Reply to "Comments on 'Error Analysis of Satellite Precipitation Products in Mountainous Basins'"

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Evaluation on the accuracy of global satellite precipitation products is of great interest to the hydrologic community. Recently, Mei et al. (2014) evaluated the performance of four widely used satellite precipitation products over an Alpine basin in northeastern Italy. Yong (2015) commented on the representativeness of these results by comparing their findings to other studies, giving particular emphasis on a similar evaluation study over mainland China. The four quasi-global satellite products involved in Mei et al. (2014) are the TMPA 3B42 in real time [3B42-RT; calibrated according to the climatology of TMPA 3B42, version 6 (3B42-V6); hereafter named 3B42-RT-CCA]; TMPA 3B42, version 7 (3B42-V7); Climate Prediction Center (CPC) morphing technique (CMORPH); and PERSIANN [see section 2b in Mei et al. (2014) for descriptions]. Yong (2015) states that selection of real-time products [e.g., QMORPH (a variation on CMORPH), Global Satellite Mapping of Precipitation in near–real time (GSMaP_NRT), and the uncalibrated 3B42-RT (hereafter named 3B42-RT-UC)] would have been more appropriate for evaluating the potential of satellite precipitation estimation in real-time hydrological applications. We agree that the near-real-time satellite datasets can be of great interest to the hydrologic community focusing on flood hazard warnings. However, we believe that evaluation of post-real-time satellite precipitation products provides evidence on their potential use for a number of water resource applications (e.g., water budget calculations, derivation of precipitation intensity–frequency–duration curves, and derivation of rainfall thresholds for hydrologic hazard warning systems), which is of interest to the hydrologic community as well. Moreover, Mei et al. (2014) presented a comparison of a near-real-time (i.e., the 3B42-RT-CCA) product with the corresponding gauge-adjusted (3B42-V7) product, which provides an assessment on the effectiveness of current climatological and post-real-time adjustment techniques in satellite precipitation estimation.

The comments in Yong (2015) focused particularly on the results reported in Table 4 of Mei et al. (2014) and specifically regarding the effect that climatological gauge adjustment may have on the random error of satellite estimates for moderate to high rainfall rates. Yong (2015) states that "[b]ecause of the dynamic balance between systematic and random errors caused by the CCA, we speculate that the RMSE values of uncalibrated 3B42-RT might also be lower than 3B42-RT in this Italian basin." To address this point, we have expanded the analysis presented in Table 4 of Mei et al. (2014) to include the 3B42-RT-UC product and contrasted its error characteristics to the corresponding error properties of the climatological-mean-adjusted (3B42-RT-CCA) and post-real-time (3B42-V7) products. Results shown in Table 1 confirm the quoted statement by Yong (2015); namely, 3B42-RT-UC is characterized with a lower degree of random error than that of the 3B42-RT-CCA at event scale. Moreover, the cold season error statistics [RMSE and correlation coefficient (CC)] of 3B42-RT-UC exhibit improvements over both 3B42-V7 and 3B42-RT-CCA.

Yong (2015) further commented on the results and justification we gave regarding the higher cold season correlation coefficient values in 3B42-RT-CCA relative to 3B42-V7. Mei et al. (2014) stated that this is due to the

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TABLE 1. Satellite product evaluation statistics (RMSE and CC) for storm events exceeding the 90th quantile of storm events in our database. Boldface indicates best results among products.

Periods	Statistics	3B42-RT-CCA	3B42-RT-UC	3B42-V7
Warm	CC	0.38	0.44	**0.51**
	RMSE	0.66	0.45	**0.38**
Cold	CC	0.34	**0.39**	0.04
	RMSE	0.72	**0.50**	0.54

storm characteristics of the cold season upon which climatological (i.e., long term) gauge adjustment has a higher degree of influence relative to the monthly based gauge adjustment. We recognize that the justification provided in Mei et al. (2014) is speculative since we have not provided evidence on the spatiotemporal variability of storms in the two regimes (cold vs warm); this is an interesting research question but beyond the scope of the work of Mei et al. (2014). We should point out that differences between 3B42-RT-CCA and 3B42-V7 are attributed to differences in their respective processing algorithms (i.e., different adjustment schemes) since they are both derived from the original uncalibrated 3B42-RT. Yong (2015) states that "[t]he statistics in [Mei et al.'s] Table 4 are just regarded as a reflection of the large uncertainties for TRMM-based multisatellite precipitation estimates during the cold season"; while that may provide an explanation of a general degraded performance of satellite products during the cold season, it cannot explain the seasonal change in the relative difference between 3B42-RT-CCA and 3B42-V7.

Yong (2015) also commented on the results in Figs. 5 and 7 from Mei et al. (2014) regarding the relative performance of satellite products. According to Mei et al. (2014), the two 3B42 products (i.e., 3B42-RT-CCA and 3B42-V7) yield better performance, especially 3B42-V7, compared to the CMORPH and PERSIANN products. Yong (2015) argues that this finding cannot be generalized, as the two 3B42 algorithms may not always be superior to CMORPH or PERSIANN, pointing to, as an example, the Shen et al. (2010) study and differences in the results presented therein for the upper–middle Huai River basin. We recognize the heterogeneity in hydroclimate and land surface properties of the Huai River basin relative to the Alpine Alto Adige basin. As stated in Mei et al. (2014, p. 1791), satellite performances are expected to vary across different hydroclimatic regimes or geomorphologic regions; therefore, "results can only be generalized for similar mountainous regions and orographic-driven precipitation events." Having said that, we should point out that the post-real-time 3B42 product has been found to have a higher degree of consistency in some previous studies in the literature (AghaKouchak et al. 2011; Stampoulis and Anagnostou 2012; Behrangi et al. 2011). Furthermore, it is important to note that Figs. 5 and 7 in Mei et al. (2014) were derived based on basin-average storm event dynamics (i.e., storm totals accumulated over a precipitation event). The error statistics presented in Shen et al. (2010) were derived based on time series of rainfall rates at fixed time lengths (3-hourly, daily, or monthly) and determined over a large spatial domain. Arguably, different space–time aggregations of rainfall dynamics are expected to affect satellite error characteristics differently. Furthermore, the spatial extent of the Shen et al. (2010) error study (i.e., inclusion of mainland China) represents an aggregation of a variety of climatic patterns and geomorphologic regions, which are rather different from the Mediterranean climate and Alpine terrain of the Mei et al. (2014) study. Besides, Fig. 5 from Shen et al. (2010) shows that 3B42-V6 outperforms microwave combined (MWCOMB), which is a product that drives CMORPH rainfall estimates.

In summary, the differences in findings of the various satellite precipitation error studies appearing in the literature raises the need for a comprehensive error analysis that would be based on a consistent error methodology framework and supported by ground validation data from multiple climatic and geographic regions on Earth. Such a study, which is missing from the literature, requires a synergistic effort between multiple ground validation data providers.

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