Impact of Climate Variability on Hydrological Extremes over the Mississippi River Basin during the Last Millennium

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Introduction: Climate Variability Modulates Mississippi River Floods

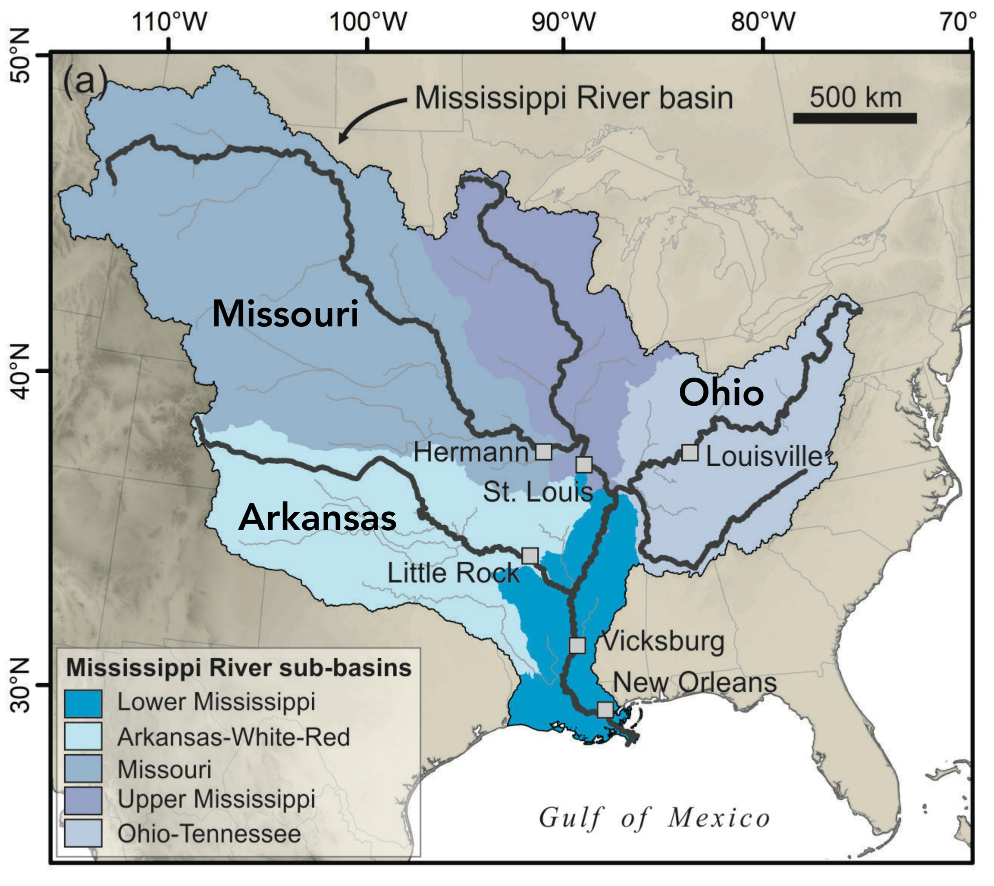


Figure 1: Geographic map of Mississippi River System. The sub-basins of Missouri, Ohio, and Arkansas-White River are highlighted

