Ocean Salinity as a Predictor of Terrestrial Precipitation

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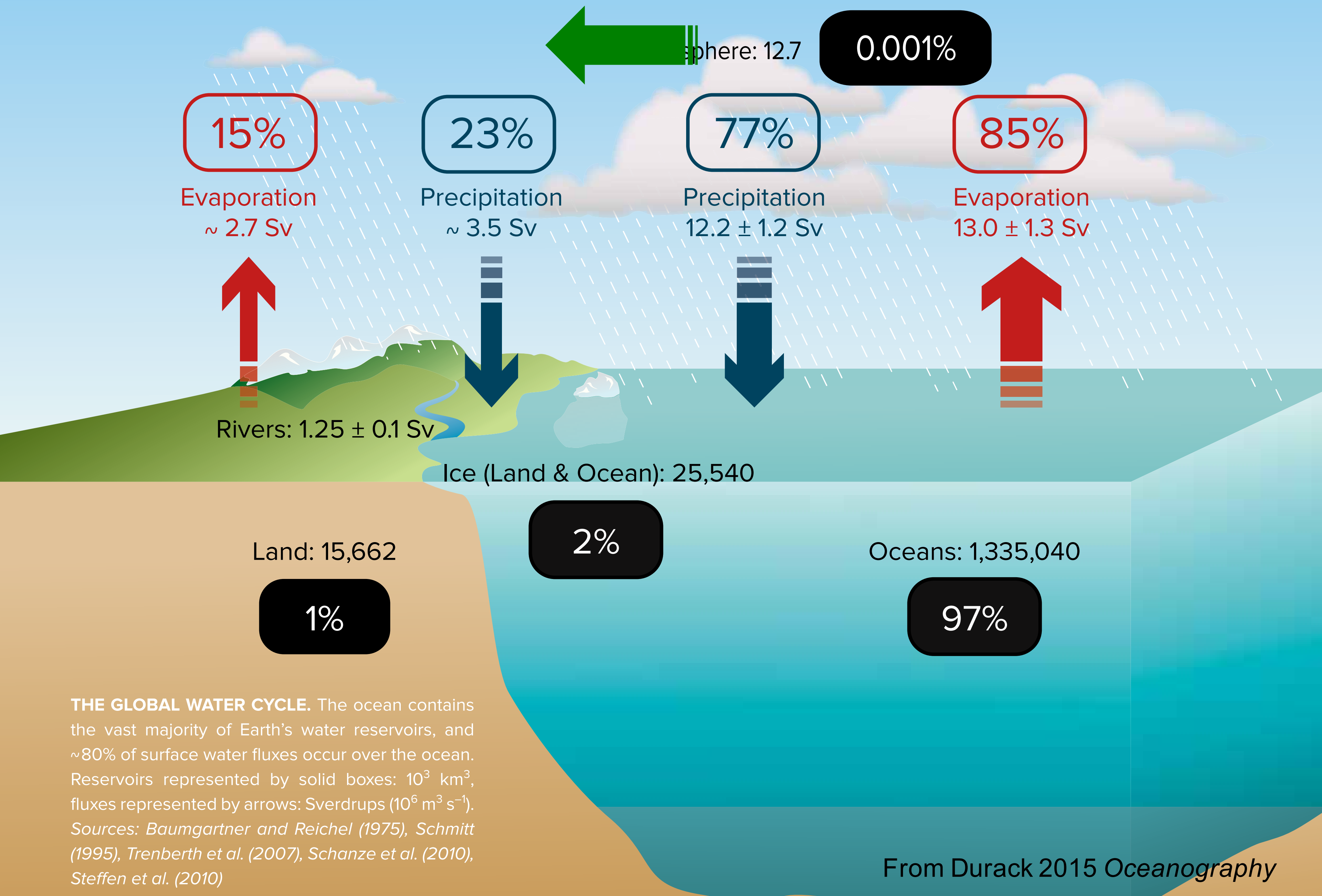
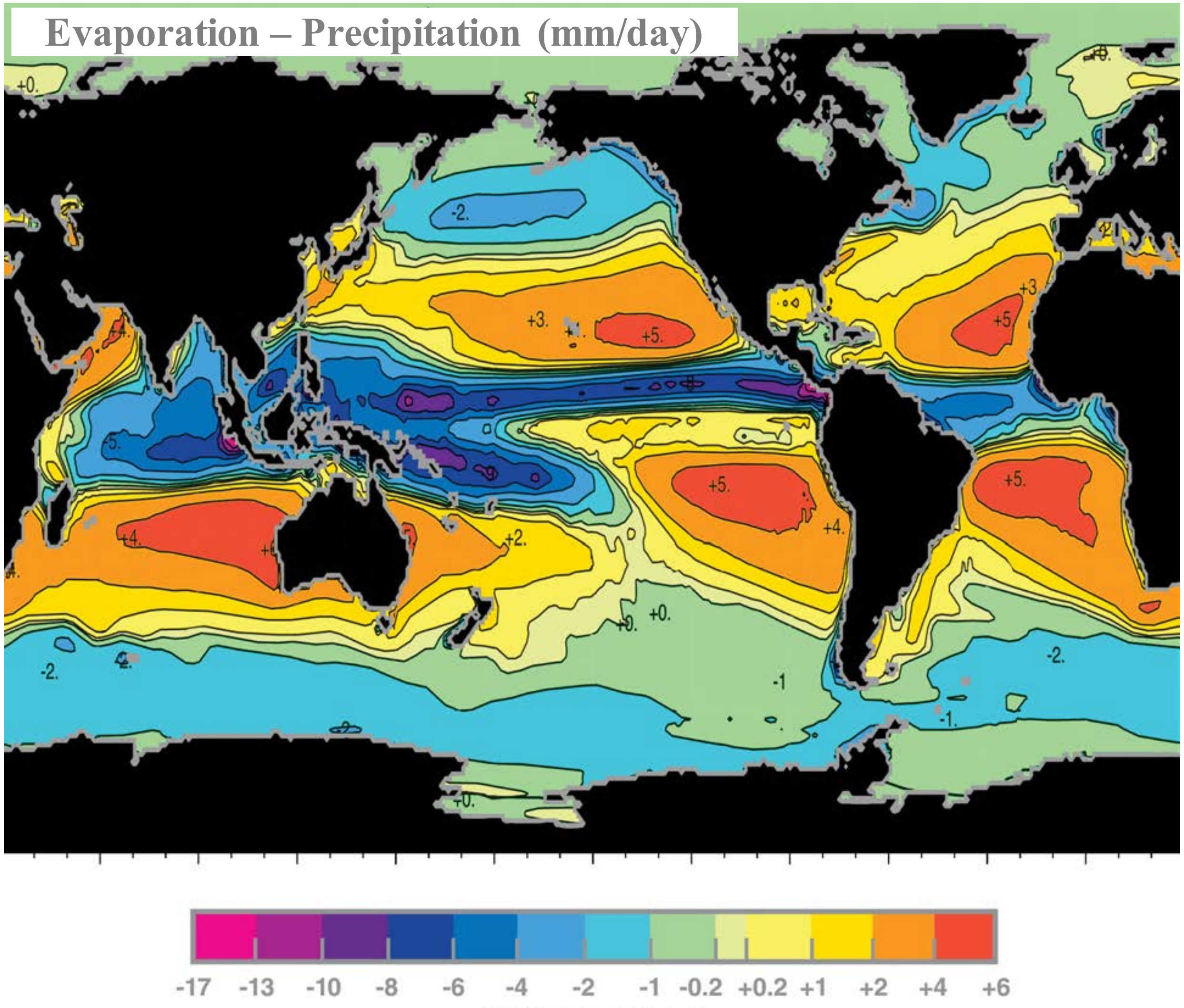
Motivation: Ocean and Global Water Cycle



THE GLOBAL WATER CYCLE. The ocean contains the vast majority of Earth's water reservoirs, and ~80% of surface water fluxes occur over the ocean. Reservoirs represented by solid boxes: 10^3 km^3, fluxes represented by arrows: Sverdrups (10^6 m^3 s^{-1}). *Sources: Baumgartner and Reichel (1975), Schmitt (1995), Trenberth et al. (2007), Schanze et al. (2010), Steffen et al. (2010)*

