The GLACE-Hydrology Experiment
Investigating the Remote and Local Responses of the Land-Atmosphere Coupling on Soil Moisture Predictability

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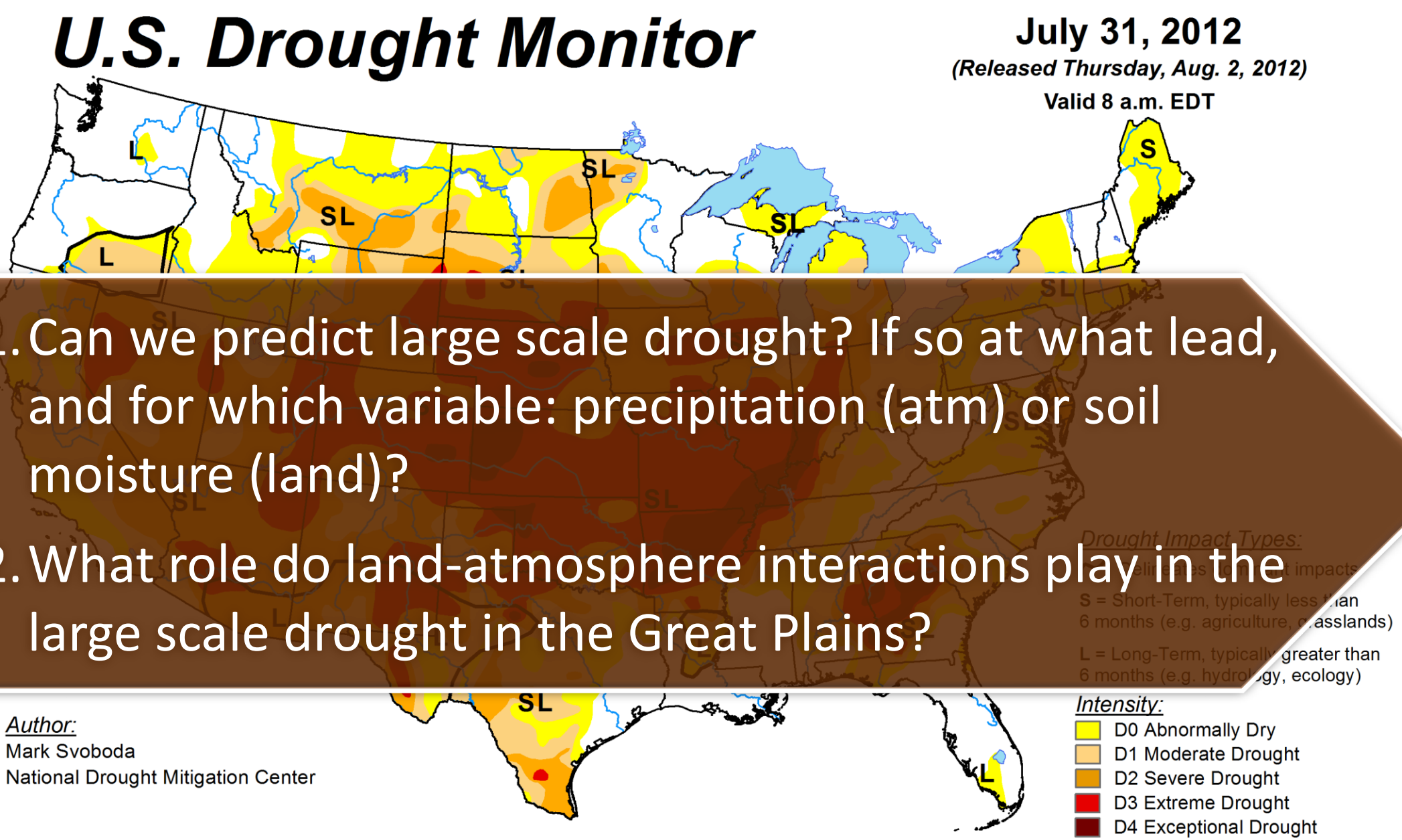
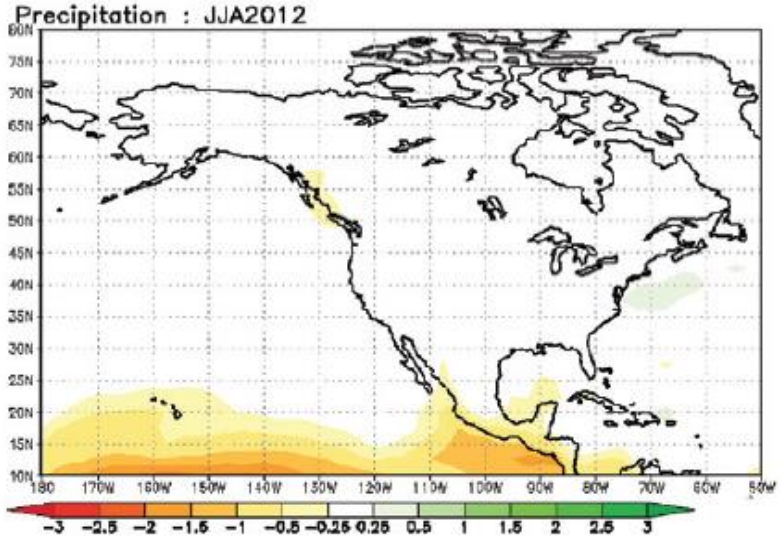

U.S. Drought Monitor
July 31, 2012
(Released Thursday, Aug. 2, 2012)
Valid 8 a.m. EDT
1. Can we predict large scale drought? If so at what lead, and for which variable: precipitation (atm) or soil moisture (land)?
2. What role do land-atmosphere interactions play in the large scale drought in the Great Plains?
Drought Impact Types:
S = Short-Term, typically less than 6 months (e.g. agriculture, grasslands)
L = Long-Term, typically greater than 6 months (e.g. hydrology, ecology)
Intensity:
D0 Abnormally Dry
D1 Moderate Drought
D2 Severe Drought
D3 Extreme Drought
D4 Exceptional Drought
Author:
Mark Svoboda
National Drought Mitigation Center

The 2012 Great Plains drought in the literature

1. No early warning for the summer 2012 drought (Hoerling et al., 2014; BAMS; 197 citations)

2. Precipitation anomaly accounted for 72 to 80% of the soil moisture depletion (Livneh and Hoerling, 2016; J. Clim.)



Summer Precipitation forecast using May initial conditions

Result 1 + Result 2 => There is limited predictability of drought in the Great Plains

