TRMM Data Improvement as Part of the GPM Data Processing

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Introduction

NASA has long recognized the importance of reprocessing its mission data. Each mission has built into its schedule some periods of reprocessing. This reprocessing takes advantage of increased understanding of the sensors' operation as well as improvements in the physical retrieval algorithms. NASA's commitment to reprocessing extends even into the period of mission close-out (known in NASA parlance as "Phase F"). In the TRMM Phase F, NASA is investing substantial resources to provide the best-calibrated instrument products as well as the latest improved precipitation retrieval algorithms.

An important part of the TRMM Phase F reprocessing effort is committed to integrating TRMM data into the Global Precipitation Measurement (GPM) mission data suite. At the completion of this TRMM reprocessing cycle (TRMM V8), TRMM data will be totally integrated into GPM. After this last TRMM reprocessing, TRMM data improvements will become part of the ongoing GPM data suite improvement. Indeed, the TRMM satellite will become part of a historical constellation of satellites within the GPM data suite. Through the TRMM satellite, the GPM dataset will extend back to the launch of TRMM in December 1997. An important goal of the GPM mission is to create a consistent data suite back to the TRMM launch. The TRMM V8 reprocessing has this as one of its major objectives. At the end of TRMM V8 reprocessing, the TRMM data will form part of GPM data version V05. In other words, the string "V05" will appear in the filenames of the TRMM V08 data products.

The following sections will describe the expected changes and improvements in the TRMM V8 data products. These improvements come under the following categories: file format and naming, geolocation improvement, sensor-calibration improvements, and retrieval-algorithm improvements including using of GPM V05 retrieval algorithms.

New File Names and Format

For long-time users of TRMM data, the changes in the file naming convention may be particularly noteworthy. While such changes are, in the larger sense, not very significant, after more than 17 years of using a particular file naming convention, it might take a while for users to adapt to the change.

Prior to TRMM V8 reprocessing, TRMM filenames included a four-character data identifier that was comprised of numbers and letters. For this reason, TRMM researchers often talked about the "2A12" product, but this often confuses new researchers. The four-character data identifier contained much information. The initial number indicated the level of processing (with the categories established by NASA's EOS program). The capital letter indicated whether the data came from a single instrument or several, as in "A" for a single instrument or "B" for multiple instruments. The next number indicated which instrument aboard the TRMM satellite provided the data: "0" or VIRS, "1" for TMI; "2" for PR, and "3" for combined TMI and PR. Table 1 provides, as examples, the swath-based data types (i.e., level 1 and 2 data products).

Table 1

Data Type	Instrument	Basic Content
1B01	VIRS	Radiances
1B11	TMI	Brightness temperature
1B21	PR	Radar power
1C21	PR	Radar reflectivity
2A12	TMI	GPROF rain retrieval
2A21	PR	Sigma 0
2A23	PR	Rain type
2A25	PR	3-D rain rate
2B31	TMI/PR	Combined radar/radiometer rain

TRMM products that are not included in Table 1 include the level 3 time/space gridded products and the TRMM latent-heating products. GPM (and with V8 TRMM) products are named using the following convention:

ProcessingLevel . Satellite . Instrument . AlgorithmID . StartDate-SstartTime-EendTime . sequenceNumber . dataVersion . HDF5

Additional information that is included in the GPM filenaming scheme is AlgorithmID. Including the AlgorithmID in the filename allows users to determine the algorithm version that actually was used to create the product. When a data type, for example 2A12, is used that information could not be passed along. The following example shows the file name for a TRMM V7 TMI GPROF retrieval and shows the product name that will be assigned during the TRMM V8 reprocessing

TRMM V7: 2A12.20150102.97577.7.HDF

TRMM V8: 2A.TRMM.TMI.GPROF2017v2-0.20150102-S222908-E000048.097577.V05A.HDF5

The "V05" is included in the filename because the TRMM V8 reprocessing creates products within the GPM V05 data suite and based on GPM V05 algorithms. Also, the file is an HDF5 file with data stored using internal compression. Starting with TRMM V8 reprocessing, PPS will no longer support HDF4. Importantly, the name identifies GPROF2017v2-0 as the retrieval algorithm that was used. Indeed in a GPM sense, the discussion is always about the TMI GPROF2017 retrieval and not 2A12 as it was previously in TRMM.

The Precipitation Processing System (PPS) will keep the entire TRMM V7 data suite online in addition to the TRMM V8 reprocessed one. Previous versions are maintained online for FTP download. However when using the search and query interface only the final reprocessed data sets would be returned.

TRMM Geolocation Improvements

The first improvement comes from corrections in the definitive ephemeris files that were provided by the TRMM Flight Dynamic System (FDS) team for the orientation of the satellite. While generally very accurate there were times when errors due to out-of-date Earth-rotation parameters were introduced into the definitive ephemeris. Some errors were also introduced during leap-second events. PPS worked with TRMM FDS personnel to regenerate the mission ephemeris files using corrected information. This corrected ephemeris will be the basis for the TRMM V8 reprocessing.

