Diurnal Variation Characteristics of Warm-Season Precipitation in Gansu Province (Postprint)

Authors: Zhou Zihan, Wang Jixin(1, 2), Liu Weicheng, Wang Yong(1, In recent years, machine learning has achieved remarkable success in many fields, especially in deep learning. This paper proposes a novel method that combines and to solve the problem. Experimental results demonstrate that our method outperforms existing methods on multiple benchmark datasets [?].

Specifically, our model utilizes the loss function defined in (??) and validates its effectiveness through experiments in Section ??. As shown in Figure ??, the network architecture comprises multiple layers.

The development of deep learning technology has provided new possibilities for this direction. We believe that future research will further explore this area., 4), Zhang Junxia, Guo Runxia

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Abstract

Using hourly precipitation observation data from 340 meteorological stations in Gansu Province from April to October during 2013–2022, this study reveals the refined diurnal evolution characteristics of warm-season precipitation in Gansu and conducts a regional discussion and analysis, providing a scientific reference for research on extreme precipitation events in the province. The results show that: (1) The diurnal peaks of precipitation amount and intensity in Gansu' s warm season mainly occur between 10:00–13:00, while the diurnal peak of precipitation frequency mostly appears at night between 22:00–01:00. Seasonal differences in diurnal precipitation variation are significant, with relatively concentrated autumn rainfall distribution in the central-southern regions. (2) The diurnal variation of precipitation exhibits distinct regional characteristics. In the Qilian Mountains, central Gansu, and plateau slope regions, precipitation occurs mainly during daytime, with stronger precipitation intensity at noon dominating the daytime peak of precipitation amount. In western Hexi, the diurnal peaks of precipitation amount and frequency mostly appear at night, but short-duration heavy precipitation shows certain abruptness between 18:00–

21:00. In southeastern and eastern Gansu, precipitation is non-uniformly distributed, with frequent nocturnal rain under the influence of the nighttime peak in precipitation frequency, but the periods of stronger precipitation occur in the afternoon and morning, respectively. (3) Precipitation characteristics vary with different durations. For short-duration precipitation lasting 6 h or less, the diurnal variation mostly exhibits a "bimodal pattern." For precipitation lasting more than 6 h, the diurnal variation is approximately "unimodal," typically beginning in the evening, peaking at night, and ending around noon the following day.

Full Text

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Diurnal Variation Characteristics of Warm Season Precipitation in Gansu Province

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Abstract

Based on hourly precipitation observation data from 340 meteorological stations in Gansu Province from April to October 2013 to 2022, this study reveals the refined evolution characteristics of warm season precipitation in Gansu Province at the diurnal scale and conducts regional discussions and analyses to provide scientific reference for the study of extreme precipitation events in Gansu. The results show that: (1) The daily peaks of precipitation amount and precipitation intensity in Gansu' s warm season mainly occur between 10:00 and 13:00, while the daily peak of precipitation frequency occurs at night between 22:00 and 01:00. The diurnal variation of precipitation exhibits obvious seasonal differences, with a relatively concentrated distribution of autumn rain in central and southern Gansu. (2) The diurnal variation of precipitation shows distinct regional characteristics. In the Qilian Mountains and the plateau slope region of central Gansu, precipitation occurs mainly during the day, with stronger precipitation intensity at noon dominating the daytime peak. In western Hexi, the daily peaks of precipitation amount and frequency generally occur at night, with occasional sudden heavy rainfall between 18:00 and 21:00. In southeastern and eastern Gansu, precipitation is non-uniformly distributed; nighttime rain is frequent due to the frequency of precipitation peaks during the night, but periods of stronger precipitation tend to occur in the afternoon and morning, respectively. (3) Precipitation characteristics vary with duration. For short-term precipitation events lasting 6 hours or less, the diurnal variation of precipitation mostly exhibits a "bimodal pattern." For long-term precipitation events lasting more than 6 hours, the diurnal variation is approximately "unimodal," typically beginning in the evening, peaking at night, and ending around noon.

Keywords: diurnal variation; warm season precipitation; different regions; different durations; Gansu Province

Introduction

The diurnal variation of precipitation plays a crucial role in the energy budget of the climate system. As an important indicator for studying the diurnal cycle, precipitation variation is driven by atmospheric dynamic and thermodynamic processes. Diurnal precipitation also exhibits strong feedback mechanisms with shortwave and longwave radiation, thereby contributing to the regulation of global energy budget and water cycle. Previous studies have investigated precipitation diurnal variation characteristics across different regions. In most inland areas of the United States, summer precipitation shows significant diurnal cycles, with pronounced nocturnal precipitation along the coasts of Lake Erie and Lake Ontario. In New Guinea, solar heating effects and sea breeze circulation result in a distinct afternoon peak in precipitation diurnal variation. Near the western coast of Sumatra, which receives the highest annual precipitation globally, precipitation peaks predominantly occur at night. In China, warm season precipitation over the mainland also exhibits clear seasonal and regional characteristics, with bimodal structures in precipitation amount and frequency.

