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CHARACTERISTICS OF ZONAL ANOMALY OF ANNUAL PRECIPITATION IN THE NORTHEASTERN CHINA

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ABSTRACT: The characteristics of zonal anomaly and change rule of temporal distribution of annual precipitation in the northeastern China are revealed in this paper with EOF (Empirical Orthogonal Function) and REOF (Rotated Empirical Orthogonal Function) methods and results are drawn in the standard relief maps with GIS technology for practical application. Data used in the study were obtained from 208 meteorological stations over the northeastern China from 1961 to 2001. EOF results show that the first 3 loading vectors could give entire spatial anomaly structure of annual precipitation. In the Northeast Plain including the Songneng Plain and the Liaohe Plain, there is a regional compatibility (whether wet or dry) of annual precipitation change and this precipitation pattern has occurred since the late 1980s to the present. There also exist annual precipitation patterns of wet (or dry) in south and dry (or wet) in north and wet (or dry) in east and dry (or wet) in west. REOF results display 8 principal precipitation anomaly areas by the first 8 rotated loading vectors: the west plain, the Liaodong hills, the Sanjiang Plain, the Liaoxi hills, the Changbai Mountains, the Hulun Buir Plateau, the southwest plateau and the Liaodong Peninsula.

KEY WORDS: annual precipitation; northeastern China; zonal anomaly; precipitation characteristics

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1 INTRODUCTION

Precipitation as a source of global fresh water is not only important resources of daily life and the production of industry and agriculture but also the most valuable natural and strategically economic resources for a nation, a region even global sustainable development. The region of the northeastern China (38°43′–53°33′N, 115°21′–135°05′E) including Heilongjiang, Jilin and Liaoning provinces and four leagues (cities) in the eastern Inner Mongolia Autonomous Region, with an area of 1.244×10^6km^2, is a well-known industrial base and one of the largest base of commodity grain in China. It is surrounded by mountains, hills and plateaus in the east, north and west and has a vast expanse of plain in the middle. There are humid, semi-humid and semi-arid climates of temperate zone over the study region. Because fragility of regional water system has been aggravated owing to big industrial and agricultural water requirement, serious water shortage since the 1970s and increasing frequency and intensity of flood and drought, public has paid close attention to how to utilize and manage regional precipitation scientifically. The characteristics of zonal anomaly and patterns of annual precipitation revealed in this paper are a basis of reasonable utilization and management of regional precipitation and an important background for distribution of industry and agriculture and economic development.

The previous studies on precipitation over the region had been in various ways such as precipitation division (ZHU, 1957; CHEN and WU, 1994), wet and dry changes of climate (ZHANG and CHEN, 1991; YAN *et al*., 2003), establishment of precipitation time series (ZHANG, 1993) and characteristics of seasonal and annual precipitation (DENG and TAO, 1989; HUANG, 1991; SUN *et al*., 2000; ZHOU, 1995; ZHOU *et al*., 2000). There are few studies to choose an entire geographical unit which includes Liaoning, Jilin and Heilongjiang provinces and the east four leagues (or cities) of Inner Mongolia Autonomous Region as a whole

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study region. Data used in the study were obtained from 208 meteorological stations over the study region from 1961 to 2001. Field of annual precipitation is expanded with EOF and REOF methods. And with GIS technologies, spatial distributions of annual precipitation were directly generated on standard relief map to reveal characteristics of zonal anomaly of annual precipitation in the region.

2 DATA AND METHODS

2.1 Data

Data of annual precipitation from 1961 to 2001 derived from 208 meteorological stations in the region were used in the study. Time series of annual precipitation of each station was normalized with 41 years′ normal and standard deviation to obtain normalizing time series of 208 stations′ annual precipitation.

2.2 Methods

Empirical Orthogonal Function (EOF) and Rotated Empirical Orthogonal Function (REOF) methods were sed in the study.

