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The Relation between Atmospheric Intraseasonal Oscillation and Summer Severe Flood and Drought in the Changjiang–Huaihe River Basin

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ABSTRACT

The intraseasonal oscillation (ISO) is studied during the severe flood and drought years of the Changjiang–Huaihe River Basin with the NCEP/NCAR reanalysis data and the precipitation data in China. The results show that the upper-level (200 hPa) ISO pattern for severe flood (drought) is characterized by an anticyclonic (cyclonic) circulation over the southern Tibetan Plateau and a cyclonic (anticyclonic) circulation over the northern Tibetan Plateau. The lower-level (850 hPa) ISO pattern is characterized by an anticyclonic (cyclonic) circulation over the area south of the Changjiang River, the South China Sea, and the Western Pacific, and a cyclonic (anticyclonic) circulation from the area north of the Changjiang River to Japan. These low-level ISO circulation patterns are the first modes of the ISO wind field according to the vector EOF expansion with stronger amplitude of the EOF1 time coefficient in severe flood years than in severe drought years. The analyses also reveal that at 500 hPa and 200 hPa, the atmospheric ISO activity over the Changjiang–Huaihe River basin, North China, and the middle-high latitudes north of China is stronger for severe flood than for severe drought. The ISO meridional wind over the middle-high latitude regions can propagate southwards and meet with the northward propagating ISO meridional wind from lower latitude regions over the Changjiang–Huaihe River Basin during severe flood years, but not during severe drought years.

Key words: summer severe flood and drought in the Changjiang–Huaihe River Basin, intraseasonal oscillation, ISO circulation pattern

1. Introduction

Atmospheric intraseasonal oscillation has been the concern of meteorologists (Murakami et al., 1984; Lau and Chan, 1985; Li, 1991; Chen et al., 2000) since its discovery by Madden and Julian (1971) due to its close relation with anomalous rainfall and short-term climatic variation. For instance, precipitation in East China has a pronounced intraseasonal oscillation period. Intensified rainfall ISO is believed to be associated with flood. It indicates that the atmospheric 30–60-days oscillation has an important influence on the rainfall in East China (Li, 1992; Chen et al., 2001; Lu and Ding, 1996; Li and Li, 1999).

After studying the effect of ISO on the onset of the rain belt, (Lau and Chan, 1985) suggested that the Mei-yu front was related to the movement of a strong convection belt with a 45-day oscillation from the equatorial region to the north. The atmospheric ISO wave originates from the southern region of the South China Sea (Tao et al., 1998). Therefore, the northward propagation of this ISO wave would carry abundant water vapor to the Changjiang River Valley creating a favorable condition for large rainfall in this valley. This perspective has been confirmed by Chen et al. (2001). They pointed out that the torrential rain was clearly relevant to the activities of low-frequency circulation systems during 1998. However, the rainfall in the Changjiang–Huaihe River basin usually has the opposite relation to the atmospheric ISO activity of the South China Sea monsoon (Li and Li, 1997), and has a positive relation to the ISO activity of the Indian monsoon (Li and Li, 1999; Ye and Huang, 1992) and the western Pacific high (Sun and Tang, 1994). Although the low-frequency wave in lower latitudes may have different propagation directions, warm and moist air masses from different sources can all be transported

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to the Changjiang–Huaihe River basin in modes of low-frequency oscillation and interact with cold air masses from the north to produce heavy rain (Lu and Ding, 1996). As for the rainfall in East China, the mechanism involves the convection belt over the Philippines exciting a wavetrain of the atmospheric 30–60 day low-frequency oscillation (Ye and Huang, 1992).

Since the circulation distribution, evolution, and propagation of the atmosphere ISO in the flood years are greatly different from those in drought years (Chen et al., 1994, Huang et al., 1997), further work must be done on clearly identifying the characteristics and activities of ISO in severe flood and drought years in the Changjiang–Huaihe River basin. In particular, the ISO circulation pattern for severe flood and drought must be studied.

2. Data and analysis procedures

The National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis daily mean (0000, 0600, 1200 and 1800 UTC average) data on a 2.5°×2.5° grid from 1961 to 2000 are used together with the rainfall data compiled by the China Meteorological Administration. The rainfall in the Changjiang River basin is defined as the mean of the rainfall over 15 stations: Shanghai, Nanjing, Hefei, Bengbu, Anqing, Jiujiang, Nanchang, Hankou, Yueyang, Changde, Qingjiang, Gushi, Tunxi, Fuyang, and Hangzhou. In this study of the atmosphere ISO, the Murakami (1979) band-pass filter is used to get 20–70-day low-frequency oscillation. Before filtering, the seasonal tendency is removed in the following way.

If $R(m,n)$ stands for a variable on the nth day in the mth year, then, the daily climatology is expressed by

$$R_{\rm c}(n)=\sum_{m=1}^{40}R(m,n)/M\ ,$$

where M is the 40 years from 1961 to 2000.

So the daily anomaly with seasonal information is obtained as

$$R'(m,n)=R(m,n)-R_{\rm c}(t)\ .$$

The $R(m,n)$ is used to calculate the seasonal anomaly

$$R'_{\rm s}(m)=\sum_{n=1}^{153}R'(m,n)/N\ ,$$

and the daily anomaly

$$R''(m,n)=R'(m,n)-R'_{\rm s}(m)\ ,$$

where N is the 153 days from 1 May to 30 September. The Murakami (1979) band-pass filter is applied to R''.

3. Characteristics of periods in precipitation and circulation

According to the percentage departure of summer (June 1 to August 31) rainfall from the 1961–2000 mean in the Changjiang–Huaihe River basin, the six severe flood years (with percentage departure above 40%) are 1969, 1980, 1991, 1996, 1998, and 1999. The five severe drought years (with percentage departure below −25%) are 1961, 1966, 1967, 1978, and 1985. The temporal evolution of dekad rainfall in the Changjiang–Huaihe River basin shows remarkable ISO. The intensity of the ISO of rainfall anomaly is stronger in severe flood years than in severe drought years (figure not shown). To further clearly understand the characteristics of time-frequency of rainfall, Morlet wavelet analysis is carried out with the daily rainfall data in the Changjiang–Huaihe River basin. Figure 1 shows the time-frequency diagrams for the modules of the Morlet wavelet transform coefficients of the daily rainfall in the Changjiang–Huaihe River Basin during the period from 1 May to 31 August in the years of severe flood and drought.

For severe flood (Fig. 1a), the ISO signals become very strong in summer. During the period of 1 June–1 August in 1969, the 40–50-day signal as well as the 20–30-day signal are very pronounced. Three kinds of ISO signals are obvious in the summer of 1980: one of about 70 days, another of 12–15 days, and a third of 5–7 days. The pronounced period in 1991 is centered around 20–30 days, which coincides with the result of Yang et al. (1994). Yang et al. (1994) showed the Meiyu rainfall of 1991 had a 20–25-day period based on the power spectral method. Now let us examine the wavelet analysis of rainfall in 1996. We can see obvious ISO in the summer of 1996: a 10–25-day period and a period centered at 55–60 days. The main period of rainfall in 1998 is around 25–30 days. The wavelet analysis of rainfall also shows the dominant periods of about 60 days, 35 days and 15–20 days in the summer of 1999.