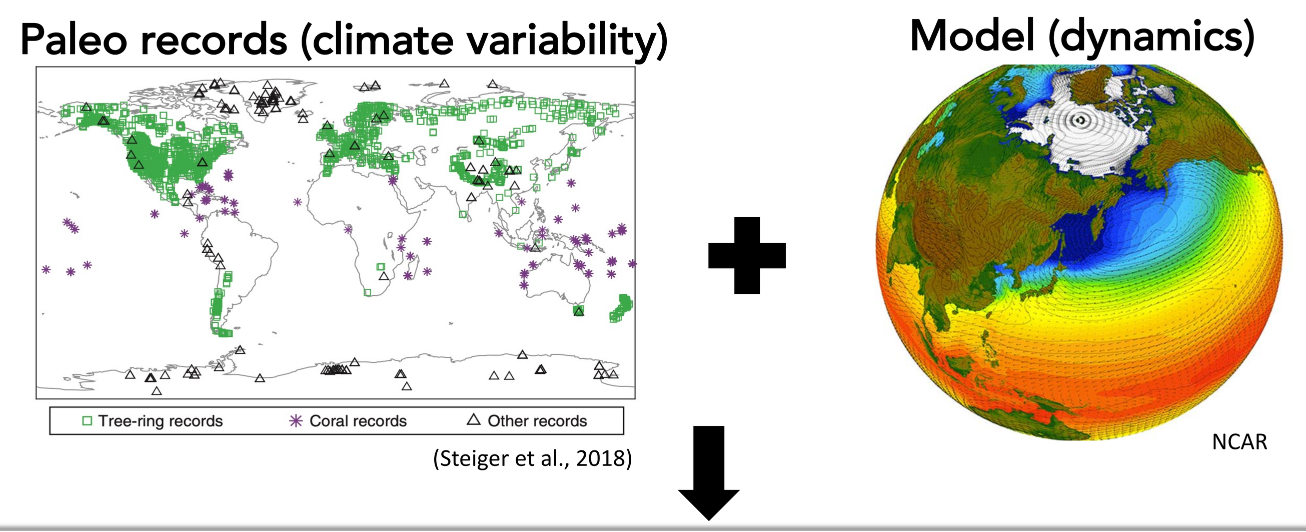
The Mississippi River system imparts large socioeconomic impacts via its interdependencies with transport, agriculture, and urban environments. Significant efforts have been made throughout the 20th century to monitor, predict, and manage discharge and flooding in the Mississippi River basin. Recent studies have shown that climate variability (e.g., El Niño and AMO cold phases) may increase the risk of Mississippi flooding. However, instrumental records only offer a small sample size of Mississippi floods and ENSO/AMO events, which are too short to constrain the dynamical controls of climate variability on Mississippi discharge.

Key Questions:

- What are the primary sea surface temperature (SST) modes over the tropical Pacific that control extreme hydroclimate conditions over the Mississippi river basin?
- How do different ENSO SST patterns affect the Mississippi river hydroclimate conditions? How heterogeneous are the spatial hydroclimate changes over the major Mississippi sub-basins (Missouri, Ohio, Arkansas-White Rivers, and Lower Mississippi)?
- How does AMO affect the hydroclimate conditions over the Lower Mississippi basin?

Method: Data Assimilation Reconstructions over the Last Millennium

Paleo Hydrodynamics Data Assimilation product (**PHYDA**, Steiger et al., 2018): Sea Surface Temperature (SST), Palmer Drought-Severity Index (PDSI), AMO Index



Globally-resolved gridded paleoclimate reanalysis data over the last millennium (LM) offer 100s of additional climate variability and wet extreme events. (Closer to Nature).

