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SSTA SIGNAL CHARACTERISTIC ANALYSIS OVER THE INDIAN OCEAN DURING RAINY SEASON IN CHINA

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ABSTRACT: The teleconnection distribution characteristics of sea surface temperature (SST) over the India Ocean and the precipitation during rainy season in China were studied by using the methods of EOF and CCA. The results indicate that the change of SST field will affect the change of rain belt during rainy seasons in China, and greatly affect the precipitation in northwest and southwest China, the Yangzi and Yellow River downstream basins. Strong signal phenomena of SSTA over India Ocean were revealed that showed the anomalous distribution of drought and flood in China. It shows that the precipitation during rainy seasons in China may be forecast by analyzing SST distribution characteristics over the India Ocean.

Key words: precipitation in China's rainy season; SSTA; canonical correlation analysis; signal characteristics

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1 INTRODUCTION

The air-sea interaction is one of the main causes for climatic anomaly and oscillation. As the ocean has a strong "memory" and persistence, the sea surface temperature anomaly (SSTA) plays an essential role in long-term weather and climate changes. Among discussions on the effect of the oceans on the precipitation in rainy seasons in China, many are focusing on the Pacific region. As shown in much of the work[1-4], the anomalous changes in SST of the equatorial eastern Pacific (El Niño or La Niña) are well corresponding to the variation of precipitation over the rainy season in most parts of China. The changes in the rain belts and precipitation over the rainy season in China are brought about through influences on the interactions of planetary-scale Asian monsoon systems between the high and low latitudes. Here comes the point: the SST changes are of global structure with geographic links and peculiarities and the air-sea interaction affects the rainy season precipitation in China from regions in addition to the Pacific area. Earlier study has already confirmed the argument that the southwest monsoon is one of the moisture channels to provide for the summertime precipitation in China. As the source and passageway for the southwest monsoon, the Indian Ocean, by its varying distribution, directly affects the monsoon and in turn the precipitation in Chinese rainy seasons so that anomalies occur. It looks much more important to study the effect of SST variation in the Indian Ocean on the rainy season precipitation in China. Back in the 1980's, Jin et al.[5] made a statistic study of the Indian Ocean SST and summertime precipitation in China, discovering that the distribution patterns of SST in northern Indian Ocean and South China Sea

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during the autumn and winter are good indicators of precipitation in summer over the middle and lower reaches of the Changjiang R. (Yangtze) — a warm (cold) pattern of water implies the appearance of wet (dry) mei-yu period. It is unfortunate to find that the SST variation over the Indian Ocean is related to the precipitation in most parts of China in a complicated manner. To have a clear corresponding relationship between the SST field and precipitation field as well as their own characteristics, the current work employs the empirical orthogonal function method (EOF) and canonical correlation analysis method (CCA)[6] to study the teleconnection between the two element fields, the Indian Ocean SST and China's precipitation in rainy seasons. The aim of the effort is to have a deeper understanding of how the variation of SST in the Indian Ocean could affect the precipitation in the rainy seasons so as to lay basis for short-term climatic prediction in China.

2 DATA AND METHODS

Monthly mean SSTA data resolvable by 5.0°×5.0° for the Indian Ocean (32.5°N ~ 17.5°S, 32.5°E ~ 122.5°E) from January to August 1951 through 1995 were selected, which is part of a specialized climatic dataset in “research on short-term climatic prediction operational system” with grant No. 96-908-04-08 (1), a core scientific and technological project in the 9th-five-year economic development plan of China. In a corresponding move, the amount of rainfall recorded at 42 weather stations in China in June ~ August from 1951 to 1995 was selected. The stations distribute in a geographic region bounded by 20°N ~ 50°N, 100°E ~ 130°E and the locations are shown in the figure below (“○” indicates where the stations are).

It was with the CCA method that the distribution of telecorrelation was studied between the SSTA field of the Indian Ocean and precipitation field in the rainy season of China. To fully extract principal information of the original fields undertaking the CCA analysis and analyze more of the main features of climatological distribution of the rainy season precipitation in China, a truncation treatment is first applied using the EOF for reservation of a number of primary components that have relatively large contribution of accumulative variance for the follow-up CCA analysis. As they reflect the main features of the variation in the original fields by retaining major information of large-scale spatial distribution of the original fields, filtering out small-scale spatial disturbances and keeping in orthogonal relation among themselves, the primary components can be used to represent the original fields for analysis.

