Comparative Analysis of Fine-scale Characteristics of Different Types of Summer Heavy Rainfall in Southern Xinjiang (Postprint)

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Date: 2021-06-13T17:46:32+00:00

Abstract

Heavy rainfall in Southern Xinjiang is a low-probability event, and its forecasting and early warning are challenging. Some heavy rainfall processes in Southern Xinjiang are characterized by short duration, high precipitation intensity, and are accompanied by short-duration heavy precipitation events (i.e., "short-duration heavy precipitation rainstorms"); whereas other heavy rainfall processes have relatively longer precipitation periods without accompanying short-duration heavy precipitation events (i.e., "non-short-duration heavy precipitation rainstorms"). To investigate the differences between these two types of heavy rainfall in Southern Xinjiang, this study utilized hourly precipitation data from 426 automatic weather stations during 2013–2019 to conduct a comparative analysis of the differences between short-duration heavy precipitation rainstorms and non-short-duration heavy precipitation rainstorms in Southern Xinjiang during summer. The results indicate: (1) Heavy rainfall in Southern Xinjiang during summer is dominated by short-duration heavy precipitation rainstorms, with over 70% of stations experiencing short-duration heavy precipitation events on heavy rainfall days; short-duration heavy precipitation rainstorms occur mainly in July, when approximately 95% of heavy rainfall days feature short-duration heavy precipitation events. (2) Stations in Southern Xinjiang at altitudes of 2000–2500 m have the highest proportion of heavy rainfall occurrences, while stations below 1000 m have the lowest. Short-duration heavy precipitation rainstorms in Southern Xinjiang occur mainly in areas below 2000 m, whereas non-short-duration heavy precipitation rainstorms occur mainly in areas above 2000 m; both types of heavy rainfall exhibit distinct nocturnal rainfall characteristics. (3) The diurnal variation characteristics of cumulative precipitation, precipitation frequency, and average precipitation intensity for total heavy rainfall and short-duration heavy precipitation rainstorms are similar, but differ substantially from those of non-short-duration heavy precipitation rainstorms. The peak periods of cumulative precipitation, precipitation frequency,

and average precipitation intensity for non-short-duration heavy precipitation rainstorms all occur in the morning; the peak periods of cumulative precipitation and average precipitation intensity for short-duration heavy precipitation rainstorms appear around evening and the first half of the night, while the peak period of cumulative precipitation frequency occurs mainly from the second half of the night to early morning, and the relationship between precipitation intensity and cumulative precipitation for short-duration heavy precipitation rainstorms is closer than that with precipitation frequency. The observational characteristics of short-duration heavy precipitation rainstorms and non-short-duration heavy precipitation rainstorms in Southern Xinjiang exhibit significant differences, and their precipitation formation mechanisms also differ.

Full Text

Comparative Analysis of Fine-Scale Characteristics of Different Rainstorm Types in Southern Xinjiang During Summer

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Abstract

Rainstorms in southern Xinjiang are low-probability events that pose significant challenges for forecasting and early warning. Some rainstorm processes in this region are characterized by short duration, high intensity, and accompanying short-term heavy rainfall events (referred to as "short-term heavy rainfall rainstorms"), while others feature relatively longer precipitation periods without short-term heavy rainfall events (referred to as "non-short-term heavy rainfall rainstorms"). To investigate the differences between these two rainstorm types, we analyzed hourly precipitation data from 426 automatic weather stations during the summer months (June–August) from 2013 to 2019.

The results reveal several key findings. First, summer rainstorms in southern Xinjiang are dominated by short-term heavy rainfall events, with over 70% of stations experiencing such events during rainstorm days. These events occur primarily in July, when approximately 95% of rainstorm days include short-term heavy rainfall. Second, short-term heavy rainfall rainstorms mainly occur at altitudes below 2000 m, whereas non-short-term heavy rainfall rainstorms are concentrated above 2000 m. Both rainstorm types exhibit pronounced nocturnal precipitation characteristics, particularly at stations between 2000–2500 m elevation where nighttime precipitation exceeds 50% of total rainfall. Third, the

