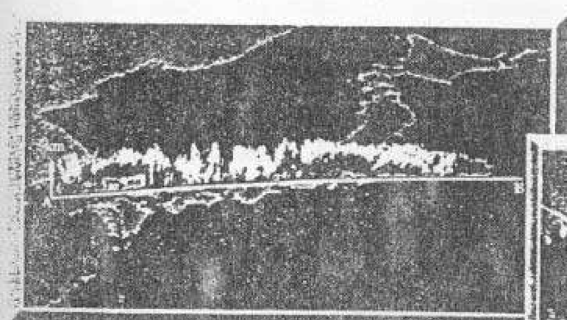
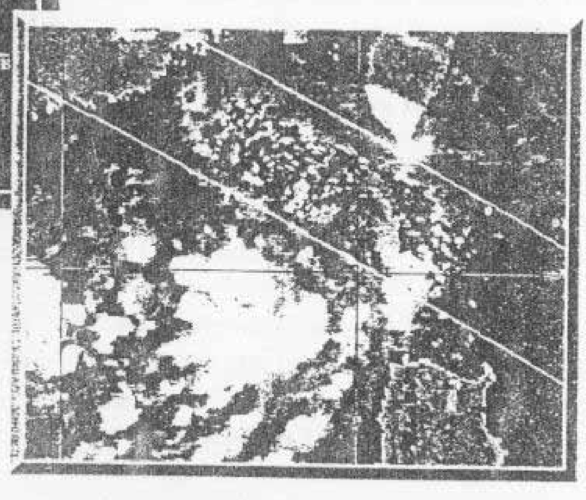
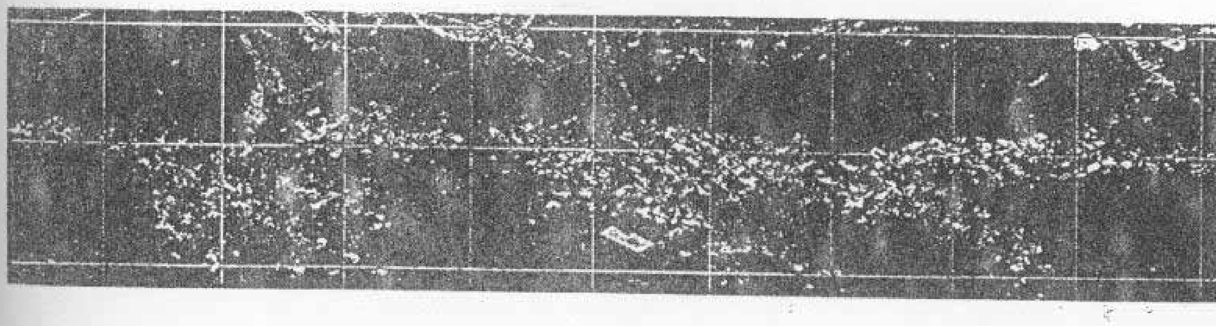
CCSR TOKYO

気候システム研究叢書　No.3

気候システム変動の謎に挑む







2.3 Further Investigation on the Impact of the Tropical Western Pacific on the East Asian Summer Monsoon

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Abstract

In this paper, the impact of the tropical western Pacific on the interannual variations of the East Asian summer monsoon is analyzed by using the observed data of TBB, precipitation and height fields. The analyzed results show that the thermal state in the tropical western Pacific has significant influence on the interannual variability of the East Asian summer monsoon. In the summer with the warming state in the tropical western Pacific, the convective activities are intensified around the Philippines and the convective activities indicated by TBB and monsoon rainfall are weak from the Yangtze River and the Huai River basin to Korea and Japan, but in the summer with the cooling state in the tropical western Pacific, the convective activities and monsoon rainfall are opposite to that in the summer with the warming state in the tropical western Pacific.

The analyzed results also show that the interannual variability of the East Asian summer monsoon can be described by using the EAPI index, which is defined by using the 500hPa height anomalies and according to the P-J oscillation proposed by Nitta (1987) and the EAP (East Asia/Pacific) pattern teleconnection suggested by Nitta (1987) and Huang et al.(1987).

