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Accuracy Assessment of Precipitation Products from GPM IMERG and CAPPI Ground Radar over South Korea

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Abstract: High-quality precipitation data are crucial for various industries, including disaster prevention. In South Korea, long-term high-quality data are collected through numerous ground observation stations. However, data between these stations are reprocessed into a grid format using interpolation methods, which may not perfectly match actual precipitation. A prime example of real-time observational grid data globally is the Integrated Multi-satellite Retrievals for Global Precipitation Measurement (GPM IMERG) from National Aeronautics and Space Administration (NASA), while in South Korea, ground radar data are more commonly used. GPM and ground radar data exhibit distinct differences due to their respective processing methods. This study aims to analyze the characteristics of GPM and Constant Altitude Plan Position Indicator (CAPPI), representative real-time grid data, by comparing them with ground-observed precipitation data. The study period spans from 2021 to 2022, focusing on hourly data from Automated Synoptic Observing System (ASOS) sites in South Korea. The GPM data tend to underestimate precipitation compared to ASOS data, while CAPPI shows errors in estimating low precipitation amounts. Through this comparative analysis, the study anticipates identifying key considerations for utilizing these data in various applied fields, such as recalculating design rainfall, thereby aiding researchers in improving prediction accuracy by using appropriate data.

Keywords: ASOS, CAPPI, GPM, Precipitation

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1. Introduction

Precipitation significantly impacts agriculture and ecosystems, and recently, the severity of heavy rainfall events has escalated, exacerbating both environmental issues and economic damages (Kim et al., 2023). In South Korea, there are over 100 Automated Synoptic Observing System (ASOS) stations and more than 600 Automated Weather System (AWS) stations. Nevertheless, there is an increasing demand for more spatially detailed and precise observational data. For this reason, various methodologies have been employed to generate gridded precipitation data for research purposes (Hwang and Ham, 2013).

In South Korea, efforts have been made to produce gridded data, including the development of modified Parameter-elevation Regressions on Independent Slope Model for South Korea (K-PRISM) (Hong et al., 2007), which is tailored to Korean topography and based on the PRISM developed by Oregon State University (Daly et al., 1994; 2002). These efforts aim to achieve results that closely approximate actual observations (Jeong and Eum, 2015). One of the well-known hourly gridded observational data is the Tropical Rainfall Measuring Mission (TRMM) provided by the National Aeronautics and Space Administration (NASA). However, TRMM has limitations in accurately reflecting the complex climate patterns of South Korea (Shon, 2020).

The Integrated Multi-satellite Retrievals for Global Precipitation Measurement (GPM IMERG) offers high-resolution precipitation data globally at 30-minute intervals and 10 km spatial resolution, enhancing the accuracy of precipitation estimates through the utilization of multiple satellites (Huffman et al., 2023). In South Korea, the Korea Meteorological Administration (KMA) provides 1 km resolution ground radar reflectivity data via its Application Programming Interface (API), and extensive research is being conducted to convert this reflectivity data into rainfall intensity (Choi et al., 2018). Additionally, KMA provides representative radar reflectivity data, Constant Altitude Plan Position Indicator (CAPPI), and representative gridded observation data such as radar data. There are few studies that compare GPM IMERG and CAPPI with ground-based precipitation data. Therefore, in this study, various evaluation techniques were applied to compare and analyze the potential issues that may arise when directly utilizing improved radar and GPM data by comparing them with ground-based precipitation data.

2. Materials and Methods

2.1. GPM IMERG

In this study, we utilized the GPM IMERG V07, which enhances the detection capability of light precipitation (less than 0.5 mm) through the addition of high-frequency channels at 165.5 GHz and 183.3 GHz on the GPM Microwave Imager (GMI). This improvement is crucial for accurately capturing light rainfall events, which are often challenging to measure with lower-frequency channels. V07 includes climate coefficients, improving the overall accuracy of the data. We used the Final Run, which provides data approximately 3.5 months after the observation month, ensuring the highest possible quality of post-processed data. The spatial resolution of the GPM IMERG data is 0.1°, and it offers a temporal resolution of 30 minutes. For this study, we converted the 30-minute precipitation data into hourly precipitation amounts to match the temporal resolution of the ground-based observations and facilitate direct comparison.

