TELECONNECTION BETWEEN INDIAN MONSOON AND EAST ASIAN CIRCULATION*

DAI Xingang (戴新刚), *WANG Ping*(汪 萍), *WU Guoxiong*(吴国雄)

LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029

and *CHOU Jifan* (丑纪范)

China Meteorological Administration Training Center, Beijing 100081

Received June 1, 2004

ABSTRACT

Correlation analysis identified that Indian summer rainfall and East Asian 500 hPa geopotential height field are significantly correlated. A teleconnection pattern between Indian monsoon and East Asian summer circulation (IEA pattern) was proposed. We suggested that the Pacific-Japan teleconnection pattern (PJ pattern) primarily influences the meridional position of the northwestern Pacific subtropical high (NPSH) in summer, while IEA pattern partly affects its zonal stretch or the anomaly of geopotential height field over China mainland. The numerical experiments imply that the IEA pattern has important impact on East Asian circulation and it can be stimulated by the SST anomaly of the Indian Ocean. We summarized that there are two ways, a directive way and a selective way, by which ENSO exerts impacts on East Asian summer monsoon.

Key words: IEA (India-East Asia) pattern, ENSO, Asian monsoon, selective way

I. INTRODUCTION

The subtropical high over the northwestern Pacific plays a key role for East Asian summer monsoon. Generally, its anomalies lead to large-scale abnormal rainfall or drought in the East of China (Tao et al. 1962a, 1962b; Huang and Yu 1960). Every year, a crucial assignment for Chinese meteorologists is to predict the strength, the location, and the western edge of the northwestern Pacific subtropical high (NPSH), so as to forecast the approximate position of the major rainfall belt and its intensity thereafter. The physical mechanism for NPSH anomaly and its possible factors have been explored extensively (Dong and Chou 1988; Li and Chou 1998; Zhao and Chen 1995; Zhao 1999). For example, the NPSH is associated with SSTA (sea surface temperature anomaly) of the warm pool in western Pacific (Huang and Li 1988; Huang and Sun 1994), the snow cover of the Tibetan Plateau, the sea ice in high latitudes and so on. Some previous studies demonstrated that the pre-winter plateau snow cover has a notable correlation with rainfall over the Yangtze River Valley, because the snow cover changes the heating field, which affects the Tibetan high and NPSH as a result (Wei and Luo 1993; Chen and Song 2000).

* This study is jointly supported by the National Natural Science Foundation of China (No. 49875024) and LASG.

The sea ice in high latitudes can influence the mid-latitude circulation and rainfall over China in rainy season via Arctic Oscillation (Fang 1986). In El Nino years, the NPSH usually moves onto a position further south than its climate. A possible explanation is that, during El Nino years, the weak thermal convection in western Pacific near the Philippines changes the phase of PJ (Pacific-Japan teleconnection) pattern, and hence affects the NPSH. However, El Nino events may not only influence the western Pacific, but also the Indian Ocean through the Walker circulation, which results in a weak South Asian monsoon (Slingo and Annamalai 2000). Some papers showed an opposite trend of the Indian monsoon against Meiyu front in summer (Zhang 1998). This paper carried out data diagnosis and numerical modeling on the relationship between the Indian summer monsoon and the summer general circulation over China.

II. DATA

In this paper we have used NCAR/NCEP monthly reanalysis data sets, including 500 hPa geopotential height, monthly precipitation (Xie and Arkin 1996) with a resolution of $2.5°\times2.5°$, the precipitation rate at Gaussian grids in about $1.875°\times1.875°$, and global SST with a resolution of $2°\times2°$. The all-Indian rainfall for June throughout September was also employed. All these datasets are obtained from the Data Center of the Institute of Atmospheric Physics, Chinese Academy of Sciences.

III. EAST ASIAN 500 HPA HEIGHT AND MONSOON CONVECTION

The anomaly of heat sources in low latitudes often behaves as an unusual thermal convection in the atmosphere, and influences the mid- or high-latitude circulation via some dynamic processes (Huang and Li 1988; Huang and Sun 1994). Such effect can be, to some extent, detected by the correlation between the summer rainfall over a local area and the 500 hPa height. The spatial pattern in which thermal convention impacts height field can be regional or remote. We mainly concerned with the monsoon domain in this study, such as South Asia and Southeast Asia due to their tremendous latent heat released, which are possible heat sources for the East Asian circulation.

1. *Southeast Asian Monsoon*

We selected a box nearby the Philippines (5—15°N, 115—125°E) and calculated the correlation between the box summer precipitation and the height field. Figure 1a clearly shows the well-known PJ pattern.

The significant correlation center in the southern part of PJ pattern covers the Indo-China Peninsula. The area enclosed by isopleth -0.45 (0.05 confidence level) stretches from the Philippines to South China Sea, and throughout the northern Bay of Bengal. The northern part of the pattern concentrates on Japan around. The pattern approximately situates on the area where the NPSH lives. Hence, its anomaly can affect the NPSH directly. The intensity of thermal convection over the Philippines is usually under the control of the warm pool SSTA, in other words, the phase of the PJ pattern is fairly determined by the western Pacific SSTA. Therefore, meteorologists try to forecast the strength and position of the NPSH in the light of previous prediction for the western

