LOW FREQUENCY OSCILLATION IN EAST ASIA DURING THE 1991 EXCESSIVELY HEAVY RAIN OVER THE CHANGJIANG-HUAIHE RIVER BASIN

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ABSTRACT

The activity of low frequency oscillation (LFO) widely exists in East Asia during the period of 1991 excessively heavy rain over the Changjiang-Huaihe River Basin (Jianghuai). Both the rainfall amount of Jianghuai and the atmosphere from subtropical area to mid-high latitudes have the dominant period of 10—20 d, while the atmospheres in tropical area and high latitudes have the dominant period of 30—60 d.

Compared with normal Meiyu season, the anomaly of the 1991 Meiyu process may be reflected in the following two low frequency synoptic events: (a) The Meiyu process onsets extremely early (in the second dekad of May, which is nearly one month earlier than in normal Meiyu) and is immediately followed by the first episode of heavy rain. (b) In the first dekad of July, there occurs the heaviest episode of rainfall of the whole Meiyu season, and it is even the heaviest rainfall for the recent 30 years in China. For these two periods, corresponding to the adjustment of large-scale situation from "double blocking high" to "bipolar blocking high", the propagation direction of LFO in East Asia has a distinct seasonal variation, from eastward/northward propagation (passing through Jianghuai) during the first episode to westward/southward propagation during the third episode. Oscillations of different frequency bands are superposed in phase. The LFO activity of the cold and warm/moist airs over Jianghuai can be strengthened through those LFO propagation processes in East Asia, although they may have different directions in three episodes. Particularly, the eastward (westward) propagation in low latitudes makes the southwest (southeast) airflow transport intensively the low frequency warm/moist air to the south of Jianghuai from the Indian Ocean (tropical West Pacific Ocean) in the first (third) episode. Such warm/moist airs meet and interact with the cold air which vigorously invades Jianghuai persistently, and finally three episodes of heavy rain occur in mode of LFO.

Key words: low frequency oscillation (LFO), propagation, heavy rain, blocking situation

I. INTRODUCTION

The importance of low frequency oscillation (LFO) to monsoon precipitation has been addressed by many researchers. Lau et al. (1988) pointed out that summer monsoon precipitation in East Asia was mainly subject to the LFO in atmosphere with frequency bands of 10—20 d and 30—60 d. Li (1992) compared LFO situations of rainfall amount in flood and drought years, and revealed that LFO was quite active in flood years and not obvious in drought years. Chen et al. (1994) suggested that LFO in flood year might have same propagation direction as in normal year, while the propagation direction in drought year might be the opposite. These results imply that LFO has close relation to summer

monsoon precipitation in East China.

In the Meiyu season of 1991, three episodes of heavy rain occurred over the Changjiang-Huaihe River Basin (hereafter referred to as Jianghuai), thus there came the rarely-seen flood in the present century. In the study of cold air activity during this period, Lu et al. (1994) found that the cold air in north vigorously invaded Jianghuai three times, with one time corresponding to one rain episode. This fact reminds us to systematically investigate the activity of LFO, especially in the warm air south of Jianghuai, under this particular background of heavy rain, and seek to obtain answers to the following questions. Is LFO active this year? What is the feature about its propagation? Does the propagation have any relation to large-scale condition? What role may LFO play in the occurrence of the three episodes of heavy rain?

II. DATA AND METHOD

We use the uninitialized daily (12 UTC) grid point (2.5°×2.5°) data from ECMWF (European Centre for Medium-range Weather Forecasts). Wind component u at 850 hPa is the main element for analysis, and the sequence is taken from 1 April to 30 September (183 d). Rainfall amount data from a variety of stations over Jianghuai are also analyzed, and it covers 92 d (1 May—31 July).

