Article ID: 1006-8775(2002) 02-0121-11

RELATIONSHIP BETWEEN DIPOLE OSCILLATION OF SSTA OF INDIAN OCEAN REGION AND PRECIPITATION AND TEMPERATURE IN CHINA

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ABSTRACT: The work is a general survey using SSTA data of the Indian Ocean and of precipitation at 160 Chinese weather stations over 1951 ~ 1997 (47 years). It reveals that the dipole oscillation of SST, especially the dipole index of March ~ May, in the eastern and western parts of the ocean correlates well with the precipitation during the June ~ August raining season in China. As shown in analysis of 500-hPa Northern Hemisphere geopotential height height by NCEP for 1958 ~ 1995, the Indian Ocean dipole index (IODI) is closely related with geopotential height anomalies in the middle- and higher- latitudes in the Eurasian region. As a negative phase year of IODI corresponds to significant Pacific-Japan (PJ) wavetrain, it is highly likely that the SST for the dipole may affect the precipitation in China through the wavetrain. Additionally, correlation analysis of links between SST dipole index of the Indian Ocean region and air temperature in China also shows good correlation between the former and wintertime temperature in southern China.

Key words: Indian Ocean SSTA; dipole indexes; precipitation in raining seasons; correlation analysis

CLC number: P732 **Document code:** A

1 INTRODUCTION

Much work has been done in the aspect of strong signals for anomalous SST in equatorial eastern Pacific, drawing a lot of useful conclusions. Changes in SST over a particular area are not a phenomenon that stands on its own. As shown in Chen et al. [1, 3], the western-Indian-Ocean SST is not only featured by significant interannual variation, but by close positive correlation with that in eastern equatorial Pacific. More recent study on ocean surface near the equator shows that significant dipole oscillations exist in the Indian Ocean region in addition to the east-west fluctuation of SST in the Pacific. Although an El Niño event, the strongest of the kind, took place in 1997, severe drought that was generally expected in such condition did not occur over the Indian subcontinent. What aroused interest was that anomalously warm SST was as high as 2 degrees in the equatorial western Indian Ocean. It draws great attention to the dipole oscillation of SST anomalies in the Indian Ocean and its role. Studying the SST anomalies in the Indian Ocean, Sagi et al[4]. pointed out that they were out of phase in the western part (10°S ~ 10°N, 50°E ~ 70°E) and eastern part (10°S ~ 0°, 90°E ~ 110°E) of the ocean. Webster et al[5]. thought that the dipole was a structure that was independent of ENSO. Li et al[6]. analyzed the temporal and spatial distribution of the SST of Indian Ocean during the ENSO episode. It showed that the variation of SST in the region was well correlated with that in the equatorial eastern Pacific. For the Indian Ocean, the dipole oscillation was significant during the ENSO event and was in substantial out-of-phase relation with ENSO. Does the dipole of SST anomalies being cool in the

Received date: 2001-05-18; **revised date:** 2002-11-21
Foundation item: Research on the Mechanism and Prediction of Major Climatic Calamities in China —a national key program for developing basic science (G199804090303); Science Foundation of Yunnan (97D022G)
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east but warm in the west in 1997 have any important effects on ENSO? Using numerical modeling, Xiao et al[7]. studied the effects of such allocation on Asian climate and showed that it did relieve to some extent drought prevailing over the Indian subcontinent. As we know, the Indian Ocean is a region in which the southwest monsoon originates and transports through and any anomalous performance of SST there is bound to play an important role in anomalous activity of the southwest monsoon. It is therefore reasonable to infer that such dipole oscillation of SST will affect the climate of East Asia as well as the Indian subcontinent. How the dipole oscillation of Indian Ocean SST affects precipitation in China is focused in the current study. Furthermore, as precipitation is distributed in a manner that is related to specific patterns of general circulation, the current work will discuss the general circulation in combination with the distribution of seasonal rainfall in China. Similar works include Nitta[8, 9] and Huang et al[10, 11]. The former found in 1986 an oscillating phenomenon across the Pacific-Japan region (or the so-called PJ wavetrain) and it was present in the general circulation of summer, with a pattern of positive and negative wavetrains appearing alternatively over the Philippines through southern China, Sea of Japan through northern China / Sea of Okhotsk. Afterwards, Huang et al[10, 11].suggested that the PJ wavetrain relate with convection and distribution of precipitation in China.

