Understanding Historical Streamflow Variability: The Wavelet Approach

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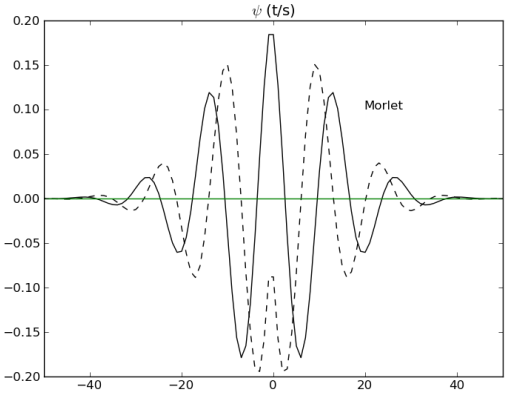
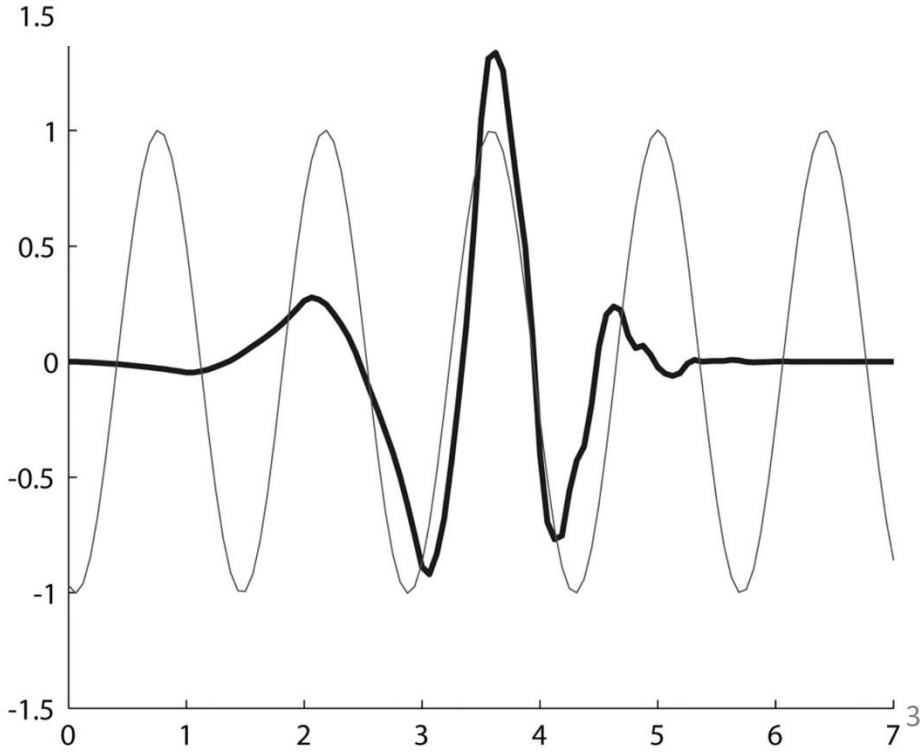


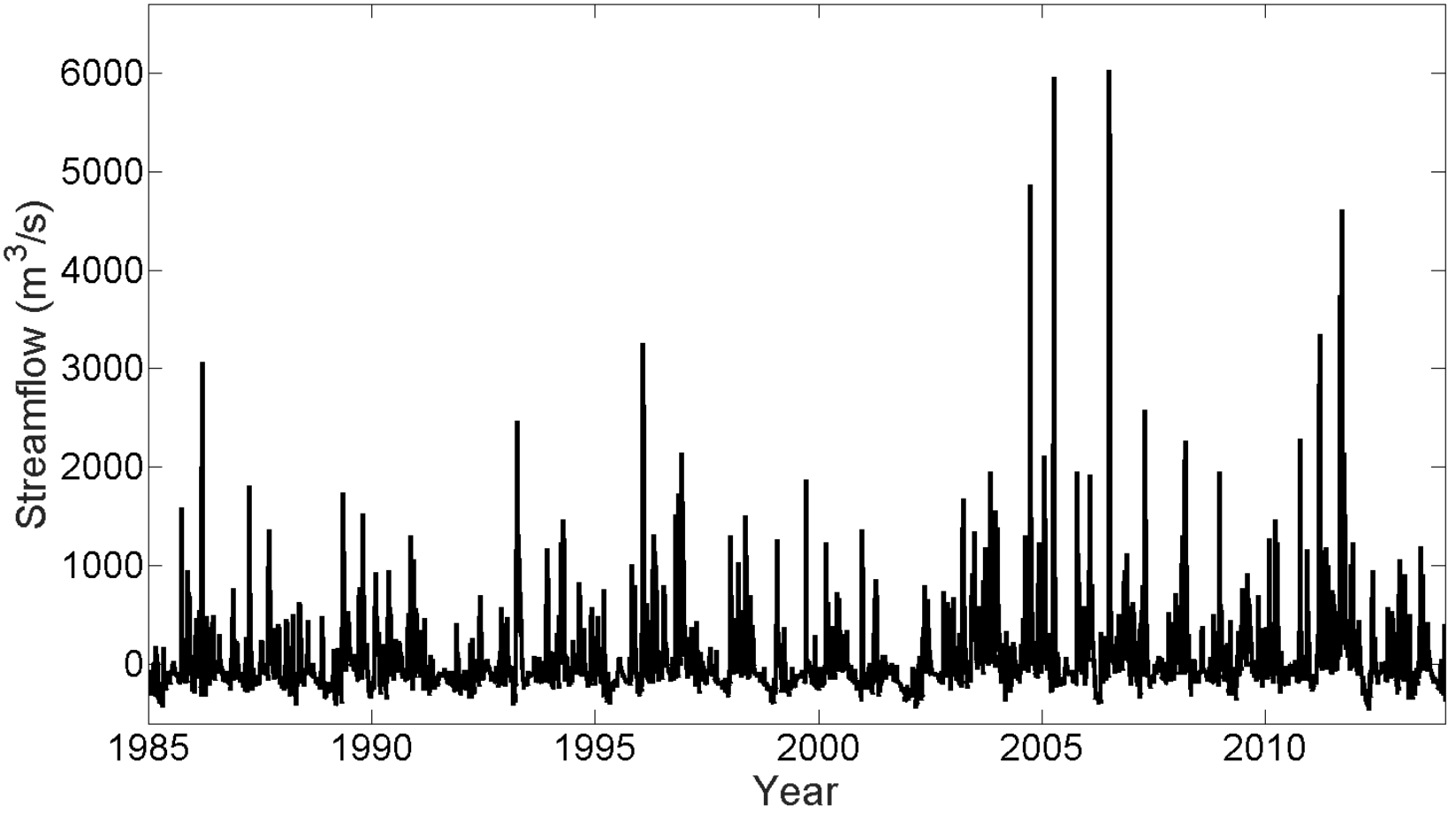
Research Questions/Outline

- Can new wavelet methods help us understand historical streamflow variability?
- Can a new climate index be constructed that is better correlated with mid-Atlantic streamflow than existing climate indices?
- Was historical streamflow variability influenced by tropical convection?

