Impacts of the Tropical Western Pacific on the East Asian Summer Monsoon

By Huang Ronghui and Sun Fengying

Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100080, China
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Abstract

In this paper, the impacts of the convective activities in the western Pacific warm pool on the interannual and intraseasonal variations of the summer monsoon in East Asia are analyzed by using the observed data for 12 summers from 1978 to 1989. The analyzed results show that both interannual and intraseasonal variabilities of the East Asian summer monsoon are greatly influenced by the convective activities in the warm pool. Generally, the monsoon rainfall is below normal in East Asia and the abrupt change of the monsoon circulation is obvious in the summer of strong convective activities around the Philippines.

The impacts of the convective activities in the warm pool on the summer monsoon in East Asia and the East Asia/Pacific teleconnection pattern of summer circulation anomalies due to the convection are discussed by using the theory of planetary wave propagation and the numerical modelling by the IAP-GCM, respectively.

1. Introduction

East Asia is a part of the monsoon climate region in the world. There are many characteristic weather systems in different seasons, such as Mei-Yu in China (Baiu in Japan) in summer, tropical cyclones, persisting northwest and northeast winds and cold surges in winter. According to Tao (1985)'s suggestion, the main components of the East Asian summer monsoon system are: the monsoon trough in the South China Sea and the western Pacific, the cross-equatorial flow to the east of 100°E, the subtropical high in the western Pacific, the upper-level easterly flow, the Mei-Yu (or Baiu) frontal zones in East Asia and the mid-latitude disturbances. Therefore, the summer monsoon in East Asia is influenced not only by the Indian monsoon, but also by the western Pacific subtropical high. Because of large interannual and intraseasonal variations of the western Pacific subtropical high, the anomalies of summer monsoon rainfall and circulation are large in East Asia. Summer drought and floods frequently occurred there, especially in the area from the Yangtze River valley to south Japan.

Concerning the causes of the Asian summer monsoon, previously, many investigations emphasized the thermal effect of the Tibetan Plateau (See Ye and Gao, 1979, Nitta, 1983, Luo and Yanai, 1984, Huang, 1982). Huang (1984, 1985) pointed out that

the heating anomaly over the Tibetan Plateau can cause the anomaly of the Asian summer monsoon. 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". Because the warm pool has the highest SST, the air-sea interaction is very strong in the region. Moreover, due to the ascending branch of the Walker circulation over this area, the convergence of air and moisture leads to strong convective activities and heavy precipitation. According to the results studied by Cornejo-Garrido and Stone (1977), Hartmann *et al.* (1984), the heating of the atmosphere due to the convective activities over the warm pool also supplies the energy to drive the Walker circulation in the zonal direction.

The thermal states of the warm pool and the convective activities over the warm pool may play an important role in the variability of summer circulation over the Northern Hemisphere. Huang and Li (1987) have discussed the effect of a heat source due to the convective activities over the warm pool on the circulation anomalies over the Northern Hemisphere from the observed data and the theoretical analysis. They pointed out that there may be a teleconnection pattern of the summer circulation anomalies from the area around the Philippines to North America through East Asia and explained that the effect may be due to the propagations of quasi-stationary planetary waves forced by

Fig. 1. Summer monsoon rainfall anomaly percentage in some regions of China during June–August. (a) in the Yellow River valley, (b) in the Yangtze River and the Huaihe River valley. The black shaded pillars indicate ENSO events. Because the SSTA in the equatorial eastern Pacific in 1980 was above normal, but it was not an ENSO year, 1980 also is marked by a shaded pillar.

the heat source over the warm pool. Nitta (1987) investigated the effect of the convective activities over the tropical western Pacific on the Northern Hemispheric circulation from the observed data of high-cloud amount by satellite and suggested the so-called Pacific-Japan oscillation. Kurihara and Kawahara (1986), Kurihara (1989) analyzed the relationship between the summer climate anomalies in Japan and the thermal states in the tropical western Pacific and pointed out that there is a good positive correlation between the summer temperature in Japan and the thermal states in the tropical western Pacific.

Although many studies have been made by meteorologists regarding the summer monsoon in East Asia, there remain many unsolved problems. Particularly, the physical mechanisms of interannual and intraseasonal variabilities of the East Asian summer monsoon should be studied further. Therefore, in this paper, the impacts of convective activities in the western Pacific warm pool on the East Asian monsoon are analyzed by using the observed data. Moreover, the physical mechanism of the impacts are simply discussed by using the theory of planetary wave propagation and the numerical modelling of the IAP-GCM.

