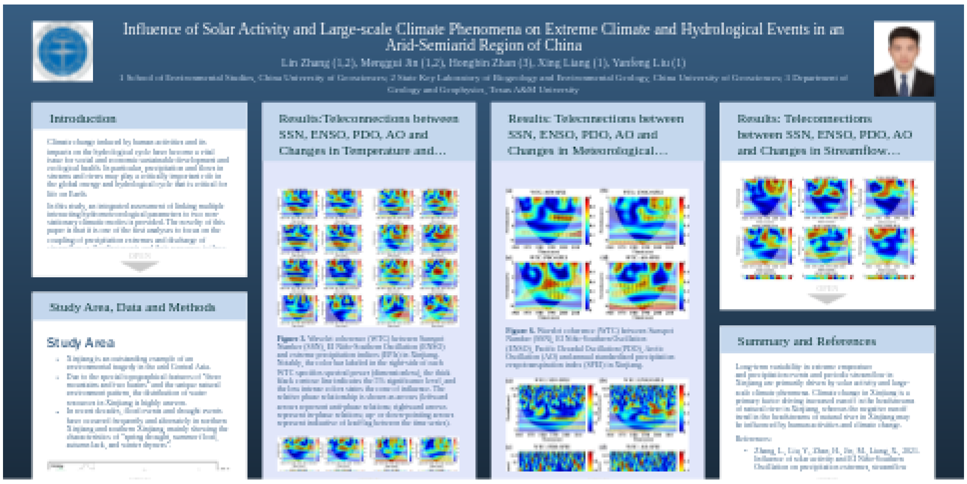
Influence of Solar Activity and Large-scale Climate Phenomena on Extreme Climate and Hydrological Events in an Arid-Semiarid Region of China



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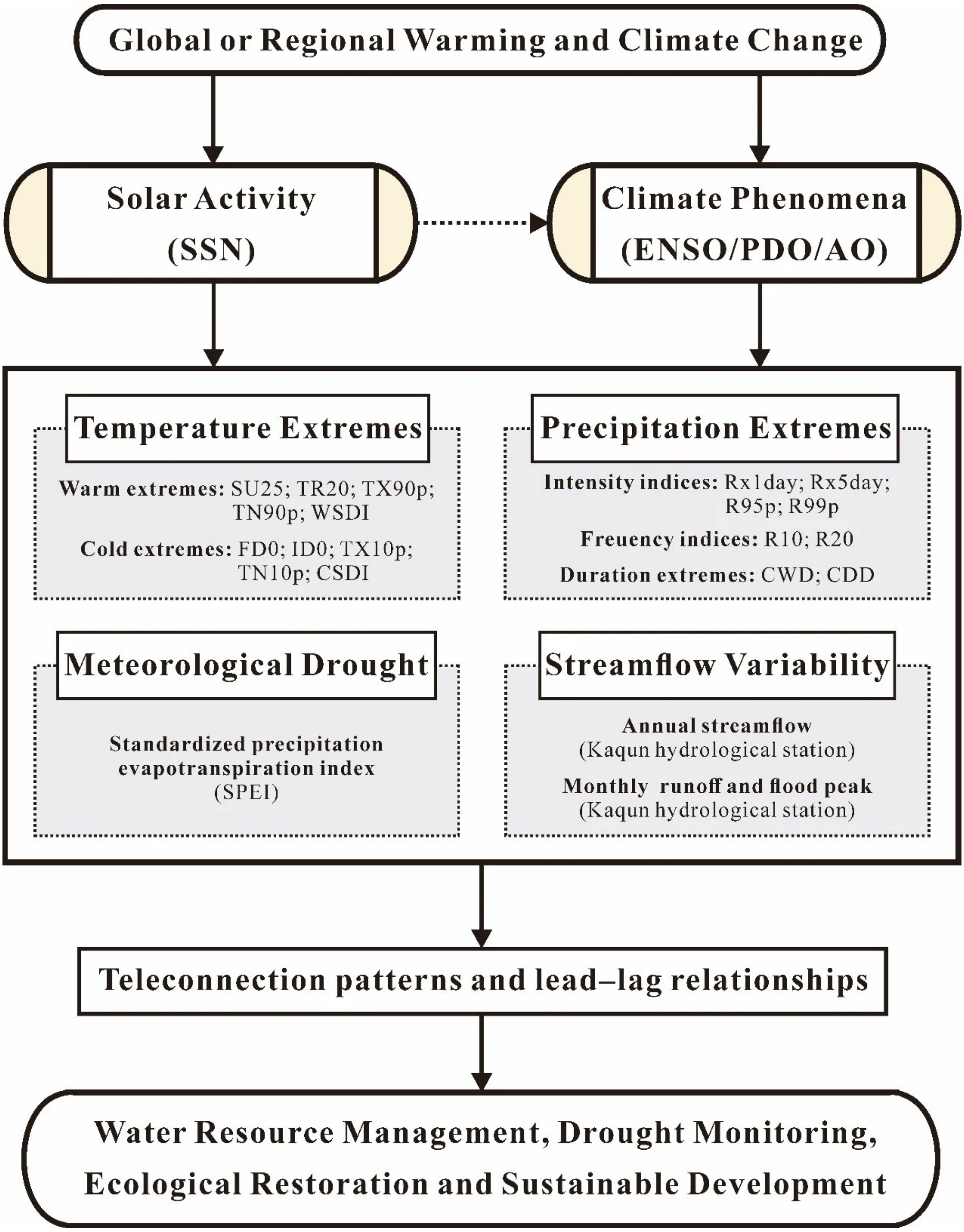
PRESENTED AT:

INTRODUCTION

Climate change induced by human activities and its impacts on the hydrological cycle have become a vital issue for social and economic sustainable development and ecological health. In particular, precipitation and flows in streams and rivers may play a critically important role in the global energy and hydrological cycle that is critical for life on Earth.

