The 1997/ 98 ENSO Cycle and Its Impact on Summer Climate Anomalies in East Asia①

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ABSTRACT

The observed data of the sea surface temperature (SST) anomalies and the sea temperature (ST) in the sub–layer of the equatorial Pacific, the NCEP/ NCAR reanalysis data and the data set of daily precipitation in China are used to analyze the characteristics of the 1997 / 98 ENSO cycle and its impact on summer climate anomalies in East Asia. The results show that the 1997 / 98 ENSO cycle, the strongest one in the 20th century, might be characterized by rapid development and decay and eastward propagation from the West Pacific warm pool. Influenced by the ENSO cycle, in 1997, the serious drought and hot summer occurred in North China, and in the summer of 1998, the severe floods occurred in the Yangtze River valley, especially in the Dongting Lake and Boyang Lake valleys, South Korea and Japan.

The analysis also shows that: influenced by the 1997 / 98 ENSO cycle, the water vapor transportation by the Asian monsoon in the summer of 1997 was very different from that in the summer of 1998. In the summer of 1997, the water vapor transportation by the Asian summer monsoon was weak in North China and the northern part of the Korea Peninsula. Thus, it caused the drought and hot summer in North China. However, in the summer of 1998, the sea temperature in the sub–layer of the West Pacific warm pool dropped, the western Pacific subtropical high shifted southward. Thus, a large amount of water vapor was transported from the Bay of Bengal, the South China Sea and the tropical western Pacific into the Yangtze River valley of China, South Korea and Japan, and the severe flood occurred there.

Key words: ENSO cycle, Climate anomaly, Monsoon, Drought and flood

1. Introduction

The ENSO event can be considered as the most important phenomenon of the air–sea interaction in the equatorial Pacific. When an ENSO event occurs in the equatorial Pacific, severe climate anomalies will be caused in many regions of the world (Namias, 1976; Horel and Wallace, 1981; Rasmusson and Carpenter, 1982; Rasmusson and Wallace, 1983). Similarly, the ENSO event also has a large impact on climate anomalies in East Asia (Wang and Zhu, 1986; Fu and Ye, 1988). In respect of the impact of ENSO event on climate anomalies in China, the investigation of Huang and Wu (1989) showed that the influence of ENSO event on climate anomalies in China varies with different stages of ENSO cycle. They pointed out that in the developing stage of ENSO event, drought may be caused in North China, and summer rainfall may be above normal in the Huaihe River valley, but in the decaying stage of ENSO event, severe flood may be caused in the Yangtze River valley, especially in the

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Dongting Lake and the Boyang Lake valleys, and summer rainfall may be below normal in the Huaihe River valley.

During 1997–1998, the strongest ENSO event occurred in the equatorial central and eastern Pacific, and it brought serious climate anomalies in many regions of the world. Particularly, the severe drought and hot summer appeared in North China and the northern part of the Korea Peninsula in the summer of 1997. And in the summer of 1998, the severe floods occurred in the Yangtze River valley and Northeast China, and heavy rainfalls also occurred in South Korea and Japan. These disasters brought huge economic losses in these countries. Thus, in this paper, the NCEP data of the sea temperature at surface and in the sub–layer of the tropical Pacific, the NCEP / NCAR reanalysis data and the data set of daily precipitations in China are used to analyze the process of 1997 / 98 ENSO cycle and its impact on climate anomalies in East Asia, especially in China.

2. The evolution process of the sea temperature (ST) at surface and in the sub–layer of the equatorial Pacific during the 1997/ 98 ENSO cycle

The evolution process of the SST anomalies in the equatorial Pacific during the 1997 / 98 ENSO cycle is shown in Fig. 1. It can be seen from Fig. 1 that the SST in the tropical western Pacific was very high in the autumn and the winter of 1996. Under the effect of the westerly anomalies near the sea surface of the tropical western Pacific shown in Fig. 2, the positive SST anomalies quickly propagated eastward from the West Pacific warm pool, and in May 1997, the positive SST anomalies became larger in the equatorial central and eastern Pacific. Thus, the ENSO event bursted out in the equatorial Pacific in May 1997. Moreover, the SST anomalies continuously increased after that and the maximum SST anomaly was 4.5°C above normal in the equatorial eastern Pacific in October 1997, i.e., the ENSO event reached its mature phase. This is the warmest episode of the equatorial eastern Pacific in the 20th century. However, in the winter of 1997, the larger easterly anomalies appeared near the sea surface of the West Pacific warm pool, and then, these wind anomalies propagated eastward from the warm pool. Due to the effect of the easterly anomalies, the ENSO event decayed rapidly, and the SST anomalies in the equatorial central and eastern Pacific were below normal from June 1998, and then, the La Niña event bursted out in the equatorial central and eastern Pacific.

The evolution process of the 1997 / 98 ENSO cycle can also be seen obviously from the sea temperature in the sub–layer of the equatorial Pacific, as shown in Figs. 3a–f. From the autumn of 1996, the West Pacific warm pool was in the warming state, and the positive ST anomalies in the depth of 100–200 m of the equatorial western Pacific were larger, as shown in Fig. 3a. Under the effect of the westerly anomalies near the sea surface of the equatorial western Pacific, this warm sea water quickly propagated eastward from the West Pacific warm pool, and as shown in Fig. 3b, it propagated to 140°W in March 1997 with a maximum ST anomaly of 5.5°C, and then, to the equatorial eastern Pacific. In May 1997, the ST anomalies in the sub–layer of all the equatorial Pacific became large positive anomalies, as shown in Fig. 3c, thus, the ENSO event bursted out in the equatorial central and eastern Pacific. Moreover, after that, these positive ST anomalies continued to be intensified in the sub–layer of the equatorial central and eastern Pacific, and in October 1997, the maximum positive ST anomaly shown in Fig. 3d reached 8.0°C, i.e., the ENSO event was in its mature phase. From Fig. 3d, it can be also seen that the ST anomalies in the sub–layer of the equatorial western Pacific became negative. This evolution process of ST in the sub–layer of the equatorial Pacific may be due to the westward propagation of the cooling Rossby waves excited by the unstable

