U.S. Drought: Observed Changes in Drought Risk during 1901-2012 and NMME Climate Forecasting Performance

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October 1st, 2015

Outline

I. Short Biography

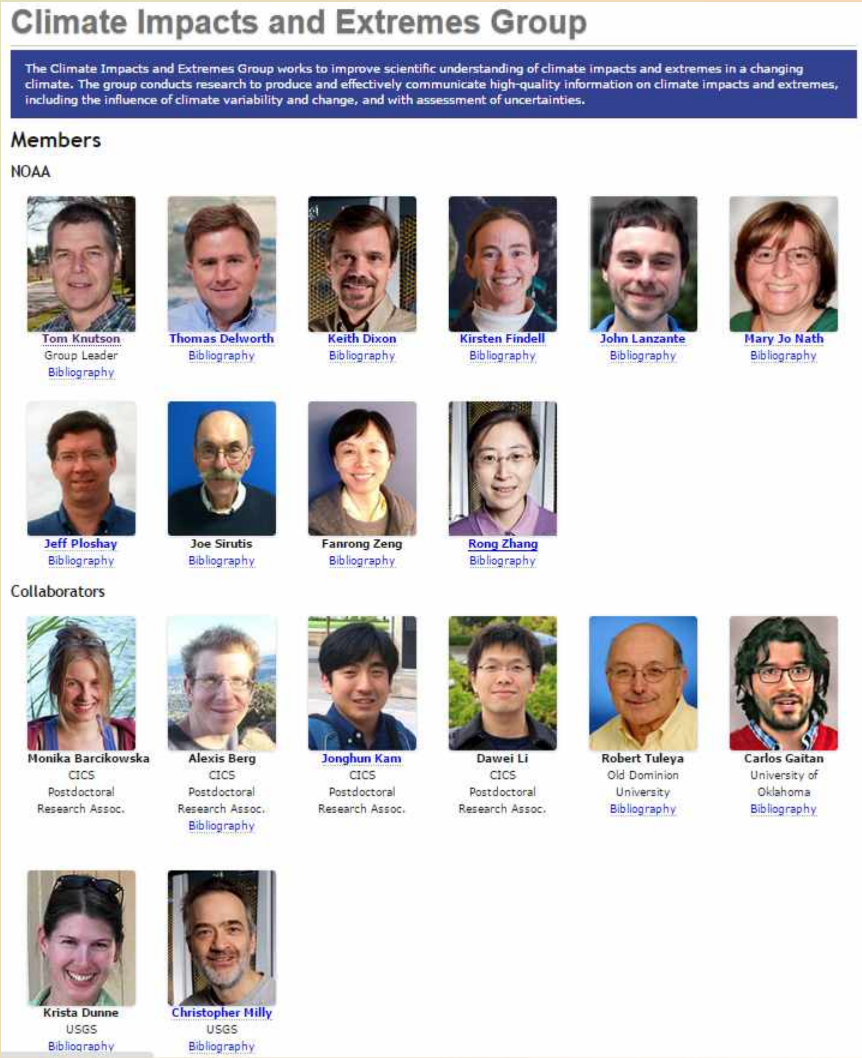
II. Background: What is drought?

III. Pat 1: Observed changes in U.S. drought risk (1901-2012): The influence of Atlantic and Pacific Oceans

IV. Part 2: NMME climate forecast performance for U.S. drought

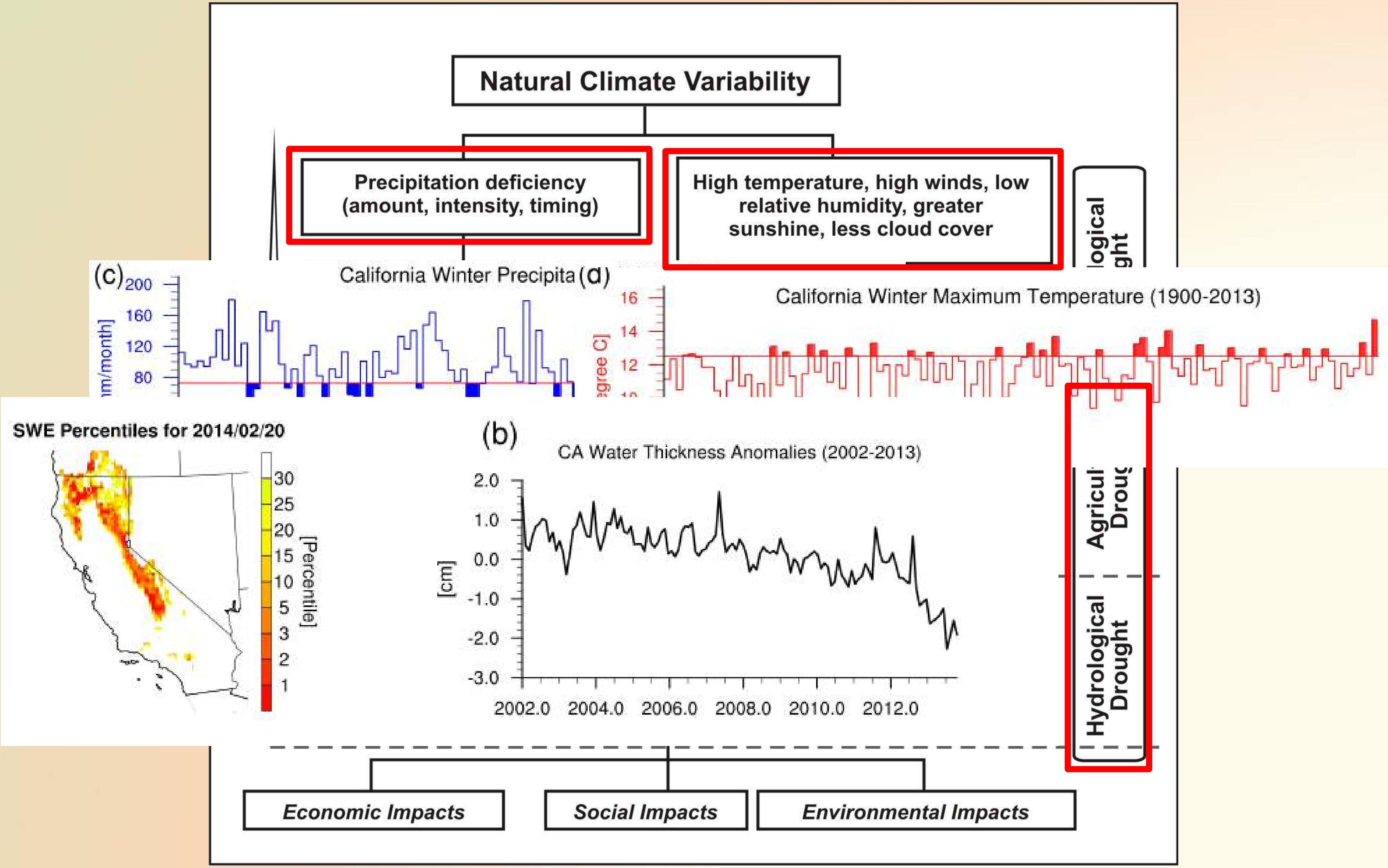
V. Future research plan

At GFDL/NOAA



At Princeton

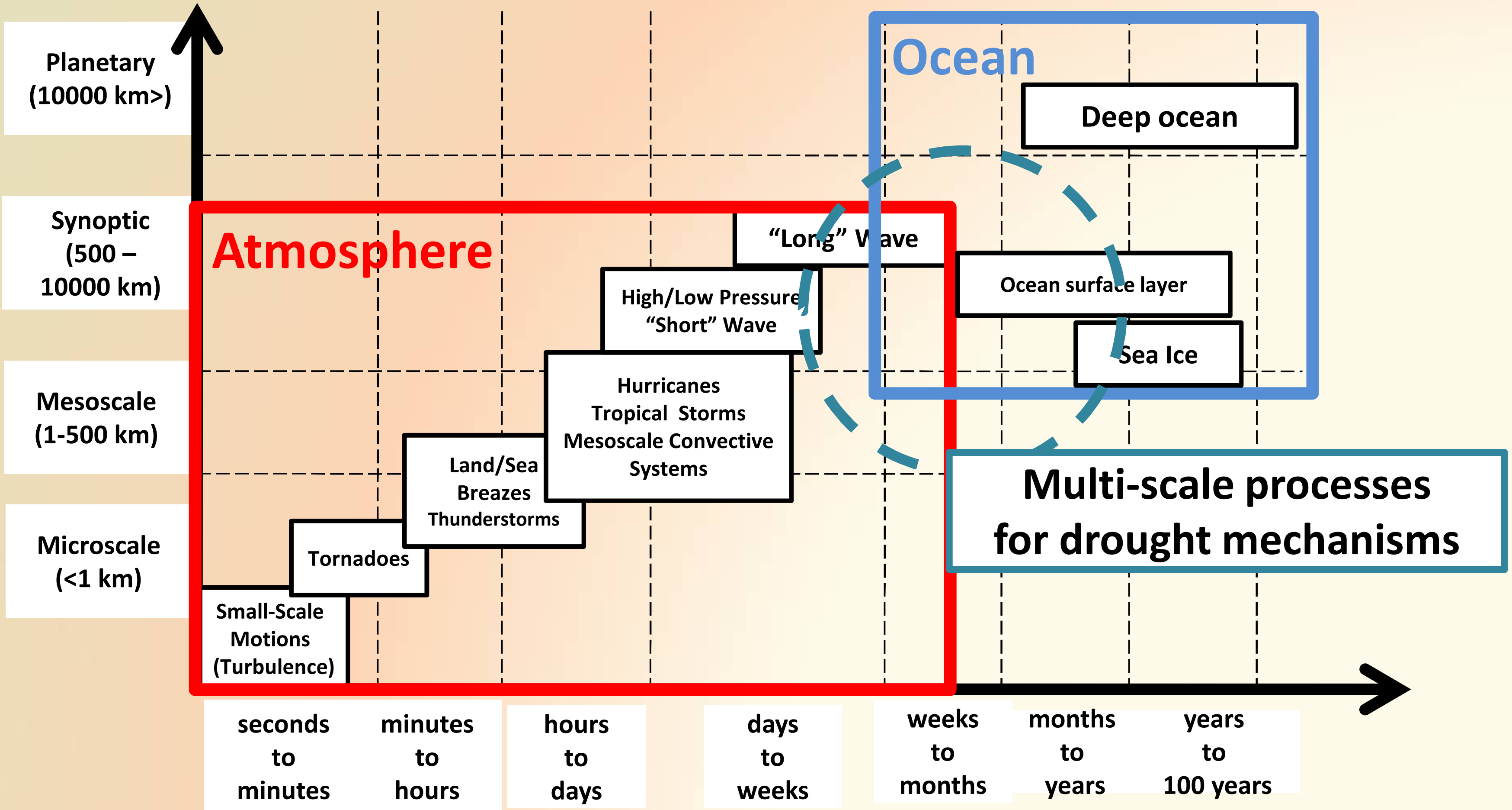
What is Drought?