In China' s Northwest Arid Region, the driest area at its latitude globally and particularly sensitive to climate change, precipitation variation has received considerable research attention. Early studies systematically analyzed precipitation climate change characteristics across Northwest Chinese provinces at annual and seasonal scales, revealing opposite phase patterns between eastern-western and northern-southern regions. Recent research has also examined precipitation diurnal variation characteristics in Northwest China. In Xinjiang, hourly precipitation frequency shows significant regional differences, with summer precipitation peaks in the Ili River Valley occurring mainly at night and dominated by short-duration events. In Shaanxi, warm season precipitation diurnal variation exhibits a clear north-south boundary along the 34°–37°N zonal belt. However, current research on precipitation diurnal variation in Northwest China has primarily focused on Xinjiang and the Qinling region, lacking systematic investigation of Gansu Province' s precipitation diurnal variation characteristics.

Gansu Province, located in the eastern-central part of Northwest China at the intersection of the Loess Plateau, Tibetan Plateau, and Inner Mongolia Plateau, features a narrow terrain, diverse landforms, variable climate, and weak disaster resilience. During the flood season, influenced by westerly trough-ridge systems and monsoon circulation, Gansu experiences frequent mountain floods and debris flows under the combined effects of heavy precipitation and complex topography, causing severe ecological impacts and economic losses. Therefore, this study utilizes hourly precipitation observation data from 340 meteorological stations across Gansu Province to conduct a detailed analysis of the diurnal peak phase distribution of various precipitation indices from both global and regional perspectives. Additionally, we systematically analyze the diurnal variation characteristics of single-station precipitation events that reflect precipitation evolution processes, aiming to fill the research gap on precipitation diurnal variation in the central-eastern Northwest China region, reveal the refined evolution characteristics of Gansu' s precipitation at the diurnal scale, and provide scientific reference for extreme precipitation event studies in Gansu.

1. Data and Methods

1.1 Data Sources

The precipitation data used in this study consist of hourly precipitation observations from 340 meteorological stations in Gansu Province, obtained from the China Meteorological Administration's "Tianqing"meteorological big data cloud platform (CMADaaS). The data have undergone quality control and are used to analyze the diurnal variation characteristics of precipitation in Gansu.

1.2 Research Methods

Based on the precipitation observation data, we calculated multi-year average precipitation amounts and daily precipitation intensities to analyze the basic distribution characteristics of precipitation in Gansu. We computed the diurnal peak time phases and corresponding amplitudes of multi-year hourly average precipitation, precipitation frequency, and precipitation intensity for analyzing precipitation diurnal variation features. We also statistically analyzed the diurnal peak time phases of precipitation amount and frequency for single-station precipitation events of different durations, as well as the total number of events that begin, peak, and end at any moment within 24 hours.

The study area was divided into six regions based on Gansu' s multi-year precipitation distribution characteristics and referencing geographic zoning standards from the China Meteorological Administration and Gansu Provincial Meteorological Geographic Zoning specifications: Western Hexi, Qilian Mountains, Central Gansu, Plateau Slope, Southeastern Humid Region (referred to as Longdongnan), and Eastern Semi-arid Region (referred to as Longdong). The specific distribution is shown in [Figure 1: see original paper].

Single-station precipitation events were classified into four categories based on duration: 1-3 h, 4-6 h, 7-12 h, and above 12 h, following the research of Yu Rucong et al. [9].

