# Analysis of the Characteristics of 30–60 Day Low–Frequency Oscillation over Asia during 1998 SCSMEX[①]

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ABSTRACT

The wavelet analysis is performed of the mid– and low–latitude circulation index at 850 hPa over East Asia, the East Asian monsoon index and the precipitation over the middle and lower reaches of the Yangtze River during 1998 South China Sea Monsoon Experiment (SCSMEX) from May to August. Analysis shows that distinct 30–60 day low–frequency oscillation (LFO) exists in all of the above elements during the experiment period. Analysis of low–frequency wind field at 850 hPa from May to August with 5 days interval is performed in this paper. Analysis results reveal that: (1) A low–frequency monsoon circulation system over East Asia, characterized by distinct 30–60 day low–frequency oscillation, exists over 100°–150°E of East Asian area from the middle and eastern parts of China continent and the South China Sea to the western Pacific in both the Northern and Southern Hemisphere. The activity of East Asian monsoon is mainly affected by the low–frequency systems in it; (2) All of the tropical monsoon onset over the South China Sea in the fifth pentad of May, the beginning of the Meiyu period and heavy rainfall over the middle and lower reaches of the Yangtze River in mid–June and the heavy rainfall after mid–July are related to the activity of low–frequency cyclone belt over the region, whereas the torrential rainfall over the upper reaches of the Yangtze River in August is associated with the westward propagation of low–frequency anticyclone into the mainland; (3) There are two sources of low–frequency oscillation system over East Asia during SCSMEX, i.e. the equatorial South China Sea (SCS) and mid–high latitudes of the middle Pacific in the Northern Hemisphere. The low–frequency system over SCS propagates northward while that in mid–high latitudes mainly propagates from northeast to southwest. Both of the heavy rainfall over the middle and lower reaches of the Yangtze River in June and July are associated with the northward propagation of the above–mentioned SCS low–frequency systems from the tropical region and the southwestward propagation from mid–high latitudes respectively and their convergence in the middle and lower reaches of the Yangtze River; (4) There are two activities of low–frequency cyclone and anticyclone belt each in the East Asian monsoon system during May to August. However the activity of these low–frequency circulation systems is not clearly relevant to the low–frequency circulation system in the Indian monsoon system. This means that the low–frequency circulation systems in Indian monsoon and East Asian monsoon are independent of each other. The concept previously put forward by Chinese scholars that the East Asian monsoon circulation system (EAMCS) is relatively independent monsoon circulation system is testified once more in the summer 1998.

**Key words:** SCS monsoon onset, Flood in the summer 1998, Low–frequency monsoon circulation

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## 1. Introduction

Four observational research experiments— South China Sea Monsoon Experiment (SCSMEX), Torrential Rainfall Experiment over the Both Sides of Taiwan Strait and Adjacent Area (HUAMEX), Huihe River Basin Energy and Water Cycle Experiment and Research Program (HUBEX) and Observations and Theoretical Study of the Physical Process of Land–air Interaction over the Tibetan Plateau and Its Impact on the Global Climate and Severe Weather in China (TIBEX for short) were performed in China in the summer 1998. Many special observations have been done and valuable data have been obtained. During June to August of 1998 heavy rainfall occurred over the Yangtze River valley, and it is the second serious flood–year in China since the 1950s. In addition, general results indicate that the tropical monsoon onset over SCS in 1998 started in the fifth pentad of May, which is a little later than that of the normal case (Chen and Zhu, 1999; Chen et al., 1999; Li and Qu, 1999; He et al., 1994). The Meiyu over the middle and lower reaches of the Yangtze River occurred in the third pentad of June, which belongs to the normal case once more. Therefore how this nearly normal onset of tropical and subtropical monsoon induced the succeeding abnormal weather deserves our further study. Firstly we should study the characteristics of the large–scale variation in the monsoon system. In this case, it is especially necessary to study the characteristics of low–frequency oscillation in the summer monsoon system. Krishnamurti and Bhalme (1976) studied the quasi bi–week low–frequency oscillation in the Indian monsoon system in 1979 and indicated the members of Indian monsoon system and the intrinsic interaction among them and their effect on the Indian summer monsoon onset. Chen (1984), Tao and Chen (1987) studied the characteristics of East Asian monsoon system and put forward the members of East Asian monsoon system. Using OLR data, Chen and Xie (1988) studied the characteristics of 30–60 day low–frequency oscillation (LFO) in the East Asian monsoon system over the subtropics and indicated that its latitudinal propagation was right–about to that over the equator. i.e. it mainly propagates from east to west. The meridional propagation of LFO is northward from the tropics and is southward from high latitudes. They merge into each other at about 30°N. So whether there exists its own low–frequency monsoon circulation system over East Asia that influenced the flood over the Chinese mainland in 1998 is the emphasis to be studied in this research work.

The results of research indicate that in the summer 1998 a distinct low–frequency East Asian monsoon circulation system existed over East Asia. The low–frequency low–level cyclone belt propagating northward from equatorial SCS combined with cyclonic LFO that propagated southwestward from middle and high latitudes of the Pacific over the middle and lower reaches of the Yangtze River. They were the main circulation systems responsible for the severe flood over the middle and lower reaches of the Yangtze River in mid–late June and mid–late July, whereas the low–frequency anticyclone entering the mainland of China in August is the main circulation system which caused the heavy rainfall over the upper reaches of the Yangtze River.

## 2. Characteristics of LFO in precipitation and circulation

The reanalysis data of NCEP wind field from April to September of 1998 and the precipitation data for the Chinese region are mainly used in the paper. The low–frequency filtering method is adopted as that in Murakami et al. (1986).

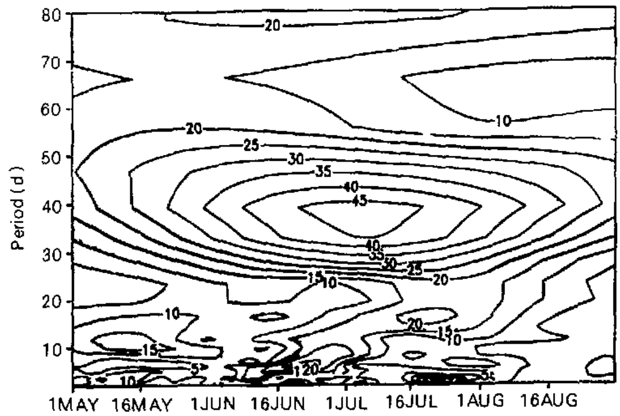



Fig. 1. Wavelet power of daily rainfall over the middle and lower reaches of the Yangtze River during the period from May to August, 1998.

