Diurnal Variation Characteristics of Warm-Season Precipitation in Shaanxi and North-South Differences (Postprint)

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Abstract

Using the hourly precipitation fusion product from CMORPH satellite and automatic weather stations during 2008–2015, this study analyzes the diurnal variation characteristics of precipitation amount, frequency, and intensity in Shaanxi region from May to October, as well as the differences in diurnal precipitation variation between northern and southern Shaanxi. The results indicate: (1) Precipitation amount and frequency decrease significantly from south to north, with zonal variation under topographic influence being the most prominent feature of precipitation in Shaanxi. However, precipitation intensity exhibits a distribution pattern of high values in both north and south with low values in the middle, with two high-value centers located in southern Shaanxi and northeastern Shaanbei, respectively. EOF analysis reveals pronounced nocturnal rainfall characteristics in southern Shaanxi. (2) In southern Shaanxi, the diurnal variations of precipitation amount, frequency, and intensity are consistent, all showing high values from nighttime to early morning and reaching minima around noon. In northern Shaanxi, precipitation amount and frequency peak mainly in the morning, while precipitation intensity peaks in the evening. Regional comparative analysis demonstrates that the diurnal variation of precipitation amount in southern Shaanxi primarily originates from precipitation intensity contributions, whereas in northern Shaanxi, it is dominated by precipitation frequency contributions. (3) The north-south dividing line characteristic of precipitation in Shaanxi is distinct: areas south of 34°N exhibit significant diurnal variation with precipitation concentrated mainly at night; the central region between 34°N and 37°N shows weak diurnal variation; and areas north of 37°N display diurnal variation patterns opposite to those of southern Shaanxi. (4) Except for Yulin, Weinan, and eastern Shangluo, daytime precipitation is significantly lower than nighttime precipitation in most other regions, particularly in the Qinba mountainous area of southern Shaanxi where nighttime precipitation is more than double the daytime precipitation.

Full Text

Diurnal Variation Characteristics and North-South Differences of Precipitation in Warm Season in Shaanxi Province

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Abstract

Using hourly precipitation fusion products from CMORPH satellite data and automatic weather stations, this study analyzes the diurnal variation characteristics of precipitation amount, frequency, and intensity in Shaanxi Province, as well as the differences between southern and northern regions. The results indicate that: (1) Both precipitation amount and frequency decrease significantly from south to north, with zonal variation under topographic influence being the most important feature of precipitation in Shaanxi. However, precipitation intensity shows a distribution pattern of high values in both the south and north with lower values in the middle, with two high-value centers located in southern Shaanxi and northeastern Shaanxi respectively. (2) Southern Shaanxi exhibits pronounced nighttime rainfall characteristics. The diurnal variations of precipitation amount, frequency, and intensity are consistent, all showing high values from night to early morning and reaching minimum values around noon. In northern Shaanxi, peaks in precipitation amount and frequency occur mainly in the morning, while precipitation intensity peaks in the evening. Regional comparative analysis shows that diurnal variation of precipitation amount in southern Shaanxi primarily comes from contributions of precipitation intensity, whereas in northern Shaanxi it is mainly contributed by precipitation frequency. (3) The north-south boundary of precipitation in Shaanxi is particularly distinct. South of 34°N, precipitation shows obvious diurnal variation and is concentrated mainly at night. The central region between 34°N and 37°N shows weak diurnal variation. North of 37°N, the diurnal variation characteristics are opposite to those in southern Shaanxi. (4) Except for Yulin, Weinan, and eastern Shangluo, daytime precipitation in most other areas is significantly lower than nighttime precipitation, especially in the Qinba mountainous area of southern Shaanxi where nighttime precipitation exceeds daytime amounts by more than double.

Keywords: Shaanxi; warm season precipitation; diurnal variation; north-south differences

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1. Data and Methods

This study employs the hourly precipitation fusion product (CMORPH) released by the China Meteorological Administration, which combines satellite and radar

data. The data period spans from 2008 to 2015, with a spatial resolution of 0.05°$×$0.05°. The high temporal and spatial resolution of this dataset provides more detailed information for analyzing precipitation diurnal variations. The analysis focuses on the warm season months from May to October, using Beijing time.

