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A STUDY ON THE RELATIONSHIP BETWEEN THE SUMMER PRECIPITATION IN NORTHEAST CHINA AND THE GLOBAL SEA SURFACE TEMPERATURE ANOMALY (SSTA) IN PRECEDING SEASONS

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ABSTRACT: Based on the NCEP/NCAR reanalysis global SST, 500-hPa geopotential height, 850-hPa wind monthly mean data and summer precipitation from 80 observation stations of Northeast China for the period 1961-2000, the summer precipitation field of Northeast China was decomposed by using the principal component analysis method, then the relationships between the first three precipitation leading modes and the global SSTA in preceding seasons were studied, and the responses of the 500-hPa atmospheric circulation in East Asia to the preceding winter SSTA in north Pacific and its influence on the summer precipitation in Northeast China were probed. The results show that the SSTA, especially the ENSO event in preceding seasons has really very important influence on the occurrence of the whole coincident precipitation episode in Northeast China, and relates to the precipitation episodes of the reverse variation in south-north and in west-east direction closely. The north Pacific SST anomalies in preceding winters are associated with the summer precipitation in Northeast China through its influence on the western Pacific subtropical high and the East Asia subtropical monsoon in summer. Therefore, taking the global SSTA distribution in preceding seasons, especially the ENSO event, as the precursor signal to predict the precipitation anomaly in Northeast China has good reliability and definite indicative significance.

Key words: summer precipitation in northeast China; SST anomaly; subtropical high; climate prediction

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1 INTRODUCTION

Chilling damage, flooding and drought in summer are the major climatic disasters in Northeast China. Before the 1980s chilling damage often occurred, and after 1990s flooding and drought disasters were more noticeable in this region. These climatic disasters associated with the precipitation anomaly (for example the serious flooding in 1994, 1995 and 1998 and the serious drought in 1997, 1999, 2000 and 2001) caused enormous losses to the local economy, especially to the agriculture production. Although some studies on the flooding and drought disasters in Northeast China have been done from different points of view[1–4] and it is considered that the climatic pattern and general circulation characteristics of the precipitation anomaly in the region are not only distinct from that in the eastern part of China but also have obvious differences from that in the North China. Besides, we still lack a due understanding about the predictor and strong signals of the rainfall anomaly in the region. It is well known that the ocean plays an important role in the short-range climatic variation, especially the ENSO phenomenon is considered the strongest information above the climate noise, which can reflect interannual changes in the atmosphere and ocean discovered up to now. The tropical oceanic SSTA not only has direct and important impacts on the precipitation anomaly in the low latitude, but also can play an important

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role in climatic variations in the mid- and high- latitude[5], but the relations are more complicated and changeable comparing with that of the tropics[6]. Many meteorologists have investigated into the relationship between the SSTA and the rainfall of China in the past years, but they mainly focused their attention on the influence of the SSTA on the climatic variation in the eastern and northwest parts of China[7 – 13], and only a few studies that dealt with Northeast China have a wide variety of views about whether ENSO phenomenon can influence the precipitation in the region and what is the extent of the influence[14]. Therefore it is significant to address this problem further. In this paper, based on the NCEP/NCAR reanalysis global SST, 500hPa geopotential height, 850hPa wind monthly mean data and summer precipitation from 80 observation stations of Northeast China for the period 1961-2000, the summer precipitation field of Northeast China was decomposed by using the principal component analysis method firstly, then the relationships between the first three precipitation leading modes and the global SSTA in preceding seasons have been studied, and the responses of the 500-hPa atmospheric circulation in East Asia to the preceding winter SSTA in North Pacific and its influence on the summer precipitation in Northeast China have been probed. We wish the study could contribute to short-range climatic prediction in the region.

2 DATA

The dataset used in this study mainly contains the monthly precipitation data from 80 meteorological stations distributing in Northeast China covering a 40-year period from 1961 to 2000, and the NCEP/NCAR (National Centers for Environmental Prediction / National Center of Atmospheric Research) global atmospheric reanalysis monthly mean data, which are distributed onto a 2.5 latitude / longitude mesh in the same period including SST, 500-hPa geopotential height and 850-hPa wind field.