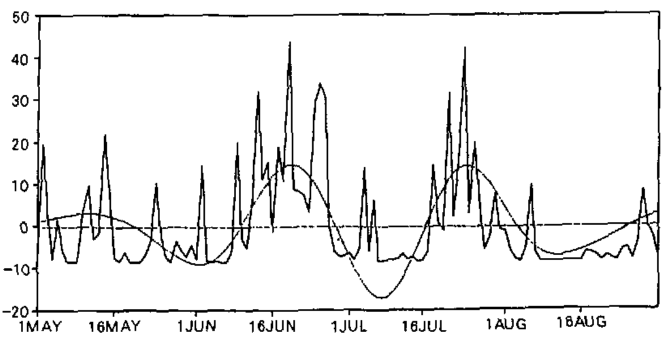



Fig. 2. Rainfall departure over the middle and lower reaches of Yangtze River valley during the period from May to August, 1998 and reconstructed 30–60 day LFO.

The mean daily rainfall data from 18 stations located in the middle and lower reaches of the Yangtze River (28°–31°N, 110°–120°E), the mean zonal wind for the domain of 100°–120°E, 0°–10°N in low latitudes and 30°–40°N in middle latitudes at 700 hPa (hereinafter named low– and mid–latitude circulation index over East Asia) are selected for Morlet wavelet analysis. Figures 1 and 2 are respectively the Morlet wavelet and power spectrum analysis of the daily rainfall and the precipitation departure and reconstructed 30–60 day LFO component over the middle and lower reaches of the Yangtze River during the period from May to August, 1998.

During the period May–August of 1998 there are mainly two kind of rainfall LFO: One is of the dominant scale of 40 days and the other with approximately 12–day period lies over the middle and lower reaches of the Yangtze River. Among them the 30–60 day LFO with the dominant scale of 40 days has the strongest power spectrum density. To show the importance

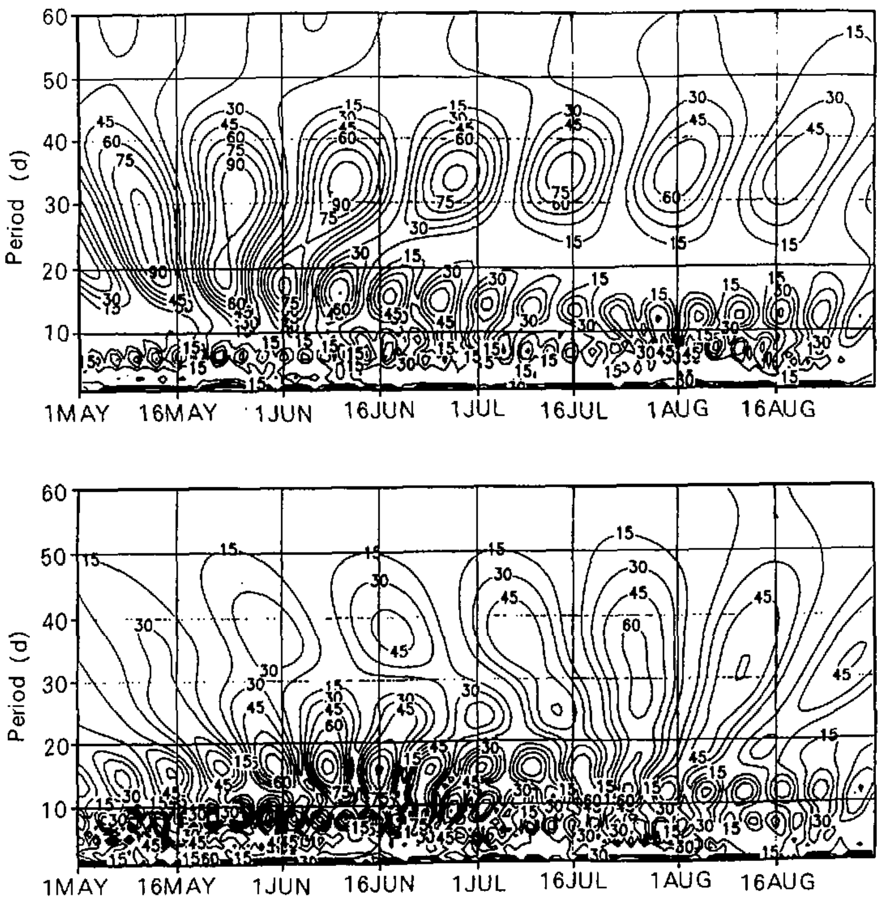



Fig. 3. Wavelet analysis of the regional mean 700 hPa $U$ for domains 100°–120°E, 0°–10°N (a) and 100°–125°E, 30°–40°N (b) during the period from May to August, 1998.

of the 30–60 day LFO we presented a figure of daily rainfall over the middle and lower reaches of the Yangtze River and 30–60 day low–frequency filtering component (Fig. 2). It is shown that all the peaks of 30–60 day low–frequency component occurred in the precipitation period in the first half of May, the heavy rainfall time during the Meiyu period after June 11 and the heavy rainfall period in mid–late July over the middle and lower reaches of the Yangtze River. Although the reconstructed amplitude of LFO is only one third to two thirds of the real value, the peak time of LFO coincide with the observational result. This indicates that the 30–60 day LFO played a main role in inducing rainfall over the middle and lower reaches of the Yangtze River in the summer 1998.

Now let's see the wavelet analysis of the low–and middle–latitude circulation index over East Asia at 700 hPa. In the low–latitude region (Fig. 3a), we can find that obviously LFO with the dominant scale of 35 days exists except for the first half of May. Besides, other two less important LFOs of 12–15 day period and 5–8 day period exist. While in the mid–latitude region (Fig. 3b), since May 16 the main central period of zonal circulation index at 700 hPa is 35–40 days, next to that are 15 days and 8–10 days. The wavelet analysis of East Asian monsoon index (EAMI) has also been done (neglected here for space limitation). The results show that 30–60 day LFO exists in rainfall and zonal circulation at 700 hPa, and it is the main oscillation. See also the definition of EAMI in Zhu et al. (2000).