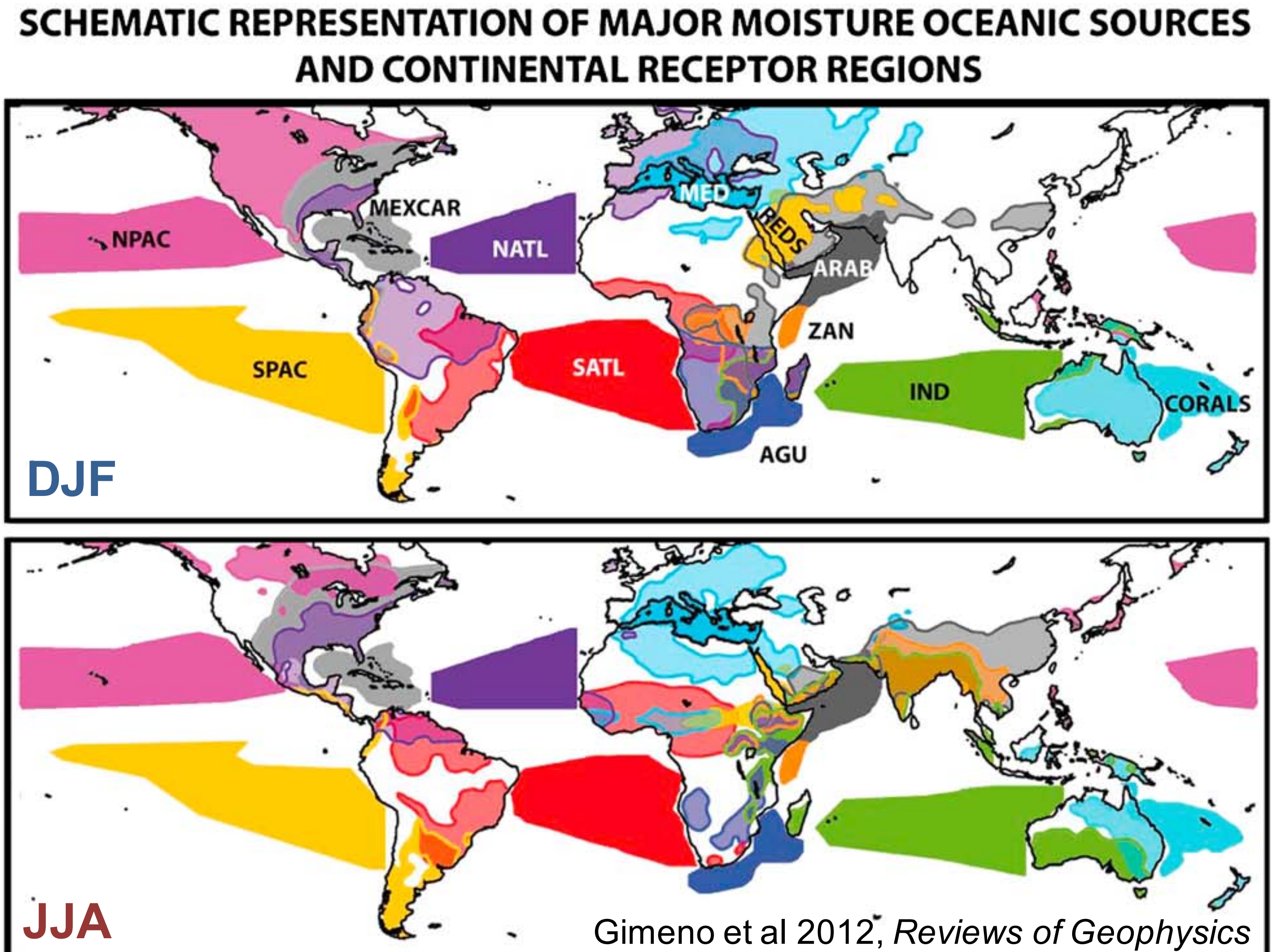
From Durack 2015 *Oceanography*

Moisture Source Regions: Subtropical Oceans



Evaporation>Precipitation→ net moisture export: Moisture sources
Precipitation>Evaporation→ net moisture input: Moisture sinks

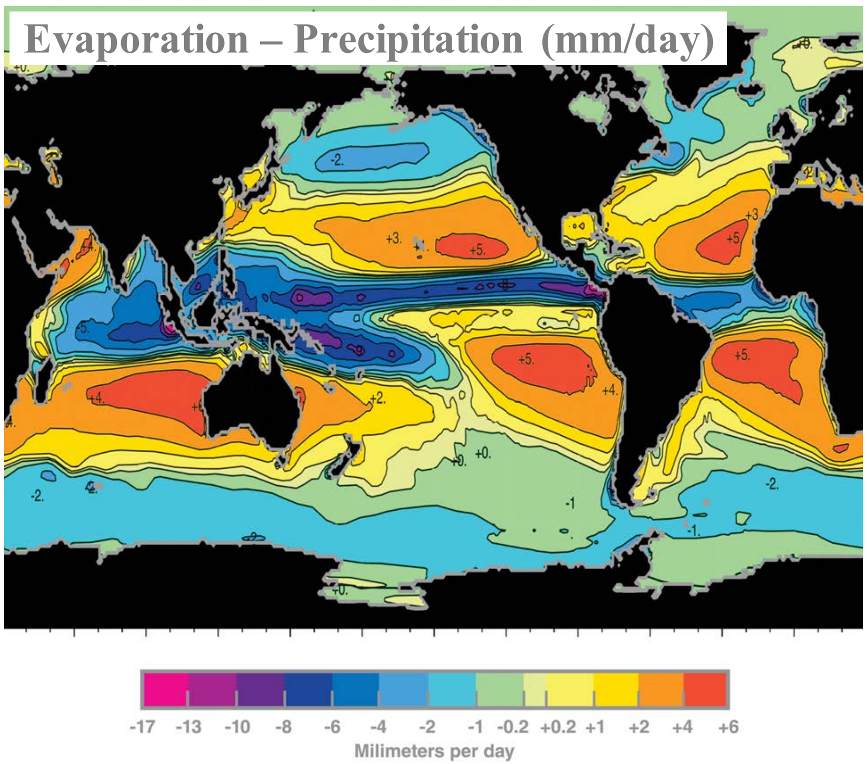
Oceanic Moisture & Terrestrial Precipitation

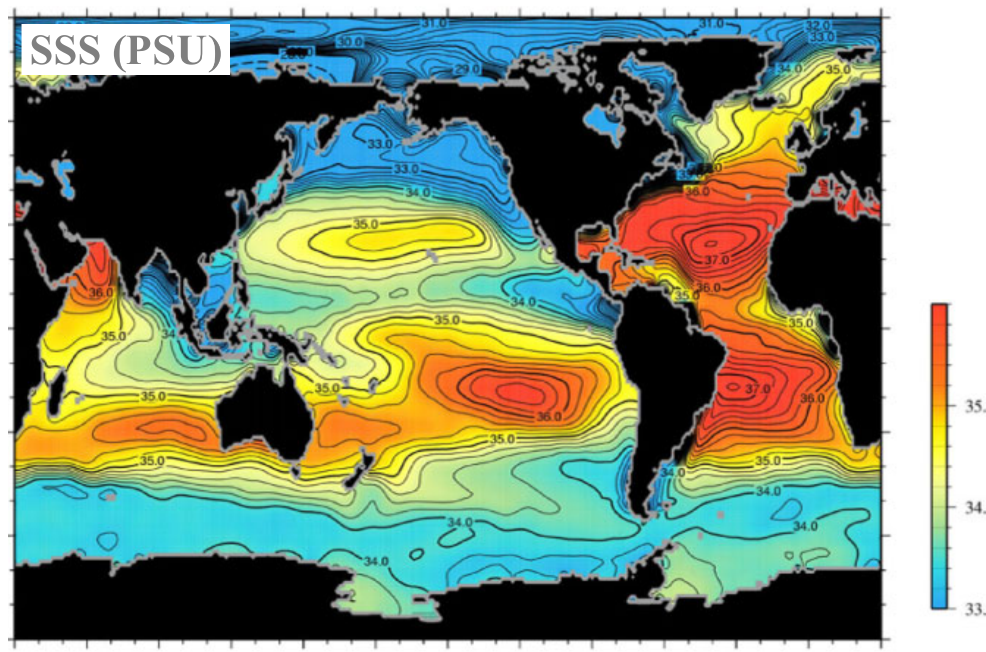


Evaporation>Precipitation→ net moisture export: Moisture sources
Precipitation>Evaporation→ net moisture input: Moisture sinks

Sea Surface Salinity: Indicator of Oceanic Water Cycle

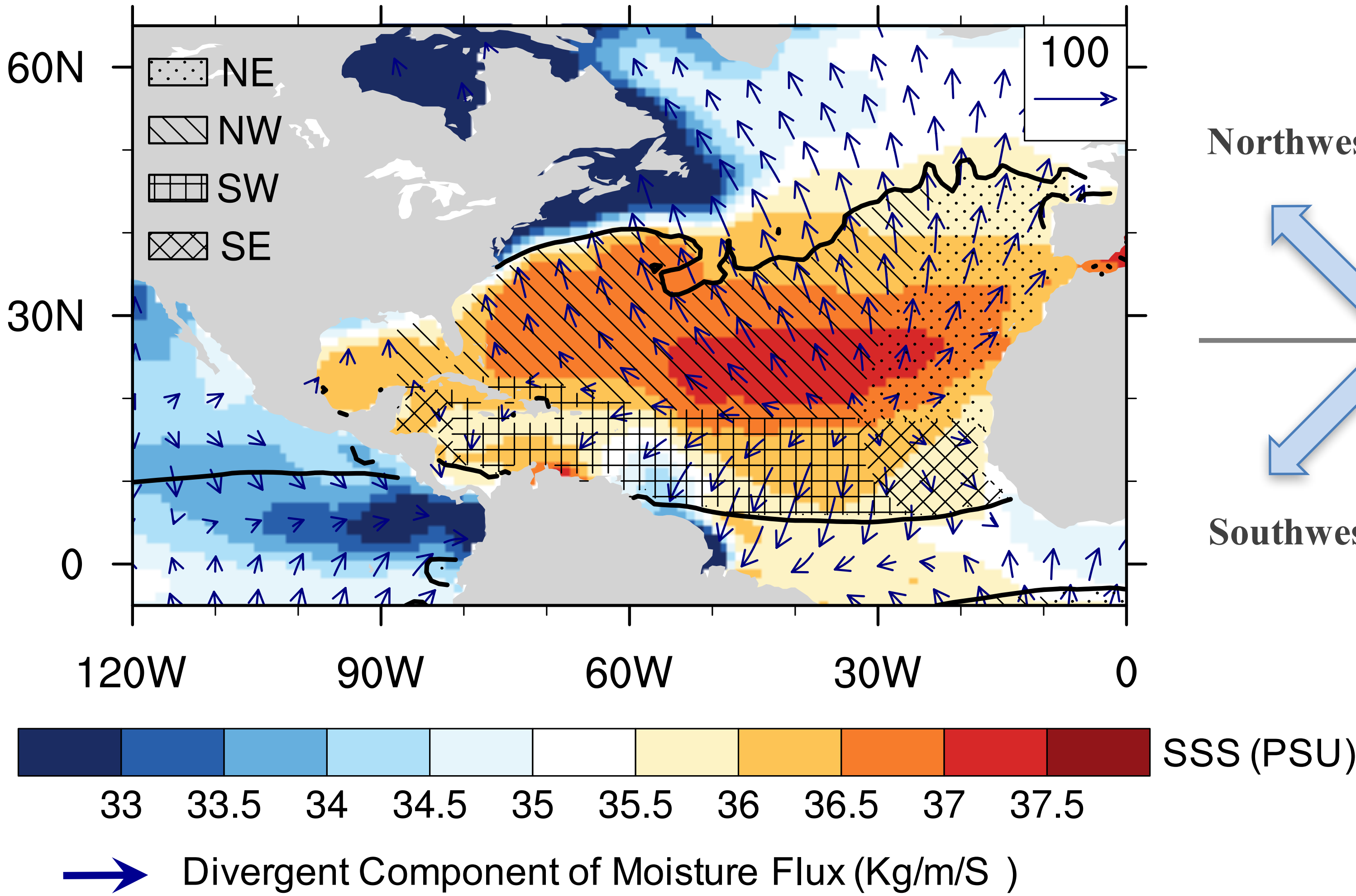
The oceanic water cycle leaves an imprint on SSS, making SSS "nature's rain gauge".

