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A STUDY ON RELATION BETWEEN EAST ASIAN WINTER MONSOON AND CLIMATE CHANGE DURING RAINING SEASON IN CHINA

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ABSTRACT: Based on the data of NCEP, OLR and rainfall of China, we studied the influences of the East Asian winter monsoon activities on the precipitation during the raining season over China by correlation analysis and composite analysis. The result shows that annual and interdecadal change of East Asian winter monsoon is distinct. It is strong from 1950s to the middle of 1980s but weak after the middle of 1980s. The effect of abnormal winter monsoon on the precipitation during raining season is significant over the middle and lower reaches of the Changjiang River basin. It is revealed that the precipitation will increase when preceding winter monsoon is weak but decrease when preceding winter monsoon is strong. In this paper, some appropriate reasons are given to explain the abnormal rainfall by analyzing the distribution of SSTA and the variation of summer circulation. It is pointed out definitely that the variation of SSTA and summer circulation is a primary cause for abnormal rainfall over the middle and lower reaches of the Changjiang River.

Key words: East Asian winter monsoon; East Asian subtropical summer monsoon; summer precipitation over the middle and lower reaches area of the Changjiang River

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1 INTRODUCTION

The Asian monsoon and its anomalies play an important role in the global general circulation and climatic change. As an essential component of the monsoon system, the East Asian winter monsoon is not only the most vigorous across the globe but also the most active circulation system in the boreal winter. Its anomalous changes can not only result in the changes in the general circulation in global winter to cause destructive weather like low temperature, cold damages and high winds but also bring about delaying effect on droughts and floods in summer in many parts of the nation. With a study on preceding circulation characteristics prior to either droughts or floods in the Changjiang and Huaihe River valleys, Sun et al. [1] report that the weather is well correlated with the East Asian trough in winters that come before it; circulation anomalies in wintertime have important effect on its performance later, especially in the low and middle latitudes. Liu's study [2] gives specific patterns responding to spring precipitation in eastern China in preceding winters. In their modeling experiment, Ji et al. [3] further show with evidence that the winter monsoon affects the global climate change and the influence is correlated every other season.

Being major natural disasters in China, summer drought / floods pose serious threats on national economy and the well-being of people. It is therefore economically important for their causes to be probed with the aim to mitigate damages. Locating in a well-known monsoon climate zone in East Asia, China is dominated by the winter monsoon that takes regular control

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of the continent for six months. It is an important restraint for the circulation changes in the winter and summer in the region. It is then significant to investigate their patterns of activity and variation and the relationship between them and precipitation in China, for it helps extract precursory signals predicting the onset of droughts and floods in China and improve the ability to predict short-term climate during the spans.

Mainly by studying observations, the work is an attempt to study the winter monsoon in East Asia from the viewpoint of circulation and thermodynamics in terms of its effect on droughts and floods in China.

2 DATA AND DEFINITION OF EAST ASIAN WINTER MONSOON

The data used in the work include:

(1) NCEP 500-hPa reanalysis data from 1948 to 2000 and low-level longitude-latitude wind data from 1958 to 1997.

(2) Global sea surface temperature anomalies (SSTA) data from 1948 to 1997 with grid intervals of 5°×5°.

(3) Surface outgoing longwave radiation (OLR) data from 1979 to 1997 with grid intervals of 5°×5°.

(4) Monthly mean precipitation data over 160 stations in China from 1951 to 1995, which is provided by the China Meteorological Administration.

East Asian winter monsoon is a complicated climate system, which originates from periodic southward flow of the northeast airflow on the front edge of the Siberia high. As far as the circulation situation is concerned, the intensity of the winter monsoon is mainly reflected in the variation of the 500-hPa East Asian trough and surface Mongolian cold high. As the formation of monsoon is associated with land-sea contrast and difference in thermodynamic capacity between the two features, Guo[4], in early 1980's, used longitudinal accumulated values of sea level pressure difference over the region from 20°N to 50°N at 110°E and 160°E, respectively, to express the intensity of summer monsoon. To eliminate the effect of inhomogeneous distribution of mean square deviation for individual grids on the intensity of the East Asian monsoon, Shi et al[5].(1996) use a similar method to rerun a standardization treatment of the sum of the difference at 110°E and 160°E between standardized sea level pressures every 5 latitudes from 20°N to 50°N, and define the result as the index for winter monsoon in East Asia. Sun et al[6]. use standardized 500-hPa geopotential height, which is related to active winter monsoon in East Asia, air temperature over the Asian continent, and northerly component at 1000 hPa on the coast of southeastern China, to see whether the winter monsoon is strong. In this work, the 500-hPa East Asian trough, which depicts the winter monsoon intensity in the region, is used to define an index using the monthly mean 500-hPa geopotential height field in preceding December and successive January and February (DJF), which is standardized to take regional mean of the geopotential height over 110°E – 130°E, 25°N – 40°N and the result is put through standardization processing again to describe the winter monsoon intensity. It is denoted $\boldsymbol{I}_{win}$. The $\boldsymbol{I}_{win}$ set in this work is one that is averaged seasonally, which better displays the variation of the winter monsoon on the seasonal scale.

