Chinese Science Bulletin 2003 Vol. 48 No. 24 2730—2734

Multiscale characteristics of the rainy season rainfall and interdecadal decaying of summer monsoon in North China

DAI Xingang[1,2], WANG Ping[3] & CHOU Jifan[1]

1. College of Resources and Environment, Lanzhou University, Lanzhou 730000, China;
2. LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China;
3. College of Physics, Peking University, Peking 100871, China

Correspondence should be addressed to Dai Xingang (e-mail: daixg@lzu.edu.cn)

Abstract **This paper focuses on the rainfall spectrum and its evolution of North China in rainy season with summer monsoon decaying in interdecadal time scale. The interannual component of the rainfall is the dominant part, accounting for 85% of the total variance, and has been changed significantly during the last 30 years. According to wavelet analysis its 5a periodic spectrum suddenly disappeared in the late 1960s, and its biennial oscillation gradually become weaker and weaker since 1970, accompanied by the summer monsoon decaying. Contrarily, the interdecadal component is principal in the summer monsoon over North China and is very similar to the counterpart of the rainfall. Their interdecadal parts are significantly correlated, and the correlation coefficient is nearly equal to the one of the original sequences. Besides, the dry and wet climate alternated with the monsoon abrupt changes in the 1960s and the 1970s over East Asia, apart from North China, climate drifted from a light drought to a severe drought during the past 30 years.**

Keywords: North China drought, wavelet, spectrum abruption, monsoon decaying.

DOI: 10.1360/03wd0199

North China has experienced a severe shortage of water resources, which has made serious impacts on economic development and daily life, due to persistent drought since 1970[1] and increasing requirement of water[2]. What causes the drought is one of important scientific problems, and has been investigated by many scientists from many aspects, such as global warming[3], the thermal effect of black carbon aerosols over Asia[4], sea surface temperature anomaly[5—7], the drifts of the surface properties in China[8]. Though there are so many factors they must affect the monsoon and atmospheric circulation over East Asia before influencing North China rainfall. As the most of the annual precipitation of North China falls in rainy season (July—September), based on observation, so, the drought is likely involved in the fluctuation of East Asian summer monsoon[9,10], while two abrupt attenuations of the East Asian monsoon occurred in the last 50 years[11,12]. In this paper, we, first, analyze the spectra of North China rainfall in rainy season for investigating its characteristics in the long-term drought and then try to find its possible relationships with the interdecadal change or decaying of the summer monsoon in North China during the last 50 years.

1 Multiscale analysis of rainfall

(i) Wavelet power spectrum. North China, named Huabei district, consists of three boreal provinces, i.e. Inner Mongolia, Shanxi and Hebei, situated on the arid and half-arid climate zones in middle latitude. There are 17 meteorological observatories that belong to Huabei district among the 160 standard observatories in China. Climate statistics shows about 70% of its annual precipitation falls during June through September, in which most of it was distributed within July and August, based on the rainfall records supplied by China Meteorology Agency (CMA). In the last 20 years the rainfall increased in spring and June, and decreased in rainy season. For studying the drought in North China, we only analyze the standardized rainfall records in rainy season from 1951 to 2002 in this paper. The rainfall records (Fig. 1(a)) clearly show that there were three stages: 1951—1964, 1965—1978 and 1979—2002, corresponding to wet climate, dry climate and severe drought, respectively in North China. Such rainfall evolution might imply the existence of general circulation background for the drought.

