Numerical Simulation of the Effect of the SST Anomalies in the Tropical Western Pacific on the Blocking Highs over the Northeastern Asia①

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ABSTRACT

The effects of the sea surface temperature (SST) anomalies in the tropical western Pacific on the atmospheric circulation anomalies over East Asia are simulated by the IAP–GCM with an observed and idealized distributions of the SST anomalies in the tropical western Pacific, respectively.

Firstly, the atmospheric circulation anomalies during July and August, 1980 are simulated by three anomalous experiments including the global SST anomaly experiment, the tropical SST anomaly experiment and the extratropical SST anomaly experiment, using the observed SST anomalies in 1980. It is shown that the SST anomalies in the tropical ocean greatly influence the formation and maintenance of the blocking high over the northeastern Asia, and may play a more important role than the SST anomalies in the extratropical ocean in the influence on the atmospheric circulation anomalies.

Secondly, the effects of the SST anomalies in the tropical western Pacific on the atmospheric circulation anomalies over East Asia are also simulated with an idealized distribution of the SST anomalies in the tropical western Pacific. The simulated results show that the negative anomalies of SST in the tropical western Pacific have a significant effect on the formation and maintenance of the blocking high over the northeastern Asia.

Key words: Blocking high, SST anomaly, Atmospheric circulation anomaly

I. INTRODUCTION

Generally, the formation and collapse of the blocking situations are accompanied with the acute changes of zonal and meridional circulations.

Moreover, since the maintained periods of the blocking situations are longer, their spatial distributions are stable and their changes are small, the persistent anomalies of climate are frequently caused in the regions of the blocking highs and in their surrounding areas, and occasionally, the anomalies may establish the local records of monthly mean temperature and precipitation (Taubensee, 1979; Wanger, 1981).

The blocking highs can cause the anomalies of atmospheric circulaiton and climate not only in the mid–high latitudes, but also in the middle latitudes. Chinese meteorologists early discovered that the blocking situations affect greatly the climate in China, especially the Meiyu in the Yangtze River and the Huaihe River basin (Dao, 1957; Ye et al., 1962; Tang, 1957; Chen, 1957). These investigations showed that the blocking highs over the eastern coastal areas of Russia and the Okhotsk Sea have an obvious effect on the Meiyu in the Yangtze River and the Huaihe River basin. For example, in the summer of 1954, since the

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blocking high over the Okhotsk Sea was anomalously strong, it caused the westerly flow to split into two branches. The southward flow shifted to the lower latitudes, and the westerly jet and the subtropical high also shifted southward. Therefore, the Meiyu season was maintained until the end of July, being one month longer than the normal ones, and a severe flood, which was the most severe since the observed precipitation data were available in China, occurred in the Yangtze River and the Huaihe River basin.

In the summer of 1980, a severe flood appeared in the Yangtze River basin and a severe drought in North China. A particularly severe flood, which was only weaker than the flood occurred in the summers of 1954 and 1991, appeared in the Yangtze River basin; while a hot and dry weather, which was seen very little from 1949, appeared in North China. Recently, Bi and Ding (1992), and Wu et al. (1994) analysed the circulation during the summer of that year and pointed out that the above–mentioned climate anomalies in China were related to the stable maintenance of the blocking high over the northeastern Asia during July and August, 1980.

Recently, Wang (1992) also investigated the impact of the blocking situations over the northeastern Asia on the Meiyu in the Yangtze River and the Huaihe River basin and the Baiu in Japan. According to the occurrence region of the blocking situations over Eurasia, he divided them into three types, i.e., the blocking high over Ural, the blocking high over Baikal Lake and the blocking high over the northeastern Asia. He also discovered that the blocking highs over the northeastern Asia have obvious effect on the Meiyu in the Yangtze River and the Huaihe River basin.

The previous studies generally emphasize the actual evolution processes of blocking highs, and many investigations on the possible physical mechanism of the formation and maintenance of blocking highs are made. Undoubtedly, these studies make us understand the blocking processes in detail and may provide us a basis for forecasting the formation and collapse of blocking highs. However, with the deep investigation on the blocking highs recently, the studies on the favourable circulation background for the frequent occurrance of the blocking situations, i.e., under which kind of large–scale circulation condition the blocking situations will be easy to be formed and maintained, have begun to be made (Lu and Huang, 1996 a.b; Kaas and Branstator, 1993).

Because this kind of investigations may provide a forecasting basis for forecasting the frequency of appearance of blocking high, the short–term climate anomaly caused by it may be predicted. Therefore, this investigation is very significant.

Many investigations show that the variability of the tropical SST anomalies can influence the formation and maintenance of the blocking situations in the mid–high latitudes, and it may provide the circulation condition of the frequent appearance of the blocking situations (See Lu and Huang, 1995; Ferrant et al., 1994). However, these investigations have not discussed the blocking situations over the northeastern Asia, which have obvious effect on the summer precipiation in China. Therefore, it is necessary to investigate the impact of the tropical SST anomalies on the blocking situations over the northeastern Asia.

