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The Analysis of the Relationship between the Spatial Modes of Summer Precipitation Anomalies over China and the General Circulation

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The precipitation data at 5° by 5° grid (June, July and August) from 1959 to 1994 are used to analyze the monthly change of the spatial mode of summer precipitation anomalies over China. The relation between the spatial mode of summer precipitation anomalies and the atmospheric general circulation is analyzed by using indices of the Northwestern Pacific High, and the geopotential height index *B* of the Tibetan Plateau. The Monte–Carlo method is used to evaluate the significance level of the collective significance of the correlation field between the circulation index and precipitation. Our results show that the negative correlation between the precipitation anomaly over the lower–reaches of the Yangtze River and Huaihe River valley region and that over the middle–reaches of the Yellow River region and over the South China (Spatial mode 1, or SP1) is the most significant in August. The negative correlation between the precipitation anomaly over the southern part of the eastern Tibetan Plateau and that over the northern part of the eastern Tibetan Plateau (Spatial mode 2, or SP2) is more significant in June and August than in July. The analyzes for the correlation between indices of the Northwestern Pacific High and monthly precipitation show that the anomaly of the north boundary of the Northwestern Pacific High in August has the greatest influence on SP1. If the Northwestern Pacific High is steadily located in a position that is north to its normal, it is very likely that the precipitation over the LRYH region is below normal, and the precipitation over the middle–reaches of the Yellow River region and South China is above normal, and vice versa. The analyzes of the correlation between the geopotential height index *B* over the Tibetan Plateau and monthly precipitation show that the activity of the high and low vortex has an influence on SP2. If the activity of the high over the Tibetan Plateau is more frequent, then it is very likely that the precipitation of the southern part of the Tibetan Plateau is above normal, and the precipitation over the northern part is below normal, and vice versa. The activity of the Northwestern Pacific High in August can also influence the spatial mode of the summer precipitation anomalies over the northern and southern part of the eastern Tibetan Plateau.

Key words: spatial modes of summer precipitation anomalies; indices of the northwest Pacific high; geopotential height index *B* of the Tibetan Plateau.

1. INTRODUCTION

The analyzes by using the spatial nonuniform station precipitation data[1,2] showed that the most significant spatial mode of summer precipitation anomalies is the negative correlation in precipitation between the lower-reaches of the Yangtze River and the Huaihe River (LRYH) region and South China, and between the LRYH region and the middle-reaches of the Yellow River (MRY) region. In other words there is an "M" or "W" pattern of precipitation anomalies over East China[3]. However, the analyzes by using the spatial uniform 47 grid point precipitation data over China showed that besides the aforementioned correlation, there are negative correlation between the northern and southern parts of the central and eastern Tibetan Plateau (CETP) region, and positive correlation in precipitation between the southern part of the CETP region and the eastern part of North China and the southern part of Northeast China [4]. These two spatial modes are in fact the first and second spatial mode of Varimax EOF analysis of total summer precipitation (total precipitation in June, July and August), respectively.

There are many researches in the aspect of the influence of the Northwest Pacific High (NWPH) on summer precipitation anomaly over China. It has long been noticed that the abnormal position of the NWPH can affect the summer precipitation over the LRYH region, and North and South China[5] and that the vortex and anticyclone activity at 500 hPa over the Tibetan Plateau can affect the weather over and around the Tibetan Plateau[6].

The present research focuses on the monthly variation of the first and second spatial modes of summer precipitation anomalies and the influence on summer precipitation over China of the NWPH and the activity of 500 hPa vortex and anticyclone over the Tibetan Plateau. The data set used was presented in details in Ref.[4]. It covers the period of 1959–1994, and the region from 15°N to 55°N and from 75°E to 135°E, which is divided into 5° Lat. by 5° Long. grid boxes. When the number of stations in one grid box is equal to or larger than 2, the average monthly precipitation of the grid box is calculated as the arithmetic average of the stations within the grid. The NWPH indices used are the area index, northern boundary index, ridge line index, strength index, and the index of the western extension of ridge line. In Section 2 the results of the spatial modes of summer precipitation are presented. The monthly variation of spatial modes of summer precipitation is analyzed in Section 3. Section 4 presents the Monte Carlo results of collective significance of August monthly precipitation. The relation of general circulation with the spatial modes of summer precipitation is analyzed by the NWPH indices and the geopotential height index B over the Tibetan Plateau (index B). The summary is presented in Section 5.

