Impacts of 30-60-Day Oscillations over the Subtropical Pacific on the East Asian Summer Rainfall *

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ABSTRACT

The relationships between the precipitation over East Asia (20°-45°N, 110°-135°E) and the 30-60-day intraseasonal oscillation (ISO) over the Pacific during the boreal summer are studied in the paper. The daily wind and height fields of NCEP/NCAR reanalysis data, the 24-h precipitation data of 687 stations in China during 1958-2000, and the pentad precipitation of CMAP/NOAA from 1979 to 2002 are all analyzed by the space-time filter method. The analysis results, from every drought and flood summer in four different regions of East Asia respectively during 1958-2000, have shown that the flood (drought) in the East Asian summer monsoon region is absolutely companied with the strongly (weakly) westward propagations of ISO from the central-east Pacific, and depends little on the intensity changes of the East Asian summer monsoon. And the westward ISO is usually the low-frequency cyclones and anticyclones from the Bay of Alaska in northeastern Pacific and the Okhotsk in the northwestern Pacific of mid-high latitudes, and the ISO evolving in subtropical easterlies. In mid-high latitudes the phenomena are related to the westward propagating mid-ocean trough and the retreat of blocking high. Therefore the westward propagating ISO from the central-east Pacific to East Asia is indispensable for more rainfall occurring in East Asia in summer, which results from the long-wave adjustment process in the mid-high latitudes and ISO evolving in tropical easterlies.

Key words: intraseasonal oscillation (ISO), zonal propagation, summer drought and flood, space-time spectral analysis, Pacific

1. Introduction

At the beginning of 1980s Chinese scientists put systematically forward the concepts of East Asian monsoon (Chen and Jin, 1982; Chen, 1984; Tao and Chen, 1987). Then the study of East Asian monsoon was further carried out (Chen et al., 1991; Ding and Murakami, 1994). Tao and Chen (1987), Ma and Ding (1997) summarized the achievements made by the Chinese scholars in early times and nowadays, but the scholars, who advanced the systematical concepts of East Asian monsoon, considered more on the mechanism of the meridional atmospheric systems, i.e., the interactions between the Australian atmospheric systems and East Asian atmospheric systems, and ignored the influences of the transmeridional atmospheric disturbances on East Asian monsoon. Although the climate characteristics of the zonal atmospheric activities have been studied at some regions, such as the Tibetan Plateau (Ye and Gao, 1979; Wu and Zhang, 1998, 1999) and the West Pacific warm pool (Huang and Li, 1988) for over 20 yr till now, the summer rainfall of East Asia still embarrasses the short-term climate prediction due to complicated factors presented by many scholars such as Webster et al. (1998), Yasunari and Tetsuzo (1991). Thus the researchers were urged to look for the neglected and potential domains, and especially the influences of the central-east North Pacific on the adjacent East Asia are not quite clear yet.

Since Madden and Julian (1971, 1972) detected 40-50-day oscillations, many researchers have proved that the 30-60-day intraseasonal oscillation (ISO) is one of dominant periods in the activities of Indian monsoon and East Asian monsoon (Yasunari, 1981; Krishinamurti and Subrahmanyam, 1982; Murakami and Nakazawa, 1985; Lau and Lau, 1986; Lau et al., 1988; Chen and Murakami, 1988; Knuston and Weickmann, 1987; Li, 1985). Meanwhile the study of Murakami et al. (1986) showed that the onset and withdrawal of the Australian summer monsoon appears to be determined by not only the phase changes of the

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seasonal cycle but also the low-frequency oscillations. Then it was found that the onset of South China Sea monsoon (SCSM) owes to the trigger of an intruded low-frequency cyclone from the east of Philippine Islands (Li and Qu, 2000; Mu and Li, 2000), and Chen and Chen (1995) showed that the onset of SCSM in the summer of 1979 was triggered by the northward propagating trough of ISO and the westward propagating low center of the 10-24-day low frequency oscillations together. Therefore the researchers tried to predict the monsoon from low frequency oscillations in the atmosphere. On the mechanism study of the zonal activities for monsoon, both the westward and eastward propagating ISO between the tropical western Pacific and the tropical Indian Ocean are dependent on the strong or weak convections in the vicinity of Philippine Islands (Huang, 1994). In addition, Krishinamurti and Gadgil (1985) presented that ISO is significant in the monsoon region, tropics, and the high latitudes. Magana and Yanai (1991) considered that the ISO of the South Asian (Tibetan) high and the mid-Pacific trough is associated with the ISO of tropics. Chen and Murakami (1988) and Chen (1991) indicated that a coherent manner with an intraseasonal period exists in the Meiyu front south of Japan, the low-level trough over the equatorial western Pacific, and the mid-Pacific trough. Therefore the behavior of East Asian monsoon in a short time is often shown by ISO.

The westward propagating low frequency mode has received less attention in the literature and deserves more discussions here. Murakami (1980) and Murakami et al. (1984) presented evidences of 20-30-day perturbations propagating westward along 10°S-20°N at west of the dateline, using both OLR and wind data. Based on the analysis of 10-yr pentad mean OLR anomaly, Wang and Rui (1990) identified the primary tracks of the westward-moving intraseasonal convective anomalies. Chen (1993, 1995) also found that the westward propagation of the 10-20-day oscillations existed not only in South Asian monsoon region, but also in SCSM region. Actually Krishinamurti (1980) has already drawn the same conclusion in Indian monsoon region. To differ from traditional views, the study of Chen and Xie (1988) showed that the westward propagating ISO dominates in the area of 15°-30°N. Recently, Chen et al. (2004) have shown that there are distinctly quasi-bi-week and westward propagating disturbances of the kinetic energy in 850-hPa level between the Indian and East Asian monsoon regions in the vicinity of tropics, and the disturbances almost propagate westward in each summer of 18 yr. In East Asian monsoon region of subtropics, during the flood period of the Yangtze River Basin in the summer of 1998, the convections remarkably took on a feature of ISO, and consecutively heavy rainfall was identified to be closely related to the westward propagating ISO via the Northwest Pacific, south of Japan, and from the central-east Pacific in mid-high latitudes (Chen et al., 2001; Zhu et al., 2003).

Above studies revealed that westward propagating ISO is prominent over Northwest Pacific and the impacts of westward propagating ISO over the Northwest Pacific on East Asian monsoon are very strong in the summer of 1998. Therefore, the problems arise, what relationships exist between the propagations of ISO at various latitudes of the North Pacific and the precipitation anomalies in the East Asian monsoon region for decades? That is not clear yet. And where is the origin of the westward propagating ISO of the western Pacific? Even if SCSM (tropic monsoon) is weak such as in the summer of 1998, the East Asian region of subtropics still suffered from the flood by any possibility. Consequently, where do the energy and moisture of the consecutively heavy rainfall come from without strong southwesterly surge of SCSM? What roles do the SCSM and low frequency disturbances from the North Pacific play in the summer rainfall of East Asia respectively? The paper will try to answer the problems, and is expected to benefit the short-term climate prediction of East Asia.