In this study, an integrated assessment of linking multiple interacting hydrometeorological parameters to two non-stationary climatic modes is provided. The novelty of this paper is that it is one of the first analyses to focus on the coupling of precipitation extremes and discharge of streamflow or flooding events and their responses to these non-stationary climate modes, such as Sunspot Number (SSN), EI Niño-Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and Arctic Oscillation (AO).



STUDY AREA, DATA AND METHODS

Study Area

- Xinjiang is an outstanding example of an environmental tragedy in the arid Central Asia.
- Due to the special topographical features of "three mountains and two basins" and the unique natural environment pattern, the distribution of water resources in Xinjiang is highly uneven.
- In recent decades, flood events and drought events have occurred frequently and alternately in northern Xinjiang and southern Xinjiang, mainly showing the characteristics of "spring drought, summer flood, autumn lack, and winter dryness".

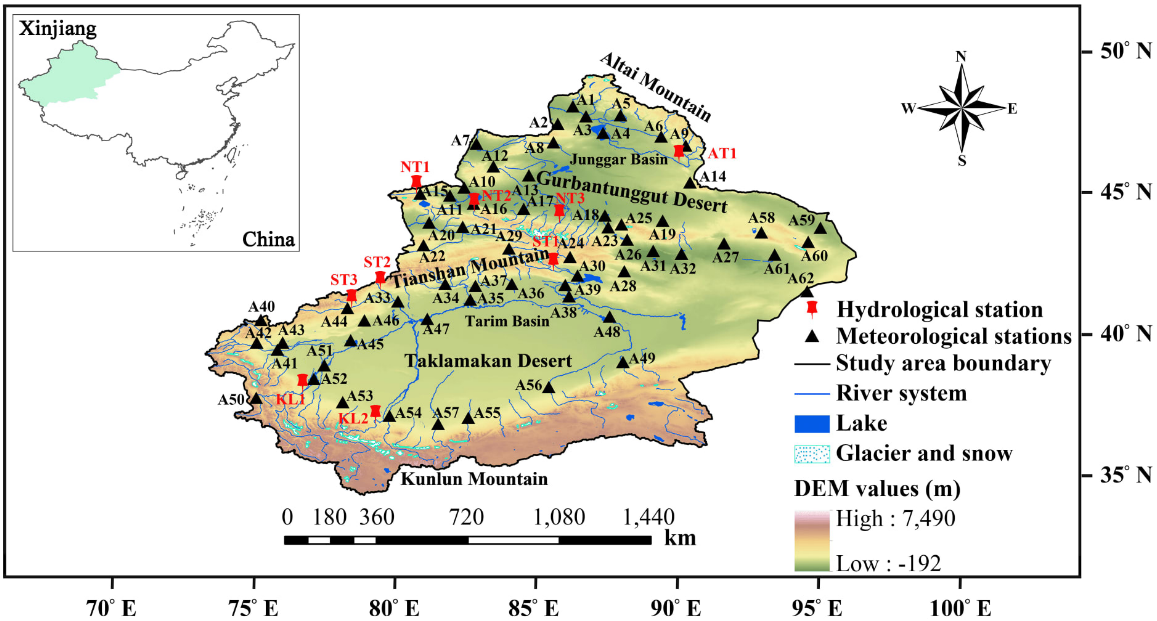


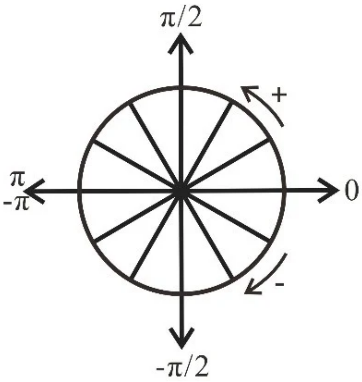
Figure 1. Geographical location of hydrological station, meteorological stations and river system in typical inland arid-semiarid region in Xinjiang, China. A1–A62 are the selected meteorological stations according to Table S1 in supplementary material. ID names of the hydrological station located in upper reaches of nine natural rivers according to Table 1 (AT1: Ulungur River; KL1: Yarkant River; KL2: Karakash River; NT1: Bortala River; NT2: Jinghe River; NT3: Manasi River; ST1: Kaidu River; ST2: Kunmalike River; ST3: Tuoshigan River).

Data Sources

- Daily temperature dataset and daily precipitation dataset of 62 meteorological stations in Xinjiangduring the period 1960–2019 were obtained from the National Meteorological Information Center of the China Meteorological Administration (http://data.cma.cn/).
- Nine hydrological stations located in different upper reaches of natural rivers and streams with pristine watersheds, have a minimum record length of 47 years, and good quality and reliable data.
- The international SSN is obtained from the Solar Influences Data Analysis Center (SIDC), World Data Center for the Sunspot Index, at the Royal Observatory of Belgium, Brussels (https://wwwbis.sidc.be/silso/).
- Climate Phenomena is mainly including Multivariate ENSO Index Version 2 data (MEI.v2), monthly AO data and monthly PDO data (https://psl.noaa.gov/data/climateindices/list/).

