Influences of the Extratropical Pacific SST on the Precipitation of the North China Region

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ABSTRACT

The influences of the extratropical Pacific SST on the precipitation of the North China region are reexamined with the observational data and studied with numerical simulations by using NCAR CCM2. It is found that there exist high positive correlations between the annual precipitation of the North China region and the extratropical Pacific SST in late spring, especially in two regions, e.g., the Kuroshio Current region and the midlatitude central Pacific region. The numerical simulations with NCAR CCM2 show that the warmer SSTs in the Kuroshio Current region and the midlatitude central Pacific in late spring can generate a large-scale circulation pattern over the Asia-Pacific region that is favorable to the precipitation of the North China region.

Key words: Extratropical Pacific SST, Influence, Precipitation, North China region

I. INTRODUCTION

The influence of the sea surface temperatures on the large-scale East Asian monsoon circulations and summer precipitation in China has long been a subject of interest to investigators of seasonal to interannual climate predictions. For many years, Chinese scientists have recognized the importance of extratropical Pacific SST variations for the East Asian summer monsoon (especially the western Pacific subtropical high) and summer precipitation in China. As early as 1970's, Long-range Forecast Reseach Group of IAP / CAS analyzed the influences of the Pacific SST anomaly on the East Asian atmospheric circulation and the floods and droughts in China (IAP / CAS Long-range Forecast Research Group, 1973,1978). They found that the winter and spring SST anomalies in the Kuroshio Current region have strong impacts on the summer precipitation of the North China region and the lower and middle reaches of the Yangtze River valley. When the SST in the Kuroshio Current region is warmer, summer precipitation of the North China region will increase. They also found close relationships between the SST in the Kuroshio Current region and the advance and retreat of the western Pacific subtropical high. Many other studies also show the strong influences of the Kuroshio Current region SST on the summer precipitation of China and on the western Pacific subtropical high (Fu Congbin et al., 1979; Chen Lieting, 1977; Pan Yihang, 1978; Zhang Xingfa, 1981; Wang Shaowu et al., 1983; Climate Research Group of the Institute of Geography / CAS, 1973).

Although the observational evidence of the previous studies and the experiences of the long-range forecasters clearly show that SST on the Kuroshio Current region is an important predictor for the East Asian monsoon and the summer precipitation of China (the SST indices of the Kuroshio Current region is now routinely published on the China's Climate Monitoring Bulletin as a reference of short-term climate prediction), much attention has recently been focused on the response of the atmospheric circulation to the equatorial Pacific SST anomalies, partially as a result of the intense research efforts devoted to the ENSO phenomena. The study of the impacts of the extratropical Pacific SST on the East Asian monsoon and precipitation of China has almost been neglected for more than a decade, except a few numerical simulation works recently made (Li Chongyin and Long Zhenxia, 1992; Ge Xiaozheng and Yu Zhihao 1986).

In the present paper, the relationships of the annual precipitation over the North China region with the extratropical Pacific SST are reexamined with the observational data. The mechanisms are studied with the numerical simulations of the NCAR Community Climate Model CCM2.

II. OBSERVED RELATIONSHIPS BETWEEN THE PRECIPITATION OVER THE NORTH CHINA REGION AND EXTRATROPICAL PACIFIC SST

The North China region in this study is defined as the area between 34.36°N–42.35°N and 110.15°E–120.00°E, with the Inner Mongolia Plateau in the north, the Bohai Sea in the east and the Yellow River as the western and southern boundaries.

The data used in this study are the annual total amount of precipitation of the North China region with a period of 29 years from 1956 to 1984 (the "6.5" China National Key Scientific Research Program 38–1–5 Research Group, 1987). In the North China region, the annual precipitation amount is mainly contributed by the four months of June, July, August and September. So although the data are the annual values, we may take them approximately as the values of summer season. Another data set used in this study is the China monthly precipitation of 160 stations of 1951–1990. The global SST data used in this study are COADS dataset of 1946–1988 with a resolution of 7.5 degrees in longitude and 4.5 degrees in latitude.

