Correction of Radar QPE Errors for Non-Uniform VPRs in Mesoscale Convective Systems Using TRMM Observations

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1. Introduction

As we know, water is a source of many hazards especially in the warm season. It is essential to monitor and predict water-related hazards, such as flash floods, debris flows, and to determine current and future availability of water resources. The radar network provides high-resolution observations on a scale of 1-10 km and every 5-min of rainfall, which is very important for detecting flash floods and mudslides that have small time and spatial scales and for the monitoring of precipitation rate and type in cities, farms, watersheds and along associated rivers and streams. Also, there is a basic necessity to monitor and predict water inputs into the hydrological cycle given that fresh water is an increasingly expensive resource, while the effective management and prediction of flooding has a direct economic impact on nearly all aspects of society. Every year, lots of severe weather systems, which are responsible for property and crop damage, interruption of travel and outdoor activity, and, in the most extreme cases, injuries and death, will attack the conterminous United States (CONUS). Mesoscale Convective Systems (MCSs) is one kind of the severe weather systems that will bring us large number of rainfall or excessive water. The current study mainly focuses on reducing the error of radar-based quantitative precipitation estimation (QPE) for MCSs in warm season.

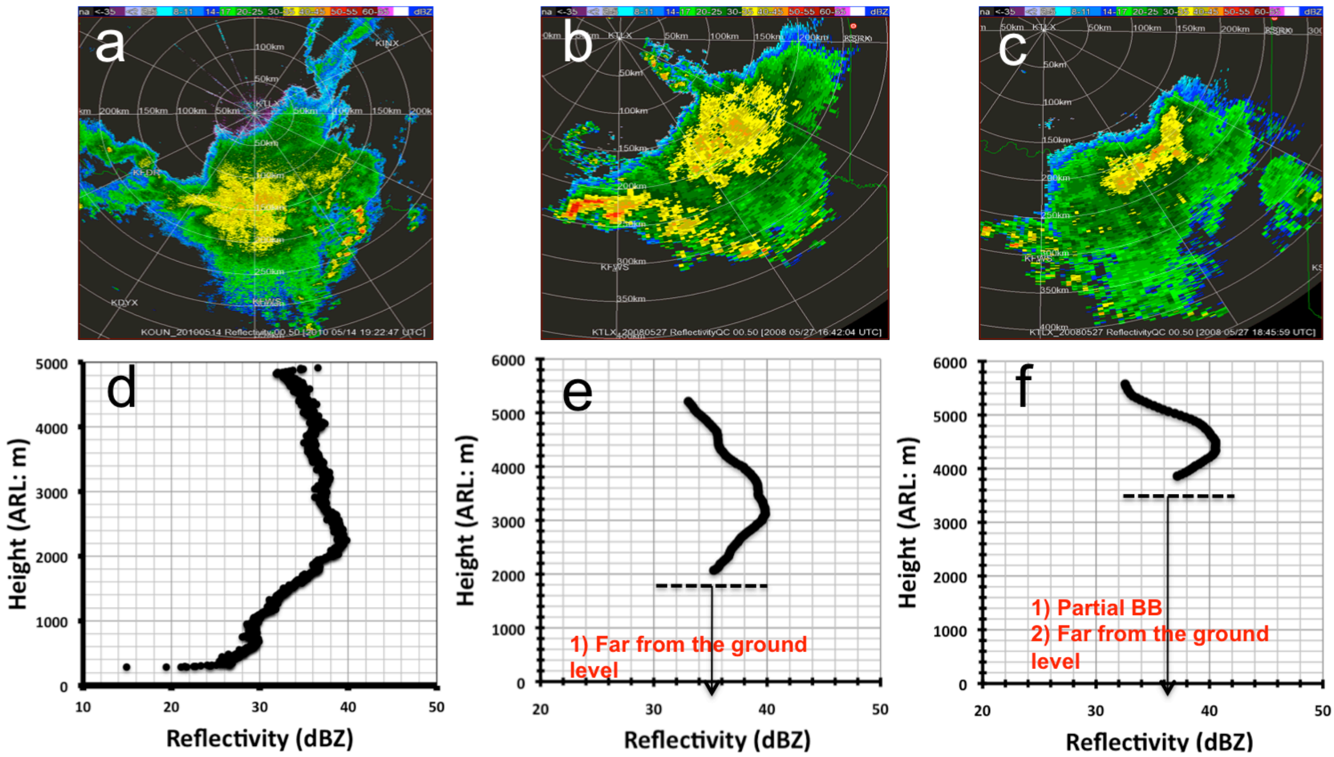

Fig. 1 (a), (b), and (c): the basic reflectivity from tilt 0.5°. (d), (e), and (f): the apparent VPRs from 0.5° tilt in (a), (b) and (c) respectively, which is derived through ZQ10 algorithm.