regionally averaged precipitation duration is 12.0 hours for total rainstorm days, 7.9 hours for short-term heavy rainfall rainstorm days (with 48.1% of stations recording durations within 7 hours), and 15.3 hours for non-short-term heavy rainfall rainstorm days. All three categories show increasing precipitation duration with altitude. Fourth, the diurnal variation characteristics of cumulative precipitation, precipitation frequency, and average precipitation intensity are similar between total rainstorm days and short-term heavy rainfall rainstorm days, but differ markedly from non-short-term heavy rainfall rainstorm days. For non-short-term heavy rainfall rainstorms, the peaks of all three metrics occur in the morning. In contrast, for short-term heavy rainfall rainstorms, peaks in cumulative precipitation and average intensity appear in the evening and first half of the night, while precipitation frequency peaks from the second half of the night through early morning, indicating that precipitation intensity is more closely related to cumulative precipitation than to frequency in these events.

The observed characteristics of short-term heavy rainfall rainstorms and non-short-term heavy rainfall rainstorms differ significantly, suggesting distinct precipitation formation mechanisms that warrant further investigation.

Keywords: rainstorm; short-term heavy rainfall; altitude; fine-scale characteristics; southern Xinjiang

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1. Data and Methods

This study utilizes hourly precipitation data from 426 regional automatic weather stations in southern Xinjiang during summer (June–August) from 2013 to 2019. The dataset was quality-controlled to remove abnormal values and missing records. Given that national standards for heavy rain and short-term heavy rainfall are not applicable to Xinjiang's arid and semi-arid climate, we adopted the current Xinjiang operational standards: a rainstorm day is defined as daily precipitation (08:00–20:00 UTC) $ 24.1mm, withcategoriesofsevererainstorm(48.1–96.0mm)andextremerainstorm($96.1 mm). Short-term heavy rainfall events are defined as hourly precipitation $ $10.0 mm.

A rainstorm day at a station refers to any day meeting the Xinjiang rainstorm threshold. A regional rainstorm day is recorded when any station within southern Xinjiang experiences a rainstorm day. If one or more stations record short-term heavy rainfall during a regional rainstorm day, it is classified as a short-term heavy rainfall rainstorm day; otherwise, it is classified as a non-short-term heavy rainfall rainstorm day. The total rainstorm station count equals the sum of short-term and non-short-term heavy rainfall rainstorm stations.

Key metrics include: average precipitation hours per rainstorm day (the ratio of total precipitation hours to rainstorm days at a station), cumulative precipitation frequency (the count of hours with precipitation $ $0.1 mm during

rainstorm days), and average precipitation intensity (the ratio of hourly cumulative precipitation to corresponding cumulative frequency).

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2. Results

2.1 Rainstorm Days From 2013 to 2019, southern Xinjiang experienced 201 total rainstorm days, averaging 28.7 days annually. Short-term heavy rainfall rainstorm days numbered 168 (24.0 days annually), while non-short-term heavy rainfall rainstorm days totaled 33 (4.7 days annually). The proportion of short-term heavy rainfall rainstorm days averaged 83.7% of total rainstorm days, reaching a maximum of 94.5% in 2016 and a minimum of 65.6% in 2018.

Monthly distribution shows that total rainstorm days peak in July (73.1% of all rainstorm days) and are lowest in June (26.9%). Short-term heavy rainfall rainstorm days follow a similar pattern, with July accounting for 94.5% of such days and June only 5.5%. Non-short-term heavy rainfall rainstorm days also peak in July (67.7%) and reach their minimum in August (32.3%). Notably, July rainstorms are overwhelmingly dominated by short-term heavy rainfall events, with nearly 95% of rainstorm days in this month featuring such events.

Elevation analysis reveals that total, short-term, and non-short-term heavy rainfall rainstorm days all increase with altitude. However, stations below 1000 m average only 0.21 total rainstorm days, while those at or above 2500 m average 1.29 days. Short-term heavy rainfall rainstorm days predominate below 2000 m, whereas non-short-term heavy rainfall rainstorm days are more frequent above 2000 m. Specifically, at altitudes $ $2500 m, short-term heavy rainfall rainstorm days exceed non-short-term events, while the opposite is true at altitudes $ $2000 m but <2500 m.