PDSI Validation

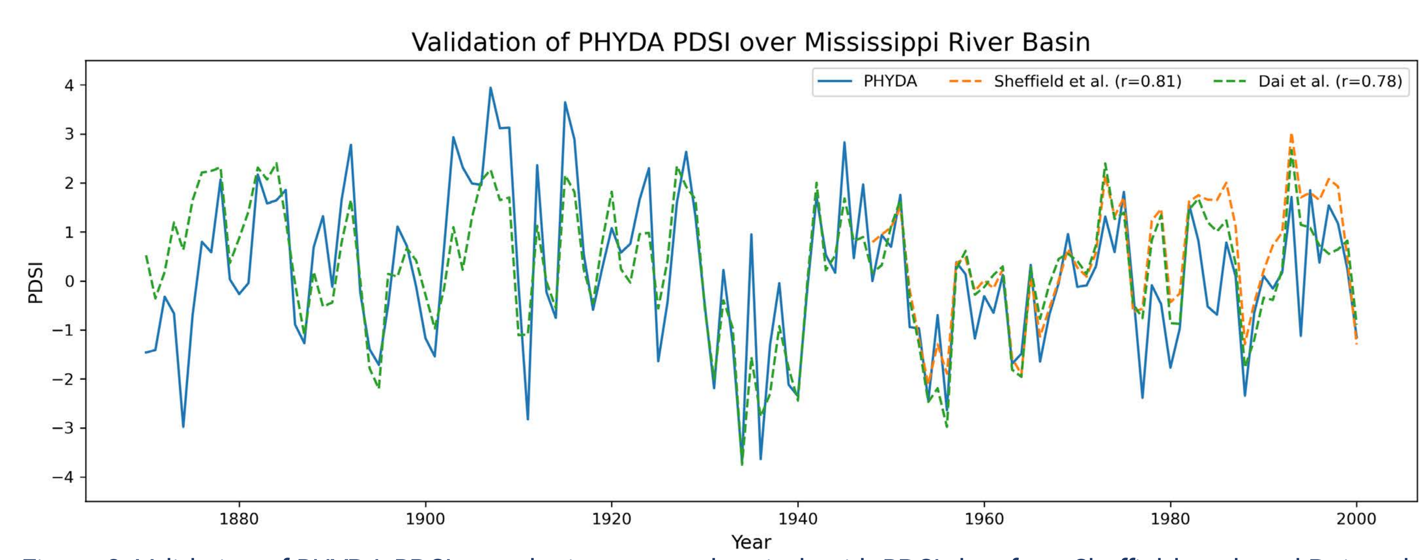


Figure 2: Validation of PHYDA PDSI over the instrumental periods with PDSI data from Sheffield et al. and Dai et al.

Defining Hydroclimate Extremes

- Extreme wet events: top 1%/10% of normalized PDSI over Mississippi
  Normal years: 25% — 75%

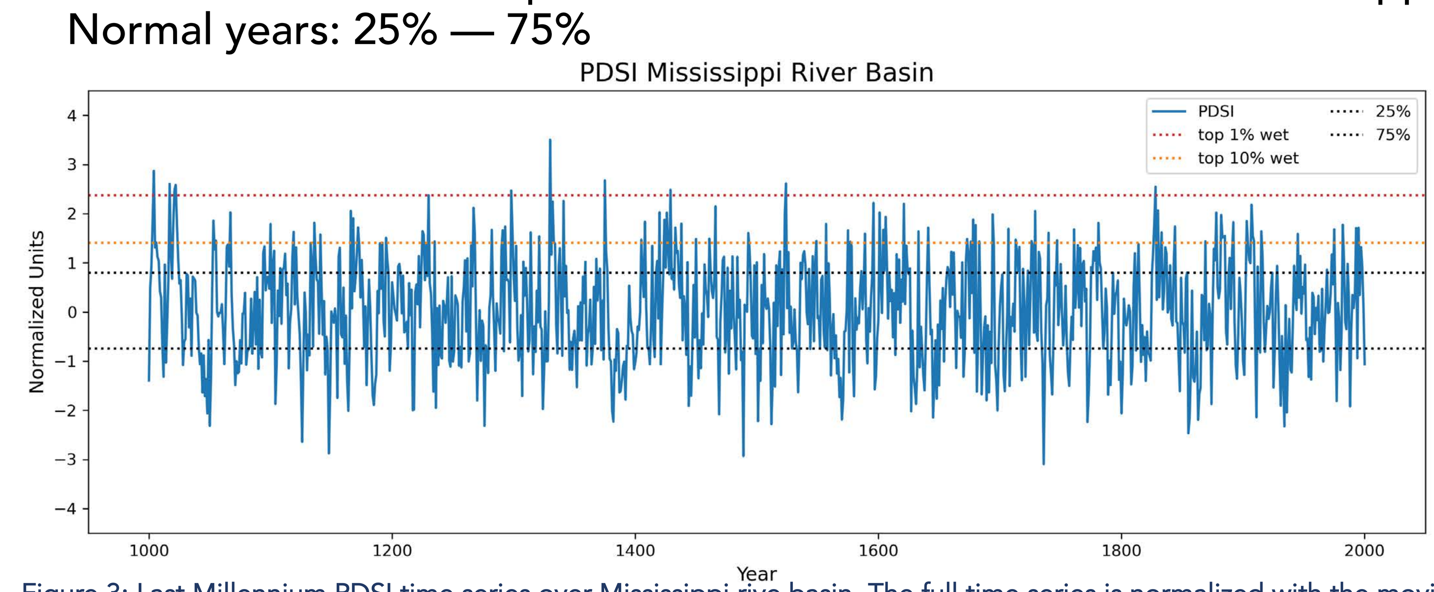


Figure 3: Last Millennium PDSI time series over Mississippi rive basin. The full time series is normalized with the moving 30-year standard deviation.