3 INTERANNUAL AND INTERDECADAL VARIATION OF EAST ASIA WINTER MONSOON

The definition of winter monsoon in East Asia in [5] reflects the interannual variation of zonal difference of surface pressure between land and sea. Compared with its variation over the period from 1951 to 1990 (Fig.1), the current index agrees well with the interannual variation, though with a different definition. They are correlated at a rate of 0.65, far surpassing the 0.01 confidence test. In the figure, the winter monsoon is weak when the index is $I > 0$; it is strong when the index is $I < 0$. For the period from 1950 to 1980, both indexes indicate strong winter monsoon in 1962/1963, 1967/1968 and 1973/1974 and weak winter monsoon in 1988/1989 and 1989/1990, varying over a range of ± 1.0. For the years 1962/1963 and 1967/1968 in which the winter monsoon is the strongest, both indexes surpass –1.5.

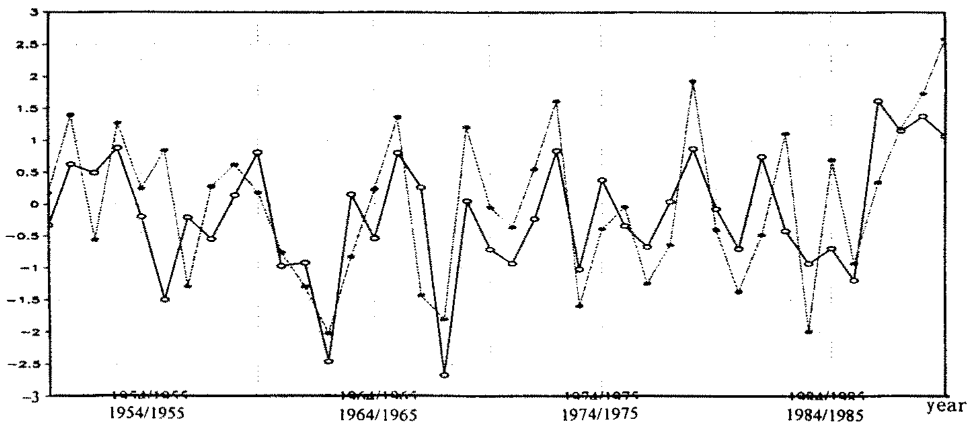

Fig.1 Land-sea pressure difference at sea level (the dashed line) between 1951 and 1990 and variation of winter monsoon index for 500 hPa in East Asia (the solid line).

Fig.2 gives the variation of winter monsoon index as defined by the work between 1948/1949 and 1999/2000 (the solid line), in which $I_{\rm win} > 0$ indicates that the winter monsoon is weak while $I_{\rm win} < 0$ means that it is strong. It can be seen that the winter monsoon is marked by obvious interannual and interdecadal variation. The former fluctuation is larger with the index up to 1.7 (1986/1987) for the maximum and down to –2.7 (1967/1968) for the minimum, with the

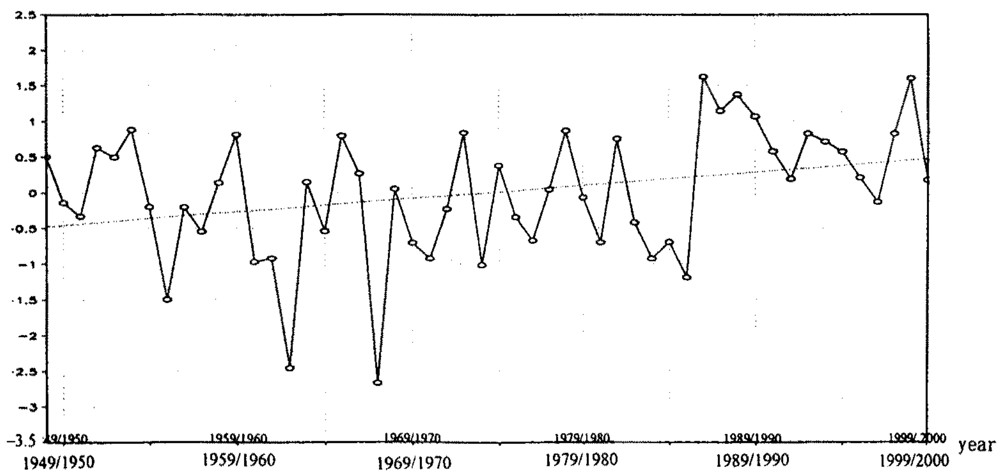

Fig.2 Winter monsoon index (the solid line) for East Asia and linear variation trend (the dashed line) in the 500-hPa geopotential height field between 1948/1949 and 1999/2000 (ranging from 25°N – 40°N, 110°E – 130°E).

highest interannual difference as high as 4.4. To make the following discussion more representative, the year in which $I_{win} > 1$ is set as a weak monsoon year while $I_{win} < 1$ is set as a strong monsoon year. For the period between 1948/1949 and 1999/2000, there are six years of strong winter monsoon and five years of weak one. The former category includes 1955/1956, 1960/1961, 1962/1963, 1967/1968, 1973/1974, and 1985/1986; the latter includes 1986/1987, 1987/1988, 1988/1989, 1989/1990, and 1998/1999.