2.2 Rainstorm Station Counts During the study period, southern Xinjiang recorded 1,407 total rainstorm station occurrences, averaging 201.0 annually. Short-term heavy rainfall rainstorm stations accounted for 1,206 occurrences (172.3 per year), while non-short-term heavy rainfall rainstorm stations totaled 201 occurrences (28.7 per year). The interannual variation in station counts is more pronounced than for rainstorm days, with 2018 recording the maximum (343 stations) and 2013 the minimum (98 stations), a difference of 245 stations.

Monthly patterns indicate that short-term heavy rainfall rainstorm stations peak in July (89.3% of all such stations) and are lowest in June (10.7%). Non-short-term heavy rainfall rainstorm stations also peak in July (70.1%) and reach their minimum in August (29.9%). Overall, summer rainstorms in southern Xinjiang are dominated by short-term heavy rainfall events, with both day counts and station counts substantially exceeding those of non-short-term events.

Elevation-based analysis shows that average total rainstorm station counts increase with altitude: from 0.90 stations at <1000 m to 6.45 stations at $ $2500

m. Short-term heavy rainfall rainstorm stations dominate below 2000 m, comprising over 50% of total stations at these elevations, with the highest proportion (63.7%) occurring at 1500–2000 m. Above 2000 m, non-short-term heavy rainfall rainstorm stations become dominant, particularly at $ $2500 m where they account for over 50% of all stations.

2.3 Precipitation Duration The regionally averaged precipitation duration for total rainstorm days is 12.0 hours, with 19.5% of stations recording $ $7 hours, 42.1% recording 7–12 hours, and 38.4% recording >12 hours. Duration increases consistently with altitude, from 7.6 hours at <1000 m to 16.9 hours at $ $2500 m.

For short-term heavy rainfall rainstorm days, the regional average is 7.9 hours, with 48.1% of stations recording $ $7 hours and only 20.7% exceeding 12 hours. The elevation gradient is steep: stations at $ $2500 m average 11.7 hours, nearly double the 5.8 hours at <1000 m. Non-short-term heavy rainfall rainstorm days average 15.3 hours regionally, with 78.2% of stations recording >12 hours. Their duration also increases with altitude, from 14.1 hours at <1000 m to 17.7 hours at $ $2500 m.

Spatial analysis reveals that for stations below 1000 m, high-duration centers are concentrated in northern Bayingolin Mongol Autonomous Prefecture. At 2000–2500 m, duration shows an east-west gradient (higher in the east), while at $ $2500 m, the pattern reverses (higher in the west). No significant regional differences exist between short-term and non-short-term heavy rainfall rainstorm days within specific elevation bands.

2.4 Day-Night Precipitation Ratio Previous research indicates pronounced nocturnal precipitation characteristics in Xinjiang during summer. To examine whether southern Xinjiang rainstorms share this feature, we calculated day (08:00–20:00) and night (20:00–08:00) precipitation ratios. Results show substantial spatial variation: nighttime precipitation dominates in Kashgar, Kizilsu Kirghiz Autonomous Prefecture, western Hotan, and western Aksu (exceeding 50% of total), while daytime precipitation prevails in eastern Aksu, Bayingolin, Turpan, and Hami.

Elevation-based analysis demonstrates that total rainstorm nighttime precipitation peaks at 2000–2500 m (52.3% of total) and is lowest at $ $2500 m (47.7%). Short-term heavy rainfall rainstorm nighttime precipitation exceeds daytime amounts at all elevations except $ $2500 m, with the 2000–2500 m band showing the strongest nocturnal signature (56.3%). Non-short-term heavy rainfall rainstorm nighttime precipitation dominates at all elevations except 1000–1500 m, reaching 63.2% at 2000–2500 m. These patterns indicate that both rainstorm types exhibit stronger nocturnal characteristics than total rainstorms, particularly in the 2000–2500 m elevation band.

2.5 Diurnal Variation Diurnal variation represents a fundamental mode of global weather and climate systems, with precipitation showing particularly significant variation. Analysis of cumulative precipitation diurnal cycles reveals distinct patterns among rainstorm types. For total rainstorm days, high-value periods occur at 17:00–19:00, with minima at 21:00. Elevation strongly modulates this pattern: at <1000 m, a single peak occurs at 09:00–11:00; at 1000–1500 m, a multi-peak structure emerges with relative maxima at 10:00 and 21:00; at 1500–2000 m, a double-peak appears with minima at 15:00–19:00; and at $ $2000 m, single peaks dominate with maxima shifting from 14:00 at 2000–2500 m to 18:00 at $ $2500 m.