In the paper it is concerned with the zonal propagation ISO over the subtropical to midlatitude Pacific (20°-45°N). However it may hold some characteristics similar to tropics, e.g., both are accompanied with prominent convection activities despite of the different background circulations in a way.

2. Data and methodology

Three kinds of data employed here are: 1) the daily 850-hPa wind and height data during 1958-2000 from NCEP/NCAR reanalysis (Kalnay and Coauthors, 1996); 2) the actually observed 24-h rainfall of 687 stations in China from 1951 to 2000, provided by the Information Center of China Meteorological Administration; and 3) the Climate Prediction Center's (CPC) pentad precipitation data from 1979 to 2000, i.e., the merged analysis of precipitation (CMAP) data (Xie and Arkin, 1997), which is produced by merging rain gauge data and five kinds of satellite estimates, i.e., the GOES precipitation index (GPI), OLR-based precipitation index (OPI), special sensor microwave/imager (SSM/I) emission, and microwave sounding unit (MSU).

The space-time spectral analysis and filtering methods (Kao, 1968; Hayashi, 1982; Pratt, 1976; Zhang and Dong, 2004) are carried out for wind, height, and CMAP precipitation data along every latitudes of 20°-45°N at intervals of 2.5° in annual series, in order to get the 30-60-day intraseasonal low frequency oscillations. In addition, Morlet wavelet analysis (Christopher and Compo, 1998) was employed to get the power spectrums of certain frequency band (i.e., 10-72 days) and certain time range (June-August). The ideology of space-time spectral analysis is mainly as follows: it is assumed that a given space-time series $W(x,t)$ is cyclical in longitude (x) and limited in time ($0 < t < T$). For convenience, a discrete representation is used for frequencies (ω) and wavenumbers (k) in the space-time Fourier expansion of $W(x,t)$, namely:

$$W(x,t) = R_{\mathrm{e}}\Sigma[\hat{W}_{k,+\omega}\mathrm{e}^{-i(kx+wt)} + \hat{W}_{k,-\omega}\mathrm{e}^{i(kx-\omega t)}],$$

and the expression of space-time power spectrum:

$$P_{k,\omega}(W) = \frac{1}{2}\left|\hat{W}_{k,\omega}\right|^2,$$

where positive and negative frequencies ($\pm\omega$) are corresponding to westward and eastward phase velocities respectively for positive k, and $\hat{W}_{k,\pm\omega}$ is the complex space-time Fourier coefficients determined by

$$\hat{W}_{k,\omega} = \frac{1}{2\pi T}\int_0^T \left[\int_0^{2\pi} W(x,t)\mathrm{e}^{-ikx}\mathrm{d}x\right]\mathrm{e}^{-i\omega t}\mathrm{d}t.$$

The paper computed directly the space-time Fourier expansion of annual series of elements by the Fast Fourier Transform (FFT). Then the ISO element fields filtered in space and time, including the meridional and zonal wind velocities, height, and CMAP precipitation, are gotten by the inverse FFT, in which only the waves of the positive and negative frequencies corresponding to 30-60-day periods and the 1st to 6th spatial wave numbers are saved, and the other waves are all taken out.

3. Analysis results

3.1 *Some basic facts*

The longitude-time sections of the original (no filtering) 850-hPa meridional wind velocity (v) are shown in Fig.1. It shows the facts that the zonal propagations of ISO do exist for the 850-hPa v, from the central-east Pacific to the East Asian continent in 20°-45°N, and the westward propagation is dominant in 20°-30°N zone (consistent with Chen et al., 1988) while the westward and eastward propagations exist together in 30°-45°N zone. But the westward propagation in 30°-45°N zone seems to be the retrograde wave of the maximum of eastward propagating ISO, which is different from the westward propagating ISO in 20°-30°N zone.

With the actually observed 24-h rainfall of 687 stations in China from 1951 to 2000, the summer monsoon region of East Asian continent can be divided into four different precipitation zones according to climate characteristics: ① Hua'nan (South China, 21.5°-25.0°N, 110.0°-121.5°E), ② Jiangnan (south of the Yangtze River, 25.0°-31.5°N, 110.0°-121.5°E), ③ Jianghuai (the Yangtze River-Huaihe River Basin, 31.5°-35.0°N, 110.0°-121.5°E), and ④ The North (northern China 35.5°-45.0°N, 110.5°-127.0°E). Here the years with absolute values of summer (June-August) rainfall anomalies for each zone bigger than the mean square deviation of 50 yr are defined as drought or flood years (listed in Table 1).