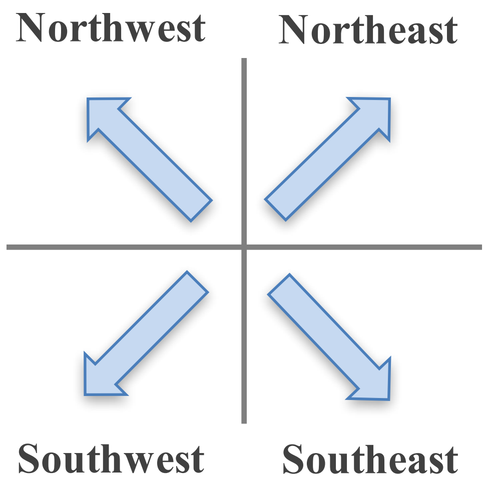




Q: Is SSS a predictor of terrestrial precipitation?

Definition of North Atlantic SSS Indices

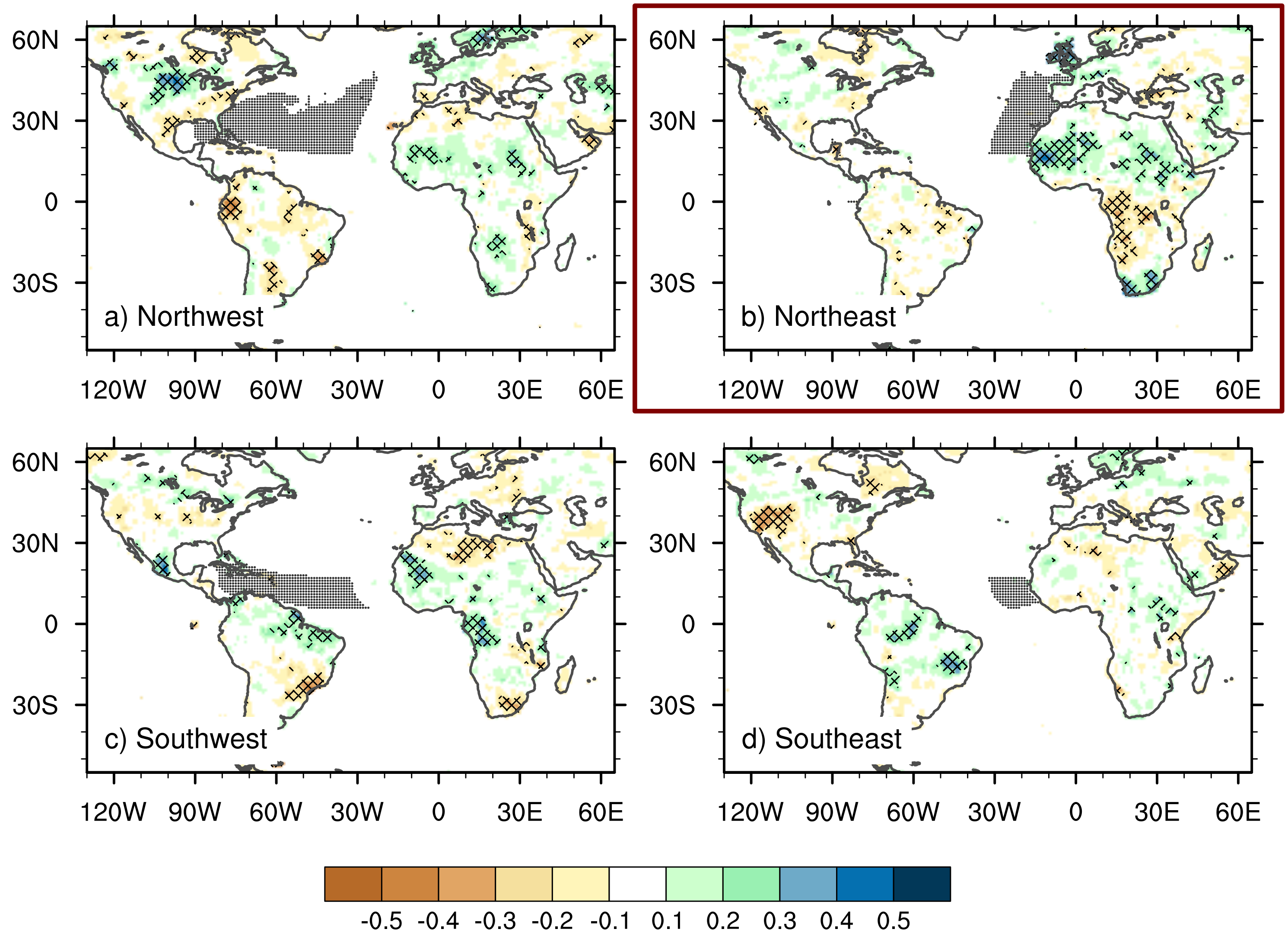




March-April-May (MAM) climatology (1950-2009) of SSS (shaded, unit: PSU), moisture flux divergence (contours, unit: mm/day) and the divergent component of moisture flux (vectors, unit: Kg/m/S) over the North Atlantic. The bold contours are the moisture flux divergence = 0 isoline.

N. Atl. SSS and Terrestrial Precipitation: Sahel

SSS in NE subtropical N. Atl. leads Sahel monsoon precipitation



Correlation between Springtime North Atlantic SSS and Warm season (JJA) precipitation: a) Northwest index; b) Northeast index; c) Southwest index; and d) Southeast index.

OCEANOGRAPHY

North Atlantic salinity as a predictor of Sahel rainfall

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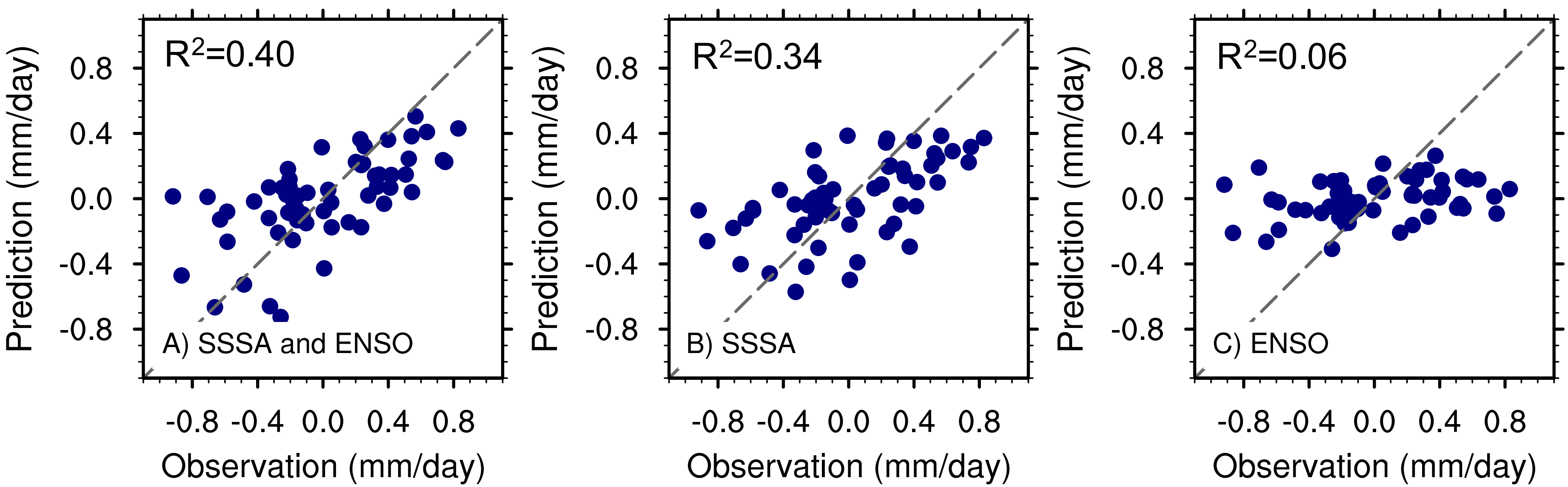
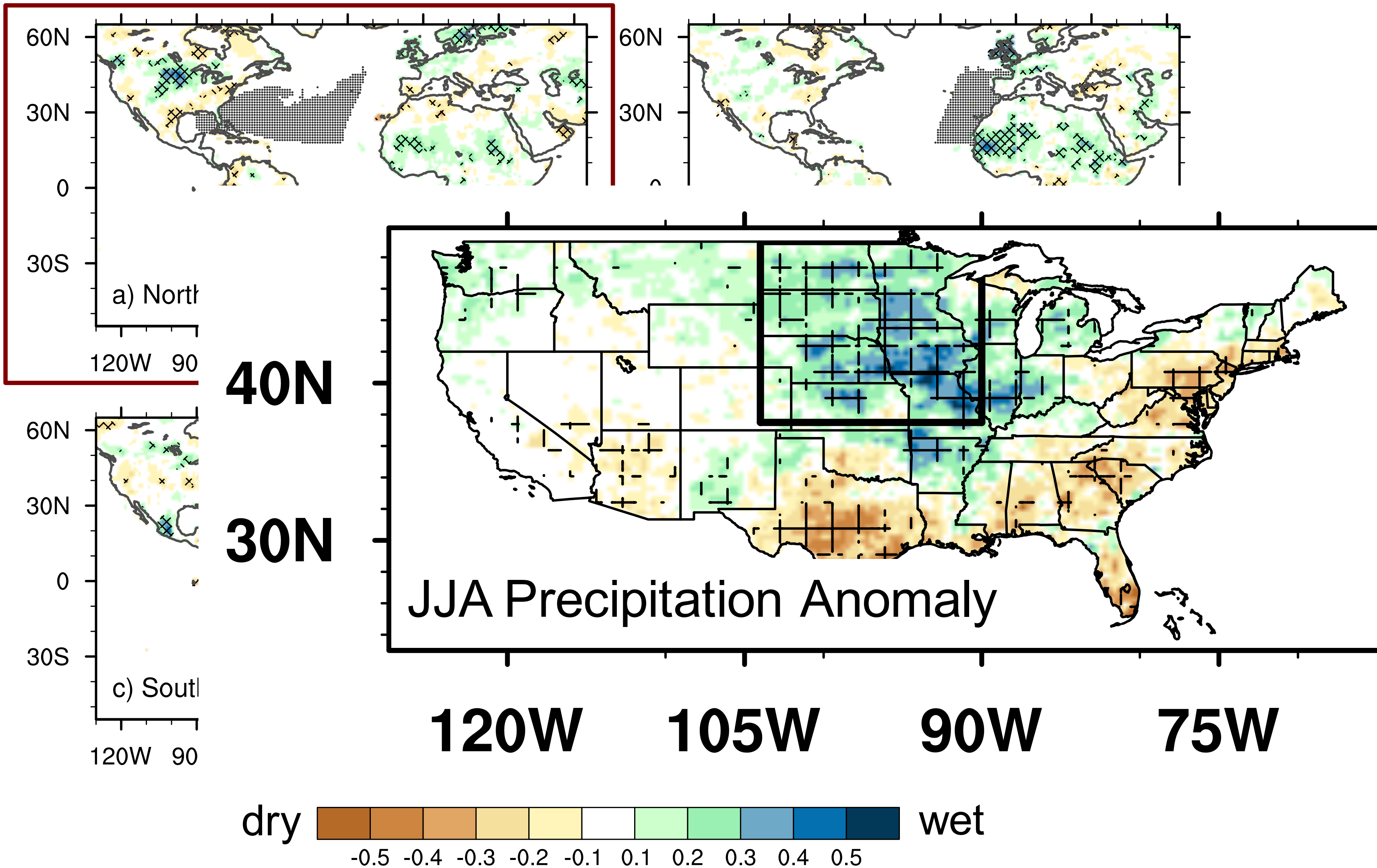
Water evaporating from the ocean sustains precipitation on land. This ocean-to-land moisture transport leaves an imprint on sea surface salinity (SSS). Thus, the question arises of whether variations in SSS can provide insight into



