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EFFECTS OF PACIFIC SSTA ON SUMMER PRECIPITATION OVER EASTERN CHINA, PART I: OBSERVATIONAL ANALYSIS

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ABSTRACT: With the methods of REOF (Rotated Empirical Orthogonal Function), the summer precipitation from 43 stations over eastern China for the 1901 – 2000 period was examined. The results show that South China and Southwest China, the middle and lower reaches of Changjiang River, North China and the southwestern of Northeast China are the three main areas of summer rainfall anomaly. Furthermore, correlation analysis is used in three time series of three mostly summer rainfall modes and four seasonal Pacific SSTA (Sea Surface Temperature Anomaly), and the results suggest that the Pacific SSTA which notably causes the summer rainfall anomaly over eastern China are the SSTA of the preceding winter over Kuroshio region of Northwest Pacific, SSTA of the preceding spring in the eastern and central equatorial Pacific, and SSTA of the current summer in the central region of middle latitude. The relationship between summer precipitation over eastern China and SSTA of Pacific key regions was further verified by SVD (Singular Value Decomposition) analysis. The composite analysis was used to analyze the features of atmospheric general circulation in the years of positive and negative precipitation anomaly. Its results were used to serve as the base of numerical simulation analysis.

Key words: eastern China; summer precipitation; Pacific; SSTA

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1 INTRODUCTION

The summer precipitation variation is an important aspect of the climate variation research. Many scholars have studied the distinct characteristics of China summer rainfall, and divided them into three precipitation patterns with the inclusion of a northern (N) pattern, middle (M) pattern and southern (S) pattern[1-3]. Wang and Zhao[4] and Deng et al.[5] analyzed the inhomogeneously distributed rainfall data, showing that the most outstanding characteristic of Chinese precipitation is an anti-interrelation between the Changjiang-Huaihe basins and Hetao/South China. Wu et al.[6] proposed that precipitation in eastern China showed a W or M pattern on north and south sides. In the recent 10 years, some investigators have studied the last 100-year rainfall variation using interpolated station observations. Zhang[7] analyzed the 1891 – 1988 yearly averaged rainfall data of eastern China and proposed that the rainfall variation is alternately wet and dry. Li et al.[8] analyzed the spatial-temporal variations of 1880 – 1999 rainfall north of 25°N in eastern China. On the other hand, a lot of research results show that SSTA is closely related with precipitation and temperature. In the 1950s, Lu[9], Lu and Zhang[10] proposed that there was a close relationship between North Pacific SSTA and Meiyu rainfall in the valleys of Changiiang and Huaihe Rivers. It is pointed out that there is a close relationship between SSTA of the Kuroshio region and summer rainfall of the reaches of Changjiang River[11]. Deng and Wang[12] discussed the relationship between SST over offshore waters in China and precipitation anomalies in the annually first raining season (April-June) in southern China. Cai et al. (2003)[13] examined the correlation relationship between the variations of West Pacific subtropical high indices in the summer half of the year and SST in North Pacific during previous time, indicating that the correlation between

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the subtropical high indices and preceding SST in the equatorial East Pacific was the strongest of all and has great persistency from previous autumn to spring. The results showed that rainfall distribution of the rainy season in Fujian was directly affected by the subtropical high activities, pronouncedly caused by ENSO effect. Tan et al.[14] analyzed the relationship of summer rainfall patterns in eastern China with the Northern Hemisphere atmospheric circulation and SST fields in the simultaneous and previous (winter) seasons in the period of 1951 – 1995 northern summer monthly mean 500 hPa height and north Pacific SST, pointing out that the S pattern of summer rainfall in China will appear when the previous winter SSTA is warmer (colder) in eastern-central equatorial Pacific (northern Pacific and Kuroshio region) and shows latitudinal distribution in the whole North Pacific. Huang and Wu[15] suggested that summer rainfall was more (less) in the valleys of Changjiang and Huaihe Rivers and less (more) in South China and North China at the strengthening (weakening) stage of El Niño. Lin and Yu[16] discussed the relationship between El Nino and rainfall during the raining season in China, indicating that when the peak period of east-pattern of El Niño elapsed, the rainfall during the flood season will be less (more) in the Changjiang River valleys (North China and south of the Changjiang River valleys), and when the peak period of middle-pattern of El Niño passed, the rainfall in these regions will be reverse. Gong and Wang[17] studied the influence of ENSO on the seasonal rainfall in China based on the long time rainfall series of 35 stations from 1880 and on the instrumental rainfall records of 120 stations from 1951, showing that in El Nino years, the rainfall over the northern area of east China will decrease in summer, autumn and winter, and the rainfall over the south basin of Changjiang River in autumn and the rainfall over southeast China in winter will increase significantly, but in La Nina years, the rainfall in these region will be reverse. There is no significant connection between ENSO and rainfall in spring. In this paper, the distribution characteristics of summer rainfall anomaly is analyzed for 43 stations over eastern of China in the 1901 – 2000 period and focus is placed on the relationship of the rainfall anomaly with the Pacific SSTA.