WAVELET ANALYSIS



Delaware River Streamflow



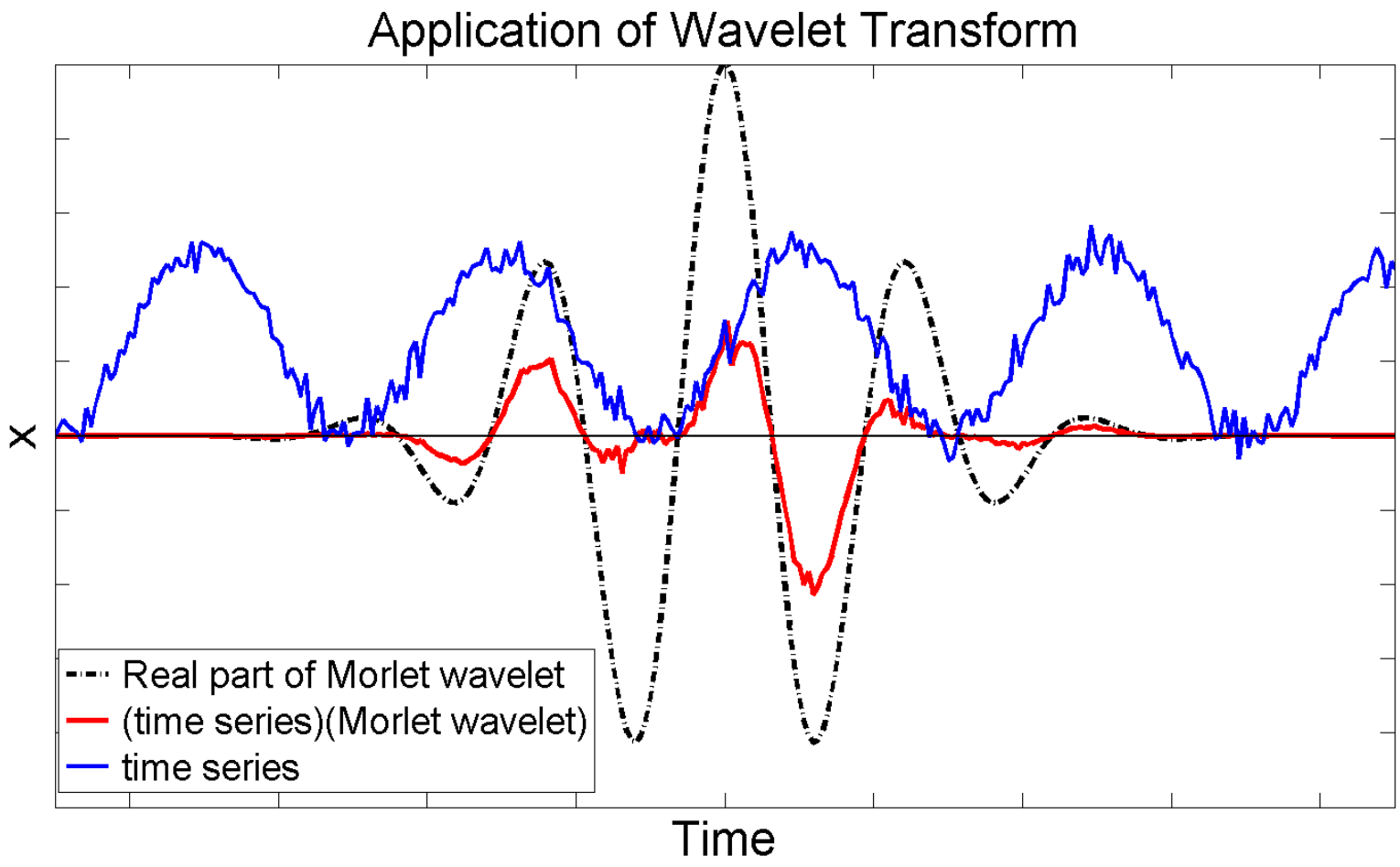
Wavelet Analysis

- Used to decompose variance (power) of a time series as a function of time and frequency
- Wavelet analysis can detect embedded oscillations in time series

The Wavelet Transform

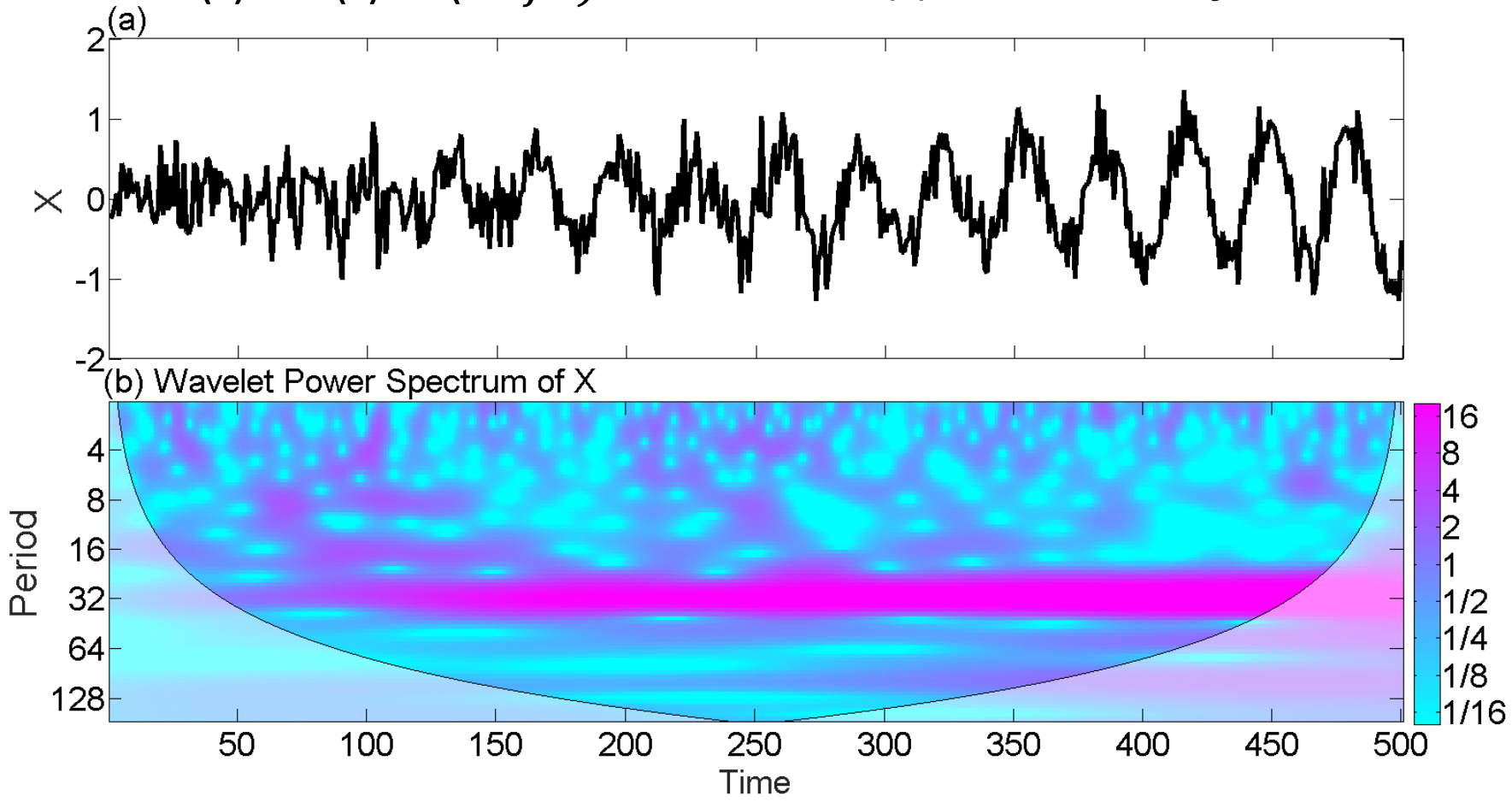
- $W_n^X(s) = \sqrt{\frac{\delta t}{s}} \sum_{n'=1}^{N} x_{n'} \psi_0[(n'-n)\frac{\delta t}{s}]$
- $x_{n'}$ = time series
- δt = time step determined from data
- $\psi_0(\eta) = \pi^{-1/4} e^{i\omega_0 \eta} e^{-\frac{1}{2}\eta^2}$,
- Wavelet power = $\left(W_n^X(s)\right)^2$