N. Atl. SSS & Terrestrial Precipitation: Midwest

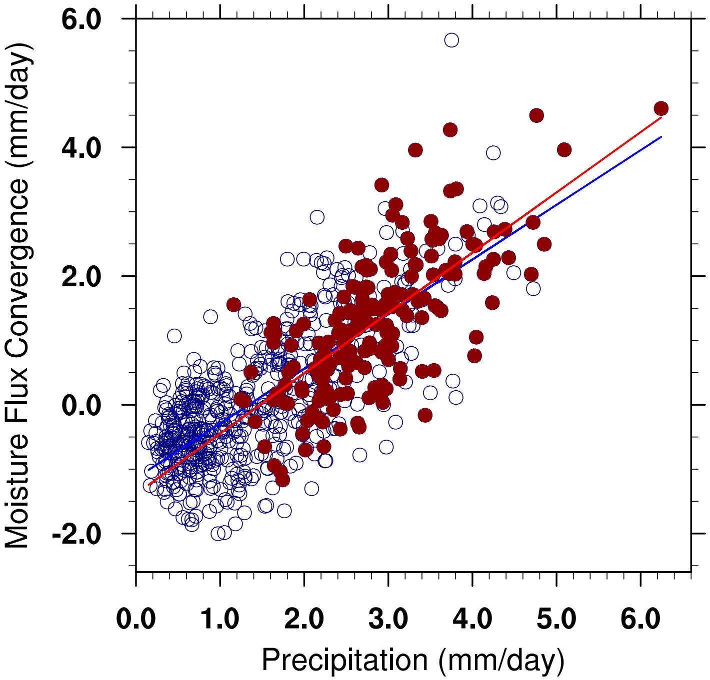
SSS in NW subtropical N. Atl. leads Midwest summer precipitation



Correlation between Springtime North Atlantic SSS and Warm season (JJA) precipitation: a) Northwest index; b) Northeast index; c) Southwest index; and d) Southeast index.

What Cause Rainfall Anomaly?

Methods: Thermodynamic and dynamic decomposition of the regional water cycle



In US Midwest: $P \sim -\frac{1}{g}\nabla \cdot \int_0^{p_s} \overline{q}\vec{\overline{V}}\,dp$

$$-\frac{1}{g}\nabla \cdot \int_0^{p_s} \overline{q}\vec{\overline{V}}\,dp = \underbrace{-\frac{1}{g}\int_0^{p_s} \overline{q}\nabla \cdot \vec{\overline{V}}\,dp}_{\text{mass divergence}} \underbrace{-\frac{1}{g}\int_0^{p_s} \vec{\overline{V}} \cdot \nabla \overline{q}\,dp}_{\text{moisture gradient}}$$

Thermodynamic and Dynamic Decomposition: $q = q_c + q_a$; $\vec{V} = \vec{V}_c + \vec{V}_a$

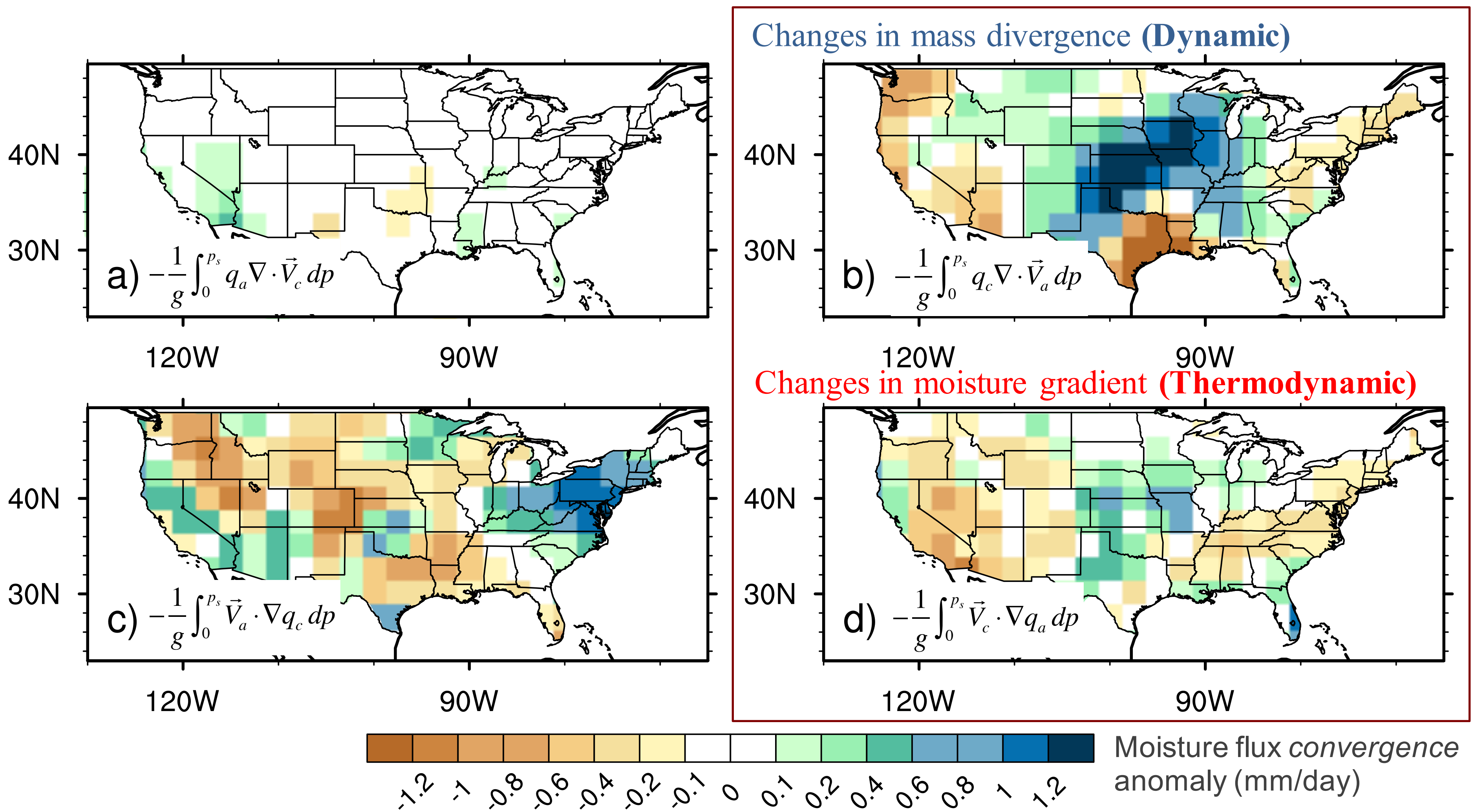
(_c: climatology; _a: anomalies)

$$\underbrace{-\frac{1}{g}\int_0^{p_s} q\nabla \cdot \vec{V}\,dp}_{\text{Mass Divergence}} = -\frac{1}{g}\int_0^{p_s} q_c\nabla \cdot \vec{V}_c\,dp - \frac{1}{g}\int_0^{p_s} q_c\nabla \cdot \vec{V}_a\,dp - \frac{1}{g}\int_0^{p_s} q_a\nabla \cdot \vec{V}_c\,dp - \frac{1}{g}\int_0^{p_s} q_a\nabla \cdot \vec{V}_a\,dp$$

$$\underbrace{-\frac{1}{g}\int_0^{p_s} \vec{V} \cdot \nabla q\,dp}_{\text{Moisture Gradient}} = -\frac{1}{g}\int_0^{p_s} \vec{V}_c \cdot \nabla q_c\,dp - \frac{1}{g}\int_0^{p_s} \vec{V}_a \cdot \nabla q_c\,dp - \frac{1}{g}\int_0^{p_s} \vec{V}_c \cdot \nabla q_a\,dp - \frac{1}{g}\int_0^{p_s} \vec{V}_a \cdot \nabla q_a\,dp$$