3.2 *The ISO filtered in space and time*

3.2.1 *The zonal propagation ISO of 850-hPa v over the northern Pacific*

With the analyses of the zonal and meridional

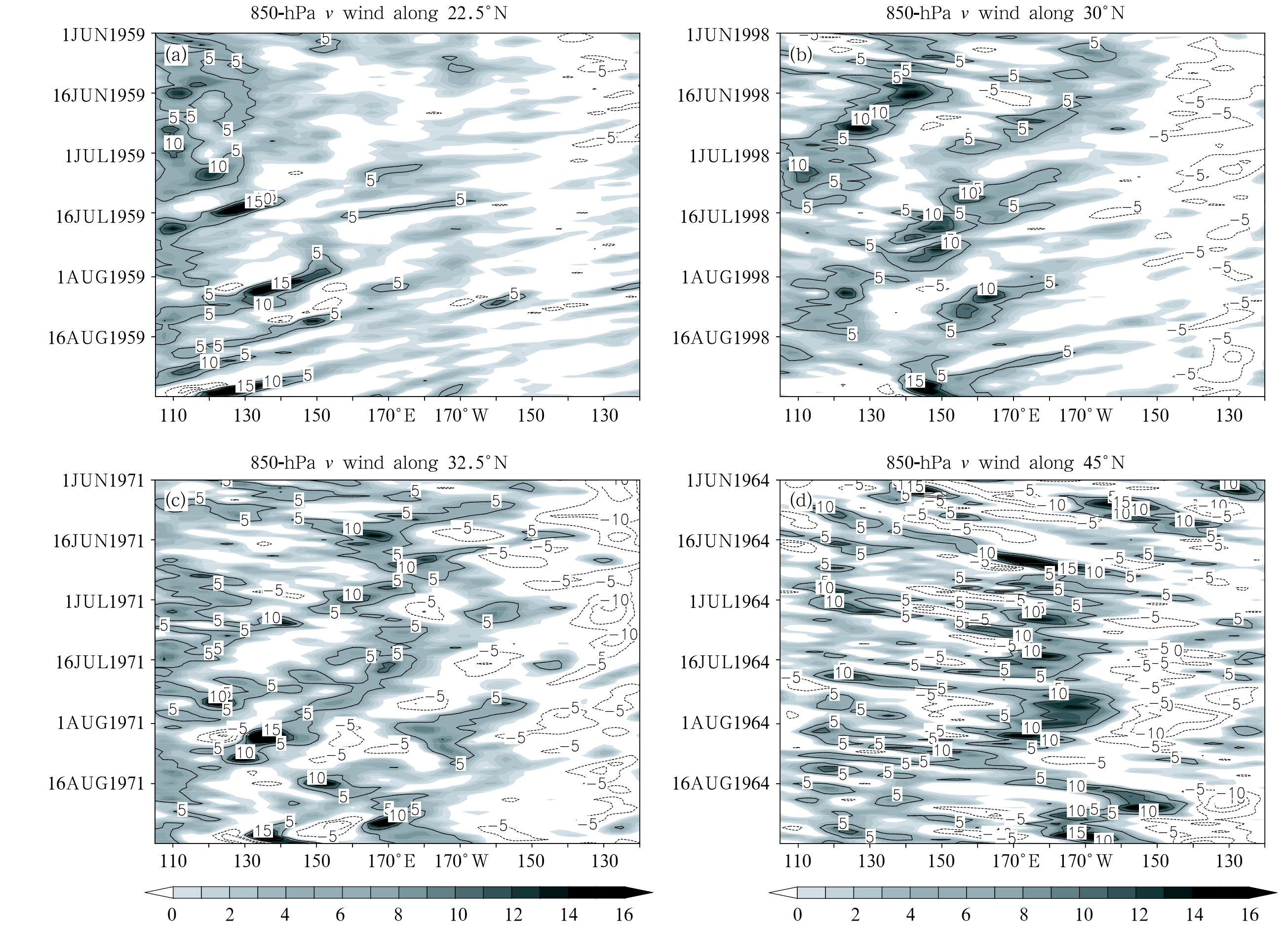

Fig.1. Time-longitude cross sections of the meridional wind velocity (m s^{-1}) at 850 hPa in the summer of 1959 (a), 1998 (b), 1971 (c), and 1964 (d). Solid and dashed lines represent southerly and northerly, respectively.

wind velocity (v) filtered by the space and time spectrum method (figure omitted), it was found that the zonal propagation feature of the ISO for the meridional wind velocity at 850-hPa level is the most distinct. Therefore the paper puts the analysis emphasis on the meridional wind velocity at 850-hPa level. The power spectrum of ISO is generally dominant in 10-72-day periods from Morlet wavelet analysis for annual series data of 850-hPa wind field. For example, Fig.2 is the latitude-period cross section of space-time power spectrum of 850-hPa v, in which the 30-60-day period spectra usually cover the maximal value (Figs.2a, 2b, and 2c), but around 20-day periods in the 10-72-day periods are also remarkable for a few situations (Figs.2d, 2e, and 2f).

Some elements such as wind velocity, height, and temperature in the lower and higher troposphere take on remarkable 30-60-day oscillation, which including outgoing long-wave radiation (OLR) (Yasunari, 1981), and the same situation also occurs in some derived variables such as velocity potential, kinetic energy, and stream function (Chen and Yen, 1991).

A total of 850-hPa v data from 1958 to 2000 were filtered by the space-time spectrum method in spatial series along latitudes and in temporal series for every year, in order to get westward propagating and eastward propagating disturbances of 30-60-day periods with single side wave numbers 1-6 respectively in spatial field, as shown in Figs.3 and 4. There are more precipitation in the summer of 1972, 1998, and 1964, corresponding to Hua'nan, Jiangnan, and the North, respectively, and the westward propagations of ISO are all conspicuously stronger than the eastward propagations in these flood years as shown in

Fig.3. However, in these years for less precipitation in summer, the westward propagations of ISO over the Pacific are usually weak, e.g., Figs.4a and 4c are the situations of less precipitation summer for Jianghuai in 1966 and the North in 1992, respectively. But the strength variations of eastward propagating ISO seem to hold the complexity because the strongly or weakly eastward propagations ever showed up regardless of flood or drought summers, in despite of the strongly eastward propagations shown only in here (Figs.4b and 4d). Moreover Gao et al. (2006) also found the westward propagation ISO of 850-hPa v existing in tropics.

Consequently we analyzed every situation for flood and drought summers of the four different regions during 43 yr from 1958 to 2000 (see Table 1). Table 1 is the interannual variations of the zonal