First of all, the average value and seasonal tendency (using quadratic function for fitting) are removed from the original sequence. Then, to the stationary time sequence, analyses are focused on the following two aspects. One is using maximum entropy spectrum (MES) method to find out the dominant period of LFO and its regional distribution; the other is using a bandpass (Batterworth) filter (Murakami 1979) to get

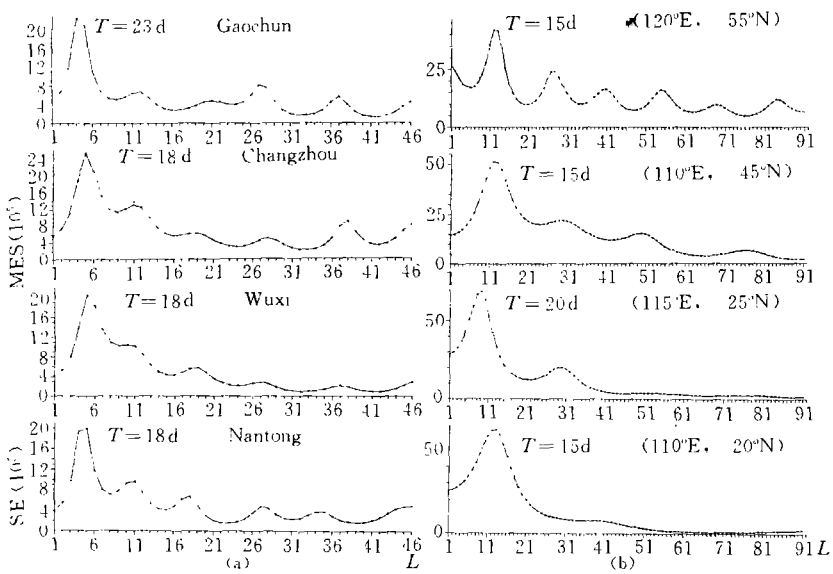

Fig. 1. Distribution of maximum entropy spectrum (unit of MES: 10^5, $L=N/T$) for (a) precipitation sequence of 4 stations (Gaochun, Changzhou, Wuxi and Nantong), and (b) 4 examples of grid point u at 850 hPa in East China.

components of several different frequency bands, and analyze their latitudinal and longitudinal propagations.

III. DOMINANT PERIOD AND ITS REGIONAL DISTRIBUTION

Figure 1a presents the MES distribution of daily precipitation sequence for 4 stations which are in the center of heavy rain area. These 4 curves all show a peak around the period of 18 d, so the LFO with period of quasi-18 d is the main mode of precipitation. Actually, we find most of the stations in heavy rain area have this dominant period. Figure 1b gives 4 examples of grid point *u* in both south and north of Jianghuai, and they have the dominant period of 15—20 d.

Table 1. Regional Distribution of Dominant Period for Grid Point *u* at 850 hPa in East Asia*

	80°E	85	90	95	100	105	110	115	120	125	130	135	140	145	150°E
60°N	15 45	15	38	13 42	14 42					36	9 28	9 23	18	18	19
55			12 30	10 20	12	13	14	18	15	15	13			17	18
50	14 30	17	20	28	9 22	9 18	20	19	10	11	9	10	8	14	13
45	10	18	16		14	15	15	12	13	11	11	13	9 19	10 25	
40			20	20	19	18		20		11 30	10 32	38			
35	13	15	17		18	10	8 20		9 18	9	8	9			12
30		8	8	10	9	18		25		9 25	8 45	10	15	17	15
25				18	23			20	8 23	9 25	10	12	13	14	16
20		26	14		12	13	14	15	14	17	14	20			
15			9		56	38			28	36		36	60		
10		30	56	10 32							36				11 60 23
5°N	45			30	30	10 36			23		12 30	30	10 30	26	9 30

* Note: Numbers at different corners in the table represent different periods: (upper left) <10 d, (upper right) 10—20 d, (lower left) 30—60 d, and (lower right) 20—30 d, respectively.

Table 1 shows the regional distribution of dominant period for *u* sequence at all grid points of East Asia. In nearly 70% of the grid points we can find obvious periods, which means that the activity of LFO widely exists in East Asia of this season. Dominant period

covers a wide frequency spectrum (8 — 60 d), but is mainly concentrated on the two famous bands: 10—20 d and 30—60 d. In tropical area (5 — 15°N), dominant period is mainly 30—60 d. While in the wide area from subtropical region to mid-high latitudes (20 — 55°N), the period is mainly 10—20 d. And of course, in some areas, two periods may exist simultaneously but with different importance. In high latitude of 60°N, both periods exist, but with 30 — 60 d being the main period. The above results illustrate that in frequency spectrum, LFO in East Asia of this year has two relatively concentrated frequency bands, and the distribution of dominant period shows distinct regional difference. In heavy rain area of Jianghuai, 10—20 d is of the main period.