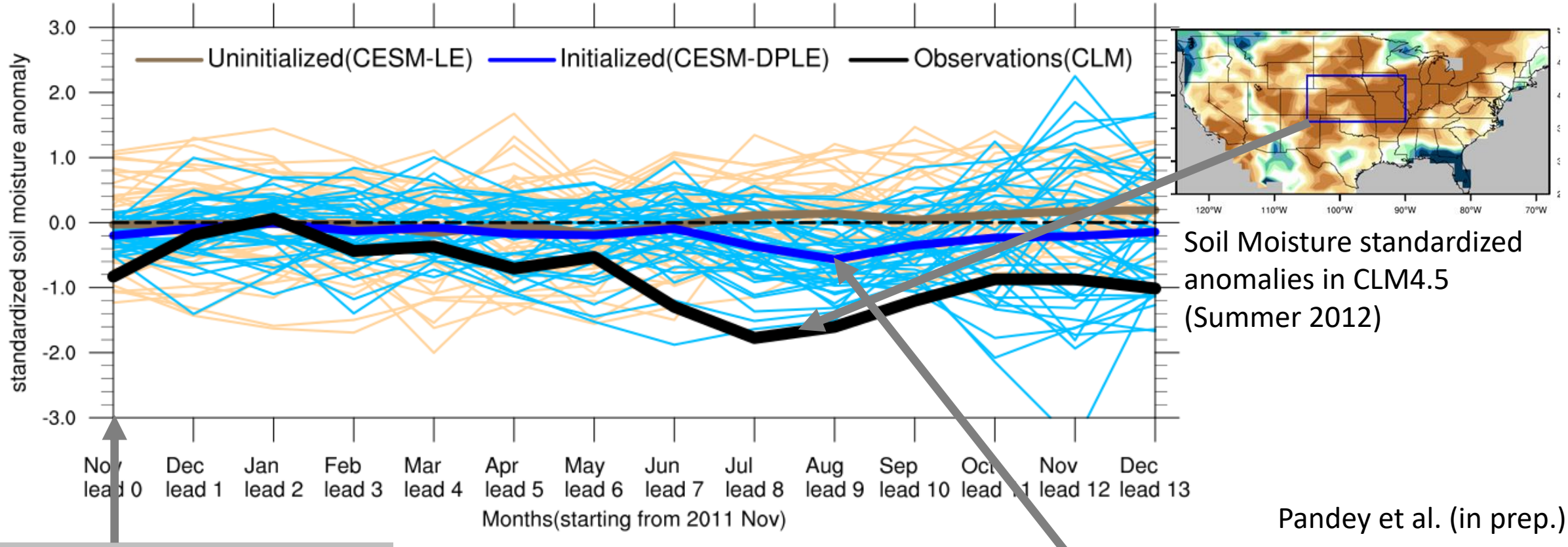
New Findings

1. **There was early warning in the soil moisture forecast:** Soil moisture has a higher predictability than precipitation (CESM-DPLE experiment data; Yeager et al., 2018)

2. **Land-atmosphere interactions played an important role** that along with natural variability resulted in the observed magnitude of precipitation anomalies (remote effects) and get intensified locally (The GLACE-Hydrology Experiment; Kumar et al., in prep.)

New Result 1 + New Result 2 => We can improve drought prediction skill in the Great Plains

The 2012 soil moisture drought forecast in the DPLE experiment



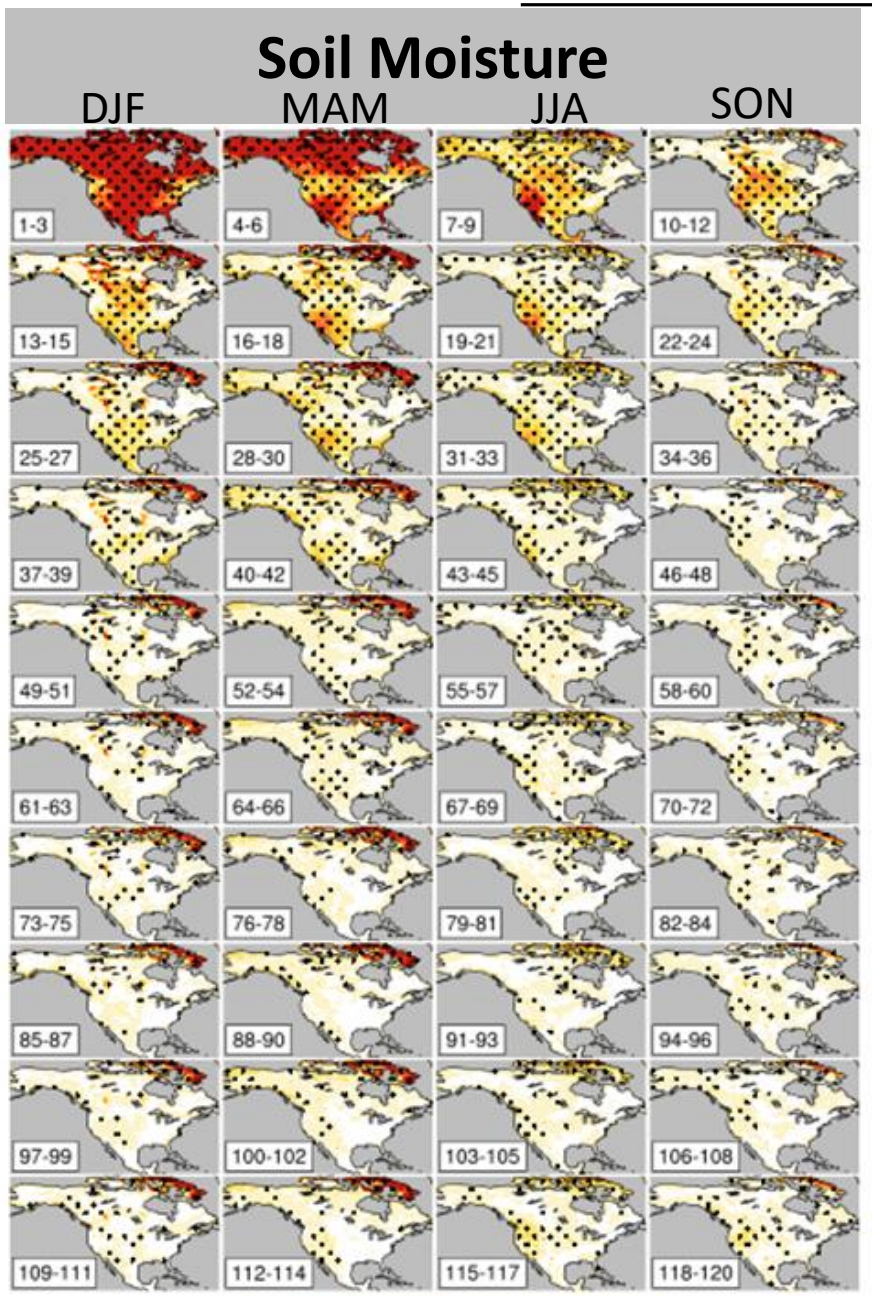
Soil Moisture standardized anomalies in CLM4.5 (Summer 2012)

