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Performance evaluation of the TRMM precipitation estimation using ground-based radars from the GPM validation network

Tanvir Islam *, Miguel A. Rico-Ramirez, Dawei Han, Prashant K. Srivastava, Asnor M. Ishak

Department of Civil Engineering, University of Bristol, Bristol, UK

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A B S T R A C T

The Global Precipitation Measurement (GPM) mission is scheduled to fly in the year of 2013 to measure the earth's precipitation structure. Since the precipitation measurement by the GPM platform will be very similar to its predecessor, the Tropical Rainfall Measuring Mission (TRMM), hence, the development of GPM algorithms to improve precipitation retrievals can be addressed through the lessons learnt from the former TRMM mission in terms of precipitation retrievals and its associated uncertainty. To support the future GPM mission, this paper assesses the performance of the TRMM precipitation estimation using ground-based radars from the GPM validation network. A total of 22 significant overpass instantaneous events from 22 different radar sites has been evaluated in view of different surface and rain type flags. The overall results show that attenuation corrected reflectivity from the TRMM precipitation radar agrees well to the measured reflectivity from ground based radars with correlation coefficients $r=0.91$ (without frequency adjustment) and $r=0.92$ (with frequency adjustment). However, the correlation decreases by 10–30%, once the reflectivity are transformed to rainfall rates. The lower correlations on the basis of precipitation estimation by the TRMM are exhibited over the coast than those of ocean and land surface terrain. Taking into account the rain type flags, the analysis shows a poor correlation during convective precipitations, in particular, those retrieved from the TRMM precipitation radar. In contrast, the combined algorithm, which utilizes both radar and microwave imager instrument on-board TRMM, outperforms throughout the analysis, yet, there is a scope to improve the precipitation retrievals.

1. Introduction

Precipitation is one of the fundamental variables of earth's hydrological cycle. From profound understanding of the global water and energy cycle to improving weather, climate and hydrological forecasting, accurate measurements of precipitation are very imperative. Despite the correct knowledge of intensity and distribution of precipitation, the problems associated with weather, climate and hydro-meteorological aspects cannot be unraveled. At the same time, it is one of the most difficult physical quantities to measure accurately due to its random character in temporal and spatial scales. Conventionally, rain gauges are being used for decades to estimate precipitation over a particular region. However, the performance of precipitation estimation with the rain gauges depends upon the density of the gauges distributed in the given area. Establishment of a good gauge density network in the remote area has always been a challenge. Furthermore, in developing countries, the gauges are sparsely distributed, and over the ocean, the gauges are almost non-existent. Besides, ground based radars have shown a great promise since its invention during the second world war by providing the spatial extent of precipitation (Hunter, 1954). Conversely, again, the problem is that maintaining a good coverage of the radar network is difficult, and normally radars are also available in those areas where rain gauges are well covered. Transformation of the radar reflectivity factors into precipitation rates at certain altitude is another problematic issue. Indeed, weather radars are subjected to several errors and uncertainties like ground clutter, anomalous propagation, attenuation, beam blockage, bright band contamination, etc. (Bringi et al., 2011; Rico-Ramirez and Cluckie, 2007, 2008; Rico-Ramirez et al., 2007).

Satellite-based precipitation estimates are an alternative option by studying the emission and scattering properties of clouds and precipitation in the atmosphere. For more accurate three dimensional precipitation retrievals, the first ever space born active microwave sensor, the precipitation radar (PR) was deployed along with the TRMM microwave imager (TMI) aboard TRMM in 1997 (Kidd and Levizzani, 2011; Kozu et al., 2001). The term TRMM represents here as Tropical Rainfall Measuring Mission, designed to monitor and study tropical rainfall. It has a

* Corresponding author. Tel.: +44 1173315724; fax: +44 1173315719.
E-mail address: tanvir.islam@bristol.ac.uk (T. Islam).

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limited earth view covering only the diurnal cycle within the tropical region ranging from 35°S to 35°N. To improve the coverage, the next generation Global Precipitation Measurement (GPM) mission is planned to launch in 2013 to study precipitation (rain, snow, ice) in a global scale. In fact, this mission is the successor of the TRMM, which is at the end of its life limit. In comparison with the TRMM, the GPM will measure precipitation to higher latitudes of up to 65° with more frequent sampling and higher sensitivity to precipitation, thus quantifying rain and snow. The core GPM satellite will carry both the dual-frequency precipitation radar (DPR) and the GPM microwave imager (GMI). The GMI instrument is a conical-scanning, microwave radiometer carrying channels similar to those of the TMI with addition of four high frequency millimeter-wave channels of 166 GHz and 183 GHz. Relative to the single frequency of Ku-band in the TRMM, the DPR consists of Ku and Ka band dual frequency radars. The key specifications and scanning science of the GMI and DPR in the GPM can be found in Furukawa et al. (2007), Masunaga and Kummerow (2005), Seto and Iguchi (2011), among others.

Success of the GPM mission depends upon the algorithm development for both GMI and DPR. Since the structure and concept of the GPM core component are very similar to the TRMM, the understanding and scope of future GPM precipitation estimation can be explored through the lessons learnt from the TRMM. In this study, the relative performance of the TRMM precipitation estimation is assessed using ground based radars from the GPM validation network (VN) supporting the GPM mission in terms of understanding satellite-based rainfall retrieval uncertainty and algorithm development. We refer to the past TRMM ground validation studies, which are conducted primarily in four validation sites—the Kwajalein Atoll, Republic of the Marshall Islands; Melbourne, Florida; Houston, Texas; and Darwin, Australia (Wang and Wolff, 2010; Wolff et al., 2005). Nevertheless, we have adopted the similar approach herein using a new validation network radar dataset, established for the GPM validation studies. The remainder of this paper is structured as follows. Section 2 summarizes the dataset and methodology used in the study, Section 3 describes the performance of the TRMM precipitation estimation with respect to ground based radars from the GPM VN and Section 4 provides the conclusions.