3 Climatological characteristics of precipitation in rainy seasons of China

EOF expansion is conducted for the precipitation in the rainy seasons in China. Fig.1a and 1b are the first and second characteristic-vector fields. It is shown that the precipitation is unevenly distributed with large regional difference. The first characteristic-vector field (variance contribution of 16.6% as shown in Fig.1a) has indicated that the precipitation in the rainy season of China is predominantly of east-west zonal distribution that alternates drought and floods. The trends of drought/flood variation in northeast China and Changjiang R. valley are opposite to those in the south of China, in rainy seasons. When there is more precipitation in the former regions, there is less in the south of China and the middle and lower reaches of the Yellow R. Otherwise is true. The most dramatic changes in precipitation occur in the southern part of China. The second characteristic vector gives a distribution of rainy season precipitation much different from the one given by the first characteristic vector, indicating that the secondary distribution of the precipitation is nearly north-south in the longitudinal direction. When there is more precipitation in the lower reach of the Yellow R., middle reach of the Changjiang R. and central South China, there is less in

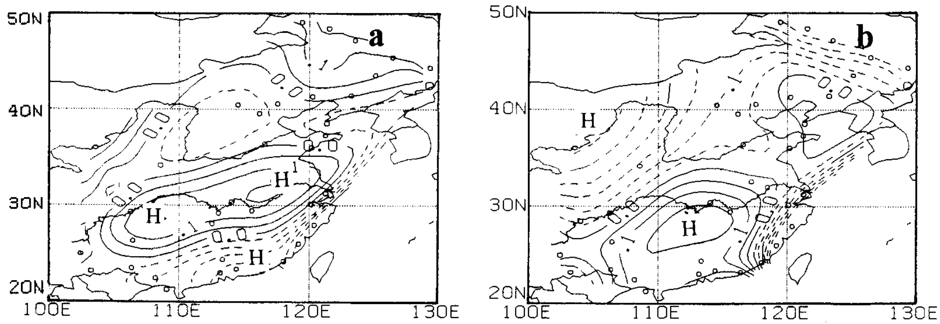

Fig.1 The first (a) and second (b) characteristic vector fields of precipitation during the rainy season in China. "o " is where the observation stations locate.

northwestern China, western North China, northern Southwest China and eastern South China. Otherwise is true. There may be some differences between the past and present conclusions depending on the data used. Two of the major patterns of precipitation in the rainy season of China as given in the conclusions are generally able to describe the basic characteristics of changes in the precipitation.

4 TELECONNECTION BETWEEN RAINY SEASON PRECIPITATION FIELDS OF CHINA AND SSTA FIELDS OF INDIAN OCEAN

In view of the obvious seasonal changes in tropical SST and monsoon, the January ~ August monthly mean SSTA in the Indian Ocean are divided into three periods of January ~ March, April ~ May and June ~ August. Then the EOF method is used to isolate monthly mean SSTA fields in these periods, which are put through a CCA analysis with a number of primary components with the accumulative variance taking up by more than 85% of the June ~ August precipitation anomalies from 1951 to 1995. The number of the primary components is listed in Tab.1. It is seen that all element fields converge rapidly and the first 16 primary components have extracted more than 85% of the information in the original fields (the first 9 primary components by more than 70% of the information in the original fields). Next, an X^2 examination[6] is performed with the CCA results. The results (Tab.2) show that the correlation of SSTA is high between the Indian Ocean and the rainy season precipitation in China, in the preceding and concurrent periods and the CCA coefficient surpasses 0.9, being the best with the transition season April ~ May, followed by the period

Tab.1 The number of principal components with variance contribution being 85% in the elements field

Elements field	Precipitation in Jun. ~ Aug.	SSTA in Jan. ~ Mar.	SSTA in Apr. ~ May	SSTA in Jun. ~ Aug.
No. of principal components	16	16	17	15

Tab.2 Significance test results for canonical teleconnection field

month	Jan. ~ Mar.	Apr. ~ May	Jun. ~ Aug.
No. of canonical teleconnection fields through test	2	2	2
Correlation coefficient of 1st and 2nd fields	0.96986 0.95932	0.98212 0.95936	0.97808 0.96133

January ~ March. Due to limitation of the text length, discussions will be held on the first couple of canonical teleconnection fields due to good correlation between them.