3 RESULTS ANALYSIS

3.1 *The relationship between the preceding global SSTA and the precipitation anomaly in Northeast China*

Fig.1 (a, b and c) shows the first three leading modes of spatial distribution of summer precipitation anomaly in Northeast China obtained by using the principal component analysis method. We can see from the first leading mode that the whole Northeast China appears positive in the same sign, indicating that the precipitation in Northeast China is generally consistent. This leading mode accounts for 30.2% of the total variance contribution. The significant loading vector area is notable in the plain region of central part of Northeast China. The spatial distribution of the second leading mode is of the structure of reverse variation in South-North direction. This leading mode accounts for 12.6% of the total variance contribution. The north part of Jilin province, Heilongjiang province and the north part of Inner Mongolia are areas of positive values, and the south part of Jilin province, Liaoning province and the east part of Inner Mongolia are ones of negative. The tendency of reverse variation in east–west direction is the characteristics of the third leading mode spatial distribution. This episode accounts for 10.2% of the total variance contribution. The zero isopleths of the loading value runs through the central parts of Heilongijang, Jilin and Liaoning province. To the west of the zero isopleths is the negative value distribution and to the east of the zero isopleths is the positive value distribution. The first three leading modes can account for 53.0% of the total variance contribution, and the first six leading modes can account for 66.2% of the total variance contribution. But after the fourth leading mode the variance contribution of every loading vector is all below 5%, therefore these leading modes will not be discussed in this paper.

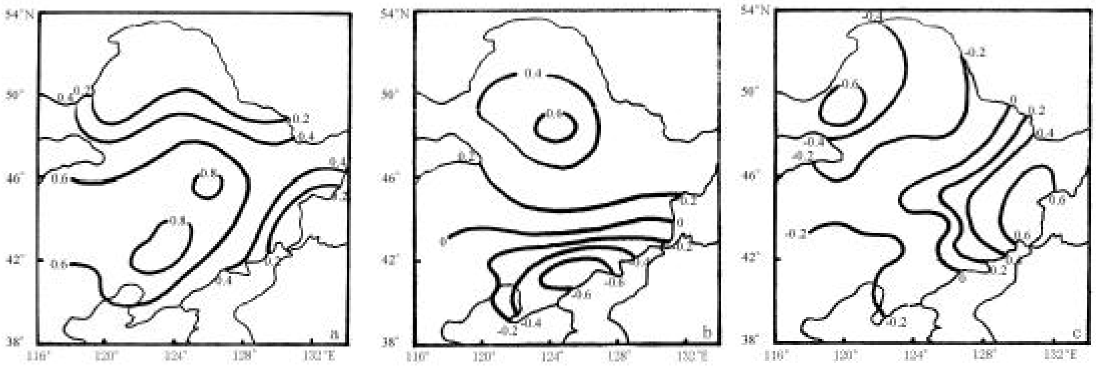

Fig.1 The spatial distribution of the first (a), second (b) and third (c) loading modes of the summer precipitation anomaly in Northeast China.

Fig.2 (a, b, c & d) depicts the correlation distribution between the time coefficient of the first leading mode of the summer precipitation anomaly in Northeast China and the global SST fields in preceding summer, autumn, winter and spring. We can see from the figures that the equatorial central and eastern Pacific, Alaska Gulf locating in the north-east part of Pacific and the sea surface close to Mexico are of significant positive correlation distribution. The correlation coefficients at the centers are above 0.5, exceeding the 99.9% significance level. And the notable negative correlation area covers the west wind drift region. The correlation coefficients at the centers can range from –0.40 to –0.50, also exceeding the 99% – 99.9% significance level. The results mentioned above imply that when the equatorial middle-east Pacific SST distributes positively (negatively) and the west wind drift region SST negatively (positively), i.e. the north Pacific SSTA emerges in the El Niño (or La Niña) episode from the preceding summer to the preceding spring, it is favorable for the precipitation to be above (or below) its normal in Northeast China in summer as a whole (or most parts of the region), especially to the plain region of the central part in that region. Because the above-mentioned significant correlation areas (Fig.2) are quite stable and obviously persist from the preceding summer right up to the preceding spring, it is therefore quite reliable and indicative to certain extent to take the preceding SSTA distribution of north Pacific, especially the ENSO event, as the precursor signal to predict the precipitation anomaly in Northeast China.