The long-term drought must have been reflected in the rainfall spectra. The Morlet wavelet power spectrum of the North China rainfall in rainy season is calculated by using the fortran codes designed by Torrence[13] (NCAR, National Center of Atmospheric Research of the United States). It shows a series of spectrum peaks at 2a, 5a, 10a and 18a periods for the rainfall (Fig. 1(b), (d)), and only the former two passed a significant test at a 0.05 level in some periods, in which the areas circled by white curves are significant spectra at more than 95%. The spectra show an apparent variation with time, for instance, the 5a component was significant in the 1950s and the beginning of the 1960s, and then suddenly disappeared after mid-1960s. Meanwhile, the 10a spectrum peak appeared. The biennial component decreased gradually on interdecadal time scale. In short, its interannual variability had been decaying since mid-1960s (Fig. 1(c)), in which the significant one covered 1960s and the second half of 1950s, while its weakest period is in the 1990s since 1951. The evolution of the rainfall spectra can be roughly illustrated by the mean spectra over the periods 1951—1976 and 1977—2002, respectively (Fig. 1(e), (f)).

The interdecadal spectra in Fig.1(b), (d) should be regarded just as a reference because of insufficient length of the rainfall sequence for analyzing such time scale variability. The longer the scale is, the bigger the boundary effect is[13]. The interdecadal oscillation of the rainfall will be treated by orthogonal wavelet in the next section.

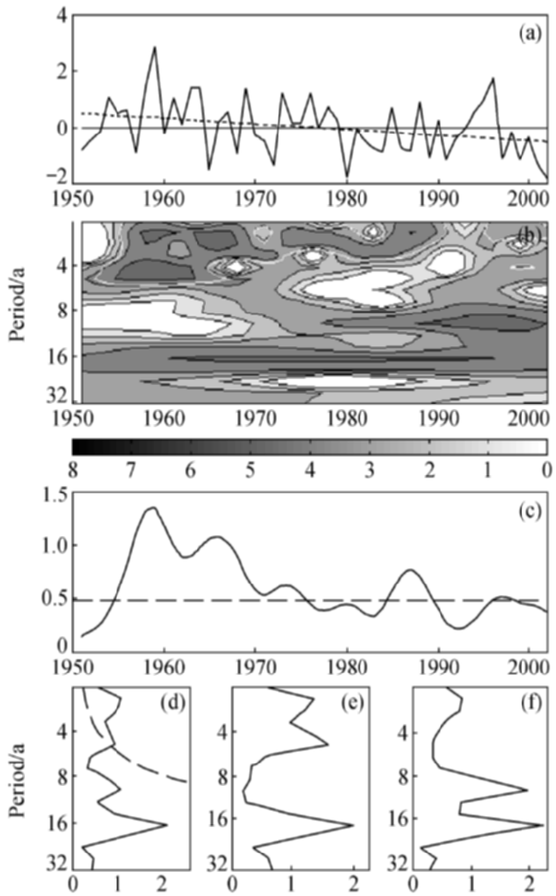

Fig. 1. Wavelet power spectrum of North China rainfall in rainy season from 1951 to 2002. (a) Standardized rainfall; (b) Morlet power spectrum; (d) global wavelet spectrum; (c) 2a—8a scale-mean variance; (e) 1951—1976 mean spectrum; (f) 1977—2002 mean spectrum, where the dote line in (a) is the trend, the white curve in (b) and dashed lines in (c), (d) correspond to a significance level at 0.05.

The interannual rainfall variance could be obtained by the product of the total variance and the power spectrum averaged over 2a—8a scale (Fig. 1(c)). It shows that the interannual variability is very intensive from the mid-1950s to the 1960s, which is significant at more than 95%, and then become very weak after 1970. Comparing Fig. 1(a), (c) one can immediately realize that the rainfall in rainy season is of a similar trend with its interannual part. Therefore, the rainfall decreasing or the climate drying in North China can be characterized by the interannual variabilities of the rainfall, i.e. the disappearance of 5a spectrum and the weakening of biennial oscillation on interdecadal time scale. Evidently this is an interdecadal change of the interannual spectra for the North China rainfall.