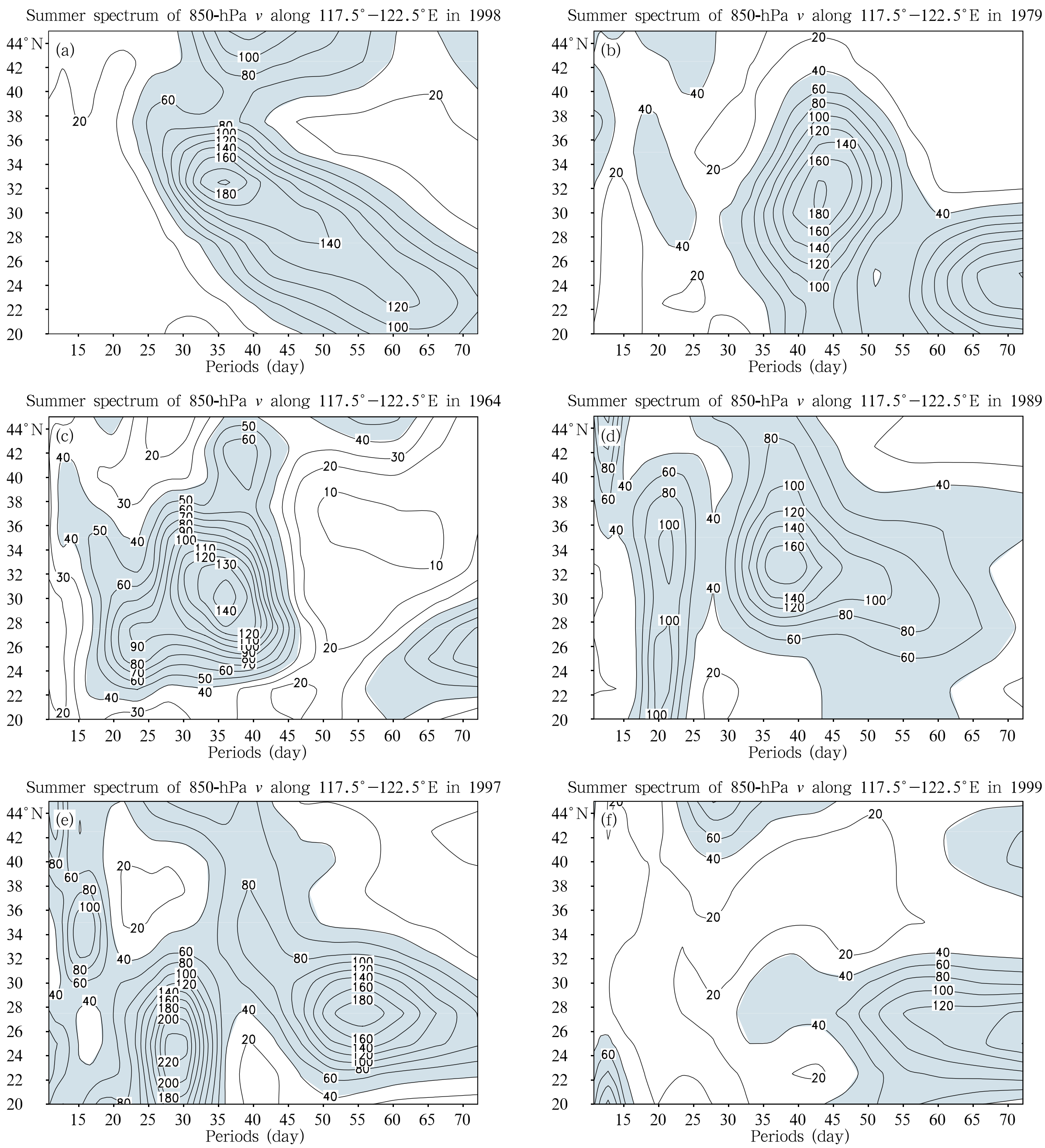

Fig.2. Morlet wavelet power spectra for 10-72-day periods of 850-hPa v in summer. The power spectra are averaged in June-August (units: $\mathrm{m^2\ s^{-2}}$).

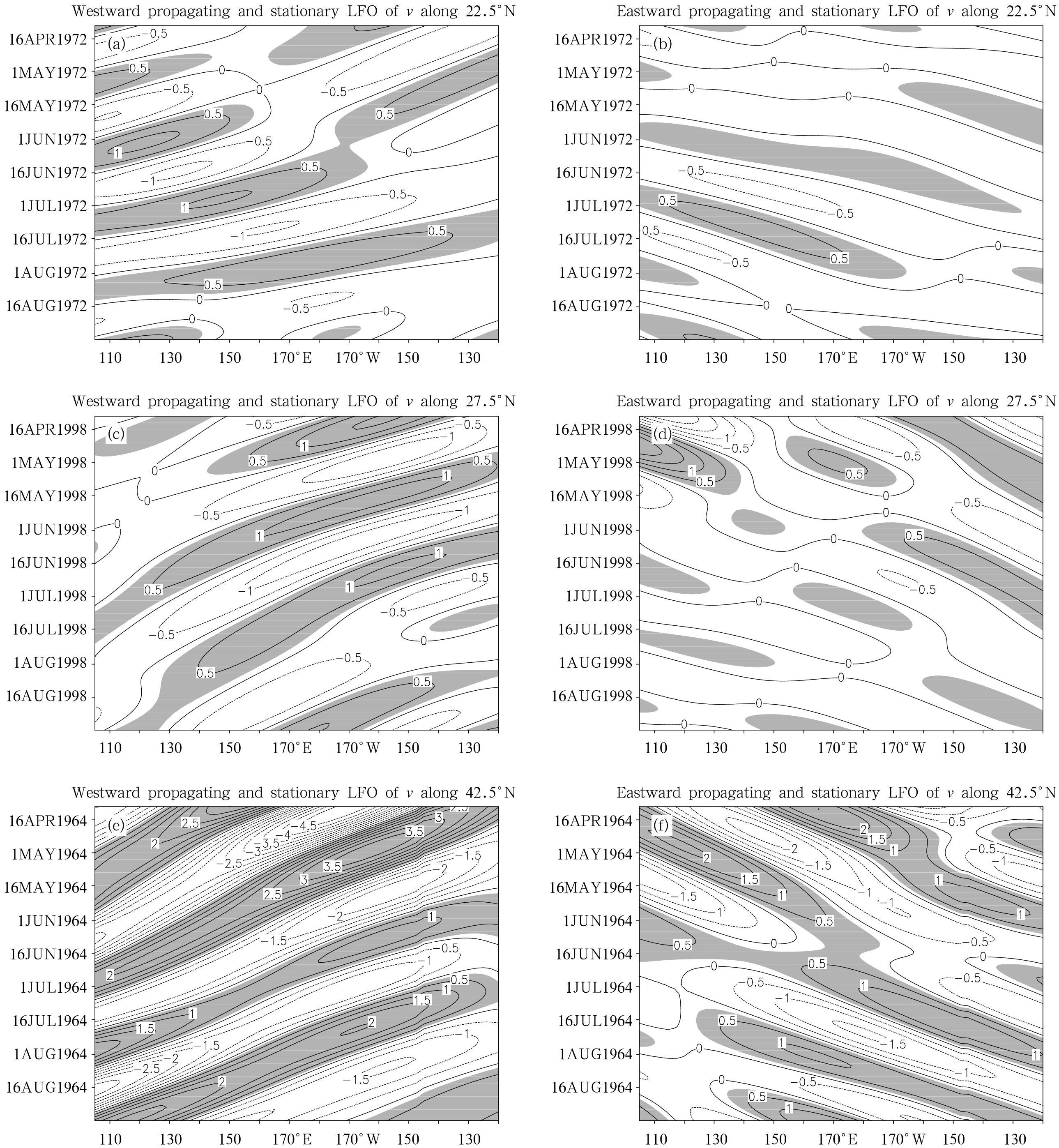

Fig.3. Time-longitude cross sections of westward and eastward ISO filtered by time-space spectrum method for 850-hPa v (m s^{-1}) in the flood summers. Solod lines mean ISO southerly in which shadow areas are more than 0.2; dashed lines mean ISO northerly.

propagation ISO strength of 850-hPa v over the subtropical North Pacific as the summer flood and drought occurred in the four regions of China during 1958-2000. Here two criteria are defined as that distinguishing the strong from the weak of westward or eastward ISO propagation. Namely, on a certain

