Characteristics of Summer Runoff Variations in the Yangtze River Basin and its Connections with Asian Summer Monsoons

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Abstract. In this research, characteristics of summer runoff variations during monsoon season in the Yangtze River basin and their connections with Asian summer monsoons were detected by using continuous wavelet transform and wavelet coherence analysis methods. The following results were obtained: (i) The periodic character of summer runoff along the mainstream of the Yangtze River basin has distinct differences upstream and downstream of Yichang station. (ii) Summer runoff of the source and upper regions of the Yangtze River basin is mainly influenced by the South Asian summer monsoons. Summer runoff of the midstream and downstream regions of the Yangtze River basin are controlled by the East Asian summer monsoons. (iii) An in-phase relationship between summer runoff and South Asian summer monsoon intensity indices is detected in the source region of the Yangtze River basin, and an anti-phase relationship between summer runoff and East Asian summer monsoon intensity indices dominates in the midstream and downstream regions of the Yangtze River basin.

1. Introduction

More than 60% of the world's population depends on Asian summer monsoon rainfall, giving this phenomenon a crucial role in providing water resources for agriculture, industrial development, and basic human needs [1, 2]. Given the reliance of lives and economies of many countries on Asian summer monsoon rainfall, understanding how Asian summer monsoons affect hydrological processes is an imperative of both scientific and societal importance [3-5].

The approximately 6380 km Yangtze River is the longest river in Asia and the third longest river in the world. Asian summer monsoons are heat conveyors and rain-bearing systems of the Yangtze River basin. The monsoons determine the runoff changes of the region [6-8]. Therefore, research on runoff variations in the Yangtze River basin and their connections with Asian summer monsoons can improve our understanding of hydro-meteorological interrelations and their implications for river dynamics and water resources management. Currently, research has focused on detecting possible connections between the El Niño–Southern Oscillation and runoff in the Yangtze River basin through statistical analysis and numerical modeling [9-11]. These studies are helpful for understanding and controlling flood and drought problems in the Yangtze River basin. However, Asian summer monsoons impacts on runoff in the Yangtze River basin remain understudied. As such, the aim of this study is to explore characteristics of average annual summer runoff variations during the Asian summer monsoon season in the Yangtze River basin, and detect the connections between average annual summer runoff and Asian summer monsoons from 1957 to 2012. The continuous wavelet transform method was employed to analyze the periodic characteristics of average annual summer runoff and Asian summer monsoons intensity indices. The relationships between summer runoff and Asian summer monsoons intensity indices were investigated with wavelet coherence analysis methods.

2. Study area and data

Summer runoff data from Zhimenda, Yichang, Hankou, and Datong hydrological stations are analyzed in this study. These four hydrological stations are used to represent the source, upper, middle, and lower reaches of the river (figure 1). Runoff data for the selected stations were collected from the hydrological yearbooks of China. Runoff data were quality controlled, and provide a continuous record from 1957 to 2012. Summer runoff data during the Asian summer monsoon season were averaged runoff over June-July-August (JJA) during the period. The Asian summer monsoons are composed of two subsystems, East Asian summer monsoons and South Asian summer monsoons [12]. Asian summer monsoons indices data were collected from http://www.lasg.ac.cn/staff/ljp.

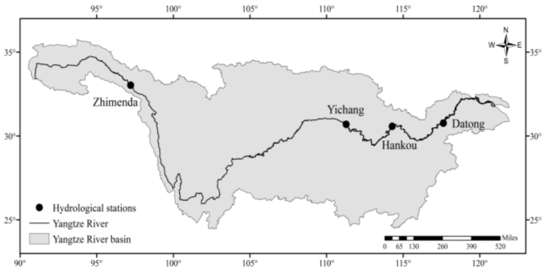

Figure 1. Sketch map of the study area.

3. Methods

In this study, the relationships between summer runoff and Asian summer monsoons intensity indices were explored by cross-wavelet and wavelet coherence analysis. The statistical confidence level of the wavelet coherence spectrum is determined by a Monte Carlo method. In order to estimate the mean and confidence interval of the phase difference, the circular mean of the phase for those regions with higher than 5% statistical significance and which are outside the cone of influence were used to quantify the phase relationship[13, 14].