In Fig.2, the dashed line shows the tendency of linear decreasing variation of winter monsoon for 1949 – 2000. For the time before 1986, the variation is mainly that of increase, with two of the stronger years 1962/1963 (–2.4) and 1967/1968 (–2.8) appearing at the time. Over the same period, however, the monsoon index is all below 1.0, with the maximum year (1953/1954) only 0.8. For the time after 1986, the winter monsoon changes in just a reversed way, with weak monsoon dominating. For the 14 years that span from 1986 to 2000, the winter monsoon is relatively weak in all but 1996/1997 (–0.3) and the weakest monsoon occurs in 1987 (1.7) and 1999 (1.7).

4 EAST ASIA WINTER MONSOON AND PRECIPITATION IN CHINA'S RAINING SEASON

4.1 *Geopotential height characteristics of strong and weak winter monsoon years*

Following the definitions above, Fig.3 (a & b) gives the composite field of 500-hPa geopotential height in DJF concurrent with the years of strong or weak winter monsoon. It is seen that the distribution of geopotential height in the middle and high latitudes in the Eurasian continent is generally reversed for the strong and weak years of winter monsoon. For the years of strong monsoon, the distribution is two negatives plus one positive, with negative values east of the Mt. Ural and along the coast of East Asia and positive values between Lake Baikal and Lake Balkhash. As shown in the distribution of composite anomalies field, a pattern of two troughs alternating with a ridge in the region helps increase the East Asia trough. On the other hand, for the strong winter monsoon, the distribution of the anomalous field in the middle and high latitudes of the Eurasian continent is just the reversed from that for the weak winter monsoon, facilitating the strengthening of the East Asia trough. The distribution is just the reversed in years of weak winter monsoon, when two positives alternating with a negative. The entire northern Asia is controlled by a positively anomalous area, with the center of greater than 40 gpm around

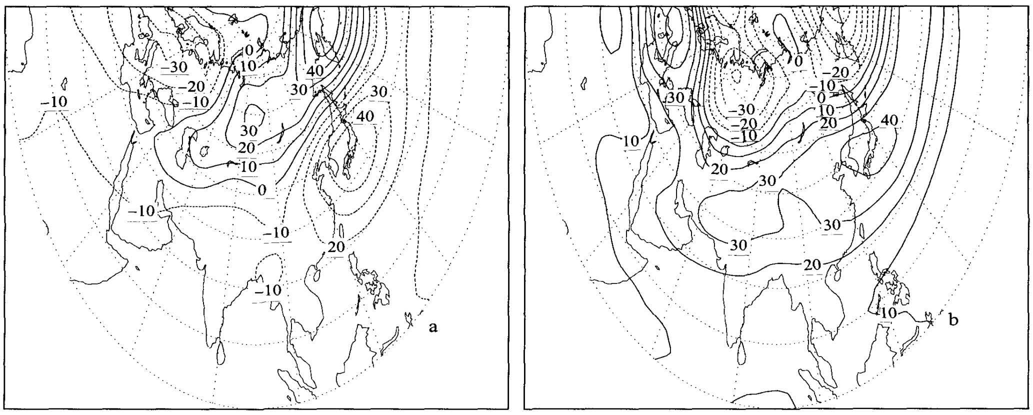

Fig.3 Composite 500-hPa geopotential anomalous fields in DJF of strong (a) and weak (b) winter monsoon years (unit: geopotential meter).

East Asia, showing that the East Asia trough is more northward and weaker than normal.

4.2 *Winter monsoon and precipitation in the raining season of China*

Due to the interactions between the ocean, land and atmosphere, the winter monsoon anomalies have some impact on the precipitation in the summer. Fig.4 gives the distribution of the winter monsoon index for 1951 – 1999 in correlation with precipitation measured at the 160 stations in China's raining season for June – August. It is known that the winter monsoon is well correlated with the precipitation in southern and part of northwestern China at a rate greater than 0.3, passing the 0.5 confidence level. The correlation is especially good between the monsoon and the raining season precipitation over the middle and lower reaches of the Changjiang R., with the maximum coefficient being 0.4. As shown in the distribution of the correlation field, there is more precipitation in the years of weak winter monsoon over the reaches and northwestern Xinjiang but less precipitation over Yunnan, southern China and parts of the Changjiang-Huaihe Rivers valleys. The precipitation distributes in just a reversed manner when the years are with strong winter monsoon. As the variation of East Asian winter monsoon correlates well with the precipitation in the middle and lower reaches of the Changjiang R., the following section will be mainly about the possible causes for the formation of precipitation anomalies as they are affected by the distribution of successive summer monsoon activity and thermodynamics of sea surface temperature (SST) over the years of either strong or weak winter monsoon.