MCSs contain both regions of convective and stratiform precipitation, and a bright band (BB) or equivalent high-reflectivity region is often found in the stratiform precipitation. Inflated reflectivity intensities in the BB often cause positive biases in radar quantitative precipitation estimation (QPE), and a vertical profile of reflectivity (VPR) correction is necessary to reduce the error (Zhang and Qi 2010, hereafter ZQ10). VPR corrections of the radar QPE is more difficult for MCSs than for a widespread cool season stratiform precipitation because of the spatial non-homogeneity of MCSs. Further, microphysical processes in the MCS stratiform region are more complicated than in the large-scale cool season stratiform precipitation. A clearly defined BB bottom (Figs. 1a and 1d), which is critical for accurate VPR corrections, is often not found in ground radar VPRs from MCSs (Figs. 1b and 1e; Figs. 1c and 1f). This is a big challenge when the stratiform region of MCSs is far away from the radar (Figs. 1b and 1e; Figs. 1c and 1f) where the radar beam is too high or too wide to resolve the BB bottom. Further, variations of reflectivity below the freezing level are much more significant in MCSs than in a large-scale cool season precipitation, requiring high-resolution radar observations near the ground for an effective VPR correction.

The current study seeks to use the vertical precipitation structure observed from Tropical Rainfall Measuring Mission Precipitation Radar (TRMM PR) to aid VPR corrections of the ground radar QPE in MCSs. High-resolution VPRs are derived from TRMM data for MCSs and then applied for the correction of ground radar QPEs. The new method was tested on three MCS events from different regions in the United States and the methodology and the results will be addressed next.