The relevant calculation formulas are as follows:

- Rs: Total precipitation during the observation period (mm)
- Dr: Total number of non-missing observation days during the observation period (d)
- Ds: Total number of precipitation days during the observation period (d)
- Hr: Number of hours with precipitation at a certain time (h)
- SRh: Total precipitation at a certain time (mm)
- Hs: Number of non-missing hours at a certain time (h)
- Ry: Multi-year average warm season precipitation (mm), reflecting the basic precipitation characteristics of a region
- Id: Daily precipitation intensity ($mm \cdot d^{-1}$), reflecting the average daily precipitation amount in a region
- Fh: Average hourly precipitation frequency, representing the number of precipitation occurrences per unit time
- Ih: Hourly precipitation intensity ($mm \cdot h^{-1}$), representing the precipitation amount per unit time during the study period
- PRh: Average hourly precipitation amount ($mm \cdot h^{-1}$), representing the average precipitation amount for all non-missing hours during the study period

The diurnal variation evolution of precipitation amount, precipitation frequency, and precipitation intensity is represented by the time series of hourly means divided by daily means. The diurnal variation amplitude is represented by the ratio of the hourly maximum to the mean. As an important characteristic of precipitation diurnal variation, amplitude indicates precipitation anomaly—larger amplitude means greater oscillation or fluctuation at that moment, suggesting more extreme precipitation.

2. Results

2.1 Basic Characteristics of Warm Season Precipitation in Gansu

The spatial distribution of average warm season precipitation in Gansu shows a gradual increase from west to east, with high-precipitation areas distributed in a southwest-northeast band in southern Gansu [Figure 2: see original paper]. Annual precipitation in the Hexi Corridor and central Gansu is mostly below 400 mm, with western Hexi receiving less than 100 mm annually. Southern Gansu receives more than 600 mm annually, with some local areas reaching 800-1200 mm. The major precipitation centers are located in Dongxiang, Linxia and Kangxian, Longnan, both exceeding 900 mm annually, with the Kangnan Forest Farm station in southeastern Longnan reaching 1217.7 mm.

The spatial distribution of average daily precipitation intensity is similar to that of annual precipitation. The Hexi region shows significantly lower daily precipitation intensity, with most stations below 1 $mm \cdot d^{-1}$ [Figure 2: see original paper].

2.2 Diurnal Variation Characteristics of Precipitation

2.2.1 Spatial Distribution of Precipitation Peak Time Phase To more clearly demonstrate the regional characteristics of precipitation peak time phase in Gansu, we divided peak times into six periods: 02:00–05:00, 06:00–09:00, 10:00–13:00, 14:00–17:00, 18:00–21:00, and 22:00–01:00. Figure 3 shows the spatial distribution of multi-year average precipitation amount, precipitation frequency, precipitation intensity peak time phases, and corresponding diurnal amplitude variations in Gansu during the warm season.

The daily peak of precipitation amount in Gansu' s warm season mostly occurs between 10:00 and 13:00, primarily distributed in western Hexi, central-western Qilian Mountains, plateau slopes, and southern parts of central Gansu. Most stations in these regions experience peak precipitation exceeding 1.4–1.6 times the average precipitation amount. In contrast, eastern western Hexi, eastern Qilian Mountains, and Longdong show precipitation peaks between 06:00–09:00 and 18:00–21:00. Most areas exhibit noon peaks in precipitation intensity, though western Hexi, western Qilian Mountains, northern central Gansu, and southern Longdongnan show afternoon-to-evening peaks. Notably, western Hexi shows precipitation intensity peaks between 18:00–21:00 exceeding 1.6 times the average state, indicating significant and localized precipitation characteristics during this period.

The spatial distribution of precipitation frequency peak time phase is most prominent between 22:00–01:00, with a significant increase in peak stations reaching 214, mainly distributed in western Hexi, northeastern Longdongnan, and western Longdong. Most stations show precipitation frequency 1.4–1.6 times higher than average, demonstrating clear nocturnal rain characteristics. In the Qilian Mountains and eastern Longdong, precipitation frequency peaks mainly occur between 10:00–13:00, while plateau slopes peak between 14:00–17:00.

The spatial evolution of seasonal changes in precipitation frequency peak time phase shows that both late spring-early summer and midsummer precipitation amount peaks occur mainly between 10:00–13:00, with 214 and 214 stations respectively. In autumn (September–October), precipitation amount and frequency peak time phases show obvious nocturnal increases, with 214 stations peaking at night. This seasonal difference is particularly evident in central and southern Gansu, where autumn rain is concentrated, corroborating previous research on Huaxi autumn rain [Figure 4: see original paper].

In summary, nocturnal precipitation is frequent in Gansu, but periods with strong precipitation intensity and large amounts occur mainly between 10:00–13:00. Precipitation diurnal variation also shows obvious seasonal differences, with concentrated autumn rain distribution in central and southern Gansu. The uneven distribution of peak time phases for precipitation amount, frequency, and intensity, along with the spatial distribution of amplitudes corresponding to peak times, indicates that precipitation diurnal variation characteristics in

Gansu are complex and show significant local differences.

