THE RELATIONSHIP BETWEEN TROPICAL PACIFIC SEA SURFACE TEMPERATURE AND SUMMER RAINFALL OVER NORTHWEST CHINA

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ABSTRACT

In this paper, the data of summer precipitation in Northwest China were expanded by means of EOF. According to major eigenvectors in expansion the area of Northwest China was divided into four natural rainfall regions. Among them the region of greatest precipitation variability is found over the East Qinghai–North Shaanxi region, including East Qinghai, Central and East Gansu, Ningxia and North Shaanxi. There is apparent teleconnection between the first and second time–dependent coefficients in EOF expansion and the tropical Pacific SST in the corresponding period and earlier months. The variation of the east tropical Pacific SST in winter and spring is able to predict precipitation trend of Northwest China next summer. Moreover, in the El Nino years precipitation trend is opposite to the following year, and the region from East Qinghai to North Shaanxi is most sensitive.

Key words: empirical orthogonal function (EOF), time–dependent coefficient, sea surface temperature (SST), summer rainfall, Northwest China

I. INTRODUCTION

Numerous recent studies have suggested that the variation of tropical sea surface temperature (SST) affects the changes of weather and climate not only directly in low–latitudes but slso remotely on global scale (e.g. Horel and Wallace, 1981; Rasmussen and Carpenter, 1982). Some Chinese scholars have also noticed the abnormality of tropical Pacific SST associated with anomalous changes of weather and climate in China. Li et al. (1987) presented a good relationship between the drought and flood in the Changjiang River drainage area of China and the SST of east equatorial Pacific and Black Current area in Northwest Pacific; Zeng and Zhang (1987) demonstrated the remote influence of abnormal variation of east tropical Pacific SST on microtherm of Northeast China; the others studied the mechanism of teleconnection in abnormality between tropical Pacific SST and weather and climate. All of these are no doubt significant. Most of such researches are on eastern China, only few papers on the relationship between the precipitation of Northwest China and tropical Pacific SST are presented. In this paper, we divided natural rainfall region according to spatial distribution feature of summer precipitation in Shaanxi, Gansu, Ningxia and Qinghai (hereafter referred to as Northwest China) and then analyzed the teleconnection between SST of north and equatorial Pacific and summer rainfall in each of the natural rainfall regions in the corresponding and preceding period. It is found that the teleconnection between summer rainfall of Northwest China and tropical Pacific SST is significant in the concurrent period, and the variation of east tropical Pacific SST in the earlier month is a good predictor for summer precipitation trend of Northwest China.

