Characteristics of Regional Short-Duration Heavy Precipitation in Summer in Hedong, Gansu (Postprint)

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Abstract

Based on summer hourly precipitation observation data from 2010–2021 in the Hedong region of Gansu Province, 50 regional short-duration heavy rainfall events were selected to analyze characteristics including intensity and spatiotemporal distribution from a synoptic process perspective. The results indicate: (1) During each synoptic process, the intensity of short-duration heavy rainfall was predominantly 20–30 $mm \cdot h^{-1}$, accounting for over 60% of all events, while events exceeding 40 $mm \cdot h^{-1}$ comprised less than 10%. In 74% of regional short-duration heavy rainfall events, rainfall with intensity exceeding 50 $mm \cdot h^{-1}$ occurred. (2) Regional short-duration heavy rainfall occurred primarily from mid-June to late August, with a peak period from late July to mid-August. Events took place annually, but with substantial interannual variations in frequency, which is closely associated with the position of the western Pacific subtropical high, anomalous warm and moist water vapor transport from the South China Sea or East China Sea, and the significant baroclinic characteristics resulting from interactions between mid- and low-latitude weather systems. (3) The average affected area of regional short-duration heavy rainfall processes accounted for merely 3.17% of the total area of the Hedong region, and the spatial distribution exhibited distinct regional characteristics. High-incidence areas were concentrated primarily near Taizi Mountain, the western extension of the Qinling Mountains, Liupan Mountain, and Ziwu Ridge, with high-frequency centers generally accompanied by short-duration heavy rainfall exceeding 40 $mm \cdot h^{-1}$. (4) The distribution of station occurrences of short-duration heavy rainfall differed significantly among circulation patterns. The eastward-moving plateau trough type exhibited a relatively scattered distribution yet yielded the highest overall number of stations experiencing short-duration heavy rainfall; the southwestern flow at the subtropical high edge type had the lowest median among the four categories; the dual-high shear line type showed relatively concentrated station occurrences, while the northwest flow type had the fewest. Differences in the distribution of short-duration heavy rainfall intensity were not pronounced, with precipitation of 30–50 mm·h^{-1} occurring more frequently in the dual-high shear line type.

Full Text

Characteristics of Regional Short-Time Heavy Rainfall in Eastern Gansu Province in Summer

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Abstract: Using hourly precipitation observations from automatic weather stations in eastern Gansu Province during the summers of 2010–2021, 50 regional short-term heavy rainfall events were identified. From the perspective of synoptic processes, this study analyzes the intensity and spatiotemporal distribution characteristics of these events. The results indicate: (1) During each event, the intensity of short-term heavy rainfall was mainly concentrated in the range of 20–30 mm·h^{-1}, accounting for over 60% of occurrences, while intensities exceeding 50 mm·h^{-1} represented less than 10% of events. However, 74% of regional short-term heavy rainfall events featured precipitation intensities exceeding 40 mm·h^{-1}. (2) Regional short-term heavy rainfall primarily occurred from late June to late August, with the peak period from late July to mid-August. These events occurred every year, but showed substantial interannual variability in frequency, which is closely related to the position of the Western Pacific subtropical high, anomalous warm-moist water vapor transport from the South China Sea or East China Sea, and significant baroclinic features resulting from interactions between mid- and low-latitude weather systems. (3) The average affected area of regional short-term heavy rainfall events accounted for only 3.17% of the total area of eastern Gansu, with distinct regional characteristics in spatial distribution. High-frequency areas were concentrated near the Taizi Mountains, western extension of the Qinling Mountains, Liupan Mountains, and Ziwu Mountains, with centers of maximum frequency generally accompanied by short-term heavy rainfall exceeding 40 mm·h^{-1}. (4) The distribution of station occurrences varied significantly under different circulation patterns. The eastward-moving plateau trough type showed a relatively dispersed distribution and the highest overall number of stations recording short-term heavy rainfall. The southwestern flow pattern at the subtropical high edge had the lowest median among the four types.