As shown in Figure 1, there are close correlations between the annual precipitation of the North China region and the extratropical Pacific SST in May, especially in two regions, e.g., the region of about 130°E–150°E and 25°N–35°N to the south of Japan (Kuroshio Current region, hereafter defined as region–A1) and the region of about 170°E–180–160°W and 30°N–40°N in the central Pacific (defined as region–A2). The combination of region–A1 and region–A2 is defined as region–A12. We take the spatial average of the SST in region–A1 and region–A2 as the region–A1 and region–A2 SST and define their combination as region–A12 SST. Figure 2 shows the standardized anomalies of the annual total precipitation of the North China region, and region–A1, region–A2 and region–A12 SST. A very good correspondence between precipitation and SST anomalies can be seen. For further investigation, we computed the correlations of the region–A12 SST in May with China's annual precipitation (as shown in Figure 3). The high correlations cover most part of the North China region and the southern parts of Northeast China region.

It should be pointed out that using the precipitation in JJA over the North China region will probably be better than using the annual precipitation for the analysis here. That we use the annual total amount of precipitation instead of the summer total values is because originally this part of the work in the present paper is not deliberately done for the study of the relationships between the extratropical Pacific SST and the summer precipitation in the North China region, but for the study of the influences of SST on the water resources (including runoff, total water resources and precipitation) (Geng, 1996). Without monthly runoff data, we have to use the annual data. In this paper we just borrow some of the results in that work to reexamine the previously discovered relationships between the SST in the Kuroshio current region and the summer precipitations in the North China region (as mentioned in the introduction) and provide some necessary information (like the location, area and the strength of the SST anomalies etc.) for the following numerical simulations. The main aim of the present

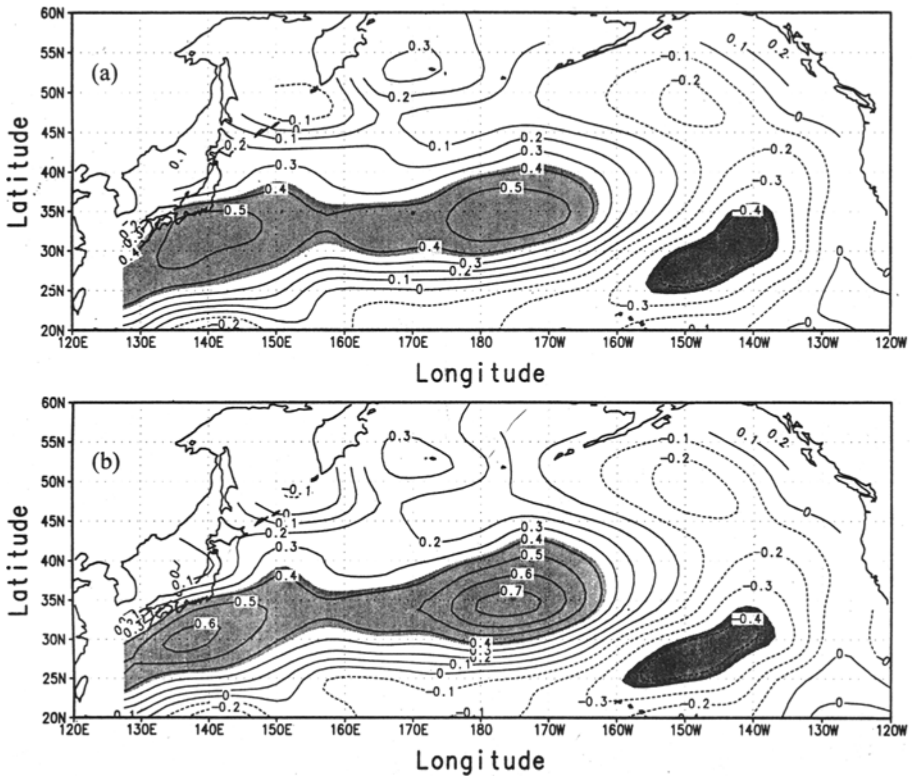

Fig. 1. Correlations between annual precipitation of (a) the whole North China region and (b) the south branch of Haihe River basin, and the extratropical Pacific SST in May. Shadings indicate areas with 95% significance level.

paper is to confirm the influences of the extratropical Pacific SST on the summer precipitation of the North China region with numerical simulations and study its mechanisms. Considering these reasons and that in the North China region the annual total precipitation amount is mainly contributed by the summer months, using the annual total precipitation amount instead of the summer values is probably acceptable.