(Source: National Drought Mitigation Center, University of Nebraska-Lincoln, U.S.A.)

Drought Mechanisms: Multi-scale Processes

- Drought is one of **the least understood** natural hazards due to complexity of the generating mechanisms.

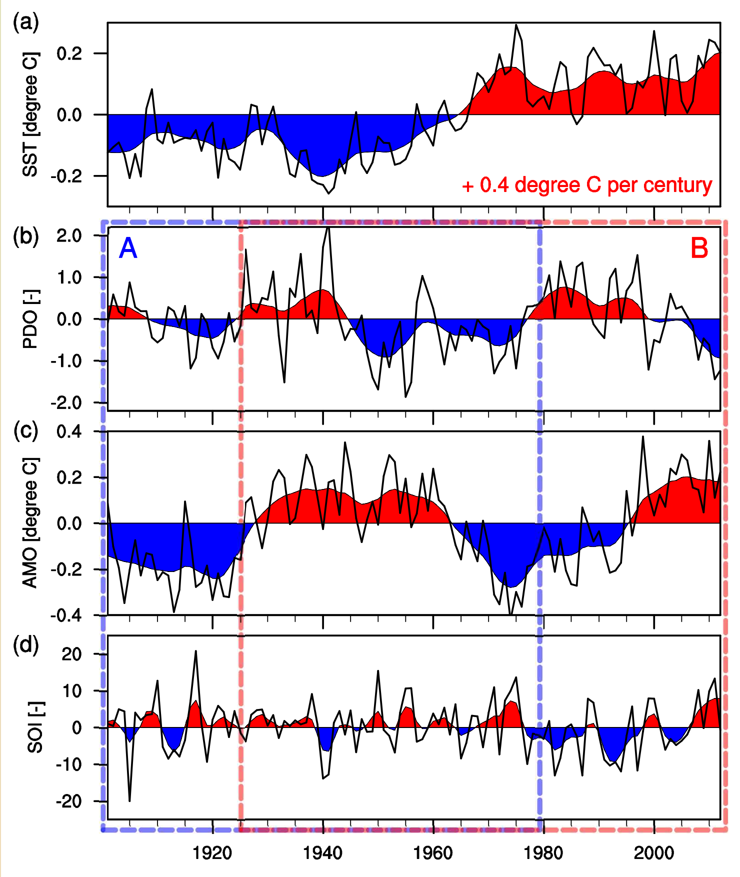


Part 1. Observed changes in U.S. drought risk (1901-2012): The influence of Atlantic and Pacific Oceans

References:

Kam, J., Sheffield, J., and Wood, E.F., 2014: Changes in drought risk over the contiguous United States (1901 -2012): The influence of the Pacific and Atlantic Oceans, *Geophys. Res. Lett*., **41**, 5897-5903, doi: 10.1002/2014GL060973.

Recent Changes in Sea Surface Temperatures



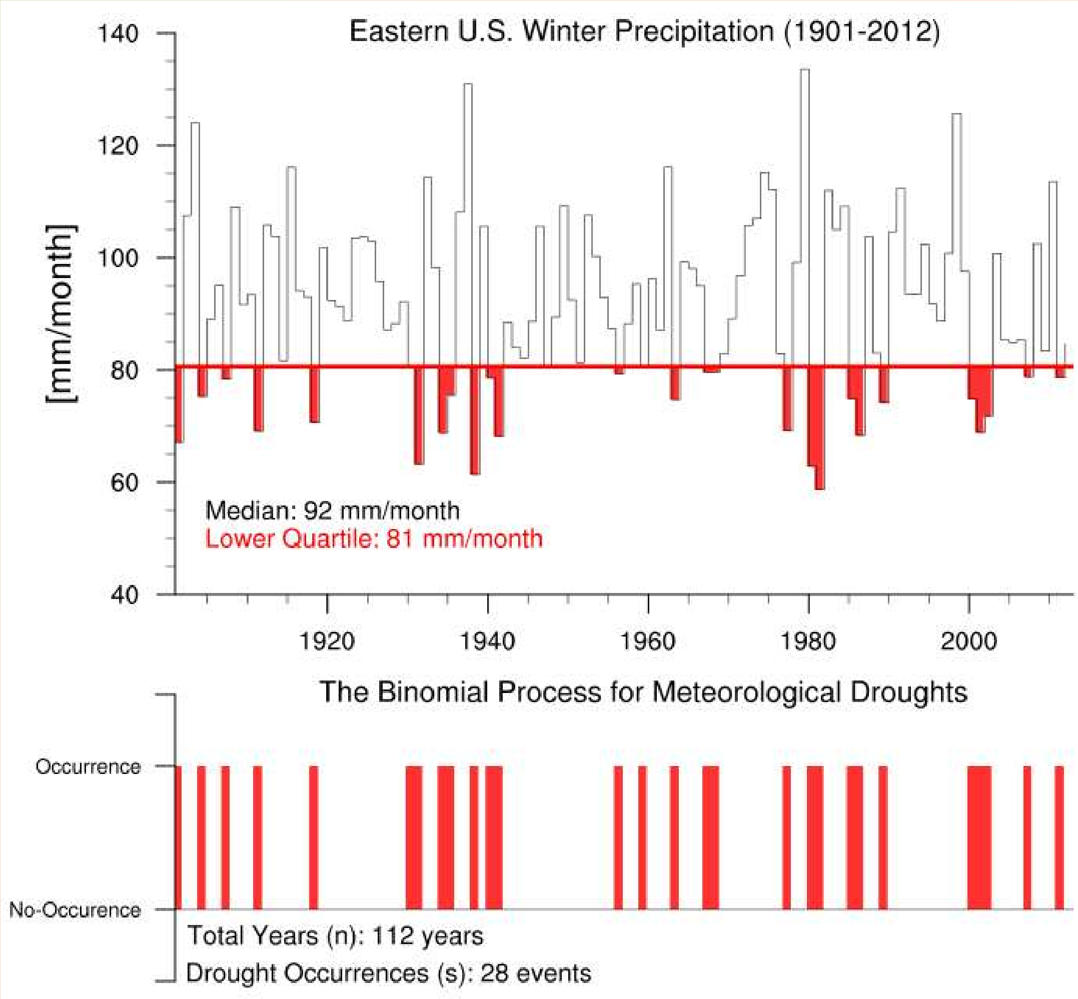
- Pacific Decadal Oscillation (PDO)
  - **A recent phase shift: positive to negative**
- Atlantic Multi-Decadal Oscillation (AMO)
  - **A positive phase since 2000.**
- Southern Oscillation Index (SOI)
  - Opposite sign of El Niño-Southern Oscillation (ENSO) index.
  - Negative: El Niño Event
  - Positive: La Niña Event

Scientific Questions:

What phases of SST indices cause to elevate the risk of drought over the U.S.?

What is the impact of SSTs on drought over the U.S. given their recent phase changes?

Drought Occurrence as a Binomial Process



- Data:

  Climatic Research Unit (CRU) Version 3.21 (0.5-degree) precipitation

- Meteorological drought:

  Precipitation under a threshold value during a given time

- Threshold Value:

  Lower quartile of precipitation during 1901-2012

- Drought Frequency (p):

  A fraction of total drought occurrences over total years

Uncertainty Analysis from the Bayesian Framework

Bayesian Inference:

$$\text{Prob}(p \mid \text{data}) \propto \text{Prob}(\text{data} \mid p)\,\text{Prob}(p)$$

p: Drought Frequency

Prob(p | data): Posterior

Prob(data | p): Likelihood

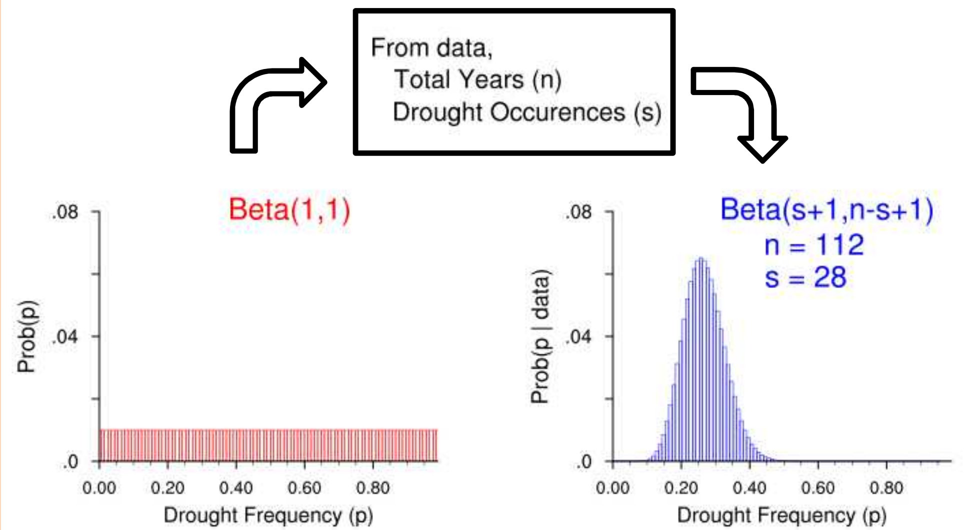
Prob(p): Prior

Assume that the Prior is the Uniform Distribution(Uninformative Prior):