The shear pattern between two high-pressure systems showed concentrated station occurrences, while the northwest flow pattern had the fewest stations. No significant differences were observed in the intensity distribution of short-term heavy rainfall among circulation types, though precipitation of 30–50 mm · h^{-1} occurred more frequently in the two-high shear pattern.

Keywords: eastern Gansu Province; short-term heavy rainfall; weather events; spatiotemporal distribution

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1. Data and Methods

Precipitation observations consisted of hourly data from automatic weather stations in eastern Gansu Province during June–August from 2010 to 2021, provided by the Gansu Provincial Meteorological Bureau. After quality control using climatic boundary value tests and spatial consistency checks, data from 201 stations with good continuity and stability were selected (Fig. 1). The NCEP/NCAR Final Operational Global Analysis reanalysis dataset was also employed, with a temporal resolution of 6 hours and spatial resolution of $1° \times 1°$.

Following the short-term heavy rainfall standard for eastern Gansu specified in the Gansu Provincial Local Standard (DB62/T) and used by Kong et al. [24], the total number of stations with short-term heavy rainfall $20 mm \cdot h^{-1}$ on a given day was recorded as the daily station count for eastern Gansu (using 08:00–08:00 Beijing Time). If a station experienced short-term heavy rainfall on a given day, it was counted as one station occurrence; multiple occurrences at the same station on the same day were accumulated. Regional short-term heavy rainfall events were defined as those with 10 stations on a single day. A total of 50 regional short-term heavy rainfall events were identified during the summers of 2010–2021. Based on synoptic circulation characteristics, these 50 events were classified into four types: eastward-moving plateau trough, southwestern flow at the subtropical high edge, shear between two highs, and northwest flow. This study further analyzes the distribution characteristics of short-term heavy rainfall under these different circulation patterns.

2.1 Intensity Distribution of Regional Short-Term Heavy Rainfall Events

During the 50 regional short-term heavy rainfall events in eastern Gansu from 2010–2021, the frequency of occurrence decreased rapidly with increasing precipitation intensity. Short-term heavy rainfall with intensities of 20–30 mm · h^{-1} accounted for over 60% of all occurrences (Fig. 2). The proportion of 20–30 mm · h^{-1} precipitation exceeded 60% in all events, reaching a maximum of 97.45%, while stations with intensities above 50 mm · h^{-1} represented only 0.6% of the total. When the number of stations with short-term heavy rainfall was large, the corresponding maximum hourly precipitation values were also high. For events with fewer than 50 stations, the average maximum hourly precipitation was 54.2 mm · h^{-1}, accounting for 65.7% of events; for events with 50 or more stations, the average was 65.7 mm · h^{-1}, representing 74% of events. Among the 50 events, 37 featured precipitation exceeding 40 mm · h^{-1}, accounting for 74% of all events. Thus, the probability of precipitation exceeding 40 mm · h^{-1} is not low for regional short-term heavy rainfall events (Fig. 3), consistent with the understanding that stronger synoptic processes produce both higher maximum hourly precipitation values and more stations with short-term heavy rainfall.

2.2 Spatial Distribution of Regional Short-Term Heavy Rainfall Events

With an average spacing of approximately 10 km between automatic weather stations in eastern Gansu, each station represents an area of about 10 km$×$10 km. To investigate the spatial distribution characteristics, the region was divided into a uniform grid with 10 km spacing. A grid cell was considered to have experienced short-term heavy rainfall if it contained at least one station with such precipitation; multiple stations within the same grid cell did not accumulate spatial area. Using this criterion, the affected areas of the 50 events were calculated, yielding average affected areas overall and for each circulation pattern (Table 1). County-level administrative boundaries were also used to map the distribution for each event.

The average affected area of regional short-term heavy rainfall events was 5,941.08 km^2, representing only 3.17% of the total area of eastern Gansu. Even for the two-high shear pattern, which had the largest average affected area (7,430.00 km^2), the proportion was just 3.97%. This indicates that the affected areas are small and relatively dispersed, consistent with the region' s semi-arid to semi-humid climate background.