EOF method (WEI, 1999): normalizing matrix of climatic variable, which is composed of m stations and n observed records, is transformed into linear combination of p spatial loadings and their corresponding time weighting coefficients.

$$X_{m\times n}=V_{m\times p}T_{p\times n} \quad (1)$$

where V is the matrix of spatial loading coefficients; T is the matrix of time weighting coefficients.

REOF method (WEI, 1999): For V and T obtained from EOF expansion, rotation of maximum variance is conducted. P, the number of rotation vectors, is determined by rate of accumulative variance to enable larger loadings to concentrate on a small area and at the same time loadings in other areas are close to zero. Finally, matrixes of rotated spatial loadings and principal components are obtained.

3 DISTRIBUTION OF ANNUAL AND SEASONAL PRECIPITATION

3.1 Distribution of Annual Precipitation

The normal (1961–2000) of annual precipitation (Fig. 1a) varies from 240mm to 1100mm and there is much difference among various areas in the study region. Their contours have a longitudinal distribution. And 500mm contour along Aihui, Dedu, Harbin, Nong′an, Zhangwu, and Fuxin stations divides the study region into two parts, the eastern part and western part. Annual precipitation in the eastern part is more than that in the western part. It is less than 350mm in the Hulun Buir Plateau and the Xiliaohe Plain, but in contrast it is more than 800mm in the area near the Yalujiang River. Its minimum is 244mm occurred at the Xinyouqi Station in the Hulun Buir Plateau and the maximum is 1075mm at the Kuandian Station. There is more annual precipitation in the eastern mountainous areas, compared with that in plain areas at the same latitude. Annual precipitation decreases gradually with latitude increase in plain areas. And there is the greatest zonal gradient in the Liaohe Plain.

3.2 Distribution of Summer and Winter Precipitation

The study shows that 60%–80% of precipitation concentrates in summer in a year. For a certain area, the less precipitation is, the more concentrated it is. For example, more than 70% annual precipitation happens in summer in the western part of the study region. Distribution of summer precipitation is similar to that of annual precipitation (Fig. 1b). The minimum (191mm) and the maximum (714mm) occurred at the Xinyouqi Station and Kuandian Station respectively.

Under the control of Mongolia High, only 1%–4% of precipitation happens in winter in the study region in a year. And winter precipitation is under 10mm in the western part and 10–40mm in the eastern part (Fig. 1c).

4 CHARACTERISTICS OF ZONAL ANOMALY OF ANNUAL PRECIPITATION

With the method (NORTH *et al*., 1982) of calculating error range of eigenvalues, test of significance was done for EOF and REOF expansions′ results of annual precipitation. Test results showed that expanded orthogonal functions were significant. So results from EOF and REOF revealed regional variability distributions and characteristics of zonal anomaly of annual precipitation respectively in the region.

4.1 Results of EOF Expansion

The first 3 loading vectors represented variability distributions of annual precipitation at the very most.

In LV_1 (the first loading vector, LV_2 and LV_3 may be deduced by analogy below) shown in Fig. 2a, loading values in all stations of whole study region were positive, which means that there was a regional compatibility of annual precipitation change, and this distribution took 30.4% of total variances (Table 1). It was