Methodology

- Extreme temperature and precipitation indices were recommended on climate change detection and indices based on previous investigations.
- Wavelet coherence analysis can be applied to estimate the effect of both solar activity and large-scale climate phenomena on coupling non-stationary hydro-climatic processes.



in-phase (positive)

- $\phi_n(s) = 0$, phase arrow is →; movements of $X(n)$ and $Y(n)$ are synchronized.
- $\phi_n(s) \in \left(0, \frac{\pi}{2}\right)$, phase arrow is ↗; $X(n)$ leads $Y(n)$ by 0~1/4 period length.
- $\phi_n(s) \in \left(-\frac{\pi}{2}, 0\right)$, phase arrow is ↘; $Y(n)$ leads $X(n)$ by 0~1/4 period length.
- $\phi_n(s) = -\frac{\pi}{2}$, phase arrow is ↓; $Y(n)$ leads $X(n)$ by 1/4 period length.

anti-phase (negative)

- $\phi_n(s) = -\pi$ or π, phase arrow is ←; movements of $X(n)$ and $Y(n)$ are synchronized.
- $\phi_n(s) = \left(\frac{\pi}{2}, \pi\right)$, phase arrow is ↖; $Y(n)$ leads $X(n)$ by 1/4~1/2 period length.
- $\phi_n(s) = \left(-\pi, -\frac{\pi}{2}\right)$, phase arrow is ↙; $X(n)$ leads $Y(n)$ by 1/4~1/2 period length.
- $\phi_n(s) = \frac{\pi}{2}$, phase arrow is ↑; $X(n)$ leads $Y(n)$ by 1/4 period length.

Figure 2. Eight phase angle conditions denoted by the arrows of the WTC spectra and their corresponding lead-lag relationship between the two series *X(n)* and *Y(n)*.

RESULTS:TELECONNECTIONS BETWEEN SSN, ENSO, PDO, AO AND CHANGES IN TEMPERATURE AND PRECIPITATION EXTREMES

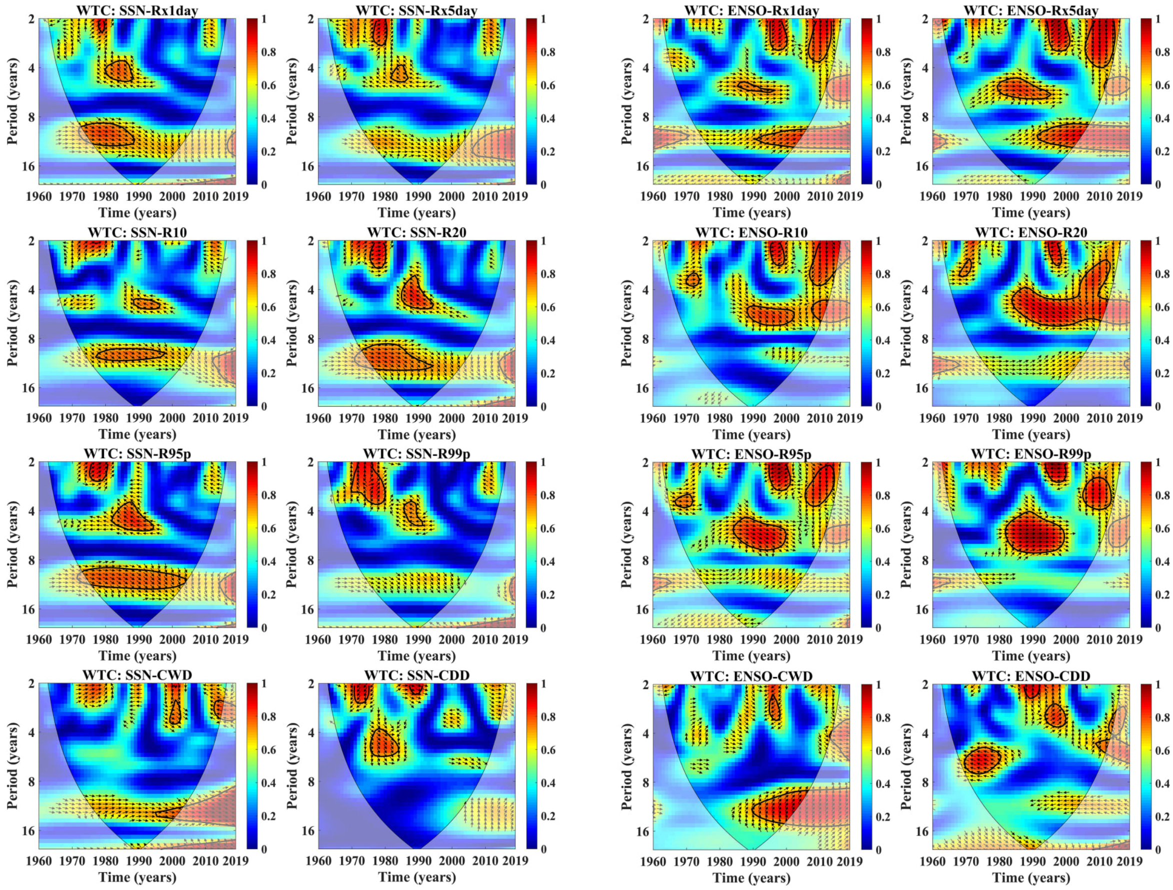


Figure 3. Wavelet coherence (WTC) between Sunspot Number (SSN), EI Niño-Southern Oscillation (ENSO) and extreme precipitation indices (EPIs) in Xinjiang. Notably, the color bar labeled in the right-side of each WTC specifies spectral power (dimensionless), the thick black contour line indicates the 5% significance level, and the less intense colors states the cone of influence. The relative phase relationship is shown as arrows (leftward arrows represent anti-phase relations; rightward arrows represent in-phase relations; up- or down-pointing arrows represent indicative of lead-lag between the time series).