With SST anomalies data of the Indian Ocean for 1951 ~ 1997 from the Hadley center, corresponding precipitation data recorded at 160 weather stations in China and NCEP reanalyzed Northern Hemisphere geopotential height data, we made correlation analysis of monthly dipole index from preceding May to current June ~ August for the Indian Ocean and the precipitation field for June ~ August. Then, more efforts were made to study the relation between the dipole oscillation of the Indian Ocean SST and precipitation in China's raining seasons.

2 VARIATION OF DIPOLE INDEX IN INDIAN OCEAN

Based on reference [12], the SST has the largest difference in the eastern and western parts of southern equatorial Indian Ocean. For the description of the intensity of dipole oscillation, mean SSTA over the regions in equatorial western Indian Ocean (5°S ~ 10°N, 50°E ~ 65°E, designated as S_W) and equatorial eastern Indian Ocean (10°S ~ 5°N, 85°E ~ 100°E, designated as S_E) and an Indian Ocean dipole index (IODI) was defined using their difference $S_W - S_E$. From the evolution of their temporal series, we know that monthly and inter-annual variations of IODI are quite large, with the month-to-month amplitude about 1°C and the difference between the maximum and minimum more than 2 °C. The change in IODI reduces for the inter-annual variation due to smoothening. Fig.1 gives the year-to-year variation of IODI which has been standardized over 1951 ~ 1997. It is seen that years with large IODI are 1961, 1972, 1994 and 1997 and years with small IODI are 1958, 1959, 1960, 1984 and 1996.

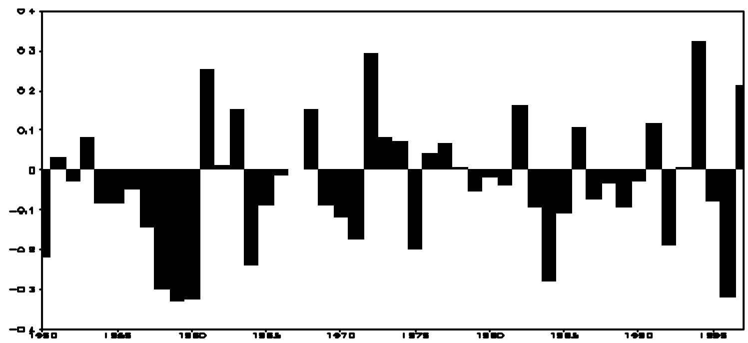

Fig.1 The temporal variation of the Indian Ocean Dipole Index from 1951 to 1997.

3 RELATIONSHIP BETWEEN IODI AND PRECIPITATION IN CHINA RAINING SEASON

As the tropical ocean is extensive and holds huge amount of heat, anomalies of SST can affect weather and climate not only in concurrent but also subsequent periods. By means of general surveys of correlation between the monthly IODI from preceding September to current June ~ August (or simultaneous correlation) and the precipitation at 160 weather stations of China in June ~ August, we found that the IODI for either preceding or concurrent periods was closely related with the rainfall in June ~ August. The correlation is the most significant in May, the transitional season. Twenty-one weather stations for the May correlation passes the 0.05 test. During winter monsoon periods, the correlation coefficient is moderate, especially in the preceding November and current March when there are only 7 stations passing the test of correlation confidence. There are 18 stations that pass it in the current June ~ August period. Tab.1 and Tab.2 give the number of stations that have passed the test of 0.05 correlation confidence on the monthly and seasonal scales. Next is the study of distribution characteristics of the correlation coefficients.

Table 1 The number of the stations passing the 0.05 statistical significance test of the correlation coefficient between monthly IODI and precipitation from June to August over China

Month	7_{pre}	8_{pre}	9_{pre}	10_{pre}	11_{pre}	12_{pre}	1_{cur}	2_{cur}	3_{cur}	4_{cur}	5_{cur}
Number of stations	7	17	14	12	7	8	8	11	7	14	21

Note: "pre" stands for preceding and "cur" for current. Same in Tab.2.

