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PRELIMINARY DISCUSSIONS OF BASIC CLIMATIC CHARACTERISTICS OF PRECIPITATION DURING RAINING SEASONS IN REGIONS SOUTH OF CHANGJIANG RIVER AND ITS RELATIONSHIP WITH SST ANOMALIES

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ABSTRACT: Basic climatic characteristics are analyzed concerning the precipitation anomalies in raining seasons over regions south of the Changjiang River (the Yangtze). It finds that the regions are the earliest in eastern China where raining seasons begin and end. Precipitation there tends to decrease over the past 50 years. Waters bounded by 9°S –1°S, 121°E – 129°E are the key zones of SST anomalies that affect the precipitation in these regions over May ~ July in preceding years. Long-term air-sea interactions make it possible for preceding SST anomalies to affect the general circulation that come afterwards, causing precipitation anomalies in the raining seasons in regions south of the Changjiang River in subsequent years.

Key words: precipitation anomalies in raining seasons of regions south of Changjiang River; SST anomalies; correlation analysis

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1 INTRODUCTION

The Jiangnan Region is in the eastern part of China that is south of the Changjiang River and north of Nanling Mountains. It encompasses southern Hunan, southern Jiangxi, most of Fujian and southern Zhejiang. It is a base for the production of grain and cotton among other well-developed agricultural economy. Its eastern coastal area is also an important industrial base. Climatic anomalies in the region are threats to human life and property for tens of millions people and bring damages to industrial and agricultural production and national economic construction. Few work in the past treat the region as a whole in the study of climatic characteristics while the period of interest is mostly in the summer (June to August). Chen[1] points out in a study on its regional climate that the raining season usually begins in early April and ends in late June. For the region, large difference can be seen in either the seasonal or interannual variation as compared to the Changjiang River valley and area south of the Nanling Mountains. It is therefore of much significance to deeper understanding of the regional climatic characteristics as well as to disaster mitigation by separately studying the precipitation during the raining season for activity laws.

With the main effort first on basic climatic characteristics and its relationship with SST anomalies during the raining season (April to June), the work then uses the composite analysis to discuss the anomalies of the general circulation in raining seasons subsequent to cold / warm

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water years and to probe into the mechanism in which SST anomalies affect the precipitation.

2 DATA AND METHODS

The data used in the work include month-to-month rainfall at 160 weather stations in China from January 1951 to December 1999 as compiled by the National Climate Center, global monthly gridpoint data with intervals of 2°×2° from January 1950 to December 1999 as compiled by the British Meteorological Office, and the NCEP / NCAR reanalysis data of monthly mean geopotential height and wind field with intervals of 2°×2°.

To ensure that the selected stations have consistent precipitation anomalies in April – June, the fuzzy cluster method is used to study precipitation anomalous series for the 49 years of raining season south of 35°N. For the analysis of interdecadal variation, a new smoothing processing method, the binomial coefficient weight averaging, is used.

In addition, techniques like wavelet analysis, correlation analysis, composite analysis and *t*-test are also used in the work.

3 CLIMATOLOGICAL CHARACTERISTICS OFRAINING SEASON PRECIPITATION IN THE JIANGNAN REGION

3.1 *Selection of representative stations in the Jiangnan Region*

To ensure that the selected stations have consistent precipitation anomalies in April – June, the fuzzy cluster method is used to study precipitation anomalous series for the 49 years of raining season south of 35°N (89 stations in all). With standardized mean precipitation anomalies for April – June (the raining season in Jiangnan Region) from 1951 to 1999, a time series that spans 49 years is formed. Correlation coefficients are used to measure the quantitative indexes of two samples with high resemblance.

With a preset correlation standard (ë = 25, Fig.1), Jiujiang, Anqing, Shanghai, Hanzhou, Ningbo, Dunxi, Pucheng, Quxian, Guixi, Nanchang, Changde and Yueyang weather stations in the middle and lower reaches of the Changjiang River, and Lingling, Yongan, Guangchang, Jian, Ganzhou and Shaoguan stations north of the Nanling Mountains, are clustered in a group. Considering the natural division in the region, we select 14 stations to represent the Jiangnan Region, namely, Nanchang, Guixi, Dunxi, Quxian, Pucheng, Hanzhou and Ningbo in the middle