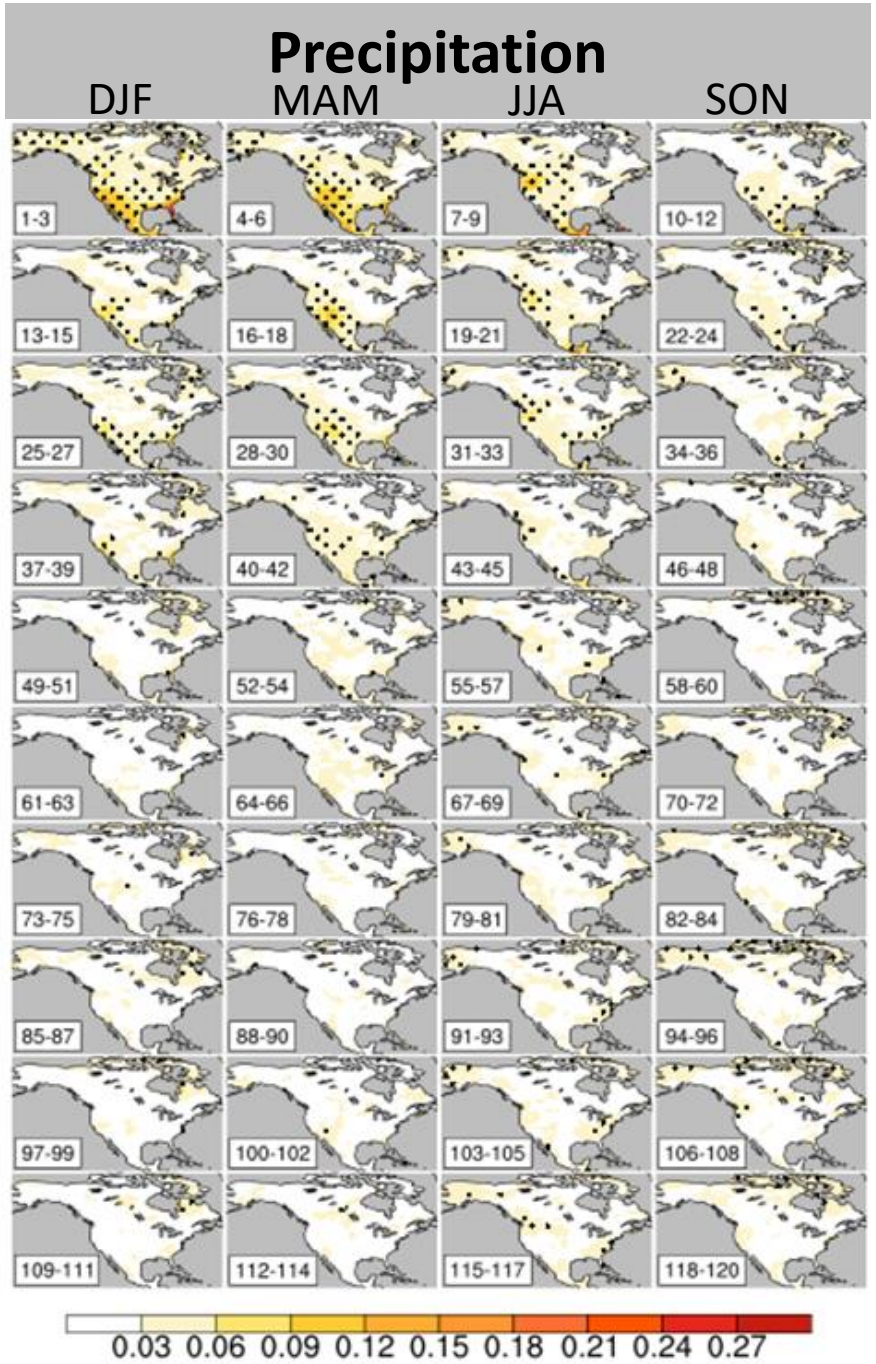
Pandey et al. (in prep.)

November, 2011 Ocean Initial Condition

8 to 12 months lead forecast

Seasonal to Decadal Predictability (DPLE, 1980 to 2015)





Year 1

Year 2

Year 3

Year 4

Year 5

Year 6

Year 7

Year 8

Year 9

Year 10

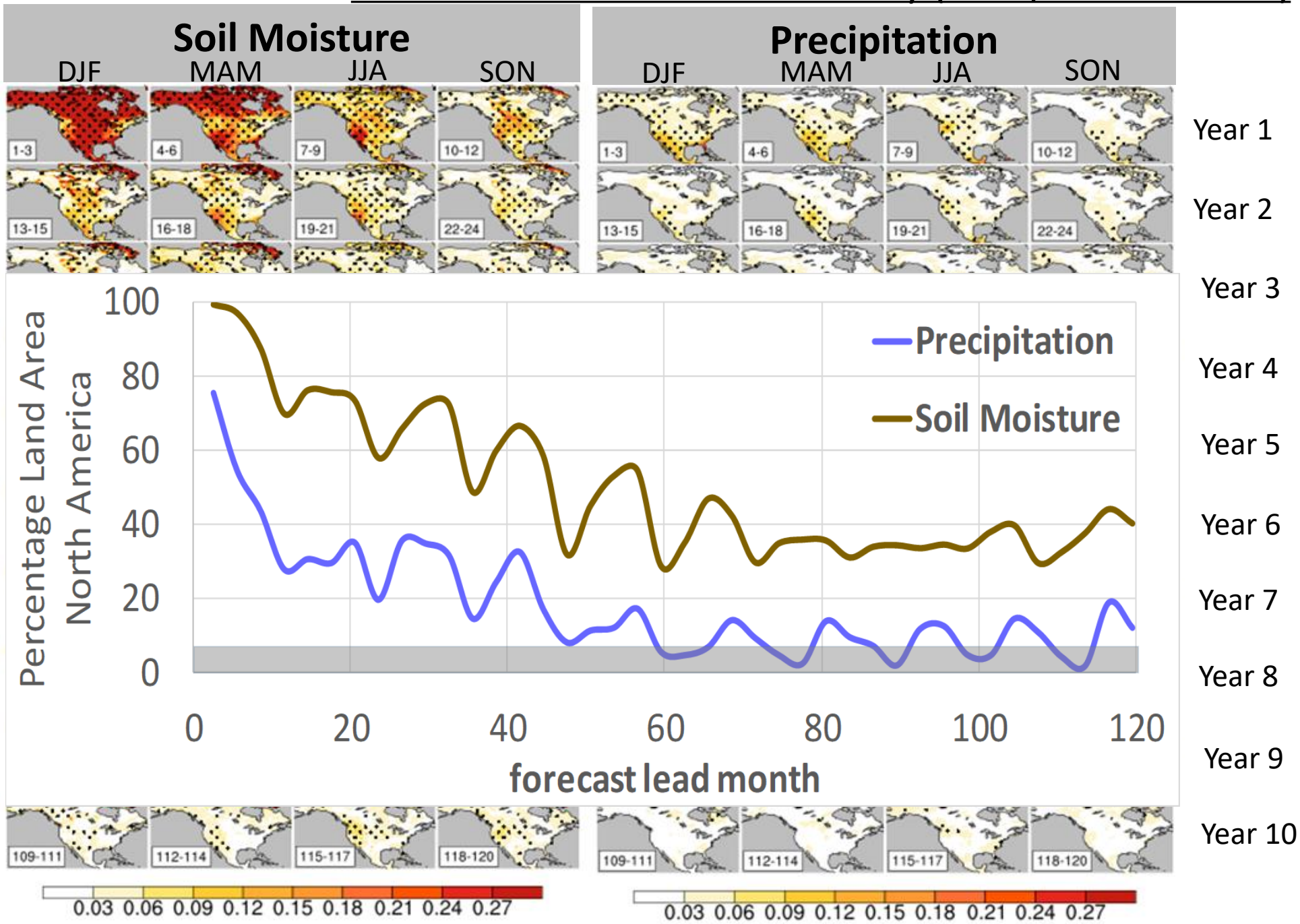
40 ensemble X 36 years

$$\frac{\boldsymbol{Signal\ Var.}}{(\boldsymbol{Signal + Noise})\ \boldsymbol{Var.}}$$

Methodology from Guo et al. (2011)

Pandey et al. (in prep.)