Figures 4a and 4b show rainfall over the middle and lower reaches of the Yangtze River, EAMI at 850 hPa, variations of the 30–60 day LFO component of the circulation index at 700 hPa over low latitudes and middle latitudes. We can see from Figs. 4a, 4b that the peak of low–frequency precipitation advances approximately 7 days than that of EAMI and lies in the enhancement period instead of peak time of the southwesterly flow in EAMI low–frequency wave. Besides, the low–frequency oscillation of precipitation is nearly out of phase with that in the low–latitude circulation index at 700 hPa (Fig. 4b), i.e. the peak time of precipitation LFO nearly coincides with the valley time of the low–latitude

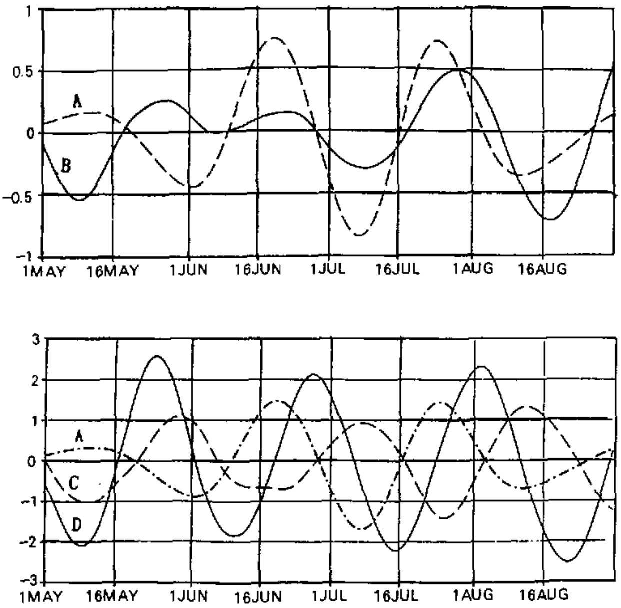



Fig. 4. (a) Evolutions of the 30–60 day low–frequency precipitation over the middle and lower reaches of the Yangtze River (dashed line) and the 30–60 day low–frequency East Asian monsoon index (solid line). (b) Evolutions of the 30–60 day low–frquency precipitation over the middle and lower reaches of the Yangtze River (dot–dashed line) and 30–60 day low–frequency low–latitude (dashed line) and mid–latitude (solid line) circlulation indexes at 700 hPa during the period from May to August, 1998.

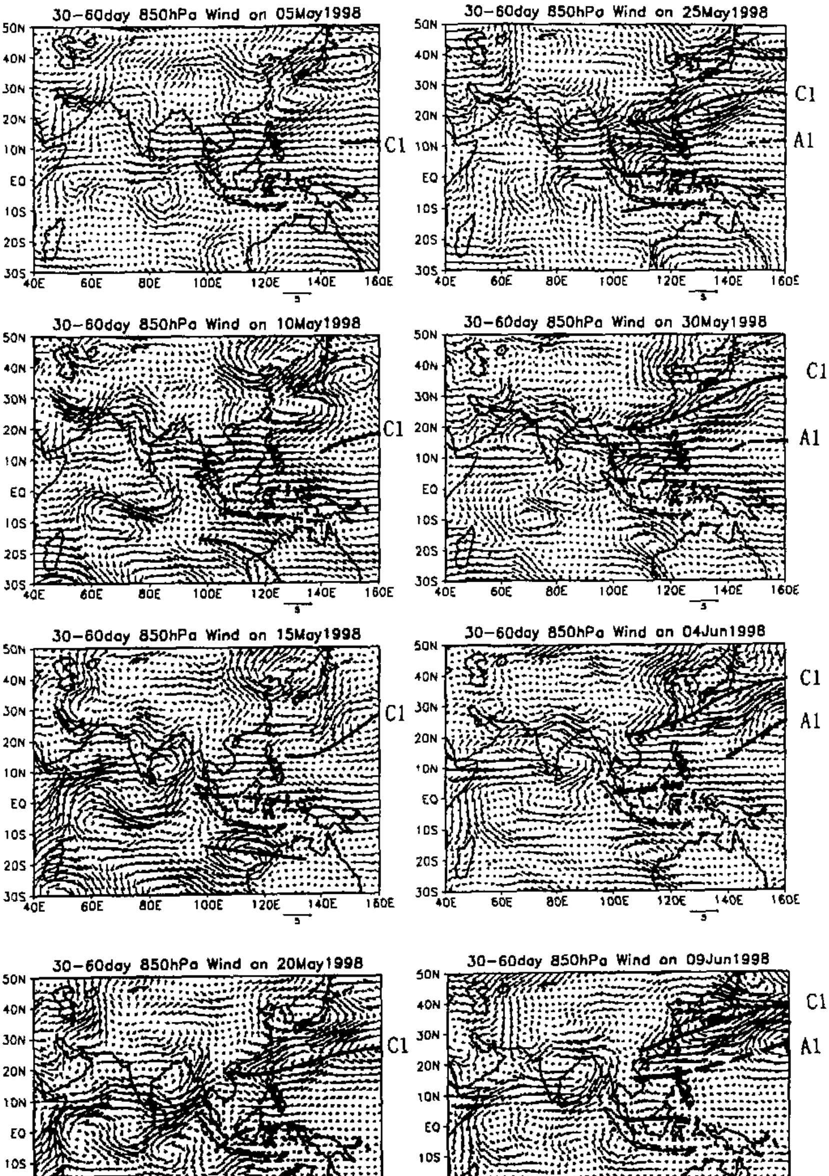
circulation index at 700 hPa, which suggests that it is in the low–frequency tropical easterly abnormal period or low–frequency weak tropical SW summer monsoon period. In comparison of the low–frequency precipitation (30°–40°N) with the mid–latitude circulation index at 700 hPa (Fig. 4b), the peak time of low–frequency precipitation is just in the transition period of the low–frequency mid–latitude circulation index from negative to positive (easterly to westerly). This indicates that the peak time of low–frequency precipitation over the middle and lower reaches of the Yangtze River occurred in the period when the axis of low–frequency cyclone belt at 700 hPa is located in the north of the middle and lower reaches of the Yangtze River, i.e. the middle and lower reaches of the Yangtze River lies in the low–frequency westerly belt south of the axis of low–frequency cyclone belt. Therefore the circulation pattern for the peak of the low–frequency precipitation over the middle and lower reaches of the Yangtze River should be: low–frequency easterly anomaly in low latitudes, the middle and lower reaches of the Yangtze River lying in the south of low–frequency cyclone belt and in the intensifying period of low–frequency southwesterly over the East Asian subtropical region (but not in the peak time of low–frequency southwesterly).

