DOI:10.16555/j.1006-8775.2014.02.007

Article ID: 1006-8775(2014) 02-0154-09

THE NORTH-SOUTH ANTI-PHASE DISTRIBUTION OF RAINFALL IN MEIYU PERIODS AND ITS RELATIONSHIP WITH QUASI-BIWEEKLY OSCILLATION IN THE ATMOSPHERE

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Abstract: Based on the daily rainfall datasets from 740 stations in China from 1954 to 2005 and the NCEP/NCAR reanalysis data, the relationship between the north-south anti-phase distribution (APD) of rainfall during Meiyu periods and the Quasi-Biweekly Oscillation (QBWO) in the atmosphere was analyzed. Diagnostic results are as follows: (1) there was significant north-south oscillation of Meiyu rainfall during the 16 years from 1954 to 2005. Since the 1990s, the APD enhanced significantly and showed 2- and 4-6-year period. In the region with more rainfall, the QBWO was always more active. (2) The APD of Meiyu and north-south movements of precipitation in eastern China belong to the same phase. (3) The 10-25 day filtered water vapor flux could spread to the area north of 30°N in 1991. The divergence of the water vapor flux which propagated from middle- and higher- latitudes to the of Yangtze-Huaihe River Basins (YHRB) was significant in 1991, but the latitudes that the water vapor flux could reach were further southward and there was no southward propagation of divergence in 1993. (4) The locations of Western Pacific Subtropical High (WPSH) and 10-25 day anti-cyclone, which modulated WPSH's advancement in and out of the South China Sea, were relatively northward in 1991. Furthermore, the vertical circulation showed north-south deviation between 1991 and 1993, just as other elements of the circulation did.

Key words: Meiyu; anti-phase distribution; Quasi-Biweekly Oscillation; low frequency oscillation; water vapor flux

CLC number: P434.4 **Document code:** A

1 INTRODUCTION

Meiyu is a common weather phenomenon over Yangtze-Huaihe River Basins (YHRB) and Japan in early summer. Not only its development represents the adjustment of atmospheric circulation, but also has a direct impact on the drought and flood disasters over YHRB. Previous study mostly focuses on the whole area of YHRB during the Meiyu period and related factors[1-4]. However, some pointed out the coexistence of drought and flood in the Meiyu period over the YHRB is significant both temporally and spatially, which means both disasters of drought and flood over YHRB happened. The damage caused by such kind of extreme precipitation over limited area and period is very serious if it occurs without early warning. Wu et al.[5] have done detailed research on the temporal imbalance of the precipitation over the YHRB. They pointed out that during the year with drought and flood coexistence, the Western Pacific Subtropical High (WPSH) is spatially larger and the summer monsoon is weaker than normal. Furthermore, Zhu et al.[6] found the anti-phase distribution (APD) of Meiyu shifting phase about the Yangtze River. For example, it is a flood year over YHRB in 1991, but the precipitation to the south of the Yangtze River was below normal. The excessive concentration of precipitation over limited area has resulted in serious flood to the north of the Yangtze River. During Meiyu of a south-flood versus north-drought (SFND) year, the front in the lower troposphere and the convergent center of water vapor flux were further southward, and the subtropical summer monsoon was weak. At the same time, the WPSH and the South Asia High at 200 hPa were further south, and vice versa.

The heterogeneous temporal distribution of

Received 2013-05-06; **Revised** 2014-03-14; **Accepted** 2014-04-15
Foundation item: Beijing Excellent Talents Cultivation Project; Oceanography Science Foundation for Youth Scholars of State Oceanic Administration (2013256)
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Meiyu over YHRB is also significant, such as the Quasi-Biweekly Oscillation (QBWO) with 10-25 day period, which has been proved by much research. For example, Lau et al.[7] found a 10-day variation period of rainfall during the East Asia summer monsoon. He et al.[8] proposed a 20-day oscillation period of rainfall over YHRB. Wang and Ding[9] discovered remarkable 10-30 day oscillation of rainfall over the mid- and lower-Yangtze Basin in summer, which takes on different features during the drought or flood year respectively. Chen and Yen[10] also proved the existence of a 10-24 day oscillation of Meiyu. Besides, Yin and Wang[11] also found remarkable annual variations of Meiyu in QBWO. In addition, the QBWO of the convection over the South China Sea (SCS) was found to be crucial to the development of the Meiyu front and temporal northward movement of the Meiyu belt. The Rossby wave was significantly stretching from the SCS to the mid- and higher-latitudes during Meiyu periods, and the southwestward movement of cyclones and anticyclones can modulate the water vapor transportation and the east-west movement of the WPSH, thus affecting the rainfall of Meiyu[11]. Diagnostic analysis of the catastrophic precipitation over YHRB in 1991 indicated that factors like the northward movement with QBWO of the summer monsoon in East Asia, the southward invasion of cold air and the oscillation of the subtropical high with low frequency all exerted great influence on the rainfall.

At present, the short-range climate prediction of Meiyu over YHRB focuses on the average precipitation during the whole Meiyu period in the whole area. Thus the precision both in time and space cannot meet the need in practice. Yet less work has been taken on the relationship between the APD of Meiyu and the QBWO, making the study more worthwhile. Besides, the relationship between the APD and the traditional north-south difference of rainfall in East China also should be discussed. Therefore, the two issues are examined in detail based on the chosen APD years.