2 DATA AND METHODOLOGY

2.1 *Data*

In this study, The NCEP dataset were derived from the reanalysis of the National Center for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR). The dataset, which is in a grid format of 2.5 long. × 2.5 lat. resolution, spans the period of 1951-2000. Summer rainfall of 43 selected stations (Fig.1) over the east part of China in the 1901 – 2000 period includes two parts as follow:

(1) The rainfall data of the 1901 – 1950 period come from Precipitation Data in China, which was edited by Central Meteorological Bureau and Institute of Geophysics Chinese Academy of Science (1954)[18]. The vacant data are mended by using neighbor stations' data firstly. The linear regression method is used when neighboring stations' data are also absent. The method is the same as that of Li et al.[19]; (2) the rainfall data of the 1951 - 2000 period come from the 160-station monthly precipitation data of China Climate Center. SST data are downloaded from www.cdc.noaa.gov. In this paper, focus is on the region (20°S - 60°N, 110°E - 290°E) of the Pacific.

2.2 *Methodology*

Summer rainfall of different areas has different characteristics in eastern China. REOF analysis, which can reflect the local features[20], is used in this paper to analyze the 43 selected stations summer rainfall over the east part of China, in such a way that the main spatial patterns are obtained. The relationship of time coefficients of the main patterns with the Pacific SSTA is investigated based on correlation analysis. The singular value decomposition (SVD) method[21] is used for the relationship of the key SSTA region and the 120 selected stations summer rainfall over eastern China in the 1951 – 2000 period. The SVD method is widely employed to analyze the spatial correlation relationship between two meteorological fields, which has steady mathematic basis and clear physical meaning. In this paper, the SSTA field is the left field, and the rainfall field is the right field. The first left (right) field of SVD gives the distribution of SST (rainfall) spatial teleconnection and the key region reflecting their interactions and the time coefficient series show the evolutions of the corresponding pattern.

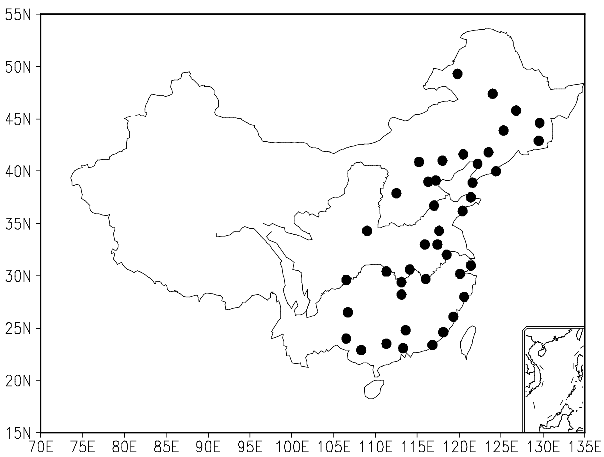

Fig.1 Location of the selected 43 stations over eastern China.