## 3. Characteristics of evolution in 30–60 day low–frequency flow pattern over East Asia at 850 hPa during summer 1998

As proved above, the distinct 30–60 day LFO exists in precipitation over the middle and lower reaches of the Yangtze River and the subtropical monsoon index at 850 hPa over East Asian region and variations of low– and mid–latitude circulation indexes at 700 hPa. Meanwhile, the low–frequency precipitation and flow pattern are well matching. To fully understand the evolution in low–frequency flow pattern over the whole Asian region, we show the vector chart of 30–60 day low–frequency wind at 850 hPa during the period from May 5 to August 30 with 5 days interval (Figs. 5a, 5b, 5c). Thereinafter we will discuss its evaluation characteristics during different periods.

### 3.1 *Evolution of the low–frequency flow pattern during SCS summer monsoon onset*

As indicated in the introduction, many scholars have studied the onset date of the SCS tropical summer monsoon in 1998. The rough onset date is the fifth pentad of May, i.e. between 20–25 May. The onset date defined by one of the authors is May 23 (Chen and Chu, 1999). It can be seen from Fig. 5a that, in the low–frequency wind vector chart on May 5 and 10, at 105°–160°E of East Asian region, there are the following distinct low–frequency systems from the Southern to Northern Hemisphere (i.e. from south to north): (1) South subtropical low–frequency cyclone belt, which has a center over Australia and the northwestern region; (2) Equatorial vortex belt, whose axis is located near 5°S; (3) North subtropical low–frequency cyclone belt (axis C1 of cyclone belt in Fig. 5), centered at 17.5°N, 155°E, on May 10, the cyclone belt only extended westward to about 140°E; (4) Subtropical low–frequency anticyclone belt, whose axis is located at 27.5°N, centered at 130°E; (5) Mid–latitude low–frequency cyclone belt, whose axis is located at 32.5°N, centered at 150°E; (6) North mid–latitude low–frequency anticyclone with the axis located between 40°–50°N, centered at 42.5°N, 120°E. Thus a series of S–N orientation low–frequency systems existed in the East Asia monsoon system. Also a series of low–frequency systems existed in the Indian monsoon system in 40°–80°E. It shows that in the Southern Hemisphere, the low–frequency system in Indian monsoon activity is out of phase with that in East Asian monsoon system. However north of 10°N, they are nearly inphase. To the north of 20°N, however, the in–phase systems are about 10° in distance meridionally. The axis of Indian monsoon system is approximately SSE–NNW orientation from south to north, while that of East Asian monsoon system is SSW–NNE. All the features show that the East Asian monsoon system has obviously different characteristics from that of Indian monsoon system.


30-60day 850hPa Wind on 05May1998
C1
30-60day 850hPa Wind on 25May1998
C1
A1
30-60day 850hPa Wind on 10May1998
C1
30-60day 850hPa Wind on 30May1998
C1
A1
30-60day 850hPa Wind on 15May1998
C1
30-60day 850hPa Wind on 04Jun1998
C1
A1
30-60day 850hPa Wind on 20May1998
C1
30-60day 850hPa Wind on 09Jun1998
C1
A1
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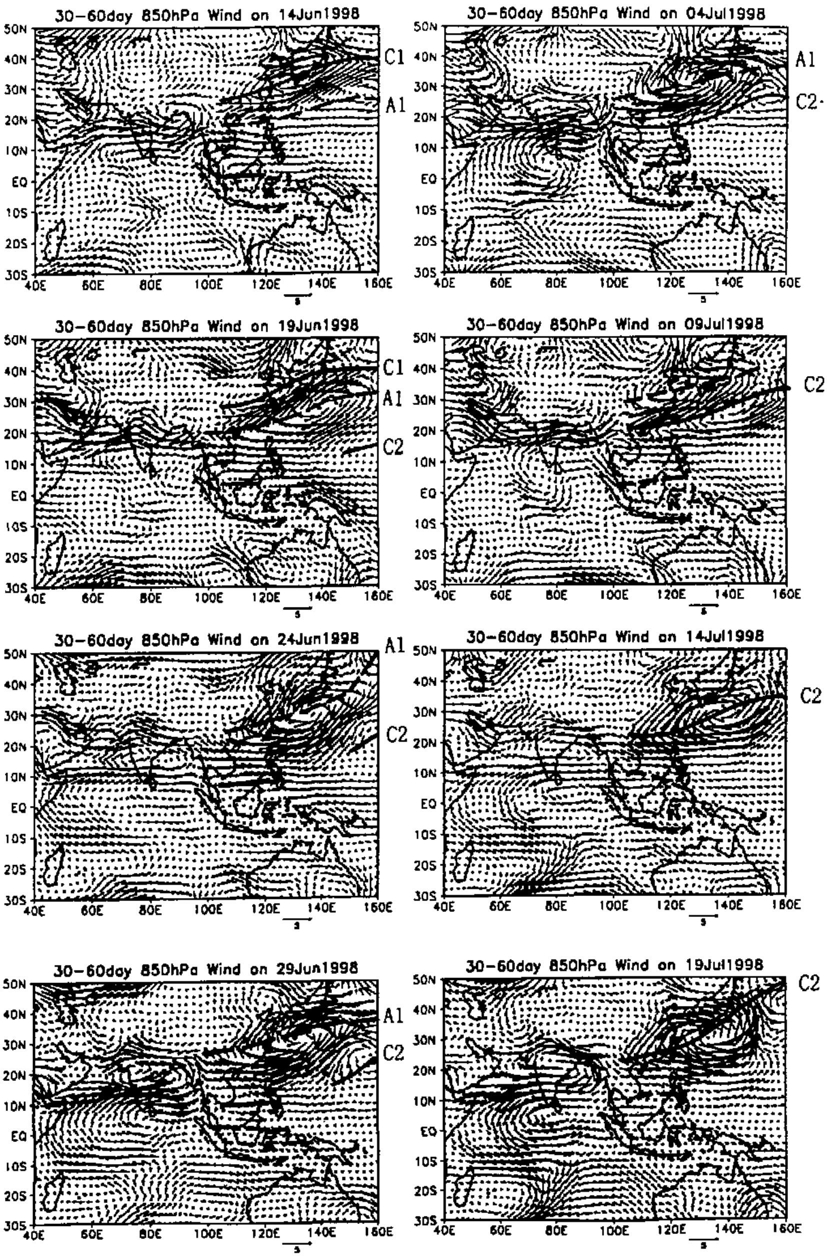
30–60day 850hPa Wind on 14Jun1998
C1
A1
30–60day 850hPa Wind on 04Jul1998
A1
C2
30–60day 850hPa Wind on 19Jun1998
C1
A1
C2
30–60day 850hPa Wind on 09Jul1998
C2
30–60day 850hPa Wind on 24Jun1998
A1
C2
30–60day 850hPa Wind on 14Jul1998
C2
30–60day 850hPa Wind on 29Jun1998
A1
C2
30–60day 850hPa Wind on 19Jul1998
C2
50N 40N 30N 20N 10N EQ 10S 20S 30S
40E 60E 80E 100E 120E 140E 160E