IV. PROPAGATION OF LFO AND HEAVY RAIN PROCESS

1. General Latitudinal Propagation in East Asia

In order to understand, on the whole, the general characteristics of the latitudinal propagation of LFO in East Asia, an averaging procedure is taken to different low frequency (LF) u over the domain of 80—150°E. The three pictures of Figs. 2b, 2c and 2d are latitude-time sections for three frequency bands: 10—20 d, 20—30 d, and 30—60 d. For the purpose of comparison, we also give another picture that is not filtered, and thus contains information of all frequency bands (Fig. 2a). It has been mentioned in the previous section that in the area from subtropical region to mid-high latitudes the oscillation is in period of 10—20 d. Here, it may be noticed that Fig. 2b (10—20 d) may reflect the basic feature of Fig. 2a.

The propagation of the maximum value (amplitude of LFO) in Fig. 2a clearly shows that during the period from mid-May to mid-July, the propagation process of LFO can be divided into 4 stages: southward propagation (3rd dekad of April—1st dekad of May, 45 — 15°N), northward propagation (2nd dekad of May — 1st dekad of June, 15 — 40°N), quasi-stationary oscillation (1st dekad of June — 3rd dekad of June), and southward propagation (3rd dekad of June — 2nd dekad of July, 35 — 15°N). The three episodes of heavy rain over Jianghuai (18 — 26 May, 2 — 20 June, and 30 June — 13 July) occur just during the above 2nd stage (northward), 3rd stage (quasi-stationary), and 4th stage (southward), respectively. So the propagation direction of LFO has a seasonal variation, from northward propagation in the first episode to southward propagation in the third episode. The second episode is a period for adjustment, and propagation is very weak. Relatively, LFOs of 20—30 d and 30—60 d are less important in the area from subtropical region to mid-high latitudes. Figures 2c and 2d show that they have similar propagation process, and also have 4 stages like in the case of 10—20 d. The difference, however, lies in that in the 2nd stage the northward propagation appears for only a shorter time (in mid-late May) and is limited in the area south of Jianghuai. In the 4th stage (3rd dekad of June — 2nd dekad of July, 40—15°N), however, their southward propagations passing through Jianghuai are quite similar to that of 10—20 d. So the oscillations of the three frequency bands are superposed in phase, which is benefit to the occurrence of the heaviest rain of this stage.