Short-term heavy rainfall rainstorm days exhibit similar diurnal patterns to total rainstorm days. In contrast, non-short-term heavy rainfall rainstorm days show a single peak at 09:00–11:00 and a broad minimum from 05:00–14:00, with consistent patterns across all elevations.

Precipitation frequency analysis shows that both total and short-term heavy rainfall rainstorm days peak during 18:00–23:00 and reach minima at 02:00–10:00. Non-short-term heavy rainfall rainstorm days peak at 18:00–22:00 with minima at 07:00–11:00. Average precipitation intensity for total rainstorm days displays a double-peak pattern (maxima at 18:00 and 20:00, minimum at 11:00), while short-term heavy rainfall rainstorm days show similar diurnal evolution. Non-short-term heavy rainfall rainstorm days exhibit a single peak at 09:00–11:00.

These results demonstrate that total and short-term heavy rainfall rainstorm days share similar diurnal characteristics for cumulative precipitation, frequency, and intensity, all differing substantially from non-short-term heavy rainfall rainstorm days. For non-short-term events, all three metrics peak in the morning. For short-term events, cumulative precipitation and intensity peak in the evening and first half of the night, while frequency peaks from the second half of the night through early morning, indicating that intensity is more closely coupled with cumulative precipitation than with frequency.

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3. Conclusions

Using hourly precipitation data from 426 automatic weather stations during summer months from 2013 to 2019, this study compared the fine-scale characteristics of total rainstorms, short-term heavy rainfall rainstorms, and non-short-term heavy rainfall rainstorms in southern Xinjiang. The main conclusions are:

1) Summer rainstorms in southern Xinjiang are dominated by short-term heavy rainfall events, with over 70% of stations experiencing such events during rainstorm days. The number of short-term heavy rainfall rainstorm days is approximately five times that of non-short-term heavy rainfall rainstorm days. These events occur primarily in July, when about 95% of

rainstorm days include short-term heavy rainfall.

2) The day counts and station counts for total, short-term, and non-short-term heavy rainfall rainstorms all increase with altitude. Short-term heavy rainfall rainstorms mainly occur below 2000 m, while non-short-term heavy rainfall rainstorms dominate above 2000 m. Both rainstorm types exhibit pronounced nocturnal characteristics, most evident at 2000–2500 m where nighttime precipitation exceeds 50% of the total.

3) The regionally averaged precipitation duration is 12.0 hours for total rainstorm days, 7.9 hours for short-term heavy rainfall rainstorm days (with 48.1% of stations recording $ $7 hours), and 15.3 hours for non-short-term heavy rainfall rainstorm days (with 78.2% of stations recording >12 hours). All three categories show increasing duration with altitude.

4) The diurnal variation characteristics of cumulative precipitation, precipitation frequency, and average precipitation intensity are similar between total rainstorm days and short-term heavy rainfall rainstorm days, but differ substantially from non-short-term heavy rainfall rainstorm days. For non-short-term events, all three metrics peak in the morning. For short-term events, cumulative precipitation and intensity peak in the evening and first half of the night, while frequency peaks from the second half of the night through early morning, demonstrating that precipitation intensity is more closely related to cumulative precipitation than to frequency.

The significant differences in observed characteristics between short-term and non-short-term heavy rainfall rainstorms suggest distinct precipitation formation mechanisms requiring further research.

References

[1] Zhang Jiabao, Deng Zifeng. Xinjiang Precipitation Generality[M]. Beijing: China Meteorology Press, 1987: 400.

[2] Ma Shuhong, Xi Yuanwei. Some regularities of storm rainfall in Xinjiang China[J]. Acta Meteorologica Sinica, 1997, 55(2): 239-248.

[3] Tao Shiyan. Heavy Rainfalls in China[M]. Beijing: Science Press, 1980: 255.

[4] Bao Ming, Huang Ronghui. Characteristics of the interdecadal variations of heavy rain over China in the last 40 years[J]. Chinese Journal of Atmospheric Sciences, 2006, 30(6): 1057-1067.