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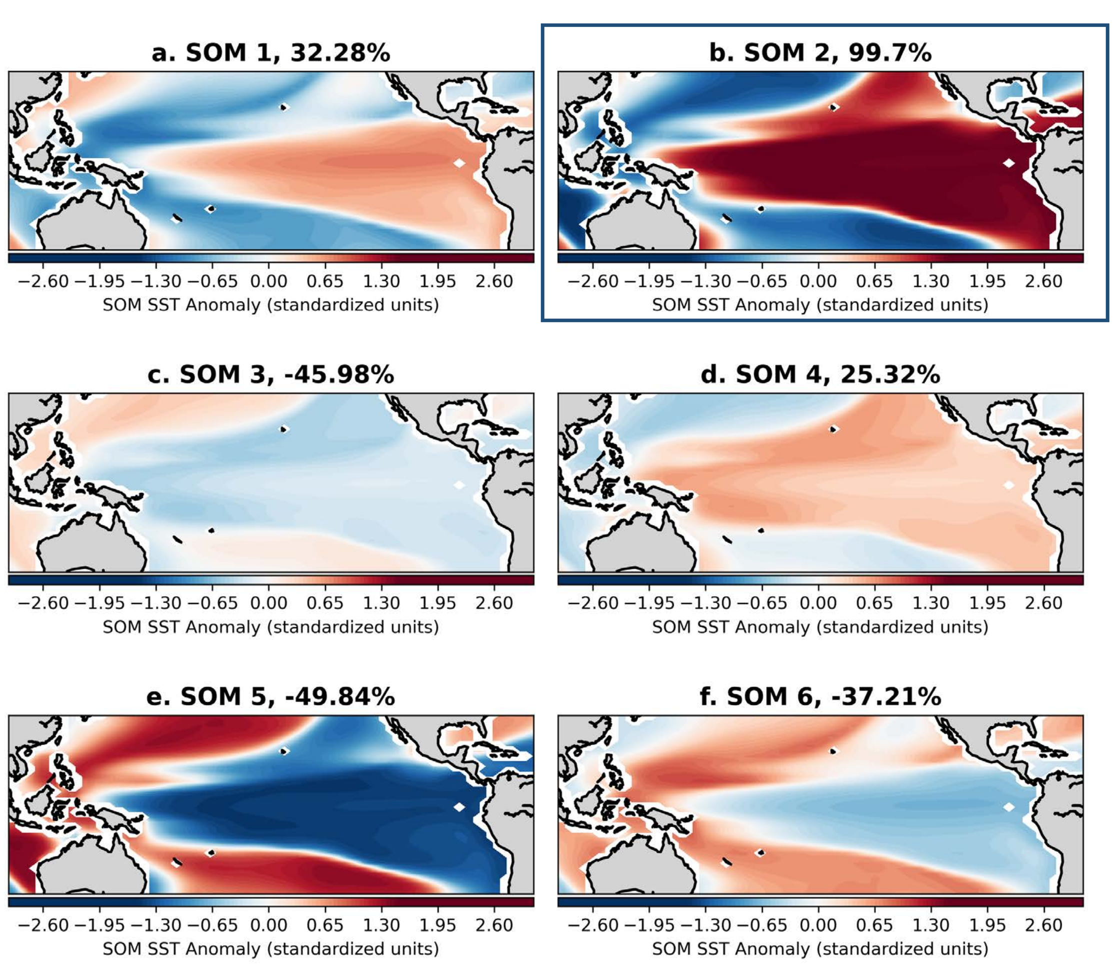
Result 1: Wet Extremes over Mississippi Rive Basin Are Associated with El Niño Events