2 DATA AND METHODS

Datasets used in this study include (1) the daily precipitation of the 740 stations over China from 1954 to 2005 (2) Daily NCEP/NCAR reanalysis data of wind, geopotential height and humidity (2.5°×2.5°). For the data in (1), it has been preprocessed to ensure the quality. The precipitation during June to July of the 47 stations is regarded as Meiyu precipitation, which is picked according to the definition of Hu et al.[19].

The methods used include the Lanczos time filter[20], EOF analysis[21], wavelet analysis of Morlet[22] and other relevant composite analysis methods.

3 SPATIAL DISTRIBUTION OF MEIYU PRECIPITATION

The EOF results of the precipitation of the 47 stations over YHRB from 1954 to 2005 are shown in Fig. 1. The first pattern displays a consistent rainfall pattern over YHRB, with 35.8% of the variance explained. The second pattern shows the APD pattern shifting phase about the Yangtze River, the 21.09% the variance explained. The APD of Meiyu has significant annual variation, as shown by the time series of the second pattern, which has enhanced greatly since the 1990s. The wavelet analysis of the second time series shows no obvious cycle before the 1990s but has remarkable periods of 2 years and 4-6 years after that (figures omitted). The correlation coefficient between the second time series of EOF and the precipitation during June and July from 1954 to 2005 is shown in Fig. 2. There is clear difference on 30°N with significant negative correlation centers over the east and central China and part of Northeast China but positive centers over central and southern parts of central China and South China. The study of the Meiyu APD can not only show the variation of the Meiyu belt, but also the general change of the rainfall over East China. Not surprisingly, much of the current work directs toward better forecasting of the mechanism for Meiyu rainfall.

Following Zhu et al.[6], a typical Meiyu APD year is confirmed only when its absolute value of the time series of the first two eigenvectors (standardized) is larger than 0.8 and the time series of the second mode is also large. Table 1 shows the respective typical years with SDNF and south-flood meanwhile north-drought (SFND) features determined according to the criteria. The rainfall of 47 stations is calculated, with 19 stations over the southern area (S19) and 28 stations over the north area (N28). A normal year is thought to be established when the standardized rainfall is between -0.6 and 0.6. A drought or flood year is defined by the absolute value of 0.6. There are obvious APD in the typical years determined. Therefore, it can be known that the definition of a typical APD year is reasonable. Take 1991 and 1993 as the most typical APD years, as their standardized rainfall differences are larger than 2.5 and the whole area rainfall are close to each other. The distributions of precipitation anomaly in 1991 and 1993 are displayed in Fig. 3. In 1991, Centers of significant positive anomaly are found to the north of Yangtze River, and significant negative anomalies are to the south. It is also found that rainfall is more to the south and less to the north of 30°N in 1993.

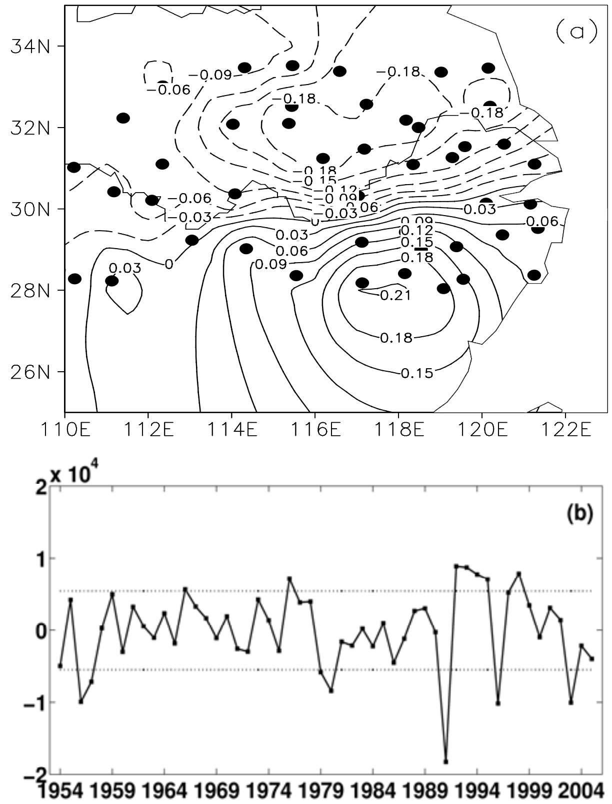


Figure 1. Spatial distribution (a) and time series (b) of the second EOF mode. The black dots denote the 47 stations over Yangtze-Huaihe basin.

