Comparing GPM's At-launch Version 3 Products to Reprocessed Version 4 Products

Erich Franz Stocker (Erich.F.Stocker@nasa.gov)[1], John Kwiatkowski [2], Yimin Ji [3], Owen Kelley [2], John Stout [2], and Lawrence Woltz [3]

[1]NASA/GSFC, Code 610.2, Greenbelt, Maryland, USA; [2]George Mason University, Fairfax, Virginia, USA; [3]Wyle Corporation, USA

EGU 2016

Introduction

The Global Precipitation Measurement (GPM) mission core satellite launched in February 2014 [1]. The Japan Aerospace eXploration Agency (JAXA) provided the core satellite's Dual-frequency Precipitation Radar (DPR) that observes at 13.6 and 35.5 GHz. The core satellite also carries the GPM Microwave Imager (GMI) with 13 conically-scanning channels. During the first two years after launch, the Precipitation Processing System (PPS) at NASA Goddard generated data products based on "at-launch" retrieval algorithms, also known as the Version 3 algorithms. The at-launch GMI precipitation-retrieval algorithm used a database constructed from the earlier Tropical Rainfall Measuring Mission (TRMM) satellite, previous imagers, ground radar, and model data. The GMI and DPR data products were first released in July and September 2014, respectively.

GPM algorithms were to be updated within a year of the Version 3 release or as soon as feasible thereafter. On March 1, 2016, the DPR algorithms were updated to Version 4, as were the level-1 GMI algorithms. The level-2 and level-3 GMI algorithms are in the process of being updated to Version 4. The lag in updating these algorithms is due to algorithm inter-dependencies, the complexity of precipitation retrieval, and the need to analyze how each algorithm is affected by changes to its inputs.

The GPM mission also processes data from a constellation of microwave radiometers that includes the AMSR-2 conically-scanning radiometer on the GCOM-W satellite, the SSMIS conically-scanning radiometer on various DMSP satellites (F16, F17, F18, and F19), and the MHS cross-track radiometer on the Metop-A, Metop-B, NOAA18, and NOAA19 satellites. The Version 4 inter-calibrated brightness temperature product uses GMI to calibrate the other constellation radiometers because GMI is one of the best-calibrated radiometers.

One of the most complex algorithm upgrades was to the GMI precipitation-retrieval algorithm known as GPROF, i.e., the GPM profiling algorithm. GPROF estimates precipitation for all of the constellation radiometers and GMI. Version 4 of GPROF uses a database based on the Version 4 GMI-DPR Combined Matched-Swath (MS) precipitation retrieval. For this reason, the Version 4 database could not be constructed until the Version 4 Combined algorithm was available. A candidate algorithm for Version 4 GPROF is currently under analysis, and during analysis, it is designated as the PPS Integration and Testing Environment run #60, i.e., "ITE060." GPROF Version 4 should be publically available soon after the General Assembly.

GMI Calibration Changes

The following list summarizes Version-4-related GMI-calibration analysis performed by the Inter-calibration Working Group (XCAL). This list comes from a report that XCAL-chairman Wesley Berg presented to the Joint Precipitation Measurement Missions (PMM) Science Team (JPST) as part of the acceptance process for Version 4 [2].

Calibration Analysis

1. Data from on-orbit calibration maneuvers were used to check for calibration anomalies and to develop corrections (**Figure 1**).

2. Calibration checks

2a. Emissive reflector: No evidence found

2b. Polarization check: Differences <0.3 K at nadir

3. Calibration corrections

3a. Magnetic anomalies: Along-track due to spacecraft flying through Earth's magnetic field. Cross-track due to magnetic latches on GMI's cover. Correction developed/applied. Residual anomalies are very small.

3b. Spillover correction: The forward part of the antenna pattern was measured before launch by Ball Aerospace at near-field range, but the spillover region could not be measured, so Ball used two different models that gave different results. The initial spillover correction η for the 166 GHz and 183 GHz channels was exactly 1.0, which is unphysical. Data from two inertial-hold maneuvers were analyzed by David Draper at Ball Aerospace. The resulting η values for Version 4 reprocessing (see **Table 1** or **Figure 2**) are based on physical observations rather than models.