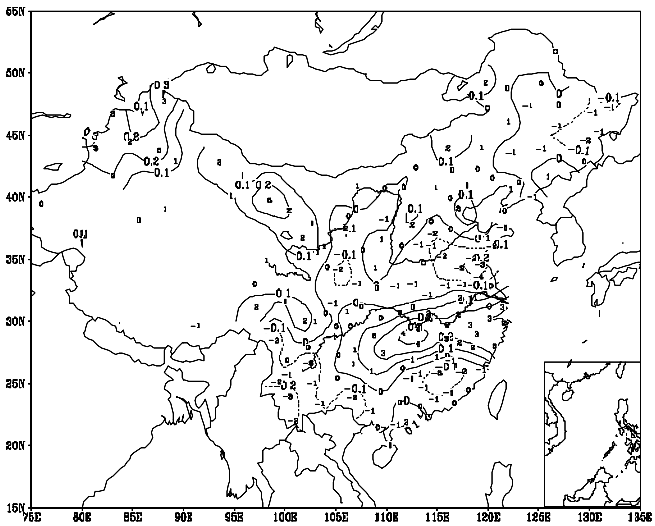

Fig.4 Distribution of correlation between East Asia winter monsoon index and precipitation measured at the 160 stations in the raining season of China (unit: 0.1).

5 EAST ASIA WINTER MONSOON AND FLOW FIELD VARIATION IN SUMMER

To study the effect of winter monsoon anomalies on the precipitation in the raining season of China, the relationship between the monsoon and circulation variation in summer is discussed. Fig.5 (a & b) gives the 850-hPa composite vector wind field from June to August (JJA) in the late period of strong and weak winter monsoon years.

The figure shows that the flow field is showing different characteristics in South Asia and most parts of East Asia for both strong and weak years of winter monsoon. During the summer in corresponding strong monsoon years, anomalous westerly prevails over the Bay of Bengal,

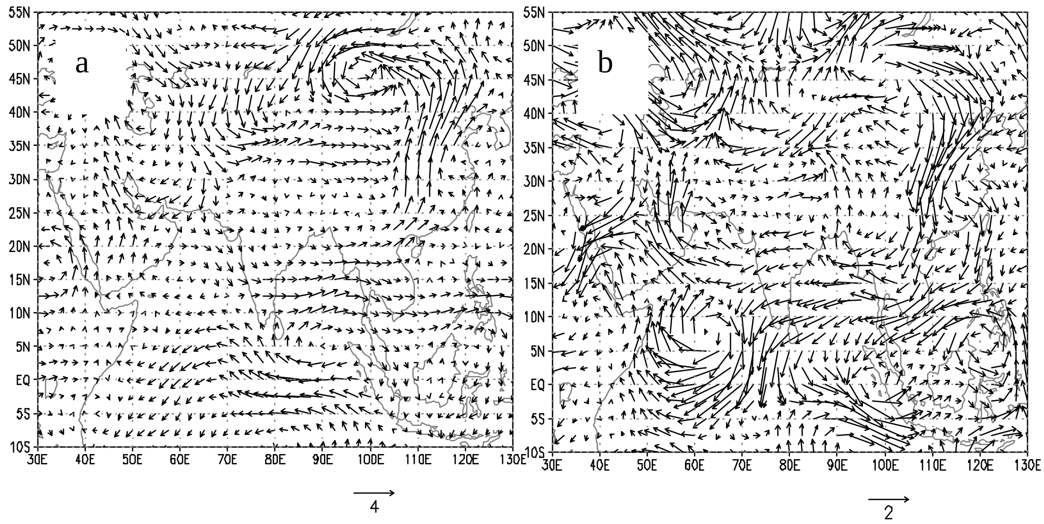

Fig.5 Composite vector wind at 850-hPa in the summer of strong (a) and weak (b) winter monsoon years (unit: m/s).