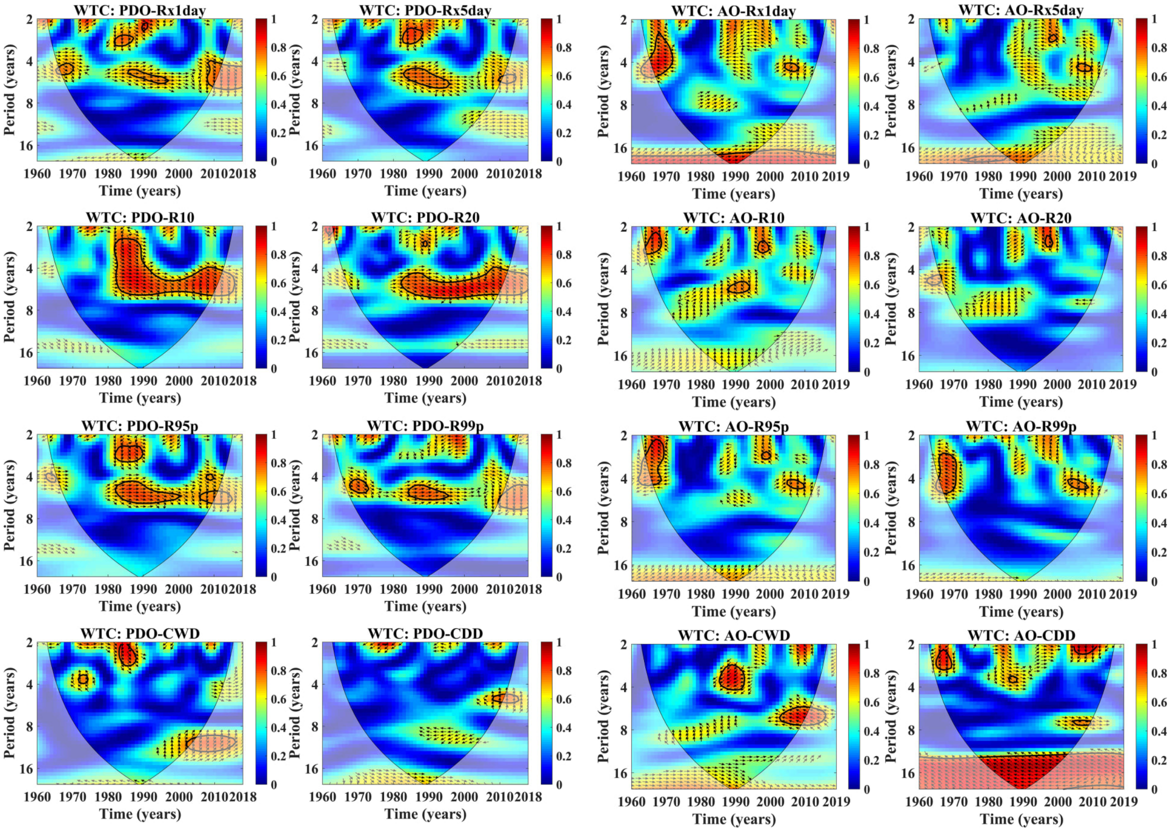


Figure 4. Wavelet coherence (WTC) between Pacific Decadal Oscillation (PDO), Arctic Oscillation (AO) and extreme precipitation indices (EPIs) in Xinjiang.

