THE CORRELATIONS BETWEEN SST AND SUMMER PRECIPITATION OVER EASTERN CHINA AND THE EFFECT OF THE SST ANOMALY IN THE SOUTH CHINA SEA ON THE SUMMER MONSOON AND PRECIPITATION

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ABSTRACT

By use of the method of empirical orthogonal function resolution a study is made of the distribution patterns of summer rainfall percentage anomalies over eastern China with the result that such anomalies are able to reflect the relative amount of local precipitation. Then the correlations are obtained through calculation between the patterns and the January and June global SST, indicating key regions in association with China's summer rainfall. On this basis, an 11-layer atmospheric circulation model by the U. K. Meteorological Office is used to simulate the effect of a weak SST anomaly of the South China Sea upon the summer monsoon circulation in China's mainland. Results show that 'attraction' is available for the Indian monsoon with a warm anomaly of the SST and 'repelling' with a cold, representing one of the reasons for the anti-phase between the monsoons over the South China Sea and India. Such functions of SST anomalies have a significant influence on summer rainfall over eastern China.

I. INTRODUCTION

It is known that East-China is affected by summer monsoon with greater concentration of rainfall, which is of importance to agriculture. So Chinese meteorologists have been seeking for the regularities of the precipitation both in theoretical and operational aspects. The influence of SST anomalies in the North Pacific upon the climatic problem over eastern Asia was already studied (Lü, 1951, 1963). As indicated in the paper by the Long-Range Weather Forecasting Group, Institute of Atmospheric Physics (1978), there exists an appreciable positive correlation between the precipitation of the middle and low Changjiang reaches and North-China plains in the rainy season and the precedent SST in the region of Kuroshio. Recently Luo et al. (1985) have shown that SST of the Indian and South-China Sea has subsequent effect on the summer rainfall of the reaches. All these studies are explorations of the relationship between SST and China's summer precipitation from a

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variety of aspects.

In view of the fact that long-range weather processes are of global nature, there is necessity of investigating the dependence of rainfall in the country upon the global SST. For this reason, the principal patterns of the summer rainfall distribution and their correlation to the SST over the globe are examined using the 1950—1981 data of the total precipitation for June—August, with the result that some key regions are located which have influence on the distribution.

Recently Tao et al. (1983) have indicated that the seasonal displacement of East-China rainband is bound up with the northward advance of low-tropospheric summer monsoon as well as the northward trend of the subtropical high ridge-line, according to their study on the relation to the monsoon circulation of the precipitation in the early summer (about May) over South China and rainfall in the Meiyu (plum rain) season over the Changjiang-Huaihe reaches. Also, in the paper dealing with the response of Indian monsoon precipitation to the SST anomaly of the Arabian Sea, Shukla (1982) indicates that the reality of the monsoon circulation modelling has a direct effect on that of the rainfall there.

In order to make a further verification of the effect of these key regions on the general circulation and rainfall the 11-layer model is employed to show its response to the SST of the South-China Sea, the experimental results indicating that the weak SST anomaly affects mainly the summer monsoon and then the rainfall over eastern China.

II. PATTERNS OF SUMMER RAINFALL DISTRIBUTION IN EAST-CHINA

For the present study the rainfall at each station is represented in terms of the total over the period of June—August for each year, based on the 1950—1981 data from 25 stations covering the country*.

In view of the fact that the distribution of our summer rainfall is characterized basically by being greater in amount in the south and east than in the north and west, respectively, the first few eigenvectors reflect mainly these properties if the rainfall or its anomaly is put into direct use for analysis. For us, however, the relative amount for each observing station is of more interest. To make the distribution features projected the percentage anomalies of rainfall are used for analysis, which has the form

$$R_p = \frac{R - \bar{R}}{\bar{R}} \times 100\%,$$

where R denotes the rainfall at a station for a particular year and $\bar{R}$ the average over these years. Then with the aid of R_p empirical eigenvectors are found out, of which only the first three are sorted out. It should be noted that the selected indicate a greater percentage of the total variances, showing a spatial distribution of larger scale, closer to the real affairs of the summer rainfall distributed over China.