In addition, the flooding and drought in summer of Northeast China also relate to the SSTA of other sea areas closely in preceding seasons. We can see from the figures that from the preceding autumn up to the preceding spring there is also a large positive correlation area in equatorial Atlantic. The maximum correlation coefficient is above 0.5, exceeding the 99.9% significance level. From the last winter to the preceding spring, some sea areas of the Bay of Bengal, Arabian Sea, the central part of the Indian Ocean and the south-east Pacific are also obviously in positive correlation. The maximum correlation coefficients can reach 0.40 to 0.50, exceeding 99% to 99.9% in significance level. This indicates that besides the north Pacific, the SSTA of some key sea areas in the Atlantic, the Indian Ocean and the south-east Pacific probably has significant impact on and obvious lag correlation to the precipitation in Northeast China. This is the result that we hardly paid attention to in the past.

Fig.3a demonstrates the correlation distribution between the time coefficient of the second leading mode of the summer precipitation anomaly in Northeast China and the global SST field in preceding spring. It can be seen from the figure that the summer precipitation episode of the reverse variation in south-north direction in Northeast China is also related to the global SSTA in preceding seasons closely. From the last summer to the last winter, the equatorial east Pacific is positively correlated and the west wind drift region is negatively correlated. But the correlation level is weaker than that of the Fig. 1 (figures omitted). This correlation patterns persist up to the preceding spring and enhance greatly (Fig.3a), the maximum correlation coefficient in the equatorial eastern Pacific can reach 0.50, exceeding the 99.9% significance level. In the meantime, the Bay of Bengal also maintains the obvious positive correlation distribution from the last summer up to the preceding spring. This indicates that in the preceding seasons (especially in the preceding spring) if the SST in the equatorial east Pacific is higher (or lower) than its normal (confining to the equatorial east Pacific only), the SST in the west wind drift region is lower (or higher) than its normal, and the SSTA in the Bay of Bengal is in notably positive (or negative) distribution, then it is favorable for the occurrence of more (or less) precipitation in the north part and less (or more) precipitation in the south part of Northeast China.

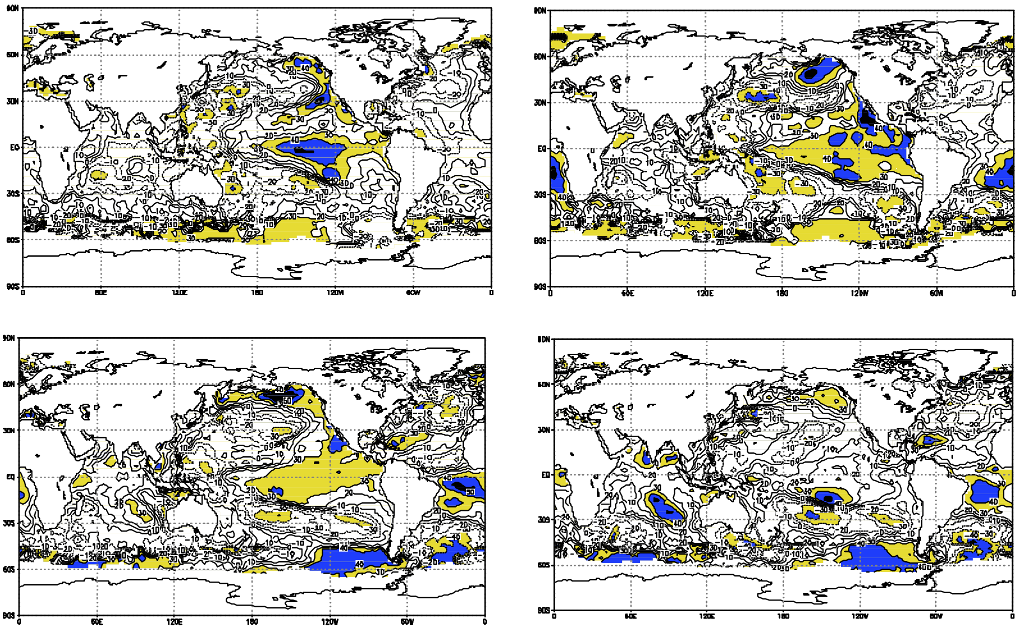

Fig.2 The correlation distribution between the time coefficient of the first leading mode of the summer precipitation anomaly in Northeast China and the global SST fields in preceding summer (a), autumn (b), winter (c) and spring (d). The shaded areas from light to heavy show the regions where the correlation is statistically significant at the 95%, 99% and 99.9% confidence levels. Numerals in the panels are already multiplied by 10.

