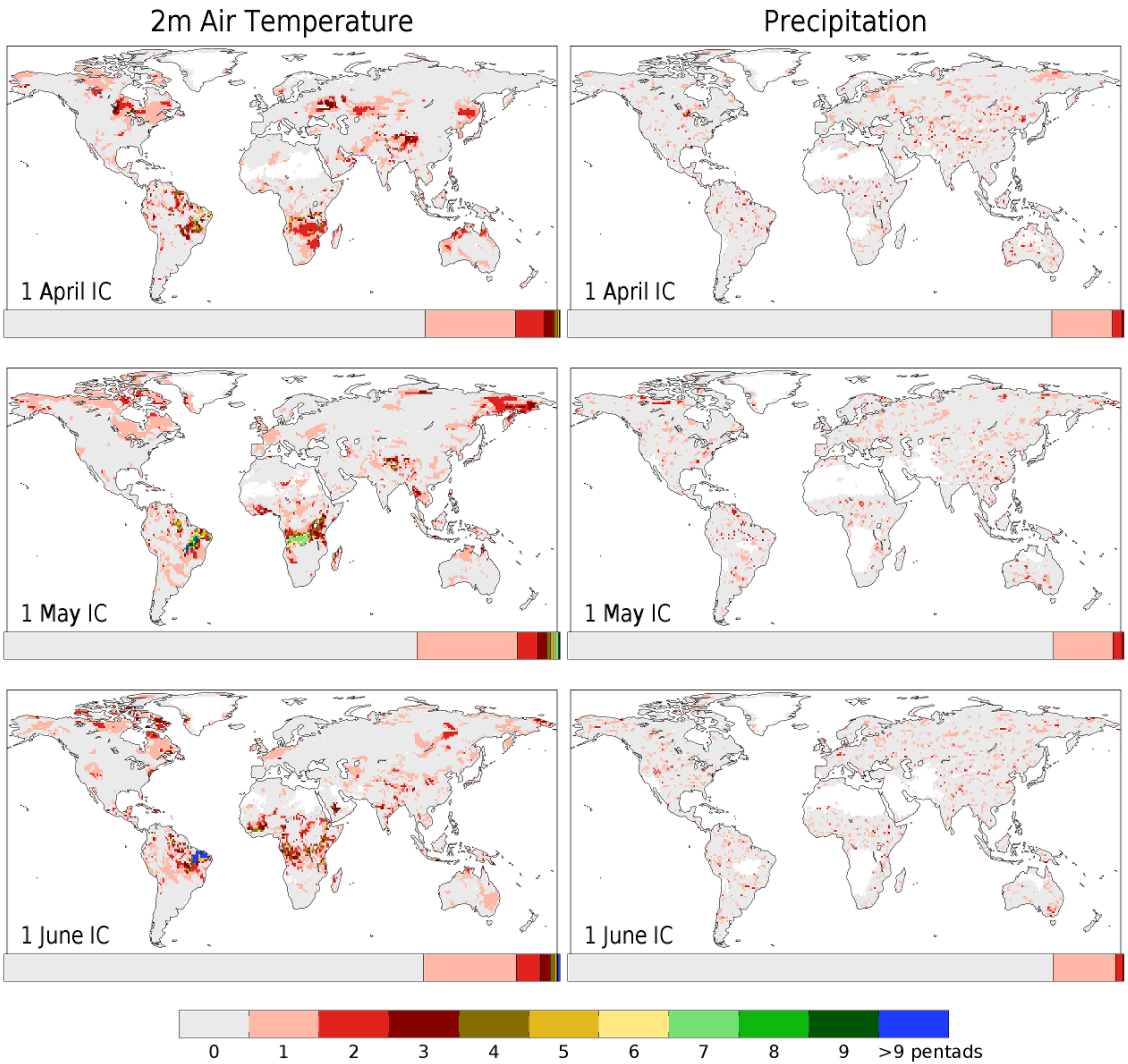
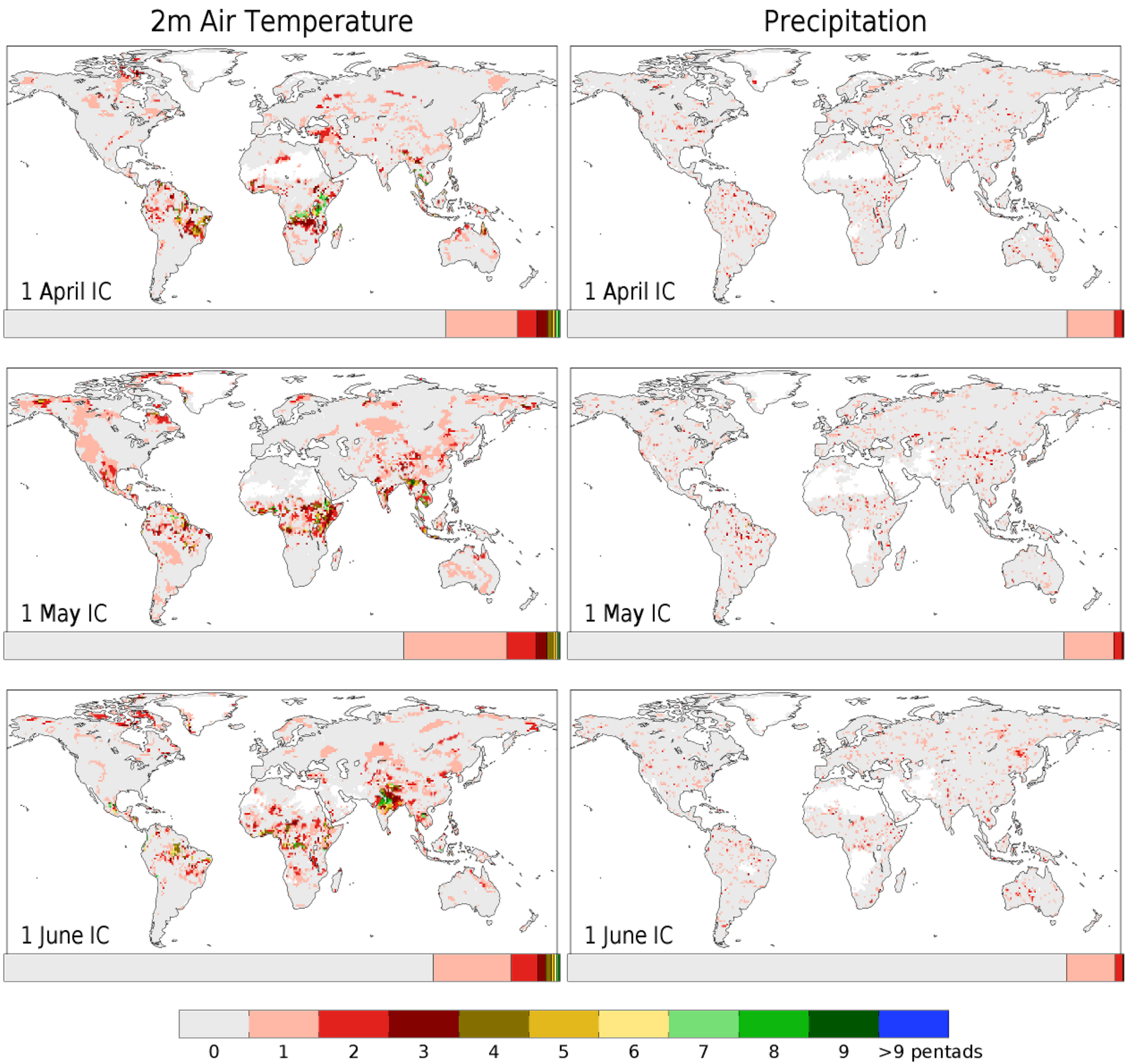


- Skill (pentads where ACC p ≤ 0.05 during 1981-2008) based on atmosphere and ocean initialization only (land surface randomized across years).
- Pentad averages get at subseasonal predictability and prediction skill.

