Validation of NASA's Global Precipitation Measurement Mission with a High-Resolution Ground Radar Network

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***Abstract*—The Global Precipitation Measurement (GPM) Core Observatory satellite was launched on February 27, 2014. As an indispensable part of any satellite mission, ground validation has been conducted from the pre-launch era to post-launch era of GPM. This paper presents a GPM validation methodology using the high-resolution radar network over Dallas-Fort Worth (DFW), Texas, which is the first urban remote sensing testbed deployed by the National Science Foundation (NSF) center for Collaborative Adaptive Sensing of the Atmosphere (CASA). The cross-comparison between GPM satellite measurements and ground radar observations will be presented in details. The space rainfall rate product is also evaluated based on the high-performance rainfall products derived from the ground radar network. The quantitative evaluation results show good agreement between space borne and ground radars.**

Keywords—dual-polarization, radar, precipitation, remote sensing, CASA, GPM, ground validation.

I. INTRODUCTION

Over the past two decades, a number of precipitation products have been developed on global and regional scales, based on satellite and radar observations, as well as in situ measurements from ground instrument such as rain gauges (e.g., [1],[2]). However, it is still challenging to achieve optimal rainfall estimation for a given region due to the spatial and temporal sampling limitations of different rainfall instruments. Building upon the success of Tropical Rainfall Measuring Mission (TRMM), which focused primarily on monitoring rainfall for weather and climate research over tropical and subtropical regions, the National Aeronautics and Space Administration (NASA), collaborating with the Japan Aerospace Exploration Agency (JAXA) successfully launched the Global Precipitation Measurement (GPM) Core Observatory satellite on February 28, 2014 [3]. The observatory carries the first space borne Dual-frequency Precipitation Radar (DPR) that is operating at Ku- and Ka-band frequencies, and GPM Microwave Imager (GMI), which is a multi-channel (frequency ranging from 10 to 183 GHz), conical-scanning, microwave radiometer [3]. These two advanced instruments onboard GPM extend the observation range attained by TRMM, and provide measurement of rainfall, snowfall, and other precipitation types over most of the globe. Particularly, light rainfall and cold-season solid precipitation can be detected, which account for a significant fraction of occurrence in middle and high latitudes.

As an integral part of GPM mission, ground validation helps to quantify the uncertainties of various GPM products and provide insight into the physical and statistical basis of precipitation retrieval algorithms. In the pre-launch era, several international validation experiments had already generated a substantial set of measurements that contribute to the development and test of pre-launch GPM algorithms, such as the Light Precipitation Validation Experiment (LPVEx), the Midlatitude Continental Convective Clouds Experiment (MC3E), the GPM Cold Season Precipitation Experiment (GCPEX), and the Iowa Flood Studies (IFloodS). After launch, the Integrated Precipitation and Hydrology Experiment (IPHEx) and the Olympic Mountain Experiment (OLYMPEx) were conducted to further evaluate GPM precipitation data products as well as assumptions made in the retrieval algorithms. Among various validation instruments, ground-based dual-polarization radar has shown to be a powerful tool to estimate rainfall and characterize rainfall microphysics [4][5][6]. Therefore, it is of great importance if we have high-quality operational radar products that can be used for GPM validation on a regular basis. Nevertheless, most of the National Weather Service (NWS) operational rainfall systems based on Weather Surveillance Radar - 1988 Doppler (WSR-88DP) network produce mosaicked rainfall products typically on 1 km by 1 km spatial grids, and focus on rainfall accumulations at temporal scales of 1-h, 3-h, 6-h, 12-h, and/or 24-h (daily). These kinds of products, in terms of accuracy and resolution, have limitations to validate instantaneous GPM products. In order to accurately estimate rainfall rates and amounts for urban flash flood prediction and mitigation in a timely manner (within 60seconds), the National Science Foundation (NSF) center for Collaborative Adaptive Sensing of the Atmosphere (CASA) has developed its first urban testbed in Dallas-Fort Worth (DFW), Texas [2][7]. This urban testbed consists of a NWS WSR-88DP radar and a network of six (to date) high-resolution dual-polarization X-band radars. The high spatial and temporal resolution observations, real-time products, and post-event analysis, have demonstrated the excellent performance of CASA DFW radar network for Quantitative Precipitation Estimation (QPE) [2].

