Prototype of NASA's Global Precipitation Measurement Mission Ground Validation System

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***Abstract*— NASA is developing a Ground Validation System (GVS) as one of its contributions to the Global Precipitation Mission (GPM). The GPM GVS provides an independent means for evaluation, diagnosis, and ultimately improvement of GPM spaceborne measurements and precipitation products. NASA's GPM GVS consists of three elements: field campaigns/physical validation, direct network validation, and modeling and simulation. The GVS prototype of direct network validation compares Tropical Rainfall Measuring Mission (TRMM) satellite-borne radar data to similar measurements from the U.S. national network of operational weather radars. A prototype field campaign has also been conducted; modeling and simulation prototypes are under consideration.**

I. INTRODUCTION

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. These prototypes take advantage of the current operations of the TRMM satellite which can be used to test requirements and operations concepts that will later be employed in GPM. The lessons learned from these prototypes will be applied to the incremental builds of the GVS, and will help ensure that a robust ground validation capability is in place to support launch and operations of the GPM Core and Constellation satellites.

II. THE GVS VALIDATION NETWORK PROTOTYPE

In the GPM era the GVS Validation Network (VN) will compare GPM satellite data products to similar measurements and products from the national network of operational weather radars. A prototype of the VN is operating at present using TRMM data as a proxy for GPM. The goal of the VN is to identify and resolve significant discrepancies between the U.S. national network of ground radar observations and satellite observations. The VN was designed to be scaleable: it is possible to add more radars to the network, from both U.S. and international sites. The ultimate goal of VN comparisons is to understand and resolve the first order variability and bias of precipitation retrievals in different meteorological and hydrological regimes at large scales.

The VN prototype is currently being implemented for the sites identified in Figure 1 as a match-up dataset consisting of NOAA WSR-88D (NEXRAD) radar reflectivity and TRMM Precipitation Radar (PR) reflectivity. At present, the match-up data are collected for a 21-site subset of the 59 NEXRAD radars that are within view of the PR instrument. This 21-site subset falls within a bounding area of the continental U.S. with latitudes below 33°N and longitudes east of 98°W, plus KHTX at 34.9°N and 86.1°W (see Figure 1).

The VN is built on methods, research results and computer code described by Anagnostou et al. [1], Bolen and Chandrasekar [2], and Liao et al. [3].[1]

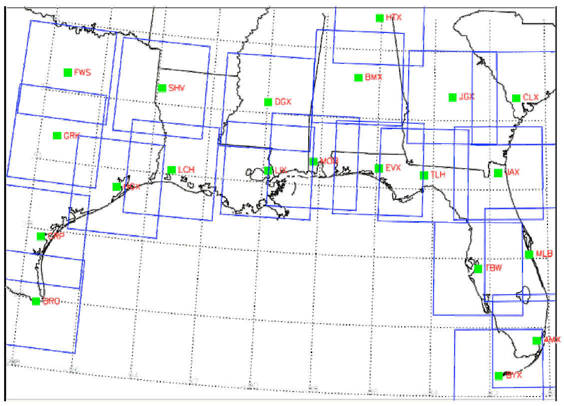

Figure 1. Location of 21 VN match-up sites and associated 300x300 km grid domains in the southeastern US.

[1] Anagnostou, E.N., C.A. Morales, T. Dinku. 2000. The use of TRMM Precipitation Radar observations in determining ground radar calibration biases. Journal of Atmospheric and Oceanic Technology. 18:616-628.

[2] Bolen, S.M. and V. Chandrasekar. 2000. Quantitative cross validation of space-based and ground-based radar observations. Journal of Applied Meteorology. 39:2071-2079.

[3] Liao, L., R. Meneghini, and T. Iguichi. 2001. Comparisons of rain rate and reflectivity factor derived from the TRMM Precipitation Radar and the WSR-88D over the Melbourne, Florida, site. Journal of Atmospheric and Oceanic Technology. 18:1959-1974.

The specific objectives of the VN prototype include:

- Collection of NEXRAD data and associated TRMM PR overpass data.
- Transformation of the NEXRAD and TRMM PR data to a common 3-dimensional Cartesian grid.
- Harvesting metadata from the NEXRAD and TRMM PR data, and storage into a relational database.
- Archive of the raw and transformed NEXRAD and TRMM PR overpass data.
- Generation of summary statistics that compare NEXRAD and PR radar reflectivity.
- Completion of prototype lessons learned, particularly with regard to: checking data quality; scaling the VN to include an arbitrary number of ground radars from around the world; and evaluating the scalability of the VN for comparison of additional data sets (e.g., TRMM Microwave Imager products) and additional parameters (e.g., rain rate, drop size distribution).