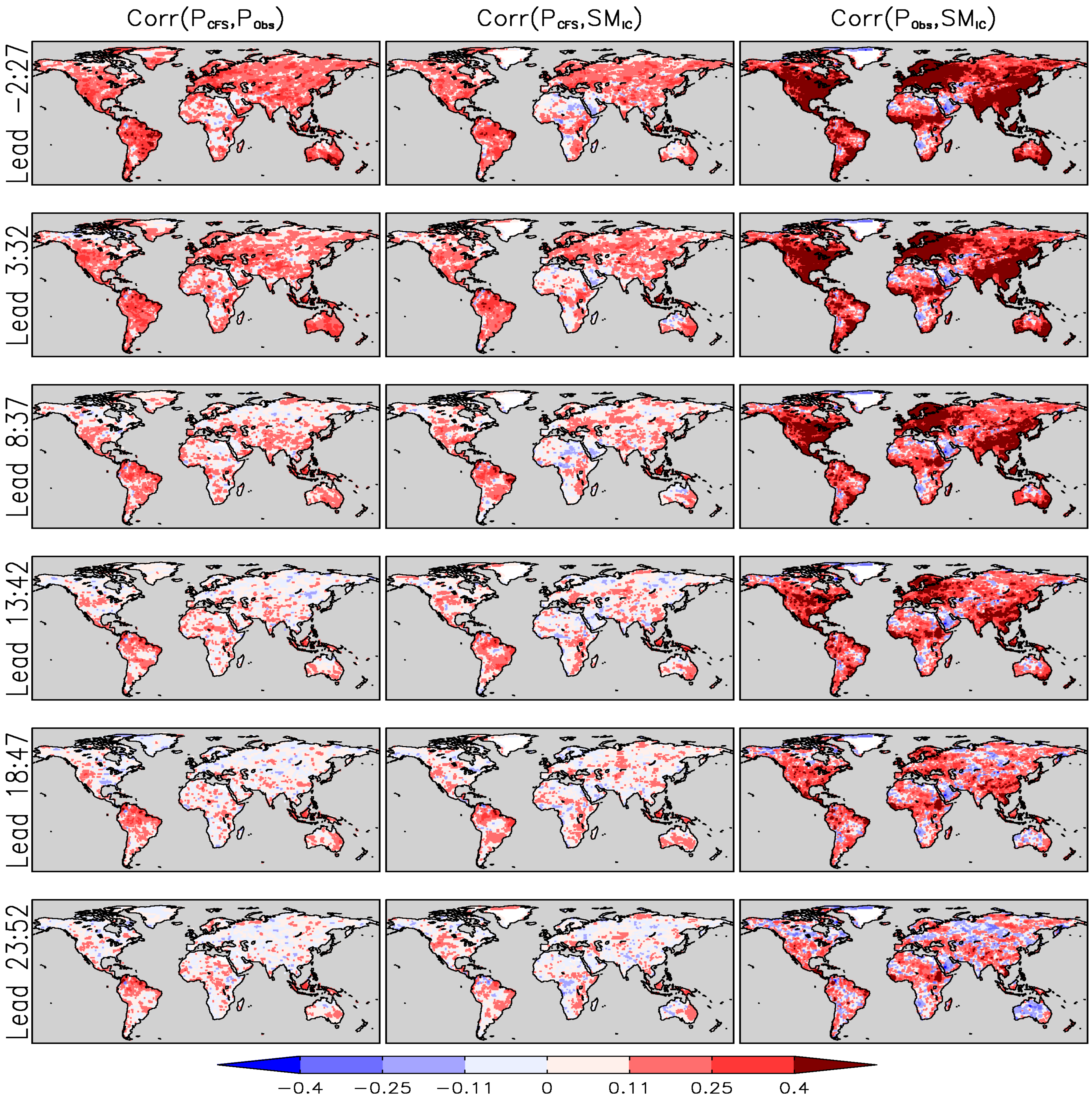


- Number of pentads gained by “realistic” land surface initialization (states taken from CFSR).
- Positive impacts on surface fluxes, T_{2m}, q_{2m}, PBL develop-ment, <u>but not precipitation!</u>. Something amiss with convection.



- Gain beyond realistic land IC by specifying GLDAS soil moisture throughout forecast (perfect soil moisture prediction).
- Similar additional gains – globally about 25% land area has extended T_{2m} skill, 10% are for precip.
- Still hole over GP!

Why?



- CFS Reforecasts: Model precip does not correlate well with observed P (left) or with initial soil moisture (middle). Observed precip correlates quite well with initial soil moisture (right)!
- CFS precipitation forecasts lack observed persistence.

Dirmeyer (2013; *Climate Dyn.*, doi: 10.1007/s00382-013-1866-x).

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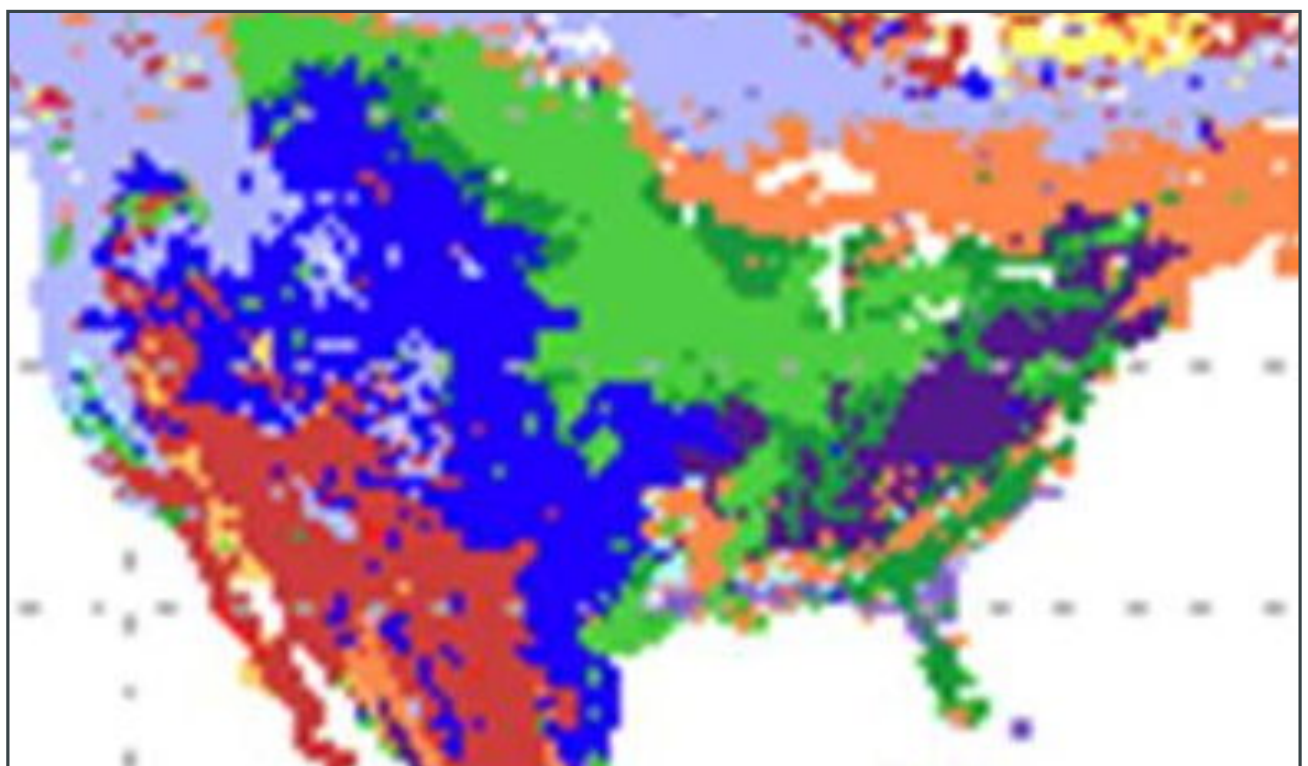
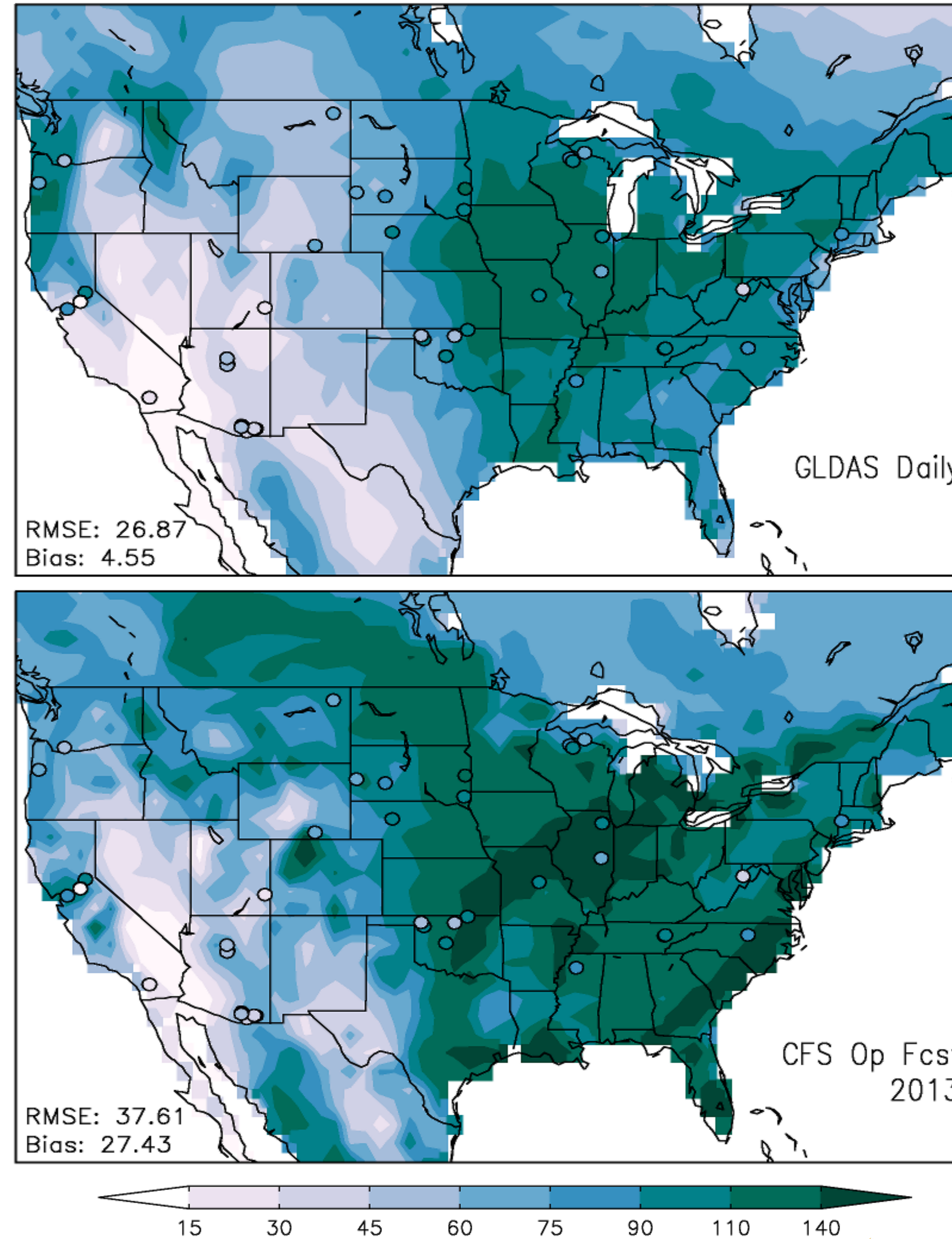
The Quick Fix