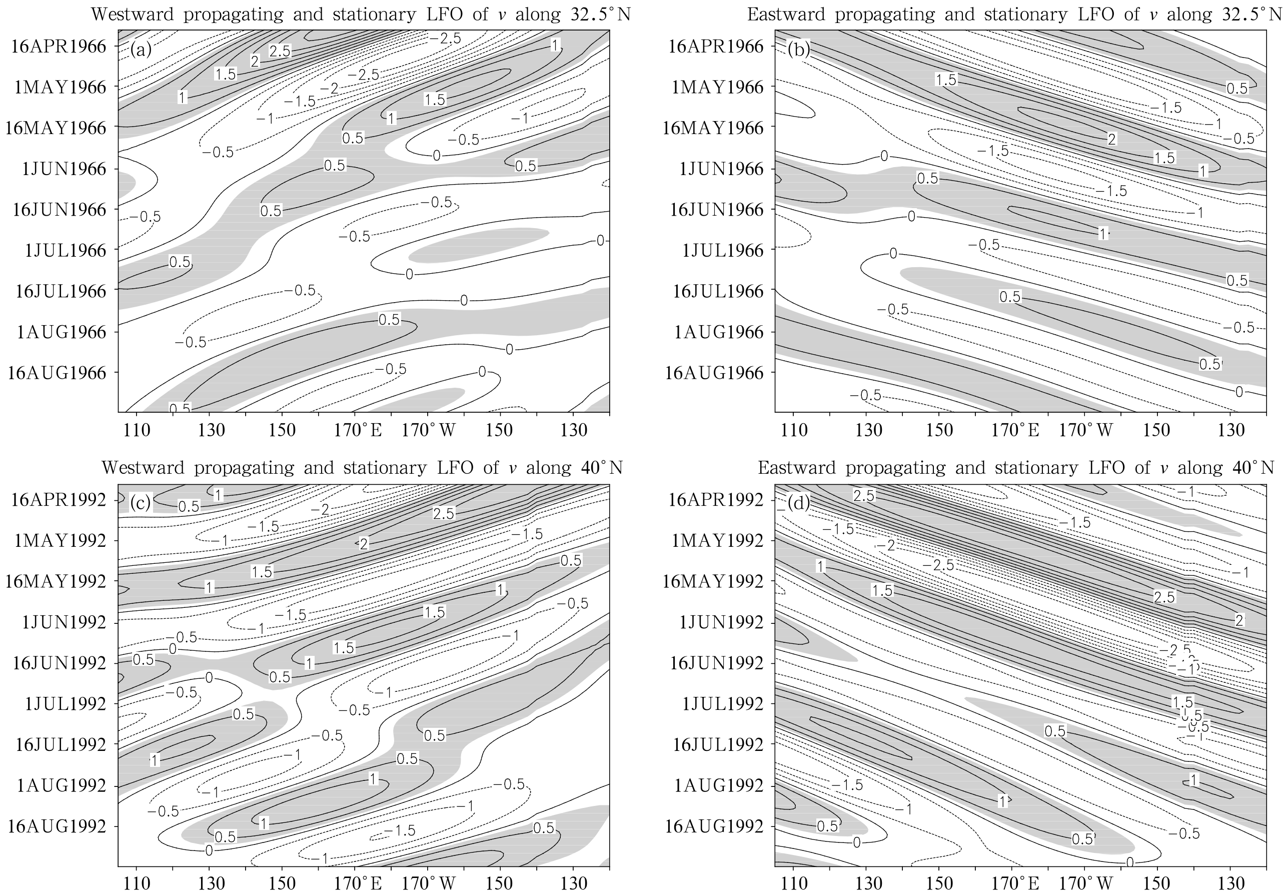

Fig.4. As in Fig.3, but for drought years.

latitude, criterion 1 can be written as

$$\frac{1}{n}\sum_{x=1}^{n}(\frac{1}{T}\sum_{t=1}^{T}|V_{\mathrm{westward}}|)/\frac{1}{n}\sum_{x=1}^{n}(\frac{1}{T}\sum_{t=1}^{T}|V_{\mathrm{eastward}}|) > 1. \tag{1}$$

And criterion 2 can be described below. From the vicinity of 130°E to the east vicinity of 170°E during summer, the times (N_{WP}) of westward continuous-propagation ISO for the 850-hPa southerly are more than the times (N_{EP}) of eastward continuous-propagation ISO for the 850-hPa southerly, i.e.,

$$N_{\mathrm{WP}} > N_{\mathrm{EP}}. \tag{2}$$

In Eq.(1), variables are taken as 110°E$\leqslant x \leqslant$140°E, at intervals of 2.5 degrees of longitude; June 1$\leqslant t \leqslant$August 31, at intervals of one day. In criterion 2 stress is put on the ISO that propagates westward to East Asia from the central-east Pacific. Although the ISO southerly and northerly propagate alternately with time (Figs.3 and 4), the precipitation usually takes place in phase with ISO southerly in East Asia (see Fig.5). Thus only ISO southerly is considered in criterion 2. The positive examples of criterion 2 can be seen from Fig.3, and the reverse examples can be seen from Fig.4. Therefore, the fact can be summed up as four situations below.

(1) If criteria 1 and 2 (C1 and C2 for short below) are all true, the westward propagations are defined as strong and the eastward propagations are defined as weak. (2) If C1 and C2 are all false, the westward propagations are weak and the eastward propagations are strong. (3) If C1 is true and C2 is false or the westward and eastward propagations are all inconspicuous, the westward and eastward propagations are all defined as weak. (4) If C1 is false and C2 is true, the westward and eastward propagations are all strong.

Table 1. The interannual variations of the zonal propagation ISO strength of 850-hPa v over the subtropical North Pacific as the summer flood and drought occurring in the four regions of China during 1958-2000

Precipitation region	The scope of zonal ISO propagation	Fd	WP	EP	Dr	WP	EP
Hua′nan (21.5°-25.0°N, 110.0°-121.5°E)	20.0°-25.0°N 110.0°E-120.0°W	1959	S	W	1962	W	W
		1966	S	W	1989	W	W
		1968	S	W			
		1972	S	W			
		1973	S	W			
		1994	S	W			
		1995	S	W			
		1997	S	W			
Jiangnan (25.0°-31.5°N, 110.0°-121.5°E)	25.0°-31.5°N 110.0°E-120.0°W	1969	S	W	1963	W	W
		1980	S	S	1967	W	W
		1993	S	W	1971	W	W
		1994	S	W	1978	W	W
		1995	S	W	1985	W	W
		1996	S	S			
		1998	S	W			
		1999	S	W			
Jianghuai (31.5°-35.0°N, 110.0°-121.5°E)	31.5°-35.0°N 110.0°E-120.0°W	1965	S	S	1959	W	W
		1980	S	S	1961	W	W
		1982	S	S	1966	W	W
		1991	S	W	1978	W	W
		2000	S	W	1985	W	W
					1988	W	W
					1992	W	S
					1994	W	W
					1997	S	W
					1999	W	W
The North (35.0°-45.0°N, 110.0°-121.5°E)	35.0°-45.0°N 110.0°E-120.0°W	1959	S	S	1968	W	S
		1960	S	W	1972	W	S
		1964	S	W	1980	W	S
		1985	S	W	1982	W	W
		1998	S	W	1989	S	W
					1992	W	S
					1997	W	S
					1999	S	W
					2000	W	S

Note: Fd-flood; Dr-drought; WP-westward ISO propagation; EP-eastward ISO propagation; S-strong; and W-weak.

It is clear from Table 1 that the westward propagations of v component ISO at 850 hPa over the subtropical Pacific are always strong in all flood summers of the same latitudes in China regions, and in the majority of drought summers the westward propagations of ISO for 850-hPa v showed weak, and strongly westward propagations existed only in three drought summers during 1958-2000, i.e., Jianghuai in 1997 and the North in 1989 and 1999, which may be related to about 20-day oscillations because of about 20-day period being the most prominent in the intraseasonal periods of these three years (see Figs.2d, 2e, and 2f). While the eastward propagations are usually weak in the south of around 30°N, and the weak or strong of eastward propagations seem to occur stochastically in the north of 30°N regardless of flood or drought summers.