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In this study, we take advantage of the unique, high-quality CASA DFW radar data for GPM product validation.

This paper is organized as follows. In Section II, sample rainfall products from CASA DFW ground radar network will be provided to demonstrate its qualification for GPM validation. The validation concept of GPM using ground radar, as well as cross-comparison between GPM space radar and CASA DFW ground radar observations will be detailed in Section III. Section IV presents the preliminary evaluation of GPM rainfall rate product with rainfall estimates from CASA DFW radar network, and the main findings of this paper will be summarized in Section V.

II. CASA DFW RADAR RAINFALL SYSTEM

The DFW radar network (see Fig. 1) was developed to demonstrate the Distributed Collaborative Adaptive Sensing (DCAS) paradigm in an urban environment. The DCAS concept, proposed by CASA, uses a large number of small X-band dual-polarization radars that operate collaboratively within a dynamic information technology infrastructure, to monitor the changing atmospheric conditions according to the end user needs [7][8]. Compared to conventional NWS S-band radars, such a network can observe rapid changing meteorological phenomena in a real-time manner, such as urban flash flood, hail, high wind and tornado, etc.

Chen and Chandrasekar have developed a high-resolution real-time QPE system for this urban radar network via fusion of observations from both the network of X-band radars (marked in blue in Fig. 1), and a local NWS S-band radar (marked in red in Fig. 1) [2]. The dual-polarization rainfall techniques in [2] have a number of advantages compared to traditional single-polarization method (i.e., *Z-R* relations). Particularly, with the aid of dual-polarization measurements such as reflectivity, differential reflectivity, differential propagation phase, and co-polar correlation coefficient, radar data quality can be greatly enhanced, the raindrop size distribution information can be retrieved in more efficient and effective ways, and different hydrometeor types can be identified as well. The specific radar rainfall algorithms, as well as the fusion methodology combining observations at different temporal resolution can be found in [2]. In order to further demonstrate the performance of CASA DFW QPE system, point-wise traces are used for diagnostic purposes for comparison against gauges. Fig. 2 shows sample rainfall products from this QPE system and rainfall measurements from ground gauge at a specific gauge location during the 2015 Thanksgiving storm event. It can be clearly seen that CASA DFW radar rainfall estimates agree well with the ground measurements. The stable rainfall products are being used as input to hydrologic models for downstream applications such as flood forecast.

In addition, the CASA DFW radar network is one of the few ground instruments that can produce rainfall rate estimates that meet the accuracy requirements of GPM space rainfall product. In this research, we take the opportunity to use this unique high-quality high-resolution radar network to validate the GPM DPR observations and evaluate the DPR based rainfall rate product.

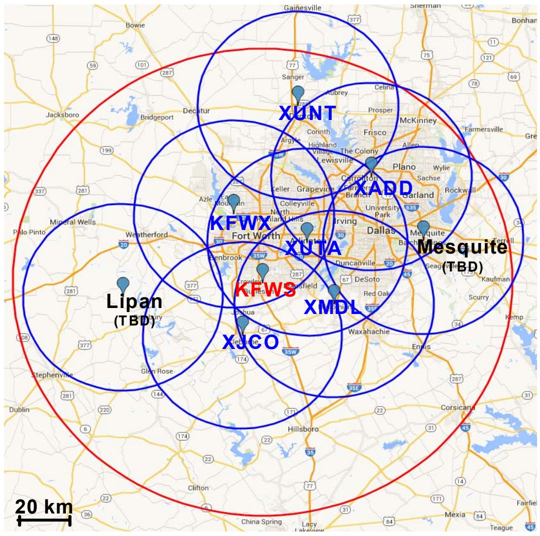

Fig. 1. Radar layout in CASA DFW urban remote sensing network.