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



Green: Total and partial cropland

Latent Heat Flux **JJA**



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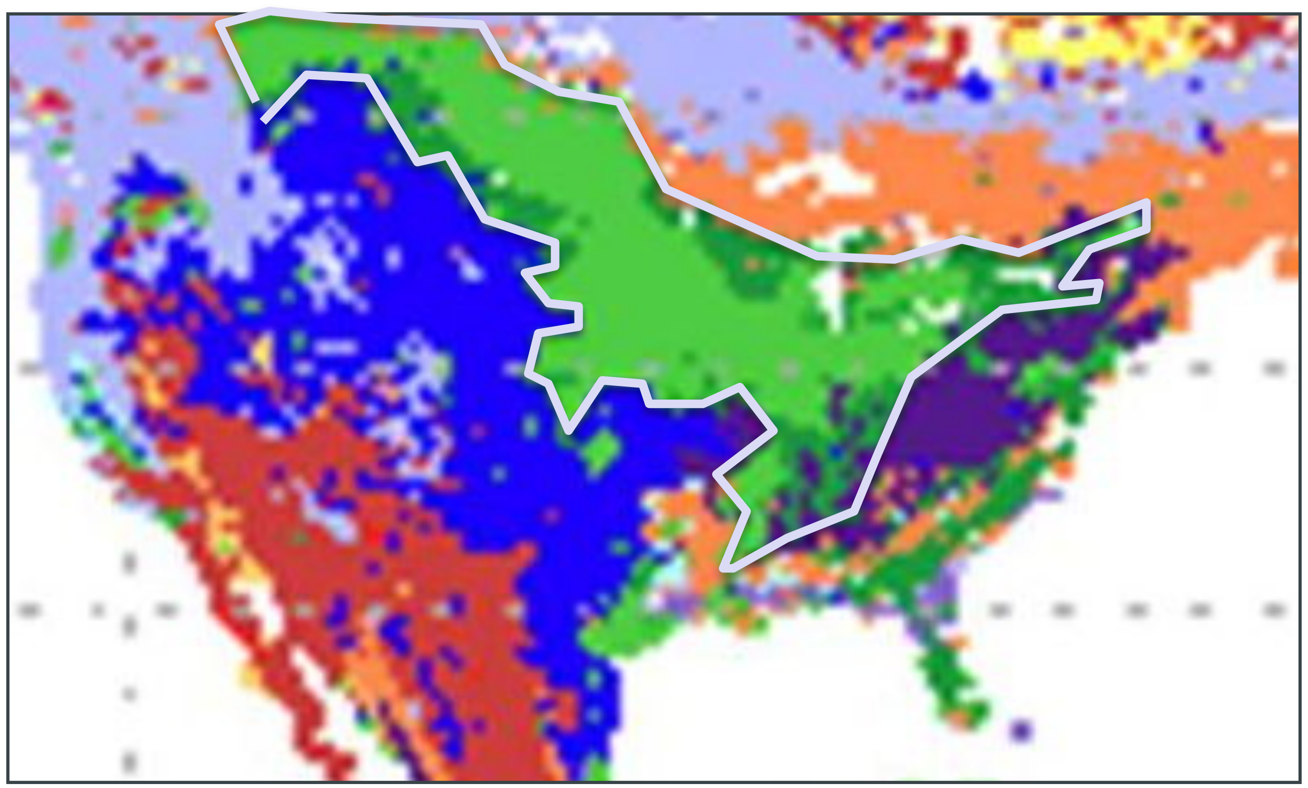

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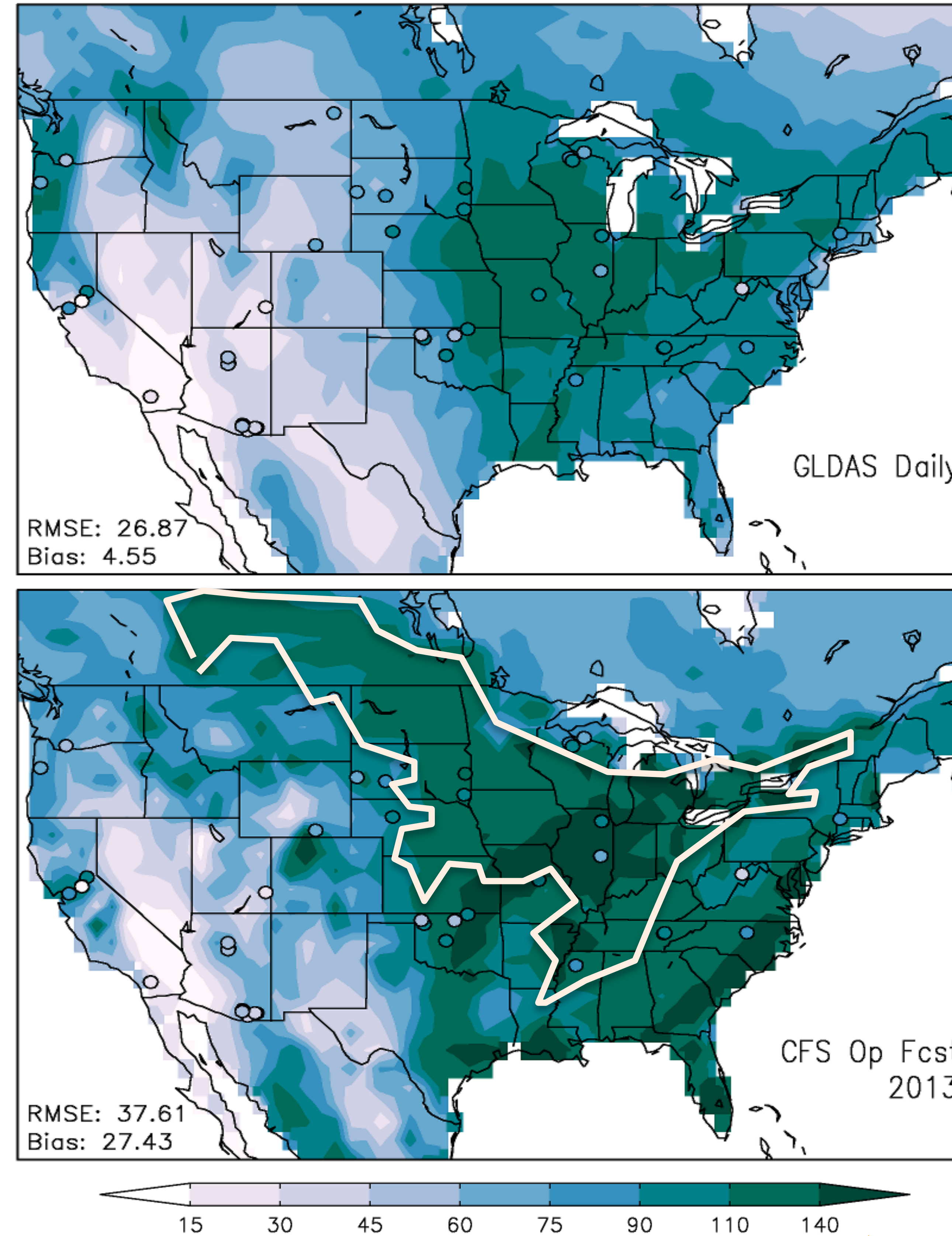
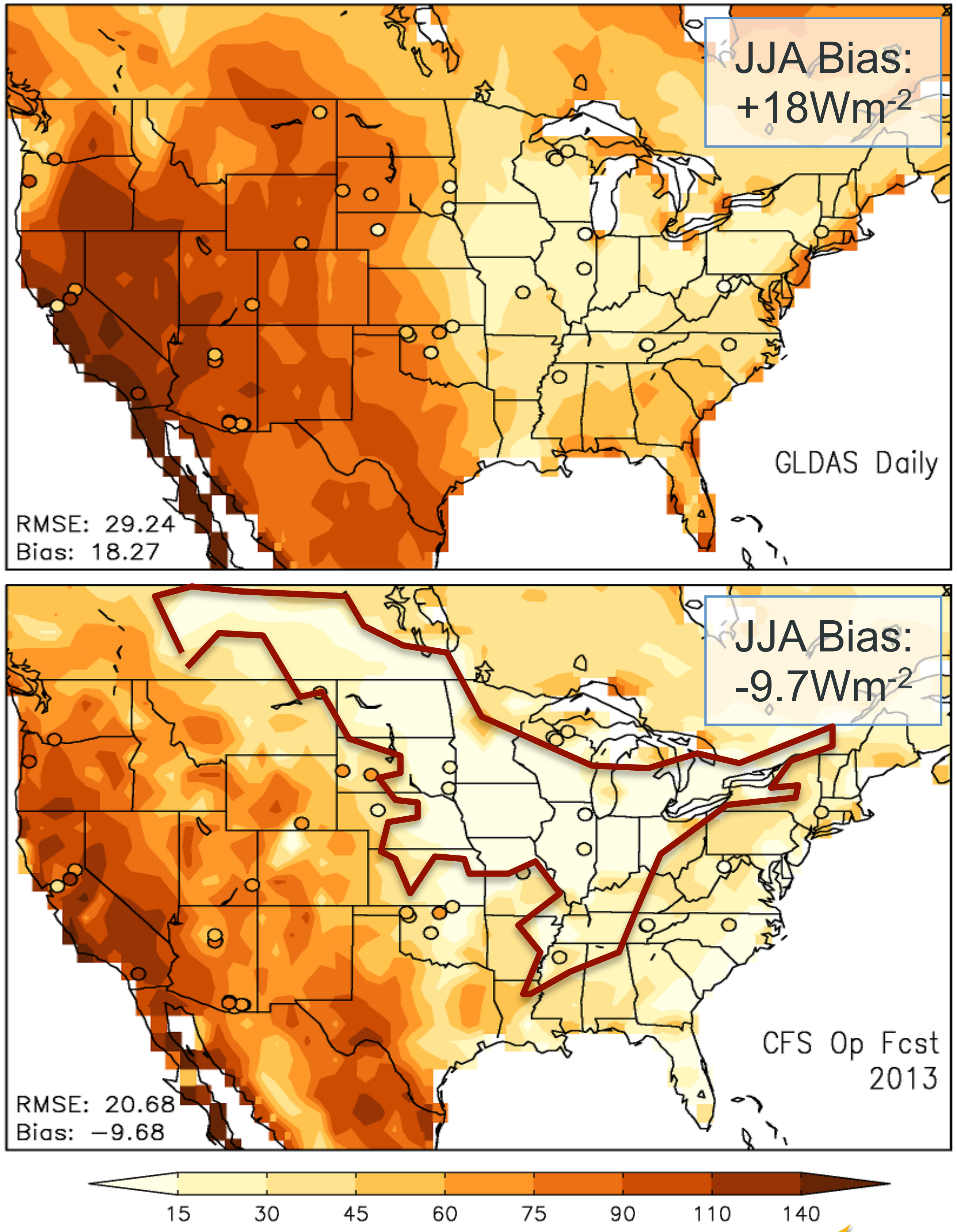


