4B.4 A GLOBAL PRECIPITATION MISSION (GPM) VALIDATION NETWORK PROTOTYPE

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1. INTRODUCTION

A Validation Network (VN) prototype is currently underway that compares data from the Tropical Rainfall Measuring Mission (TRMM) satellite Precipitation Radar (PR) to similar measurements from the U.S. national network of operational weather radars. This prototype is being conducted as part of the ground validation activities of the Global Precipitation Measurement (GPM) mission. The purpose of the VN is to provide a means for the precipitation community to identify and resolve significant discrepancies between the U.S. national network of ground radar observations and satellite observations. The ultimate goal of such comparisons is to understand and resolve the first order variability and bias of precipitation retrievals in different meteorological/hydrological regimes at large scales. The VN prototype is based on research results and computer code described by Anagnostou et al. (2001), Bolen and Chandrasekar (2000), and Liao et al. (2001).

2. GPM PLANNING

The GPM Core Satellite is scheduled for launch no later than June 2013, with the GPM Constellation Satellite launch scheduled to follow 18 months later. Current plans call for the GPM Ground Validation System (GVS) to be operational at least 6 months prior to the launch of the Core Satellite, and to support the GPM Core and Constellation satellites throughout the mission. During its early development phase the GVS will conduct a series of prototypes that take advantage of the current operations of the TRMM satellite. These prototypes will be used to develop and test GPM precipitation retrieval algorithms. The prototypes will also be used to test requirements and operations concepts for the GVS that will later be employed in the GPM era. Lessons learned from these prototypes will thus be applied in the development of GPM data products and in the incremental builds of the GVS. The results will help ensure that a robust ground validation capability is in place to support launch and operations of the GPM Core and Constellation satellites.

3. VN DATA COLLECTION AND PROCESSING

The VN dataset consists of matched TRMM PR and quality-controlled, ground-based WSR-88D (Weather Surveillance Radar – 1988 Doppler, or WSR-88D) radar reflectivity, for 21 sites in the Southeastern U.S. located within a bounding rectangle extending from 24° to 35° N latitude and 80° to 98° W longitude (Figure 1 and Table 1). The current period of record for the VN data starts on August 8, 2006 and runs to the present.

Site ID	Site name	Latitude deg. N	Longitude deg. W
KAMX	Miami, FL	25.6111	80.4128
KBMX	Birmingham, AL	33.1722	86.7697
KBRO	Brownsville, TX	25.9161	97.4189
KBYX	Key West, FL	24.5975	81.7031
KCLX	Charleston, SC	32.6556	81.0422
KCRP	Corpus Christi, TX	27.7842	97.5111
KDGX	Jackson, MS	32.3178	89.9842
KEVX	Eglin AFB, FL	30.5644	85.9214
KFWS	Dallas-Ft Worth, TX	32.5731	97.3031
KGRK	Fort Hood, TX	30.7219	97.3831
KHGX	Houston, TX	29.4719	95.0792
KHTX	Huntsville, AL	34.9306	86.0833
KJAX	Jacksonville, FL	30.4847	81.7019
KJGX	Robins AFB, GA	32.6753	83.3511
KLCH	Lake Charles, LA	30.1253	93.2158
KLIX	Slidell, LA	30.3367	89.8256
KMLB	Melbourne, Florida	28.1133	80.6542
KMOB	Mobile, AL	30.6794	88.2397
KSHV	Shreveport, LA	32.4508	93.8414
KTBW	Tampa Bay, FL	27.7056	82.4017
KTLH	Tallahassee, FL	30.3975	84.3289

Table 1. WSR-88D sites included in the current GPM GVS Validation Network prototype.

A new event record is added to the VN database any time the TRMM PR ground track passes within 250 km of one of the VN sites. For each overpass event, a WSR-88D volume scan (Level II archive product) for the closest volume scan beginning at or prior to the satellite overpass is acquired. WSR-88D Level II data are processed to a standard TRMM 2A-55 gridded dataset, including automated and manual quality control. Coincident PR data are extracted from the standard TRMM 1C-21 and 2A-25 datasets, which include radar reflectivity (both raw and attenuation corrected, respectively) as well as other parameters. Because the input WSR-88D datasets for the VN match-ups are quality controlled by a human analyst there is a time lag of up to several weeks from observation to VN product