In recent years, China has established a dense meteorological observation network, transitioning from approximately 2,400 county-level stations to over 40,000 automatic weather stations, combined with weather radar observations and satellite retrievals. Studies by Pan Yang et al. and Shen Yan et al. have shown that the CMORPH satellite-station fusion data has a mean bias of -0.035 mm, correlation coefficient of 0.77, and root mean square error of 4.404 mm compared with independent observations, demonstrating its ability to accurately represent actual precipitation distributions. This new high-resolution, reliable dataset provides strong support for studying refined precipitation diurnal variation characteristics.

Shaanxi Province is located in mid-latitude regions, with the Qinling Mountains traversing its central-southern part. The unique geographical location and climatic characteristics of the Qinling Mountains make them the boundary between subtropical and warm temperate zones, as well as between humid and semi-humid climates, representing an important geographical dividing line in China. The region features diverse landforms including plateaus, basins, and hills, making it one of the world' s most complex topographic areas. This unique geography and climate create substantial differences in precipitation patterns between southern and northern Shaanxi, with annual average precipitation exceeding 1,000 mm in the south while the Great Wall 沿线 region in the north receives only about 300 mm. Analyzing the warm season precipitation characteristics in southern and northern Shaanxi not only helps understand precipitation differences under complex terrain conditions and provides references for numerical model parameterization adjustments, but also offers important operational support for meteorological disaster prevention and mitigation by deepening understanding of precipitation evolution characteristics and triggering mechanisms.

When examining the diurnal variation and north-south differences of precipitation in Shaanxi, we first analyzed the overall characteristics of precipitation diurnal variation in different regions during the warm season (figure omitted). The results show that southern Shaanxi exhibits consistent nighttime-to-early-morning precipitation peaks, while the diurnal evolution in Guanzhong and northern Shaanxi shows different characteristics. Considering the significant differences in precipitation diurnal variation between southern Shaanxi and the Guanzhong-northern Shaanxi regions, this study uses the Qinling Mountains as the boundary to divide Shaanxi into southern and northern parts for detailed analysis. Figure 1 shows the specific division and the locations of automatic observation stations and the Qinling Mountains.

When investigating the diurnal variation characteristics and north-south differ-

ences of precipitation in Shaanxi, we adopted previously established precipitation statistical methods (Yu Rucong et al.; Tang Yuhong et al.). The specific definitions are as follows:

- **Precipitation amount:** Accumulated precipitation greater than or equal to 0.1 $mm \cdot h^{-1}$
- **Precipitation frequency:** Total number of precipitation events during the statistical period
- **Precipitation intensity:** Calculated as accumulated precipitation divided by precipitation hours for different time periods

2. Overall Distribution Characteristics of Warm Season Precipitation in Shaanxi

Figure 2 presents the spatial distribution of average accumulated precipitation amount, frequency, and intensity in Shaanxi from 2008 to 2015. From the perspective of multi-year precipitation climatology, warm season total precipitation in Shaanxi shows a clear decreasing pattern from south to north, with the highest values in the south exceeding 1,000 mm. The distribution of precipitation frequency also shows a south-to-north decreasing trend, but with high-value centers located not only in southern Shaanxi but also around the Qinling Mountains in Zhouzhi, Huxian, Foping, and Ningshan areas, where the multi-year average warm season precipitation frequency exceeds 600 hours. Precipitation intensity distribution shows two high-value centers in southern Shaanxi and northeastern Shaanxi, both with intensity greater than 1 $mm \cdot h^{-1}$, presenting a pattern of high values on both sides and low values in the middle. The low-value center is located in Dingbian and Jingbian in western Shaanxi, with intensity below 0.8 $mm \cdot h^{-1}$. These spatial distribution characteristics of multi-year average warm season precipitation amount, frequency, and intensity further validate previous conclusions.

Figure 3 shows the monthly variations of precipitation amount, frequency, and intensity. From the monthly curves, the order of monthly accumulated precipitation amount in southern Shaanxi from high to low is July > August > June > September > May > October. Precipitation frequency follows the order of July > August > September > June > May > October. Precipitation intensity is also highest in July, reaching 1.5 $mm \cdot h^{-1}$. In northern Shaanxi, the order of monthly precipitation amount from high to low is July > August > June > September > May, with precipitation frequency following July > August > September > June > May, and precipitation intensity peaking in July at 1.1 $mm \cdot h^{-1}$. Overall, July is the month with the highest precipitation amount and intensity in Shaanxi, as well as the month with the most precipitation days, primarily due to increased convective weather activity.