Seasonal to Decadal Predictability (DPLE, 1980 to 2015)



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New Findings

1. **There was early warming in the soil moisture forecast:** Soil moisture has a higher predictability than precipitation (CESM-DPLE experiment data; Yeager et al., 2018)

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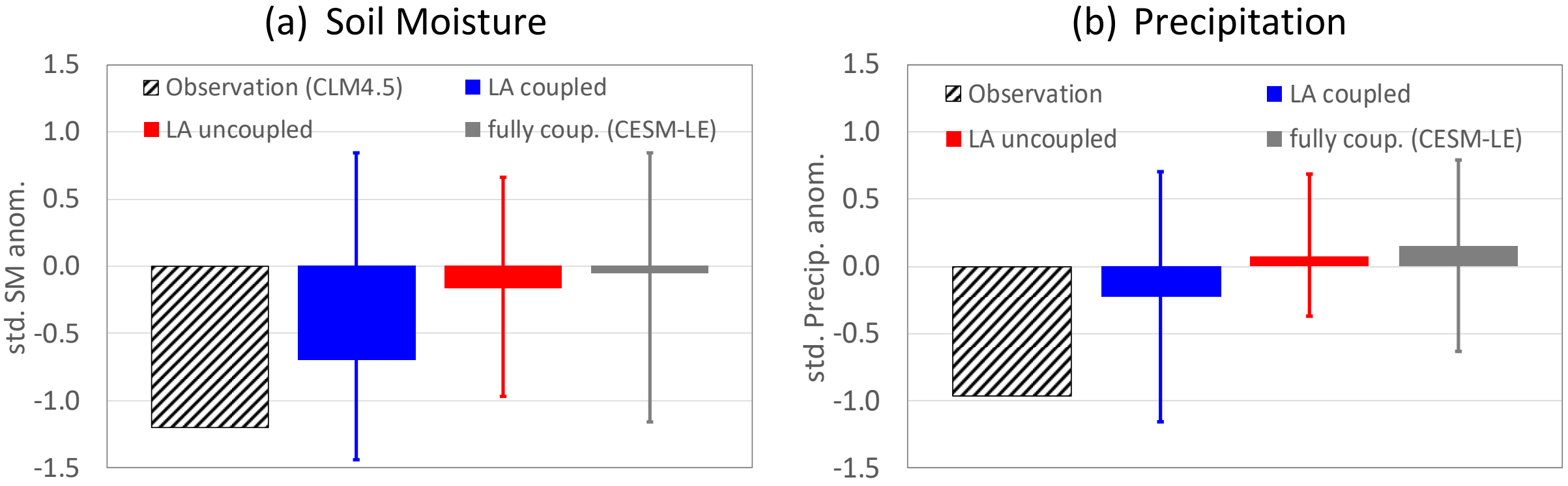
New Result 1 + New Result 2 => We can improve drought prediction skill in the Great Plains

Land-Atmosphere (LA) Coupling contributed to the 2012 Great Plains drought

(LA uncoupled run did not produce observed level of the drought in the Great Plains)



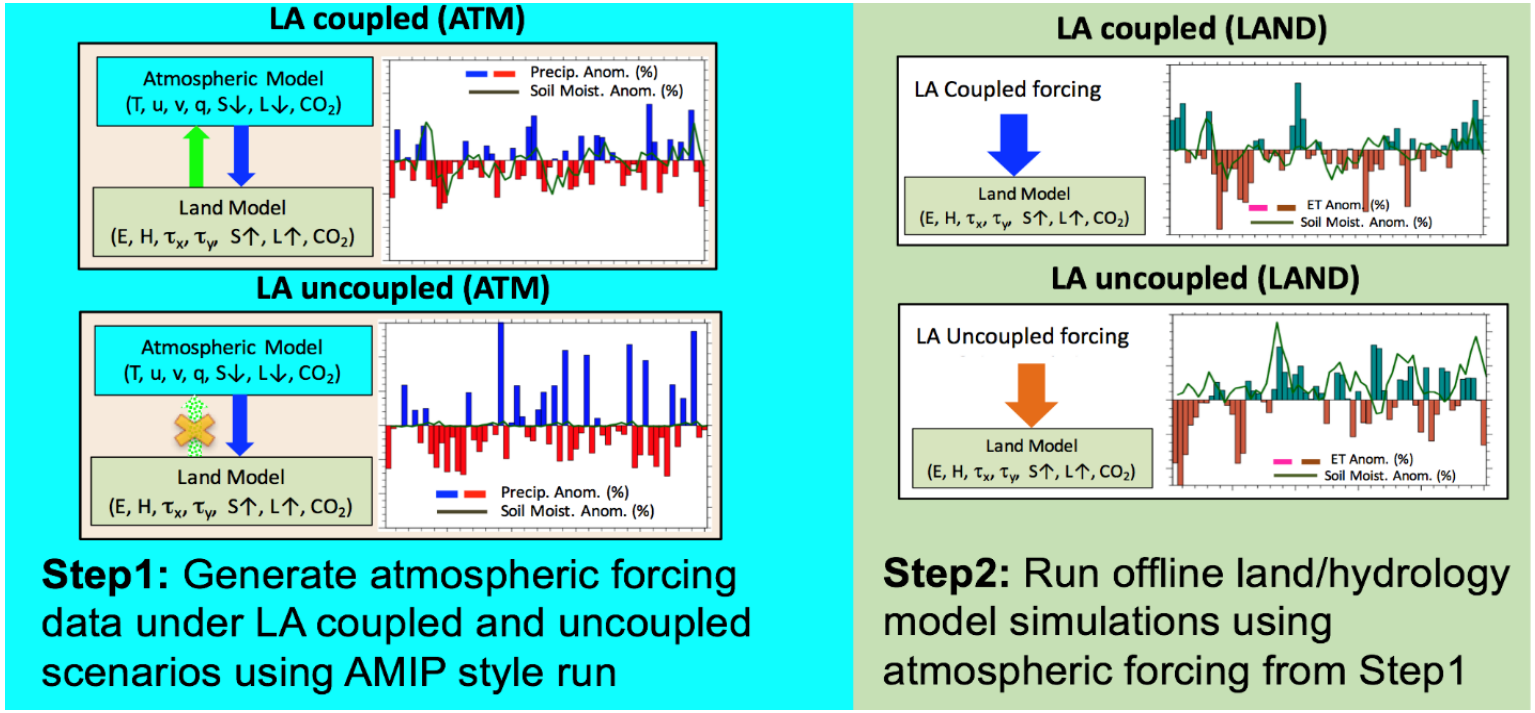
LA coupled: Land-Atmosphere coupled experiment (CAM5 + CLM4.5) with observed SST (10 member ensemble)

LA uncoupled: Land-Atmosphere uncoupled experiment with observed SST, and climatological soil moisture conditions (Step1), then climate forcing from Step1 is used to drive offline land model simulation (Step2)

CESM-LE: Fully coupled experiment with model simulated SST, 40 member ensemble 2012 runs are analyzed (Kay et al., 2015)

Kumar et al. (in prep.)