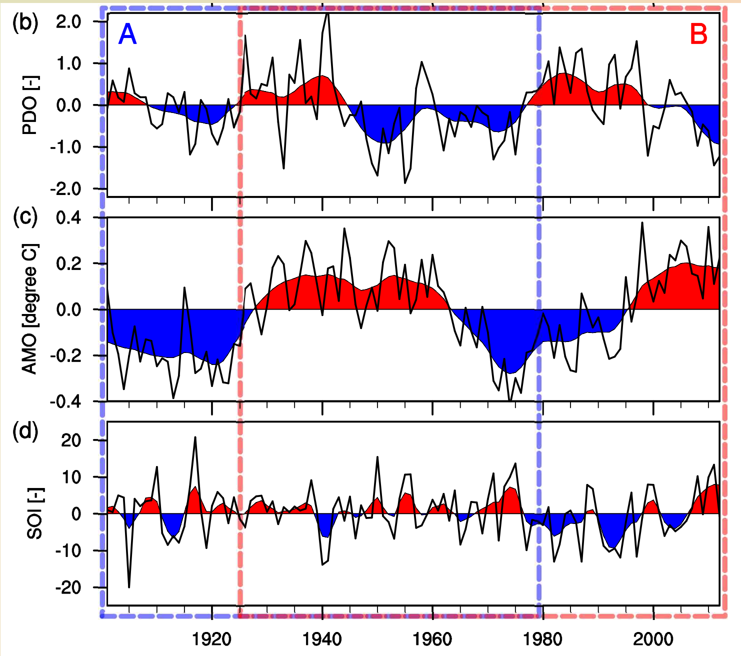
$$f(p; s, n-s) = \binom{n}{s} p^s (1-p)^{n-s} * \text{constant}$$

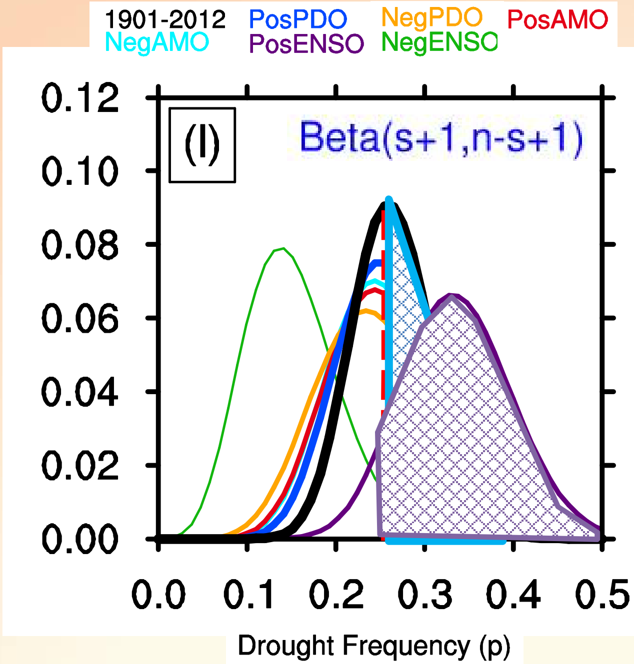
$$= \frac{\Gamma(n)}{\Gamma(s)\Gamma(n-s)} p^s (1-p)^{n-s} * \text{constant}$$

$$= \frac{1}{B(s+1,\ \ n-s+1)} p^s (1-p)^{n-s}$$



Conditional Posterior Distribution: Prob(p|data, SST)





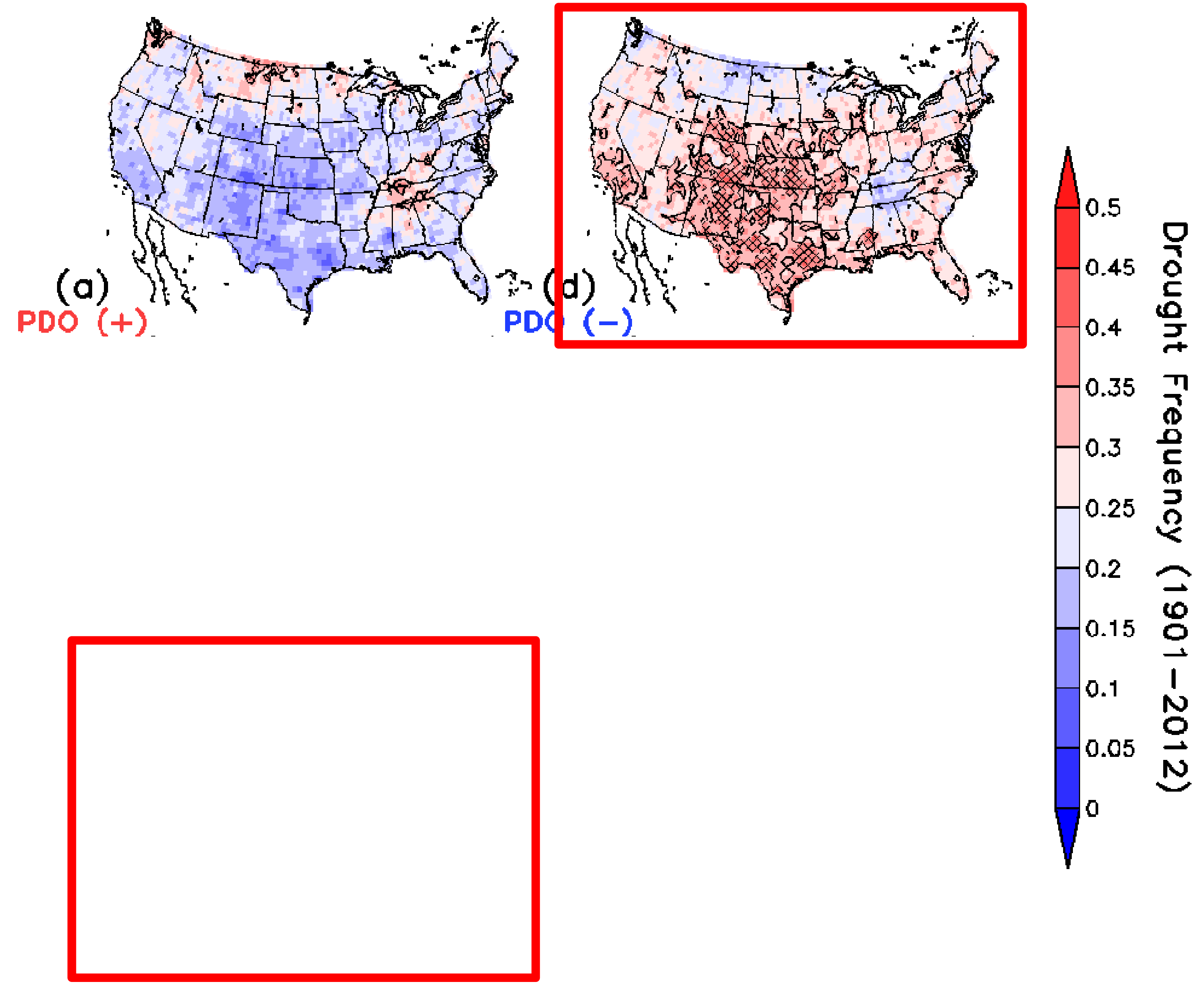
EAST	Total Years	PDO		AMO		SOI	
		+	-	+	-	+	-
Total Years (n)	112	67	45	55	57	52	60
Drought Occurrences(s)	27	17	10	13	14	7	20
Drought Frequency (p)	0.25	0.25	0.23	0.25	0.25	0.18	0.32
Return Period (1/p)	4	4	4.3	4	4	5.5	3

Area above p=0.25 (Red line): A measure of certainty for drought frequency

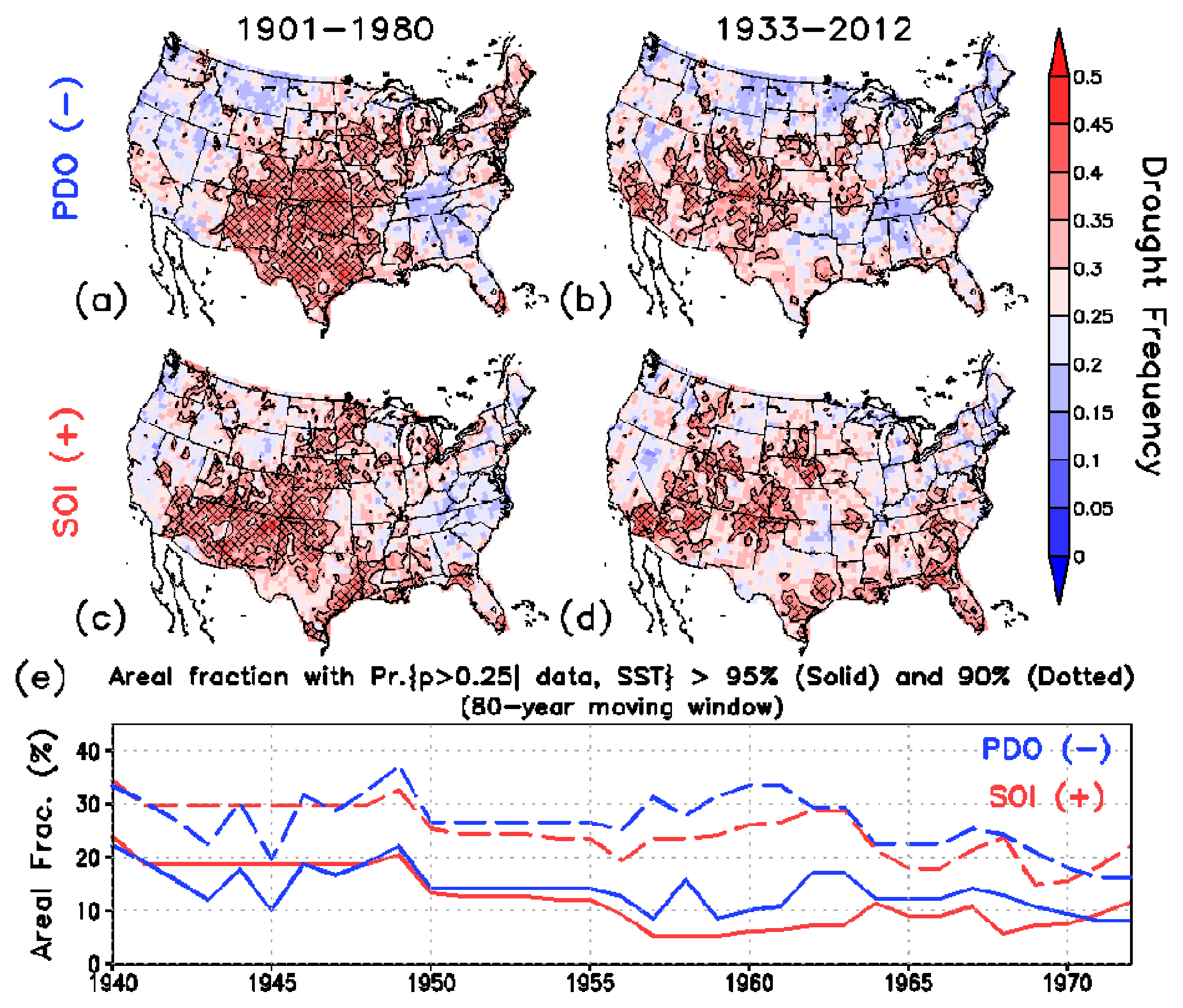
More certain for higher drought frequency: P(p>0.25|data, PosENSO) ≈ 0.8