The Wavelet Transform



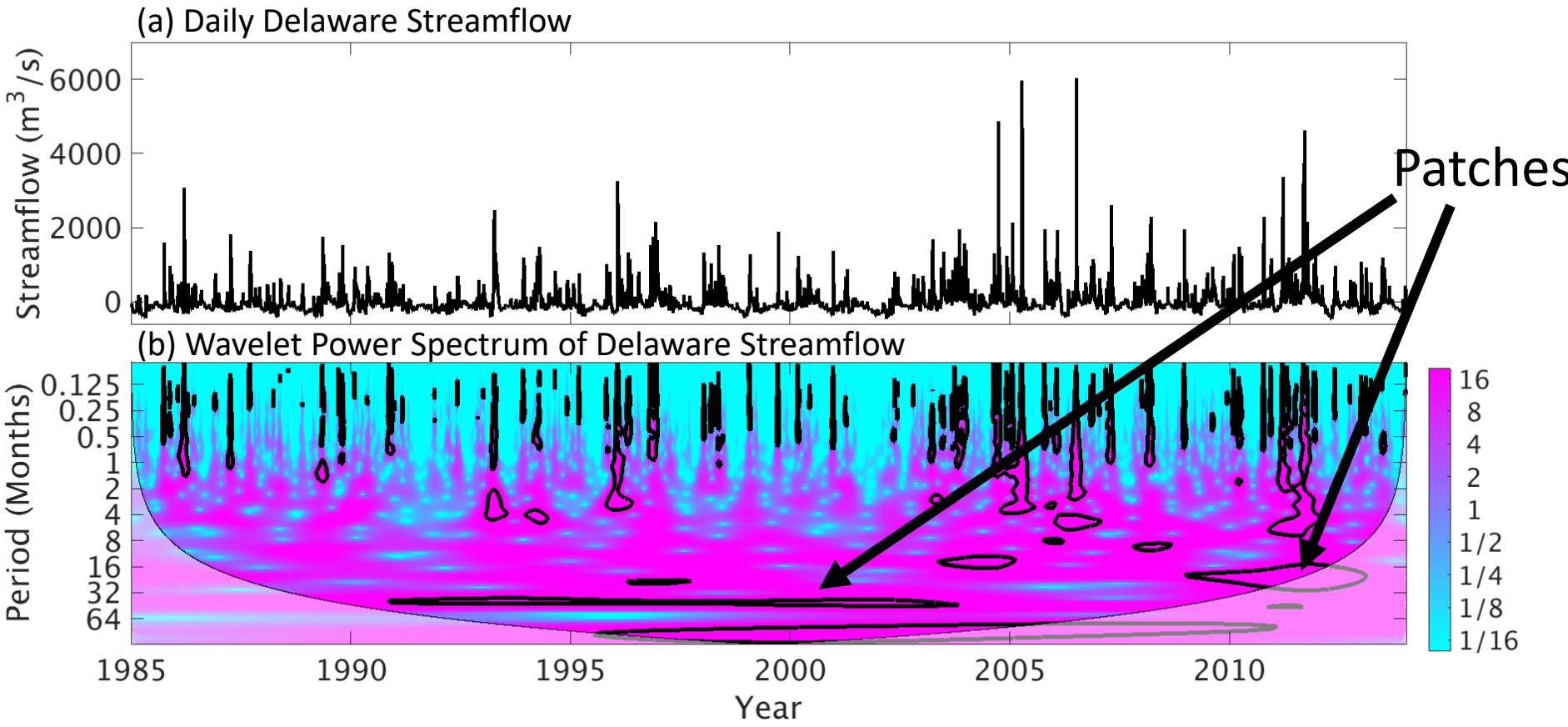
The Wavelet Power Spectrum

$X(t) = A(t)\sin(2\pi f t) + noise \quad A(t) = t/500 \quad 2\pi f = 0.2$



Pointwise Significance Testing

- The wavelet power needs to be compared to that of a red-noise background.
- Red-noise can produce large wavelet power
- Tests each wavelet power coefficient independently



Key Features

- **Significant variability at periods less than 2 months due to weather events**
- **Significant low-frequency variability at a period of 4-years**

Cumulative Areawise Testing (Schulte, 2015)

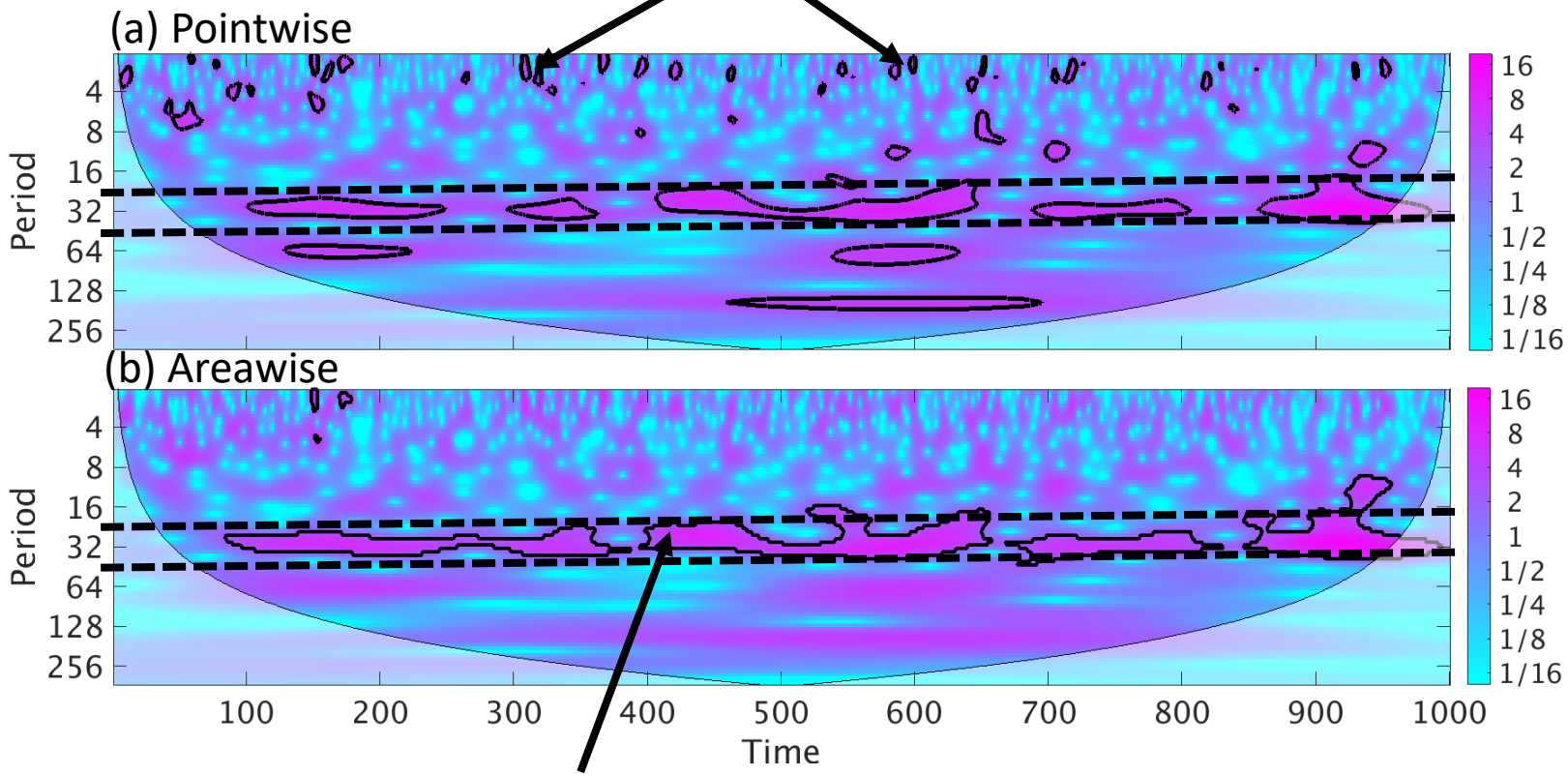
- Assesses the significance of patches based on **cumulative area** at different pointwise significance levels
- Uses ideas from persistent homology (Edelsbrunner, 2010)
- Reduces multiple-testing artifacts (Maraun et al., 2007)
- Researcher need not choose a pointwise significant level
- Test takes advantage of the autocorrelation among wavelet power coefficients