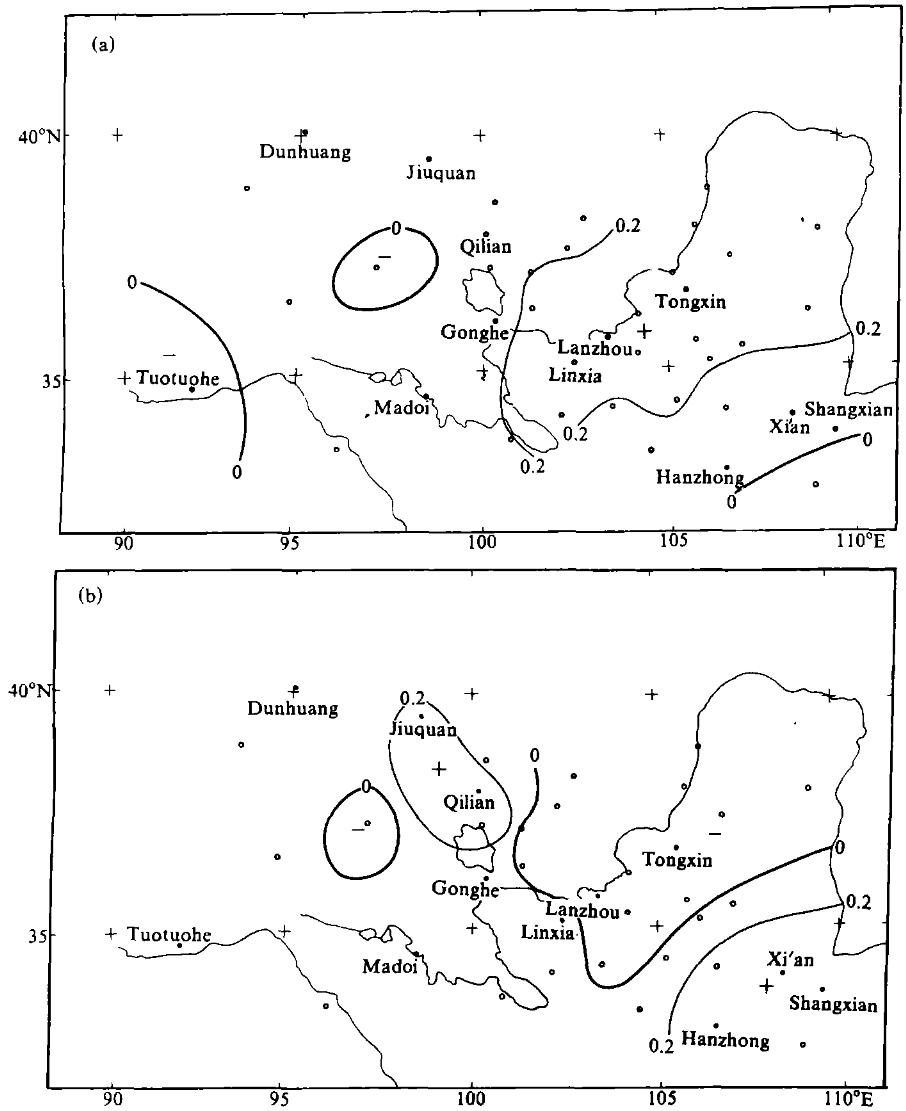

Fig. 1 Eigenvectors E1 (a) and E2 (b) in EOF expansion of summer (June—August) rainfall in Northwest China.

II. THE NATURAL SUMMER RAINFALL DIVISION OVER NORTHWEST CHINA

Northwest China has spacious area and complex topography, and the rainfall is quite different from one place to another. In order to easily analyse the major feature of precipitation on spatial field, we expanded summer rainfall data at 39 stations in the period of 29 years (1958—1986) in Northwest China by means of EOF, and then used the major eigenvectors in the expansion to analyse the spatial distribution feature of summer rainfall in Northwest China and divided natural rainfall region. To select representative stations in each natural rainfall region, we used the main time–dependent coefficients in expansion to compute the loading values of each station. Fig. 1 shows the first and second eigenvectors (E1 and E2) in the expansion of Northwest China summer rainfall. E1 has positive centers over East Qinghai, mid–east Gansu, Ningxia and North Shaanxi where the rate of change in summer rainfall is greatest. We called the area the East Qinghai–North Shaanxi region. E2 is positive over Northwest China expect for the East Qinghai–North Shaanxi region, and two positively maximal centers are found in South Shaanxi and Hexi–Qilian Mountain area respectively, that explains that the opposite trend of summer precipitation exists between East Qinghai–North Shaanxi region and the others. According to the distribution features of E3 and E4 and cluster analysis (not shown) of summer rainfall in Northwest China, the area where E2 is positive can be divided into three regions, that are Hexi–North Qinghai, South Qinghai and South Shaanxi regions located in northwest, southwest and southeast parts of Northwest China respectively. Together with the East Qinghai, Northwest China was divided into four natural rainfall regions, as shown in Fig.2. Among these four regions, the summer rainfall of East Qinghai–North Shaanxi region located along the northeast side of the Qinghai–Xizang Plateau is the most important to NPE, especially to agricultural production.