2. Impacts of the western Pacific warm pool on the interannual variations of the East Asian summer monsoon

Because the western Pacific warm pool has the highest SST and the most intense convective activities, it is a strong heat source for the atmospheric general circulation, and the impacts of the heat source on the summer monsoon circulation and monsoon rainfall in East Asia may be large. We have analyzed the relationships between the summer monsoon circulation in East Asia and the thermal states of the warm pool and convective activities over the warm pool by using the observed data including the SST data for 1951–1989, based on COADS, OLR and High Cloud Amount data for 1978–1989, edited by the Long-range Forecast Division J.M.A., the ST anomaly data for 1972–1989 in the subsurface layer of the western Pacific warm pool along 137°E, collected by the Marine Department, J.M.A. and daily 500 hPa height fields. A data set of daily precipitations in summer for 1951–1989 at 336 stations in China is used to analyze the interannual variations of the summer precipitation in some regions of China.

Figure 1a is the rainfall anomaly percentage in summer in the Yellow River valley and north China during June–August, and Fig. 1b is that in the

Fig. 2. Interannual variations of SST anomaly averaged for the area of 125°E–145°E, Eq.–15°N.

Fig. 3. Vertical-time section of sea water temperature anomaly averaged for the 137°E line from 2°N to 10°N. The contour interval is 0.5°C and dashed lines show negative values (After Yasunari, 1990).

Yangtze River and the Huaihe River valley. The Huaihe River is located between the Yellow River and the Yangtze River, as shown in Figs. 4 and 6. Because the Mei-Yu front is frequently maintained in the region of the Yangtze River and the Huaihe River valley in summer (*e.g.* Gao and Xu, 1962), the interannual variations of summer monsoon rainfall in the region are emphasized in this paper. It may be seen from Fig. 1b that in the summers of 1978, 1981, 1985, 1988, the summer monsoon rainfalls were below normal, and there were droughts in the Yangtze River and the Huaihe River valley, while in 1981, 1982, 1983, 1987, the summer rainfalls were above normal, and floods occurred there.

The summer rainfall anomalies are closely related to the thermal states of the western Pacific warm pool. In order to explain this relationship, the interannual variations of SST anomalies in some regions are analyzed from the COADS data set. Figure 2 is the interannual variation of SST anomaly averaged for the area of 125°E–145°E, Eq.–15°N. We found that in years when there were above- (below-) normal summer monsoon rainfall in the Yangtze River and the Huaihe River valley, such as in the summers of 1980, 1982, 1987, (1978, 1981, 1988) the SST anomalies of the western Pacific warm pool

were negative (positive).

Although the western Pacific warm pool is characterized by a deep thermocline compared to the eastern Pacific, the heat content anomalies in the western Pacific warm pool are in close association with the SST (Yamagata, 1991). Moreover, the heat content anomalies are well related to the sea temperature (ST) anomalies in the subsurface layer of the depth about from 50 m to 300 m, as shown in Fig. 3 (after Yasunari, 1990). Obviously, in the period from 1978 to 1989 the sea temperatures in the subsurface layer of the warm pool in 1980, 1982, 1986, 1987 were below normal. In the summers of these years, the monsoon rainfalls were above normal in the Yangtze River and the Huaihe River valley, but the sea temperatures in 1978, 1988 were above normal and the summer monsoon rainfalls were below normal in the Yangtze River and the Huaihe River valley. Moreover, comparing Fig. 2 with Fig. 3, it may be seen that the sea temperature anomaly in the subsurface layer is larger and more obvious than the SST anomaly in the western Pacific warm pool. Therefore, the ST anomaly in the subsurface layer of the warm pool may be a better signal of a strong or weak summer monsoon in East Asia.