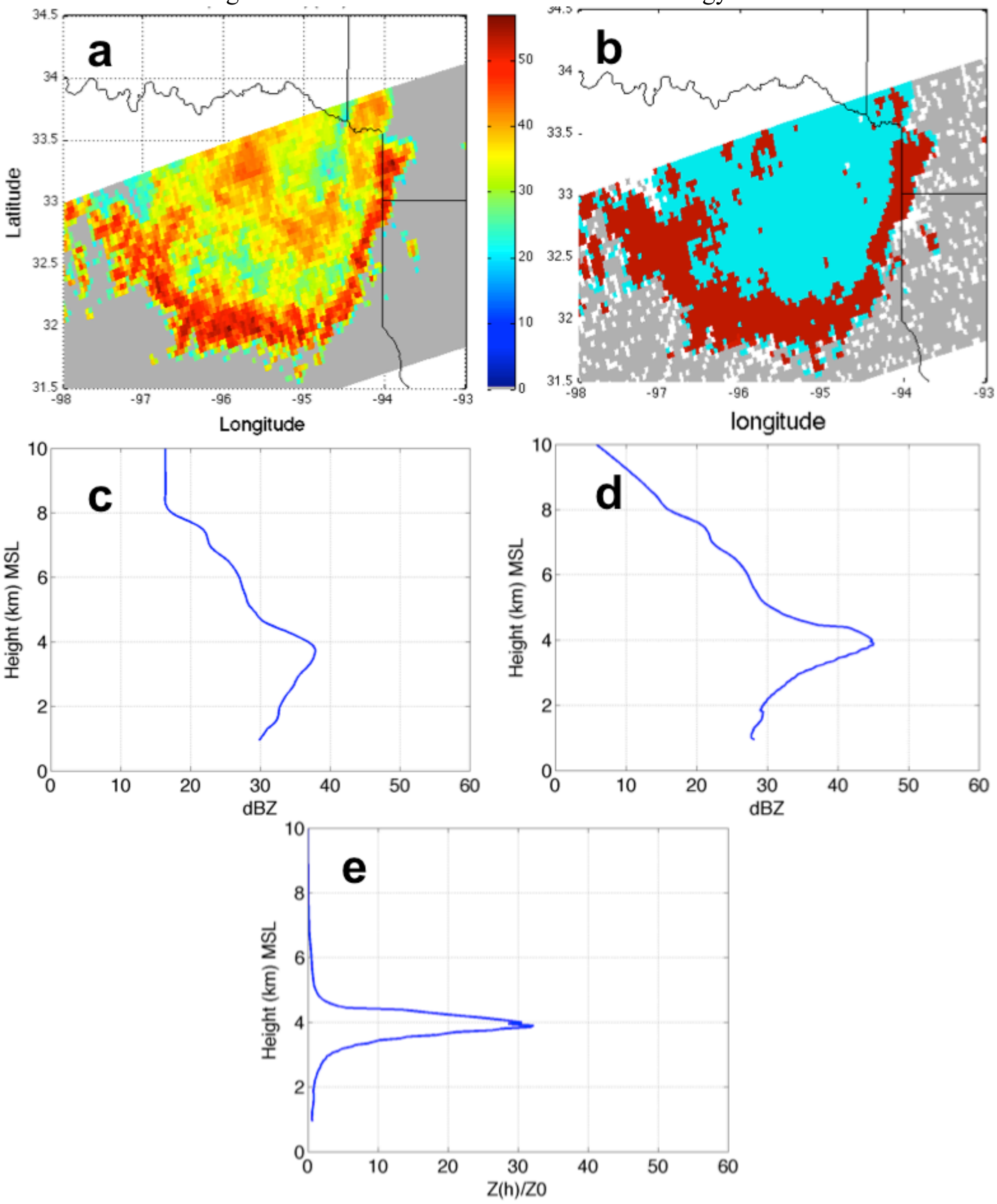

Fig. 2 (a) TRMM PR observed composite reflectivity, (b) rainfall types, convective (red area) and stratiform (light blue area) at 19:20UTC 27 May 2008. (c) TRMM PR averaged VPR from stratiform area where the composite reflectivity is not less than 30dBZ, (d) the corrected VPR from KU-band to S-band based on (c), and (e) the normalized VPR from (d).

2. Methodology

2.1 KU-band to S-band

In order to obtain representative VPR from TRMM PR observations (Fig. 2a), the rainfall is first segregated into two precipitation types (convective (red) and stratiform (light blue), Fig. 2b), and then derive the mean VPR (Fig. 2c) from the stratiform area with the composite reflectivity (Fig. 2a) not less than a threshold (default=30dBZ). However, TRMM PR operating at Ku band (13.8 GHz) often suffers scattering effects and attenuation, and the attenuation has been corrected by a combination of the surface reference and Hitschfeld-Bordan methods (Iguchi et al. 2000). In order to solve the scattering effects, the TRMM PR observations need to be converted from Ku-band to S-band. The conversion of radar reflectivity from Ku-band to S-band is based on the empirical polynomial relations between Ku- and S-band radar reflectivity. The development of these empirical relations depends on the scattering theory, which is utilized to simulate the radar reflectivity. The scattering amplitudes for different hydrometers (e.g., raindrop, ice particle, and snowflake) are calculated using the T-matrix method with the appropriate assumption of particle shape, density, and orientation of ice, snowflake, raindrop, and melting ice/snowflake. It is worth noting that different microphysical processes exist in three regions of the storm, which are ice, melting, and rain regions from the storm top to the surface. To simulate the radar reflectivity, the particle size distribution (PSD) is assumed to be exponential form in ice and melting regions while the PSD in rain region, i.e. raindrop size distribution (DSD), is assumed to be gamma distribution. The melting process is assumed to be linear with the change of the height. The procedure for deriving the empirical relations is briefly described as follows:

- Calculate the scattering amplitudes for different sizes of ice, snowflake, raindrop, or melting ice/snowflake.
- Assume the parameters of PSD/DSD be uniformly distributed within a given range and calculate Ku- and S-band radar reflectivity for each PSD/DSD.
- Use the polynomial regression method to fit the scatter data points of Ku- and S-band reflectivity and acquire the empirical conversion relations for different microphysical processes.

In this study, we have derived the conversion relations for dry ice, dry snow, rain, melting ice and melting snow. The latter two have been developed with a series melting ratios (use an increase of 5% from 0 to 100%) to account for the linear melting process within the melting layer. A composite conversion scheme using these relations is then developed for the directly conversion of Ku-band vertical profile of reflectivity (Figs. 2c vs. 2d).

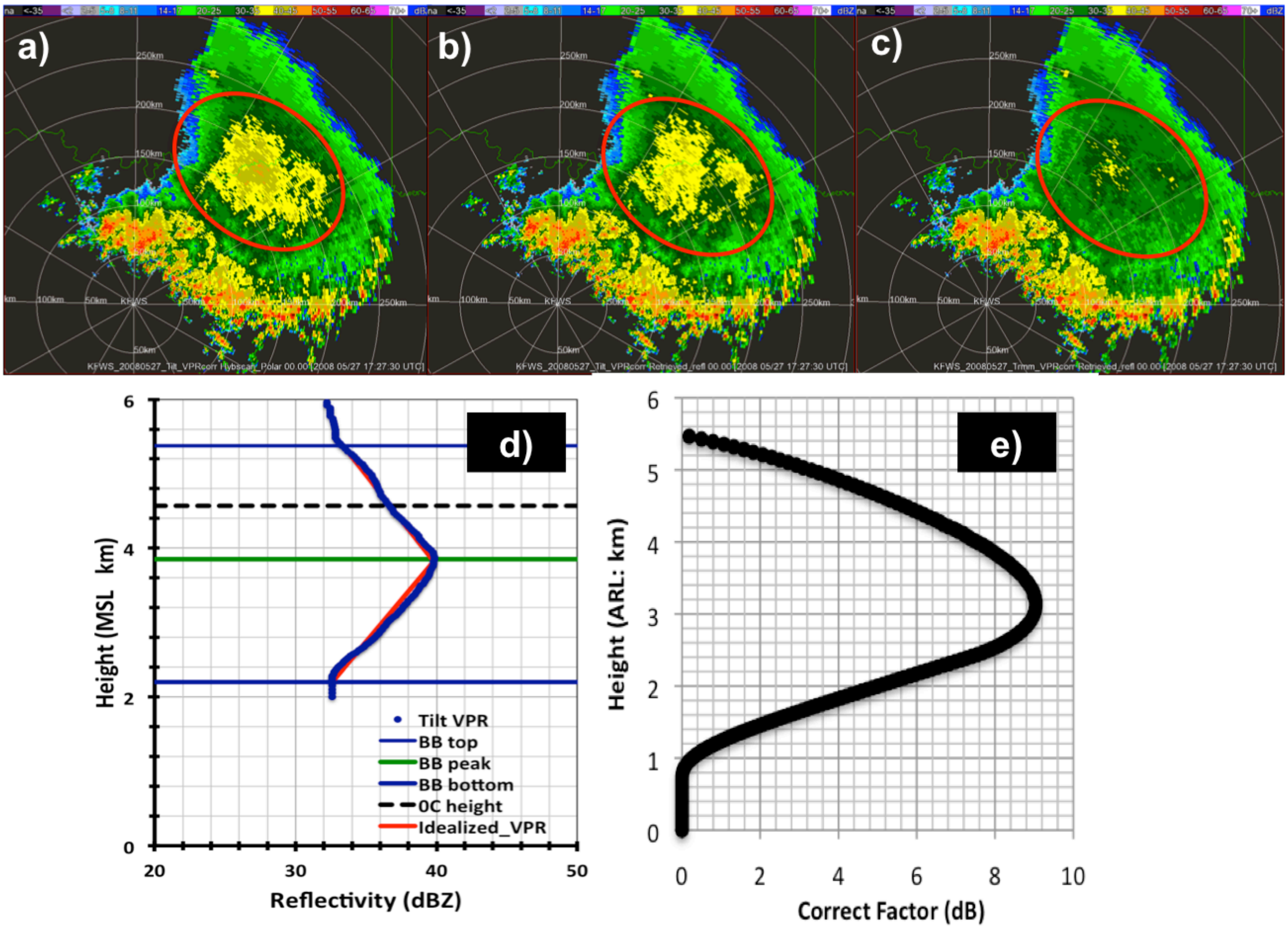

Fig. 3 Base level reflectivities 0.5°: (a) before apparent vertical profile of reflectivity (AVPR), (b) after the AVPR correction with ZQ10, and (c) after the VPR correction with NEW (TRMM VPR correction). These images are from KFWS at 17:27UTC 27 May 2008. d) the AVPR derived from (a) with ZQ10, and (e) Reflectivity correct factor calculated with $10 \bullet \log_{10}(\int_{x=h-\Delta h}^{x=h+\Delta h} \rho(x) \bullet f^4(x) \bullet dx)$ *from Fig.2e.*

2.2 VPR correction

The VPR corrected reflectivity, $\hat{Z}(h_0)$, is obtained by:

$$\hat{Z}(h_0) = Z_{obs}(h) - 10 \bullet \log_{10}\left(\int_{x=h-\Delta h}^{x=h+\Delta h} \rho(x) \bullet f^4(x) \bullet dx\right) \tag{1}$$

Where h_0 is a low level reference height (the ground level), and $Z_{obs}(h)$ is the observed reflectivity from a WSR-88D radar. h is the height of the beam center, and Δh is the half beam width. $f^4(x)$ is the two-way radar antenna gain function, and ρ is the normalized VPR derived from section 2.1 (Fig. 2e). It can be expressed as:

$$\rho(h) = Z(h)/Z(h_0) \tag{2}$$

$Z(h)$ and $Z(h_0)$ are reflectivities (Unit: dBZ) in the parameterized or volume mean VPRs at the heights of h and h_0, respectively. The 4/3 earth radius model is assumed for the beam propagation path.

Figure 3a shows a MCSs precipitation event from radar KFWS at 17:27UTC 27 May 2008, and the high-reflectivity region (BB area) behind the squall line has been flagged (red circle in Fig. 3a), which will result in large overestimation of radar QPE. Fig. 3b shows that the high-reflectivity region in Fig. 3a has been corrected with apparent vertical profile of reflectivity (AVPR, Fig. 3d), which is derived with ZQ10. However, the ground radar can't provide full AVPR (Fig. 3d) due to the stratiform region of MCSs is far away from the radar, and the derived BB bottom from AVPR is ~2km far away from the radar site level. So the correction with ZQ10 has insufficiently reduced the BB affecting rainfall (Fig. 3b), and however, Fig. 3c shows that the BB affecting rainfall can be further corrected with the new derived reflectivity correct factor (Fig. 3e).