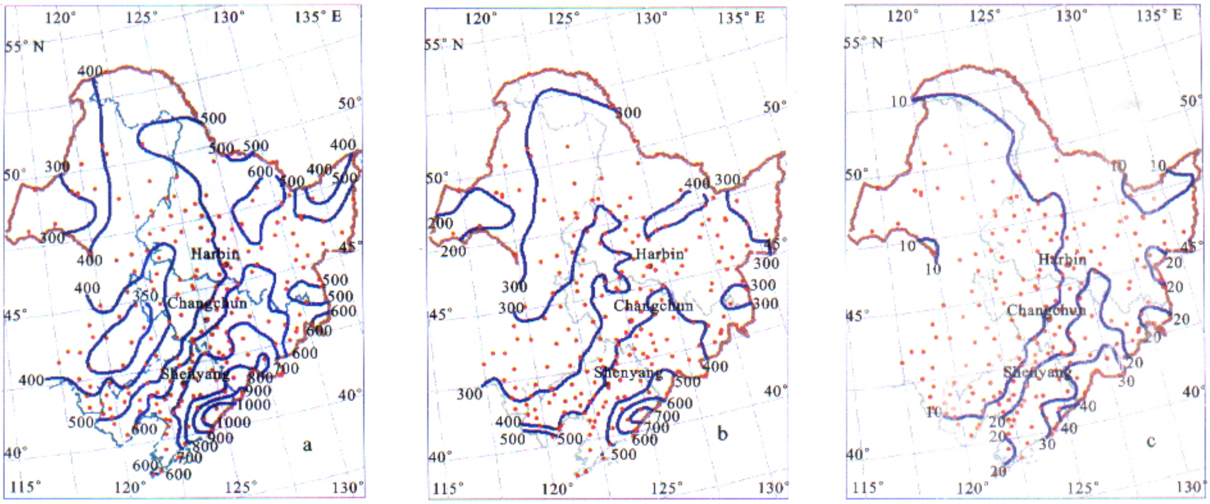

Fig. 1 Normal distribution of annual precipitation (a), summer and winter precipitation (b, c) in the northeastern China from 1961 to 2000