High risk of drought over the Eastern US during El Niña year!!!

Drought Risk Map: Impact of Oceanic States

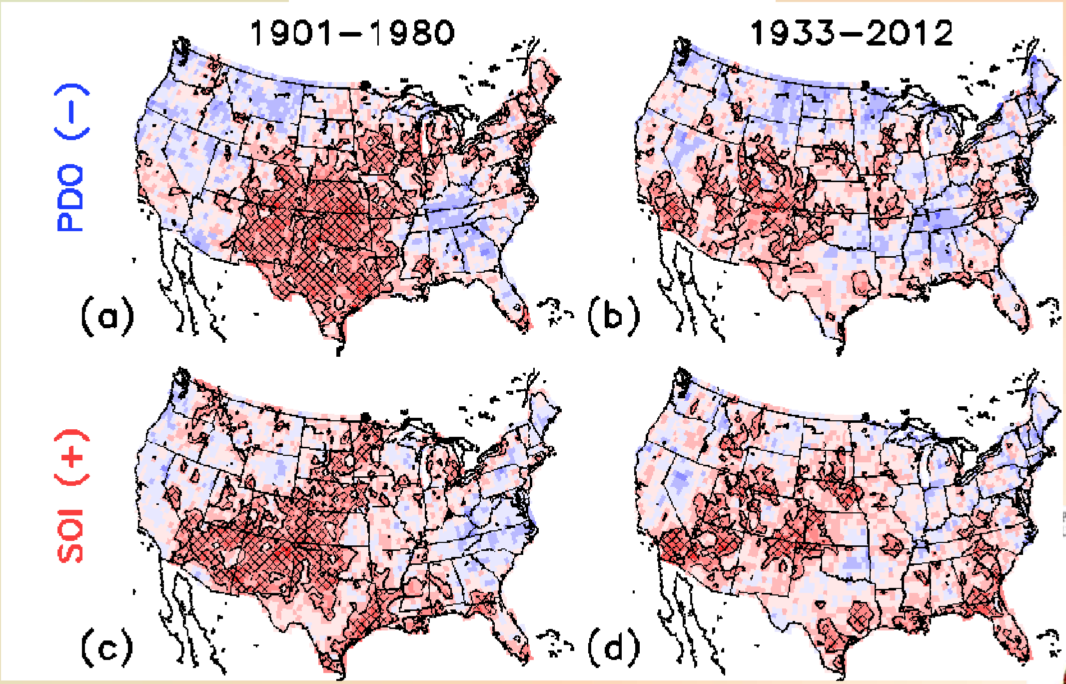


Impact of Oceanic States: Stationarity? Non-stationarity?

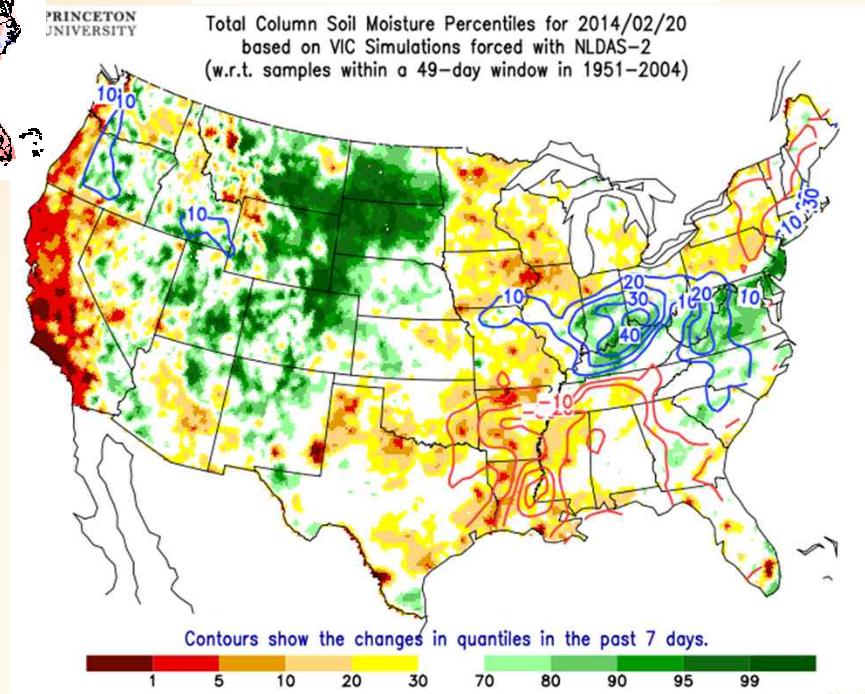


Example: 2013-4 California Drought

Winter 2013



02/20/2014



Conclusions

1. The Bayesian approach allows us to investigate **observed SST teleconnections with annual meteorological droughts over the US**.

2. For annual meteorological drought,

- **PDO (-) :** High risk of drought over **the south-central US.**
- **ENSO (-) :** High risk of drought over **the southern US**.

3. However, the impact of SSTs on drought risk has been **less certain** in recent years.

4. The causes of these changes in SST teleconections are still unclear (e.g. phase shift? or global warming?).

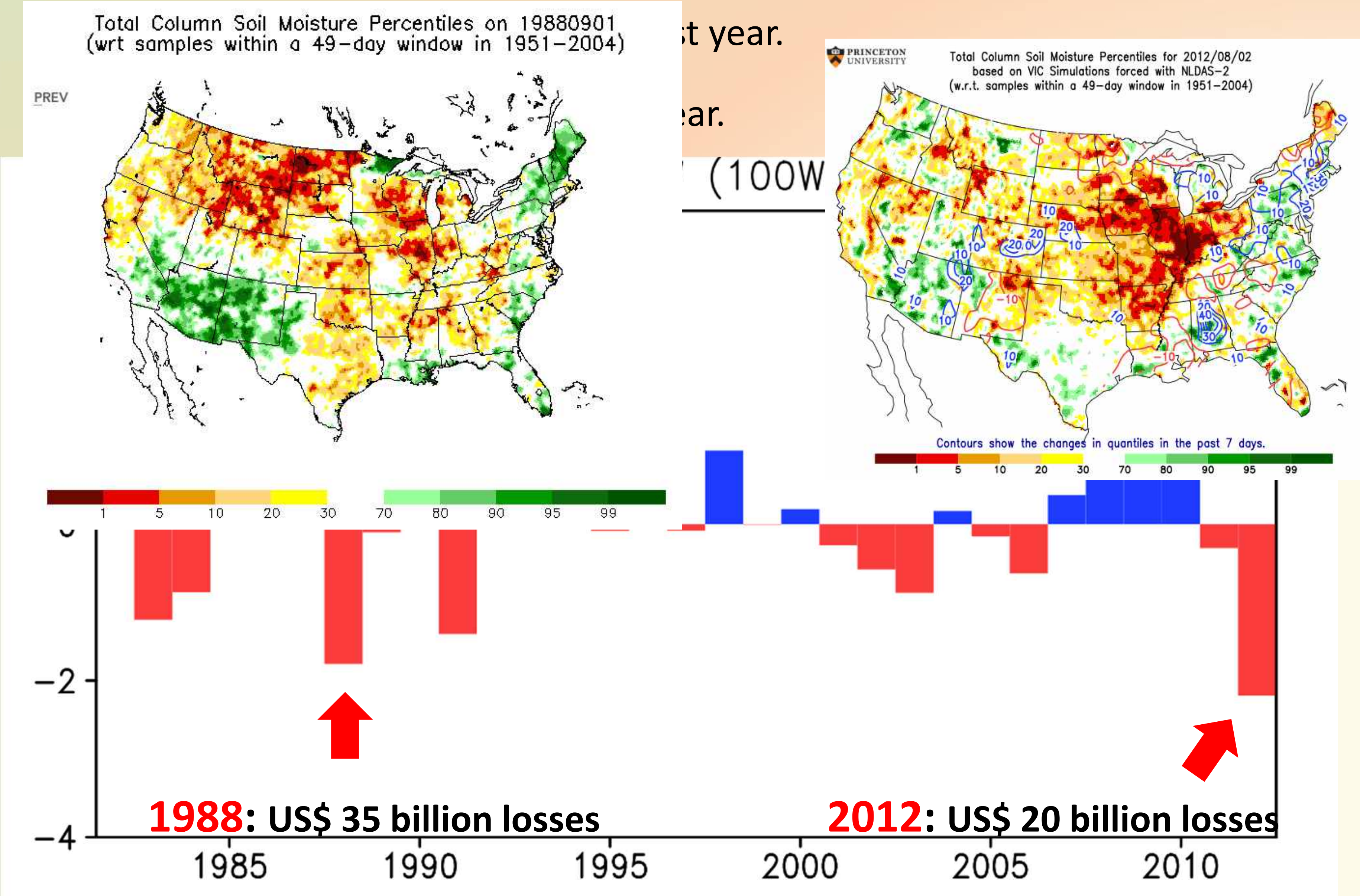
5. Better understanding of **true SST teleconnections** can help translate the information from SSTs **more appropriately** to seasonal and annual drought forecasting.