2.2. Ground Radar CAPPI

The ground radar reflectivity data, measured and stored in binary format, are provided by the KMA. The CAPPI provides radar reflectivity factors in dBZ with a spatial resolution of 1 km and a temporal resolution of 10 minutes. These high-resolution data are crucial for capturing detailed precipitation patterns across South Korea. To estimate the rainfall intensity from radar reflectivity, the Z-R relationship shown in Eq. (1) is utilized.

$$Z = \alpha \times R^{\beta} \tag{1}$$

Here, α and β have been derived and published in various studies, with the Z-R relationship proposed by Marshall and Palmer (1948) being widely used (Ayo et al., 2015). In this study, we applied the coefficients α=148 and β=1.59 as suggested by Ro et al. (2022) to estimate rainfall intensity.

The CAPPI data's high spatial and temporal resolution makes it an invaluable resource for analyzing precipitation events with greater accuracy. By integrating CAPPI data with other observational data, such as ASOS and GPM IMERG, this study aims to provide a comprehensive assessment of precipitation patterns and improve the understanding of rainfall dynamics in South Korea. The application of CAPPI data allows for detailed analysis and validation of rainfall estimates, contributing to more reliable and precise precipitation modeling.

2.3. ASOS

The ground observation data used in this study are from the ASOS in South Korea, as shown in Fig 1. We selected 95 stations that have been continuously operating from January 2021 to December 2022 for comparative analysis. The ASOS precipitation observations primarily use a weighing precipitation gauge, which measures the weight of collected water in a storage container.

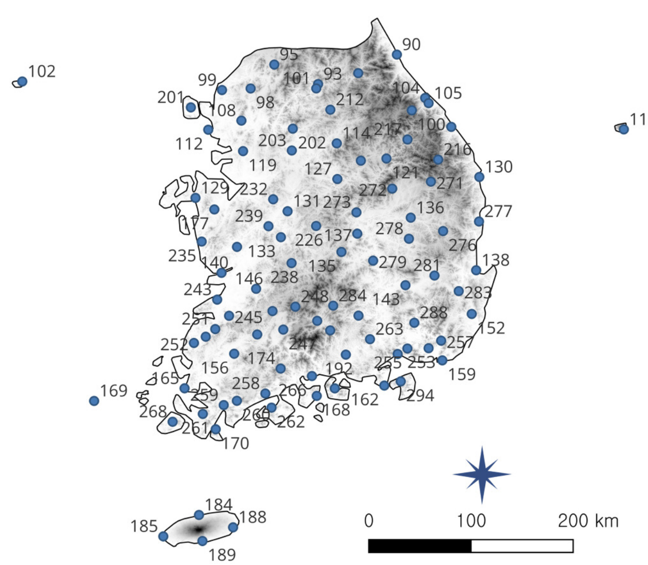

Fig. 1. Locations of ASOS stations in South Korea.

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2.4. Performance Evaluation Metrics

In this study, GPM and CAPPI data were averaged within a 20 km radius around the nearest grid point to each ASOS station for comparative evaluation. To validate the data extracted at each station against ground observation data, the Correlation Coefficient (CC) was calculated. For quantitative comparison, Root Mean Squared Error (RMSE) and Relative RMSE (rRMSE) were computed. The rRMSE used in this evaluation is defined by Eq. (2), where an rRMSE below 10% is considered excellent, between 10% and 20% is good, between 20% and 30% is fair, and above 30% is poor (Despotovic et al., 2016).

$$rRMSE = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(Ref - Pred)^2}}{\sum_{i=1}^{n} Ref} \times 100(\%) \tag{2}$$

In addition to rRMSE, sensitivity was used to verify the accuracy of precipitation detection, and specificity was evaluated to compare the accuracy when there is no precipitation. These metrics were employed to assess the performance of GPM and CAPPI against ground observation precipitation data (Table 1).

