Refined characteristics of rainfall in Guangxi area for mountain flood based on hourly precipitation

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Abstract. On the basis of hourly rainfall dataset from 92 meteorological stations for the 10 years (2008-2017), the spatial and temporal distribution of precipitation in Guangxi were analyzed. Results showed that high value precipitation centers were found over different districts during two time frame, 6:00-12:00 and 18:00-24:00. The rainfall over north of Guangxi mainly happened during 18:00-24:00, but over the middle of Guangxi was during 6:00-12:00. The hourly precipitation distributed unevenly on season scale. Seasonal differences in diurnal variation of rainfall were distinguished. Summer rainfall events concentrated at morning, but the events during other three seasons were more likely to happen in the evening. Using empirical orthogonal function (EOF), the first principal component displayed apparent spatial distribution, which would be helpful to classify the security of mountain flood. During the 6:00-12:00, the patterns were more typical to describe the high rainfall centers in summer. As for the other three seasons, the patterns were appropriate during 18:00-24:00.

1. Introduction
Climate changes happen frequently in recent years, causing different kinds of disasters. Mountain flood is one of the natural disasters on account of abnormal climate events. Under the influence of rainfall intensity, soil moisture, underlying surface types and human activities, mountain flood disasters occur frequently and bring serious damages. Above all the reasons, the rainfall variation is the immediate cause. Therefore, the precision of precipitation prediction can be helpful to improve the accuracy of flood warning.

There is a trend of increasing extreme precipitation intensity over China in nearly 50 years[1]. The precipitation of Guangxi is growing each year[2]. Guangxi is in the south of China. Due to its mountainous topographic conditions, there are different regional mountain flood disasters in Guangxi. Ni et al show that the longer the flood return period is, the more serious the disaster is[3]. Also, Hu et al and He et al point out that the flood disasters are in an increasing trend[4-5]. So it is necessary to explore the distribution of precipitation in Guangxi. At present, there are many studies exploring the distribution of Guangxi rainfall events[6-8]. These papers implicit the reason of extreme precipitation. And there are other papers showing that Guangxi has three high value precipitation centers based on daily data. However, the application of hourly precipitation data is relatively less. Actually, this study based on hourly data can find out exact results of the region[9].

As for flash flood, more exquisite studies will be helpful to classify different district characteristics and predict it more properly. This paper applies hourly precipitation data to analyze the spatial-temporal precipitation distribution in Guangxi to help us improve the accuracy of mountain flood warning.
According to the spatial distribution, we can further classify the warning grade of the whole district, enhancing the security in advance.

2. Data and Methods

2.1. Data
The observed hourly precipitation data analyzed in this paper is from the Guangxi 92 national meteorological stations during 2008-2017. And the default values have been interpolated.

Fig 1. Location of 92 stations over Guangxi province and shaded color presents the region terrain.

2.2. Methods
EOF represents empirical orthogonal function, one of the typical methods of principal component analysis (PCA), which is being used in the spatial-temporal data. This study used the method in order to analyze the precipitation feature. EOF decomposition transforms an original data matrix into a linear superposition of several orders of eigenvectors (spatial mode), using matrix decomposition technologies. The order of the eigenvectors is based on the variance contribution rate, which reduces the dimensions. First, the data $X$ were constructed by $M$ (represents the number of spatial station)*$N$ (represents the number of time), so $X_{mn}$ is the observed value at a specific position and a specific moment. EOF decomposition recognizes the matrixes $V$ and $T$[10]:

\[ X = VT \]  

Where $V$ is a spatial feature and each column of $V$ is a spatial mode. This is called space coefficient. $T$ is a time feature and each row of $T$ corresponds to each column of $V$. This is called time coefficient. Each mode in $V$ has its own contribution, the proportion of mode $k$ can be expressed by $R_k$, the cumulative of mode $k$ can be expressed by $G$, as follows:

\[ R_k = \frac{\lambda_k}{\sum_{i=1}^{m} \lambda_i} \]  

(2)

\[ G = \frac{\sum_{i=1}^{p} \lambda_i}{\sum_{i=1}^{m} \lambda_i} \]  

(3)

where $\lambda$ represents the eigenvalue of each mode.

To prove the results of EOF decomposition, North proposed a method to examine[11]. It mainly uses the eigenvalue of each mode $\lambda$ to calculate the reasonable error range, as follows:

\[ \lambda_j - \lambda_{j+1} \geq x_j \left( \frac{2}{n} \right)^{\frac{1}{2}} \]  

(4)
where \( n \) represents the number of time. If each \( \lambda \) satisfies this inequation which means the results is valuable. This paper puts the precipitation anomaly data as the X matrix applying the EOF decomposition.

