Diurnal Variation Characteristics of Summer Precipitation in the Tianshan Mountains of Xinjiang and Its Relationship with Altitude: Postprint

Authors: Guo Yulin, Zhao Yong

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Abstract

The Tianshan Mountains region represents the most precipitation-abundant area within the arid region of Xinjiang. Existing research on precipitation in this area has predominantly employed daily or coarser-scale data, with relatively limited analysis of diurnal variation characteristics. Based on hourly precipitation data from 11 national meteorological stations in the Tianshan Mountains region during summer (June–August) from 2012 to 2018, this study analyzes the diurnal variation characteristics of precipitation variables (including precipitation amount, precipitation frequency, and precipitation intensity) and reveals the relationship between precipitation and altitude. The results indicate that peaks in total precipitation amount and total precipitation frequency occur during 20:00–22:00, while troughs appear during 12:00–13:00. Nocturnal precipitation exceeds daytime precipitation, primarily contributed by long-duration precipitation events. Total precipitation intensity exhibits a pattern of overall enhancement during daytime and relative weakening at night. Precipitation is closely associated with altitude, with light-rain-grade precipitation occurring frequently in high-altitude mountainous areas, and a maximum precipitation belt exists at approximately 2000 m altitude.

Full Text

Diurnal Variation Characteristics of Summer Precipitation and Its Relationship with Altitude in the Tianshan Mountains of Xinjiang

Guo Yulin[1,2], Zhao Yong[2], , Zhou Yaman[2,3], Huang Qiuxia[4], Yu Zhenyi[2,5], Gu Zhangjie[1]

[1] Altay Prefecture Meteorological Bureau, Altay 836500, Xinjiang, China
[2] School of Atmospheric Sciences, Chengdu University of Information Technology, Chengdu 610225, Sichuan, China
[3] Xinjiang Meteorological Observatory, Ürümqi 830002, Xinjiang, China
[4] Changji Meteorological Bureau, Changji 831100, Xinjiang, China
[5] Lushan Meteorological Bureau, Jiujiang 332900, Jiangxi, China

Abstract: The Tianshan Mountains represent the most precipitation-rich region within Xinjiang' s arid zone. Previous studies of precipitation in this area have primarily utilized daily or longer timescale data, with relatively limited analysis of diurnal variation characteristics. Based on hourly precipitation data from 11 national meteorological stations in the Tianshan Mountains during summer months (June–August), this study analyzes the diurnal variation characteristics of precipitation metrics (including precipitation amount, frequency, and intensity) and reveals the relationship between precipitation and altitude. Results show that peak values of total precipitation amount and frequency occur between 20:00–22:00 Beijing Time, with minimum values appearing between 12:00–13:00. Nighttime precipitation exceeds daytime precipitation, primarily contributed by long-duration events. Total precipitation intensity exhibits an overall enhancement during daytime and weakening at night. Precipitation is closely related to altitude, with light rain grade events occurring frequently in high-altitude mountainous areas, and a maximum precipitation belt existing at approximately 2000 m elevation.

Keywords: precipitation amount; precipitation frequency; precipitation intensity; diurnal variation; altitude

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Introduction

Precipitation diurnal variation represents one of the most significant signals in global weather and climate systems, exhibiting pronounced regional differences. Analysis of precipitation diurnal variation in specific regions more accurately reflects local weather and climate evolution patterns, making it a focal research topic among meteorologists. Early studies date back to the 1940s when Lü Jiong first documented the "Bashan Night Rain" phenomenon in China. Since the 21st century, Yu Rucong has noted that China' s complex topography and land-sea distribution provide favorable conditions for investigating precipitation diurnal variation characteristics. Chen Jiong and colleagues demonstrated that mesoscale convective systems and short-duration heavy rainfall across different regions of China exhibit distinct propagation characteristics and active periods, which cannot be easily separated from large-scale atmospheric circulation patterns and geographic distributions such as terrain and land-sea configuration. Lü Xiang et al. examined summer precipitation diurnal variation over the Indo-China Peninsula using TRMM data, finding that diurnal variation amplitude and phase over land are jointly influenced by topography, mountain ranges, and solar radiation. Li Deshuai identified that precipitation diurnal variation in eastern South China is primarily driven by sea-land circulation, while western South China is mainly affected by mountain-valley circulation. He et al. proposed that large-scale circulation and the Tibetan Plateau's topography, through their combined effects, lead to nocturnal precipitation peaks in the Yangtze River Basin. Yuan et al. revealed the close relationship between regional precipitation diurnal variation and topography, finding that convective systems over the central Tibetan Plateau intensify around evening before propagating eastward, reaching the Sichuan Basin precisely after midnight—this being the famous basin "night rain" phenomenon.