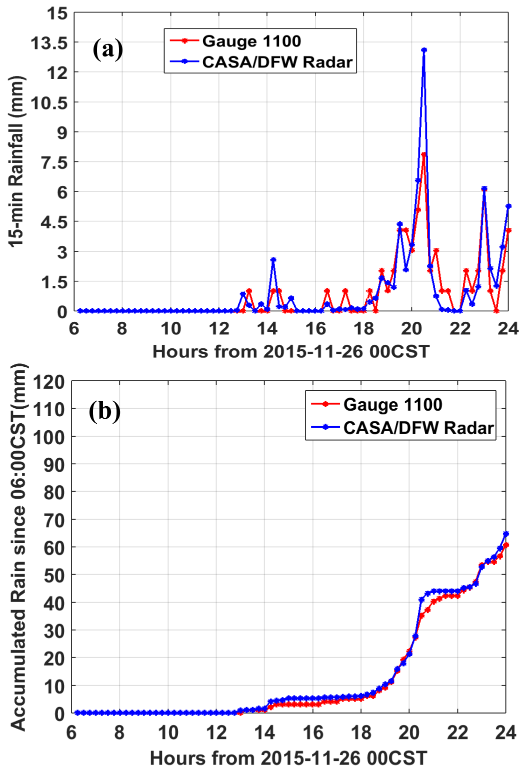

Fig. 2. Rainfall estimates from CASA/DFW radar and gauge at the location of gauge 1100 (Lat: 32.7952, Long: -97.3368) during 2015 Thanksgiving event: (a) 15-min rainfall, (b) rainfall accumulations.

III. GPM GROUND VALIDATION WITH CASA DFW RADAR NETWORK

Cross comparison and validation of GPM space radar products with ground radar observations are conceptually simple but they are difficult to accomplish in practice. The main challenge to conduct point-by-point comparison is caused by the mismatch between space and ground radar resolution volume, which can be attributed to different operati-