Table 2 The number of the stations passing the 0.05 statistical significance test of the correlation coefficient between seasonal IODI and precipitation from June to August over China

Month	$9\sim11_{pre}$	$12\sim2_{pre}$	$3\sim5_{pre}$	$6\sim8_{cur}$
Number of stations	12	12	16	18

Fig.2 gives the distribution of correlation between the IODI in the current May and the precipitation in the June ~ August raining season in China. It is known that the correlation is high, with positive areas over the western part of southern China, middle and lower reaches of the Changjiang River basin, which has the most significant magnitude (0.4 at the center) and largest coverage, and the southern part of northeast China, and negative areas over eastern Sichuan, eastern part of southern China area and the Yellow River basin with a negative coefficient of -0.37. From the correlation analysis for preceding months (figure omitted), we know that the similar distribution is in the months after February regarding the correlation between the IODI and the precipitation over the period. Therefore, when the preceding IODI is in positive phase, or, the SST is cool in the east but warm in the west, it is likely that precipitation will be more in the raining season in the basin of middle and lower reaches of Changjiang River but it will be less in the eastern part of Sichuan and Yellow River basin. In contrast, when the IODI is in negative phase, or, the SST is warm in the east but cool in the west, it will be dry in northern but wet in southern China.

Fig.3a and 3b are the distribution of the IODI-precipitation correlation between precipitation in the June ~ August raining season and IODI respectively in March ~ May and June ~ August. As shown in Fig.3a, the positive correlation areas are in the western part of southern China region, the middle and lower reaches of the Changjiang River basin and the southern part of northeast China, and the negative correlation areas are in most of northern China. It is generally consistent with the correlation distribution in May shown in Fig.2. The correlation varies in the correlation pattern for June ~ August, which is shown in Fig.3b. Except for the eastern part of the southern China region, which is negatively correlated, most of China is dominated by negative correlation. What Fig.3a and Fig.3b show is a pattern in which opposite phases is present in southern and northern China. Viewed from the distribution of correlation coefficient on a seasonal basis, the IODI is well related with the north-south pattern of precipitation in China in that positive (negative) IODI corresponds to wet (dry) spans in southern China versus dry (wet) periods in northern China. A positive (negative) dipole index indicates that the Indian Ocean SSTA is of a dipole SST structure, which is cool in the east but warm in the west or vice versa. Cool (warm) SST in eastern Indian Ocean gives rise to anomalously divergent, descending (convergent, ascending) flows over the region, while warm (cool) SST in western Indian Ocean results in anomalously convergent, ascending (divergent, descending) flows over the region. Easterly (westerly) anomalies will then be formed in equatorial Indian Ocean, the Walker cell will weaken (strengthen), the southwest monsoon will decrease (increase) and the southwest monsoon passing through the Indochina Peninsula and the southwest monsoon trough (Mei-yu trough) going northward after advancement to the South China Sea will be southward (northward) located. They may be responsible for a precipitation distribution that marks wet (dry) southern China versus dry (wet) northern China.

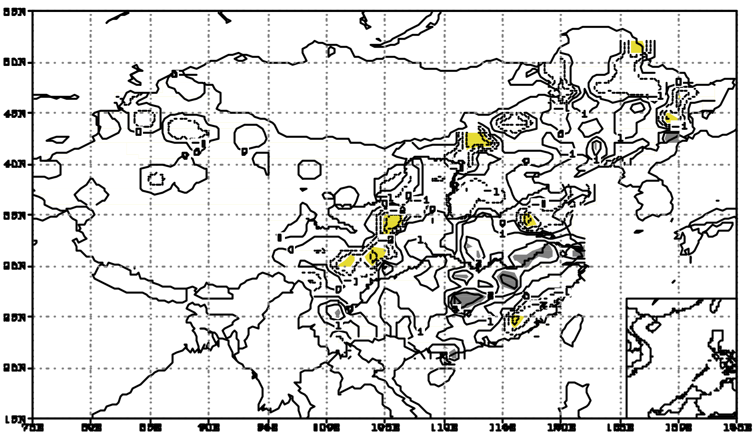

Fig.2 The distribution of the correlation coefficient between the Indian Ocean dipole index in May and the rainfall over China from June to August in the same year. The shadow area represents the correlation coefficient beyond 0.05 statistical significance test.

