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NUMERICAL SIMULATION OF INFLUENCE OF INDIAN OCEAN SSTA ON WEATHER AND CLIMATE IN ASIAN MONSOON REGION

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ABSTRACT: Sea surface temperature anomaly (SSTA) exerts great influence on the generation of global weather and climate. Much progress has been made with respect to SSTA in the Pacific Ocean region in contrast to the Indian Ocean. The IAP9L model, which is developed at the Institute of Atmospheric Physics of the Chinese Academy of Science, is used to simulate the influence of the Indian Ocean SSTA on the general circulation and weather/climate anomalies in the monsoon region of Asia. It is found that the warm (cool) SSTA in the equatorial low latitudes of the Indian Ocean triggers winter (summer) teleconnection patterns in middle and higher latitudes of the Northern Hemisphere that are similar to PNA or EAP. They play a very important role in the anomaly of circulation or weather and climate in the middle and lower latitudes of the Asian summer monsoon region. With the warm (cool) SSTA forcing in the Indian Ocean, the Asian summer monsoon sets up at a late (early) date and withdraws at a early (late) date, lasting for a short (long) duration at a weak (strong) intensity. The Indian Ocean SSTA is shown to be an indicator for precipitation variation in China.

Key words: Asian summer monsoon; Indian Ocean SSTA ; numerical simulation

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1 INTRODUCTION

SSTA has been the focus of atmospheric science study concerning the generation of global weather and climate. As shown in many of the observational facts and numerical experiments, atmospheric dynamic processes realized through external forcing account for most of the climatic anomalies. The effect of forcing by tropical SSTA is especially significant for climatic anomalies (Wallace and Blackmon, 1983; Xiao and Li, 1992; Keshavamurty, 1982). Much progress has been made in the past few years in the field of SSTA in the warm pools of equatorial east Pacific and west Pacific as it affects the general circulation or climatic anomalies. For instance, the SSTA in the equatorial eastern Pacific is found to be closely related with cold temperature in Northeast China, precipitation in the middle and lower reaches of the Changjiang River (Yantze), and variation in the subtropical high (Fu and Teng, 1988). When the SSTA is higher in the equatorial eastern Pacific, there is less rain in southwest China and more rain in northeast China (Chen, Zhu and Luo et al., 1991). When the warm pool gets warmer in the tropical western Pacific, the subtropical high of the west Pacific will stay more northward to cause less rain over the Changjiang-Huaihe River Basin in summer. The rainfall will increase otherwise. (Huang and Sun, 1994).

It is a well-known fact that Asia is the largest monsoon region in the world and the Asian monsoon is an important feature of the general circulation in the region, which not only contributes

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as one of the essential governing forces to the variation of weather and climate in Asia, but interacts closely with the global circulation. Being the birthplace and passage for the Indian summer monsoon, which is a primary member of the Asian summer monsoon, the Indian Ocean can be, through different distribution of SST, responsible for anomalous changes in weather and climate in China by affecting the interactions between high and low latitudes of the planetary-scale Asian summer monsoon systems. In their study of numerical modeling, Yang, Xie and Huang (1996) find that the anomalous variation of the monsoon systems are closely related with tropical SSTA — a warming ENSO episode is accompanied by weaker Indian summer monsoon and stronger East Asia summer monsoon. It was pointed out in 1990 that for the equatorial westerly zone in summer, the atmospheric trajectory is traced back from the Somali low-level jet stream all the way to the South China Sea and affects the precipitation in the middle and lower reaches of the Changjiang River given some right pattern of weather. It is seen that the anomalous SST variation in the Indian Ocean is also an important factor in contributing to the general circulation and climatic anomalies. In spite of it, the study on SSTA, for social or economic reasons, has long been concerning the Pacific Ocean primarily, making the Indian Ocean a less-addressed topic.

It is the attempt of this work to study numerically the influence of the SSTA forcing in the Indian Ocean on the general circulation and weather/climate.

