ADVANCES IN ATMOSPHERIC SCIENCES, VOL. 26, NO. 4, 2009, 614–620

Variations in the Summer Monsoon Rainbands Across Eastern China over the Past 300 Years

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(Received 15 January 2009; revised 21 March 2009)

ABSTRACT

Based on reconstructions of precipitation events from the rain and snowfall archives of the Qing Dynasty (1736–1911), the drought/flood index data mainly derived from Chinese local gazettes from 1736–2000, and the observational data gathered since 1951, the spatial patterns of monsoon rainbands are analyzed at different time scales. Findings indicate that monsoon rainfall in northern China and the middle-lower reaches of the Yangtze River have significant inter-annual (e.g., 5–7-yr and 2–4-yr) as well as inter-decadal (e.g., 20–30-yr and quasi-10-yr) fluctuation signals. The spatial patterns in these areas also show significant cycles, such as on a 60–80-yr time scale, a reversal phase predominates the entire period from 1736–2000; on a quasi-30-yr time scale, a consistent phase was prevalent from 1736 to 2000; and on a 20-yr time scale, the summer monsoon rains show different spatial patterns before and after 1870.

Key words: long-term variations, monsoon rainbands, historical documents, China

Citation: Hao, Z. X., J. Y. Zheng, and Q. S. Ge, 2009: Variations in the summer monsoon rainbands across eastern China over the past 300 years. *Adv. Atmos. Sci.*, **26**(4), 614–620, doi: 10.1007/s00376-009-8011-0.

1. Introduction

The East Asian Monsoon is a key component of the Earth's climate system, affecting nearly one third of the world's population, especially in China, Japan, and North and South Korea (Lau and Li, 1984; Chang, 2004). In most years, regulated by the East Asian Summer Monsoon (EASM), rainband movement over eastern China exhibits obvious advance and retreat characteristics. Controlled by airflow from the north side of a subtropical high over the western Pacific, the observed rainbands are generally located over southern China from April to May, advancing northward and stagnating south of the Yangtze River from May to early or mid-June. In late June, the rainbands, called "mei-yu" (plum rain), continue moving northward over the Yangtze River and Huaihe River valleys. They remain in this region until mid-July before moving in northern China, persisting across areas in the northeast, the east, and then the northwest, in sequence. Finally, at the end of August, the rainbands rapidly retreat southward, thus ending the summer monsoons (Zhang, 1991; Ding, 1994). The time, location, and intensity of changes in the summer monsoon activities cause significant variations in the monsoon rainbands and precipitation amounts, with some areas experiencing flooding while others suffer droughts. Hence, analysis of long-term rainband variability over eastern China is not only a fundamental mission of climate prediction in China but also plays an important role in the development of a complete understanding of the long-term changes observed in the EASM.

To date, research into the summer monsoon rainbands in eastern China has focused on inter-annual fluctuations and monsoon circulations, but only using observational data from the past 50 years (Samel et al., 1999; Chen et al., 2004; Wei, 2007). Except for Wang and Huang (2006), who used a drought/flood index covering the last millennium, few researches have analyzed long-term rainband variations. Previous research has demonstrated that the location of the rainbands, based on the distribution of summer monsoon rainband precipitation anomalies, can be divided into 3 areas: the south of the Yangtze River, the Yangtze River and Huaihe River valleys, and northern China (Wang, 2006). Furthermore, observational rainband patterns in eastern China on an inter-decadal time scale have also been identified. In the 1960s, more

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rainfall occurred in northern China (NC), while less rainfall was registered in the middle and lower reaches of the Yangtze River (MLRYR); in the 1970s, more rainfall occurred to the south of the Yangtze River, especially in southern China, while less rainfall occurred in both NC and MLRYR; and since the 1980s, persistently more rain has fallen in MLRYR, while persistently less rain has fallen in northern China (Wang et al., 2005). These observations indicate that an inverse spatial pattern of precipitation has existed between NC and MLRYR in eastern China over the past 50 years. In most years, when one of these areas receives more precipitation, the other receives less, and vice-versa, despite the two regions having shown consistent drought/flood trends over several years. However, does this north-south reversal spatial pattern at an inter-decadal time scale exist over a long-term period? This is the key issue to be discussed in this paper.