(ii) Orthogonal wavelet decomposition. It would be interesting to decompose the rainfall sequence into interannual and interdecadal parts. It is not suitable to make such a decomposition with the continued wavelet transform, say Morlet wavelet, if apparent interdecadal change exists in the sequence its reconstruction rate is very low according to our calculation. Generally, people like to use the running-mean method to decompose the sequence, but it is not an ideal technique since it makes the treated sequence shorter than the original one. Nevertheless, by use of orthogonal wavelet a sequence or a function $f(x)(\in L^2(IR))$ can be precisely decomposed into different parts on different scales or levels[14]. Using Daubechies wavelet (Daub4) the North China rainfall sequence is decomposed into the third level, in which the approximate is the decadal part, and the sum of the three details on the three levels makes of the interannual part. The reconstruction rate for the rainfall sequence reaches an accuracy of order 10^{-12}. The interannual sequence reconstruction (Fig. 2(a)) is very similar to the original one (Fig. 1(a)), and has a variance 0.8348 or 83% of the total. This confirms again that North China rainfall in rainy season is characterized by the interannual variability.

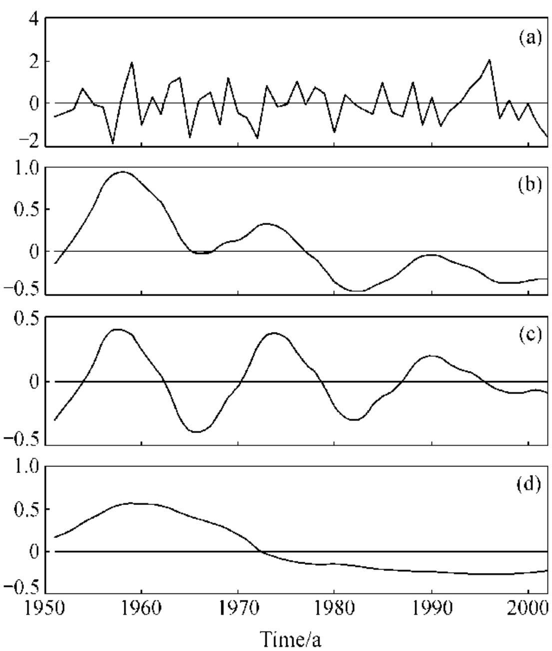

Fig. 2. Orthogonal wavelet decomposition of North China rainfall in rainy season using Daubechies wavelet (Daub4). (a) Interannual part; (b) interdecadal part; (c) detail of the interdecadal part at the 4th level; (d) approximate of the interdecadal part at the 4th level.

The approximate of the decomposition seemingly has two interdecadal components, i.e. 18a and about 50a periods (Fig. 2(b)). The latter has a positive phase before 1977 and then a negative phase (1978—2002), which correspond to a relatively wet climate and severe drought, respectively, in North China. It is very clear that the phase of 50a period component approximately determined the distribution of the wet and dry climate on interdecadal time scale.

Besides, the comparison of Fig. 1(a) and Fig. 2(a) reveals that the extreme events of the rainfall is mainly contributed by the interannual component, for example, the severe drought in1980 and 2002, and the torrential rain in 1959 and 1996. The interdecadal component is somewhat important for the ranging of the extremes else. For instance, the 5 driest years ranged as 1957, 1965, 1973, 2002 and 1980 for the interannual sequence of the rainfall, while the 5 driest years ranged as 2002, 1980, 1965, 1973 and 1957 for the rainfall in rainy season.

2 Summer monsoon in North China

The relationship between summer monsoon and the drought in North China is an important problem needed to be studied in detail. The summer monsoon over North China is the most intensive in July and August amid rainy season. Strong summer monsoon can bring a great quantity of warm and wet air to North China, which can make abundant rainfall there, and *vice versa*. It is conventional to define a monsoon index to describe the East Asian monsoon[15] . For convenience, we defined a monsoon index by a box-mean wind component v, noted as HBV, at 850 hPa to represent the intensity of the summer monsoon in North China, where the box covers the area (110°—120°E, 35°—40°N). The wind field used is NCEP reanalysis data set from 1951 to 2000 with a resolution 2.5° × 2.5° for both latitude and longitude directions.