III. DESCRIPTION OF THE NUMERICAL EXPERIMENTS

The model used to study the mechanisms of the impacts of the extratropical Pacific SST on the precipitation in the North China region in this study is the NCAR CCM2 which has a standard horizontal spectral resolution of T42 in global domain (approximately a 2.8×2.8 degree transformation grid), with a terrain–following hybrid vertical coordinate of 18 vertical levels and a top at 2.917 hPa. Realistic orography and land–sea contrast were incorporated in the lower boundary condition. The model physics includes cloud parameterization, physical parameterization of radiation, surface energy exchanges, surface / soil temperature calculation, vertical diffusion and atmospheric boundary layer processes, gravity wave drag, Rayleigh friction, moist convection, stable condensation and dry adiabatic adjustment. A shape–preserving semi–Lagrangian transport scheme is used for advecting water vapor. Detailed description of the NCAR CCM2 can be found in Hack et al (1993).

According to the study of Geng (1996), the spatially averaged SST anomaly in the

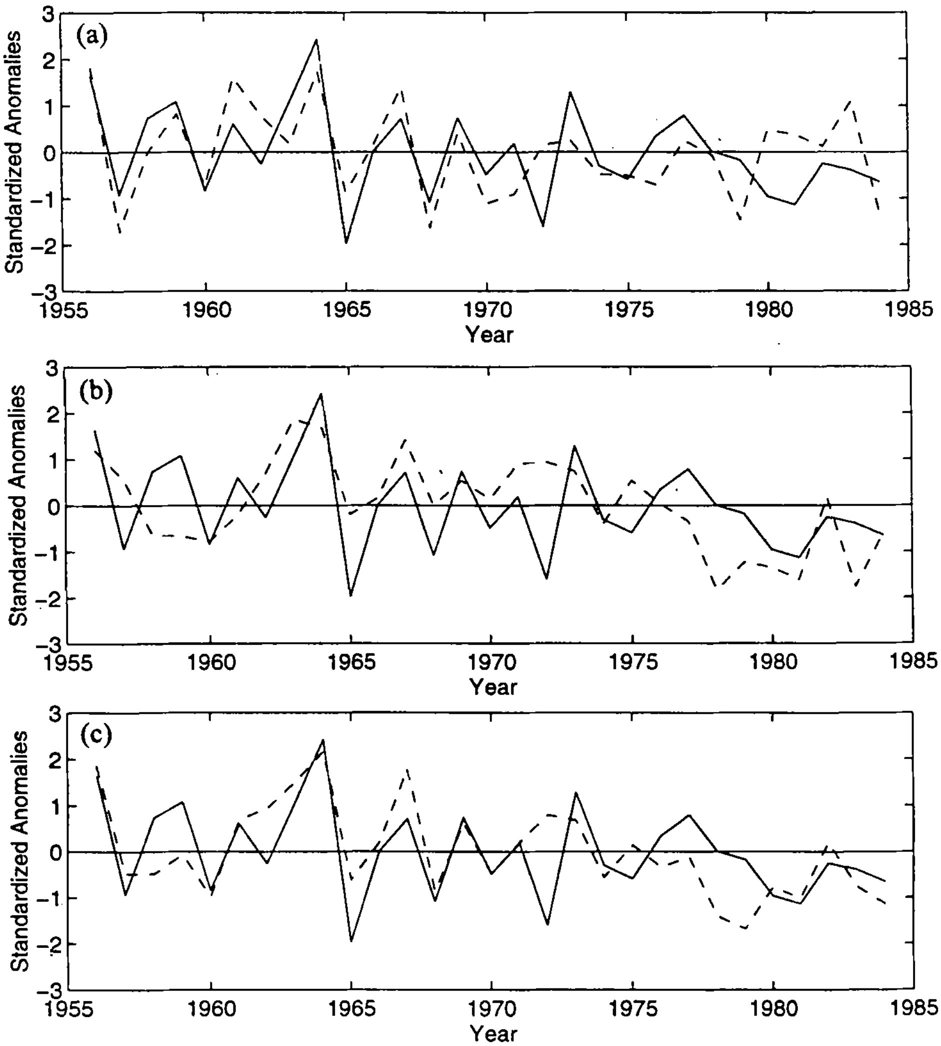

Fig. 2. Standardized anomalies of annual precipitation (solid line), and (a) region-A1, (b) region-A2 and (c) region-A12 SST of the extratropical Pacific in May (dashed line).