Overview of Calibration Results

1. Significant changes were made to the spillover correction (see item #3b above). The limitations of pre-launch GMI calibration measurements likely led to significant Version 3 calibration differences between sensors, particularly for lower frequency channels.
2. Version 4 calibration corrections are based on data from on-orbit calibration maneuvers and are not dependent on radiative transfer models.
3. Independent comparisons by both Ball/RSS and XCAL indicate that the GMI calibration is consistent with clear-sky ocean simulated Tb.
4. A conservative estimate for the absolute calibration errors that remain in the GMI window channels is <1 K.
5. Comparisons that were made between GMI's 166 GHz and 183 GHz channels and the MHS and SAPHIR cross-track sounders indicate differences of only <0.5 K.

Brightness Temperature (Tb) Changes Due to Calibration Changes [3]

1. Adjustment of spillover coefficients of all GMI channels. This adjustment is the major improvement from Version 3 to 4 in the GMI antenna pattern correction. The adjustment of spillover is based on data from the GMI inertial hold and refinements of the analysis performed by the GMI manufacturer. Tb changes vary as a function of the channel and of the Tb itself. For channels 1 to 5, Tb is reduced by ~3–6 K at the high end of the Tb range. For channels 10 to 13, Tb is increased by ~2–4 K at the high end of the Tb range. For channels 6 to 9, Tb is increased by ~0.1 K at the high end of the Tb range.
2. Adjustment of antenna-induced along-scan bias correction. This small adjustment results in Tb changes of less than 0.1 K.
3. Adjustment of magnetic-correction coefficients. This small adjustment results in Tb changes of less than 0.1 K.

Table 1. Versions 3 and 4 spillover correction

Channel	V3 (η_F)	V4 (η_G)	ΔTb ocean	Total Error
10V	0.94435	0.95404	1.7	0.45
10H	0.94369	0.95404	1.0	0.24
18V	0.93968	0.95603	3.3	0.61
18H	0.94082	0.95603	2.0	0.42
23V	0.96601	0.97075	1.1	0.42
36V	0.99590	0.99535	-0.1	0.14
36H	0.99590	0.99535	-0.1	0.10
89V	0.99810	0.99734	-0.2	0.12
89H	0.99810	0.99734	-0.2	0.11
166V	1.00000	0.98814	-3.2	0.26
166H	1.00000	0.98814	-3.2	0.26
183±3V	1.00000	0.99212	-2.1	0.24
183±7V	1.00000	0.99212	-2.1	0.24

Fig. 1. GMI deep-space calibration

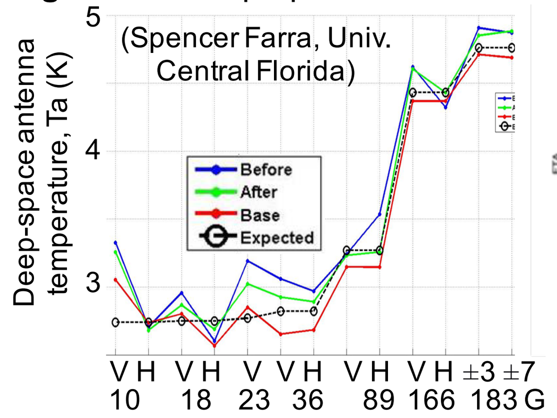
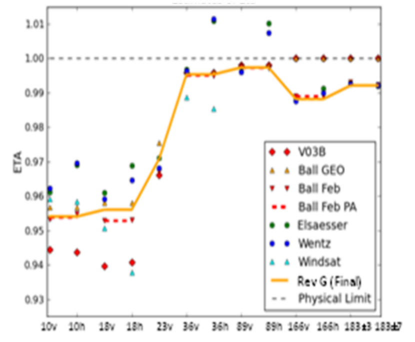


Fig. 2. Spillover correction



Yellow indicates the V4 correction (Tom Wilheit)

Fig. 4. Monthly time series of Versions 3 and 4, DPR and Combined retrievals on narrow swath (MS) and wide swath (NS)