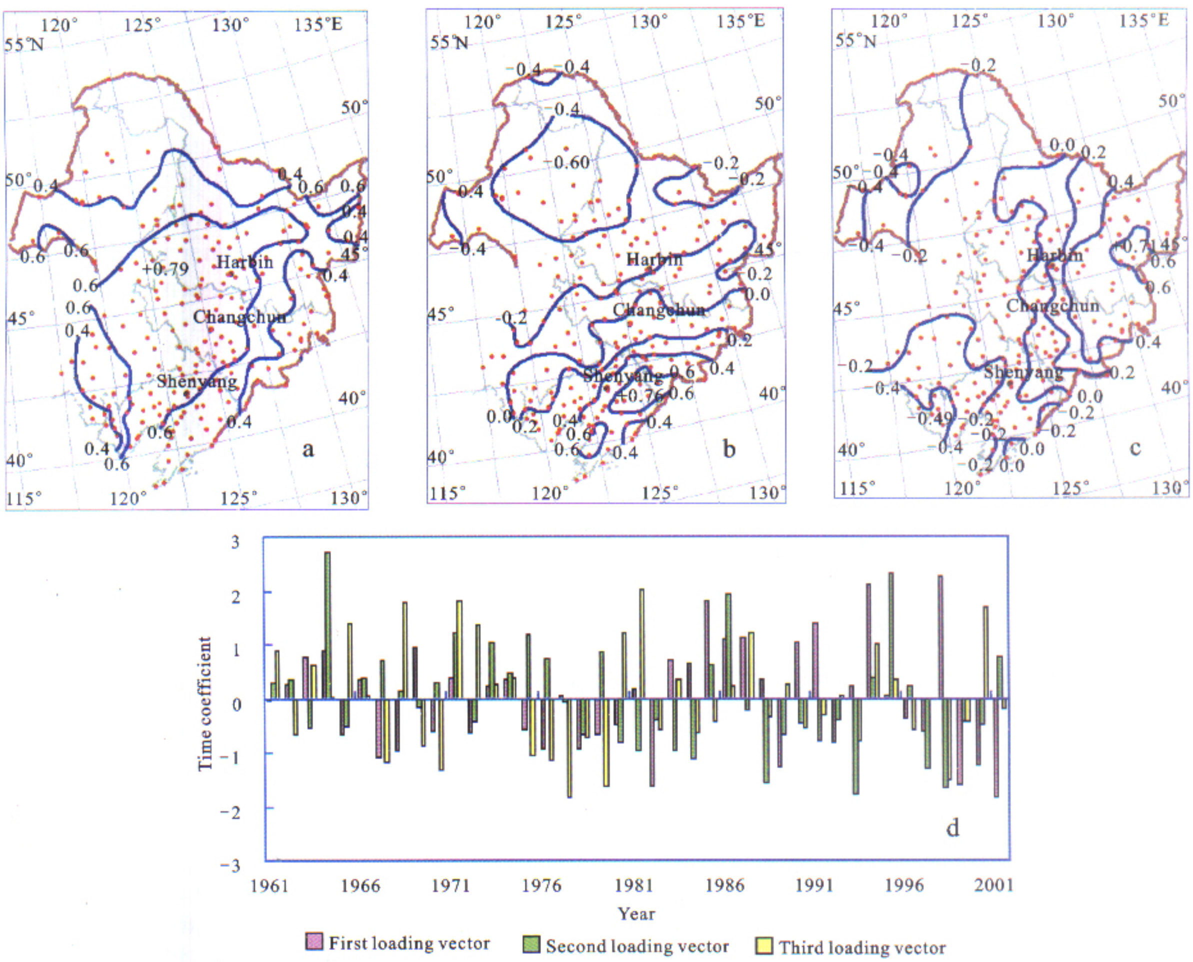

Fig. 2 The first (a), second (b) and third (c) loading vectors from EOF expansion and their corresponding time weighting coefficients (d) of annual precipitation in the northeastern China

obvious that large-scale weather systems controlled precipitation over the whole region. Area with larger loading value was located in the Songneng Plain and the maximum was +0.79. That indicated that the plain was a sensitive area where there was so maximum an interannual variability that it was easy to occur extreme precipitation events such as extreme drought. The vector represented wet (or dry) pattern of annual precipitation over entire study region.

There was an opposite trend of the precipitation between the south and the north in LV_2 (Fig. 2b). In general, the contours of loading coefficients presented a zonal distribution. And this structure feature held 11.6% of total variance. The positive values were distributed in the middle and east of Jilin Province, whole Liaoning Province and Chifeng City of the Inner Mongolia and the maximum (+0.76) occurred near the Xiaoshi and the Xinbin stations in the east of Liaoning Province. The minimum (−0.6) occurred at the Oroqen Station of the Inner Mongolia. In the pattern, it is relatively dry in the south if wet in the north, and reverse is also true.

In LV_3 (Fig. 2c), the precipitation change in the east contrasted with that in the west and longitudinal contours were presented. This pattern took 8.5% of total variance. Larger loading values occurred in Wanda Mountain and the north of the Changbai Mountains and smaller ones in Hailar area of the Inner Mongolia Autonomous Region and Jianping hills of the western Liaoning respectively. The maximum (+0.71) occurred at the Jixi Station and the minimum (−0.49) appeared at the Jianping Station. This pattern showed that topography of the east mountainous area influenced precipitation distribution, that is, precipitation on windward side of mountain in the east was more than that in the west, which presents basic precipitation features that it was relatively wet in the east but dry in the west in study region.

The larger absolute value of time coefficient of a certain vector is, the more typical pattern represented by the vector is, which means the pattern is main one of climatic variable at that time. Features of various patterns over time may be gotten through analysis of their corresponding time coefficients. Assuming the pattern of annual precipitation represented by LV_1 was the first pattern, by analogy, the patterns represented by LV_2 and LV_3 were the second and third pattern respectively. In the recent 41 years, the first pattern took 13 years mainly during 1989 to 2001 (Fig. 2d); the second pattern held for 12 years and stronger ones happened in a period of about 11 years (happened in 1964, 1975, 1986 and 1995); the third pattern appeared mostly in the 1960s and the 1970s.

4.2 Results of REOF Expansion

Because spatial structure of vectors obtained from EOF expansion cannot clearly reveal features of variable change in different geographical zones, REOF development must be made based on vectors from EOF to reveal variable′s characteristics of zonal anomaly. Rotated components expanded from REOF can indicate spatial correlation of various geographical zones clearly because corresponding variance of each component concentrates on a certain geographical zone, which makes local features more outstanding. It is easy to find that variances of rotated components are scattered and their values also change compared to those of EOF (Table 1).