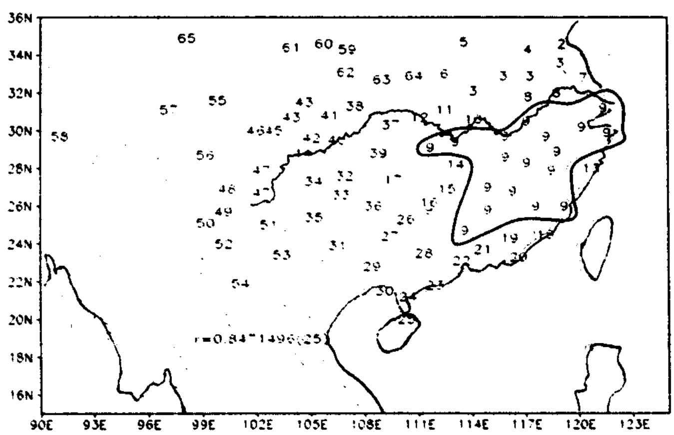

Fig.1 Fuzzy cluster results of precipitation series for April – June over the 49 years in areas south of 35°N in China.

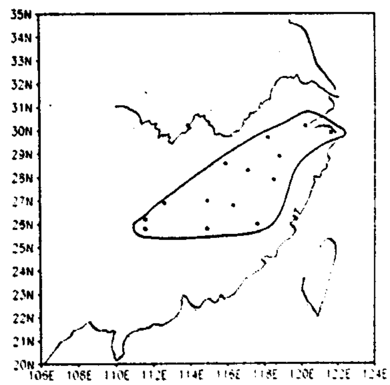

Fig.2 Stations selected to represent the Jiangnan Region.

and lower reaches of the Changjiang River, and Lingling, Yong' an, Guangchang, Ji' an, Ganzhou and Hengyang stations north of the Nanling Mountains (Fig.2). They are different from either the middle and lower reaches of the Changjiang River or the Huanan Region (Huanan Region). They are generally consistent with the stations selected by Chen[1] to stand for the Jiangnan Region.

3.2 *Seasonal variations of the precipitation in the Jiangnan Region*

The work uses the difference between monthly precipitation and multi-year annual mean precipitation to represent seasonal variations. The raining season is defined to be months for which the difference is positive in the course of the year. Fig.3 gives the curves for monthly rainfall in the Jiangnan, middle-and lower- reaches of the Changjiang River and the Huanan Region. The line across the figure is the annual mean rainfall. By comparison, we know that the three curves are in a dual-peak pattern in the Huanan Region, with the first peak appearing in June over the Jiangnan, the middle-and lower- reaches of the Changjiang River and Huanan Region. The raining season is from March to June in Jiangnan Region, which is relatively dry from July. The period in which we have the most rainfall is from April to June, which takes up 44.1% of the annual total. The figure also shows that an obvious drop of rainfall is seen in July over the Jiangnan and Huanan Regions, even more so with the former. It may be explained by the fact below. The subtropical high is more southward location of in May and June so that the Huanan Region and most of the Jiangnan Region are at its northern edge. The water vapor is so rich that rainfall increase sharply in the two regions. In early July, however, the subtropical high jumps north and controls most of Jiangnan and eastern Huanan, exposing them to the subtropical high that brings much sunshine and little rain and drastically reduces the rainfall[1]. In August, a secondary rain peak appears in the Huanan Region as a result of typhoon-related rain while the subtropical high is still controlling the Jiangnan Region and the middle- and lower- reaches of the Changjiang River, leading to a smaller rainfall than in June. It is then seen that it is indeed unique in the Jiangnan Region as compared to the other two. It is apparently inappropriate to take the period June to August as the raining season for Jiangnan. In this work, therefore, the raining period will be from April to June for the region.