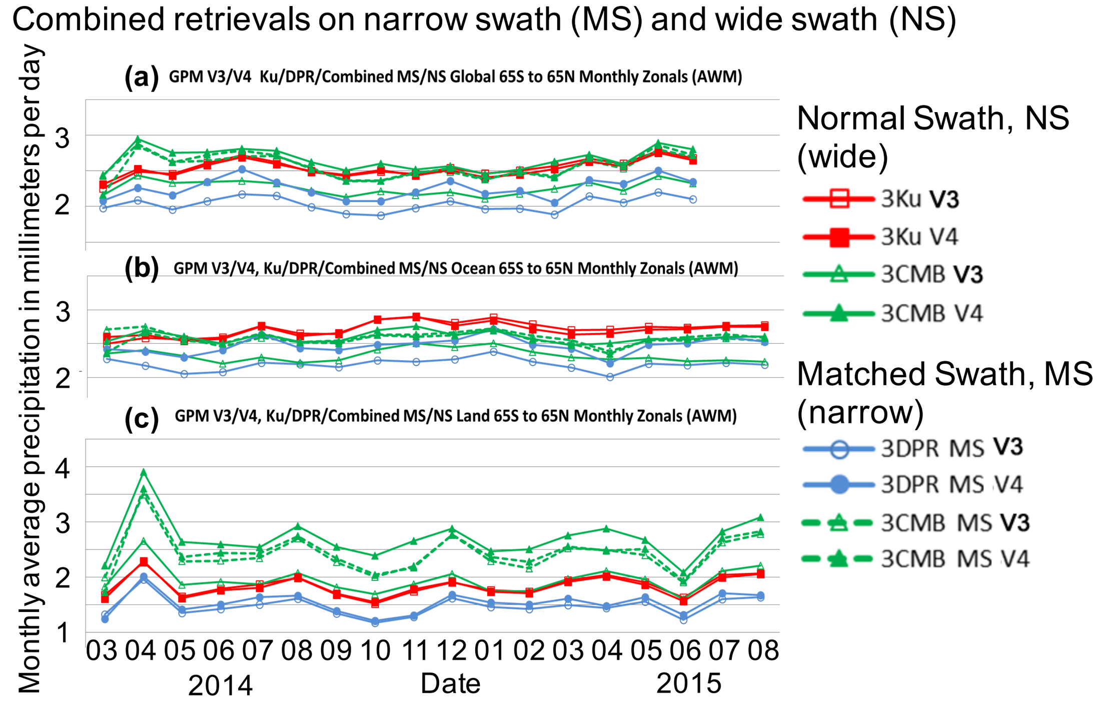
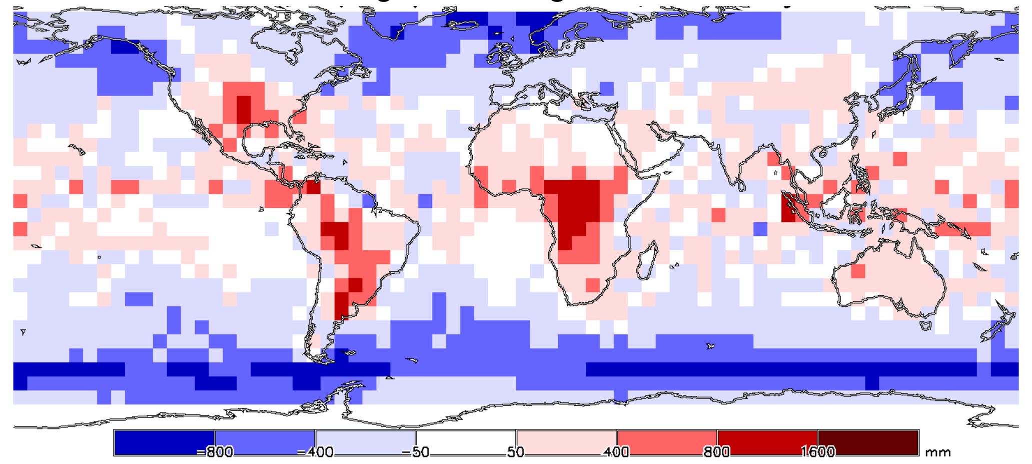