Kuroshio Current region of 130°E–150°E and 25°N–35°N to the south of Japan can sometimes reach about 0.8°C, and that in the central Pacific of 175°E–180–160°W and 30–45°N can sometimes reach about 1.0°C. The maximum SST anomaly in these two regions may be much larger than those values. So, in our experiments we assume an idealized SST anomaly distribution in the form

$$SSTA = SSTA0 \times \left(\cos\frac{\pi(\lambda-\lambda_c)}{\lambda_d}\cos\frac{\pi(\varphi-\varphi_c)}{\varphi_d}\right)^2$$

$$\text{when } |\lambda-\lambda_c| \leqslant \lambda_d/2; \ |\varphi-\varphi_c| \leqslant \varphi_d/2,$$

$$SSTA = 0 \qquad \text{elsewhere.}$$

Here the SSTA0 is the amplitude of the SST anomaly, (λ_c, φ_c) the center point of the anomaly region and λ_d and φ_d the longitudinal and latitudinal diameter of the anomaly region. The values of these parameters chosen for the Kuroshio Current region and the central Pacific are shown in Table 1.

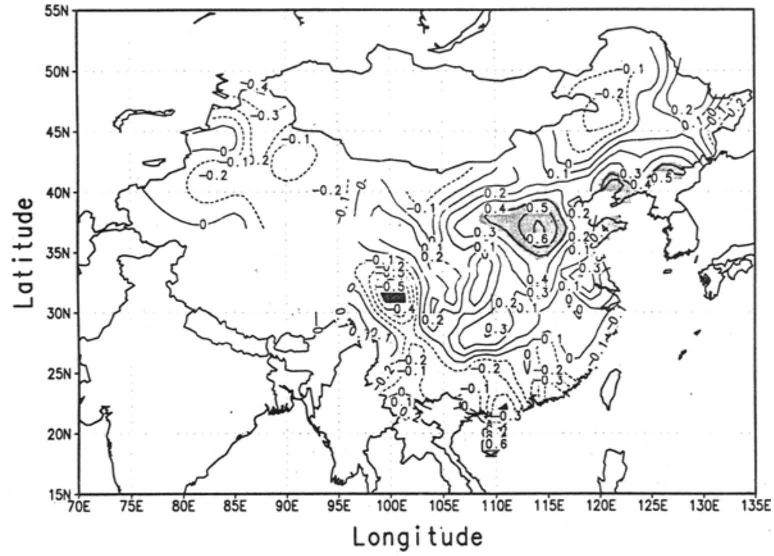

Fig. 3. Correlations of the annual precipitation over China with region-A12 SST of the extratropical Pacific in May. Shadings indicate areas with 95% significance level.

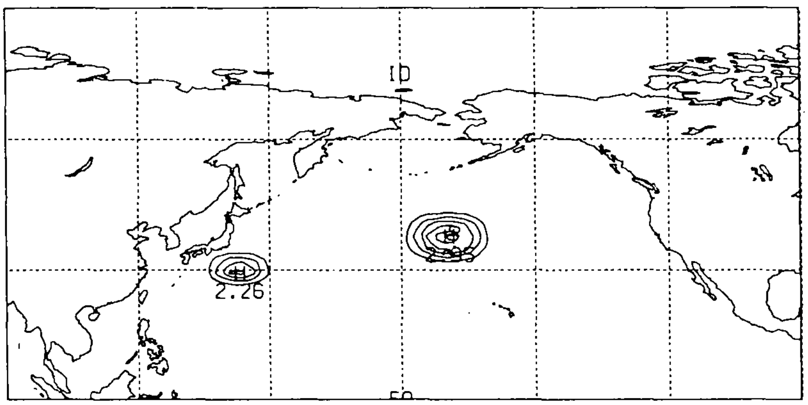

Fig. 4. Idealized SST anomaly of extratropical Pacific in April, May and June. Contour interval is 0.5°C.

Table 1. Specification of the Idealized SST Anomaly

Region	Kuroshio Current Region	Central Pacific Region
Domain	130°E 150°E and 25°N 35°N	175°E–180–160°W and 30°N–45°N
SSTA0	2.4°C	3.0°C
(λ_c, φ_c)	(140°E, 30°N)	(187.5°E, 37.5°N)
(λ_d, φ_d)	(20, 10) degrees	(25, 15) degrees

The spatial distribution of the idealized SST anomaly is shown in Figure 4. In the control experiment the SST was specified as the climatological values during the integration. In the extratropical Pacific SST anomaly experiment, the SST anomalies described in Table 1 was added to the climatological SST in April, May and June and the SST in other months still remains unchanged. Both the control run and the Pacific SST anomaly run start from a model atmospheric state of March 1, which were generated in a six months (or 180 days) spin-up run using the climatological SST from an initial state of September 1 provided by NCAR.