Sensible heat fluxes

- Essentially zero over much of Midwest in CFS over crop vegetation type.



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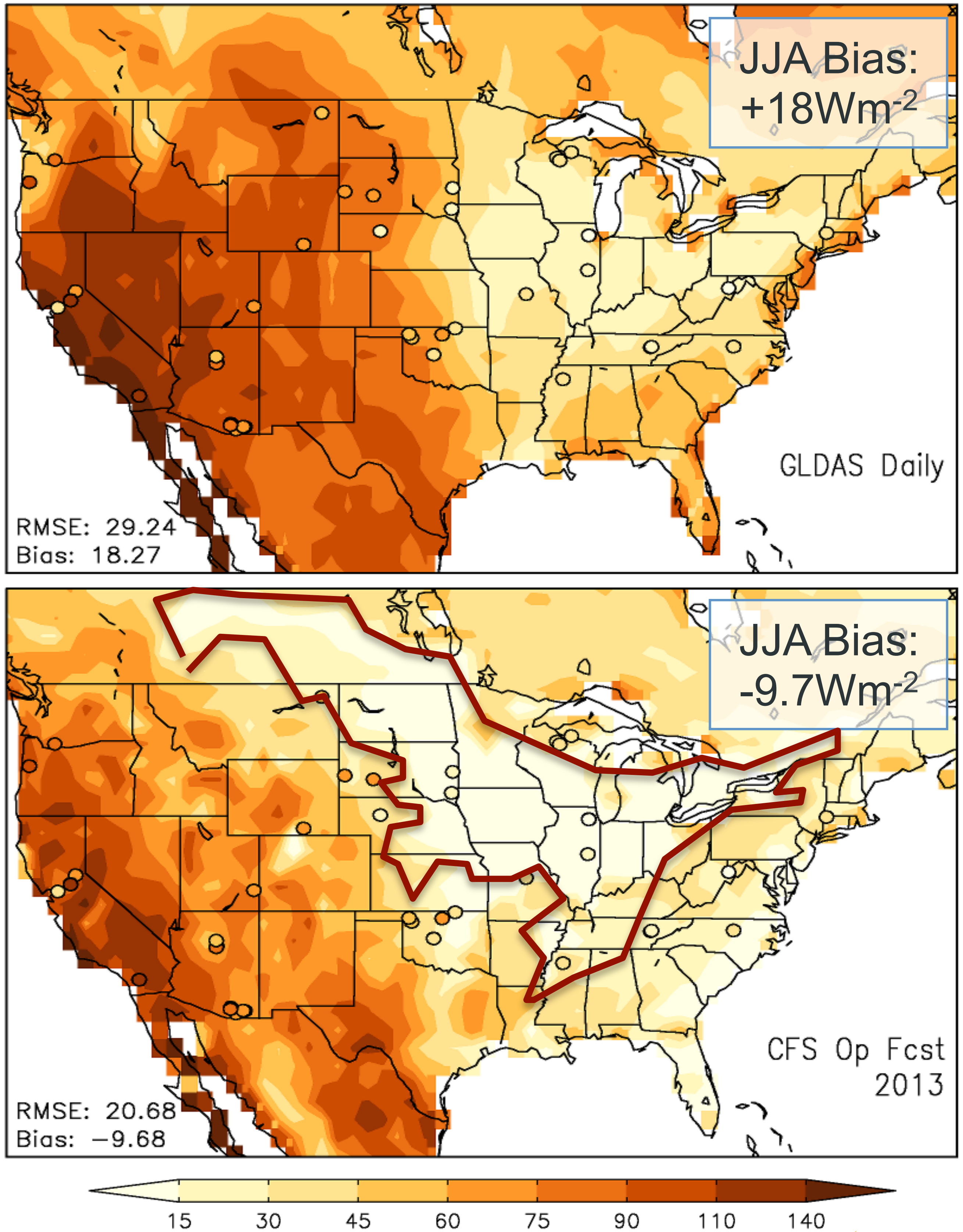

