A Comparative Study of Doppler Weather Radar and GPM Over Mountainous Terrain In North-East India

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Abstract

GPM is one of the crucial satellite radars for rainfall study over the globe and widely being used for several application areas. However, the performance of the same is yet to be understood over orographic regions due to inherent limitations of the Ku/Ka band space borne radars. In this study, we explored a few rainfall events over the complex terrain on Himalayas in North-east India using a ground-based C-band doppler weather radar. The study focused on the representation of the precipitation in terms of rain types which plays a critical role in the Radar QPE. Results indicate a significant underestimation of convective rain by GPM satellite while overestimation of stratiform rain in some cases. The reason could be orographic lifting which may not be well captured at lower levels by the GPM satellite. The study also generated a combined DWR-GPM dataset which could be useful to understand the evolution of rainfall over this location.

Keywords — GPM, Doppler Weather Radar, Rain classification, Orographic rain

1. Introduction

Accurate rainfall measurement over hilly regions is often difficult due to its complex topography and scarcity of proper observational structure. Gauge based precipitation measurement is limited by challenging terrain, making it difficult to install and maintain an optimal network. There lie several challenges in analyzing extreme rainfall events in the North Eastern Region of India, including the lack of good documentation due to limited high resolution rainfall data [1]. Satellite based rainfall estimates, echo classifications and other cloud microphysical measurements are invaluable in such data sparse regions. GPM era products like IMERG and GSMap have shown consistent performance by capturing precipitation variability and were capable of detecting precipitation extremes, however they underestimate observed precipitation amounts [2]. Doppler weather radar (DWR) is, however, more useful for estimating the near-ground rainfall but prone to error due to beam blockages in mountainous regions. Since Ka/Ku band GPM DPR are not very sensitive to near-ground echo measurements during heavy precipitation, it is worthwhile to study the performance in orographic regions, particularly places like North-East India which receive significant rainfall.

For accurate quantitative precipitation estimates convective-stratiform classification is necessary, which can improve the accuracy of numerical models. Not only that, accurately classifying rainfall into convective and stratiform components is needed for the understanding of energy balance in the tropical atmosphere. Studies have shown that not only convective component but also the stratiform component of rainfall significantly contribute to the vertical profile of heating from convective systems as different microphysical processes in each component [3-7].

The Convective-Stratiform Algorithm of GPM relies on radar reflectivity patterns, vertical profiles and dual frequency observations and brightband detection [8]. This study focuses on the assessment of GPM 2ADPR rain type classification data product, with radar measurements as reference, focusing primarily on hilly regions, hence giving an idea about location-specific error characterization to estimate uncertainties associated with GPM product.

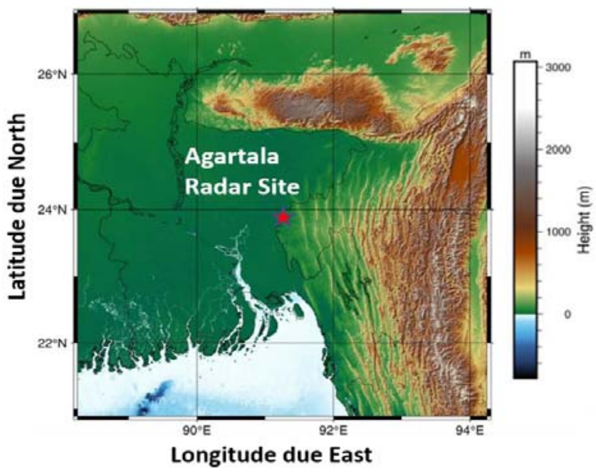

Figure 1: Topography map of study region

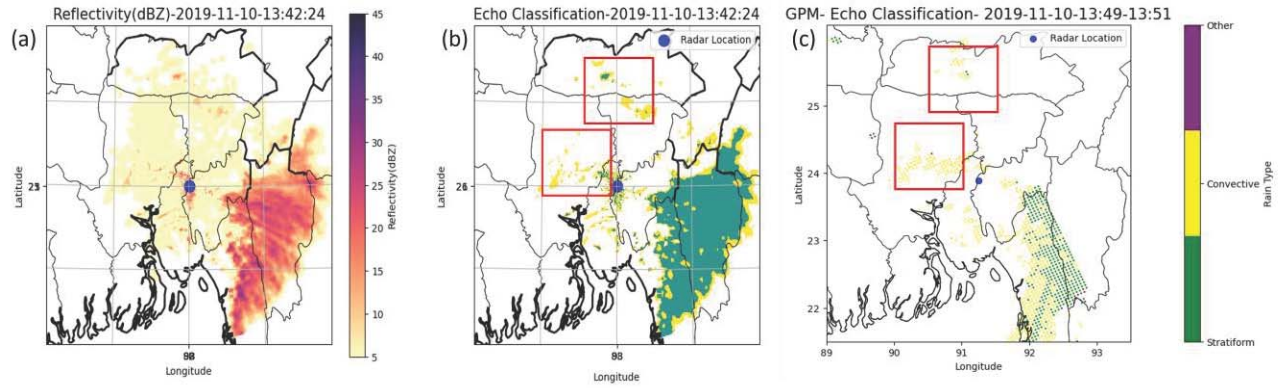

Figure 2: (a) Reflectivity Echo around 13:42 UTC (b) Rain type classification of radar reflectivity data around 13:42 UTC (c) GPM 2ADPR Rain type Classification product around 13:42 UTC, 10 November 2019, over the Study location