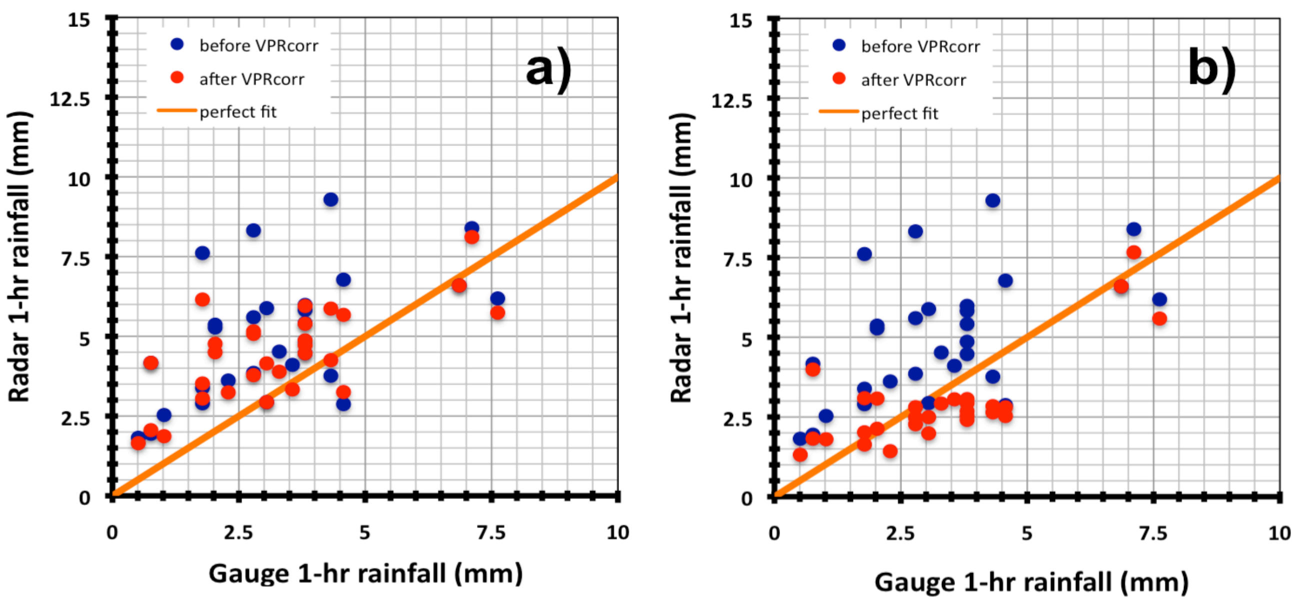

Fig. 4 Scatter plots of hourly radar precipitation estimates versus gauge observations before (blue dots) and after (red dots) a VPR correction using the ZQ10 (a) and the NEW (b) methods. The data are from KFWS 1300–2000 UTC 27 May 2008.

3. Case study

In the current study, the reflectivity field is converted into rainfall rate using two Z–R relationships: one for convective areas ($Z=300R^{1.4}$) and the other one for stratiform areas ($Z=200R^{1.6}$). The rainfall rates are aggregated into hourly rainfall and compared to the surface gauge observations. Appropriate convective and stratiform rainfall separation algorithm (Qi et al. 2012) will lead to a proper Z-R relationship application. Fig. 4 shows a comparison of hourly radar rainfall estimates before and after VPR correction algorithms (ZQ10 and New) against gauge observations for one MCSs event occurred on 27th May 2008. Radar estimates with New agree with gauge observations much better than those with ZQ10. As Fig. 4 shows, both new and ZQ10 approaches improve the radar rainfall estimation, which may be degraded by BB contamination, and the severe overestimation can be effectively reduced. Compared to ZQ10, the New approach provide a further improvement on the BB effect mitigation.

Figure 5 shows that the three scores of radar hourly rainfall estimates with respect to the Hydrometeorological Automated Data System (HADS, http:/www.nws.noaa.gov/oh/hads) observations for 6 radars during the three events. Both ZQ10 and the current VPR correction techniques significantly reduced the radar overestimation errors due to bright band effects. The new technique performed consistently better than the ZQ10 in all three statistic scores. The most significant improvements are for KTLX20080527, where the hourly RMSE error was reduced more than 3.5mm (Fig.5a) and the relative mean bias was reduced more than 77% (Fig.5c).