We also computed the correlation coefficient between the main time–dependent coefficient of summer rainfall of Northwest China in EOF expansion and the time series of raw rainfall data at every station, which is called loading value. In East Qinghai–North Shaanxi region the loading values corresponding to the first time–dependent coefficient are high, of which the values at Stations Linxia, Lanzhou, Tongxin are highest. These three stations are selected as representative stations for the region. The highest loading values corresponding to the second time–dependent coefficient in the Hexi–North Qinghai region are at Stations Qilian, Jiuquan, Dunhuang and in the South Shaanxi region are at Stations Hanzhong, Xi'an, Shangxian. The representative stations in the South Qinghai region are Tuotuohe, Maduo and Gonghe, at which the loading values are calculated according to the fourth time–dependent coefficient. The locations of the representative stations are shown in Fig.2.

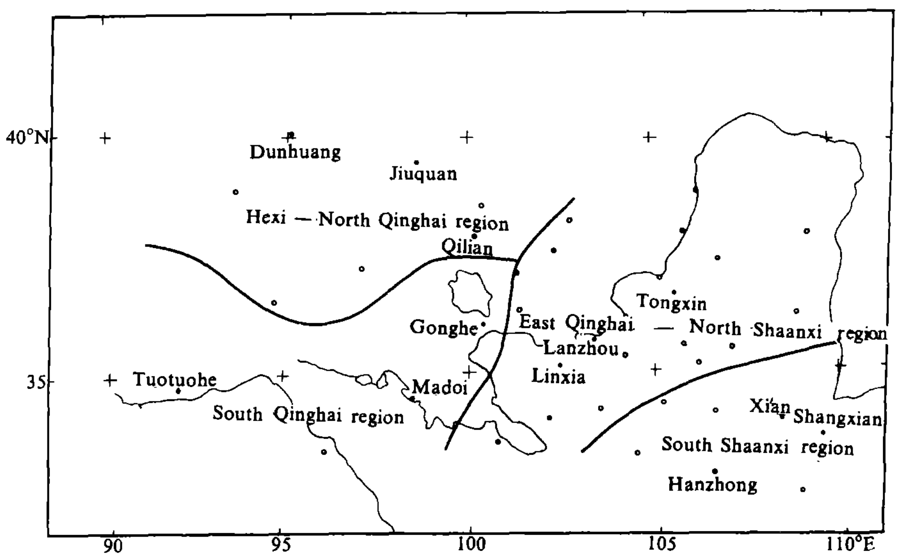

Fig. 2. The natural summer rainfall divisions over Northwest China.