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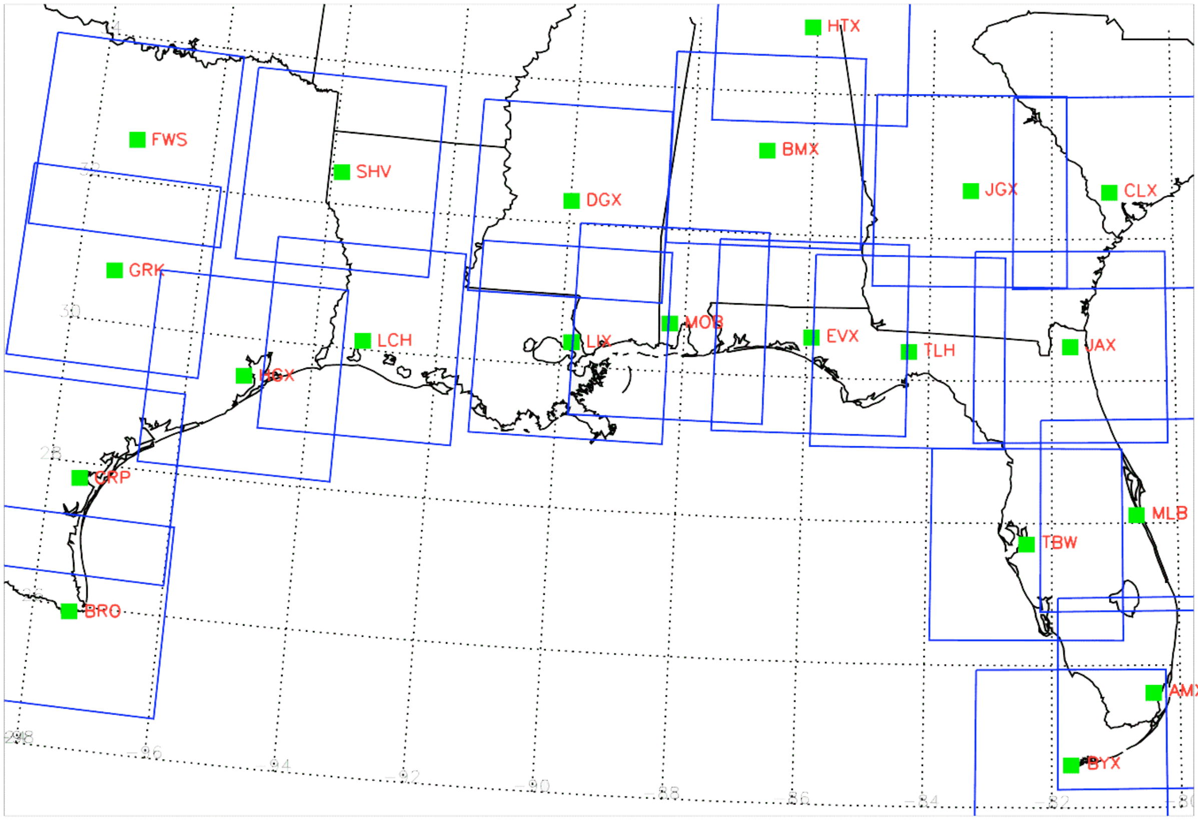

Figure 1. WSR-88D sites included in the GPM Validation Network prototype. Blue boxes indicate the 300x300 km analysis grids centered on each radar site.

generation. Both the original Level II and final quality-controlled WSR-88D products are retained in the VN dataset, along with all PR data for the portion of the orbit within the bounding rectangle.

A major component of the GPM VN prototype is the automated collection of metadata about each overpass event and storage of these metadata in the VN relational database. As PR data products are obtained, selected PR data parameters are analyzed to a 2-D horizontal grid over the grid domain described below, and scalar statistics about these gridded parameters are computed and stored. These statistics include the average height of the bright band over the analysis area, and the number of gridpoints:

- total, in a horizontal grid slice
- covered by the PR data swath
- indicating Rain Certain
- indicating convective rain type
- indicating stratiform rain type
- indicating rain type “other”
- indicating the bright band exists

The distance of the nearest approach of the TRMM orbit track to the ground radar site is also stored in the database. Queries to the database allow the analyst to easily identify those events with significant areal precipitation, precipitation of a given type (convective or stratiform, or unknown), or precipitation events where the orbital track is within a threshold distance of the ground radar. All associated data files cataloged in the database and are linked to the site overpass events, making it easy to assemble the data files for significant events for detailed analysis, downloading by a science team member, etc. As most site overpass events will have no occurrence of precipitation, it is easy to weed out the data for no-echo events without the need to process all the data or make complicated time/space associations to external data sources (e.g., surface rain gauges, aviation observations, climatic data). The prototype VN data processing system and database are designed with the flexibility to add additional data products, ground radar sites, and metadata parameters. Any ground radar sites within the TRMM PR area of coverage are supported within the current prototype as long as the reflectivity data are available in Universal Format or the WSR-88D Archive Level II format.