IV. RESULTS OF THE NUMERICAL EXPERIMENTS

Fig. 5 shows the JJA precipitation anomaly of the extratropical Pacific SST anomaly experiment. As we expected, there is a positive JJA precipitation anomaly in the northern part of the North China region and Northeast China region. Although the positive anomaly center has a little northeastward shift compared with the correlation patterns in Fig. 3, the main features of the precipitation anomalies in North China and Northeast China regions have been captured by the numerical simulation. The northeastward shift of the positive anomaly center is probably because we have used a little too strong SST anomaly in the numerical experiments or other reasons which are unknown.

To illustrate the mechanisms of the precipitation anomaly caused by the extratropical Pacific SST anomaly in late spring, we have examined the large-scale summer monsoon circulation patterns demonstrated in the experiments. Figure 6a shows the JJA 850 hPa geopotential height anomalies in the Asia-Pacific region for the extratropical Pacific SST anomaly experiment. There are positive anomalies over large part of the Asian Continent, and most part of the western Pacific, and negative anomalies between them over the coastal regions. As shown in Figs. 6b and 6c, these geopotential height anomalies cause three major differences between the geopotential height fields of the control experiment and SST anomaly experiment in the Asia-Pacific region. Compared with the control experiment, the Asian continental low is weaker, the western Pacific subtropical high extends further northwestward near Japan and a cut-off low appears over the eastern Russia in the SST anomaly experiment.

Fig. 7a shows the JJA streamline field anomaly at 850 hPa. It is clear that the weaker Asian continental low caused a strong anomalous northerly wind over the eastern China. This anomalous northerly wind meets, over the North China region, with the anomalous southeast

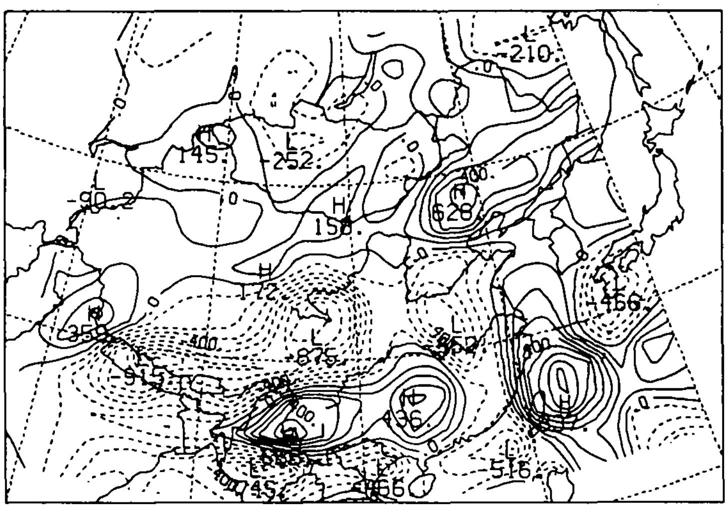

Fig. 5. JJA total precipitation anomaly for the extratropical Pacific SST anomaly experiment. Contour interval is 100.0 mm. Dashed lines indicate negative anomalies.