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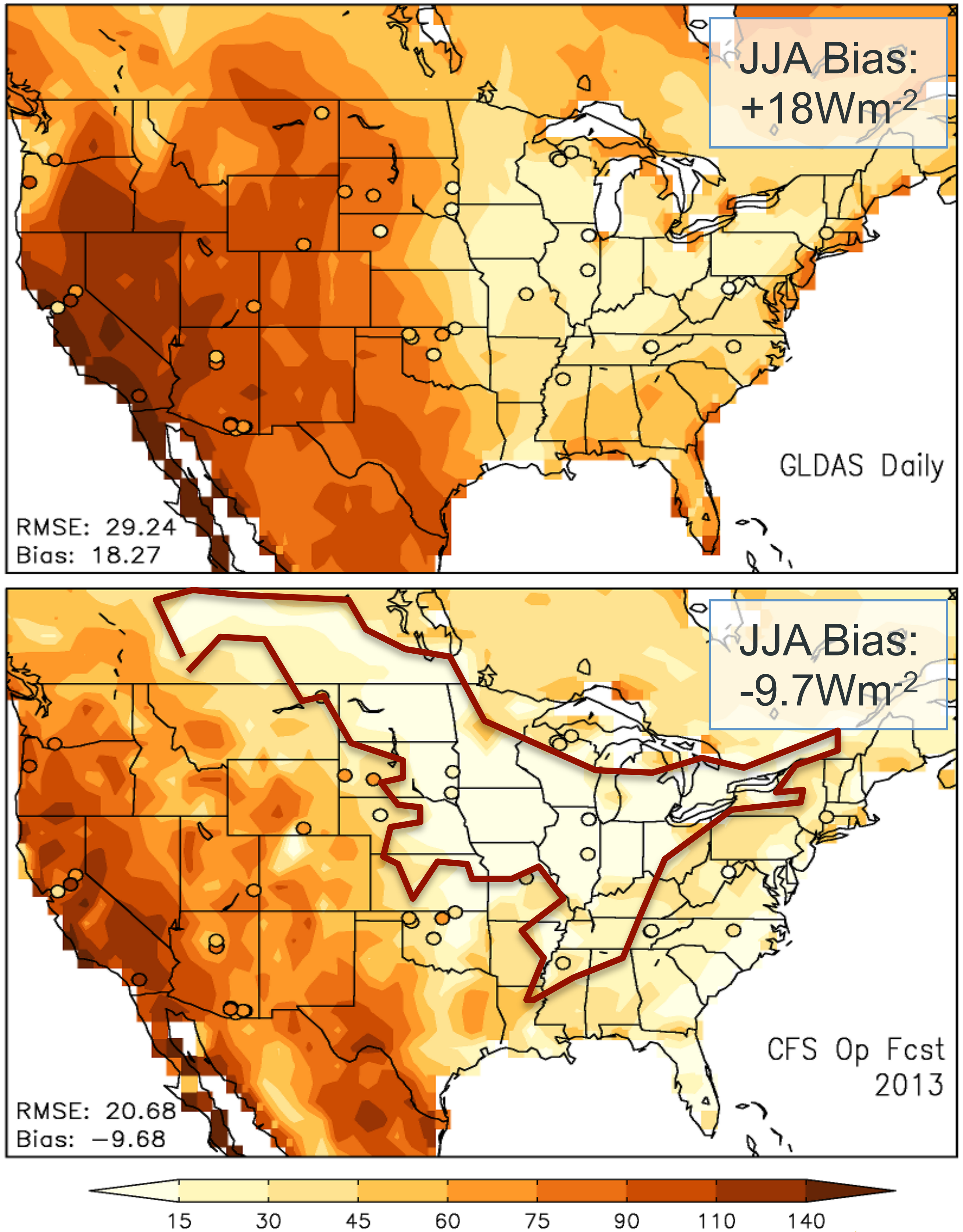
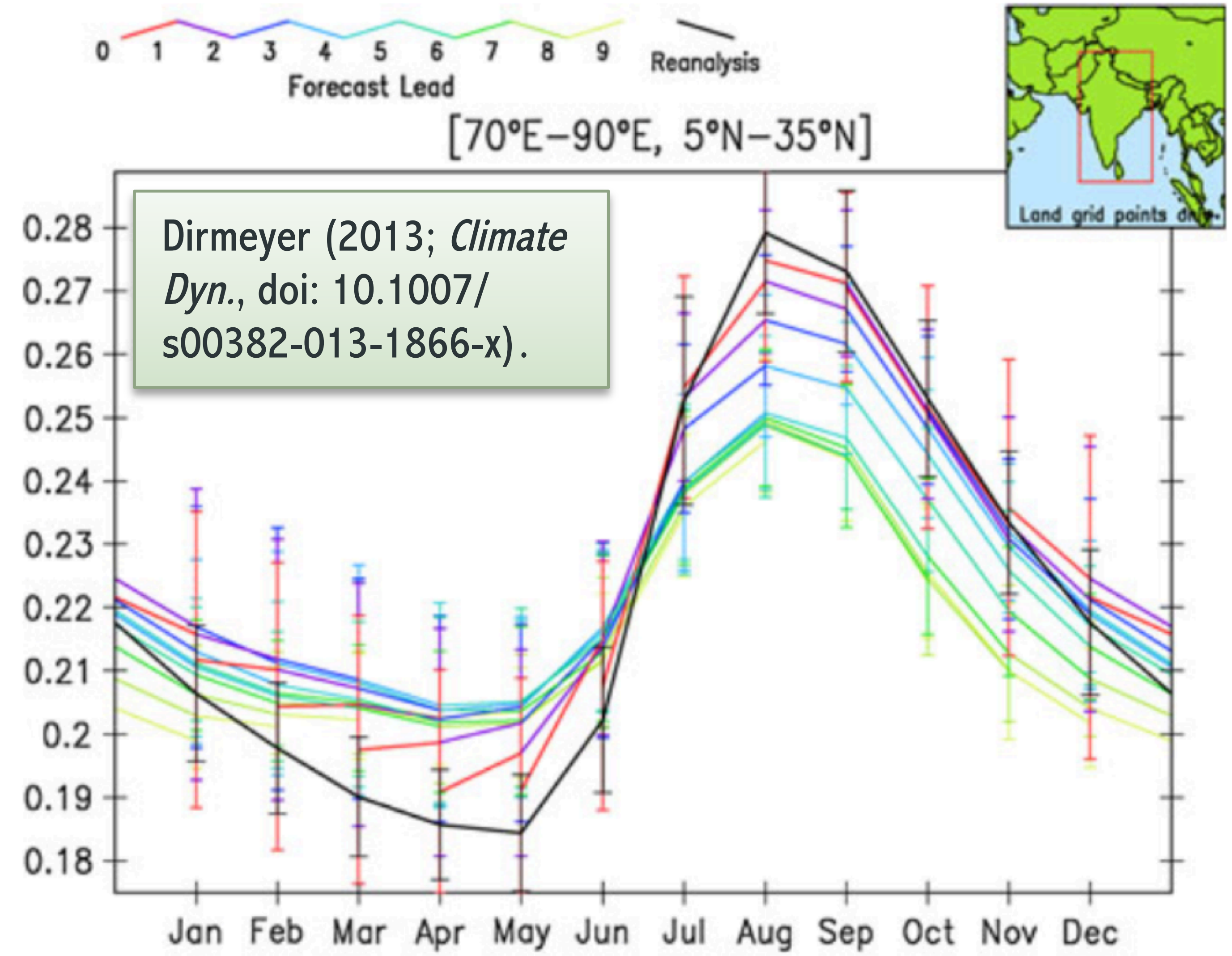
- But hey, the temperature error was reduced! Right result for wrong reason.



Focus over South Asia

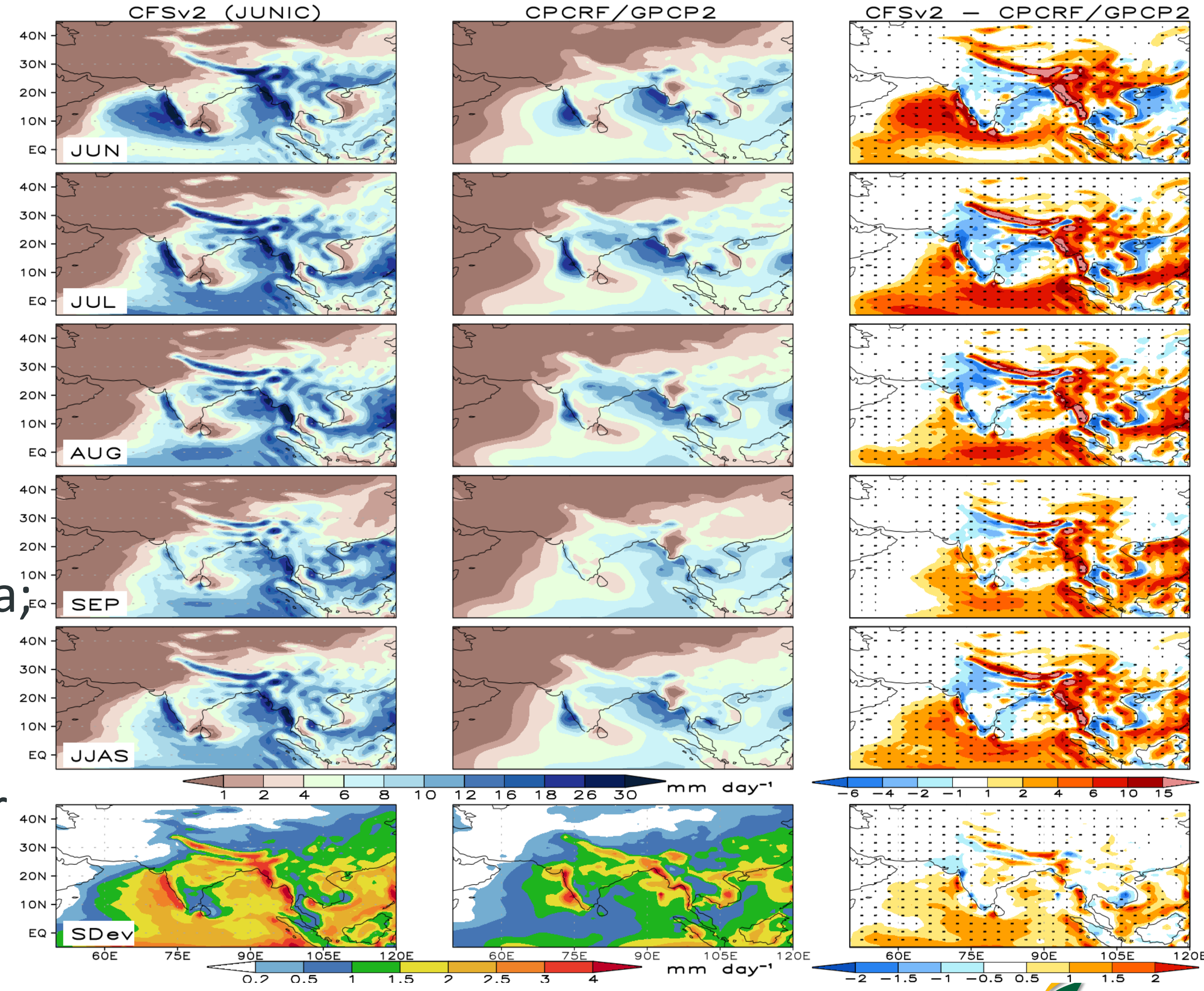
- How do biases, errors, kludges impact Asian Monsoon predictability from land surface initialization?
- Most importantly, what about drift?
- Soil moisture forecasts bias wet when initialized prior to June, dry afterwards over India in CFSv2 Reforecasts (right).
- Model's tendency for a damped annual cycle of soil moisture is one of many drifts that affect monsoon prediction.