VN grid data match-up products consisting of coincident TRMM PR data and WSR-88D data are generated for overpass events meeting data coverage and precipitation occurrence criteria, with both data types resampled to a common 3-dimensional Cartesian grid centered locally on the overpassed radar site. Grids used in the current prototype have a 4 km horizontal and 1.5 km vertical spacing, and extend 300 km by 300 km in the horizontal and from 1.5 to 19.5 km in the vertical. The current criteria require ≥25% areal overlap of the grid domain by the PR data swath, and ≥25% confirmed rain in the overlap area, although these criteria are adjustable by modification of queries to the metadata stored in the database. Confirmed rain is where the Rain Flag parameter has a value of Rain Certain in the TRMM 2A-25 product. PR data are resampled to grids as described in Liao et al. (2001). The VN grid definition parameters are flexible but are constrained by the available ground radar analysis software.

On average, about 515 coincident events with available matching data are collected each month. Of these coincident events with data, about 22 per month meet the overlap and rain criteria. In the period from 8 August 2006 through 31 March 2007, a total of 7945 coincident overpass events were recorded by the VN. Of these, 192 individual match-up events met the overlap and rain area criteria. Thus, about 1.5 match-up events per month per site met the VN selection criteria.

3.1 *VN netCDF Datasets*

Data for events that meet the VN selection criteria are stored as netCDF files, three files per event. One PR and two WSR-88D netCDF files are generated separately. Each PR netCDF data file contains PR data that have been resampled to a Cartesian grid centered on the WSR-88D radar and oriented north-south along the local meridian. The data in the PR file consist of three, 3-dimensional "data cubes;" five, 2-dimensional data layers; and a number of scalar variables. The horizontal dimensions of the data cube and the 2-dimensional data layer form a 75 by 75 element grid, with a grid spacing of 4 km, thus the horizontal grids extend 300 by 300 km, centered on the WSR-88D radar. There are 13 vertical layers in the data cubes, each with 1.5 km vertical spacing. The data cubes extend from 1.5 km above ground level to 19.5 km in height. The PR 1C-21 and 2A-25 data are resampled to the common grids using a nearest neighbor (flags and categorical data fields) or bilinear horizontal interpolation (for reflectivity and rain rate) approach, with the following data included in each of the 3 data cubes:

- Raw PR radar reflectivity (Zr) from TRMM product 1C-21
- Attenuation-Corrected PR radar reflectivity (Zc) from TRMM product 2A-25
- Rain rate (mm/hr) from TRMM product 2A-25

A land/ocean flag, near-surface rain rate, bright band height, rain type, and rain/no-rain flag from PR products 1C-21 and 2A-25 are re-sampled to the same x-y grid as the Zr and Zc data, but these data layer grids are each only 1 level deep in the vertical. All corresponding PR grids and associated variables for one overpass of a given site are saved in the same netCDF file.

At present, the primary VN WSR-88D resampled product is generated from TRMM product 2A-55, which is WSR-88D reflectivity that has been quality controlled and gridded by the TRMM GV project. The NCAR SPRINT program is used to resample the WSR-88D data to the 2A-55 grid. The native 2A-55 product grid elements occupy a 2 by 2 km horizontal and 1.5 km vertical volume. The product is re-gridded by the VN prototype to 4 km horizontal resolution that corresponds exactly to the PR re-sampled product. Thus, the grid elements of the VN PR and WSR-88D products can be compared directly to one another. Two additional data variables will soon be added to the VN WSR-88D product. These are rain rate from the TRMM 2A-53 product and stratiform/convective type from the TRMM 2A-54 product. The rain rate and straiform/convective type will be resampled to the same 4 by 4 km grid so that these data will also be intercomparable with other WSR-88D and TRMM PR data. The rain rate and stratiform/convective rain type data will be included in all of the WSR-88D netCDF files.

