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Analysis of ECMWF Model Forecast Performance for Diurnal Variation Characteristics of Summer Precipitation over the Northern Slope of the Kunlun Mountains: Postprint

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Abstract

The complex terrain of the northern slopes of the Kunlun Mountains and the unique diurnal variation characteristics of precipitation pose significant challenges to fine-scale precipitation forecasting, resulting in low accuracy. The ECMWF model demonstrates world-leading overall forecast performance, yet its capability to forecast the diurnal variation characteristics of precipitation over the complex terrain of the northern slopes of the Kunlun Mountains remains unclear. This study utilizes summer precipitation observation data from automatic weather stations during 2020–2023 to verify and evaluate the forecasting performance of the ECMWF model for the diurnal variation characteristics of summer precipitation in different regions of the northern slopes of the Kunlun Mountains. The results indicate that: (1) The 24-hour accumulated precipitation forecast initialized at 20:00 outperforms that initialized at 08:00; the model's skill in forecasting precipitation for regions on the northern slopes of the Kunlun Mountains above 2000 m elevation is superior to that for regions below 2000 m; and the model's capability to capture precipitation on the northern slopes of the western Kunlun Mountains is superior to that on the northern slopes of the central Kunlun Mountains. (2) The discrepancy in diurnal variation characteristics between modeled and observed precipitation is most pronounced from 17:00 to 02:00 the following day; modeled precipitation frequency is significantly higher than observed, while precipitation intensity is significantly lower than observed; during periods with low (high) observed precipitation, the model tends to overestimate (underestimate) precipitation; the discrepancy in diurnal variation characteristics between modeled and observed precipitation is considerable on the northern slopes of the western (central) Kunlun Mountains for regions with elevation >2000 m ($ $2000 m). (3) Precipitation forecasts on the northern slopes of the western Kunlun Mountains are dominated by convective precipitation, while on the northern slopes of the central Kunlun Mountains they are dominated by large-scale precipitation; the errors in diurnal variation characteristics between modeled and observed precipitation are primarily attributable to convective precipitation forecasts. These findings can serve as a reference for improving the accuracy of summer precipitation forecasts on the northern slopes of the Kunlun Mountains and for correcting ECMWF model precipitation forecast products.

Full Text

Preamble

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ECMWF Model Performance Analysis for Diurnal Variation Characteristics of Summer Precipitation on the Northern Slope of the Kunlun Mountains

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Abstract: The northern slope of the Kunlun Mountains features complex terrain and unique diurnal precipitation characteristics, resulting in significant challenges for refined precipitation forecasting with low accuracy. While the ECMWF model demonstrates world-leading forecast performance, its capability to predict diurnal precipitation variation in this complex terrain remains unclear. This study utilized precipitation observations from automatic weather stations during the summers of 2020–2023 to verify and evaluate the ECMWF model' s forecast performance for diurnal variation characteristics of summer precipitation across different regions on the northern slope of the Kunlun Mountains. The results indicate: (1) The 24-hour cumulative precipitation forecast initialized at 20:00 outperformed that initialized at 08:00; the model' s precipitation forecast capability for areas above 2000 m elevation on the northern slope was superior to that for areas below 2000 m; the ECMWF model demonstrated better precipitation capture capability in the Western Kunlun Mountains than in the Central Kunlun Mountains. (2) The most significant differences between modeled and observed diurnal precipitation characteristics occurred between 17:00 and 02:00 the following day, with modeled precipitation frequency substantially overestimated and intensity significantly underestimated compared to observations. During periods of low observed precipitation, the model tended to overestimate, while during high precipitation periods it tended to underestimate. (3) In the Western Kunlun Mountains, modeled precipitation was dominated by convective precipitation, whereas in the Central Kunlun Mountains it was dominated by large-scale precipitation. The model’ s large-scale precipitation component showed better capture capability for observed precipitation than the convective component, with diurnal variation errors primarily originating from the convective precipitation forecasts. These findings provide valuable references for improving summer precipitation forecast accuracy on the northern slope of the Kunlun Mountains and for correcting ECMWF model precipitation forecast products.

