Postprint: Applicability Assessment of Three Precipitation Data Products over the Eastern Tibetan Plateau

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Abstract

Daily precipitation data from ground meteorological stations across the eastern Tibetan Plateau in 2022 were selected to evaluate precipitation datasets from the China Meteorological Administration Multi-source Precipitation Analysis System (CMPAS), the China Meteorological Administration Land Data Assimilation System (CLDAS), and the China Meteorological Administration's Global Atmospheric Reanalysis (CRA). Employing error metrics and categorical evaluation methods, the applicability of the three precipitation products over the eastern Tibetan Plateau was regionally validated. The results demonstrate: (1) For the eastern Tibetan Plateau, when analyzing annual-scale precipitation, CMPAS precipitation exhibits the minimal error and maximal correlation with observations, significantly outperforming the other two datasets. CMPAS precipitation products should be prioritized for selection. (2) From an intra-annual perspective, CMPAS monthly precipitation most closely approximates observations with minimal errors and high correlation, CRA monthly precipitation consistently exceeds observations, while CLDAS is significantly lower than observations in most months. For monthly-scale precipitation analysis over the eastern Tibetan Plateau, CMPAS yields optimal results. (3) During two extensive precipitation events in the eastern Tibetan Plateau, CLDAS most accurately reflects the process cumulative rainfall, whereas CMPAS can precisely capture the maximum precipitation center, rainfall amount at the maximum center, light-to-heavy precipitation categories, and the timing and location of concentrated precipitation. For precipitation event analysis over the eastern Tibetan Plateau, CMPAS demonstrates superior performance. These research findings provide data support for refined monitoring in sparsely gauged regions of the eastern Tibetan Plateau and establish a robust foundation for the application of gridded precipitation products in weather and climate operations and meteorological disaster prevention and mitigation.

Full Text

Abstract

Based on daily precipitation data from ground meteorological stations in the eastern Qinghai-Xizang Plateau in 2022, this study evaluated three precipitation datasets: the China Meteorological Administration Multi-source Precipitation Analysis System (CMPAS), the China Meteorological Administration Land Data Assimilation System (CLDAS), and the China Meteorological Administration Global Atmospheric Reanalysis product (CRA). Using error metrics and graded evaluation methods, we assessed the applicability of these three precipitation products across different subregions of the eastern plateau. The results indicate that: (1) For annual precipitation analysis, CMPAS shows the smallest error and strongest correlation with observations, significantly outperforming the other two products and should be prioritized. (2) In terms of seasonal variation, CMPAS monthly precipitation values are closest to observations with minimal error and high correlation, while CLDAS overestimates precipitation in most months and CRA underestimates it in most months. (3) During two large-scale precipitation events in the eastern plateau, CMPAS most accurately captured the accumulated rainfall, correctly identified the maximum precipitation center and its intensity, and properly represented light to heavy rainfall categories, timing, and spatial distribution. Overall, CMPAS demonstrates the best performance for analyzing precipitation processes in the eastern Qinghai-Xizang Plateau. These findings provide data support for refined monitoring in sparsely instrumented areas and establish a solid foundation for applying gridded precipitation products in weather and climate operations and meteorological disaster prevention and mitigation.

Keywords: precipitation; data products; applicability; evaluation; Qinghai-Xizang Plateau

Introduction

With the rapid development of meteorological monitoring systems, data from weather stations, radar, and satellites have become increasingly abundant. While meteorological stations are typically considered reliable representatives of actual values, their uneven spatial distribution limits the ability to provide precise regional precipitation data. Radar enables regional precipitation observations but remains constrained by station deployment and has not achieved nationwide coverage, with significant observation errors in cold climates and complex terrain. In recent years, satellite precipitation products have successfully filled observation gaps through global coverage, but these products are derived from cloud observations and have limited accuracy, particularly over the complex terrain of the Qinghai-Xizang Plateau.