In contrast, the ISO signals in severe drought years (Fig. 1b) are weaker than those in severe flood years (Fig. 1a). The periods of 25–30 days, 50 days and 5–10 days are dominant in 1961. The near 10-day period and 40–50-day period are strong in 1966. The main period in 1967 is 7–10 days. Another period changes from 17 days to 22 days, and its signal increases with time. The period of 45–50 days is also relatively obvious in May and June of 1967. Three kinds of periods are dominant in 1978: 10–16 days, around 50 days and

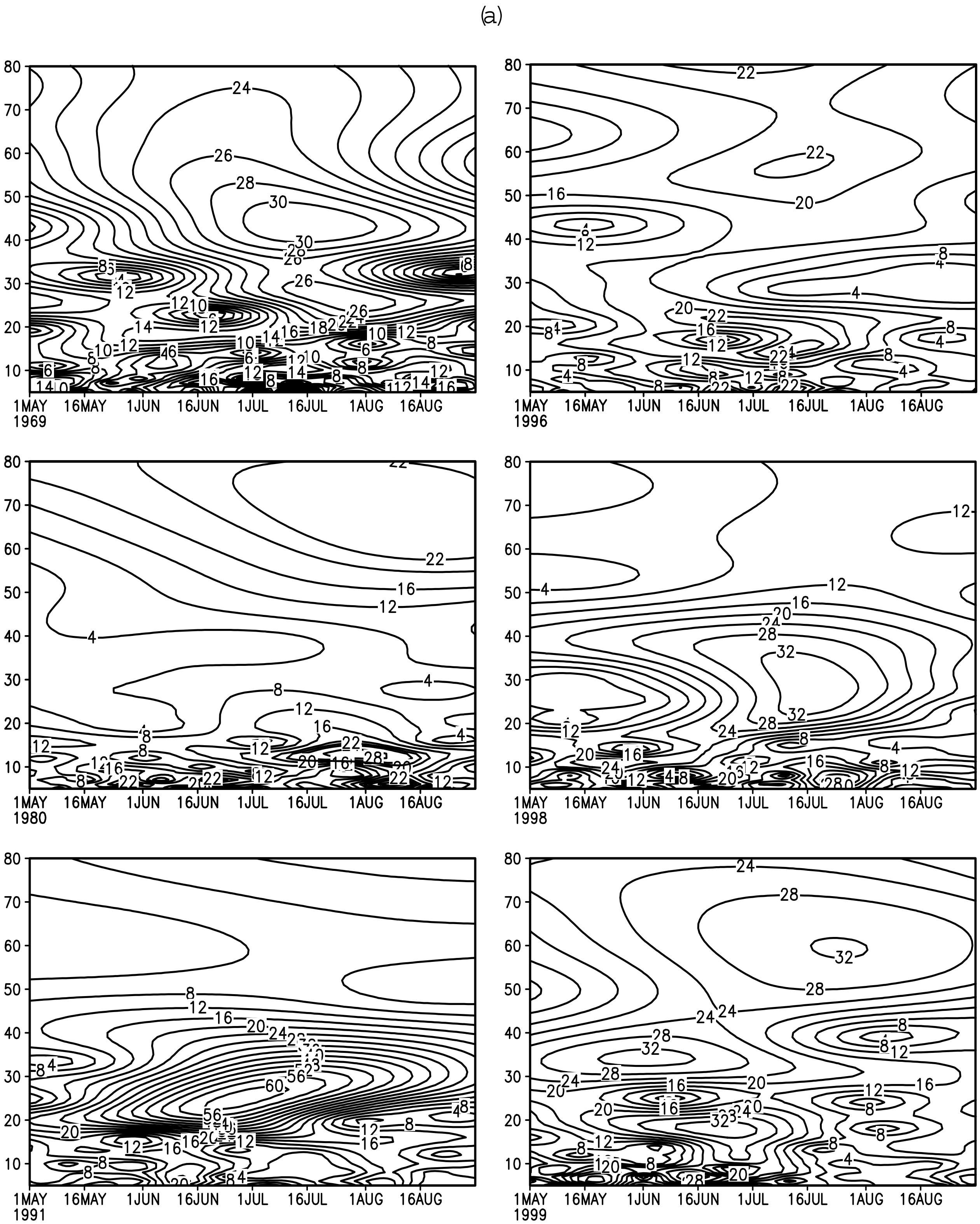

Fig. 1. Time-frequency diagrams for the modules of the Morlet wavelet transform coefficients of the daily rainfall in the Changjiang–Huaihe River Basin (a) in severe flood years,(b) in severe drought years. The ordinate is period in days.

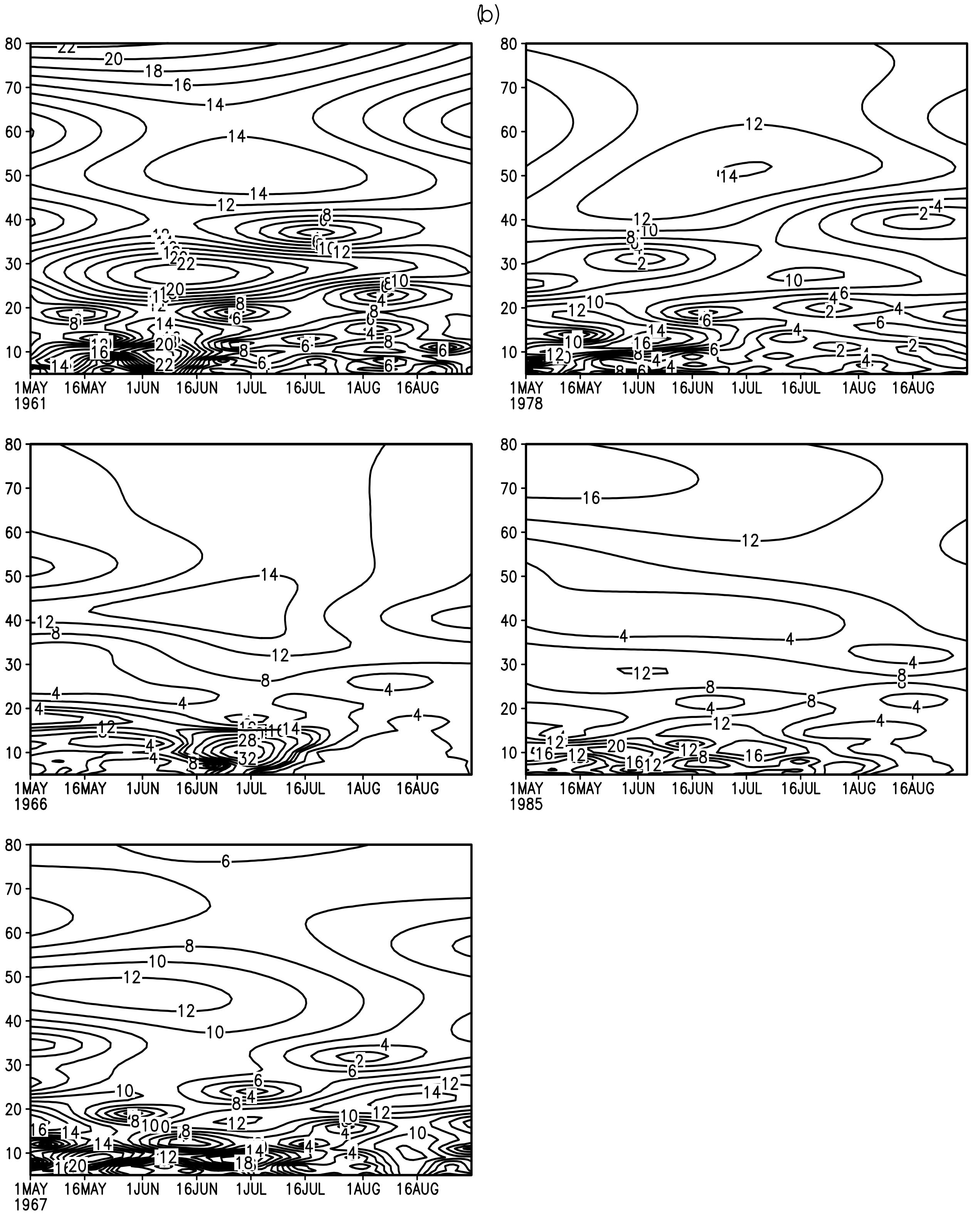

Fig. 1. (Continued)