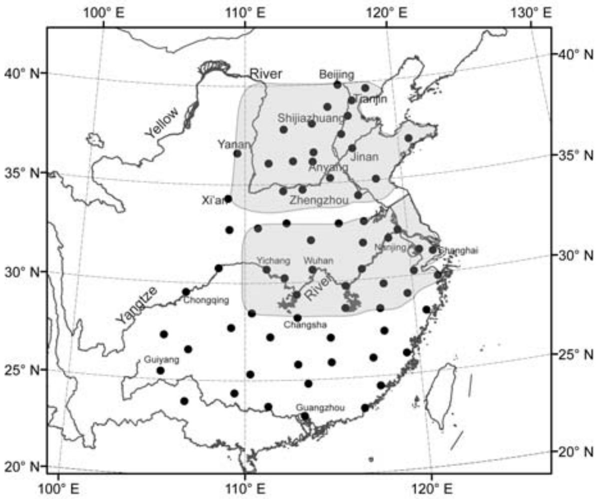

Fig. 1. A spatial distribution map of the 68 stations and the shaded areas are North China and the MLRYR region, respectively.

2. Data sources

Both the mei-yu precipitation series, covering the MLRYR region (geographically located at 28°–33°N, 110°–123°E), and the NC region (at 33°–40°N, 108°–120°E) precipitation series from 1736–2000 are utilized in this investigation. These two series are both reconstructed from the Yu-Xue-Fen-Cun archives, which have been considered an accurate and better continuity record of weather events with high resolution during the Qing Dynasty (1736–1911), and from observational data gathered since 1911 (Zheng et al., 2005; Ge et al., 2005, 2008). Additionally, the drought/flood index (a numerical index from 1 to 5, where 1 indicates very wet conditions and 5 indicates very dry conditions), consisting of data from 68 stations mainly derived from Chinese local gazettes (see Fig. 1) from 1736–2000 (Academy of Meteorological Science of China-Central Meteorological Administration, 1981; Zhang and Liu, 1995; Zhang et al., 2003), and observed precipitation amounts from May to September in the years 1951–2000 were also referenced in this analysis. Together, these three disparate sources provide high quality data with an annual time resolution and evenly distributed stations in the reconstruction of spatial rainband patterns over the last several centuries.

In order to extract inter-annual and inter-decadal oscillation signals of precipitation changes, the mei-yu series in MLRYR, the precipitation series in NC, and the drought/flood index from 1736–2000 have first been standardized and then filtered by a low pass with a 0.1-Hz frequency indicating variations at a 10-yr time scale. The drought/flood index over the areas 28°–33°N (27 stations total) and 33°–40°N (22 stations total) has been averaged to develop an accurate representation of the index in the MLRYR and the NC regions.

Correlation analyses show that the correlation coefficient between the precipitation and drought/flood index filtered dataset with a 10-year resolution from 1736–2000 in NC is −0.73, which is better than the −0.49 coefficient between the mei-yu precipitation and drought/flood index in MLRYR at a significance level of 0.001 (sample number is 265). The higher coefficient between the two series in NC can be explained by the fact that the drought/flood index data were mainly derived from documented dry/wet events in May–September when the annual rainfall was concentrated in NC, accounting for 50%–60% of the annual total. The mei-yu is only one of several important factors determining the instance of drought/flood events in MLRYR, causing the coefficient between the two series to be relatively low. Nevertheless, the coefficients in the two areas both pass the $\alpha = 0.001$ significance level, suggesting that the reconstructed series from the two kinds of historical documentary evidences are very consistent in reflecting inter-decadal fluctuation signals of the summer monsoon rains.

3. Results and analyses

Figure 2 clearly shows that consistent and opposite inter-decadal change trends existed in both the precipitation series and the drought/flood index between NC and MLRYR from 1736–2000. For the quasi-10-yr oscillation signal (Figs. 2c and 2d), 26% of the NC and 18% of the MLRYR variances of the raw annual