2 NUMERICAL SIMULATION AND DATA TREATMENT

The numerical experiment conducted here is the 9-layer IAP-GCM model developed at the Institute of Atmospheric Physics, Chinese Academy of Sciences. It is a primitive equations model that includes a complete set of physical processes, details of which refer to relevant reference. The anomalous variation is generally ±0 ~ 2°C, as the SST variation near the equatorial Indian Ocean is significantly correlated with that in the strong signal zone of eastern equatorial Pacific (You and Qian, 1997) and the anomalous variation of annually mean SST is consistent over the entire region (Yan, Xiao and Xie, 2000). Therefore, the domain of SSTA for the Indian Ocean covers 10°S ~ 14°N, 45°E ~ 100°E. For the control test, the conducting year is set some years after the model integration and the SST is the climatological mean averaged over years (denoted as Field A). In the warm SSTA experiment for the Indian Ocean, the SST is 2°C higher than multi-year mean, i.e. SSTA=SST+2, and integrates for a year (denoted as Field B). In the cool SSTA experiment for the Indian Ocean, the sea temperature in the SSTA forcing area is 2°C lower than the mean and integrates for a year (denoted as Field C). Two of the response fields of disturbance are B-A and C-A for warm and cool SSTA respectively. Through the two disturbance fields, effects of the Indian Ocean SSTA on the weather and climate in the Asian monsoon region are studied.

3 ANOMALIES OF ATMOSPHERIC CIRCULATION INDUCED BY INDIAN OCEAN SSTA

As early as in early 1980's, Wallace and Shukla (1983) and Wallace and Horel (1981) point out that by means of 2-dimensional Rossby wavetrain the tropical SSTA is transporting disturbance energy to extratropical areas and results in significant response on the part of the general circulation. Studying the response field of SSTA forcing which is numerically simulated for the Indian Ocean, we find that the general circulation exerts strong response to the SSTA in the ocean, which is accompanied by obvious wavetrains. It is understood from the month-to-month response fields that due to the response of the general circulation to the SSTA forcing of the Indian Ocean in the middle and higher latitudes of the Northern Hemisphere in winter, there appear teleconnection wavetrains similar to PNA and EAP patterns. Fig.1a gives the response fields of geopotential anomalies at 500 hPa in January with warm SSTA in the ocean. The fields are similar to the teleconnection-pattern wavetrains appearing with warm SSTA forcing over the equatorial eastern Pacific. Positive response areas dominate East Asia and North America while negative response areas are mainly distributed over Siberia, central North Pacific and eastern North America. To verify the authenticity of the numerical simulation, the year 1997 (the period when there was significant warming in the SST of the ocean) is selected for examination of the distribution of geopotential anomalous fields in January (Fig.1b). It is shown in relevant comparisons that except for more eastward and stronger troughs and ridges than simulated fields, the wavetrains are similar; the region of East Asia is controlled by positive geopotential anomaly and Siberia and north Pacific by negative one. In summer, the wavelength of the wavetrains decreases while waving increases. Fig.2a gives the response fields of 500-hPa geopotential anomalies in July when there is warm SST forcing in the Indian Ocean. In Fig.2a, the 500 hPa response field for the Eurasian continent in July is of 2-ridge versus 1-trough pattern, in which the ridge regions are located across 50°E ~ 70°E and 120°E ~ 160°E. In other words, they are geographically favorable for the maintenance of blocking highs over the Ural Mountains and Okhotsk Sea, thus positive for more rain over the Changjiang River Valley (Ye and Huang, 1996).

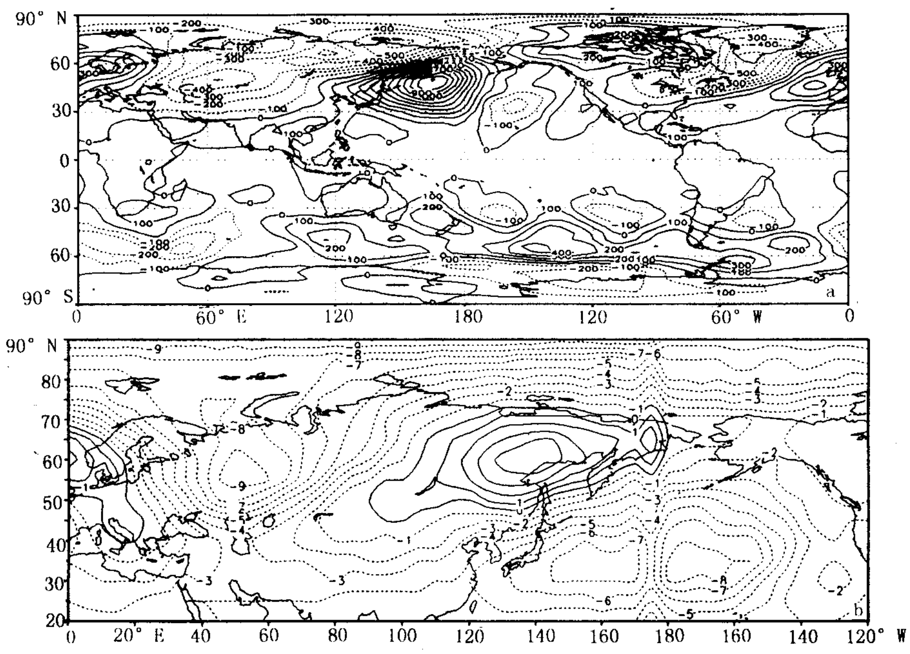

Fig. 1 500 hPa geopotential height response field in January by using numerical simulation warm SSTA (a); 500 hPa geopotential height anomaly field in January with warm SSTA over Indian Ocean (b)