In order to show the relationship between the

Fig. 4. Simultaneous correlation between the July monsoon precipitation in China and the July Sea temperature averaged for 137°E line from 2°N to 10°N in the 150 m depth of the western Pacific warm pool.

summer monsoon rainfall in East Asia and the sea temperature in the subsurface layer of the western Pacific warm pool, the monthly precipitation anomalies in China and the sea temperature anomalies in the subsurface layer of the warm pool in July for 18 months from 1972 to 1989 are used to calculate the one-point correlation between them. Figure 4 is the distribution of one-point correlation coefficients between the monsoon rainfall in China and the ST in the 150 m depth averaged from 2°N to 10°N along 137°E in July. The negative correlation coefficients in the Yangtze River and the Huaihe River valley are statistically significant at the 95 % confidence level, and the positive correlation coefficients are also statistically significant in the Yellow River valley. Figure 4 shows that there is a remarkable negative correlation between the summer monsoon rainfall in the Yangtze River valley and the ST in the subsurface layer of the warm pool and also a positive correlation between the summer monsoon rainfall in the Yellow River valley and the ST in the subsurface layer of the warm pool. Therefore, when the ST in the subsurface layer of the western Pacific warm pool is below normal, there is an above normal summer monsoon rainfall in the Yangtze River valley and a below normal rainfall in the Yellow River valley.

The thermal states in the western Pacific warm pool greatly affect the convective activities there. The active area of convection in a warm year of the warm pool is different from that in a cold year. Fig-

Fig. 5. Interannual variations of the normalized anomaly 3-month running mean high-cloud amount averaged for the area around the Philippines (110°E–140°E, 10°N–20°N) (a) and the equatorial area near the dateline (170°E–170°W, 5°N–5°S) (b), respectively.

ures 5a and 5b indicate interannual variations of the normalized anomalies of monthly mean high-cloud amount around the Philippines (110°E–140°E, 10°N–20°N) and over the equatorial area near the dateline, respectively. Comparing Fig. 5 with Figs. 2 and 3, we see that when the SST in the warm pool

Fig. 6. Simultaneous correlation between the monthly monsoon precipitation in China and the monthly mean convective activities around the Philippines in summer.

is above normal, *i.e.* when warm sea water is accumulated in the western Pacific warm pool, such as in 1978, 1981, 1984, 1988, the convective activities are intensified around the Philippines. On the other hand, when the SST in the warm pool is below normal, *i.e.*, the warm sea water shifts eastward from the warm pool along the equatorial western Pacific, such as in 1982, 1986, 1987, the convective activities are weak around the Philippines, but may be intensified over the equatorial area near the dateline. However, there are some exceptions to the relationship. For example, the ST in the subsurface layer of the warm pool in the summer of 1985 was below normal, but the convective activities were intensified around the Philippines. On the contrary, the ST in the subsurface layer of the warm pool in the summer of 1983 was above normal, but the convective activities were weak, and it also was above normal in the summer of 1989, but the convective activities were normal.

Comparing Fig. 5 with Fig. 1, it is obvious that in the summers of strong convective activities around the Philippines, the summer monsoon rainfalls are below normal in the Yangtze River and the Huaihe River valley. On the contrary, in the summers of weak convective activities around the Philippines, the summer monsoon rainfalls are above normal in the Yangtze River and Huaihe River valley, while the summer rainfalls are below normal in the Yellow River valley. Figure 6 is the simultaneous correlation between the monthly precipitation anomalies in China and the monthly mean anomaly of high-cloud

amount around the Philippines during June, July and August from the summer of 1978 to the summer of 1989. It can be seen that there is a high negative correlation in the Yangtze River and the Huaihe River valley. The correlation coefficients are statistically significant at the 95 % confidence level in the middle and lower reaches of the Yangtze River. This analyzed result is in good agreement with the result analyzed by Huang (1987) using the observed data of 1985 and 1987.

The western Pacific subtropical high is a component of the East Asian summer monsoon system. If its location shifted northward, a hot summer and drought may occur in the region from the Yangtze River valley, Korean Peninsula to south Japan. On the contrary, if its location shifted southward, a flood summer may occur there. The interannual variations of the subtropical high are closely related to the convective activities over the warm pool. Figures 7a and 7b show monthly mean 500 hPa height field over East Asia averaged for the summers of strong and weak convective activities around the Philippines, respectively. In years when there were strong convective activities around the Philippines, the location of the western Pacific subtropical high shifts northward, and its ridge line is located at 30°N in August. On the contrary, in the years of weak convective activities around the Philippines, the subtropical high shifts southward and its ridge line is located to the south of 30°N in August.