4. Results and discussion

4.1. Characteristics of summer runoff variations in the Yangtze River basin

Summer runoff variation characteristics have distinct differences between the upper and lower reaches of the Yangtze River. For the Zhimenda and Yichang stations located in the upper reaches, high wavelet power in the 1- to 3-year band is detected in the wavelet power spectra for summer runoff around 1991~1995. In the Hankou and Datong stations located in the lower reaches, high wavelet power in the 7- to 10-year band is detected in the wavelet power spectra for summer runoff around 1972~1990(figure 2).

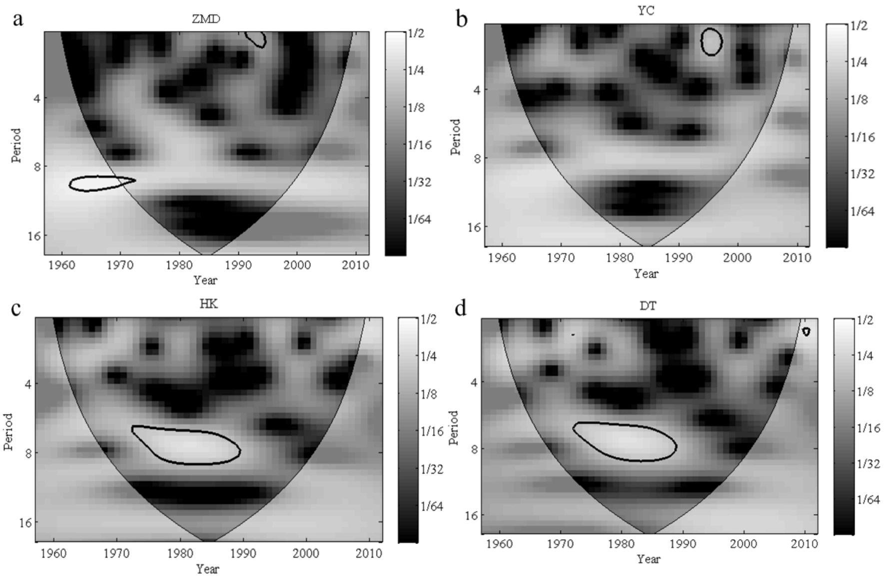

Figure 2. Power spectra of continuous wavelet transform for normalized summer runoff time series in the Yangtze River basin at (a) Zhimenda, source reach; (b) Yichang, upper reach; (c) Hankou, middle reach and (d) Datong stations, lower reach.

4.2. Connections between summer runoff and Asian summer monsoons

To elaborate the relationship between Asian summer monsoons and summer runoff in the Yangtze River basin, wavelet coherence analysis is applied to detect the links between the two time series. Wavelet coherence results show a coherence phase in the 3- to 5-year band around 1986~1995 and 2000~2005. These regions show an in-phase relationship between summer runoff and East Asian summer monsoon intensity indices (figure 3a). From 1990 to 1998, an anti-phase relationship between summer runoff and South Asian summer monsoon intensity indices is detected in the 2- to 6-year band (figure 3b).

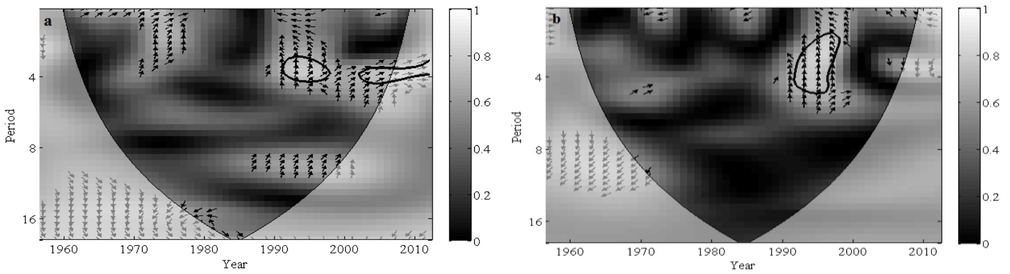

Figure 3. Wavelet coherence spectra for summer runoff at Zhimenda station and Asian summer monsoon intensity indices.

A coherence phase of 1- to 5-year band around 1980~1990 and 1992~1998 is detected in the wavelet coherence power spectra. These regions show anti-phase relationships between summer runoff and East Asian summer monsoons. An in-phase relationship between summer runoff and East Asian summer monsoons is detected in the 4- to 7-year band around 1965~1975 (figure 4a). The wavelet coherence for summer runoff and South Asian summer monsoons shows there are relationships in the 1- to 6-year band around 1963~1971 (in-phase relationship), 1980~1990 (in-phase relationship), and 1991~2002 (anti-phase relationship) (figure 4b).