The HBV (Fig. 3(a)) shows that the summer monsoon in North China was intensive in the 1950s and the beginning of the 1960s, and then two interdecadal depreciations sharply occurred at the mid-1960s and the late 1970s (Fig. 3(a)), consistent with the abrupt changes of the East Asian monsoon during the same period[11,12]. The Morlet wavelet power spectrum shows that there are two spectrum peaks at periods 3a and 15a (Fig. 3(b)), but only the former is significant at the 0.05 level from the end of 1950s and 1960s. The two spectrum components had been gradually decaying since the mid-1960s (Fig. 3(c)). The 15a spectrum of HBV must be regarded as reference for the same reason as in the rainfall case.

The HBV is also precisely decomposed into interannual and interdecadal parts by the Daubechies wavelet (Daub4) (Fig. 4(a), (b)). Its reconstruction rate reaches an accuracy of order 10^{-11}. The interannual variability was intensive in the 1950s and the beginning of the 1960s, same as the Morlet wavelet spectrum showed in Fig. 3(d). The interdecadal part is of about 50a period with a positive phase before 1974 (Fig. 4(b)). In contrast to the rainfall, the interdecadal variance of HBV is 0.6843, much

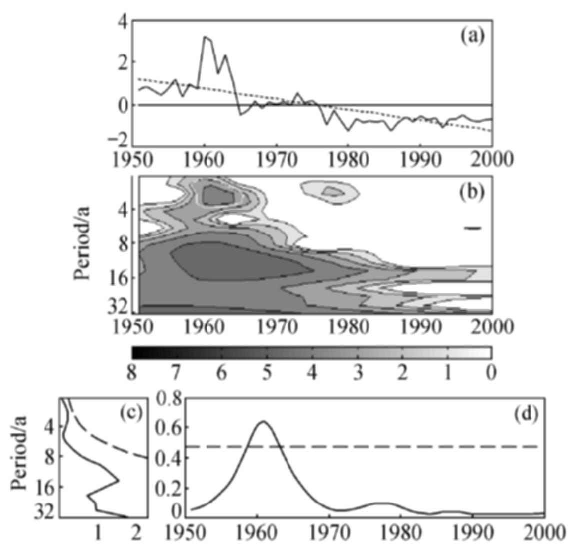

Fig. 3. Wavelet power spectrum of the box-mean wind component v (HBV) in 850 hPa. (a) Standardized HBV; (b) Morlet power spectrum; (c) global wavelet spectrum; (d) 2a—8a scale-mean variance; (e) 1951—1976 mean spectrum; (f) 1977——2000 mean spectrum, where the dote line in (a) is trend, the white curve in (b) and dashed lines in (c), (d) correspond to a significance level at 0.05.

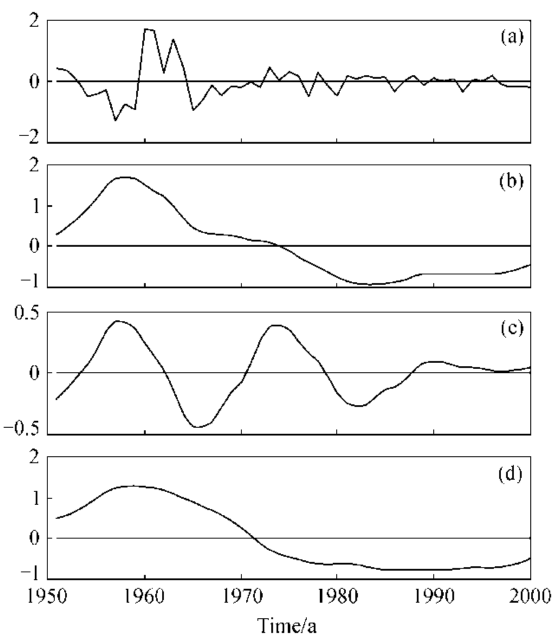

Fig. 4. Orthogonal wavelet decomposition of the HBV with Daubechies wavelet (Daub4). (a) Interannual part; (b) interdecadal part; (c) detail of the interdecadal part at the 4th level; (d) approximate of the interdecadal part at the 4th level.

greater than its interannual one 0.2976, and takes up about 60% of the total variance. A further calculation shows a lower proportion (%) for the interannual variance in the last 20 years due to the weakening interannual oscillation of the summer monsoon. In consequence, the weak summer monsoon in North China is characterized by its interdecadal part during the last 20 years.