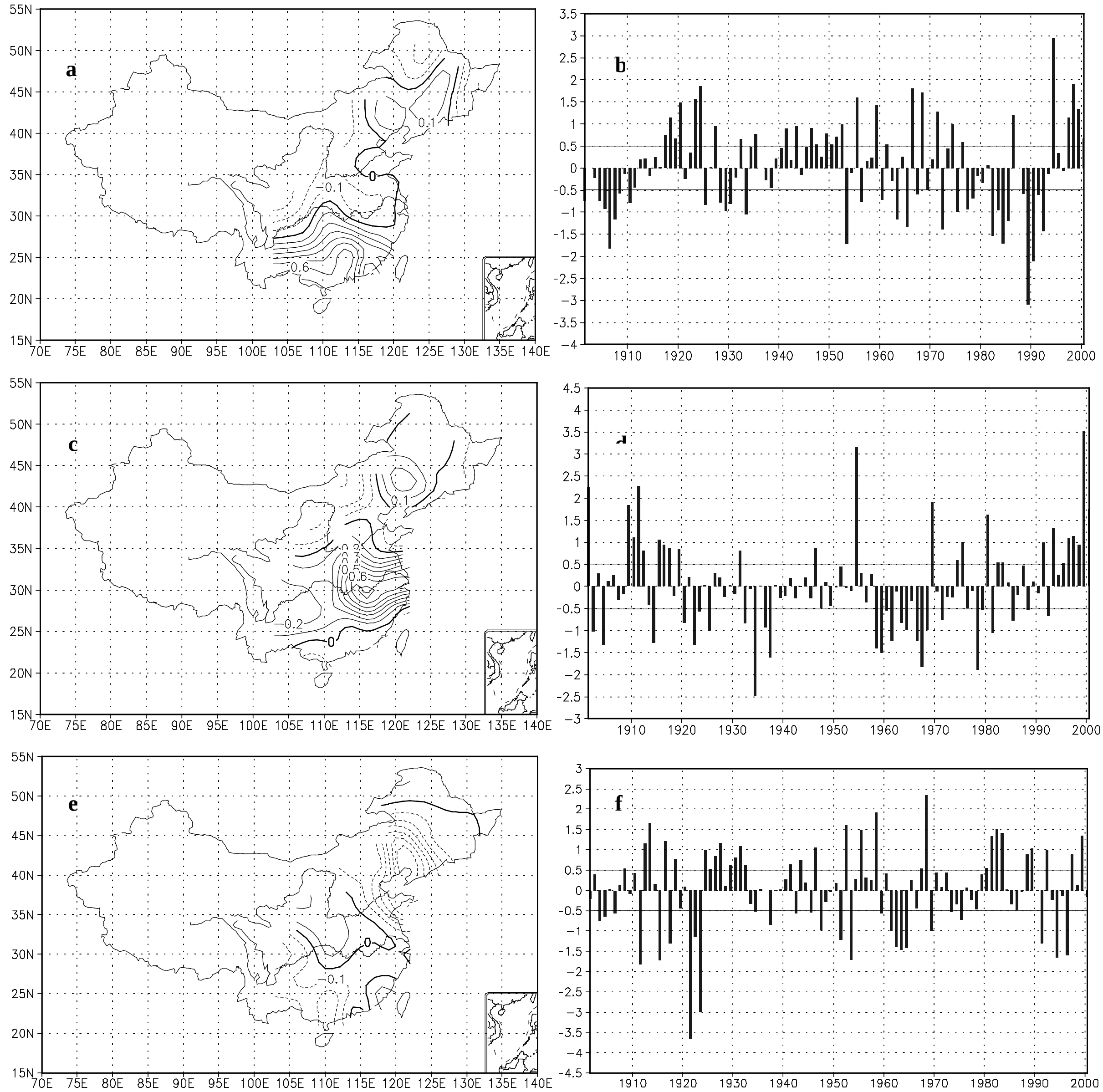

Fig.2 Three leading REOF spatial modes of summer rainfall over eastern China in the 1901 – 2000 period (a.REOF-1；c.REOF-2；e.REOF-3) and their time coefficients (d. REOF-1；e. REOF-2；f. REOF-3).

3 SPATIAL DISTRIBUTION OF SUMMER RAINFALL OVER EASTERN CHINA

Fig.2 gives the three leading REOF modes and their time series with their accumulation explaining 31.15% of the total variance. The first leading REOF mode, accounting for 11.5 % explaining variance, is mainly south of the Changjiang River with the higher centers in South and Southwest China. The second leading REOF mode, accounting for 10.36 % of the total variance, is mainly over the mid- and lower- reaches of Changjinag River and Basins of Changjang and Huaihe Rivers with the maximum center in the mid- and lower- reaches of Changjiang River. The third leading REOF mode accounts for 9.29% of the total variance, and anomalous areas are mainly over the southwestern part of Northeast China and northeastern of North China.