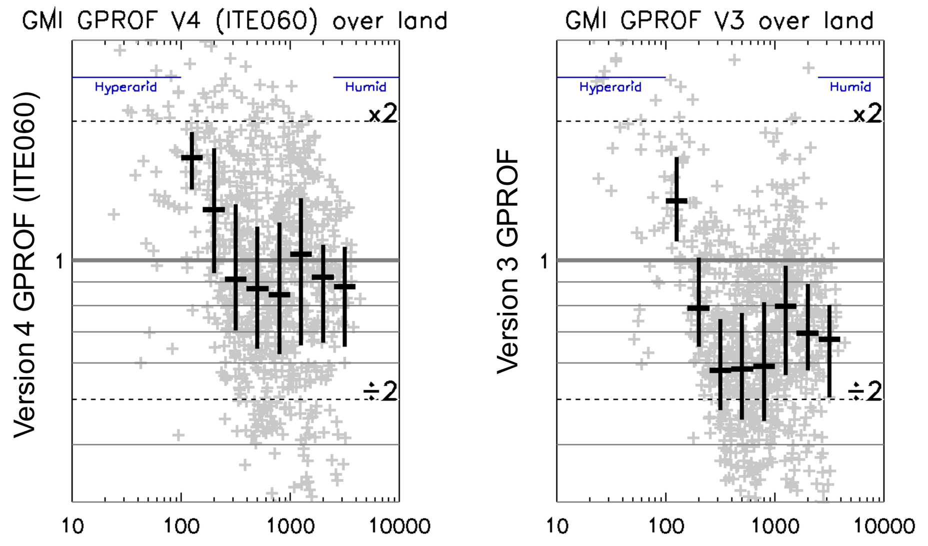