Since the international proposal of data fusion in 2000, merging multiple data sources has become a development trend in precipitation products. Representative examples include the Global Precipitation Climatology Project (GPCP), the Climate Prediction Center Merging Analysis of Precipitation (CMORPH), the Global Precipitation Measurement (GPM) program, and Japan's Global Satellite Mapping of Precipitation (GSMaP). China has also conducted extensive research on fusion precipitation products. Shen et al. used probability density matching and optimal interpolation to merge national automatic weather station data with CMORPH precipitation products, generating a high-resolution hourly precipitation fusion product for China. Yu et al. further employed motion vectors and temporal weighting interpolation to optimize the temporal series length and precipitation distribution in sparsely instrumented regions. Pan et al. introduced radar precipitation products and proposed a three-source precipitation fusion method, achieving higher accuracy than previous fusion products. In addition to data fusion, data assimilation technology has developed rapidly, including the U.S. Global Land Data Assimilation System (GLDAS), the European Land Data Assimilation System (ELDAS), and the China Meteorological Administration Land Data Assimilation System (CLDAS). Atmospheric reanalysis products are also widely used in regional climate monitoring, such as the European Centre for Medium-Range Weather Forecasts' ERA5, the U.S. National Centers for Environmental Prediction's CFSR, and China's self-developed first-generation global atmospheric reanalysis CRA-40.

Although fusion, assimilation, and reanalysis data can effectively integrate multiple sources, their accuracy is greatly limited by data sources and assimilation/fusion methods. Therefore, applicability assessment of multi-source precipitation products is crucial. Numerous evaluation studies have been conducted across China, but most focus on large-scale spatial distributions, leaving gaps in research on local important precipitation processes. The Qinghai-Xizang Plateau exhibits unique and pronounced sensitivity, precursory signals, and regulatory effects on global climate change, serving as a key region for global climate circulation patterns. Its eastern region, with relatively lower elevation, is a populated area where extreme precipitation events pose significant threats to agricultural production and people's lives, causing severe socioeconomic losses. Consequently, there is an urgent need to conduct applicability studies of precipitation products in the eastern Qinghai-Xizang Plateau.

This paper evaluates three high-resolution precipitation products in the eastern plateau, examining annual precipitation elements and two typical precipitation processes to investigate their applicability across different scales and identify the most suitable high-precision precipitation product. This will compensate for the uneven spatial distribution of station observations, promote refined climate monitoring and assessment, and provide data support for meteorological disaster prevention and mitigation.

1. Data and Methods

1.1 Data Sources

The year 2022 was selected as the study period because the average precipitation in the eastern Qinghai-Xizang Plateau was equivalent to the climatological mean, providing general representativeness of current weather and climate conditions. Additionally, extreme precipitation during the flood season was particularly intense, especially in July and August, with concentrated precipitation periods and overlapping rainfall areas that triggered multiple flood and landslide disasters, making it notably typical.

Three high-resolution precipitation products were evaluated against daily precipitation data from national meteorological stations:

1. **CMPAS (China Meteorological Administration Multi-source Precipitation Analysis System)**: A high spatiotemporal resolution multi-source precipitation fusion product that employs probability density function, Bayesian model averaging, and optimal interpolation methods to merge automatic weather station data, Chinese radar quantitative precipitation estimates, and CMORPH satellite precipitation products. The near-real-time product used in this study was obtained from the "Tianqing" meteorological big data cloud platform, with a temporal resolution of 5 minutes and spatial resolution of 1 km × 1 km.

2. **CLDAS (China Meteorological Administration Land Data Assimilation System)**: A fusion analysis product covering Asia in equal latitude-longitude grids, merging ground observation precipitation with CMORPH satellite retrieval products using multi-grid variational assimilation, optimal interpolation, and probability density function matching techniques. The near-real-time product from "Tianqing" has a spatial resolution of 0.0625° × 0.0625° and temporal resolution of 1 hour.

3. **CRA/Land (China Meteorological Administration Global Atmospheric Reanalysis)**: China's first-generation global atmospheric reanalysis dataset, including both atmospheric and land surface reanalysis products. The CRA/Land product used in this study merges satellite precipitation products with ground rain gauge observations, obtained from the China Meteorological Data Network with a spatial resolution of 0.25° × 0.25° and temporal resolution of daily.

The study area was divided into five subregions based on topography, climate characteristics, and administrative divisions: Qaidam Basin, Qinghai Lake Basin, Qilian Mountains, Three-River Source Region, and Eastern Agricultural Region [Figure 1: see original paper].

1.2 Interpolation Method

To evaluate the quality of the three precipitation datasets, the high-resolution gridded data were interpolated to station locations for comparison. Bilinear interpolation was selected for its small error and good performance, widely used in meteorological applications. The method performs linear interpolation first in the x-direction and then in the y-direction:

First, linear interpolation in the x-direction yields:

$$f(x,y_1) \approx \frac{x_2 - x}{x_2 - x_1} f(Q_{11}) + \frac{x - x_1}{x_2 - x_1} f(Q_{21})$$

$$f(x,y_2) \approx \frac{x_2 - x}{x_2 - x_1} f(Q_{12}) + \frac{x - x_1}{x_2 - x_1} f(Q_{22})$$

Then, linear interpolation in the y-direction yields the final interpolated value:

$$f(x,y) \approx \frac{y_2 - y}{y_2 - y_1} f(x,y_1) + \frac{y - y_1}{y_2 - y_1} f(x,y_2)$$

where Q_{11}, Q_{12}, Q_{21}, and Q_{22} are the four surrounding grid points, and $f(Q_{ij})$ represents the variable values at corresponding grid points.