With cool SSTA forcing in the Indian Ocean, the geopotential response field is negative in the forcing area and equatorial west Pacific and obvious positive and negative wavetrains appear in the middle and higher latitudes. In contrast to the response fields associated with warm SSTA forcing, the positive geopotential response is much weakened and more southward over East Asia with the center near 30°N. Negative geopotential anomaly is over the coastal area of East Asia in middle and higher latitudes. The wavetrains in North Pacific-North America look very much like those in the geopotential response fields associated with warm SSTA forcing (figure omitted). Fig.2b is the response fields of 500 hPa geopotential anomalies associated with cool SST forcing in the Indian Ocean. It clearly shows that in the middle and higher latitudes of the Northern Hemisphere the position of the ridges and troughs are apparently more westward in the response fields with cool SST forcing than those with warm SST forcing.

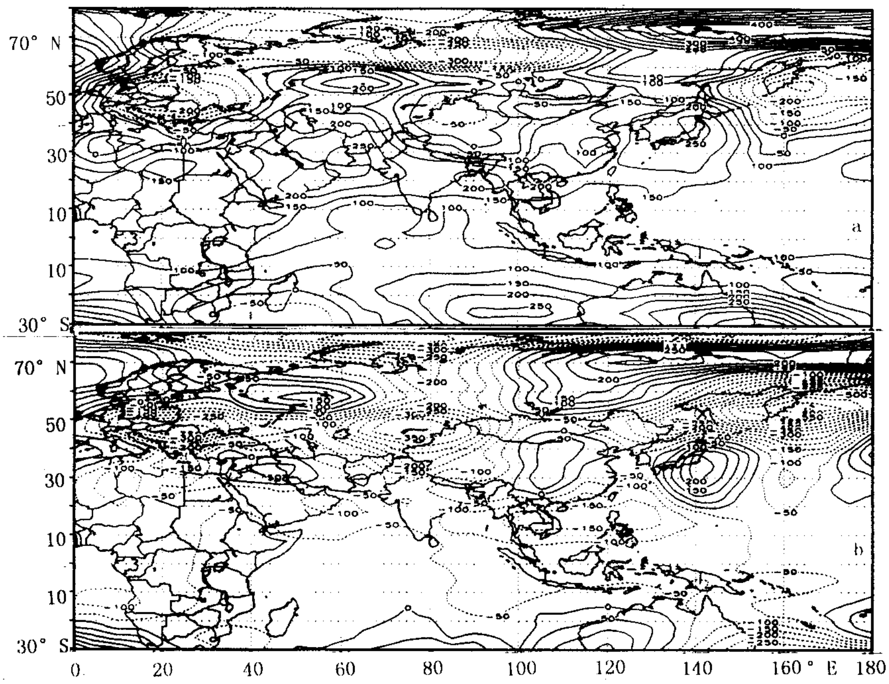

Fig.2 500 hPa geopotential height response field in July with warm (a) and cold (b) SSTA forcing over the Indian Ocean.

4 INFLUENCE OF INDIAN OCEAN SSTA ON ASIAN SUMMER MONSOON

Much research for the past few years has shown that it is mainly by affecting the variation of the Walker cell and Hadley cell that the tropical SSTA governs the anomalous changes in the general circulation. It has been shown that warming of SSTA in the equatorial eastern Pacific is associated with weakened Walker cell over the Pacific Ocean and strengthened mean Hadley cell (Chen and Ding, 1992). In view of the close links between the establishment of the Asian Southwest Monsoon and seasonal north-south oscillation of the South Asia High in the upper level, the summer monsoon sets up in the South China Sea and south China when the South Asia High moves from tropical ocean to northern Indochina Peninsula. When the High moves up over the Tibetan Plateau, the Indian monsoon sets up. It is therefore possible to examine the evolution of the Southwest Monsoon by looking into the establishment of the easterly jet stream at upper level (figure omitted). As shown in the control experiment, the East Asia monsoon usually starts in May and ends in October while the Indian monsoon starts a little later in the middle of June. Fig.3 gives the multi-year profile of the variation of meridionally mean winds with time between 50°E and