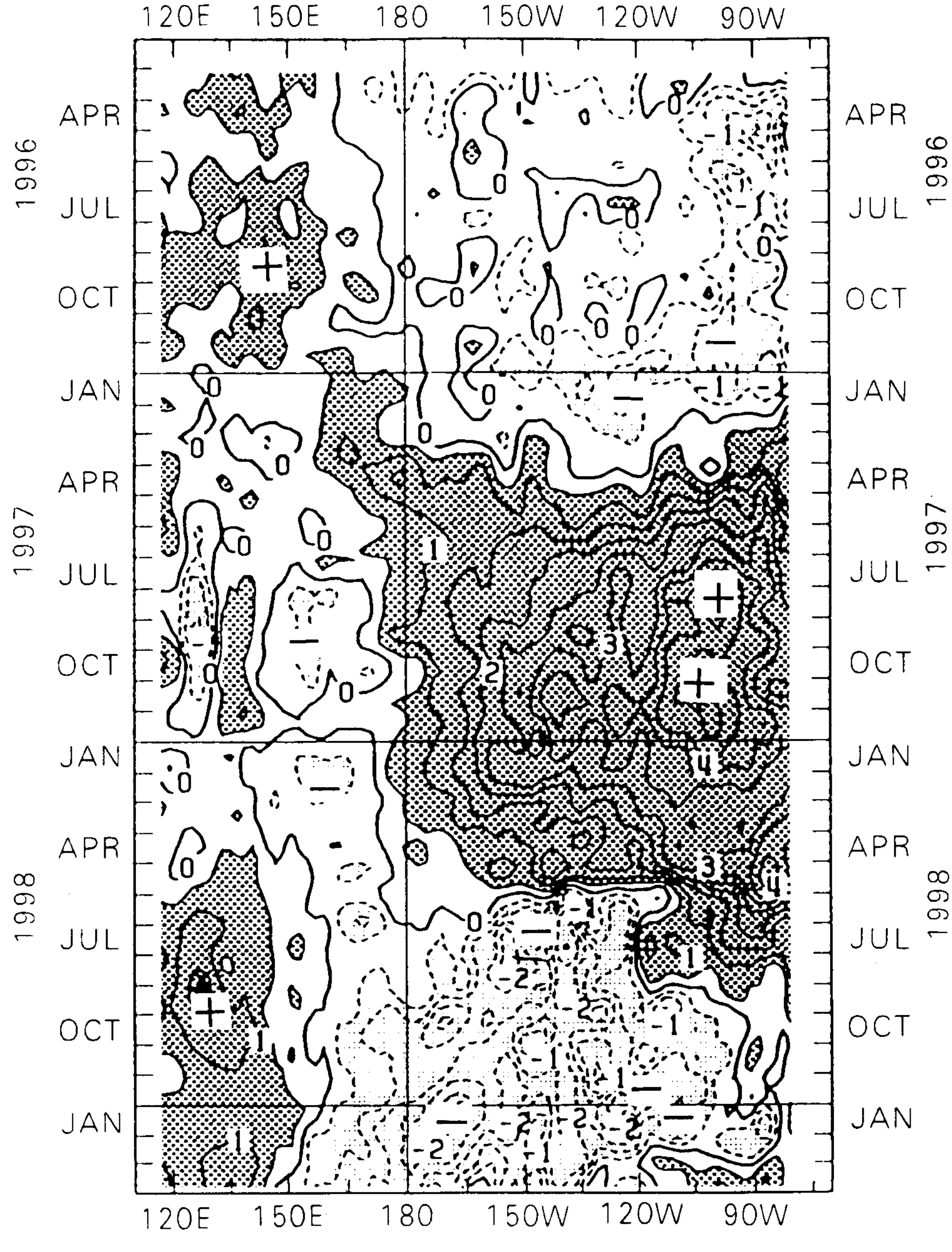


Fig. 1. Longitude–time cross–section of the SST anomalies in the equatorial Pacific (5°N–5°S) during the 1997 / 98 ENSO cycle. Units: °C

air–sea interaction in the equatorial central Pacific (see Huang et al., 1998; Zhang and Huang, 1998).

Therefore, from the above–mentioned developing process of the ENSO event, it may be clearly found that the occurrence of the ENSO event in 1997 is due to the eastward propagation of the warm sea water in the West Pacific warm pool under the influence of the westerly anomalies near the sea surface of the West Pacific warm pool, which is also the same as the developing processes of the ENSO cycles occurred in the period from 1980 to 1994.