(a)

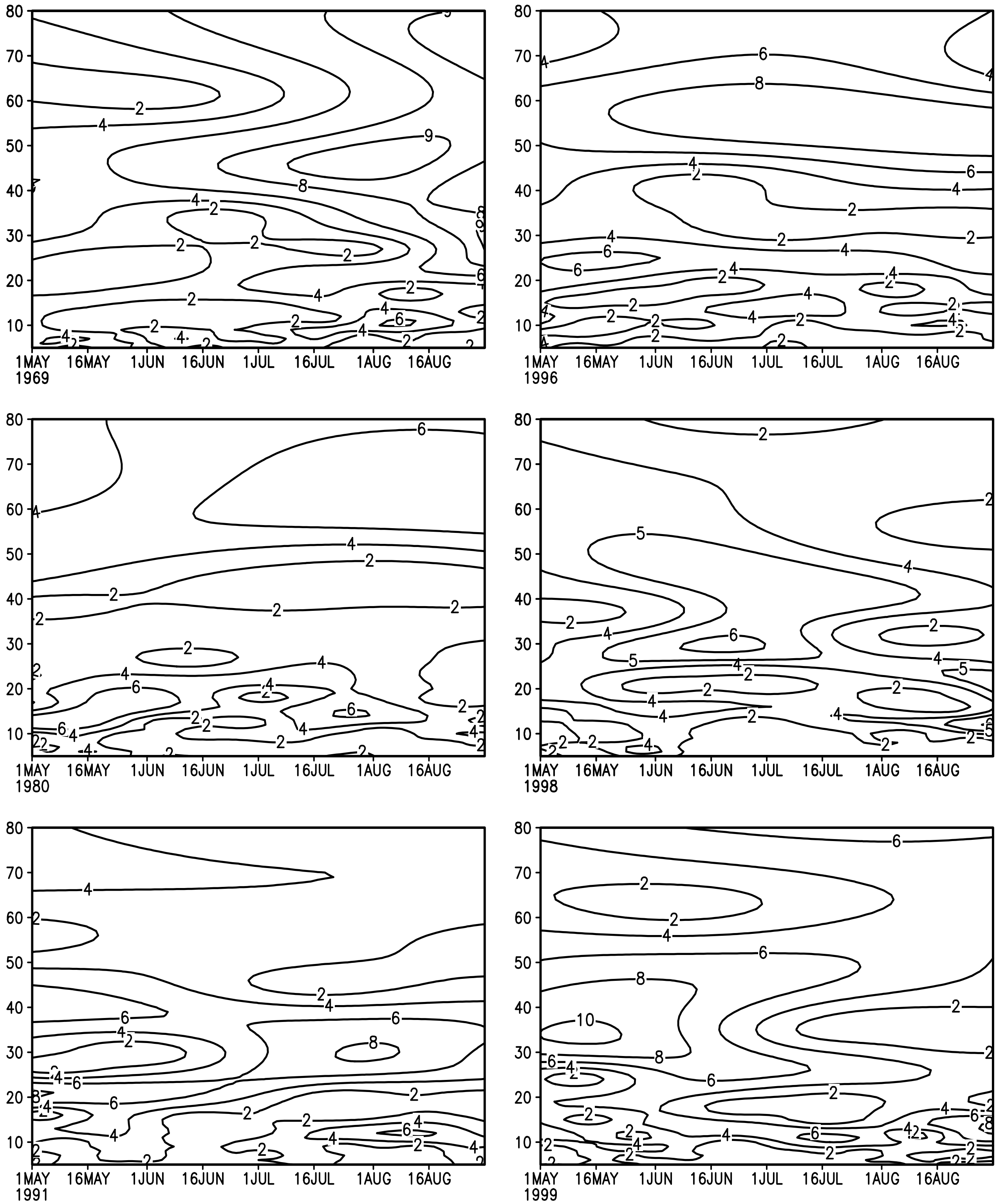

Fig. 2. As in Fig. 1, except showing the mean zonal wind in the domain of 20°–35°N, 100°–120°E at 850 hPa.

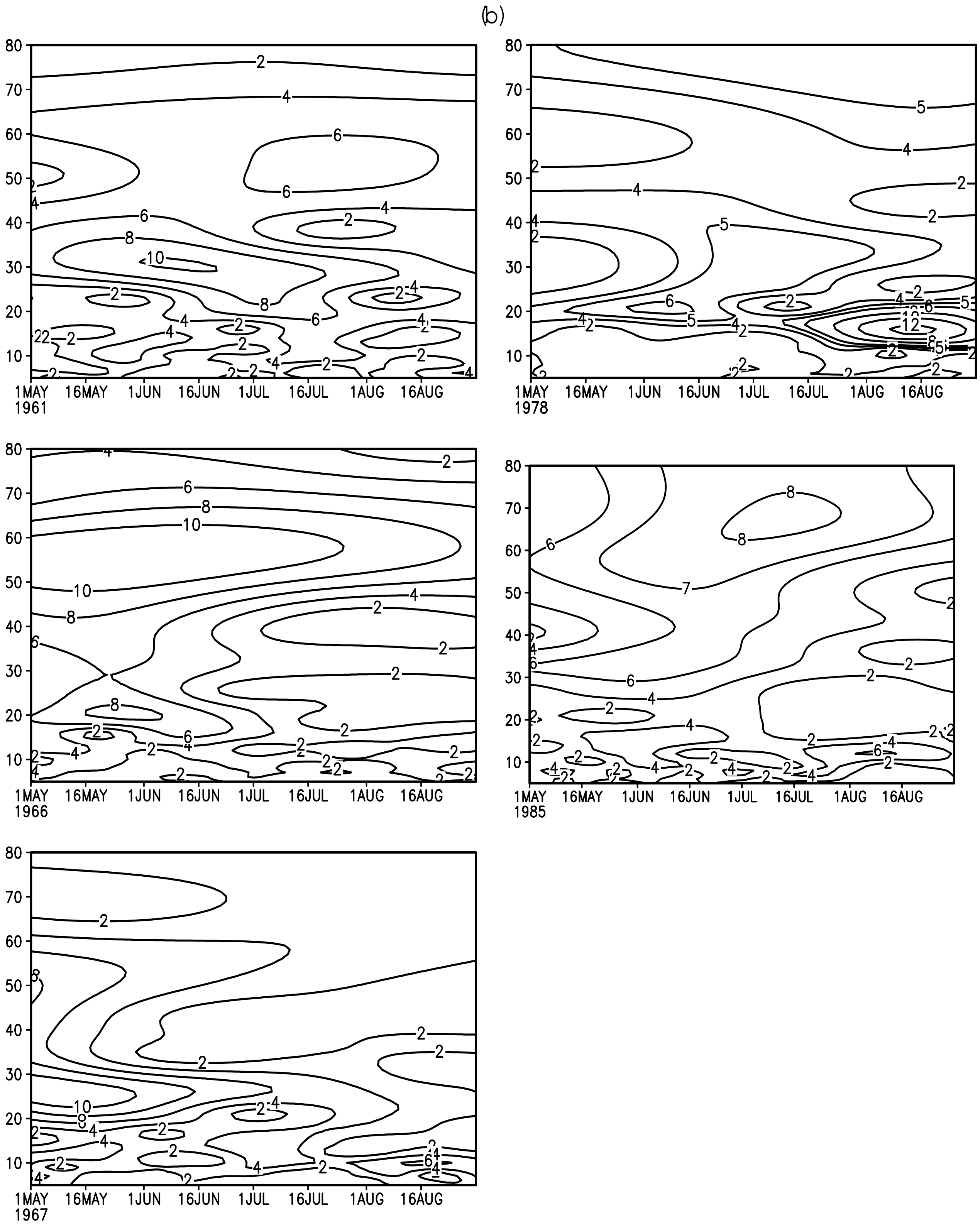

Fig. 2. (Continued)

25–30 days. In 1985, strong period signals are found around 10 days, 65–70 days, and 30 days.