The influences of the tropical SST on the atmospheric circulation over the extratropics have been extensively studied. Especially, recent investigations showed that the thermal state of the western Pacific warm pool greatly influences the circulations over East Asia and the northern Pacific through the East Asia / Pacific pattern teleconnection (EAP pattern)(See Huang, 1992; Huang and Li, 1987; Huang and Sun, 1992). The results of these investigations show that when the SST is warming in the tropical western Pacific around the Philippines, the convective activities are intensified around the Philippines, the circulation anomalies will be propagated to the middle and high latitudes through the wave–train in the EAP pattern. In this case, in the 500 hPa height field, there is a negative anomaly over the areas around the Philippines and the South China Sea, a positive anomaly over the eastern part of China and another negative anomaly over the northeastern Asia including the eastern coastal area of Russia and over the Okhotsk Sea. On the contrary, when the SST is cooling around the Philippines, a positive anomaly of the 500 hPa potential height may be found over the northeastern Asia. On the basis of the teleconnection pattern, we may consider that the SST anomalies around the Philippines may influence the blocking situations over the northeastern Asia. That is to say, when the SST is cooling around the Philippines, more blocking highs may be formed and maintained over the northeastern Asia, on the contrary, the above–mentioned results are opposite.

In this paper, the above–mentioned possibility will be investigated. In Section 2, the circulation anomalies in the summer of 1980 and the global distributions of SST anomalies in the spring and summer of the same year are described. Numerical simulations of the influence of SST anomalies in the summer of 1980 on the circulation anomalies over East Asia and the blocking situations over the northeastern Asia with the realistic distribution of SST anomalies in the summer of 1980 are shown in Section 3. Moreover, the influence of negative SST anomalies in the tropical western Pacific on the blocking situations over the northeastern Asia is investigated in Section 4. Finally, the conclusions are summarized in Section 5.

II. THE BLOCKING SITUATIONS OVER THE NORTHEASTERN ASIA IN THE SUMMER OF 1980

In the summer of 1980, the blocking situations appeared frequently over the northeastern Asia and affected greatly the climate anomalies in China. Bi and Ding (1992) analysed the mechanism for the maintenance of the circulation anomaly during the summer of 1980 and pointed out that the frequent appearance of the blocking situations over the northeastern Asia may be due to the high potential vorticity transport by eddy forcing resulting from the long–wave trough over Ural located in the upper reaches of the northeastern Asia and the air transport with low potential vorticity originating over the Tibetan Plateau. Wu et al. (1994) selected a full process of the formation and intensification of the blocking high over the northeastern Asia during July, 1980 and made the analysis of this process. They pointed out that the forcing role of the transport process of transient synoptic systems was resulted from the strong baroclinic zone over Europe in the formation of the blocking high.

In this paper, the circulaiton anomaly during the summer of 1980 will be also analysed as a case. Fig. 1 shows the distributions of the 500 hPa geopotential height anomalies in July and August, 1980. The data used in the study are from the grid data base of ECMWF for 1980–1989. It may be seen from Fig.1(a) that there was a positive anomaly over the northeastern Asia in July, and that in August the anomaly area became larger, and the anomaly value increased and arrived at 105 gpm, as shown in Fig.1 (b). The anomaly distribution was in agreement with the evolution process of the blocking situations. After a blocking high was formed and intensified in July, during August the blocking situations were stable by and large and were maintained up to the early September. The anomaly distribution over East Asia was almost in agreement with the EAP teleconnection pattern, i.e., a positive anomaly area was located over the south to the Yangtze River and the South China Sea, and a negative anomaly area was located over the Yangtze River and Huaihe River basin and North China, while another positive anomaly area was located over the northeastern Asia. This anomaly