- All following results from Halder and Dirmeyer (2016; in prep).

Biases over S. Asia

- Precipitation from 1 June CFSv2 (left), observations (center) and error (right) in monthly (J, J, A, S) and JJAS; bottom shows the interannual standard deviations.
- Dry bias prevalent over India; wet over many surrounding areas.
- *Relative* variability high over India – symptomatic of incorrect BC controls?



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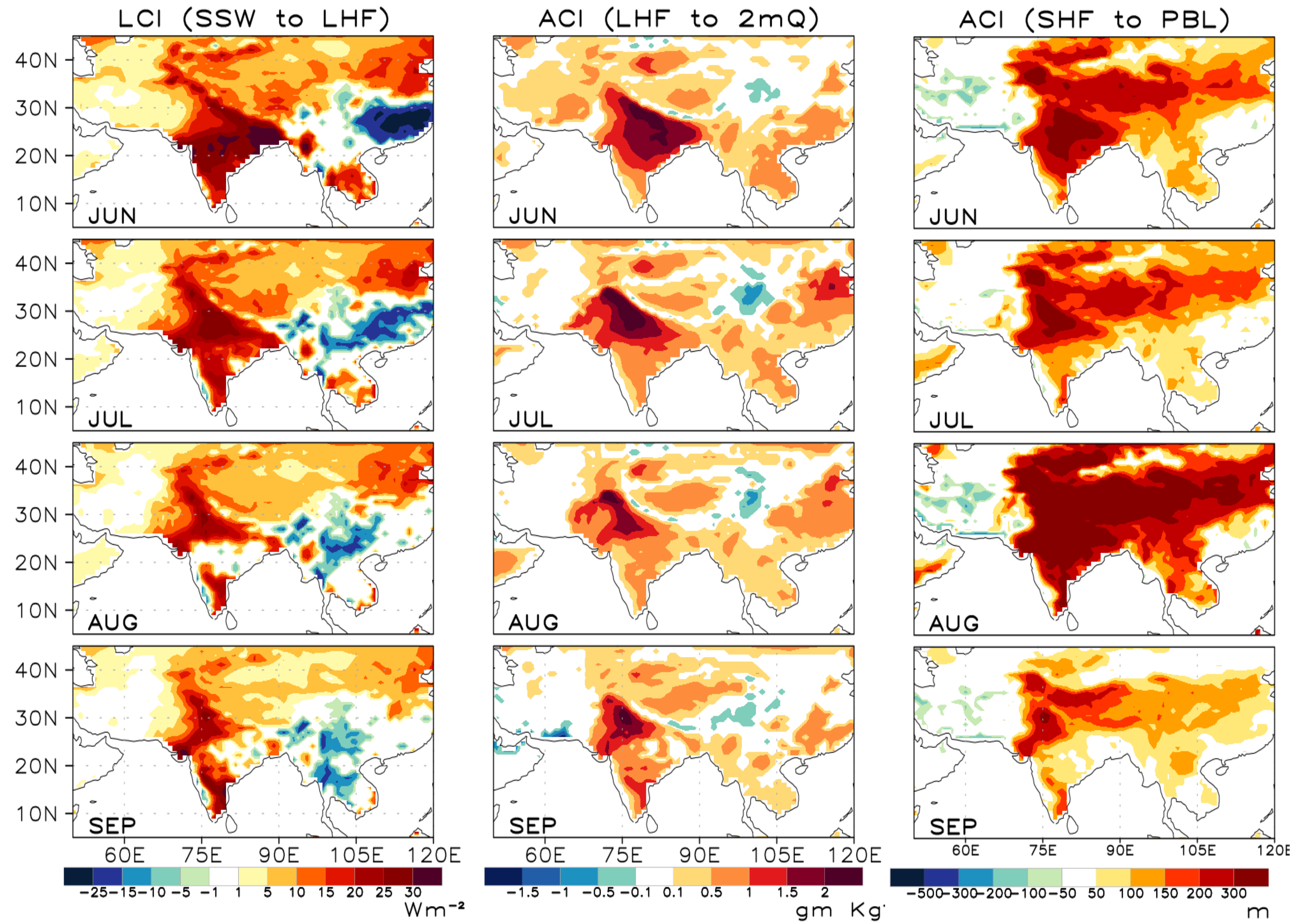
Coupling Metrics

- Terrestrial coupling index surface soil wetness and latent heat flux (left), and atmospheric coupling indices between LHF and 2m specific humidity (middle) and SHF and PBL height (right).
- As seen before, promising indicators of potential predictability from the land surface