Fig. 5. Difference in annual accumulation between GPROF ITE060 and GPCP V2 gridded microwave precipitation retrieval, 5 degree lat/lon grid boxes



Millimeter/year precipitation difference for Sept 2014 through August 2015

Fig. 6. Ratio of GPROF precipitation to GPCC V2 gridded rain-gauge data: a scatter plot of continental 5 degree lat/lon grid boxes



Precipitation accumulation (mm/year) for 2014/09 to 2015/08 from the GPCC V6-monitoring gauge data product

Fig. 7. Monthly time series of GPROF Version 3 and ITE060

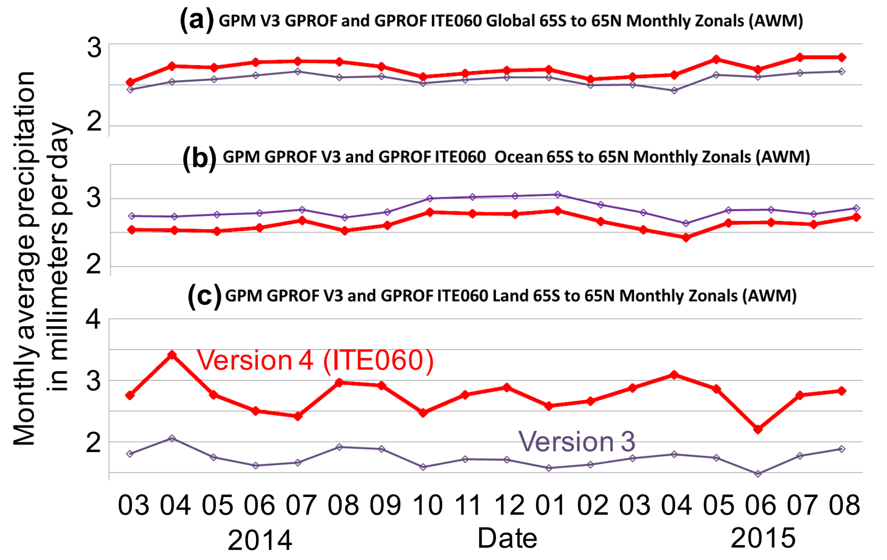
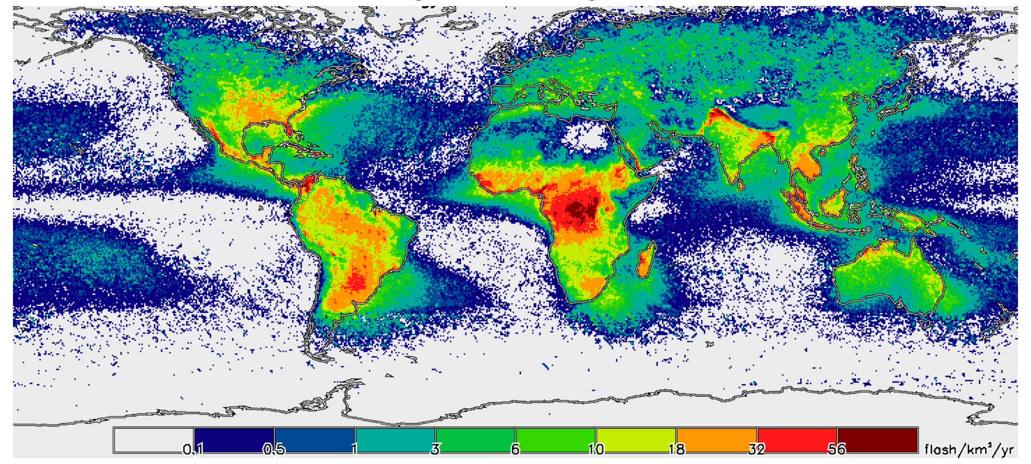
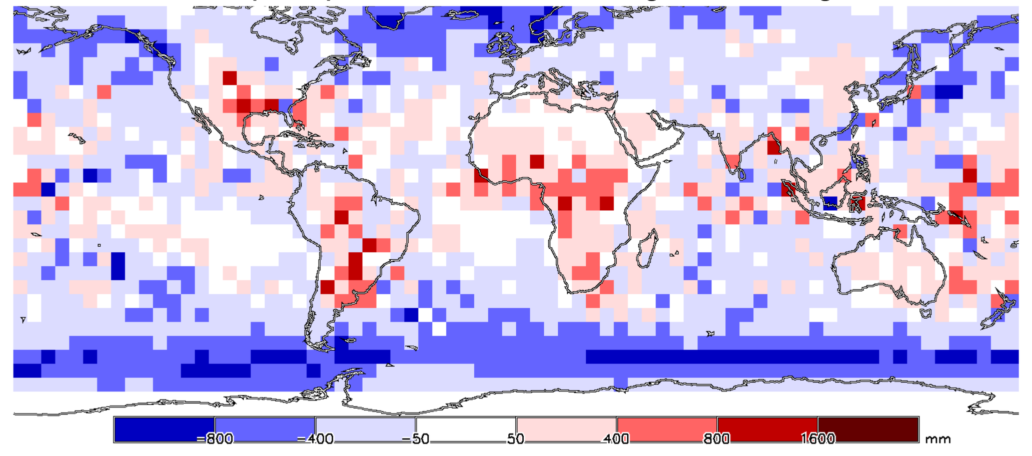


Fig. 8. Lightning climatology from Cecil et al. (2014), 1 degree lat/lon grid boxes



Annual flash count per square kilometer

Fig. 9. Difference in annual accumulation between Version 4 Combined Matched Swath (MS) and GPCP V2 gridded-microwave precipitation retrieval, 5 degree lat/lon grid boxes