4 THE RELATIONSHIP BETWEEN SUMMER RAINFALL ANOMALY OVER EASTERN CHINA AND GENERAL CIRCULATION ANOMALY

The positive (negative) rainfall anomaly years are selected with the leading two REOF coefficients greater than 0.5 (less than -0.5) south of the

Changjiang River in Fig.2d and the mid- and lower-reaches of Changjiang River and Basins of the Changjang and Huaihe Rivers in Fig.2e, and positive (negative) years are selected with the third REOF

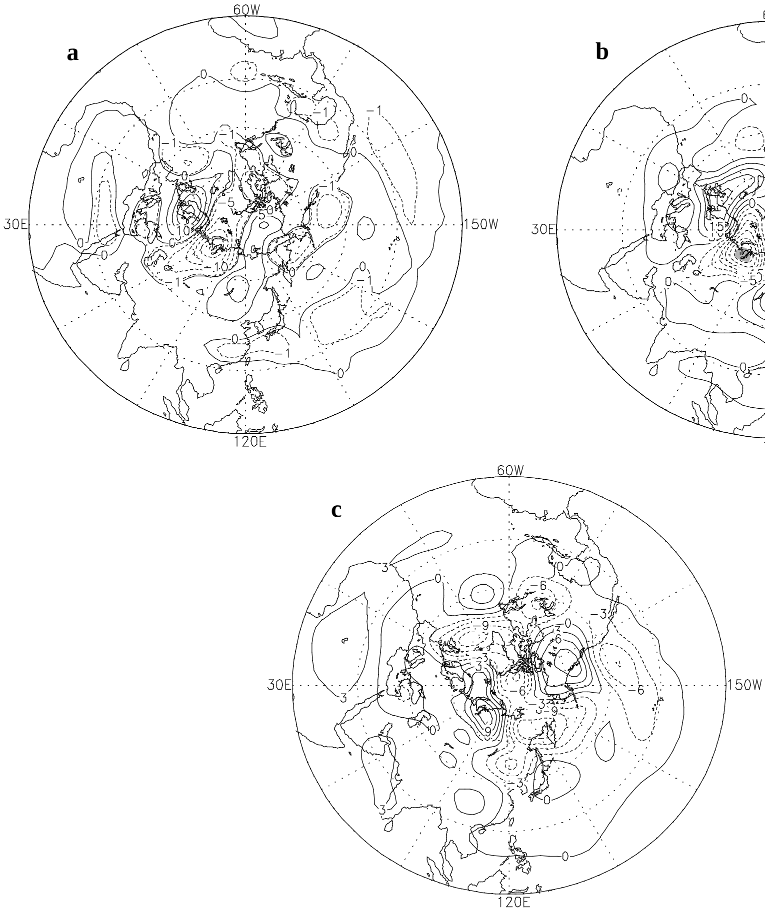

Fig.3 Composite geopotential heights (units: dagpm) in the years of positive (a) and negative (b) rainfall anomaly in South and Southwest China, and their difference (units: dagpm) and *t*-test result (c; shaded areas with a 0.01 significance level).