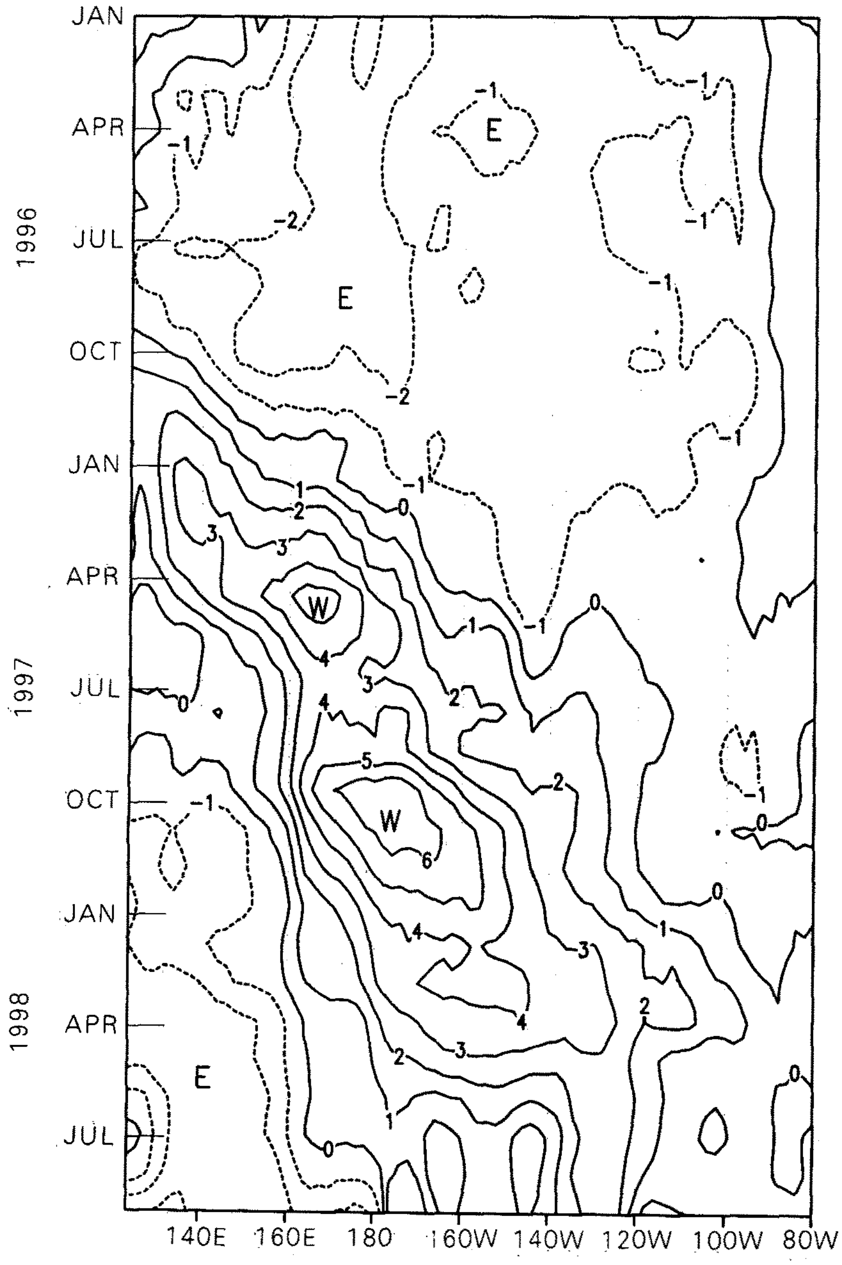
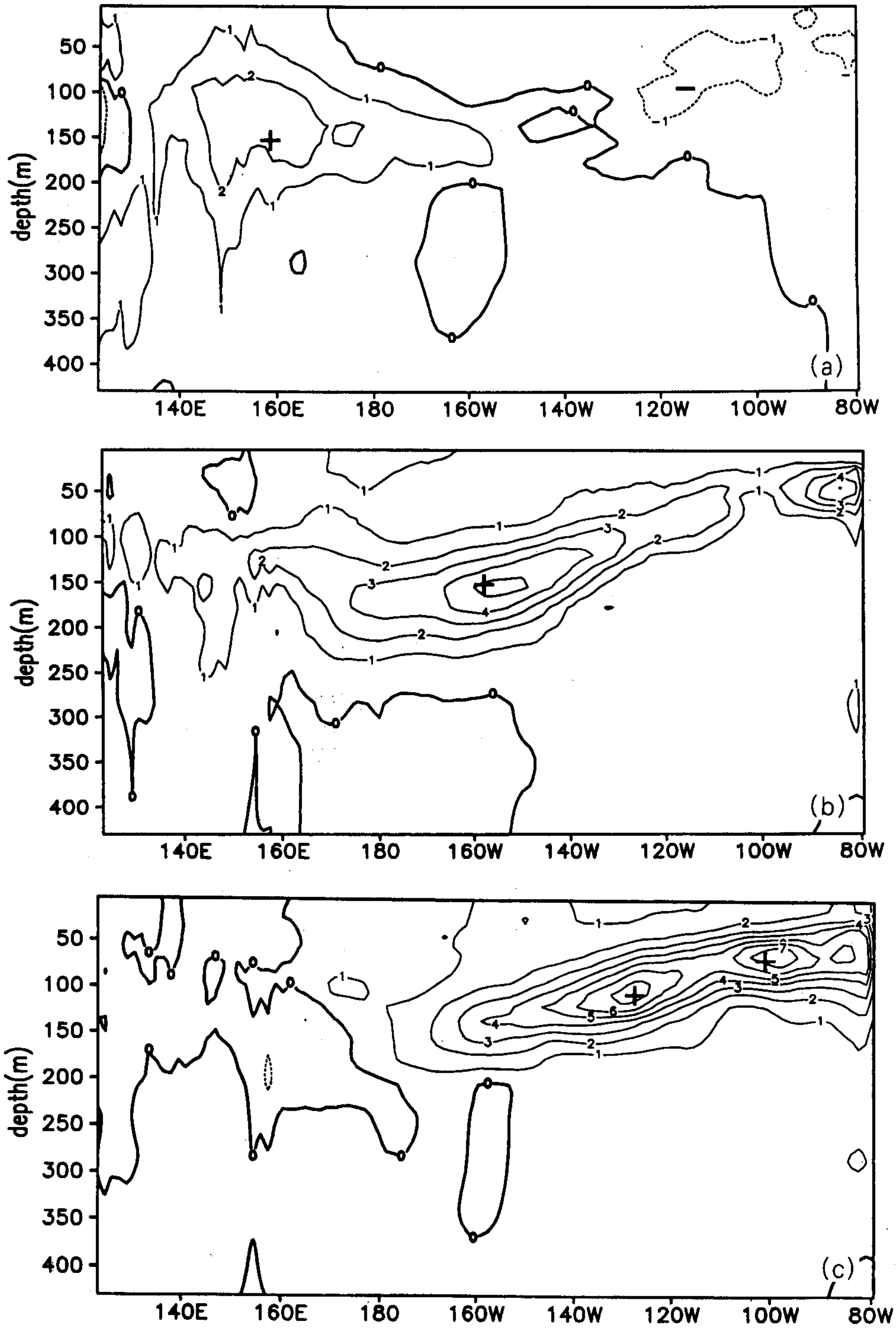


Fig. 2. Longitude–time cross–section of the zonal wind anomalies (5°N–5°S) during the 1997 / 98 ENSO cycle. Units: m / s.

Moreover, the eastward propagation of the warm sea water may be due to the eastward–propagating warm Kelvin wave exited by the westerly anomalies (Huang et al. 1998).

However, from the winter of 1997, because the strong easterly appeared near the sea surface of the equatorial western Pacific and propagated eastward from the equatorial western Pacific, the cold sea water quickly propagated eastward from the West Pacific warm pool to the equatorial central and eastern Pacific under the effect of the easterly anomalies. This made


depth(m)
50
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150
200
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(a)
(b)
(c)