1.3 Evaluation Metrics

Specific quality assessment metrics include:

1. **Mean Error (ME)**:

$$ME = \frac{1}{N}\sum_{i=1}^{N}(G_i - O_i)$$

2. **Mean Absolute Error (MAE)**:

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|G_i - O_i|$$

3. **Root Mean Square Error (RMSE)**:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(G_i - O_i)^2}$$

4. **Correlation Coefficient (COR)**:

$$COR = \frac{\sum_{i=1}^{N}(G_i - \bar{G})(O_i - \bar{O})}{\sqrt{\sum_{i=1}^{N}(G_i - \bar{G})^2 \sum_{i=1}^{N}(O_i - \bar{O})^2}}$$

5. **Threat Score (TS)**:

$$TS = \frac{N_A}{N_A + N_B + N_C}$$

where O_i is the observed station value, G_i is the interpolated grid product value, N is the total number of stations, N_A represents cases where both forecast and observation occurred, N_B represents forecast occurred but observation did not, and N_C represents forecast did not occur but observation did.

2. Results

2.1 Evaluation of 2022 Precipitation

From the evaluation metrics, all three precipitation products show correlation coefficients passing significance tests at the 99% level ($p < 0.001$) . CMPAS demonstrates the smallest average error and highest correlation, making it closest to observations.

The average precipitation in the eastern Qinghai-Xizang Plateau in 2022 was 364.9 mm. CMPAS shows an average precipitation of 478.2 mm, which is higher than observed. Except for Qingshuihe, most areas show overestimation, with Xizaohuo showing the largest overestimation of 1.0–2.7 times. CLDAS shows an average of 379.9 mm, close to observations, with deviations within $±$20% for most areas except Xizaohuo (11.5–60.9% overestimation). CRA shows an average of 295.1 mm, significantly lower than observed, with most areas showing underestimation of 2.7–70.3%, particularly in Lenghu [Figure 2: see original paper].

In terms of seasonal variation, CMPAS monthly precipitation is closest to observations with small errors and high correlation. CLDAS overestimates precipitation in most months, while CRA underestimates in most months with poor correlation [Figure 3: see original paper]. Evaluation indicators by month show CMPAS maintains the highest correlation coefficients throughout the year .

Overall, for annual precipitation analysis in the eastern Qinghai-Xizang Plateau, CMPAS shows the smallest error and highest correlation among the three products. CLDAS overestimates annual precipitation, while CRA underestimates it with larger errors and weaker correlation. Therefore, CMPAS should be prioritized for analyzing precipitation at annual and monthly scales.

2.2 Evaluation of Significant Precipitation Processes

Heavy precipitation occurred frequently in the eastern plateau during July–August 2022, with the frequency of daily precipitation exceeding 25 mm reaching the highest since 2011. Extreme precipitation events triggered floods and secondary disasters, particularly the “8 · 18” mountain torrent disaster in Datong

County. Two typical precipitation processes were selected for detailed evaluation, incorporating data from 98 regional automatic weather stations [Figure 4: see original paper] to improve assessment accuracy.

August 12–15, 2022 Precipitation Process Error evaluation shows average errors ranging from -0.294 to 2.828 mm, absolute errors from 0.112 to 6.104 mm, and RMSE from 0.144 to 7.338 mm across the three products. CMPAS shows the smallest errors and is closest to observations .

During this process, observed average precipitation was 21.7 mm, with the maximum center at Yong'an Village, Hongshuiquan Township, Ping'an (143.8 mm). The event produced 98 light rain stations, 28 moderate rain stations, 6 heavy rain stations, and 2 storm stations, with storms concentrated in the eastern agricultural region on August 14.

CMPAS shows an average of 26.7 mm (slightly higher than observed), with the maximum center correctly located at Yong'an Village (128.1 mm, close to observed). It captured 99 light rain, 28 moderate rain, 6 heavy rain, and 1 storm station, closely matching observations. CLDAS shows an average of 18.1 mm (underestimation), with the maximum center incorrectly located and significantly underestimated (58.0 mm). It captured fewer heavy precipitation stations overall. CRA shows an average of 10.4 mm (significant underestimation), with the maximum center inconsistent and underestimated (62.4 mm), and notably fewer storm stations [Figure 5: see original paper].

