URSI - RCRS 2022, IIT (Indore), India, 1 - 4 December, 2022

Assessment of radar reflectivity measurements between ground-based radars and space borne radars over East Coast and Southern Peninsula region, India

Shruti Saini*(1), Subrata K. Das(1), and Abhishek K. Jha (1)
(1) Indian Institute of Tropical Meteorology, Pune

Abstract

Weather radar reflectivity measurements are used for applications like rainfall estimation, severe weather monitoring and nowcasting and assimilation in numerical weather prediction models. Hence, the accuracy of the reflectivity data is very important. In this study, we compare the radar reflectivity between space borne radar (SR) TRMM/GPM with ground based radar (GR) in an attempt to quantify the calibration bias.Beam blockage fraction map and corresponding quality map is generated for the GR. The comparison between reflectivities between the two radars is obtained by matching the resolution volumes and viewing geometry of SR and GR. A quality map is assigned for each matched point for SR-GR matching and comparison is carried out for both TRMM and GPM.The comparison is carried out between SR and GR at different locations across the Eastern coast and Southern peninsula region of India. This study can be used to implement corrections to the GR dataset to further improve our understanding of the convective systems. Results of one station have been discussed. Given the opportunity, analysis for other stations will be presented at the conference.

1. Introduction

Ground based radars (GR) providea unique remote platform for the finest resolved measurements of atmospheric species (clouds, convection, and precipitation). However, these measurements suffer from reliability issues as they are affected by various factors such as beam attenuation, ground clutter, beam blockage (to name a few). Uncertainty in calibration of measurements is a severe problem in generating accurate products from radar observations. For example, an offset as low as 2dB could lead to uncertainty of approximately 30% in monthly rainfall estimates[1]. Quantitative precipitation estimates and their accuracy in the tropics is one of the prime goals in the weather and climate science services.

Reflectivity measurements from weather radars have various quantitative applications; thus, it is essential to quantify the calibration bias.

Among all the reliable approaches for quantifying calibration bias, comparing GR against SR is the most popular and convincing.The Ku-band precipitation radar (PR) on the Tropical Rainfall Measuring Mission [2] satellite (from 1997 to 2014) and The Ku-band component of the Dual-Frequency Precipitation Radar (KuPR) on board the Global Precipitation Measurement mission [3] Core Observatory satellite(2014 onwards) are shown to be accurate within ~1dB ([4]; [5]). Therefore, SR provide the best reference point to quantify and calibrate the GR reflectivity measurements. Using 3D volume matching technique, Warren et al. [6] quantified calibration errors in GR reflectivity observations at Sydney, Wollongong and New Castle using TRMM and GPM. Crisologo et al. [7] used TRMM observations over Subic, Philippines, whereas Biswas and Chandrasekar[8] used GPM Ku- and Ka-band for cross validation of NEXRAD GR. Das et al. [9] observed GR bias lies between −2.6 and −1.8 dB for stratiform cases and −2.4 to −0.7 dB for convective samples relative to SR observations for X-band radar over Western Ghats, India. The above studies indicate that the SR measurements can be used as a reference for GR calibration and thus help to improve the consistency of dataset.

In this study, we compare the GR and SR reflectivities over different locations across India's East Coast and Southern Peninsula region. Here, we attempt to first time quantify the calibration bias by comparing GR and SR measurements over such a large Indian domain.This study can thus be used to implement suitable calibration bias to GR datasets.

The paper is organized as follows. Section 2 presents ground-based radars (GR) data, Space-borne radars (TRMM--PR) data description along with the methods used for the analysis. The comparison between GR and SR reflectivities and the findings of this work are presented in section 3. Section 4 provides the summary of work.

2. Data, Analysis and Methods

2.1 Ground Radar Data

India Meteorological Department (IMD) operates a wide network of ground radars. This study uses the high-resolution volumetric reflectivity measurements from various ground radars across the Eastern Coast and Southern Peninsula region of India. For each GR, volume scan data for at least 2 monsoon seasons are utilized.

Quality control measures, like removal of ground clutter and anomalous propagation echoes in the reflectivity data are implemented by IMD.

For the preliminary analysis, S-band Doppler weather Radar (DWR) deployed at Kolkata (22.57 ˚N, 88.35 ˚E, 35 m AMSL) is used. The radar has a gate size of 500m and beam width of 1˚. Each volume scan consists of 10 elevation angles from 0.2° to 21°. The scan takes approximately 7 min, repeating every 10 min.Data within 150 km of radar range from center is used to avoid the effects due to curvature of the earth and beam widening. Data within 5km from the radar site is not considered.