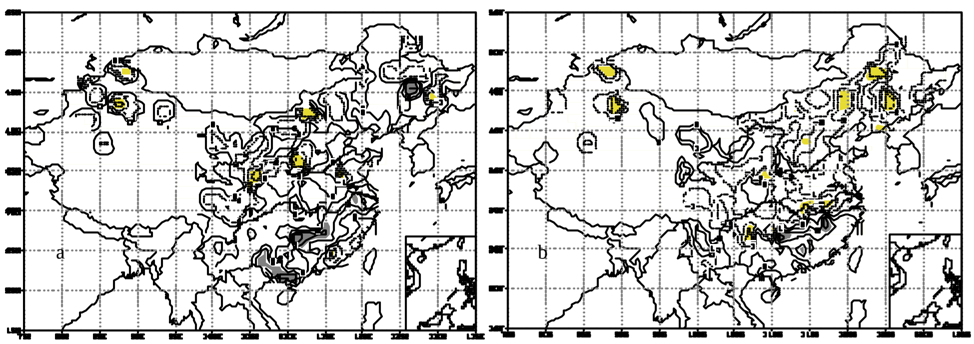

Fig.3 The horizontal distribution of the correlation coefficient between the IODI from March to May (a); from June to August (b) and the rainfall in the same year from June to August. The shadow area represents the correlation coefficient beyond 0.05 statistical significance test.

Fig.4 (a & b) gives a composite analysis of precipitation fields over the raining season of June ~ August for years of large positive IODI (1961, 1972, 1994 and 1997) and years of small negative IODI (1958, 1959, 1960, 1984 and 1996). When the IODI's phase is positive, i.e. the Indian Ocean is of a SST dipole structure of cooler in the east than in the west, as shown in Fig.4a, dry weather prevails in northern China and the Changjiang-Huaihe Rivers basins while rainy weather dominates in the coastal areas of southern China. Additionally, Yunnan province, northern middle reach of the Yellow River and northern part of North China are also areas of positive precipitation anomalies. When the IODI is in negative phase, or, the Indian Ocean is of a SST dipole structure being warm in the east but cool in the west, rain bands for the June ~ August season differs from the one above, which is characteristic of more rain in both southern and northern China but less rain in the Changjiang River basin. It is especially noted that a negative-phase IODI will bring more rain in regions of northern China, Yellow River basin and southern part of North China but less rain in regions of middle and lower reaches of the Changjiang River and northern part of northeast China. Precipitation in these regions is out of phase with years of extremes for positive and negative phases of the IODI. As shown in comparisons to Fig.3, for the years of positive extremes of IODI, precipitation in raining seasons is consistent with the distribution of IODI and the current June ~ August precipitation, which are concurrently correlated. In other words, the effect of the IODI is more obvious. It is then concluded that an Indian Ocean SSTA that is cool in the east but warm in the west exerts more influence on the precipitation in China's raining seasons than the one that is warm in the east but cool in the west.

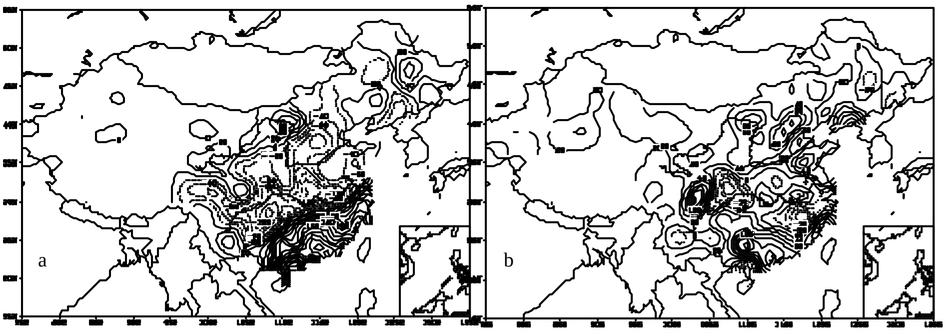

Fig.4 The composite precipitation anomalies over China from June to August for the positive phase (a) and negative phase (b) of the IODI