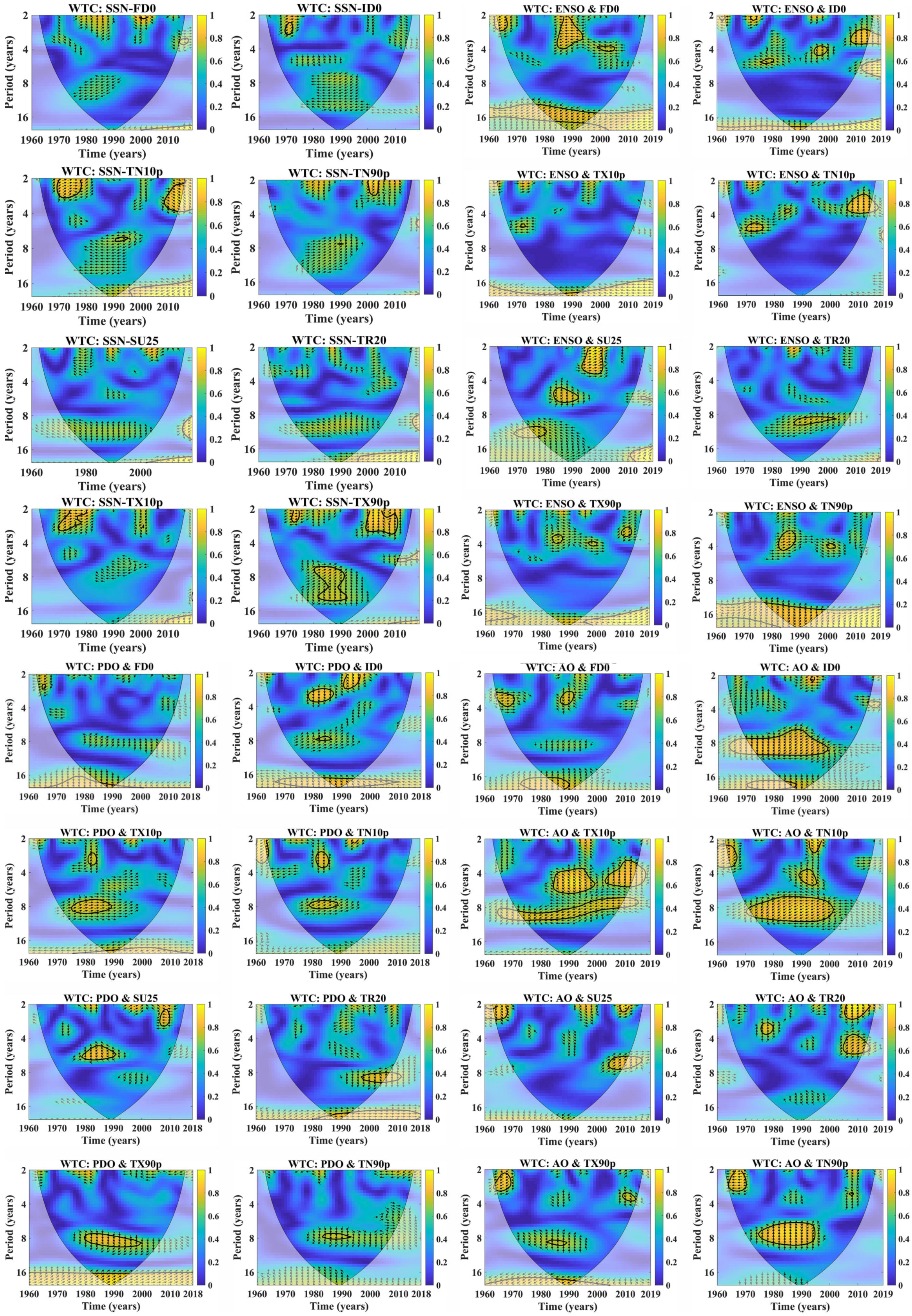


Figure 5. Wavelet coherence (WTC) between Sunspot Number (SSN), EI Niño-Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), Arctic Oscillation (AO) and extreme precipitation indices (EPIs) in Xinjiang.