The GLACE-Hydrology Experiment



Step1: Generate atmospheric forcing data under LA coupled and uncoupled scenarios using AMIP style run

Step2: Run offline land/hydrology model simulations using atmospheric forcing from Step1

Simulation Period: 1971 to 2014

Analysis Period: 1980 to 2014

Results shown are for the Boreal Summer (JJA)

Step1 (GLACE) + Step2 (Hydrology) = The GLACE-Hydrology Experiment

LA coupled: Land-Atmosphere coupled experiment (CAM5 + CLM4.5) with observed SST (10 member ensemble)

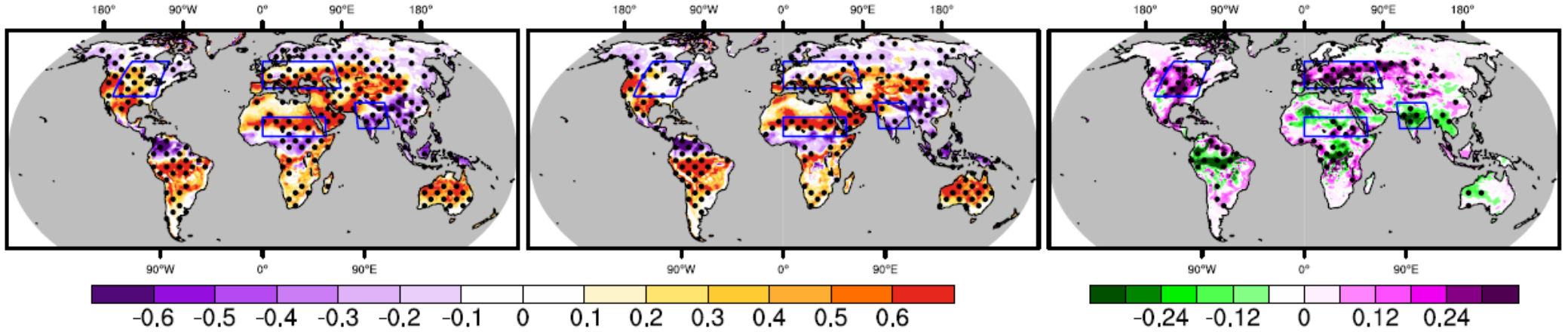
LA uncoupled: Land-Atmosphere uncoupled experiment with observed SST, and climatological soil moisture conditions (Step1), then climate forcing from Step1 is used to drive offline land model simulation (Step2)

Kumar et al. (in prep.)

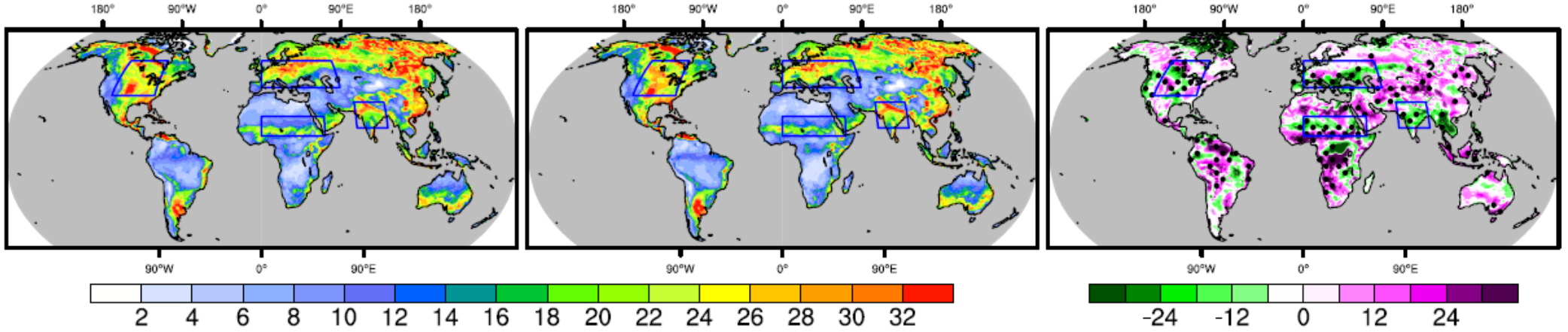
LA coupling gets built in the climate forcing

LA coupled LA uncoupled Coupled- Uncoupled

(a) SM'ET' correlations, JJA (Units: NA, NA)



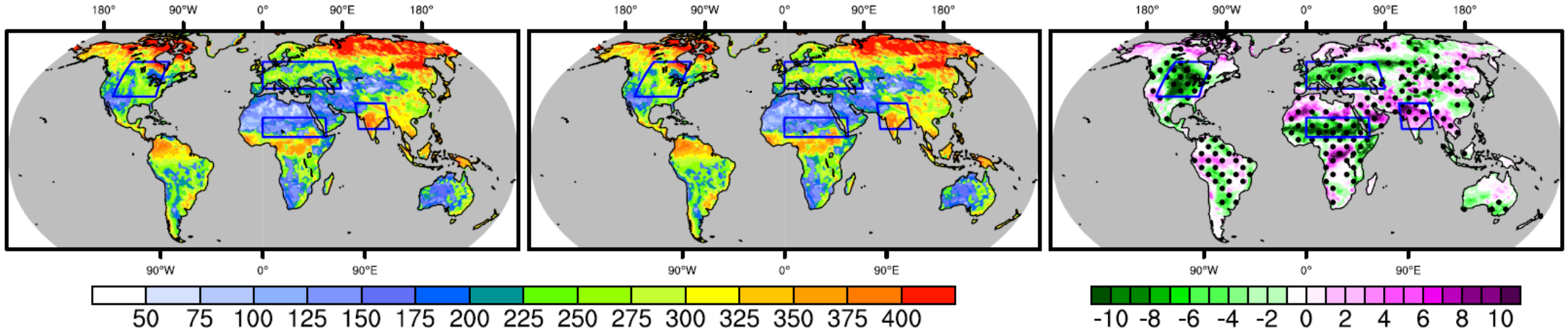
(b) Soil moisture variability (inter-annual standard deviation) (Units: mm/m, and %)



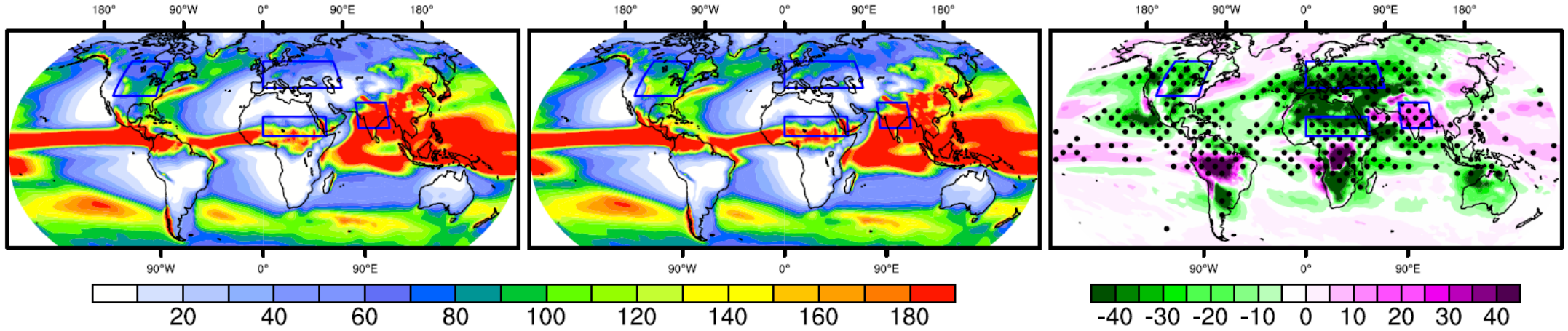
LA coupling makes the summer drier in the Great Plains

LA coupled | LA uncoupled | Coupled- Uncoupled

(a) Soil moisture (Units: mm/m, %)