As precipitation is caused by an array of complicated factors and the IODI is one of them that affect the precipitation in China (maybe it is not the most important one), there may be more factors causing the precipitation to distribute the way it does. It is therefore difficult to make the corresponding relation established the other way round. One should, however, note from the analysis presented above that precipitation in northern China is generally more (less) in the negative (positive) IODI extreme years. In retrospective calculation, mean June ~ August precipitation for Beijing, Shijiazhuang, Xi'an and Ji'nan are used to determine the IODI for years with annual rainfall anomalies going above 100 mm. It shows that the mean IODI is –0.05 for years surpassing 100 mm in positive precipitation anomalies and the mean IODI is 0.14 for years surpassing 100 mm in negative precipitation anomalies. It illustrates the IODI does affect the precipitation in China, especially in the northern region to the extent that it cannot be ignored and further proves that the Indian Ocean SSTA being cool in the east but warm in the west has greater effect on precipitation in raining seasons of China.

4 RELATIONSHIP BETWEEN IODI AND GENERAL CIRCULATION CHANGE

From the analysis above, we can see that the dipole oscillation of SST in the Indian Ocean in preceding and current periods is indeed well correlated with precipitation in raining seasons in China. To study the oscillation more, we will discuss the mutual relationship between the IODI and 500-hPa anomalous geopotential height fields

Fig.5 gives the simultaneous correlation between the IODI in June ~ August and 500-hPa anomalous geopotential height fields. The figure shows that correlation is of significant distribution of positive and negative wavetrains for middle and higher latitudes. Positive and negative correlation areas passing the 0.05 test of correlation confidence are mainly located in the middle and higher latitudes of the Eurasian region and western part of North America. The maximum positive correlation center is in east of Siberia and the maximum negative one is near the Ural Mountains, which has a coefficient larger than 0.4, the most significant of all. The northwestern Pacific Ocean is also controlled by negative correlation. The correlation pattern over the Eurasian region indicates that a positive extreme IODI is accompanied by a year of weak East Asian trough, southward subtropical high in the Pacific and southward raining areas in mainland China, likely constituting to a precipitation pattern of floods in the south but drought in the north; a negative extreme IODI is accompanied by a year of strong East Asian trough and northward subtropical high in the Pacific, likely resulting in more precipitation in the north of the country.

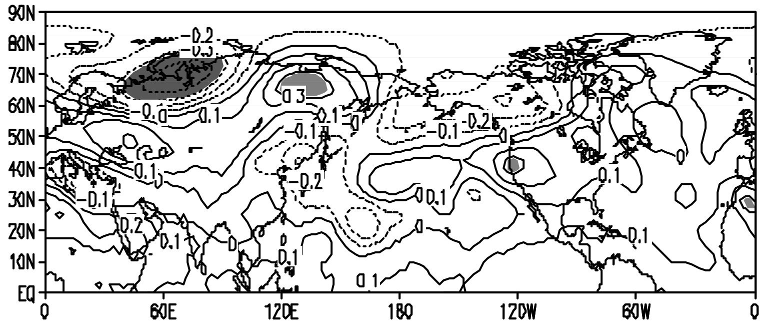

Fig.5 The horizontal distribution of the correlation coefficient between the IODI from June to August and the 500 hPa height field during the same time. The shadow area represents the correlation coefficient beyond 0.05 statistical significance test.

Likewise, the June ~ August 500-hPa geopotential height fields for years of positive and negative IODI extremes are selected for set analysis. Due to limited data availability, the years 1961, 1972 and 1994 are defined to have positive phase extremes and the years 1958, 1959, 1960, 1964 and 1984 are set to have negative phase extremes. Fig.6 (a & b) gives 500-hPa geopotential height composite fields for positive and negative phase years of IODI. When the IODI phase is positive, the Ural Mountains and areas to the west are negatively in anomaly and regions from Lake Bajkal to China are positive while the northwestern Pacific is negatively anomalous. When the IODI phase is negative, however, the situation in the 500-hPa geopotential height field is almost reversed, showing a center of positive anomaly in western Europe, a center of negative anomaly in Lake Bajkal and Siberia and positive anomalies over western Pacific Ocean. Such distribution shows that in the prime season of precipitation from June to August, a positive IODI substantially reduces the troughs over East Asia and the Ural Mountains and decreases precipitation over most of northern China while a negative IODI is favorable for the strengthening of the troughs and increasing of the precipitation.