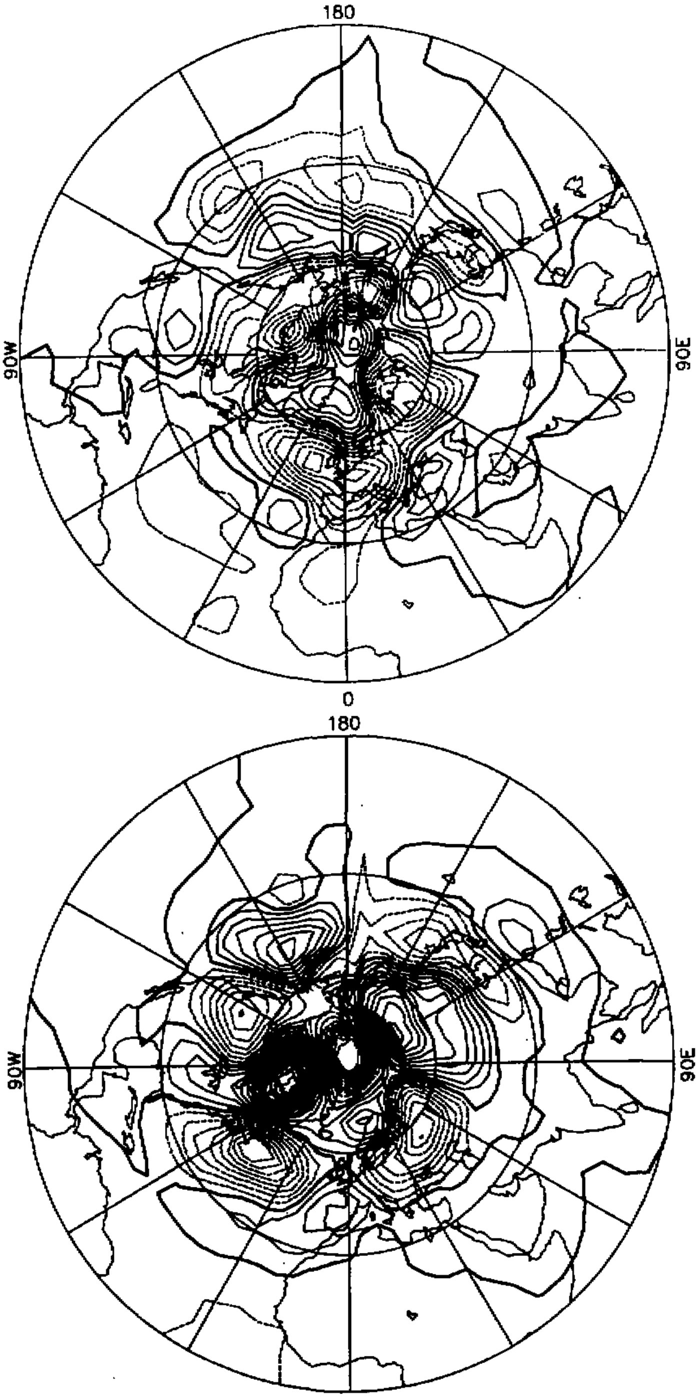

Fig.1. The 500 hPa geopotential height anomalies in July (a) and August (b), 1980. Units are in gpm.

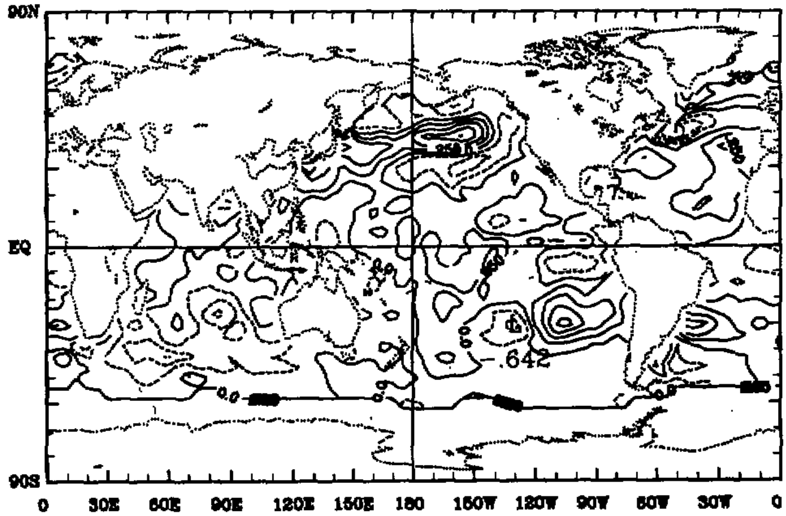

Fig.2. Distribution of the SST anomalies averaged over the period from March to August, 1980. Units are in ℃.

distribution with a positive anomaly over the northeastern Asia and a negative anomaly over the south to the northeastern Asia is helpful for the formation and maintenance of blocking situations over the northeastern Asia.

Because the main objective of this paper is to discuss the large–scale circulation background which is favourable for the formation and maintenance of the blocking situation, in the following investigation, we will focus on the anomaly distribution of the 500 hPa geopotential height and do not discuss directly on the blocking situation. In this way, it is possible to avoid the error resulting from the shortage of models described on the blocking situations.

In order to investigate the cause of the above–mentioned teleconnection, the SST anomalies averaged over the period from March to August, 1980 are shown in Fig.2, in which the mean SST is averaged for 10 years from 1979 to 1988. Fig.2 shows that during the period from March to August, 1980, a negative anomaly area of SST was generally located in the tropical western Pacific around the Philippines. In fact, it was always located there, especially in May and August, moving around a little (not shown detailedly in Fig.2). This kind of SST anomalies may be the cause of the EAP teleconnection pattern.