Table 1. Contingency table for comparison of GPM and CAPPI with ASOS gauge

Condition	ASOS ≥ 0.5 mm/hr	ASOS < 0.5 mm/hr
GPM, CAPPI ≥ 0.5 mm/hr	x	y
GPM, CAPPI < 0.5 mm/hr	w	z

Given that the addition of 166 and 183 GHz sensors to the GMI has improved the observation accuracy of GPM IMERG for light rain, the accuracy verification was conducted with a threshold of 0.5 mm/hr.

$$Sensitivity = \frac{x}{x+w} \tag{3}$$

$$Specificity = \frac{z}{y+z} \tag{4}$$

3. Results

In this study, various evaluations were conducted to understand the characteristics of GPM IMERG and ground radar CAPPI in comparison with precipitation data from the ASOS stations. First, Fig. 2 shows the scatter plots representing the rainfall intensity using ASOS precipitation data, GPM IMERG, and CAPPI. The results indicate that GPM tends to underestimate rainfall as the amount increases. On the other hand, a comparison with ASOS data revealed that CAPPI has a smaller tendency to underestimate compared to GPM IMERG, but the rainfall distribution is more scatted compared to the GPM IMERG data. This scattering suggests that while CAPPI provides a closer estimation of ground observations, there are still discrepancies in the rainfall distribution patterns. These results highlight the limitations and strengths of using satellite and radar data for rainfall estimation. The tendency of GPM to underestimate

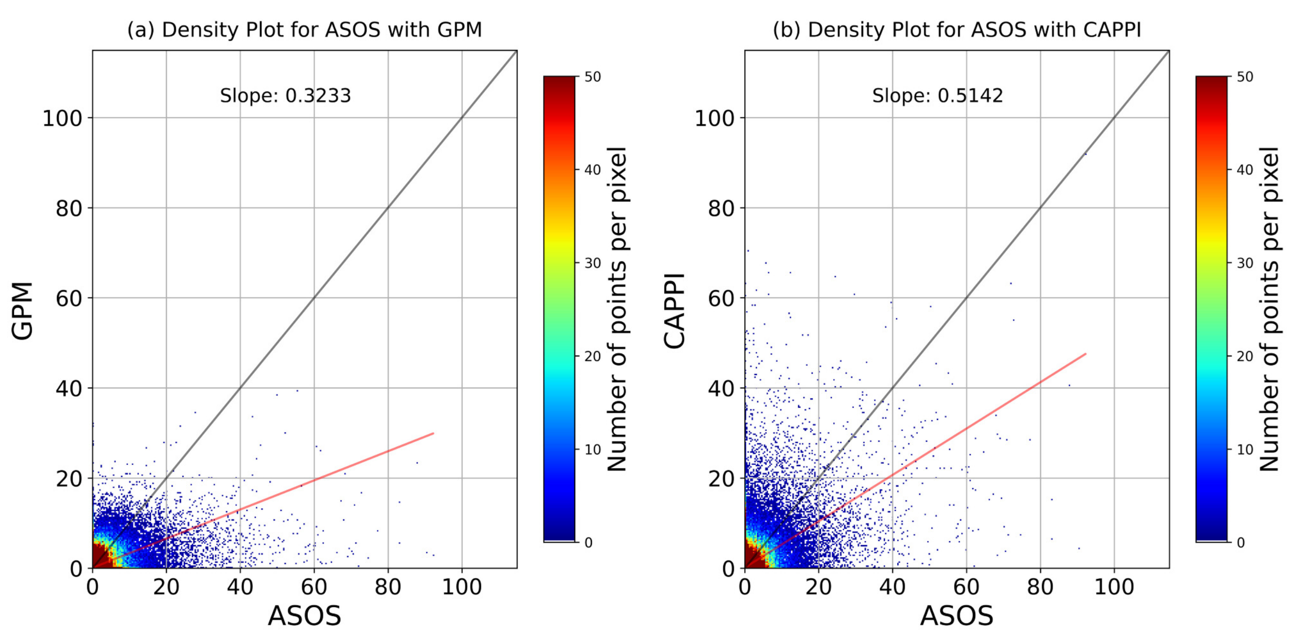

Fig. 2. Comparative density plots for ASOS with (a) GPM and (b) CAPPI.