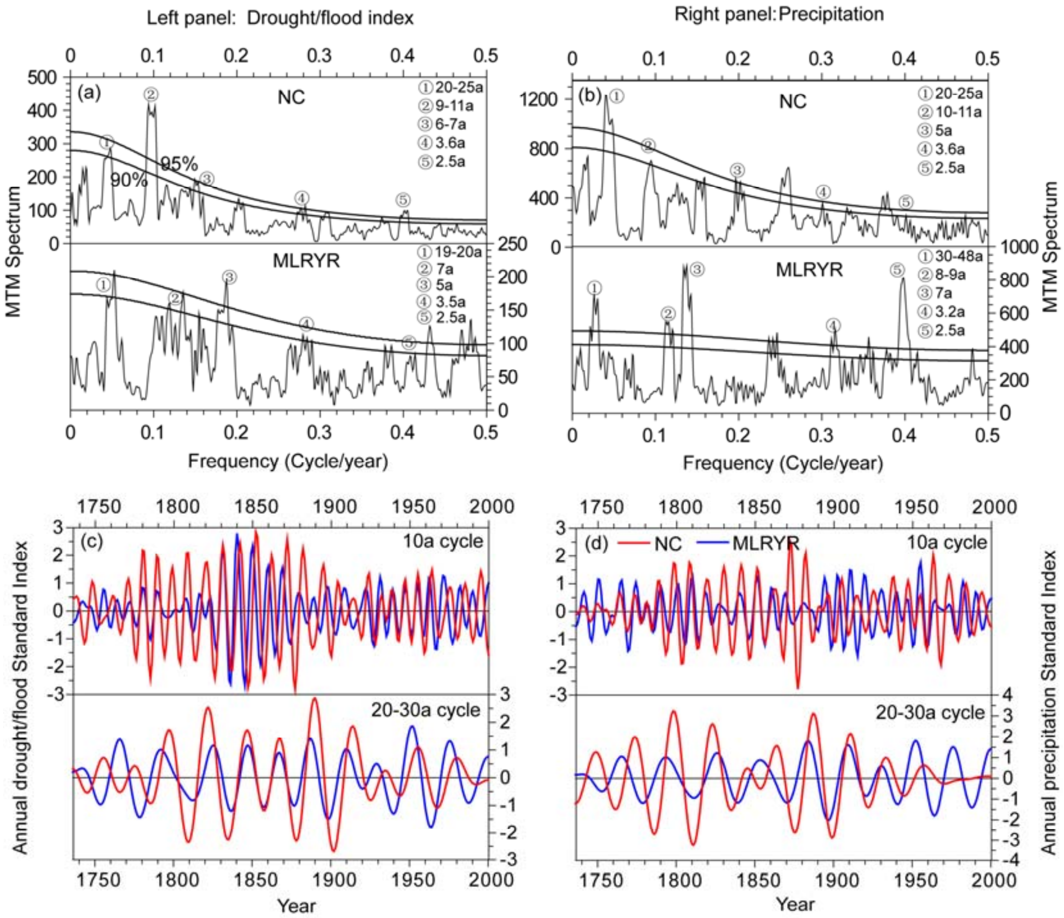

Fig. 2. The results of MTM and the wavelet analysis on the (a, c) drought/flood index and (b, d) precipitation; (a) and (b) indicate the Multi-Taper Method (MTM) spectrum with 95% and 90% confidence levels; (c) and (d) indicate significant fluctuation signals at 10-year and 20–30-year cycles from Morlet wavelet analysis in NC marked with red color and MLRYR marked with blue color.

drought/flood index data was explained; the periods from 1765–1820 and 1930–1965 show very consistent trends, but the periods from 1860–1920 and 1975–2000 show reversal trends (i.e., relatively light mei-yu in MLRYR with relatively heavy precipitation in NC, and vice versa); the correlation coefficient between NC and MLRYR is 0.24 for the precipitation series and 0.20 for the drought/flood index, both of which pass the α=0.001 significance level. For the 20–30-yr oscillation signal, 11% of the NC and 8% of the MLRYR variances of the raw annual drought/flood index data was explained; the 19th century and the early part of the 20th century both show a consistent trend, but the 18th century shows a reversal trend; the correlation coefficient between NC and MLRYR is 0.37 for the precipitation index and 0.50 for the drought/flood index, which passes the α=0.001 significance level. Worth noting is that the 20–30-yr signal in NC becomes weaker and weaker as it progresses through the cycle. Beyond the inter-decadal fluctuations, the inter-annual climatic cycles are also shown here significantly, i.e., the NC and MLRYR both have 5–7-yr and 2–4-yr fluctuations (Figs. 2a and 2b).