III. INFLUENCE OF SST ANOMALIES ON THE GEOPOTENTIAL HEIGHT ANOMALIES OVER THE NORTHEASTERN ASIA

In this section, it is investigated by numerical simulation that whether SST anomalies can cause the positive geopotential height anomalies at 500 hPa level over the northeastern Asia, and the relative importance of the tropical SST anomalies and the extratropical SST anomalies in the influence on the circulation anomalies over the northeastern Asia.

The model used in this study is IAP–L2 AGCM (Institute of Atmospheric Physics's Two–Level Atmospheric General Circulation Model) designed by Zeng et al. (1986).

The result of control run (CNTL) in the study is the geopotential height fields obtained by integrating this model to 22nd year under the forcing by the climatological mean distribution of SST. In the anomalous runs, only the SST anomalies in 1980, as shown in Fig. 2 are added to the climatological mean SST, and others are same as in the control run. Moreover, the anomalous runs are performed from March 1 to August 31, and only the results integrated for July and August are analysed in this study.

In this study, the following three anomalous runs are performed, i.e., the experiment of the global SST anomalies (Exp.G), the experiment of the tropical SST anomalies (Exp.T) and the experiment of the extratropical SST anomalies (Exp.E). Here, the tropics is defined as 22°S–22°N, and the extratropics as the south or north to the tropics. In Exp.T and Exp.E, the integrations are made from March to May taking the distribution of the global SST anomalies as forcing and from June to August taking the distributions of the tropical and extratropical SST anomalies as forcing, respectively. Thus, the circulation anomalies due to the SST anomalies can be obtained by subtracting CNTL from the anomalous runs.

1. *The Experiment of the Global SST Anomalies (Exp.G)*

In this experiment, the anomalous run is made by using the integrations of the model from March to August and taking the monthly mean global SST anomalies in 1980 as forcing. Figure 3 shows the distribution of 500 hPa height anomalies due to the global SST anomalies. It can be seen clearly from Fig.3 that a positive anomaly area is located over the northeastern Asia, while a negative anomaly area over East China. Moreover, the values and area of the positive anomalies in August become larger than those in July. This result is inagreement with the observational fact shown in Fig.1. This explains that the SST anomalies influence greatly the monthly time–scale anomalies of the atmospheric circulation over East Asia. Moreover, this can illustrate that the IAP–AGCM used in this study can simulate well the atmospheric circulation anomalies over East Asia caused by SST anomalies.

2. *The Experiment of the Tropical SST Anomalies (Exp.T)*

In this experiment, the anomalous run is made by using the integrations of the model from March to May taking the monthly mean global SST anomalies as forcing and from June to August taking the monthly mean tropical SST anomalies as forcing. Figure 4 shows the distribution of the 500 hPa height anomalies due to the tropical SST anomalies. It can be found from Fig.4 that the distribution of 500 hPa height anomalies is very similar to that obtained from Exp. G both in July and in August. There is a positive anomaly area over the northeastern Asia in July and in August, respectively. And both the area and the values of the positive anomalies in August are much larger than those in July. The differences with that observed (Fig.1) and Exp.G (Fig.3) are only that the area and values of the positive anomalies over the northeastern Asia in July obtained by Exp.T are notably smaller.

3. *The Experiment of the Extratropical SST Anomalies (Exp.E)*

In this experiment, the anomalous run is made by using the integrations of the model from March to May taking the monthly mean global SST anomalies as forcing and from June to August taking the monthly mean extratropical SST anomalies as forcing. Figure 5 shows the distribution of the 500 hPa height anomalies due to the extratropical SST anomalies. It can be seen from Fig.5(a) that in July there is a positive anomaly area over the northeastern Asia, while a negative anomaly area is located over the Okhotsk Sea and the Aleutian Islands. However, as shown in Fig.5 (b) the distribution of the 500 hPa height anomalies in August is