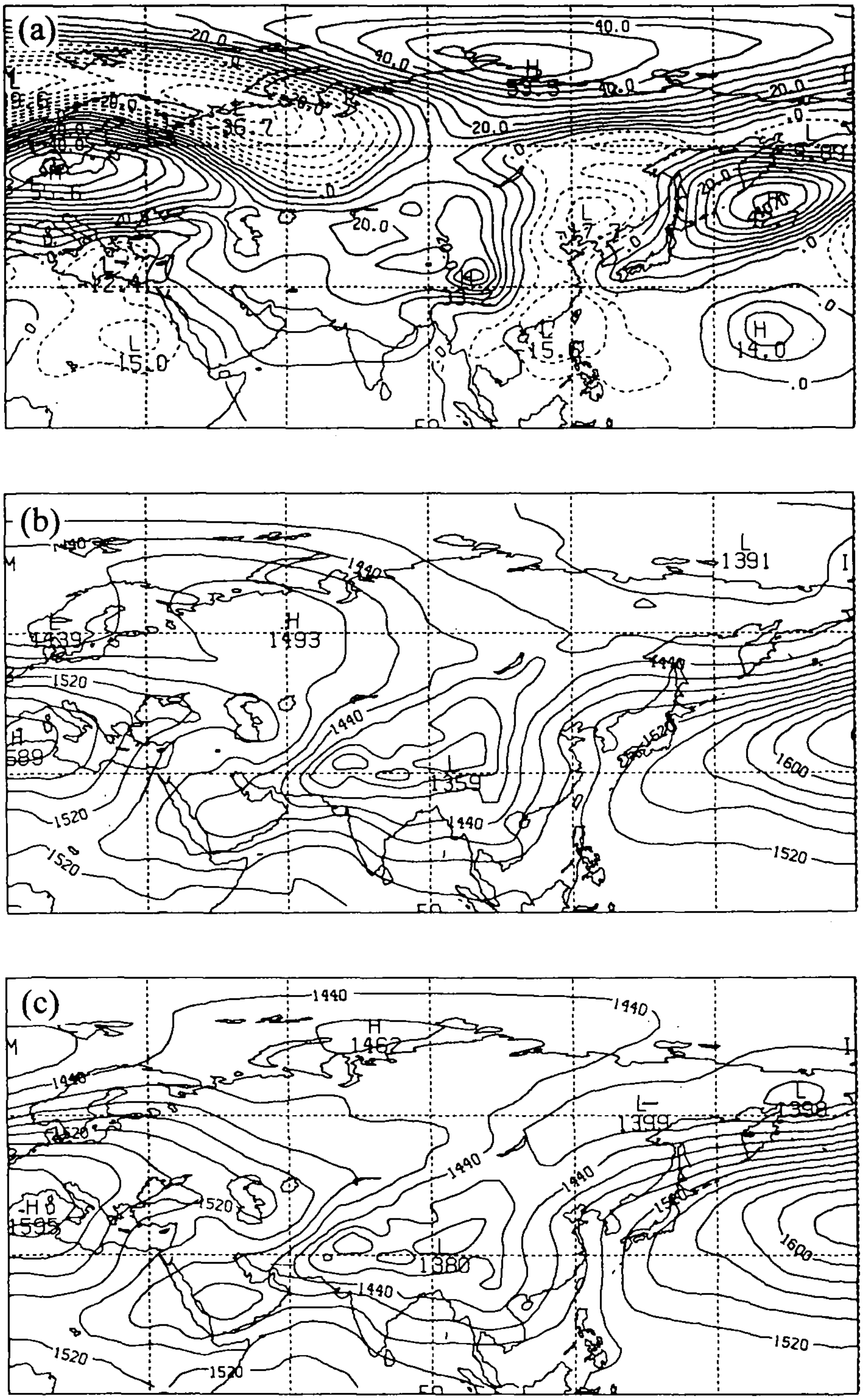

Fig. 6. JJA 850 hPa (a) geopotential height anomalies for the extratropical Pacific SST anomaly experiment (Contour interval is 5.0 gpm. Dashed lines indicate negative anomalies.), and geopotential height fields for (b) the control experiment and (c) the extratropical Pacific SST anomaly experiment (Contour interval is 20.0 gpm).