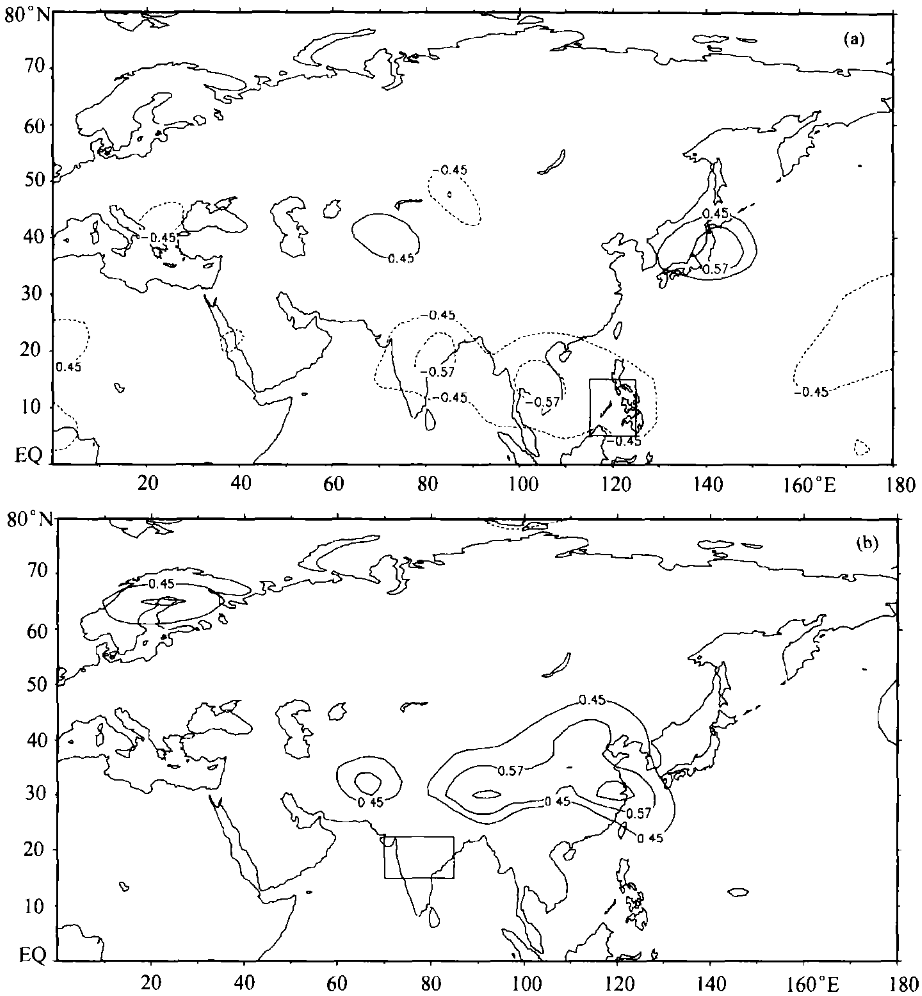

Fig. 1. Correlation fields between the box-mean rainfall (Xie and Arkin 1996) and summer 500 hPa geopotential height for 1980—1996, the contours with ±0.45, ±0.57 are corresponding to 0.05 and 0.01 confidence levels, respectively. (a) box in the Philippines, (b) box in India.

Pacific SSTA and then the phase of PJ pattern (Huang and Li 1988). However, a case study made by Nitta (1987; 1990) described some uncertainty of the relationship. It implies that some other important factors may exist for East Asian circulation, especially for the NPSH.

2. *South Asian Monsoon*

South Asia is the well-known monsoon region in the world. During summertime, there are strong convective activities on large-scale, and giant latent heat released by the monsoon. Their anomalies may have impact on the East Asian monsoon through some ways. The correlation between the summer 500 hPa height and the precipitation in a box over Indian subcontinent (15—22.5°N, 70—85°E) exhibits two significant correlation centers (Fig. 1b), one is in the mainland of China, the other, in northern Pacific. The former one paves on the most part of East China, in a confidence greater than 99%. This reveals that Indian summer monsoon has a close relationship with the East Asian circulation. When South Asian monsoon is robust with more rainfall in India, the 500 hPa height over eastern China is higher and NPSH stretches more westward than normal, which results in less rainfall in the valley of the Yangtze River and Huaihe River, and vice versa.

For further confirmation, we calculated the correlation pattern using NCAR/NCEP precipitation rate (Fig. 2a) as well as 1958—1997 all-Indian rainfall in its monsoon season (Fig. 2b). The spatial structures or patterns of the correlation are very similar to the one in Fig. 1b despite of tiny difference in the coverage of the patterns. There are also some other significant correlation centers in northern Pacific Ocean, North America and the Atlantic (Fig. 1b, Fig. 2a), which implies the remote connection among Indian monsoon and the general circulation of atmosphere over the above regions.

The Indian monsoon is linked with the summer circulation over East Asia by the correlation pattern. When the Indian summer monsoon is strong (weak), East Asian summer 500 hPa geopotential height is high (low), and the NPSH extends northward and westward (southward and eastward). We call the correlation structure the India-East Asian pattern (IEA). Since no significant correlation is just above the Indian subcontinent, the South Asian monsoon has little influence on the 500 hPa height field over India. The IEA pattern, different from the PJ pattern, which has a pair of positive and negative correlation centers, exhibits only one remote positive center far away from the forcing source in South Asia. Thus it is difficult to find the pattern if we only apply point-to-point correlation analysis on the height field. In this sense, the IEA pattern may be regarded as an implicit teleconnection pattern.

Another main convective center of South Asian monsoon is in the northern Bay of Bengal, we select a box (15—24°N, 85—97°E) and calculate the correlation between the summer rainfall in the box and 500 hPa height field (Fig. 3a). It shows that there is one significant positive center over the marginal sea to East China, which indicates that there is little influence on the NPSH when the convection is active. Therefore the convection just affects the rainfall over the sea adjacent to East China. Other significant centers are over northwestern China, North America, Atlantic Ocean, and Europe. These imply that South Asian monsoon is associated with the global atmospheric circulation.

The Tibetan Plateau is a huge heating source in mid-troposphere (Wu and Li 1997). It may exert a great influence on the East Asian circulation. The precipitation in the plateau might be used to measure the convection intensity. The correlation field between summer rainfall in the box (28—35°N, 85—90°E) on the eastern Plateau and 500 hPa height (Fig. 3b) shows a small significant correlation center close to the box and a big one along the eastern coast of China, which is related to location of the NPSH in summer. Therefore, the NPSH is situated more northward as a result of the strong convection above the plateau, and vice versa.