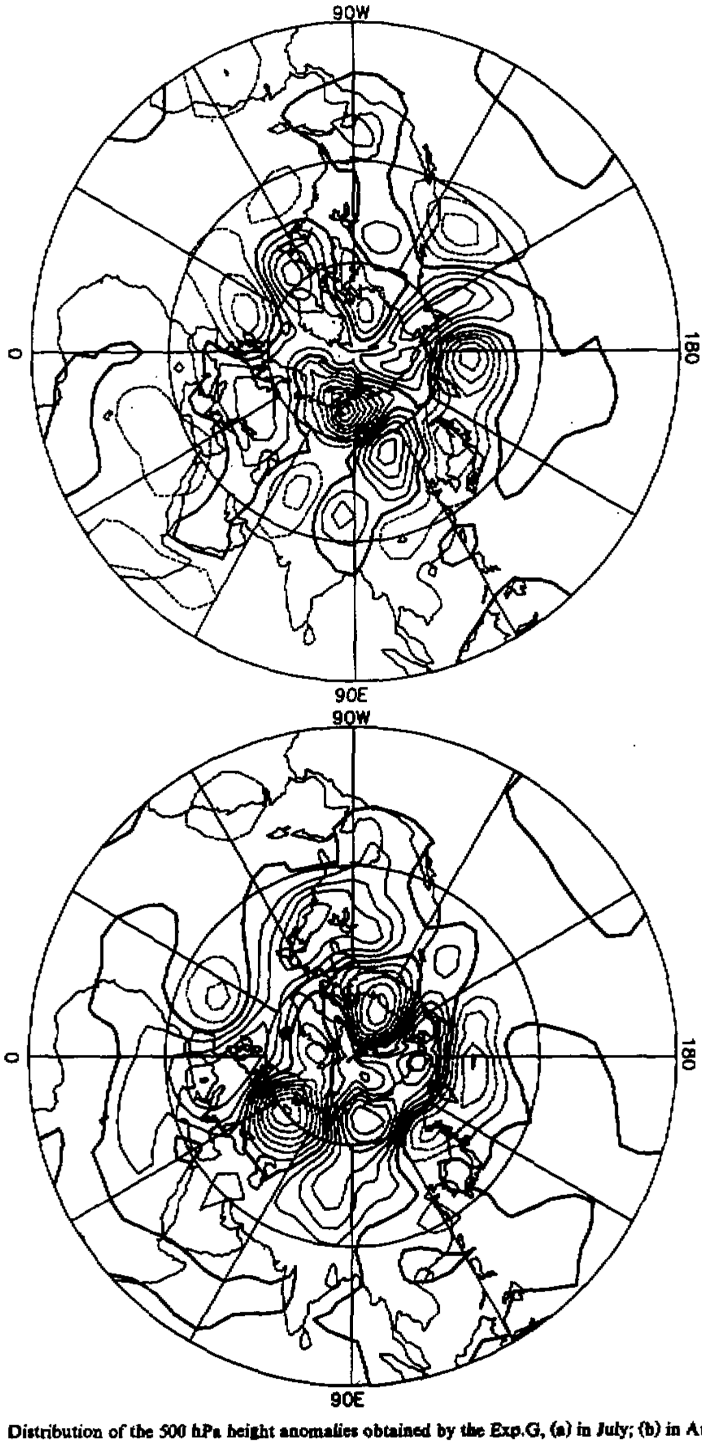

Fig.3. Distribution of the 500 hPa height anomalies obtained by the Exp.G, (a) in July; (b) in August. Units are in gpm.