Xinjiang, located in northwestern China, is an extremely typical arid and semi-arid region with unique climatic characteristics of precipitation diurnal variation across different areas. Chen Chunyan et al. revealed that under a warm-wet background, June–August precipitation in northern and southern Xinjiang does not consistently show a pattern of less in the east and more in the west, likely related to local climate characteristics shaped by Xinjiang' s complex topography. Yang Xia et al. compared regional differences between winter snowfall and summer rainfall in Ürümqi, showing that urban areas experience more intense winter snowfall while mountainous areas are more prone to intense summer rainfall. Yang Xia et al. also identified significant seasonal differences in the high-frequency regions of cumulative precipitation in the Ili River Valley, with summer maxima primarily in mountainous areas and winter maxima in plains. Zheng Bohua et al. found that precipitation in Kashgar occurs mainly in the latter half of the year and in the morning, mostly as short-duration events. Zhao Zhancheng et al. discovered that rainfall at stations along the eastern edge of the Taklimakan Desert is dominated by light rain frequency, with heavy rain showing the lowest frequency.

Most previous studies have identified topography as an important factor causing precipitation diurnal variation. Current research on precipitation diurnal variation in Xinjiang predominantly uses longer timescale data such as daily precipitation. In contrast, hourly-scale data offer higher temporal resolution and can more accurately capture temporal variation characteristics and development patterns of precipitation events. The Tianshan Mountains represent the most precipitation-rich region in Xinjiang's arid zone, yet existing studies of this area have primarily utilized daily or longer timescale precipitation data, with diurnal variation characteristics receiving relatively little attention. Therefore, this study employs hourly precipitation data from 11 national meteorological stations in the Tianshan Mountains during summer months to analyze diurnal variation characteristics of summer precipitation and reveal its relationship with altitude.

1.1 Study Area

The study area is located in the Tianshan Mountains within Xinjiang, China, between 81°08 -94°42 E and 42°46 -43°53 N. The Tianshan range stretches across the interior of Asia in a latitudinal direction and represents the largest mountain system in central Asia. The portion within China is customarily called the Eastern Tianshan, while that in central Asia is called the Western Tianshan. The Eastern Tianshan traverses the entire Xinjiang region, serving as the climatic watershed between northern and southern Xinjiang. It extends approximately 1700 km east-west, accounting for two-thirds of the total Tianshan length, with a north-south width of 250–350 km and an average ridge height of about 4000 m. Precipitation in the Tianshan Mountains is influenced by both topography and westerly circulation, characterized by a pattern of "more in the west and north, less in the east and south."

1.2 Data Sources

This study utilizes hourly precipitation data from 11 national meteorological stations in the Tianshan Mountains provided by the National Meteorological Information Center for the period 2012-2018. During the study period, stations at Balikun, Tianchi, Ürümqi Pastoral Experimental Station, Xiaoquzi, Baluntai, Bayinbuluke, Nileke, Tekes, Yiwu, and Zhaosu had no missing data. Only the Tianshan Daxigou station had missing data accounting for less than 0.001%. The data integrity is good, and strict quality control was applied before use, with abnormal and missing data removed. Among the 11 stations (Fig. 1, Table 1), five stations (Nileke, Tekes, Balikun, Yiwu, and Baluntai) are located below 1800 m in low-altitude basin or valley areas, while six stations (Zhaosu, Xiaoquzi, Ürümqi Pastoral Experimental Station, Tianchi, Bayinbuluke, and Tianshan Daxigou) are above 1800 m in high-altitude mountainous areas. The lowest altitude is 1105.3 m at Nileke, and the highest is 3539.0 m at Tianshan Daxigou.