Considering Figs.3, 4, and Table 1 together, although the atmospheric moisture of eastern China is mainly from the South China Sea (Shen et al., 1980; Hu and Ding, 2003), the weather change of East Asia is yet highly forced by the westward propagating ISO disturbances from the Pacific. And not all the

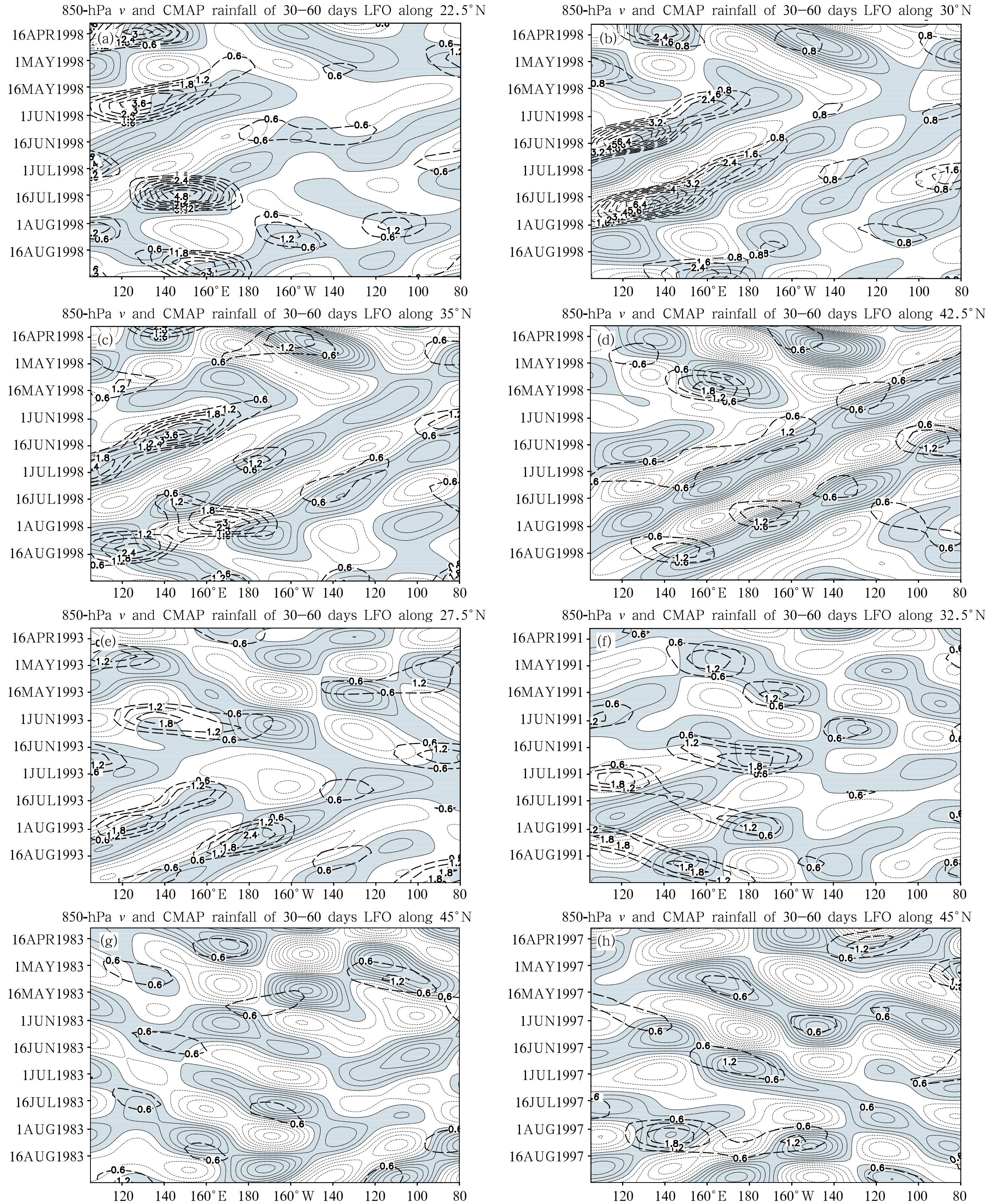

Fig.5. Time-longitude cross sections of the westward and eastward ISO propagations for 850-hPa v (m s^{-1}) and CMAP precipitation (mm day^{-1}). The v: shadow⩾0, others same as Fig.3; CMAP precipitation: thick dashed lines.

disturbances come from the western Pacific, but more from central-east Pacific (Figs.3 and 4). Compared with the East Asian summer monsoon index (Zhao, 1999) during 1958-2000, it can be concluded that the strong (weak) westward propagation ISO of 850-hPa v over the boreal Pacific are the strong signal of flood (drought) for East Asia in summer regardless of the strength of East Asian monsoon.

Figure 5 is the time-longitude section of ISO for CMAP precipitation and 850-hPa v from April 10 to August 31 at 105°E-120°W, filtered in annual series and space series along latitude, which is the composite of the westward and eastward propagations. It is clear that the directions of zonal propagating ISO for 850-hPa v are nearly consistent with that of CMAP precipitations, and the ISO precipitation often occurs with ISO southerly. Thus in combination with the above analyses, it can be inferred that the propagation manner of ISO southerly and northerly (as shown in Figs.3, 4, and 5) means the spread of meridional atmospheric systems, and brisk weather activities will occur on its spread direction. In the summer of 1998, three regions of Jiangnan, Jianghuai, and the North suffered from flood (Table 1), and Figs.5a-5d show that the westward propagating ISO of v and CMAP precipitation in summer (June-August) is distinct and the propagating directions of the both variables are coherent. Figures 5e and 5f correspond to the flood occurring in Jiangnan in 1993 and Jianghuai in 1991, respectively (see Table 1), the westward propagating ISO of v is still distinct during June-August, and the strong precipitation also shifted westward with the time. On the contrary, in drought summers, e.g., the situations of the North in 1983 and in 1997 (see Table 1), as shown in Figs.5g and 5h, the westward propagations are distinctly weaker than those of flooding summers, and the eastward propagations are stronger.

3.2.2 *The modes and synoptic mechanism of zonal propagating ISO*

On the basis of the 850-hPa wind vector and height fields all filtered by the same methods as shown in Fig.5, it is found that the similar zonal propagations exist from the central-east Pacific to East Asian continent as the aforementioned 850-hPa ISO v.