The same kind of investigation is also carried out for the mean zonal wind in the domain of 20°–35°N, 100°–120°E, at 850 hPa (Fig. 2). This investigation shows that the main periods of zonal wind are, to a certain extent, identical with those of the rainfall in each year. The ISO signal of zonal wind is also enhanced in summer.

For severe flood, the main periods are 40–50 days and 20–30 days in 1969. Periods of 60–70 days and 10–15 days are pronounced in 1980. In 1991, the main period increases from 20 days in May to 30 days in summer. In 1996, the signal of the 55–60-day period is pronounced, and the signals of the 10–15-day period and the near 25-day period are also obvious. The period signal is strong in 1998: one period about 30 days, the other about 45 days. In 1999, the main period is about a 35-day period in May, and then both increase gradually changes to 55 days and 25–30 days in the summer. The 10–15-day period signals is also strong. On the whole, the main periods of zonal wind are the same as those of rainfall in each severe flood year.

In severe drought years, main periods of zonal wind at 850 hPa are mostly the same as those of rainfall. In 1961, the signal around the 30-day period is obvious and is strongest in June. Another period is centered at 50–55 days. The two periods are the same as those of the rainfall of the same year. The period with a strong signal in 1966 is around 50–60 days. Upon comparison of Fig. 1b and Fig. 2b, we find the main period center of zonal wind is not identical with that of the rainfall in 1966. In 1967, the main period changes from 25 days to 20 days, and the signal intensity decreases from May to August. Another strong signal is about 10 days in summer 1967. The signal of the 15–20 day period is very pronounced in 1978. Another strong period increases from 20 to 35 days. There is very little signal around the period of 50 days, which is not identical with that of rainfall in the same year. In May 1985, there are pronounced oscillations with period centered at 75 days. The main periods are 65–70 days and 30–35 days in summer 1985.

The above results indicate that the intraseasonal periods are the main periods, which exist in both precipitation of the Changjiang–Huaihe River basin and zonal circulation at 850 hPa. The periods of rainfall and atmospheric circulation are mostly identical in each year. This indicates the atmospheric ISO is responsible for flood and drought in the Changjiang–Huaihe River basin.

4. Characteristics of the atmosphere ISO in severe flood years and severe drought years

The composites of JJA-mean ISO wind field at 850 hPa, 500 hPa, and 200 hPa are analyzed respectively in order to study the relationship between the atmospheric ISO and severe flood (Fig. 3) and drought (Fig. 4). For severe flood, the composite features at 850 hPa (Fig. 3c) are characterized by a pronounced ISO anticyclonic circulation over the area south the of the Changjiang River, the South China Sea, and the western Pacific, and an ISO cyclonic circulation from the area north of the Changjiang River to Japan. An ISO southerly prevails south of the Changjinag–Huaihe River basin. An ISO northerly prevails north of the Changjiang–Huaihe River basin. The ISO southerly is stronger than the ISO northerly. The ISO southerly and the ISO northerly form a strong convergence zone that is just in the area of the Changjiang–Huaihe River basin. Using the data of 1980, Chen et al. (1994) also found this phenomenon of convergence over the Changjiang–Huaihe River basin. The same ISO pattern also shows up at 500 hPa (Fig. 3b). In addition, the ISO westerly dominates the zonal belt from the southeastern Tibetan Plateau to Japan.

For severe drought, the distribution of the ISO circulation displays almost the reverse character at 850 hPa (Fig. 4c) in comparison with severe flood (Fig. 4c). The area south of the Changjiang River, the South China Sea, and the western Pacific are controlled by an ISO cyclonic circulation. The area north of the Changjiang River and Japan are controlled by an ISO anticyclonic circulation. The ISO circulations for severe drought appear to be weaker and smaller than those for severe flood. The ISO southerly to the north of the Changjiang River and the ISO northerly to the south of the Changjiang River diverge from the Changjiang–Huaihe River basin. As a result, a strong divergence zone is located over the Changjiang–Huaihe River basin. Thus such an ISO circulation pattern is unfavorable for the rainfall in the Changjiang–Huaihe River basin. At 500 hPa (Fig. 4b), the ISO pattern is similar to that of 850 hPa. But these ISO circulations shift westward in comparison with those of 850 hPa, leading to the ISO easterly flow from the southeastern Tibetan Plateau to the Changjiang River.

At 200 hPa for the severe flood (Fig. 3a), an ISO anticyclonic circulation is located in the southeast

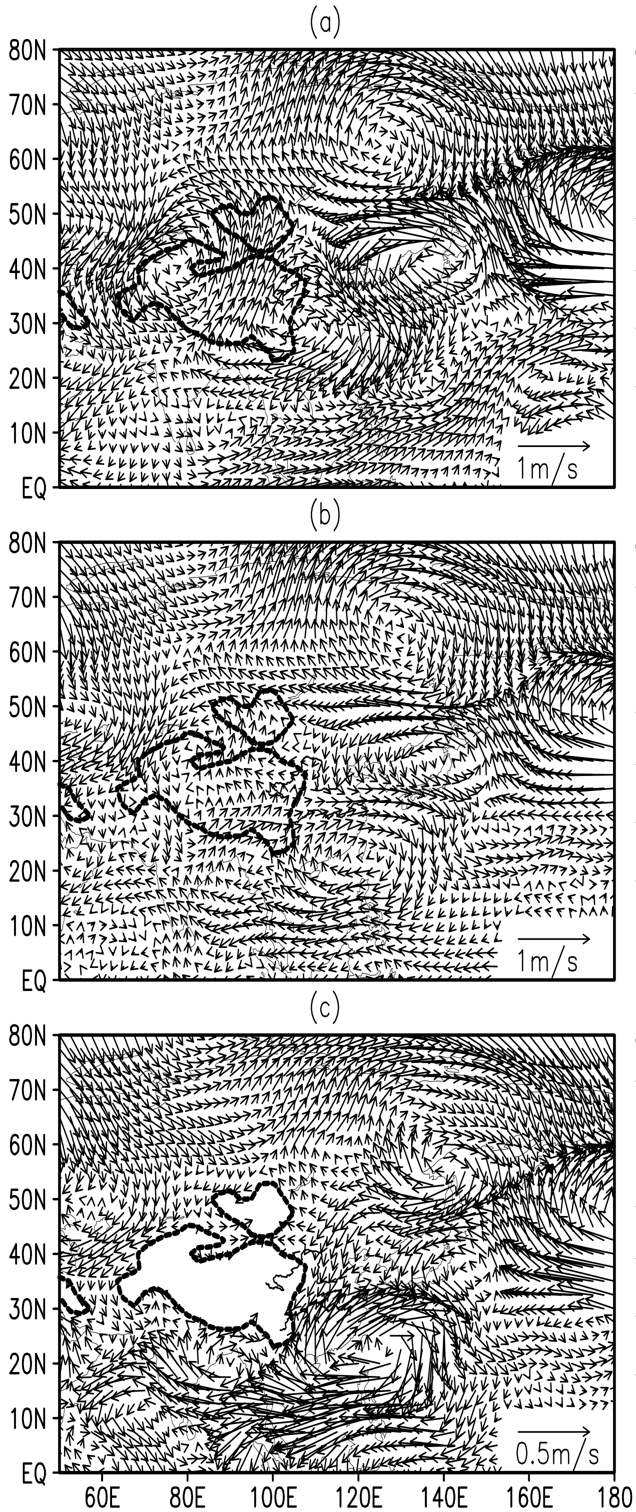

Fig. 3. The composites of JJA-mean ISO wind vector for severe flood (a) at 200 hPa, (b) at 500 hPa, and (c) at 850 hPa.