The spatial distribution exhibited pronounced regional characteristics (Fig. 4), with high-frequency zones concentrated near mountainous terrain: the Taizi Mountains, western extension of the Qinling Mountains, Liupan Mountains, and Ziwu Mountains. Along the Taizi Mountains, occurrence frequencies ranged from 0.1–0.2, slightly higher than surrounding areas. The western Qinling extension showed significant topographic influence, with frequencies generally 0.2–0.3 and some stations reaching 0.4–0.5. The Liupan Mountains and Ziwu Mountains also featured frequencies of 0.3–0.5. In terms of precipitation intensity (Fig. 5), the distribution of rainfall exceeding 40 mm · h^{-1} was related to topography, with concentrated areas corresponding to high-frequency zones, further demonstrating that under favorable synoptic-scale circulation conditions, terrain exerts important influence on the development of mesoscale weather systems.

2.3.1 Ten-Day Distribution of Regional Short-Term Heavy Rainfall Events

Analysis of the ten-day distribution of regional short-term heavy rainfall events and maximum hourly precipitation values reveals that these events mainly occurred from late June to late August, with the highest frequency during late July to mid-August, accounting for over 76% of all events (Fig. 5). Notably, mid-August saw frequent regional events, though few reached 50 stations; events exceeding 50 stations primarily occurred in late July. This pattern likely relates to thermal and moisture conditions in eastern Gansu (Fig. 6) and cold air activity. From late June to mid-July, although moisture conditions differed little from late July, thermal conditions weakened significantly, with the 200 $J \cdot kg^{-1}$ CAPE contour retreating from central to eastern and southern boundaries of the region (Fig. 6). This weakening reduced the persistence and areal extent of short-term heavy rainfall, though cold air disturbances increased in frequency and intensity, with positive geopotential height anomalies at 700 hPa and positive pseudo-equivalent temperature anomalies at 500 hPa.

2.3.2 Interannual Variation of Regional Short-Term Heavy Rainfall Events

The interannual distribution from 2010–2021 shows that regional short-term heavy rainfall events occurred every year, but with substantial interannual variability (Fig. 7). The maximum frequency was 11 events in 2018, followed by 8 events in 2019, while 2012, 2014, and 2015 had no events exceeding 50 stations. The areal extent and intensity also varied by year, corresponding well with event frequency. Further analysis of circulation patterns in high-frequency years (2018) and low-frequency years (2012, 2014, 2015) reveals that in high-frequency years, the 500 hPa mean geopotential height anomaly over eastern Northwest China was positive, with 700 hPa pseudo-equivalent temperature anomalies larger than at 500 hPa and centered over western Gansu. A strong anomalous easterly flow existed south of the 500 hPa positive height anomaly. Water vapor transport differences created distinct moisture conditions (Fig. 8). Typically, moisture for heavy rainfall in eastern Gansu originates from the Bay of Bengal and South China Sea. Comparing 2018 and 2015, the Bay of Bengal transport showed no anomaly, but differences arose from the South and East China Seas. In 2018, anomalously strong southerly flow (Fig. 8) enhanced transport from the South China Sea, while in 2015, anomalously strong easterly flow brought warm, moist air from the East China Sea westward along the Yangtze River to the Sichuan Basin, then northward into eastern Gansu—an uncommon pattern requiring attention in future forecasting. This pattern relates to the higher number and more northerly tracks of typhoons making landfall in China in 2018 [33], when the Western Pacific subtropical high was anomalously strong and northward-shifted, with its ridge line often north of 30°N. These analyses demonstrate that interannual variability in regional short-term heavy rainfall frequency is closely related to the position and intensity of the Western Pacific subtropical high, baroclinic features of synoptic systems, and anomalous warm-moist water vapor transport from the South or East China Sea.