Figure 8 shows the relations between the thermal states of the warm pool, the atmospheric convec-

Fig. 7. Monthly mean 500 hPa height field over East Asia, averaged for the summers of strong (a) and weak (b) convective activities around the Philippines, respectively. Units are GPM.

tions over the warm pool, the western Pacific subtropical high and the East Asian summer monsoon rainfall. When the SST in the warm pool is above normal, *i.e.*, the warm sea water is accumulated in the western Pacific warm pool, and when a cold tongue extends westward from the Peruvian coast along the equatorial eastern Pacific, the convective activities are intensified from the Indo-China Peninsula to the area around the Philippines, the western Pacific subtropical high may shift unusually northward, and the East Asian summer monsoon rainfall may be below normal (Fig. 8a). When the SST in the warm pool is below normal, *i.e.*, the warm sea water extends eastward from the warm pool along the equatorial western Pacific, the convective activities are weak around the Philippines and are intensified over the equatorial central Pacific near the dateline, the western Pacific subtropical high may shift southward, and the East Asia summer monsoon rainfall may be above normal (Fig. 8b).

3. Impacts of the convective activities over the warm pool on the intraseasonal variation of the East Asian summer monsoon

Generally, the rain band of the East Asian summer monsoon rainfall is located to the south of the Yangtze River valley during May and in the first 10 days of June, and it moves abruptly northward and is located to the north of the Yangtze River valley, the Huaihe River valley and Japan in mid-June. This is the beginning of the Mei-Yu season in China or the Baiu season in Japan. Obviously, the abrupt movement of the rain band is closely associated with the abrupt northward shift of the western Pacific subtropical high. Yeh and Tao (1959) discovered the abrupt change of circulation over East Asia during June. This abrupt change of planetary-scale circulation will bring the onset of the East Asian summer monsoon. Later on, Krishnamurti and Ramanathan (1982), McBride (1987) also pointed out the abrupt change of the Indian summer monsoon and Australian summer monsoon. In late July, the rain band moves abruptly northward again and ar-

Fig. 8. Schematic map of relationship between the SST in the western Pacific warm pool, the convective activities around the Philippines, the western Pacific subtropical high, the summer monsoon rainfall in the Yangtze River valley and the Huaihe River valley. (a) in the warming case of the western Pacific warm pool. (b) in the cooling case of the western Pacific warm pool.

rives in north China, and the Mei-Yu season in the Yangtze river valley or the Baiu season in Japan ends. This is also associated with the abrupt northward shift of the subtropical high. Thus, the early and late northward shift of the subtropical high may greatly influence the summer monsoon rainfall in the Yangtze River and the Huaihe River valley.

Although the change of the East Asian summer circulation during June is abrupt in a climatic sense, it is different in different years, and in some years the change is not obvious. This may be seen from the intraseasonal variations of the low-pass filtered daily 500 hPa height field for 12 summers from 1978 to 1989. By latitude-time cross sections of low-pass filtered 500 hPa along 135°E, it is found that the intraseasonal variations of the East Asian summer monsoon circulation in the drought years are not the same as those in the flood years of the Yangtze River and the Huaihe River valley. In the drought summers, such as in the summers of 1978, 1981, 1985 and 1988, the abrupt change of the East Asian summer monsoon circulation and the northward shift of the western Pacific subtropical high were very obvious, while they were not obvious in the flood summers, such as in the summers of 1980, 1982, 1983, 1986, 1987.

Figure 9 is a latitude-time cross section of the low-pass filtered 500 hPa height along 135°E during the summer of 1985. It can be seen that the western Pacific subtropical high shifted abruptly from 18°N to 28°N in mid-June, in which the monsoon rain band moved to the Huaihe River valley. The subtropical

Fig. 9. Latitude-time cross section of low-pass filtered 500 hPa height along 135°E during the summer of 1985. Units are GPM.

Fig. 10. Latitude-time cross section of 10-day precipitation along 115°E during the summer of 1985. Units are mm.

high shifted abruptly northward again in mid-July and its ridge shifted to 35°N , and the monsoon rain band moved to the Yellow River valley and north China. Figure 10 is a latitude-time cross section of 10-day's precipitation along 115°E during the summer of 1985. The monsoon rainfall was very weak and was 30–50 % less than the normal in the Yangtze River and the Huaihe River valley in the summer of 1985. Due to the anomalous northward movement of the rain band, a hard drought occurred in the Yangtze River and the Huaihe River valley in this summer. Similar cases also occurred in the summers of 1981 and 1988.