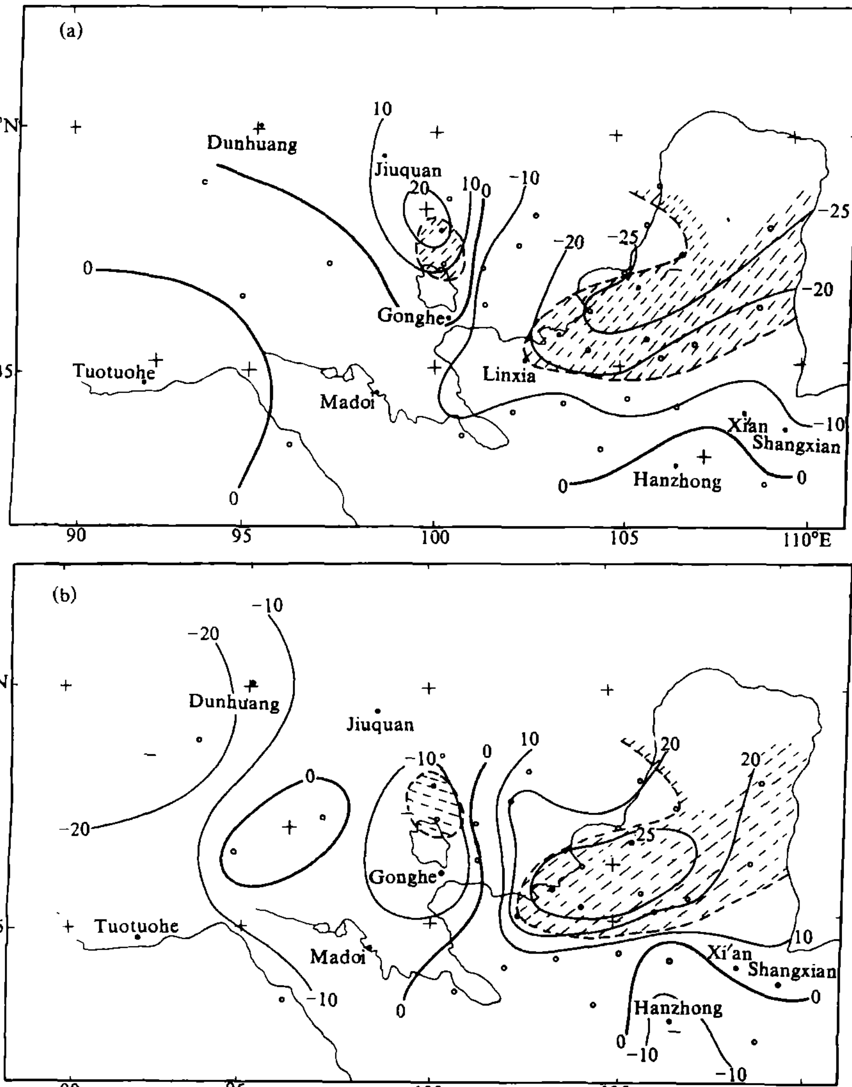

Fig. 3. The departure percentage of mean summer rainfall of Northwest China in the El Nino years (a) and that in the years immediately after El Nino events (b).

III. THE STATISTICAL RELATIONSHIP BETWEEN EL NINO AND SUMMER RAINFALL OF EVERY REGION OF NORTHWEST CHINA

The El Nino years are taken based on the time series composed of seven sets of data by Wang (1985) and on the ENSO years defined by National Meteorological Center of China. In order to match the rainfall data, only eight El Nino years are taken from 1958 to 1986, i.e. 1963, 1965, 1969, 1972, 1976, 1982, 1983 and 1986. The distribution of anomalous percentage of average summer rainfall in Northwest China is depicted in Fig.3a. The amount of precipitation in the Hexi–North Qinghai region, most of South Shaanxi and South Qinghai regions are above the average, but it is quite dry in the East Qinghai–North Shaanxi region. Especially the isomer with value 10% less than the normal is almost along with the profile of the border of the region, the minimum in the region is 25% less than the normal. The departure percentage of means summer rainfall in Northwest China in the immediately following years (1958, 1964, 1966, 1970, 1973, 1977, 1984) of El Nino events is opposite to that in El Nino years (see Fig.3b). Hexi–North Qinghai, South Shaanxi and South Qinghai regions are drier but the East Qinghai–North Shaanxi region is quite wet. The maximum is 25% more than the normal. The difference values of the corresponding stations are shown in Fig.3 which is the mean summer rainfall anomaly percentage difference between El Nino years and the years immediately after the El Nino years. Two sections are significant at the 95% level by t–test. The main one is in the East Qinghai–North Shaanxi region, the other is near Qilian in the Hexi–North Qinghai region (shown in Fig. 3 by hatched lines).

Fig. 3 demonstrates that the teleconnections between El Nino events and summer rainfall of Northwest China are pronounced and the summer rainfall distribution in the years of El Nino events is opposite to the following years. The East Qinghai–North Shaanxi region is most sensitive, and the Hexi–North Qinghai region comes next.

IV. THE RELATIONSHIP OF TROPICAL PACIFIC SST WITH SUMMER RAINFALL OF NORTHWEST CHINA IN THE CONCURRENT PERIOD

Correlation analysis is carried on of monthly mean Pacific SST data on grid–points (10°S—50°N, 120°E—80°W) available by National Meteorological Center of China and summer precipitation of Northwest China. To test the teleconnectivity between summer rainfall of Northwest China and concurrent SST, the main time–dependent coefficients of summer rainfall of Northwest China in EOF expansion are related to the SST in north and equatorial Pacific in the concurrent period (June—August) as shown in Fig.4. There are four sections in Fig.4, the correlation is strongly negative in east equatorial Pacific and strongly positive in California Ocean Current Zone, west tropical Pacific and "Northern Cold Water Zone", achieving the 95% significance level ($r_{0.05}=0.37$). Among them, the strongest positive correlation center is found in California Ocean Current Zone (15—30°N, 140—110°W) being significant at the 99% level ($r_{0.01}=0.47$).