A second radar data interpolation method is currently being used by the VN prototype for resampling the WSR-88D data. The REORDER program, which is also a NCAR product, is used to analyze reflectivity to compare with the PR product for each match-up case. The REORDER-based WSR-88D reflectivity analysis is stored in a separate netCDF file.

The PR and WSR-88D netCDF products both include a number of scalar variables that define the site name, site latitude and longitude, grid layer heights, x-, y-, and z-grid spacings, and time. For the WSR-88D files time is recorded as the start time of the volume scan. For PR files time is recorded as the time of the TRMM nearest approach to the ground radar. A Data User's Guide is available that provides additional detail on the structure and content of the VN netCDF files. The User's Guide can be found on the GPM Ground Validation website: http://gpm.gsfc.nasa.gov/groundvalidation.html.

4. VN RESULTS

Reflectivity comparison statistics are routinely generated for each match-up dataset on a site-by-site basis. Tables of mean error, standard deviation, and bias are computed for each event for a selected vertical level. Graphics are also generated including histograms and scatter plots of reflectivity. Results are computed for pooled data, and are also stratified between convective and stratiform rain, and position relative to the bright band (above, within, below). Examples of each will be shown in the following section. These results may be further stratified by whether the data lie over land, coast or ocean. Additional routine products such as probability density function and vertical reflectivity profiles are being developed; methods for addressing the temporal and spatial offsets between the satellite and ground radars are being evaluated. As the number of coincident precipitation events grows, it is expected that the statistical products will provide information on the reflectivity calibration accuracy and stability of the WSR-88D radars relative to the well-calibrated and stable TRMM PR.

4.1 *Statistical Comparisons*

The attenuation-corrected TRMM PR reflectivity has been compared to the WSR-88D reflectivity for the 192 cases of significant precipitation, as defined above. These preliminary results are based on the mean difference of the WSR-88D reflectivity from the TRMM PR reflectivity for a variety of data stratifications. In all cases, the set of data points considered was limited to those where both the PR and the WSR-88D reflectivity were both 18 dBZ or greater.

Site	Mean dBZ Difference	samples
KAMX	-0.54	3090
KBMX	-2.09	19173
KBRO	-0.22	4428
KBYX	-1.39	1519
KCLX	-2.21	11190
KCRP	0.49	2702
KDGX	-0.42	12095
KEVX	-1.71	6491
KFWS	0.39	17789
KGRK	2.43	6181
KHGX	-1.26	2376
KHTX	-0.97	11201
KJAX	-1.35	3967
KJGX	0.65	7916
KLCH	-2.22	4225
KLIX	-1.5	8235
KMLB	-0.6	1301
KMOB	1.22	3309
KSHV	-1.76	12939
KTBW	-1.57	1544
KTLH	-2.65	550

Table 3. Mean reflectivity difference (dBZ) between PR and WSR-88D above the bright band. Negative values indicate WSR-88D higher than TRMM PR.

The mean reflectivity differences between the PR and the WSR-88D for each radar site over all events are shown in Table 3. The subset of data included in the difference computations for this table are limited to those grid cells where the PR rain type is indicated as stratiform, and the base of the 1.5-km-deep vertical layer represented by the grid point is at least 250 m above the bright band height, as indicated in the TRMM 2A-25 PR product. This subset of points was chosen to limit the attenuation effects on the PR and the beam-filling effects on the WSR-88D. Positive (negative) mean differences in the table indicate PR reflectivity higher (lower) than the WSR-88D. The total numbers of grid points meeting these criteria at each site are also shown in the table.

A number of differences between WSR-88D sites are apparent in the statistics. These differences are assumed to be due primarily to site-specific calibration differences between the ground radars. For instance, the Fort Hood, Texas radar (KGRK) indicates a low reflectivity bias compared to the PR. This low bias was consistent among all the individual KGRK cases included in the aggregate results, indicating that the KGRK calibration was stable but low by a factor of over 2 dBZ. More commonly, individual sites showed a high reflectivity bias relative to the PR, most notably KBMX, KCLX, KLCH, and KTLH. Other sites were within 2 dBZ of the PR, on average.

