REGIONAL CHARACTERISTICS OF SUMMER PRECIPITATION ANOMALIES OVER CHINA *

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ABSTRACT

The regional characteristics of precipitation anomalies of total summer precipitation of June, July and August and individual monthly precipitation are analyzed by using the method of Varimax EOF and correlation analysis. The data set used is the precipitation of a 5° Lat. × 5° Long. spatial uniform network over China in the period of 1959 to 1994.

The analysis of total summer precipitation shows that the most significant regional characteristic is the existence of negative correlation in precipitation anomalies between the lower reaches of the Changjiang River and the Huaihe River Valley (the LRCH region) and the middle reaches of the Huanghe River Valley (the MRH region), and between the LRCH region and South China. The precipitation anomaly over the Sichuan Basin is negatively correlated with that over eastern part of Qinghai-Xizang Plateau and that over the LRCH region. The regional characteristics of summer precipitation anomalies in western China are that there exists negative correlation between the summer precipitation anomalies over the southern part of the central and eastern Qinghai-Xizang Plateau and that over its northern part. There also exists positive correlation between the southern part of the central and eastern Qinghai-Xizang Plateau and the eastern part of North China and the southern part of Northeast China. The above spatial correlation modes have significant periods of about 3 years and ten years. The analysis of the monthly precipitation shows that in June there exists positive correlation among the precipitation anomalies over the LRCH region, the eastern part of North China and Northeast China. In July, the precipitations in the MRH region and the LRCH region are negatively correlated. The regional characteristic of precipitation anomalies in August is very similar to that of the total summer precipitation anomalies.

Key words: Varimax EOF, total summer precipitation, monthly precipitation

I. INTRODUCTION

The regional characteristics of summer precipitation anomalies over China, the phenomena that the precipitation anomalies over different regions of China present well organized spatial patterns, have been the subject of numerous researches (Wang and Zhao

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1979; Deng et al. 1989). Since station observational data were used directly in most of these researches, not surprisingly they focused on the regional characteristics of summer precipitation of East China over where there is a much denser station network than that over West China. In the present research, we will concentrate on the regional characteristics of precipitation anomalies over the whole China. The precipitation of a spatial uniform network is used instead of station observation and the results are compared with those achieved by using the station observation directly.

Another different perspective of our research is that the method of Varimax EOF is used. Compared with the EOF method, the Varimax EOF has the following advantages (Richman et al. 1986; Huang 1988): spatial pattern is less sensitive to the region selected for analysis (e. g., the achieved spatial mode is not sensitive to the distribution of stations), less sampling error, and the spatial mode achieved is similar to the teleconnection pattern. For the present research, these advantages make the analysis of regional characteristics of summer precipitation more convenient. But the Varimax EOF method can not give a significant level of the correlation pattern presented in its spatial mode. So the traditional point correlation method is also used in our analysis. Besides the analysis of total summer precipitation (total precipitation of June, July and August), the monthly precipitation is also analyzed.

In recent researches, the phenomena of quasi-biennial oscillation have been noticed in the precipitation anomaly analysis (Huang 1988). The spatial mode is just one aspect of the regional characteristics of precipitation anomalies. The time series of expansion coefficient of the spatial mode is also an important aspect of the Varimax EOF analysis. So the temporal change of spatial mode is also analyzed in the present research. The outline of the present research is as follows: after an introduction in Section II to the Varimax EOF and the data used in this study, Section III presents the analysis of total summer precipitation anomalies. The results for individual monthly precipitation are given in Section IV. Section V gives the conclusions of the present research.

II. METHOD AND DATA

1. *Varimax EOF*

The derivation of Varimax EOF can be found in Huang (1988). In the following, only the basic idea and the relevant formulas are presented for the convenience of discussion in later sections. In EOF analysis, a data matrix $\boldsymbol{A}_{n\times m}$, in which n is the number of grid points or stations, and m is the length of data, can be decomposed as

$$\boldsymbol{A}_{n\times m} = \boldsymbol{V}_{n\times m}\boldsymbol{T}_{n\times m}, \quad (1)$$

in which the columns of $\boldsymbol{V}_{n\times m}$ are the unified eigenvectors of the matrix $\frac{1}{m}\boldsymbol{A}\boldsymbol{A}^T$, and $\boldsymbol{A}^T$ is the transposition of $\boldsymbol{A}$.