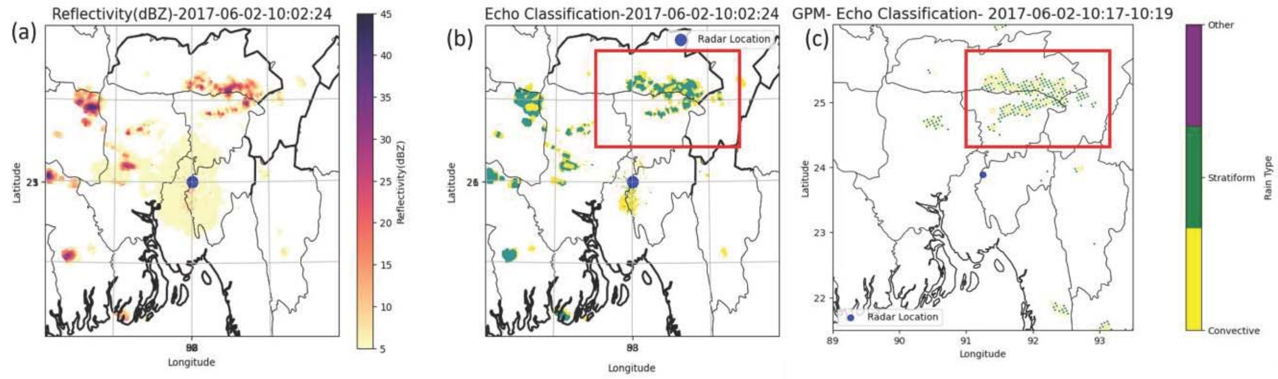

Figure 3: (a) Reflectivity Echo around 10:00 UTC (b) Rain type classification of radar reflectivity data around 10:00 UTC (c) GPM 2ADPR Rain type Classification product around 10:00 UTC, 02 June 2017, over the Study location

2. Data and Methodology

This study utilized the GPM-DPR Standard level 2 (L2) product Version 9, from the matched beam scan swath over the North East region (Latitude: 21°N to 26.5° N, Longitude: 89°E to 93.5°E). Precipitation type classification variable "typePrecip" was compared with rain classification obtained from Radar reflectivity. The time information for which it crosses the region of Agartala was calculated using the "ScanTime" data product. Only one of the GPM's daily orbits crossed our study domain for very severe cyclonic storm Bulbul approximately around 13:49 UTC on 10 November 2019, while two of the GPM's daily orbits crossed our daily domain for severe cyclonic storm Mora at approximately 10:17 UTC and 23:35 UTC on 2nd June 2017.

For comparison with ground truth data, rain type classifications obtained from reflectivity values of Agartala C-band Doppler Weather Radar (23.88° N, 91.25 ° E, 35m) as shown in Figure 1 is used. The rain type classification on the radar reflectivity data was done using Py-ART convective stratiform algorithm [9-11]. Operating on the lowest sweep reflectivity fields, the algorithm calculates a background average using a specified circular footprint and identifies convective cores by comparing the original field to this average.

3. Results and Discussion

In this section, we have compared the GPM 2ADPR rain type classification product with radar rain type classification data for two rainfall events caused by two cyclonic storms- Very Severe Cyclonic Storm Bulbul and Severe Cyclone Mora.

3.1 Case Study 1: Very Severe Cyclone Storm Bulbul

Cyclone Bulbul, a very severe cyclonic storm, made landfall between Sagar Islands in West Bengal and Khepupara in Bangladesh with significant wind speeds and associated impacts on 9th November 2019. While Agartala did not experience direct landfall, it was not immune to the influence of the cyclonic system. This case study examines the rainfall event caused by the Cyclone event over Agartala on 10th November 2019, by comparing the GPM 2ADPR rain type classification product with the Radar rain type classification. The radar reflectivity data shows a large reflectivity echo to the eastern side of the radar location (Figure 2(a)).