2.2 Space-borne Radar Data

2.2.1 Tropical Rainfall Measurement Mission Precipitation Radar (TRMM PR)

TRMM – PR operates at a frequency 13.8GHz. It has a horizontal resolution of about 5 km, vertical resolution of 250 m and a swath width of 247 km. It is sensitive to light rain rates as low as 0.5mm/hr. TRMM PR observations are available from December 1997 to September 2014. Level 2 TRMM orbital products 2A23 and 2A25 (version 7) have been considered in this study. TRMM 2A23 gives information about precipitation type and characteristics whereas TRMM 2A25 contains variable 'correctZfactor', which gives the attenuation-corrected reflectivity.

2.3 Partial beam shielding and quality index based on beam blockage fraction

GR measurements can be affected by the effects of beam blockage based on the topography of the location due to weakening or loss of signal as the radar beam interacts with surface of terrain. To quantify these effects, beam blockage map is generated using algorithm proposed by [10] which utilizes the Digital Elevation Model (DEM) to assess the extent of occultation. Shuttle Radar Topography Mission (SRTM) data, with 1 arc-second (approximately 30 m) resolution provides DEM, which is then resampled to the coordinates of GR bin centroids to match the resolution of radar data. The beam blockage fraction (BBF) map and the corresponding quality map are generated for available elevation angles. The quality index Q_{BBF} is calculated from BBF using [11].

$$Q_{BBF} = \begin{cases} 1 & BBF \leq 0.1 \\ 1 - \frac{BBF-0.1}{0.4} & 0.1 < BBF < 0.5 \\ 0 & BBF > 0.5 \end{cases} \quad (1)$$

As the antenna elevation increases, BBF decreases. BBF of 1.0 corresponds to complete beam blockage of radar signal and a value of 0.0 to perfect visibility.

2.4 GR – SR volume matching

SR and GR have different viewing geometries; thus, a direct comparison is not straight forward. Thus, the volume matching method provides a quantitative comparison between SR and GR reflectivities. Intersections between SR beam and GR elevation sweeps are identified. Firstly, the location of each SR bin with respect to GR is determined using parallax correction[12]. SR and GR operate on different frequencies, promoting systematic differences between the reflectivity observations in the two systems depending on the scattering characteristics of particles within the sample volume. The scattering differences between GR and Ku-band can be quantified using the dual-frequency ratio (DFR) which is used to scale SR reflectivity to GR reflectivity as

$$Z_{SR} = Z_{GR} - DFR \quad (2)$$

DFR is calculated based on Cao et al.[13]. Reflectivity measurements from both SR and GR are averaged to equate the sample volumes[6]. Constraints such as reflectivity threshold 18dBZ for both SR and GR measurements are applied. The time difference of maximum 5 minutes is considered acceptable between the two measurements. Further the measurements having fraction of accepted bins to total bins less than 0.7 are rejected for both SR and GR.

3. Results and Discussion

The location of the S-band radar and topography of the region along with the BBF and single ray terrain profile for elevation 0.2˚ is illustrated in figure1. Negligible BBF is observed for the smallest elevation angle 0.2. No BBF is observed for further higher elevations.

For preliminary analysis, radar data from one wet season (2009) is compared with corresponding TRMM PR data. Four events are considered which qualified the required selection criterion for the volume matching method (total samples 2543).

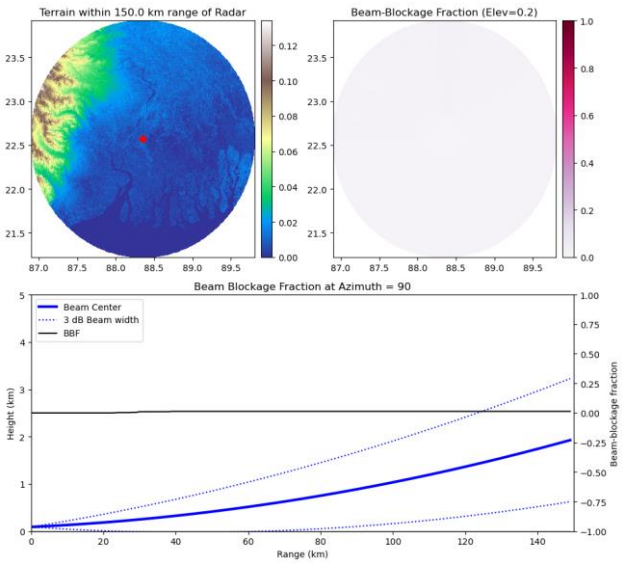

Figure1: Topography map of GR location, BBF at 0.2˚ elevation angle and corresponding single ray terrain profile.