RESULTS: TELECNNECTIONS BETWEEN SSN, ENSO, PDO, AO AND CHANGES IN METEOROLOGICAL DROUGHT

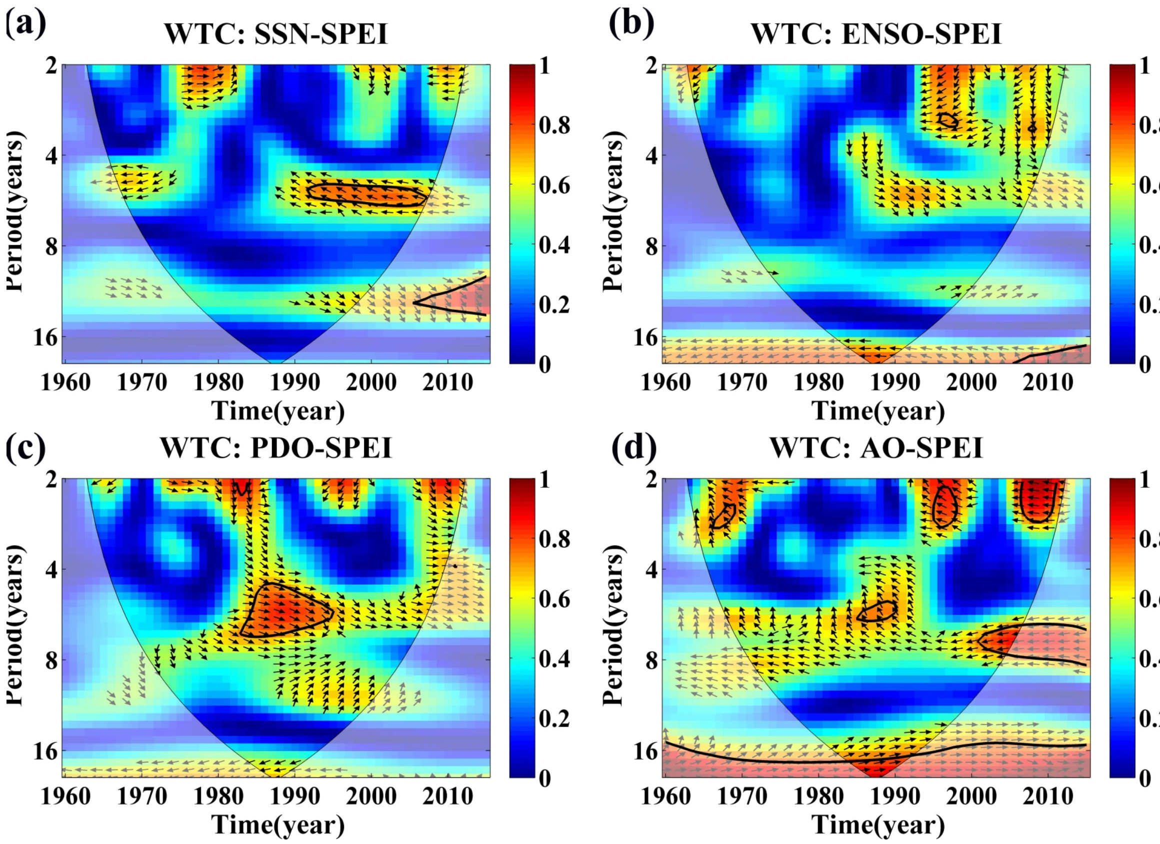


Figure 6. Wavelet coherence (WTC) between Sunspot Number (SSN), EI Niño-Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), Arctic Oscillation (AO) and annual standardized precipitation evapotranspiration index (SPEI) in Xinjiang.

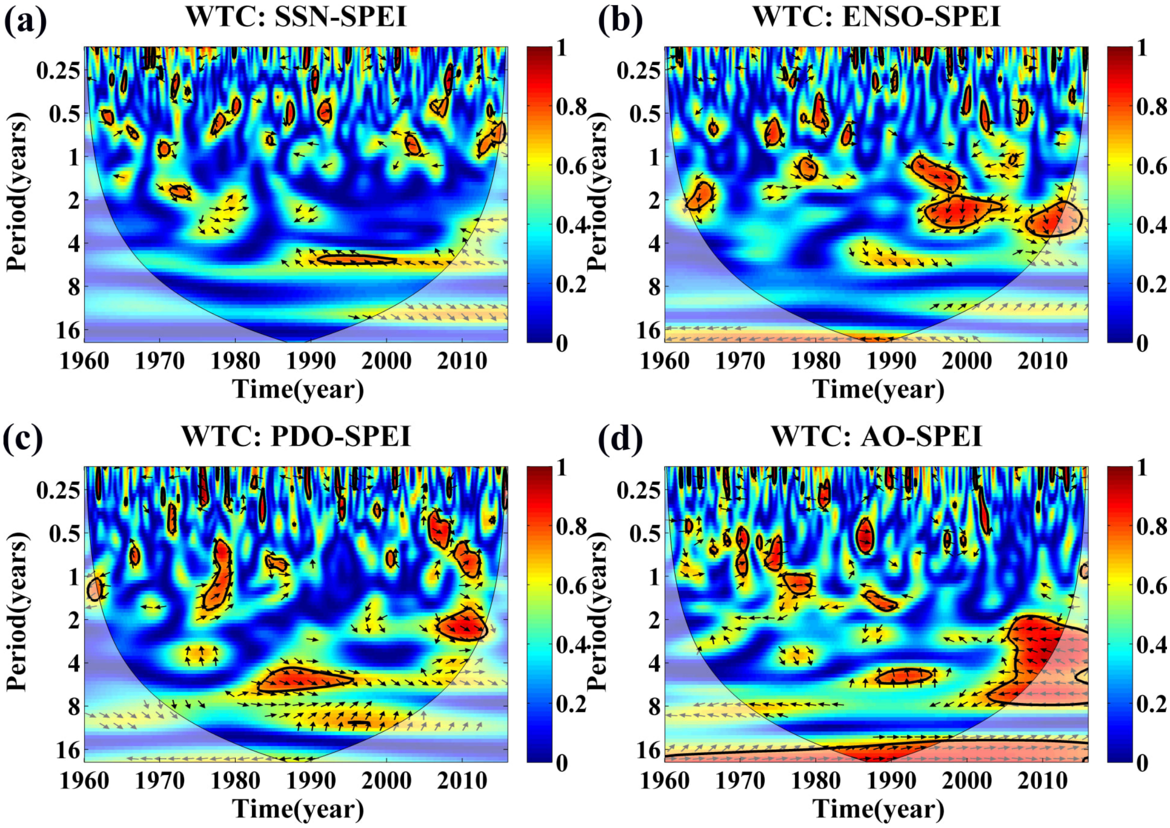


Figure 7. Wavelet coherence (WTC) between Sunspot Number (SSN), EI Niño-Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), Arctic Oscillation (AO) and monthly standardized precipitation evapotranspiration index (SPEI) in Xinjiang.