Anomalous winter snowfall on the plateau can effectively affect radiation properties in next spring and summer (Wu et al. 1995). The statistical analysis (Chen and Song 2000;

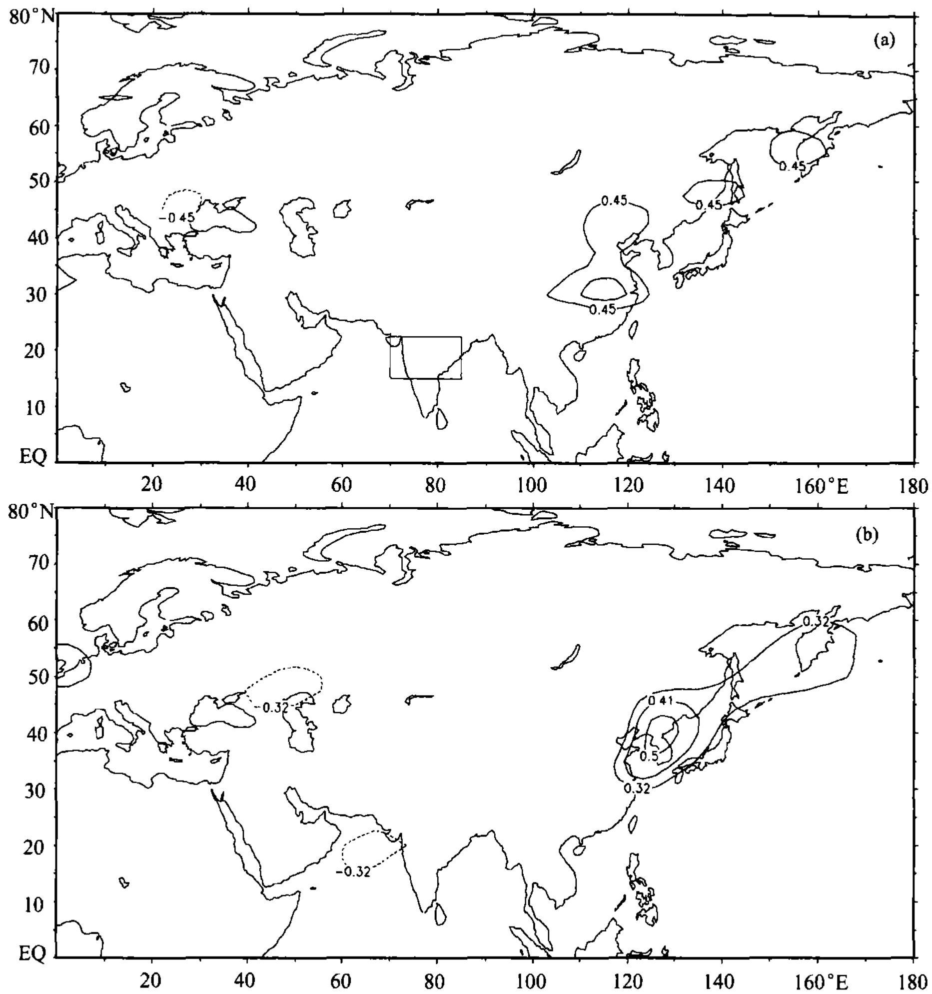

Fig. 2. Correlation fields between summer 500 hPa geopotential height and box-mean precipitation rate in India (a), and between the 500 hPa geopotential height and all-Indian rainfall during June throughout September (b), for 1980—1996, the contours with ± 0.45, ± 0.57 in (a) and ± 0.32, ± 0.42 in (b) correspond to 0.05 and 0.01 confidence levels, respectively.

Chen and Wu 1998) pointed out that a great deal of snow cover on the plateau can postpone the season transition in the following year, and lead to a heavy rainfall spreading onto the Valley of the Yangtze River as the rain belt locates more southward than its climate position. It is easy to turn out the following conceptual mode:

More pre-winter snow cover on the plateau → weak plateau convection in coming spring and summer → NPSH located more southward

The correlation analysis shows that the thermal convection of the Tibetan Plateau, the PJ pattern and IEA pattern can all affect the geopotential height over East Asia in summer, significantly. According to the patterns, the plateau convection and the PJ pattern chiefly make effects on the meridional location of the NPSH, while the IEA pattern exerts effects on the zonal position of its western edge in the mainland of China.