2.2.2 Regional Characteristics of Precipitation Diurnal Variation Based on the diurnal evolution curves of warm season precipitation in different regions of Gansu (Figure 5) and their spatial distribution characteristics (Figure 3), we find distinct regional patterns [Figure 6: see original paper]. Table 1 summarizes the occurrence times of precipitation, precipitation frequency, and precipitation intensity peaks in the six different regions of Gansu, along with the corresponding station proportions and amplitudes.

In western Hexi, most stations show precipitation amount and frequency peaks around 00:00, while precipitation intensity peaks at 18:00–21:00. However, the proportion of stations with intensity peaks at 18:00-21:00 is only 0.30%, demonstrating the localized nature of diurnal variation amplitude in western Hexi. This suggests the need to monitor sudden short-duration heavy precipitation at individual stations in western Hexi during evening hours, as previous research also indicates increasing extreme hourly precipitation in this region.

The Qilian Mountains show approximately "unimodal" diurnal variation curves for precipitation amount, frequency, and intensity, with peaks appearing between 10:00–12:00. The proportion of stations with peaks at 12:00 reaches 32.40%, with most stations experiencing maximum precipitation intensity at 08:00. This indicates that precipitation in the Qilian Mountains concentrates in the morning, with less afternoon precipitation.

Central Gansu shows approximately "unimodal" diurnal variation curves for precipitation amount and intensity, with most stations peaking around 12:00. This suggests that the noon peak in precipitation amount mainly results from strong noon precipitation intensity. The nocturnal peak in precipitation frequency demonstrates nighttime rain characteristics in central Gansu, though precipitation amount and frequency in northern central Gansu show evening peaks between 18:00–21:00.

The plateau slope region shows consistent daytime peaks, with most stations having precipitation amount, frequency, and intensity peaks between 11:00–14:00. This indicates uniform precipitation characteristics in this region, with maximum precipitation amount and intensity occurring at noon.

In Longdongnan, the number of stations with nocturnal precipitation is significantly higher, with precipitation frequency peaking at 00:00 at 8.26% of stations. Most stations show stronger precipitation between 11:00–14:00, while the evening peak in precipitation amount is related to stronger afternoon precipitation. The concentration of precipitation at 14:00–17:00 and 02:00–05:00 represents the main periods of increased nocturnal precipitation amount.

In Longdong, most stations show precipitation amount and intensity peaks between 06:00–09:00, with precipitation frequency peaking at night at 00:00 at 4.42% of stations. However, precipitation amount and intensity at this time are not significant. Spatially, nighttime precipitation in Longdong is characterized by "wide coverage and gentle intensity," with short-term fluctuations in nocturnal precipitation amount mainly contributed by the nocturnal peak in precipitation frequency. Stronger precipitation occurs mainly during daytime and in eastern locations, more associated with increased precipitation intensity.

2.2.3 Diurnal Variation Characteristics of Different Duration Precipitation Events For short-duration precipitation events lasting 1–3 hours in Gansu, most stations show main peaks of precipitation amount and frequency between 06:00–09:00 and 14:00–17:00, exhibiting a "bimodal pattern" [Figure 7: see original paper]. For 4–6 hour events, western Hexi, central Gansu, and Longdong show main peaks between 18:00–21:00, while the Qilian Mountains and plateau slope show morning peaks, and Longdongnan shows scattered evening peaks. For long-duration events exceeding 6 hours, precipitation amount main peaks mostly occur between 02:00–05:00 at 31.18% of stations, though plateau slope and Qilian Mountains show afternoon peaks, and Longdong shows scattered evening peaks.

For precipitation events lasting 7–12 hours, main peaks of precipitation amount appear between 18:00–21:00 in Longdongnan at 40.59% of stations, while western Hexi, central Gansu, and Longdong show scattered daytime peaks. Precipitation frequency main peaks occur mainly between 02:00–05:00 at 37.11% of stations and 06:00–09:00 at 35.57% of stations. The Qilian Mountains mainly show evening peaks between 18:00–21:00.

For precipitation events exceeding 12 hours, main peaks of precipitation amount occur between 18:00–21:00 in Longdongnan, while plateau slope and Qilian Mountains show concentrated evening peaks, and western Hexi, central Gansu, and Longdong show scattered daytime peaks. Precipitation frequency main peaks are distributed between 02:00–05:00 and 06:00–09:00, with station proportions of 37.11% and 35.57% respectively. Central Longdong shows concentrated noon peaks between 10:00–13:00.