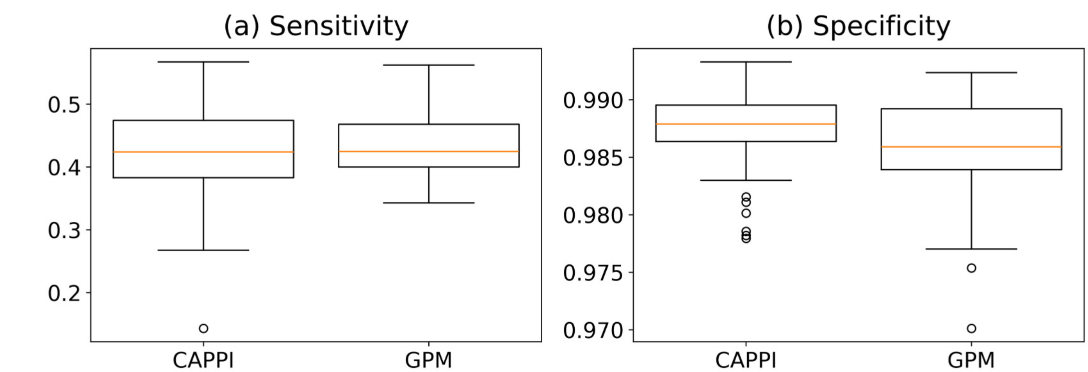

Fig. 3. Comparative sensitivity and specificity of precipitation detection.

high rainfall events may impact its applicability in regions experiencing heavy precipitation. Meanwhile, the scattered distribution in CAPPI data suggests the need for further refinement in radar-based rainfall estimation methods.

The results of analyzing sensitivity and specificity for rainfall detection performance at each station are shown in Fig. 3. Sensitivity measures the ability of CAPPI and GPM to correctly predict rainfall events when they are present at the ASOS stations. Overall, both CAPPI and GPM demonstrated similar performance in terms of sensitivity. However, there were certain stations where CAPPI exhibited lower prediction performance.

The overall sensitivity averaged across all stations was 0.4109 for CAPPI and 0.4300 for GPM, indicating almost similar performance. Specificity measures the ability of CAPPI and GPM to correctly predict the absence of rainfall when no rainfall is observed at the ASOS stations. The results indicated excellent prediction performance for both CAPPI and GPM across all stations. The overall specificity for all stations was 0.9876 for CAPPI and 0.9858 for GPM. These results suggest that while CAPPI and GPM are comparable in their ability to detect rainfall, there is room for improvement in CAPPI's performance at certain locations. The high specificity values for both datasets highlight their reliability in predicting non-rainfall events, which is crucial for accurate weather forecasting and modeling.

The analysis of GPM and CAPPI's prediction performance considering the critical changes in rainfall at ASOS stations is shown in Fig. 4. The changes in correlation coefficients with varying rainfall thresholds were examined by setting thresholds from 1mm to 50 mm per hour and extracting the correlation coefficients for values below each threshold. For GPM, the correlation coefficient peaked at 0.5517 at a threshold of 18mm per hour and gradually decreased. In contrast, CAPPI showed