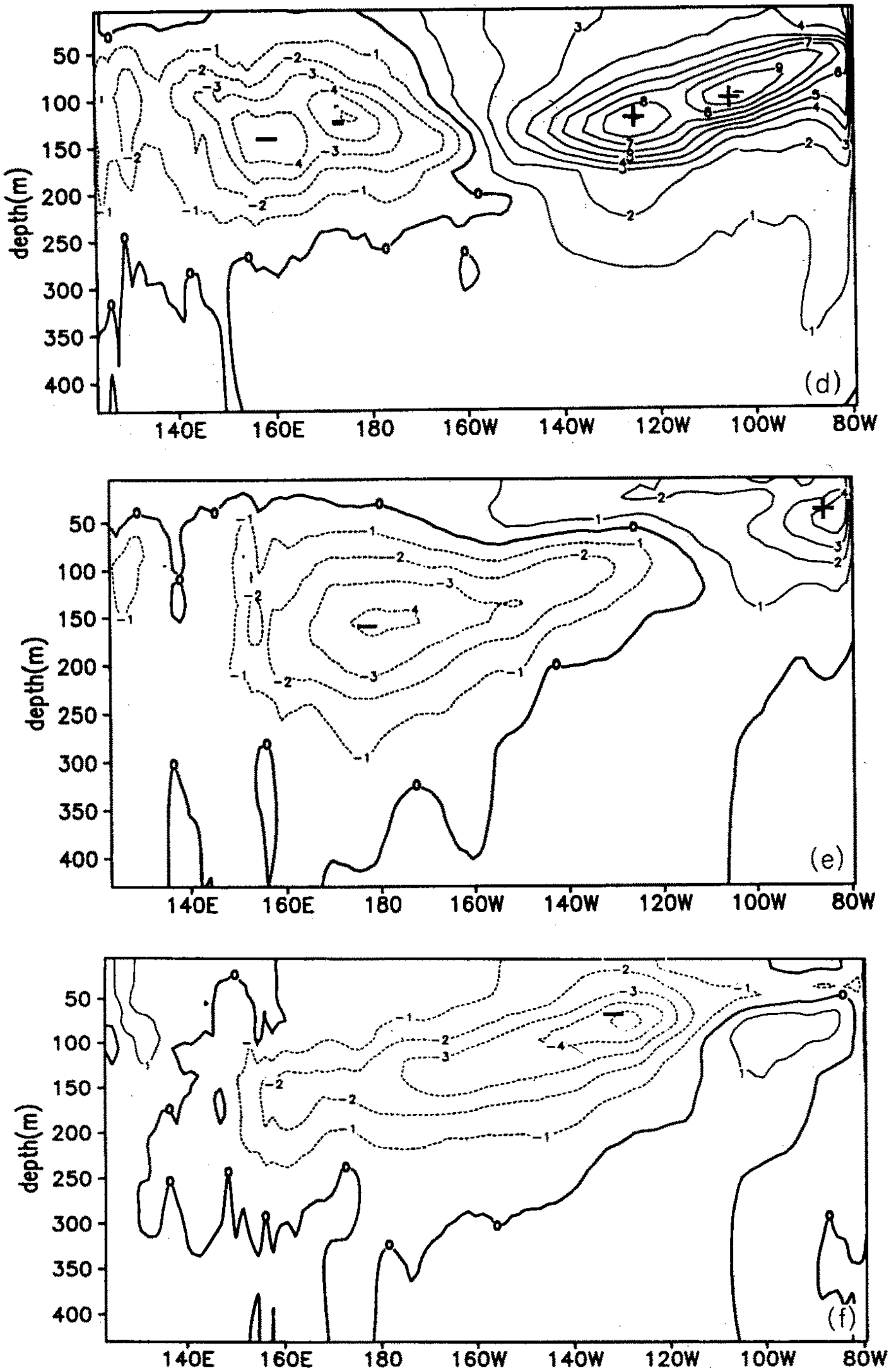


Fig. 3. Longitude–depth cross–section of the monthly–mean ST anomalies in the sub–layer of the equatorial Pacific (5°N–5°S) during the 1997 / 98 ENSO cycle. Units: °C. (a) September 1996; (b) March 1997; (c) May 1997; (d) October 1997; (e) March 1998; (f) July 1998.

the ENSO event decay, as shown in Figs. 3e and 3f. Up to July 1998, the ST anomalies became large negative ones in the sub–layer of all the equatorial Pacific. Thus, this ENSO event fell into repid decay. Moreover, these negative ST anomalies were continuously intensified in the sub–layer of the equatorial central and eastern Pacific.

From the above–mentioned decaying process of the ENSO event, it may be also seen that the decay of the ENSO event occurred in 1997 is due to the eastward propagation of the cold sea water in the West Pacific warm pool under the influence of the easterly anomalies near the sea surface of the West Pacific warm pool, which is the same as the decaying processes of the ENSO cycles occurred in the period from 1980 to 1994. Moreover, the eastward propagation of the cold sea water may be also caused due to the eastward–propagating cold Kelvin wave excited by the easterly anomalies (Huang et al., 1998; Zhang and Huang, 1998).

3. Influence of the 1997/ 98 ENSO cycle on summer climate anomalies in East Asia

As described in the introduction, the ENSO event that occurred in May 1997 has a large impact on climate anomalies in many regions of the world. It caused severe floods in the eastern coast of the tropical Pacific Ocean and severe drought in the western coast. However, it has different impact on summer climate anomalies in China in different stage of this cycle. Moreover, because climate anomalies in East Asia are seriously influenced by the Asian monsoon and the summer monsoon rainfall anomalies are very important, the influence of the 1997 / 98 ENSO cycle on summer rainfall anomalies in East Asia in different stage of this cycle is emphasized in the following.

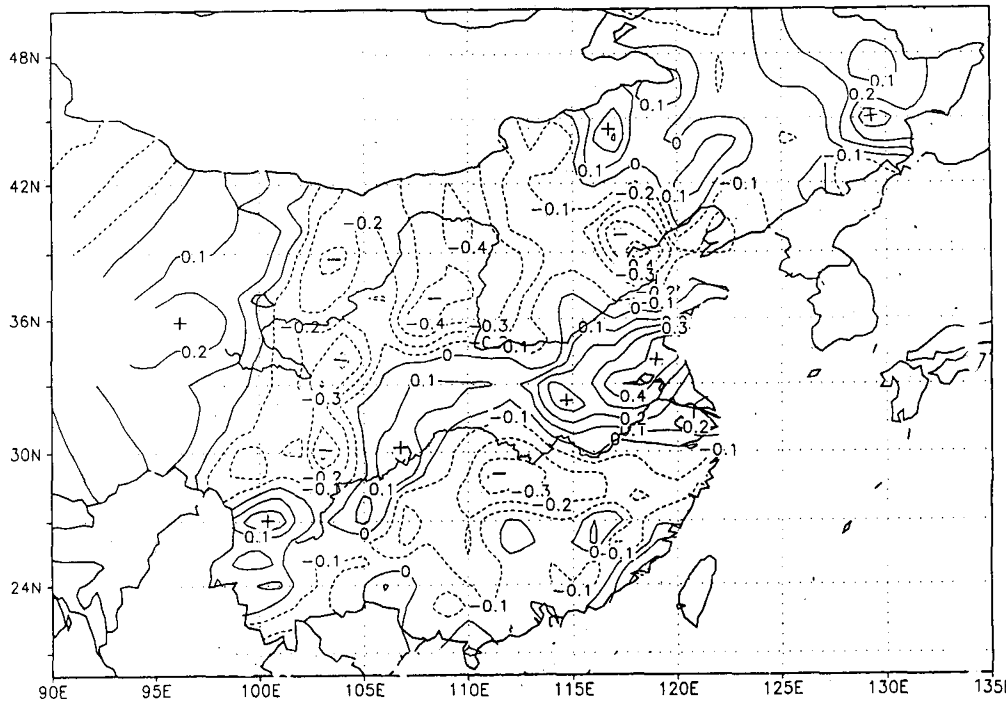
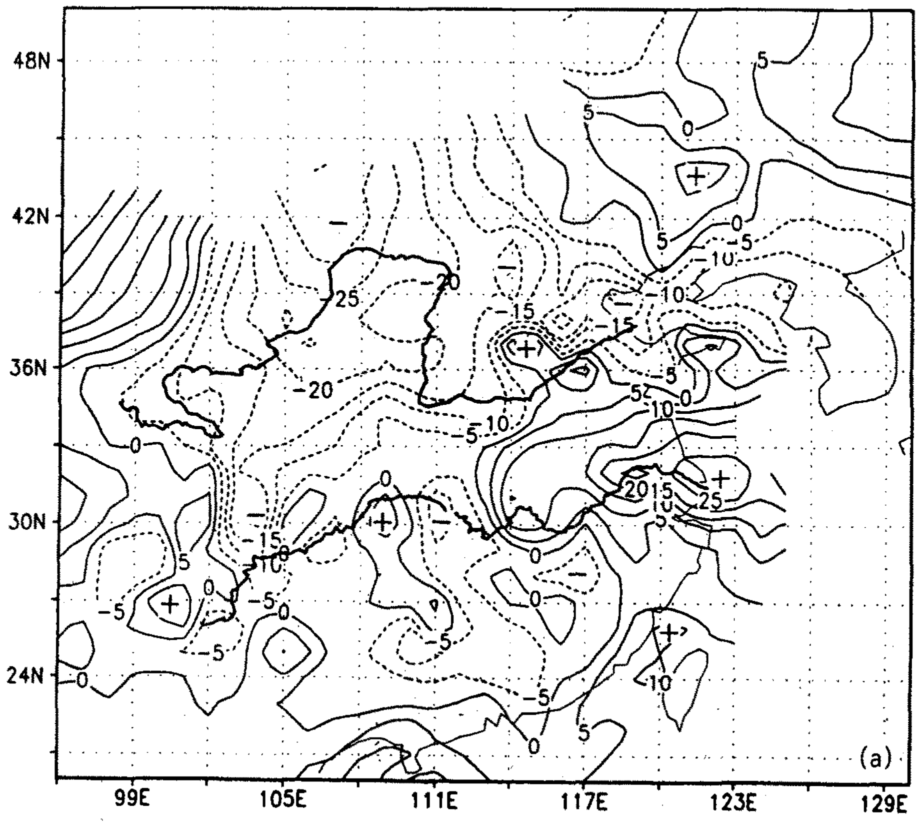