GR-centered maps of volume-matched samples at elevation angles 0.2˚, 1˚, 2.5˚, 4˚, 6˚ of (a) SR reflectivity, (b) GR reflectivity, (c) difference between GR and SR reflectivities are shown in figure 2. Negative bias is observed in this case, implying that GR underestimates the values for reflectivity measurements compared to SR.

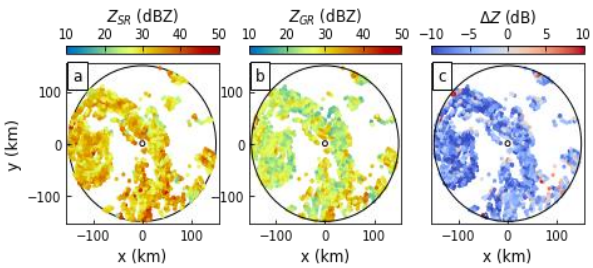

Figure2:GR centered maps (a) TRMM reflectivity, (b)GR reflectivity, (c) difference between GR and TRMM reflectivities for all four events at different elevations

Three statistical indices mean bias ($\overline{\Delta Z}$), mean absolute error (MAE) and Pearson's correlation coefficient (Corr) are used for evaluating GR observations with respect to SR. Mean bias gives the systematic bias in the observations, MAE quantifies the average magnitude of error and Corr gives information about how well the two observations are related. Mathematically,

$$\overline{\Delta Z} = \frac{1}{N}\sum_{n=1}^{N}(Z_{GR} - Z_{SR}) \quad (3)$$

$$MAE = \frac{1}{N}\left|\sum_{n=1}^{N}(Z_{GR} - Z_{SR})\right| \quad (4)$$

$$Corr = \frac{\sum_{n-1}^{N}(Z_{GR}-\overline{Z_{GR}})(Z_{SR}-\overline{Z_{SR}})}{\sqrt{\sum_{n-1}^{N}(Z_{GR}-\overline{Z_{GR}})^2(Z_{SR}-\overline{Z_{SR}})^2}} \quad (5)$$

TRMM and GR reflectivity scatter diagram(total samples 2543) and corresponding statistical indices are shown in figure3 (a). A high correlation 0.7 is observed between the two measurements with a mean bias of –5.4dB.
The variation in measurement bias for each volume sample is studied with respect to height and range from radar. A statistical method is implemented over the GR dataset to reduce this mean bias and improved results are illustrated in figure3 (b). The mean bias has reduced to -0.04 dB and the MAE has reduced to 2.9 dB.

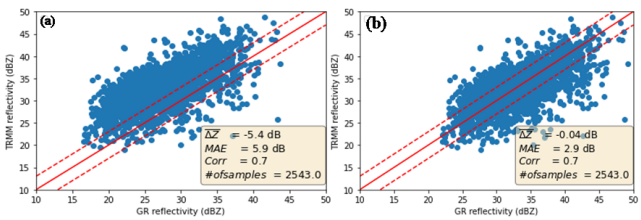

Figure3:(a) Scatter plot of volume matched reflectivity between TRMM and Kolkata S-band GR. (b) Scatter plot after correction. Solid red line is 1:1 line. Dotted red lines are ±3 dB lines.

4. Summary

The preliminary results for one station have been included in this work. Similar analysis is carried out with GPM data for the same station. Further results of the analysis for other stations will be presented at the conference.
This study provides a valuable tool which can be utilized to monitor radar calibrations and even quantify the calibration bias over long series of data. The study can also be used to examine the effects of topography on the SR and GR reflectivity measurements. Corrected GR reflectivity measurements can help us improve the quantitative application of GR data and thus further improve our understanding of convective systems.