In Figs.6 and 7, the negative contour (dashed) means the low pressure of ISO height field and its center corresponds to the convergent zone of ISO wind field, while the positive contour (solid line) means the high pressure of ISO height field and its center corresponds to the divergent zone of ISO wind field. It is easy to find the several general modes of westward propagating ISO in Figs.6 and 7 as follows:

The first mode is the Easterlies ISO (EISO) evolving mode. On 16 June 1998, a small cyclone was formed around 27.5°N in the south of the northeastern Pacific high whose ridge just turned into perpendicular to latitudes. The northeasterly was prevailing in the foreside trough of the small cyclone and the southeasterly prevailing in the rearward trough of the cyclone, thus the wind field took on an inverted V shape, which looked like a typical easterly wave mode, and a situation was generated by the disturbances of tropical convergence entering into easterlies. Then the EISO gradually shifted northwestwards with the Northeast Pacific high reinforcing and westward extending. On 1 July, it evolved into a big shear between 20° and 60°N and still propagated westward, and then on 11 July its strong center arrived at the northern Japan and shifted toward the southwest. On 21 July, its center arrived at south of Japan and its outfield influenced Jiangnan of China, and therefore it produced the extreme rainstorm in lower reaches of the Yangtze River of China during 21-25 July 1998.

The second mode is the breaking mode of blocking high in the Sea of Okhotsk which leads to the West Pacific high enhancing. On 11 June 1966, there was an ISO high center with the northwest-southeast oriented ridge line in the sea of Japan, and an ISO cyclone in East Asian continent, while it was being Meiyu period. On 26 June, the high shifted northeastward and its northern part reaching Okhotsk and its south part shifted to the central-east Pacific, at the same time the continental cyclone arrived in the Northwest Pacific while Meiyu broke. Then on 6 July the Okhotsk high disappeared and the West Pacific high showed up till 16 July the West Pacific high enhanced and its

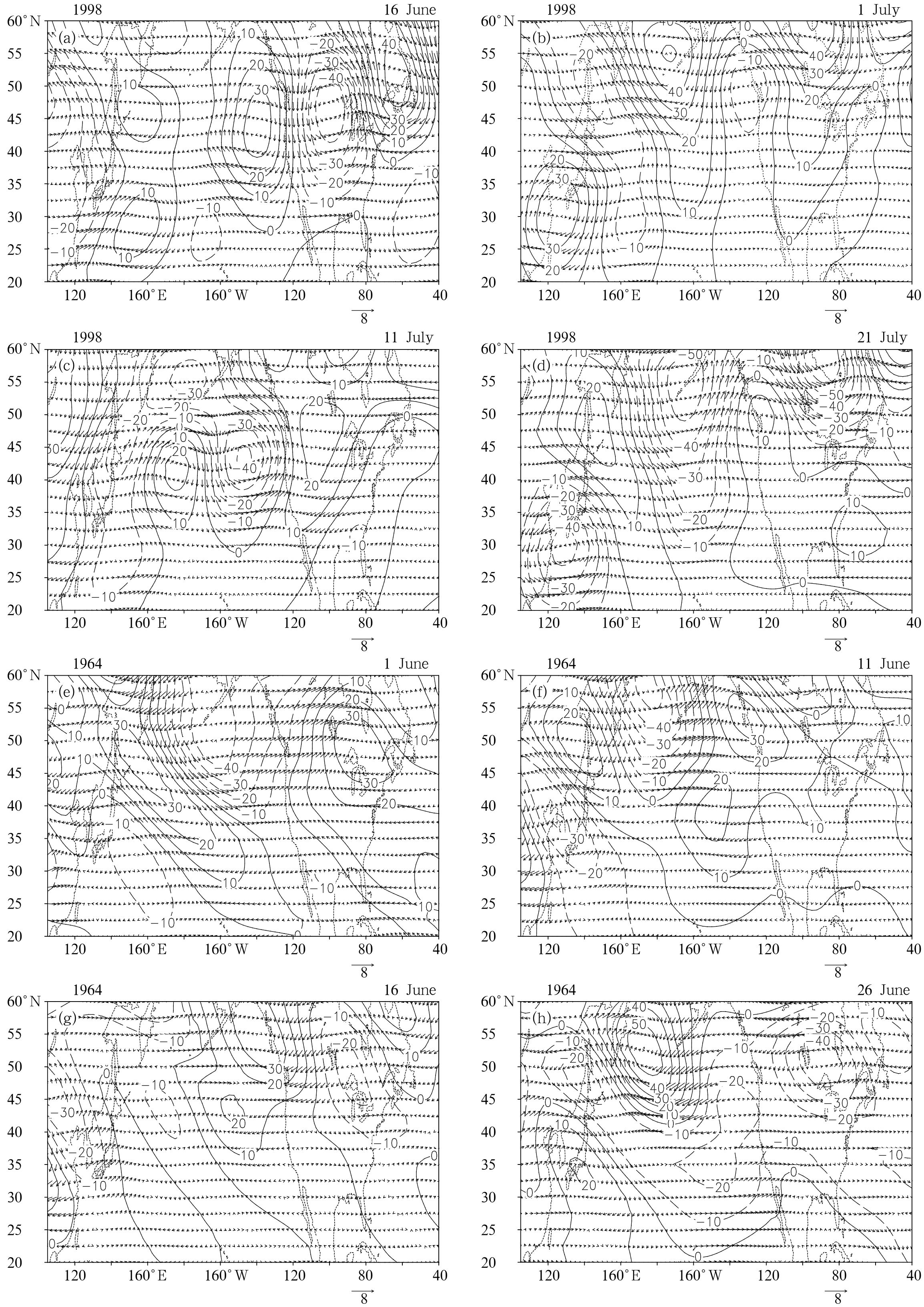

Fig.6. The daily evolving ISO of 850-hPa height (m) and wind vector (m s^{-1}) in summer. Filtering is same as Fig.5.