To further reveal the diurnal variation of precipitation evolution processes in Gansu, Figure 8 shows the diurnal evolution curves of frequency for beginning, peak, and end times of different duration precipitation events [Figure 8: see original paper]. For events lasting 1–3 hours, precipitation shows a "bimodal pattern" with two major amount periods at 06:00–09:00 and 14:00–17:00. For 4–6 hour events, precipitation mostly begins around 19:00, peaks at 21:00, and ends at 09:00, reaching maximum amount at 06:00 with less precipitation at noon and 02:00–05:00. For events lasting 7–12 hours, more stations show precipitation beginning at night between 18:00–05:00, peaking at night, with Longdongnan peaks occurring 4–5 hours earlier than Longdong. Plateau slope events lasting over 12 hours mostly end before noon, though plateau slope 7–12 hour events show concentrated evening peaks between 18:00–21:00.

In summary, precipitation events of different durations in Gansu can be characterized as follows: short-duration precipitation concentrates in daytime across most regions, with two major amount periods at 06:00–09:00 and 14:00–17:00. Long-duration precipitation is approximately "unimodal," mostly beginning in the evening, peaking at night, and ending at noon. The plateau slope region, influenced by the eastward movement of plateau short-wave troughs at night, shows evening-to-nocturnal precipitation characteristics across different duration events.

3. Discussion

The diurnal variation of precipitation accurately reflects a region' s response to climate change. This study utilizes dense meteorological station observations to complete a statistical analysis of the spatiotemporal distribution characteristics of warm season precipitation diurnal variation in Gansu, summarizing its refined evolution features and visually presenting seasonal and regional differences. These findings provide scientific reference for meteorological forecasters to conduct refined forecasting services and offer guidance for the localized interpretation of numerical model products and the development of objective hourly precipitation forecasting methods.

Although this study reveals regional differences in Gansu' s precipitation, it does not deeply investigate the influence of complex topographic forcing on precipitation diurnal variation. Additionally, seasonal differences in precipitation diurnal variation are directly related to atmospheric circulation, particularly for long-duration precipitation events. Therefore, future work will utilize longer time series from national basic station observations and denser regional station data, combined with high-resolution reanalysis data, to conduct more detailed studies on precipitation diurnal variation in different topographic regions. We will also analyze the diurnal variation characteristics of meteorological factors related to precipitation, such as wind fields and temperature, and explore the triggering mechanisms of atmospheric circulation on precipitation diurnal variation characteristics and the influence mechanisms on precipitation duration from dynamic and thermodynamic perspectives.

4. Conclusions

Based on hourly precipitation observation data from 340 meteorological stations in Gansu Province from 2013 to 2022, this study analyzed the diurnal peak phase distribution of precipitation amount, frequency, and intensity during the warm season, as well as the diurnal variation characteristics of precipitation in different regions and with different durations. The main conclusions are:

1) Annual average precipitation in Gansu gradually increases from west to east, with high-precipitation areas distributed in a southwest-northeast band in the southeast. Two high-value precipitation centers exist in Dongxiang, Linxia and Kangxian, Longnan.

2) During the warm season in Gansu, daily peaks of precipitation amount and intensity mainly occur between 10:00–13:00, while precipitation frequency peaks at night between 22:00–01:00. The diurnal variation shows obvious seasonal differences, with concentrated autumn rain distribution in central and southern Gansu. The uneven distribution of peak time phases and the localized distribution of amplitudes corresponding to peak times indicate that precipitation diurnal variation characteristics in Gansu are complex and variable.

3) Regional characteristics of precipitation diurnal variation are distinct in Gansu. In the Qilian Mountains and plateau slope regions, precipitation periods and amounts are concentrated, with short duration and distributed mainly at 12:00–14:00. In western Hexi, precipitation amount and frequency peaks occur consistently at night, though the evening peak in precipitation intensity reveals extreme characteristics at individual stations. In central Gansu, larger precipitation amounts concentrate at noon, showing nighttime rain features but with small amounts. In Longdongnan and Longdong, precipitation is non-uniformly distributed; although nighttime rain is frequent, larger precipitation amounts occur in the afternoon and morning, respectively.

4) For short-term precipitation events lasting 6 hours or less, the diurnal variation mostly shows a "bimodal pattern," with short-duration precipitation concentrating in daytime at 06:00–09:00 and 14:00–17:00. Long-duration precipitation events lasting more than 6 hours are approximately "unimodal," mostly beginning in the evening, peaking at night, and ending at noon. The plateau slope region, influenced by the eastward movement of plateau short-wave troughs at night, shows evening-to-nocturnal precipitation characteristics across different duration events.

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