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2.3.1 Introduction

Recently, many observational facts have shown that the tropical western Pacific is a region of the highest SST in the world's sea surface. Thus, this region is known as "warm pool". Due to the warming state in the tropical western Pacific, the air-sea interaction is very strong , and the ascending branch of the Walker circulation is in the region. Thus, the convergence of the air and moisture leads to strong convective activities and heavy precipitation there. Nitta (1986) systematically studied the variability of convective activities over the tropical western Pacific and showed that the long-term variation of high-cloud amount is closely associated with the SST in the tropical western Pacific. Leter on, Nitta (1987, 1997), Kurihara (1989), Huang and Li (1987), Huang and Sun (1992) investigated the impact of the tropical western Pacific on the East Asian summer monsoon. These investigations have shown that there are close relations among the thermal state of the tropical western Pacific, the convective activities over the tropical western Pacific, the western Pacific subtropical high and the summer monsoon rainfall in East Asia. Particularly, Nitta (1987) analyzed the relationship between the convective activities around the Philippines and that in East Asia from the observed data of high-cloud amount by GMS-satellite and put forward the so-called the Pacific-Japan oscillation, i. e., the P-J oscillation.

In this paper, the TBB dataset, which is GMS-observed 1°×1° daily data from 1980 to 1992 and coversan area of 80°E-160W°, 60°N-60°S, the NMC monthly height data from 1951 to 1957 and the height dataset from 1958 to 1994 reanalyzed by NCAR/NCEP and the precipitation data in China from 1951 to 1994 are used to analyze the interannual variability of the East Asian summer monsoon, and the convective activities in East Asia and over the tropical western Pacific and their association with the thermal state in the tropical western Pacific.

2.3.2 Interannual variability of the convective activities associated with the summer monsoon in East Asia

Huang and Sun (1992) pointed out from the analyses of height fields and precipitations that the thermal state in the tropical western Pacific and the convective activities around the Philippines may play an important rôle in the interannual variability of the East Asian summer monsoon circulation and rainfall. In this session, the GMS-observed 1°×1° monthly TBB data is used to investigate the interannual variability of the East Asian summer monsoon.

TBB data used in this study is the temperature of black body at cloud top retrieveled from the radiation observed by GMS-satellite. In an area of cloud-free, TBB indicates the temperature of black body at the surface, and the value of TBB may be higher. Thus, the high value of TBB indicates weak convective activity. On the contrary, in an area of cloudy, TBB indicates the temperature of black body at cloud top, and the value of TBB may be lower. Thus, the low value of TBB indicates strong convective activity. Chen et al. (1996) pointed out that the results of convective activities reflected by using TBB data are very similar to that reflected by using OLR data. Therefore, in this paper.TBB data is used to investigate the interannual variability of the convective activities associated with the summer monsoon in East Asia.

Figure 2.3.1 shows the interannual variations of TBB anomaly in the Yangtze River and the Huai River basin, averaged for June-August and the area of 112°-122°E, 27°-34°N and that over the tropical western Pacific, averaged for June-August and the area of 110°-150°E, 10°N-20°N, respectively. It may be seen from Fig. 2.3.1 that the interannual variations of the convective activities associat-

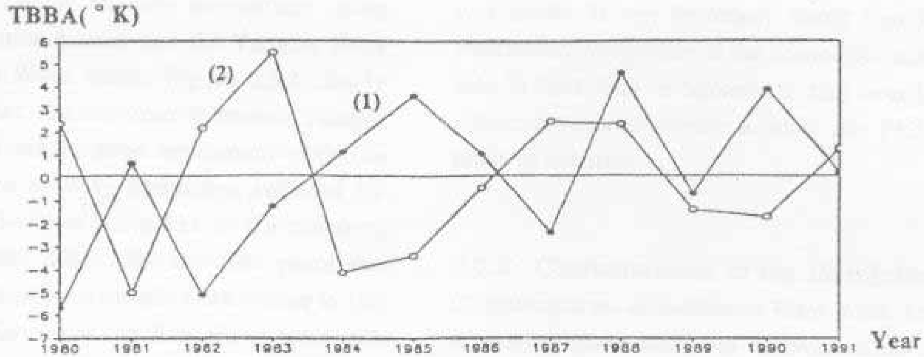

Fig.2.3.1 Interannual variations of TBB anomalies averaged for June-August in the Yangtze River and the Huai River basin, i.e., 112°-122°E, 27°-34° N (curve 1) and in the area around the Philippines, i. e., 110° -150° E, 10° -20° N (curve 2), respectively. Units: °K.