Fig. 4. Correlation between the summer (June–August) rainfall anomalies in China and the differences between the SST in Niño 3 region in summers and that in last autumns during 1951–1996. The correlation coefficients over 0.28 are significant with significance levels of over 95%.

3.1 *Influence of ENSO cycles on summer climate anomalies in China*

In order to explain the impact of the 1997 / 98 ENSO cycle on climate anomalies in East Asia, first, the influence of ENSO cycles on the summer rainfall anomalies during 1951–1996 is analyzed by using the observed data. Figure 4 shows the correlation between the summer (June–August) rainfall anomalies in China and the differences between the SST in the Niño 3 region in summers and that in last autumns during 1951–1996. It can be seen from Fig. 4 that positive correlations are located in the Huaihe River valley, and negative correlations are located in North China and the Yellow River valley and to the south of the Yangtze River. It means that during the summer when an ENSO event is in the developing stage, the summer monsoon rainfall may be below normal in North China, the Yellow River valley and to the south of the Yangtze River, but it may be above normal in the Huaihe River valley and the lower reaches of the Yangtze River. On the contrary, during the summer when an ENSO event is in the decaying stage, the summer monsoon rainfall may be above normal to the south of the Yangtze River, especially in the Dongting Lake and Boyang Lake valleys, and in North China and the Yellow River valley, severe floods may occur, but the summer monsoon rainfall may be below normal in the Huaihe River valley.

In order to explain the above-mentioned facts, the composite analyses of the summer monsoon rainfall anomalies are made for the summers when the ENSO events are in the developing or decaying stages in the period of 1951–1998. Figures 5a and 5b show the composite distributions of the monsoon rainfall anomaly percentage in China for the summers when



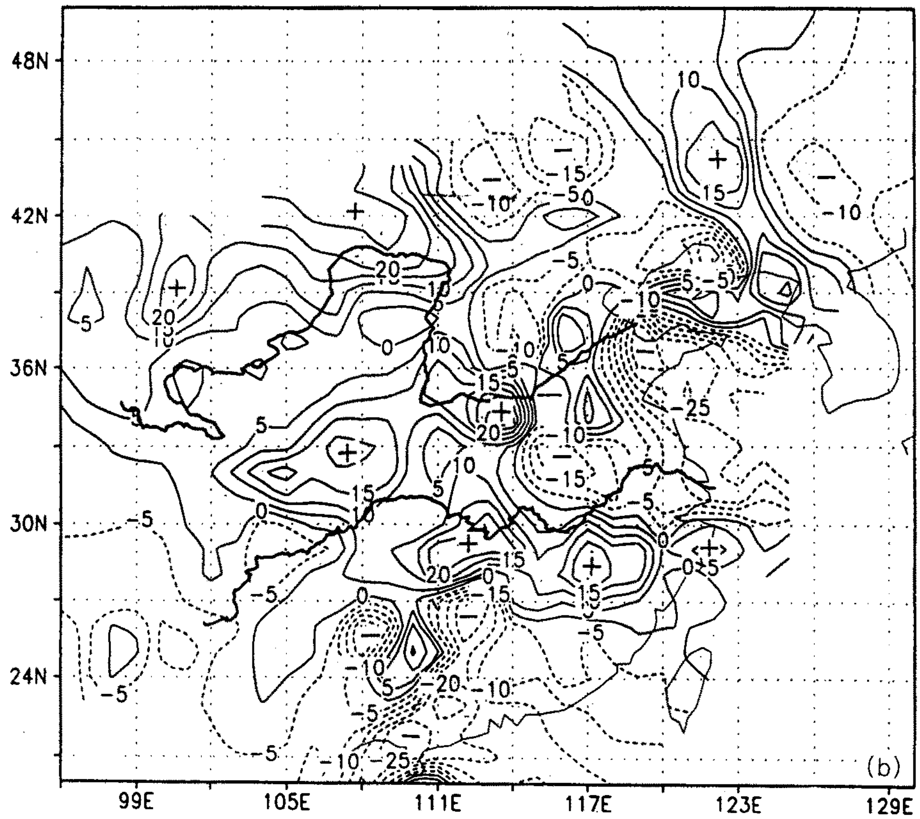


Fig. 5. Composite distributions of the monsoon rainfall anomaly percentage in China for the summers when the ENSO events are in the developing (a) or decaying (b) stages. The anomaly percentages over 10% are significant.

the ENSO events are in the developing and decaying stages, respectively. It is evident from Fig. 5a that positive rainfall anomalies are in the Huaihe River valley, and negative rainfall anomalies are located in the Yellow River valley, North China and to the south of the Yangtze River. This can explain that during the summer when an ENSO event is in the developing stage, drought may occur in North China, but floods may be caused in the Huaihe River valley. However, during the summer when an ENSO event is in the decaying stage, the composite distribution of summer rainfall anomalies shown in Fig. 5b is contrary to that shown in Fig. 5a. This shows that during the decaying stage of an ENSO event, severe floods may occur to the south of the Yangtze River, especially in the Dongting Lake and Boyang Lake valleys, and the summer rainfall may be above normal in the Yellow River valley and North China, but drought may be caused in the Huaihe River valley. During the 20th century, the most severe flood disasters in China occurred in the summers of 1954, 1998 and 1931, respectively. These summers are in the decaying phases of the ENSO events or the developing phase of the La Niña events.