In order to decompose the major modes of the drought/flood spatial pattern of 1736–1911, we performed an EOF analysis and obtained the first two leading EOFs. The EOF1 having a consistent north-south trend is able to account for 14.8% of the total variance at 68 stations, and the EOF2 shows the reversal pattern in NC and MLRYR and explains 10.7% of the total variance. Furthermore, the typical spatial distribution pattern recognized from the precipitation fluctuations in Figs. 2d for the summer rainbands from the drought/flood index is illustrated in the four individual maps of Fig. 3. Figures 3a and 3b clearly show a reversal phase, while Figs. 3c and 3d indicate a consistent phase between the NC and MLRYR. From 1745–1757, the mean annual precipitation in NC increased by 35% relative to the mean value for the period of 1736–2000, while in MLRYR, the mei-yu decreased

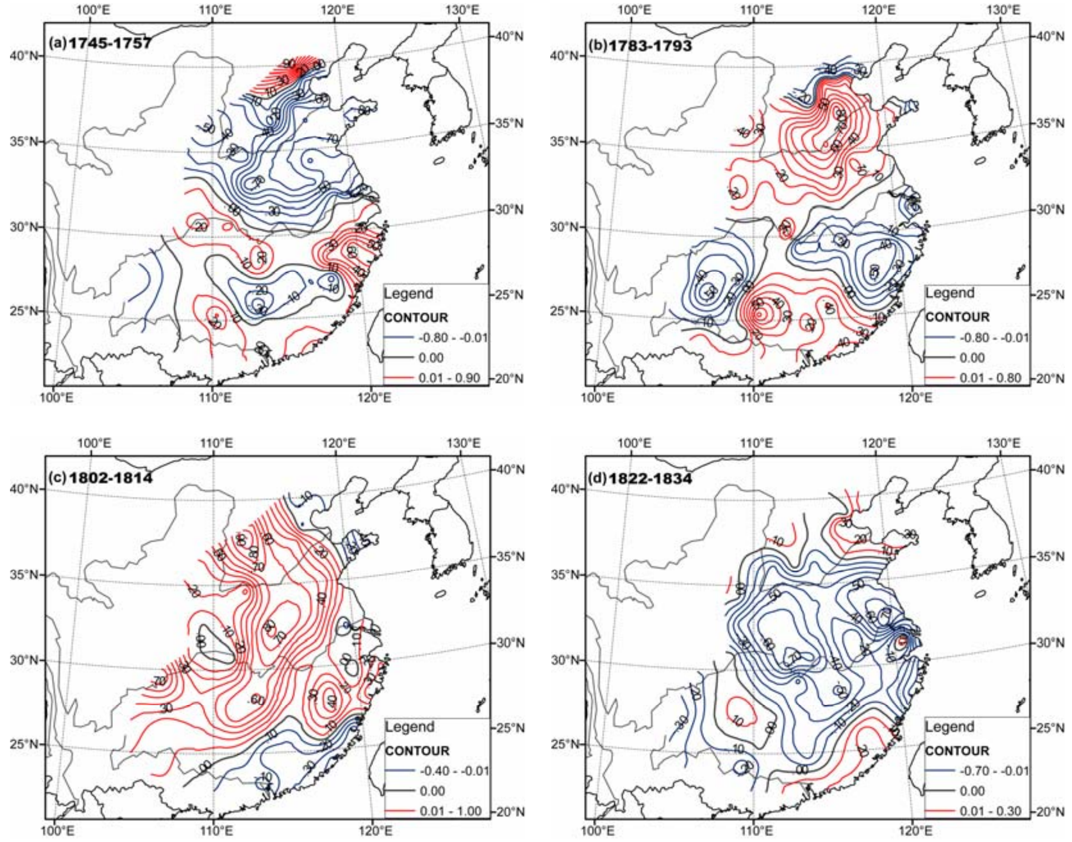

Fig. 3. The 4 typical spatial patterns chosen from Fig. 2d for the summer monsoon rainbands from the drought/flood index data in eastern China from 1736–1911. The blue contour indicates more precipitation, while the red contour indicates less. The contour indicates the drought/flood index anomalies referenced to the mean value for the period of 1736–2000.

45%, which resulted in an inverse pattern of flooding in the north (NC) and drought conditions in the south (MLRYR) (Fig. 3a). From 1783–1793 (Fig. 3b), the spatial pattern reversed to that indicated by Fig. 3a; the mean precipitation in NC decreased by 43%, while the mei-yu in MLRYR increased by 25%. The two areas were both in droughts from 1802–1814 (Figs. 3c), with precipitation decreasing 32% and 18% in NC and MLRYR, respectively, which is similar to the spatial pattern observed in the periods from 1856–1865 and 1872–1881, and when both were flooded from 1822–1834 (Fig. 3d), a period which showed a 30% precipitation increase in NC and a 27% increase in MLRYR.