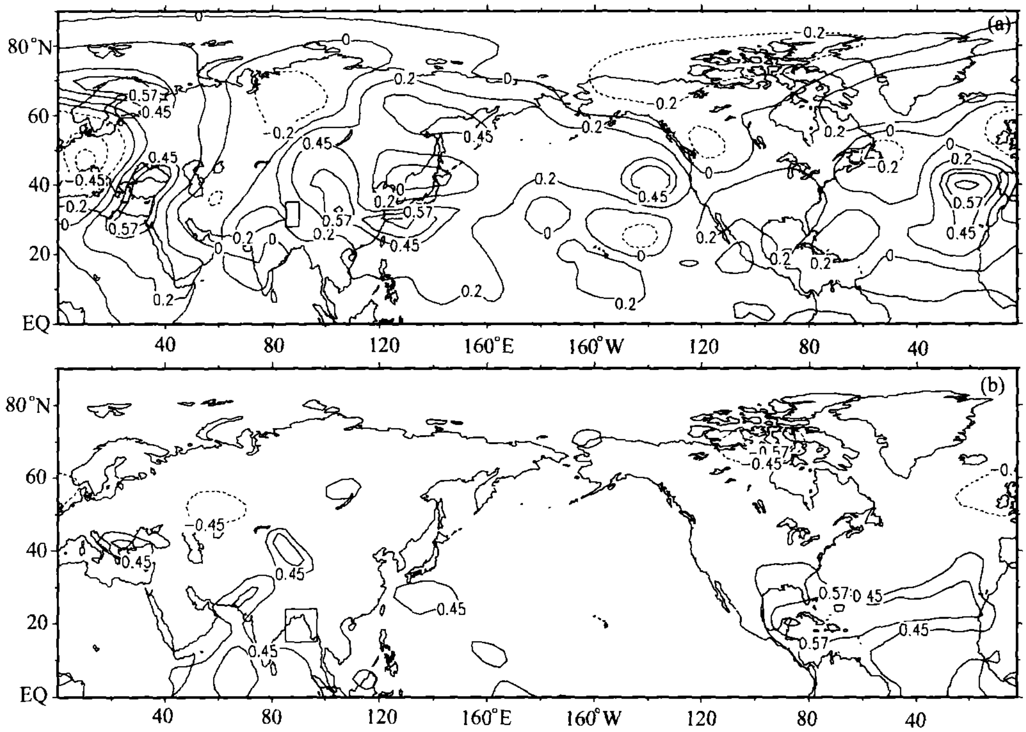

Fig. 3. Correlation fields between the box-mean rainfall (Xie and Arkin 1996) and summer 500 hPa geopotential height for 1980—1996, the contours with ±0. 45, ±0. 57 are corresponding to 0. 05 and 0. 01 confidence levels, respectively. (a) box in the northern Bay of Bengal; (b) box in the eastern Tibetan Plateau.

The different allocations of the three patterns would cause various and sophisticated distributions of the major rainfall belt in China during summertime.

IV. THERMAL CONVECTION SOURCES

It is more objective to find the dominant sources of the thermal convection by calculating the correlation between a grid or regional height and the global precipitation field. The correlation between 500 hPa height averaged over the box (26—33°N, 110—122°E) in the Valley of Yangtze River and summer rainfall field reveals that the most significant center of low latitude is on the India subcontinent (Fig. 4a). The second one situates in the Indo-China Peninsula, which confirms that Indian summer monsoon is the most important heat source for the height anomaly over the Valley of Yangtze River. Moreover, the analysis also confirms the existence of the IEA pattern and its linkage with the circulation over East Asia. The IEA pattern implies the robust Indian summer monsoon, with an NPSH extending more westward, is often related with deficient rainfall over the Valley of the Yangtze River.

Figure 4a shows that there are two other significant correlation centers, which though not very big, are over the south or southwest to the selected box in the Valley of Yangtze River. They may be associated with the feedback of thermal adjustment, such as latent heat released by precipitation and NPSH extending westward (Liu et al. 1999; Wu et al.

1998).

Note that there is no significant correlation center over the equatorial Pacific in Fig. 4a. However, a large positive correlation center will come forth over the equatorial mid-eastern Pacific if the box is placed on the South China coastal area (20—25°N, 110—120°E), as shown in Fig. 4b. This indicates that the large-scale SST anomaly of the equatorial Pacific can influence the height anomaly in South China.

In the light of the IEA pattern mentioned above we find that, whether the Valley of

