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RELATIONSHIPS BETWEEN AUTUMN INDIAN OCEAN DIPOLE MODE AND THE STRENGTH OF SCS SUMMER MONSOON

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Abstract: Based on 1948 – 2004 monthly Reynolds Sea Surface Temperature (SST) and NCEP/NCAR atmospheric reanalysis data, the relationships between autumn Indian Ocean Dipole Mode (IODM) and the strength of South China Sea (SCS) Summer Monsoon are investigated through the EOF and smooth correlation methods. The results are as the following. (1) There are two dominant modes of autumn SSTA over the tropical Indian Ocean. They are the uniformly signed basin-wide mode (USBM) and Indian Ocean dipole mode (IODM), respectively. The SSTA associated with USBM are prevailing decadal to interdecadal variability characterized by a unanimous pattern, while the IODM mainly represents interannual variability of SSTA. (2) When positive (negative) IODM exists over the tropical Indian Ocean during the preceding fall, the SCS summer monsoon will be weak (strong). The negative correlation between the interannual variability of IODM and that of SCS summer monsoon is significant during the warm phase of long-term trend but insignificant during the cool phase. (3) When the SCS summer monsoon is strong (weak), the IODM will be in its positive (negative) phase during the following fall season. The positive correlation between the interannual variability of SCS summer monsoon and that of IODM is significant during both the warm and cool phase of the long-term trend, but insignificant during the transition between the two phases.

Key words: Tropical Indian Ocean; Indian Ocean Dipole Mode; SCS Summer Monsoon

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1 INTRODUCTION

The SCS Summer Monsoon is the component in the Asian summer monsoon system that has the earliest onset of the year. As shown in some studies[1, 2], its anomalies are significantly related with the climate in China, especially the valleys of the Yangtze and Huaihe Rivers. Studies on East Asian summer monsoons[3] pointed out that three cross-equatorial summertime airflows at low levels between the tropical easterlies in Southern Hemisphere and tropical westerlies in Northern Hemisphere are playing an important role in maintaining the East Asian monsoons. It is noteworthy that the airflows are all in the tropical Indian Ocean, indicating the importance of SST anomalies (SSTA) of the tropical Indian Ocean for the circulation of summer monsoon in East Asia. With a discussion of the role of zonal anomalies of Indian Ocean SST, Saha[4] pointed out that the anomalies of east-west SST gradient can greatly modify monsoonal circulation and affect the Asian monsoon system via the vertical circulation. Studying the relationships between Indian Ocean SST and Indian Monsoon, Weare et al.[5] pointed out that the precipitation in the South Asia subcontinent was in weak correlation with the SST of the Indian Ocean while the Indian Ocean SST significantly affects the East Asian Monsoon. As

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in the analysis by Liang et al.[6], the variation of Southwest Monsoon intensity in the SCS is significantly correlated with SST, specifically, variations on the interannual or above scales are mainly displayed as negative correlation between the intensity of Southwest Monsoon in the SCS and SST in the eastern Pacific, SCS and Arabian Sea. In their study on the main eigenvector field of SSTA from East Asia to the tropical eastern Indian Ocean in May, Zhao et al.[7] showed that the anomalies of tropical ocean temperature centered around the Sumatra was closely related with the onset of summer monsoon in the SCS.