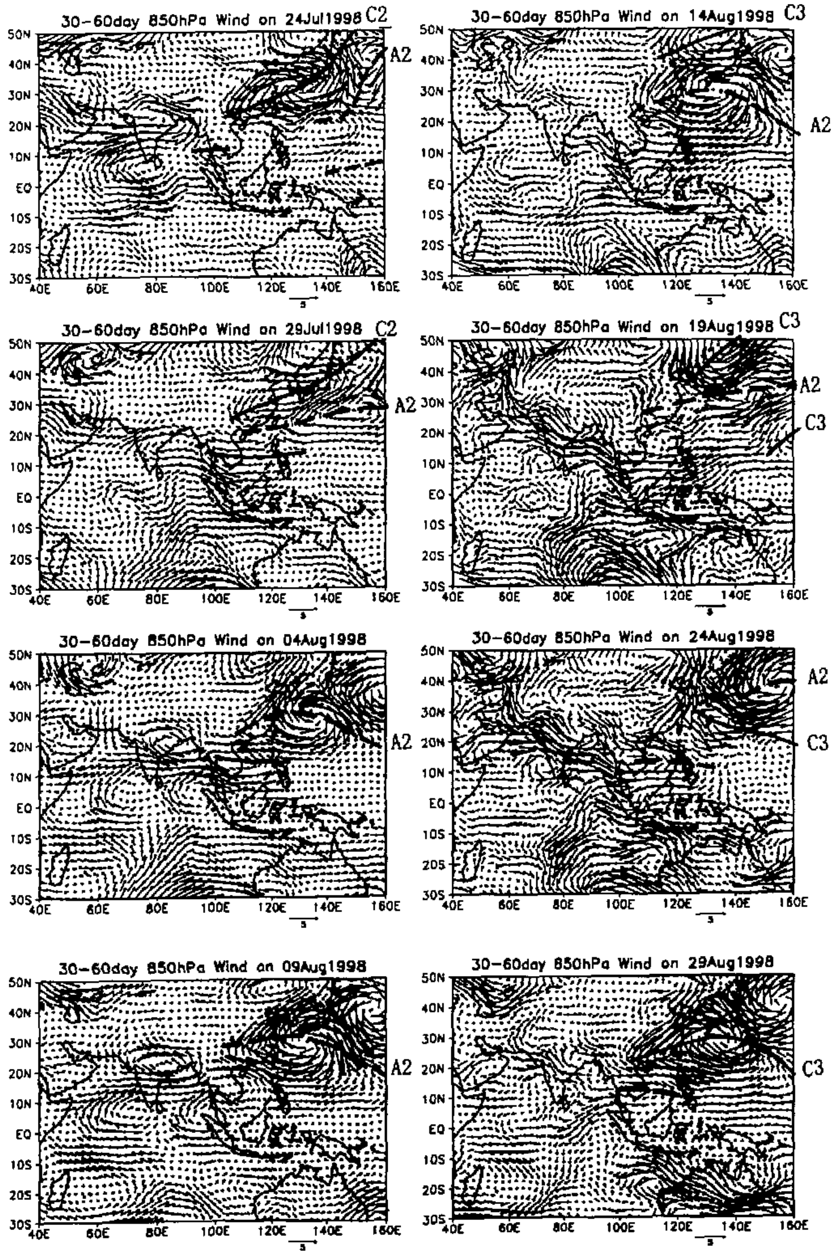


Fig. 5. 30–60 day low-frequency wind vector at 850 hPa during the periods May 5–June 9 (a), June 14–July 19 (b) and July 24–August 29 (c) in 1998.

On May 15, every subtropical low–frequency system in the East Asian monsoon system intensified markedly. The south subtropical low–frequency cyclone accentuated. The equatorial low–frequency vortex moved northward to the equator. The west part of north subtropical low–frequency cyclone belt C1 extended westward from 140°E to 120°E. The initial center of low–frequency cyclone at 155°E intensified evidently. It was shown from the daily low–frequency wind in the whole Asia and Pacific chart that the time of intensification was related to the southward movement of the mid–latitude low–frequency cyclone in its north and succeeding combination with it. A new weak center formed at 130°E too. By May 20, the equatorial vortex entered SCS, the circulation turned clockwise. Low–frequency south flow occurred in its west side, i.e. over SCS. Meanwhile the north subtropical cyclone belt C1 extended westward to middle–Indochina peninsula and formed a low–frequency cyclone center at 130°E. So two distinct low–frequency cyclone centers occurred in C1. Under these circumstances, subtropical low–frequency WNW wind occurred in mid–SCS. This was the first time that westerly flow appeared in SCS. While in tropical SCS, southerly flow instead of southwesterly occurred. So we can only say that the SCS tropical low–frequency summer monsoon has not broken out yet.