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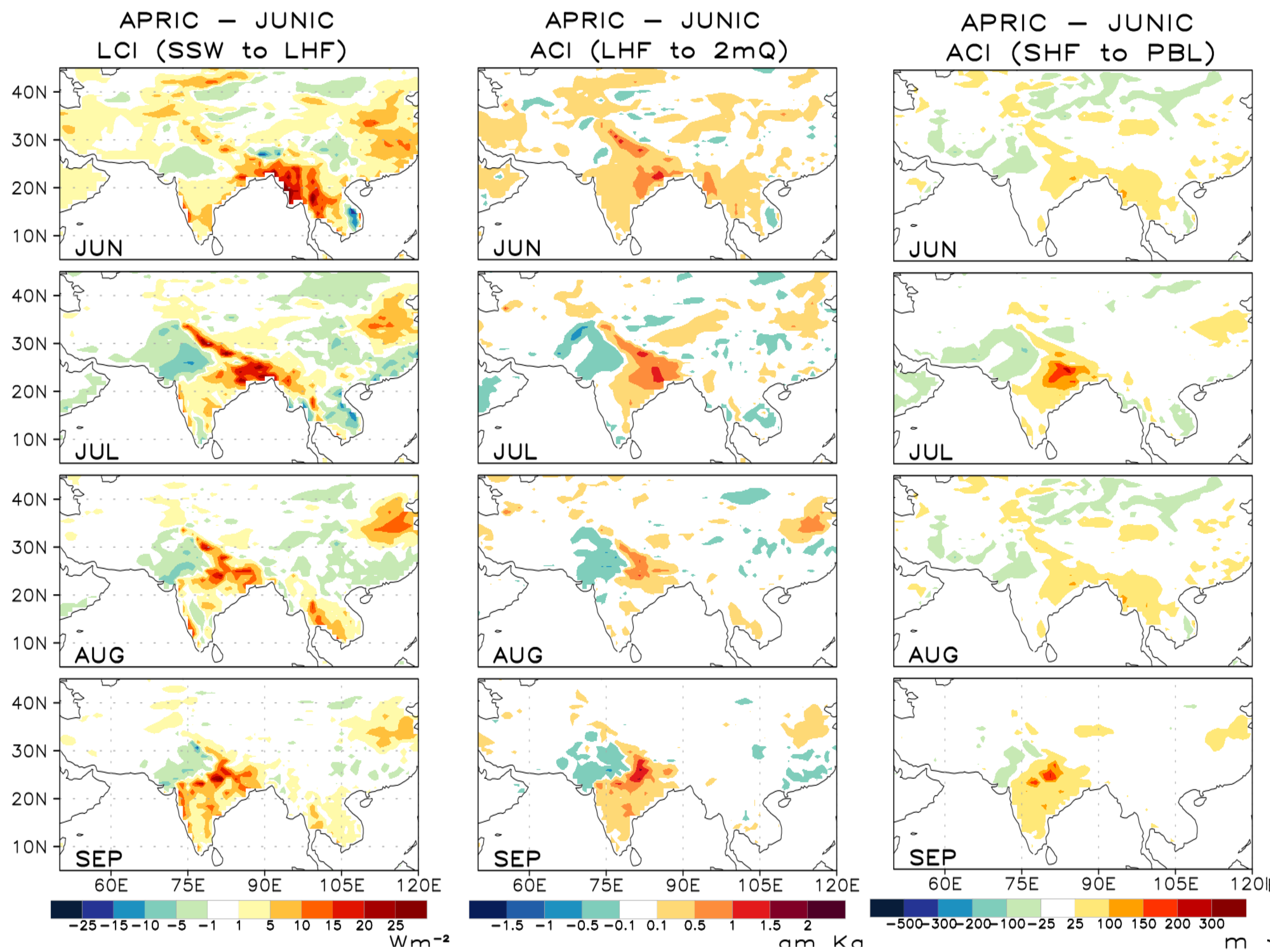
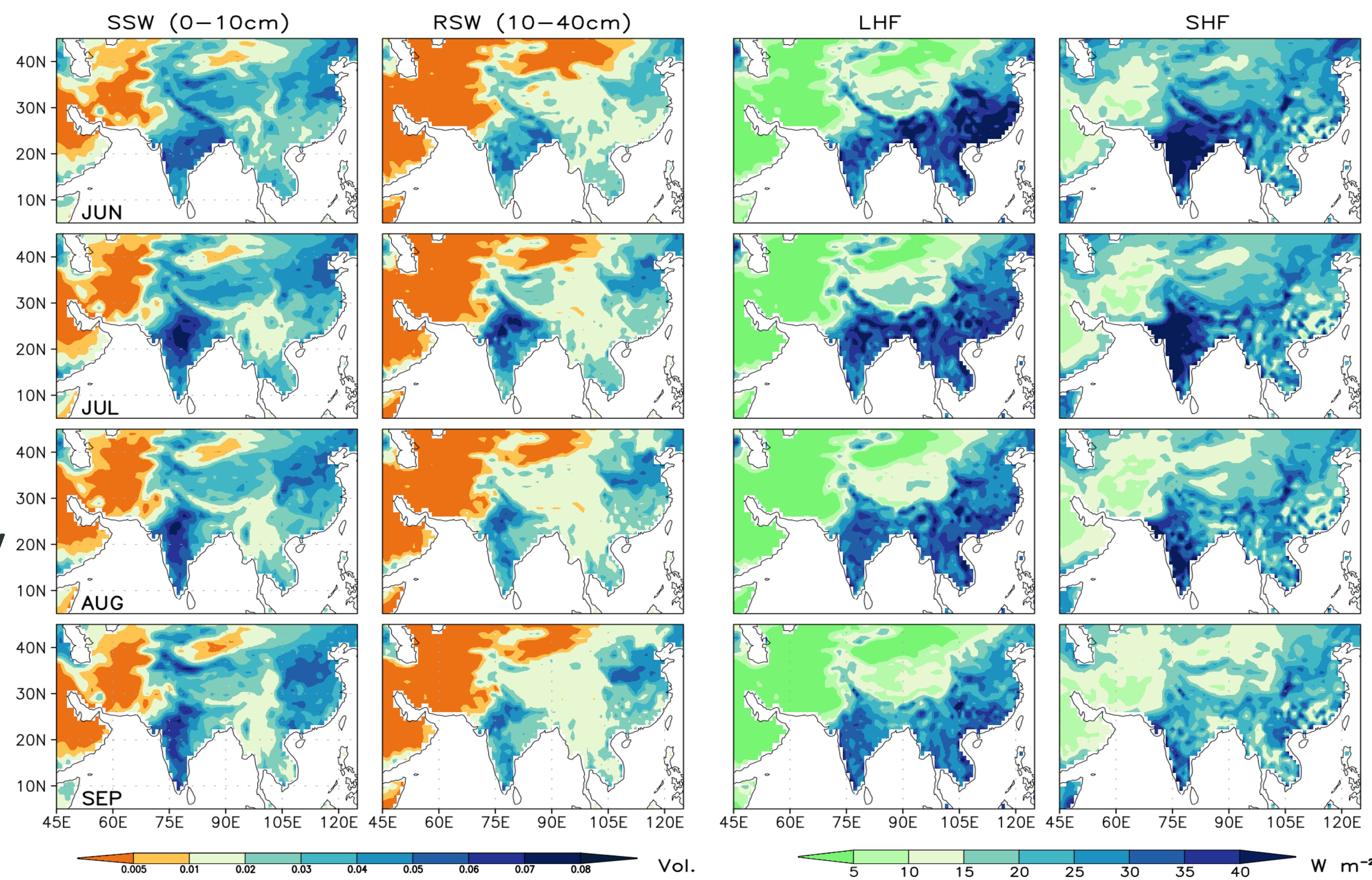
Drift in Coupling Indices

- Radiation and precipitation biases cause coupling to strengthen over most o the area with lead time (NW India and Pakistan is an exception.
- Stronger coupling of an incorrect signal! Not beneficial to forecast.



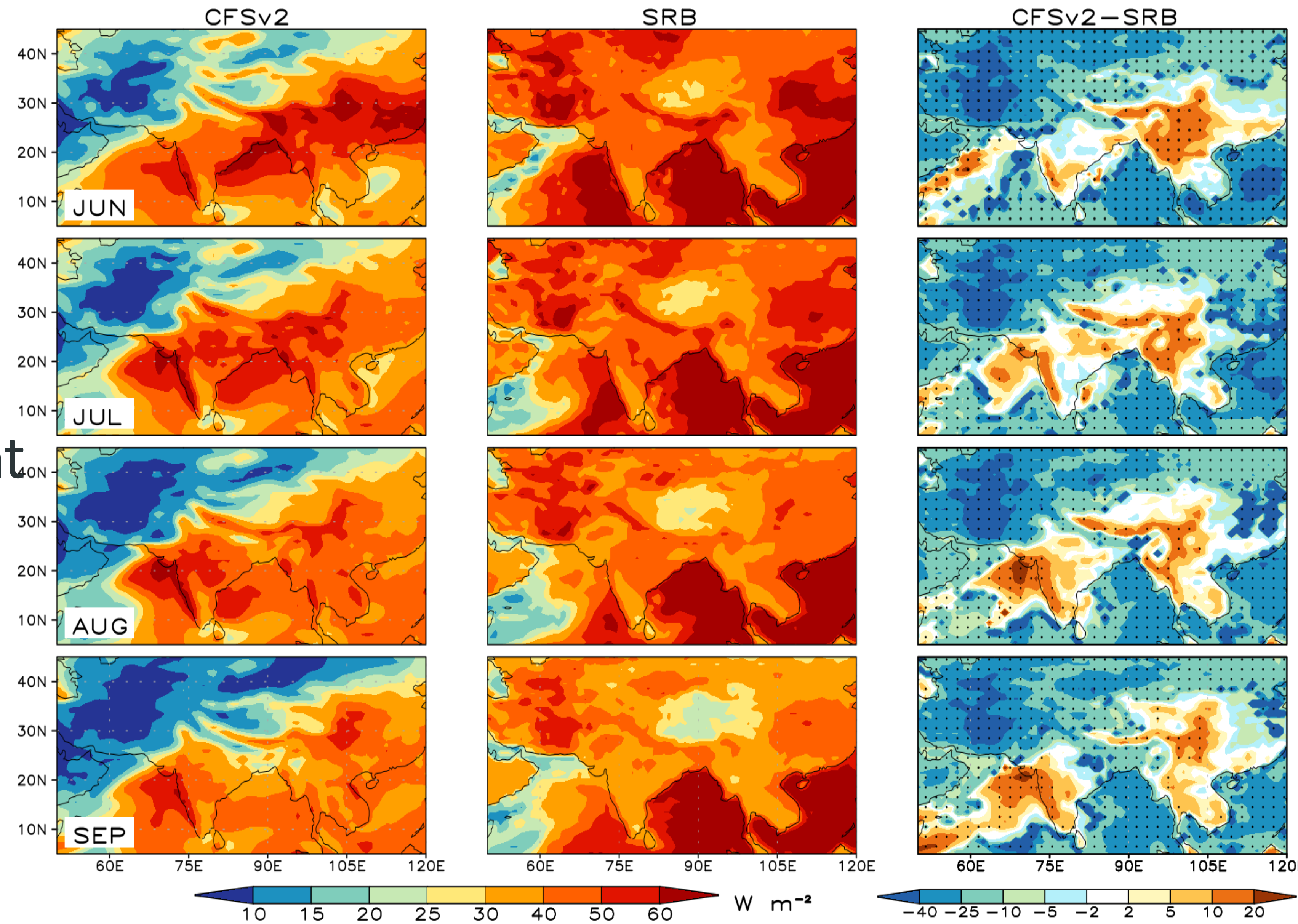
Model Variability over S. Asia

- Variability in daily soil moisture and surface fluxes.
- India: flux variations appear tied to soil moisture, potential for predictability.
- SE Asia, China: variability is driven by atmosphere.
- Deserts: variability absent although sensitivity is strong.