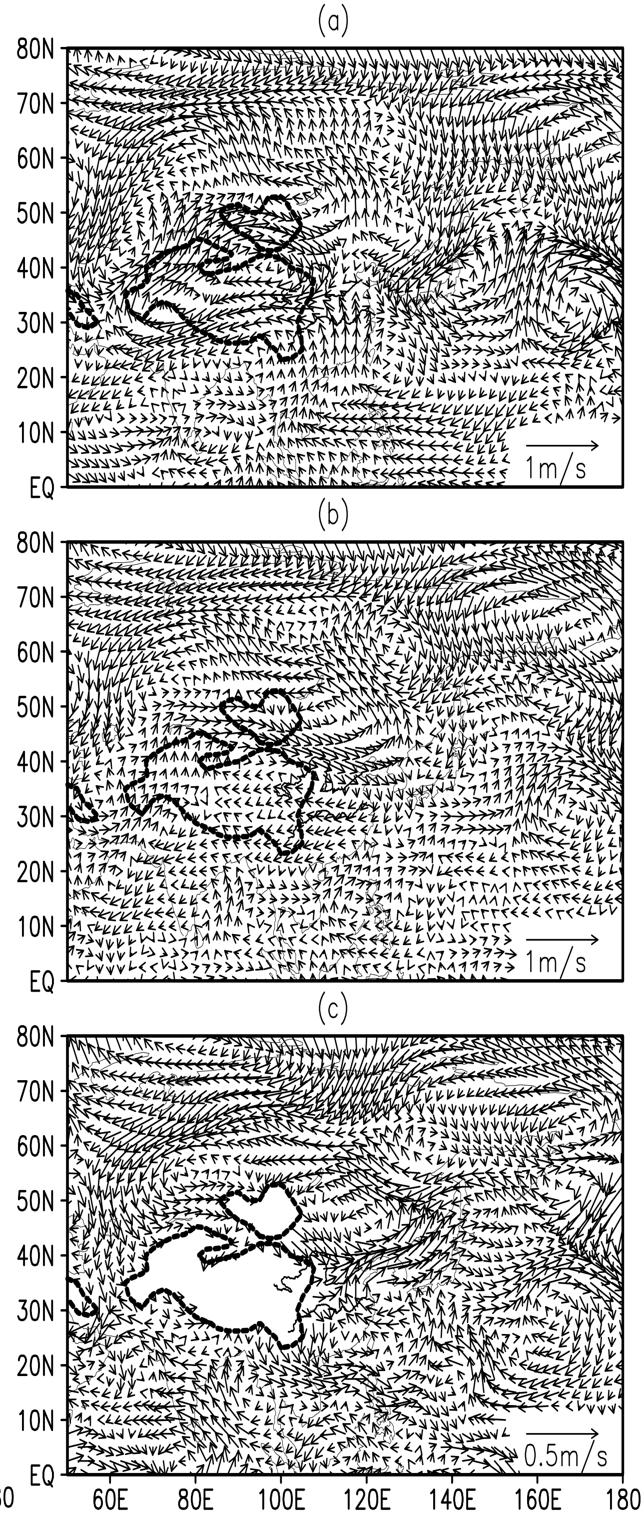

Fig. 4. As in Fig. 3, but for severe drought.

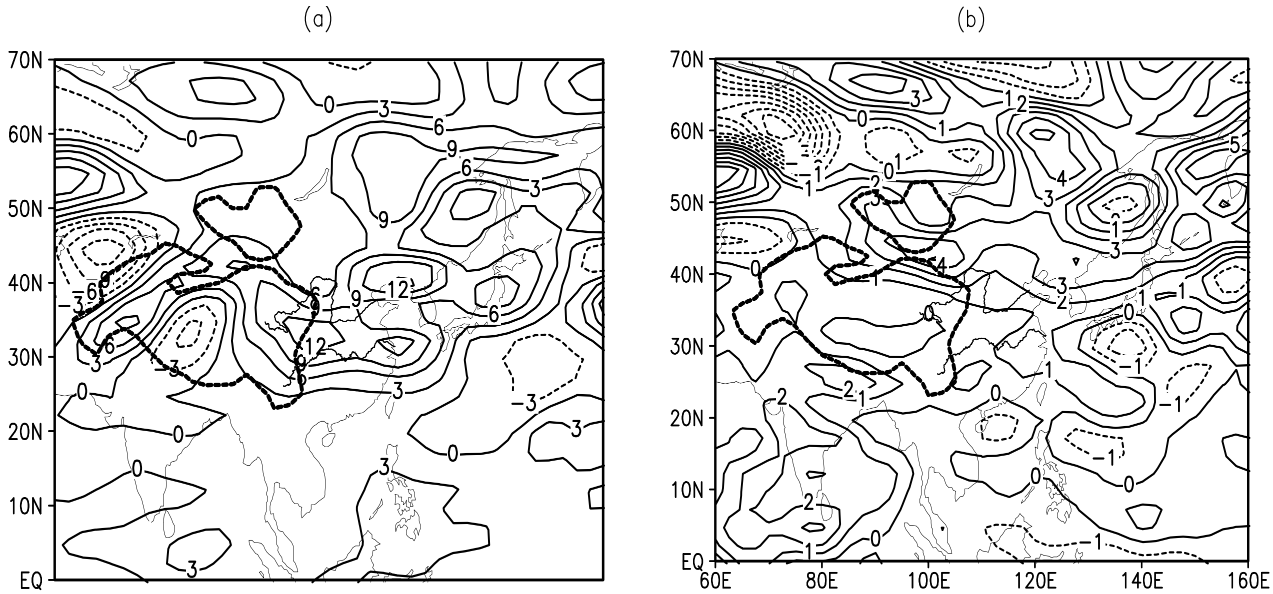

Fig. 5. Composite difference of JJA-mean atmospheric ISO kinetic energy between severe flood years and severe drought years (a) at 200 hPa, (b) at 500 hPa.

of the Tibetan Plateau with the center at 30°N, 105°E, and an ISO cyclonic circulation is located in the northwest of the Tibetan Plateau with the center at 40°N, 75°E. Therefore, an ISO northerly dominates the Changjiang–Huaihe River basin and the area south of it. By contrast, for severe drought (Fig. 4a), the whole north of the Tibetan Plateau is controlled by an ISO anticyclonic circulation centered at 40°N, 95°E. The south of the Tibetan Plateau is controlled by an ISO cyclonic circulation centered at 20°N, 95°E. So an ISO southerly dominates the Changjiang–Huaihe River basin and the area south of it.

Figure 3b also reveals that for severe flood, the areas from Lake Baikal to Okhotsk at middle-high latitude are controlled by an atmosphere ISO anticyclonic circulation with center at 65°N, 130°E. For severe drought (Fig. 4b), the Lake Baikal regions are dominated by an atmosphere ISO cyclonic circulation with a center at 48°N, 110°E. Such an ISO pattern also exists at 850 hPa and 200 hPa.

To describe the intensity of atmospheric ISO activity, the band-pass filtered data (u_b, v_b) are used to calculate the ISO kinetic energy $K{=}(u_b^2{+}v_b^2)/2$. Figure 5 respectively shows the composite difference of JJA-mean atmospheric ISO kinetic energy between the severe flood years and severe drought years at 200 hPa and 500 hPa. It shows that the ISO kinetic energies in severe flood years and in the drought years are very different in North China and the middle-high latitude regions north of China. A large difference also exists over the Changjiang–Huaihe River basin especially at 200 hPa. This indicates that the atmospheric ISO activity over these areas is stronger in the severe flood years than in severe drought years.