Keywords: ECMWF model; diurnal variation; summer precipitation; performance assessment; northern slope of the Kunlun Mountains

Introduction

The northern slope of the Kunlun Mountains represents a typical inland arid region characterized by complex terrain including high mountains, Gobi deserts, and oases, presenting unique precipitation patterns that make regional precipitation forecasting particularly challenging. In recent years, global climate change has led to increased precipitation frequency and intensity on the northern slope of the Kunlun Mountains, posing significant threats to the region’ s fragile ecological environment. For instance, on July 19, 2022, a short-duration heavy rainfall event in Pishan County on the northern slope of the Central Kunlun Mountains recorded 53.8 mm, approaching the local annual average precipitation of 56.4 mm. In August 2021, a continuous heavy rainfall process occurred on the northern slope of the Central Kunlun Mountains, with the daily precipitation at Qiemo Station in Bayingol Prefecture reaching 2.3 times the local annual average and breaking historical records. Consequently, improving precipitation forecast accuracy in this region has become an urgent priority.

With advances in numerical forecasting technology and modeling methods, numerical weather prediction models have become the core tool for modern meteorological forecasting. The global weather forecast model developed by the European Centre for Medium-Range Weather Forecasts (ECMWF) demonstrates world-leading performance and serves as an important reference for weather forecasting operations in Xinjiang. However, numerical model forecasts are constrained by uncertainties in initial conditions, limitations in physical process parameterization schemes, and data assimilation, making forecast errors unavoidable. To properly understand numerical model forecast product performance and reveal precipitation forecast biases, conducting refined verification and evaluation of model precipitation forecasts is essential.

Previous studies have verified and compared the precipitation forecast performance of various operational numerical models in different regions, consistently showing that ECMWF outperforms other global models. Other research has indicated that ECMWF model’ s convective precipitation location forecast bias constitutes the primary source of precipitation location forecast errors during the spring rain period in southern China. Precipitation diurnal variation represents the product of comprehensive atmospheric thermodynamic and dynamic processes acting on the water cycle. Studying diurnal precipitation characteristics helps understand precipitation formation and development mechanisms and reveals regional weather evolution patterns. Numerical models exhibit significant differences in forecasting precipitation processes across various regions, making diurnal variation assessment crucial for enhancing model application levels.

Numerous scholars have investigated diurnal precipitation characteristics in Xinjiang, revealing significant regional differences between southern and northern Xinjiang during summer, distinct from patterns in central and eastern China. Research on the Tianshan Mountains in Xinjiang shows that summer total precipitation and frequency peak between 20:00–22:00 and reach minimum values between 12:00–13:00, with nocturnal precipitation exceeding daytime precipitation and strong relationships to altitude. However, research on numerical models' diurnal forecast capabilities remains relatively limited, particularly regarding performance evaluation for precipitation diurnal variation characteristics in the Kunlun Mountains region. This gap prevents deep understanding of numerical model forecast uncertainties in this area and fails to provide clear directions for model improvement and forecast product correction.

This study employs ECMWF model precipitation forecast products and automatic weather station observations to examine the model's forecast performance for summer precipitation diurnal variation characteristics across different regions on the northern slope of the Kunlun Mountains, identifying primary error sources. This analysis will help forecasters further understand ECMWF model performance in summer precipitation forecasting for this region, with the goal of improving forecast accuracy and providing references for correcting ECMWF model precipitation forecast products.

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1. Data and Methods

1.1 Data

This study utilized two main datasets: (1) ECMWF model precipitation forecast products, available twice daily at 08:00 and 20:00 UTC with a spatial resolution of 0.125°$×$0.125° and forecast lead times of 0–72 hours. The products include total precipitation (TP), large-scale precipitation (LSP), and convective precipitation (CP) forecasts. LSP is determined by the model' s microphysics scheme and associated with large-scale ascent under stable stratification, while CP is determined by the cumulus convection scheme and primarily related to local unstable stratification. (2) Precipitation observations from 83 automatic weather stations (47 in the Western Kunlun Mountains and 36 in the Central Kunlun Mountains) on the northern slope of the Kunlun Mountains during the same period as the ECMWF model data [Figure 1: see original paper]. ECMWF model data were obtained from the European Centre for Medium-Range Weather Forecasts official website (https://www.ecmwf.int/), while precipitation observation data were provided by the Xinjiang Meteorological Information Center.

The Kunlun Mountains constitute the main western mountain system in China, geographically divided into western, central, and eastern sections. Following relevant literature and Xinjiang weather forecasting operational standards, 85°E serves as the boundary between the Western and Central Kunlun Mountains, while 90°E separates the Central and Eastern Kunlun Mountains.