Till May 25, the SCS equatorial vortex continuously moved northward. Low–frequency southwesterly flow appeared in SCS tropical region. In virtue of the distinct intensification of the subtropical cyclone belt in its north (C1 in Fig. 5), in daily flow pattern and daily LFO wind chart, a cyclonic vortex formed in the western Pacific, then moved westward into SCS. The vortex intensifies the westerly in mid–SCS at 850 hPa. The low–frequency WNW wind over the mid–SCS intensified correspondingly. The mid–SCS was obviously controlled by the low–frequency westerly flow combined by the tropical southwest wind in its south and northwest wind in its north. On this day the SCS tropical summer monsoon has broken out already. Therefore the onset date of SCS tropical low–frequency summer monsoon should be between May 20 and May 25, which was consistent with the previous result.

In terms of Indian monsoon system, the low–frequency system has once intensified over the Southern Hemisphere on May 15. At first a strong cross equatorial low–frequency flow occurred over the Bay of Bengal and then formed a low–frequency cyclone. By May 20, the Somali cross equatorial low–frequency westerly flow also arrived in the Bay of Bengal and formed a low–frequency southwesterly flow. But we can also see that the southwesterly flow has transited to southeast wind in the region west of Indochina peninsula of 105°E. In the region east of 105°E, the subtropical low–frequency westerly flow in the east of Indochina peninsula and SCS was mainly formed by the intensification and westward extension of the subtropical low–frequency cyclone belt C1 in East Asian monsoon system. According to the definition by Indian meteorological administration, the onset date of summer monsoon over Calcutta in India in 1998 was late May, which indicates that it is independent of the process of SCS tropical monsoon onset. Besides, seen from the low–frequency wind vector chart on May 25, the low–frequency tropical monsoon in Indian monsoon system has become very weak and nearly disappeared. The westerly flow in the Indian monsoon system in the Northern Hemisphere is all–subtropical westerly flow.

It is concluded that the LFO in the process of the SCS tropical summer monsoon onset during May 15 to 20 was mainly induced by the variation of the low–frequency system in East Asian monsoon circulation system instead of that in Indian monsoon system.

### 3.2 *The beginning of Meiyu in East Asia and evolution of the low–frequency system causing the heavy rainfall twice over the middle and lower reaches of the Yangtze River during June–July*

We have pointed out in the introduction that in 1998 the Meiyu in the middle and lower reaches of the Yangtze River started on about June 11. Two heavy rainfall processes occurred in mid–late June and late July. As is clear from Figs. 5a, 5b, the subtropical low–frequency C1 over East Asia moved northward step by step since May 25. The center of the cyclone belt moved northward from 25°N to 30°N till June 4 (over the Pacific south of Japan.). By June 9 the center of the low–frequency cyclone belt C1 landed in Japan while its west part of axis passed through the south of the Yangtze River. At 850 hPa, the south of Yangtze River remained under low–frequency westerly flow. On June 14, C1 passed through the Yangtze River and the south of Yangtze River was completely under the influence of the low–frequency westerly flow in the south of low–frequency cyclone belt C1. The rainy season of Meiyu over the middle and lower reaches of the Yangtze River started between June 9 to 14. The northern branch of the low–frequency cyclone belt C1 weakened on June 19 and left cyclone center to the north of the Yangtze River. We can see that with the northward movement of the cyclone belt C1, the SCS equatorial vortex moved northward along with. Meanwhile a new anticyclone belt A1 formed in the subtropical region of the western Pacific on June 4. Afterward, A1 extended westward and connected with the equatorial vortex in SCS. On June 9 they formed a subtropical low–frequency anticyclone belt A1 extending from 27.5°N, 160°E to west of SCS. By June 14 the axis of A1 moved northward with C1 to north of SCS. Torrential rainfall occurred in the south of the Yangtze River in mid–late June. From June 14–24, the anticyclone belt A1 intensified continuously. Distinct low–frequency southwest wind occurred over the south of the middle and lower reaches of the Yangtze River, which maintains the heavy rainfall over the middle and lower reaches of the Yangtze River. However, the anticyclone belt A1 moved northward since June 24 and arrived at the middle and lower reaches of the Yangtze River by June 29, the rain belt moved northward to North China correspondingly. The rainfall over the middle and lower reaches of the Yangtze River ended. Thereby the action of low–frequency system in East Asian monsoon coincides very much with the beginning of Meiyu and the heavy rainfall process and the end of precipitation over the mainland of China in June.

With A1 entering the mainland, another low–frequency cyclone vortex from the equator appeared over SCS. It moved to 2.5°N by June 19, 7.5°N by June 24, 10°N by June 29 and maintained till July 4. Meanwhile a new low–frequency cyclone belt C2 formed over the middle Pacific to the south of the low–frequency anticyclone belt A1. The north part of C2 connected with the mid–latitude low–frequency cyclone belt over the middle and eastern Pacific (figure not shown). Actually it was the southwestward extending part of the latter. The principal part of C2 extended southward from northeast to the western Pacific constantly. It intensified synchronously with low–frequency cyclone over SCS after June 19 and combined with it on July 4. They formed a low–frequency cyclone belt C2 over the region from middle latitudes of the eastern Pacific to SCS. After July 4 the part of C2 over the western Pacific and SCS moved northward constantly. The center of the cyclone moved northwestward as well. By July 14, the west part of axis arrived at the coastal region of South China and the center is located in the Pacific near south of Japan. By July 19 the axis entered the mainland of China. By July 20 the coastal axis arrived at the middle and lower reaches of the Yangtze River (figure not shown). The low–frequency westerly flow persisted over South China once more and another heavy rainfall occurred. This circulation pattern maintained until the end of July. During the period the region south of the middle and lower reaches of the Yangtze River remained under the low–frequency southwesterly flow all the time and heavy rainfall also was maintained.