Fig. 1 delineates the distribution pattern represented by the first three empirical eigenvectors of the percentage anomalies. The first one shows two high-value regions labelled by '+', one stretching from East Hubei to the southeastern coastal area down the Changjiang reaches and the other situated in southwestern Guizhou and South Sichuan, with a negative-value region along the coastal area of North Shandong (Fig. 1a); the second indicates two negative-value centers, one covering the zone south of the middle and low Changjiang

* These stations include Harbin, Shenyang, Beijing, Tianjin, Taiyuan, Lanzhou, Xi'an, Zhengzhou, Qiangdao, Nanjing, Shanghai, Yichang, Guiyang, Hankou, Fuzhou, Zhijiang, Xichang, Chengdu, Nanchang, Wenzhou, Shantou, Nanning, Kunming, Hongkong, Taibei.

basins and northern parts of Guangdong and Guangxi and the other extending from southern Hebei via central Shaanxi (west of the Huanghe River) to northeastern Sichuan, with a positive-value center located in southwestern Guizhou and Yunnan (Fig. 1b); the third is featured by two negative-value regions, one (belt-like) stretching from Central Sichuan down both sides of the Changjiang and the other extending from Northeast China to the northern parts of both Shaanxi and Shanxi Provinces (divided by the Huanghe River) (refer to Fig. 1c).

Fig. 1. Eigenvectors of the summer rainfall percentage anomalies, with the first, second and third eigenvector shown in a, b, and c, respectively.

It should be pointed out that, although capable of representing the maximal percentage of the total variances with no orthogonal restraint, the first eigenvectors alone cannot show all meaningful distribution properties and therefore the subsequent two are put into use for fhe real distribution. When the time coefficients are negative, the patterns of these eigenvectors will turn to anti-phase, that is. the positive value centers are to be changed to negative and vice versa.

The patterns shown in the present work have been compared with those of the summer rainfall precentage anomalies of China (Academy of Meteorological Science, 1981). Results indicate that the present patterns of the eigenvectors could reveal actual distribution of the relative amount of the summer precipitation with more accuracy.

III. RELATION OF THE SUMMER RAINFALL TO SST

Since a particular SST can persist for a longer period of time, the correlation maps are constructed and analyzed of the time coefficients of the eigenvectors (shown in Fig. 1) with the June and January SST averages, respectively.

Fig. 2 delineates the correlation map of the distribution patterns of the first three eigenvectors with the June mean SST, where the regions with the correlation coefficients being statistical significant at the confidence level of 5% are shown. The significant regions in the map of the correlation involving the first eigenvector present a negatively correlative region covering the seas on both sides of Hokkaido and the vicinity of the Bohai and Huanghai Seas and positively correlative regions including the vicinity of the South-China Sea, the sea east of U.S. eastern coast and Caribbean Sea. Obviously, these regions are relevant to the Oyashio, Kuroshio current, Gulf Stream and Guyana current, respectively. From the map of the correlation involving the second eigenvector it can be seen that two negative correlations are present in the sea west of Central America and Peru, respectively, and one in the neighbourhood of the Luzon (South Asia). The correlation map involving the third eigenvector indicates two negative correlation regions in the sea west of Peru and in the vicinity of the Arabian Sea, respectively.