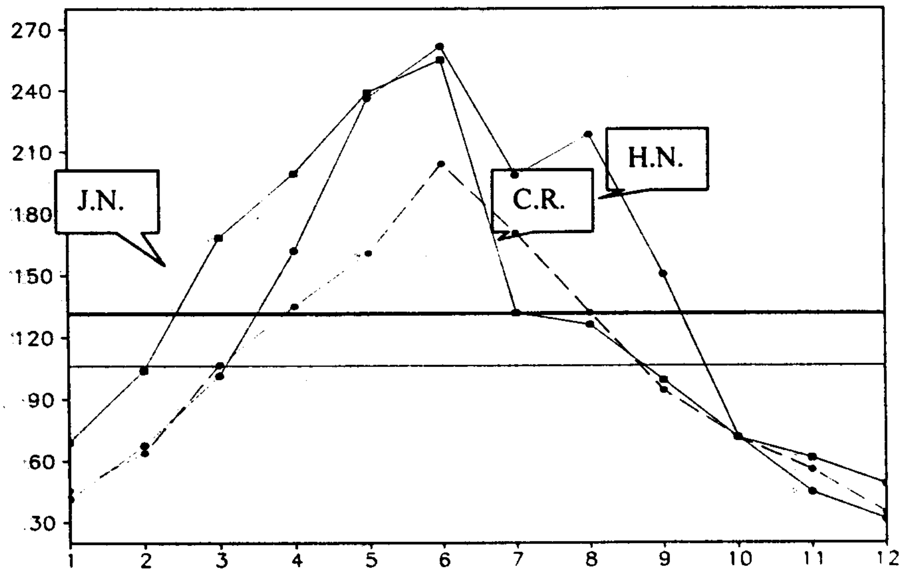

Fig.3 The curves for monthly rainfall in the Jiangnan, middle-and lower- reaches of the Changjiang River and the Huanan Region. J.N. stands for Jiangnan, C.R. for Changjiang River and H.N. for Huanan.

For the climatological characteristics of precipitation, the interannual and interdecadal variations are subjects meteorologists are more interested in, apart from seasonal changes. For the purpose, the wavelet analysis is used to study the temporal distribution of anomalous periods of precipitation.

3.3 *Wavelet analysis of precipitation anomalies in the Jiangnan Region*

With the wavelet transform, we can understand the temporal distribution in different periods. For the temporal series of standardized anomalies of precipitation in April – June over the 49 years in the Jiangnan Region, the Morlet and Marr wavelet methods (figure omitted) are separately used to study it. On the Morlet wavelet correlation chart (Fig.4), we can clear see that an interdecadal variation of about 22 years is always evident in the 49 years. It also shows that obvious 10-year periodic oscillations exist before 1984, 7-year oscillations in the 1950's and 1970's and there are steady 6-year oscillations from the 1980's. In the mid-1950's, 1970's and the years after 1986, quasi-biennial oscillations appear, more dominantly in the 1970's. For the time after 1986, the 3-year periodic oscillations become more significant.

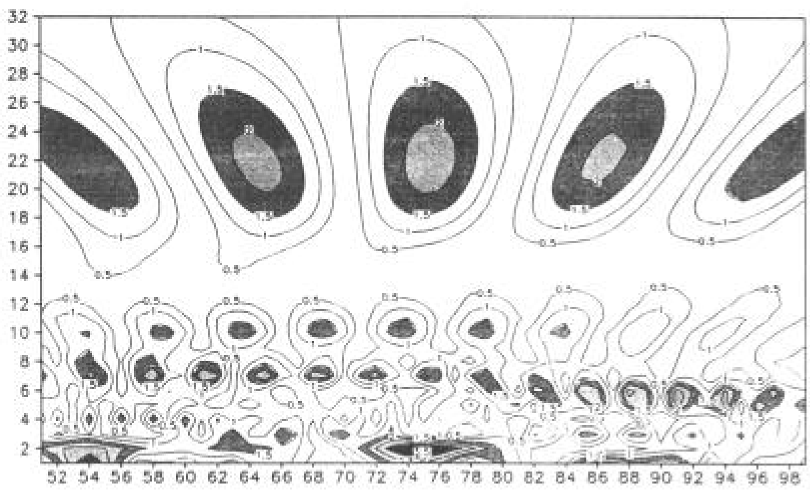

Fig.4 Morlet wavelet coefficients for April – June precipitation anomalies in the 49 years in Jiangnan region.

3.4 *Interdecadal variation of precipitation anomalies in the raining season of Jiangnan Region*

To analyze the interdecadal variations and tendency changes of the precipitation in the raining season of Jiangnan, the standardized anomalies of the April – June precipitation (1951 – 1999) are used to run 11-year smoothing mean and linear fitting and compare them with the precipitation in the raining season of Huanan.