The Varimax EOF is based on the results of EOF. The matrix $\boldsymbol{T}_{n\times m}$ can be normalized as (in the following, the subscription for matrix is ignored)

$$\boldsymbol{F} = \Lambda^{-1/2}\boldsymbol{T}, \quad (2)$$

where Λ is the diagonal matrix composed of the eigenvalues of $\frac{1}{m}\boldsymbol{A}\boldsymbol{A}^T$. We denote

$$L = V\Lambda^{1/2}. \tag{3}$$

So Eq. (1) can be rewritten as

$$A = V\Lambda^{1/2}\Lambda^{-1/2}T = LF, \tag{4}$$

where L is the correlation matrix of data matrix A and matrix F. In factor analysis, L is called the loading matrix. In meteorological application, L is called spatial mode.

F can be rotated, and L will also be rotated correspondingly while Eq. (2) holds true. The method of Varimax EOF is to rotate the F in such a way that the relative variance for every column of F achieves its maximum. Specifically, if the first p spatial modes are kept, the F is rotated as such that

$$S = \sum_{\alpha=1}^{p}\left[\frac{1}{n}\sum_{i=1}^{n}\left(\frac{l_{i\alpha}^2}{h_i^2}\right)^2 - \left(\frac{1}{n}\sum_{i=1}^{n}\frac{l_{i\alpha}^2}{h_i^2}\right)^2\right], \tag{5}$$

achieves its maximum, in which $h_i^2 = \sum_{\alpha=1}^{p} l_{i\alpha}^2$, and $l_{i\alpha}$ is the element in matrix L. In the equation of S, $l_{i\alpha}^2$ is used instead of $l_{i\alpha}$ in order that the variance of every column in L becomes larger and the matrix L will have larger positive or negative values after rotation. The h_i^2 is used to eliminate delimit the differences among columns.

The number p of spatial modes used in the Varimax EOF analysis can be decided by the Scree method (Cattell 1966). The eigenvalue is presented as a function of its order. The change of eigenvalue with its order is analyzed. The spatial modes before the last changing point, after which the eigenvalue distribution with respect to its order becomes quite flat, are kept for rotation. In the selection of spatial modes for the Varimax EOF analysis, the criterion suggested in North et al. (1982) can also be used. The sampling error for the eigenvalue λ is $\lambda(2/m)^{1/2}$ in which m is the number of independent realizations of the data series (for the estimation of the number of independent realizations of a time series, see Davis 1976). When the difference between the two neighbouring eigenvalues is greater than the value given by $\lambda(2/m)^{1/2}$, the eigenvalue and the relevant spatial mode are significant. But the criterion is quite strict. Even when m is 300, the first spatial mode still has very large sampling error. Based on the Scree method, the criterion given by North et al. (1982), and our experiment with shorter sub-dataset of the dataset used, the first two spatial modes are analyzed for the total summer precipitation. In the case of monthly precipitation, only the first mode is analyzed.

2. *Data*

The precipitation anomaly of a spatial uniform network of 5° Lat. × 5° Long. over China is analyzed. The observation data are processed in the following way in order to get precipitation for a spatial uniform network. The region from 15°N to 55°N, and from 75°E to 135°E is divided into 5° Lat. × 5° Long. boxes. When the number of stations in a 5° Lat. × 5° Long. box is ≥2, the arithmetic average of precipitation data from all these stations is taken as the precipitation of the box. When the number of stations in a 5° Lat. × 5° Long. box is <2, the precipitation of the box is not calculated (Sun 1992).

Observations of more than 300 stations over China are used. Totally there are 47 boxes over China in which the precipitation can be calculated. The period we analyzed is from 1959 to 1994. As an example Fig. 1 presents the number of stations for each box in

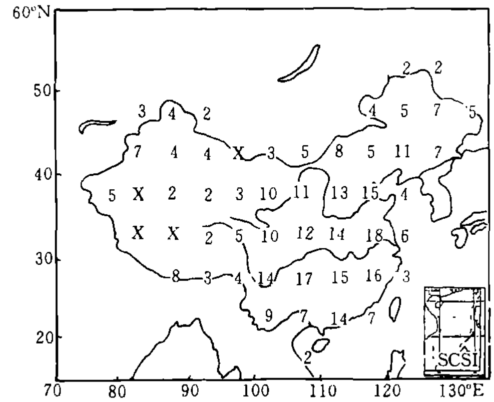

Fig. 1. The number of stations at each 5° Lat. × 5° Long. box over China in 1981.