1.3 Methods

A precipitation hour is recorded when hourly precipitation $ 0.1*mm.Thedurationofaprecipitationeventisdefin* *duration*(1–3*h*)*orlong* − *duration*($4 h). Precipitation intensity is defined as precipitation amount per unit time. According to the rainfall intensity classification standard for Xinjiang, events are categorized as: micro rain (0.1 mm $\leq$ R $<$ 1.0 mm), light rain (1.0 mm $\leq$ R $\leq$ 3.0 mm), and moderate rain or above (R $>$ 3.0 mm). Following Cui Caixia et al., daytime is defined as 09:00-20:00 Beijing Time and nighttime as 21:00-08:00 for analyzing diurnal variation characteristics. This study examines diurnal variations of precipitation amount, frequency, and intensity (ratio of precipitation amount to frequency) during summer (June-August) in the Tianshan Mountains, and investigates how altitude affects precipitation characteristics.

2 Results

2.1 Diurnal Variation Characteristics of Precipitation

2.1.1 Basic Diurnal Characteristics of Total Precipitation Based on the diurnal variation curves of annual average summer hourly cumulative total precipitation characteristics in the Tianshan Mountains (Fig. 2), comparison between precipitation frequency and intensity curves shows that the diurnal variation of precipitation frequency closely resembles that of precipitation amount, indicating that precipitation frequency contributes more to the diurnal variation of precipitation amount than intensity does—a pattern consistent with precipitation diurnal variation characteristics in southwestern China. Both annual average summer hourly cumulative total precipitation amount and frequency exhibit nighttime values greater than daytime, with peaks occurring between 20:00–22:00 and valleys between 12:00–13:00. Annual average summer hourly cumulative total precipitation intensity shows an overall increasing trend during daytime and the opposite at night, with high-value periods roughly between 16:00–03:00 and low-value periods approximately between 04:00–15:00.

2.1.2 Diurnal Characteristics of Precipitation Events with Different Durations The diurnal variation of precipitation is closely related to precipitation persistence. Fig. 3 shows diurnal variation curves of annual average summer hourly cumulative precipitation characteristics for three different duration categories. The influence of precipitation duration on precipitation characteristics is evident. Compared with the diurnal variation of total precipitation characteristics (Fig. 2), not all duration categories show nighttime values greater than daytime. The nighttime-dominant pattern of total precipitation amount is jointly produced by long-duration precipitation ($ $4 h) and medium-duration precipitation (4–6 h), while the nighttime-dominant pattern of total precipitation frequency is dominated by long-duration precipitation frequency. The peak and valley of medium-duration (4–6 h) precipitation amount determine the peak and valley of total precipitation amount, and the peaks and valleys of precipitation frequency across all three duration categories collectively influence those of total precipitation frequency. As shown in Fig. 3, long-duration precipitation intensity exhibits the most significant diurnal variation, with high-value zones roughly between 03:00–13:00 and low-value zones between 16:00–17:00. The diurnal variation of long-duration precipitation intensity is opposite to that of total precipitation intensity, showing gradual nighttime enhancement and daytime weakening. Short-duration (1–3 h) precipitation intensity shows relatively small fluctuations.

2.1.3 Diurnal Characteristics of Different Precipitation Grade Events The influence of precipitation grade on diurnal variation distribution cannot be ignored. Fig. 4 presents diurnal variation curves of annual average summer hourly cumulative precipitation amount and frequency for three precipitation grades. The diurnal variation patterns of amount and frequency are relatively consistent across grades. Compared with total precipitation (Fig. 2), micro rain, light rain, and moderate rain or above all contribute to the diurnal variation of total precipitation amount and frequency. The peak and valley periods of precipitation frequency for all three grades are broadly distributed between 16:00–03:00, with the highest values around 16:00 and the lowest around 04:00–15:00.