III. VN Product Description

The current period of record for VN match-up datasets starts on August 8, 2006 and runs to the present. A match-up event occurs when the ground track of the PR instrument passes within 250 km of a NEXRAD radar in the VN network. When an event occurs, TRMM PR products (1C-21, 2A-23, and 2A-25) and NEXRAD data are collected and processed (into TRMM Ground Validation product 2A-55). Because the generation of the TRMM 2A-55 datasets requires quality control by a human analyst, there is a time lag of up to several weeks from observation to VN product generation.

Although all overpass event data are stored by the VN, match-up products are generated only when an overpass event occurs during a "significant precipitation event." In this case, a significant precipitation event is defined as one with ≥25 per cent confirmed precipitation coverage in the PR swath and ≥25 percent overlap between PR and NEXRAD 2A-55 product domain. On average, there have been about 1.5 significant precipitation events per site per month. Of those with matching NEXRAD data, a total of 192 such events have been observed between August 2006 and March 2007 out of a total of 7945 coincident overpass events.

VN products are generated as separate, gridded netCDF files for PR and NEXRAD data. Each PR netCDF data file contains PR data that have been resampled to a Cartesian grid centered on the NEXRAD 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 NEXRAD 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 or bilinear horizontal interpolation 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.

The VN NEXRAD resampled product is generated from TRMM product 2A-55, which is NEXRAD reflectivity that has been quality controlled and gridded by the TRMM GV project. 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 NEXRAD products can be compared directly to one another. Two radar data interpolation methods are currently being used by the VN prototype for resampling the NEXRAD data: SPRINT and REORDER, both of which are NCAR products. All VN products are archived as separate netCDF files (see Section IV).

The PR and NEXRAD 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 NEXRAD 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.

IV. PR-NEXRAD Bias Evaluation

A preliminary study evaluated PR-NEXRAD bias in the VN data. In this study, bias was simply defined as PR minus NEXRAD reflectivity in a given coincident grid cell. Grid cells were selected for the study in cases where both the PR and NEXRAD reflectivity was ≥18 dBZ. For this study, 715,685 samples met the selection criteria. In a second study the data were stratified by altitude, with bias comparisons at 5 heights from 1.5 km to 13.5 km above ground level. Results are summarized in Table 1.

Overall, there was a nearly zero average bias between PR and NEXRAD radar reflectivity for the case where all samples from all sites were considered (Table 1A). In the second case, there was an apparent altitude-related bias. On average, the PR reflectivity was lower than the corresponding NEXRAD reflectivity at higher altitudes, and the PR reflectivity was relatively higher than the NEXRADs at lower altitudes (Table 1B-1F).

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TABLE I. AVERAGE BIAS IN CORRECTED PR RADAR REFLECTIVITY (ZC) MINUS NEXRAD RADAR REFLECTIVITY (NEXRAD VN PRODUCT RESAMPLING USING REORDER)

A. All samples from all sites	
average PR-NEXRAD bias	= +0.148 dBZ
number of samples	= 715,685
B. Samples from altitude 10.74-13.75 km	
average PR-NEXRAD bias	= -1.452 dBZ
number of samples	= 1,135
C. Samples from altitude 7.74-10.75 km	
average PR-NEXRAD bias	= -0.474 dBZ
number of samples	= 14,602
D. Samples from altitude 4.74-7.75 km	
average PR-NEXRAD bias	= -0.428 dBZ
number of samples	= 124,419
E. Samples from altitude 2.25-4.75 km	
average PR-NEXRAD bias	= +0.211 dBZ
number of samples	= 378,036
F. Samples from altitude 0.75-2.24 km	
average PR-NEXRAD bias	= +0.445 dBZ
number of samples	= 197,493

V. DATA ARCHIVE AND DISTRIBUTION

VN data are available on a GPM password-protected ftp site. Methods for access to the ftp site are described on the GPM GV web site http://gpm.gsfc.nasa.gov/groundvalidation.html. A VN Data User's Guide is also available that describes the format and content TRMM Precipitation Radar and NEXRAD match-up dataset.

VI. NEXT STEPS FOR THE VN PROTOTYPE

The VN is now running as an essentially automated process, aside from the manual control applied in the generation of the TRMM 2A–55 product. Sustaining engineering will be applied to the VN to make incremental improvements in the scripts and procedures that collect and store the TRMM PR and NEXRAD data.