In 1998, the two heavy rainfall over the middle and lower reaches of the Yangtze River of East Asian continent in middle and late June and late July were caused by the two low–frequency cyclone belts C1 and C2. Both of the low–frequency cyclone belts were formed by the equatorial vortex which entered SCS and developed into a low–frequency cyclone. Meanwhile, another low–frequency cyclone belt extended southwestward from middle latitudes of the middle and eastern Pacific, combined with the low–frequency cyclone over SCS and finally formed the low–frequency cyclone belts (C1 and C2) extending from the middle Pacific to SCS. The west part of the low–frequency cyclone belt moved northward while the east part moved westward. The axis extended from south of Japan to the middle and lower reaches of the Yangtze River. At the time low–frequency anticyclone vortex occurred over SCS once more. In the region south of the middle and lower reaches of the Yangtze River of the mainland of China subtropical low–frequency southwest wind prevailed and induced heavy rainfall twice over the region. In the short–term weather analysis, the heavy rainfall seems to be caused by the southward retreat of subtropical high in July. But in the process of low–frequency East Asian monsoon circulation, the heavy rainfall was caused by another low–frequency cyclone belt which was formed and moved northward with a new–born low–frequency anticyclone accompanying in its south instead of the southward retreat of subtropical high. In normal years the low–frequency cyclone belts also formed twice, but most of them could not enter the mainland of China for the second time. However in 1998, the second low–frequency cyclone belt enter the mainland of China once more after it formed and caused the second heavy rainfall over the middle and lower reaches of the Yangtze River.

Secondly it was found from Figs. 6a–6c that since the onset of SCS tropical summer monsoon on May 23 till June 19, the Arabian Sea, India and the Bay of Bengal were dominated by the low–frequency anticyclone belt all the time. The anticyclone belt formed over the Arabian Sea on May 25, then intensified and moved northward slowly. The center of anticyclone moved eastward from the Arabian Sea to the Bay of Bengal and disappeared after June 19. On this day a cyclone belt formed at 10°N. It moved northward and the axis arrived at 15°N by June 24, and 20°N by June 29. It was the second time of cyclone belt occurence in Indian monsoon system. So we can conclude that the variations of Indian monsoon system and East Asian monsoon system are very much independent of each other. They clearly divide each other in 100°–105°E. The variation of the low–frequency cyclone belt in Indian monsoon system occurred firstly in the west and propagated eastward to the Bay of Bengal, whereas in East Asian monsoon system the variation occurred firstly in the east and then propagated eastward to SCS.

### 3.3 *Low frequency system in the precipitation over the upper reaches of the Yangtze River in August*

By the end of July, with the weakness of the low–frequency cyclone belt C2 over East Asia, the low–frequency anticyclone belt A2 in the south of C2 moved northward with it. On July 29 a low–frequency anticyclone center formed over the western Pacific intensified and moved westward. During the time from August 4–9, it entered the East China Sea. The low–frequency anticyclone has persisted over the eastern China until August 19. No distinct precipitation occurred over the region. The recurved southerly and southwesterly flow in the west side of anticyclone prevailed over the region as far as 100°–105°E. The low level of the upper reaches of the Yangtze River is dominated by the low–frequency southerly flow in west part of the anticyclone which caused heavy rainfall over the region. We can see that no low–frequency southerly flow in the Indian monsoon system entered the Provinces of Yunnan and Sichuan of China. Especially since August 14, the region of India remained under the influence of the low–frequency anticyclone, the low–frequency summer monsoon in Indian monsoon system could not arrive at the upper reaches of the Yangtze River even more. After August 19, a new low–frequency cyclone belt C3 rapidly formed over the subtropical region of East Asia. By August 24, the mainland of China was dominated by the low–frequency northerly flow in the west part of the cyclone belt and precipitation over the whole China rapidly ended.

Therefore the rainfall over the upper reaches of the Yangtze River in early and middle August is mainly caused by the low–frequency southerly and southwesterly flow in west part of the anticyclone after the low–level low–frequency anticyclone dominated East China. The low–frequency flow came from SCS and the East China Sea, whereas not from the Bay of Bengal.

The above analysis indicated that concerning the process of low–frequency variation, the East Asian monsoon circulation system is independent of the Indian monsoon system in the summer 1998. The most prominant difference is that the low–frequency system in Indian monsoon propagates from southwest to northeast while that in East Asian monsoon is formed by the combination of the low–frequency system propagating northward from the equator via SCS and southwestward from middle latitudes of the Northeast Pacific. Both low–frequency cyclone and anticyclone belts were formed and arrived at the continent of China during the period from May to August of 1998, which caused heavy rainfall twice over the middle and lower reaches of the Yangtze River in June and July and the heavy rainfall over the upper reaches of the Yangtze River in August.

To further confirm the above conclusion, we have presented Fig.6. The left side of the figure is longitude–time cross section of low–frequency divergence along 115°–120°E during May to August while the right side is longitude–time cross section of low–frequency divergence along the diagonal from 50°N, 180°E to 30°N, 120°E at 850 hPa. We can see that along 115°–120°E there are some times of northward movements of low–frequency convergence, at the time some low–frequency convergence propagates from northeast to southwest, finally they converged in 25°–30°N. The two periods of the convergence of the low–frequency systems are June 5–25 and July 16–30, which are approximately the period of two heavy rainfalls over the middle and lower reaches of the Yangtze River. Meanwhile there are two combinations of low–frequency divergence systems associated with the period of rainfall break in the region. This is consistent with the analysis of low–frequency circulation.

## 4. Concluding remarks

The following conclusions are obtained from the above analysis:

(1) There exist distinct 30–60 day LFO of rainfall over the middle and lower reaches of the Yangtze River, the tropics of East Asia (0°–10°N) and mid–latitude (30°–40°N) westerly circulation index and East Asia subtropical monsoon index. The peak of low–frequency precipitation occurs in the period of intensification of low–frequency easterly flow in the tropics and low–frequency southwesterly flow in the subtropics. While the axis of the low–frequency cyclone belt in the peak time of low–frequency precipitation lies in slightly north of the