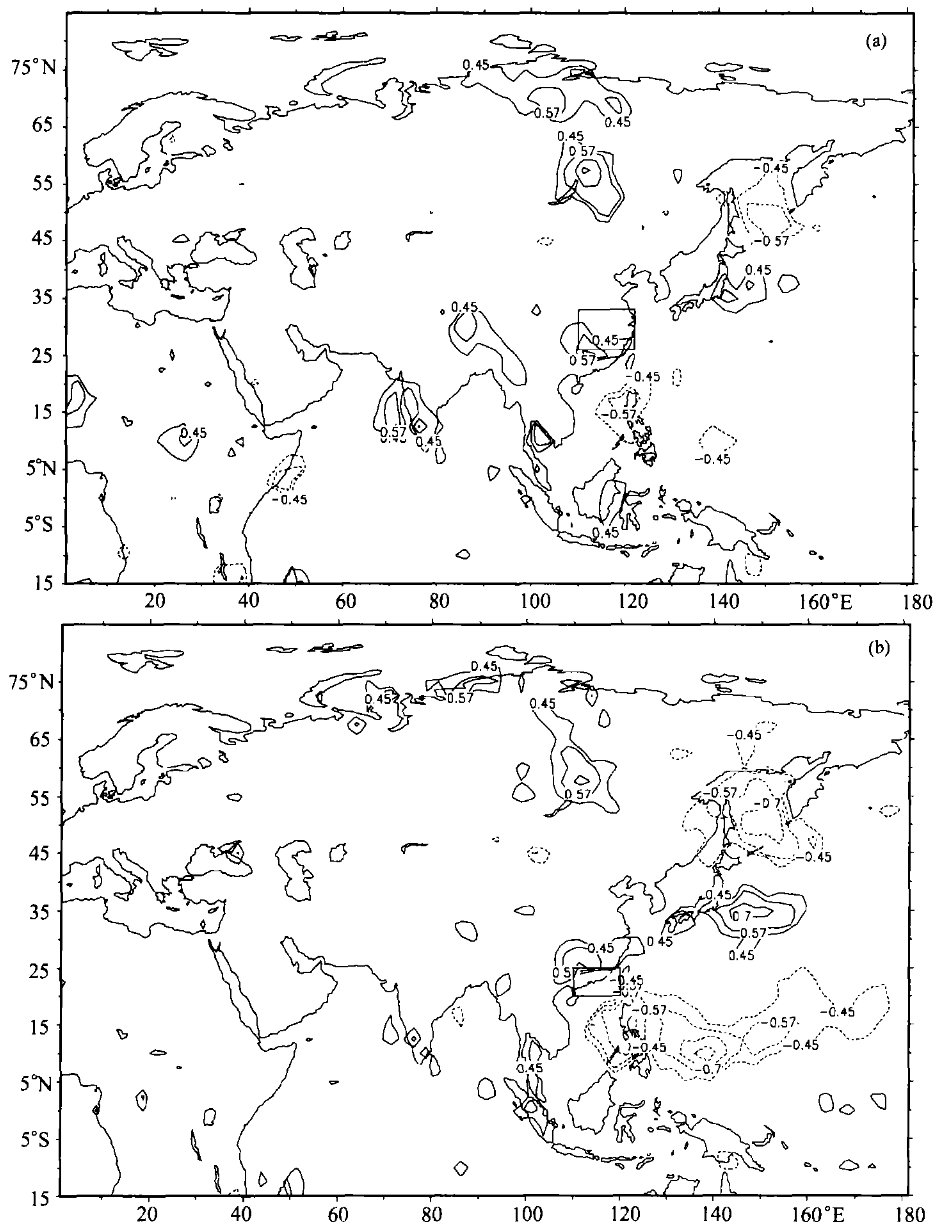

Fig. 4. Correlation between a box-mean summer 500 hPa height and summer rainfall field, (a) box over the Valley of Yangtze River; (b) box in the coastal area of South China.

the Yangtze River is under the control of NPSH in summertime, to some extent, depends on Indian monsoon and plateau convection. Actually, the Indian monsoon and the Southeast Asian monsoon belong to different monsoon systems, and their variations are different sometimes. In consequence, Wang and Fan (1998) suggested two monsoon indices defined for South Asian monsoon and Southeast Asian monsoon, respectively, in stead of Webster-Yang Asian monsoon index (Webster and Yang 1992). The southeast Asian monsoon is mainly affected by ENSO cycle, whereas the South Asian monsoon includes more frequency components, such as the quasi-biennial oscillation (Meehl 1994; 1997), interdecadal changes, ENSO signal, and so on. Thus, the IEA pattern and PJ pattern hold different characteristic frequencies that therefore make complicated impacts on East Asian monsoon.

V. NUMERICAL EXPERIMENT

1. *Motivation*

Interannual variability of SST in the equatorial Pacific is dominated by ENSO cycle, which is, to a great extent, correlated with the anomaly of Southeast Asian monsoon. But more factors can make impacts on SST in Indian Ocean, such as quasi-biennial oscillation, interdecadal changes and so on. The Morlet wavelet analysis of summer mean SST in northern Indian Ocean shows that the relative importance of ENSO cycle decreases with latitude, whereas the importance of the interdecadal changes increases (Torrence and Webter 1998). If we calculate the correlation between all-Indian rainfall (June — September) and global SST field, the significant correlated region is still in the equatorial mid-eastern Pacific rather than in Indian Ocean. The similar result can be reached if we use 500 hPa height averaged in the Valley of the Yangtze River and SST to calculate their correlation. Usually, the SST in the equatorial mid-eastern Pacific will increase several degrees as El Nino develops, but in Indian Ocean, SST often varies no more than one degree, though its distribution changes distinctly. Observations (Slingo and Annamalai 2000) show that in 1982, 1987, and 1997 when El Nino occurred, a little change took place in Indian Ocean SST, and in the meantime South Asian monsoon and Southeast Asian monsoon became weakened, apart from that the Indian monsoon rainfall in 1997 was kept in its normal state due to some intra-seasonal disturbances. We conjuncture that during El Nino year, South Asian monsoon rainfall may be associated with the distribution of the Indian Ocean SSTA. Therefore we design a sensitive numerical experiment, taking 1982 El Nino event as an example, to explore the possible influence of Indian Ocean SST on NPSH.

2. *Model and Experiment*

The IAP/LASG GOALS we used is a global sea-land-atmosphere coupled spectral model with a horizontal resolution of $7.5° \times 4.5°$ for latitude and longitude respectively, and nine layers in vertical direction (Wu and Zhang 1997). The model is only forced by the monthly SST in our numerical integration. We designed two experiments. For the first, noted as E-1, the model running is under monthly SST of 1982 and then we use the atmospheric output of the model to calculate summer 500 hPa height and rainfall field. For the second, noted as E-2, the forcing is almost the same as E-1, except that monthly SST averaged over 1979—1988, which is regarded as a climate SST approximately, replaces the SST of the Indian Ocean. The comparison of the two experiments may tell the effect of the Indian Ocean SST variation on the South and East Asian monsoon in the El Nino year.

3. *Results*

The difference of summer rainfall between E-1 and E-2 reveals the sensitivity of the Asian monsoon rainfall to Indian Ocean SST variation in 1982. As the Indian Ocean SST changed, the large-scale rainfall zone in South Asia shifted eastward and became weak (Fig. 5). The most significant region of the rainfall reduction is in Indo-China Peninsula; the next is in Indian subcontinent. Moreover, a big difference appears at the central and western part of equatorial Pacific. A little increase of rainfall is along the southeast coastal area of China. Therefore, the SST variations coupled with the El Nino developing in the eastern equatorial Pacific would make a significant variation in the South and Southeast Asian rainfall in summer, which then alter the IEA pattern and PJ pattern as a result.

We subtract the summer 500 hPa height of E-2 from that of E-1, to explore the impact of Indian Ocean SSTA on East Asian height field, and obtain the difference field (Fig. 6a). It shows that a wave train extends from South China Sea to Bering Strait and then turns to North America along the coast of North Pacific, where a −30 gpm center is at the Yellow Sea. This illustrates that the Indian Ocean SST variations in 1982 could force the NPSH into a further south position. The existence of the wave train indicates that the Indian Ocean SSTA cannot only influence the East Asian circulation, but also the North American circulation. Consequently the effect of the Indian Ocean SST variations on South Asian monsoon and East Asian height should not be ignored.