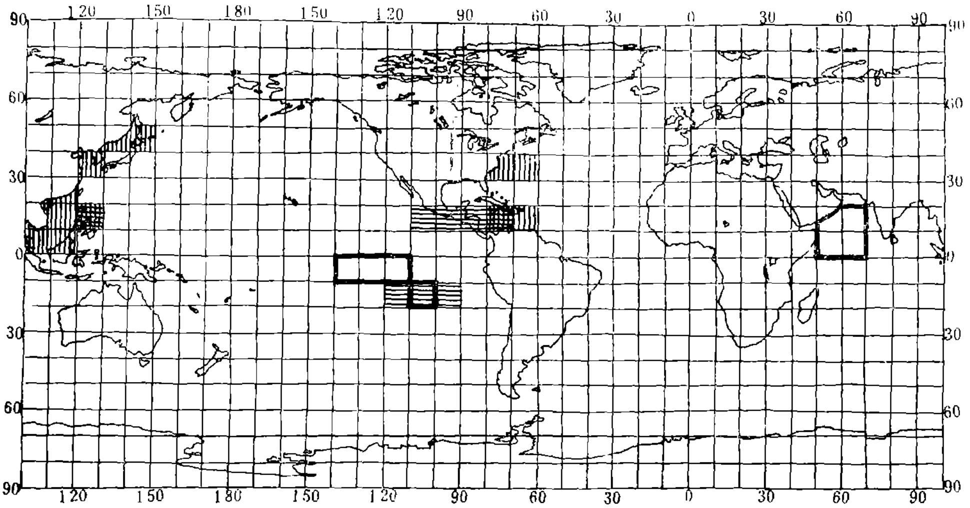


Fig. 2. Statistical significant regions at the confidence level of 5% of the correlations between June mean SST and the first three eigenvectort of the summer rainfall anomaly percentage anomalies.
concerned with the first eigenvector,
with the second eigenvector,
with the third eigenvector.

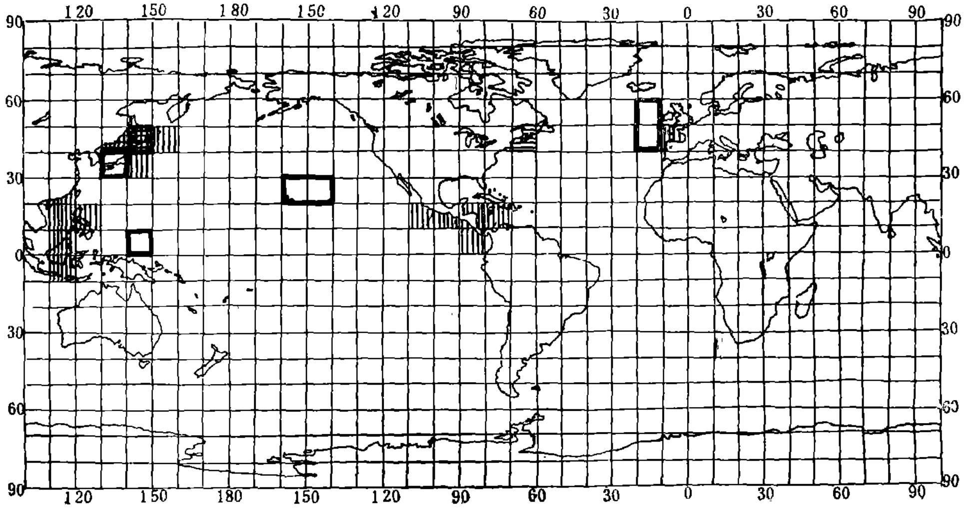


Fig. 3. As in Fig. 2, but for January.

Because of the strong persistence the distribution pattern of SST, once formed, will last for months. Hence SST can be used as one of the possible factors for long-range weather forecasting. In addition, the statistical significant regions at the confidence level of 5% of the correlation between the patterns of China's summer rainfall percentage anomalies represented by the eigenvectors and January mean SST are shown in Fig. 3. From the correlation map involving the first eigenvector it can be seen positive correlations in the South China Sea, to the east of the Sea of Japan, and on either side of Central America. The correlations involving the second eigenvector shows a positive correlation in the north of the Sea of Japan and a negative one close to the Bay of Newfoundland. The significant correlations involving the third eigenvector present a positive correlation near the Sea of Japan.

To sum up, the key regions having effect on China's summer rainfall include the South-China Sea, seas on both sides of Japan, ocean to the east of North America, sea in the vicinity of Central America and west of Peru.

IV. INFLUENCE OF SST OF THE SOUTH-CHINA SEA ON THE SUMMER MONSOON CIRCULATRON AND RAINFALL OVER CHINA

From the foregoing observational analyses it follows that a certain dependence exists on the SST of the summer precipitation over China. Shukla (1982) indicates that in spite of the important role of the intra-atmosphere dynamical processes in the variation of the general circulation, external forcing has profound effect on it and the change in SST is none other than one of the forcing factors of most importance.