2. SPATIAL MODES OF SUMMER PRECIPITATION ANOMALY

The first spatial mode of Varimax EOF analysis for total summer precipitation is shown in Fig. 1. The significant characteristic is the negative correlation in precipitation between the LRYH region and the MRY region, and between the LRYH region and South China. There exists a "W" or "M" pattern of precipitation anomalies over East China. The correlation analysis shows that these negative correlations are significant at the level of 95%[4]. Besides, there also exists a "W" or "M" pattern in east-west direction along the Yangtze River. This spatial mode can explain 12.4% of the total variance.

Fig. 2 shows the second spatial mode of summer precipitation anomaly. It can be noticed from Fig. 2 that there exists negative correlation in precipitation anomalies between the northern and southern parts of the CETP region. There also exists positive correlation between the southern part of the CETP region and the southern part of Northeast China and the eastern part of North China. The correlation analysis with the southern part of the CETP region as base point shows that the above correlations are significant at the level of 95%[4]. This spatial mode can explain 11.4% of the total variance. There exists obvious monthly difference of these two spatial modes. This will be the subject of the next section.

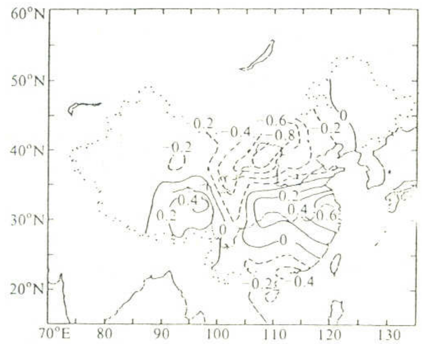

FIGURE 1. The first spatial mode of Varimax EOF analysis of total summer precipitation (total precipitation of June, July and August).

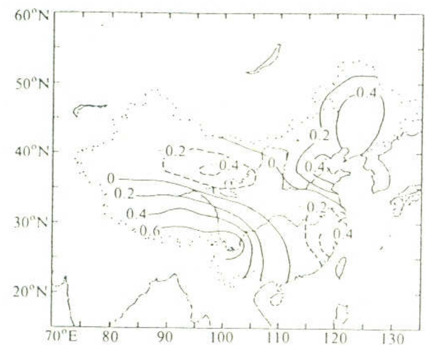

FIGURE 2. The second spatial mode of Varimax EOF analysis of total summer precipitation.

3. MONTHLY VARIATION OF SPATIAL MODES

3.1 *Monthly Variation of the First Spatial Mode*

The correlation patterns of monthly precipitation for June, July and August with the LRYH region as base point are shown in Figs. 3a, b, c, respectively. The short-dashed line in the figure indicates the region with significant correlation at the level of 95% (solid line for positive correlation, dashed line for negative correlation). In June there is positive correlation over the LRYH region, the eastern part of North China and the southern part of Northeast China (Fig. 3a). At this time the ridge line of the NWPH is located around 20°N on an average. The cyclones in the westerlies are the main precipitation weather system. In July there exists negative correlation between the LRYH region and North China (Fig. 3b). It is interesting to note that, in comparison with Fig. 1, both the negative correlation region and positive correlation region are located further east. This may be related with the fact that at this time of the year the position of the NWPH is still to the east of its position in August. The main region influenced by the NWPH is the eastern part of China. In August (Fig. 3c) the "W" or "M" pattern in north-south direction along East China is quite obvious. There exists negative correlation in precipitation anomalies between the LRYH region and South China, and between the LRYH region and the MRY region. Besides, the "W" or "M" pattern in east-west direction along the Yangtze River is also obvious. There are negative correlation regions in Sichuan basin, and positive correlation regions over the LRYH region and the eastern part of the Tibetan Plateau.

3.2 *Monthly Variation of the Second Spatial Mode*

The correlation patterns of monthly precipitation for June, July and August with the southern part of the CETP region as base point are shown in Figs. 4a, b, c, respectively. It can be noticed that the negative correlation between the southern and the northern parts of the CETP region is quite obvious even as early as in June. The positive correlation between the southern part of the CETP region and the eastern part of North China and the southern part of Northeast China is also obvious. The main features in Fig. 4a are similar to those in Fig. 2.