1.2 Research Methods

The nearest-neighbor interpolation method was first applied to interpolate ECMWF model precipitation to observation stations, using observed precipitation as the "truth" for model performance evaluation. Evaluation metrics include correlation coefficient (COR), root mean square error (RMSE), false alarm rate (FAR), and skill score (SS), calculated as follows:

COR = RE = (1/N) i × 100%
RMSE = (1/N) i
FAR =

Note: The base map uses standard maps from the Ministry of Natural Resources with approval number GS(2017)3320, with no modifications to boundary lines. The same applies below.

[Figure 1: see original paper] Map of the research area

In the formulas: Oi represents station precipitation observations (mm); Gi represents model precipitation values interpolated to stations (mm); N is the number of verification samples; NA indicates the number of stations where both observations and model produced precipitation; NB represents stations where the model predicted precipitation but none was observed; NC represents stations where the model predicted no precipitation but precipitation was observed. Precipitation amount refers to cumulative precipitation over a time period; precipitation frequency records the number of precipitation events during a period; precipitation intensity is the ratio of cumulative precipitation amount to precipitation frequency during a period.

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2. Results

2.1 Overall Summer Precipitation Performance Evaluation

The spatial distribution of annual average summer precipitation on the northern slope of the Kunlun Mountains from 2020–2023 shows significant regional differences [Figure 2: see original paper]. Low-elevation areas generally receive less than 50 mm annually, while regions exceeding 100 mm are primarily distributed in mid-to-high elevation areas. In the Western Kunlun Mountains, summer average precipitation initially increases then decreases with altitude, reaching minimum values in low-altitude plains, peaking around 2000 m elevation (100–200 mm), and decreasing below 100 mm when altitude exceeds 3000 m. In contrast, the Central Kunlun Mountains show a consistent increase in summer average precipitation with altitude.

ECMWF model precipitation forecasts at both 08:00 and 20:00 initializations show significantly higher precipitation amounts in high-altitude regions compared to observations. Both initialization times exhibit increasing precipitation with altitude, failing to capture the observed decrease in precipitation at high altitudes in the Western Kunlun Mountains. The model overall overestimates precipitation in the Western Kunlun Mountains, particularly in high-altitude areas such as the Taxkorgan River valley where overestimation exceeds 50%. In the Central Kunlun Mountains, model precipitation deviations are more complex, with nearly equal proportions of overestimation and underestimation. Unlike the Western Kunlun Mountains, stations with overestimation exceeding 50% in the Central Kunlun Mountains are primarily located in low-altitude areas.

Verification results for 24-hour cumulative precipitation forecasts using the ECMWF model during summer 2020–2023 show that the 20:00 initialization outperformed the 08:00 initialization. The model' s precipitation forecast capability for areas above 2000 m elevation was superior to that for areas below 2000 m. The skill score (SS) was higher in the Western Kunlun Mountains than in the Central Kunlun Mountains, indicating better precipitation capture capability in the Western Kunlun Mountains. Since false alarm and missed precipitation rates significantly impact SS, and these rates were similar across altitude intervals, the higher SS in high-altitude areas primarily resulted from lower false alarm rates.

2.2 Diurnal Variation Characteristics

2.2.1 Precipitation Amount Observed precipitation diurnal curves on the northern slope of the Kunlun Mountains show minimum values at 11:00–14:00, after which precipitation increases rapidly, peaking at 20:00–23:00. The 20:00-initialized model precipitation reaches its peak at 23:00–02:00, consistent with observed precipitation timing, while the 08:00-initialized model peaks at 17:00–20:00, 3–6 hours earlier than observations. The 20:00 initialization demonstrates significantly better performance than the 08:00 initialization, with higher correlation coefficients and substantially lower error metrics.

Model precipitation diurnal variation curves differ significantly from observations, particularly between 17:00 and 02:00 the following day. During this period, observed precipitation is minimal while model precipitation remains high. The differences between modeled and observed precipitation diurnal curves are most pronounced in high-altitude regions. In areas $ $2000 m, model and observed precipitation diurnal trends are generally consistent, while in areas >2000 m, significant differences exist with model precipitation peaks occurring much earlier than observed peaks.

In the Western Kunlun Mountains, observed precipitation diurnal variation shows minimum values at 11:00–17:00 and maximum values at 20:00–02:00. Model precipitation diurnal curves show the opposite pattern, with high values during 11:00–17:00 when observed precipitation is low, and low values during 17:00–02:00 when observed precipitation peaks. In the Central Kunlun Mountains, observed precipitation diurnal variation shows a bimodal pattern with primary peaks at 20:00–23:00 and secondary peaks at 02:00–05:00, while model precipitation shows a unimodal pattern peaking at 02:00–05:00. The differences between model and observed precipitation diurnal characteristics are most significant in high-altitude regions of the Western Kunlun Mountains and low-altitude regions of the Central Kunlun Mountains.