Fig.2 gives the first couple of CCA-correlated fields in January ~ March between the Indian Ocean SSTA and the rainy season precipitation in China. It is known that the positive and negative correlation zones of the rainy season precipitation (Fig.2a) are distributed north-south in the longitudinal direction, the negative correlation being east of 118°E except in the western part of Southwest China and southern part of South China and the positive correlation being in the rest of the area. The most pronounced positive correlation is found in the "Hetao" (Knot of the River) region on the Yellow R. while the most obvious negative correlation is observed in the western Southwest China. In their respective preceding January ~ March period in the Indian Ocean, the most outstanding negative correlation of canonical SSTA field appears in the central and southwestern equatorial parts of the ocean while the most outstanding positive correlation in the Arabian Sea.

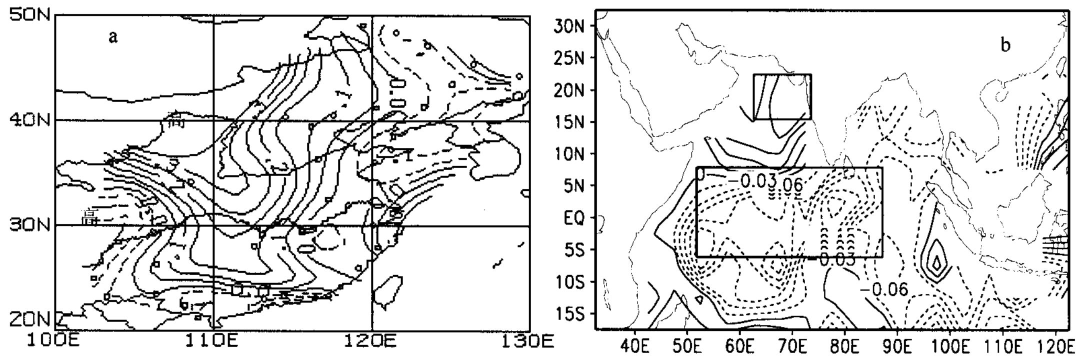

Fig.2 The first couple of canonical correlation field between the precipitation in the rainy season in China and the SSTA from January to March over the Indian Ocean. (R = 0.96986)

As we know, it is relatively warm over the ocean than the land in the winter-half year in the tropics and low-level atmosphere flows from the land towards the ocean in what is known as the prevailing winter monsoon, due to larger thermal capacity of the latter as compared to the former. Studying Fig.2b, we learn that the significant rise of temperature in most of the central and western equatorial Indian Ocean is recorded in January ~ March, the winter monsoon strengthens as a result of increased wintertime thermodynamic difference between land and sea brought about by the heating effect of the ocean on the atmosphere. The winter monsoon weakens otherwise. Correspondingly, when there is more precipitation in Central China, Northwest China through North China in the rainy season of June ~ August, there is less rain in most of Southwest China and East China. When the SST varies by a reversed phase, e.g. as temperature rises sharply in the most of the central and western parts of the Bay of Bengal ~ equatorial Indian Ocean region, especially in the central and western parts of the equatorial Indian Ocean, the winter monsoon intensifies. Corresponding changes are evident in the precipitation of successive periods, which are marked by decreased precipitation in the rainy season in Central China through Northwest and North China and increased precipitation in Southwest China and most of East China. The most obvious response in precipitation occurs in Northwest China and western Southwest China.