Though there is negative correlation between the northern and southern parts of the CETP region in July (Fig. 4b), the correlation centers move further westward compared with those in June (Fig. 4a). In August the negative correlation between the northern and southern parts of the CETP region is also prominent. Another positive correlation region is located in the northern part of the LRYH region instead of the eastern part of North China or the southern part of Northeast China. From the above analysis it is clear that the second spatial mode

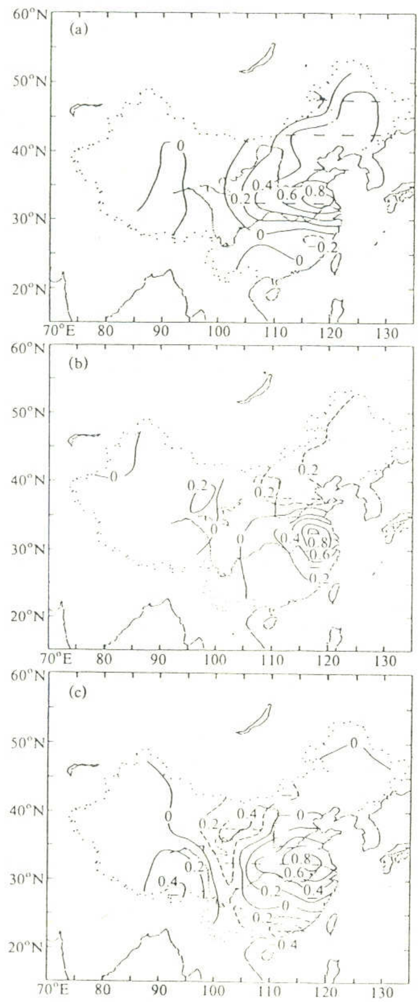

FIGURE 3. The correlation patterns for June, July and August monthly precipitation with the lower-reaches of the Yangtze River and the Huaihe River (LRYH region 30–35°N, 115–125°E) as base point, a: June, b: July, c: August.

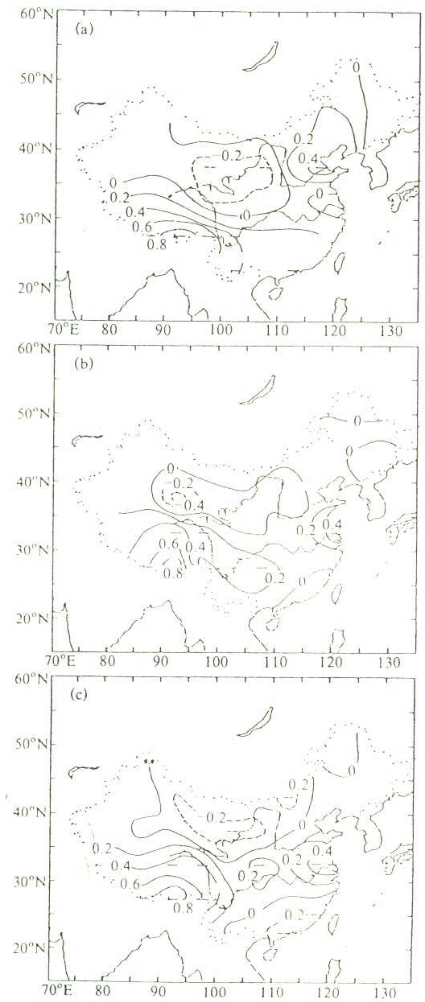

FIGURE 4. The same as Figure 3 except with the southern part of the central and eastern Tibetan Plateau (25–30°N, 90–95°E) as base point, a: June, b: July, c: August.

presents in the precipitation of each month, though it is more evident in June and August than in July.

4. SPATIAL MODES OF PRECIPITATION ANOMALY AND GENERAL CIRCULATION

4.1 *Monte Carlo Results of Collective Significance*

The following two subsections will present the result of correlation analysis of the NWPH indices and index $B^{[8]}$ with monthly precipitation. As discussed in Ref.[9], the neglecting of the issue of collective significance may lead to misleading result. Their analyzes show that the problem of whether the correlation coefficient for one grid point is significant is a typical statistical problem; whereas the problem of collective significance concerns whether a correlation pattern as a whole is significant. The latter is determined by the number of grid points which have significant correlation coefficients at a certain level. The reasons for verifying collective significance are, 1) the numbers of grid points used in analysis are limited (in the present analysis it is 47), 2) the data of each grid point are interdependent. The Monte Carlo method is used to address the problem of collective significance. The monthly precipitation of August is used in analysis. For every grid point calculated is the correlation coefficient between the August precipitation and a randomly generated time series satisfying normal distribution with a length of 36.