From comparisons of the values for anomaly centers of positive and negative geopotential height fields, we know that the effect of positive-phase IODI is greater than that of negative one so that the positive geopotential height field can be nearly twice as much as the negative one. It should also be noted that the anomalies of 500-hPa geopotential height is so significant that well-defined PJ wavetrains are evident in western Pacific and particularly so in years of negative-phase IODI. It is known that the Pacific PJ wavetrains are closely linked to convection around the Philippines. Huang et al[10, 11]. pointed out that years of strong convection near the Philippines witnessed the presence of western-Pacific subtropical high over Japan and Changjiang-Huaihe Rivers basins in China, which are warm and dry, in contrast to negative geopotential height anomalies at 500 hPa over the Okhotsk Sea. From comparisons with the precipitation distribution in Fig.4, we know that for the years of negative-phase IODI, precipitation is distributed in a pattern similar to that with the effect of PJ wavetrain in strong convection years in the region of the Philippines. It is then deduced that negative-phase IODI years may affect the precipitation in China through the PJ wavetrain in a pattern of being wet in northern and southern but dry in central China, rather than a pattern of north-south distribution that is just the opposite from the years of positive phase. It is reasonably inferred, combining the correlation analysis conducted above, that it is by altering thermodynamic contrast across the east and west of the Indian Ocean that positive-phase years of IODI affect the southwest monsoon and Walker cell and consequently govern the distribution of precipitation in China in a direct manner; negative-phase years of IODI lead to formation of the PJ wavetrain by increasing the SST from western Indian Ocean to the region of the Philippines so as to affect the distribution of precipitation in China.

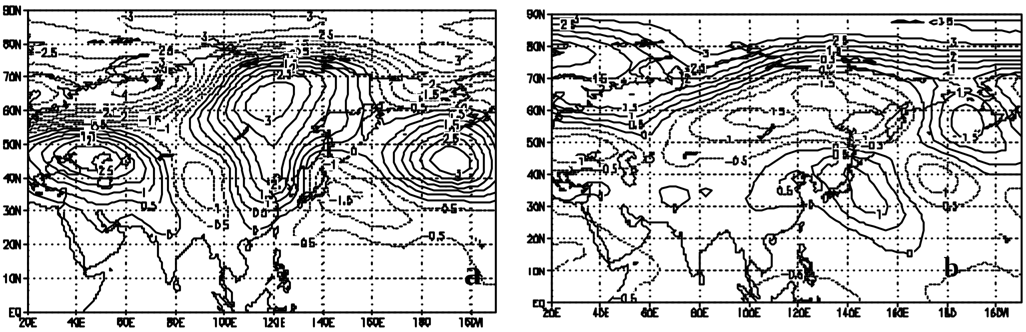

Fig.6 The composite 500 hPa height anomalous field for IODI positive phase years (a); negative phase years (b) during the period from June to August.(unit: 10 geopotential meters.)

5 IDOI AND WINTER TEMPERATURE IN CHINA

In the preceding section, correlation between the IODI and precipitation in the June ~ August raining season of China has been studied. With similar approaches, correlation is sought between the IODI and the temperature field of 160 Chinese weather stations in winter (December, January and February). It is found that the latter is closely connected with the IODI in preceding June ~ August, with 22 stations passing the 0.05 correlation test in winter but less than 10 stations passing it in seasons other than winter. Fig.7 gives the distribution of correlation between the IODI in June ~ August and subsequent winter in China (December, January ~ February in the year that follows). As it is shown, they are in consistent negative correlation, though stations passing the confidence test concentrate in the southern part of China. It indicates that the appearance of SST anomalies being cooler in the east than in the west in summertime Indian Ocean will be accompanied by lowered wintertime temperature in southern China. Contrarily, when there are SST anomalies that are warmer in the east than in the west in summertime Indian Ocean, temperature will be higher than normal in southern China.