3.2 *Influence of the 1997/ 98 ENSO cycle on summer climate anomalies in East Asia*

As the above–mentioned impact of ENSO events on climate anomalies in China, the

1997 / 98 ENSO cycle has a large influence on summer climate anomalies in East Asia. Moreover, as shown in Section 2, since this ENSO cycle is the strongest one in the 20th century and it has the characteristics of rapid onset and rapid decay, and a serious impact on summer climate anomalies in East Asia. Figure 6 shows the distribution of the rainfall anomaly percentage in China in the summer (June–August) of 1997. It can be seen from Fig. 6 that the severe drought occurred in North China and the summer rainfall anomaly percentage was 50% or more below normal in the summer of 1997. Moreover, positive surface temperature anomalies with a maximum center of about 2.0°C continuously appeared in North China and the southern part of Northeast China in July–August (Figs. 7a and 7b). Therefore, influenced by the ENSO event occurred in May 1997, the severe drought and hot summer formed in North China in 1997. This is in agreement with the composite of rainfall anomalies shown in Fig.2 for the summers when the ENSO events are in the developing stages, but the rainfall anomalies were fewer than the composite anomalies. Besides, in the summer of 1997, the severe drought also appeared in the northern part of the Korea Peninsula.

However, because the ENSO event was in rapid decay from the spring of 1998, the SST anomalies became below–normal in the equatorial central and eastern Pacific from June 1998. Influenced by the decay of this ENSO event, the rainfall anomalies were 100% and more above normal in the Yangtze River valley, especially in the Dongting Lake and Boyang Lake valleys and in Northeast China in the summer of 1998, as shown in Fig. 8. In June 1998, the summer monsoon rain belt was located in the lower reaches of the Yangtze River, and the

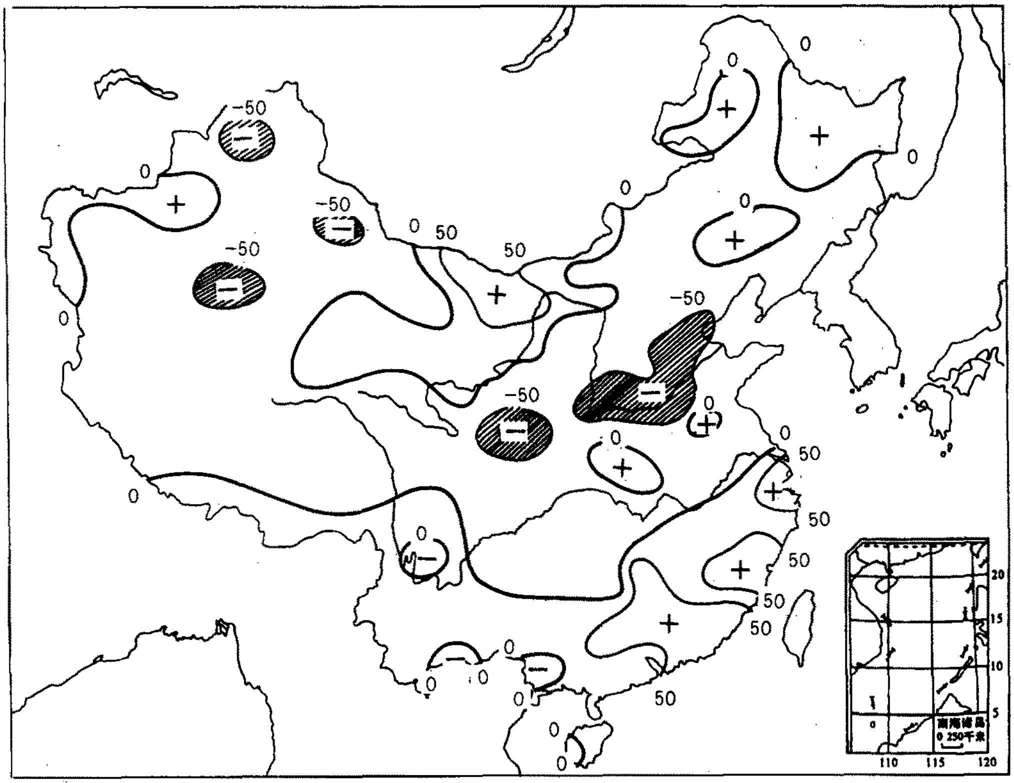


Fig. 6. The rainfall anomaly percentage in China in the summer (June–August) of 1997.