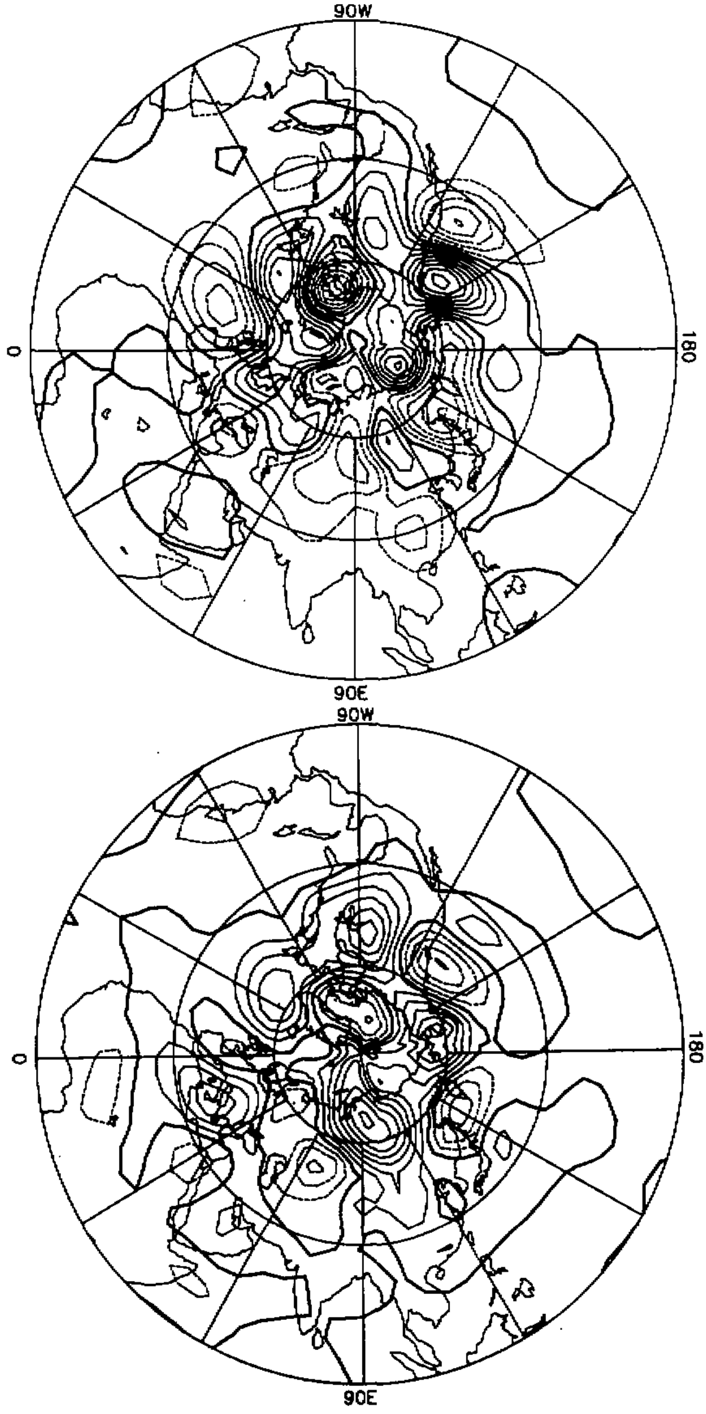

Fig. 4. Same as in Fig.3 but for the Exp.T.

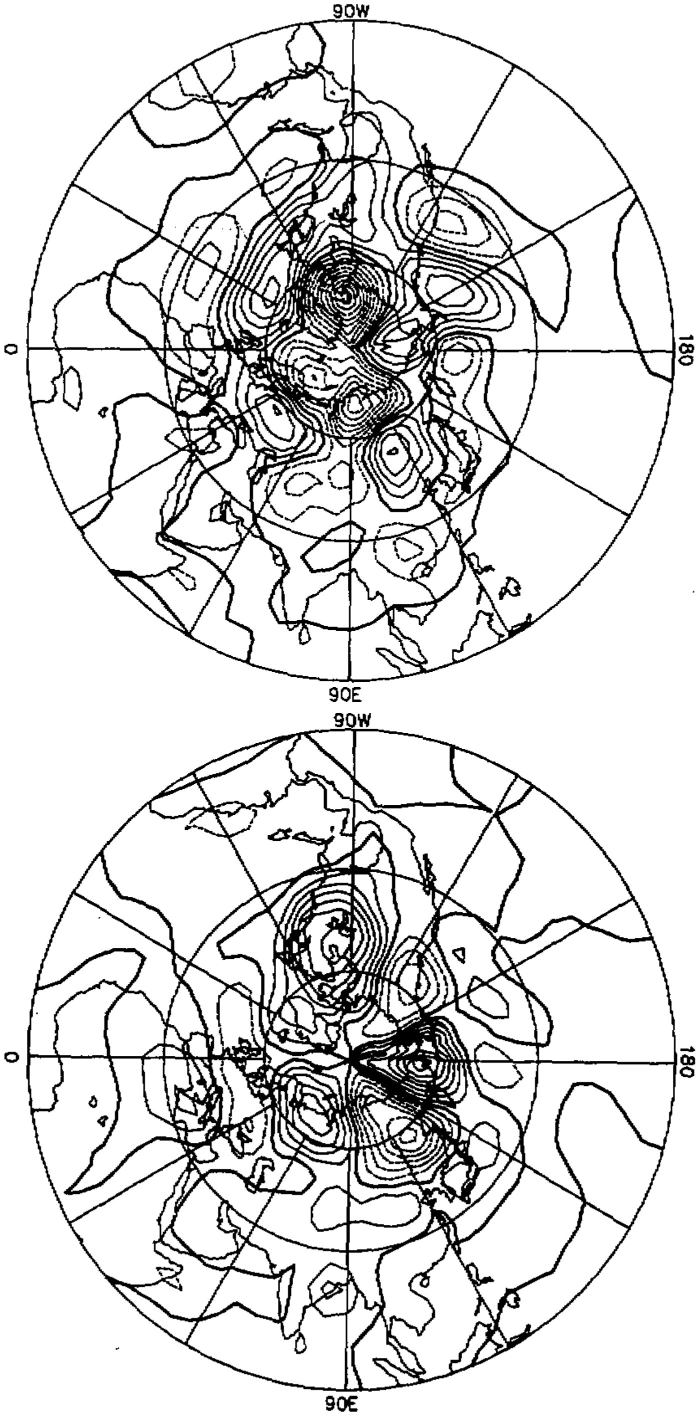

Fig. 5. Same as in Fig.3 but for the Exp.E.

completely opposite to that in July. In August, there is a strong negative anomaly area over the northeastern Asia, while strong positive anomaly area is located over the Aleutian Islands. Therefore, there are considerable differences between the result obtained by the Exp.E and that obtained by the Exp.G. Although the result obtained by the Exp.E is similar to that obtained by the Exp.G in July, the similarity is much weaker than that between the results obtained by the Exp.T and that obtained by the Exp.G in summer.