In order to ascertain the influence of the SST of the South-China Sea upon the summer circulation and rainfall over China, the 90-day integration experiments are performed with the 11-layer circulation model provided by the U.K. Meteorological Office. The relevant details of the model are indicated by Saker (1975), Corby et al. (1977) and Gadd (1982), and the description of the convection scheme adopted in the model is shown by Lyne and Rowntree (1976). For our experimentation the 10 June 1979 data are used as initial because of the comparative completeness of the FGGE data base. Three experiments are conducted in which except for the different SST of the South-China Sea all the parameters are the same. The difference in the integration results can be, therefore, regarded as being caused by the difference in the SST.

Fig. 4 depicts the region of varying SST centred at 15° N, 120° E, with the central maximum departure of 1.5 K, declining linearly outward and the value equal to the climatological mean when reaching the curve. For the first (third) experiment the warm (cold) SST anomaly is used which consists of the summer mean SST and positive (negative) anomaly of the region in question; for the second (control run) only the summer mean SST is used. It should be pointed out that in our experimentation 1.5 K is taken as the maximum SST departure, which seems quite fit for the investigation and would be pertinent if the difference in the integration results of the warm and cold SST anomalies is used for analyses.

Since the SST anomalies are artificially placed into the experiments, a certain amount of unexpected perturbation will be aroused on account of the forced combination. Instead of using the method involving subjective effect on the treatment, the difference in the wind fields is used in the following obtained by subtracting the cold SST anomaly integration result from the warm, which can be assumed to be caused chiefly by the difference in the SST departures over the Sea.

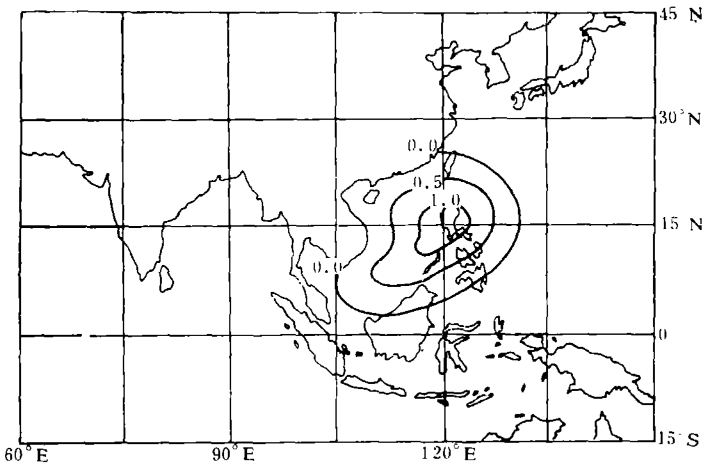


Fig. 4. The region of SST anomalies employed for the integration of the 11-layer model (units: K).