To emphasize the main spatial pattern, vector empirical orthogonal function (EOF) expansion is adopted in this study. The data used for the vector EOF analysis are the daily ISO wind from 1 June to 31 August of severe flood years (552 days intotal) and drought years (460 days in total). Figure 6 respectively depicts the spatial patterns and the corresponding time coefficients of the EOF1 for severe flood and drought years. In severe flood years (Fig. 6a), the first EOF mode accounts for 23% of the total variance. The pattern is similar to that in the composite analysis (Fig. 3c). The main feature of the vector EOF1 is an ISO anticyclonic circulation in the south of the western North Pacific region, and an ISO cyclonic circulation in the north of the western North Pacific region. The ISO anticyclonic circulation is centered between Taiwan and the Philippines. The ISO cyclonic circulation is centered over the area southeast of Japan. In the severe drought years (Fig. 6b), the ISO pattern is the reverse of that in the severe flood years (Fig. 6a). The EOF1 mode of severe drought years accounts for 15% of the total variance. Since in both severe flood and drought cases, the Changjiang–Huaihe River basin is influenced by the pair of ISO vortexes, the pair of ISO vortexes is the main ISO system responsible for the severe flood/drought over the Changjiang–Huaihe River basin.

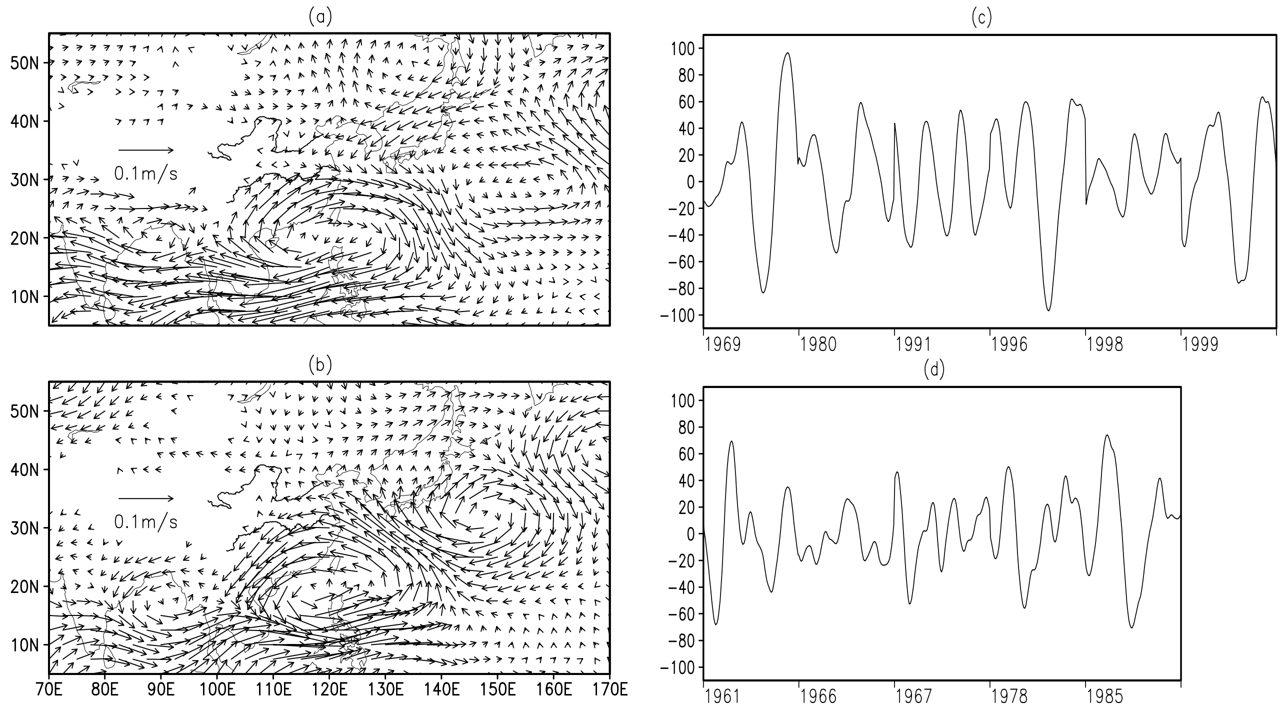

Fig. 6. EOF1 spatial pattern at 850 hPa for (a) severe flood years, (b) severe drought years. Time coefficient of EOF1 for (c) the severe flood years, and (d) severe drought years.

The time coefficients of EOF1 for severe flood years and severe drought years (Figs. 6c and 6d) reveal that the amplitude of the time coefficient for both severe flood and drought years is generally characterized by a stronger intensity of positive phase than negative phase (Figs. 6c and 6d). The amplitude of the time coefficient for severe flood years is larger than that for severe drought years. This indicates that the pair of ISO vortexes in severe flood years is stronger than that in severe drought years. The ISO southwesterly from the anticyclonic ISO circulation and the ISO northeasterly from the cyclonic ISO circulation are also stronger, as is the convergence from the two ISO vortexes over the Changjiang–Huaihe River basin.

5. Characteristics of the meridional propagation of the atmospheric ISO

From the above analysis, we can conclude that severe flood and drought of the Changjiang–Huaihe River basin are associated with the atmospheric ISO activity in middle-high latitudes. In that way, how does the atmospheric ISO in middle-high latitudes influence the Changjiang–Huaihe River basin?

Figure 7 gives time-latitude sections of the mean ISO meridional wind over 107.5°–120°E at 500 hPa in flood and drought rears, respectively. Comparison of these figures shows that the propagation of the atmospheric ISO displays a large difference between severe flood years and severe drought years. In the severe years (Fig. 7a), the meridional ISO wind at middle-high latitudes not only has an obvious center of ISO, but also propagates southward to affect the Changjiang–Huaihe River basin. Another characteristic is that the ISO meridional wind propagates northward from the lower latitude region, which converges at 30°N with the southward propagating ISO meridional wind. In each year, the ISO meridional wind appears to have different propagation features. In 1980, the ISO meridional wind does not obviously propagate northward from low latitudes. In the five other severe flood years, we can find the southward propagation from middle-high latitudes and the northward propagation from low latitudes.

In severe drought years (Fig. 7b), the southward propagation of ISO meridional wind from middle-high latitudes is seldom found. We can find the southward propagation of ISO meridional wind in the end of August of 1961, 1966, 1978, and 1985. The ISO meridional wind from low latitudes propagates northward and cross the Changjiang–Huaihe River basin in 1961 and 1966. So no convergence of the two ISO waves from high and low latitudes takes place over the Changjiang–

Huaihe River basin. It can be seen that the meridional propagation of ISO meridional wind is the important process of the effect of ISO at middle-high latitudes on the rainfall of the Changjiang–Huaihe River basin.