Part 2. Climate model forecast performance for the Midwestern U.S. drought: The role of sea surface temperature

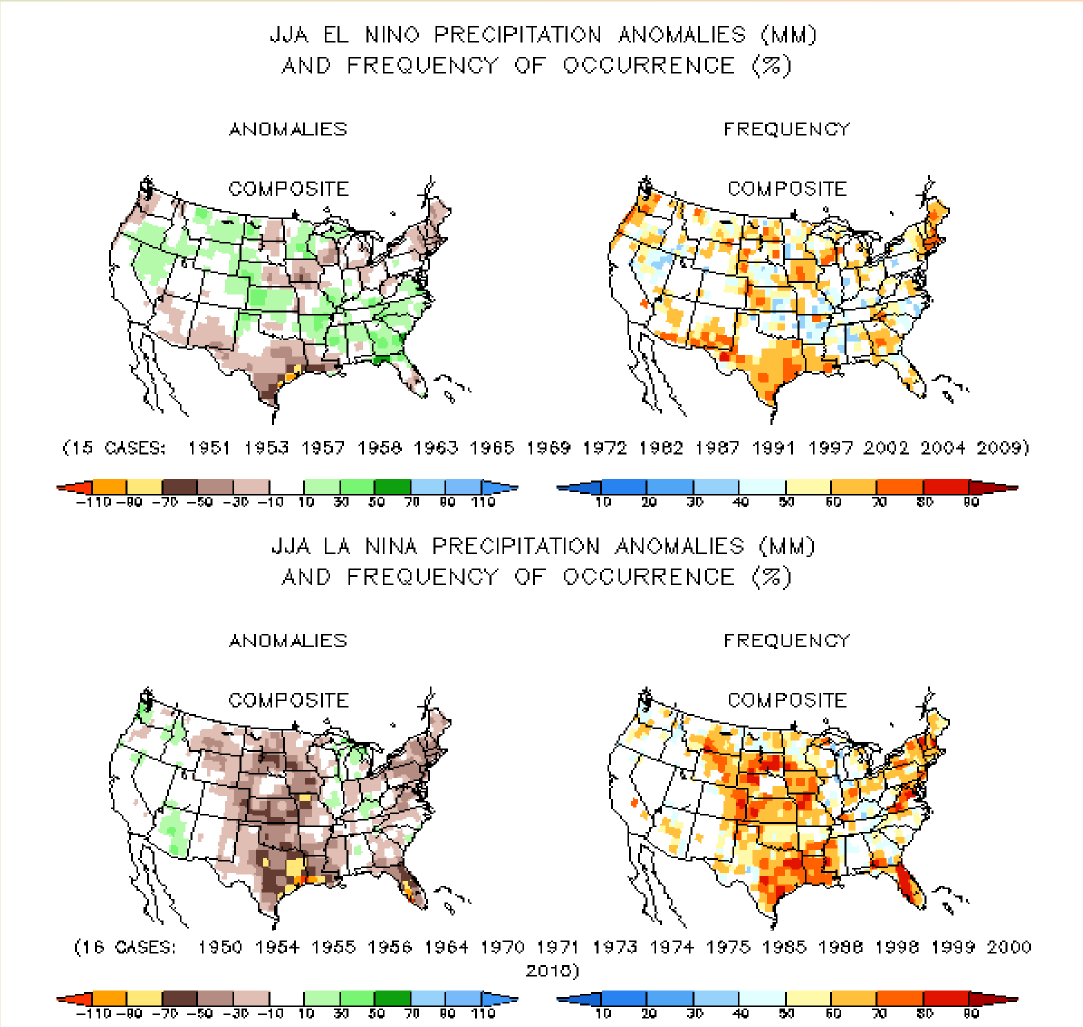
References:

Kam, J., J. Sheffield, X. Yuan, and E. F. Wood, 2014, Did a skillful prediction of sea surface temperatures help or hinder in forecasting the 2012 Midwestern summer drought?, *Environ. Res. Lett.*, **9**, doi:10.1988/1748-9326_9_3_034005.

Hydroclimate Variability in the Midwstern US



Climate Driver: Pacific and Atlantic Oceans

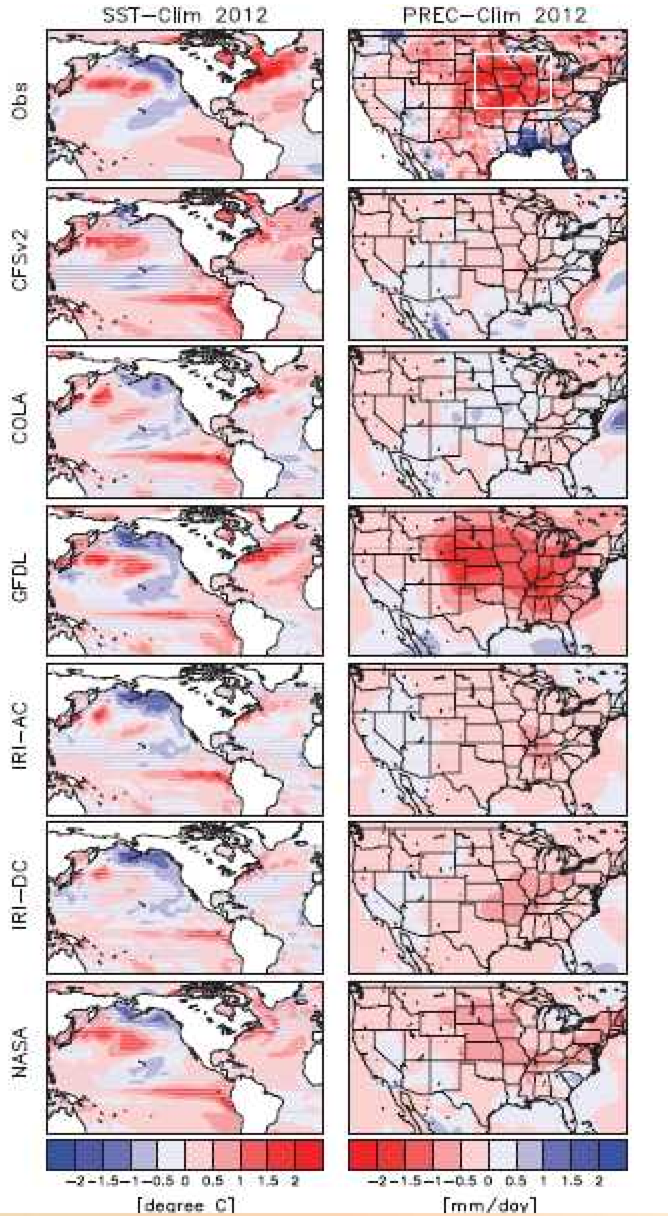


http://www.cpc.ncep.noaa.gov/products/precip/CWlink/ENSO/composites/lanina.jja.precip.gif

- **Ocean**
  - A source of seasonal forecasting due to its huge heat capacity.
  - El Niño-Southern Oscillation (ENSO)
    - A major climate driver globally.
    - Predictable at seasonal and longer time scales.
  - **La Niña phase:** Droughts over the CONUS from GCM (Hoerling and Kumar, 2003).
  - **North Atlantic warming and tropical Pacific cooling:** more frequent drought events over the U.S. (McCabe et al. 2004; Findell and Delworth 2009).

North America Multi-Model Ensemble (NMME) project

2012 SST and PREC anomalies (JJA)



- NMME project

A multi-institutional collaborative seasonal forecasting system.

- Objective:

To predict better seasonal extreme events over the U.S. and the globe via the Multi-Model Ensemble frame.

Scientific Questions:

Does a skillful prediction of SST help or hinder 2012 MW summer drought forecasting?