The frequency distribution of the correlation pattern in terms of the number of correlation coefficients whose absolute values are greater than 0.32 (significant at the level of 95%) is shown in Fig. 5. The sample number of Monte Carlo experiment is 1000. It can be noticed from Fig. 5 that most of the randomly generated time series can only have up to 4–5 grid points whose correlation coefficients are significant at the level of 95%. The frequency of a correlation field having significant grid points more than or equal to 7 is 6.1% (61 / 1000). The frequency of a correlation field having significant grid points more than or equal to 8 is 3.5% (35 / 1000). This shows that for a correlation field to be significant at the level of 95% there should be more than 7 or 8 grid points that have correlation coefficients significant at

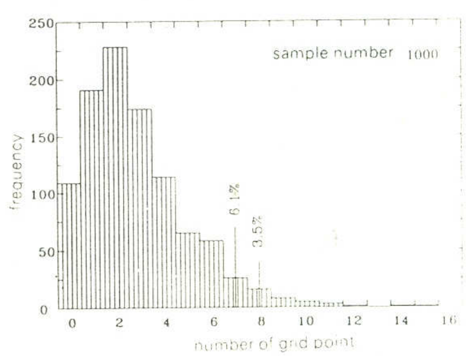

FIGURE 5. Frequency distribution of the correlation field having grid points with significant correlation coefficient at the level of 95%. The abscissa is the number of grid points that are significant at the level of 95%. The ordinate indicates frequency. The correlation is between a randomly generated time series subjecting to normal distribution and August monthly precipitation. The sample number is 1000.

the level of 95%. It should be noted that 7 grid points are 15% (7 / 47) of the total grid points analyzed. The above analysis shows the influence of the limited number of grid points analyzed and the interdependence of the precipitation data to the analysis of collective significance.

The above Monte Carlo simulation provides some kind of guidance for the collective significance analysis. However, since the 5° Lat. by 5° Long. grid point precipitation data are representative of large scale precipitation, the correlation patterns are also presented for some cases in which the correlation coefficients at some grid points are significant at the level of 95%, but the correlation pattern is not significant at the level of 95%. The correlation patterns presented in such cases have synoptic meaning, as we understood, from the point of view of abnormal general circulation.

4.2 *Relation of the NWPH with the Spatial Modes*

Five indices of the NWPH (area index, northern boundary index, ridge line index, strength index, and the index of western extension of ridge line) were used to describe the abnormal situation of the NWPH. The preliminary correlation analyzes of the above indices and precipitation in June, July and August are showed in Table 1. It can be noticed that the correlation fields of northern boundary index and ridge-line index are significant at the level of 95% for all the three summer months, whereas the correlation patterns of other three indices with precipitation are not significant at this level for all the three months. Since the northern boundary of the NWPH is roughly consistent with a rainy region over East China during summer season, the northern boundary index is used in the following analysis.

TABLE 1. The number of grid points that have significant coefficients of correlation at the level of 95% between the monthly precipitation and the indices of the Northwest Pacific High, AI: Area index; NBI: Northern boundary index; RLI: Ridge line index; SI: Strength index; WERLI: Index of western extension of ridge Line.

	AI	NBI	RLI	SI	WERLI
June	3	11	9	2	3
July	7	7	7	5	2
August	5	12	13	6	2

The correlation patterns of the northern boundary index of NWPH with precipitation for June, July and August are shown in Figs. 6a, b, c, respectively. It can be noticed from Fig. 6 and Table 1 that there are 12 grid points that are significant at the level of 95% in August. The correlation pattern (Fig. 6c) in August is similar to the first spatial mode of total summer precipitation (Fig. 1). The "W" or "M" pattern in north-south direction over East China and in east-west direction along the Yangtze River is obvious. Fig. 6c shows that when the NWPH is located to the north of its normal position in August, the MRY region and South China tend to have positive precipitation anomalies, whereas the LRYH region tends to have negative precipitation anomaly. This is consistent with other researches[5] and the experience of weather forecasters. The reason is related with the fact that in August the weather systems in the MRY region and North China are caused by the confluence of the warm air at the northern boundary of the NWPH and cold air from further north, whereas the rain region in South China is related with the tropical and subtropical weather systems. The LRYH region is under the control of the NWPH. If the NWPH is steadily located to the north of its normal position, the above weather pattern will persist for an abnormally longer period, the MRY region and South China then will have positive precipitation anomalies, whereas the LRYH region will have negative precipitation anomaly. If the NWPH is located to the south of its normal position, the above three regions tend to have precipitation anomalies with opposite signs.