Suggesting the presence of an Indian Ocean dipole mode (IODM) in the equatorial region, Webster et al.[8] and Saji et al.[9] held that IOD could lead to climatic anomalies in the Indian Ocean and surrounding areas. Based on the results of EOF analyses, Saji et al.[9] also defined a dipole mode index (DMI) using the differences of regionally averaged SSTA between the western part of equatorial Indian Ocean (50 – 70°E, 10°S – 10 °N) and the eastern part (90 – 110°E, 10°S – EQ) and with it discovered strong seasonal phase lock in six selected extreme events for composite IOD evolution and the presence of strong easterlies anomalies during IOD in the equatorial central Indian Ocean. Ever since that, the IOD phenomenon has aroused attention internationally. In the work of Li et al.[10], it was reaffirmed that an IOD-type oscillation was indeed evident in the interannual variation of SST in the equatorial Indian Ocean. They pointed out that IOD was the strongest in September – November but the weakest in January – April, displaying interannual variations with main periods at 4 to 5 years and interdecadal variations with main periods at 25 – 30 years. It was also shown in their study that IOD affects significantly the Asian summer monsoon via the flow field of lower troposphere; summer monsoon is strong in both the SCS and India in the positive phase of IOD but it is weak in the SCS but strong in southern India in the negative phase. With detailed analysis of the variation of Indian Ocean SST, Tan et al.[11] classified the IOD into two types. Analyzing the SSTA data for the tropical thermocline, Chao et al.[12] pointed out that the east-west distribution of SSTA in the Indian Ocean show that IOD is reversed in anomalous signs, in addition to suggestions that IOD be the event of large-scale air-sea interactions in the Indian Ocean. Saji et al.[13] discovered that there are multiple anomalous signals of the Indian Ocean SST, the climatic tendency, interdecadal variation and interannual oscillation at the scale of basin and IOD, to name a few. Their results once again show the existence of IOD, which is independent from the signal of ENSO. As shown in the studies above, IOD has very important effect on climatic anomalies and its seasonal phase lock reaches the maximum in autumn. What effect, then, does the IODM in preceding autumn have on the SCS summer monsoon in the successive year? What roles does the summer monsoon play in the IODM that grows to its prime intensity? It is the attempt of this work to find out the answers to these questions by studying historical data and discussing the interrelationships between the SCS summer monsoon and the preceding and successive IODM in tropical Indian Ocean.

2 DATA AND METHODS

The data used in this paper include monthly mean SST of Reynolds for September 1948 – November 2004[14] and global atmospheric reanalysis data of NCEP/NCAR for June, July and August in 1949 – 2004[15]. June – August is the summer and September – November the autumn, following the season of Northern Hemisphere. The data are averaged over the season to obtain autumn SST fields for each of the years from 1948 to 2004 and summer wind fields at 850 hPa and 200 hPa for each of the years from 1949 to 2004. For the summer wind field in the current year, the SST field in the year prior to it is treated as the one in the preceding autumn. The period of interest is from 1948 to 2003. The autumn SST field in the concurrent year of summer monsoon is treated as the one in the successive autumn. The period of interest is from 1949 to 2004.

The index for the SCS summer monsoon intensity by Wu et al.[16], who used standardized 850-hPa mean southwesterly component for June, July and August in the SCS region to define summer monsoon, is used to depict the intensity change of the monsoon, As shown in a Morlet wavelet analysis of the index[16], the monsoon intensity varies at two main sections of frequency from 9 to 12 a and from 3 to 6 a. On the

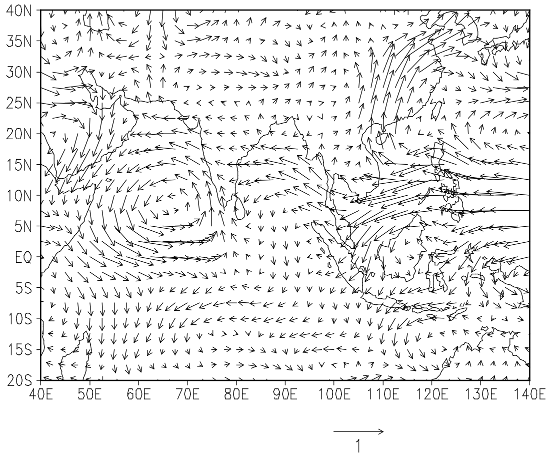

Fig.1 The distribution of regression coefficients between preceding DMI1 and 850-hPa wind field in summer.

interdecadal scale, the 12-a period predominated the time prior to mid-1970’s and the 9-10-a period became dominant after the point.