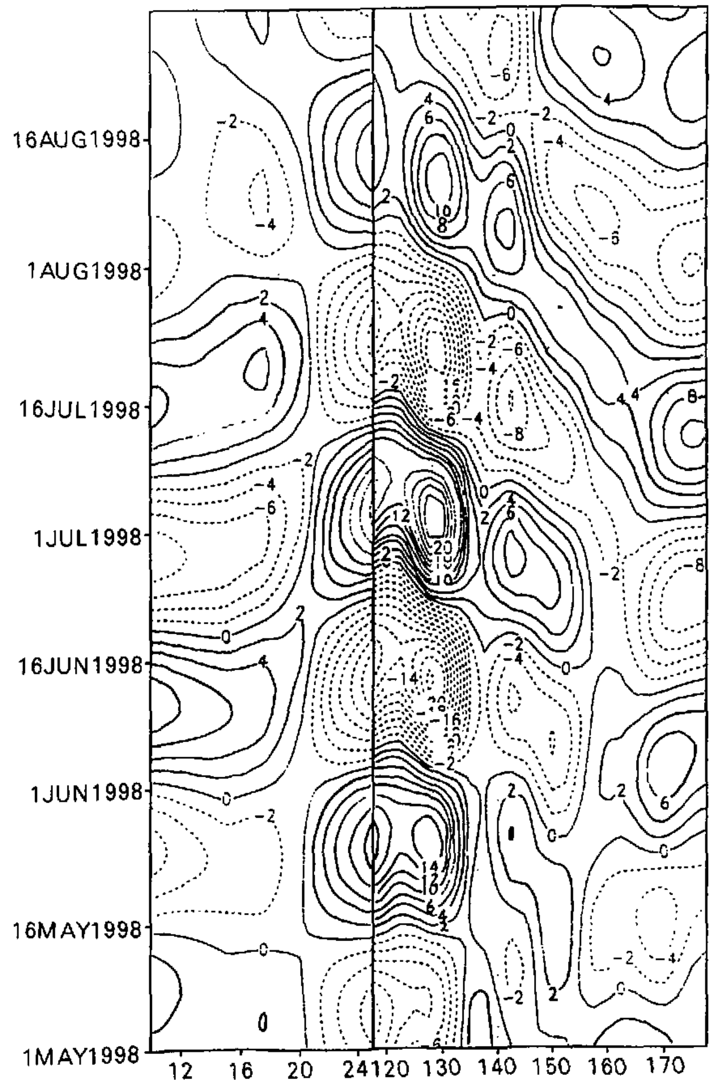


Fig. 6. Longitude–time cross section of low-frequency divergence over SCS and the North Pacific at 850 hPa in 1998. Left side: along 110°–120°E; right side: along the diagonal from 50°N, 180°E to 30°N, 120°E.

middle and lower reaches of the Yangtze River.

(2) The main characteristics of the evolution of low-frequency circulation in East Asian monsoon system during the period from May to August, 1998 are: (a) There is low-frequency vortex forming over the equator and moving northward to SCS. (b) There is low-frequency cyclone belt and anticyclone belt continuously forming over middle latitudes of the middle Pacific, propagating from northeast to southwest and to the subtropics of the western Pacific

and combining with low–frequency system over SCS to form the a low–frequency cyclone and a anticyclone belt over the region from the mid–latitude middle Pacific to SCS. During May to August there were three formation processes of either the low–frequency cyclone or anticyclone belt. (c) After the formation of the low–frequency cyclone and anticyclone, both of their west parts moved northward to SCS region while the east parts propagated from northeast to southwest, finally formed the strong cyclone and anticyclone centers located over the sea in the southwest of Japan. While the middle and lower reaches of the Yangtze River was the location of the axis or a little bit south of the axis. (d) The tropical low–frequency divergence system over SCS moved northward, combined with the southwestward propagating low–frequency divergence system from middle latitudes in 25°–30°N and caused heavy rainfall twice and two break periods in the middle and lower reaches of the Yangtze River. The third low–frequency anticyclone enters eastern China and caused the heavy rainfall over the upper reaches of the Yangtze River. The low–frequency flow, which caused the heavy rainfall in August, was the low–frequency southeasterly and southerly flow in the west part of the low–frequency anticyclone coming from SCS and the East China Sea.

(3) In the case of 1998, the characteristics of the evolution of low–frequency system in East Asian monsoon system is very much different from that in Indian monsoon circulation system. We can say that their variation is independent. The former propagated from east to west while the latter from west to east. The converged location of their propagation, i.e. the relative dividing boundary of the two systems is about 100°–105°E. The process of rainfall over the middle and lower reaches of the Yangtze River is mainly dominated by the low–frequency cyclone in East Asian monsoon circulation system while the heavy rainfall over the upper reaches of the Yangtze River was caused by the low–frequency anticyclone entering the east of mainland of China. However the Indian monsoon system affected the heavy rainfall over the upper reaches of the Yangtze River either.

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# 1998 SCSMEX 期间亚洲 30–60 天低频振荡特征的分析

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**摘　要**

对 1998 年 5–8 月南海季风试验(SCSMEX)期间东亚地区 850 hPa 中低纬环流指数、东亚季风指数和长江中下游降水进行了 Morlet 小波分析，结果表明在此期间这些要素均有明显的 30–60 天周期低频振荡。在此基础上对 5–8 月每隔 5 天的 850 hPa 低频流场进行分析，结果表明：(1) 100°–150°E 间东亚从中国东中部大陆经南海和西太平洋的南北半球中明显的存在一个以 30–60 天低频荡为特征的东亚季风低频环流系统，东亚季风活动主要受东亚季风系统中低频活动影响；(2) 5 月第 5 候南海热带季风爆发、6 月中旬长江中下游入梅及产生大暴雨以及 7 月中旬以后的该地区大暴雨均与低频气旋带在该地区活动有关，而 8 月长江上游大暴雨则与低频反气旋伸入到大陆有关；(3) SCSMEX 期间东亚低频振荡系统的源地有二个，即南海赤道和北半球中太平洋中高纬。南海低频系统向北传播，而中高纬低频系统自东北向西南传播为主。长江中下游 6、7 月二次大暴雨均与上述二个低频气旋系统自热带向北和中高纬向西南传播并于长江中下游汇合有关；(4) 5–8 月间东亚季风系统中有二次低频气旋带和二次低频反气旋带活动，这些低频环流系统的活动与印度季风低频环流系统活动并无明显关系，这表明，东亚季风低频环流系统和印度低频环流系统是相对独立的，这证实，早期中国学者提出的东亚季风环流系统是一个相对独立的季风环流系统的概念在 1998 年夏季也得到证实。

**关键词**: 南海热带季风爆发，长江中下游大暴雨，30–60 天低频环流系统