Millimeter/year precipitation difference for Sept 2014 through August 2015

Fig. 10. Monthly time series of Version 4 GPROF (ITE060) and Version 4 Combined

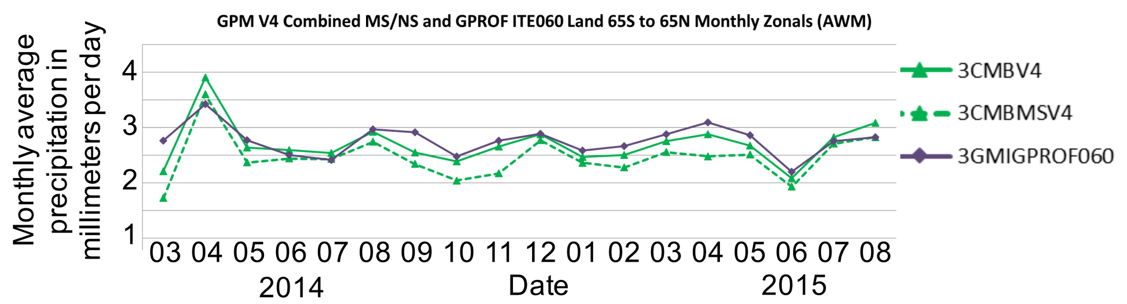
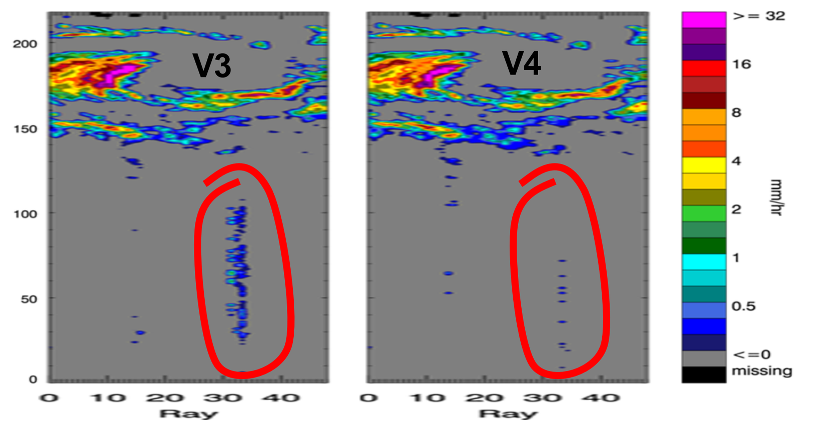


Fig. 3. Reduced clutter in DPR V4 vs. V3



Radar and Combined

The radar products changed little between Versions 3 and 4, both for level-1 (radar power) and level-2 (radar reflectivity and precipitation retrieval). In Version 4, the ground-clutter rejection routine was significantly improved in the level-2 Ku algorithm (**Figure 3**). Figure 4 shows time series of monthly means comparing Versions 3 and 4 of the DPR products and the Combined products. The time series show both the Ku-only wide swath (labeled NS for "normal swath") and the Ku+Ka dual-frequency narrow swath (labeled MS for "matched swath"). The monthly means are for the entire globe (**Fig. 4a**), ocean only (**Fig. 4b**), and land only (**Fig. 4c**).

These time series show that ocean retrievals have remained stable. In addition, the Ku retrieval has remained stable over land and ocean, while the Combined retrieval increases over some land area in Version 4. This increased precipitation over land has repercussions for GPROF Version 4, which uses the Combined retrieval to construct its database. While monthly means conceal regional differences, they do provide an effective tool for overall comparison of data product versions.

Candidate GPROF Version 4

Version 4 GPROF has not yet been approved for reprocessing because the analysis of the candidate Version 4 GPROF continues at this time. Earlier in the analysis process, it became apparent that, over certain land areas, the candidate algorithm (GPROF version ITE060) was not an improvement over Version 3 GPROF. GPROF ITE060 overestimates precipitation in certain continental regions (**Figure 5**).

Figure 6 compares GPROF ITE060 with the GPCC global-gridded rain-gauge product. Compared to Version 3 GPROF, the GPROF ITE060 retrievals are much closer to GPCC. Furthermore, monthly time series of Version 3 GPROF and the Version 4 GPROF (ITE060) show no major global issues in the candidate GPROF (**Fig. 7a**).

Time series of monthly-average precipitation shows that GPROF ITE060 and Version 3 GPROF are similar over ocean (**Fig. 7b**). However, the time series shows that GPROF ITE060 is significantly higher than Version 3 GPROF over land (**Fig. 7c**). To identify specific land regions causing the over-land increase, precipitation maps were examined. These precipitation maps compare GPROF ITE060 to the GPCP global-gridded passive-microwave precipitation product (**Figure 5**). The precipitation maps highlight that GPROF ITE060 is overestimating precipitation specifically in regions that are populated with weather systems that exhibit strong ice-scattering signatures.

