Characteristics of precipitation in the rainy season of Koxkar Glacier, Tianshan Mountain, China

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Abstract. Precipitation is widely recognized as the major driving force of hydrologic system, and changes of its pattern could have direct impacts on water resources, especially in mountains. The total precipitation and rain days based on observation were analysed in Koxkar glacier catchment in rainy season during the period of 2009 - 2016. The results have shown that the total precipitation of rainy season fluctuates randomly with no significant trend of increasing or decreasing. The rain days of different precipitation classes differ noticeably, and are inconsistent with the contribution of total precipitation in rainy season. The maximum daily precipitation influences the monthly precipitation. These characteristics of rainy season precipitation display the important factor for the study of glacier changes.

1. Introduction

Precipitation is an important part of fundamental components of the climate and hydrological cycle in understanding the water balance and the complex process of energy interactions among the small- and large-scale [1, 2]. In general, precipitation data can be obtained from three observational techniques, 1) measurement directed by rain gauge, 2) ground based radar networks, 3) space-borne satellite instruments [3, 4]. Although the weather radar and satellite remote sensing techniques are provided high spatial-temporal resolution with complete area coverage and available in real-time [5, 6], the rain gauge observations are considered relatively accurate in situ measurements in spite of suffering from various problems, such as poor spatial sampling, undercatchment due to wind and evaporation, especially snowfall [7, 8]. The observation has been widely applied in climate analysis, climate diagnostic, drought relief, and flood forecasting [9-11].

Tianshan Mountain is one of the largest mountains in the northwest of China, which is a typical arid and semi-arid region. It stretches from west to east for about 1700 km, and from south to north for about 250-300 km. The average elevation is approximately 4000 m.s.l. [12, 13]. Because it locates in the hinterland of Eurasian continent, which is far away from the ocean, precipitation is the main source of surface water to supply for river runoff, farm irrigation and drinking. Since it is located in the prevailing westerlies, the major water vapor is come from west wind current, and the dry, cold current of Arctic Ocean is the minor resource which accounts for 25-33% of that of the west wind current. Therefore, Tianshan Mountain originates several important inland rivers in northwest China and
Central Asia, and has become the mainly water resources of downstream oasis. The condition and variability of precipitation over Tianshan Mountain play an important role for the ecosystems and environment, and regional sustainable development [14, 15].

2. Materials and methods

2.1. Study area
The Koxkar glacier catchment (41°42’ N-41°53’ N and 79°59’ E-80°10’ E) is located in the southwest Tianshan, Wensu County in Xinjiang Province, China. The whole catchment covers an area of 116.5 km², out of which 62.8% is glacierized area, with an average elevation of approximately 4000 m.a.s.l. [16]. The Koxkar Glacier extends 25.1 km in length and covers an area of 73.2 km², and 93.6% of discharge of the Koxkar Glacier occurs in the ablation season [17]. The mean annual air temperature observed near the terminus of the glacier is 0.778 ℃, while the mean temperature of summer is as high as 7.748 ℃. Mean annual precipitation is near the terminus is 608 mm, of which >80% occurs during the ablation period [18]. A belt of low rainfall is around approximately 3700 m, while greater in the terminus and accumulation zones of the glacier [19].

2.2. Methods
A manual observation station is located near the glacier terminus at an elevation of 3009 m from 2008 to present in rainy season. Precipitation observation carried out at GMT 8:00 am and 8:00 pm in every day respectively. The amount of day precipitation is recorded from GMT 20:00 to 20:00 of next day. Though, there are seven automatic weather stations installed in the catchment which observed the air temperature and the precipitation automatically recently. Due to the short period of these automatic weather stations, analyzed the characteristics of precipitation is only used the data observed by manual. The precipitation was missed in September 2008; the period of analysing is from May to September when the major rainfall occurred in the period of 2009-2016.

2.3. Precipitation classes
During rainy season, the number of days with precipitation is determined in particular classes according to Elżbieta [20] criterion as shown in table 1:

| Amount (mm/d) | Classes |
|---------------|---------|
| <10           | Light   |
| 10–24.9       | Moderate|
| ≥25           | High    |

3. Results

3.1. Total precipitation in rainy season
The variation of rainy season precipitation is large in Koxkar glacier catchment over the period of 2009 – 2016 (figure 1). The average precipitation is 453.5 mm during the observation period. The maximum of rainy season is 546.4 mm occurred in 2013, while the minimum is 335.8 mm occurred in 2014. The difference exceeds 200 mm. The rainy season precipitation decreased dramatically over the period of 2010 – 2012, but increased significantly over the period of 2014 – 2016.
Figure 1. Total rainy season precipitation over the period of 2009 – 2016.