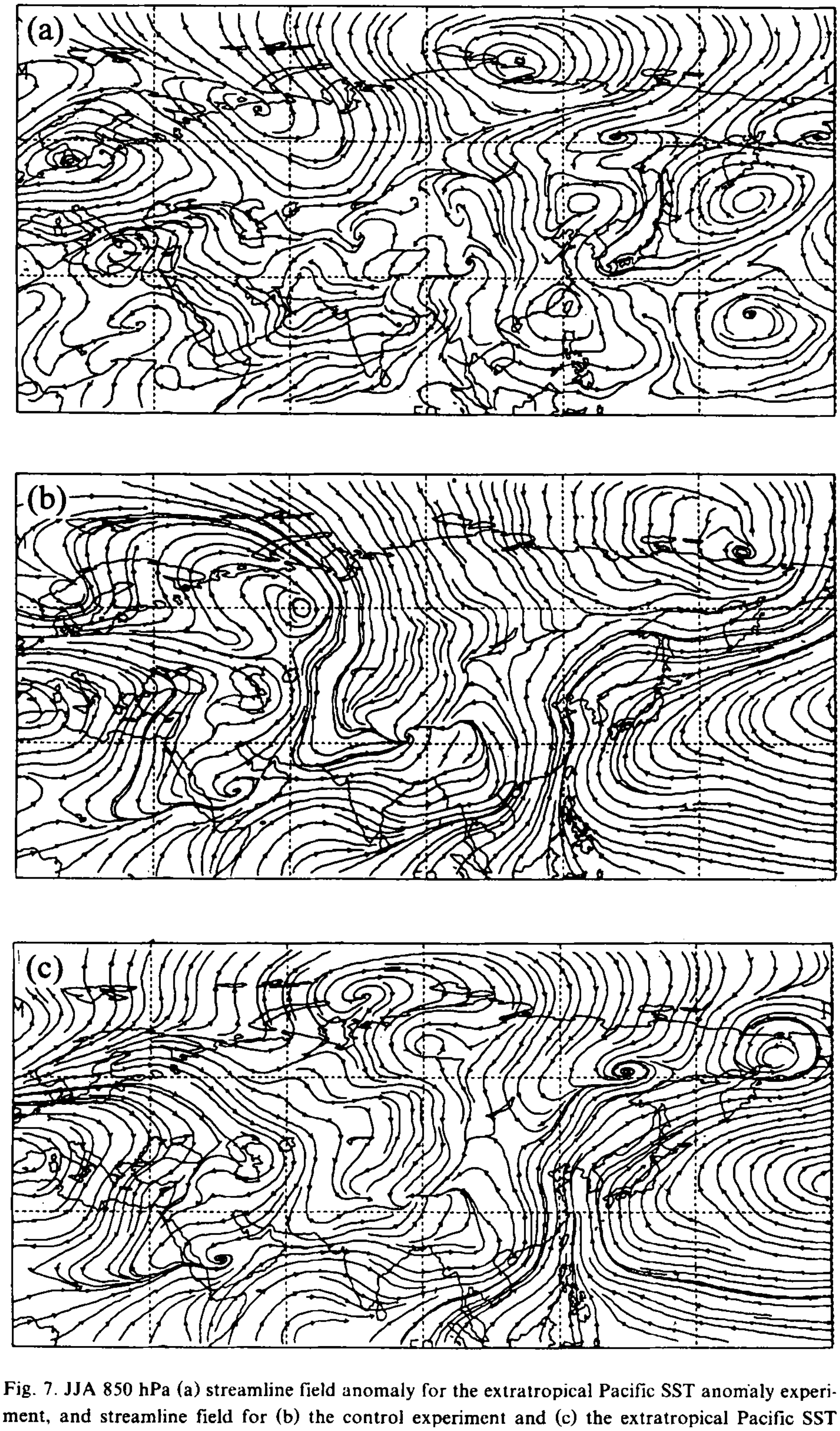

Fig. 7. JJA 850 hPa (a) streamline field anomaly for the extratropical Pacific SST anomaly experiment, and streamline field for (b) the control experiment and (c) the extratropical Pacific SST anomaly experiment.

wind from the western Pacific, causing an anomalous convergence of cold polar air and warmer moist air from the south, and thus creating a favorable circulation condition for the positive precipitation anomaly there. Figs. 7b and 7c show the JJA streamline field of 850 hPa for the control experiment and the SST anomaly experiment, respectively. The simulated circulation pattern clearly shows that the Asian summer monsoon regime is composed of two major components, the Indian monsoon covering the Indian Ocean, Arabian Sea, the Bay of Bengal, and the East Asian monsoon encompassing China, Korea, Japan, the South China Sea and the western part of the tropical western Pacific. The monsoon streamflow over the eastern China for the SST anomaly experiment does not reach as north as that of the control experiment. Also, the polar air penetrate more southward over the southeast of the lake of Baikal. This makes the convergence of polar air masses and tropical poleward moist air move further southeastward closer to North China and Northeast China region, compared with that in the control run. This kind of circulation pattern is a favorable condition for the precipitation in the North China region.