3. Basic Characteristics of Diurnal Variation of Warm Season Precipitation in Shaanxi

3.1 Two Modes of Diurnal Variation Empirical Orthogonal Function (EOF) analysis of hourly precipitation variations from May to October in Shaanxi reveals the main spatial modes and their temporal variation characteristics. The first two leading modes explain 69.6% and 11.3% of the variance respectively, with a total explained variance exceeding 80%, making them representative. According to the North criterion, these two modes can be distinguished from other modes and are separable from each other.

Figure 4 shows the spatial distribution of the first two EOF modes of hourly precipitation amount and their corresponding normalized time series. The first mode shows negative anomalies in Hanzhong, Ankang, and Baoji, and positive anomalies in Yulin, Yan' an, and Weinan, with the large negative value center in Ningqiang, Nanzheng, and Zhenba in southwestern Shaanxi, decreasing northward. This spatial pattern is very similar to the annual average accumulated precipitation distribution but with opposite phase. The phase opposition is mainly related to the time coefficients of this mode, indicating that 14:00-20:00 Beijing time is the low precipitation period, while 02:00-08:00 is the high-value period with peak precipitation at 05:00. This reveals that the main characteristic of hourly precipitation variation in Shaanxi is consistent nighttime-to-early-morning peaks across the region.

The second mode explains relatively less variance, showing consistent negative anomalies across most of Shaanxi with three centers: one in southern Hanzhong and Ankang, another in Baoji and southern Xi' an at the northern foothills of the Qinling Mountains, and one in central Yan' an. The corresponding time coefficients also show significant variations, with negative phases indicating above-normal precipitation across most of the province, particularly pronounced in southern Shaanxi, and positive phases indicating below-normal precipitation.

3.2 North-South Characteristics The diurnal variation of precipitation reflects the comprehensive influence of atmospheric thermodynamic and dynamic processes on the water cycle, while local-scale circulation also plays an important role in weather and climate. Due to the special topography of the Qinling Mountains, precipitation in southern and northern Shaanxi shows distinctly different diurnal variation characteristics. To better understand these differences, Figure 5 presents the monthly hourly variation curves of regionally averaged precipitation amount, frequency, and intensity in southern and northern Shaanxi. The curves show consistent variations among precipitation amount, frequency, and intensity, with significant differences between southern and northern regions and clear peak-valley zones.

Overall, precipitation amount, frequency, and intensity in southern Shaanxi all peak at night, showing consistent evening-to-early-morning precipitation maxima and morning-to-noon minima, presenting a single-peak pattern. In con-

trast, northern Shaanxi shows different characteristics. The diurnal variations of precipitation amount and frequency are relatively consistent, with peaks at 08:00-14:00 and less precipitation at other times. Precipitation intensity, however, shows high values from 14:00 to 20:00, peaking at 17:00. The variation of precipitation amount in southern Shaanxi is directly related to precipitation intensity, while in northern Shaanxi it is highly correlated with precipitation frequency.

From the monthly perspective, the hourly distribution of precipitation amount in southern Shaanxi shows high values concentrated at 02:00-08:00, with low values at 14:00-17:00. Precipitation frequency distribution shows greater monthly variation: May, June, and October exhibit a single-peak pattern with maximum at night and low values in the afternoon; July, August, and September show a double-peak pattern with another high-value zone appearing in the morning, most pronounced in August, before returning to single-peak pattern after September. Precipitation intensity in all months shows high values at night to early morning and low values during daytime, with minimum intensity at 14:00-17:00 in July and in the morning in September.

In northern Shaanxi, monthly precipitation amount shows significant hourly distribution differences, with high-value periods mainly concentrated at 08:00-14:00, particularly in July and August. Precipitation frequency changes correspond basically with precipitation amount changes, with precipitation events occurring mostly between 08:00 and 14:00, especially at 11:00-14:00, while 17:00-20:00 represents periods with less precipitation. Precipitation intensity differs from amount and frequency, with high-value periods at 14:00-20:00, peaking at 17:00. Notably, afternoon short-duration heavy precipitation in northern Shaanxi, though infrequent, shows high intensity, mainly due to strong surface radiative heating and upward motion in the afternoon forming a positive feedback mechanism with the westerly flow over the plateau, creating vertical circulation that leads to concentrated, high-intensity short-duration precipitation events.