3 EFFECT OF IODM IN PRECEDING AUTUMN ON THE INTENSITY CHANGE OF SOUTH CHINA SEA SUMMER MONSOON

Fig.1 gives the distribution of regression coefficients between preceding DMI1 and 850-hPa wind field in summer. Fig.2 gives the distribution of moving correlation coefficients for preceding DMI2 and I_V2, which is determined with the 850-hPa summer wind field with bandpass filter. Here, the moving window takes 31 a. Fig.3 gives the spatial distribution for different sections of time of moving correlation coefficients between preceding DMI2 and summer 850-hPa wind field with bandpass filter (1 – 8 a), with the moving window at 31 a. Phases 1 – 4 are the distribution of correlation coefficients for 1, 9, 17 and 26 moving steps and in 1949 – 1979, 1957 – 1987,

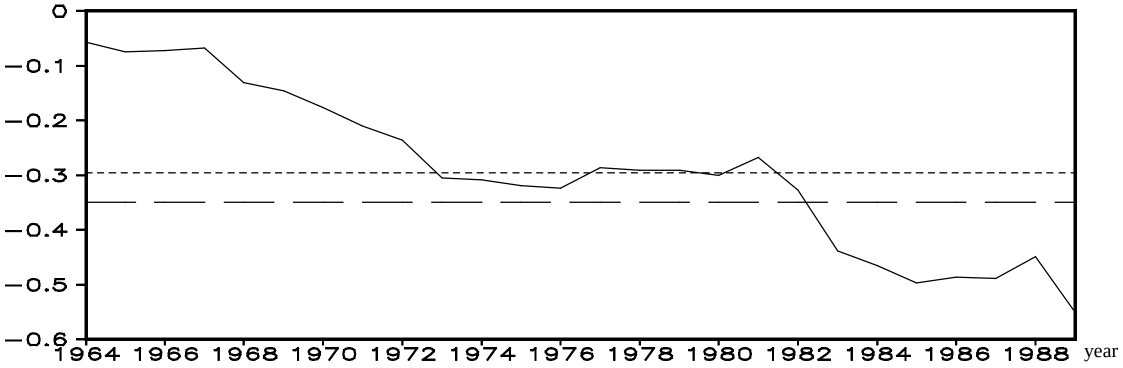

Fig.2 The distribution of moving correlation coefficients for preceding DMI2 and I_V2.