From the smoothed curves of Fig.5a, we clearly see there is generally less rain in all periods except for 1951 – 1957 and 1971 – 1977. The curve tends to rise when it comes to the 1990's, possibly in another period of relatively more rain. Examining the smoothed curve for the Huanan raining season, we know that the region witnesses a period of relatively less rain from mid-1950's to the 1960's, followed by a rapid rise in the 1970's, making it a wet decade. As in the above case, the curve begins to fall in the 1980's and a period of relatively less rain starts. The precipitation increases a little in the 1990's but it is still dry enough to label it a dry period. Based on the analysis above, we know that variations tend to be consistent on the inderdecadal

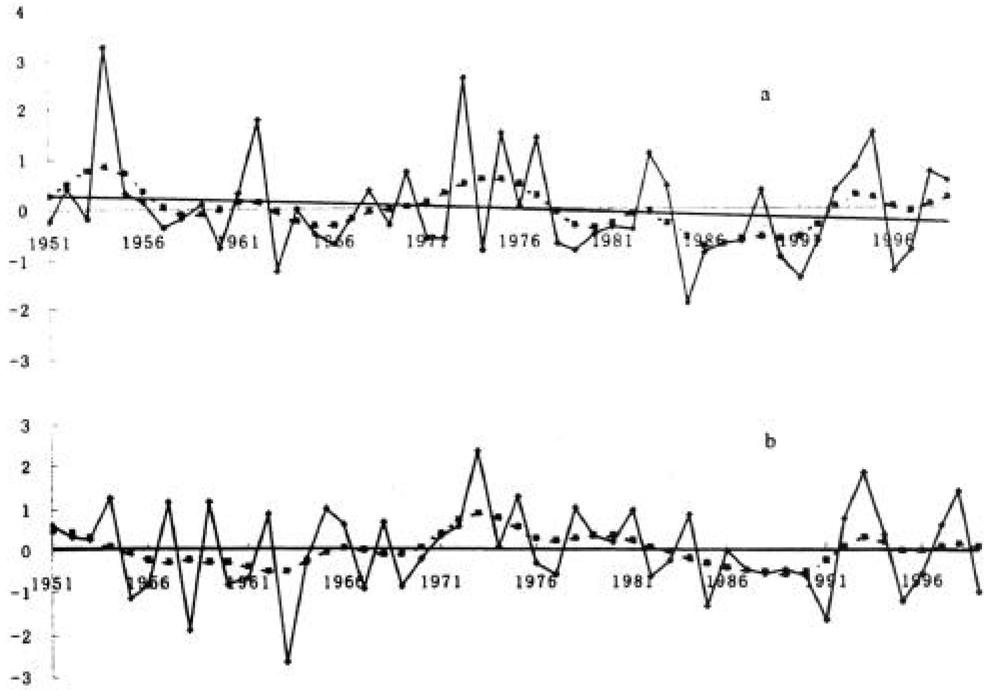

Fig.5 Standardized anomalies, 11-year smoothing and linear fitting for the precipitation in Jiangnan's raining season (April – June) (a) and the yearly first raining season in Huanan (b).

scale between the Jiangnan and Huanan Regions except for the 1950's and the time from the end of 1970's to the early phase of 1980's (with correlation as high as 0.60 for the smoothing curve). The trend curve in Fig.5a tends to descend, indicating the Jiangnan raining season (April to June) tends to have decreasing rainfall in the 49 years, though not as significantly as in North China and the Yellow River and Huai He River valleys where there is serious aridity[8]. It is known from Fig.5b that the variation of precipitation is small in the Huanan's yearly first raining season over the 49 years.

3.5 *Interannual variations of Jiangnan raining season and the selection of more and less rain years*

In the Jiangnan raining season (April to June), the monthly mean precipitation is 231 mm and the r.m.s. error for monthly mean precipitation is 47.8 mm. If the absolute value 0.8 for the standardized precipitation anomalies is used to decide if a year is with more or less rain (Fig.5a), the results are listed in Tab.1.

Tab.1 Years of more rain and less rain in the Jiangnan Region

More rain	1954、1962、1973、1975、1977、1983、1994、1995
Less rain	1960、1963、1974、1979、1985、1986、1990、1991、1996、1997

From Tab.1, there are eight years with more rain and ten years with less rain, being a comparable number. They add to 18 years together, i.e. there is one in every 2.7 years in which we have more or less rain. The table also shows that the 1970's and 1990's are two decades when there are frequent climatic anomalies in the Jiangnan Region, having much more years in which rain is more or less than normal. Positive anomalies are higher than negative ones, indicating that in more-rain years the floods can be very serious while the drought is not serious in less-rain years, with the exception of the time after the 1980' s when the drought is serious in such years.