Even more, observational May–September rainfall data also suggests that a reversal phase in the summer monsoon rainbands were prevalent in both MLRYR and NC from 1951–2000. On the inter-decadal time scale, a consistent trend also existed. The spatial pattern of the precipitation anomaly illustrated in Fig. 4 indicates that there was more precipitation in all of eastern China from 1951–1957, while there was less precipitation in MLRYR and more precipitation in NC during 1958–1971. Additionally, there was less precipitation in most parts of NC and the MLRYR from 1974–1982, though there was more precipitation in MLRYR and less in NC from 1986–2000, which confirms that the reversal and the consistent trend in monsoon precipitation in MLRYR and NC presented not only in historical times but also in the observational period.

A cross-wavelet spectrum of precipitation and the drought/flood index for MLRYR and NC both illuminated the fact that the spatial pattern was different on various time scales (Fig. 5). For example, on the 60–80-yr time scale, a reversal correlation existed over the two regions in most years from 1736–2000; on the quasi-30-yr time scale, consistent correlations were shown over the past 300 years; and on 20-yr time scale, a reversal correlation was shown before 1870, replaced by a consistent phase after 1870.

4. Conclusions and discussions

This study used reconstructions of precipitation

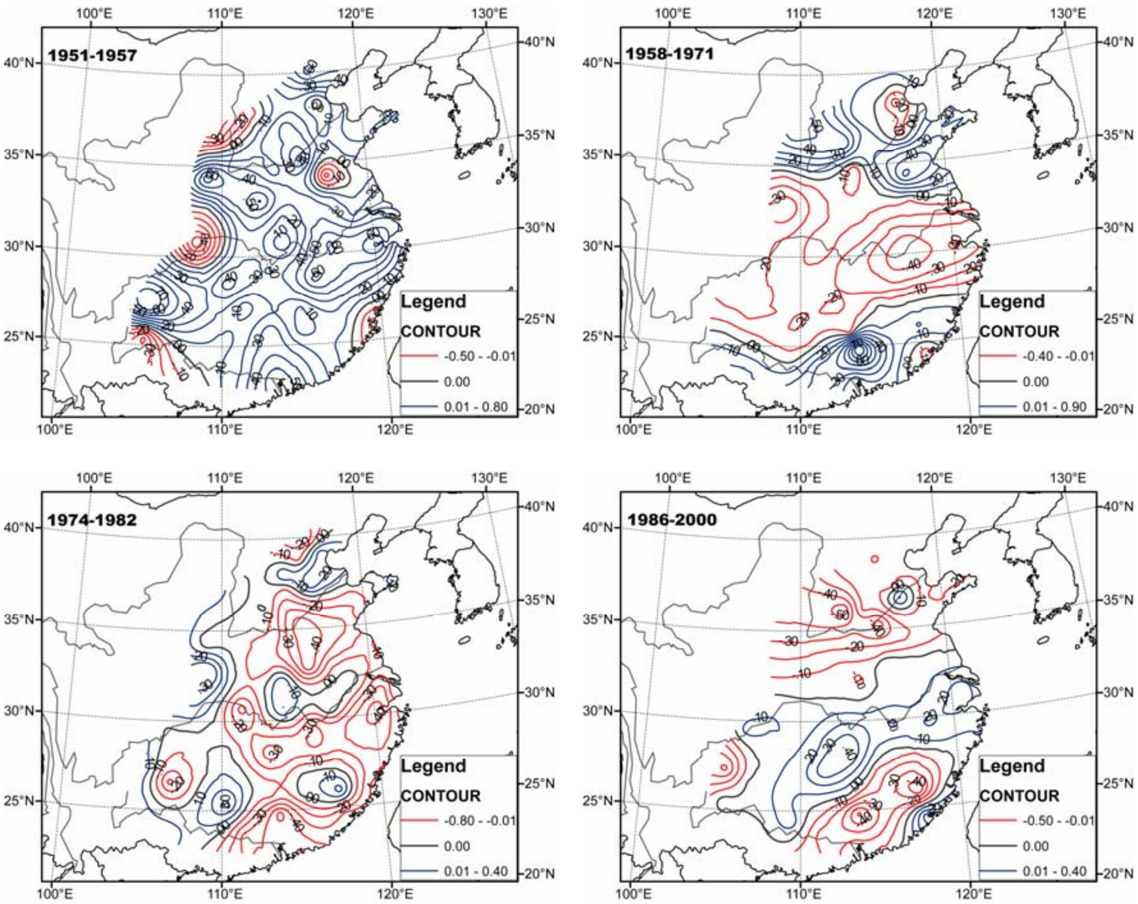

Fig. 4. Same as Fig. 3, but from observational data from 1951–2000.