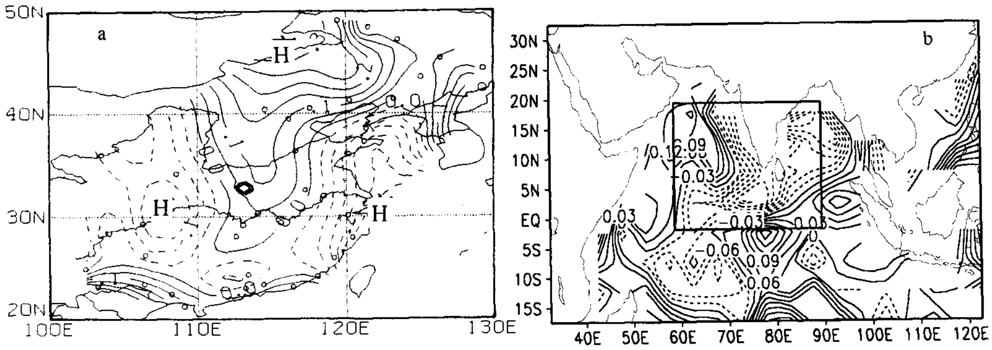

Fig.3 The first couple of canonical correlation field between the precipitation in the rainy season in China and the SSTA from April to May over the Indian Ocean. (R = 0.98212)

Fig.3 gives the first couple of fields in canonical correlation between the Indian Ocean SSTA and precipitation in China's rainy season in April ~ May. Being similar to the distribution of the precipitation in rainy seasons and SSTA field in corresponding Fig.2, both positive and negative correlation areas move eastward, increasing the precipitation in most of the region, with positive correlation in North China-Central China, and negative correlation in Northwest China-northern, Southwest China, South China and most of the East China coastal areas. The most dramatic change in precipitation happens in North China, Southwest China and lower reach of the Changjiang R.. The equatorial central Indian Ocean and the Bay of Bengal are two regions of most significant (negative) correlation for the ocean's SSTA. April and May are the key months in the transition from winter monsoon to summer monsoon, with anomalous variation of SST having a particular important effect on the monsoon in early summer. By studying the verifications of canonically correlated fields in Tab.2, one knows that the SST changes have the most significant correlation with the precipitation in the rainy seasons. As shown in Fig.3, the teleconnection fields are so distributed that low SST in April ~ May in the Bay of Bengal-equatorial central and western Indian Ocean would lead to less precipitation in Southwest China, South China and lower reaches in the Changjiang and Yellow Rivers in the corresponding rainy season; high SST would result in an opposite trend of variation in the rainy season precipitation.

Summarizing the analysis above, we know that changes in January ~ May SST in the Indian Ocean, especially in the central and western equatorial parts, affect to some degree the changes in north-south longitudinal rain belts in the rainy season of China. Correspondingly, the most significant response of precipitation are respectively located in Northwest China, Southwest China, western North China and lower reach of the Changjiang R.. Specifically, the relation between the variation of precipitation and SST in the rainy season of the lower reach of the river has something in common with the distribution of SSTA of northern Indian Ocean in the preceding winter of canonical drought/flood year for the middle and lower reaches of the Changjiang R..

Fig.4 gives the first couple of canonically correlated field in June ~ August between the SSTA in the Indian Ocean and precipitation in the rainy season of China. The rain belts in the period (Fig.4a) are obviously different from those studied above (Fig.2a & 3a), with the correlation areas, both positive and negative, in east-west zonal distribution. Positive correlation is evident in all but some small parts of northern North China which are of negative correlation, north of the Changjiang R., while negative correlation prevails in most of the region south of it The response to precipitation is the most distinct in Northwest and South China. Two of the most significant positive and negative correlation areas corresponding to the teleconnection field of Indian Ocean SSTA are respectively in the Arabian Sea and equatorial central and western Indian Ocean.