The height field at 500 hPa level might be identified as a barotropic model for geopotential height in mid- and high-latitudes, for there is a quasi-geostrophic flow there.

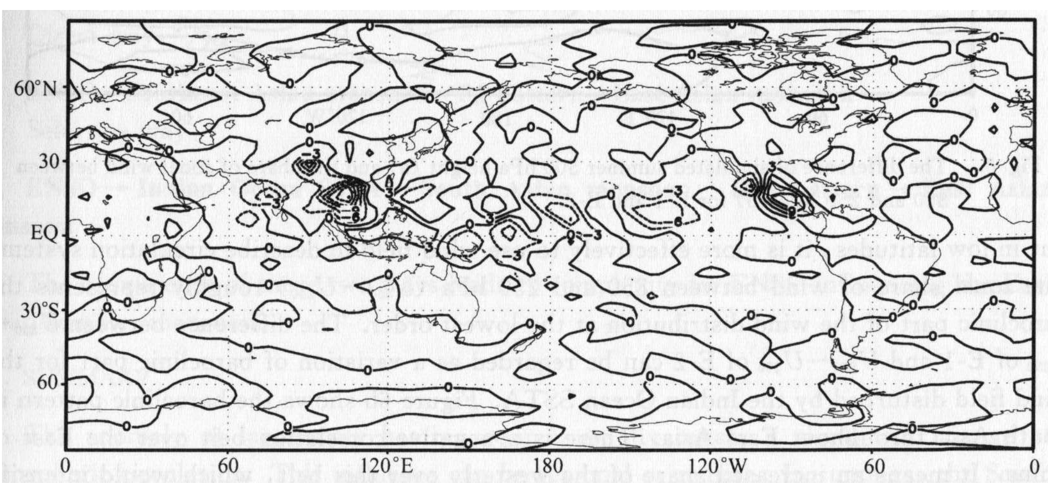

Fig. 5. The difference of simulated summer rainfall (mm) E-1 and E-2.

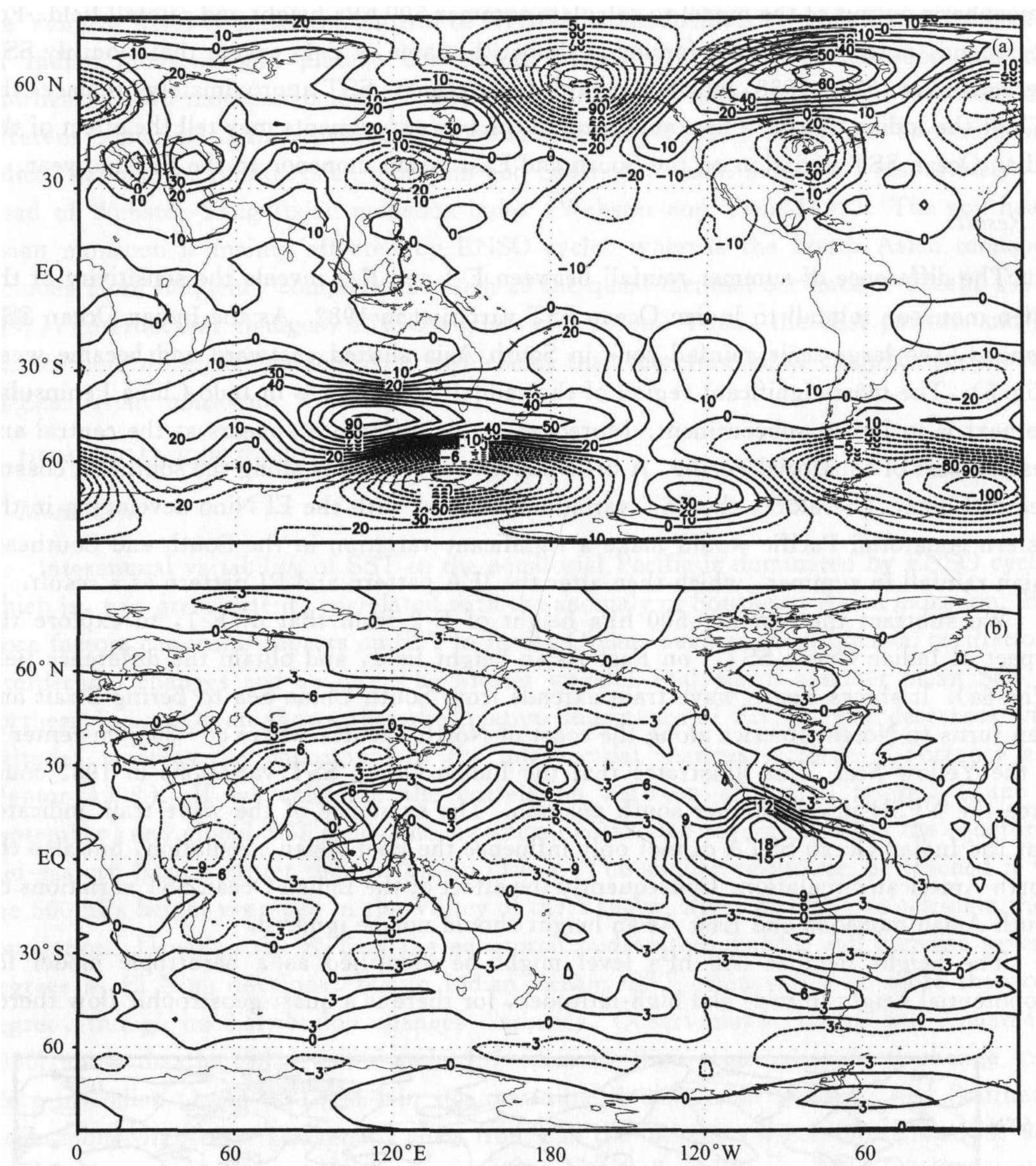

Fig. 6. The difference of simulated summer 500 hPa height (a) and the share of zonal wind between 850 and 250 hPa (b) for E-1 and E-2.