data and drought/flood index data from Chinese historical documents, together with observational data, to analyze the spatial pattern of monsoon rainband movements across the MLRYR and NC. During the past 300 years, the location of the summer monsoon rainbands in eastern China was found to have interdecadal oscillations, like 20–30-yr and quasi-10-yr, as well as inter-annual oscillations, like 5–7-yr, 2–4-yr; the rainfall spatial pattern in the south-north regions, however, was found to be different on various time scales (e.g., reversal pattern at the 60–80-yr time scale, consistent pattern at the quasi-30-yr time scale, and, at the 20-yr time scale, a reversal phase existing before 1870 and a consistent phase after). These spatially patterned cycles of rainfall over long-term time series differ from our observations since 1951, which indicate only a reversal spatial pattern in MLRYR and NC. But long-term variations in the monsoon rainband precipitation result from the overlapping of quasi-cycle changes on all time scales; although a reverse pattern has dominated the past 50 years, this has not been the case for all periods over the past 300 years.

Summer rainband precipitation variations in eastern China are closely related to the starting dates and intensities of the EASM. Many previous studies have, thus, suggested that the duration of rainband stagnation is shorter in MLRYR and longer in NC when the EASM is strong, resulting in a drought in MLRYR and flooding in NC. On the contrary, these studies found that flooding in MLRYR and a drought in NC occur when the EASM is weak, the summer monsoon intensity being strong if the EASM comes earlier, and relatively weak if it comes later. Accordingly, the inverse north-south precipitation events are rather obviously observed in eastern China (Zhao and Zhang, 1996; Ding et al., 2008). Although this paper shows that the main oscillation signals of monsoon rainband precipitation on inter-annual and inter-decadal time scales has 20–30-yr, quasi-10-yr, 5–7-yr, 2–4-yr cycles, which is very consistent with the AO, AMO, PDO, ENSO, and QBO climatic variability modes (Shen et al., 2007; Kerr, 2000; Meehl and Arblaster, 2002; Wang and Fan, 2005), a lot of investigations from long-term reconstruction data and model simulations controlled by the climate forcing (i.e., solar and volcanic activities) need to be conducted before the inherent possi-

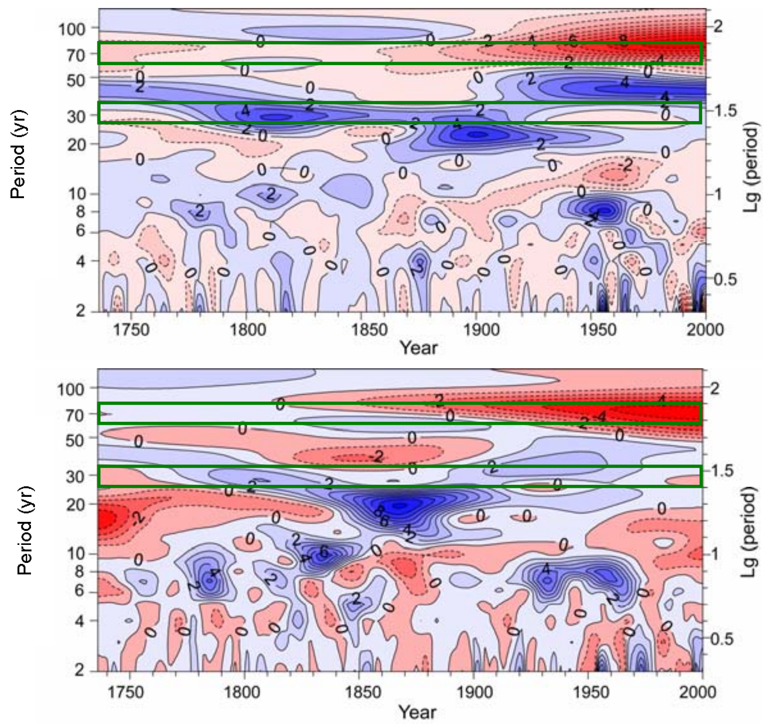

Fig. 5. Cross-wavelet spectrum analysis between precipitation (top) and the drought/flood index (bottom) over NC and MLRYR. The red circle indicates the reverse phase, while the blue circle represents the consistent phase.

ble linkages between these modes and the precipitation variations in eastern China can be clearly explained by climate dynamic mechanisms. Our paper will provide references for these works.

Acknowledgements. The authors would like to thank anonymous reviewers for their helpful comments. This research was supported by grants from the Chinese Academy of Sciences (KZCX2-YW-315-2) and the National Natural Science Foundation of China (Grant Nos. 40701021, 40625002).

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