Figure 2. The monthly percentage in rainy season over the period of 2009 – 2016.
In order to better analyse the characteristic of rainy season, we calculated the monthly percentage in rainy season during the observation period (figure 2). The variation of monthly percentage is similar to that of the rainy season, undulated significantly during the observation period. In May, the percentage of rainy season precipitation ranges from 0.1 to 0.2, and the mean value is 0.18 except 2014. The maximum value 0.27 occurred in 2011, but the minimum is only 0.1 occurred in 2014 in which the rainy season precipitation is minimum. In June, the percentage of rainy season precipitation ranges from 0.14 to 0.34, the mean value is 0.24 except in 2009 and 2016. In July, the percentage of rainy season precipitation is the range 0.13 to 0.37, the mean value is 0.22. The percentage of July is above the 0.2 from 2009 to 2014, below 0.2 nearly two year. In August, the percentage of rainy season precipitation ranges from 0.17 to 0.4, the mean value is 0.25 except in 2010. In September, the percentage of rainy season precipitation ranges from 0.13 to 0.39, the mean value is 0.22 except in 2012. The percentage of September decreased first, and then increased.

3.2. Precipitation days in rainy season
On a rainy season basis, the number of rainy days is insufficient half of observation days except 2016 (table 2). The maximum value of rainy days occurred in 2016, while the minimum occurred in 2014 which the rainy season precipitation is the minimum. It is obvious that the days of light rain are major in rainy season accounted for 70% above. However, the amount of light rain is fall short of half total precipitation in rainy season. The number of moderate rain days is below 15, there are few days of high rain. The amount of moderate rain accounts for 40% to 50% of total precipitation in rainy season. Though the fewer days of high are occurred, destructive flood can still form due to large precipitation intensity.

| Year | Days | Amount (mm) |
|------|------|-------------|
|      | Light | Moderate | High | Light | Moderate | High |
| 2009 | 53 | 11 | 2 | 145.2 | 174.9 | 75.7 |
| 2010 | 53 | 13 | 4 | 212.3 | 223 | 110.3 |
| 2011 | 59 | 14 | 1 | 244.2 | 193.4 | 26.1 |
| 2012 | 64 | 8 | 2 | 182.5 | 115.5 | 59.9 |
| 2013 | 54 | 15 | 4 | 188.8 | 222.6 | 135 |
| 2014 | 52 | 15 | 1 | 158.2 | 149.4 | 28.2 |
| 2015 | 62 | 15 | 1 | 182.9 | 237.5 | 43.5 |
| 2016 | 67 | 13 | 3 | 220.5 | 214.8 | 83.8 |

It is shown that the variation of light rainy days has direct and strong impact on the variation of rain days, and the variation of moderate rainy days and high days has weaker influence than that of light rainy days. In order to deeply analyse the effect of different precipitation classed on total precipitation of rainy season, we investigate the relationship between amount of different precipitation classes and total precipitation in rainy season (figure 3). It is easy to see that the correlation is the best between amount of moderate rain and total precipitation, the correlation coefficient is up to 0.86. However, the amount of high rain is few, the correlation is well between high rain and total precipitation, with the correlation coefficient is up to 0.68. The correlation is weak between light rain and total precipitation in spite of the maximum of rainy days.

3.3. Maximum daily precipitation in rainy season
Table 3 shows that the maximum daily precipitation in rainy season over the period of 2009 – 2016. Although the maximum amount of monthly precipitation did not occur in September, the maximum daily precipitation is the largest in September compared to that in other months. The maximum daily precipitation occurred twice, in May and July respectively, only once in August, and none in June. The
amount of maximum daily precipitation accounts for more than 30% of the monthly precipitation.

![Graphs showing the relationship between amount of light, moderate, high and total precipitation in rainy season.](image)

**Figure 3.** The relationship between amount of light, moderate, high and total precipitation in rainy season.

| Maximum daily precipitation | Amount of precipitation (mm) |
|-----------------------------|-----------------------------|
| 5 Sep, 2009                 | 38.2                        |
| 17 Sep, 2010                | 29.4                        |
| 11 Aug, 2011                | 26.1                        |
| 12 Jul, 2012                | 31.9                        |
| 16 Sep, 2013                | 45.9                        |
| 30 Jul, 2014                | 28.2                        |
| 18 May, 2015                | 43.5                        |
| 12 May, 2016                | 29.8                        |

**Table 3.** Maximum daily precipitation in rainy season over the period of 2009 – 2016.

4. Conclusion
The total precipitation, precipitation days and maximum daily precipitation in rainy season have been exhibited in this paper during the period of 2009 – 2016 over Koxkar glacier catchment. The main conclusions of the study are summarized as follows:

- In study area, due to the large variability of precipitation in rainy season, trends of significant increase or decrease did not exist. The difference of rainy season precipitation is significant during the period of observation. The variability of monthly precipitation is similar to that of total precipitation. It is critical to the study of glacier changes.
• The days of precipitation are basically above 70 days except in individual years, which account for 40% over the period of observation. The light rain days take up the majority, and the high rain days are very few. The moderate rain days are below 15 days, but the amount of moderate rain affected the total precipitation significantly in rainy season.

• The maximum daily precipitation occurs at different times during the period of observation, and its amount has contributed to the monthly precipitation.

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