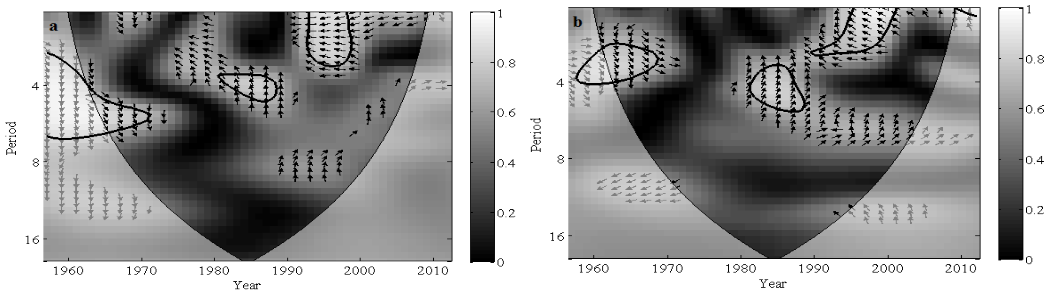

Figure 4. Wavelet coherence spectra for summer runoff at Yichang station and Asian summer monsoon intensity indices.

Wavelet coherence results show a coherence phase in the 5- to 12-year band around 1963~1973 and 1990~2005. Phase relationships between summer runoff and East Asian summer monsoon intensity indices are unstable in these regions. There is also an anti-phase relationship between summer runoff and East Asian summer monsoon intensity indices in the 1- to 4-year band around 1969~1995 (figure 5a). A coherence phase in the 2- to 5-year band around 1961~1969 is detected in the wavelet coherence power spectra for summer runoff and South Asian summer monsoon intensity indices. There is an in-phase phase relationship between summer runoff and South Asian summer monsoon in this region (figure 5b).

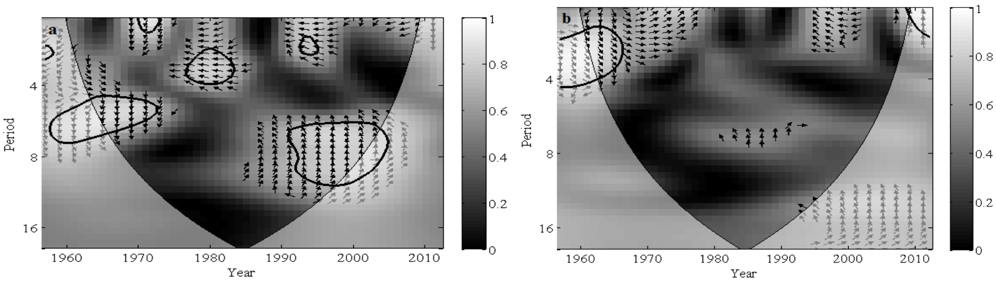

Figure 5. Wavelet coherence spectra for summer runoff at Hankou station and Asian summer monsoon intensity indices.

The phase relationships between summer runoff and East Asian summer monsoon intensity indices in the region of 1963~1973 are unstable. Phase relationships between summer runoff and East Asian summer monsoon intensity indices in the regions of 1978~1985 and 1991~1993 are anti-phase. There also is a coherence phase in the 5- to 12-year band around 1989~2005. The phase relationships between summer runoff and East Asian summer monsoon intensity indices are unstable in this region (figure 6a). The wavelet coherence for summer runoff and South Asian summer monsoon intensity indices shows there is a coherence phase in the 1- to 5-year band around 1962~1964 and 1970~1978. There is an in-phase relationship between summer runoff and South Asian summer monsoon intensity indices in this region (figure 6b).

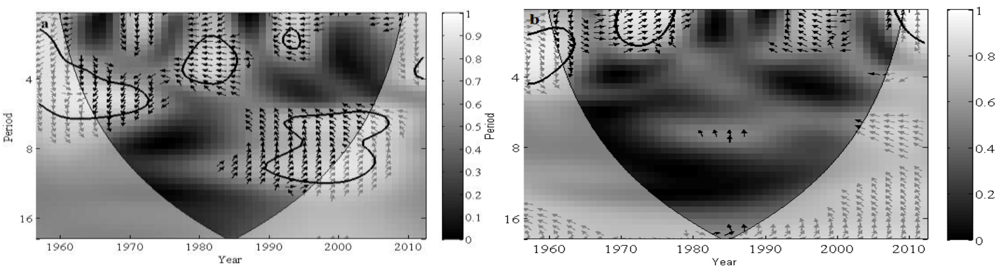

Figure 6. Wavelet coherence spectra for summer runoff at Datong station and Asian summer monsoon intensity indices.