ed with the summer monsoon in the Yangtze River and the Huai River basin is large. In the summers of 1980, 1982, 1983, 1987 and 1989 years, the convective activities were strong in the Yangtze River and the Huai River basin, while in the summers of 1981, 1984, 1985, 1986, 1988 and 1990 years, the convective activities were weak there. In the summer of 1991, the summer monsoon rainfall was very strong and caused severe flood in the Yangtze River and the Huai River basin. However, during the summer of 1991, the monsoon rainfall was begun from mid-May and was closed in mid-July,and strong and heavy rainfall processes were predominant during the summer monsoon rainfall of 1991. Therefore, the value of TBB averaged for June-August of 1991 was not larger, i.e., seasonal mean of the convective activities for June-August were not strong in the Yangtze River and the Huai River basin in the summer of 1991.

Most of the rainfall may be due to the convective activities in the East Asian summer monsoon region. Therefore, the area of strong convective activities reflected by using TBB data are in good agreement with the area of strong rainfall in the East Asian summer monsoon region, especially in the Yangtze River and the Huai River basin. Figure 2.3.2 is the interannual variations of the summer

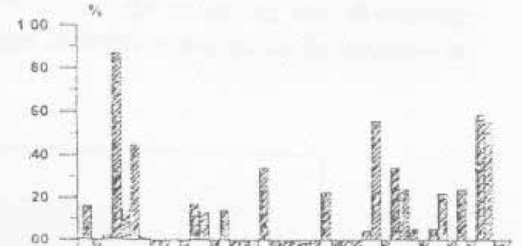

Fig.2.3.2 Interannual variation of the summer monsoon rainfall anomaly percentage averaged for June-August in the Yangtze River and the Huai River basin.

monsoon rainfall anomaly percentage averaged for June-August and the Yangtze River and Huai River basin. Figure 2.3.2 clearly shows that the summer monsoon rainfall anomalies are in good agreement with the convective activity anomalies reflectd by using TBB shown in Fig.2.3.1. In the summers of 1980, 1982, 1983, 1987 and 1989 years, the summer monsoon rainfalls were strong in the Yangtze River and the Huai River basin, but in the summers of 1981, 1985, 1986, 1988 and 1990 years, the summer monsoon rainfalls were weak there. Therefore, the convective activity anomalies reflected by using TBB are in agreement with the summer monsoon rainfall anomalies analyzed by using the observed precipitation amount. That is to say, the characteristics of the East Asian summer monsoon variability can be also described by using TBB variability.

Compared the interannual variations of TBB anomaly in the Yangtze River and the Huai River basin with the interannual variations of TBB anomaly over the tropical western Pacific around the Philippines, as shown in Fig.2.3.1, it can be clearly found that the interannual variability of the convective activities in East Asia is opposite to that over the tropical western Pacific around the Philippines in summer.

2.3.3 Characteristics of the distribution of convective activities in East Asia and its association with the thermal state of the tropical western Pacific

The SST anomalies in the tropical Pacific has a significant impact on the convective activities over the tropical western Pacific and the equatorial central Pacific. Figure 2.3.3 is the interannual variations of the normalized SST anomaly in the tropical western Pacific (130.5°-150.5°E, 0.5°-15.5°N). It is clear that in the summers of 1980, 1982, 1983 and 1987 and 1991 years, the SST anomalies were below normal in the tropical western Pacific, and this just is the distribution of SST anomalies during the occurring and developing stages of ENSO event, but in the summers of

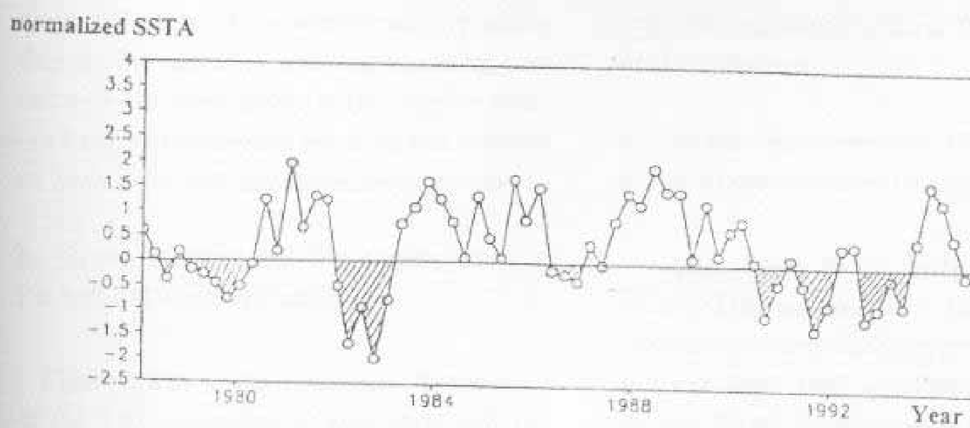

Fig.2.3.3 Interannual variations of the normalized SST anomalies in the tropical western Pacific, i.e., 130.5°-150.5°E, 0.5°N-15.5°N.

