Performance Evaluation of Warm-Season Hourly and Daily Precipitation Forecasts by the CMA-MESO Model: A Case Study of the Ili River Valley (Postprint)

Authors: Mou Huan, Chunyan Chen, Yang Xia, Zhao Li

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Abstract

Quantitative precipitation forecast performance evaluation can provide a scientific basis for the interpretation, application, and improvement of precipitation forecasts. Using hourly station precipitation observations and CMA-MESO model precipitation forecast data from May to September (warm season) of 2022–2023, and employing evaluation metrics such as precipitation/no-precipitation accuracy, Threat Score (TS), false alarm rate, and miss rate, an in-depth study was conducted on the precipitation forecast performance in the Yili River Valley. The results indicate: (1) The CMA-MESO model can reasonably characterize the 1 h and 24 h precipitation features during the warm season in the Yili River Valley. As precipitation intensity level increases, both forecast and observed precipitation frequencies exhibit a decreasing trend. (2) The TS scores for forecasts of different precipitation intensities are closely correlated with the cumulative probability bias of precipitation forecasts. The 24 h precipitation forecast for the 6.1–12.0 mm category has the lowest TS score, with its cumulative probability forecast bias reaching the highest value, with a mean exceeding 2.0%; the 1 h forecast TS score decreases significantly with increasing precipitation intensity, with the bias peaking at 1.7% at 0.1 mm. (3) Both forecast and observed precipitation frequencies increase with altitude, but the 24 h forecast frequency shows negative bias at all heights, whereas the 1 h forecast frequency shows positive bias in low-altitude regions and negative bias in sub-high-altitude regions. (4) Regarding diurnal variation, the CMA-MESO model fails to accurately simulate the characteristic of lower precipitation frequency during daytime and higher at night in the Yili River Valley. Specifically, the model exhibits excessive false alarms for daytime precipitation while showing excessive misses for nighttime precipitation, with the most significant forecast biases occurring at 13:00–14:00 noon and 02:00–05:00 early morning.

Full Text

Introduction

The Yili River Valley is a unique geographical unit located in the heart of the Eurasian continent, characterized by its complex terrain and landforms. Despite being situated in an inland arid to semi-arid climate zone, its abundant water resources play a vital role in supporting local agricultural and pastoral development, sustainable water resource management, and ecological diversity conservation. However, frequent precipitation events pose severe challenges to this geologically fragile region, making it prone to geological disasters such as landslides and debris flows. The annual precipitation and precipitation frequency in the Yili River Valley are particularly prominent within Xinjiang, especially during the warm season when precipitation accounts for a large proportion. This precipitation characteristic is closely related to the local complex topographic conditions. The valley exhibits a narrowing trend from west to east, with gradually increasing elevation. This special terrain can not only trigger precipitation but also significantly enhance and alter rainfall distribution, while simultaneously increasing the uncertainty of precipitation forecasting.

The CMA-MESO model is a mesoscale numerical prediction system developed by the China Meteorological Administration for China and its surrounding regions. Compared with global numerical forecast models, the CMA-MESO model can more accurately depict processes of local circulation and topographic forcing, playing a crucial role in disastrous weather warnings. However, due to factors such as initial field biases and differences in parameterization schemes, significant spatiotemporal distribution differences exist in precipitation characteristics. Therefore, verification and evaluation of numerical forecasts have become important components in improving numerical prediction systems and their interpretation. Classical verification methods based on station observations are mainly divided into numerical bias tests and frequency statistics tests.

Evaluation Methodology

Numerical bias tests focus on evaluating the consistency between observed station data and quantitative precipitation forecasts, with evaluation metrics including root mean square error, mean absolute error, and mean error. Frequency statistics tests, on the other hand, are based on counting the number of observed and forecasted events at stations, with evaluation metrics including precipitation forecast accuracy rate, where J represents the number of missed forecasts; the precipitation forecast bias ratio, which reflects forecast accuracy; and other indicators for correct precipitation and non-precipitation forecasts. The bias ratio represents the absolute value of the ratio between forecast and observed frequency biases, indicating whether precipitation is over-forecasted or under-forecasted. O represents the cumulative bias of precipitation forecast frequency, used to analyze the degree of cumulative bias in precipitation forecasts of different intensities. The cumulative probability distribution of forecast precipitation frequency and observed precipitation frequency are also key diagnostic variables, with J representing precipitation intensity levels. When the bias is positive, it indicates that precipitation forecast frequency is higher than observed frequency; when negative, it indicates lower forecast frequency.