2.2 Relationship Between Precipitation and Altitude

2.2.1 Relationship Between Maximum Hourly Cumulative Precipitation and Altitude Xinjiang precipitation is closely related to topography. Zhao Yong et al. found that summer heavy precipitation characteristics in northern Xinjiang increase with terrain height, while winter precipitation shows less clear topographic influence. How do summer precipitation characteristics in the Tianshan Mountains relate to altitude? Fig. 5 shows that maximum values of annual average summer hourly cumulative precipitation amount and frequency exhibit similar oscillating patterns with increasing altitude, with peaks in high-altitude areas and valleys in low-altitude areas. High-altitude regions show greater maximum precipitation amount and frequency than low-altitude regions, indicating that high-altitude areas are more prone to extreme precipitation amounts and frequencies. Maximum precipitation intensity shows a decreasing trend with altitude in low-altitude areas, while high-altitude areas exhibit oscillating changes with peaks and valleys both appearing in high-altitude zones. Neither maximum precipitation amount nor intensity increases continuously with altitude; both peak at 1942.5 m (Tianchi station) and 3539.0 m (Tianshan Daxigou station), consistent with previous findings. Precipitation amount decreases with altitude above 2000 m but increases again around 3600 m, likely related to dynamic effects of Tianshan topography.

2.2.2 Relationship Between Different Duration Events and Altitude Among the three duration categories (Fig. 6), annual average summer hourly cumulative precipitation amount and intensity are dominated by long-duration events ($ $4 h). Precipitation amount and frequency for all three durations do not increase continuously with altitude; all show peaks in high-altitude areas and valleys in low-altitude areas. Maximum precipitation amount (Fig. 6a) shows a bimodal distribution, with peaks at 1851.0 m and 3539.0 m, and low-value zones between 1679.4–1732.4 m. Precipitation frequency peaks for all three durations occur in high-altitude areas and valleys in low-altitude areas. The intensity trends differ among durations: long-duration precipitation intensity shows the most significant fluctuation, with its peak and the peak of maximum precipitation intensity both at 1942.5 m. Both short-duration (1–3 h) and medium-duration (4–6 h) precipitation amount and frequency peaks occur in high-altitude areas. High-altitude areas experience more short-duration precipitation amount and medium-duration precipitation frequency than low-altitude areas, indicating that high-altitude regions are prone to short-duration precipitation amounts and medium-duration precipitation frequencies.

2.2.3 Relationship Between Different Grade Events and Altitude Among the three precipitation grades (Fig. 7), micro rain contributes little to annual average summer hourly cumulative precipitation amount but dominates precipitation frequency. Precipitation amount and frequency for all grades do not increase continuously with altitude; maximum values occur in high-altitude areas and minimum values in low-altitude areas. Micro rain and light rain amount and frequency peak at 3539.0 m, while light rain amount and frequency in low-altitude areas are less than those in high-altitude areas. Maximum precipitation amount (Fig. 5a), long-duration precipitation amount (Fig. 6a), and moderate rain or above amount (Fig. 7c) all peak at the high-altitude Tianchi station (1942.5 m), with valleys at the low-altitude Yiwu station (1728.6 m).

3 Discussion

Many researchers have investigated the physical mechanisms through which topography influences precipitation diurnal variation. Barros and Lang found that nighttime convergence on the southern slopes of the Himalayas results from gravity waves generated by mountain forcing combined with local atmospheric thermodynamic states. Yuan et al. attributed nighttime precipitation peaks in the Sichuan Basin and plains east of the Tibetan Plateau to large-scale "mountain-valley breeze" circulation between the high-altitude plateau and low-altitude basin. He and Zhang proposed that mountain-plain solenoids are the primary cause of different diurnal variation characteristics across regions in northern China. The Tianshan Mountains, located deep within the Eurasian continent far from oceans, have complex topography and unique climatic precipitation diurnal variation characteristics. Compared with previous Tianshan studies that used daily or longer timescale data, this research provides a more detailed analysis of diurnal variation characteristics using hourly data from 11 stations, yielding preliminary understanding of precipitation-altitude relationships. However, the mechanisms of topographic influence remain unclear. Additionally, this study only considered the relationship between altitude and precipitation, while other topographic factors such as slope, aspect, basins, and vegetation also exert important effects. Future research should employ numerical simulations to further explore the physical mechanisms generating summer precipitation diurnal variation in the Tianshan Mountains and incorporate additional topographic factors.