1981. It can be noticed from Fig. 1 that the distribution of station is far from even. In the lower reaches of the Changjiang River and the Huaihe River Valley (the LRCH region, hereafter), the number of stations for one box can be as many as 18. But on the western part of Qinghai-Xizang Plateau, there are boxes whose precipitation can not be calculated. There are four boxes over China for which the box precipitation can not be calculated. So it is not surprising that if the station data alone are used, then the EOF analysis provides merely the regional characteristics of East China. The spatial uniform network can provide further insight of the regional characteristics of summer precipitation over West China. In the present research, we will concentrate on the correlation of precipitation anomalies over different regions, and the normalized precipitation anomalies are used instead of original precipitation anomalies.

III. REGIONAL CHARACTERISTICS OF TOTAL SUMMER PRECIPITATION

1. *Spatial Modes*

We begin our analysis with the spatial modes of total summer precipitation. The Scree method is used to select the number of spatial modes for Varimax EOF. Figure 2 shows the change of eigenvalue as a function of its order. It can be noticed from Fig. 2 that with the increasing of the order of eigenvalues, the eigenvalues become smaller and smaller and the differences among eigenvalues also become smaller. According to North et al. (1982), the sampling error of eigenvalue becomes greater. Thus the first 5 spatial modes are used in the Varimax EOF analysis based on the Scree method.

Figures 3a and 3b present the first spatial mode and the correlation pattern with the grid point that has the maximum loading as base point. The spatial mode can account for 12.4% of the total variance of the normalized precipitation anomalies. It is worth noticing that the most significant regional characteristic is the negative correlation between the LRCH region and the middle reaches of the Huanghe River Valley (the MRH region, hereafter) and between the LRCH region and South China. The relevant correlation coefficients (Fig. 3b) are significant at the level of 95%. The spatial mode presents a "W" or "M" pattern along north-south direction over East China. When the precipitation

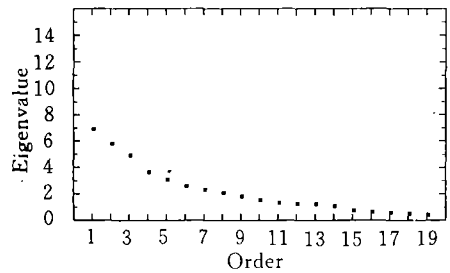

Fig. 2. The change of eigenvalue as a function of its order. The abscissa denotes order and the ordinate is eigenvalue.

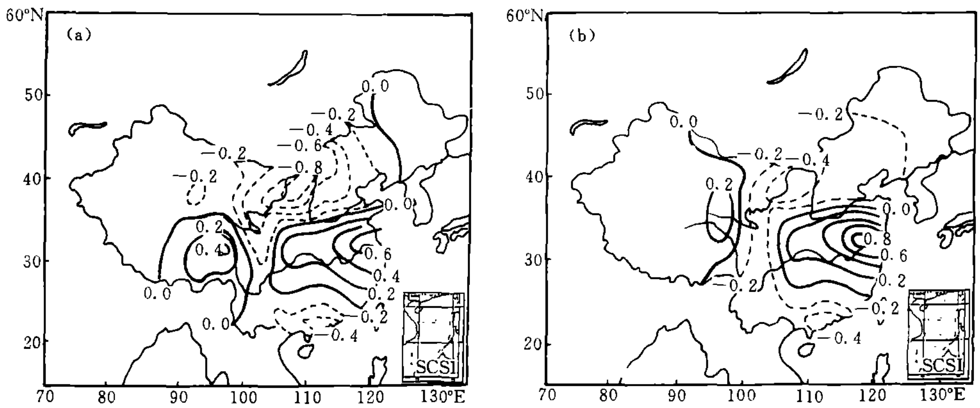

Fig. 3. The first spatial mode of Varimax EOF of normalized total summer precipitation (a), and the correlation pattern with the grid point that has the maximum loading (30—35°N, 115—120°E) as base-point (b). The short line in the box denotes that the correlation is significant at the level of 95%. The solid line is for positive correlation. The dashed line is for negative correlation.