The wavelet coherence spectra results indicate that the meridional water vapor fluxes carried by the East Asian summer monsoons are dominant in the midstream and downstream regions of the Yangtze

River basin. In contrast, the zonal water vapor fluxes are relatively large in the source and upper regions of the Yangtze River, located in arid and semiarid regions of North-western China [15]. An anti-phase relationship between summer runoff and East Asian summer monsoon intensity indices dominates in the midstream and downstream regions of the Yangtze River basin (figure 5 and 6). In these regions, weak East Asian summer monsoons will result in floods, and relatively strong East Asian summer monsoons are usually associated with droughts [16]. In the source region of the Yangtze River basin, an in-phase relationship between summer runoff and south Asian summer monsoon intensity indices is detected. Phase relationships between summer runoff at Yichang station and Asian summer monsoons are ambiguous, and have in-phase and anti-phase relationships simultaneously.

5. Summary

With the help of continuous wavelet transform and wavelet coherence analysis methods, this research explored the characteristics of summer runoff variations along the mainstream of the Yangtze River basin and its connections with Asian summer monsoons from 1957 to 2012. The following conclusions were drawn:

(1) There are obvious differences in periodic characteristics of summer runoff along the mainstream of the Yangtze River basin.

(2) Summer runoff of the source and upper regions of the Yangtze River basin is mainly influenced by zonal water vapor fluxes carried by South Asian summer monsoons. Summer runoff of the midstream and downstream regions of the Yangtze River basin is controlled by meridional water vapor fluxes carried by East Asian summer monsoons.

(3) Anti-phase relationships between summer runoff and East Asian summer monsoons dominate in the midstream and downstream regions of the Yangtze River basin, and in-phase relationships between summer runoff and South Asian summer monsoons are detected in the source region of the Yangtze River basin. Phase relationships between summer runoff at Yichang station and Asian summer monsoons are ambiguous.

Acknowledgments

This study was supported and funded by National Natural Science Foundation of China (Grants No. 51609008); China Postdoctoral Science Foundation (Grants No. 2015M572124), and China CDM Fund Project (Grants No. 2012044).

References

[1] Turner A G and Annamalai H 2012 Nat. *Climate Change* **2** 587-595
[2] Wu G X, Liu Y M, He B, Bao Q, Duan A M and Jin F F 2012 *Sci. Rep*. **2** 404
[3] Asharaf S, Dobler A and Ahrens B 2012 *J. Hydrometeor*. **13** 1461-1474
[4] Lu H Y et al. 2013 *Geology* **41** 1023-1026
[5] Sun Y B et al. 2015 *Quaternary Sci. Rev*. **115** 132-142
[6] Blender R, Zhu X H, Zhang D and Fraedrich K 2011 *Quatern. Int*. **244** 194-201
[7] Zeng G, Wang W C, Shen C M and Hao Z X 2014 J. *Atmos. Sci*. **50** 355-364
[8] Kubota Y, Tada R and Kimoto K 2015 *Climate Past* **11** 265-281
[9] Zhang Q, Xu C Y, Jiang T and Wu Y 2007 *J. Hydrol*. **333** 265-274
[10] Hu K M, Huang G and Wu R G 2013 *J. Climate* **26** 2205-2221
[11] Zhang Z Z, Chao B F, Chen J L and Wilson C R 2015 *Global Planet. Change* **126** 35-45
[12] Wang Y Q and Zhou L 2005 *Geophys. Res. Lett.* **32** doi:10.1029/2005GL02257
[13] Torrence C and Compo G P 1998 Bull. *Amer. Meteor. Soc*. **79** 61-78
[14] Sang Y F 2013 *Atmos. Res*. **122** 8-15
[15] Huang R H, Chen J L, Wang L and Lin Z D 2012 *Adv. Atmos. Sci*. **29** 910-942
[16] Qian Y F, Zheng Y Q, Zhang Y and Miao M Q 2003 *Int. J. Climatol*. **23** 593-613