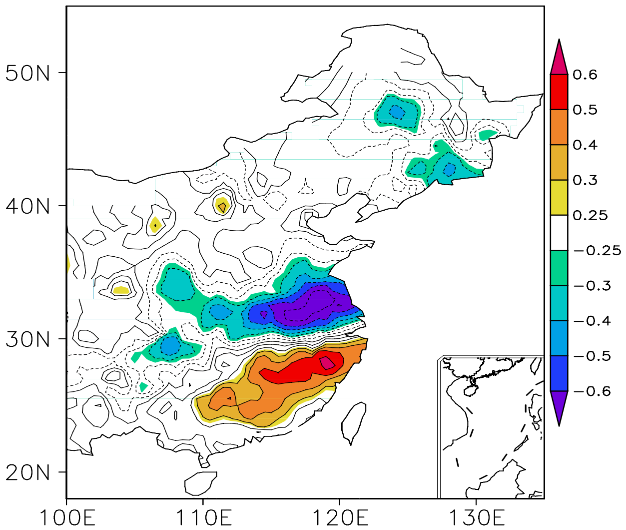


Figure 2. Correlations between time series of the second EOF mode and rainfall in June and July. The shaded areas denote the confidence level over 95%.

Figure 4 shows the wavelet analysis of the daily rainfall of S19 and N28 in 1991 and 1993 respectively. There is an obvious 15-30 day cycle in the N28 precipitation, while the low frequency cycle of S19 is not obvious in 1991. The situation is reversed in 1993 with obvious 10-25 day oscillation in the south and no obvious period in the northern region. The QBWO features of the rainfall are strikingly different in accordance with the south-north difference of rainfall. That is, the QBWO is strong on the more rainy side and weak on the less rainy side. The filtered series of daily rainfall with the 10-25 day period are shown in Fig. 5. The amplitude of the oscillation is found to be large on the rainy side and small on the less rainy side, and the amplitude of averaged rainfall for the whole area is between that of the two sides. The results of the wavelet analysis and filter of other typical APD years also display similar characteristics (figure omitted).

Table 1. Standard precipitation anomaly over Yangtze-Huaihe basin, northern and southern region.

SFND Type				SDNF Type			
Year	47	N28	S19	Year	47	N28	S19
1959	−0.84	−1.14	−0.15	1956	0.17	1.19	−1.04
1966	−0.89	−1.33	−0.02	1957	−0.29	0.63	−1.19
1976	−0.44	−1.02	0.40	1979	0.11	0.84	−0.75
1992	−0.56	−1.27	0.47	1980	0.75	1.40	−0.29
1993	**0.88**	**−0.50**	**2.02**	1986	0.12	0.60	−0.46
1994	−0.44	−1.32	0.73	**1991**	**1.06**	**2.57**	**−1.08**
1995	0.80	−0.15	1.51	1996	1.49	2.04	0.24
1997	−0.05	−0.66	0.65	2003	0.26	1.24	−0.94

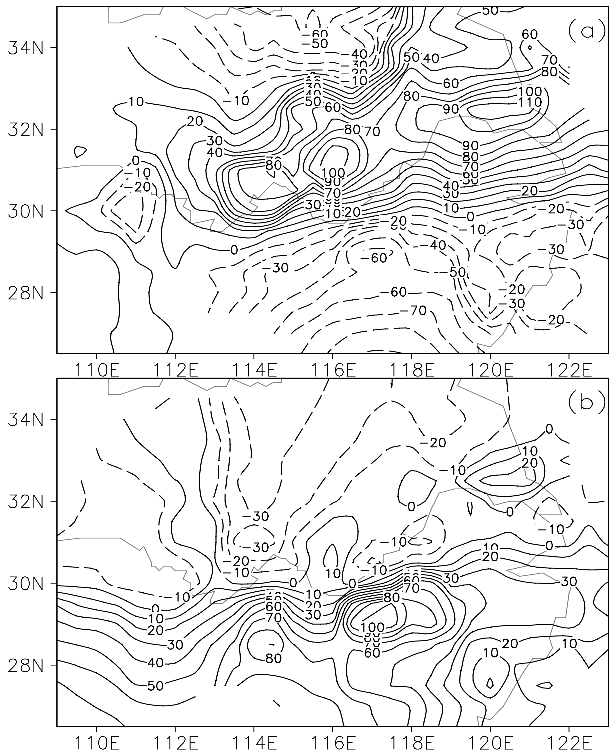


Figure 3. Precipitation anomaly in 1991 (a) and 1993 (b) over Yangtze-Huaihe basin.