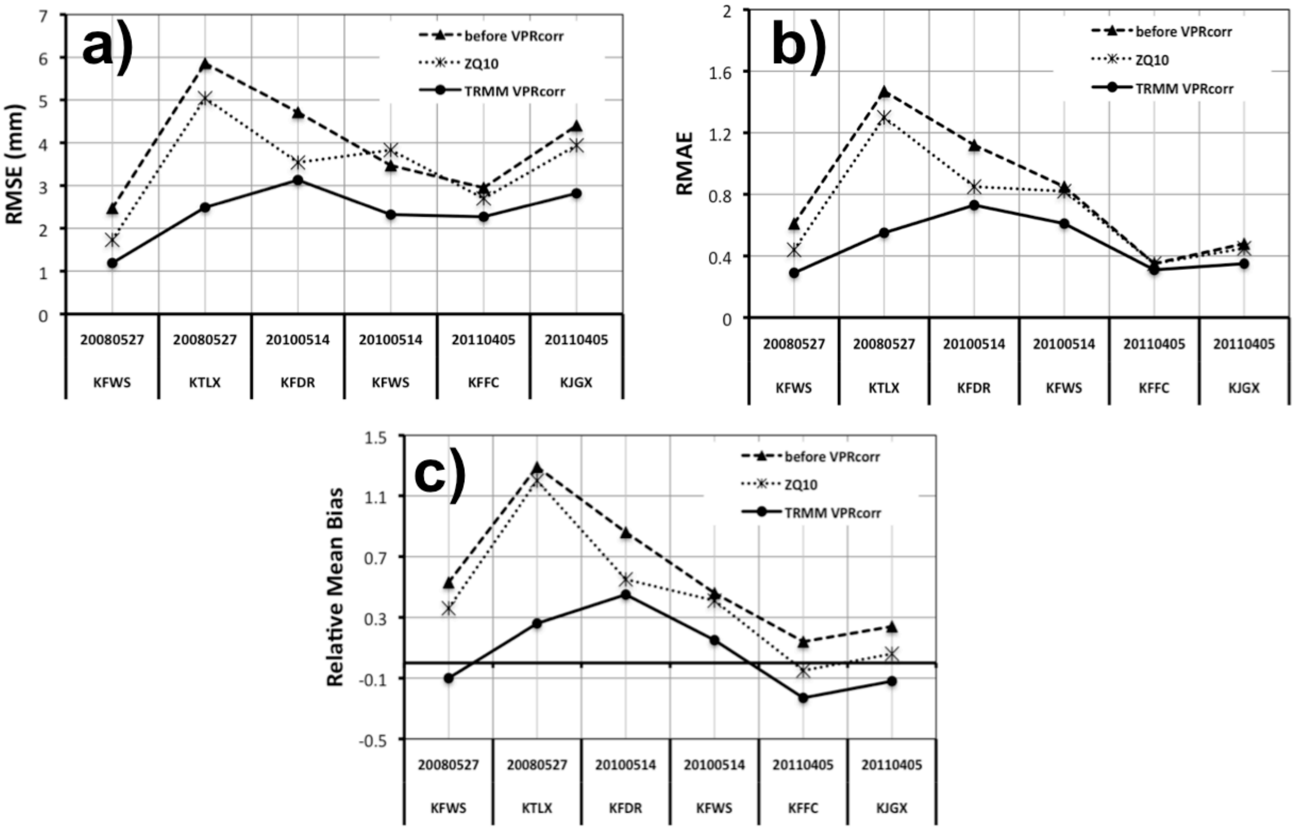

Fig. 5. The (a) RMSE, (b) relative MAE, and (c) relative bias scores for radar precipitation estimates before (dash triangle line) and after the AVPR correction (dash star line (ZQ10), solid dot line (New)).

4. Conclusion

The new VPR correction algorithm based on TRMM PR observations was developed, and the TRMM PR observations has been converted from Ku-band to S-band based on the empirical polynomial relations between Ku- and S-band radar reflectivity. The New correction scheme was tested on three MCSs precipitation events from different geographical regions in the United States, and make further improvements on BB affect radar QPEs stably, when compared with ZQ10. This is mainly because the new algorithm can provide much more accurate VPRs, and especially, the information below bright band peak or bright band bottom, where ZQ10 can't.

Acknowledgment

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