anomalies over the LRCH region are negative, it is more likely that the MRH region and South China have positive precipitation anomalies (Wu et al. 1995). The result is similar to the result achieved in earlier analyses (Fig. 2 in Wang et al. 1979; Fig. 3 in Deng et al. 1989). The major difference between our analysis and those achieved in earlier analyses is that the negative correlation center of North China in our analysis is located at the MRH region, whereas this negative correlation center is located at eastern part of North China in earlier researches. This is because in this study we concentrate on the correlation of precipitation among different regions of China, and we have used only the normalized precipitation anomaly instead of precipitation anomalies. Since the climate distribution of summer precipitation has larger value over southern and eastern part of China and gradually decreases northward and westward, if the precipitation anomaly is used, the variance of the stations over East China must be larger than that over West China. Another reason is that in those earlier researches the station data in denser distribution over East China were used.

Another characteristic in Fig. 3 is that there exists a "W" or "M" pattern in west-east direction along the Changjiang River Valley, i. e. there exists negative correlation between

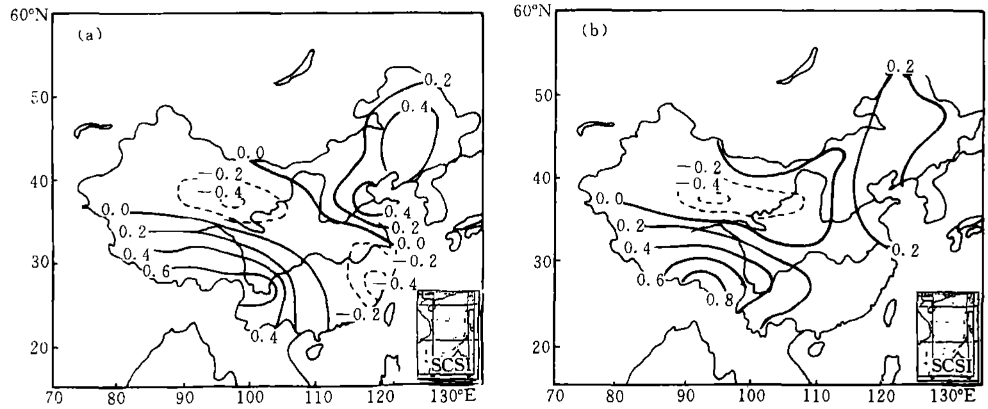

Fig. 4. As in Fig. 3. except for the second spatial mode of Varimax EOF of the normalized total summer precipitation (a), and the correlation pattern with the grid point that has the maximum loading (25—30°N, 90—95°E) as base point.

the precipitation anomalies of the Sichuan Basin and that of the LRCH region, and between the Sichuan Basin and the eastern part of the Qinghai-Xizang Plateau. The phenomena are not clear in the EOF analysis of station precipitation. But this kind of spatial pattern of precipitation anomaly distribution is quite clear in some typical drought or flood years (e. g. 1954 as shown in "Atlas of drought/flood in recent 500 years over China").

The second spatial mode and the correlation distribution with the grid point that has the maximum loading as base point are shown in Figs. 4a and 4b. The spatial mode accounts for 11.4% of the total variance. It reveals the existence of negative correlation in the summer precipitation between the northern and southern parts of the central and eastern Qinghai-Xizang Plateau, and between the region of the southern part of the central and eastern Qinghai-Xizang Plateau and the region of the eastern part of North China and the southern part of Northeast China. Since the precipitation over the southern part of the central and eastern Qinghai-Xizang Plateau is influenced by Indian monsoon, the above correlation seems to show that there exists positive correlation between the monsoon precipitation over Indian area and the precipitation over the eastern part of North China. The result is consistent with the results achieved in earlier research (Liang 1988). Though the phenomena of the existence of negative correlation between the southern and northern parts of the central and eastern Qinghai-Xizang Plateau are not obvious in the EOF analyses of station precipitation data which often have a bias over East China, the phenomena are quite clear in the correlation pattern of Fig. 4b. Also, the result is consistent with the result of correlation analysis of the drought/flood index over ancient Chang'an region and the date of monsoon onset over India (Li and Qian 1987). It is interesting to note that Fig. 3a depicts the regional characteristics of East China, and Fig. 4a depicts the regional characteristics of West China. These are the most significant regional characteristics of total summer precipitation anomaly.