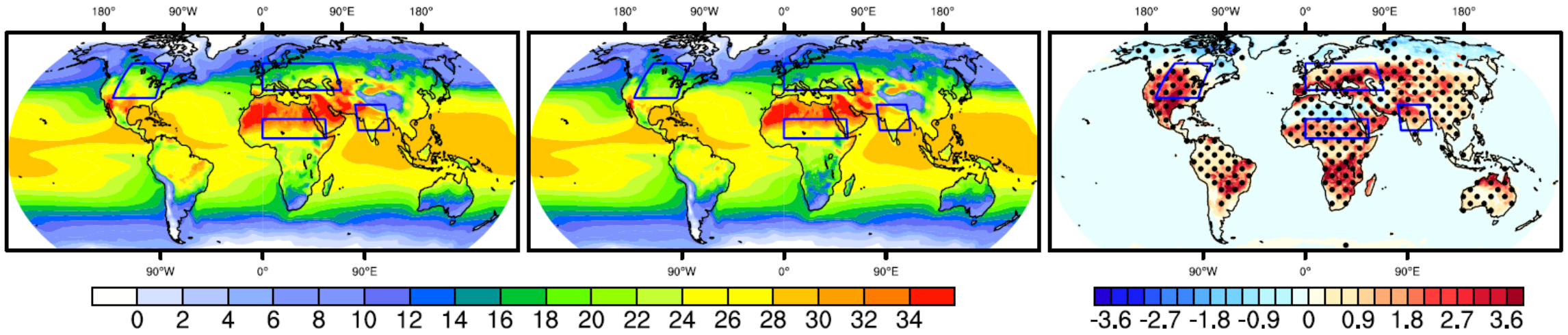
(b) Precipitation (Units: mm/month, %)



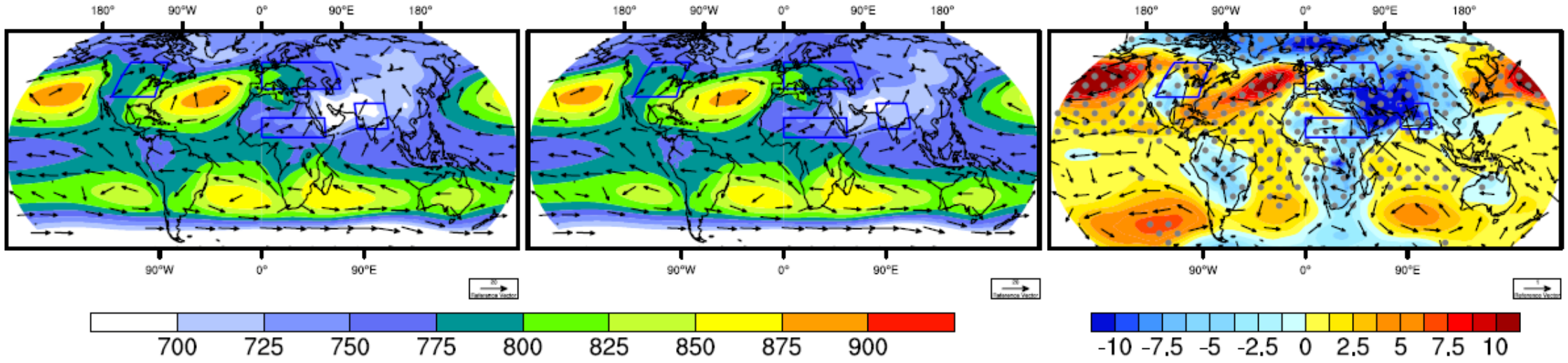
LA coupling causes surface warming that changes global circulation

LA coupled | LA uncoupled | Coupled- Uncoupled

(a) Surface Temperature (Units:°C,°C)