2.4 Distribution Characteristics Under Different Circulation Patterns

Spatial distributions of short-term heavy rainfall varied among circulation patterns (Fig. 9). The eastward-moving plateau trough type exhibited a relatively wide distribution (Fig. 9a), with concentrated 40–50 $mm \cdot h^{-1}$ rainfall areas corresponding well to high-frequency zones, though areas with >50 $mm \cdot h^{-1}$ precipitation were scattered. The northwest flow pattern showed the smallest affected area and fewest counties, with an average area of only 4,500.00 km^2 (2.45% of the region) and rare occurrences exceeding 50 $mm \cdot h^{-1}$. The subtropical high edge southwestern flow pattern had a slightly larger average affected area than the plateau trough type (6,514.29 km^2, 3.48% of the region), with high-frequency zones for >40 $mm \cdot h^{-1}$ rainfall concentrated in the southern part of the western Qinling extension (frequency 0.4–0.5), showing stronger intensity than the plateau trough type and widespread >50 $mm \cdot h^{-1}$ precipitation. Two concentrated areas of >40 $mm \cdot h^{-1}$ rainfall existed: along the Taizi Mountains and west of Ziwu Mountains.

The two-high shear pattern had the largest average affected area (7,430.00 km^2, 3.97% of the region) and most counties (34.33% of total counties), with high-frequency zones concentrated south and east of Liupan Mountains and west of Ziwu Mountains (Fig. 9d). Intensities were similar to the subtropical high edge pattern (Fig. 9d), with scattered >50 $mm \cdot h^{-1}$ areas.

Station occurrence distributions differed markedly among patterns (Fig. 10). The plateau trough type showed a dispersed distribution with 60–180 stations (median 110), representing the highest overall station count. The subtropical high edge southwestern flow pattern had the lowest median among the four types, with most events having fewer than 90 stations. The two-high shear pattern showed concentrated station occurrences with a median similar to the plateau trough type. The northwest flow pattern had the fewest stations, primarily 60–90, with a median only slightly higher than the subtropical high edge pattern.

Intensity distributions showed less variation (Fig. 10). Median intensities ranged 24–26 $mm \cdot h^{-1}$ across patterns. The plateau trough type had the most concentrated distribution at 30–40 $mm \cdot h^{-1}$, with rare occurrences above 70 $mm \cdot h^{-1}$. The subtropical high edge pattern showed the highest frequency of extreme precipitation above 50 $mm \cdot h^{-1}$. The two-high shear pattern featured more precipitation in the 30–50 $mm \cdot h^{-1}$ range and the highest quantiles for rainfall above 70 $mm \cdot h^{-1}$ among all types.

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3. Conclusions

(1) The intensity of regional short-term heavy rainfall in eastern Gansu mainly concentrates in the 20–30 mm · h^{-1} range. Although stations with precipitation exceeding 40 mm · h^{-1} are relatively few, the probability of occurrence at the event level is not low. Maximum hourly precipitation values correlate with the number of stations experiencing short-term heavy rainfall, with larger station counts generally corresponding to greater maximum hourly precipitation values.

(2) Regional short-term heavy rainfall mainly occurs from late June to late August, with peak frequency in late July to mid-August. However, few events exceed 50 stations, with such large-scale events primarily occurring in late July. This pattern likely relates to thermal and moisture conditions and cold air activity in eastern Gansu.

(3) Regional short-term heavy rainfall events occur annually, but with substantial interannual variability in frequency, closely related to the position and intensity of the Western Pacific subtropical high, significant baroclinic features from interactions between mid- and low-latitude weather systems, and anomalous warm-moist transport from the South or East China Sea.

(4) The affected area during these events is small, accounting for only 3.17% of the total area of eastern Gansu, with relatively dispersed distribution. Terrain significantly influences short-term heavy rainfall, with high-frequency zones concentrated near the Taizi Mountains, western extension of the Qinling Mountains, Liupan Mountains, and Ziwu Mountains. Areas with concentrated >40 mm · h^{-1} rainfall correspond well to high-frequency zones.

(5) Station occurrence distributions vary significantly among circulation patterns. The eastward-moving plateau trough type shows a dispersed distribution with the highest overall station count. The subtropical high edge southwestern flow pattern has the lowest median. The two-high shear pattern shows concentrated station occurrences, while the northwest flow pattern has the fewest stations. Intensity distribution differences are not pronounced, though precipitation of 30–50 mm · h^{-1} occurs more frequently in the two-high shear pattern.

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