Consequently, the difference in ISO propagation features is remarkable between severe flood years and severe drought years. The ISO waves from middle-high latitudes and low latitudes converge around 30°N in severe flood years. In severe drought years, although the ISO can propagate northward from low latitudes, there is no southward propagating ISO and no convergence around 30°N. These differences can also be found at 850 hPa. We only present the time-latitude sections of 1998 and 1961 (Fig. 8), which are characterized by the remarkable above-mentioned propagation features. In 1998, the activity of ISO is very strong around 30°N, and the ISO from middle-high latitudes propagates southward and the ISO from low latitudes propagates northward, and the two ISO waves converge around 30°N. In 1961, the activity of ISO around 20°N is greater and the activity of ISO around 30°N is less compared with 1998. The ISO meridional wind from low latitudes can propagate northward and cross 30°N, but the ISO of middle-high latitudes cannot propagate to the Changjiang–Huaihe River basin. Researchers have discovered that the rainfall in the

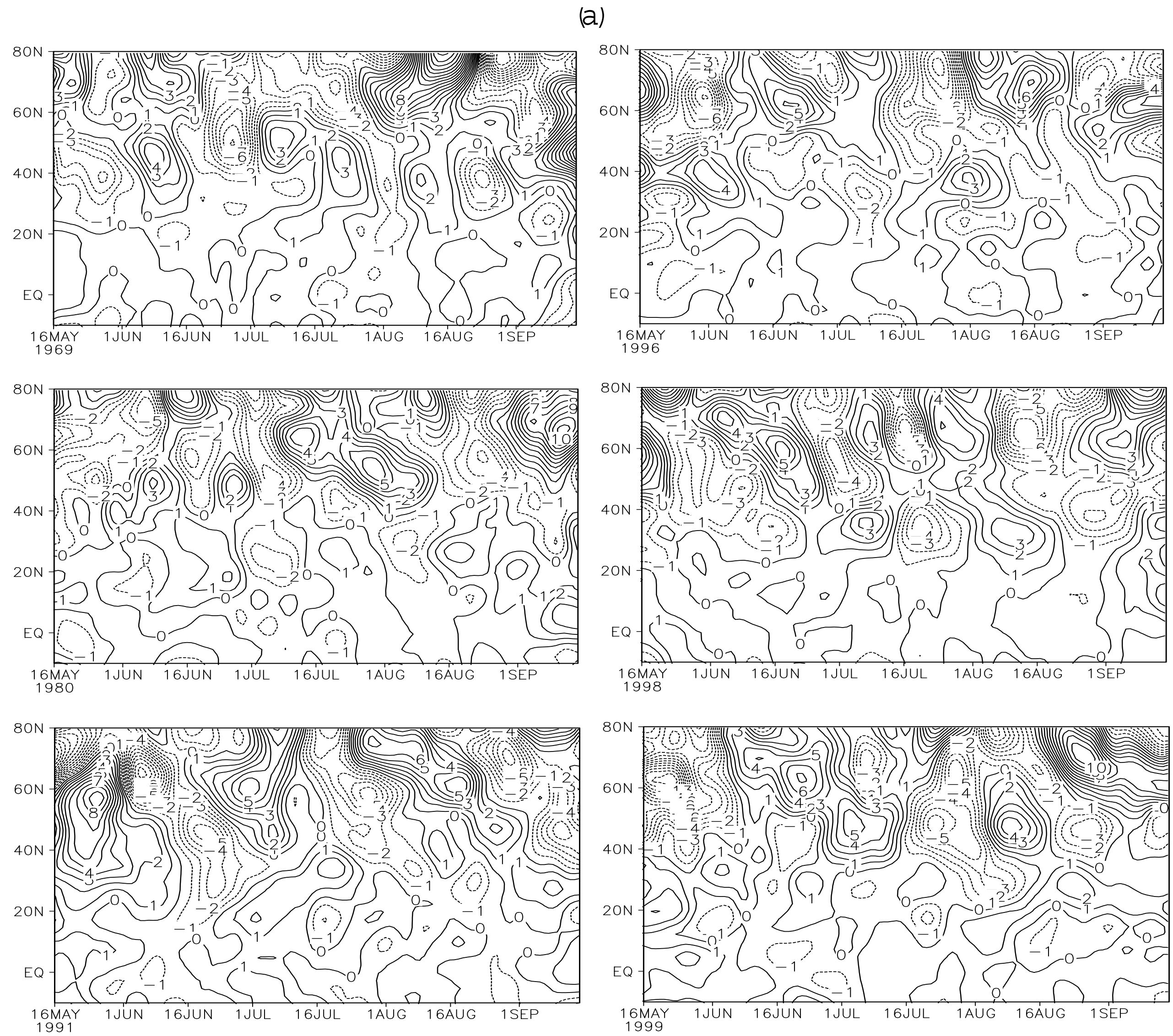

Fig. 7. Time-latitude section of the ISO meridional wind averaged over 107.5°E to 120°E at 500 hPa, (a) in severe flood years, (b) in severe drought years.

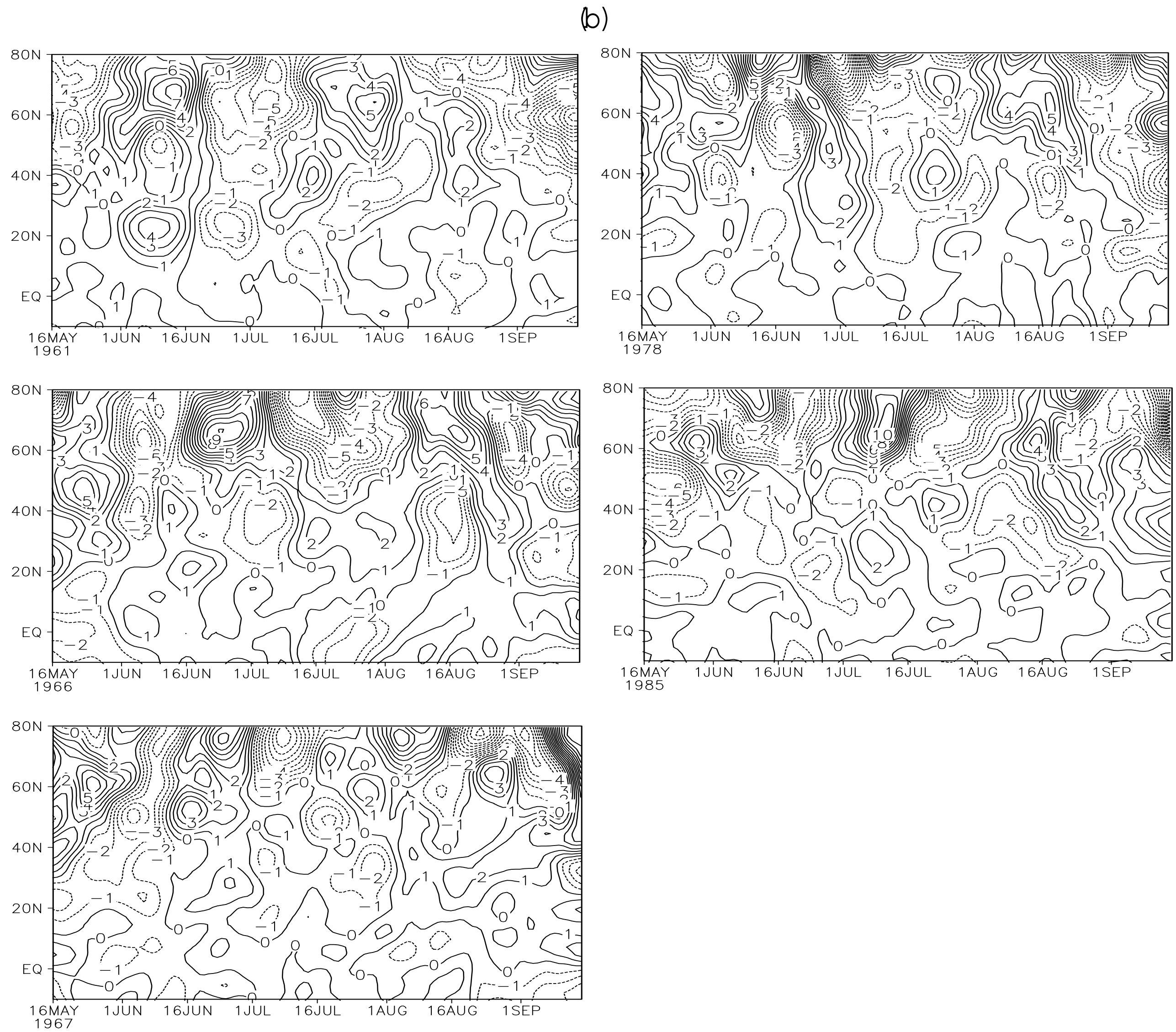

Fig. 7. (Continued)

Changjiang–Huaihe River basin is related to the propagation direction of low frequency waves (Chen et al., 1994; Lu and Ding, 1996; Huang et al., 1997; Chen et al., 2001). They point out that the interaction between the low-frequency waves from both north and south over the Changjiang–Huaihe River basin is favorable to the occurrence of hard rainfall. In summary, the meridional propagation of the atmospheric ISO can influence the rainfall anomaly over the Changjiang–Huaihe River basin.