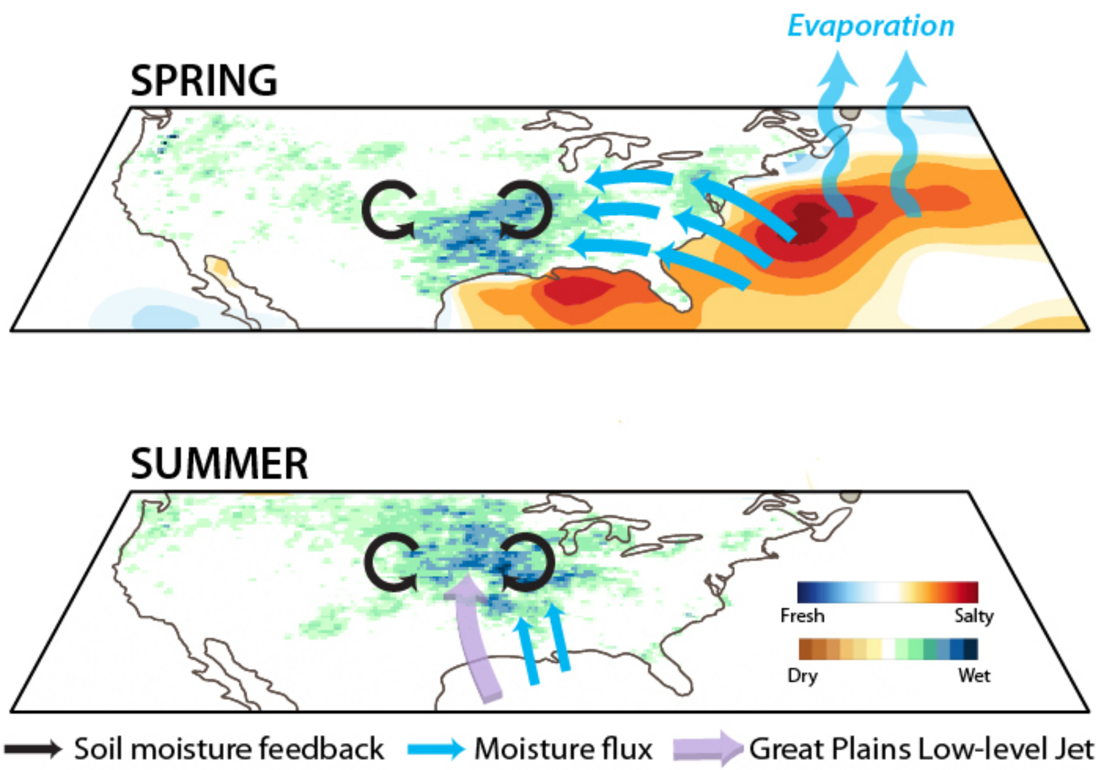
What Cause Rainfall Anomaly?

Combination of dynamic and thermodynamic processes

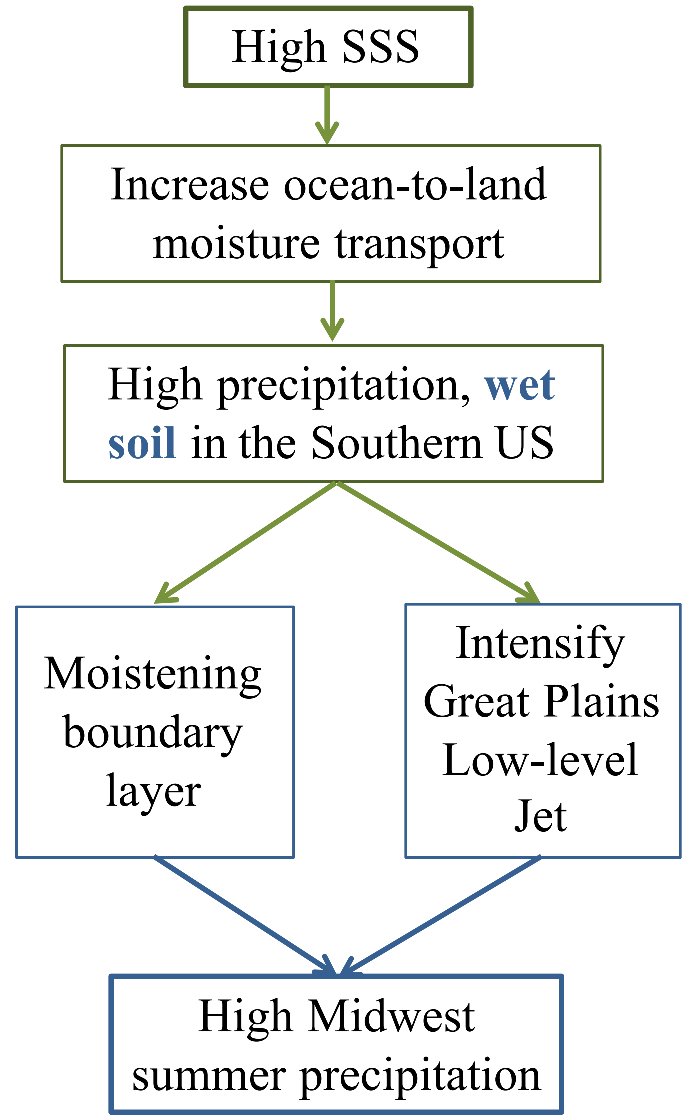


Physical Mechanism

Dual effects of soil moisture on regional water cycle

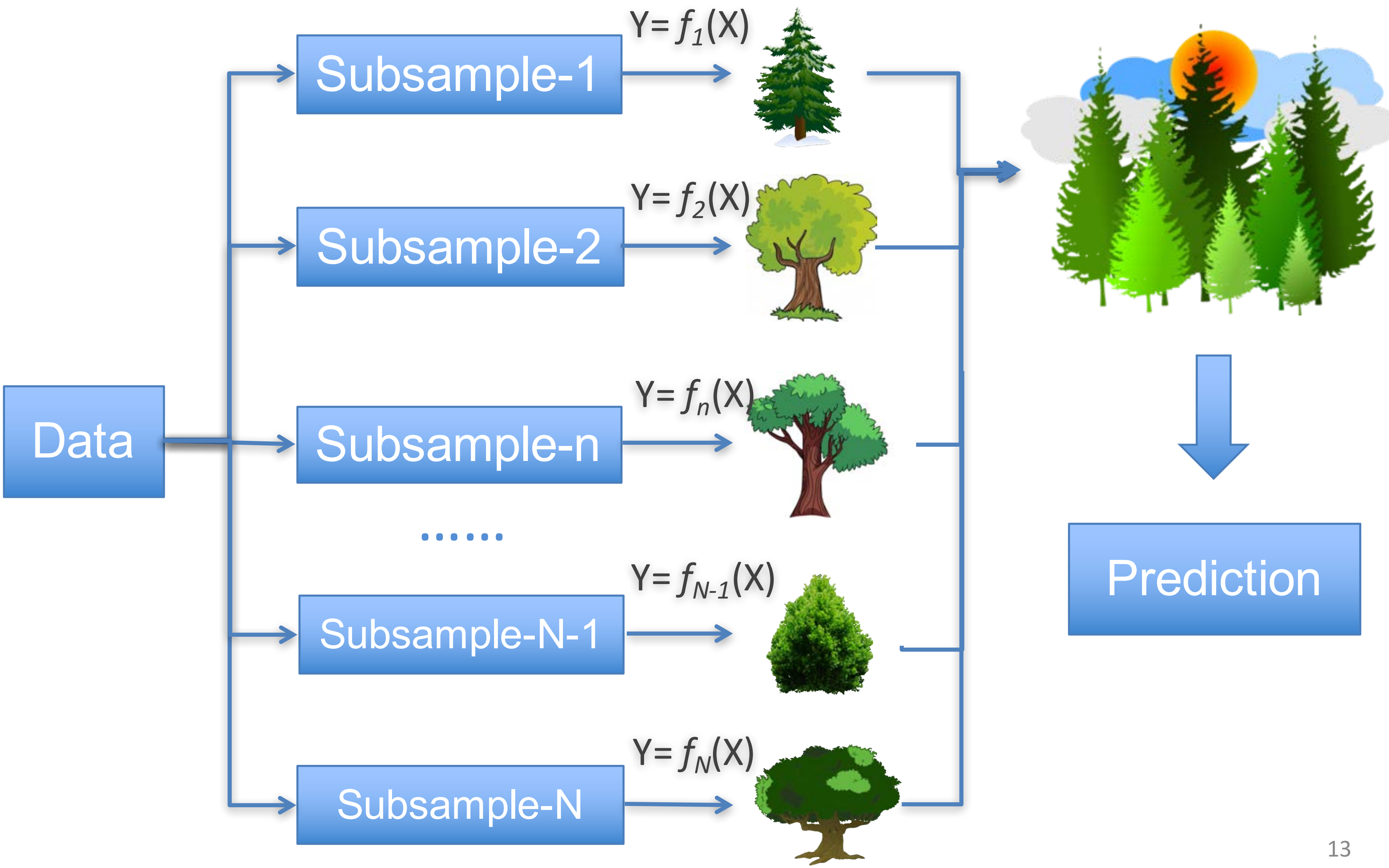


Schematic figure showing the mechanism of North Atlantic SSS-Midwest precipitation relationship. (See Li, Schmitt, Ummenhoffer and Karnauskas, 2016. J. Climate, 29, 3143-3159. [Illustration by Jack Cook, WHOI]).