1981, 1984, 1985, 1988 and 1990 years, the SST anomalies were above normal in the tropical western Pacific, and this just is the distribution of SST anomalies during the decaying stage of ENSO event, as shown in Fig. 2.3.3. Compared Fig. 2.3.1 with Fig. 2.3.3, it may be found that in the summer with the cooling case in the tropical western Pacific, the convective activities are weak over the tropical western Pacific around the Philippines and are strong over the equatorial central Pacific, then the convective activities are intensified in the Yangtze River and the Huai River basin. On the contrary, in the summer with the warming case in the tropical western Pacific, the convective activities are strong over the tropical western Pacific and are weak over the equatorial central Pacific, then, the convective activities are weak in the Yangtze River and the Huai River basin.

The above-mentioned results show that the interannual variability of the convective activities associated with the summer monsoon in East Asia has a close relationship with the distribution of SST anomalies in the tropical western Pacific. Therefore, in the following, the distributions of convective activity anomalies for the summers with the warming case and with the cooling case in the tropical western Pacific are analyzed by using the composite analysis of TBB anomalies, respectively.

a. In the summer with the cooling case in the tropical western Pacific

Figure 2.3.4a is the composite distribution of the TBB anomalies in East Asia and the tropical western Pacific averaged for the summers of 1980, 1982, 1983 and 1987 years. As shown in Fig. 2.3.4a larger negative anomalies of TBB was found in the area from the Yangtze River basin and the Huai River basin to Korea and Japan, and large positive anomalies of TBB covered a large region including the Indo-China Peninsula, the northern part of the South China Sea and the tropical western Pacific. Besides, another large negative anomalies of TBB, whose maximum negative anomaly of TBB is below −8℃, were found over the equatorial central Pacific to the east of the Indonesia.

The above-mentioned distribution of TBB anomalies shows that in the summer with the cooling case in the tropical western Pacific, the convective activities may be intensified from the Yangtze River and the Huai River basin in China to Korea and Japan, and the convective activities may be weak over the tropical western Pacific around the Philippines, the northern part of the South China Sea and the Indo-China Peninsula. Obviously, influenced by the thermal effect of SST anomalies in the tropical Pacific during the occurring and developing stages of ENSO event, the convective activities are very strong over the equatorial central Pacific to the east of the Indonesia.

b. In the Summers with the warming case in the tropical western Pacific

Figure 2.3.4b is the composite distribution of the TBB anomalies in East Asia and the tropical western Pacific averaged for the summers of 1981, 1985 and 1988 years. As shown in Fig. 2.3.4b, positive anomalies of TBB was found in the area from the Yangtze River and the Huai River basin to South Korea and the