From the above–mentioned anomalous experiments, it can be found clearly that the distribution of the circulation anomalies obtained by the Exp.G is in good agreement with the observed distribution shown in Fig.1. Moreover, the distribution of the circulaiton anomalies obtained by the Exp. T is in good agreement with that obtained by the Exp.G and is also in agreement with the observed distribution. However, the result obtained by the Exp.E is much different from the observation. Thus, it can be concluded that the SST anomalies in the tropical ocean may play a significant role in the influence on the global circulation anomalies, but the role of SST anomalies in the extratropical ocean on the global circulation anomalies may be next to this.

Besides, on the simulation of the circulation anomalies over East Asia, the result obtained by the Exp.G is also the best among these three experiments. Except for the simulation of the positive height anomalies over the costal area of the northeastern Asia in July, the simulated result by the Exp. T is much similar to that observed shown in Fig.1. However, the simulated result by the Exp.E is much different from that observed, except for the simulation of the positive height anomalies over the northeastern Asia in July. This also explains the important influence of the tropical SST anomalies on the global circulation anomalies from other hands. Just through this influence, the tropical SST anomalies change the large–scale circulaiton background and then influence the blocking situations over the northeastern Asia.

IV. EFFECT OF THE SSTA IN THE TROPICAL WESTERN PACIFIC ON THE BLOCKING SITUATIONS OVER THE NORTHEASTERN ASIA

It is pointed out in the introduction of this paper that the previous studies have shown that the negative SSTA in the tropical western Pacific may cause positive geopotential height anomalies over the northeastern Asia through the EAP teleconnection pattern. In fact, we have shown in Section 2 and Section 3 that during the July and August of 1980, the geopotential height anomalies similar to EAP teleconnection pattern could be found either in the observed results or in the simulated results (Exp. G and Exp.T). We have also shown that negative SST anomalies were located in the tropical western Pacific from March to August. In addition, the situation in 1991 was similar to that in 1980 in many aspects. In the summer of 1991, an anomalously strong blocking high was located over the northeastern Asia, and a clear dipole pattern of the geopotential height anomalies appeared over East Asia. The blocking situations caused a drought in North China and a severe flood in the Yangtze River and Huaihe River basin. In the July and August of 1991, the geopotential height anomalies were also similar to the EAP teleconnection pattern, and the SST anomalies in the tropical western Pacific were negative (not shown here). The above facts show that negative SST anomalies in the tropical western Pacific may cause the atmospheric circulation anomalies and then influence the blocking situations over the northeastern Asia.

In Section 3, it has been shown that the tropical SST anomalies have an important influence on the atmospheric circulation anomalies in the July and August of 1980. Among the tropical SST anomalies, the SST anomalies in the tropical western Pacific may have a major role in the influence on the atmospheric circulation anomalies over East Asia.

In order to show clearly the influence of the negative SST anomalies in the tropical western Pacific on the blocking high over the northeastern Asia, in the following, an idealized distribution of SST anomalies will be used to investigate the influence. As same as the former, instead of discussing the blocking high directly, we will investigate indirectly the influence of negative SST anomalies in the tropical western Pacific on the blocking situations over the northeastern Asia through the investigation of the circulation anomaly pattern. The model used here is still IAP–AGCM. The results obtained by control run are also the results integrated the model to 22nd year taking the climatological mean SST distribution as forcing. An idealized distribution of the SST anomalies in the tropical western Pacific shown in Fig.6 is added into the climatological distribution of SST in the control run. The scope of the SSTA is: 2–22°N, 110–150°E and the maximum of the SST anoamlies is at 12°N, 120°E. The anomalous run is performed from June 1 to July 31. Among the simulated results, only the results in July will be analysed in the study.

Figure 7 shows the distribution of the 500 hPa geopotential height anomalies simulated by the negative SSTA in the tropical western Pacific shown in Fig.6. It can be found from Fig.7 that a positive anomaly area of geopotential height field is located over the northeastern Asia. The positive anomalies of the height field provide a precondition of the atmospheric circulation for the formation and maintenance of the blocking high. Moreover, there is a negative anomaly area over East China. This distribution of the positive and negative anomalies is much similar to that shown in Fig.1, Fig.3 and Fig.4. Thus, among the tropical SST anomalies, the SST anomalies in the tropical western Pacific have a major role in the circulation anomalies over East Asia.

The above simulated results show that due to the negative SSTA in the tropical western Pacific, on the one hand, the subtropical high shifts southward, thus, it can lead to prolonged maintenance of the East Asian summer monsoon rainband over the Yangtze River and Huaihe River basin; on the other hand, the blocking high occurs frequently over the