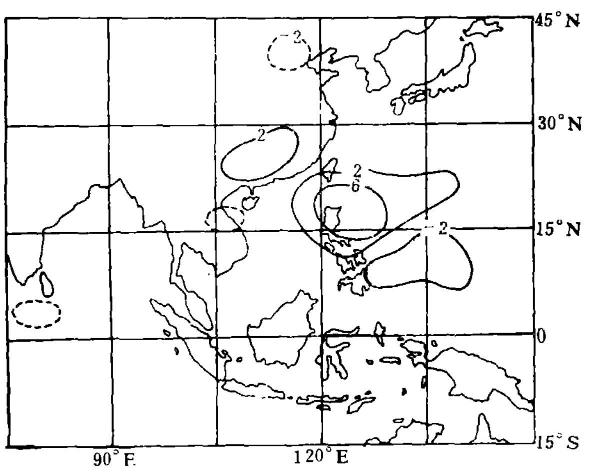


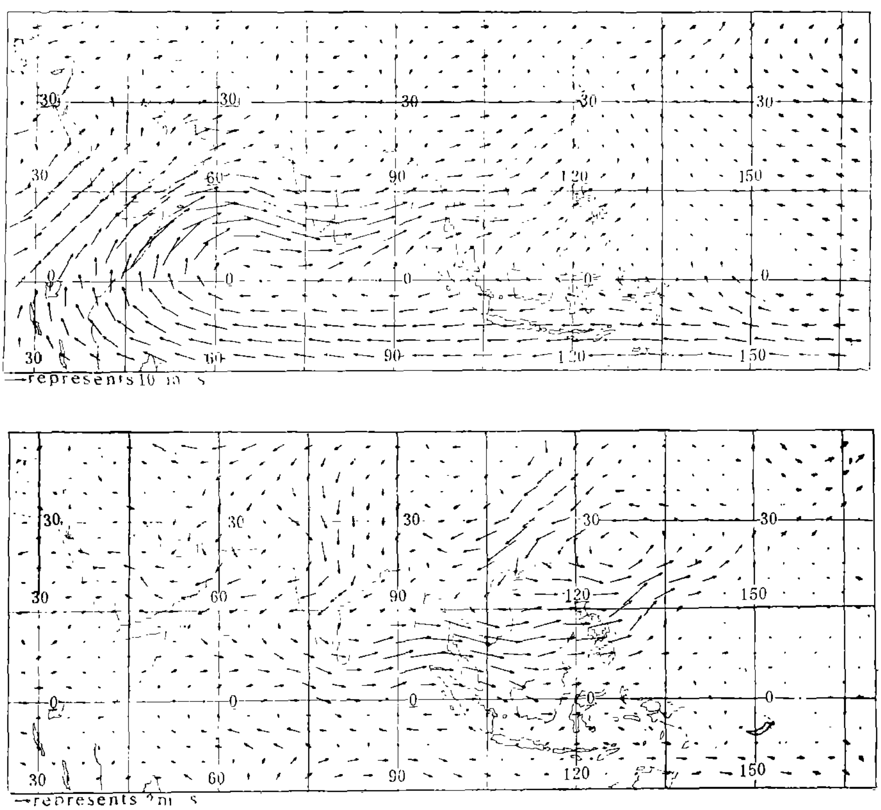
Fig. 5. Difference in rainfall due to the warm and cold SST anomalies (units: mm/d).

Fig. 5 shows the difference in the response of the model atmospheric precipitation to the cold/warm SST anomaly. It can be seen that there is great difference in rainfall in the northeastern part of the region with the anomaly imposed on, mainly at the sea, and that a 2 mm per day difference is observed in North and South China, respectively. implying that there will be a 180 mm difference in the total for the 90–day integration. This difference is about 60 mm per month. It is noted that such difference is brought about in the convective rainfall and little or no difference is found in large-scale precipitation.

The change in rainfall due to the SST anomaly is accomplished by altering water content in the air. The experimental results indicate that the SST anomaly of the South-China Sea exercises influence on the eastern rainfall by modifying the activity of summer monsoon.