2.2.2 Precipitation Frequency In the Western Kunlun Mountains, observed precipitation frequency diurnal variation trends are similar to precipitation amount variation, with frequent precipitation occurring from evening to early morning (20:00–08:00), peaking at 02:00–05:00, and minimum frequency at 14:00–17:00. Model precipitation frequency diurnal characteristics differ significantly from observations, with model frequency consistently higher across all time periods. The differences between model and observed precipitation frequency diurnal curves are similar to those for precipitation amount, showing better agreement in low-altitude areas and opposite trends in high-altitude areas, which constitutes the primary error source.

In the Central Kunlun Mountains, observed precipitation frequency shows a bimodal diurnal pattern with primary peaks at 20:00–23:00 and secondary peaks at 02:00–05:00, while model precipitation frequency shows a unimodal pattern with high values at 02:00–05:00 and low values at 08:00–20:00. In different altitude zones, the model precipitation frequency diurnal curve in the 1500–2000 m region shows some similarity to observations, while other altitude regions exhibit consistent unimodal patterns that differ from the observed bimodal or transitional patterns.

2.2.3 Precipitation Intensity Model precipitation intensity is significantly lower than observed intensity across all time periods, primarily due to the model' s substantial overestimation of precipitation frequency. In the Western Kunlun Mountains, observed total precipitation intensity diurnal variation trends are consistent with precipitation amount variation, with low intensity during 11:00–17:00 and high intensity from evening to early morning (20:00–02:00), peaking at 23:00–02:00. Model precipitation intensity shows small fluctuations across most time periods, with a minimum at 14:00. In altitude zones $ $1500 m, observed precipitation intensity peaks at 23:00–02:00, while model intensity peaks at 14:00–17:00, showing a 6–9 hour difference. In altitude zones >2000 m, model and observed precipitation intensity diurnal curves are relatively consistent but with differences in peak and minimum timing.

In the Central Kunlun Mountains, observed total precipitation intensity is lowest at 08:00–11:00, then increases rapidly, peaking at 20:00–02:00. Model precipitation intensity diurnal variation shows small amplitude fluctuations, with minimum values during low-observed-precipitation periods (08:00–14:00) and maximum values during high-observed-precipitation periods (20:00–02:00). The model fails to capture the observed characteristic of high precipitation intensity during evening to early morning hours. The differences between model and observed precipitation intensity are primarily attributed to discrepancies in low-altitude areas during afternoon to early morning periods.

2.2.4 Verification Metrics In the Western Kunlun Mountains, the correlation coefficient between model and observed precipitation shows clear diurnal variation, with relatively large values during low-precipitation periods (11:00–17:00) and relatively small values during high-precipitation periods (20:00–02:00). The root mean square error (RMSE) is relatively small during low-precipitation periods and larger during high-precipitation periods. The false alarm rate is relatively high during 14:00–17:00, leading to lower accuracy. In high-altitude regions, RMSE is significantly larger than in low-altitude regions. During low-precipitation periods, the false alarm rate is relatively low, with lower values in high-altitude areas compared to low-altitude areas. The higher false alarm rates in low-altitude regions contribute to the observed patterns.

In the Central Kunlun Mountains, the correlation coefficient between model and observed precipitation is relatively large during low-precipitation periods and small during high-precipitation periods. RMSE shows greater variation amplitude in low-altitude regions than in high-altitude regions. Model precipitation tends to be overestimated during low-precipitation periods and underestimated during high-precipitation periods. The correlation coefficient is significantly larger in high-altitude areas than in low-altitude areas.

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3. Discussion

ECMWF model total precipitation forecasts consist of large-scale precipitation (LSP) and convective precipitation (CP) components. Analysis reveals that the 20:00-initialized model forecasts are dominated by CP in low-altitude regions of the Western Kunlun Mountains, with CP proportion exceeding 70% during 17:00–20:00. In the Central Kunlun Mountains low-altitude regions, LSP dominates. The proportion of CP decreases with altitude in the Western Kunlun Mountains, while remaining relatively stable across altitudes in the Central Kunlun Mountains. Calculations show that in the Western Kunlun Mountains, CP proportion in model precipitation amount and frequency is higher than LSP across most time periods except 14:00–17:00, while in the Central Kunlun Mountains, LSP proportion exceeds CP across all time periods.