RESULTS: TELECONNECTIONS BETWEEN SSN, ENSO, PDO, AO AND CHANGES IN STREAMFLOW VARIABILIY

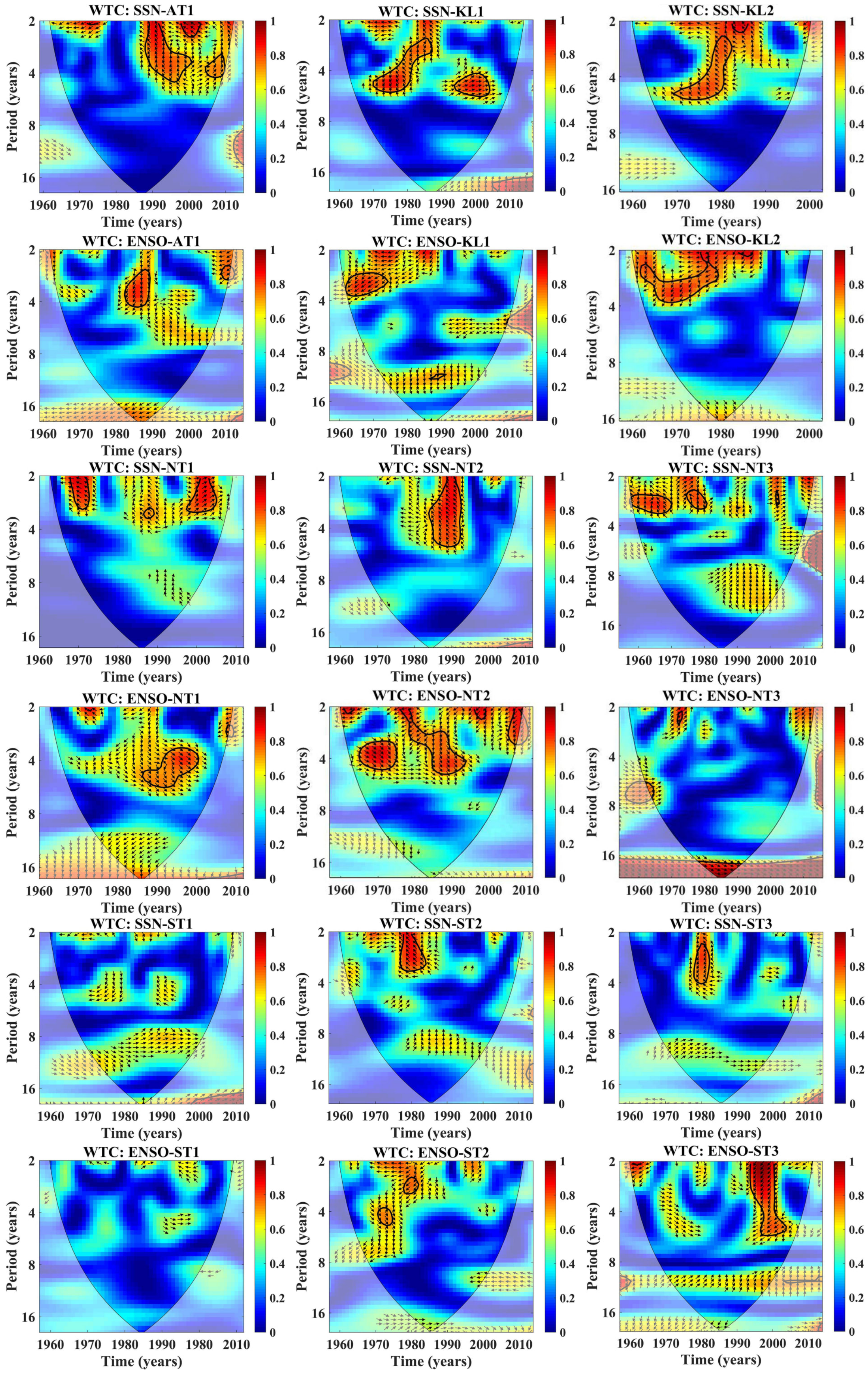


Figure 8. Wavelet coherence (WTC) between Sunspot Number (SSN), EI Niño-Southern Oscillation (ENSO) and annual mean streamflow runoff (Qa) of nine rivers (AT1: Ulungur River; KL1: Yarkant River; KL2: Karakash River; NT1: Bortala River; NT2: Jinghe River; NT3: Manasi River; ST1: Kaidu River; ST2: Kunmalike River; ST3: Tuoshigan River) in Xinjiang.