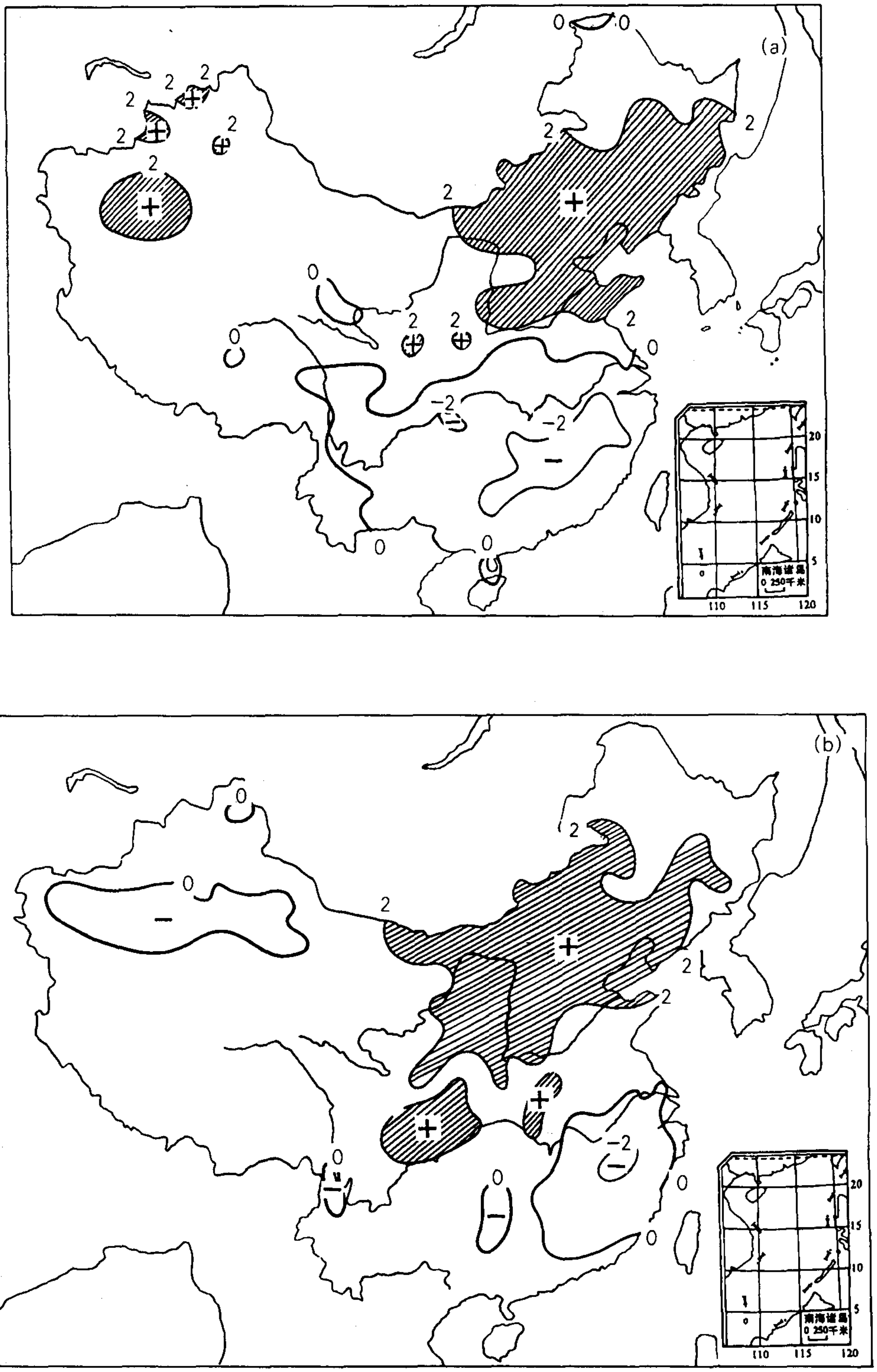


Fig. 7. The distributions of air temperature anomalies near the surface in China in July (a) and August (b), 1997. Units: °C.

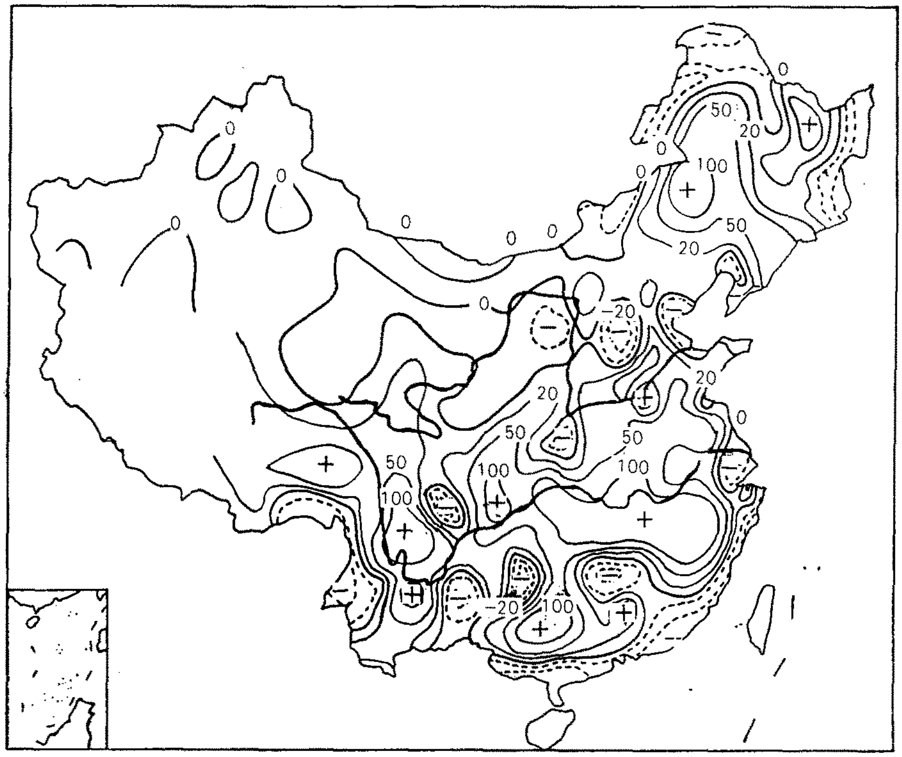


Fig. 8. The same as in Fig. 7, but for the summer of 1998.

monsoon rainfall anomalies were about 100% above normal in the Boyang Lake valley. Up to July, the rain belt shifted westward to the middle and upper reaches of the Yangtze River, and heavy rainfall continuously appeared there and the rainfall anomalies were about 100% above normal in the Dongting Lake valley and the upper reaches of the Yangtze River. This caused particularly severe floods in the Yangtze River valley. Besides, severe floods also occurred in Northeast China and heavy rainfalls frequently appeared in South Korea and Japan.

From the above–mentioned facts, it may be concluded that the 1997 / 98 ENSO cycle seriously influenced the summer climate anomalies in East Asia.

4. Influence of the 1997/ 98 ENSO cycle on the water vapor transport in East Asia

Because the Asian summer monsoon can transport a large amount of water vapour from the tropical western Pacific, the South China Sea and the Indian Ocean into East Asia, the summer monsoon greatly influences summer rainfall in East Asia through the water vapor transport, and it can cause severe drought and floods there. In order to analyze the cause of the impact of the 1997 / 98 ENSO cycle on summer climate anomalies in East Asia, especially the severe drought in North China in the summer of 1997 and the heavy rainfalls in the Yangtze River valley and South Korea in the summer of 1998, the water vapor transport anomalies influenced by the ENSO cycle are discussed in the following.

Huang et al. (1998) pointed out from the interannual variations of the anomaly distribution of water vapour transport that the water vapor transport by the Asian summer monsoon flow is closely associated with the thermal state of the equatorial Pacific. In order to discuss how the 1997/98 ENSO cycle influences the summer climate anomalies in East Asia, the anomalies distributions of water vapor transport in the summers of 1997 and 1998 are calculated by using the NCEP/NCAR reanalysis data (see Figs. 9 and 10). As shown in Fig. 9, in the summer of 1997, there is a cyclonic anomaly of water vapor transport from South China, the Indo–China Peninsula to the tropical western Pacific and an anticyclonic anomaly to the south of Japan. Obviously, there exists southward anomaly transport of water vapor from North China, the Huaihe River valley to the Indo–China Peninsula. This can explain that influenced by the ENSO event occurred in May 1997, the water vapor transport by the summer monsoon flow was weak in North China, the Huaihe River valley and the northwest part of the Korea Peninsula. Thus, the summer monsoon rainfalls were below normal in North China and the northern part of the Korea Peninsula, and the severe drought and hot summer appeared in North China and North Korea.