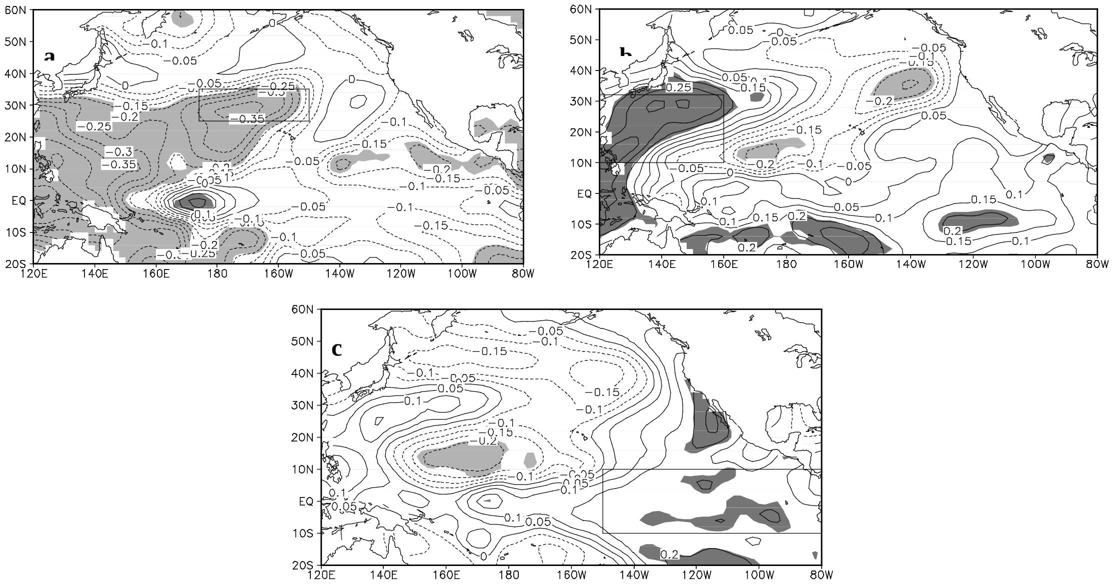

Fig.4 Correlation coefficient distribution between Pacific SSTA and the three leading REOF time coefficients of rainfall a. REOF-1 and current summer SSTA; b. REOF-2 and preceding winter SSTA; c. REOF-3 and preceding spring SSTA.

coefficient less than -0.5 (greater than 0.5) for the southwestern of Northeast China (northeastern of North China) in Fig.2f. Composite analysis is used for the positive (negative) years.

In the positive rainfall anomaly years of South and Southwest China (Fig.3a), there is a long/narrow longitudinal zone with negative geopotential departure south of Changjiang River in China and south of Japan, an area of positive geopotential departure in Lake Baikal and Mongolia south of it, a negative geopotential departure region in high latitude area northwest of Lake Baikal, and a positive geopotential departure near the Baltic Sea, showing a "－＋－＋" wavetrain from south of Changjiang River/south Japan to the Baltic Sea. The northern high latitude region of Lake Baikal is of positive departure, indicating that the polar vortex is shallow such that the cold air can go forward from the northeast to the south, which is favorable for the cold air to be forced to areas south of Changjiang River where the geopotential departure is negative. In contrary, there is a "＋－＋－" wavetrain in the negative years(Fig.3b) with positive departure in the areas south of the Yellow River and strong negative departure in areas south of Lake Baikal and Okhotsk Sea, which is not favorable for the cold air to go forward to areas south of Changjiang River. The difference field (Fig.3c) shows that the variation of geopotential height in Lake Baikal is key to elements influencing summer rainfall south of Changjiang River.

In positive rainfall anomaly years of the mid- and lower- reaches of Changjiang River and valleys of Changjiang and Huaihe Rivers (Figure omitted), there is a negative departure zone south of Japan and Korean Peninsula, and a positive departure area in Lake Baikal, Okhotsk Sea and Ural Mountain, and a positive departure area in South China and South China Sea, and a transitional region of the two positive departure in the mid- and lower- reaches of Changjiang River and valleys of Changjiang and Huaihe Rivers. The geopotential height anomaly distribution is favorable for the cold air and warm moisture to converge in the mid- and lower- reaches of Changjiang River and valleys of Changjiang and Huaihe Rivers. On the other hand, the geopotential height anomaly distribution in negative anomaly years (Figure omitted), which is opposite to that in positive anomaly years, not only obstruct the southeast warm moisture of West Pacific from transporting to the mid- and lower- reaches of Changjiang River and valleys of Changjiang and Huaihe Rivers, but also conduct the southwest warm moisture in transporting to North China, leading to more rainfall in North China. The difference field (Figure omitted) shows that geopotential height variation of high- and middle- and low latitude regions of Eurasia is key to elements influencing summer rainfall in the mid- and lower- reaches of Changjiang River and valleys of Changjiang and Huaihe Rivers.

In the positive rainfall anomaly years of southwest of Northeast China and north of North China, there is a "－＋－" wavetrain from Lake Balkhash to the polar zone at 500hPa geopotential height anomaly field(Figure omitted) with a negative departure area between the area east of Lake Baikal and the Okhotsk Sea, indicating that a low trough region lies in east of Lake Baikal, and the west Pacific subtropical high lies poleward of its normal position, leading to more summer rainfall in the southwest part of Northeast China and northern part of North China. In contrary, there is a "＋－＋" wavetrain from Lake Balkhash to North Pacific in the negative anomaly years(Figure omitted). It is dominated by the descending airflow of high ridge in the southwestern part of Northeast China and northern part of North China, leading to less summer rainfall there. The difference field (Figure omitted) shows that the geopotential height is higher in South Japan which passes a 95 % confidence level test, indicating that the geopotential height variation in South Japan is one of the key elements influencing summer rainfall in the southwestern part of Northeast China and northern part of North China.