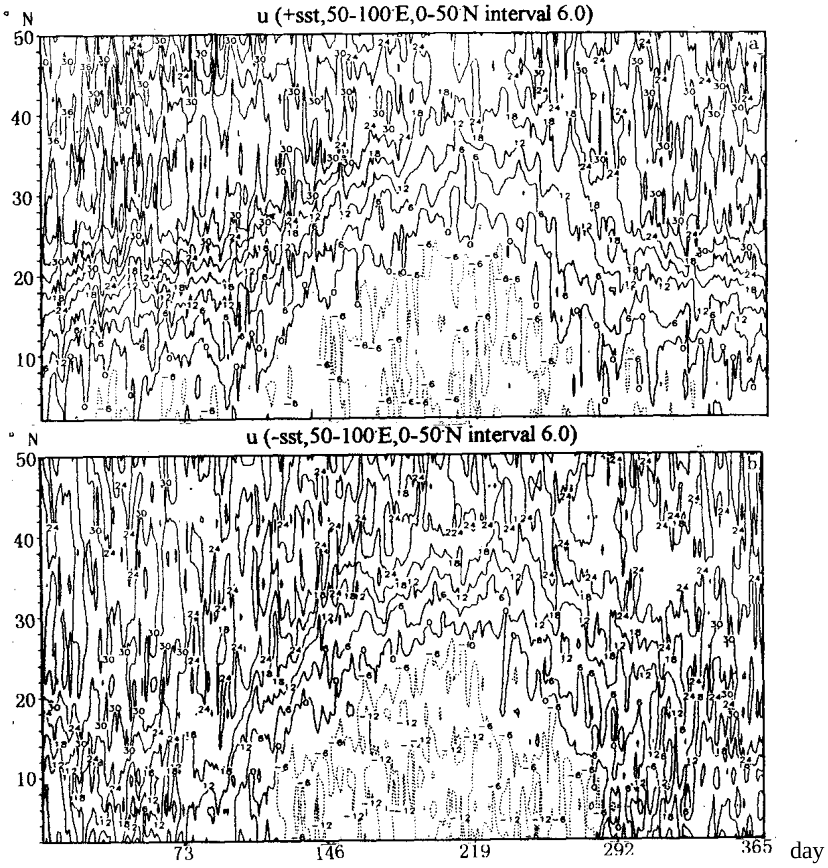

Fig.3 Time-latitude cross section of 200 hPa zonal wind along 50°E ~ 100°E. The ordinate: number of days; the abscissa: latitude; the solid line: westerly; the dashed line: easterly; (a) warm SSTA (b) cool SSTA

100°E associated with cool and warm SSTA forcing in the Indian Ocean. It is clear from Fig.3a that with warm SSTA the line dividing the easterly and westerly has been south of 10° N before early May. It gradually moves north from the middle of May as a result of the northward shift of the South Asia High. It does not cross 20°N until after late June. This is corresponding to the establishment of the South Asia Monsoon. In Fig.3b, the dividing line crosses 10° N in early May, leaves behind 16°N in mid-May and goes well ahead 20°N in early June. It is also known from comparisons of the intensity and northward advancement of the upper-level easterly jet stream between the two forcing states that the easterly blows faster with cool SSTA and stays steadily north of 25°N for a longer period (about a month) than with warm SSTA. As regard to the timing of summer monsoon retreat, it is earlier with warm SSTA than with cool SSTA. As a result, warm SSTA in the Indian Ocean causes a late break-out, early withdrawal, shortened duration, and weakened intensity, while cool SSTA there brings about an early break-out, late withdrawal, extended duration, strengthened monsoon, of the South Asia Monsoon. Similar trends are found with the East Asia Monsoon.

Fig.4a & b present the profiles of variation of meridionally mean winds with time within 100°E ~ 120°E associated with warm and cool Indian Ocean SSTA. The figures show that the warm SSTA forcing causes the Southwest Monsoon to break out later with weaker intensity and there has not been any steady easterly during the whole period of summer monsoon; the cool SSTA causes it to break out earlier with stronger intensity. It is therefore clear that the Indian Ocean

SSTA affects monsoons in both East Asia and South Asia, with the largest difference in the intensity of monsoon.