Fig.8 (a & b) gives composite mean temperature fields for subsequent winter months of December, January and February in China corresponding to years of large positive IODI values

(1961, 1972, 1994 and 1997) and years of large negative IODI values (1958, 1959, 1960, 1984 and 1996). They have the same distribution of correlation as in Fig.7. Fig.8 shows a generally out-of-phase pattern of winter temperature anomalies in southern China, especially in areas south of the Changjiang River. For the winter subsequent to a year of maximum IODI, the maximum negative anomaly is 0.6 degree along the coast of southern China. For the winter after a year of maximum IODI, the maximum positive anomaly is 1.0 degree there. It may be explained by the fact that in the maximum positive IODI year, the eastern Indian Ocean is of anomalous cooler SST, whose persistence may lower air temperature over waters in nearby areas and on the continental coast. In contrast, in the maximum negative IODI year, the eastern Indian Ocean is of anomalous warmer SST, which may increase air temperature there.

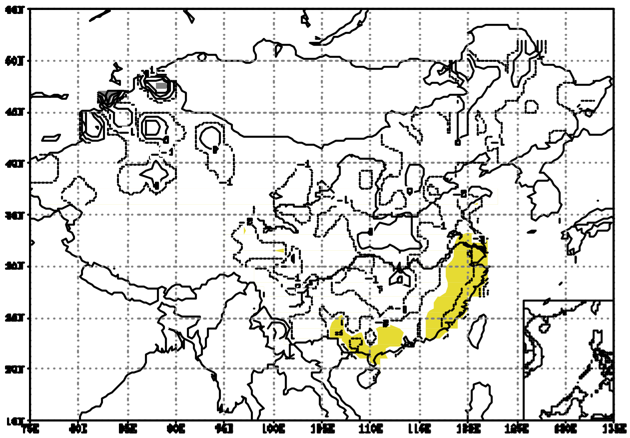

Fig.7 The horizontal distribution of correlation coefficient between the IODI from Jun. to Aug. and temperature in the winter (DJF) followed. The shadow is for the coefficient over 0.05 statistical significance test.

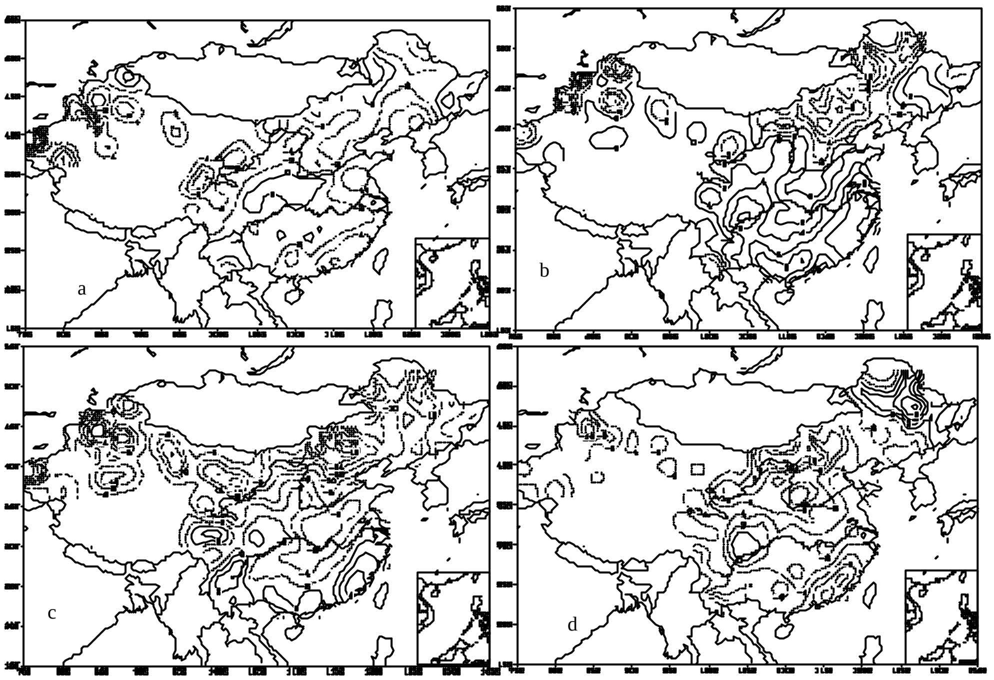

Fig.8 The composite temperature in winter (Dec. Subsequent Jan. & Feb.) after positive IODI phase years (a) or negative phase years (b); and in winter (preceding Dec. & current Jan. and Feb) before IODI positive phase years (c) or negative phase years (d).