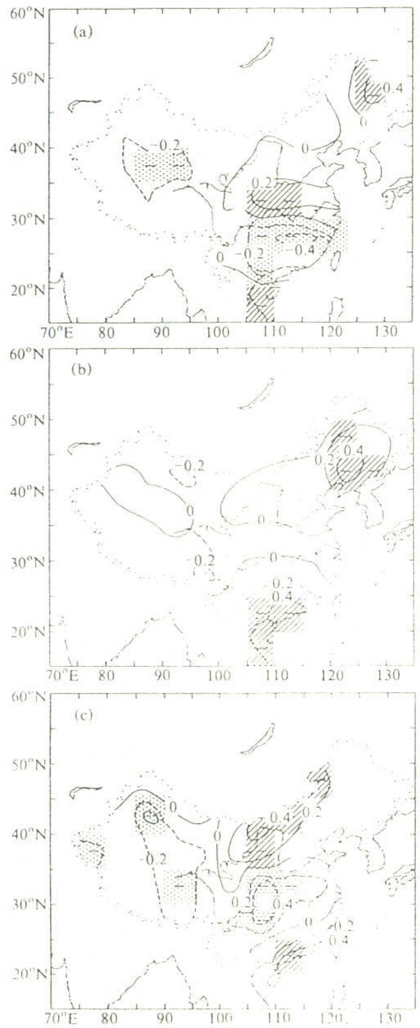

FIGURE 6. The correlation patterns between the northern boundary index of the Northwest Pacific High and monthly precipitation. The short line indicates that the correlation at the grid point is significant at the level of 95% (solid line for positive correlation, dashed line for negative correlation). a: June, b: July, c: August.

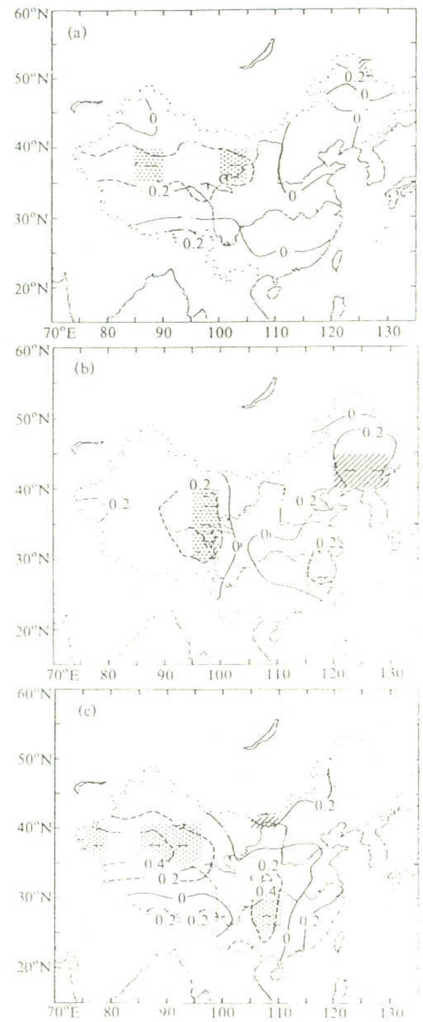

FIGURE 7. The same as Figure 6, except for the correlation pattern between the geopotential height index B over the Tibetan Plateau and monthly precipitation.

The number of grid points that have significant correlation coefficients at the level of 95% is the smallest in July (Fig. 6b and Table 1). There are positive correlation regions over Northeast China and South China. There is no significant correlation over the LRYH region. The above correlation pattern may be related with the fact that in July the rainfall over the LRYH region which is under the control of the NWPH is mainly convective in nature, whereas the positive correlation over Northeast China and South China shows the influence of the NWPH on the rain region in North China and Northeast China and the influence of the NWPH on the tropical weather systems. In June (Fig. 6a) if the NWPH is located to the north of its normal position, the LRYH region tends to have positive precipitation anomaly, whereas South China tends to have negative precipitation anomaly. This shows the influence of the position of the NWPH the ending of the rainy season in April and May over South China and the starting of the Mei–yu season over the LRYH region in mid June. The above analysis shows that the correlation pattern of the northern boundary of the NWPH with precipitation possesses obvious synoptic meaning. From the perspective of the first spatial mode of summer precipitation, the influence of the position of the NWPH in August is very important.