3 Drought and monsoon decaying

There appears to be a complex relationship between the summer monsoon and rainfall in rainy season in North China during the last 50 years. For the interannual variability the rainfall has 2a, 5a and 10a spectra, while the monsoon has only a 3a spectrum, associated with ENSO cycle. The interannual parts of the monsoon and the rainfall have not a significant correlation, for their correlation coefficient is only of 0.1967. It turns out that the interannual fluctuation of the monsoon is not the major cause of the rainfall interannual variation, coincided with Lu's results[16,17]. On the other hand, their interdecadal parts have a correlation coefficient of 0.9041, which is significant at more than 99%. This implies that the interdecadal variation of the rainfall may be forced by the summer monsoon variability on interdecadal time scale. For more details, we decompose again the approximate part of the rainfall and HBV into further approximates (Figs. 2(d), 4(d)) and details (Fig. 2(c), Fig. 4(c)) at the 4th level by orthogonal wavelet decomposition. It is easy to find that they are all made up by the components of 18a and 50a periods with almost the same phase and decaying during the last 30 years.

The correlation coefficient between the interdecadal part of the monsoon and that of the rainfall is 0.3441 at a significance above 0.01 level, close to that (0.3841) between their original sequences, which can be well understood if notice that the interdecadal variance of the HBV is much greater than its interannual part. It reveals that the summer monsoon, especially its interdecadal part, can significantly influence both the interdecadal and interannual variations of the rainfall in rainy season in North China. Moreover, the rainfall is also significantly correlated with 850 hPa wind component v over whole eastern China. An evident conjecture is that the weakening of the East Asian monsoon might be one of the most important factors in the formation of North China drought in the last 30 years. According to our calculation the summer monsoon is so important that the decadal wet and dry climate over the most parts of China alternated with the two abruptions of the East Asian monsoon during the last 40 years. Despite of those alternatives the North China climate has developed from partly drought in the 1960s and the 1970s into a severe drought in the last 20 years.

4 Conclusion and discussion

The wavelet analysis has exhibited the characteristics of the North China rainfall in rainy season, which gives us some implications on what would be available factors for the long-term drought in North China. A multiscale spectrum has been found in both the summer monsoon index HBV and the rainfall sequence of North China. The summer monsoon has the spectra of 3a, 18a and about 50a periods, while there are 2a , 5a, 18a, and 50a spectra for the rainfall. Their interdecadal spectra are very similar, whereas they are very different on their interannual components. The interannual variance of the rainfall takes up about 85% of the total, and thus approximately represents the main characteristics of the rainfall in rainy season, especially for the dry period of the last 30 years in North China. The disappearance of the 5a spectrum in the late 1960s and the decaying of the biennial oscillation since 1970 characterize the drought development in North China.

On the other hand, the summer monsoon in North China is characterized by its interdecadal part with a variance about 60% of the total. The significant correlation between the interdecadal part of the monsoon and the rainfall in rainy season confirms the importance of the summer monsoon in the development of severe drought in North China during the last 30 years. The abrupt decaying of the Asian summer monsoon does be the background of general circulation of atmosphere.