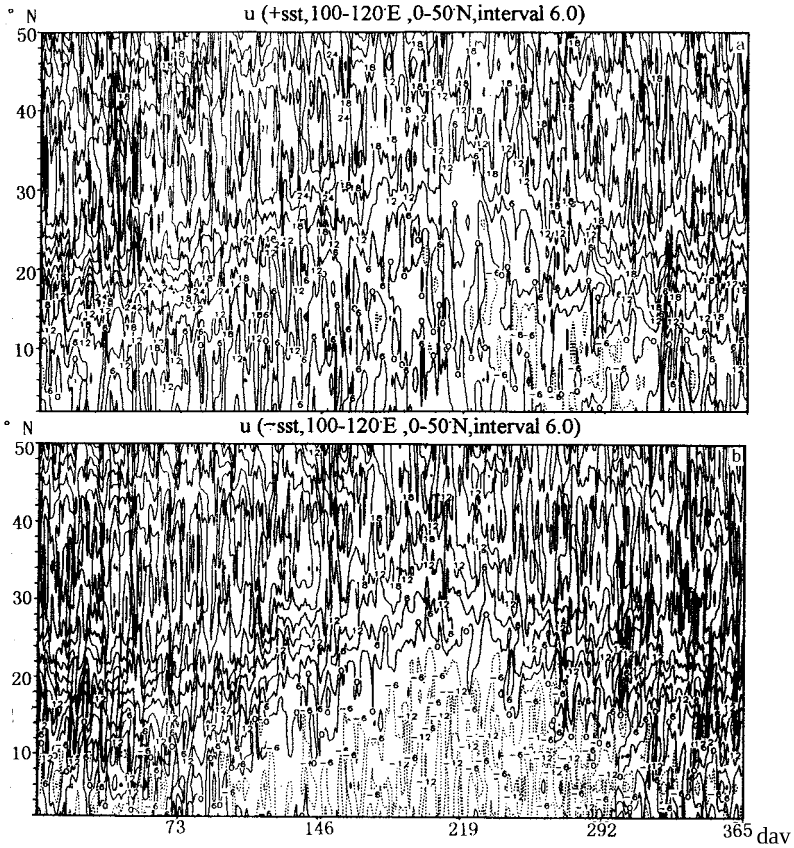

Fig.4 Time-latitude cross section of 200 hPa zonal wind along 100°E ~ 120°E. The ordinate: number of days; the abscissa: latitude; the solid line: westerly; the dashed line: easterly. (a) warm SSTA; (b) cold SSTA

5 INFLUENCE OF SSTA ANOMALY IN INDIAN OCEAN ON PRECIPITATION IN ASIAN MONSOON REGION

Climatic anomalies are inevitable in the monsoon region as the SSTA in the Indian Ocean influences the general circulation and monsoon in Asia. In Figs. 5a & b, we observe response fields

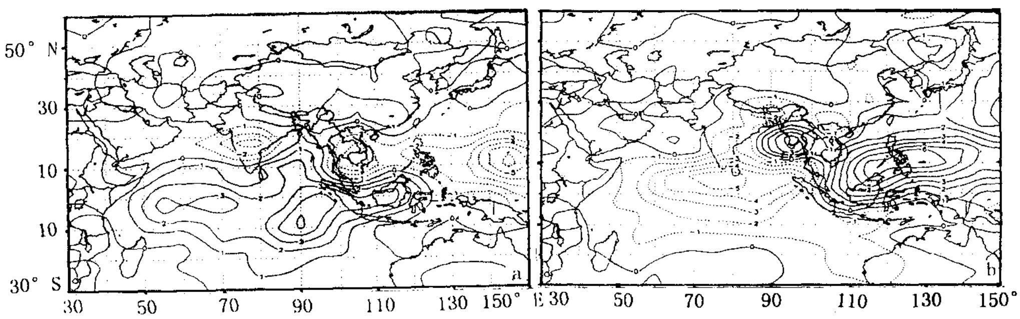

Fig. 5 Response precipitation fields from June to August (mm/d) when the Indian Ocean is with warm SSTA (a) and cool SSTA (b). The solid line: opposite anomaly; the dashed line: negative anomaly

of precipitation anomalies in association with warm and cool SSTA experiments in June ~ August respectively. The figures show that there is more (less) precipitation through southwest China, the Changjiang River basin, South China and northern North China (the warm pools, Indochina Peninsula and Indian Peninsula) in June ~ August in response to warm SSTA. On the other hand, the cool SSTA is associated with less (more) rain in the southwest of China and the middle and lower reaches of the Changjiang River basin (northeast China) in these months. Over the same period, more rain is recorded over the Indochina Peninsula and warm pools while it is unevenly distributed over the Indian Peninsula. Having roughly the same response to both warm and cool SST, precipitation in Indonesia increases under both circumstances. It is concluded that the Indian Ocean SSTA poses a great influence on the precipitation over the Indochina Peninsula, Indian Peninsula and the Chinese mainland. As far as summer precipitation over the latter is concerned, the SST forcing in the ocean is different in itself, with climatic anomalies caused by warm SSTA more significant.