Examining the composite temperature field for the winter prior to a maximum IODI extreme, we also find that positive and negative IODI extremes for southern China are corresponding to opposite temperature anomalous fields; but temperature is positively (negatively) anomalous in the region over the winter prior to maximum positive (negative) IODI values (Fig.8a & Fig.8d). Previous studies on winter monsoon in East Asia[13, 14] have shown that frequent southward progression of strong winter monsoon are strengthening convection in the equatorial tropical region, i.e. turning the region from western Pacific Ocean to eastern Indian Ocean into a convective convergent zone and increasing the prevailing westerly over the equatorial tropical Indian Ocean. Thereby, the atmosphere affects the SST by means of ocean to cause relatively small IODI in corresponding summer. On the contrary, weak winter monsoon will bring about relatively large IODI in corresponding summer. It is then known that the summer IODI affects the air temperature of wintertime southern China coast in a manner just opposite to how the latter affects the former.

From the analysis above, we can see that there is good connection between the air temperature in southern China and the IODI, which acts in the order of high temperature in the winter of southern China → positive-phase extreme IODI year → low temperature in the winter of southern China in the subsequent year, or, low temperature in the winter of southern China → negative-phase extreme IODI year → low temperature in the winter of southern China in the subsequent year. Temperature recorded at Guangzhou, Fuzhou and Xiamen are made the representative values for southern China in retrospective calculation of the IODI for the years of temperature extremes in winter. It is then found that when temperature in southern China in winter (December, subsequent January and February) is high, i.e. mean anomalous temperature is greater than 1.0℃ at Guangzhou, Fuzhou and Xiamen, mean IODI will be –0.039 for the current year and 0.034 for the subsequent year; when it is low, i.e. mean anomalous temperature is lower than –1.0℃ at the three stations, mean IODI will be 0.075 for the current year and –0.145 for the subsequent year. Our results have once again proved the conclusion above.

6 CONCLUDING REMARKS

With the IODI, summer precipitation in the region of China, winter temperature fields and 500-hPa geopotential height field for the Eurasian region, we have performed a preliminary analysis on the effect of the IODI on the climate in China. By means of correlation analysis and composite analysis of element fields of the IODI extreme years, we have come to preliminary conclusions as follows:

a. The IODI is well correlated with precipitation in June ~ August in China and significantly in terms of leading and concurrent periods of March ~ May, the transitional season. The distribution of correlation shows that the positive phase of the IODI brings less rain to northern China but more rain to southern China while the negative phase causes more rain to northern China but less rain to southern China.

b. Compared with the negative phase, the positive phase of IODI has greater influence on the climate of China. The former affects the summer precipitation distribution in a way similar to the correlation characteristics of the IODI, being typical of immediate effect of anomalous SST of the Indian Ocean on summer precipitation field. On the other hand, the negative phase of IODI affects the summer precipitation distribution in a way similar to the leading correlation characteristics of the index, which may depict the indirect influence on the precipitation field by the anomalous SST of the Indian Ocean through the air-sea interactions.

c. The IODI has an obvious effect on the general circulation in the middle and lower latitudes and patterns of anomalous circulation of the extreme years of IODI are playing an important role in the anomalous distribution of precipitation in China in corresponding years.

d. The positive phase of the IODI may directly affect the summer precipitation in China via the southwest monsoon while the negative phase may do so by way of the PJ wavetrain.

e. The IODI is also closely connected with the wintertime temperature in southern China. If it is in positive (negative) phase in summer, the temperature will be lower (higher) and the IODI is generally in negative (positive) phase in the summer of the subsequent year.

Acknowledgements: Mr. CAO Chao-xiong, who works at the Guangzhou Institute of Tropical and Oceanic Meteorology, China Meteorological Administration, has translated the paper into English.

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