In the flood years of the Yangtze River and the Huaihe River valley, the abrupt change of the East Asian summer monsoon circulation and the abrupt northward shift of the western Pacific subtropical high were not remarkable. It can be seen from Fig. 11 that in 1987 the abrupt northward shift of the western Pacific subtropical high was not obvious. The ridge line of the subtropical high remained at about 20°N from early June to mid-July and it moved to 30°N in late July. This made the monsoon rain band stay in the Yangtze River and the Huaihe River valley (see Fig. 12). The precipitation anomaly percentage was +30 % and more in the Yangtze River and the Huaihe River valley, and a severe flood occurred in the region. The same cases also occurred in 1989, 1982, 1983 *etc.*

What causes the difference between the intraseasonal variations of the western Pacific subtropical high in the drought summers and in the flood sum-

mers of the Yangtze River and the Huaihe River valley? This difference may be caused by the difference of the intraseasonal variations of the convective activities around the Philippines.

Kawahara and Hayashi (1987) showed that the interannual and intraseasonal variations are significant around the Philippines. Kurihara (1989) also pointed out that the standard deviations of the 10-day mean OLR are large in the eastern equatorial Indian Ocean and in the region from the South China Sea to the east to the Philippines along 15°N – 20°N and the standard deviation is the largest around the north of the Philippines. We have analyzed the intraseasonal variations of the OLR around the Philippines and their effects on the intraseasonal variations of the OLR around the Philippines and their effects on the intraseasonal variations of the subtropical high. The analyzed results show that the intraseasonal variations of the convective activities were remarkable around the Philippines in the summers of strong convective activities around the Philippines, such as in the summers of 1978, 1981, 1985 and 1988 *etc.* Figure 13 is a latitude-time cross section of the 5-day mean OLR around the Philippines from May to October 1985. The convective activities were intensified around the Philippines and their intraseasonal variations were remarkable. The convective activities intensified from early June to late June and intensified again from mid-July to late August. Similar cases also occurred in the summers of 1981, 1988. Comparing Figs. 9 and 10 with Fig. 13 it is very clear that there is a close relationship

Fig. 11. Same as in Fig. 9 but for the summer of 1987.

Fig. 12. Same as in Fig. 10 but for the summer of 1987.

between the intraseasonal variations of the East Asian summer monsoon circulation and the intraseasonal variations of the convective activities around the Philippines, and the abrupt northward shift of the subtropical high is closely associated with the intensified convective activities around the Philippines. The appearance of the intensified convective activities around the Philippines seems to be about 10 days earlier than the northward shift of the

subtropical high.

In the years of weak convective activities around the Philippines, such as in the summers of 1980, 1982, 1983, 1986, 1987, their intraseasonal variations were weak, as shown in Fig. 14. In these years the abrupt northward shift of the subtropical high was not obvious. The subtropical high remained at the normal position or shifted southward.

Fig. 13. Latitude-time cross section of 5-day mean OLR around the Philippines from May to October 1985. The shaded area indicates OLR below 200 W/M^2 . (After Monthly Report on Climate System, J.M.A.)

Fig. 14. Same as in Fig. 13 but for the summer of 1987.

4. Teleconnection pattern of the summer circulation anomalies

The convective activity anomalies in the western Pacific warm pool may influence not only the East Asian summer monsoon circulation, but also the circulation anomalies over North Pacific and North America. The one-point correlation of low-pass filtered daily 500 hPa disturbance height is computed with the basic point 20°N , 120°E for the summers of strong and weak convective activities around the Philippines, respectively. The computed results show that the teleconnection pattern of summer circulation in the summer of strong convective activities around the Philippines is different from that in the summers of weak convective activities around the Philippines.

Figure 15 is the distribution of correlation coefficients between the filtered daily 500 hPa disturbance height at various grid-points of the Northern Hemisphere and that at the basic point 20°N , 120°E in the summer of strong convective activities around the Philippines. One-point correlation coefficients in Fig. 15 are calculated by using the low-pass filtered daily 500 hPa disturbance height fields from 1 June to 31 August for 5 summers of strong convective ac-