The summer precipitation episode of the reverse variation in west-east direction of Northeast China is also associated with the global SSTA in preceding seasons to a certain degree. But the correlation level is weaker than that of Fig. 1 (see Fig.3b for the correlation distribution between the time coefficient of the third leading mode of the summer precipitation and the global SST field in preceding winter, the other figures are omitted). Generally speaking, when the SST in equatorial east Pacific is in notably negative departure in preceding seasons (especially in the last winter) and the SST in the west wind drift region is of the positive departure distribution (analogous to the La Niña episode, but the negative anomaly is limited to the equatorial east Pacific only), then it is favorable for more precipitation to occur in the east part and less precipitation in the west part of Northeast China. Conversely, the precipitation anomaly distribution is just opposite to the above.

The correlation between the global SST fields (especially the ENSO events) in preceding seasons and the other precipitation episodes (after the fourth leading mode) is very close.

Basically there are not any significant correlation areas which have large-scale scope and high persistence and can exceed 95% significance level in the correlation diagrams (figures omitted), i.e. the impacts of the SSTA are not essential to the formation of these precipitation episodes. We can see from the above-mentioned study that the SSTA, especially the ENSO cycle in preceding seasons, has really very important influence on the occurrence of whole coincident precipitation episode in Northeast China, and relates to the precipitation episodes of the reverse variation in south-north and in west-east direction closely. These three precipitation anomaly distribution episodes can account for 53.0% of the total variance contribution. But the other precipitation anomaly distribution episodes accounting for 47.0% of the total variance contribution probably have no definite responses to the global SSTA in preceding seasons. It implies that the relations of the precipitation anomaly in Northeast China and the global SSTA in preceding seasons do not simply relate to one another correspondingly. Even in the case of ENSO episode, if its heating modes or its developing stages or its allocations with the SST distribution in other sea areas are different, the summer precipitation in Northeast China probably appears to have striking differences. Especially, the relations of the SSTA and the summer precipitation anomaly in the same period are even more complicated (figure omitted).

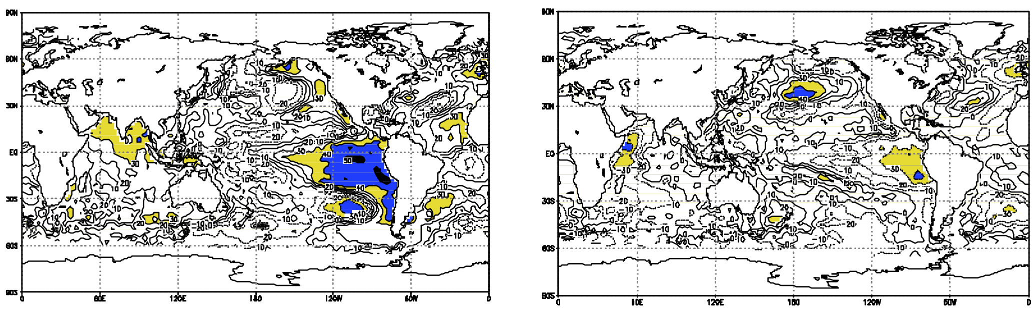

Fig.3 The correlation distribution between the time coefficient of the second leading mode of the summer precipitation anomaly in Northeast China and the global SST field in preceding spring (a), and the correlation distribution between the time coefficient of the third leading mode of the summer precipitation anomaly in Northeast China and the global SST field in preceding winter (b). The light to heavy shaded areas show the regions where the correlation are statistically significant at the 95%, 99% and 99.9% confidence levels. Numerals in the panels are already multiplied by 10.

3.2 *The responses of the summer atmospheric circulation in East Asia to the SSTA in last winter and its possible influence on the precipitation in Northeast China*