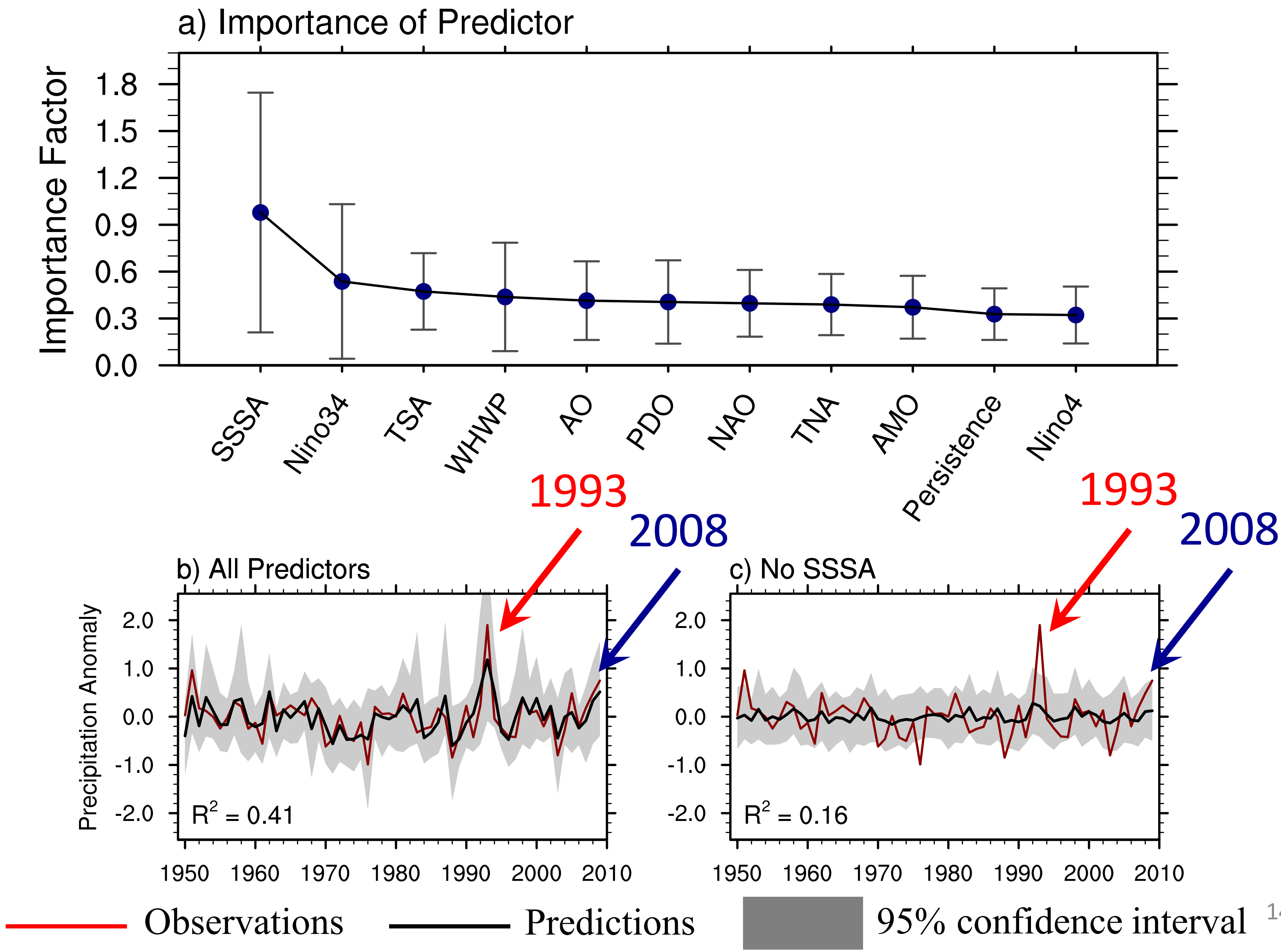
Predicting Midwest Precipitation Using SSS

Random Forest Algorithm

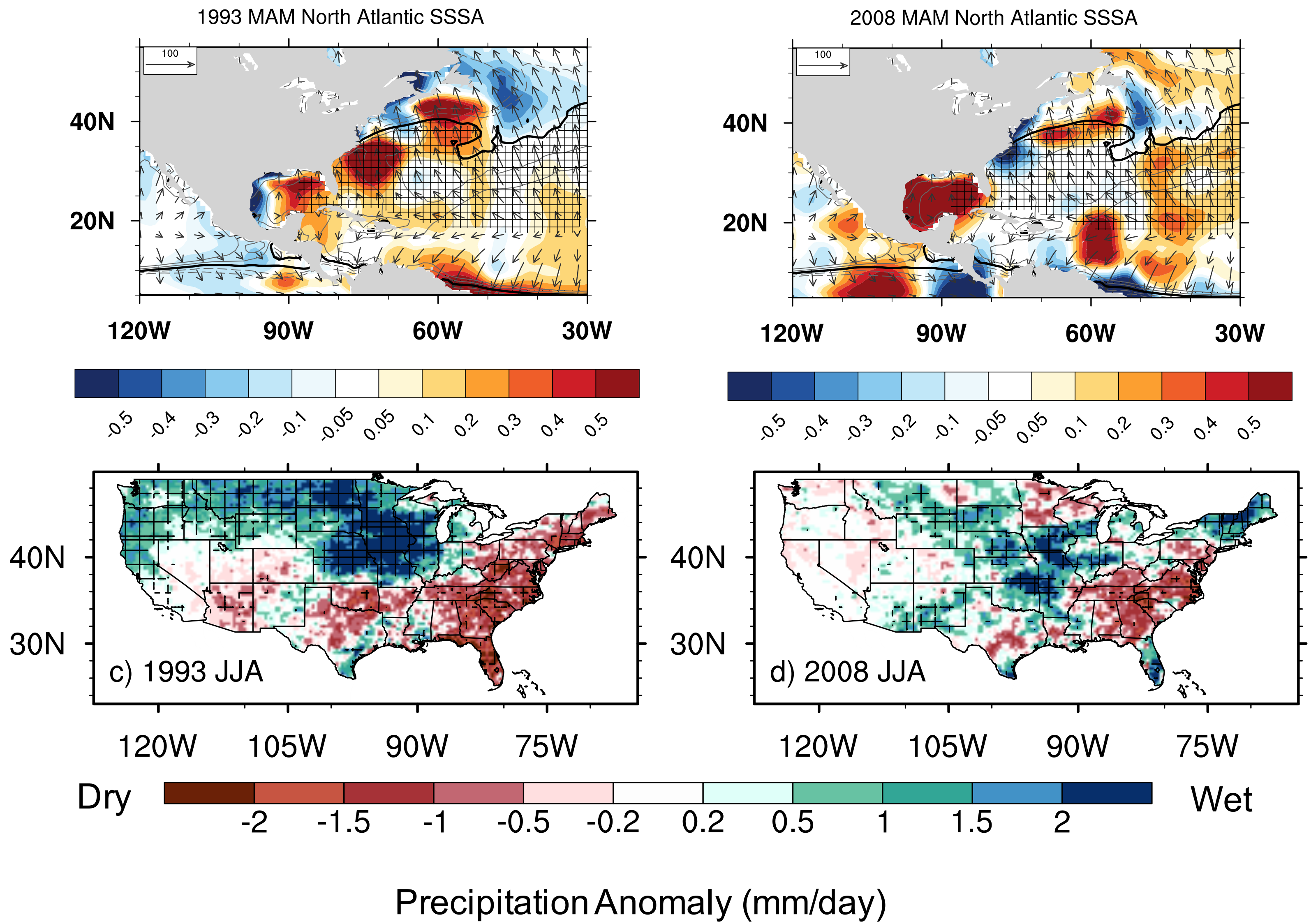


Predicting Midwest Summer Precipitation

Knowledge of NW SSS can improve rainfall prediction in US Midwest



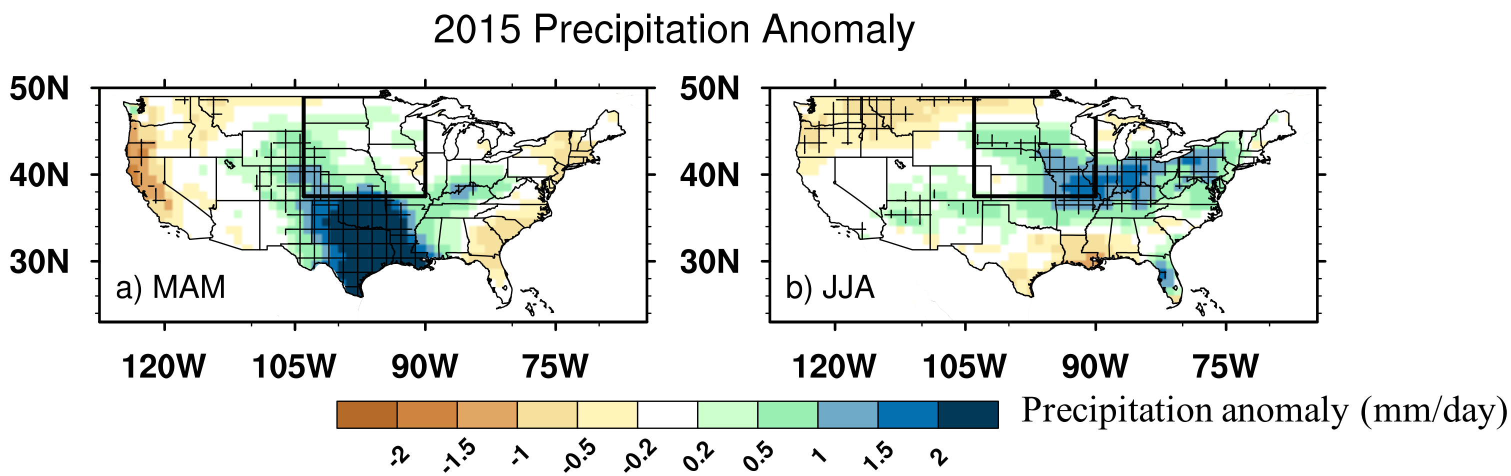
Salinity Precursor and Extreme US Precipitation