Indochina Peninsula through southern Philippines while anomalous southerly dominates over the mid-latitudes in East Asia. For the years of weak winter monsoon, however, the flow field varies in just the opposite way. The variation at 850 hPa shows that the changes in the summer monsoon are associated with those in the winter monsoon so that for the summer with strong (weak) winter monsoon in the preceding winter, the southwest monsoon in the Bay of Bengal and the South China Sea and the subtropical monsoon in East Asia will increase (decrease), the latitudes from which the summer monsoon expands northward will be high (low) and the trade wind in the equatorial western Pacific will strengthen (weaken). In addition, the cross-equatorial airflow also varies differently near 90°E – 100°E, increasing (decreasing) in the summer of strong (weak) monsoon years. Liang[8] points out in his study of the summer monsoon in the South China Sea and South Asia monsoon that the changes in the intensity of summer monsoon in early summer over the South China Sea and the Bay of Bengal are well positively correlated with those of the winter monsoon in East Asia. The figure of the flow field in this work is further proof of the relationship between the cross-equatorial current near 90°E and winter monsoon variation in East Asia. From Fig.5, it is also known that the variation of wind field in the subtropical high in the summer of East Asia varies significantly in years of strong or weak winter monsoon. The region is dominated by anomalous southerly in the summer of strong winter monsoon years, in which the subtropical summer monsoon increases; in the summer of weak winter monsoon years, however, it decreases. It is therefore known that the anomalous variation of the meridional wind field in the subtropics reflects not only the anomalous activities of the subtropical monsoon but also the cold air activity in the middle latitudes.

Fig.6 gives latitude-time cross sections of pentad-based meridional 1000-hPa winds along 110°E – 120°E from June to August, in which the weak winter monsoon years are subtracted from the strong ones.

Fig.6 clearly shows that over the entire summer monsoon period in the subtropical monsoon zone in East Asia, the southerly in the summer of strong winter monsoon years is stronger than that in the summer of weak ones, with the largest difference in the meridional wind appearing near 40°N. From the pentad-based variation of monthly meridional wind difference from June to August, we know that June is the month when the summer monsoon sets off and moves north, causing large fluctuation in the meridional wind difference. The difference is the largest in the

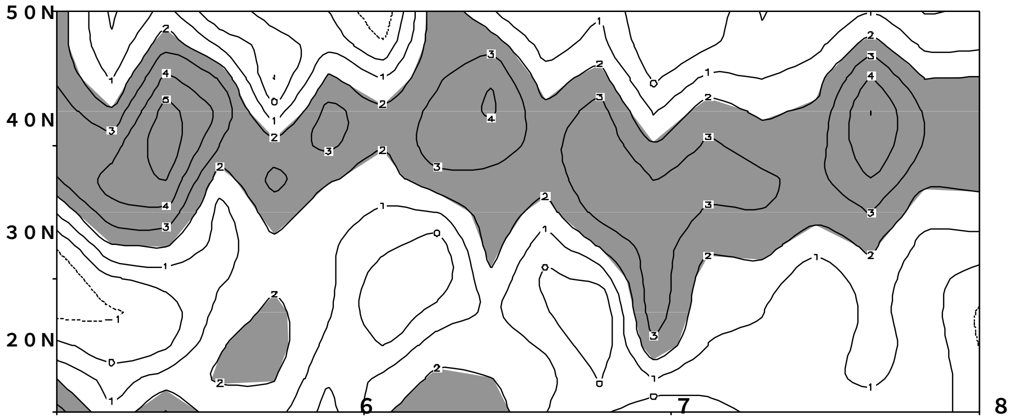

Fig.6 Latitude-time cross section of the difference in the 1000-hPa meridional wind at 105°E – 120°E in the summer of strong and weak winter monsoon years (unit: m/s). The abscissa is the month.

first half of June, about 5 m/s, while it is relatively small in the latter half. In July and August, the variation of the meridional wind is relatively smooth and its center moves close to 35°N. As the low-level southerly activity is unfavorable for the southward advancement of cold air, the above variation also indicates that the cold air activity in the middle and high latitudes of East Asia is stronger in the summer of weak winter monsoon years and moves southward to lower latitudes than in the summer of strong ones. In the meantime, the variation of meridional wind difference as shown in Fig.6 also indicates that the anomalous winter monsoon has serious effect on the activity of cold and warm air in the middle and low latitudes in East Asia during successive periods. More analysis of the correlation between the index for 1958 – 1997 and 1000-hPa meridional wind field for June – August also shows the presence of the correlation between the winter monsoon and flow field changes in summer. The winter monsoon index has a significant negative correlation with the changes in the meridional wind in eastern China during the yearly second raining season (JJA).

As pointed out by Zhao's study[9], the variation of summer monsoon in South and East Asia is well correlated with the changes in the location of rain bands in China. For the strong summer monsoon years, the probability is the largest for the Category I in China, with the rain band northward and less precipitation in the middle and lower reaches of the Changjiang R. for the weak summer monsoon years, Category III precipitation appears most frequently, with the rain band southward and more precipitation in these reaches of the river. It is then known from the changes in the flow field in summer that the anomalous variation of precipitation in these reaches of the river in both strong and weak winter monsoon years is immediately related to the anomalous activity of summer monsoon and anomalous variation of cold air in the middle latitudes.