But in low latitudes, it is more effectively to use wind field to describe circulation system. The zonal share of wind between 850 and 250 hPa ($U_{850}-U_{250}$) roughly represents the baroclinic part of the wind distribution at the lowest order. The difference between $U_{850}-U_{250}$ of E-1 and $U_{850}-U_{250}$ of E-2 can be regarded as a variation of baroclinic part for the wind field disturbed by the Indian Ocean SSTA. Figure 6b shows the baroclinic pattern in South Asia throughout East Asia. There is a negative correlation belt over the East of China. It means an increased share of the westerly over this belt, which would intensify the Meiyu front along the Yangtze River. There is a pair of zonal dipoles along equatorial Indian Ocean throughout the Pacific. Its maximum (18 m/s) appears at eastern equatorial

Pacific, in agreement with the biggest rainfall difference nearby the Central America.

In terms of physical mechanism, tiny variations of SST in Indian Ocean during El Nino years seemingly cannot stimulate the remarkable change of sensible heating, since the sensible heat flux over the sea is much less than that over the land according to NCAR/NCEP reanalysis data. However, the numerical experiment shows that the distribution of South Asian summer rainfall and the zonal share of wind as well as height field are all very sensitive to the tiny variation of SST in Indian Ocean (Fig. 5). Because summer height field is significantly correlated with the Indian monsoon rainfall instead of with the Indian Ocean SST, we suggested that SST and its distribution variation, firstly, lead to changes of the South Asian monsoon convection, whose released heat then results in changes of the IEA pattern and the wind shear, and finally causes anomalies of the whole East Asian height field and wind field.

VI. DIRECT AND SELECTIVE WAYS

The interaction between ENSO and the Asian monsoon, especially the East Asian monsoon, is one of the most important problems, because it is linked with the rainy season prediction for China in every spring. In El Nino years, the NPSH usually moves more southward, whereas in La Nina years, more northward than its climate. One explanation is due to the shift eastward of the convections over the western Pacific warm pool to middle Pacific and the phase change of the PJ pattern in El Nino years. Meanwhile the Indian Ocean SST also varies a little, correspondingly. The case study points out that the effect of a tiny change in the Indian Ocean SST would be multiplied by the convection of the Indian monsoon, which then influences the East Asian monsoon by the IEA pattern. The interaction between ENSO and the South Asian monsoon can be regarded as selective interaction and has its uncertainty, for there are a great number of factors that have influence on the South Asian monsoon (Webster and Yang 1992). Therefore we conclude two ways in which the ENSO impacts East Asian monsoon. They are conceptually expressed as follows.

Direct way:

ENSO→Southeast Asian monsoon→PJ pattern→East Asian monsoon

Selective way:

ENSO → Indian Ocean SSTA → South Asian monsoon → IEA pattern → East Asian monsoon

The coexistence of these two ways leads to complexity for ENSO influencing the East Asian summer monsoon.

VII. SUMMARY

The anomaly of large-scale heating source usually causes a significant change of atmospheric circulation. This influence can be regional or remote. In summer, the South Asian monsoon region is a huge latent source, and can affect the circulation either nearby or faraway. Our study in this paper shows that the large amount of latent heat released by the monsoon rainfall can stimulate a regional teleconnection pattern, namely the IEA pattern, over South and East Asia. The IEA pattern may disturb the circulation over East China and even the whole East Asian summer monsoon. When summer Indian monsoon is strong, the height field over East Asia is usually higher than its normal, and the NPSH situates further north and further west. Therefore the positive departure of height over China mainland is dominant, which leads to more droughts in the Valley of Yangtze River, whereas when Indian monsoon is weak, the region often experiences more floods. There is no doubt that the PJ teleconnection pattern, which is associated with thermal convection anomaly of Southeast Asian monsoon, also plays an important role in summer rainfall over East Asia. In some years, the variations of South Asian monsoon and Southeast Asian monsoon are coherent, but in some other years they are not. Thus there can be very complicated collocations between the PJ and IEA patterns, in addition to the influence of thermal convection over the Tibetan Plateau. This is partly why the prediction of the East Asian monsoon is very difficult.

The spatial structures of the correlations imply that the IEA pattern can influence the zonal position of NPSH whereas the PJ pattern affects its meridional position. Since no significant correlation is over India we may call the IEA an implicit teleconnection pattern.

The numerical experiment shows that the anomalies of Indian SST or South Asian monsoon rainfall can not only influence the 500 hPa height over East Asia but also stimulate a wave-train propagating along the coast of North Pacific to North America. In addition, the baroclinic pattern produced by the Indian Ocean SSTA can exerts effects on the Walker circulation over the equator. These results all show the importance of the Indian Ocean SSTA for global circulation of atmosphere.

We also focus on the ways through which the ENSO impacts the East Asian monsoon. The correlation between summer SST averaged over Nino3 region and 500 hPa height field shows that there is a significant correlated area covered from Japan to the Valley of Yangtze River of China. We proposed there are two ways in which ENSO influences the East Asian monsoon, one is a direct way, and the other is a selective way. These results may provide a new forecasting method for rainy season rainfall in China.

The mechanism of the IEA pattern needs to be studied. The impact of intra-seasonal variations of the South Asian and Southeast Asian monsoon on the Asian summer monsoon also should not be ignored. These questions will be discussed in the future.

REFERENCES

Chen Lieting and Wu Renguang (1998), Interannual and interdecadal variations of snow cover over the Tibetan Plateau and their relationships to summer monsoon rainfall in China, in *East Asian Monsoon and Torrential Rainfall in China*, edited by the Institute of Atmospheric Physics. Beijing, China Meteorological Press, pp. 230—239 (in Chinese).