The reasons for the formation of the summer precipitation anomaly in Northeast China are very complicated. The SSTA in preceding seasons is not the only factor. But anyhow, by what intermediate links the SSTA in preceding seasons (especially to El Niño / La Niña event) is associated with the precipitation in Northeast China, i.e. how the summer atmospheric circulation in East Asia responses to the SSTA in preceding seasons, is well worth dealing with further. In consideration of the summer precipitation in Northeast China which mainly relates to a certain specified allocation of the SST in the north Pacific (i.e. the west wind drift region and the equatorial middle-east Pacific is the retro-correlation distribution), therefore, the Ts_1, the average value of the SST in every gridpoint over the area 35°N – 40°N, 150°E – 150°W, is used to represent the SST variation of the west wind drift region, the T_{s2}, the average value of the SST in every gridpoint over the area 5°N – 5°S, 160° – 100°W, is used to represent the SST variation of the equatorial middle-east Pacific. In order to reduce the latitude effect, the T_{s1} and T_{s2} are processed with respective standard variables. And we define the I_{ST}=-0.50T_{s1}+0.50T_{s2} as the index representing the SST distribution pattern of the north Pacific. If the I_{ST} is the notable positive value or the negative value then it is implied that the north Pacific SST has the El Niño episode or the La Niña episode. By calculation, the correlation coefficients of the summer precipitation in Northeast China and the I_{ST} in preceding summer, autumn, winter and spring are 0.40, 0.41, 0.43 and 0.28 respectively. It can be seen that besides the preceding spring, the correlation of the remaining seasons can all exceed the 99.0% significance level, especially the last winter is the most significant. We choose 7 years of the SST with strong El Niño episodes and 7 years of the SST with strong La Niña episodes in winter respectively from the past 40 years (1961 – 2000) (they are 1998, 1994, 1987, 1983, 1969, 1966 and 1964 in the El Niño episodes and 2000, 1999, 1989, 1976, 1974, 1972 and 1968 in the La Niña episode) according to the I_{ST} index. The composite figures of the 500-hPa geopotential height departure, 850-hPa streamline field and the south wind component departure in summer of the years with strong El Niño and La Niña episodes in the last winter are made respectively based on the NCEP/NCAR reanalysis global monthly mean data from 1961 to 2000. And their *t*-tests are calculated. The time lag coupling singular value decomposition (SVD) analysis of the SST field in the north Pacific in the last winter (as the left field) and the 500-hPa geopotential height in East Asia in summer (as the right field) is also conducted. The purpose is to probe the main responses of the summer atmospheric circulation anomaly in East Asia to the SSTA in the north Pacific in the preceding winter and its possible influence on the precipitation in Northeast China. Fig.4 displays the difference distribution of the 500-hPa geopotential height anomaly in the summer of the years with strong El Niño episodes and La Niña episodes in the preceding winter and its *t*-test. The main characteristic of the figure is that the west Pacific subtropics are in notable positive distribution. The remarkable positive value area is oval in shape in the northeast-southwest direction. The positive center is located in the southwest part of Japan (about 30°N, 131°E), the position is north and west to that of the west Pacific subtropical high of the average year in summer, the *t*-statistical test value is 2.45, exceeding the 98.0% significance level. The significant negative value area covers the region of the central and western part of Northeast China and areas to the west. The *t*-statistical test value in the center is –1.61, approaching the 90.0% significance level. This indicates that when the north Pacific SST is of the significant El Niño or La Niña episode distribution in winter, the intensity of the western Pacific subtropical high tends to be stronger (or weaker) than its average, the position of the western Pacific subtropical high tends to be north and west (or south and east) to its normal (the normal position of the ridge line and its western point of the western Pacific subtropical high is 24°N and 123°E, respectively), and the trough tends to develop (or not to develop) in the region from Northeast China to Mongolia in summer. All these results are consistent with the 500-hPa atmospheric circulation anomaly pattern in summer in the flooding years (or drought years) of Northeast China[3].

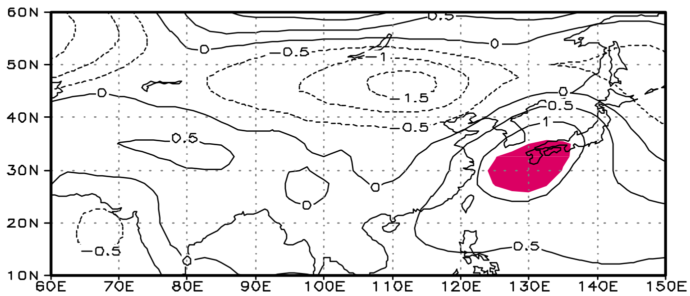

Fig.4 The difference distribution of the 500-hPa geopotential height anomaly in summer of the years with strong El Niño episodes and La Niña episodes in preceding winters and its *t*-test (unit: dagpm). The shaded area shows the region where the difference is statistically significant at the 95% confidence level by *t* –test.