4 CORRELATION BETWEEN JIANGNAN RAINING SEASON PRECIPITATION AND GLOBAL SSTA

4.1 *Correlation analysis*

For standardized precipitation anomalies over the 49 years during the raining season of Jiangnan and the global SSTA from January the year before last to the current December. In the work here, the 14 stations in the Jiangnan Region are averaged as a single point, which is sought for correlation with the SST. The length of the global SST data is between 1950 and 1999. From the figure (omitted) of correlation between month-to-month SST and raining season precipitation in the region, we see that the region with the highest and steadiest correlation is the Banda Sea north of East Timor. The correlation coefficient stays below 0.40 from May to November before the preceding year (surpassing the 0.01 confidence test), being the most in May, June and September. Other regions with comparable correlation include the equatorial eastern Pacific and North Pacific. As correlation persists for quite a long time in the Banda Sea and with stable high correlation area, it is the region we focus our effort on.

4.2 *Selection of key SST areas and time periods*

From the text above we know that the SST anomalies from May to November before the preceding year in the Banda Sea are well correlated negatively with the precipitation in the raining season of the Jiangnan Region (passing the 0.05 confidence test). To select key SST areas and time periods, correlation is sought between the precipitation during the time and mean SST over the raining season. Then, the region (9°S – 1°S, 121°E – 129°E) whose coefficient is below –0.40, is preliminarily selected before month-to-month smoothing clustering is determined and correlation is sought between the precipitation in Jiangnan and the selected region for the period from May to November before the preceding year. The results are presented in Tab.1. The numerals therein are the correlation coefficients of mean SST over the period from *I* month to *J* month between the raining season precipitation in Jiangnan and the selected region.

Tab.2 Correlation coefficients between the Jiangnan raining season and SST of the selected region over individual periods

	5	6	7	8	9	10	11
5	-0.42	-0.45	-0.46	-0.45	-0.47	-0.47	-0.47
6		-0.43	-0.43	-0.43	-0.45	-0.45	-0.45
7			-0.39	-0.40	-0.43	-0.43	-0.42
8				-0.39	-0.42	-0.42	-0.42
9					-0.43	-0.42	-0.41
10						-0.38	-0.37
11							-0.30

As shown in Tab.2, the correlation coefficients are relatively large in periods May – July, May – September, May – October, May – November in the year before last. Incorporating all possible factors, the work uses the period from May to July as the key in addressing the effect of the SST. Fig.6 gives the distribution of correlation coefficients for the Jiangnan raining season precipitation and global mean SST over May – July in the year before the last. The key areas so

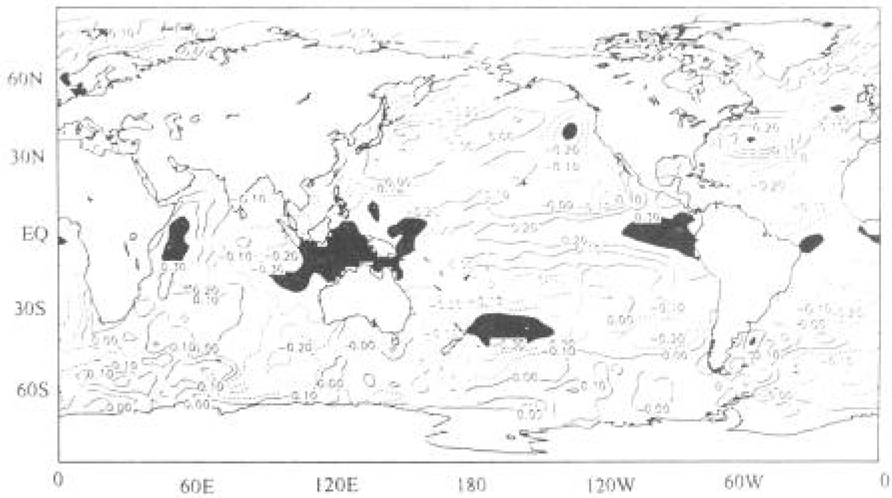

Fig.6 The distribution of correlation coefficients for the Jiangnan raining season precipitation and global mean SST over May – July in the year before the last. The shades are areas where the 0.05 confidence level is passed.

obtained is still bounded by 9°S – 1°S, 121°E – 129°E, called the Key region. (Refer to the area with the correlation coefficient less than –0.40).