Self-organizing Maps (SOMs) and Frequency Analysis



- Frequency change = $\frac{f_w - f_n}{f_n}$

  f_w: frequency in extreme wet years

  f_n: frequency in normal years
- Perform resampling of normal years to test the significance of wet extreme frequency change

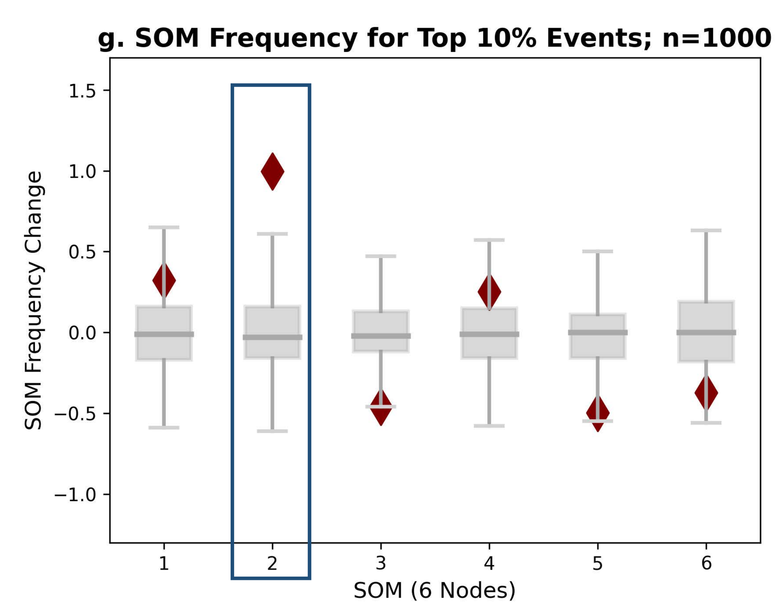


Figure 4: Self-organizing maps (SOMs) and frequency analysis for top 10% wet events over the Mississippi rive basin. (a)-(f) show 6 SOM SSTA patterns with frequency change number labeled. (g) shows resampling results (grey boxplots) and wet extreme frequency changes (red diamonds).

- El Niño-like SSTA patterns generate significant increases in the frequency of extreme wet events over the whole Mississippi River basin.
- Changes over the Missouri and Arkansas river tributaries comprise major contributions to the significant response.

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Table 1: Frequency Changes of SOM modes for Top 1%/10% wet extremes over different tributaries of the Mississippi River basin (Missouri, Ohio, Arkansas, and Lower Mississippi). Significant frequency changes are highlighted; N/A means no such mode in wet extreme events.

Subbasin	Extreme	SOM1	SOM2	SOM3	SOM4	SOM5	SOM6
Missouri	Top 1%	42%	**255%**	NA	NA	NA	92%
	Top 10%	32%	**100%**	-52%	11%	-40%	-23%
Ohio	Top 1%	113%	114%	NA	54%	-49%	NA
	Top 10%	24%	17%	0%	6%	11%	-57%
Arkansas	Top 1%	18%	17%	-50%	102%	2%	NA
	Top 10%	-16%	**91%**	-24%	43%	-44%	-48%
Lower Mississippi	Top 1%	47%	-42%	-3%	-7%	45%	-38%
	Top 10%	20%	13%	-10%	6%	0%	-26%

Result 2: Mississippi Hydroclimate Patterns during Central Pacific (CP) and Eastern Pacific (EP) El Niño Events

- Dry conditions (CP El Niño) vs. wet conditions (EP El Niño)
- Ohio basin exhibits the most significant change, which means that dry vs. wet conditions are most severe over Ohio basin.