Chen Xingfang and Song Wenling (2000), Circulation analysis associated with different impacts of snow cover over the Tibetan Plateau and Eurasia in winter on summertime droughts and floods of China, *Chinese Journal of Atmospheric Sciences*, **24**(5): 585—592 (in Chinese).

Dong Buwen and Chou Jifan (1988), Observation study and numerical modeling on seasonal variations of subtropical high ridge, *Acta Meterologica Sinica*, **46**(3): 361—363 (in Chinese).

Fang Zhifang (1986), Interaction between Northern Hemisphere subtropical high and polar sea ice, *Chinese Science Bulletin*, **4**: 286—289(in Chinese).

Huang Shisong and Yu Zhihao (1960), A study on structure of subtropical high and its relative circulation, *Acta Meteorologica Sinica*, **31**(4): 339—359 (in Chinese).

Huang Ronghui and Li Weijing (1988), Impacts of thermal source anomaly over tropical western Pacific warm pool on East Asian subtropical high during summertime and its mechanism, *Chinese Journal of Atmospheric Sciences* (special issue), 107—116 (in Chinese).

Huang Ronghui and Sun Fengying (1994), Impacts of the thermal state and the convection activities in the tropical western Pacific warm pool on the summer climate anomalies in East Asia, *Chinese Journal of Atmospheric Sciences*, **18**(2): 141—151 (in Chinese).

Li Jianping and Chou Jifan (1998), Dynamical analysis on the broken of subtropical high-geostrophic action, *Chinese Science Bulletin*, **43**: 434—437 (in Chinese).

Liu Yiming et al. (1999), The effect of specially non-uniform heating on the formation and variation of subtropical high, Part I: Latent heating in connection with South Asian high and western Pacific subtropical high, *Acta Meteorologica Sinica*, **57**(5): 525—538 (in Chinese).

Meehl, G. A. (1994), Coupled land-ocean-atmosphere processes and South Asian monsoon variability. *Science*, **265**: 263—267.

Meehl, G. A. (1997), The South Asian monsoon and the tropospheric biennial oscillation, *J. Climate*, **10**: 1921—1943.

Nitta, T. (1987), Convective activities in the tropic western Pacific region, *J. Meteor. Soc. Japan*, **65**: 373—390.

Nitta, T. (1990), Unusual summer weather over Japan in 1988 and its relationship to the tropics, *J. Meteor. Soc. Japan*, **68**: 575—587.

Slingo, J. M. and Annamalai H. (2000), The El Nino of the century and the response of the Indian summer monsoon, *Mon. Wea. Rev.*, **128**: 1778—1797.

Tao Siyang and Xu Shuying (1962a), Circulation Characteristics of persistent summer droughts and floods over the valley of Yangtze and Huaihe River, *Acta Meteorologica Sinica*, **32**(1): 1—10 (in Chinese).

Tao Siyan, Xu Shuying and Guo Qiyun (1962b), Meridional and zonal circulation over East Asian tropical and subtropical regions, *Acta Meteorologica Sinica*, **32**(1): 91—102 (in Chinese).

Torrence, C. and Webster, P. J. (1998), The annual cycle of persistence in the El Nino-Southern Oscillation, *Quart. J. Roy. Meteor. Soc.*, **124**:1985—2004.

Wang Bin and Fan Zhen (1998), On choice of dynamically coherent South Asian summer monsoon indices, in *East Asian Monsoon and Torrential Rainfall in China*, edited by the Institute of Atmospheric Physics. Beijing, China Meteorological Press, pp. 170—183(in Chinese).

Webster, P. J. and Yang Song (1992), Monsoon and ENSO: Selectively interactive systems, *Quart. J. Roy. Soc.*, **118**: 877—926.

Wei Zhigang and Luo Siwei (1993), Impact of snow cover in West China on rainy season rainfall of China, *Plateau Meteorology*, **12**(4): 247—253 (in Chinese).

Wu Guoxiong and Zhang Xuehong (1997), LASG global ocean-atmosphere-land model (GOALS/LASG) and simulations, *Applied Meteorology*, **8**: 15—28(in Chinese).

Wu Guoxiong and Li Weiping (1997), *Thermal Pumping over Tibetan Plateau and Asian Monsoon, in Festschrift of Zhao Jiuzhang*, edited by Ye Duzheng, Beijing, Science Press, pp. 116—126 (in Chinese).

Wu Guoxiong et al. (1995), The modification of radiation effect of snowmelt sooner or later on the seasonal variation in the Tibetan Plateau, *Gansu Meteorology*, **65**: 373—390 (in Chinese).

Wu Guoxiong et al. (1998), The effect of special non-uniform heating on the formation and variation of subtropical high, Part I: scale analysis, *Acta Meteorologica Sinica*, **57**(3): 257—263 (in Chinese).

Xie, P. P. and Arkin, P. A. (1996), Analysis of global monthly precipitation using gauge observations, satellite estimate, and numerical model predictions, *J. Climate*, **9**: 840—858.

Zhang Qinyun (1998), Relationships between the East Asian monsoon and Indian monsoon in summer, *East Asian Monsoon and Torrential Rainfall in China*, edited by the Institute of Atmospheric Physics. Beijing, China Meteorological Press, pp. 266—273 (in Chinese).

Zhao Zhenguo and Chen Guozhen (1995), The cause and forecast of long term change of the longitudinal position of western Pacific subtropical high in early summer, *Journal of Tropical Meteorology*, **11** (2): 223—229(in Chinese).

Zhao Zhenguo (1999), *Summer Drought and Flood in China and Ambient Field*, Beijing, China Meteorological Press, pp. 44—50 (in Chinese).