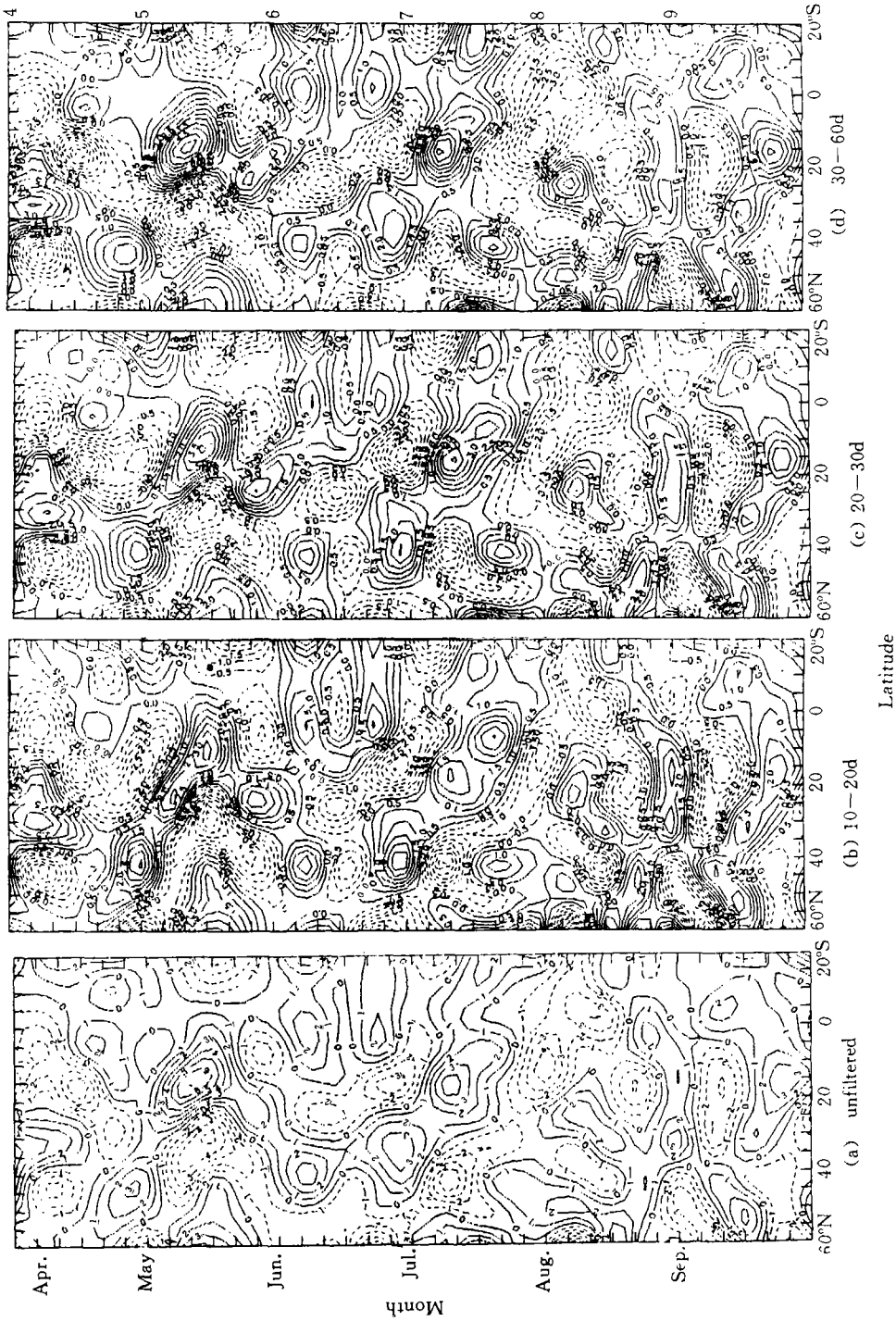

Fig. 2. Latitude-time section of averaged (over 80—150°E) LF u (m/s) for (a) unfiltered, (b) 10—20 d, (c) 20—30 d, and (d) 30—60 d.

2. Longitudinal Propagation in Mid-High Latitudes

Comparing the four pictures concerning the longitudinal propagation in mid-high latitudes for four frequency bands (in Fig. 3, the other two pictures for unfiltered and 20—30 d are omitted), we get two important points. (a) Propagation processes of the four frequency bands are quite similar. In each rain episode, they almost have same propagation direction, maintaining time and region of amplitude propagation. Thus the LFOs of different frequency bands are superposed in phase. (b) From the early to the late of the Meiyu season, the longitudinal propagation of LFO also has seasonal variation. During the period from the second half of May to the end of July, there are four strong amplitude propagation processes over Eurasian Continent, and they are well coincident with those of latitudinal propagation. The first three propagations (3rd dekad of April—1st dekad of May, 2nd dekad of May—1st dekad of June, 1st dekad of June—3rd dekad of June) are all eastward, and may have direct effect on the weather of Jianghuai. Each amplitude propagation process maintains about 20 days, with an interval of about 25 days. The 4th propagation is westward for all frequency bands. The oscillation of 10—20 d propagates from east of Jianghuai to the west in early July (Fig. 3a). While the oscillation of 30—60 d (Fig. 3b) has the propagation process in mid-June, and besides, it has another