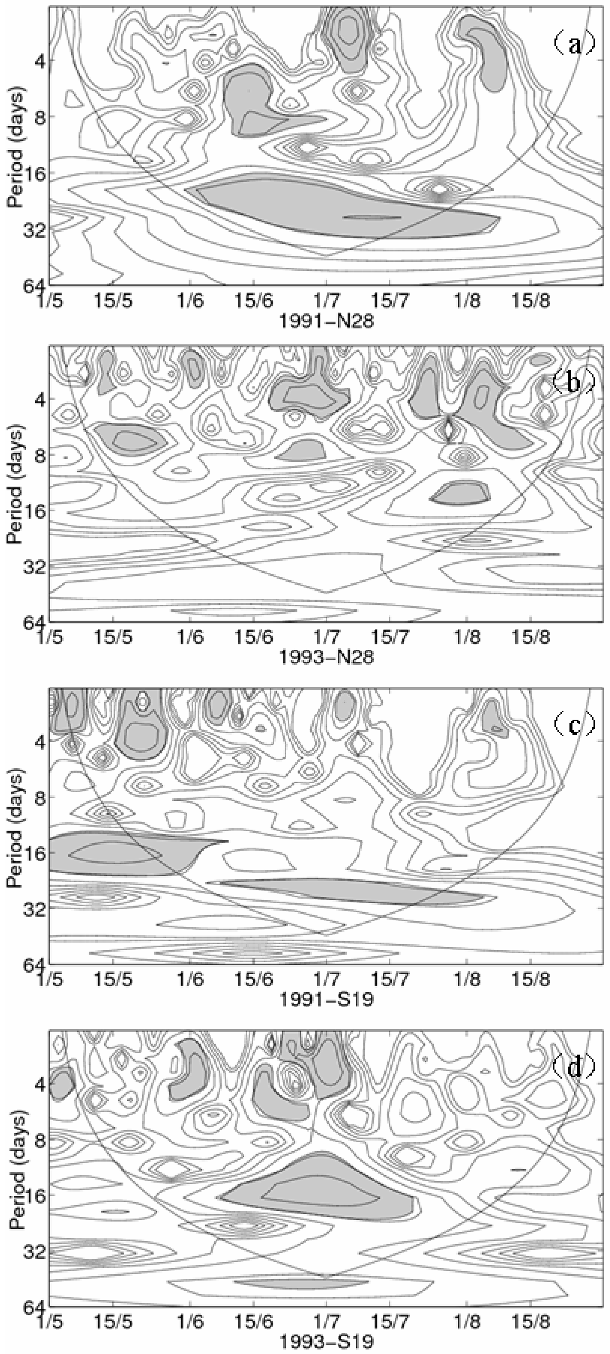
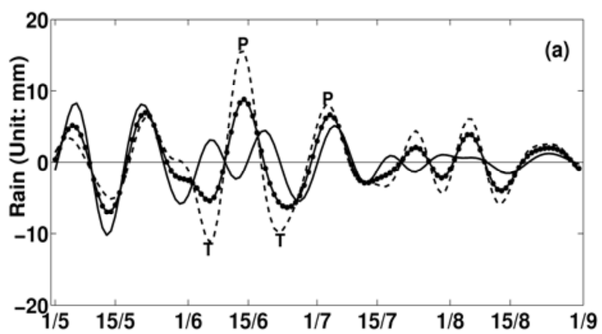


Figure 4. Wavelet power of the rainfall sequence in 1991 (a, c) and 1993 (b, d).



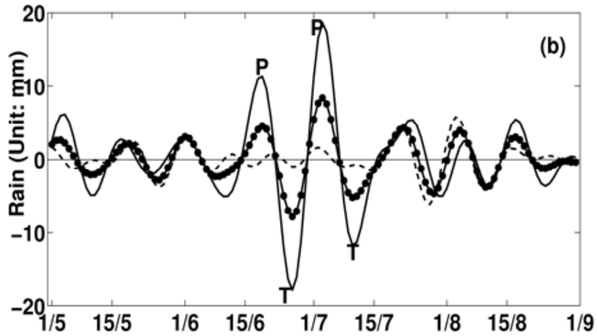


Figure 5. 10-25-day rainfall over Yangtze-Huaihe basin (dotted line), southern (solid line) and northern region (dashed line), in 1991 (a) and 1993 (b).

4 WATER VAPOR PROPAGATION IN TYPICAL APD YEARS

Water vapor flux is a physical quantity in combination with wind and water field, the propagation feature of which can influence the precipitation of Meiyu over YHRB. The propagation of 110-120°E averaged water vapor flux (filtered) and rainfall (observed) in 1991 and 1993 are shown in Fig. 6 respectively. Relative to the rainfall distribution, the water vapor flux with QBWO can reach the area north of 30°N in 1991. Generally, heavy rainfall will take place when the southwestern water vapor is transported to the northernmost location, as is demonstrated by the precipitation process on June 10, 30 and late July. Different from that in 1991, the water vapor with QBWO in 1993 can only get to areas south of 30°N, and the rainfall also concentrated to the south of Yangtze River.

The distribution of the water vapor flux divergence is shown in Fig. 7. In order to manifest the characteristics of divergence field more clearly, 15-30 day and 10-20 day are chosen as the periods in the wavelet analysis for 1991 and 1993 respectively. The main distinction is whether there is strong water vapor flux convergence spreading from mid-high latitudes to YHRB. In early June 1991, the water vapor flux with low frequency from the SCS propagated northward clearly, and the southward propagation from mid-high latitudes was also clear. They intersected to the north of 30°N on June 10 when the rainfall occurred. In the middle of June, the two propagations of water vapor convergence intersected once more, which corresponded to another concentrated precipitation. The water vapor convergence was weak in 1993, and there was only weak southward propagation at the end of June.