tivities around the Philippines, such as 1978, 1981, 1984, 1985 and 1988. The low-pass filter is designed to pass the low-frequency modes whose periods are larger than 10-days. All maximum correlation coefficients in various regions from Southeast Asia to North America are statistically significant. There is an obvious teleconnection pattern of the summer circulation anomalies from East Asia to North America through the North Pacific. Generally, since the negative anomaly of the 500 hPa height field is frequently located around the Philippines in the summer of strong convective activities around the Philippines, an area of positive correlation in Fig. 15 may mean that a negative anomaly of 500 hPa height field occurred frequently over this area. It may be seen from Fig. 15 that in the summer of strong convective activities around the Philippines, negative anomalies are located over the South China Sea and the Philippines, positive height anomalies are located over north China, Japan and the Okhotsk Sea and the subtropical high shifted northward. Another negative anomaly is located over the Aleutian area, and positive and negative anomalies are found over the western part of the U.S.A. and the southern part of North America. This anomaly distribution

Fig. 15. Distribution of one-point correlation coefficients between low-pass filtered daily 500 hPa height values at every grid-point of the Northern Hemisphere and that at the basic point 120°E, 20°N for the summers of strong convective activities around the Philippines.

Fig. 16. Propagating ray path of quasi-stationary planetary waves forced by a source around the Philippines in summer.

is like the propagation of planetary-wave train (See Huang and Li, 1987). This teleconnection pattern may be called the East Asia/Pacific pattern (EAP pattern). In general, the correlation between the anomalies of the 500 hPa height field over the Northern Hemisphere and any localized anomaly around the Philippines in summer is not very obvious on the interannual time scale. The obvious teleconnection pattern shown in Fig. 15 may explain that the correlation between the circulation anomalies in the middle and high latitudes of the Northern Hemisphere and tropical circulation anomaly can be enhanced by focusing on the intraseasonal variation in the summers of strong convective activities around the Philippines. This pattern was also studied by Nitta (1987), Kurihara and Tsuyuki (1987). However, comparing Fig. 15 with Fig. 13b in Nitta's (1987) paper, there is a difference between both Figs. This may be due to the fact that Fig. 13b in Nitta's (1987) paper is obtained from the calculation of one-point correlation between the 500 hPa height fields and the convective activities around the Philippines.

5. Numerical simulation of the influence of a thermal anomaly in the western Pacific warm pool on the summer circulation over the Northern Hemisphere

Huang and Gambo (1983) investigated the quasi-stationary planetary waves forced by heat source

and topography in summer. Huang (1984) has also discussed the propagating laws of quasi-stationary planetary waves in the summer basic flow, and pointed out that during the Northern Hemisphere summer, quasi-stationary planetary waves can quasi-horizontally propagate from the subtropics to middle and high latitudes.

Huang and Lu (1989) has calculated the propagating ray path of quasi-stationary planetary waves by a source around the Philippines in a realistic summer current. From the propagating ray of the quasi-stationary planetary waves shown in Fig. 16, it may be seen that the planetary-scale disturbances forced by the heat source around the Philippines with zonal wavenumbers 1–3 can propagate toward the Atlantic Ocean through East Asia, while the long wave-scale disturbances with zonal wavenumbers about 4–6 can propagate toward the western coast of North America and Rocky Mountains.

In order to investigate the influence of the thermal state of the western Pacific warm pool on the East Asian monsoon circulation and Northern Hemisphere circulation, a numerical experiment was made using the IAP-GCM designed by Zeng Qingcun *et al.* (1986). The IAP-GCM is a two-level global circulation model, in which the finite difference scheme of calculating the dynamics is unique, but the radiation heating, sensible and latent heat transfers from the sea and land surfaces are similar to the two-level GCM of OSU (See Chen, *et al.* 1982). The distribution of climatological mean SST used in this investigation is the same as that in Shukla and Wallace's (1983) paper. In this cal-

Fig. 17. An idealized distribution of the SST anomaly in the western Pacific warm pool.

culation, an idealized distribution of positive SST anomaly located in the western Pacific warm pool shown in Fig. 17 is used. This idealized summer SST anomaly distribution is added to the climatological distribution of SST in the globe, and an anomalous SST distribution in the Pacific can be obtained. The climatological wind field and height field in June are used as initial wind field and height field in the calculation, respectively. An integration is performed for one month with an anomalous SST distribution. This calculation is called an “anomalous run”. Another integration of this model is also performed for one month with the climatological SST distribution and this is called a “control run”. The height values of 500 hPa and precipitation obtained with the control run are subtracted from that obtained in the anomalous run, and the height anomalies of 500 hPa and the precipitation anomalies caused by the idealized SST anomaly distribution in the tropical western Pacific can be obtained.