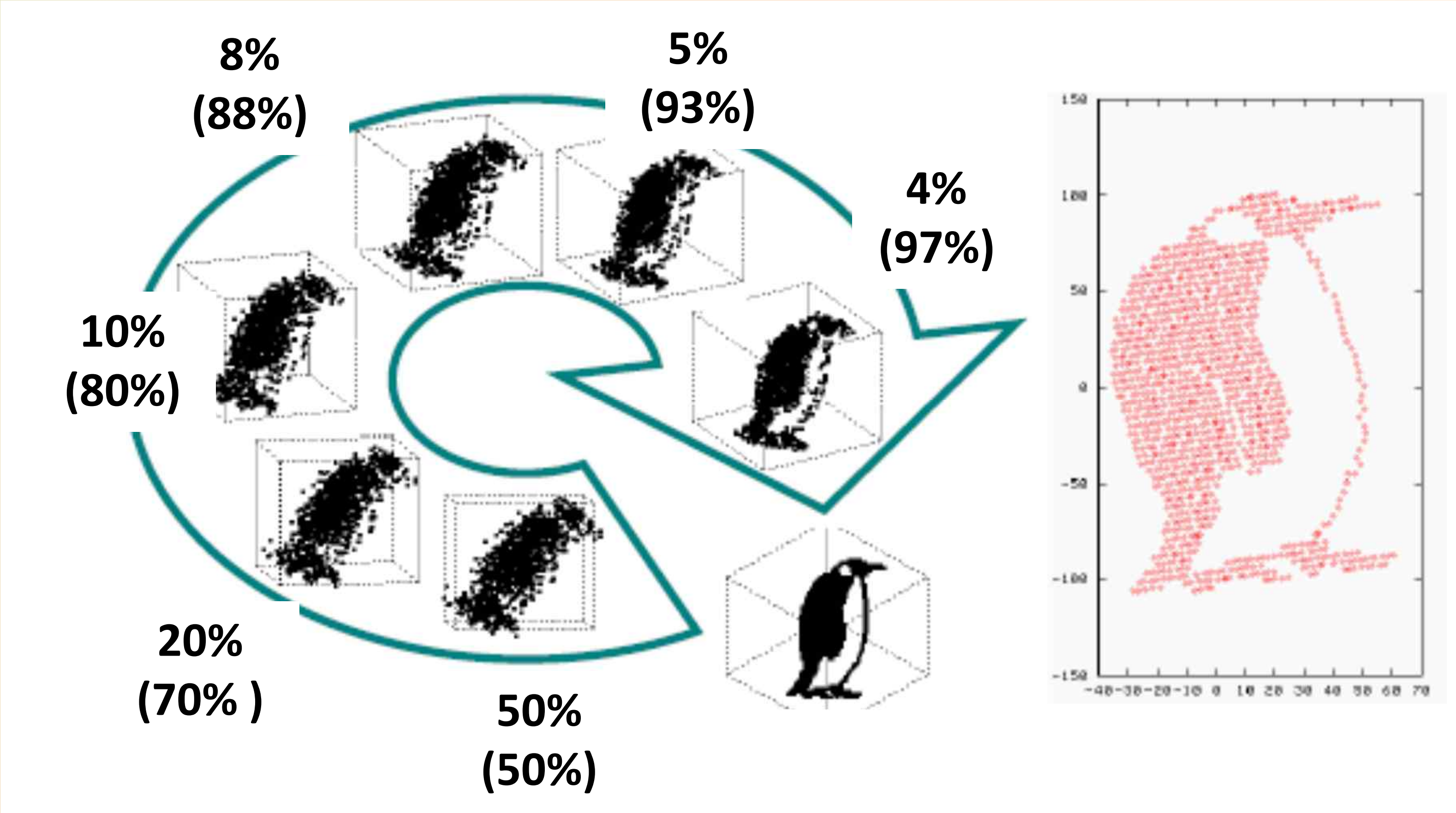
How well do NMME climate models represent SST teleconnections with the Midwestern U.S. hydroclimate variability?

Observational Data and NMMEs

Observational Data			
SSTs/Prec.	SSTs	Prec.	Prec.
Name	Expended Reconstructed Sea Surface Temperatures	University of Washington Expanded Precipitation	Climate Prediction Center Precipitation
Acronym	ERSST v3b	UW-EXP	CPC
Period	1854-2012	1918-2008	1982-2012
Resolution	2.0 degree	0.5 degree	0.5 degree
		Correlation Coefficient over the MW: 0.97	

North America Multi-Model Ensembles (NMMEs)						
Period	1982-2012 (Hindcast: 1982-2010; Real-time forecast: 2011-2012)					
Resolution	1.0 degree					
Name	NCEP-CFSv2	COLA-RSMAS-CCSM3	GFDL-CM2.1	IRI-ECHAM4.5-AnomalyCoupled	IRI-ECHAM4.5-DirectedCoupled	NASA-GMAO
Acronym	CFSv2	COLA	GFDL	IRI-AC	IRI-DC	NASA
Initial time	Every 5th day	all 1st of the month 0Z				Every 5th day
Ensemble members	24(28)	6	10	12	12	6

Singular Value Decomposition (SVD) Analysis

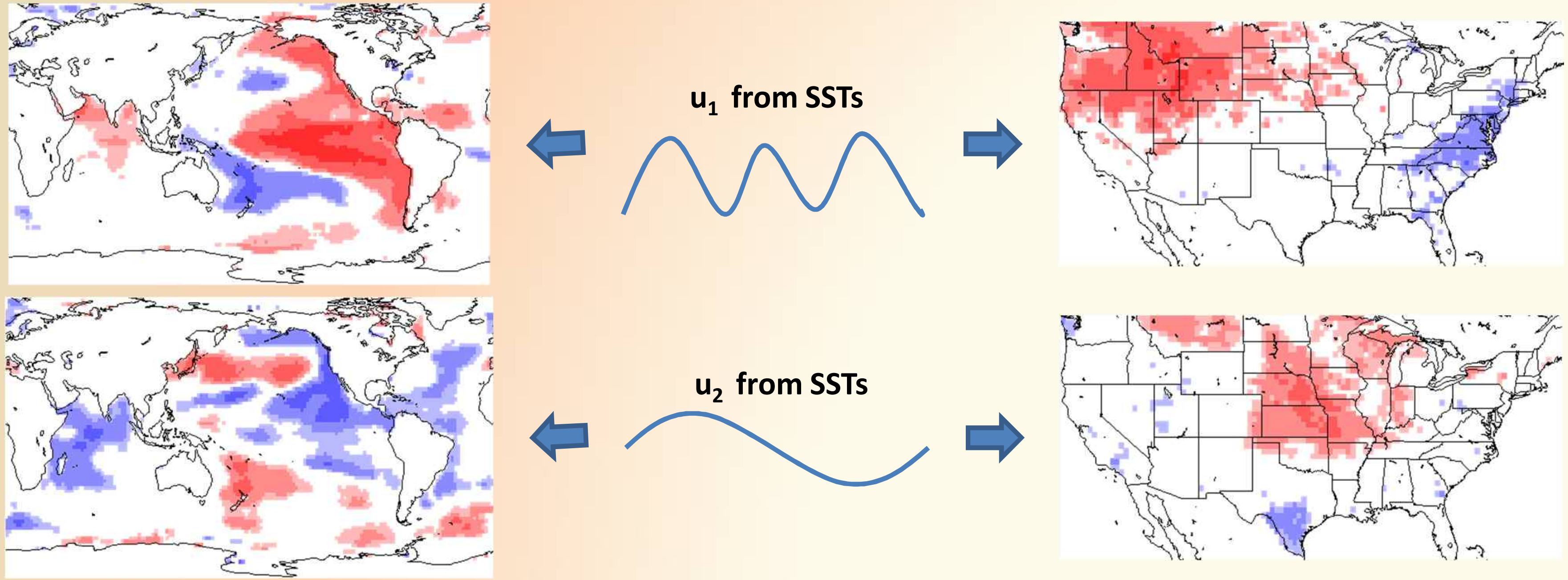


Application of SVD analysis: Climate Research

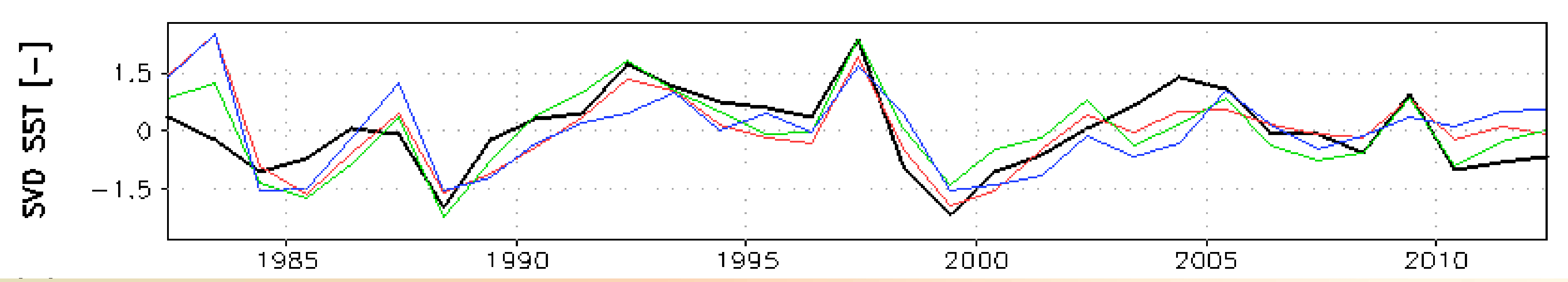
From the SVD analysis for the cross covariance between SSTs and precipitation,

- **Loadings**: derived from left (SST) and right (Prec.) vectors.
- **Explained Variance**: derived from eigenvalues.
- **Scores**: computed by projecting the loadings of the ith SVD mode on the actual data (**$\mathbf{u_i}$** and **$\mathbf{v_i}$**) .
- Homogeneous and heterogeneous correlation map: to investigate the cause/effect