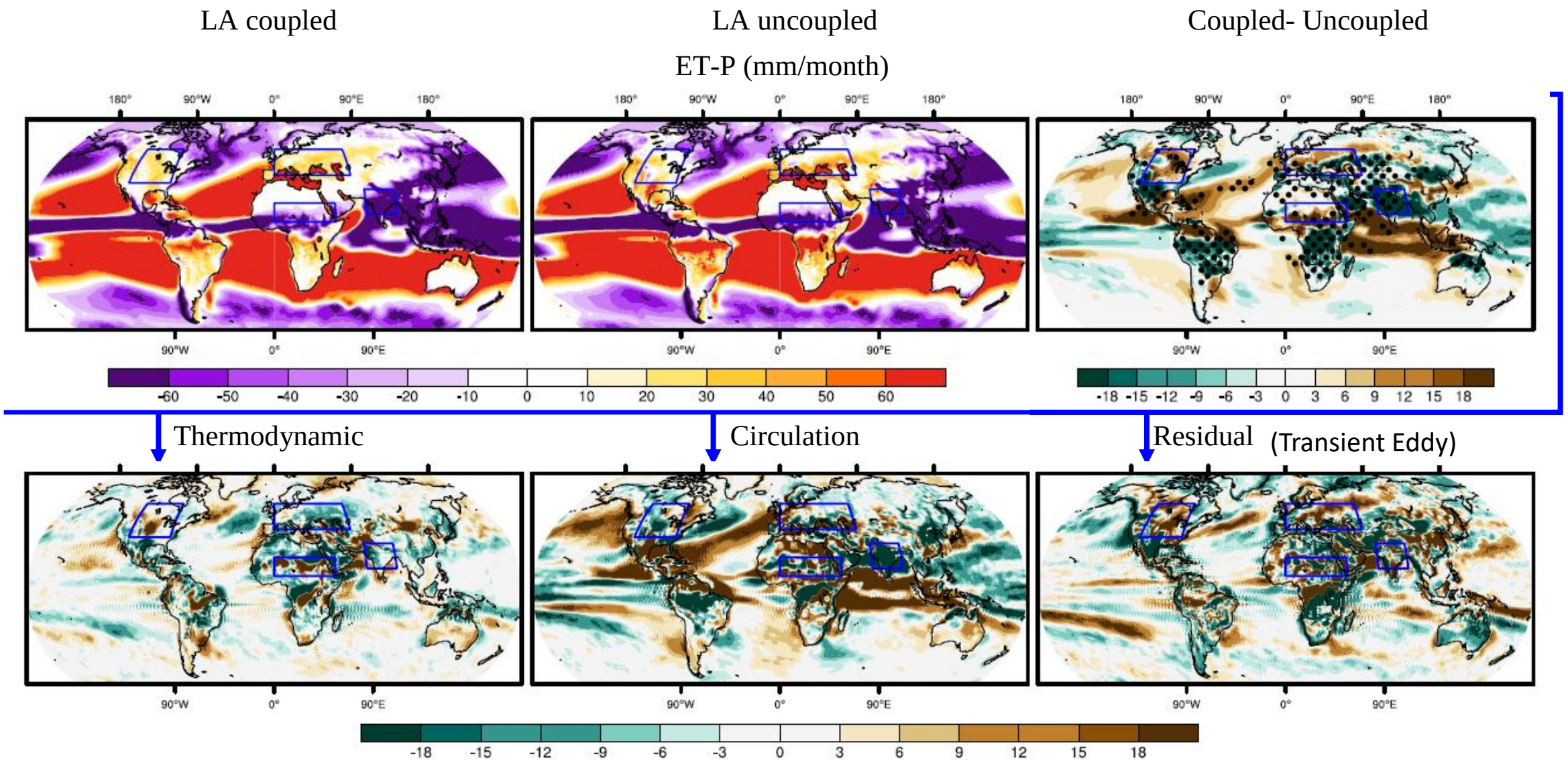


(a) 925 hpa Z and wind



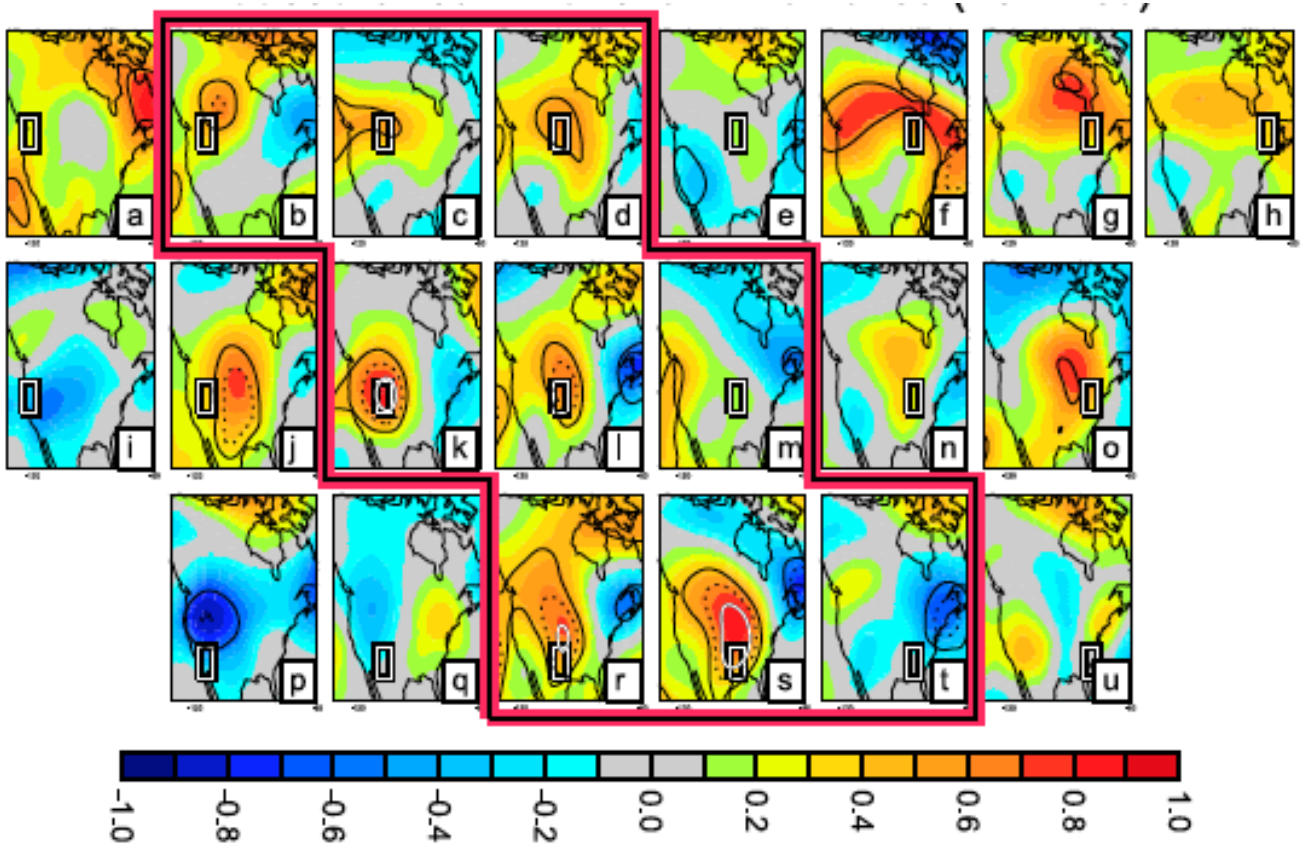
Local Evaporation + Global Circulation = Precipitation somewhere

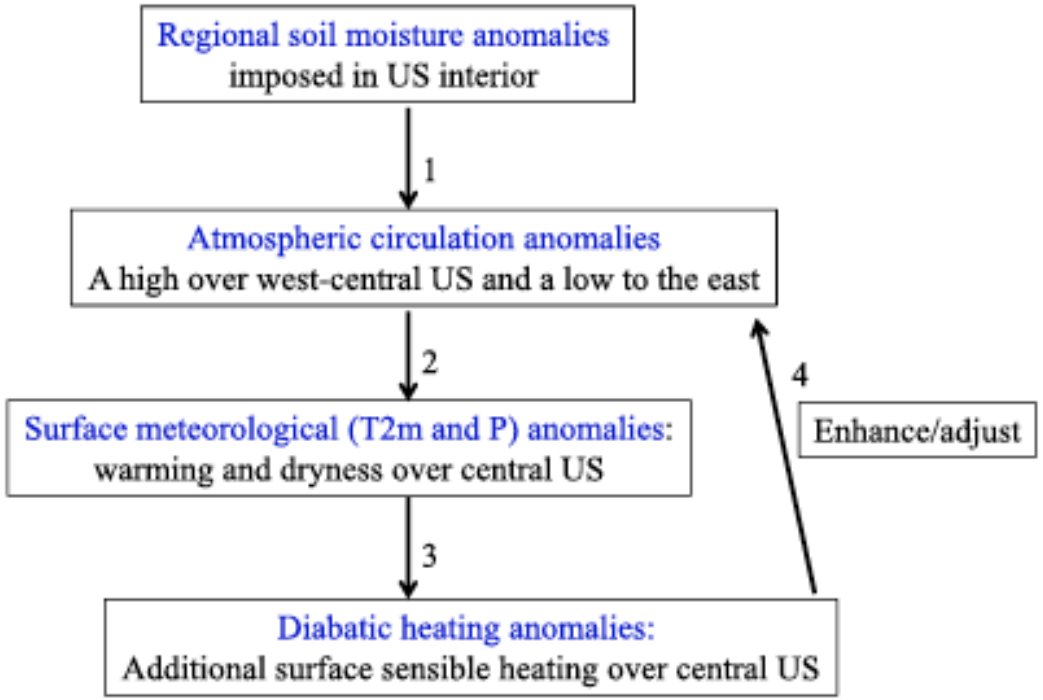
(First Order Response: Wet gets Wetter and Dry gets Drier)



Methodology from Seager et al. (2010)