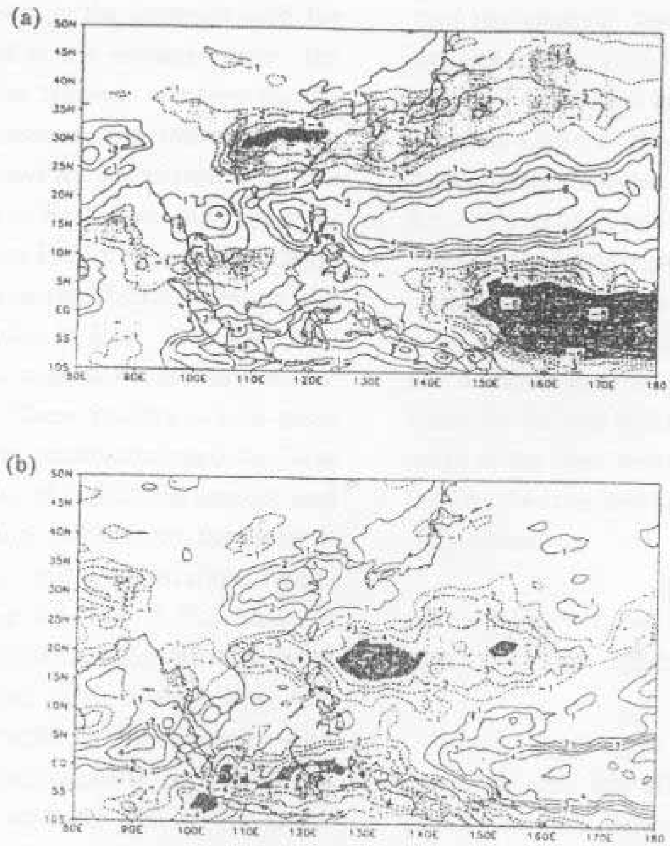

Fig.2.3.4 Composite distributions of TBB anomalies in East Asia and the tropical western Pacific averaged for the summers (June-August) with the cooling case (a) and warming case (b) in the tropical western Pacific, respectively. Shaded areas indecate negative TBB anomalies. Units: K.

southern part of Japan, and large negative anomalies of TBB covered a large region including the Indo-China Peninsula, the northern part of the South China Sea and the tropical western Pacific around the Philippines. Besides, another large positive anomalies of TBB were found over the equatorial central Pacific to the east of the Indonesia, the southern part of the South China Sea and the Bay of Bengal.

The above-mentioned distribution of TBB anomalies show that in the summer with the warming case in the tropical western Pacific, the convective activities may be weak from the Yangtze River and the Huai River basin in China to Korea and Japan, and the convective activities may be strong over the tropical western Pacific around the Philippines, the northern part of the South China Sea and the Indo-China Peninsula. Obviously, influenced by the thermal effect of SST anomalies in the tropical Pacific, the convective activities are weak over the equatorial central Pacific to the east of the Indonesia during the occurring state of anti-ENSO event.

It may be shown by the distributions of

TBB anomalies both in the summer with the warming case and in the summer with the cooling case in the tropical western Pacific that there is a negative correlation between the convective activities associated with the summer monsoon in East Asia and that over the tropical western Pacific around the Philippines and a positive correlation between the convective activities in East Asia and that over the equatorial central Pacific to the east of the Indonesia. These results are in good agreement with the results analysed by Nitta (1987) from the data of high-cloud amount and by Huang and Sun (1992) from the data of high-cloud amount and precipitation. Moreover, compared Fig. 2.3.4a. with Fig. 2.3.4b, it may be found that the anomaly distribution of convective activities in East Asia and the tropical western Pacific in the summer with the cooling case are opposite to that in the summer with the warming case in the tropical western Pacific. This may explain that the thermal distribution in the tropical Pacific, especially the thermal state of the tropical western Pacific, may play an important role in the interannual variability of the Asian summer monsoon.

2.3.4 The definition of East Asian summer monsoon circulation index EAPI and its relation to the interannual variability of the East Asian summer monsoon

Monsoon index is a criterion of measuring the strength of monsoon, and it may be used to investigate the interannual variations of monsoon. The observed facts have shown that the anomaly distributions of convective activities associated with the summer monsoon in East Asia is opposite to that over the tropical western Pacific, which is in good agreements with the P-J oscillation proposed by Nitta (1987) and with the EAP (East Asia/Pacific) teleconnection pattern suggested by Nitta (1987) and Huang et al. (1987). Thus, NMC monthly data from 1951 to 1957 the monthly data from 1958 to 1994 reanalyzed by NCAR/NCEP are used to define a index of the East Asian summer monsoon circulation, i.e., the EAPI index, using the following formula:

$$EAPI = -0.25Z_s\,(60^\circ N, 125^\circ E) + 0.50Z_s\,(40^\circ N, 125^\circ E) - 0.25Z_s\,(20^\circ N, 125^\circ E) \quad (1)$$

Where $Z_s = Z \sin 45^\circ / \sin\phi$ is the seasonal-mean standard 500 hPa height anomaly at a grid point, with Z is seasonal-mean 500 hPa height anomaly at the grid point, and ϕ is latitude of the grid-point.

a. The relationship between the EAPI index and the summer monsoon rainfall in East Asia

Figure 2.3.5 shows the interannual variations of the EAPI index defined by using formula (1) from 1951 to 1994. Compared Fig. 2.3.5 with Fig 2.3.2, it may be seen that this index can well reflect the summer monsoon rainfall anomalies in the Yangtze River and the Huai River basin. In the summers with negative EAPI index, the summer monsoon rainfalls used to be above normal in the