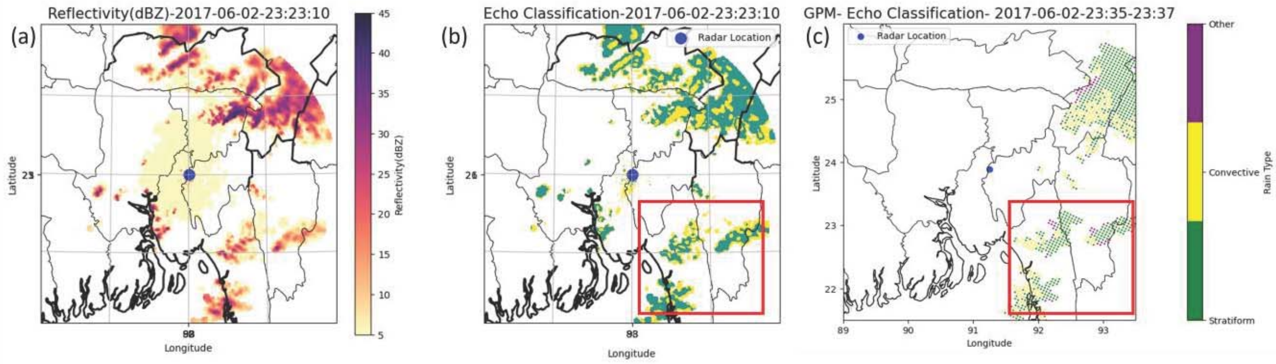

Figure 3: (a) Reflectivity Echo around 23:00 UTC (b) Rain type classification of radar reflectivity data around 23:00 UTC (c) GPM 2ADPR Rain type Classification product around 23:00 UTC, 02 June 2017 over the Study location

The rain type classification of lowest sweep radar reflectivity, at 13:42 UTC showed major portions of the area as stratiform components in green, while certain patches are classified as convective, where reflectivity is above 40 dBZ (Figure 2(b)). The GPM 2ADPR rain type classification product shows a difference in the spatial positioning, with a smaller portion showing as the stratiform component, when compared with the radar counterpart, for the largest echo (Figure(c)). However, for smaller echoes, both radar and GPM rain classification shows similar results (Figure 2: Red box). The presence of stratiform rainfall after the landfall of the cyclone may be due to the interaction between the remnants of the cyclone and the complex topography as hilly regions can significantly influence precipitation patterns through orographic lift.

3.2 Case Study 2: Severe Cyclone Storm Mora

Cyclone Mora, a severe cyclonic storm in Bay of Bengal, had far-reaching impacts on East and Northeast India. The cyclone made landfall near Chittagong and started dissipating on 31st May 2017. Agartala and the surrounding region, even though it did not experience direct landfall, encountered a reasonable amount of rainfall even after the dissipation on 2nd June 2017. Hence, we aim to explore the rainfall event in Agartala on 2nd June 2017 during this cyclone, focusing on the comparison between rain type classifications from GPM 2ADPR and radar observations. For this case study, two GPM passes were found over our area of interest, one around 10:00 UTC and another one around 11:30 UTC.

The radar reflectivity plot for 10:00 UTC shows isolated convective cells on the northern side of the radar site (Figure 3(a)). The rain type classification of lowest sweep radar reflectivity, at 10:00 UTC showed isolated reflectivity blobs with convective and stratiform counterparts (Figure 3(b)). The GPM 2ADPR rain type classification product shows a comparable result with the radar counterpart in spatial positioning and classification as well (Figure 3(c) Red Box).

However, for smaller echoes, GPM rain classification data was unable to capture the smaller blobs. For the second pass around 23:30 UTC, the Radar data shows a large reflectivity echo to the northeastern side of the radar location, which is closer to the mountains and three isolated reflectivity echoes to the south eastern side of radar (Figure 4(a)). The rain classification of radar data for the large echo shows major stratiform areas with few convective parts (Figure 4(b)). The GPM rain classification product was not entirely matching with its radar counterpart for the large reflectivity echo, because of radar's and GPM's inexact time matching. However, for the other three small, isolated reflectivity echoes, the GPM and Radar rain classification showed quite matching results (Figure 4(c), Redbox). The reason why large stratiform areas have occurred, near the northeastern part is because cyclonic remnants must have interacted with the windward side of the mountains, leading to enhanced precipitation due to orographic lift.

4. Conclusion

The northeastern region of India is a vital ground for recording numerous extreme rainfall events, due to flash floods, cloud bursts or north-east monsoon in general. Precipitation patterns show spatial and seasonal variability while it interacts with the complex topography of this region. Precipitation and Rain type classification products of satellites, like GPM, helps us to understand how terrain affects the distribution, intensity and type of precipitation in such complex topography, where there is scarcity of rain gauge and observational network. Orographic lifting in hilly terrain can lead to enhanced rainfall on windward slopes. However, GPM has underestimated and overestimated the convective and stratiform components in both the case studies, when compared to rain classification data of radar, mainly along the eastern side of the radar location. The eastern side of the radar location is a hilly region where precipitation interacts with orography, which GPM data is unable to capture properly. Satellite algorithms may struggle. There can be several factors which can hinder the accuracy of the GPM data products, like, precipitation interaction with complex terrain, rapid changes in atmospheric conditions, coarse spatial resolution of sensors which are unable to capture the small-scale variations of precipitation. Another major reason is that persistent cloud cover and dense vegetation over mountainous regions can affect data accuracy. Limited ground-based observations in such rugged topography make it difficult to validate and calibrate satellite derived precipitation and rain type classification products. Satellite based algorithms need to account for elevation dependent variations to accurately predict rainfall and classify rain types. Several studies are required to be done, which explore the interaction of cyclonic rain, monsoonal rain with topography and thereby improving the accuracy of the correct rain type classification and precipitation measurements over mountainous regions.

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