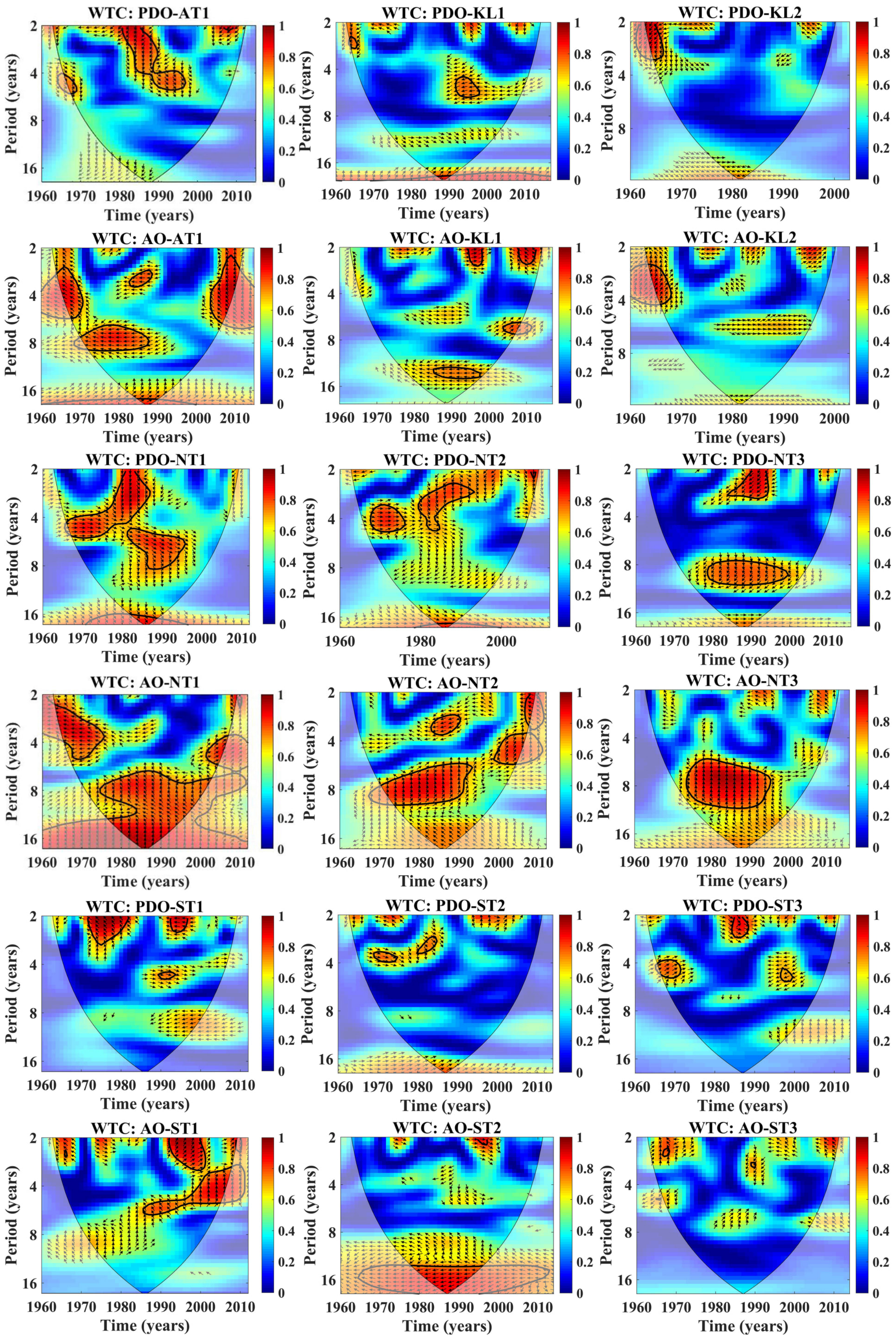


Figure 9. Wavelet coherence (WTC) between Pacific Decadal Oscillation (PDO), Arctic Oscillation (AO) and annual mean streamflow runoff (Qa) of nine rivers (AT1: Ulungur River; KL1: Yarkant River; KL2: Karakash River; NT1: Bortala River; NT2: Jinghe River; NT3: Manasi River; ST1: Kaidu River; ST2: Kunmalike River; ST3: Tuoshigan River) in Xinjiang.

SUMMARY AND REFERENCES

Long-term variability in extreme emperature and precipitation events and periodic streamflow in Xinjiang are primarily driven by solar activity and large-scale climate phenmena. Climate change in Xinjiang is a primary factor driving increased runoff in the headstreams of natural river in Xinjiang, whereas the negative runoff trend in the headstreams of natural river in Xinjiang may be influenced by human activities and climate change.

References:

- Zhang, L., Liu, Y., Zhan, H., Jin, M., Liang, X., 2021. Influence of solar activity and EI Niño-Southern Oscillation on precipitation extremes, streamflow variability and flooding events in an arid-semiarid region of China. Journal of Hydrology, 126630. https://doi.org/10.1016/j.jhydrol.2021.126630
- Zhang, L., Liu, Y., Jin, M., Liang, X., 2021.Spatiotemporal variability in extreme temperature events in an arid-semiarid region of China and their teleconnections with large-scale atmospheric circulation[J/OL]. Journal of Earth Science, 1-64. https://doi.org/10.1007/s12583-021-1517-9

ABSTRACT

With a warming climate, solar activity including Sunspot Number (SSN) and large-scale climate phenomena including EI Niño-Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO) and Arctic Oscillation (AO) have induced changes in climate extremes and changes in the hydrological cycle in arid-semiarid regions of the world, thus a detailed investigation of climate variability can play a key role in water resources management, drought monitoring, ecological restoration and sustainable development. In this study, we used wavelet coherence (WTC) based on continuous wavelet transform (CWT) to assess the impacts of SSN, ENSO, PDO and AO on multiple interacting hydrological processes and identify the teleconnection patterns and lead-lag relationships between the four principal modes and changes in extreme temperature and precipitation events, meteorological drought, and streamflow variability in Xinjiang, an arid-semiarid region of China. The results indicated that solar activity and climatic oscillations were viewed as the primary drivers for periodic variation of extreme temperature events and the evolution of drought in Xinjiang. For instance, the ENSO positively affected warm extremes with intermittent coherence in the 2–6-year band during 1984–2000 and had negative correlations with cold extremes in the 2–6-year band at the interannual scale. Compared with warm extremes, variability in cold extremes was much more sensitive to the activity pattern of AO. It was clear that the coherence of temperature variables in Xinjiang with PDO was weaker than that with ENSO and AO, and there was a nonsignificant covariance between PDO and extreme temperature events. In addition, the WTC spectra showed that teleconnection factors including solar activity and three large-scale climate phenomena had significant impacts on annual and monthly drought evolution, and AO had the strongest influence on annual standardized precipitation evapotranspiration index (SPEI) values. In general, compared with SSN, ENSO, PDO and AO all showed clear leading effects on precipitation extremes variability and annual streamflow variability for a specific time and frequency, and solar activity's influences might be transferred by ENSO to precipitation extremes or streamflow variability at the 2–7-year band. Overall, the warming and wetting trend in Xinjiang may be a local manifestation of global multivariate climate change. Thus, our findings will have important implications for designing best practice strategies for water resource management and ecological restoration in similar arid-semiarid basins around the world.