6 EFFECT OF ANOMALOUS WINTER MONSOON ON SUCCESSIVE THERMODYNAMIC FIELD

It is known that as a place from which the global atmospheric motion is powered and latent heat released, the ocean is a very important mediator to supply and adjust energy for the atmosphere via the air-sea interactions so that exchanges of all kinds of energy are especially intense over its surface. It is therefore essential to study the distribution of SST for both strong and weak winter monsoon years and the variation of summer circulation in the middle and high latitudes.

When winter monsoon begins, the bulk of cold air moves south as the northeasterly wind off the front edge of the low-level cold high is gradually expanding south to form a strong northerly belt on the East Asia coast through the South China Sea. The variation of the latter will have immediate effect on the thermal distribution of monthly SST. Let's first examine its variation during the winter monsoon. Fig.7 gives the anomalous distribution in January and February. It can be found that it differs much in the Pacific Ocean and most of the Indian Ocean between strong and weak winter monsoon years, especially along the East Asia coast, regions south of the equator in eastern Pacific and the Indian Ocean. For the years with strong winter monsoon, the SST decreases in the coastal area of East Asia and the Indian Ocean and the negative anomalies are in control, because the northerly wind is relatively strong in the front portion of the low-level cold high to form cold surges. For the years with weak winter monsoon, however, the SST has just the opposite distribution, with positive anomalies and relatively high SST. In his study on the relationship between ENSO and winter monsoon changes in East Asia, Li[10] points out that the general circulation anomalies caused by ENSO will bring about the strengthening of the westerly belt and the northward location of the frontal zone in East Asia, both unfavorable for the outburst of the cold air to the south and easy to weaken the East Asian winter monsoon. Otherwise it will be strengthened. The conclusion generally agrees well with the variations of SST as shown in Fig.7 (a & b) in both years of strong and weak winter monsoon in the equatorial eastern Pacific.

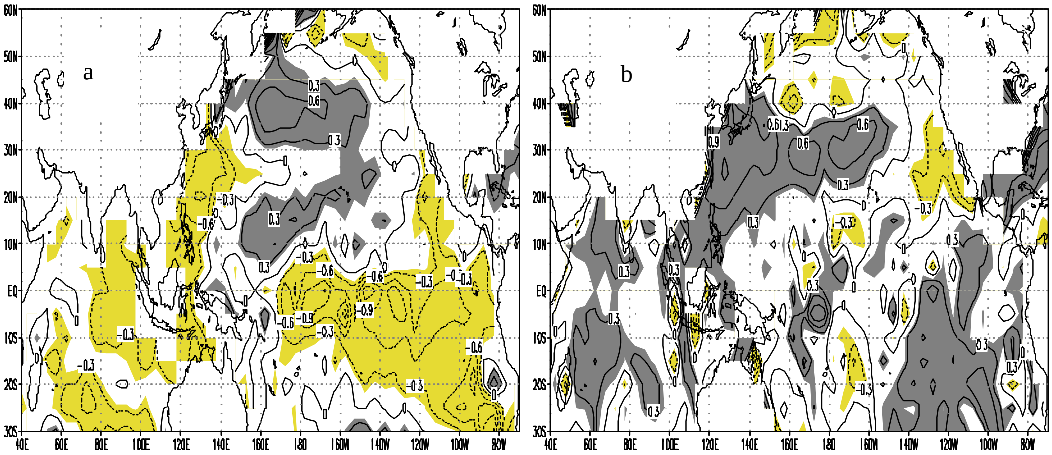

Fig.7 Composite SSTA in January and February of strong (a) and weak (b) winter monsoon years in East Asia.

Due to a large thermal capacity of the ocean, the thermodynamic changes of SST are slower over the ocean than on land surface. With a study on the distribution of the monthly SST field in the successive periods of the strong and weak winter monsoon years (figure omitted), we know how slowly such change is taking place. Fig.8 (a & b) gives the difference of composite SST anomalies between the spring and summer of the winter monsoon years. In March – August in the successive period of the strong years, the SST field generally distributes in the same way as the SST distribution for the wintertime and remains in the negative anomalous area, except for the Indian Ocean and South China Sea where it slightly decreases. The SST distribution in coastal East Asia and equatorial eastern Pacific in the strong winter monsoon years is mainly displayed as the shrinking negative anomalous area in coastal East Asia and equatorial eastern Pacific and the appearance of positive SST anomalies near 30°N, the coast of Peru and equatorial eastern Pacific. The latter is gradually increasing in size. For the years of weak winter monsoon, the positive SST anomalous area in coastal East Asia is shrinking towards the south and negative SST anomalies appear near 30°N on the East Asian coast and equatorial eastern Pacific, which is enlarging while the positive SST anomalies are decreasing over the Indian Ocean and South China Sea. Comparing Fig.8a and Fig.8b, we know that the positive difference zone for the central part of North Pacific is expanding from spring to summer, covering the coastal East Asia in the middle latitudes in summer. In addition, a positive zone also appears on the coast of Peru and near the equator in eastern Pacific.