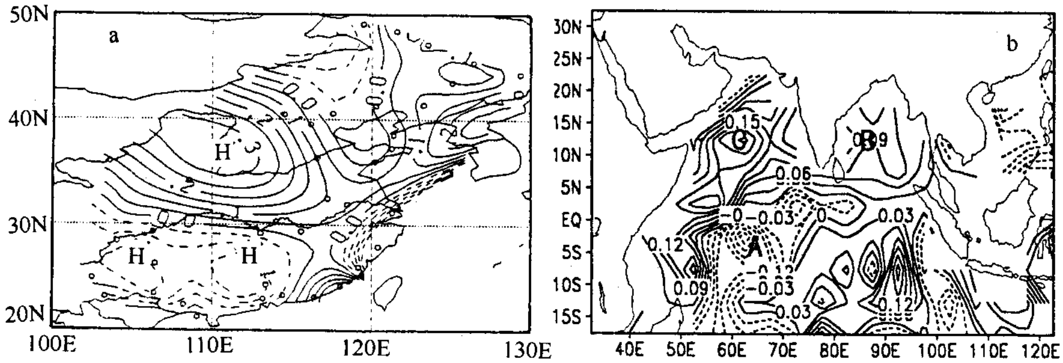

Fig.4 The first couple of canonical correlation field between the precipitation during the rainy season in China and SSTA from June to August over the Indian Ocean. (R = 0.97808)

There is an anti-Walker cell near the equatorial Indian Ocean, in which the air currents rise in the east but fall in the west. The distribution of SST teleconnection field (Fig.4b) shows that the SST varies in the equatorial central and western Indian Ocean (to be simplified as Region A) in a way opposite to that in the Bay of Bengal (Region B) and Arabian Sea (Region C). When the SST falls in Region A and rises in Regions B and C, low-level convergence strengthens in the equatorial central and western Indian Ocean, which then enhances the descending flow in the anti-Walker cell. The increased anti-Walker cell strengthens the anomalous westerly near the equator in the Indian Ocean (the southwest monsoon strengthens correspondingly). When the SST varies by an opposite trend over these waters, the anti-Walker cell weakens to decrease the anomalous easterly near the equator (the southwest monsoon weakens correspondingly). As shown in the distribution of teleconnection field for the simultaneous period (Fig.4), in association with decreased SST in the equatorial central and western Indian Ocean and much increased SST in the Arabian Sea and Bay of Bengal in June ~ August, the southwest summer monsoon will increase in the Indian Ocean, with the monsoon extending northward extensively and the westerly frontal zone going north with it, leading to less precipitation in most areas south of the Changjiang R. but more precipitation north of it. On the other hand, increased SSTs in the equatorial central and western Indian Ocean and lowered SSTs in the Arabian Sea and Bay of Bengal in June ~ August will be accompanied by the weakened southwest summer monsoon, with the monsoon extending northward mildly and the westerly frontal zone going south with it, leading to more precipitation in most areas south of the Changjiang R. but less precipitation north of it. The anomalous variation of Asian monsoon is one of the principal factors that govern the climatic changes in China. The distribution characteristics of its canonical correlation field are additional proof that such variation is indeed playing an important role in affecting the precipitation in the rainy seasons of China.

It can be concluded from the study above that the variation of SST in the equatorial central and western Indian Ocean has the largest influence on the precipitation in the rainy season of China. Computing the coefficients of correlation between the summer precipitation in the middle and lower reaches of the Changjiang R. and the SST field in the preceding and concurrent periods, Luo et al.[4, 9] discover that regions with confidence level greater than 0.05 are in the South China Sea and near the equatorial Indian Ocean, which is consistent with the findings in the current work. Further study indicates that the Indian Ocean SSTA significantly affects the precipitation in Northwest China, Southwest China and lower reaches in the Changjiang and Yellow Rivers, with the preceding periods contributing to the longitudinal (north-south) variation, and the concurrent periods to the latitudinal (east-west) variation, of the rain belts. Reference [10] is a study on the correlation between summer precipitation between China and India. It shows that the best correlation is located in Northwest China with the significance level more than 99% in the north of Shanxi province. Reference [11]'s study also points out that the rise (fall) of SST in the Indian Ocean is accompanied by less (more) precipitation in Northwest China for the simultaneous period, which bears some resemblance with the findings in this work. With more efforts, the current work presents direction description of the teleconnected fields corresponding to the two fields. The relation of variation in most-correlated region of the fields is studied, with clear inherent synoptic meaning identified.