5. Acknowledgements

The authors would like to thank India Meteorology Department for providing Radar data. The authors acknowledge the JAXA, Japan, and NASA, USA, for the provision of TRMM (http://mirador.gsfc.nasa.gov) data set and NASA/Goddard space flight center for the provision of GPM data (https://gpm.nasa.gov/data-access/downloads/gpm). The TRMM and GPM data are freely available and can be downloaded from its archival. The authors also acknowledge the NASA Shuttle Radar Topography Mission (SRTM)(2013), Shuttle Radar Topography Mission (SRTM) Global Distributed by OpenTopography *(https://doi.org/10.5069/G9445JDF) for DEM data.*

6. References

[1] R. A. Houze, S. Brodzik, C. Schumacher, S. E. Yuter, and C. R. Williams, "Uncertainties in oceanic radar rain maps at Kwajalein and implications for satellite validation," *Journal of Applied Meteorology*, vol. 43, no. 8, pp. 1114–1132, 2004, doi: 10.1175/1520-0450(2004)043<1114:UIORRM>2.0.CO;2.

[2] Simpson, J., Kummerow, C., Tao, W.K. et al. On the Tropical Rainfall Measuring Mission (TRMM). Meteorl. Atmos. Phys. 60, 19–36 (1996). https://doi.org/10.1007/BF01029783

[3] A. Y. Hou et al., "The global precipitation measurement mission," Bulletin of the American Meteorological Society, vol. 95, no. 5, pp. 701–722, 2014, doi: 10.1175/BAMS-D-13-00164.1.

[4] T. Kawanishi et al., "TRMM Precipitation Radar," Advances in Space Research, vol. 25, no. 5, pp. 969–972, 2000, doi: 10.1016/S0273-1177(99)00932-1.

[5] N. Takahashi, H. Kuroiwa and T. Kawanishi, "Four-year result of external calibration for Precipitation Radar (PR) of the Tropical Rainfall

Measuring Mission (TRMM) satellite," in IEEE Transactions on Geoscience and Remote Sensing, vol. 41, no. 10, pp. 2398-2403, Oct. 2003, doi: 10.1109/TGRS.2003.817180.

[6] R. A. Warren et al., “Calibrating ground-based radars against TRMM and GPM,” Journal of Atmospheric and Oceanic Technology, vol. 35, no. 2, pp. 323–346, 2018, doi: 10.1175/JTECH-D-17-0128.1.

[7] I. Crisologo, R. A. Warren, K. Mühlbauer, and M. Heistermann, “Enhancing the consistency of spaceborne and ground-based radar comparisons by using beam blockage fraction as a quality filter,” Atmospheric Measurement Techniques, vol. 11, no. 9, pp. 5223–5236, 2018, doi: 10.5194/amt-11-5223-2018.

[8] S. K. Biswas and V. Chandrasekar, “Cross-validation of observations between the GPM dual-frequency precipitation radar and ground based dual-polarization radars,” Remote Sensing, vol. 10, no. 11, 2018, doi: 10.3390/rs10111773.

[9] S. K. Das, U. V. M. Krishna, Y. K. Kolte, S. M. Deshpande, and G. Pandithurai, “Assessment of Ground-Based X-Band Radar Reflectivity: Attenuation Correction and its Comparison With Space-Borne Radars Over the Western Ghats, India,” Earth and Space Science, vol. 7, no. 11, 2020, doi: 10.1029/2019EA000861.

[10] J. Bech, B. Codina, J. Lorente, and D. Bebbington, “The sensitivity of single polarization weather radar beam blockage correction to variability in the vertical refractivity gradient,” *Journal of Atmospheric and Oceanic Technology*, vol. 20, no. 6, pp. 845–855, 2003, doi: 10.1175/1520-0426(2003)020<0845:TSOSPW>2.0.CO;2.

[11] S. Zhang, Y. Zhu, Z. Wang, and Y. Wang, “Consistency analysis and correction of ground-based radar observations using space-borne radar,” *Journal of Atmospheric and Solar-Terrestrial Physics*, vol. 169, no. September 2017, pp. 114–121, 2018, doi: 10.1016/j.jastp.2018.01.030.

[12] M. R. Schwaller and K. Robert Morris, “A ground validation network for the global precipitation measurement mission,” *Journal of Atmospheric and Oceanic Technology*, vol. 28, no. 3, pp. 301–319, 2011, doi: 10.1175/2010JTECHA1403.1.

[13] Q. Cao *et al.*, “Empirical conversion of the vertical profile of reflectivity from Ku-band to S-band frequency,” *Journal of Geophysical Research Atmospheres*, vol. 118, no. 4, pp. 1814–1825, 2013, doi: 10.1002/jgrd.50138.