4.3 *Selection of warm and cold water years*

Following the curves for interannual variations of standardized anomalies of SST over the Key region and periods of time (Fig.7), the r.m.s error times 0.85 is used as norm to select 11 cold water years and 11 warm water years in the 49 years of interest. They are listed in Tab.3.

Tab.3 Cold and warm water years (* stands for the year in which they are in good corresponding relationship years of more or less rainfall)

Cold water years	1951、1952、1953*、1965、1966、1967、1972*、1976*、1982*、1993*、1994*
Warm water years	1956、1958、1973*、1978*、1981、1986、1988、1989*、1990*、1996*、1998

4.4 *Corresponding relationship between SST and precipitation in temporal distribution*

From Tab.3 and Fig.1, we know that cold and warm water years predict more-rain and less-rain years by rates of 6/11 and 5/11, respectively. Examining from an opposite viewpoint, however, opposite situation does not occur in which the years subsequent to cold (warm) water years do not have less (more) rain. Corresponding to years of more rain or less rain are the years of cold water or warm water by rates of 6/8 and 5/10, respectively. In summary, a cold water year foretells more or normal precipitation while a warm water year warns of less or normal precipitation, in the coming year' s raining season.

To investigate how SST corresponds to the interdecadal variation of precipitation, we derive 11-year running mean of the SST in the Key region and standardized anomalies of precipitation in Jiangnan (Fig.8). It shows good corresponding correlation of interdecadal variation between them except for the 1960' s. The cold water periods in the 1950' s and 1970' s are with the years in which there is more rain while the warm water periods from late 1970' s to early 1990' s go with the years in which there is less rain. It is noted that the linkage is worse defined in the later stage of the 1990’ s.

From either interannual or interdecadal corresponding relationship, we find that the worst corresponding period is from 1962 to 1972 between precipitation anomalies of Jiangnan raining season anomalies and SST anomalies in the Key region. The otherwise good relationship and the abnormal linkage between them are a subject that requires more study. It also shows that SST anomalies are a major but not the only factor governing precipitation anomalies in the region.

4.5 *Circulation anomalies in April – June in the years subsequent to cold or warm water years*

SST anomalies in preceding periods gradually affect the anomalies of general circulation at a later stage via the air-sea interactions. The work will analyze how SST in the Key region affect the precipitation anomalies in Jiangnan by means of composite analysis of circulation anomalies in the years following cold or warm water years.

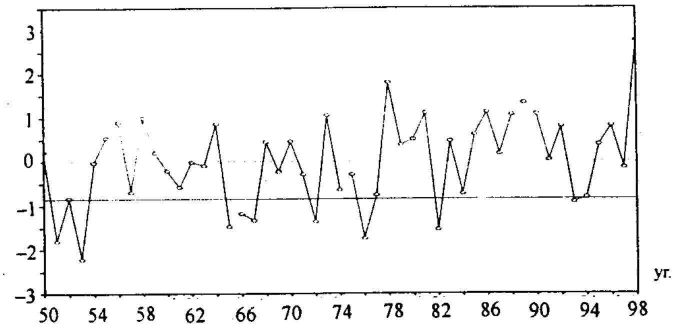

Fig.7 Interannual variations of standardized anomalies of SST over the Key region and periods of time.

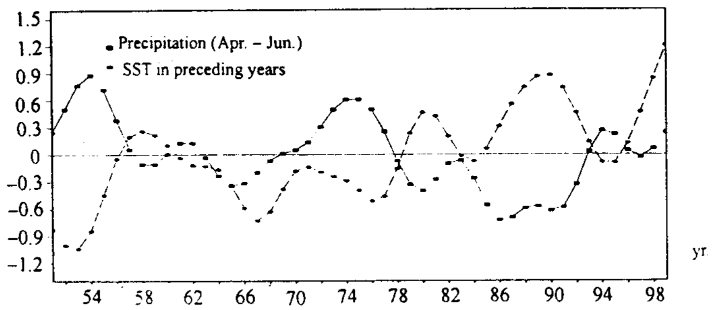

Fig.8 11-year running mean of the SST in the Key region and standardized anomalies of precipitation in Jiangnan.