Next, let's look at the effects of different SSTA on the onset of rainy seasons, as rainfall in early summer is our primary concern. Fig.6 is the response field of monthly mean precipitation in May that is associated with cool SSTA in the Indian Ocean. The figure shows that there are obviously more rain in southwest China through the middle and lower reaches of the Changjiang River while no such a center of positive anomaly exists over the region corresponding to warm SST period in the Indian Ocean (figure omitted). It is indicated that the cool SSTA has a larger effect on precipitation in China in May than the warm SSTA does.

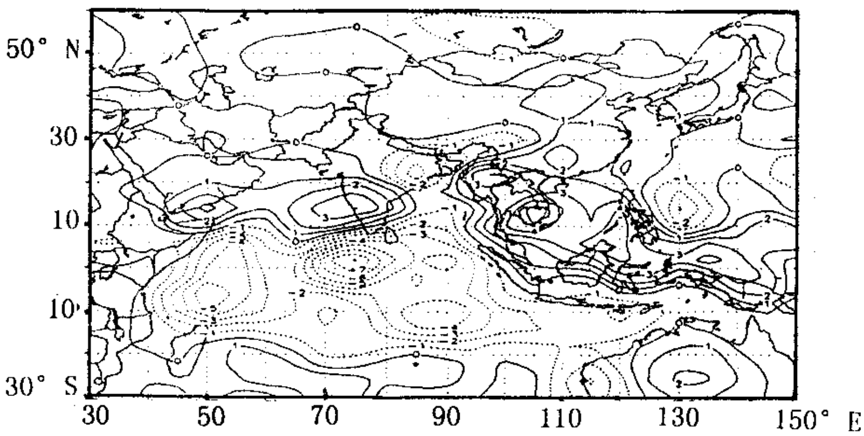

Fig. 6 Response precipitation field in May (mm/d) when the Indina Ocean is with cold SSTA. The solid line: positive anomaly; the dashed line: negative anomaly

6 INFLUENCE OF SSTA ANOMALY IN INDIAN OCEAN ON WIND FIELDS IN ASIAN MONSOON REGION

Due to limitations of numerical models in the simulation of precipitation, effects of Indian Ocean SSTA on the wind fields in the Asian monsoon region are studied to have better understanding of the influence of the SSTA on the region as a whole. Fig.7 presents the anomalous wind fields associated with warm and cool SSTA in the Indian Ocean. Specifically, Fig.7 (a & b) is the anomalous wind fields at 200 hPa with warm and cool SST forcing and Fig.7 (c & d) is the same as in Panels a and b but for 850 hPa. The figure clearly shows that the warm SST forcing there