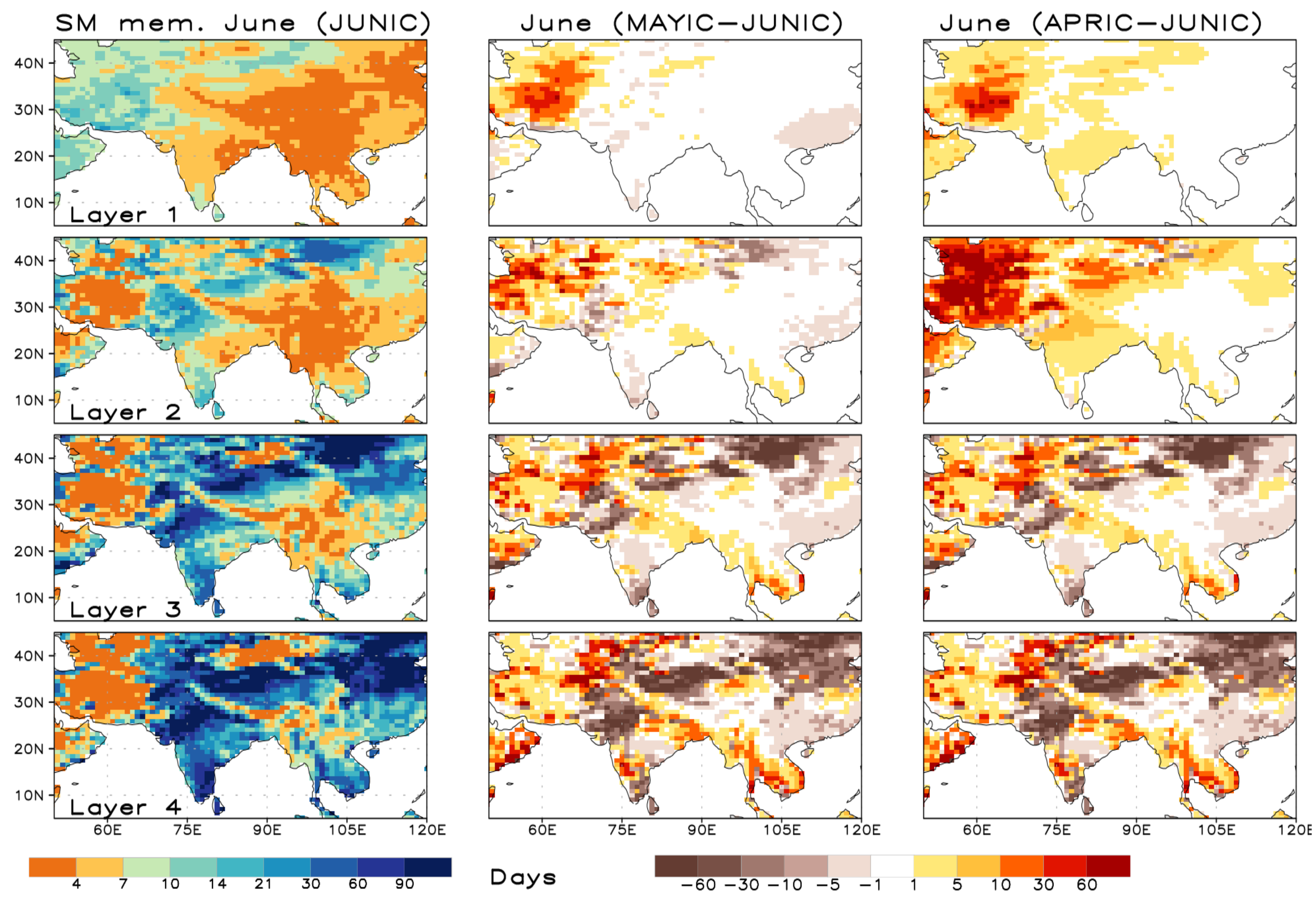
Radiation Variability Biases

- Daily mean variability in surface net radiation from (left) CFSv2 model simulations initialized in June, (middle) SRB observations and (right) difference.
- Errors appear tied to poor treatment of aerosols: model has too much variability where consistent anthropogenic aerosols suppress synoptic radiation variability
- Too little variation where dust, sea salt, sporadic natural sources tied to wind are absent.



Soil Moisture Memory

- Problems of drift are evident – large changes in memory with lead time of forecast (L to R).
- Deserts: memory grows, but no variability so not a big deal.
- NW India, China: deep soil moisture memory during June is lost at longer lead times – potential predictability lost with it.



Field Significance of Initialization Impacts

- Temperature (top) and precipitation (bottom)
- Color where a significantly large area over Indian region has increase / decrease of skill –
  - Precipitation sometimes increases significantly, never decreases, shows promise.
  - For temperature, early increases met by late season decreases – another symptom of drift, compensating errors in CFSv2.

Table-1: Percentage of area within the domain (65-105 °E; 5-40 °N) showing changes in ACORR of 2m temperature due to RELIC. Significant increases (decreases) are highlighted in red (blue).

Verification	June		July		August		September		JJAS	
Hindcast	Inc.	Dec.	Inc.	Dec.	Inc.	Dec.	Inc.	Dec.	Inc.	Dec.
JUNIC	69	31	64	36	25	75	41	59	58	42
MAYIC	55	45	52	48	32	68	68	32	58	42
APRIC	72	28	59	41	57	43	23	77	62	38

Table-2: Percentage area within the domain (65-105 °E; 5-40 °N) showing changes in ACORR of precipitation due to RELIC. Significant increases (decreases) are highlighted in red (blue).

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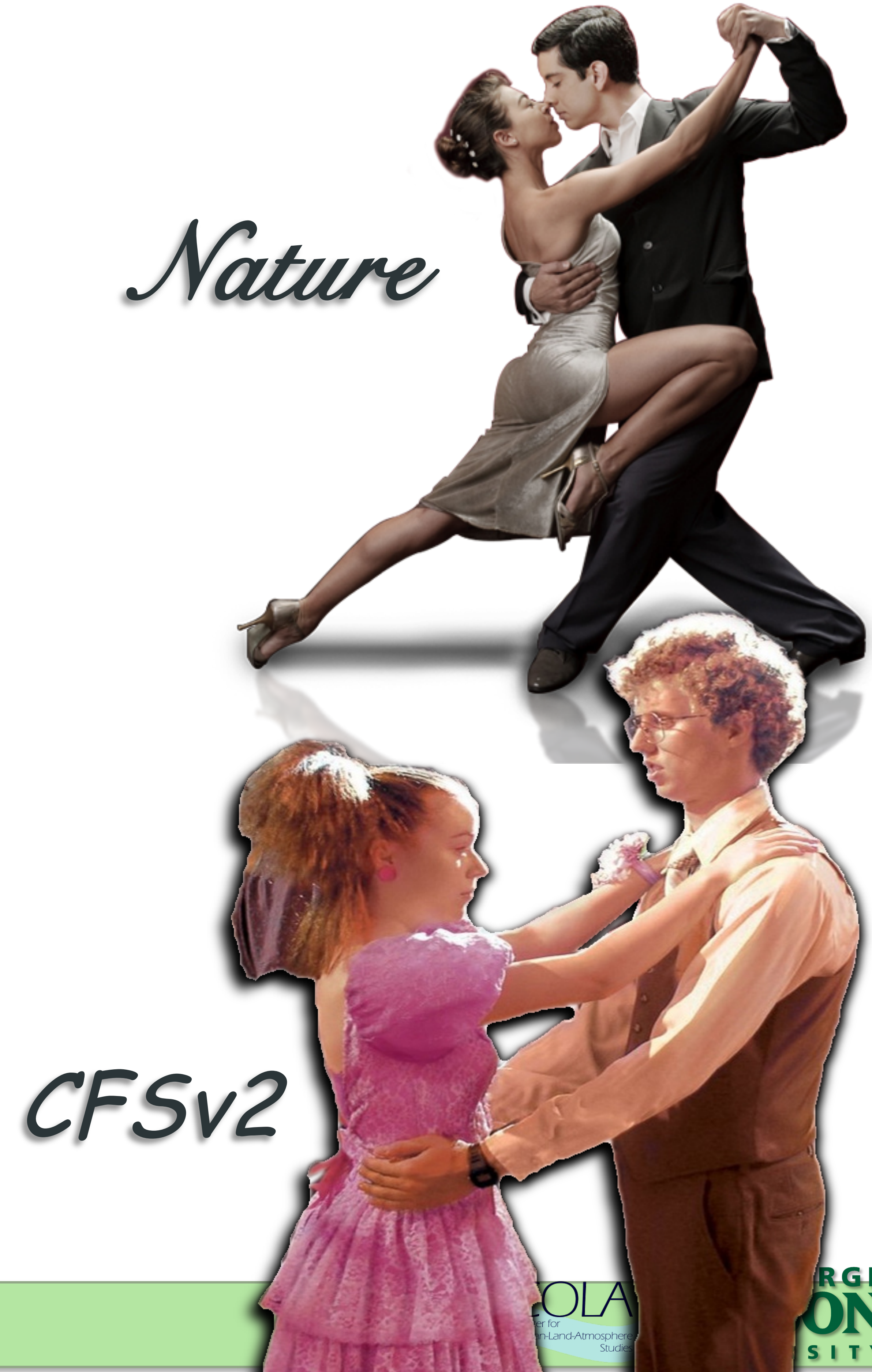

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  – Observed precipitation more correlated to antecedent soil moisture than model precipitation.
  – Model lacks known properties of nature, some appear easily correctable.
- Need the developers of land and atmosphere models to work together, just as land and atmosphere do.