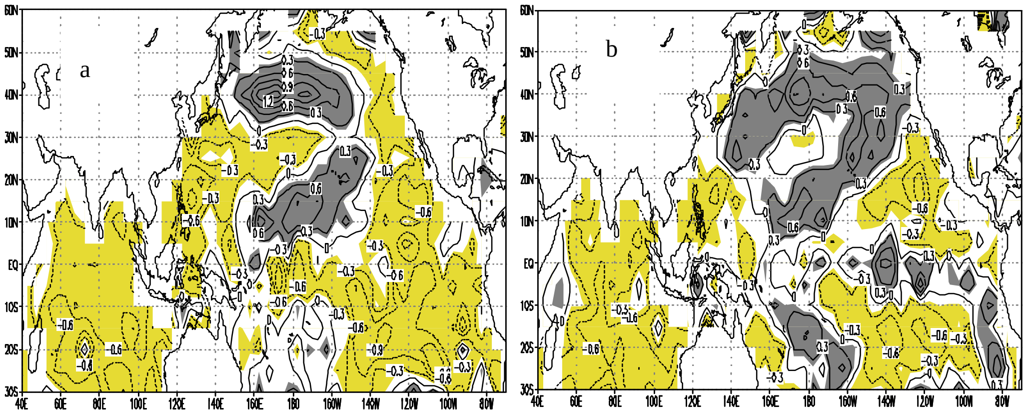

Fig.8 Composite SST for the strong winter monsoon years as subtracted by that for the weak ones over the spring time (March – May) and summer time (June – August).

As early as in 1988, Li [11] pointed out that the frequent activity of the East Asian winter monsoon causes the appearance of the westerly anomalies in the equatorial western Pacific, which have important effect on the ENSO cycles. Under the condition of the anomalous westerly, the SST is colder in the west than in the east near the equator in both eastern and western Pacific. From Fig.5, we also see that the westerly (easterly) anomalies are over the equatorial western Pacific in the summer of the years of strong (weak) winter monsoon. Such persistent effect of meridional wind from winter to summer is very important for the anomalous variation of SST in the equatorial eastern Pacific while it can also be explained by the variation of the meridional wind. Being the primary driving source for the formation of monsoon, the SST affects its activity substantially. In their numerical simulation and data analysis, Yan and Xiao[12 - 14] discover that the cold SST anomalies in the Indian Ocean are favorable for the strengthening of summer monsoon in Asia while the warm ones are favorable for its weakening. Analyses of the relationship between the SST in summertime and the general circulation for corresponding late periods of anomalous winter monsoon in East Asia also prove the results of numerical simulations.

Next is a discussion of the evolution of convection in East Asia. Due to the limitation of data, only one year of strong winter monsoon (1986) is included in the present dataset. It is therefore our focus to discuss the convection activity for the weak winter monsoon years. Fig.9 gives the time-latitude cross section of the composite field of monthly OLR along 110°E – 120°E in the years of weak winter monsoon. It is found that a zone of strong convection is around 35°N during the entire summer monsoon with the strongest period in August and a more southward location. It is the least intensive in June. The strong convection zone further shows that there is more precipitation in the middle and lower reaches of the Changjiang R. for the summer of relatively weak winter monsoon years.

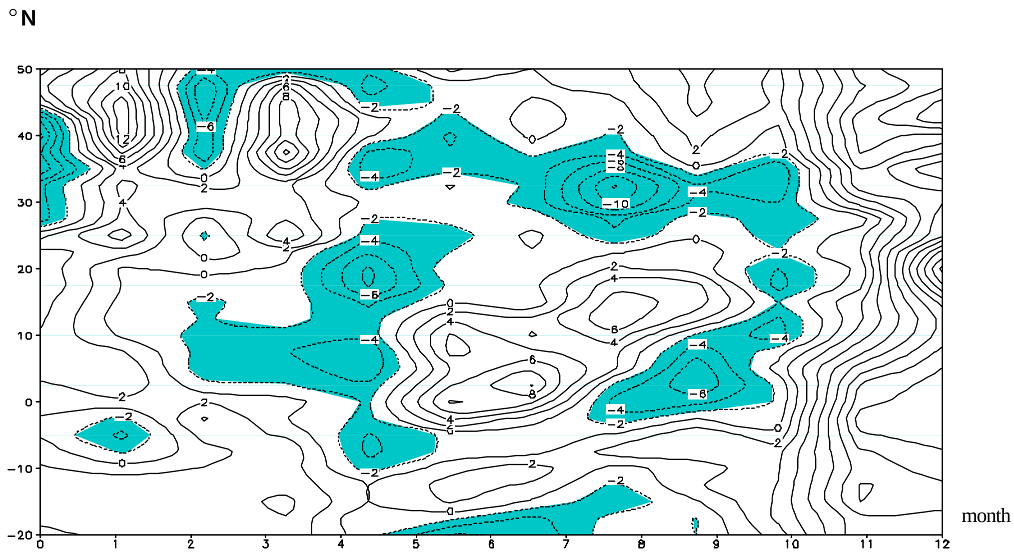

Fig.9 Latitude-time cross section of composite monthly OLR data at 110°E – 120°E in the years of weak winter monsoon.