Fig.9 gives the wind vector anomalies at 850 hPa composed for the Jiangnan raining season in the subsequent years after cold or warm water processes. In April – June following cold water years (Fig.9a), anti-cyclonic circulation and positive geopotential anomalies appear in places where there is the subtropical high, suggesting that the latter is stronger than normal. To the west of a cyclonic anomalous circulation over the East China Sea, there are northerly anomalies and those coming southeast from the Great Bend of the Yellow River are converging with southerly anomalies to the west the subtropical high. On the 500-hPa anomalous map, obvious anomalous divergence is found over the Jiangnan Region (figure omitted). In the years following warm water events (Fig.9b), we see a weak cyclonic anomalous circulation takes the place over what is formerly the subtropical high so that strong northerly anomalies prevail over vast areas of China east of 110°E. The northerly also controls the whole region of the South China Sea. For the part west of 110°E, however, low latitudes north of the equator is in the control of easterly anomalies, indicating weakened southwest monsoon over Indian in April – June following warm water episodes. The circulation situation inhibits the northward transportation of warm and humid air and is thus unfavorable for the formation of precipitation.

From the study above, we know that SST in the Key region has limited effect on the circulation at a later time. When preceding SST is lower than usual, general circulation will be affected through long-time air-sea interactions. What stand out in the patterns of anomalous general circulation in subsequent April – June is that the subtropical high gets stronger to increase tropical monsoon and activate cold air activity in the north, making low-level atmosphere in the Jiangnan Region a level of significant convergence and high-level atmosphere one of obvious anomalous divergence, thus favorable for more rain in its raining season. When SST is stronger than usual in the current time, the air interacts with the sea so that general circulation in subsequent April – June is made unfavorable for precipitation to occur in the Jiangnan's raining season, due to the dominance of northerly anomalies over extensive areas of eastern China. The governing mechanism is the internal cause for good negative correlation between SST in the Key region and the precipitation in the raining season of Jiangnan.

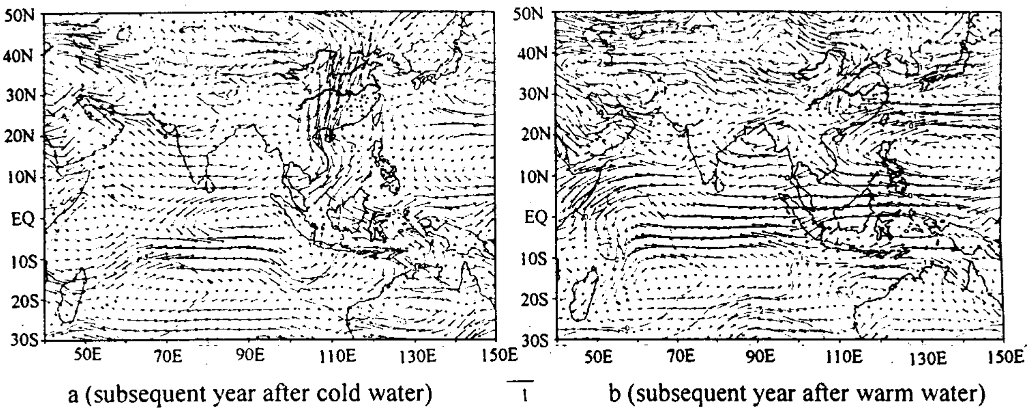

Fig.9 Wind vector anomalies at 850 hPa composed for the Jiangnan raining season in the subsequent years after cold or warm water processes. The dashed lines are for geopotential height anomalies.

5 CONCLUDING REMARKS

Basic climatological characteristics for the precipitation in Jiangnan's raining season are analyzed in the work. It is found that the regional rain concentrates in the late spring through early summer (April – June) in a unimodal seasonal distribution. The region is the earliest to begin and end the raining season in eastern China. Precipitation there tends to decrease slightly over the recent 50 years.

Good negative correlation is located between the precipitation in Jiangnan and SST off the northern coast of Australia in preceding period. The Key region is 9°S – 1°S, 121°E – 129°E and the key period of time is May through July in years prior to the raining season.

As shown in study on mechanisms, preceding SST affects the general circulation at a later stage by long-term air-sea interactions, resulting in precipitation anomalies in raining seasons in the subsequent years over the Jiangnan Region.

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