5 EFFECTS OF INDIAN OCEAN SSTA ON TYPE OF RAIN BELT IN CHINA

To some degree, the above-presented canonical correlation analyses are reflecting the teleconnection distribution between the two fields. For detailed study of the relationship between rain belt types in the rainy seasons of China and SST variation in the Indian Ocean, we have computed the coefficients of correlation between the first and second primary components in the rainy season and the annually averaged SSTA in the Indian Ocean, decomposing the EOF (Fig.5).

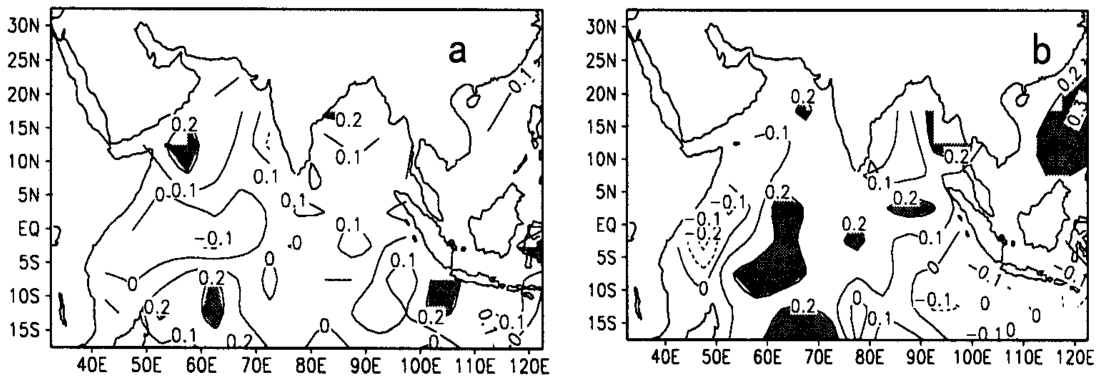

Fig.5 Coefficients of correlation between the first (a) and second (b) principal components of the precipitation during the rainy season in China and annually averaged SSTA over the Indian Ocean. The shaded areas are where coefficients larger than 0.2 are found.

As indicated in Section 3, the rain belts are distributed firstly by east-west latitudinal (first characteristic vector) components and secondly by north-south longitudinal (second characteristic vector) components. From Fig.5, we know that the first primary component of precipitation is little correlated with the SSTA in all waters but the Arabian Sea, waters east of Madagascar and near Jakarta, in which the correlation coefficient is more than 0.2. In contrast, the second primary component has a more significant correlation with SSTA than the first one does, with the coefficient higher than 0.20 and passing the 0.10 confidence test in the Arabian Sea, Bay of Bengal and part of the equatorial central Indian Ocean. More recent study with numerical simulation provides additional proof of the effects of the Indian Ocean SSTA on the north-south variation of rain belts in the summer of China[12].

6 CONCLUDING REMARKS

a. The anomalous variation of SST in the equatorial central and western Indian Ocean exerts an important influence on the precipitation in the rainy season of China, especially on the anomalous variation of precipitation in Northwest, Southwest and lower reaches of the Changjiang and Yellow Rivers. It can be used as a strong signal in the prediction of rainy season drought/floods in China.

b. Rain belts aligning in east-west or north-south direction are the major patterns of distribution of precipitation in the rainy seasons of China. The anomalous variations of the Indian Ocean SST in preceding periods have relatively large influence on the north-south longitudinal variation of rain belts while those in concurrent periods show their major effect in the east-west latitudinal variation of rain belts, in the rainy seasons of China.

c. Mainly through the anomalous variation of monsoon, the SSTA in the equatorial Indian Ocean affects the variation of precipitation in the rainy seasons of China. In January ~ March, the SSTA in the Bay of Bengal-equatorial central and western Indian Ocean is negatively correlated with the rainy season precipitation in North, Northwest and Central China but positively correlated with the rainy season precipitation in western Southwest, southern South China and lower reaches of the Changjiang and Yellow Rivers. In April ~ May, it is negatively correlated with the precipitation in North and Central China but positively correlated with the precipitation in Southwest, South, lower reaches of the Changjiang and Yellow Rivers. In June ~ August, it is negatively correlated with the precipitation in most of the region north of the Changjiang R. but positively correlated with the precipitation in most of the region south of it.

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