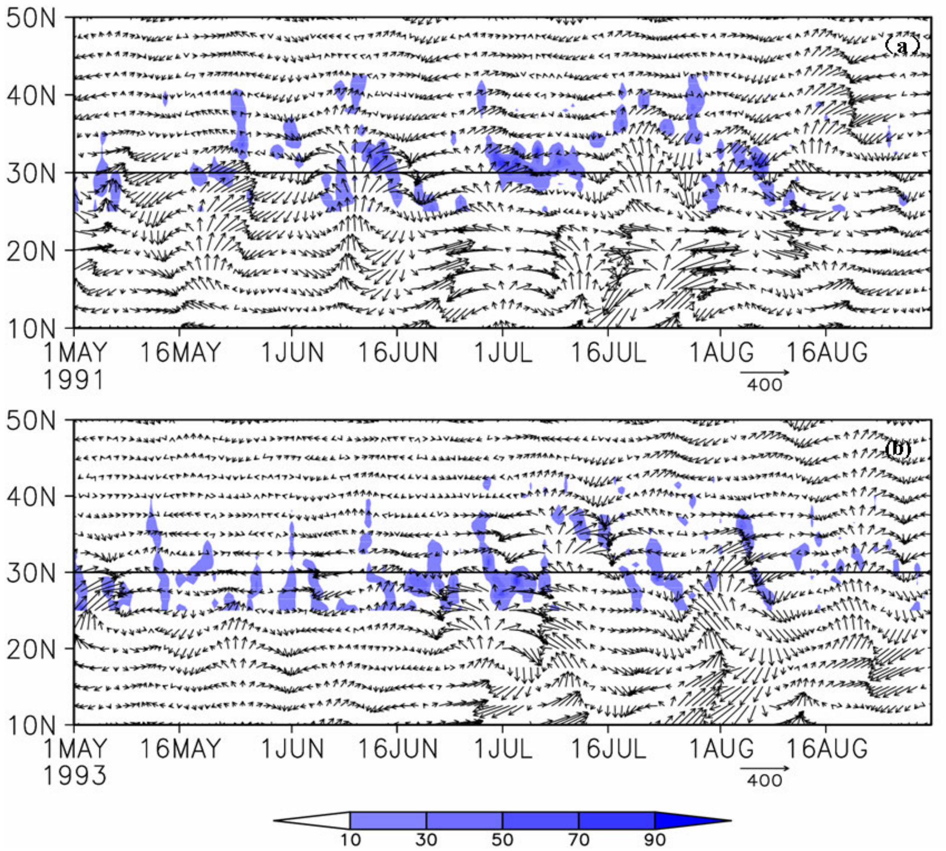


Figure 6. 10-25 day filtered water vapor flux and original rainfall in 1991 (a) and 1993 (b).