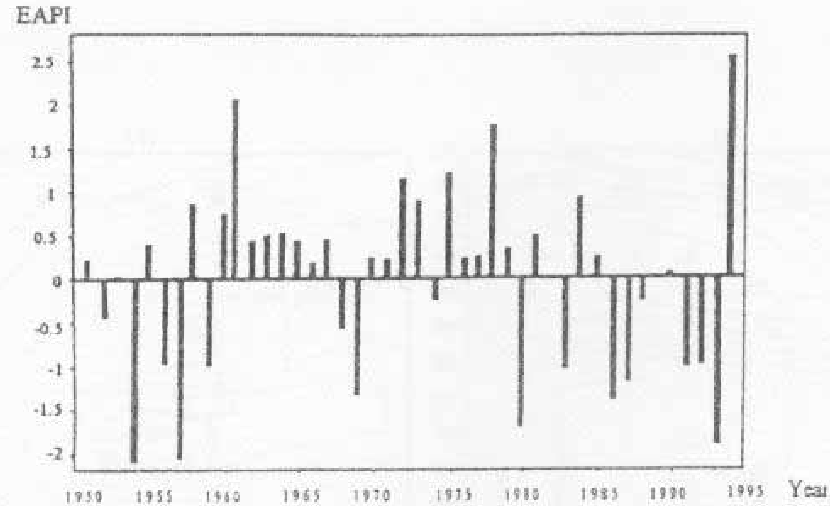

Fig.2.3.5 The interannual variations of the EAPI index for the summers from 1951 to 1994.

Yangtze River and the Huai River basin, as shown in Fig. 2.3.2, especially in the summers of 1954, 1980, 1983 and 1991, the EAPI index was lower than or equal to −1, respectivety, the severe floods occurred there. On the contrary, in the summers with positive EAPI index, the summer monsoon rainfalls used to be below normal in the Yangtze River and the Huai River basin, as shown in Fig. 2.3.2, especially in the summers of 1961, 1978 and 1994, the EAPI index was above than or equal to 1, respectively, the severe droughts occurred there. Moreover, compared Fig. 2.3.5 with Fig. 2.3.1, it may be also shown that in the summers with negative EAPI index, the convective acativities are strong in East Asia from the Yangtze River and the Huai River basin to south Korea and Japan, but in the summers with positive EAPI index, the convective activities are weak there. Therefore, the EAPI index can also reflect the anomalies of convective activities in the East Asian summer monsoon region.

b. The relationship between the EAPI index and the summer monsoon circulation anomalies

The EAPI index can reflect not only the summer rainfall and the convective activities in East Asia, but also the summer monsoon circulation over East Asia. Figures 2.3.6a and 2.3.6b indicate the composite anomaly distributions of the 500 hPa height fields over East Asia for the summers with high EAPI index, i.e., EAPI$\geq$1 and for the summers with low EAPI index, i.e., EAPI$\leq$1, respectively. Compared Fig. 2.3.6a with 2.3.6b, the composite monsoon circulation anomaly pattern for the summer with high EAPI index is opposite to that for the summer with low EAPI index. In the summer with high EAPI index, the western Pacific subtropical high is located northward, but in the summer with low EAPI index, the western Pacific subtropical high