Cumulative Areawise Testing

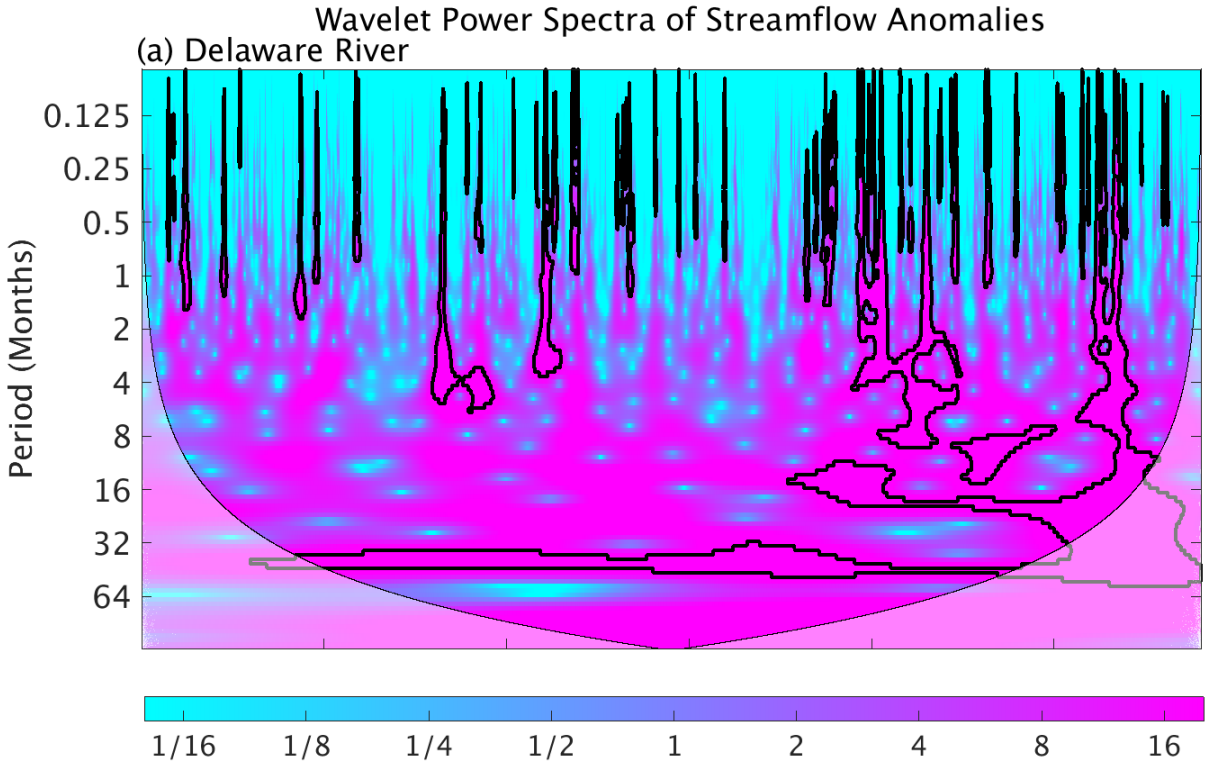
Comparison of Tests

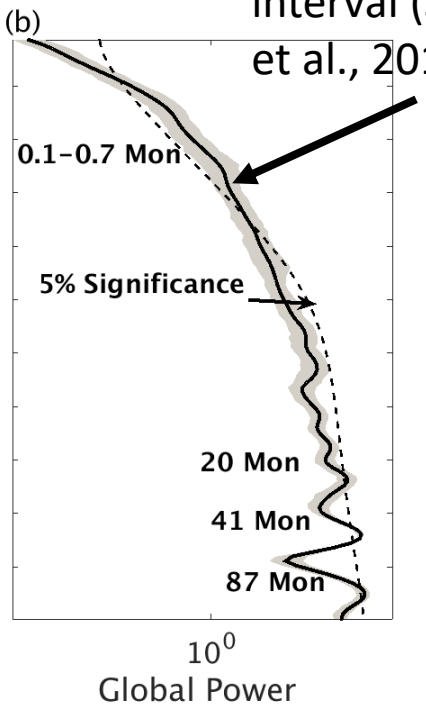
$X(t) = \sin(2\pi f t) + noise$ $2\pi f = 0.2$

Anything outside dotted region are artifacts of multiple testing/spurious results.



Anything within dotted region are true positives or what should be detected.

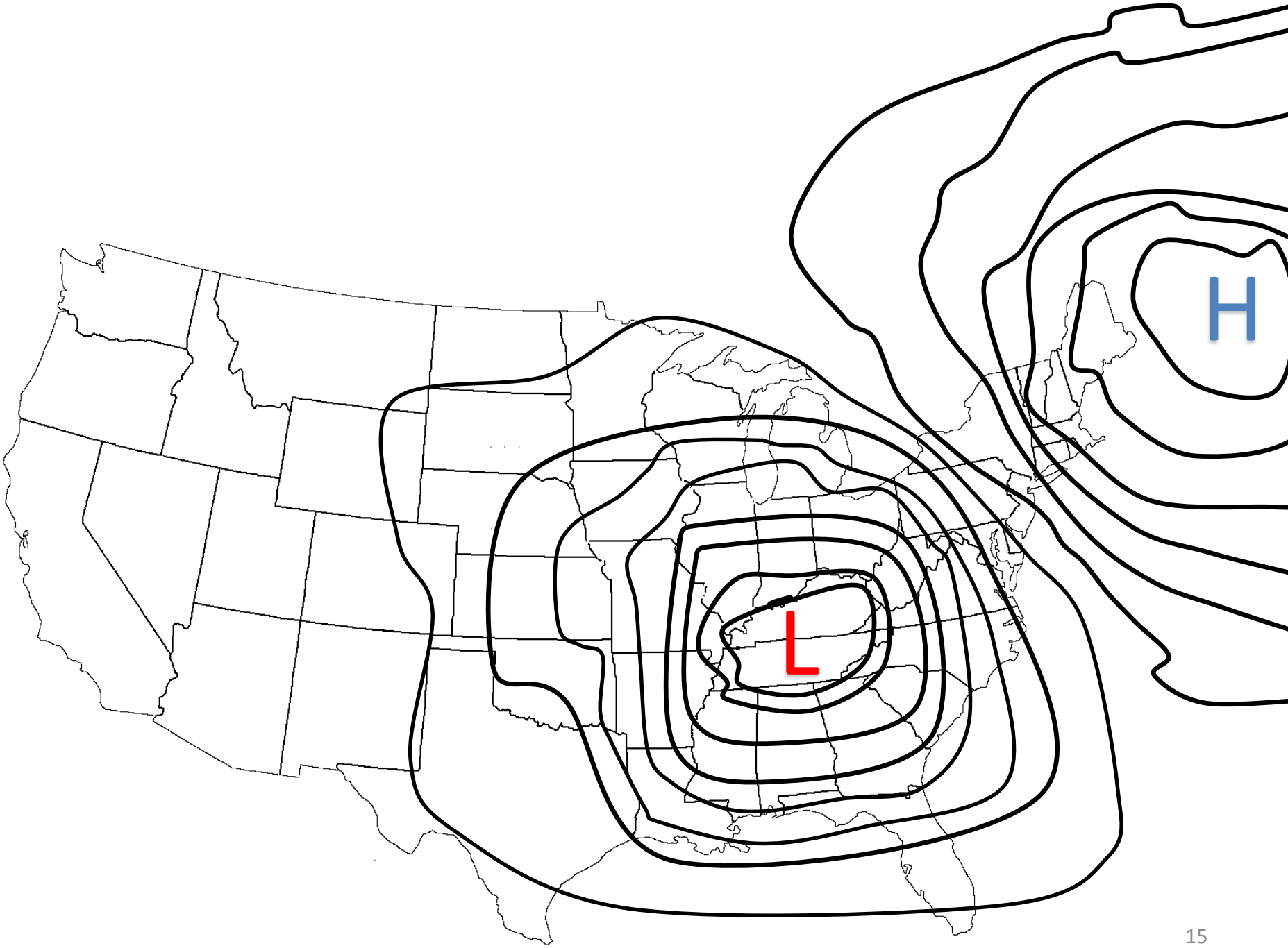




Gray shading = 95% confidence interval (Schulte et al., 2015b)

Key Features

- **Significant variability at periods less than 2 months**
- **Significant periodicity at a period of 2 years from 2003 through 2014**
- **Significant periodicity at a period of approximately 4 years**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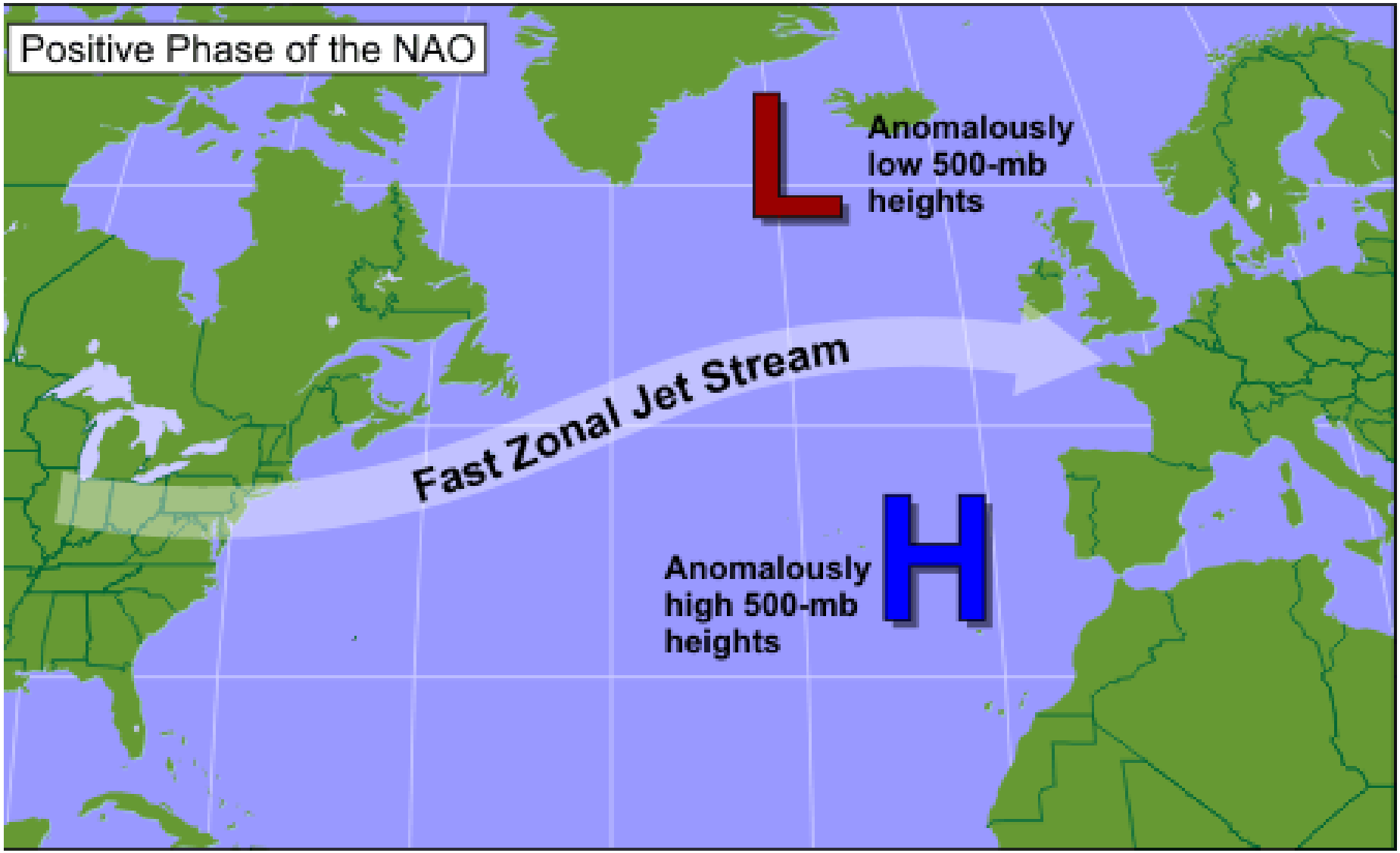
Introduction