Figure 18 shows the anomaly distribution of the 500 hPa height in July averaged for 30 days day of the model integrations, in response to a positive SST anomaly appearing in the western Pacific warm pool. It is seen from Fig. 18 that a negative anomaly of the 500 hPa height occurs in the Indo-China Peninsula and south China, while a positive anomaly appears over the west coast of Canada and the west coast of the U.S.A., is located over the Okhotsk Sea and Kamchatka, another positive and negative anomaly respectively. Besides, a positive anomaly is located over Mexico. The pattern shown in Fig. 18 is in agreement with the theoretical analysis shown in Fig. 16, and it seems to be analogous

Moreover, it is pointed out that there is a teleconnection pattern of summer circulation anomalies, *i.e.*, the so-called East Asia/Pacific teleconnection pattern, from Southeast Asia to the western coast of North America through East Asia during the Northern Hemisphere summer.

The relationship between the intraseasonal variations of the western Pacific subtropical high which may affect the onset and maintenance of the East Asia summer monsoon during June and the convective activities around the Philippines is analyzed by using the low-pass filtered daily 500 hPa height and latitude-time cross section of OLR data. It is found that there is a close relationship between the anomalous northward shift of the western Pacific subtropical high and the intensified convective activities around the Philippines. In summer, when there are intensified convective activities around the Philippines, there is an abrupt northward shift of the western Pacific subtropical high in early June or mid-June, and the summer monsoon rainfall may be weak in the Yangtze River and the Huaihe River valley. On the contrary, in summer when there are weak convective activities around the Philippines, the abrupt northward shift of the subtropical high is not obvious, and the summer monsoon rainfall may be heavy in the Yangtze River and the Huaihe River valley.

The two-level IAP-AGCM with an idealized distribution of SST anomaly in the tropical western Pacific are used to simulate this relationship. The result shows that when the SST in the tropical western Pacific warm pool is above normal, the western Pacific subtropical high will shift northward, and there is a teleconnection pattern of circulation anomalies in Southeast Asia, East Asia, the North Pacific and the western coast of North America.

We have used the above-mentioned results in the seasonal prediction of the East Asian summer monsoon rainfall and found that it improved the accuracy of our forecasting. We have successfully predicted the anomaly distributions of the summer monsoon rainfall in 1990 and 1991 using the thermal state in the surface and the subsurface layer of the western Pacific warm pool and the convective activities around the Philippines, particularly for the summer of 1991. According to the observed SST and ST in the subsurface layer of the western Pacific warm pool and the convective activities around the Philippines in the spring of this year, we predicted that, in the summer of 1991, the monsoon rainfall may be larger than normal by 30 % or more in the Huaihe River valley and the middle and lower reaches of the Yangtze River, and a severe flood may occur in these regions, but it may be below normal in the Yellow River valley and south China. Observations showed that there was a very heavy monsoon rainfall which was more than double normal, and se-

vere flood occurred in the Huaihe River valley and in the lower reaches of the Yangtze River from later May to mid-July, and there was a drought in the Yellow River valley and south China. It seems to us that the thermal state of the western Pacific warm pool may be a good predictor for the forecasting of the summer monsoon rainfall anomaly in East Asia, especially in the long-range prediction of droughts and floods in East Asia.

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熱帯西太平洋の夏期東アジアモンスーンに対する影響

黄栄輝・孫鳳英

(中国科学院大气物理研究所、北京 100080、中国)

1978年から1989年までの12年間にわたる観測資料を用いて、東アジアにおけるモンスーンの年年変動と季節内変動に対する熱帯西太平洋の影響について調べた。解析した結果から、熱帯西太平洋の暖水域(Warm pool)が東アジアモンスーンの年年変動と季節内変動に大きな影響を及ぼすことがわかった。フィリピン周辺における対流活動の強い夏には、東アジアモンスーン降水が一般的に平年より少なく、モンスーン循環の六月の突然の変動が顕著である。

暖水域の上空における対流活動が東アジアにおける夏期モンスーンに影響を及ぼすこと、およびこの対流活動による東アジア／太平洋パターンの大気大循環のテレコネクションについて、プラネタリー波の伝播理論とIAP大気大循環モデルによる数値実験結果により議論した。