Fig. 8 gives the 500 hPa geopotential height field of the control run and the extratropical Pacific SST anomaly run. In the SST anomaly experiment, the ridge from Northeast China region to the western coast of the Sea of Okhotsk in the control experiment has been greatly

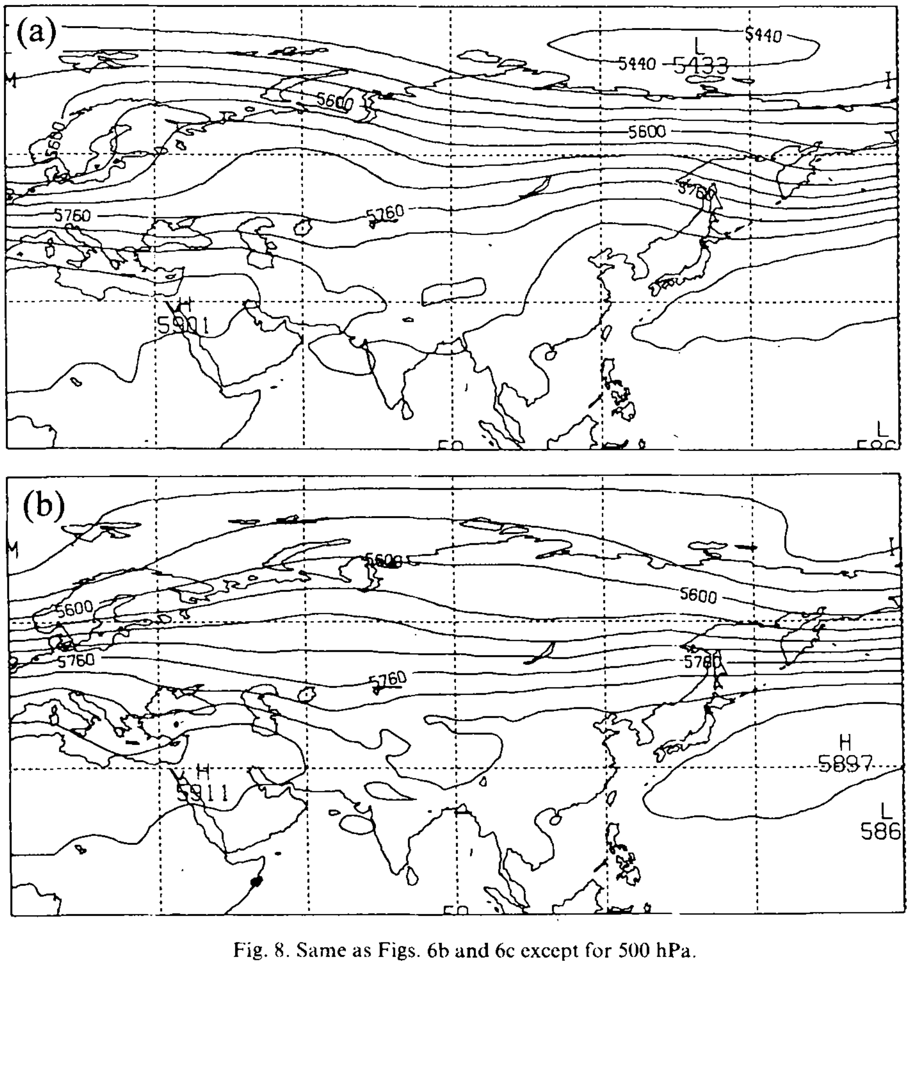

Fig. 8. Same as Figs. 6b and 6c except for 500 hPa.

reduced and become a weak trough north to the Yellow Sea. Also, in the western Pacific, the area of the subtropical high in the SST anomaly experiment is a little larger than that of the control experiment. This kind of circulation pattern is again favorable to the precipitation of the North China Region.

V. CONCULSION REMARKS

In the present study, the influences of the extratropical Pacific SST on the precipitation over the North China region are investigated with the observational data and numerical simulations with NCAR CCM2. The results show that:

(1) There exist high positive correlations between the annual precipitation the North China region and the extratropical Pacific SST in May, especially in two regions, e.g., the Kuroshio Current region and the midlatitude central Pacific region.

(2) The numerical simulations with NCAR CCM2 show that when the late spring SSTs in the Kuroshio Current region and the midlatitude central Pacific have positive anomaly, the summer Asian continental low will be weaker, the western Pacific subtropical high will extend further northwestward near Japan (especially at 850 hPa) and a cut-off low appears over the eastern Russia. As a result, the northward summer monsoon streamflow over the eastern China is weaker and the polar air penetrates more southward over the southeast of the lake of Baikal. This makes the convergence of polar air masses and tropical poleward warmer moist air move southward closer to North China and Northeast China region, thus creating a favorable condition for the precipitation there.

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