- Many studies have analyzed the impacts of the North Atlantic Oscillation (NAO) on precipitation and streamflow variability.
- It useful to compare new climate indices to the well-studied NAO.

North Atlantic Oscillation



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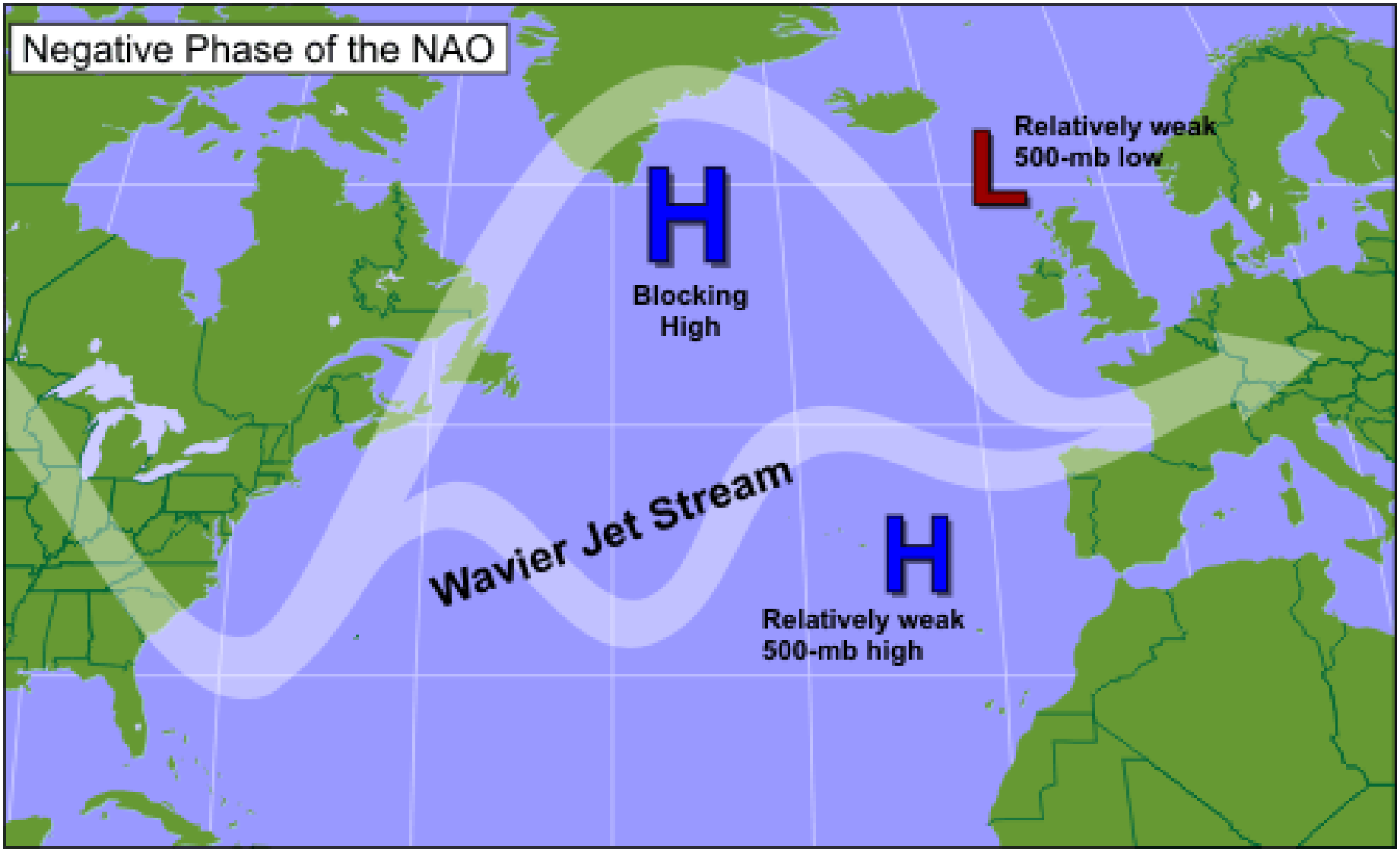
North Atlantic Oscillation