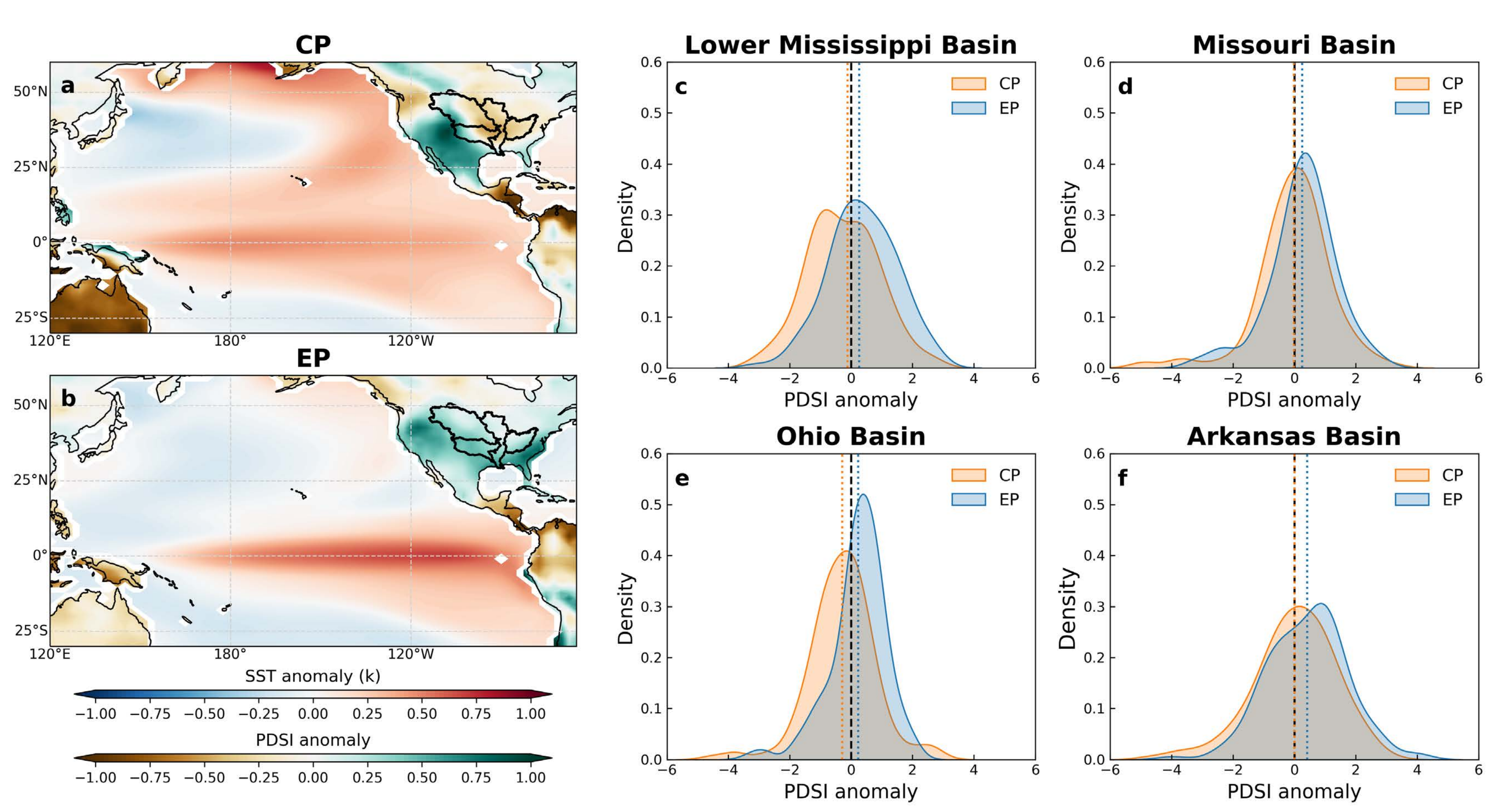

Figure 5 Hydroclimate conditions over the Mississippi rive basin during Central Pacific (CP) and Eastern Pacific (EP) El Niño events. (a) and (b) show the spatial PDSI anomaly patterns with basin highlighted. (c)-(f) show the PDFs of PDSI anomalies during CP and EP El Niño events for Lower Mississippi, Missouri, Ohio, and Arkansas river basin.

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Result 3: Non-stationary AMO Teleconnections over Lower Mississippi

- The teleconnections between AMO and Lower Mississippi hydroclimate are non-stationary. However, AMO cold phase still contributes to extreme wet conditions over the Lower Mississippi (on average).