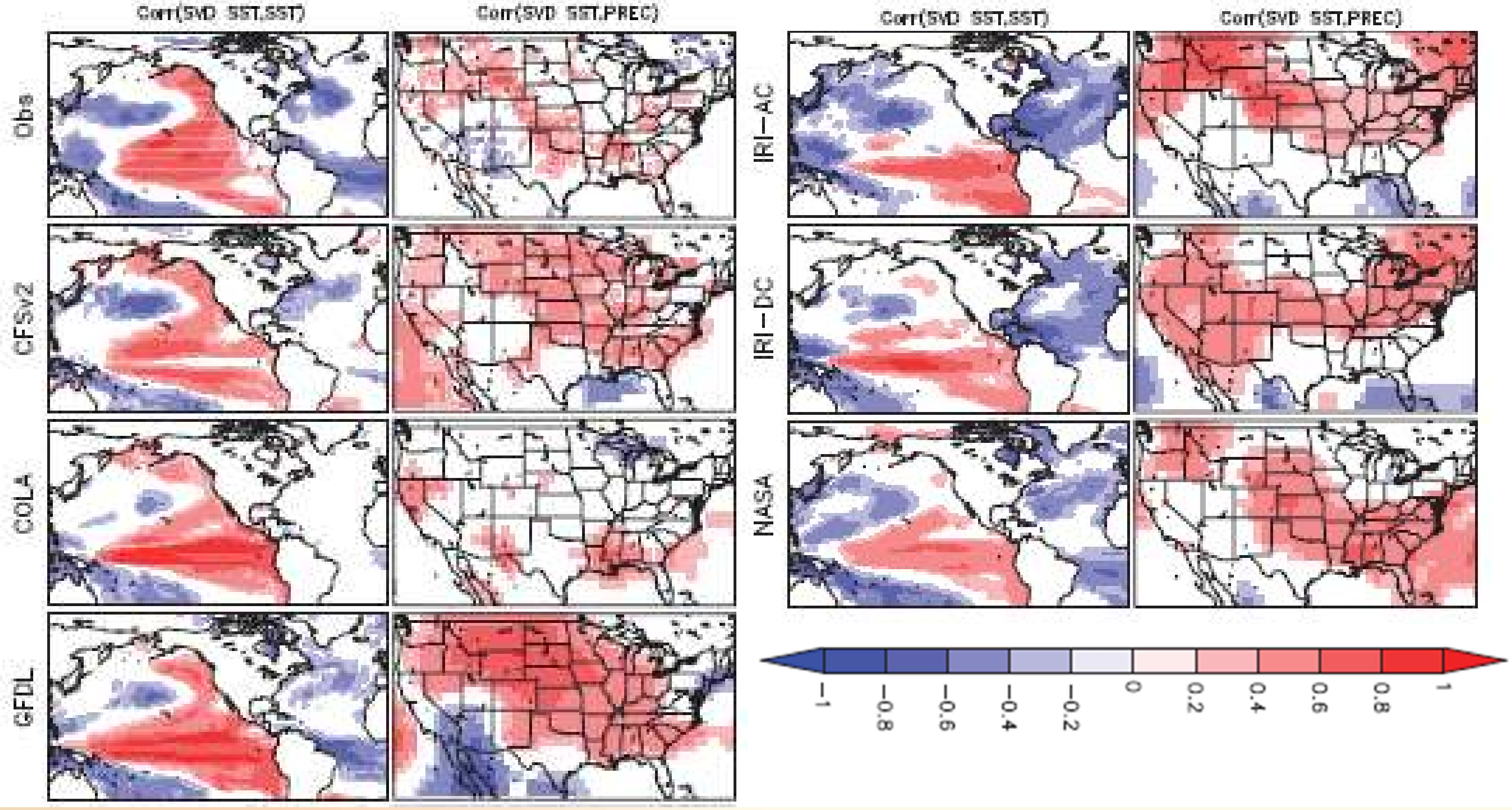
Homogeneous correlation maps **Scores** **Heterogeneous correlation maps**



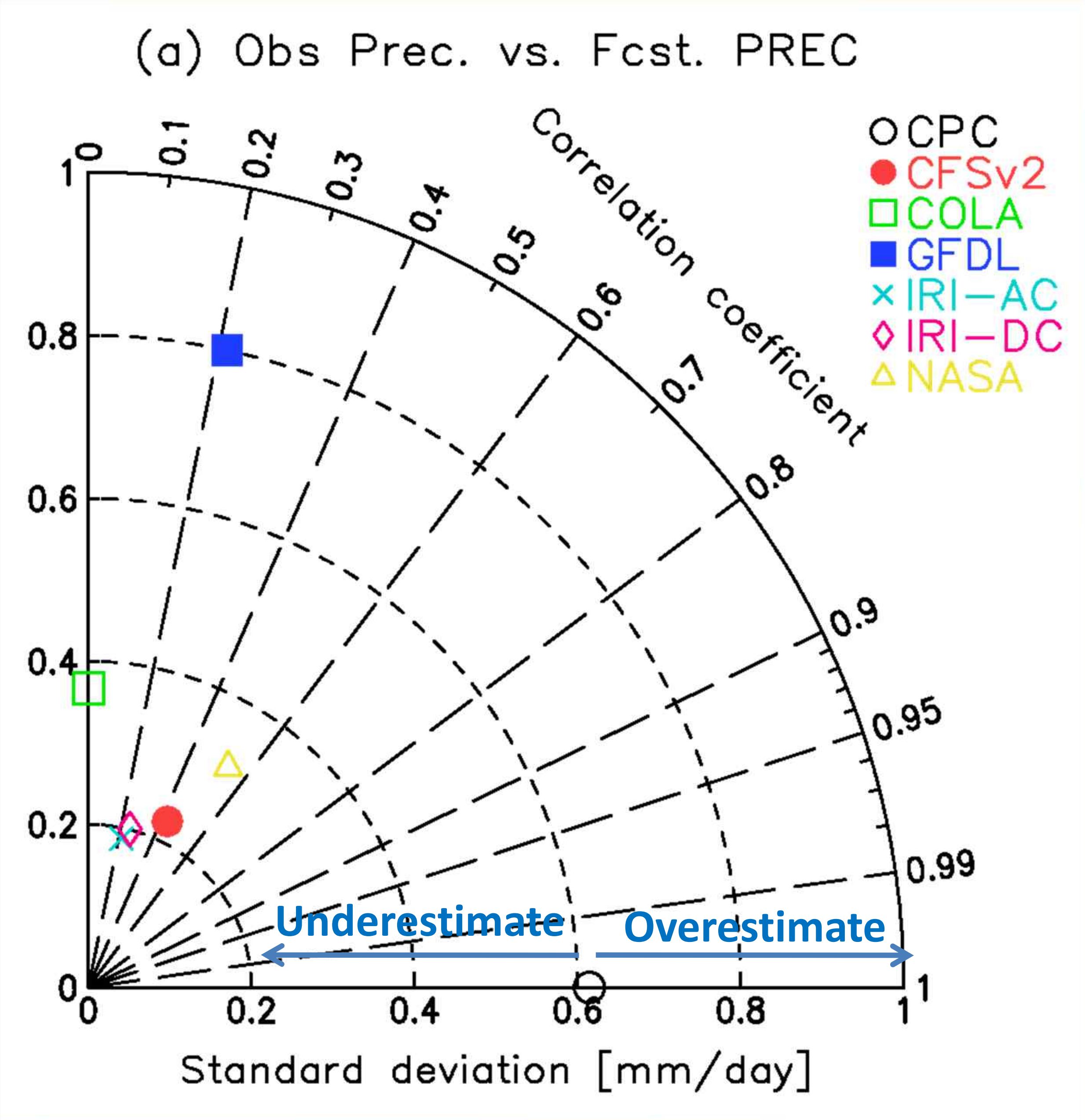
SST Teleconnections with Drought over the U.S.



Homo/Heterogeneous correlation maps

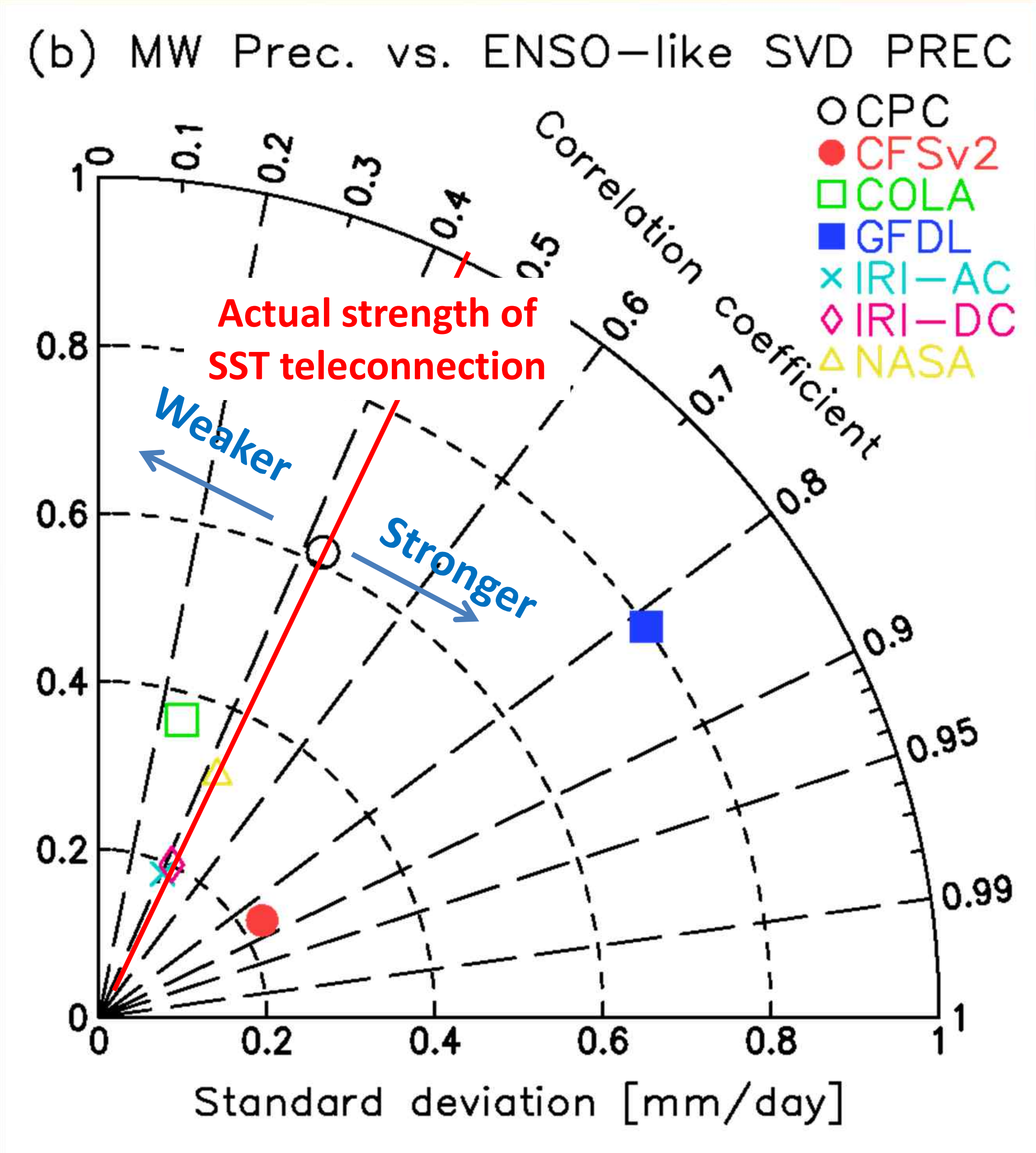


Actual Predictability of Climate Model Forecast



- How well climate model forecast precipitation?
- Most of the NMME climate models **underestimate** the MW summer precipitation variances, except for **GFDL**.