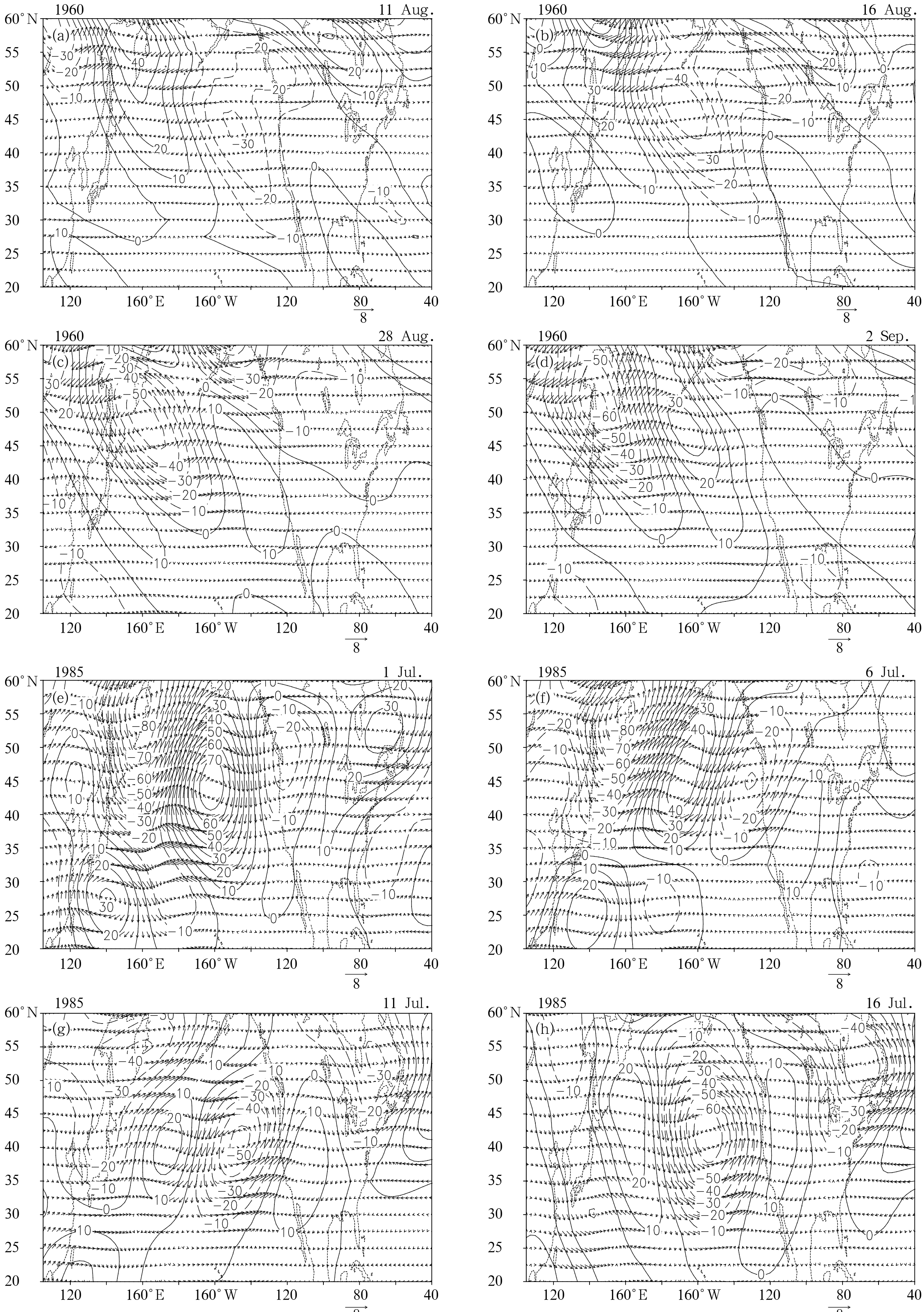

Fig.7. As in Fig.6, but for different westward propagating modes.

center spread westward to the south of Japan. Many cases indicate that the shaping of Okhotsk high is related to the beginning of Meiyu, and its break makes Meiyu end, while the West Pacific high reinforces and spreads westward in summer.

The third mode is the westward backing mode of mid-Pacific trough. On 21 July 1960, there was an ISO cyclone over the area from the Bay of Alaska to the west of the middle for the west coast of North America, which was just confirmed to be the central-Pacific trough by referring to the no-filtering height field (figure omitted). Then it shifted westward and reinforced constantly with the Okhotsk high shifting westward and weakening, and it influenced the weather of the northern Japan and the northeastern China on 23 July till 4 August as shown in Fig.7. Therefore, the North suffered the flood in summer (see Table 1).

The fourth mode is the invading Northeast Pacific high mode. On 1 July 1985, a strong high existed over the Northeast Pacific (Fig.7e) and the west of it was a strong cyclone. Subsequently the high shifted westward and weakened a little (see Fig.7f). When the center of the high arrived at the central Pacific, the cyclone in the west of it controlled the south of Okhotsk, Japan, and most of East Asian continent, and thus the summer belonged to the flood type in the North (see Table 1).

About the situation of eastward propagation ISO for 850-hPa v, the paper only found the eastward propagations from the Northeast Asia (the Sea of Okhotsk) to North America, for example, the situations for the summer of 1997 and 1983 (figure omitted), and both summers are all drought in the North due to an obvious advantage of the eastward propagation ISO. But the situations for the eastward propagations from the West Pacific in subtropics directly to North America were scarcely found in our studies. We also noticed that the eastward propagating ISO of 850-hPa v seemed to bring out the precipitation for the west coast of North America (Figs.5g and 5h), but the consequence still needs to be verified because of no marked monsoon circulation as the background field in North America.

4. Discussions and summary

The zonal propagating wave train with spatial wave numbers 1-6, analyzed in the paper, travels about 1-2 degrees of longitude per day, which seems to hold some characteristics of Rossby wave. Meanwhile the similarly zonal propagations also exist for the meridional wind ISO in the 200-hPa meridional (figure omitted), but it is less clear than the 850-hPa v's. In 850-hPa level, the easterly wind turns gradually into weak westerly wind with the latitude expanding northward between East Asia and the Pacific in summer, and therefore the Rossby-like waves are provided with the possible conditions. The ISO taking mainly on westward propagations in mid-low latitudes (Chen et al., 1988) is consistent with ours study. The strongly ISO cyclones or anticyclones deriving from the Bay of Alaska, the one of ISO propagating modes in Fig.7, spread to influence East Asia, the Pacific, and the North America of mid-low latitude regions, even tropical regions, which were ever mentioned by Namias in 1944. The southwestward propagations of ISO systems of Okhotsk, Aleutian Islands, and the Bay of Alaska are related to the mid-ocean trough propagating westward and the backing of blocking high that all owing probably to air-ocean interactions in the North Pacific (White and Clark, 1975; Lau et al., 2004). The ISO cyclones evolving in easterlies are difficult to find in height field, but they can bring on violent weather changes, and another situation of ISO cyclones from easterlies appearing in East Asian monsoon in the mid-high troposphere is not shown here. Therefore in the Pacific there may be other modes of westward propagating ISO which are not mentioned in the paper. However, from the examples of Figs.6 and 7, it is clear that not only the ISO of the West Pacific would influence the precipitation of East Asia, but also the ISO from the central-east Pacific would further impact the precipitation of East Asia in essence.

Finally the conclusions of the paper are summarized as follows:

(1) No matter strong or weak the East Asian summer monsoon is, the strong (weak) of the westward

propagating ISO over boreal Pacific is the strong signal of the flood (drought) for East Asian region at the same latitude belt in summer. The westward propagating ISO over the subtropical Pacific, in the flood summers of different East Asian zones during 1958-2000, is all distinct, but in the drought summers the westward propagating ISO is almost weak in the absolutely major summers. Although the main moist comes from southern sea area of China, the disturbances which trigger the weather changes of East Asia are derived mainly from the Pacific, especially the central-east Pacific ISO.

(2) The summer rainfall of East Asia is closely related to monsoon as well as the ISO from the subtropical easterlies and the southwestward propagating ISO via the subtropical Pacific from mid-high latitudes. The subtropical central-east Pacific, Okhotsk, Aleutian Islands, and the Bay of Alaska are the rather active regions for ISO in boreal summer.

(3) The zonal propagation ISO of 850-hPa v means the meridional-pattern atmospheric systems shifting and the brisk weather phenomena will occur in their propagating directions.

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