Because the ENSO event was in rapid decay from May 1998, the summer of 1998 was in the decaying phase of the ENSO event. However, although the SST became higher in the West Pacific warm pool, the ST anomalies in the sub–layer of the equatorial westen Pacific were still negative, the convective activities were weaker around the Philippines, and the western Pacific subtropical high shifted southward. Therefore, there is an anticyclonic anomaly of water vapor transport from the Bay of Bengal, the South China Sea to the tropical western Pacific and a cyclonic anomaly in Northeast China, the Korea Peninsula and Japan, as shown in Fig. 10. This shows that plenty of water vapor carried by the Asian summer monsoon from the Bay of Bengal, the South China Sea and the tropical western Pacific converges in the Yangtze River valley of China, South Korea and Japan, especially in the lower and middle

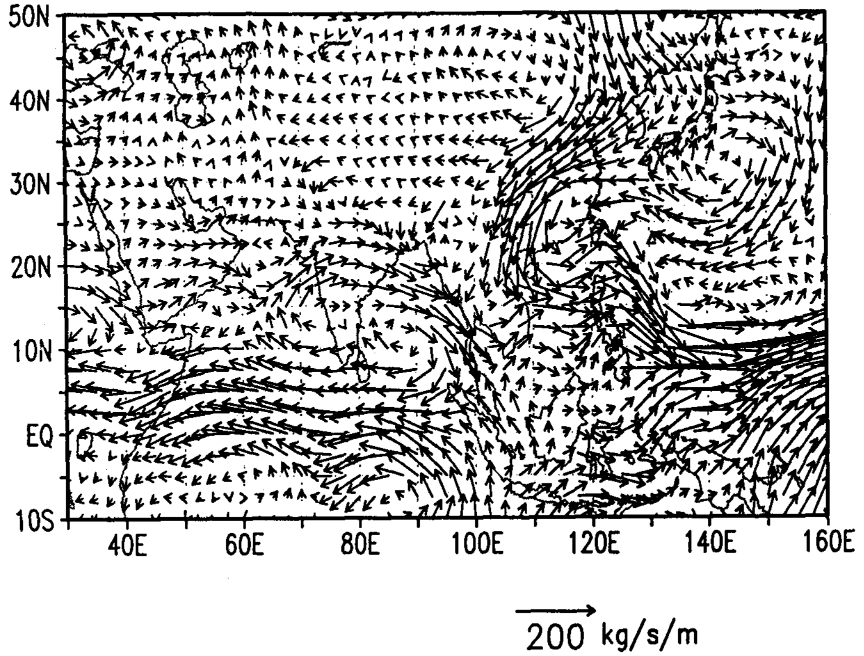


Fig. 9. The anomaly distributions of water vapor transport flux vectors in the summer of 1997.

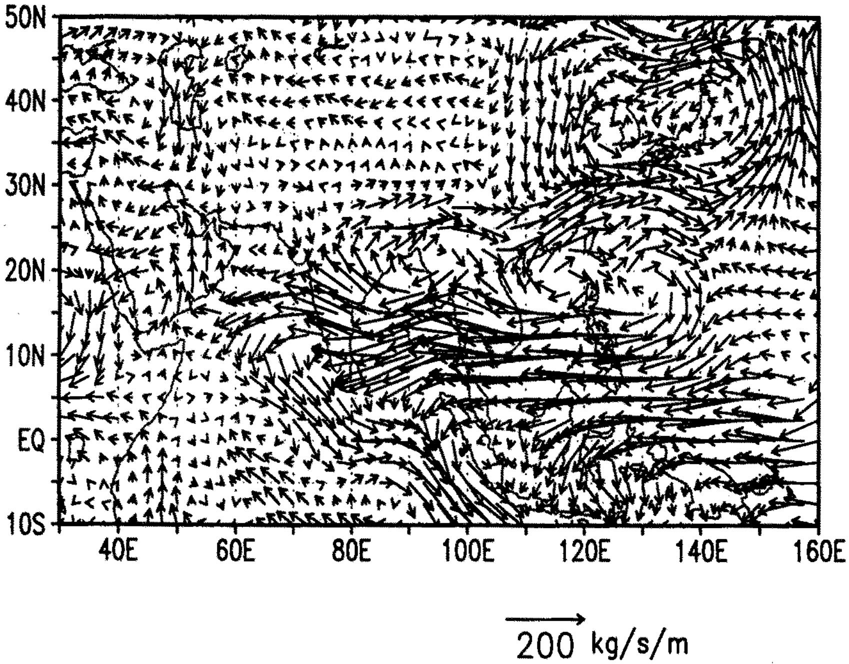


Fig. 10. The same as in Fig. 9, but for the summer of 1998.

reaches of the Yangtze River in June and in the middle and upper reaches in July and August, 1998. Thus, heavy rainfalls were caused there.

5. Conclusions and Discussion

In this paper, the observed data of the SST anomalies and the ST in the sub–layer of the equatorial Pacific, the NCEP / NCAR reanalysis data and the data set of daily precipitation in China are used to analyze the characteristics of the 1997 / 98 ENSO cycle and its impact on the summer climate anomalies in East Asia. The results show that the 1997 / 98 ENSO cycle, the strongest one in the 20th century, might be characterized as rapid development and decay and eastward propagation from the West Pacific warm pool. Influenced by the ENSO cycle, in 1997, the serious drought and hot summer appeared in North China, and in the summer of 1998 the severe floods occurred in the Yangtze River valley, especially in the Dongting Lake and Boyang Lake valleys, and in South Korea and Japan.

The analyses also show the following facts: Influenced by the 1997 / 98 ENSO cycle, in the summer of 1997, the water vapor transport by the Asian summer monsoon was weak in North China and the northern part of the Korea Peninsula, and it caused the drought and hot summer in North China. However, in the summer of 1998, the sea temperature in the sub–layer of the West Pacific warm pool dropped, the western Pacific subtropical high shifted southward. Thus, a large amount of water vapor was transported from the Bay of Bengal, the South China Sea and the tropical western Pacific into the Yangtze River valley of China, South Korea and Japan, and the severe floods occurred there.

Generally, the convective activities are strong around the Philippines in the decaying stage of the ENSO event. However, in the summer of 1998, although the ENSO event was in the decaying stage, the convective activities were weak around the Philippines, and the western Pacific subtropical high shifted southward. This explain that the evolution process of this El Niño event in the tropical Pacific was not identical with the evolution of the Southern Oscillation in the tropical atmosphere in the summer of 1998.

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