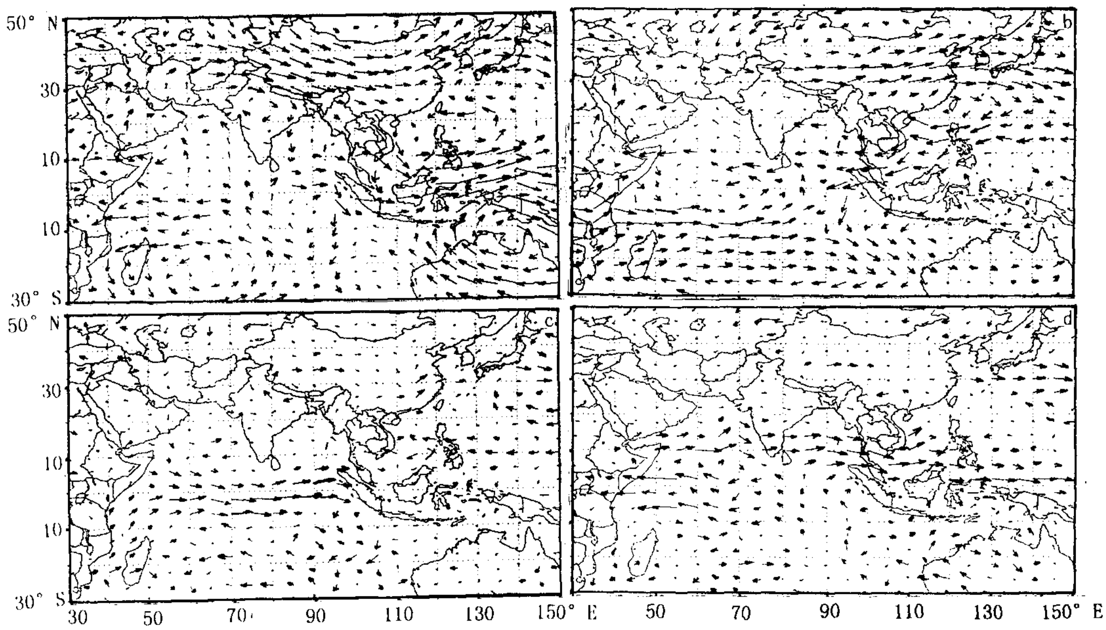

Fig.7 Response wind vector field at 200 hPa in May and at 850 hPa in May when the Indian Ocean is with warm SSTA (a & c) and cool SSTA (b & d)

corresponds to westerly anomalies in upper-level 200 hPa wind fields over the South China Sea, Indonesia, Indochina Peninsula and Bay of Bengal and a cyclonic wind field controlling eastern South China Sea. In the meantime, low-level 850 hPa wind fields are dominated by the anomalous easterly over the South China Sea, Indochina Peninsula, Bay of Bengal, and India but by the anomalous westerly over the equatorial Indian Ocean. The distribution of wind fields are indicative that warm SSTA in the Indian Ocean postpones the northward jump of the easterly at upper level in May and weakens the westerly that turns away from the Somali jet stream. The southwesterly is especially weakened over the Bay of Bengal, Indochina Peninsula and South China Sea. Consequently, the monsoons over these regions are postponed in the outbreak. The warm SSTA in the Indian Ocean has just an opposite effect on the regions.

Reflections of the cool and warm SSTA are also evident in the wind fields of the summer prime. In Fig.8, the anomalous 200 hPa wind fields in June ~ August in the experiments with both SSTA are shown in Panels a and b while the 850 hPa ones in Panels c and d. When warm SSTA occurs, the westerly anomalies are extensive, covering the South China Sea, Indonesia, Indochina Peninsula and Bay of Bengal. In contrast, the circulation at 850 hPa shows just an opposite pattern from the Asian monsoon cell: The easterly anomalies are active in the South China Sea, Indochina Peninsula, Bay of Bengal and India but the westerly anomalies are predominant in South China and the Changjiang River basin. Corresponding to cool SSTA, the upper-level 200 hPa wind fields are controlled by the easterly anomalies in the South China Sea, Indonesia, Indochina Peninsula, Bay of Bengal and the Indian Subcontinent while the lower-level 850 hPa wind fields are controlled by the westerly anomalies in southern South China Sea, Indonesia, Indochina Peninsula, Bay of Bengal and Indian Subcontinent but by the easterly anomalies over South China and the Changjiang River basin. It is therefore clear that with warm SSTA in the Indian Ocean in summer (June ~ August),