Table 1 Variances and accumulative variances of the first 8 loading vectors before and after rotation (%)

Number	Before rotation		After rotation	
	Variance	Accumulative variance	Variance	Accumulative variance
1	30.4	30.4	11.5	11.5
2	11.6	42.0	13.4	24.9
3	8.5	50.5	11.8	36.7
4	5.2	55.7	9.8	46.5
5	4.3	60.0	6.6	53.1
6	3.9	63.9	8.5	61.6
7	3.1	67.0	4.7	66.3
8	2.8	69.8	3.5	69.8

The first 8 rotated loading vectors (RLV_1–RLV_8) from REOF expansion represented 8 anomaly areas of annual precipitation in the northeastern China.

(1) Larger loading values concentrated in the west of the Songneng Plain in RLV_1 (Fig. 3a). The maximum was +0.76 at Baicheng Station. Anomaly distribution of annual precipitation in RLV_1 was named the west plain pattern. Because mountains in the eastern part of the study region obstruct water vapor carried by southeast monsoon to reach the western part, the west of the Songneng Plain has a semi-arid climate. And about 70% of annual precipitation is supplied in summer in the west of the Songnen Plain, which is an area with the maximum variance of interannual precipitation in the study region.

(2) The Liaodong (east of Liaoning Province) Hills pattern was shown in RLV_2 (Fig. 3b). Loading values were more than those before rotated and the largest loading value was +0.85 at the Xiaoshi Station.

(3) RLV_3 presents an anomalous distribution of annual precipitation named the Sanjiang Plain pattern (Fig. 3c). The largest loading value (+0.82) appeared at Yilan Station. The Sanjiang Plain is one of areas influenced frequently by activities of the northeast cold vortex. About 30% of its plain area is covered by wetlands. Its annual precipitation is more than that of the Songneng Plain in the same latitude.