Besides, the significant difference between the rainfall and monsoon on interannual components implies the existence of other important factors which may affect the drought, apart from the monsoon. For example, the cold air activity on westerlies is also important for the rainfall since North China is situated in such a region where the cold current and the summer monsoon ensemble in rainy season. The intensity of the cold air activity is determined, in great degree, by the phases and the amplitudes of the quasi-stationary waves on boreal westerlies. In the recent 20 years the quasi-stationary waves in northern Asia had been systematically shifted eastward and become weak due to ascending of the air pressure in northwestern China and Mongolia[18]. It had forced a southward anomaly of geostrophical current on the East Asian circulation and, consequently, attenuated the east Asian summer monsoon.

Acknowledgements This work was partly supported by the National Natural Science Foundation of China (Grant No. 49875024), the National Basic Science Research and Developing Program (Grant No. G1998040901) and National Key Laboratory LASG.

References

1. Huang, R. H., Xu, Y. H., Zhou, L. T., Interdecadal change of China summer rainfall and future trend of the drought climate in North

China, Chinese Plateau Meteorology (in Chinese), 1999, 18: 465—476.
2. Zhang, Q. Y., Evolution of North China rainfall and water resources since 1880, Chinese Plateau Meteorology (in Chinese), 1999, 18: 487—495.
3. Buhechaolu, Analysis of the future situation of East Asian monsoon, Chinese Science Bulletin, 2003, 48: 737—742.
4. Menon, S., Hansen, J., Nazarenko, L. et al., Climate effects of black carbon aerosols in China and India, Science, 2002, 297: 2250—2253.
5. Gong, D. Y., Wang, S. W., Impact of ENSO on rainfall of global land and China, Chinese Science Bulletin, 1999, 44(9): 852—856.
6. Dai, X. G., Chou, J. F., Wu, G. X., Teleconnection between Indian monsoon and summer circulation over East Asia, Acta Meteorologica Sinica (in Chinese), 2002, 60(5): 544—552.
7. Lu, R., Indices of the summer western north Pacific subtropical high, Adv. Atmos. Sci., 2002,19: 1002—1028.
8. Zhen, Y. Q., Qian, Y. P., Miao, M. Q., Surface vegetation change and its impact on regional climate in China Ⅰ: numerical modeling, Acta Meteorologica Sinica (in Chinese), 2002, 60: 1—15.
9. Tao, S., Chen, L., A review of recent research on the East Asian summer monsoon in China, Review in Monsoon Meteorology, Oxford : Oxford University Press, 1987, 60—92.
10. Wang, B., Lin Ho, Rainy season of the Asian-Pacific summer monsoon, J. Climate, 2002, 15: 386—398.
11. Wang, H., The weakening of the Asian monsoon circulation after the end of 1970s, Adv. Atmos. Sci., 2001, 18: 376—386.
12. Song, Y., Ji, J. J., Abrupt change of summer monsoon on 10-year time scale over Asia and Africa, Chinese Journal of Atmosphere (in Chinese), 2001, 25: 200—208.
13. Torrence, C., Compo, G. P., A practical guide to wavelet analysis, Bulletin of the American Meteorological Society, 1997, 79: 61—78.
14. Daubechies, I., Ten lectures on wavelets. CBMS-NSF Series in applied mathematics, 61, SIAM Publications, Philadelphia, 1992.
15. Huang, G., Yan, Z., The East Asian summer monsoon circulation anomaly index and the interannual variations of the East Asian summer monsoon, Chinese Science Bulletin, 1999, 44(14): 1325—1329.
16. Lu, R. Y., Decomposition of interdecadal and interannual components for North China rainfall in rainy season, Chinese Journal of Atmosphere (in Chinese), 2002, 26: 611—624.
17. Lu, R. Y., Linear relationship between interdecadal and interannual variabilities of North China rainfall in rainy season, Chinese Science Bulletin, 2003, 48(10): 1040—1044.
18. Zeng, H. L., Gao, X. Q., Dai, X. G., Analysis on interdecadal change characteristics of global winter and summer sea surface pressure and 500 hPa height field in recent twenty years, Chinese Plateau Meteorology (in Chinese), 2002, 21: 66—73.

(Received June 26, 2003; accepted August 29, 2003)