Fig.5 shows the spatial distribution of the first coupling mode of SVD analysis between the north Pacific SSTA in the preceding winter and the 500-hPa geopotential height anomaly of the East Asia in summer. This coupling mode can account for 53.0% of the total covariance contribution. The correlation coefficient of the mode is 0.86, far exceeding the 99.9% significance level. We can see from the figure that the southeast part of the north Pacific SST field is positively distributed, and the central- and northern- part is negatively distributed. There are three remarkable anomaly areas, being the notable positive valve area locating in the equatorial middle-east Pacific (the correlation coefficient at the center is 0.92), the notable negative value area locating in the west wind drift region (the correlation coefficient at the center is –0.76) and the notable positive value area locating in the Black Current region (the correlation coefficient at the center is 0.72). This is the typical SSTA distribution in the El Niño episode. In correspondence with the 500-hPa geopotential height field of the East Asia in summer, the most significant positive value area is mainly located over the region controlled by the west Pacific subtropical high of the average year in summer, but its position is north and west to its normal. The positive value center is around the south part of Japan (the correlation coefficient at the center is 0.68). Therefore, similar with the above-mentioned result, this SVD analysis also reflects that when the north Pacific SST appears the significant El Niño episode (or La Niña episode) distribution in winter, then the intensity of the west Pacific subtropical high will be usually stronger (or weaker) than its average, and the position of the west Pacific subtropical high will be usually north and west to its normal in the coming summer.

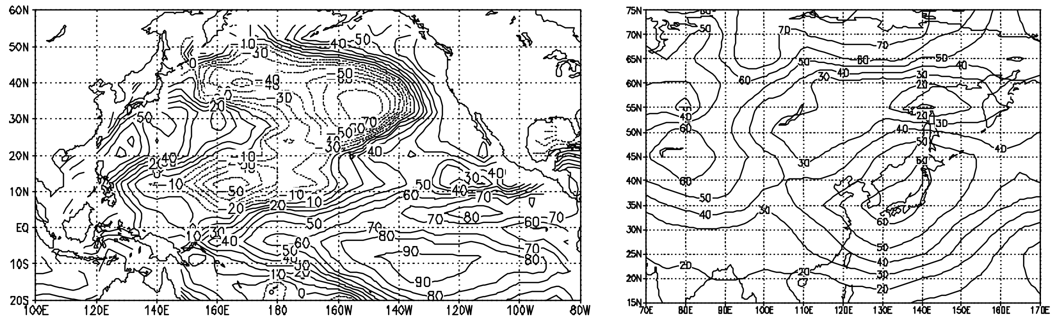

Fig.5 The spatial distribution of the first coupling mode of SVD analysis between the north Pacific SSTA in preceding winters (a) and the 500-hPa geopotential height anomaly of the East Asia in summer (b).

Figs.6 and 7 demonstrate the difference distribution of the 850-hPa south wind component departure and 850-hPa wind field anomaly in summer of the years with strong El Niño episode and La Niña episode in the last winter. It can be seen that over the eastern part of China and its coastal areas off the South China Sea right up to the south part of Northeast China, the south wind component is the notable positive value distribution. The remarkable positive value area is belt-shaped in the south-north direction and the positive value center is located in the northeast part of Korea Peninsula with the *t*-statistical value being 3.65, exceeding the 99.9% significance level. This is just the situation when the northeast Asian summer monsoon is stronger than its normal[15]. And we know that the variations of the northeast Asian summer monsoon have important impacts on the precipitation anomaly in Northeast China. The basis feature of Fig.7 is that there are four southern wind anomaly currents from different source regions coming together in the eastern part of China and extending to the north. The first current originates from the Bay of Bengal, moving eastward and then propagating northward. The second current extends up to northward originate from the South China Sea. The third current originates from the southern part of the western Pacific subtropical high, moving westward and then propagating northward. The last current originates from the eastern part of Qinghai-Xizang Plateau, extending northward by way of the Southwest China. These four south wind anomaly currents combine with the westerly anomaly currents in the region of Northeast China and its western side to form a cyclonic circulation system and the convergence of this area enhances greatly. The results mentioned above show that when the north Pacific SST is of significant El Niño episode (or La Niña episode) distribution in winter, the northeast Asian summer monsoon will be generally stronger (or weaker) than its average and the latitude of its extension northward will be generally north of its normal. It is certainly favorable for the occurrence of more (or less) precipitation in Northeast China.