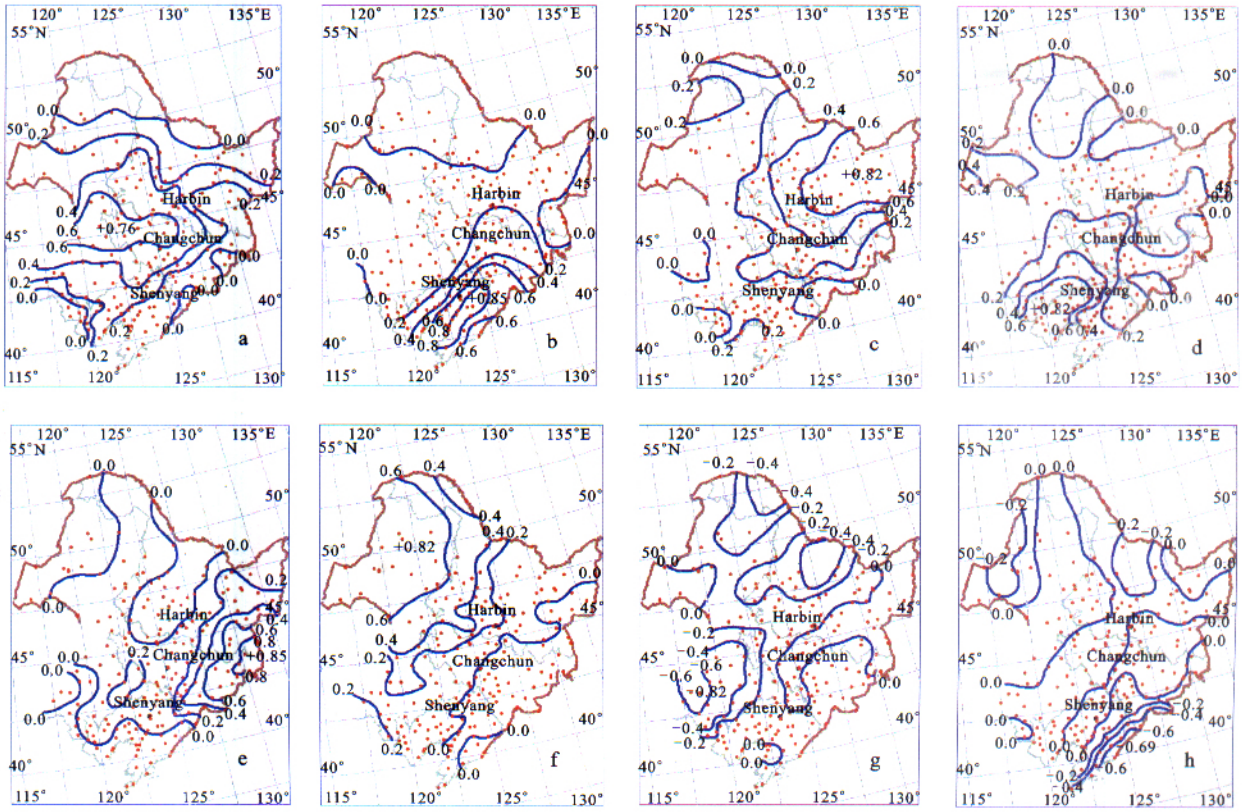

Fig. 3 The first 8 loading vectors from EOF expansion of annual precipitation in the northeastern China

(4) An abnormal district of annual precipitation shown in RLV_4 was the Liaoxi (the west of Liaoning Province) Hills pattern (Fig. 3d). The largest loading value (+0.83) appeared at the Kazuo Station. There is an arid climate in the area.

(5) The Changbai Mountains pattern was presented in RLV_5 (Fig. 3e). The center of larger rotated loading values was around the Luozigou and the Wangqing stations and the maximum was +0.85. This area has a mountainous climate.

(6) Hulun Buir Plateau pattern was showed in RLV_6 (Fig. 3f). The largest loading value (+0.82) occurred at Ewenki Station. The plateau has the minimum annual precipitation in the study region and its 95% of annual precipitation concentrates in summer.

(7) Southwest plateau pattern was represented in RLV_7 (Fig. 3g). The maximum absolute value of rotated loading was +0.82 around the Linxi and the Balin stations. There exists the minimum annual precipitation in south of latitude 45°N of the study region.

(8) Anomalous distribution of annual precipitation in RLV_8 was the Liaodong Peninsula pattern. Larger absolute values of rotated loading occurred around Dandong, the Donggang and the Changhai stations and the largest absolute value was +0.69. Because it is close to sea and is influenced by southeast typhoon to bring torrential rains frequently in a year, the Liaodong Peninsula has maximum annual precipitation in the study region.

5 CONCLUSIONS

There has been a compatible change in annual precipitation in the Northeast Plain, including the Songneng Plain and the Liaohe Plain, since the late 1980s. Owing to difference of location, topography and local circulation system, there existed opposite changes in annual precipitation between the north and the south of the study region, and this pattern had a period of 11 years and the next one was predicted to happen in about 2006. The precipitation pattern of wet (or dry) in the east and dry (or wet) in the west occurred mainly in the 1960s and the 1970s.

There were 8 anomalous zones of annual precipitation: the west plain, the Liaodong Hills, the Sanjiang Plain, the Liaoxi Hills, the Changbai Mountains, the Hulun Buir Plateau, the Southwest plateau, and the Liaodong Peninsula.

The main areas of grain production are primarily distributed in the Sanjiang Plain and the Northeast Plain that includes the Songneng Plain and the Liaohe Plain. Because the western part of the Songneng Plain and the Sanjiang Plain are two sensitive areas for precipitation anomaly, it is needed to pay close attention to anomalous precipitation trends of the two areas in the forecast study of precipitation impact on grain yield in the northeastern China.

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