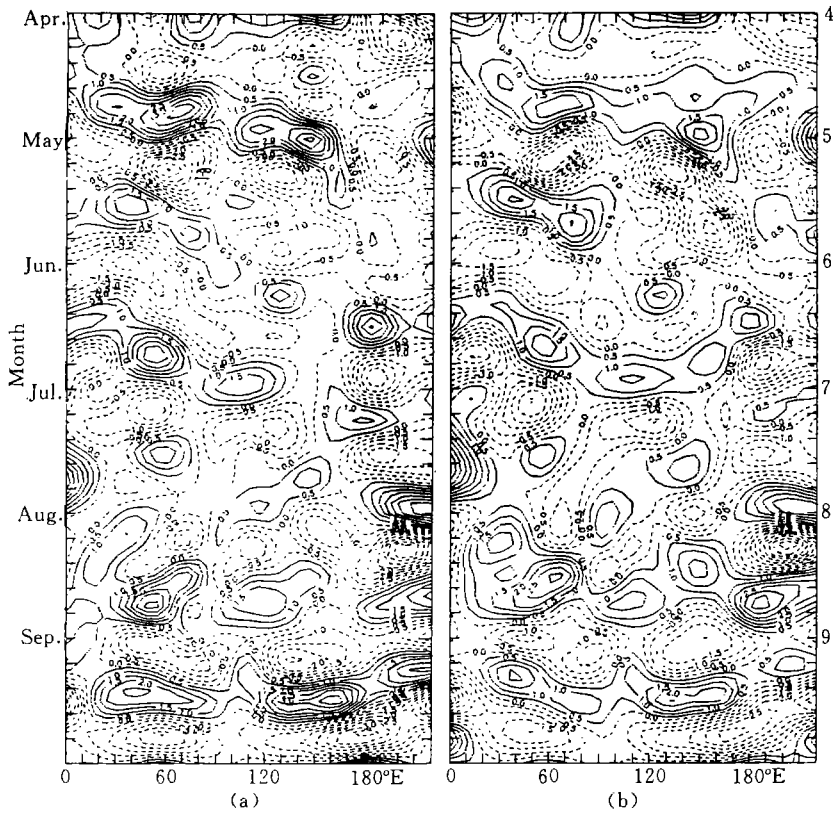

Fig. 3. Longitude-time section of LF u (m/s) at 850 hPa (averaged over 30—55°N) for (a) 10—20 d, and (b) 30—60 d.

westward propagation towards Jianghuai in mid-July. Comparing these longitudinal propagation processes with the three periods of heavy rain, we may notice that heavy rain seems to occur during negative phase stage of LFO in Jianghuai.

3. Longitudinal Propagation in Tropical Area

The propagation features of LFO in mid-high latitudes discussed above become more obvious in the case of tropical area (Fig. 4). (a) LFOs of the three frequency bands are almost exactly superposed in phase, and have nearly the same propagation pattern, especially in the two stages of May and July. Therefore, it is not difficult to imagine that such superposition, in the wide area from mid-high latitudes to tropical region, must have significant effect on the weather of these two months. Actually, compared with normal Meiyu season, there are two important LF synoptic events in these two months. (1) Early in the second half of May, the Meiyu onsets and is immediately followed by the first episode of heavy rain. (2) In the first half of July, there occurs the heaviest episode of rainfall for the whole Meiyu season, and that is even the heaviest in the recent 30 years in China. (b) The seasonal variation of propagation direction becomes more distinct. Before June (in April and May), oscillations of different frequency bands all have two times of eastward propagation, and the propagation in May is extremely active. As shown in Fig. 4a, the source of oscillation is in 20°E, and the amplitude gradually increases up to above 5 m/s when it reaches 110°E (10 — 15 May). This is the situation before the beginning of the Meiyu. In tropical area, wind has the effect of carrying water vapor. Although South Asia monsoon still does not onset at this time, the southwest wind in South and Southeast Asia prevails (Ding et al. 1993 and Lu et al. 1994), and it may transport water vapor to Jianghuai from the Indian Ocean through the above eastward propagation of LFO, thus provides the LF water vapor condition for the appearance of LF rainfall. After June (in July and August), there are two times of westward propagation, and one in July becomes tremendously strong. In tropical area, the main oscillation is of 30 — 60 d, and Fig. 4d shows that the source of oscillation is in 170°E. The amplitude reaches its peak when it propagates to 110°E. This process occurs in early July when the third episode of heavy rain appears in the north. The warm/moist southeast flow is very strong at this time, and it takes water vapor to the south of Jianghuai from the tropical West Pacific Ocean through westward propagation. In June, LFO is weak for all frequency bands and its propagation is not obvious. This is the period for adjustment.