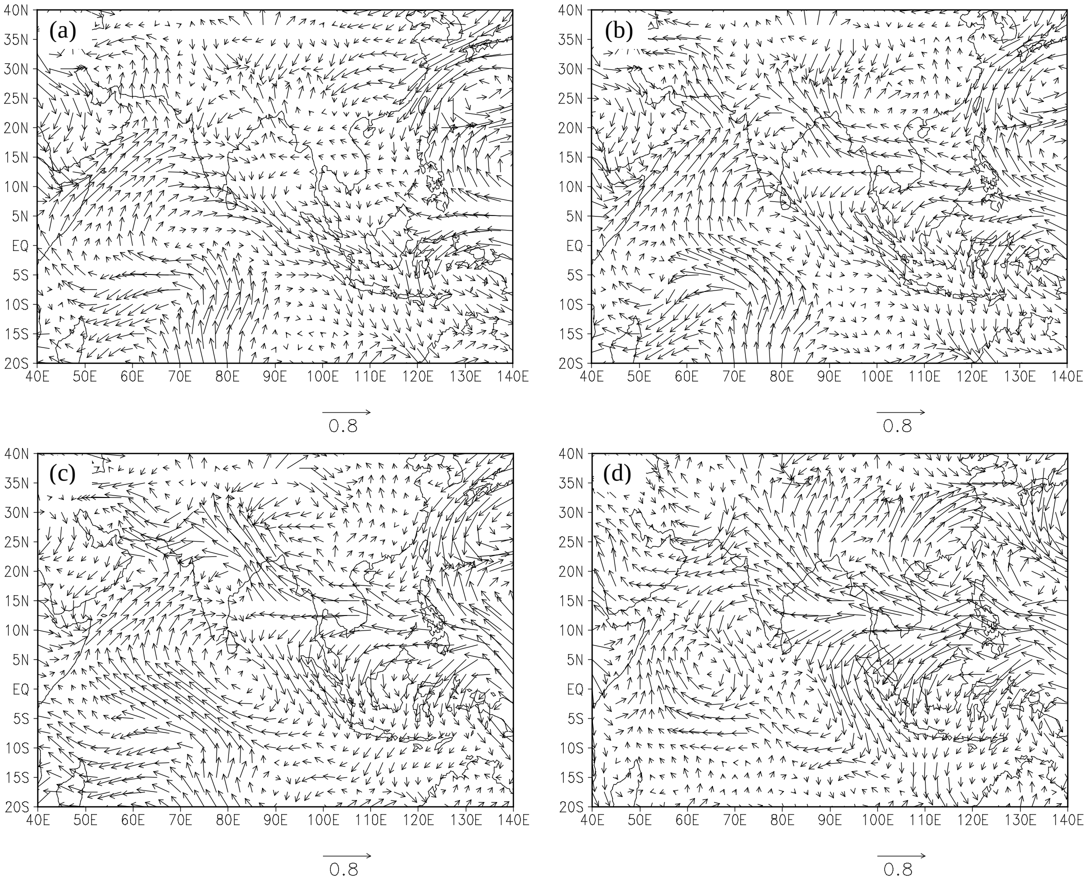

Fig.3 The spatial distribution for different sections of time of moving correlation coefficients between preceding DMI2 and summer 850-hPa wind field with bandpass filter (1 – 8 a). The interval is about 8 years between phases. (a) Phase 1; (b) Phase 2; (c) Phase 3; (d) Phase 4.

1965 – 1995, and 1974 – 2004, respectively.

4 EFFECT OF THE INTENSITY CHANGE OF SOUTH CHINA SEA SUMMER MONSOON ON IODM IN SUCCESSIVE AUTUMN

With USBM rejected from all over the region of tropical Indian Ocean for the successive autumn, the SSTA field is studied for its correlation with I_V1, which is determined with the original 850-hPa summer wind field (figure omitted). The distribution is also studied of the coefficients for the moving correlation between I_V2 and successive DMI2. Here, the moving window takes 31 a (figure omitted). For analyses of other aspects, refer to the Chinese edition of the journal.

5 CONCLUSIONS

On the basis of monthly mean SST of Reynolds for 57 a and global atmospheric reanalysis data of NCEP/NCAR for 56 a, this work analyzes the relationships between the autumn IODM of tropical Indian Ocean and the intensity change in the SCS summer monsoon.

(1) The main modes of SSTA are the uniformly signed basin-wide mode (USBM) and Indian Ocean dipole mode (IODM). The first mode mainly reflects the variation of autumn SSTA, which is uniform across the whole basin, on the interdecadal or above scales, while the IODM mainly displays the variation of autumn SSTA over the tropical Indian Ocean on the interannual scale.

(2) The autumn USBM does not correlate well with the SCS summer monsoon, whether it is the preceding or successive autumns in the tropical Indian Ocean.

(3) When IODM is positive (negative) in preceding autumns over the tropical Indian Ocean, summer monsoon weakens (intensifies) in the SCS. Negative correlation between them in the interannual variation is not significant during the cool phase of long-term warming trend of climatic background but significant during the warm phase.

(4) When summer monsoon intensifies (weakens) in the SCS, IODM is positive (negative) in the successive autumns in the tropical Indian Ocean. Positive correlation between them in the interannual variation is significant during the warm and cool phases of long-term warming trend of climatic background but insignificant during the transitional time between the two phases.

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