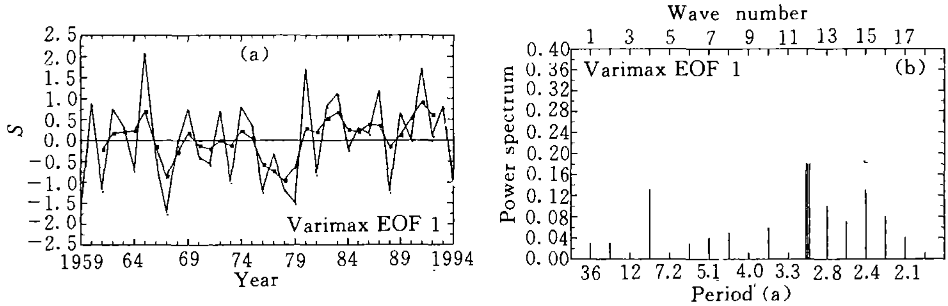

Fig. 5. The time series of expansion coefficient (S) of the first spatial mode (the line with dots) and the result of five-year running mean (the line with stars) (a), and the result of power spectrum analysis (b). The period significance at the level of 95% is depicted by three vertical lines.

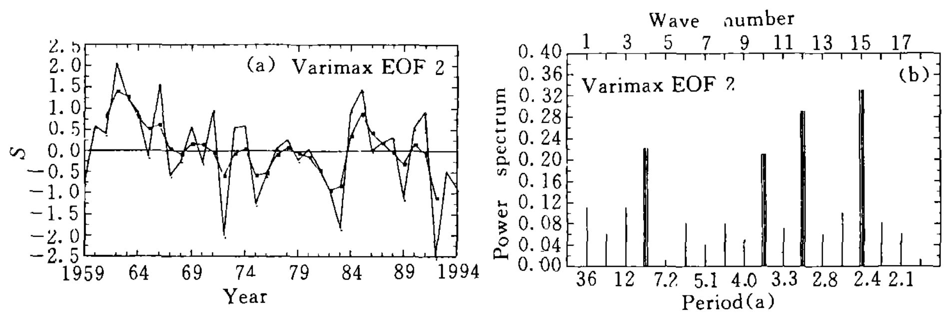

Fig. 6. As in Fig. 5, except for the time series of expansion coefficient (S) of the second spatial mode.

2. Temporal Change of Spatial Modes

The time series of expansion coefficient of spatial mode is another aspect of Varimax EOF. Figures 5a, 5b and Figs 6a, 6b give the results of expansion coefficient of the first two spatial modes and their power spectrum analysis. The time series of expansion coefficient of the mode (Fig. 5a) depicts the sign and the relative importance of the first spatial mode. The expansion coefficient can be compared with the temporal change of precipitation anomalies over the LRCH region. In the typical flood years of the LRCH region (e. g. 1962, 1969, 1980, 1982, 1983, 1987 and 1991), the expansion coefficients are positive. In the typical drought years (e. g. 1959, 1961, 1966, 1967, 1978, 1979 and 1994), the expansion coefficients are negative. These drought and flood years before 1990 are the same as those defined in Feng et al. (1985) and Wang (1990). Similarly the time series of expansion coefficient of the second spatial mode shows the temporal change of the precipitation anomalies over the central and eastern parts of the Qinghai-Xizang Plateau and the sign and strength of the second spatial mode.

It can be noticed from Fig. 5 and Fig. 6 that the quasi-three year oscillation is very clear for the time series of expansion coefficient of the first spatial mode, especially from 1960s to the middle of 1970s. The phenomena of quasi-three year oscillation are also obvious in the second spatial mode. The oscillations that are significant at the 95% level are those with the period of 2. 4, 3. 0 and 3. 5 years. It appears that there also exist oscillations with longer period in these two spatial modes. The time series of expansion coefficient of the second spatial mode has 10-year period oscillation that is significant at the level of 95%. Though it is not significant at the level of 95%, there does exist a maximum around 10-year period in the spectrum of the expansion coefficient of the first spatial mode. The above analysis shows that the 10-year period oscillation exists in the temporal change of the spatial modes of summer precipitation anomalies.

IV. REGIONAL CHARACTERISTICS OF MONTHLY SUMMER PRECIPITATION

In this section, we will present the regional characteristics of monthly precipitation of June, July and August, respectively. Figures 7a, 7b and 7c present the first spatial mode of monthly precipitation of June, July and August. In June (Fig. 7a), there exists positive correlation in the precipitation anomalies over the eastern part of North China, Northeast China and the LRCH region, especially its northern part. This spatial mode accounts for 13.7% of the total variance. The correlation pattern with the grid point that has the maximum loading as base point shows that these regions have correlation significance at the 95% level (The correlation distribution is not shown in present analysis).