5 THE CORRELATION BETWEEN SUMMER RAINFALL ANOMALY OVER EASTERN CHINA AND PACIFIC SSTA

In order to interpret the relationship between summer rainfall anomaly and Pacific SSTA, their correlation is universally examined. The correlations between the time coefficients of three leading REOF patterns and the preceding autumn, winter, spring and simultaneous summer SSTA indicate that the preceding winter, spring and simultaneous summer SSTA have best relations with the three main rainfall anomaly regions (Fig.4). There is a negative correlation relationship between summer precipitation over South and Southwest China, and the area south of the Changjiang River and current summer SSTA of the central region of middle latitude Pacific (Fig.4a), and an significantly positive relationship between summer precipitation over the mid- and lower- reaches of Changjiang River and reaches of the Changjiang and Huaihe Rivers and the preceding winter SSTA of Kuroshio region of Northwest Pacific (Fig.4b), a negative relationship between the summer rainfall over northern of North China and southwestern of Northeast China and the preceding spring SSTA of eastern and central equatorial Pacific (Fig.4c).

6 COUPLING CORRELATION BETWEEN

SUMMER RAINFALL ANOMALY OVER EASTERN CHINA AND SSTA IN PACIFIC KEY REGIONS

The above analysis shows that the key areas of Pacific SSTA notably causing the summer rainfall anomaly over eastern China are the preceding winter SSTA of Kuroshio region of Northwest Pacific (Fig.4b), the preceding spring SSTA of eastern and central equatorial Pacific (Fig.4c), and summer SSTA of the central region of middle latitudes (Fig.4a).

The first left vector field of SVD between preceding winter SSTA of the Kuroshio region and summer rainfall over eastern China shows that SSTA next to the main axis of Kuroshio region is negative (Fig.5a) with its characteristics similar to those of the correlation distribution (Fig.4). The first right vector field (Fig.5b) shows that rainfall anomaly is negative (positive) in the Changjiang River valleys and its south with the anomaly center locating in the Changjiang mid- and lower- reaches, and the Great Bend region of Yellow River (Northeast China, northeastern of North China and Shandong Peninsula). The first pair of vectors explains 66.111 % of the total variance with a 0.01 significance level, and their correlation coefficient is 0.669 with a 0.01 significance level. The extreme preceding winter SSTA of the Kuroshio region is relevant to extreme rainfall anomaly over eastern China, such as 1998 – 1999 floods event in the Changjiang River corresponding to the preceding winter positive SSTA of the Kuroshio region (Fig.5c).

The first left vector field of SVD between preceding spring SSTA of eastern-central equatorial Pacific and summer rainfall over eastern China shows that SSTA located in Niño3 region is negative (Figure omitted). The first right vector field (Figure omitted) shows that rainfall anomaly is positive (negative) in Southwest and South China, northeastern of North China and southwestern of Northeast China (northern of Northeast China, the Changjiang River valleys and south of the Changjiang River). The first pair of vectors explains 78.516 % of the total variance with a 0.01 significance level, and their correlation coefficient is 0.669 with a 0.01 significance level. The extreme preceding spring SSTA of eastern and central equatorial Pacific is relevant to the extreme rainfall anomaly over eastern China, such as 1982 – 1982, 1986 – 1987, 1992 – 1993 and 1997 – 1998 El Niño events corresponding to floods in the Changjiang River valleys (Figure omitted).

The first left vector field of SVD between the current summer SSTA of the central region of middle latitudes and the summer rainfall over eastern China shows that SSTA centering in the west wind drift region is negative (Figure omitted). The first right vector field (Figure omitted) shows that rainfall anomaly is positive (negative) in Northeast China, northern of North China and Changjiang-Huaihe Valleys (Southwest China, South China and Hetao region). The first pair of vectors explains 48.18 % of total variance with a 0.01 significance level, and their correlation coefficient is 0.56 with a 0.01 significance level. The extreme summer SSTA is simultaneously relevant to the extreme rainfall anomaly over Eastern China, such as 1998, 1999 floods in the Changjiang River valleys and 1998 flood in Northeast China