Fig.5 illustrats the correlation coefficients of the second time–dependent coefficient of summer rainfall in Northwest China in EOF expansion with SST in summer. There are two sections where the correlations are significant at the 0.95 level, one is the east equatorial Pacific (0—5°S, 115—95°W) positive correlation section, the other is middle tropical zone negative correlation section in North Pacific.

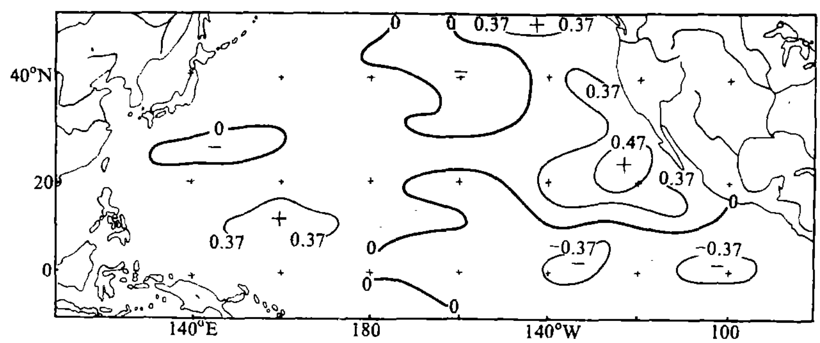

Fig. 4. Correlation coefficients between the first time–dependent coefficient and Pacific SST from June to August.

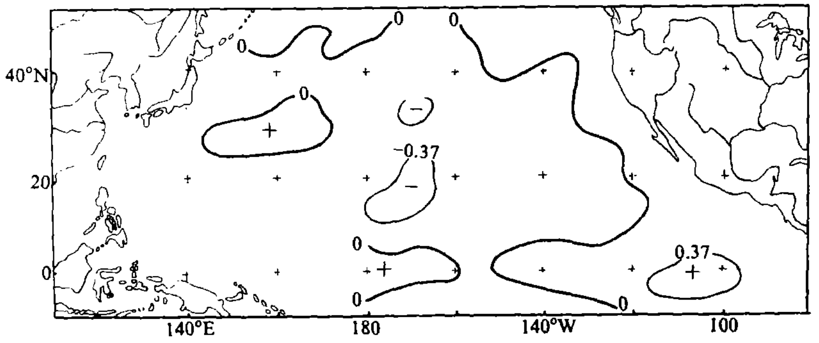

Fig. 5. Correlation coefficients between the second time–dependent coefficient and Pacific SST from June to August.

We have also computed the correlation coefficients using the summer rainfall data at the representative stations in each natural rainfall region of Northwest China. The distribution of correlation coefficients between the total summer rainfall at Linxia, Lanzhou and Tongxin (the representative stations of the East Qinghai–North Shaanxi region), and the concurrent SST is quite similar to that in Fig.4 (not shown). The locations of four strongly correlated sections, the magnitude and the signs of the correlation coefficients are approximately unchanged. These confirmed that the first time–dependent coefficient mainly explained the rainfall variational trend in the East Qinghai–North Shaanxi region. The distribution of correlation coefficients between the total summer rainfall at each representative station in the Hexi–North Qinghai, South Shaanxi and South Qinghai regions and the SST in the corresponding period is similar to that in Fig.5, but the significance is more or less different. The most pronounced positive correlation section in the Hexi–North Qinghai region is significant at the 0.95 level in east equatorial Pacific, and the spatial range is larger than that in Fig.5, in the center the correlation is significant at the 0.99 level; the strongest negative correlation section of the representative stations in the South Shaanxi region is the middle tropical zone of North Pacific, achieving the 0.95 significance level in the center. Though the distribution at representative stations in South Qinghai is similar to that in Fig.5, the correlations are insignificant.