The correlation coefficient between LSP and observed precipitation is 0.45, while that between CP and observed precipitation is only 0.12. The correlation coefficient between LSP and relative deviation is -0.31, while that between CP and relative deviation is 0.68. These results indicate that LSP has better capture capability for observed precipitation than CP, and model precipitation errors are more likely to originate from CP. Further analysis of CP and LSP diurnal characteristics shows that in the Western Kunlun Mountains, the largest differences between model and observed precipitation during 17:00–02:00 primarily come from high-altitude regions >2000 m, where CP precipitation amount and frequency far exceed LSP values, dominating the model precipitation diurnal characteristics. Therefore, CP constitutes the primary source of differences between model and observed precipitation diurnal variation.

In the Central Kunlun Mountains, observed precipitation frequency and LSP are inversely correlated during 14:00–20:00, while CP and observed precipitation are positively correlated, making CP the main contributor to differences between model and observed precipitation during this period. The model' s total precipitation intensity is significantly lower than observed values, with CP total precipitation intensity substantially lower than observed and LSP total precipitation intensity showing an inverse diurnal pattern to observations.

Coarse model grid resolution is one reason for forecast errors. Model physical process parameterization schemes for microphysics, boundary layer, and radiation are highly dependent on grid resolution, making it difficult to represent small-scale terrain' s convective triggering effects and leading to precipitation forecast biases. Additionally, the complexity of terrain scale and its interaction with the atmosphere results in complicated dynamic, thermodynamic, and microphysical effects on orographic precipitation. Numerical models' insufficient representation of physical processes can cause simulation errors in terrain-induced precipitation, which may also contribute to ECMWF model errors in the complex terrain of the northern Kunlun Mountains.

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4. Conclusions

This study evaluated the overall forecast performance of ECMWF model precipitation forecasts on the northern slope of the Kunlun Mountains, compared the model' s forecast performance for diurnal variation characteristics of summer precipitation across different regions, and discussed error sources. The main conclusions are:

(1) The 24-hour cumulative precipitation forecast initialized at 20:00 outperformed that initialized at 08:00. The model' s precipitation forecast capability for areas above 2000 m elevation on the northern slope of the Kunlun Mountains was superior to that for areas below 2000 m. The model demonstrated better precipitation capture capability in the Western Kunlun Mountains than in the Central Kunlun Mountains. Model

precipitation amounts were generally overestimated in the Western Kunlun Mountains, while the Central Kunlun Mountains showed nearly equal proportions of overestimation and underestimation. Model precipitation in both regions exhibited increasing trends with altitude, failing to accurately represent the observed precipitation decrease at high altitudes in the Western Kunlun Mountains.

(2) The most significant differences between modeled and observed diurnal precipitation characteristics occurred between 17:00 and 02:00 the following day. Modeled precipitation frequency was substantially higher than observed across all time periods, while modeled precipitation intensity was significantly lower. The model tended to overestimate precipitation during low-observation periods and underestimate during high-observation periods. The model exhibited high false alarm rates during 14:00–17:00, resulting in lower accuracy. Significant differences between modeled and observed diurnal precipitation characteristics occurred in high-altitude regions (>2000 m) of the Western Kunlun Mountains and low-altitude regions ($ $2000 m) of the Central Kunlun Mountains.

(3) ECMWF model precipitation forecasts in the Western Kunlun Mountains were dominated by convective precipitation, while large-scale precipitation dominated in the Central Kunlun Mountains. The model' s large-scale precipitation component demonstrated better capture capability for observed precipitation than the convective component, with diurnal variation errors in both regions primarily originating from convective precipitation forecasts.

Precipitation forecasting remains the greatest challenge in numerical weather prediction, with factors including coarse model spatial resolution, dynamic field forecast errors, cumulus parameterization and microphysical process errors, and insufficient terrain representation all affecting final precipitation forecast accuracy. This study focused on analyzing ECMWF model performance and error sources for diurnal variation characteristics of summer precipitation on the northern slope of the Kunlun Mountains. Future work will further investigate numerical model forecast error sources based on the physical mechanisms of precipitation in this region to provide references for refined forecasting.

References

[1] Yang Xia, Zhou Hongkui, Xu Tingting, et al. Comparative analysis of the fine characteristics of different rainstorms in southern Xinjiang during summer[J]. Arid Zone Research, 2021, 38(3): 747-756.