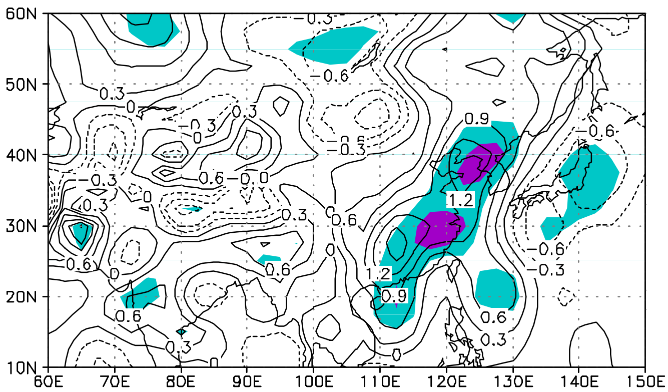

Fig.6 The difference distribution of the 850-hPa south wind component departure in the summer of the years with strong El Niño episodes and La Niña episodes in preceding winters (unit: m/s). The light to heavy shade areas show the regions where the difference are statistically significant at the 95% and 99% confidence levels by *t* –test.

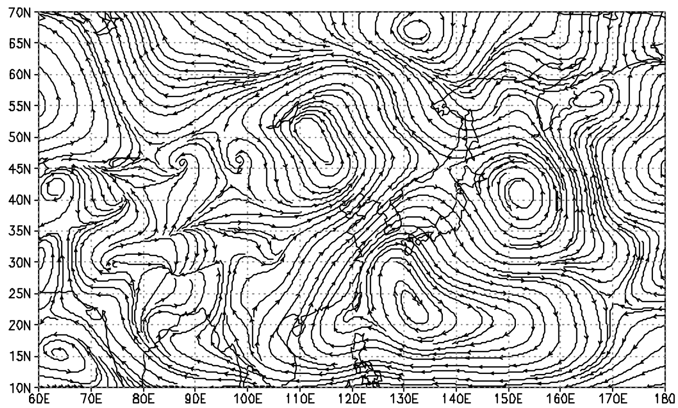

Fig.7 The difference distribution of the 850hPa wind field anomaly in the summer of the years with strong El Niño episodes and La Niña episodes in preceding winters.

4 SUMMARY AND DISCUSSION

In this paper, based on the NCEP/NCAR reanalysis globe SST, 500-hPa geopotential height, 850-hPa wind monthly mean data and summer precipitation from 80 observational stations of Northeast China for the period 1961 – 2000, the relationships between the summer rainfall in Northeast China and the global SST in preceding seasons have been studied, and the responses of the 500-hPa atmospheric circulation in East Asia in summer to the preceding winter SSTA in north Pacific and its influence to the summer precipitation in Northeast China have been probed. The results are summarized as follows:

a. When the equatorial middle-east Pacific SST is in positive (negation) departure distribution and the west wind drift region SST is in negative (positive) departure distribution, i.e. the north Pacific SSTA emerges in the El Niño (or La Niña) episode from the last summer to the preceding spring, then the Northeast China tends to have more (or less) precipitation than its normal in summer as a whole. Besides the north Pacific, the SSTA of some key sea areas in the equatorial Atlantic, the Bay of Bengal, Arabian Sea, the Indian Ocean and the south-east Pacific in preceding seasons probably has the significant impact on and obvious lag correlation with the precipitation in Northeast China in summer. If the SSTA is limited to the equatorial east Pacific only in the preceding spring or in the last winter, it is favorable for the occurrence of the reverse variation in south-north or in west-east direction of the summer precipitation in Northeast China. Therefore, taking the global SSTA distribution in preceding seasons, especially the ENSO event, as the precursor signal to predict the precipitation anomaly in Northeast China has good reliability and definitive indicative significance.

b. When the north Pacific SST is of significant El Niño episode (or La Niña episode) distribution in winter, the intensity of the western Pacific subtropical high will be generally stronger (or weaker) than its average, its position will be usually north and west of its normal in the coming summer, the northeast Asian summer monsoon will also be generally stronger (or weaker) than its average, and the latitude of its extension northward will be usually north of its usual location. It is certainly favorable for the occurrence of more (or less) precipitation in Northeast China.

The above-mentioned results are only preliminary. There remain many unsolved problems deserving further study, the physical mechanisms of the influence of the SSTA in preceding seasons on the summer precipitation anomaly in Northeast China, to name a few.

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