Figure 7b is the first spatial mode of monthly precipitation of July. There exists negative correlation between the precipitation of the LRCH region and that of the MRH

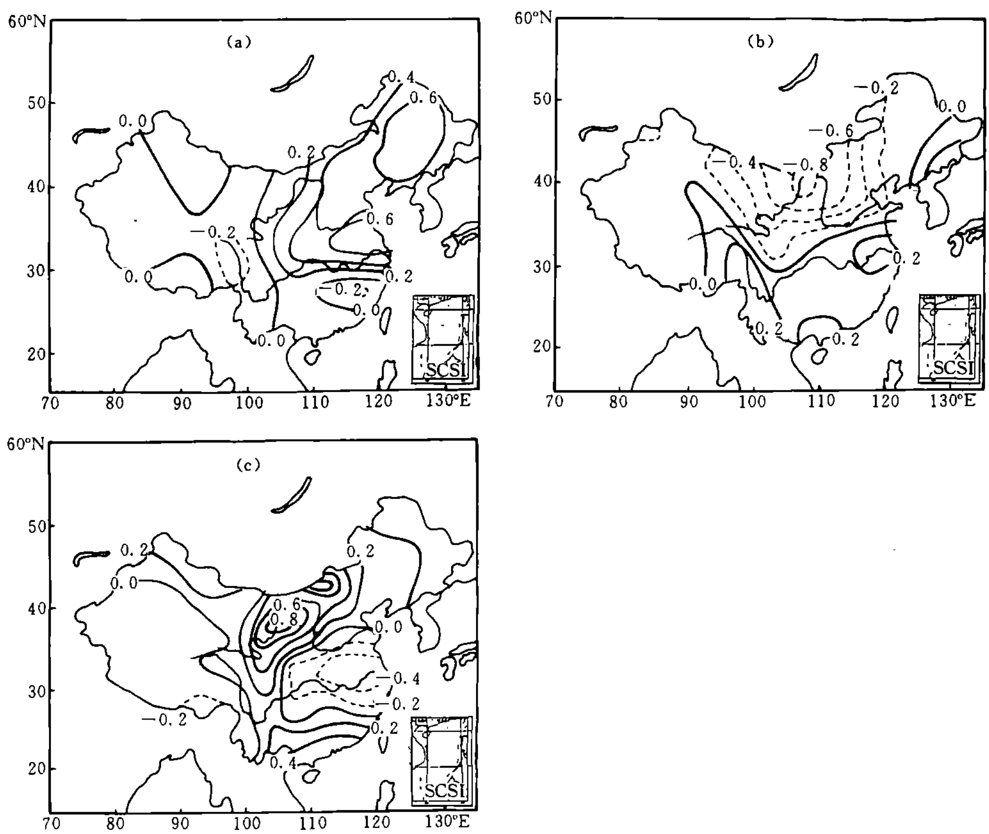

Fig. 7. The first spatial mode of monthly precipitation. (a) June; (b) July; (c) August.

region. But the correlation center over the LRCH region is smaller and shifts eastward compared with its counterpart in the case of the total summer precipitation (Fig. 3). It appears that there exists negative correlation between the precipitation anomalies over the Sichuan Basin and the eastern Qinghai-Xizang Plateau and between the Sichuan Basin and the LRCH region. But the correlation between South China and the LRCH region is not obvious for the monthly precipitation of July. The spatial mode accounts for 10.5% of the total variance.

In August (Fig. 7c), there exists negative correlation between the precipitation anomalies of the LRCH region and the MRH region, and between the LRCH region and South China. The "M" or "W" pattern along the Changjiang River Valley is also clear. Figures 3a and 7c are so similar that we may conclude that the spatial pattern of the total summer precipitation anomalies is mainly determined by the precipitation in August. This spatial mode can account for 12.8% of the total variance of the normalized precipitation anomalies of August.

It is interesting to notice the difference between the spatial mode of monthly precipitation and that of the total summer precipitation. Generally speaking, this is caused by the seasonal change of general circulation and its anomalies. We will present our analysis on this aspect in another paper. It should be noticed that the first spatial mode of July accounts for the least total variance compared with the first spatial mode of June and the first spatial mode of August. In our calculation, it is also noticed that the result of July is much more sensitive to the selection of samples (see Table 1). This may be related to the fact that the precipitation in July is mainly caused by convective processes. More researches are needed for further insight of the phenomena.