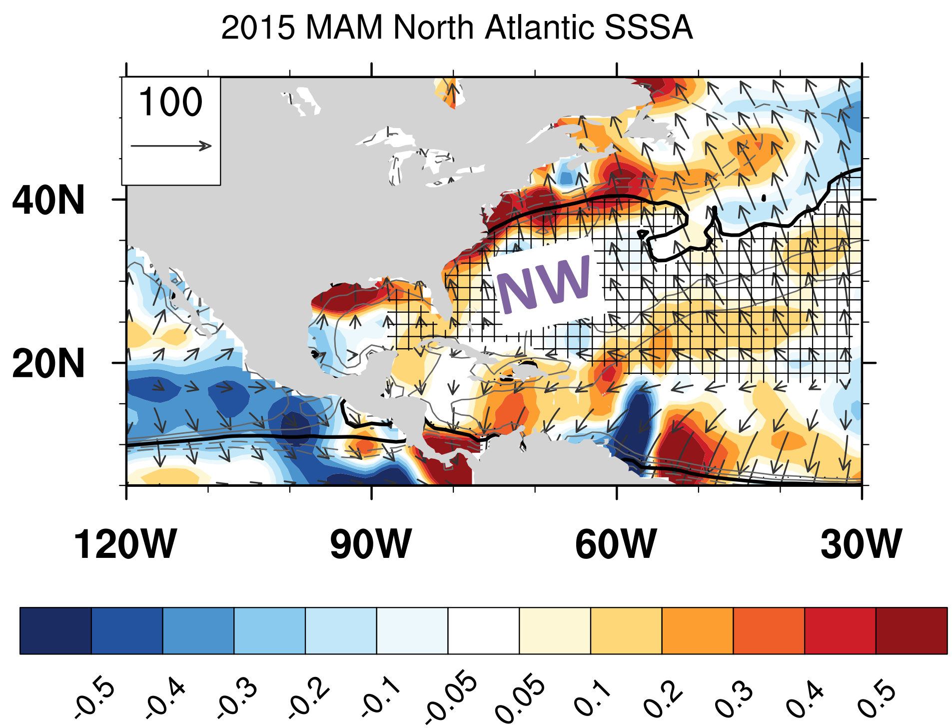


From Li, Schmitt and Ummenhofer (2017), Climate Dynamics

Case Study: 2015 US Summer Precipitation

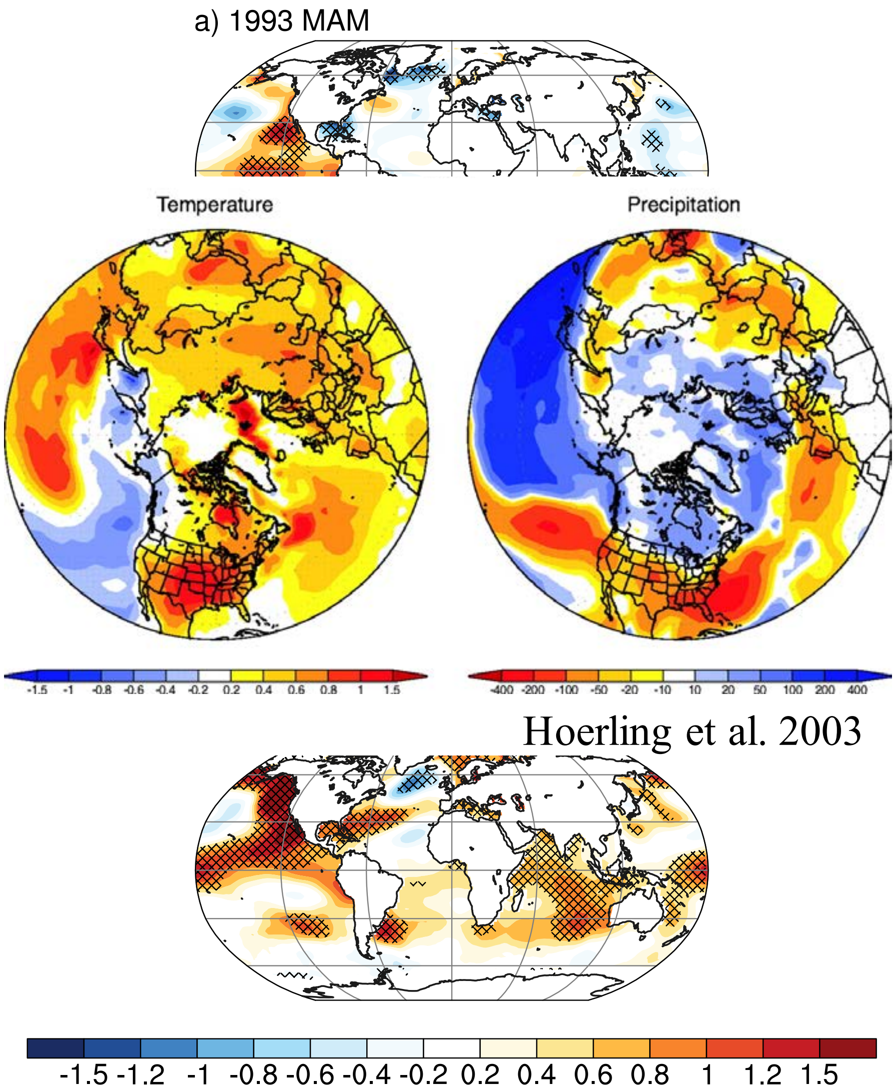
Salty subtropical N. Atl.s ~ wet summer in Midwest