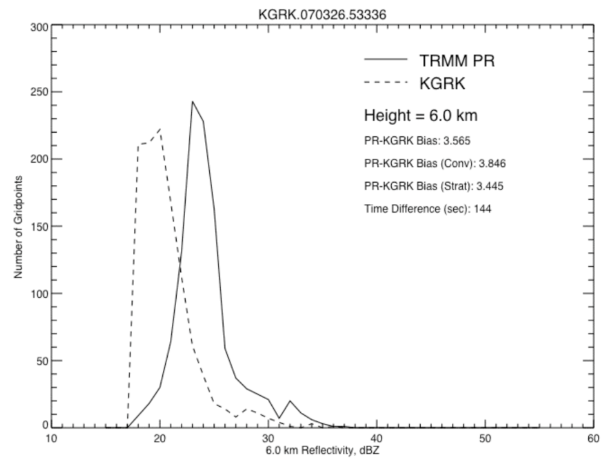

Figure 2. Distribution of reflectivity values at 6 km height for the TRMM PR (solid) and KGRK WSR-88D (dashed) for the TRMM overpass on 26 March 2007.

Figure 2 shows the distribution of reflectivity values at the 6 km grid level for KGRK for an individual TRMM overpass on 26 March 2007. The plot shows the number of grid points in 1 dBZ reflectivity increments separately for the PR and the WSR-88D. The roughly 3.6 dBZ low bias in the KGRK WSR-88D reflectivity values for this case is obvious. Biases were computed and the distributions were plotted for all matching points above 18 dBZ. Separate bias values are also computed and shown by rain type category in the PR. In this case, the WSR-88D biases by rain type were similar, at 3.8 dBZ and 3.4 dBZ too low for the grid points indicating convective and stratiform rain type, respectively. The six other overpass cases for KGRK (not shown) in the current data set had similar low biases when compared to the PR reflectivity.

In contrast, Fig. 3 shows a case of strong high bias of the Jacksonville, Florida (KJAX) WSR-88D reflectivity relative to the PR on 31 August 2006, where the WSR-88D values are more than 5 dBZ greater than the PR for all points and for those indicating stratiform rain type. The positive bias at KJAX decreased over time, approaching zero near the beginning of 2007, and rising again in late March 2007. It is not known whether this is a function of a drifting radar calibration or of the types of precipitation experienced in these different seasons. Lastly, Fig. 4 shows the reflectivity distributions on 17 October 2006 for the PR and the Jackson, Mississippi (KDGX) radar, whose calibration shows very low biases (within 1 dBZ) compared to the PR for 9 of its 15 overpass cases with significant precipitation echoes.

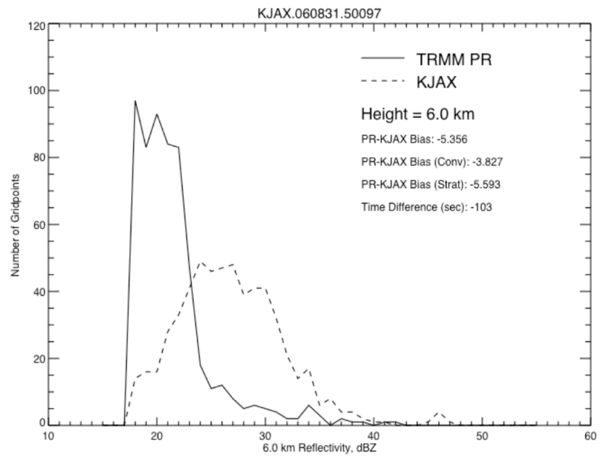

Figure 3. As in Fig.2, but for the KJAX WSR-88D on 31 August 2006.

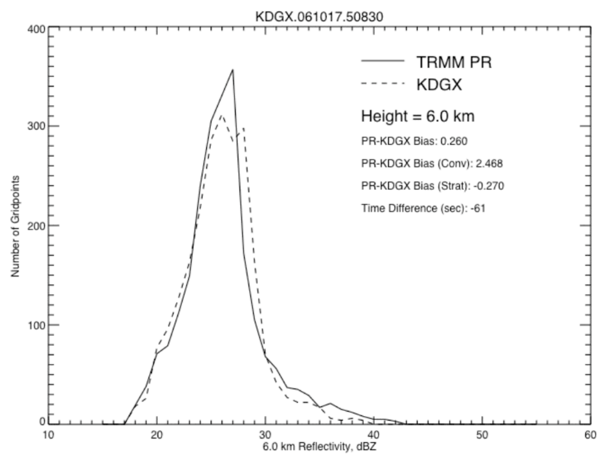

Figure 4. As in Fig. 2, but for the KDGX WSR-88D on 17 October 2006.