Potential Predictability of Climate Model Forecast



- How much can the ENSO SVD patterns explain the MW precipitation?
- **GFDL and CFSv2** show **overconfidence** in the role of ESNO in inducing the variability of MW summer precipitation.
- The rest GCMs show a comparable magnitude of ENSO teleconnections with the MW precipitation.

Conclusions:

1. Most of the NMME climate models **underestimate** variation of the MW summer precipitation, leading to predictions of relatively normal precipitation.

2. The GFDL model stands out as having **strong coupling** between SSTs and precipitation, and thus **overestimates** variability of MW summer precipitation, and thus predicts **more often** either extreme dry or wet anomalies.

3. Under the current NMME forecasting system, skillful prediction for SST may **mislead** the prediction of MW summer precipitation due to **the underestimation of the variances** in the most models and **overly strong coupling** in two models.

4. For the 2012 drought, however, strong ENSO teleconnetions in the models was **fortuitous** in the predictions **due to the correct sign of the coupling.**

Acknowledgements

Special thanks to:

Dr. Justin Sheffield

Prof. Eric F Wood

Princeton Terrestrial Hydrology Group

Questions?

14. RECORD ANNUAL MEAN WARMTH OVER EUROPE, THE NORTHEAST PACIFIC, AND THE NORTHWEST ATLANTIC DURING 2014: ASSESSMENT OF ANTHROPOGENIC INFLUENCE

JONGHUN KAM, THOMAS R. KNUTSON, FANRONG ZENG, AND ANDREW T. WITTENBERG

According to CMIP5 models, the risk of record annual mean warmth in European, northeast Pacific, and northwest Atlantic regions—as occurred in 2014—has been greatly increased by anthropogenic climate change.

Explaining extreme events of 2014 from a climate perspective, BAMS

Future Research Plan

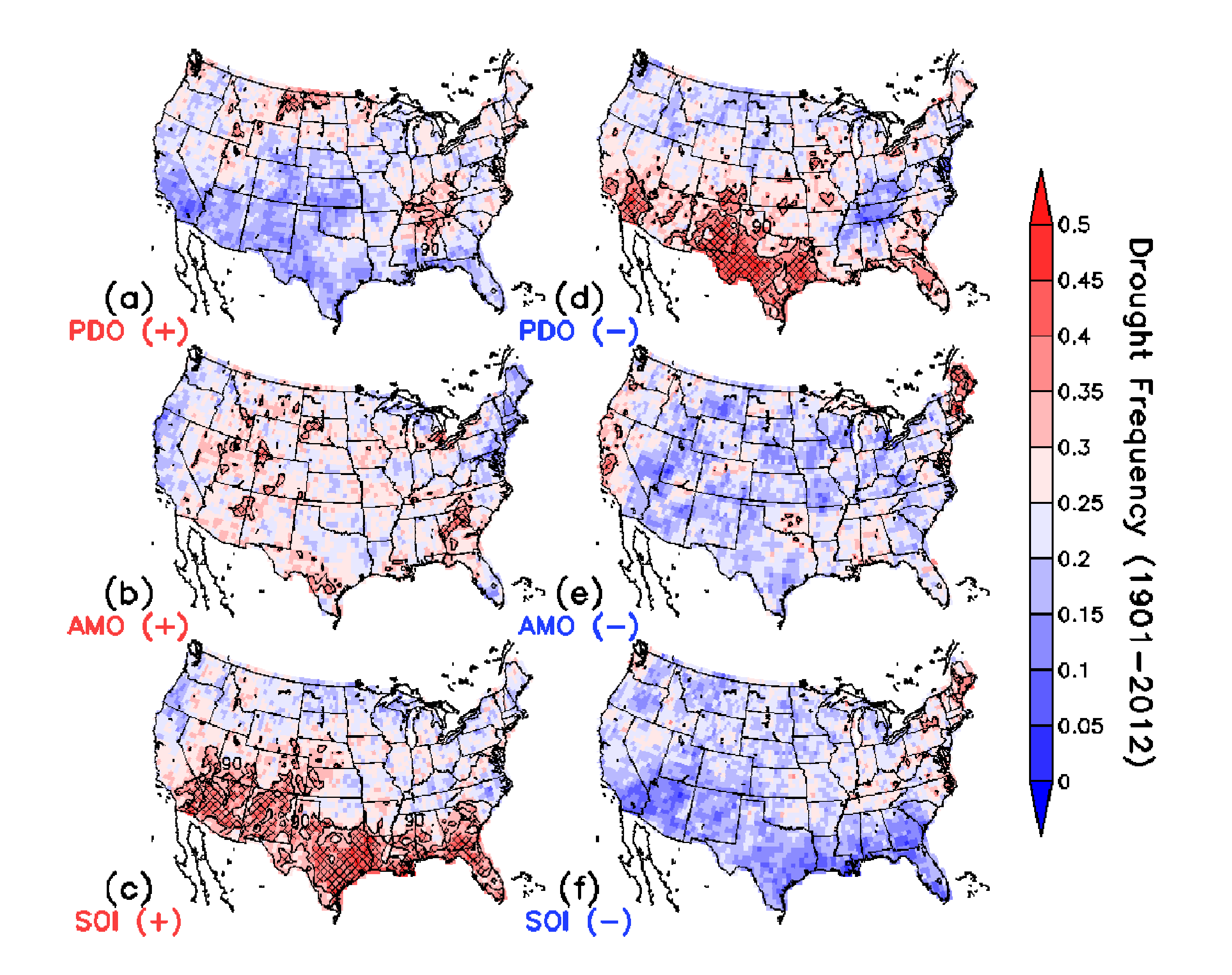
- **Questions:**

  - Attributions of changes in SST teleconnections (e.g. natural variability vs. anthropogenic impact)

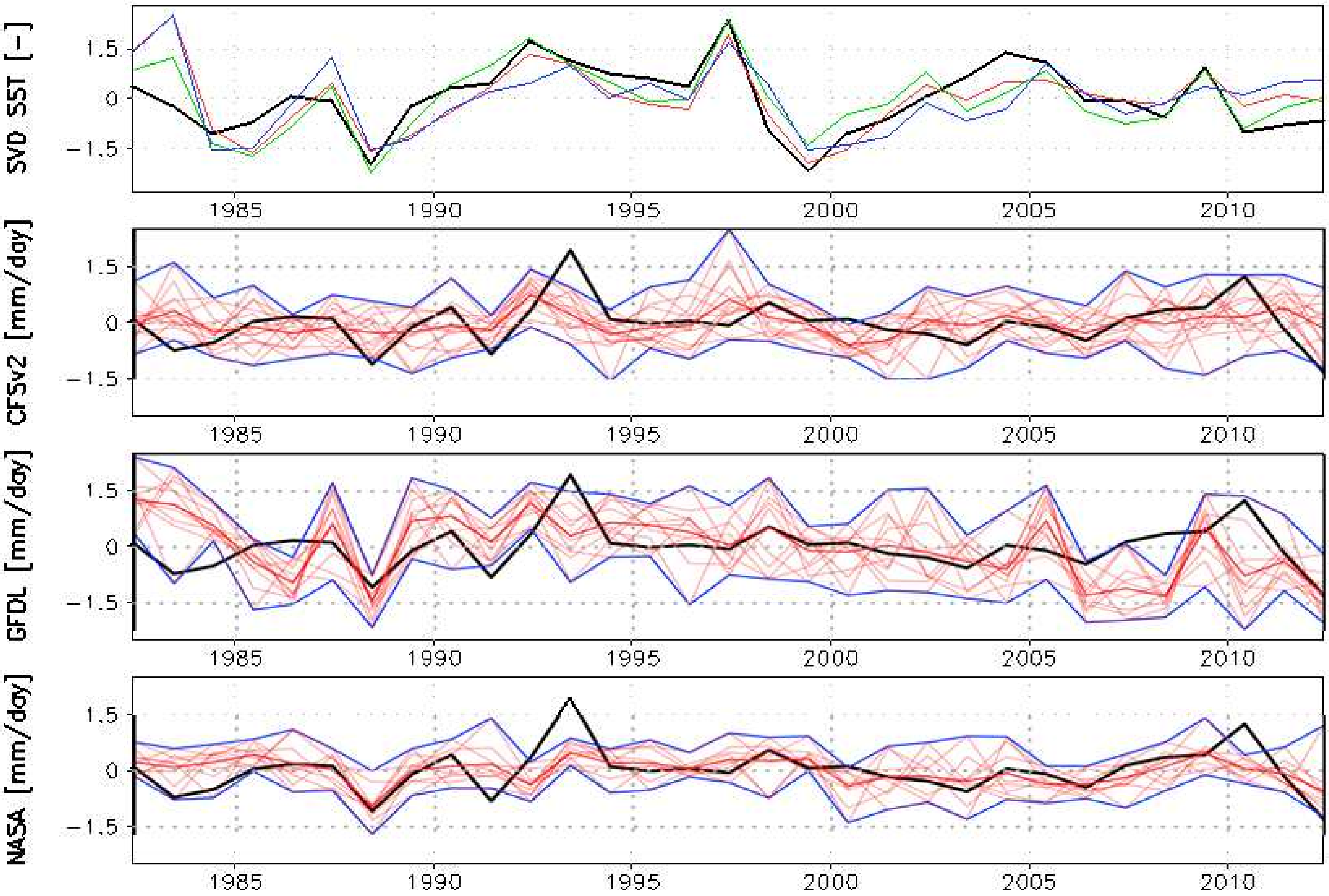
  - Changes in other climate drivers (atmosphere and land) and their impact on hydroclimate extremes

  - Changes in water availability and scarcity and their attributions
    - Available water index: $(P_{m,y}-E_{m,y})/P_{clim}$, where $_m$ is month, $_y$ is year.
    - Runoff ratio: Q/P
    - Drying index: $R_{net}/(P*\lambda_v)$, where λ_v is the latent heat of vaporization (2260 kJ/kg)

Strong Phases of PDO, AMO, and ENSO



NMME Climate Forecast Performance



NMME Climate Forecast Performance