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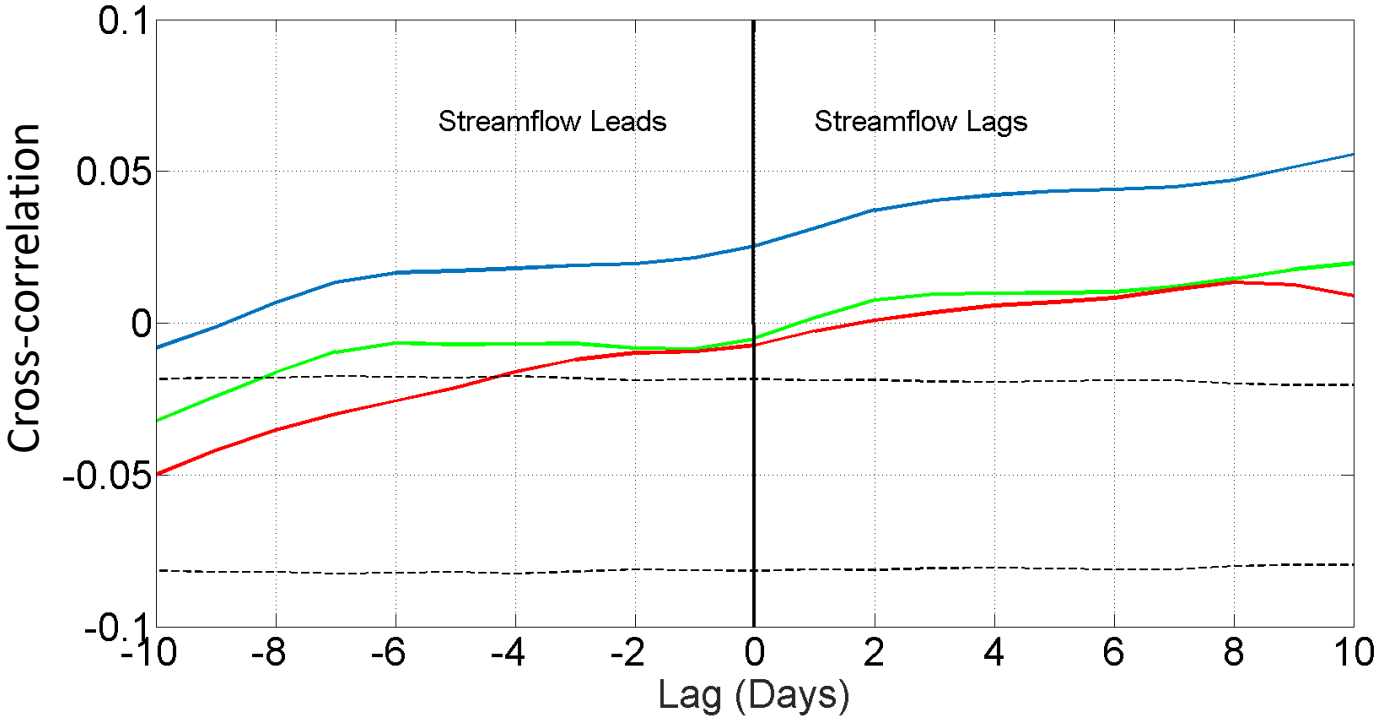
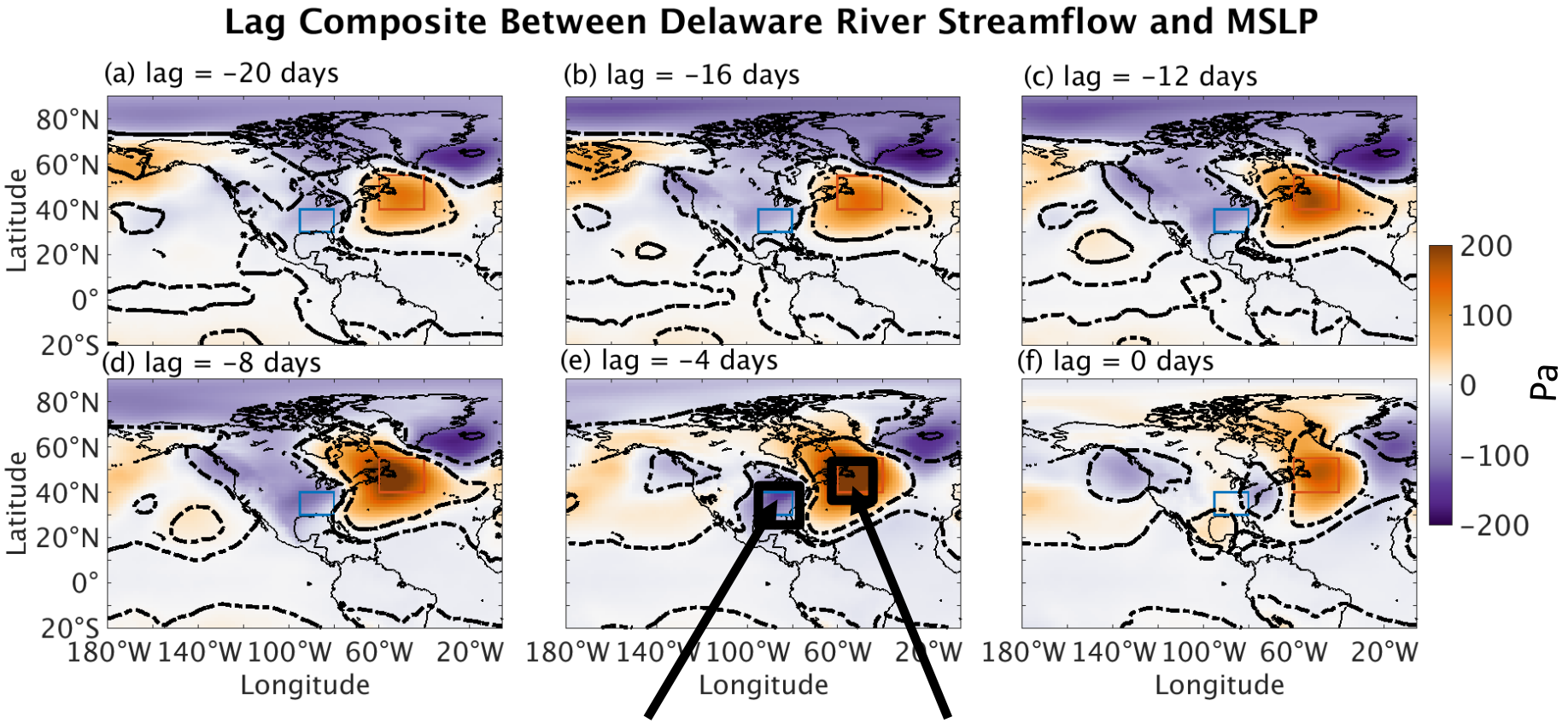
Cross-correlation between Daily NAO Index and Daily Streamflow Anomalies



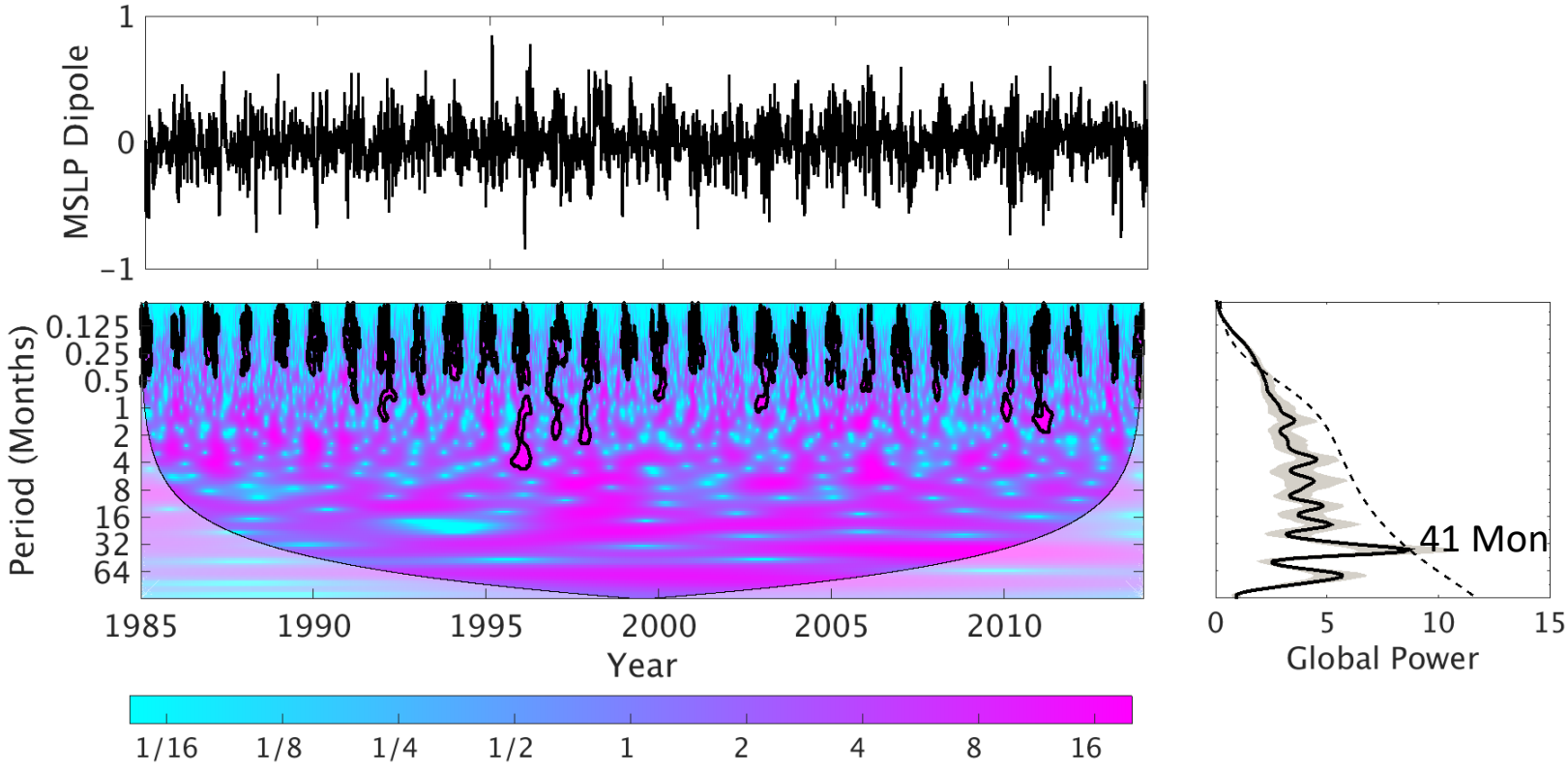
- NAO index is weakly but significantly correlated with streamflow
- Can we construct an index that is more correlated with mid-Atlantic streamflow