6. Conclusion

Morlet wavelet analysis reveals that rainfall over the Changjiang–Huaihe River basin and the mean zonal wind for the area of 20°–35°N, 100°–120°E at 850 hPa display distinct intraseasonal periods in the summers of severe flood and drought years. For each flood/drought year, the main periods of rainfall are mostly identical with those of zonal wind.

The difference of ISO circulation in summer between severe flood and drought is large. The ISO circulation patterns are even out of phase. For severe flood (drought), an ISO anticyclonic (cyclonic) circulation is located over the area south of Changjiang, the South China Sea, and the western North Pacific, while an ISO cyclonic (anticyclonic) circulation is located over the area north of Changjiang to Japan at

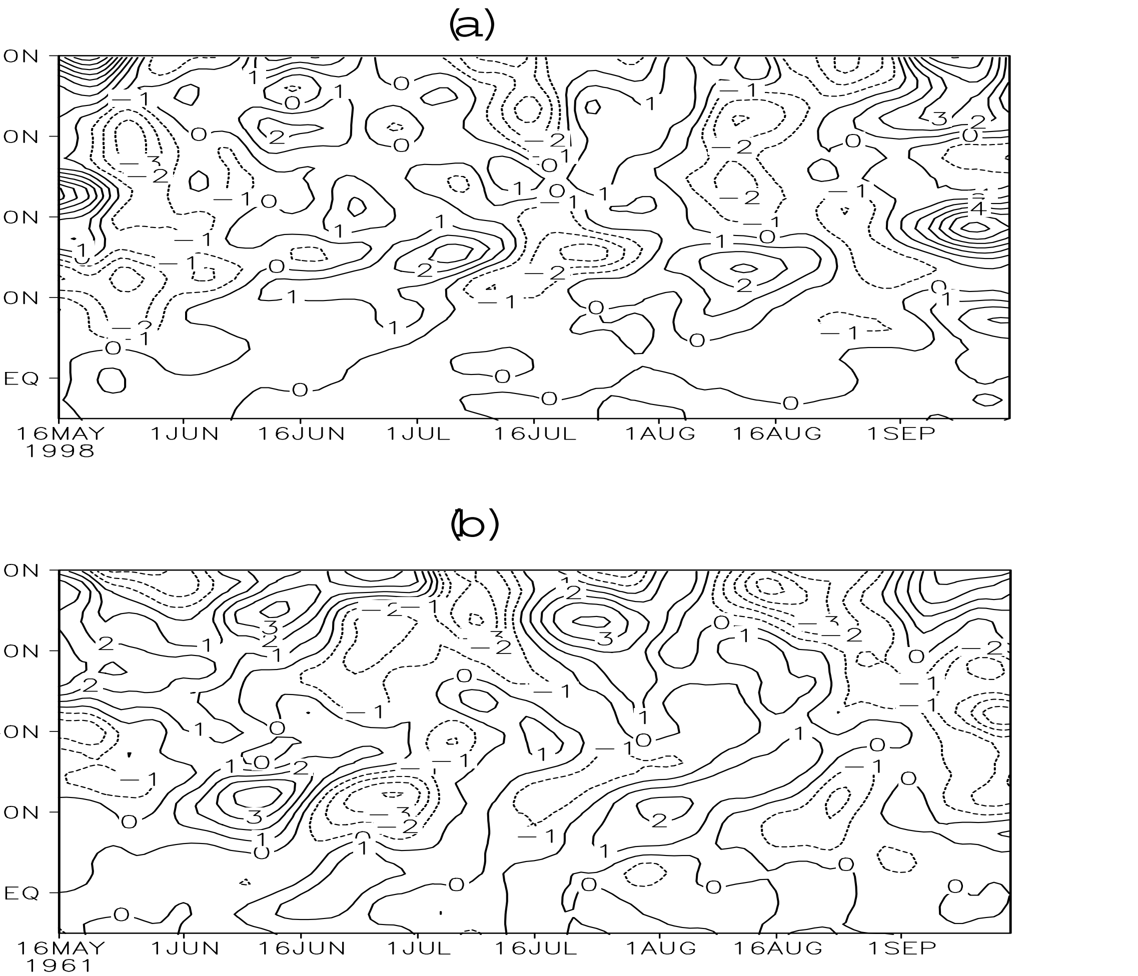

Fig. 8. As in Fig.7 but at 850hPa, (a) in 1998, (b) in 1961.

850 hPa. These ISO patterns also exist at 500 hPa. For severe flood, the ISO southerly wind in the west part of the ISO anticyclonic circulation and the ISO northerly wind in the west part of the ISO cyclonic circulation form a convergent zone over the Changjiang–Huaihe River basin, creating a favorable condition for flood in the Changjiang–Huaihe River basin, and opposite circulations for severe drought. According to the vector EOF expansion, these ISO patterns are the first modes of the ISO wind field in severe flood and drought years respectively. The ISO pattern in severe flood years is stronger than in severe drought years. At 200 hPa, an ISO cyclonic (anticyclonic) circulation lies in the south of the Tibetan Plateau, and an ISO anticyclonic (cyclonic) circulation is located in the north of the Tibetan Plateau for severe flood (drought).

The ISO activities over the Changjiang–Huaihe River basin, North China, and the middle-high latitude regions north of China at 500 hPa and 200 hPa for the severe flood are stronger than those for severe drought. A strong ISO anticyclonic circulation dominates the Baikal regions for severe flood. In contrast, a weak ISO cyclonic circulation occupies the Baikal regions for severe drought.

In severe flood year, the main characteristics of the ISO meridional wind in the time-latitude cross section are the southward propagation from middle-high latitudes and northward propagation from low latitudes, and the two ISO waves converge over the Changjiang–Huaihe River basin. In severe drought years, there is no southward propagation ISO wave from middle-high latitudes, and an ISO wave may propagate northward and pass the Changjiang–Huaihe River basin. It suggests that the interaction of the atmospheric ISO between middle-high and low latitudes plays an important role in severe flood/drought formation over the Changjiang–Huaihe River basin.

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江淮流域夏季严重旱涝与大气季节内振荡

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摘　要

利用NCEP/NCAR的再分析资料和中国气象局国家气象中心提供的中国台站降水资料，分析研究了江淮流域大范围严重旱涝的20–70天大气季节内振荡（ISO）特征。结果表明，对应江淮流域严重涝年，200 hPa青藏高原北部存在ISO气旋性环流，青藏高原南部存在ISO反气旋性环流；大气ISO流型在对流层中低层850 hPa主要是我国长江以南、南海和西太平洋地区为大气ISO反气旋性环流，我国长江以北到日本地区的大气ISO气旋性环流，我国江淮流域位于这两个ISO涡旋西侧偏南气流和偏北气流的交汇处；旱年反之。利用向量经验正交展开方法得到，上述大气ISO环流型分别是旱涝年大气ISO流型的第一模态，并且涝年大气ISO流型的振幅强，旱年振幅弱。进一步分析揭示，严重洪涝（干旱）年分别对应对流层中上层江淮流域及其以北的中高纬度地区有强（弱）的大气ISO活动。中高纬度地区的大气ISO在严重洪涝年向南传播，与低纬度向北传播的大气ISO在江淮流域汇合；而在严重干旱年，虽然大气ISO可向北传播，但向南的传播却很不明显。

关键词：江淮流域夏季严重旱涝，季节内振荡，大气ISO环流型