From the correlation coefficients among major time–dependent coefficients of summer rainfall of Northwest China in EOF expansion, the total summer rainfall at every representative station in each region and Pacific SST in the corresponding period, we can see that the East Qinghai–North Shaanxi region is the strongest to correlate to SST of California Ocean Current Zone and east equatorial Pacific where El Nino events occur frequently. The Hexi–North Qinghai region is the second strongest to correlate to SST of east equatorial Pacific, then the South Shaanxi region is negatively correlated to SST of middle warm zone of North Pacific.

V THE PREDICTION OF SUMMER RAINFALL TREND OF NORTHWEST CHINA BY USE OF THE CHANGES OF TROPICAL PACIFIC SST IN PRECEDING PERIOD

Correlation between the first time–dependent coefficient of summer rainfall of Northwest China in EOF expansion and concurrent Pacific SST has four significant areas, i.e., three positive correlation areas of California Ocean Current Zone, west tropical Pacific and "Northern Cold Water Zone" and one negative correlation area of east equatorial Pacific. Using the correlation analysis made of the first time–dependent coefficient and monthly SST in early winter and spring, we can see the development trend in the strongly correlated areas aforementioned. Fig.6a shows the correlation coefficients between the first time–dependent coefficient of summer rainfall of Northwest China and the Pacific SST in last January. It is obvious that the three strongly positively correlated sections already exist, with significance all at the 0.95 level, while a positive correlation section is found over the east equatorial Pacific, opposite in sign to that in summer. Moreover, a strongly correlated section with significance at the 0.99 level exists in the range of 5°N—10°S, 180°E—165°W. Only a small negative correlation area exists in the range of 5—10°S, 105—90°W over equatorial Pacific. Except the east equatorial Pacific section, the other positively correlated sections persist from February to May. Especially, the California Ocean Current Zone is almost unchanged in the spatial range and the magnitude of correlation coefficients. On the other lands, correlation in the east equatorial Pacific section changes timely from February to May, the positive correlation in January changes to negative. From March the negatively correlated section in the range of 5°N—10°S, 105—90°W extends westward and significant negative correlation center is apparent. In May the whole equatorial Pacific becomes negative and then persists throughout summer season.

It is the reflection of SST variations of east equatorial Pacific from winter to spring that the signs of correlation coefficients between the first time–dependent coefficient and the east equatorial Pacific SST reverse from last winter to spring. Generally speaking, the years when east equatorial Pacific is warm in January and becomes cold after March are the years of immediately after the El Nino years. It is a precursor that the first time–dependent coefficient of summer

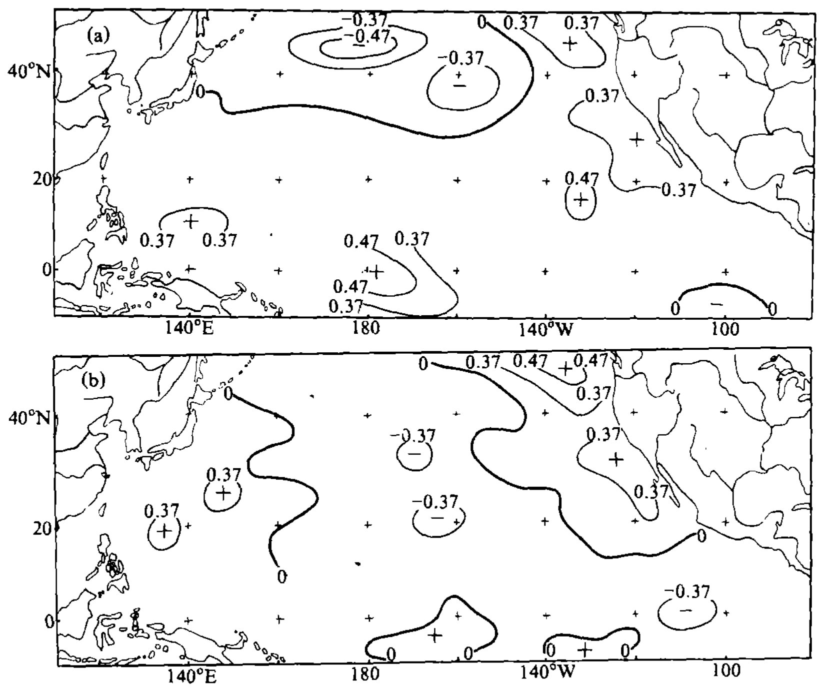

Fig. 6. Distribution of correlation coefficients between the first time–dependent coefficient and SST in January(a) and in May(b).