3. Results

3.1. Spatial and temporal distributions in Guangxi

Figure 2a describes the precipitation variation during whole day from 2008 to 2017. The number of each hour time is the average of accumulated hourly precipitation data over Guangxi during 2008-2017. This mean line presents two peaks and two troughs, the maximum of rainfall appears at 23:00, and the minimum at 14:00. Besides, the other peak occurs at 9:00 and the other trough appears at 5:00. It reveals that precipitation in Guangxi is likely to have spatial and temporal distribution based on the hourly rainfall data. Furthermore, figure 2b displays the time of maximum precipitation for each station during a day. As the figure shown, the distribution of Guangxi rainfall events has apparently spatial characteristics. The region of maximum rainfall can be classified into three subareas based on time, the northern to the Dayao mountain district, the district between Dayao and Shiwan mountain and the district to the south of Shiwan mountain. The rainfall events in the northern and southern Guangxi usually happen during about 18:00-24:00, just as the figure shows. In the rest districts of Guangxi, rainfall events appear more easily during about 6:00-12:00.

Fig 2. (a) multi-year average diurnal variation of hourly precipitation during 2008-2017 (b) multi-year diurnal maximum time of hourly precipitation at different stations during 2008-2017.

In a word, Guangxi precipitation not only has the three high value centers of rainfall by daily data, but also exists conspicuous spatial and temporal features by hourly data. Thus, in order to specify the precipitation distribution detailly, we use statistic method to find out the characters in the next charter.

Figure 3 shows that the temporal distributions of hourly precipitation in each month are clear. From 1:00 to 24:00, each month has its own maximum time frame. Standardized precipitation has three high positive value centers, one is at 9:00 in August, the other two are approximately at 23:00 in May and October. The precipitation generally concentrates during 6:00 -12:00 from July to October, however, the precipitation events in the rest months usually present during18:00 - 24:00. As the shown in figure 3, there are several features of the hourly precipitation in Guangxi. It only shows the temporal traits of precipitation across the whole region of Guangxi in this part, next part we will explore the spatial features of hourly precipitation in Guangxi. For the sake of specifying the value of precipitation during different hours in each season, this study applies the annual mean accumulative contribution rate statistics. The four seasons are defined as spring (MAM), summer (JJA), autumn (SON) and winter (DJF).
Fig 3. Standardize value of diurnal variation of hourly precipitation during 2008-2017.

Table 1 shows that rainfall events are more likely to happen during 19:00-24:00 in Guangxi in the whole year. However, there are some different situations for seasonal precipitation. The spring and autumn rainfall events concentrate during the evening time (19:00-24:00), but summer rainfall happens more frequently during the morning time (7:00-12:00). Throughout, summer rainfall makes main contribution to the annual precipitation in Guangxi. The annual mean accumulative contribution rate of summer rainfall is equal to the sum of the other three seasons during the time from 1:00 to 18:00, but in the evening, the rainfall has a little bit different feature. Thus, there are apparent temporal characteristics of precipitation in Guangxi. In order to explore the regional differences during different hours, two main period (6:00-12:00 and 18:00-24:00) rainfall events will be discussed.

Table 1. The annual mean accumulative contribution rate of rainfall in different seasons during 2008-2017.

|          | 01-06 | 07-12 | 13-18 | 19-24 |
|----------|-------|-------|-------|-------|
| Spring   | 11.51%| 7.60% | 8.85% | 16.09%|
| Summer   | 18.32%| 21.02%| 14.21%| 20.71%|
| Autumn   | 7.99% | 7.73% | 6.32% | 9.43% |
| Winter   | 3.71% | 2.80% | 3.44% | 4.83% |
| Total    | 41.53%| 39.15%| 32.83%| 51.06%|

3.2. The results of using EOF decomposition

Table 2 presents the proportion and cumulative of EOF first three components in four seasons during 6:00-12:00. As it shows, the cumulative of the first three patterns is 57.41% in spring, 61.52% in summer, 67.4% in autumn and 83.17% in winter. Obviously, the proportion of first principal component is the largest in these three modes for each season. Thus, these three patterns for each season are valuable.

Table 2. The annual mean accumulative contribution rate of rainfall in different seasons during 2008-2017

|          | Mode 1 | Mode 2 | Mode 3 |
|----------|--------|--------|--------|
| Spring   | Proportion (%) | 27.24 | 16.77 | 13.40 |
|          | Cumulative (%)  | 27.24 | 44.01 | 57.41 |
| Summer   | Proportion (%) | 34.84 | 14.22 | 12.46 |
As mentioned above, there are strong spatial, temporal and seasonal variability in Guangxi precipitation. Figure 4 shows the results of EOF spatiotemporal rainfall analysis in the duration from 6:00 to 12:00. The first principal components in four seasons are shown in Fig 4a-4d, the second and third modes are respectively in Fig 4e-4h and Fig 4i-4l. It shows that there are significant spatial and temporal differences in the precipitation during 6:00 to 12:00.