The MSLP Dipole



MSLP dipole = Atlantic MSLP Index - Southeast MSLP Index

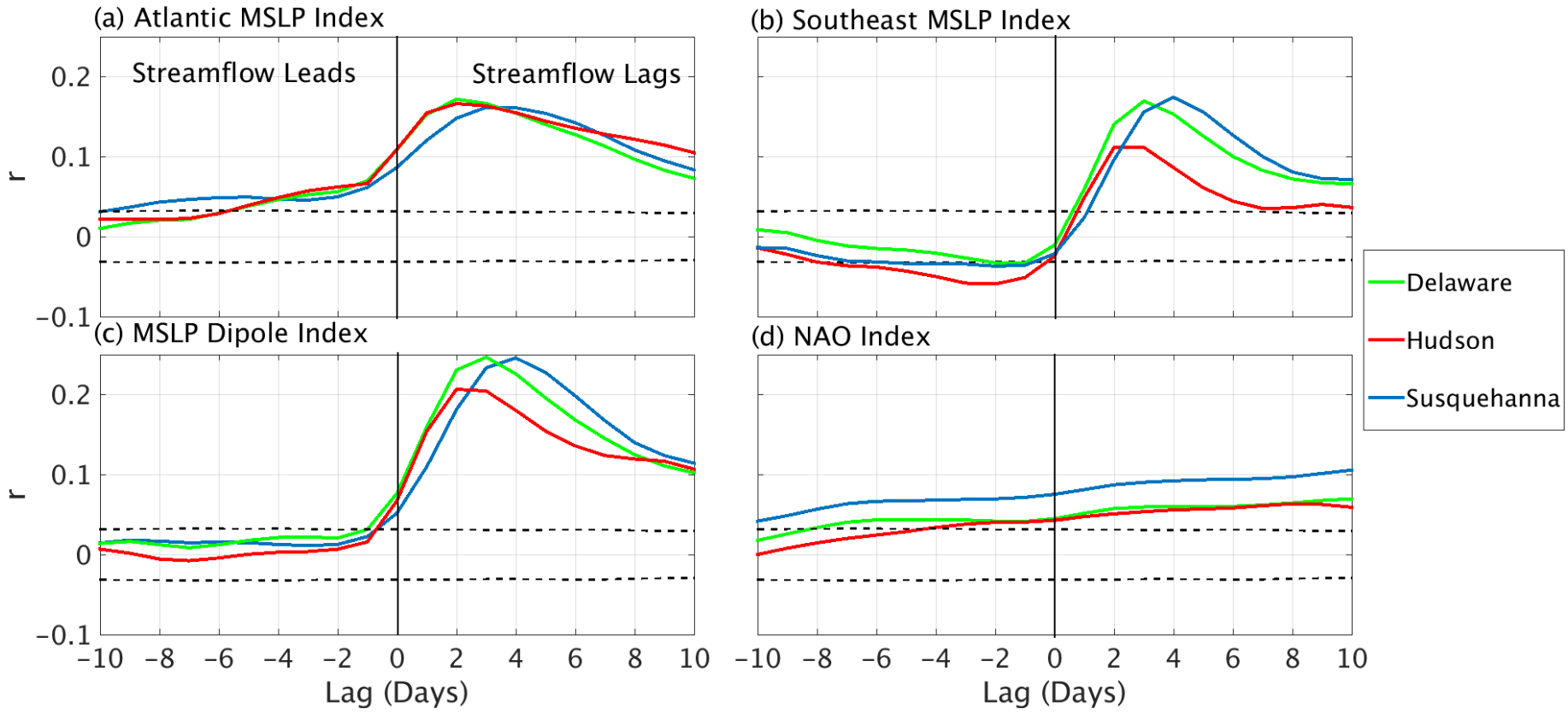
The MSLP Dipole Index



Key Features

- Significant variability at periods of 4-14 days
- Enhanced power at a period of 41 months

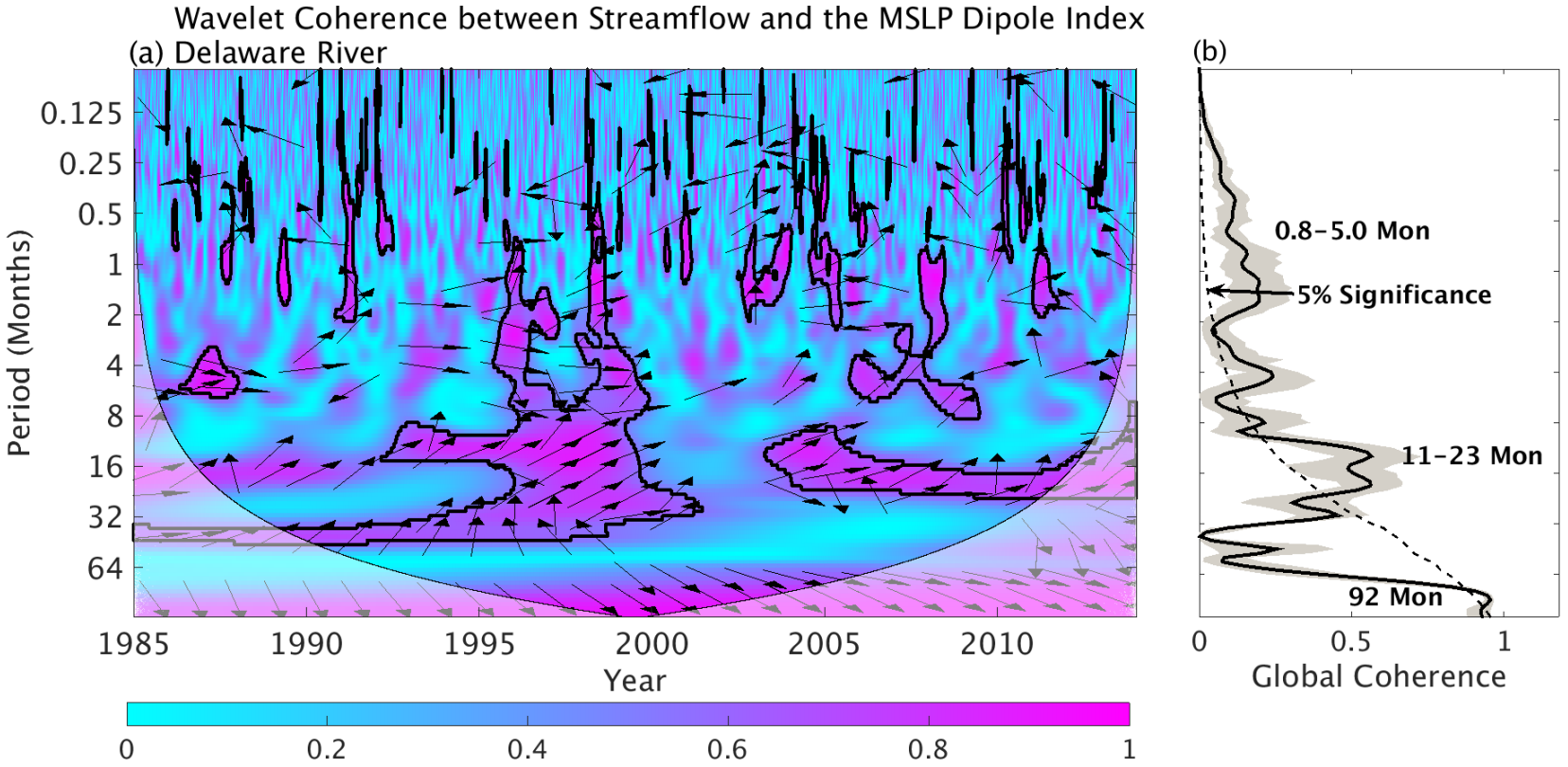
Cross-correlation Analysis



- All three new MSLP indices correlate better with streamflow than the existing NAO index

Wavelet Coherence: Predictability Beyond the Weather Forecasting Timescale?

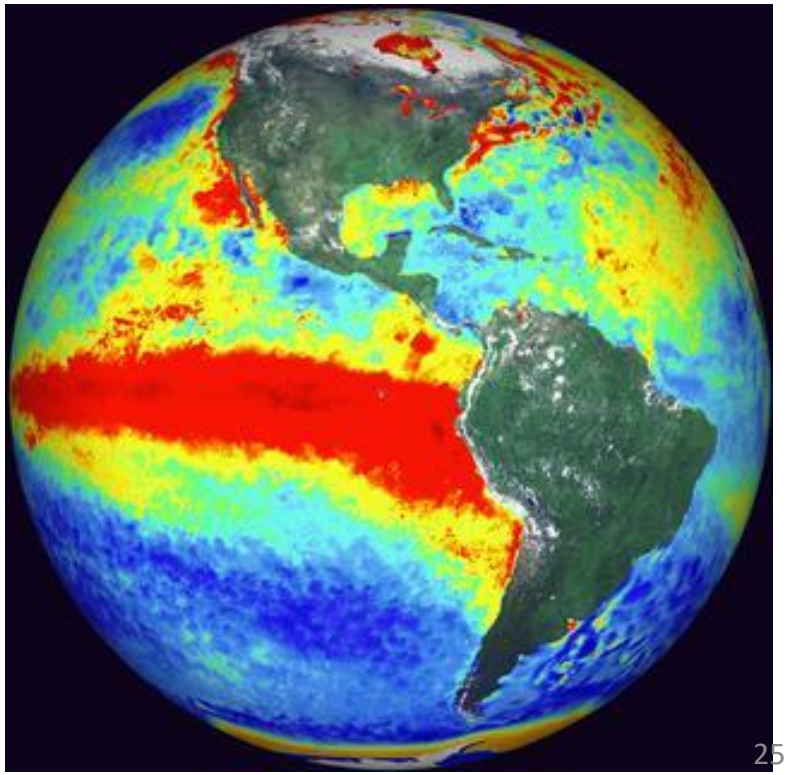
- Decomposes a correlation coefficient as a function of time and frequency (Grinsted et al., 2004)
- Wavelet coherence takes values between 0 and 1
- A value of 1 indicates the strongest possible relationship
- 0 means time series are **independent**
- Significance of wavelet coherence is assessed using Monte Carlo methods