V. MECHANISM OF LF HEAVY RAIN AND LARGE-SCALE CONDITION FOR THE PROPAGATION OF LFO

1. *LF Processes of Cold / Warm Airs and Mechanism of LF Heavy Rain*

Lu et al. (1994) carefully studied the cold air activity during the 1991 Meiyu season, making use of isentropic potential vorticity (IPV) analysis method. It was revealed that during the Meiyu season cold air with high IPV invaded Jianghuai persistently in lower layer (below 500 hPa) of the atmosphere and mainly along the track of northeast-southwest. During the invasion process, cold air was frequently cut off by southeast and

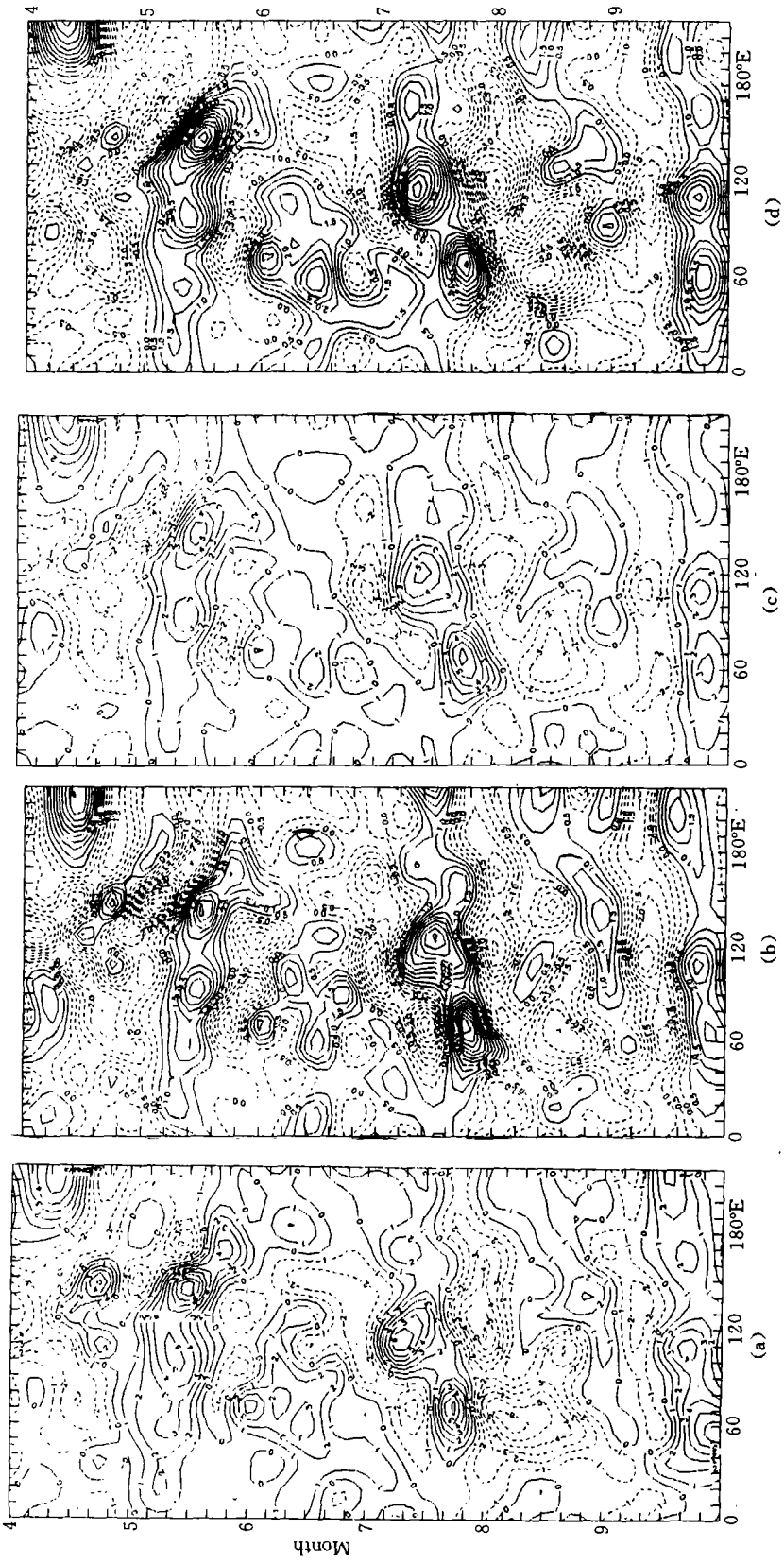

Fig. 4. As in Fig. 3, but for averaged over 5 — 15°N and for (a) unfiltered, (b) 10 — 20 d, (c) 20 — 30 d, and (d) 30 — 60 d.