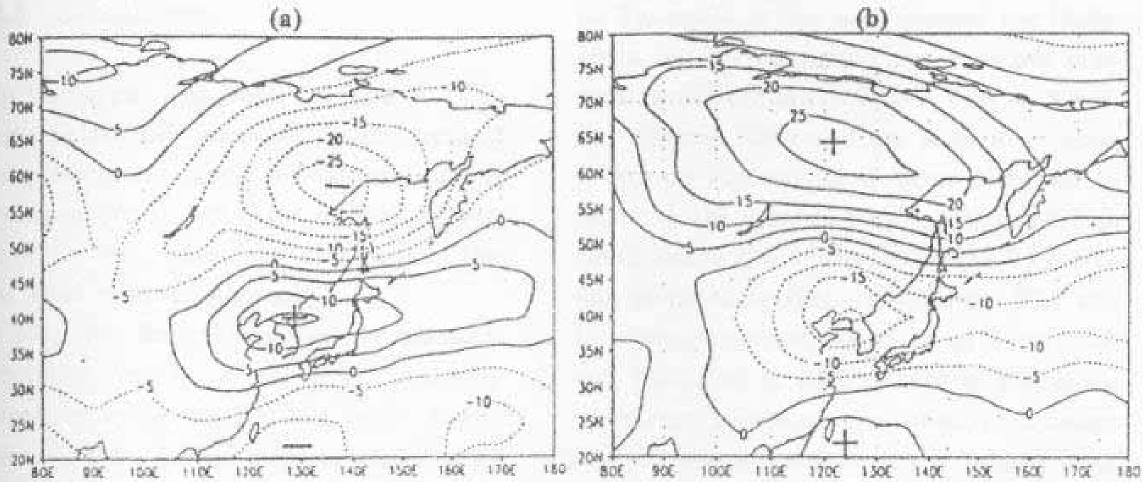

Fig.2.3.6 Composite anomaly distributions of the 500 hPa height fields over East Asia for the summers with high EAPI index (EAPI ≥ 1) and for the summers with low EAPI index (EAPI ≤ 1) Units: 10gpm

is located southward.

2.3.5 Relationship betwen the EAPI index and thermal state of the tropical western Pacific

As the above mentioned analyses, the EAPI index can well reflect the anomalies of convective activities and monsoon rainfall in East Asia and anomalous location of the west Pacific subtropical high. Compared Fig. 2.3.5 with Fig. 2.3.3, it is clear that there is a close relationship between the EAPI index and the SST anomaly in the tropical western Pacific. Generally, in the summer with the warming state in the tropical western Pacific, the EAPI index may be higher, but in the summer with the cooling state in the tropical western Pacific, the EAPI index may be lower. The results analysed in Sections 2.3.2, 2.3.3 and 2.3.4 show that in the summer with the warming state in the tropical western Pacific, i. e., the warm sea water is accumulated in the west Pacific warm pool, the convective activities are intensified from the Indo-China Peninsula to the area around the Philippines, but the convective activities and monsoon rainfall are weak in East Asia. Moreover, in this case, the EAPI index is positive and the western Pacific subtropical high shifts northward, as shown in Fig. 2.3.6a. On the contrary, in the summer with the cooling state in the tropical western Pacific, generally this case is in the developing or mature phase of ENSO event, the convective activities and monsoon rainfall are strong in East Asia, but the convective activities are weak from the Indo-China Peninsula to the area around the Philippines. Moreover, in this case, the EAPI index is negative and the western Pacific subtropical high shifts southward, as shown in Fig.2.3.6b.

2.3.6 Conclusions

In this paper, the observed data of TBB, height fields, SST anomalies in the tropical Pacific and precipitation in China are used to investigate the impact of the tropical western Pacific on the interannual variations of the East Asian summer monsoon.

Firstly, the East Asian summer monsoon circulation index, i.e., the EAPI index, is defined by using the 500 hPa height anomalies over East Asia in summer according to the P-J oscillation proposed by Nitta (1978) and the EAP (East Asia/Pacific) pattern tele-connection suggested by Nitta (1987) and Huang et al. (1987). This index not only can well describe the summer monsoon circulation anomalies, but also can reflect the anomalies of convective activities and monsoon rainfall in East Asia in summer.

From the analysed results, it may be concluded as follows :

The thermal state of the tropical western Pacific has a large influence on the interannual variation of the East Asian summer monsoon. In the summer with the warming state in the tropical western Pacific, the EAPI index may be positive, the convective activities are intensified from the Indo-China Peninsula to the area around the Philippines, but the convective activities and monsoon rainfall are weak in East Asia from the Yangtze River and the Huai River basin to Korean Peninsula and Japan. Moreover, in this case, the western Pacific subtropical high shifts northward. On the contrary, in the summer with the cooling state in the tropical western Pacific, the EAPI index may be negative, the convective activities are weak from the Indo-China Peninsula to the area around the Philippines, but the convective activities and monsoon rainfall are intensified in East Asia from the Yangtze River and the Huai River basin to Korean Peninsula and Japan. Moreover, in this case, the western Pacific subtropical high shifts southward. Influenced by the P-J oscillation proposed by Nitta (1987) or the EAP pattern tele-connection suggested by Nitta (1987) and Huang et al. (1987), there is a negative correlation between the convective activities in East Asia and that over the tropical western Pacific around the Philippines.

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