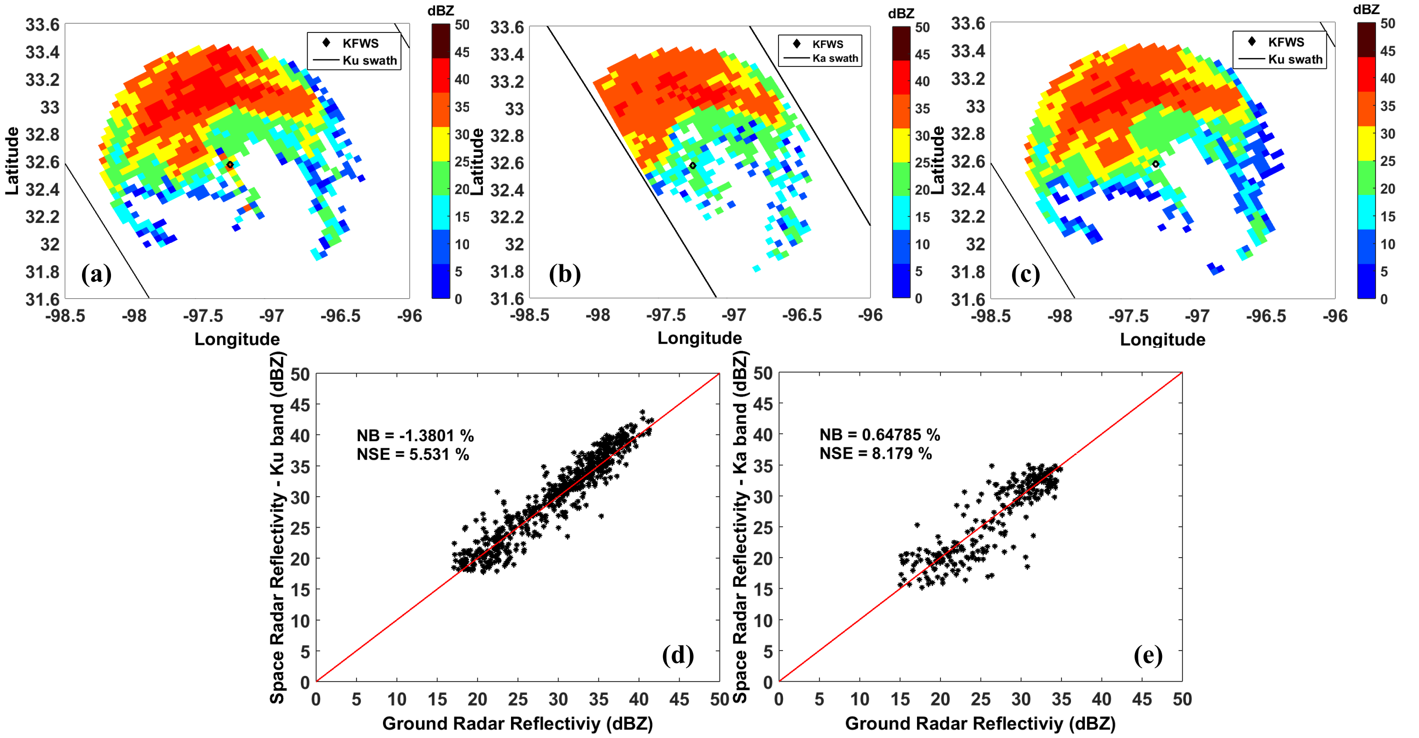

Fig. 4. Sample radar reflectivity observatons at 15:54UTC, June 17, 2015, from (a) GPM DPR Ku-band (b) Ka-band (c) CASA DFW ground radar, and scatterplots of GPM DPR (a) Ku-band and (e) Ka-band reflectivity versus ground radar reflectivity measurements.

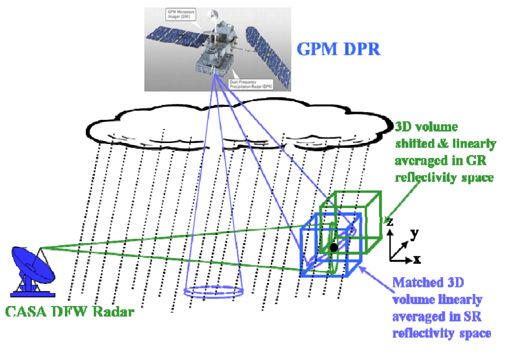

Fig. 3. Illustration of 3-D volume matching and shifting based on GPM DPR and CASA DFW radar resolution volumes.

-ng frequencies and differences in viewing geometry, as shown in Fig. 3. In addition, the movements and attitude perturbations of the spacecraft itself can introduce biases into the space radar observations. In [9], Bolen and Chandrasekar proposed a methodology to align radar observations from two different platforms based on variable resolution volume matching between the two systems. The excellent agreement between reflectivity measurements from TRMM Precipitation Radar (PR) and National Center for Atmospheric Research (NCAR) S-band POLarimetric (SPOL) radar has demonstrated the feasibility of the alignment approach [9]. In this paper, we implement this alignment method for validation and comparison of GPM DPR measurements with CASA DFW radar observations.

Fig. 4 (a) and (b) show sample GPM DPR reflectivity observations over DFW area at Ku and Ka band, respectively, during an overpass case at 15:54UTC, June 17, 2015, whereas Fig. 4(c) shows the corresponding observations from CASA DFW ground radar. It can be seen that the space and ground radar observations visually match well, which is further demonstrated by the scatter plots shown in Fig. 4 (d) and (e).