4 Conclusions

Using hourly precipitation data from 11 national meteorological stations in the Tianshan Mountains of Xinjiang during summer months (June–August) from 2012–2018, this study analyzed diurnal variation characteristics of total precipitation, different duration events, and different grade events, and revealed altitude effects on precipitation. The main conclusions are:

(1) Total precipitation amount and frequency exhibit nighttime values greater than daytime, with peaks between 20:00–22:00 and valleys between 12:00–13:00. The nighttime-dominant pattern of total precipitation frequency results from combined effects of peaks and valleys across all three duration categories, while the diurnal variation of total precipitation amount and frequency is dominated by combined contributions from all three precipitation grades. Total precipitation intensity shows daytime enhancement and nighttime weakening, with high values between 16:00–03:00 and low values between 04:00–15:00. Long-duration precipitation intensity shows the most significant diurnal variation, but its pattern differs from that of total precipitation intensity.

(2) Precipitation is closely related to altitude. Maximum precipitation amount, maximum precipitation intensity, long-duration precipitation amount and intensity, and moderate rain or above amount all show a maximum precipitation belt around 2000 m altitude. Compared with low-altitude areas, high-altitude areas are more prone to maximum precipitation amount and frequency, short-duration precipitation amount, medium-duration precipitation frequency, and light rain amount and frequency.

References

[1] Dai Zejun, Yu Rucong, Chen Haoming. Characteristics of summer precipitation diurnal variations in Hunan[J]. Plateau Meteorology, 2009, 28(6): 1463-1469.

[2] Yu R C, Zhou T J, Xiong A Y, et al. Diurnal variations of summer precipitation over contiguous China[J]. Geophysical Research Letters, 2007, 34(1): 223-234.

[3] Lü Jiong. The nighttime precipitation in the red basin of Szechuan, China[J]. Acta Meteorologica Sinica, 1942(Suppl. 1): 36-53.

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

[5] Chen Jiong, Zheng Yongguang, Zhang Xiaoling, et al. Analysis of the climatological distribution and diurnal variations of the short duration heavy rain and its relation with MCSs during the warm season over China[J]. Acta Meteorologica Sinica, 2013, 71(3): 367-382.

[6] Lü Xiang, Xu Haiming. Diurnal variations of rainfall in summer over the Indo China Peninsula[J]. Journal of Nanjing Institute of Meteorology, 2007, 30(5): 632-642.

[7] Li Deshuai. Research on the spatiotemporal characteristics of hourly precipitation over south China during the warm season and its possible causes[D].

Lanzhou: Lanzhou University, 2016.

[8] Chen H M, Yu R C, Li J, et al. Why nocturnal long-duration rainfall presents an eastward-delayed diurnal phase of rainfall down the Yangtze River Valley[J]. Journal of Climate, 2010, 23(4): 905-917.

[9] Bai Aijuan, Liu Xiaodong, Liu Changhai. Contrast of diurnal variations of summer precipitation between the Tibetan Plateau and Sichuan Basin[J]. Plateau Meteorology, 2011, 30(4): 852-859.

[10] Chen Chunyan, Zhao Keming, Ablikim Ablimitijan, et al. Temporal and spatial distributions of hourly rain intensity under the warm background in Xinjiang[J]. Arid Land Geography, 2015, 38(4): 692-702.

[11] Yang Xia, Yu Xiaojing, Zhao Yalei, et al. Diurnal variation of winter snowfall in Ürümqi of Xinjiang from 2011 to 2015[J]. Journal of Arid Meteorology, 2018, 36(4): 603-609.

[12] Yang Xia, An Dawei, Zhou Hongkui, et al. Daily variation of winter precipitation in Ili River Valley of Xinjiang from 2012 to 2017[J]. Journal of Glaciology and Geocryology, 2020, 42(2): 609-619.

[13] Zheng Bohua, Chen Sheng, Wang Yong. Interdiurnal variation characteristics of precipitation (rain and snow) in Kashi Prefecture[J]. Arid Land Geography, 2020, 43(1): 108-116.

[14] Zhao Zhancheng, Ding Guofeng, Arken. Eastern edge of the Taklimakan Desert rainfall diurnal variation[J]. Arid Land Geography, 2016, 39(6): 1181-1185.