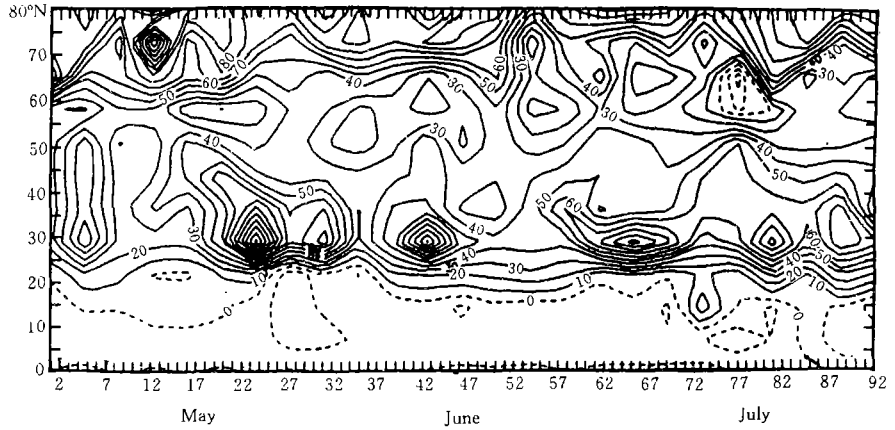

Fig. 5. Latitude-time (1 May — 31 July, 1991) section of IPV along 110°E of 850 hPa (unit: 10^{-8} km^2 s^{-1} kg^{-1}) (Lu et al. 1994).

southwest warm airflows coming from low latitudes, and finally an isolated body of cold air with maximum IPV formed persistently over Jianghuai. Figure 5 is the latitude-time section of IPV in the rain season. This picture clearly indicates that there are three periods, each corresponding to an episode of heavy rain, when cold air with high IPV appears over Jianghuai (30°N). Therefore, the activity of cold air in north has the property of LFO (with period of 10 — 20 d). Meanwhile, as pointed out in previous section, the LFO of warm/moist air is very active in the south of Jianghuai, and it is strengthened by the following two processes: The eastward (westward) propagation makes the southwest (southeast) airflow transport LF warm/moist air from Indian Ocean (tropical West Pacific Ocean) during the first (third) episode. Such LF cold air and LF warm/moist air meet and interact in Jianghuai, which finally induces the three episodes of heavy rain in mode of LFO.

2. Large-Scale Condition for the Propagation of LFO

The seasonal variation of the propagation direction of LFO revealed in this study is an interesting phenomenon. Surely, it is related to the factors which determine the source of oscillation and control its propagation, so it needs to do further dynamical analysis. Presently, it is meaningful to give a general description of the large-scale situation under which the propagations of LFO occur.

Figure 6 is the averaged geopotential height distribution at 500 hPa for three episodes. In the first episode (Fig. 6a), the large-scale situation belongs to "double blocking high" which is a typical situation of normal Meiyu. While during the heaviest rain of the third episode (Fig. 6c), the situation is of the so-called "bipolar blocking high" which appears almost at every time whenever excessively heavy rain (e. g. in 1954 and 1980) occurs over Jianghuai in history (Bi and Ding 1992). In the second episode, the circulation changes from the double blocking high to the bipolar blocking high. So the large-scale situation also has a seasonal adjustment during the rain season, and this is the background of LFO activity.