4.3 *Relation of the Tibetan Plateau Index with the Spatial Mode*

In summer over the Tibetan Plateau, there are low–pressure vortices which develop at 500 hPa and move eastward, exerting great influence on the downstream weather[8]. The central Tibetan Plateau may also be controlled by temporary high–pressure systems which are originated from the Iran High, the westward extension of the NWPH or the influence of westerly systems. During the period in which the Tibetan Plateau is under the control of high–pressure, more precipitation appears in the southeastern Plateau [6]. Besides, the activity of anticyclone system can also influence the weather over the northern part of the Plateau. The number of anticyclones over there in the drought year of 1980 is twice that of the year of 1981 in which abundant rainfall occurred[8]. The Tibetan Plateau index B is defined as the sum of the grid value of 500 hPa height based upon a (5° Lat. by 5° Lon.) network and in the region of 30–40°N, 75–105°E, which is measured in the unit of ten geopotential meters and with the hundredth digit omitted. According to the definition the index B can represent the activity of anticyclone and vortex over the Tibetan Plateau to some degree.

The correlation patterns of index B and precipitation for June, July and August are respectively shown in Figs. 7a, b, c. It can be noticed from Figs. 7a, b, c that for all the three summer months there is a significant correlation region over the northern part of the Tibetan Plateau. When the index B has a higher value (the activity of anticyclone is abnormally frequent) in June and August (Figs. 7a, c), the northern part of the Tibetan Plateau tends to have negative precipitation anomaly. The zero line is located in the middle of the Tibetan Plateau. The southern side of the CETP region has a positive correlation region. This pattern is quite similar to the second spatial mode of total summer precipitation (Fig. 2, Figs. 4a, c). It can be noticed that though the positive correlation is stronger over the southern part of the Tibetan Plateau in August than that in June, it is still not significant at the level of 95%. The negative correlation to the east of the Tibetan Plateau shows the influence of the synoptic system over the Tibetan Plateau on the downstream weather. The above analysis indicates that the vortex and anticyclone activity over the Tibetan Plateau has greater influence on the second mode of summer precipitation in June and August than that in July. It also shows that the index B alone cannot describe the precipitation anomaly pattern over the Tibetan Plateau to a satisfactory degree. The cause of the second mode of summer precipitation is then much more complicated in comparison with that of the first mode. The NWPH may also contribute to the second spatial mode. The correlation of the strength index of the NWPH with precipitation in August is shown in Fig. 8. It can be noticed that there are negative and positive correlation regions on the northern and southern parts of the CETP region, respectively. It is interesting to mention that the correlation pattern of the index of western extension of the ridge line for the NWPH with the August monthly precipitation has correlation centers at the same location but with opposite signs. All these imply that the mechanism of the second spatial mode of summer precipitation needs to be further studied.

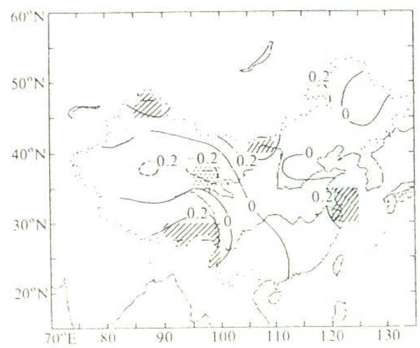

FIGURE 8. The same as Figure 6 except for the correlation pattern between the strength index of the Northwest Pacific High and August monthly precipitation.

5. CONCLUSIONS

The strength of the spatial modes of summer precipitation anomaly varies from month to month. The negative correlation in precipitation between the LRYH region and the MRY region, and between the LRYH region and South China is the most significant in August. In July, the negative correlation in precipitation exists only between the LRYH region and the eastern part of North China. In June there exists a positive correlation over the LRYH region, Northeast China and the eastern part of North China. The negative correlation in precipitation between the northern and the southern part of the CETP region is more obvious in June and August than in July.

The correlation analysis of the indices of the NWPH and precipitation for June, July and August shows that the position of the northern boundary of the NWPH in August has great influence on the negative correlation in precipitation between the LRYH region and the MRY region, and between the LRYH region and South China. When the NWPH is located to the north of its normal position, the MRY region and South China tend to have positive precipitation anomalies, whereas the LRYH region tends to have negative precipitation anomaly.

The correlation analysis of geopotential height index B over the Tibetan Plateau with precipitation shows that the vortex and anticyclone activity over the Tibetan Plateau has influence on the negative correlation in precipitation between the northern and southern parts of the CETP region. When there is abnormally frequent anticyclone activity over the CETP region, its northern part tends to have negative precipitation anomaly, whereas its southern part tends to have positive precipitation anomaly. The influence is stronger in June and August than in July. The NWPH may also contribute to this negative correlation pattern in August. However, the mechanism of the second spatial mode of summer precipitation needs to be further explored.

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