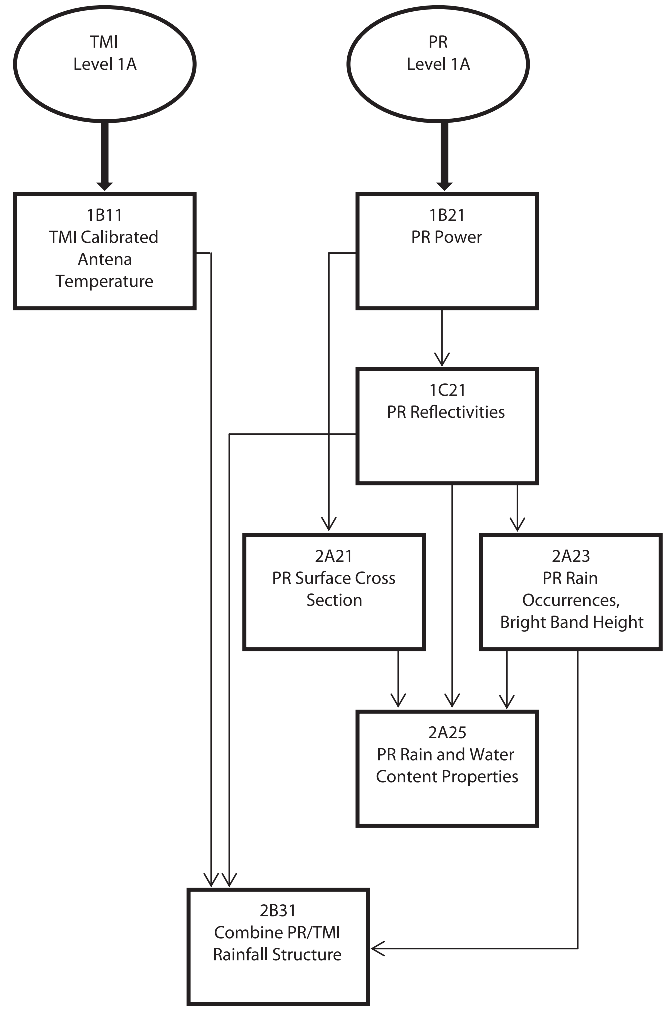

Fig. 1. TRMM data processing overview
Source: NASA.

2. Data sources and analysis methodology

2.1. TRMM dataset

The TRMM has been in operation since its launch in 1997 to measure rainfall, in particular, in the tropical area (Kummerow et al., 2000; Simpson et al., 1996). The platform carries a dual complement of passive and active sensors, the TMI as passive, and PR as active sensor to collect rain information. The TMI measures the intensity of emission at five channel frequencies: 10.7, 19.4, 21.3, 37, 85.5 GHz. The PR is an electronically scanning radar, operating at a frequency of 13.8 GHz that measures the 3-D rainfall distribution over both land and ocean, and defines the layer depth of the precipitation. A detailed description of the TRMM sensors is discussed in Kummerow et al. (1998).

This study mainly evaluates the TRMM version 6 data, the reflectivity data from 1C21 and 2A25 products, and the rain rate data from 2A25 and 2B31 products. For the sake of brevity, an overview of data processing for these products are illustrated in Fig. 1, obtained from NASA. Summarizing, the PR first level data product 1B21 originates radar return power, which is related to the reflectivity (Z_m). From the 1B21 product, the reflectivities are then included in the 1C21 product. At ranges near earth's surface, $Z_m(r)$ is dominated by surface return, and surface clutter echoes may be present in the 1C21 data product. In addition, the radar echoes at high frequency of 13.8 GHz suffer from significant attenuation and the raw radar reflectivity factors in the 1C21 product need to be corrected for attenuation. The 2A21 product provides information of path attenuation, whereas the 2A23 product provides rain type, bright band height and freezing height information. The 2A25 product is the TRMM standard algorithm that provides the vertical profiles of attenuation corrected reflectivity factor (Z_e) and rain rate (R), taking into account inputs from the products 1C21, 2A21 and 2A23. The attenuation correction is based on a combination of the surface reference method (Iguchi and Meneghini, 1994) and Hitschfield–Bordan method (Hitschfeld and Bordan, 1954), and the standard algorithm uses a globally averaged drop size distribution (DSD) to obtain the Z_e–R relationship. The rain profiling algorithm and the path integrated attenuation (PIA) correction scheme for the TRMM PR are explained in Iguchi et al. (2000) and Meneghini et al. (2000). On the other hand, the 2B31 product, which uses the TRMM PR/TMI combined algorithm, generates rain rate by combining the information collected from both the PR and the TMI. The algorithm uses the mean rain rates and a confidence interval from both sensors, and ultimately uses a Bayesian approach for the best rainfall estimation (Kummerow et al., 2000).

2.2. Ground-based radar dataset

As part of the GPM ground validation system (GVS), a validation network (VN) is set up to perform a direct match-up of space-based