[15] Tian Yalin, Li Xuemei, Li Zhen, et al. Spatial and temporal variations of different precipitation types in the Tianshan Mountains from 1980 to 2017[J]. Arid Land Geography, 2020, 43(2): 308-318.

[16] Mao Weiyi, Jiang Yuanan, Li Jiangfeng. Analysis on the linear tendency of precipitation in north Xinjiang[J]. Arid Land Geography, 2006, 29(6): 797-802.

[17] Han Xueyun, Yang Yao Junqiang. Spatiotemporal distribution characteristics of precipitation in Tianshan Mountain of Xinjiang during the last 51 years[J]. Research of Soil and Water Conservation, 2013, 20(2): 139-144.

[18] Huang Qiuxia, Zhao Yong, He Qing, et al. Daily variations characteristics of rainfall in flood season in Yining City[J]. Arid Zone Research, 2015, 32(4): 742-747.

[19] 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.

[20] Wu Weijie, Zheng Weipeng, Zheng Xiuyun, et al. Characteristics of extreme hourly precipitation in Xiamen during 1980–2017[J]. Climatic and Environmental Research, 2019, 24(3): 359-368.

[21] Hu Ruji. Physical geography of the Tianshan Mountains in China[M]. Beijing: China Environmental Science Press, 2004: 2-4.

[22] Zhao Chuancheng, Ding Yongjian, Ye Baisheng, et al. Spatial distribution of precipitation in Tianshan Mountains and its estimation method[J]. Advance in Water Science, 2011, 22(3): 315-322.

[23] Zhang Zhengyong, Liu Lin, Tang Xiangling. The regional difference and catastrophe of precipitation change in Tianshan Mountains in recent 50 years[J]. Journal of Arid Land Resources and Environment, 2013, 27(7): 85-90.

[24] Zhao Yong, Huang Danqing, Guli Jiapaer, et al. Analysis on summer heavy rainfall in the northern Xinjiang[J]. Arid Zone Research, 2010, 27(5): 773-779.

[25] Li Mingcai, Duan Liyao, Yang Yanjuan, et al. Diurnal variation of summer rainfall in Tianjin, China[J]. Journal of Meteorology and Environment, 2009, 25(6): 11-14.

[26] Yang Sen, Zhou Xiaoshan, Gao Jie. Diurnal variations of summer precipitation in Liaoning Province[J]. Meteorological Monthly, 2011, 37(8): 943-949.

[27] Yu Xiaojing, Zhao Yong. Simulation of orographic effects on summer rain in the Tianshan Mountains[J]. Journal of Desert Research, 2016, 36(4): 1133-1143.

[28] Ji Xiaolong, Wu Haomin, Huang Anning, et al. Characteristics of the precipitation diurnal variation over Qinghai-Tibetan Plateau in summer[J]. Plateau Meteorology, 2017, 36(5): 1188-1200.

[29] Liu Rongna, Zhang Guoqing, Xiao Hongbin, et al. Analysis on the characteristics of daily variation of cloud and precipitation over the Huangshui River Valley in summer[J]. Arid Zone Research, 2010, 27(1): 135-141.

[30] Zhuo H, Zhao P, Zhou T J. Diurnal cycle of summer rainfall in Shandong of eastern China[J]. International Journal of Climatology, 2014, 34(3): 742-750.

[31] He H Z, Zhang F Q. Diurnal variations of warm-season precipitation over northern China[J]. Monthly Weather Review, 2010, 138(4): 1017-1025.

[32] Barros A P, Lang T J. Monitoring the monsoon in the Himalayas: Observations in central Nepal, June 2001[J]. Monthly Weather Review, 2003, 131(7): 1408-1427.

[33] Yuan W H, Yu R C, Zhang M H, et al. Regimes of diurnal variation of summer rainfall over subtropical East Asia[J]. Journal of Climate, 2012, 25(9): 3307-3320.