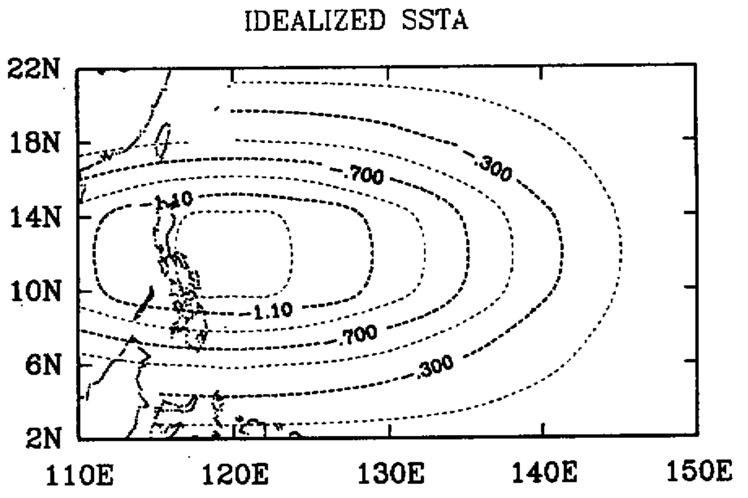

Fig.6. Idealized distribution of the SST anomalies in the tropical western Pacific. Units are in ℃.

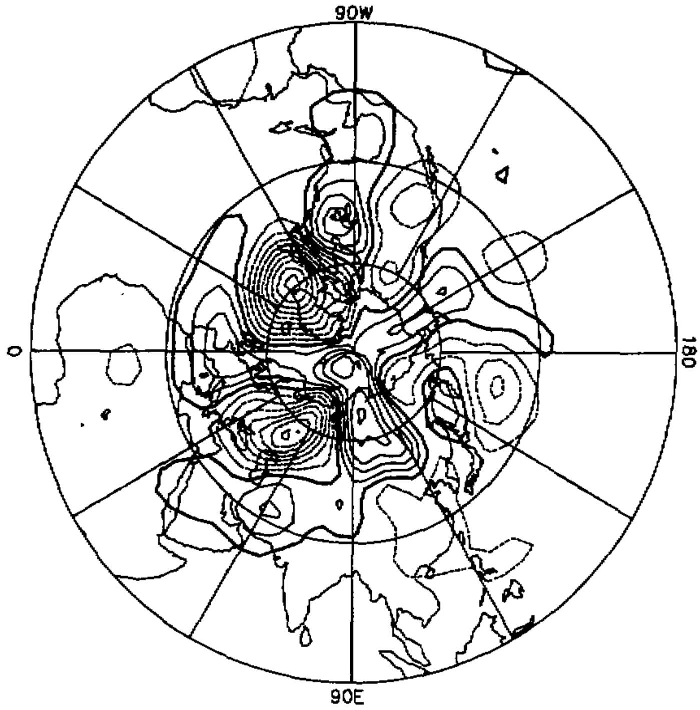

Fig.7. The monthly-mean 500 hPa geopotential height anomalies simulated with the idealized SSTA in the tropical western Pacific. Units are in gpm.

northeastern Asia, thus, it can lead to frequent appearance of the low troughs over Northeast China and the Baikal Lake. The low troughs can provide a source of the persistent cold air for the Meiyu front over the Yangtze River and Huaihe River basin and provide a favorable circulation condition over the middle latitudes for prolonged maintenance of the Meiyu season.

V. SUMMARY

In this paper, the atmospheric circulation anomalies during the July and the August of 1980 are simulated with the observed SST anomalies through three experiments including the anomalous experiment of the global SST anomalies, the anomalous experiment of the tropical SST anomalies and the anomalous experiment of the extratropical SST anomalies, and the simulated results are compared with the observed result.

The investigated results show that the EAP teleconnection pattern provided the precondition of the large-scale circulation background for the frequent appearance of the blocking high over the northeastern Asia during July and August, 1980. Moreover, it is discovered with the numerical experiments that the SST anomalies were one of the important causes of the circulation anomalies during the summer of 1980.

Besides, the circulation anomaly pattern which is favorable for the blocking situations to be formed and maintained over the northeastern Asia can be simulated well with the anomalous experiment of the global SST anomalies.

In order to investigate in detail the effect of the SST anomalies on the circulaiton anomaly, the SST anomalies are divided into the tropical and extratropical SST anomalies. The results obtained by the anomalous experiment of the tropical SST anomalies are more similar to those obtained by the anomalous experiment of the global SST anomalies than those obtained by the anomalous experiment of the extratropical SST anomalies. The results also show that the circulation anomaly pattern which can be favorable for the formation and maintenance of the blocking situations over the northeastern Asia, is simulated well with the anomalous experiment of the tropical SST anomalies. Therefore, it is possible that the SST anomalies in the tropical ocean are an important cause of the circulation anomalies over East Asia and the blocking situations over the northeastern Asia.

Finally, the EAP teleconnection pattern is simulated well with an idealized distribution of SST anomalies in the tropical western Pacifc and the simulated result is much similar to the anomalous experiment of the tropical SST anomalies. This explains that the SST anomalies in the tropical western Pacific have an important influence on the blocking situations over the northeastern Asia, especially, the negative SST anomalies in the tropical western Pacific are helpful for the formation and maintenance of the blocking situations over the northeastern Asia.

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