Studies have been ongoing to assess the relative merits of the methods used to resample the NEXRAD product to grids. So far, the NCAR tools SPRINT and REORDER have been used for this resampling. Incremental improvements will be made on the resampling methods for generating grids, and new methods may adopted.

The VN prototype was designed with scalability in mind: it can be expanded with relative ease to include additional U.S. and international sites. Software has been developed to facilitate inclusion of additional TRMM PR site-subset or full-orbit products, along with their matching ground radar products if provided in 2A-55 or Universal Format. The domain and resolution of the netCDF grids are flexible.

While the VN currently focuses on match-up of PR and NEXRAD radar reflectivity, the addition of new data types is being considered. In particular, there is considerable interest in extending the match-ups to include retrieved rain rate and drop size distribution. The addition of TRMM Microwave Imager data to the VN is also being considered as it would provide a means for evaluating the variability and bias of microwave retrieval methods over land surfaces.

Finally, although the focus of the VN has been on generating standard products, custom products can be made for Precipitation Measuring Mission Science Team members and others on request. See Section IV for VN contact information.

VII. FURTHER INFORMATION ON THE VN PROTOTYPE

All of the PR and NEXRAD products described in this paper, including resampled grids, additional data layers, ancillary variables, and summary statistics are saved as netCDF files and stored on a password-protected ftp site. A VN Data User's Guide and other documentation are also available on the ftp site. Raw PR and NEXRAD data files are stored separately and can be provided on request. Access to the VN ftp site password protected. The GPM GVS web site provides information on how to access the VN ftp site, including information on how to obtain a site account and password. The GPM GVS web site (url provided in the Conclusions section) is also the source for additional information on the VN and other aspects of GPM ground validation.

VIII. OTHER GVS PROTOTYPES

During the winter of 2006-2007, the NASA's GPM GVS and Precipitation Measuring Mission (PMM) Science Team collaborated with the Canadian CloudSat/CALIPSO Validation Programme (C3VP) field campaign activities held near Toronto, Canada. The measurements taken through C3VP, with the addition of instruments supplied by NASA, will be used by NASA to provide data for early GPM algorithm development and validation in the area of falling snow retrieval. This collaboration was used by the GPM GVS as a prototype of the field campaigns and prototypes planned for the GPM pre- and post-launch era.

The C3VP campaign was conducted as a series of four Intensive Operations Periods (IOPs) beginning in November 2006 and ending in March 2007. Each IOP spanned about 10 days during which time aircraft and specialized ground instruments were operated. Data products from the C3VP campaign included:

- In-situ aircraft microphysics in snow and mixed phase precipitation from the Canadian Convair-580 aircraft
- High resolution triple frequency polarimetric radar measurements of snow/rainfall rate, particle type, and mass-content coincident to aircraft sampling using the University of Massachusetts Advanced Multi-Frequency Radar
- Precipitation particle size distributions and shapes measured near the ground under cover of radar and aircraft using various disdrometer instruments

- Comprehensive set of ground measurements to estimate and validate falling snow characteristics and environmental conditions.

The C3VP ground-based measurements were collected predominantly at Environment Canada's Centre of Atmospheric Research Experiments (CARE). CARE is located in the Great Lakes region between Lake Ontario and the Georgian Bay of Lake Huron. The climatology of the CARE site is such that it is the site of frequent lake-effect snow storms. Indeed there were a number of lake effect snowfall events recorded during C3VP, and several synoptic snowfall events were also recorded.

Data from the C3VP campaign is currently being analyzed and validated. The data are intended for use primarily by the participants of C3VP, but plans are in place for its ultimate public distribution. The C3VP web site should be consulted for additional detail http://c3vp.org/index.html.

The third element of GPM GVS, modeling and simulation, has yet to be prototyped. Plans are underway, however, to prototype this system element during calendar year 2008.

IX. Conclusions

Although the GPM GVS is in its early design phase it is actively pursuing a series of prototypes. These prototypes serve several purposes: they help to define requirements and operations concepts for the at-launch GVS; they take advantage of the current operations of the TRMM satellite which can be used as a realistic proxy for GPM; and finally the prototypes generate useful pre-launch data that can be used to develop and validate retrieval algorithms for products that will be generated in the GPM era.

As mentioned above, more about all aspects of the GVS, including its prototypes, can be found on the GPM GVS web site http://gpm.gsfc.nasa.gov/groundvalidation.html.