Figures

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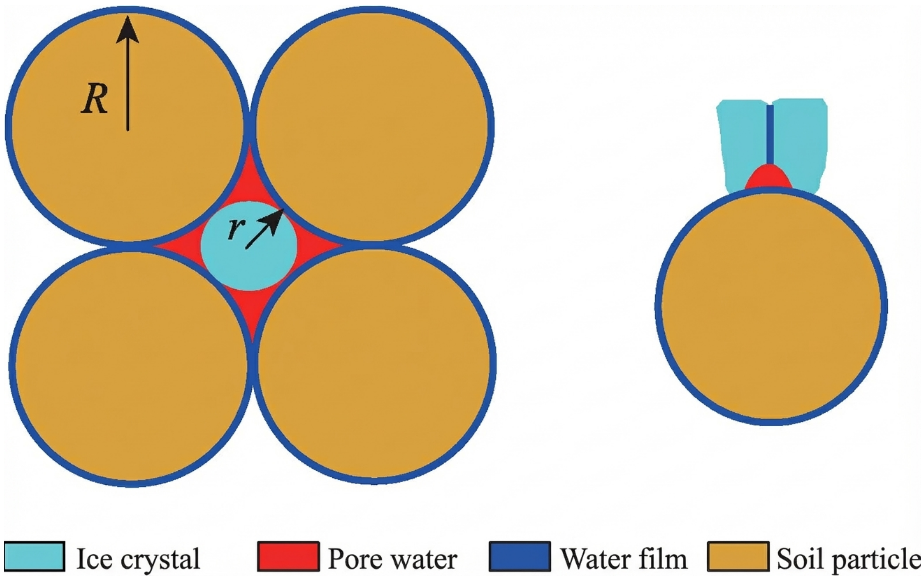

Figure 1: Figure 1

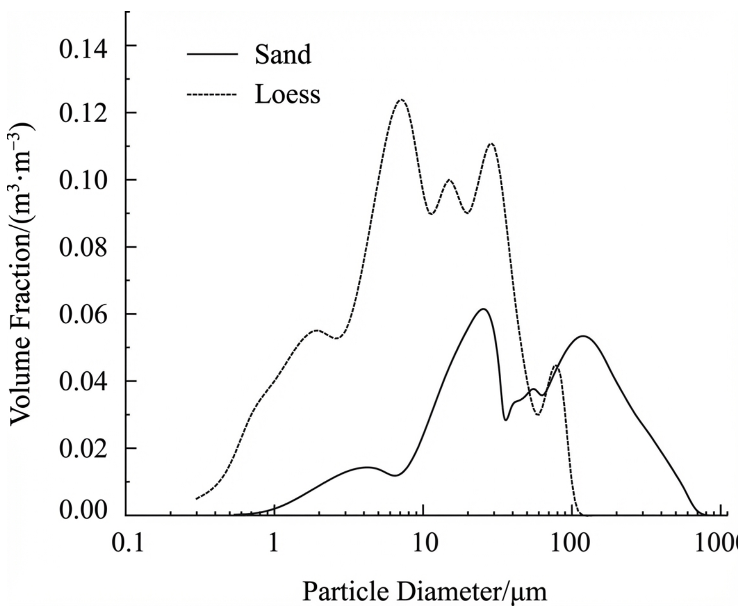

Figure 2: Figure 3

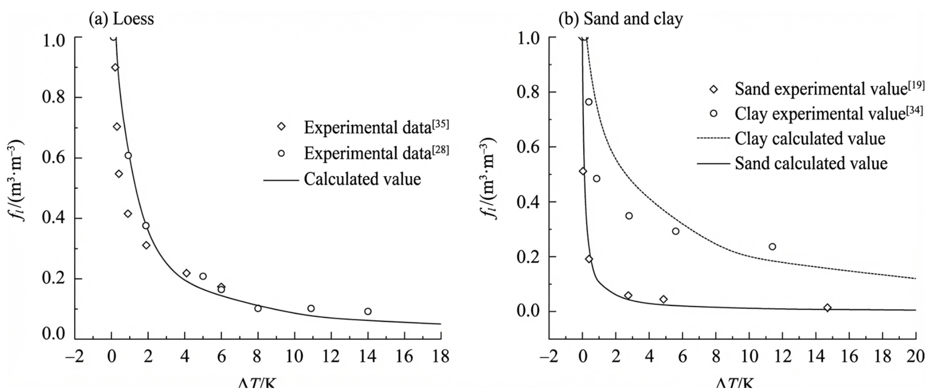

Figure 3: Figure 7