Figure 6 shows the time-latitude distribution of average precipitation amount, frequency, and intensity, revealing a consistent decreasing pattern from south to north. South of 34°N in southern Shaanxi, the hourly variations of precipitation amount, frequency, and intensity are obvious and consistent, with high values mainly at night and less precipitation after 17:00. Precipitation centers are concentrated in the Qinba mountainous area between 32°N and 34°N. In northern Shaanxi, precipitation variation at each hour is smaller, with low-value areas mainly located between 37.5°N and 38.5°N.

3.3 Day-Night Differences Figure 7 presents the spatial distribution of daytime (08:00-20:00) and nighttime (20:00-08:00) average precipitation amount, frequency, intensity, and their ratios. Although the spatial patterns of daytime and nighttime precipitation are similar, regional day-night differences are significant, with varying magnitudes across different regions. Except for parts of

Yulin, Weinan, and Shangluo, most areas of Shaanxi show significantly lower daytime precipitation than nighttime precipitation, with ratios less than 1 (indicating less daytime precipitation). Particularly in Ankang and Hanzhong in southern Shaanxi, daytime precipitation is only 0.4-0.6 times nighttime precipitation, with nighttime average precipitation reaching 750 mm and daytime only 450 mm, showing pronounced night rain characteristics. In contrast, parts of Yulin in northern Shaanxi and Weinan and Shangluo in eastern Shaanxi show ratios greater than 1 (more daytime precipitation), with the maximum ratio in central-western Yulin reaching 1.3 times.

The distribution of precipitation frequency is similar to precipitation amount but with smaller day-night differences. The ratio of precipitation intensity shows high-value centers in southern Shaanxi with values greater than 1.5, significantly higher than daytime intensity. This indicates that nighttime precipitation in southern Shaanxi is characterized by more frequent events with greater intensity.

4. Conclusions

Using CMORPH satellite and automatic station hourly precipitation fusion products, this study analyzed the diurnal variation characteristics of precipitation amount, frequency, and intensity in Shaanxi during the warm season, and compared the differences between southern and northern Shaanxi. The main conclusions are:

(1) The spatial distribution of average total precipitation and frequency from May to October in Shaanxi shows a decreasing pattern from south to north, with the highest values in southern Shaanxi. Precipitation intensity shows two high-value centers in southern Shaanxi and northeastern Shaanxi, presenting a north-south high, middle-low distribution pattern. July is the month with the highest precipitation amount and intensity, as well as the month with the most precipitation days.

(2) EOF analysis reflects the main characteristics of hourly precipitation variation in Shaanxi, with the first two modes explaining 80.9% of the total variance. The first mode shows negative phases with above-normal precipitation in southwestern Shaanxi, demonstrating clear night rain characteristics. The second mode shows positive phases with below-normal precipitation in southwestern Shaanxi but concentrated precipitation in eastern Guanzhong and northern Shaanxi.

(3) The monthly variation curves of precipitation amount, frequency, and intensity show consistent patterns, with significant differences between southern and northern regions and clear peak-valley zones. Overall, precipitation amount, frequency, and intensity in southern Shaanxi peak at night, showing consistent evening-to-early-morning maxima and morning-to-noon minima with a single-peak pattern. In northern Shaanxi, precipitation amount and frequency peak at 08:00-14:00, while precipitation intensity peaks at 14:00-20:00 with maximum at 17:00. Precipitation vari-

ation in southern Shaanxi is directly related to intensity, while in northern Shaanxi it is highly correlated with frequency.

(4) The time-latitude distribution of hourly precipitation shows a consistent decreasing pattern from south to north. South of 34°N, the hourly variations of precipitation amount, frequency, and intensity are obvious and consistent, with high values mainly at night and precipitation centers concentrated in the Qinba mountainous area between 32°N and 34°N. In northern Shaanxi, precipitation variation is smaller, with low-value areas mainly located between 37.5°N and 38.5°N.

(5) Although the spatial patterns of daytime and nighttime precipitation are similar, the magnitude of day-night differences varies across regions. Except for parts of Yulin, Weinan, and Shangluo, most areas of Shaanxi show significantly lower daytime precipitation, frequency, and intensity than nighttime values, with ratios less than 1. Particularly in Ankang and Hanzhong in southern Shaanxi, daytime precipitation is only 0.4-0.6 times nighttime precipitation, showing pronounced night rain characteristics.

This study provides a preliminary analysis and comparison of precipitation diurnal variation characteristics in Shaanxi and between its southern and northern regions, offering reference value for refined precipitation forecasting in the region. However, due to the complex mechanisms of precipitation formation in Shaanxi and limitations in data length, more detailed research and mechanism exploration warrant further investigation.

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