Forecast Performance by Altitude Zone

The evaluation scores for 24h precipitation forecasts vary significantly across altitude zones. The sub-high altitude zone exhibits the lowest scores, while the low altitude zone shows the highest scores. Analysis reveals that stations with scores above the threshold are concentrated in the eastern mountainous areas of the valley. These results indicate that the high scores are partly due to the fact that non-precipitation events far outnumber effective precipitation events in the Yili River Valley, and the model' s accuracy for non-precipitation forecasts is substantially higher than for precipitation events. The 24h forecasts better reflect the accuracy of effective precipitation forecasts compared to other forecast products.

The precipitation forecast bias shows distinct relationships with altitude. For 24h precipitation forecasts, the bias increases with altitude in the sub-high and medium altitude zones, while showing opposite trends in low altitude zones, leading to less obvious accuracy improvements. The superior performance of 24h forecasts is primarily attributed to the larger forecast time scale, which results in substantially lower false alarm and missed forecast rates compared to other products. In 24h precipitation forecasts, higher missed forecast rates in sub-high altitude zones and higher false alarm rates in low altitude zones contribute to lower evaluation scores.

Diurnal Variation Characteristics

Precipitation exhibits the most significant diurnal variation among meteorological elements. The model shows markedly different diurnal variation characteristics in precipitation forecast bias. Daytime forecasts (approximately 08:00–20:00 LST) are predominantly positively biased, with the bias ratio reaching approximately 0.6 at noon. Nighttime forecasts (approximately 20:00–08:00 LST) are mainly negatively biased, with the lowest bias ratio around 0.3. The model struggles to accurately describe the diurnal variation characteristics of precipitation frequency in the Yili River Valley. The forecast frequency bias shows significant diurnal variation, with positive biases dominating daytime precipitation forecasts and negative biases dominating nighttime forecasts. The evaluation scores are slightly higher during the day than at night, varying with observed precipitation frequency. Comparison between observed and forecast frequencies reveals that the model' s forecast trend from early morning to afternoon is completely opposite to the observed frequency, with the most significant deviations occurring around noon.

Discussion and Limitations

Traditional precipitation forecast verification methods, while effective at evaluating the matching degree between forecasted and observed values at specific locations, are sensitive to small-scale biases and prone to the “double penalty” problem in high-resolution numerical forecast model evaluation. In recent years, with the development of spatial verification methods, new approaches have been introduced to address these limitations. Further research should combine numerical simulation methods to deeply analyze the influence mechanisms of complex terrain on precipitation and improve the physical parameterization schemes in the CMA-MESO model to better capture the diurnal cycle and spatial distribution of precipitation in the Yili River Valley.

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4. Subseasonal Forecast Error Analysis

Evaluation of hourly and daily precipitation forecasting performance of the CMA-MESO model in the warm season: A case of the Ili River Valley

MOU Huan[1], CHEN Chunyan[1], YANG Xia[1], ZHAO Li[2]

Abstract: The performance evaluation of quantitative precipitation forecasts can provide a scientific basis for the application and improvement of such forecasts. In this study, hourly site precipitation observation data and the CMA-MESO model' s quantitative precipitation forecast data from May to September (the warm season) of 2023 were used. Using evaluation indicators such as the probability of correct rainfall, threat score (TS), false alarm ratio, and missed alarm ratio, precipitation forecast performance over the Ili River Valley was analyzed. The results revealed the following: (1) The CMA-MESO model can reasonably depict the 1 h and 24 h precipitation characteristics in the Ili River Valley during the warm season. As the precipitation intensity increases, both the forecast and observed frequencies of precipitation show a downward trend. (2) The TS for the CMA-MESO model forecast of precipitation of different intensities is closely related to the forecast bias of the accumulated precipitation probability. The 24 h precipitation forecast TS score for the range of 6.1–12.0 mm is the lowest, with the highest cumulative probability forecast bias, exceeding a mean of 2.0%. The 1 h forecast TS score significantly decreases with the enhancement of precipitation intensity, reaching a peak bias of 1.7% at 0.1

mm. (3) The frequency of the forecasted and observed precipitation shows an increasing trend with altitude. However, the 24 h forecast frequency exhibits a negative bias across all altitudes, while the 1 h forecast frequency shows a positive bias in the low-altitude areas and a negative bias in the sub-high-altitude areas. (4) In terms of diurnal variation, the CMA-MESO model did not accurately simulate the characteristic of low precipitation frequency during the day and higher frequency during the night in the Ili River Valley. Specifically, the model tends to have more false alarms for daytime precipitation and more missed alarms for nighttime precipitation. A comparison of the frequency of precipitation observations with forecasts shows that the pattern of the forecast trend from early morning to afternoon is completely opposite to the observed frequency; the most significant forecast biases occurs between 13:00–14:00 and 02:00–05:00.

Key words: CMA-MESO; evaluation of precipitation forecast; the warm season; hourly and daily precipitation; the Ili River Valley

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