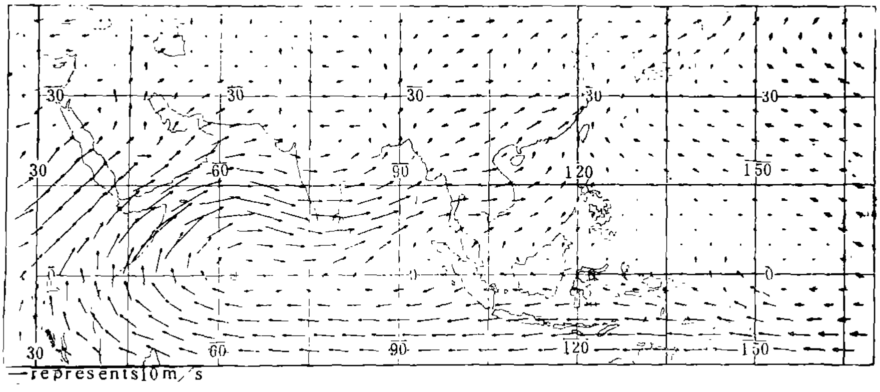
Fig. 6 delineates the response of the 850 hPa wind field (averaged over 90 days) to the positive/negative SST anomaly and the difference in these fields caused by the departure. It is apparent that when the SST is a warm (cold) anomaly, there occurs strong (weak) southwesterly monsoon in the Sea and weak (strong) with the position a little farther to the south (north) in the Mainland. If we view the Indian monsoon circulation as a whole, then we will see that with the warm SST anomaly of the Sea, the circulation is moved farther to the south, the monsoon is stronger in the Sea and the southwesterly weaker over the Mainland, with two strengthened cross-equatorial currents around 80—100 and 120—135° E affecting the South-China Sea, and that with the cold anomaly the Indian monsoon circulation is sharply marked by its passage through the Indo-China Peninsula over the Bay of Bengal to show effect on the greater part of China, resulting in the weaker monsoon in the Sea and cross-epuatorial current in comparison with the warm anomaly. It seems, therefore, that the warm (cold) anomaly of the Sea has 'attraction' ('repelling') for the Indian monsoon circulation. By referring to the difference between the wind fields due to the warm and that due to the cold SST anomaly (Fig. 6c) it can be seen that in the sea east of Taiwan there is a cyclonic circulation, quite close to the pattern indicated by Gill (1980). The difference between the wind fields shows that in the case of the warm SST anomaly the Indian monsoon is farther to the south, the wind being weaker over the Indian subcontinent, leading to more intense monsoon in the South-China Sea, stronger cross-equatorial current in the neighbourhood of Indonesia and the weaker southwesterly flow over the Mainland, and that the reversal is true for the cold anomaly.

Fig. 7 illustrates the difference of the 700 hPa wind field (similar to Fig. 6c) responding to both the anomalies, that is, with the warm SST anomaly, the Indian monsoon circulation is farther southward, giving rise to the intensified monsoon in the Sea and weakened southwesterly flow over the Mainland while the cold anomaly leads to the weaker monsoon of the Sea, stronger southwesterly flow over the Mainland and more intense monsoon in the



(a)

(b)



(c)

Fig. 6. The response of the 850 hPa wind field to the warm SST anomaly (a), cold (b), and the difference (c) in the wind fields (with the one caused by the warm minus the other by the cold SST anomaly).

Indian subcontinent. It follows that the functions of both the anomalies of the South-China Sea can be clearly reflected even in the 700 hPa wind field. The difference between the 700 hPa fields formed with the warm and cold SST anomalies has the same pattern as that at 850 hPa.

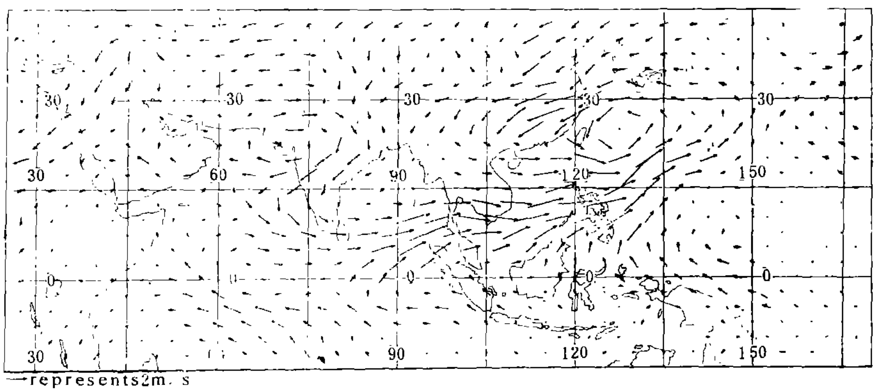


Fig. 7. The difference in the 700 hPa wind fields obtained by subtracting the cold SST anomaly from the warm.