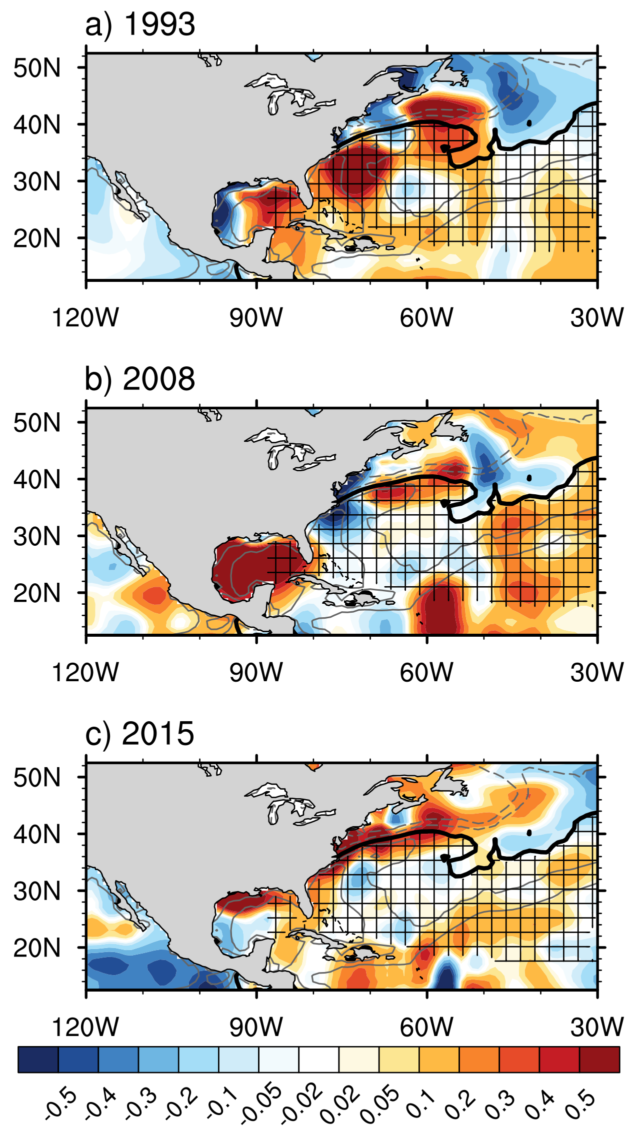


From Li, Schmitt and Ummenhofer (2017), Climate Dynamics

SST Precursors: Fail to Predict Midwest Extremes

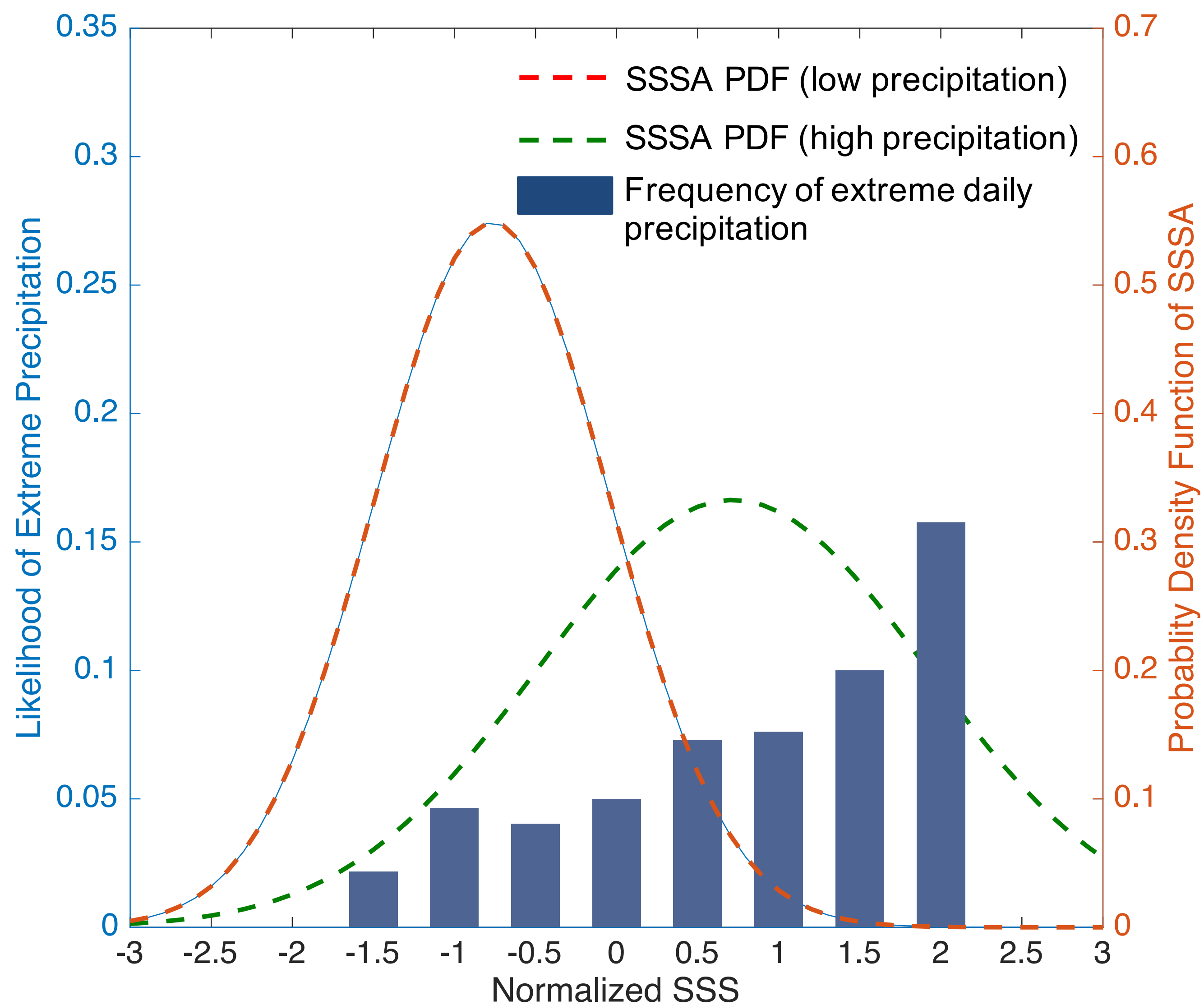


Cold **SST Anomaly (K)** Warm



Fresh **SSS Anomaly** Salty

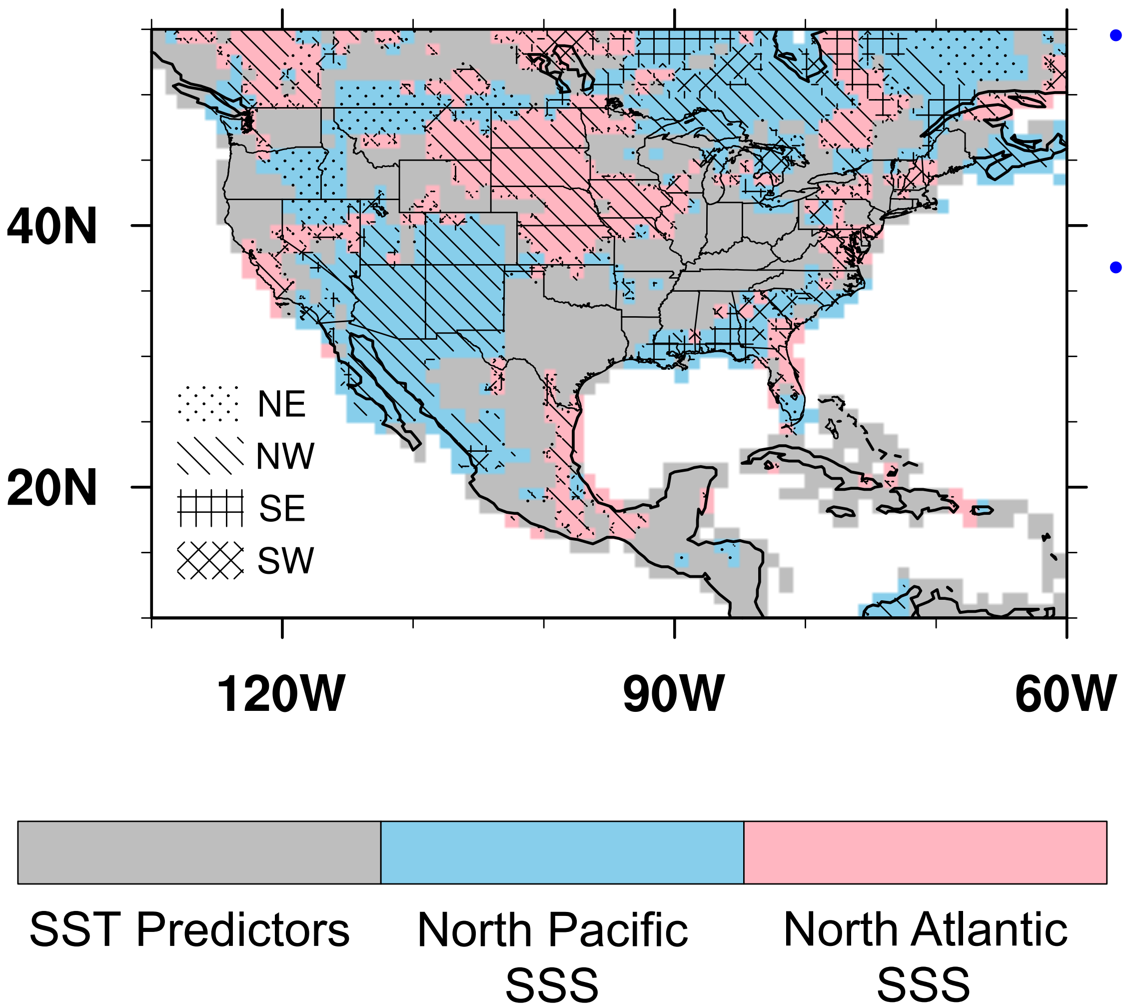
From Li, Schmitt and Ummenhofer (2017) *Climate Dynamics*



Summary of SSS and Midwest extreme precipitation: The blue bars are the probability of US Midwest extreme precipitation given the anomalies of pre-season SSS in the subtropical North Atlantic. The green (red) dashed lines are the probability density function of pre-season SSS in the years with wet (dry) events in the Midwest. The salinity PDF is constructed by assuming SSS follows a Normal distribution.

Concluding Remarks

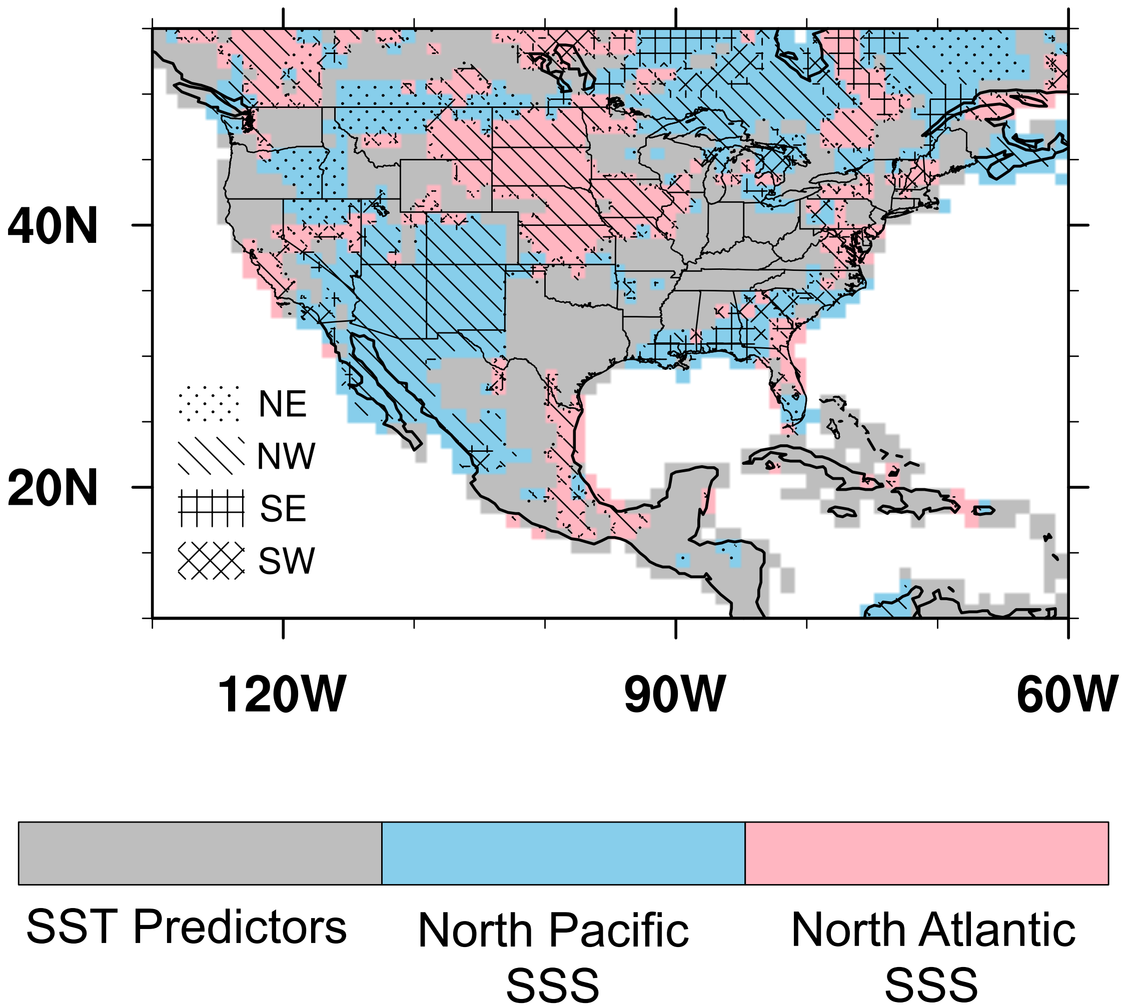
SSS provides important skill to predict terrestrial precipitation



- North Atlantic subtropical SSS is most important for prediction precipitation over the US Midwest.
- North Pacific subtropical SSS is the most important predictor for summer precipitation over the North American monsoon region.

The most important predictor for US summer (JJA) precipitation according to the random forest algorithm: gray shaded denotes regions where SST predictors (the first two SSTA mode time series in each of the three ocean basins) have the most skillful prediction. The blue and red shaded are where the most important predictor is North Pacific and North Atlantic SSS, respectively.

Thank You!



40N
20N
NE
NW
SE
SW
120W
90W
60W
SST Predictors
North Pacific SSS
North Atlantic SSS

Q&A