Figure 8 is a multi-year lightning climatology produced from the TRMM Lightning Imager Sensor (LIS) and the Optical Transient Detector (OTD). Lightning is most frequent in regions that frequently have considerable ice aloft, a necessary precursor for cloud charging. Comparing Figures 5 and 8, one sees that the regions with the most lightning are generally the regions where GPROF ITE060 overestimates continental precipitation. As expected, this lightning data are consistent with the idea that precipitating clouds in these regions contain exceptional amounts of ice.

Figure 9 verifies that the Version 4 Combined Matched-Swath (MS) retrieval does overestimate precipitation in the same regions as does the GPROF ITE060 retrieval that was shown earlier in Figure 5. It is clear that the GPROF database derived from the Version 4 Combined contributes to the GPROF ITE060 overestimation over land. **Figure 10** shows the close relationship between GPROF ITE060 and Version 4 Combined, which should be expected due to GPROF using a database built from the Combined retrievals.

In conclusion, the candidate Version 4 GPROF (ITE060) exhibits many areas of improvement over Version 3 GPROF. Over ocean, GPROF ITE060 remains close to Version 3 GPROF. Over land, ITE060 overestimates precipitation in some regions but improves precipitation estimates elsewhere. Once this overestimation issue has been addressed and a new database constructed, the output will be examined to verify that the problem is fixed. Then, the Version 4 GPROF data will be reprocessed and released to the public.

Future Reprocessing

The JPST has approved the next GPM reprocessing cycle, which will be designated GPM Version 5 and which is scheduled for the spring of 2017. In GPM Version 5, JAXA anticipates updating the level-1 calibration of both the Ku and Ka channels of DPR. In Version 5, GMI calibration is also expected to change slightly. The GPROF retrieval algorithm and the GPROF data file format are expected to change. Any algorithm that reads GPROF retrievals will need to be modified to reflect the new GPROF format.

Later in 2017, the GPM Version 5 algorithms will be used to reprocess the entire TRMM-satellite archive (1998 to 2015). From the perspective of TRMM, this final reprocessing will be known as TRMM Version 8 and will become part of the GPM archive. TRMM Version 8 will include the following changes relative to TRMM Version 7:

1. The TRMM Precipitation Radar (PR) and Microwave Imager (TMI) will be processed with GPM Version 5 algorithms.
2. The GPM Version 5 radar-radiometer Combined algorithm will be used on TRMM data.
3. TMI level-1A data will be geolocated and written in HDF5 rather than being stored in a binary format with no geolocation. This change will make TMI 1A similar to the existing GMI 1A files.
4. Additional swaths will be added to the TMI level-1 products.
5. Major improvements will be made to TMI calibration and geolocation.
6. GPM filename conventions will be followed, including the version specifier of "V05." The old TRMM names for algorithms (e.g., 2A12, 2A25) will no longer be used in filenames.
7. Products will be written in the HDF5 format rather than HDF4.

From the perspective of GPM, the TRMM Version 8 reprocessing will make the TRMM satellite another satellite in the GPM constellation. All subsequent GPM reprocessing cycles will include data from the TRMM satellite back to 1998.

References

[1] Hou, A., et al., 2014: The Global Precipitation Measurement Mission. *Bulletin of the American Meteorological Society*, **95**, 701-711.

[2] Berg, W., et al., 2015: Intercalibration of the GPM constellation using GMI as a reference. Conference presentation, *AGU Fall Meeting*.

[3] Ji, Y., 2016: The GMI level-1b Algorithm Theoretical Basis Document (ATBD), version 2.3. NASA PPS, http://pps.gsfc.nasa.gov/.

Acknowledgements

Thanks go to the algorithm development teams in Japan and the USA. Much appreciation is extended to the GPROF Principal Investigator and algorithm team for providing an early version of GPROF for analysis for this poster. The author expresses appreciation to the GPM Inter-calibration (XCAL) working group and to Dr. Wesley Berg, current chair, who provided the GMI calibration analysis included in the poster.