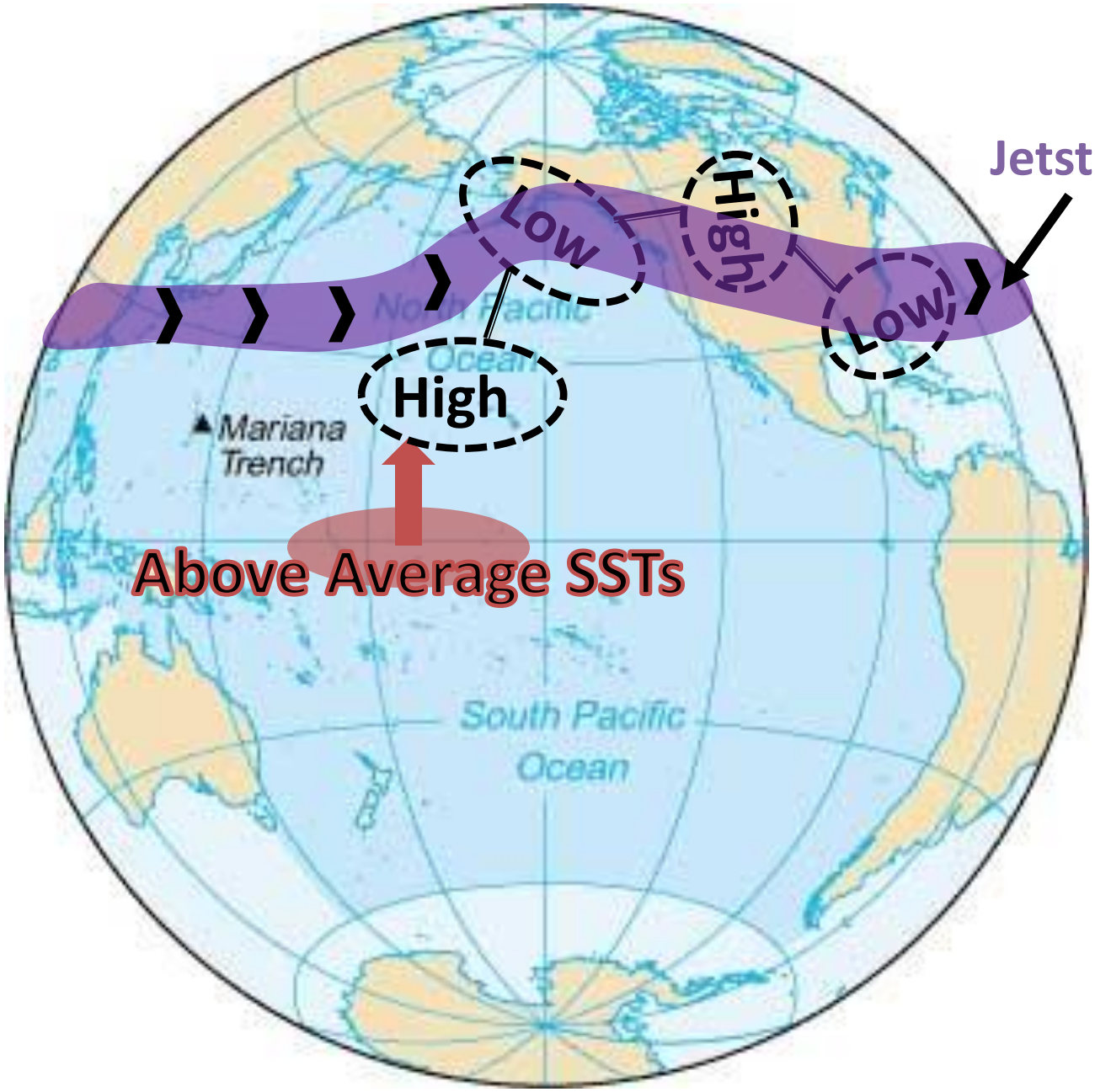
Key Features

- **Significant coherence at daily and seasonal timescales**
- **Significant coherence in the 1-4 year period band**
- **The coherence at 2 and 4 years coincides with significant streamflow variability (slide 14)**

TROPICAL INFLUENCES

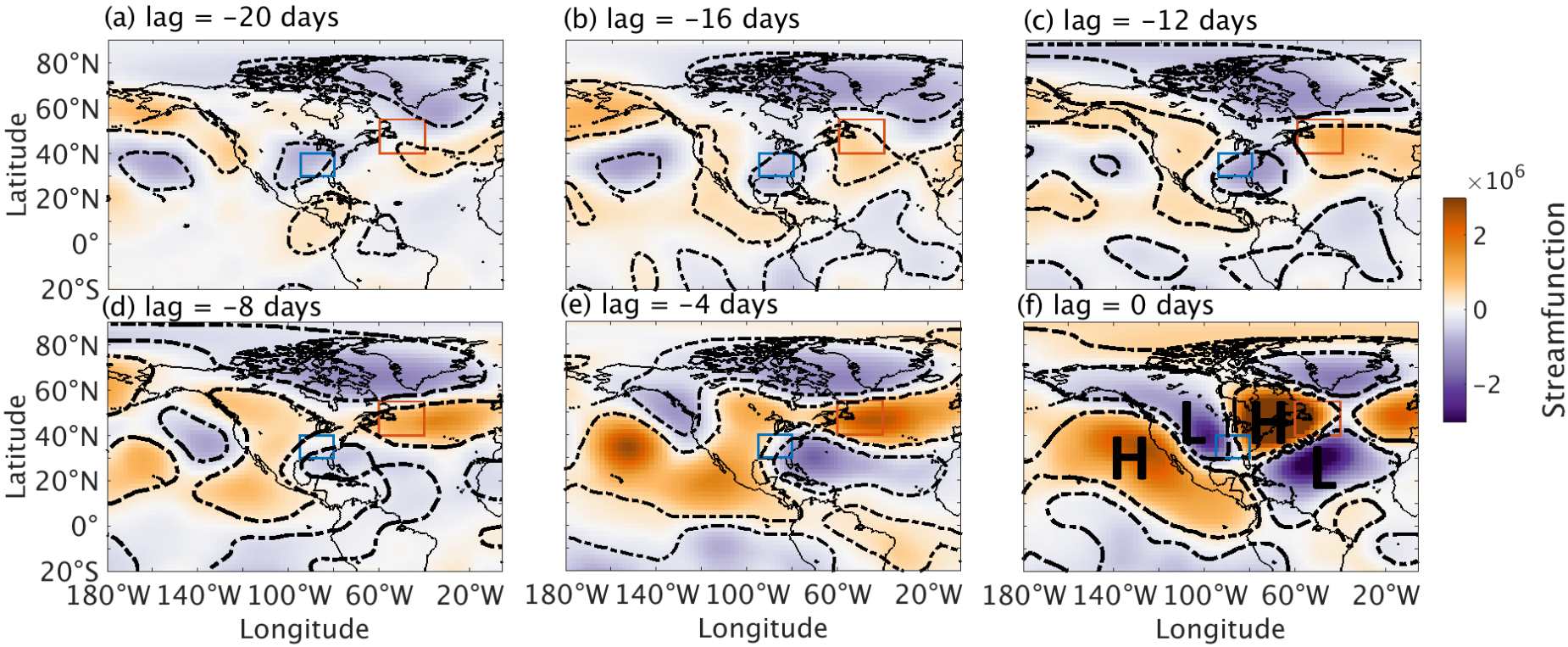


Mid-latitude Response to Tropical Convection (Hoskins and Karoly, 1981)



Tropical Convection and the MSLP Dipole Index

Lag Composite Between MSLP Dipole Index and 300 hPa Streamfunction



Conclusions

- New and powerful tools in wavelet analysis detected significant variability in the Delaware River time series at period of 2 and 4 years
- A new MSLP dipole index was constructed that is better correlated with mid-Atlantic streamflow than existing climate indices
- The MSLP dipole index may offer predictability beyond the weather forecasting timescale.
- The MSLP dipole index was related to tropical convection

Software Availability

- Software for areawise testing and confidence interval calculations will be available upon publication
- Geometric significance testing (Schulte et al., 2015) software is available through justinschulte.com
- Please email me at jas6367@psu.edu if you are interested in the software used in the presentation

References

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