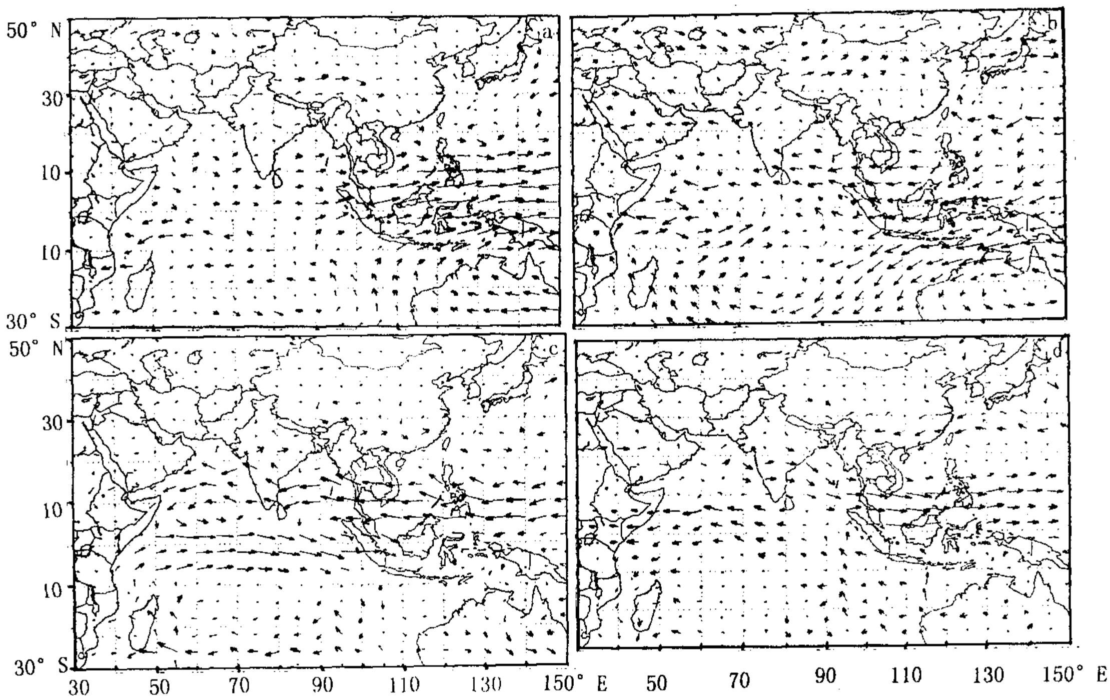

Fig.8 Response wind vector field at 200 hPa and 850 hPa from June to August when the Indian Ocean is with warm SSTA (a & c) and cool SSTA (b & d)

the circulation of the Indian Monsoon and southwest monsoon over the Indochina Peninsula and the South China Sea are weakened while the southwesterly in south China and the Changjiang River basin are strengthened. In contrast, cool SSTA there increases the circulation of the Indian Monsoon and southwest monsoon over the Indochina Peninsula and the South China Sea during the months but weakens the southwesterly in south China and the Changjiang River basin.

7 SUMMARIES

As shown in the numerical simulation of the Indian Ocean SSTA, it is known that it is closely related with the variation of climatic anomalies in the middle and lower latitudes of the Asian monsoon region. Preliminary results can be obtained from studies of warm and cool SST anomalies in the ocean.

a. In the middle latitudes of the Northern Hemisphere, SSTA in the Indian Ocean triggers wavetrains similar to PNA and EAP teleconnection patterns for winter and summer.

b. Cool and warm SSTA in the Indian Ocean poses different influence on the climate of the Asian monsoon region. The cool SSTA is more important for the onset timing of Asian summer monsoon and precipitation in China in her annually first rainy season while the warm SSTA is more important for the monsoon activity in the Asian monsoon region and precipitation in China in her primary rainy seasons.

c. During the warm SSTA period, the South Asia and East Asia summer monsoons set up late and retreat early as compared to normal, weakening the southwest monsoon in the Indian

Subcontinent, Indochina Peninsula and the South China Sea but strengthening the southwesterly in the south of China. It consequently decreases the precipitation in the Indian Subcontinent, Indochina Peninsula, South China Sea and the warm pools but increases the precipitation in the south of China and the middle and lower reaches of the Changjiang River.

d. During the cool SSTA period, the South Asia and East Asia summer monsoons set up early and retreat late as compared to normal, increasing precipitation in the south of China. The southwest monsoon in the Indian Subcontinent, Indochina Peninsula and the South China Sea is strengthened while the southwesterly is weakened in South China. There is more precipitation in the Indochina Peninsula, the South China Sea and the warm pools.

The current work attempts to give a simple simulation of the role of the Indian Ocean SSTA in the climatic anomalies within the Asian summer monsoon region. Air-sea interactions are a complicated subject. It is particularly so when it comes to the question of oceanic effect on the atmosphere as the SST shows a variety of changes. Much research has confirmed the role of SST changes by different patterns and seasons in the climatic anomaly. It was pointed out in 1990 that with the El Niño that starts warming in autumn and winter, more Meiyu (sustained rain) falls over the middle and lower reaches of the Changjiang River in the current and subsequent summer while there will be less rain if the El Niño starts warming in spring and summer. As what Jin and Shen (1987) have observed, the dry and wet Meiyu years for the middle and lower reaches of the Changjiang River are corresponding to different distribution of SST in the Indian Ocean. The study also indicates that warm (cool) SSTA in northern Indian Ocean in autumn and winter indicates a wet (dry) Meiyu period in those reaches of the river. It is now obvious that further study remains to be done on the effects of the Indian Ocean SSTA on the climatic anomalies in the Asian monsoon region.

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