Daily variation analysis shows precipitation concentrated on August 14. CMPAS and CLDAS correctly captured this timing, while CRA was 1–2 days early [Figure 6: see original paper]. TS scores decrease with increasing precipitation intensity, and none of the products accurately captured torrential rain. However, CMPAS TS scores (0.82–0.98) are significantly higher than the other two products [Figure 7: see original paper].

August 17–18, 2022 Precipitation Process Error evaluation shows average errors ranging from -0.117 to 7.068 mm, absolute errors from 0.117 to 7.068 mm, and RMSE from 0.118 to 7.116 mm. CMPAS again shows the smallest errors .

Observed average precipitation was 7.9 mm, with the maximum center at Laorigen Village, Mole Town, Qilian (80.9 mm). The event produced 98 light rain, 15 moderate rain, 4 heavy rain, and 2 storm stations, with storms in Xining and Datong on August 17.

CMPAS shows an average of 15.4 mm (nearly double observed), with the maximum center at WariGa Village, Mole Town, Qilian (78.3 mm), consistent with observations. It captured 99 light rain, 16 moderate rain, 4 heavy rain, and 1 storm station, with heavy precipitation areas and frequencies close to observed. CLDAS shows an average of 22.1 mm (significant overestimation), with the maximum center incorrectly located and underestimated (58.0 mm). CRA shows an average of 6.3 mm (slight underestimation), with the maximum center correctly located but significantly underestimated (47.1 mm), and notably fewer heavy precipitation stations [Figure 8: see original paper].

All three products correctly captured the precipitation timing on August 17 [Figure 9: see original paper]. TS scores again show CMPAS performing best across all precipitation grades, though all products underestimated storm events [Figure 10: see original paper].

Overall, for these two precipitation processes, CMPAS most accurately reflects accumulated rainfall, correctly identifies maximum precipitation centers and intensities, and best captures the timing and location of heavy precipitation. While storm events are underestimated, CMPAS significantly outperforms the other products in representing other precipitation grades.

3. Discussion

In current weather and climate operations, the demand for refined gridded precipitation products is increasingly urgent. This study evaluated the performance of CMPAS, CLDAS, and CRA in depicting precipitation over the eastern Qinghai-Xizang Plateau. CMPAS generally performs well in reflecting precipitation conditions but underestimates torrential rain events, consistent with findings by Yu et al. and Pan et al. CLDAS shows unstable performance across different precipitation intensities, similar to results reported by Wang et al. CRA overestimates overall precipitation, consistent with Wang et al.'s findings.

Through this evaluation, we understand the applicability of three precipitation products at different scales in the eastern plateau, enabling selection of optimal products for research and operations. This provides data support for refined monitoring in sparsely instrumented areas and benefits climate operations and disaster prevention. However, this study has limitations. First, it only compared domestically developed products without including international high-quality datasets, making comprehensive performance assessment and global ranking difficult. Second, the short evaluation period limits assessment of long-term applicability, and product accuracy across different elevations and terrains requires further investigation. Third, multi-source data accuracy is heavily constrained by data source selection, weight allocation, and assimilation/fusion methods, creating dataset uncertainties that require further optimization. Most existing precipitation products rely on traditional statistical models for data fusion. While combining data fusion with machine learning faces challenges, it offers new development opportunities.

4. Conclusions

This study evaluated the applicability of three high-resolution precipitation products in the eastern Qinghai-Xizang Plateau, with main conclusions as follows:

1. For annual precipitation in the eastern plateau, CMPAS shows the smallest error and strongest correlation with observations, significantly outperforming CLDAS and CRA. CLDAS overestimates annual precipitation while CRA underestimates it with larger errors and weaker correlation. CMPAS should be prioritized for annual-scale precipitation analysis.

2. In terms of seasonal variation, CMPAS monthly precipitation values are closest to observations with minimal error and high correlation. CLDAS overestimates precipitation in most months, while CRA underestimates in most months with poor correlation. CMPAS should be prioritized for monthly-scale precipitation analysis.

3. During two large-scale precipitation processes, CMPAS most accurately captured accumulated rainfall, correctly identified maximum precipitation centers and intensities, and properly represented light to heavy rainfall categories, timing, and spatial distribution. CMPAS demonstrates the best performance for analyzing precipitation processes in the eastern Qinghai-Xizang Plateau.

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