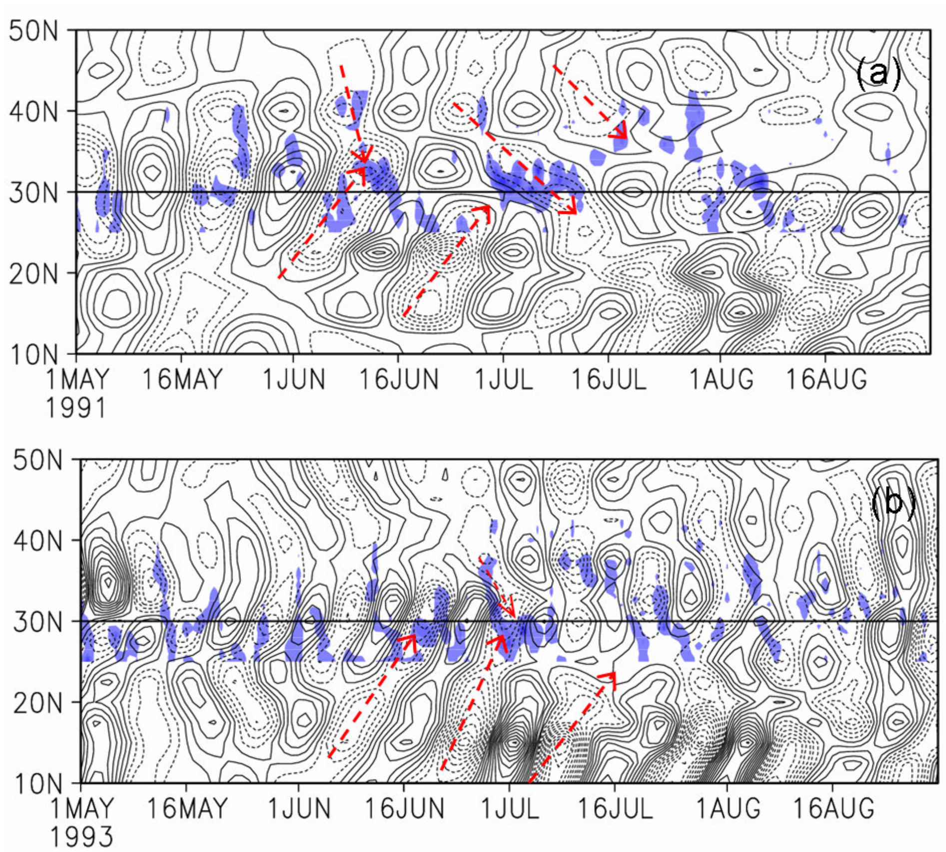


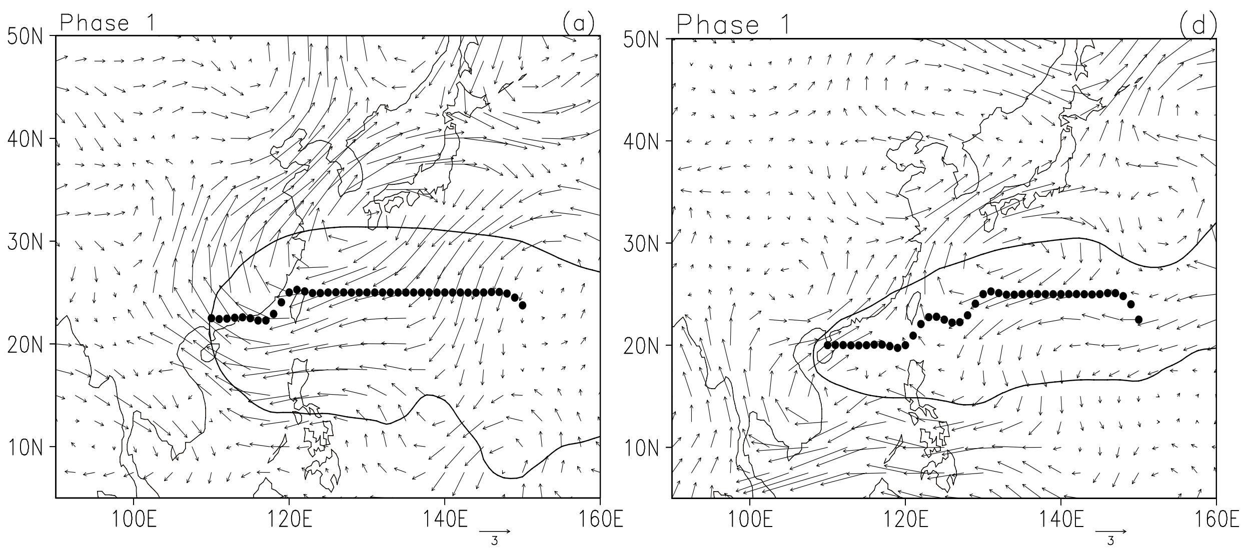
Figure 7. 10-25-day filtered divergence of water vapor flux and original rainfall in 1991 (a) and 1993 (b).

5 ATMOSPHERIC CIRCULATION OF THE APD YEAR

The 10-25 day filtered rainfall of 1991 and 1993 was divided into 8 phases when the peak (valley) surpassed one standard value. Phase 3 corresponds to the maximum positive rainfall while phase 7 to the maximum negative rainfall. Phases 1 and 5 are regarded as the conversion phases and the other phases indicate the time when the amplitude of the QBWO reaches one half of the maximum or minimum value. A Rossby wavetrain with low frequency is found to be outstanding on the low level, which stretches from the SCS to the mid-high latitudes. The southwestward movement of the cyclones and anticyclones in the western part of the wavetrain can modulate the water vapor transportation and the location of the WPSH, thus affecting the Meiyu rainfall. During the positive phase, the anticyclone of the Rossby wave spread from the East China Sea to the SCS, thus contributing to the movement of the WPSH into the SCS. Then, is there also remarkable difference of the circulation with low frequency during the year with APD anomaly of Meiyu?

The composite results of filtered wind of phases 1-3 at 850 hPa and the unfiltered ridge location of WPSH are shown in Fig. 8. The ridge in 1991 was located to the north of 22°N, making it easier for the southwesterly flow to reach YHRB. In contrast, the ridge line took on northeast-southwest orientation and was located to the south of 20°N in 1993. The flow fields with low frequency in 1991 and 1993 also take on different patterns. In 1991, the anticyclone anomaly was located in the northern part of the SCS and South China, which is favorable for the water vapor to reach the north of the Yangtze River. The southwestward movement of the anticyclone anomaly can modulate the WPSH to move in the northern part of the SCS around 22°N. Different from that in 1991, the anticyclone anomaly was more southward and over the SCS in 1993, which was conducive for the WPSH to move into the middle of the SCS. Hence, the WPSH and the north-south difference of the anticyclone anomaly play a great role in inducing the APD of rainfall over YHRB.

Vertical motion is also crucial to the precipitation distribution. The vertical motions of phases 3 and 7 are displayed in Fig. 9. It is found that the vertical motion anomaly over the SCS and YHRB were reversed to each other, with ascending motion over YHRB while descending motion over the SCS in phase 3, and vice versa in phase 7. In 1991, however, the vertical motion over the SCS and YHRB is more northward. Both the ascending and descending motion over YHRB were located to the north of 30°N, and the vertical movement anomaly in the SCS also occurred in its northern part. On the contrary, the vertical motion anomaly in 1993 was more southward. The vertical movement anomaly occurred to the south of 30°N over YHRB and south of 20°N over SCS. The north-south difference of the vertical motion resulted in the distinction of the water vapor convergence area, thus influencing precipitation processes.