Is our result model dependent? -> For most part NO





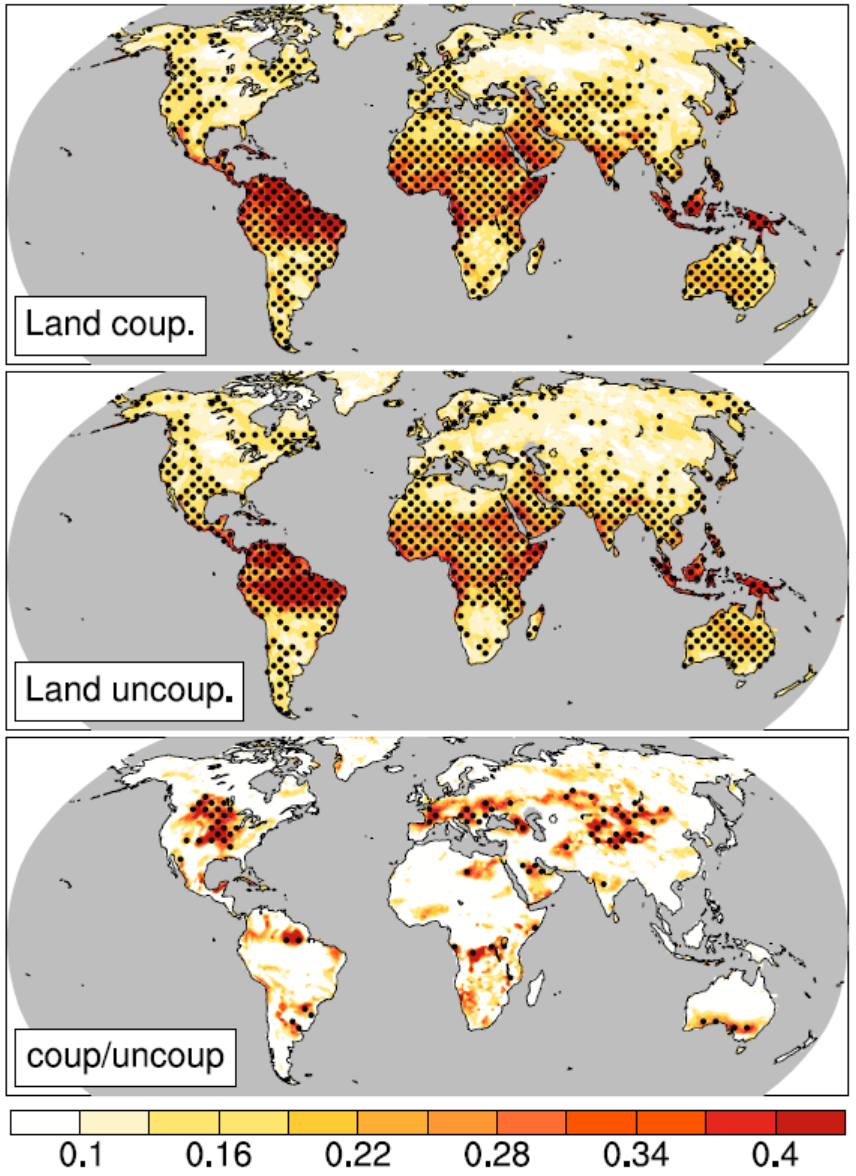
Circulation response of the localized dry surface anomalies in **NASA GEOS-5 AGCM**: Anomalies in 250 hPa stream function

Positive feedback loop over the Great Plains

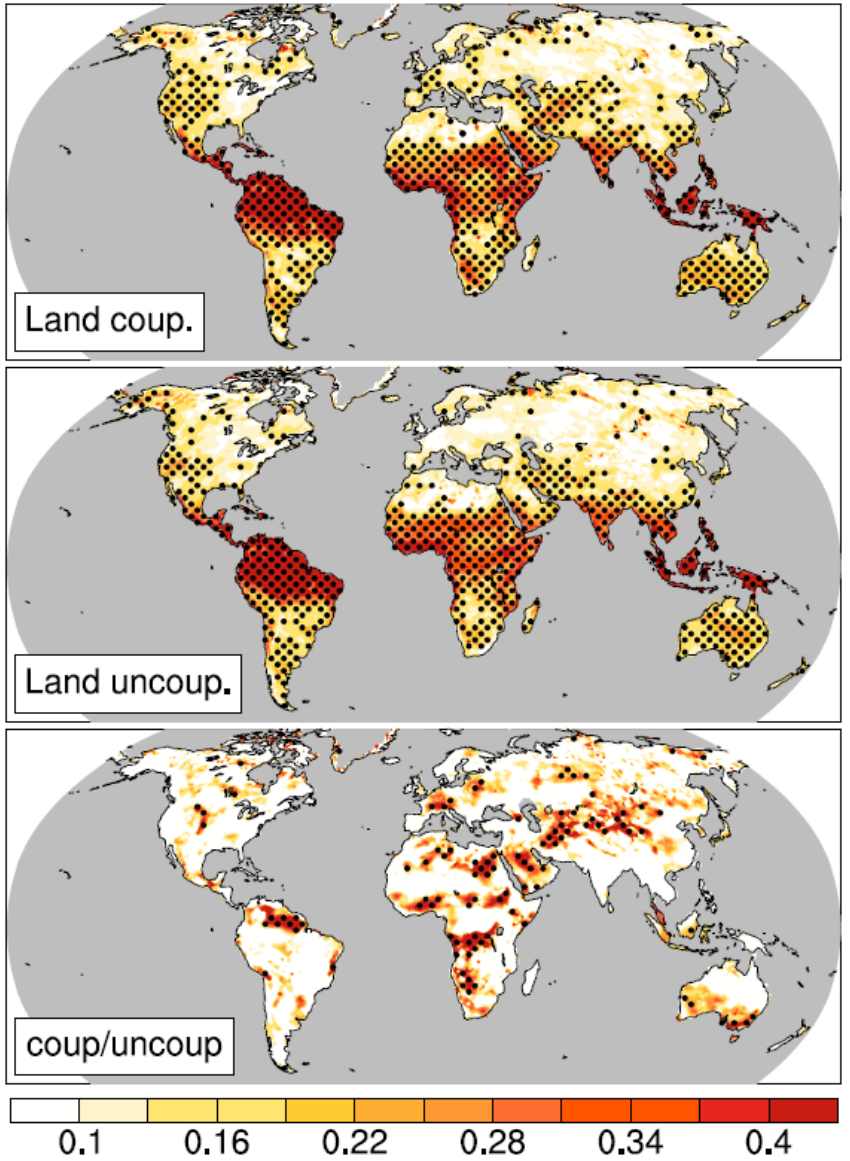
Koster et al. (2016); J. Clim.

LA coupling improves skill in prediction of evapotranspiration and Soil Moisture

Evapotranspiration (JJA)



Soil moisture (JJA)



$$\frac{Signal\ Var.Coup.}{(Signal + Noise)\ Var.Coup.}$$

$$\frac{Signal\ Var.Uncoup.}{(Signal + Noise)\ Var.Uncoup.}$$

$$\mathbf{Log_{10}}\left(\frac{Signal\ Var.Coup.}{Signal\ \ Var.Uncoup.}\right)$$

Methodology is from Guo et al., 2011

Conclusions

1. **There was early warming in the soil moisture forecast:** Soil moisture has a higher predictability than precipitation (CESM-DPLE experiment data; Yeager et al., 2018)

2. **Land-atmosphere interactions played an important role** that along with natural variability resulted in the observed magnitude of precipitation anomalies (remote effects) and get intensified locally (The GLACE-Hydrology Experiment; Kumar et al., in prep.)

New Result 1 + New Result 2 => We can improve skill in drought prediction in the Great Plains

Acknowledgement

1. NRC Research Associateship Award at NOAA ESRL PSD (2015 to 2017)
2. Auburn IGP and USDA Hatch grant (2017 to present)
3. NCAR CISL – University Large Allocation (60TB data)
4. Auburn Hopper supercomputer

Extra Slide

Geopotential height, and wind climatology difference between LA coupled and LA uncoupled experiment at pressure level of 925 hpa (a), 850 hpa (b), 500 hpa (c), and 200 hpa (d) for the boreal summer (JJA).