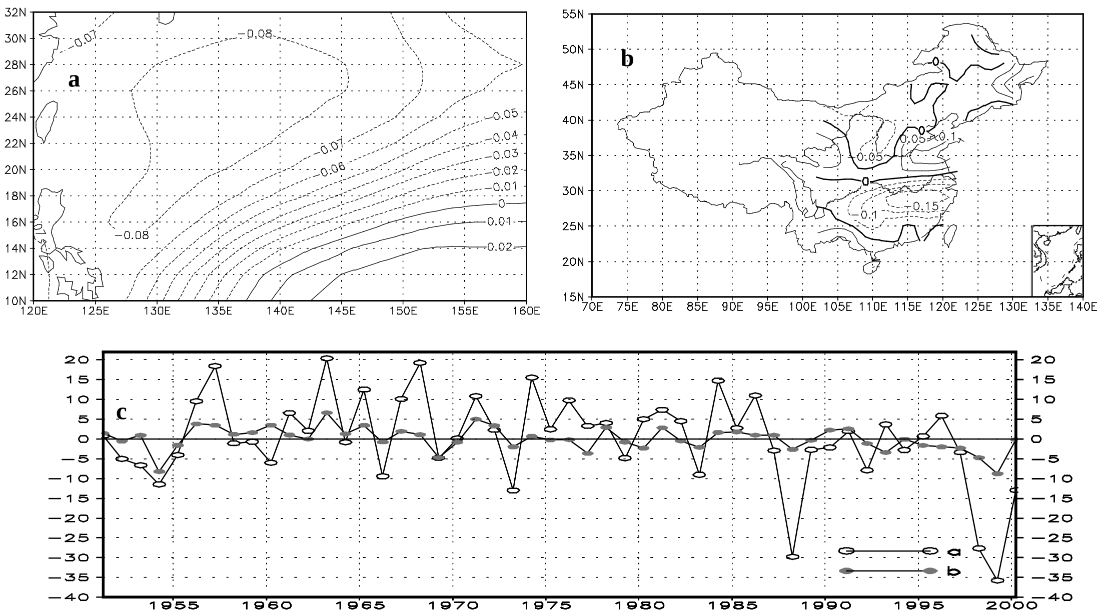

Fig.5 First pair of SVD spatial modes between the preceding winter SSTA (a) of the Kuroshio region and summer rainfall (b) over eastern China and their time coefficients (c).

corresponding to the simultaneous summer SST positive anomaly of the center region of middle latitude (Figure omitted).

7 CONCLUDING REMARKS

(1) In the 1901 – 2000 period, there are three main areas of summer rainfall anomaly over eastern China, *i.e.* South China and Southwest China, the mid/lower reaches of the Changjiang River and Changjiang-Huaihe Basins, and northern of North China and southwestern of Northeast China.

(2) When the summer rainfall anomaly over South and Southwest China is positive (negative), the geopotential height departure is positive (negative) near Lake Baikal and Okhotsk Sea, and west Pacific subtropical high is inclined to the east/west (south/north) sides. When the summer rainfall anomaly over the mid/lower reaches of Changjiang River and Changjiang-Huaihe Basins is positive (negative), the geopotential height departure is positive (negative) near the Okhotsk Sea and Ural Mountain, and west Pacific subtropical high is inclined to the west/east(north/south) sides. When the summer rainfall anomaly over the northern part of North China and southwestern part of Northeast China is positive (negative), the geopotential height departure is negative (positive) from the east of Lake Baikal to Okhotsk Sea, and west Pacific subtropical high is extremely inclined to north(south) side.

(3) The key areas of Pacific SSTA notably causing the summer rainfall anomaly over eastern China are the preceding winter SSTA of Kuroshio region of Northwest Pacific, the preceding spring SSTA of eastern and central equatorial Pacific, and summer SSTA of the central region of middle latitude.

(4) When the preceding winter SSTA of Kuroshio region of Northwest Pacific is positive, there is much more (less) summer rainfall in Changjiang-Huaihe Basins(Northeast China, northeastern and southwestern of North China, and vice versa. When the preceding spring SSTA of the eastern and central equatorial Pacific is positive, there is much more (less) summer rainfall in Southwest China, southern of South China and eastern/northern of Northeast China(northeastern of North China and southwestern of Northeast China), and vice versa. When the current summer SSTA of the center region of middle latitude is positive, there is much less (more) summer rainfall in the reaches of Changjiang River, Southwest China and southwestern of Northeast China (South China, North China and Inner Mongolia.

In this paper, the observational analysis shows the preliminary relationship between summer rainfall over eastern China and Pacific SSTA. But, how does the SSTA of the key regions influence the general circulation over East Asia and then affect summer rainfall over eastern China? What is the physical process and influencing mechanism? These will be discussed in Part II of this study.

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