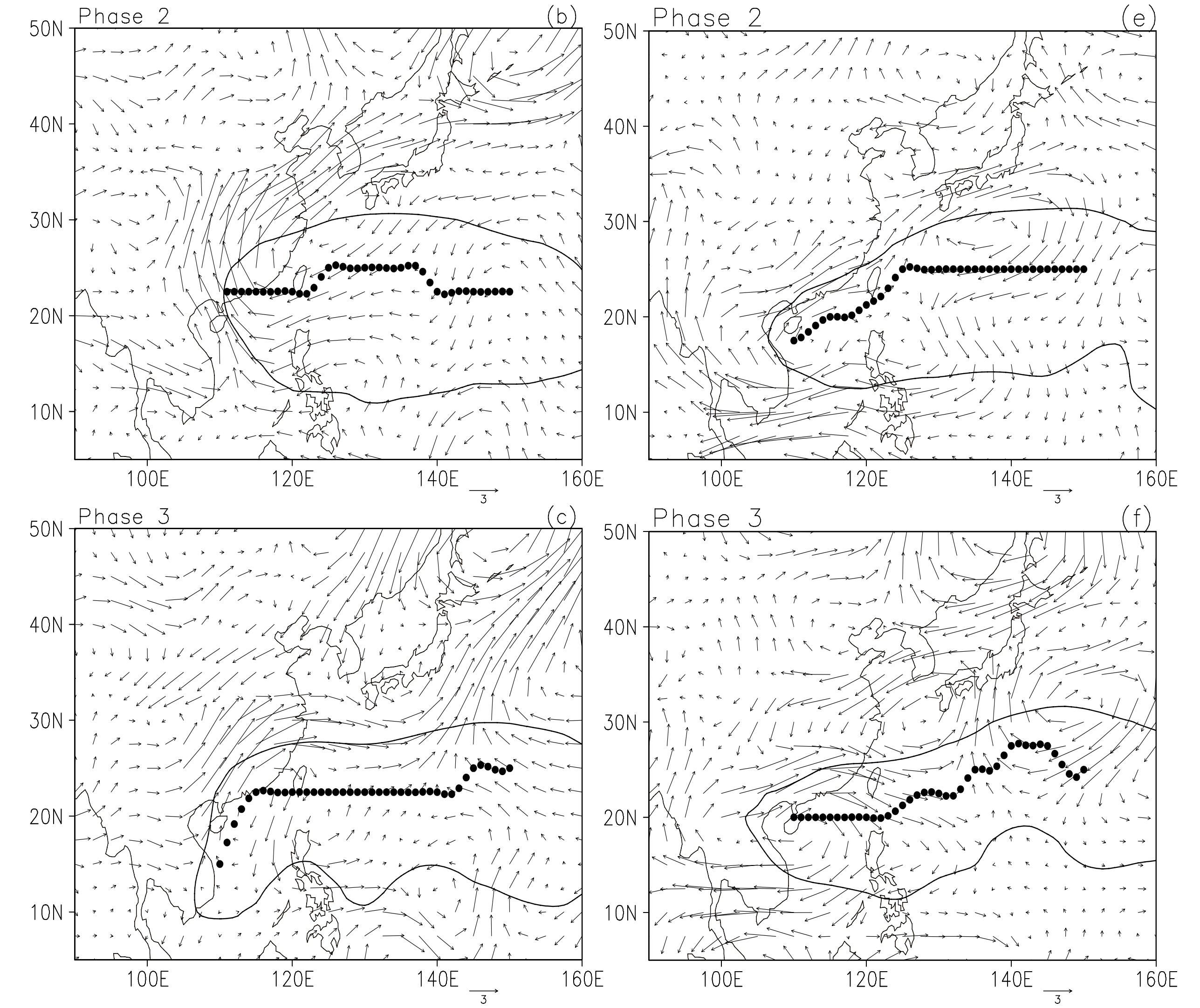
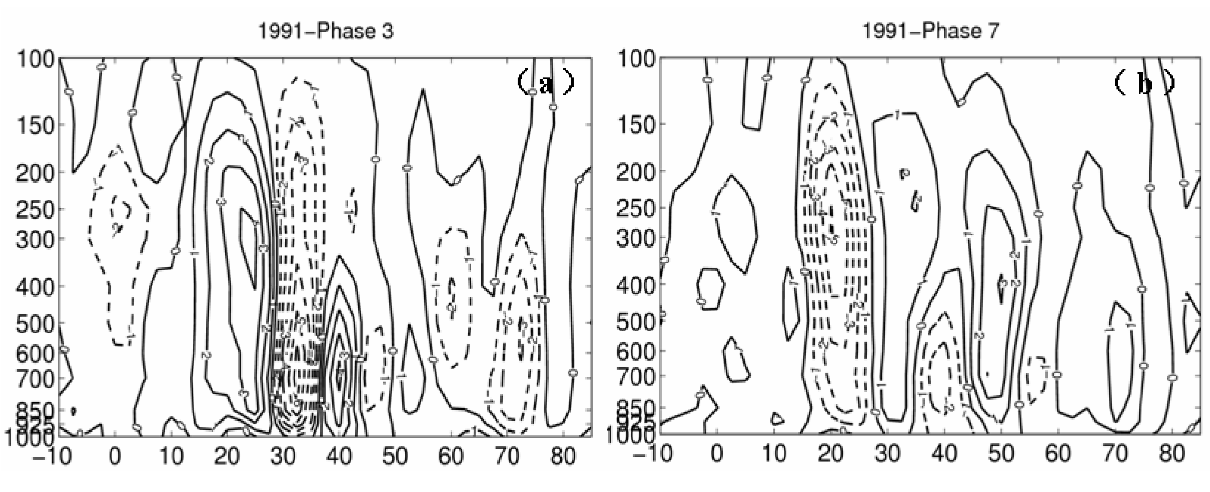