[2] Yao Junqiang, Li Moyan, Dilinuer Tuoliewubieke, et al. The assessment on warming wetting trend in Xinjiang at multi scale during 1961-2019[J]. Arid Zone Research, 2022, 39(2): 333-346.

[3] Yang Xia, Zhou Hongkui, Zhao Keming, et al. Variation features of hourly precipitation in Xinjiang Province during 1991-2018[J]. Plateau Meteorology, 2020, 39(4): 762-773.

[4] Zhang Junlan, Yang Xia, Xiao Jun' an, et al. Multi-scale temporal and spatial variation characteristics of summer precipitation in northern Kunlun Mountains[J]. Plateau and Mountain Meteorology Research, 2023, 43(3): 1-10.

[5] Han Xingsheng. Analysis of precipitation variation characteristics on the northern slope of the Middle Kunlun Mountains[J]. Yangtze River, 2017, 48(Suppl.): 85-88.

[6] Mao Weiyi, Yusup Abudula, Cheng Peng, et al. Extreme flood events in 1999 and their formation conditions in northern slopes of the Middle Kunlun Mountains[J]. Journal of Glaciology and Geocryology, 2007, 29(4): 553-558.

[7] Xin Chen, Qi Liangbo. Verification and analysis on precipitation forecast of ECMWF Model during spring rain period in South China[J]. Torrential Rain and Disasters, 2018, 37(4): 383-391.

[8] Su Xiang, Liu Mei, Kang Zhiming, et al. Verification of short-range torrential rain forecast during the 2020 Jiangsu main flood season[J]. Meteorological Monthly, 2022, 48(3): 357-371.

[9] Chen Xiaoyan, Kong Xiangwei, Peng Xiao, et al. Verification and assessment of precipitation forecast based on global and regional numerical models in Gansu in flood season of 2020[J]. Journal of Arid Meteorology, 2022, 40(3): 524-535.

[10] Li Zhiyu, Du Xiaoling, Zhu Yulei, et al. Study on characteristics of heavy precipitation and model prediction correction under typical topography in Guizhou[J]. Torrential Rain and Disasters, 2024, 43(6): 648-656.

[11] 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.

[12] Xu Yueyue, He Qing, Mao Donglei, et al. Comparative analysis of the gradient of meteorological elements at different elevations of the north slope of the Middle Kunlun Mountains from 2022 to 2023[J]. Plateau Meteorology, 2025, 44(1): 224-239.

[13] Chen Haoming, Li Puxi, Zhao Yan. A review and outlook of verification and evaluation of precipitation forecast at convection-permitting resolution[J]. Advances in Meteorological Science and Technology, 2021, 11(3): 155-164.

[14] Long Keji, Yang Kangquan, Kang Lan. Performance verification of multi-model heavy rainfall processes prediction in the Sichuan Basin[J]. Journal of Arid Meteorology, 2024, 42(3): 473-483.

[15] Chen Chunyan, Wang Jianjie, Tang Ye, et al. Diurnal variations of summer precipitation in Xinjiang[J]. Journal of Applied Meteorological Science, 2017, 28(1): 72-85.

[16] Guo Yulin, Zhao Yong, Zhou Yaman, et al. Diurnal variation of summer precipitation and its relationship with altitude in Tianshan Mountains of Xinjiang[J]. Arid Land Geography, 2022, 45(1): 57-65.

[17] Luo Yali, Gong Yu, Zhang Dalin. Initiation and organizational modes of an extreme-producing meso-scale convective system along a Mei-Yu front in East China[J]. Monthly Weather Review, 2014, 142(1): 203-221.

[18] Zhi Xiefei, Huo Ziqiang. Calibration of the probabilistic forecast of precipitation over complex terrain in Southeast China[J]. Transactions of Atmospheric Sciences, 2023, 46(2): 230-241.

[19] Lü Lachang. Geography of China[M]. Beijing: Science Press, 2016.

[20] Sun Shenqing, et al. Guidelines for Short-term Weather Forecasting in Xinjiang[M]. Urumqi: Xinjiang People' s Publishing House, 1986.

[21] Liao Fei, Hong Yanchao, Zheng Guoguang. Review of orographic influences on surface precipitation[J]. Meteorological Science and Technology, 2007, 35(3): 309-316.

[22] Zhong Shuixin. Advances in the study of the influencing mechanism and forecast methods for orographic precipitation[J]. Plateau Meteorology, 2020, 39(5): 1122-1132.

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