One of the goals of the GPM VN prototype is to help improve the attenuation correction algorithm for the TRMM PR so that this knowledge can be applied to the future GPM Dual-Frequency Precipitation Radar (DPR). PR and DPR reflectivity values are strongly attenuated at lower elevations when deep layers of precipitating cloud are penetrated, and as a result of the bright band. In a majority of cases, the PR shows increasingly positive reflectivity bias with respect to the WSR-88D at lower elevations above the surface. Figure 5 shows the vertical profiles of mean reflectivity for the PR (solid line) and the KAMX WSR-88D (dashed line) for an overpass on 8 August 2006. Above the level of the bright band (~5.7 km) the two radars show almost no bias, except at 12 km where only a single grid point is unrepresentative. Below the bright band the PR begins to show an increasing positive bias at lower altitudes. Likewise, Fig. 6 shows the vertical profiles of reflectivity for the KDGX case shown in Fig. 4. This aspect of the vertical reflectivity profiles is very common among the 192 cases investigated so far, although cases of near-zero or increasing negative bias in the PR can also be found. More investigation is required to verify the trend and identify the origin of this apparent vertical distribution in PR-NEXRAD reflectivity bias.

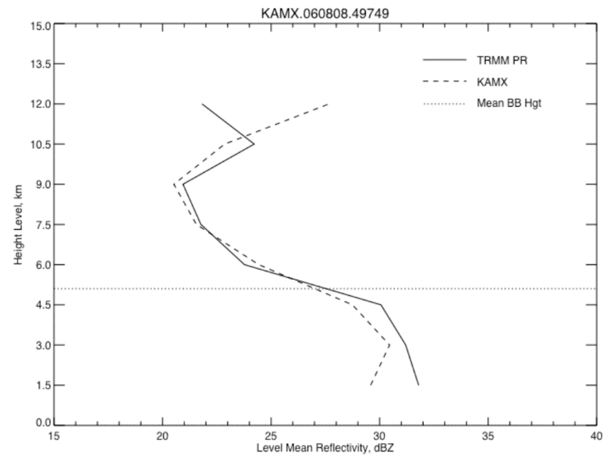

Figure 5. Layer-average reflectivity for TRMM PR (solid) and the KAMX WSR-88D (dashed) for the TRMM overpass on 8 August 2006. The dotted line indicates the mean bright band height as defined in the TRMM 2A-25 product.

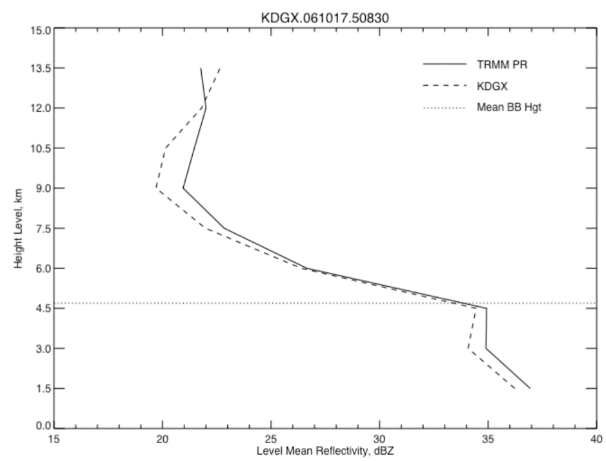

Figure 6. As in Fig. 5, but for the KDGX WSR-88D for the case shown in Fig. 4.

5. CONCLUSIONS

The VN is being used as a tool for evaluating the current TRMM PR attenuation correction algorithm. It is expected that these investigations will be used as a prototype for validating the attenuation correction and precipitation retrieval algorithms of the Dual-frequency Precipitation Radar (DPR) in the GPM era. Although the VN currently supports 21 match-up sites, the network was designed to be scalable. There are plans underway to add more U.S. domestic and international validation sites in the near-term, and additional participants are welcome to join the network. Information about the match-up grid data files and statistical products, including documentation and how to gain access to them on a password-protected ftp site, can be found on the GPM ground validation web site located at this URL: http://gpm.gsfc.nasa.gov/groundvalidation.html.

6. REFERENCES

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