[5] Chen Dong, Huang Ronghui, Chen Jilong. Recent progress and prospective scientific problems concerning climatological research on summer heavy rainfall in China[J]. Climatic and Environmental Research, 2015, 20(4): 477-490.

[6] Ren Guoyu, Yuan Yujiang, Liu Yanju, et al. Changes in precipitation over Northwest China[J]. Arid Zone Research, 2016, 33(1): 1-19.

[7] Ding Yihui, Zhang Jianyun. Heavy Rainfalls and Floods[M]. Beijing: China Meteorological Press, 2009, 290.

[8] Yang Lianmei. Climate change of extreme precipitation in Xinjiang[J]. Acta Geographica Sinica, 2003, 58(4): 577-583.

[9] Yang Lianmei, Li Xia, Zhang Guangxing. Some advances and problems in the study of heavy rain in Xinjiang[J]. Climatic and Environmental Research, 2011, 16(2): 188-198.

[10] Gao Shouting, Zhou Yushu, Ran Lingkun. A review on the formation mechanisms and forecast methods for torrential rain in China[J]. Chinese Journal of Atmospheric Sciences, 2018, 42(4): 833-846.

[11] Zhang Yunhui, Li Haiyan, Lin Xilu, et al. Analysis of continuous rainstorm circulation background and the dynamic process of synoptic scale in west of southern Xinjiang[J]. Meteorological Monthly, 2015, 41(7): 816-824.

[12] Zhang Junlan, Li Na, Qing He, et al. The observational analysis and water vapor characteristics of a rainstorm process in Xinjiang[J]. Torrential Rain and Disasters, 2016, 35(6): 537-545.

[13] Ma Yu, Wang Xu, Tao Zuyu. Study on vapors features of 96.7 heavy rain in Xinjiang[J]. Xinjiang Meteorology, 1998, 21(5): 9-13.

[14] Ji Kai, Wang Shixin, Zuo Hongchao, et al. Effect of meridional position of east Asian subtropical jet on midsummer precipitation in Eastern part on Northwest China[J]. Arid Zone Research, 2020, 37(1): 10-17.

[15] Qin He, Chen Chunyan, Ablimitijiang Ablikim, et al. Characteristics of short duration heavy rainfall in warm season in Xinjiang[J]. Arid Zone Research, 2019, 36(9): 1440-1449.

[16] Sun Yinshu, Zhou Yushu, Wang Yongqing. Analysis of dynamic process and moisture source on a heavy precipitation event in southern Xinjiang associated with the double upper level jet[J]. Chinese Journal of Atmospheric Sciences, 2019, 43(5): 1041-1054.

[17] Yang Xia, Li Yun, Zhao Yizhou, et al. Analysis of a brief torrential rain event in Autumn in Xinjiang[J]. Plateau Meteorology, 2014, 33(1): 162-170.

[18] Wang Jinhui, Zhang Xiaoxiao, Wang Dong, et al. Spatiotemporal change of precipitation in Kizilsu Kirghiz Autonomous Prefecture Xinjiang China[J]. Arid Zone Research, 2016, 33(2): 266-274.

[19] Zhang Jiabao, Su Qiyuan, Sun Shenqing, et al. Guide Handbook on Xinjiang Short Weather Forecast[M]. Urumqi: Xinjiang People Press, 1986: 456.

[20] Zeng Yong, Zhou Yushu, Yang Lianmei. A preliminary analysis of the formation mechanism for a heavy rainstorm in western Xinjiang by numerical simulation[J]. Chinese Journal of Atmospheric Sciences, 2019, 43(2): 372-388.

[21] Cui Caixia, Li Yang, Yang Qing. Spatial distribution and long term variation of nocturnal and daytime rainfall in Xinjiang[J]. Journal of Desert Research, 2008, 28(5): 903-907.

[22] Yu Rucong, Li Jian, Chen Haoming, et al. Progress in studies of the precipitation diurnal variation over contiguous China[J]. Acta Meteorological Sinica, 2014, 72(5): 948-968.

[23] Liu Jing, Zhou Yaman, Yang Lianmei, et al. The instability and its trigger mechanism of extreme precipitation event in the Ili River Valley on 31 July 2016[J]. Chinese Journal of Atmospheric Sciences, 2019, 43(6): 1204-1218.

Note: Figure translations are in progress. See original paper for figures.