7 CONCLUDING REMARKS

Following the mean location of high-level trough at 500 hPa, the work uses the 500-hPa geopotential height to define the intensity of winter monsoon and compares other definitions to select the years in which winter monsoon is relatively weak. The methods of correlation analysis and composite analysis are used to study the effect of the anomalies of winter monsoon on the precipitation in China, especially the middle and lower reaches of the Changjiang R. The effect of winter monsoon anomalies on SST distribution and the influence of SST on summertime circulation changes are focused to reveal the variations of thermodynamic field in the late period in various years of strong and weak winter monsoon and summertime flow field. Results from previous study are compared to try to explain the causes for precipitation anomalies over the middle and lower reaches of the Changjiang R. The following is the conclusion made based on it:

a. The East Asian winter monsoon is of obvious interannual and interdecadal variations. The latter is of significant descending trend, in which the period from the 1950's to mid-1980's is marked by strong winter monsoon and the period after mid-1980's by weak winter monsoon.

b. The anomalous activity of the East Asian winter monsoon has significant effects on the precipitation in the summer for most part of China, especially so for the middle and lower reaches of the Changjiang R. In weak (strong) winter monsoon years, there is more (less) precipitation in the region.

c. The anomalous activity of the East Asian winter monsoon plays an important role in the SST changes in the time after it and the associated summer monsoon activity. The summer monsoon anomalies and cold air anomalies in the middle latitudes may be the most essential cause for the changes in precipitation in the middle and lower reaches of the Changjiang R.

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REFERENCES:

[1] SUN Shu-qing, SUN Bai-min. The relationship between the anomalous winter monsoon circulation over East

Asia and summer drought / flooding in the Changjiang and Huaihe valley [J]. *Acta Meteorologica Sinica*, 1995, **53**: 438-450.

[2] LIU H, TOSI E, TIBALTI S. On the relationship between Northern Hemisphere weather regimes in winter time and spring precipitation over China [J]. *Quarterly Journal of Royal Meteorological Society*, 1994, **120**: 185-194.

[3] JI Li-ren, SUN Shu-qing. Observational and model study on interseasonal connection of atmospheric circulation [A]. General Circulation of the Atmosphere [C]. Beijing: China Meteorological Press, 1995. 365-376.

[4] GUO Qi-yun. Index for the summer monsoon intensity in East Asia and its variation characteristics [J]. *Acta Geographica Sinica*, 1983, **38**: 207-217.

[5] SHI Neng. Features of the East Asian winter monsoon intensity on multiple time scale in recent 40 years and their relation to climate [J]. *Quarterly Journal of Applied Meteorolog*, 1996, **7**: 175-181.

[6] CHEN Juan, SUN Shu-qing. Anomalies of winter monsoon in East Asia and changes in global general circulation —1. Comparison and study of effect of strong and weak monsoon [J]. *Chinese Journal of Atmospheric Sciences*, 1999, **23** (1): 101-111.

[7] CUI Xiao-peng, SUN Zhao-bo. Winter monsoon index for East Asia and analysis of its variation [J]. *Journal of Nanjing Institute of Meteorology*, 1999, **22**: 321-325.

[8] LIANG Jian-yin, WU Shang-sen, YOU Ji-ping. The establishment of the South China Sea summer monsoon and intensity changes [J]. *Journal of Tropical Meteorology*, 1999, **15**: 97-105.

[9] ZHAO Zhen-guo. Summertime Droughts and Floods in China [M]. Beijing: China Meteorological Press, 1999. 28-37.

[10] LI Chong-yin. Winter monsoon anomalies in East Asia and ENSO [A]. Study on a Number of Issues Related to Climate Changes [M]. Beijing: Science Press, 1992. 87-98.

[11] LI Chong-yin. Frequent strong East Asia Trough Activity and Occurrence of the El Niño episode [J]. *Science in China* (*Series B*), 1988, **6**: 667-674.

[12] YAN Hong-ming, XIAO Zi-niu. The numerical simulation of the Indian Ocean SSTA variation on climatic variations over Asian monsoon region [J]. *Journal of Tropical Meteorology*, 2000, **16**: 18-27.

[13] YAN Hong-ming, QI Ming-hui, XIAO Zi-niu. Relationship between precipitation in May over Yunnan and the changes of tropical sea surface temperature and Asia monsoon [J]. *Journal of Tropical Meteorology*, 2001, **12**: 366-376.

[14] XIAO Zi-niu, YAN Hong-ming. A numerical simulation of the Indian Ocean SSTA influence on the early summer precipitation of the southern China during an El Niño year [J]. *Chinese Journal of Atmospheric Sciences*, 2001, **25**: 172-183.