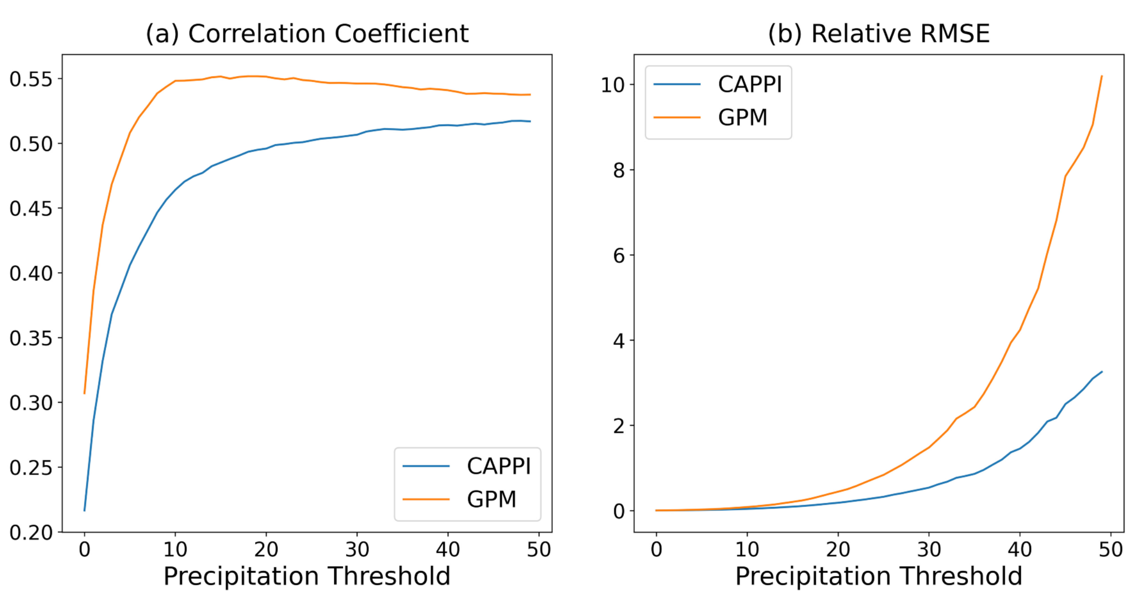

Fig. 4. Impact of precipitation threshold on (a) CC and (b) RMSE between GPM (orange) and CAPPI (blue).

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the highest correlation coefficient of 0.5173 at a threshold of 48mm per hour. Additionally, while GPM's correlation coefficient initially increased and then decreased when compared with ASOS rainfall data, CAPPI's correlation coefficient continuously increased with increasing rainfall amounts.

Fig. 4(b) shows the results of rRMSE calculated for values exceeding each rainfall threshold, with the thresholds adjusted based on ASOS data. Both GPM and CAPPI showed an increasing trend in rRMSE as the rainfall threshold increased. However, CAPPI demonstrated lower sensitivity to increases in rainfall amounts compared to GPM. Since an rRMSE below 10% indicates excellent data quality, it can be concluded that both GPM and CAPPI provided very good data quality based on the rRMSE evaluation.

4. Discussion and Conclusions

This study compared the real-time gridded observational data from GPM IMERG and ground radar CAPPI with hourly precipitation data from ASOS stations in South Korea to elucidate the characteristics of these data. The results showed that GPM IMERG tended to underestimate precipitation amounts when compared to ground observations. Additionally, the performance of GPM IMERG, as measured by correlation coefficient and rRMSE, deteriorated with increasing precipitation amounts.

However, CAPPI, while exhibiting more scattered precipitation distribution compared to ground observations, generally showed better slopes than GPM. The relatively small changes in rRMSE with varying precipitation thresholds suggest that CAPPI's performance does not significantly degrade with increasing precipitation amounts. Although GPM demonstrated superior performance at around 15 mm/hour precipitation, the performance of ground radar surpassed that of GPM as precipitation amounts increased. Therefore, it is essential to select the appropriate data based on the research focus.

This study includes data from all seasons (spring, summer, autumn, and winter) for the years 2021 and 2022. The analysis might differ if focused on the summer, which is considered the peak rainfall period in South Korea. These findings underscore the importance of selecting the appropriate data source depending on the specific requirements of the study, particularly when analyzing high rainfall events. Future research should focus on refining the estimation methods for both GPM and CAPPI, especially in regions with varying precipitation patterns.

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Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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