IV. Preliminary Evaluation of GPM Rainfall Products

In order to evaluate GPM satellite rainfall products, the high-resolution rainfall estimates from CASA DFW radar network are resampled to match the GPM resolution footprint (~5km X 5km). That is, the CASA DFW rainfall grids (250m X 250m) within a GPM footprint are averaged, and the averaged values are assumed as ground truths. Fig. 5(a) shows the rainfall rates retrieved from GPM DPR over DFW region at 15:54UTC, June 17, 2015, whereas Fig. 5(b) shows the corresponding rainfall rates from CASA DFW rainfall system. Although some discrepancy could be seen from the scatter plot in Fig. 5(c), the preliminary evaluation results are quite promising. In future, the geometric distortion generated from the velocity changes due to orbit eccentricity will be taken into account for quantitative evaluation of the space rainfall products.

V. Summary

As a joint NASA and JAXA satellite mission, the GPM can provide accurate and frequent measurements of global precipitation, which plays a critical role for assessing Earth’s water cycle and changes in climate. This paper presents a validation methodology for the GPM mission, using a high-resolution dual-polarization ground radar network deployed in DFW Metroplex. The polarization diversity has great potentia-

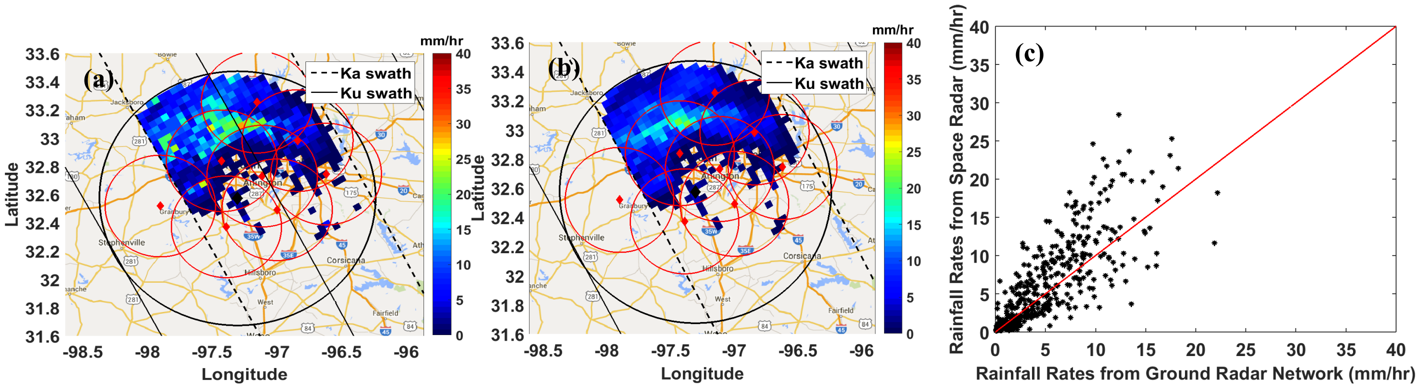

Fig. 5. (a) Space rainfall rates retrieved from GPM DPR, (b) ground rainfall rates from CASA DFW radar network, and (c) scatterplot of space and ground rain rate product at 15:54UTC, June 17, 2015.

-1 for quantitative precipitation estimation and understanding precipitation microphysics. The excellent performance of rainfall system developed for CASA DFW ground radar network has been shown to demonstrate its qualification for GPM validation.

In addition, data alignment between GPM space radar and CASA DFW ground radar is presented, and sample GPM overpass case in DFW area is used for quantitative evaluation. It has been shown that, for the case examined in this paper, the normalized standard error (NSE) of GPM space radar reflectivity observation at Ku-band is about 5.5%, and about 8.2% at Ka-band, assuming the ground radar measurements as the "truths". This paper also showed the preliminary evaluation results of GPM space rainfall products. Despite more case studies should be included in future analysis, the cross-comparison between space and ground radar rainfall products is quite promising.

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