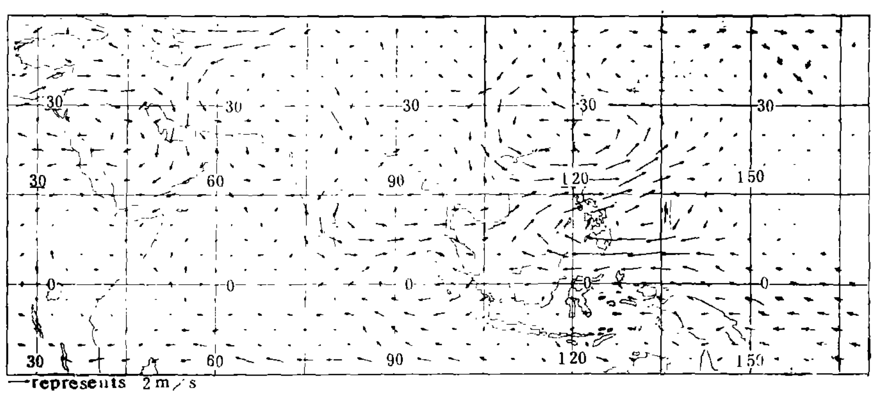


Fig. 8. The same as in Fig. 7, but for 500 hPa.

Fig. 8 indicates the difference of the 500 hPa wind field responding to the SST anomalies of the sea, with the result analogous to that of 700 and 850 hPa fields, and so only the difference in the 500 hPa wind fields is given. It is plain that a cyclonic circulation is formed northeast of Taiwan and the circulation in relation to the wind-field difference shows that when the SST is of warm (cold) anomaly, the southwest wind gets stronger (weaker) over the Sea, and the southwesterly flow weaker (stronger) in the Mainland.

The numerically experimental results discussed above indicate that the various SST of the Sea can give rise to the variation in position of the southwest monsoon over China and thus in the rainfall. It is clear that when the Sea has warm SST anomaly the southwest wind occurs farther southward, leading to higher rainfall in South China; with the cold, farther northward, in North China. Such a situation is created by the transport of warm and moist air by the monsoon, and hence the characteristic of the rainfall is tallied with the distribution over China (see Fig. 5).

Zhu and He (1985) indicates that the Indian monsoon is in anti-phase with the Sea monsoon on the 100 hPa cross-section, obtained based on the observations. And the results given in the present work show that with the warm (cold) SST anomaly of the Sea, the Indian monsoon is farther to the south (north), the subcontinental southwest monsoon weaker (stronger), the wind in the Sea stronger (weaker) and the southwesterly flow weaker (stronger) in the Mainland with the position moved farther southward (northward), which fully supports their statement. These results, therefore, suggest that the anomalies represent at least one of the reasons for the Indian monsoon in anti-phase with the Sea and phase with the southwest monsoon of the Mainland.

V. CONCLUSION

Using the empirical orthogonal function resolution method for the June—August rainfall data from 25 stations a study is made of the patterns of the eigenvectors of the summer rainfall precentage anomalies for 1950—1981 and the correlations are obtained between these patterns and the January and June global SST, respectively. The results show that between the percentage anomalies of the eastern summer precipitation, on one hand, and the South-China Sea, the seas on either side of Japan, east of North America, in the neighbourhood of Central America and west of Peru, on the other, there exist correlations which are statistically significant at the confidence level of 5%.

The results of the 11-layer model used for the experiments show that the warm SST anomaly of the South-China Sea has 'attraction' for the Indian monsoon, leading to its farther-southward position, strong monsoon occurring in the Sea (with intensified cross-equatorial flow west of 105°E and east of North Kalimantan), accompanied by the Indian and Mainland monsoons getting weaker and farther to the south, with the result of more rainfall (convective) in South and less (large-scale precipitation) in North China; and that, to the contrary, the cold anomaly has 'repelling' for the Indian monsoon, leading to its farther-northward position, strong monsoon happening in India, which turns northeastward from the Bay of Bengal to North China so that the South-China Sea monsoon gets weaker, with feeble cross-equatorial current, resulting in more rainfall (convective) in North and less in South China. Thence we can arrive at the conclusion that the SST anomaly of the South-China Sea is responsible, at least in part, for the anti-phase and in-phase of the Indian with the Sea and Mainland monsoon, respectively.

The large-scale sea-atmosphere interaction is of global nature and so it appears that more attention should be directed towards the effect of the western Pacific on the general circulation.

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