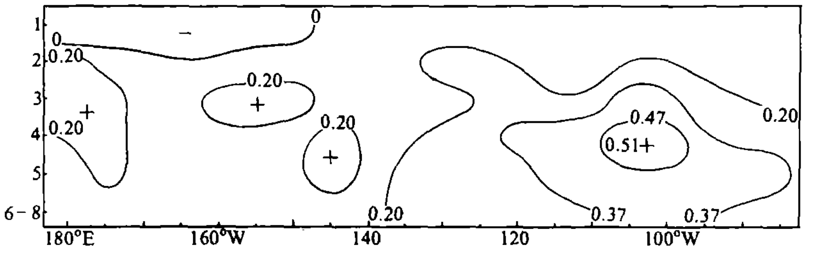

Fig.7. Evolution of the correlation coefficients between the second time-dependent coefficient and equatorial Pacific SST.

rainfall of Northwest China is positive when east equatorial Pacific SST changes from warm (last winter) to cold (last spring). Because the first time-dependent coefficient mainly explained the summer rainfall trend in the East Qinghai-North Shaanxi region, then in those years it is wetter than normal. We would note here that most of the years immediately after the El Nino years have no El Nino events, but some of El Nino events may persist for two years. In this case, more summer rainfall in the East Qinghai-North Shaanxi region occurs in the third year. It is clearer in physical mechanism to predict the wetter summer in the East Qinghai-North Shaanxi region using the evolution trend of east equatorial Pacific SST in the preceding winter and spring than using statistical data in the years after El Nino years.

Fig.7 shows the evolution of correlation coefficients between the second time-dependent coefficient of summer rainfall in Northwest China and east equatorial Pacific SST from January to August. The correlation coefficients are positive from January to August, and since March the strongly correlated section achieving the 0.95 significance level appears in the range of 105—110°W, then extends to May and maintains in summer. Due to the fact that the second time-dependent coefficient could mainly explain the summer rainfall trend of Hexi-North Qinghai, South Shaanxi and South Qinghai sections, a wetter summer would be expected in these sections when east equatorial Pacific SST is warmer in spring and summer, meanwhile a pronounced dry summer occurs in the East Qinghai-North Shaanxi region.

VI ·CONCLUSIONS

(1) The spatial distribution of summer rainfall of Northwest China in EOF expansion can be divided into four kinds of natural regions, they are East Qinghai-North Shaanxi, Hexi-North Qinghai, South Qinghai and South Shaanxi regions. The first time-dependent coefficient in EOF expansion mainly explains the trend of summer rainfall in the East Qinghai-North Shaanxi region; the second time-dependent coefficient mainly explains the trend of summer rainfall in the other three regions.

(2) The teleconnectivity between El Nino events and summer rainfall of Northwest China is pronounced. In the years of El Nino events, there are dry summers in the East Qinghai-North Shaanxi region and wet summers in the other three regions, particularly in the Hexi-North Qinghai region. In the years immediately after El Nino years, there are quite wetter summers in the East Qinghai-North Shaanxi region.

(3) It is illustrated from the analysis of correlation coefficients between the first and second time-dependent coefficients of summer rainfall in Northwest China and tropical Pacific SST in

the concurrent and preceding periods that the connection between tropical Pacific SST and summer rainfall of Northwest China is significant, especially when east equatorial Pacific is warm from winter to summer. In that year the summer is quite dry in the East Qinghai–North Shaanxi region and wet in the other three regions, especially in the Hexi–North Qinghai region; when east equatorial Pacific changes from warm winter to cold summer, especially quite cold after March, then the summer of that year is quite wetter in the East Qinghai–North Shaanxi region and dry in the other three regions, especially in the Hexi–North Qinghai region.

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