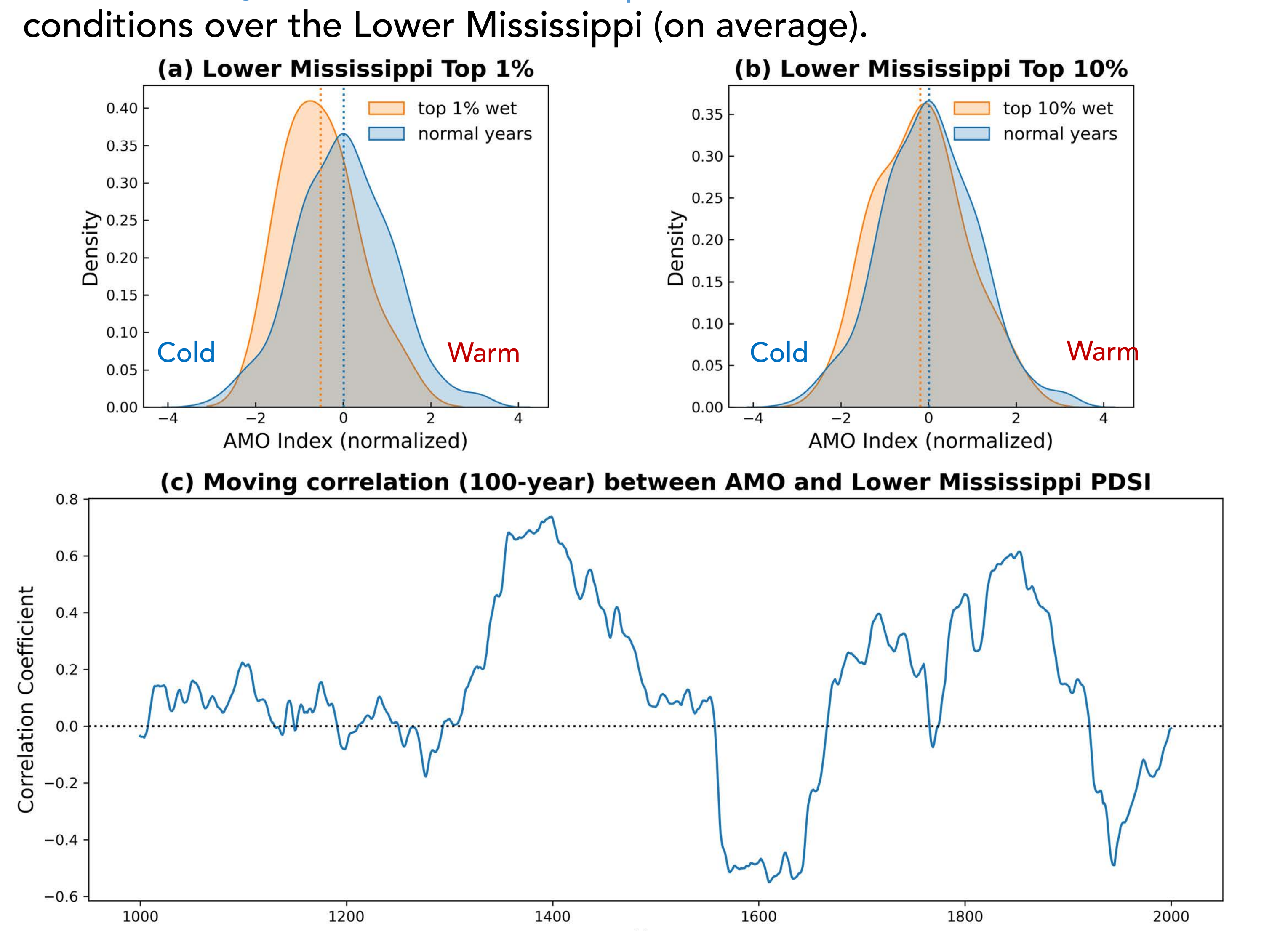

Figure 6: AMO's impacts on Lower Mississippi hydroclimate over the Last Millennium. (a) and (b) show PDFs of normalized AMO index for top 1% and top 10%, respectively compared to normal years (p<0.1). (c) shows the 100-year moving correlation between AMO index and Lower Mississippi PDSI.

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