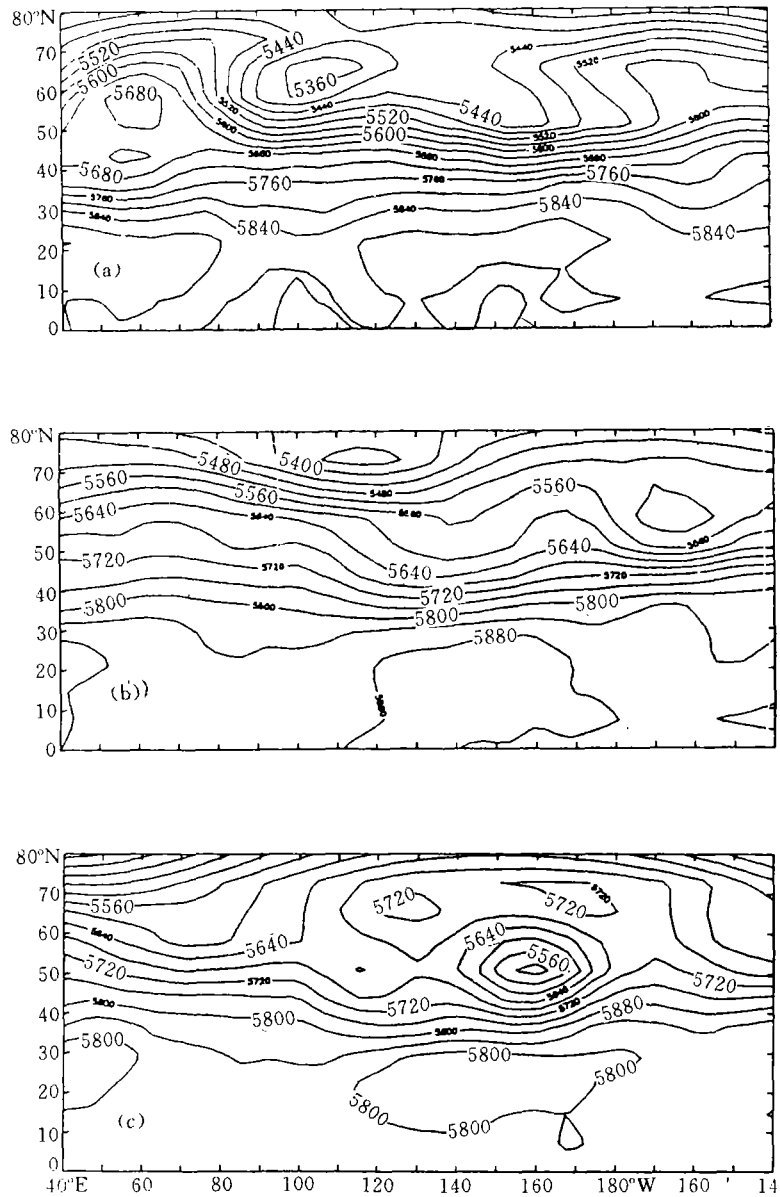

Fig. 6. Field of geopotential height at 500 hPa for three episodes.

VI. SUMMARY

(1) The activity of low frequency oscillation (LFO) widely exists in East Asia during the period of 1991 excessively heavy rain over the Changjiang-Huaihe River Basin (Jianghuai). Both the rainfall amount of Jianghuai and the atmosphere from subtropical area to mid-high latitudes have the dominant period of 10—20 d, while the atmospheres in tropical area and high latitudes have the dominant period of 30—60 d.

(2) For LFO of different frequency bands in East Asia during the Meiyu season, there are several times of active latitudinal and longitudinal propagation processes. Propagation direction shows distinct seasonal variation, from eastward/northward propagation (passing through Jianghuai) during the first episode to westward/southward propagation during the third episode. This variation may be related to the adjustment of large-scale circulation from "double blocking high" of the first episode to "bipolar blocking high" of the third episode.

(3) Though different in direction in the three episodes, the propagation of LFO in tropical wind field can all transport low frequency warm/moist air to Jianghuai. The southwest airflow in low latitudes transports warm/moist air to Jianghuai from the Indian Ocean through the eastward propagation of LFO in tropical region. And similarly, the southeast airflow transports warm/moist air from the West Pacific Ocean through the westward propagation. Low frequency warm/ moist airs in south meet and interact with the cold air in north which vigorously invades Jianghuai three times, and finally three episodes of heavy rain occur in mode of LFO.

(4) Oscillations of different frequency bands are superposed in phase. So the intensive activity of LFO in the first and the third episodes will surely have significant effect on the weather of these two periods. Actually the two most important low frequency synoptic events of this Meiyu case just appear in these two periods which may reflect the general anomaly of the 1991 Meiyu process, compared with normal Meiyu season. (a) This Meiyu onsets extremely early that is in the second half of May and nearly one month earlier than in normal year. (b) In the first half of July, there occurs the heaviest episode of rainfall of the whole Meiyu season, that is even the heaviest rainfall for the recent 30 years in China.

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