Fig 4. The first three modes of EOF decomposition based on anomalies of hourly precipitation during the time 6:00-12:00.

Besides, the results of first three principal components have been proved by significant testing. Based on the first principal components results of four seasons, each season has different spatial patterns. Figure 4a shows that spring rainfall has a high positive value center in the northwestern Yulin, figure 4b finds that summer rainfall has multiple high value centers over the southern Nanning, and southeastern Guangxi exhibits a negative correlation. It also implicates that summer rainfall events mainly occur during 6:00-12:00. As shown in figure 4c, autumn rainfall concentrates in the southeastern Chongzuo, in addition, a low value center is shown in southwestern Yulin. Figure 4d shows winter first principal component, the values in this pattern are relatively low which representing that the rainfall events happen less frequently during 6:00-12:00 in winter, furthermore, there is a negative correlation between northwestern Guangxi and southeastern Guangxi in winter.

Table 3 presents the proportion and cumulative of EOF first three components in four seasons during 18:00-24:00. The cumulative of the first three patterns is 89.5% in spring, 86.87% in summer, 76.64% in autumn and 88.69% in winter. The proportion of mode 1 in each season reaches the highest proportion, which represents that the first principal component can clearly describe spatial features of precipitation. The mode 2 and mode 3 have low proportion in the pattern contribution.
Table 3. The proportion and cumulative of EOF first three results in different seasons during 2008-2017.

|        | Mode 1 | Mode 2 | Mode 3 |
|--------|--------|--------|--------|
| Spring | 78.66  | 6.52   | 4.32   |
|        | 78.66  | 85.19  | 89.50  |
| Summer | 68.95  | 11.01  | 6.91   |
|        | 68.95  | 79.96  | 86.87  |
| Autumn | 47.21  | 22.42  | 7.01   |
|        | 47.21  | 69.63  | 76.64  |
| Winter | 72.70  | 9.72   | 6.28   |
|        | 72.70  | 82.41  | 88.69  |

Besides, the first three principal components for precipitation during 18:00-24:00 have also been proved by significant testing. As for spring, the most regions of Guilin and Liuzhou occupy the high value center and have negative correlation with southeastern Guangxi. Different from the distribution of 6:00-12:00, the values of the first principal component for summer are relatively low, only one region in Fangchenggang has the high value center. As for autumn and winter, they all present northwest-southeast distribution, the difference is that the positive region in autumn occurs in the northwestern Guangxi, but the positive regions in winter present in Guilin and Liuzhou.

Fig 5. The first three modes of EOF decomposition based on anomalies of hourly precipitation during the time 18:00-24:00.

4. Discussion and Conclusion
In this paper, we have studied the hourly precipitation variation and its temporal and spatial distribution. The hourly precipitation in Guangxi describe unique characters. Analyzing seasonal rainfall with different time frame, the results show regional differences. The conclusions are as follows:

(1) As the hourly precipitation data of 2008-2017 shows, the rainfall is mainly concentrated at 23:00 in the whole day. Otherwise, the precipitation over northern Guangxi and small region of Fangchenggang more easily happens during 18:00-24:00. But over the middle region of Guangxi, the rainfall events appear more frequently during 6:00-12:00. It may be connected with the topographic conditions.
(2) Seasonal study displays different features of precipitation distribution during different seasons. Summer rainfall events mainly happen during 6:00-12:00. However, spring, autumn and winter rainfall concentrate during 18:00-24:00.

(3) Using EOF method, the first three modes are proved to be typical. The four seasons have different high value centers. For summer, the pattern during 6:00-12:00 can be able to describe a typical spatial distribution. For the other seasons, the typical time is different, the pattern in the time of 18:00-24:00 is appropriate.

Based on hourly precipitation data, this study presents a refined discussion over Guangxi. The conclusion of the spatial and temporal features will be helpful to predict the extreme rainfall events, especially for the mountain flood warning. But on account of the limited data, we only have recent ten years hourly precipitation data. It is possible that the features would be lack of the regional representativeness. Aim at this problem, the next step for us will be applying more data information, including the assimilation data, to study about the distribution characters in this region. Furthermore, considered with other relative data, the mountain flood prediction can use these results and divide the region into subareas with different grades. Therefore, the refined study still needs the further discussion.

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