Figure 8. Spatial distribution of 850-hPa wind in the 10-25 band from phase 1 through phase 3 in 1991 (a-c) and 1993 (e-f). The curve denotes the unfiltered 5880gpm line, and the dotted line denotes the ridge.



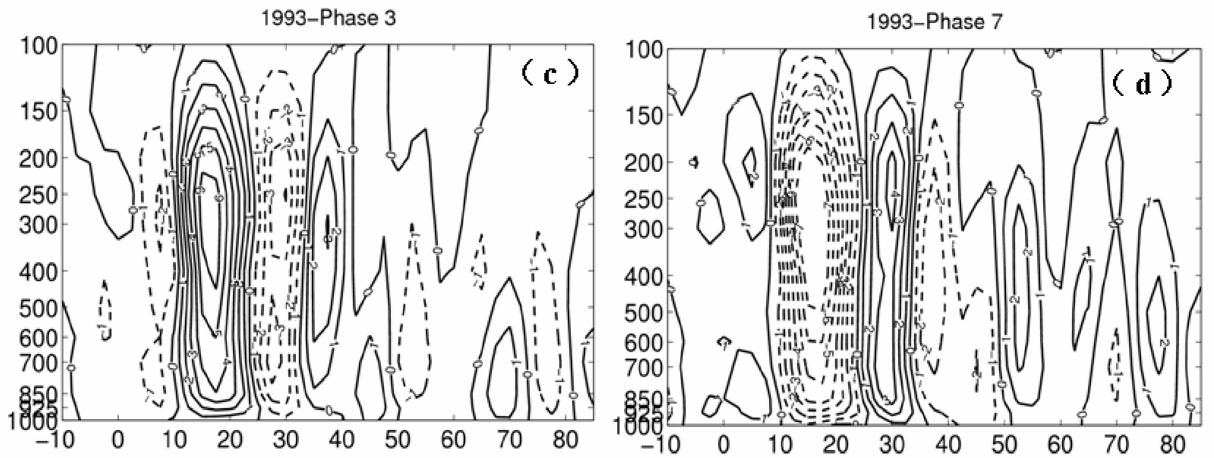


Figure 9. Composite latitude-height cross section of vertical velocity (averaged over 110-120°E) in the 10-25 day band in phase 3 and phase 7, in 1991 (a, c) and 1993 (b, d).

6 CONCLUSIONS AND DISCUSSION

Besides the overall consistency of Meiyu over YHRB, APD is a significant feature bounded by Yangtze River. The relationship between the Meiyu APD and the QBWO are discussed in detail, and main conclusions are as follows:

(1) From 1954 to 2005, there are totally 16 years with remarkable feature of APD, which enhanced strikingly since the 1990s with obvious oscillation cycles of 2 years and 4-6 years. During the APD year, the QBWO of precipitation was found to have obvious north- south differences. In the region with more rainfall, the QBWO was always more active.

(2) The APD of Meiyu and north-south movements of precipitation in eastern China belong to the same phase, that is, the SFND or SDNF in China can be explained by APD over YHRB to a large extent.

(3) During SDNF year, the 10-25 day filtered water vapor flux can spread to the area north of 30°N and there was strong water vapor flux convergence from mid- and high-latitudes to YHRB. However, the flux spread more southward and there was no significant southward convergence during the SFND year.

(4) During the positive phase of the SDNF year, the location of the WPSH ridge was to the north of 22°N, and the anti-cyclone at 850 hPa was more northward. What is more, the vertical circulation anomaly over the SCS and YHRB was also more northward.

Some conclusions in this paper are quite similar with the discussion on the original fields, which proves the significance of the QBWO of the Meiyu over YHRB. However, remarkable differences lie in the conception and practical statistics analysis. Besides, the sea surface temperature (SST) anomaly over Kuroshio at mid-latitudes, mentioned in Zhu et al.[6], has great impact on the APD of Meiyu and the QBWO of Meiyu, which is mentioned in Yin and Wang[11]. Thus, the SST anomaly over Kuroshio is of great importance on the imbalanced distribution of the precipitation of Meiyu both temporally and spatially. Therefore, it makes sense to have further study on this topic both from the perspectives of diagnostic analysis and numerical simulation.

Acknowledgement: We thanked Professor WANG Ya-fei for his enlightening discussions and support.

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Citation: YIN Zhi-cong, ZHU Li-juan and YUAN Dong-min. The north-south anti-phase distribution of rainfall in Meiyu periods and its relationship with quasi-biweekly oscillation in the atmosphere. *J. Trop. Meteor.*, 2014, 20(2): 154-162.