Table 1. The Percentage of Total Variance That is Accounted for by the First Two Spatial Modes of Varimax EOF of Total Normalized Summer Precipitation and the Percentage of Total Variance That is Accounted for by the First Mode of Normalized Monthly Precipitation

Total summer precipitation		June	July	August
1st Mode	2nd Mode	1st Mode	1st Mode	1st Mode
12.40%	11.40%	13.66%	10.51%	12.78%

V. CONCLUSION

The use of the spatial uniform network is very helpful for the understanding of the regional characteristics of summer precipitation anomalies over China. Besides the regional characteristic of summer precipitation over East China, the analysis in present research provides further insight of the regional characteristics of summer precipitation over West China and along the Changjiang River Valley.

The most significant regional characteristics are the existence of negative correlation between the LRCH region and the MRH region and between the LRCH region and South China. There also exists negative correlation between the precipitation anomalies over the Sichuan Basin and the eastern Qinghai-Xizang Plateau and between the Sichuan Basin and the LRCH region. The most significant regional characteristic over West China is the negative correlation between the northern and southern parts of the central and eastern Qinghai-Xizang Plateau. There also exists positive correlation between the southern part of the central and eastern Qinghai-Xizang Plateau and the region of eastern part of North China and southern part of Northeast China. The temporal change of the above spatial modes possesses quasi 3-year and 10-year oscillations.

The analysis of the monthly precipitation shows that there is positive correlation between the LRCH region. eastern part of North China and Northeast China in June. In July there exists negative correlation between the precipitation anomalies over the LRCH region and that of the MRH region. The spatial mode of monthly precipitation anomalies in August is similar to that of the total summer precipitation.

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REFERENCES

Cattell. R. B. (1966). The Scree test for the number of factors. *Multivar. Behav. Res.*. **1**: 245—276.

Davis. R. E. (1976). Predictability of sea surface temperature and sea level pressure anomalies over the North Pacific Ocean. *J. Phys. Oce.*. **6**: 249—266.

Deng Aijun. Tao Shiyan and Chen Lieting (1989). The EOF analysis of summer precipitation over China. *Chinese J. Atmos. Sci.*. **13**: 289—295.

Feng Peizhi. Li Cuijin and Li Xiaoquan (1985). The analysis of meteorological disasters over China (1951—1980). China Meteor. Press (in Chinese).

Huang Jiayou (1988). The presentation of quasi-biennial oscillation in the monthly precipitation of China. *J. Atmos. Sci.*. **12** : 267—273.

Li Zhaoyuan and Qian Xiaowei (1987). The climatic changes of drought-wet in ancient Chang' an region of China during the last 1604 years. *The Climate of China and Global Climate.* Ye Duzheng et al. (Eds.). China Ocean Press. pp. 57—62.

Liang Pingde (1988). Indian monsoon and summer precipitation over North China. *Acta Meteoro. Sinica.* **46**: 75—80 (in Chinese).

North. G. R., Bell. T. L. and Cahalan. R. F. (1982). Sampling errors in the estimation of empirical orthogonal functions. *Mon. Wea. Rev.*, **110**: 699—706.

Richman. M. B. et al. (1986). Review Article. rotation of principle components. *J. Cli.*. **6**: 193—333.

Sun Fengyin (1992). The sub-data set generated from the ten-day mean precipitation data of 336 stations in china. Newsletter No. 13. Data Center. Institute of Atmospheric Physics. Chinese Academy of Sciences.

Wang Shaowu (1990). The climate change and its temporal trend. Ye Duzheng and Huang Ronghui (Eds.). *Advances in the Research of Drought/Flood Climate.* Chinese Meteor. Press (in Chinese).

Wang Shaowu and Zhao Zongci (1979). The analysis historical document of 500 year drought/flood of China. *J. Geography.* (in Chinese). **34**: 329—340 (in Chinese).

Wu Guoxiong. Sun Fengyin. Wang Jingfang and Wang Xiaochun (1995). Neighbourhood response of rainfall to tropical sea surface temperature anomalies II: Data Analysis. *Chines J. Atmos. Sci.*, **19**: 663—676 (in Chinese).