The second area of correction was in the spacecraft-attitude files. Even during TRMM V7 reprocessing, PPS recognized that the spacecraft onboard pointing information was not always correct. During TRMM V7 reprocessing, PPS used PR data to correct orbit-period roll and yaw errors (https://pps.gsfc.nasa.gov/trending/trending_v7/rp_trending_v7/attitude.html). It is important to note that TRMM V7 reprocessing started in 2011, and the PR-based orbit-period analysis was done from the start of the mission only through 2009. This schedule means that TRMM V7 contains no orbit-period corrections for observations collected from 2010 to 2015 (the end of the TRMM mission).

For TRMM V8 reprocessing, the PPS orbital mechanics/geolocation analyst, Stephen Bilanow, developed an approach to use spacecraft gyro data as well as PR roll data to provide improved ground-computed attitudes. This required a substantial analysis effort as well as developing a detailed knowledge of the gyro biases. Separate analysis was performed for the period before the boost in 2001 (when the earth sensor was still being used) and for the post-boost period. This two-part analysis led to the development of software that processed the gyro data and corrected the attitude data that will be used in the TRMM V8 reprocessing.

Figure 1 provided by Stephen Bilanow shows examples of gyro-based attitude corrections. In this figure, the blue lines show the attitude that was used for TRMM V7 processing whereas the green lines show the attitude that will be used in the TRMM V8 reprocessing.

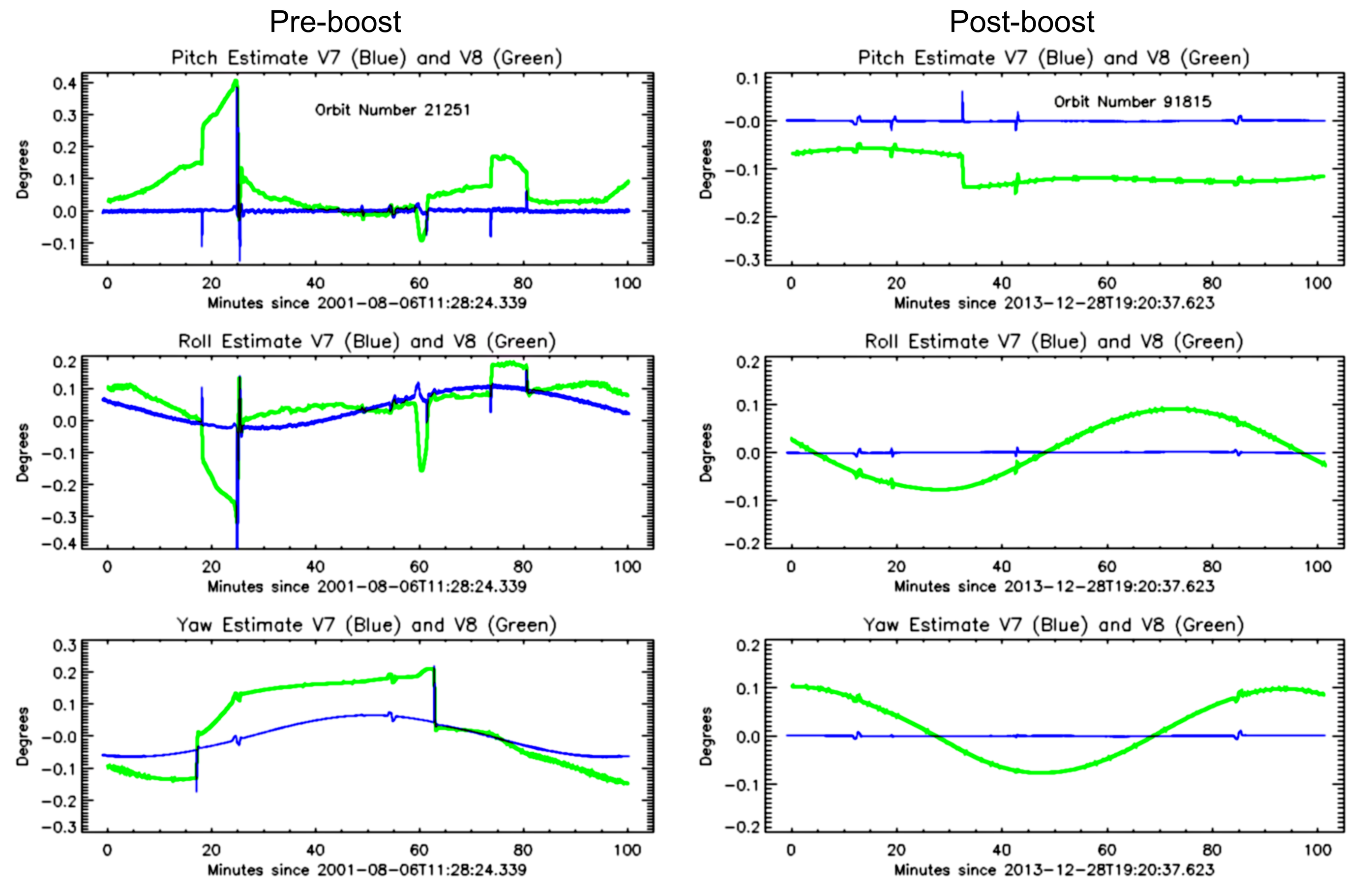

Figure 1: Comparison of TRMM V7 and TRMM V8 spacecraft-pointing information in TRMM orbit #21251 prior to the 2001 orbit boost and in orbit #91815 after the 2001 orbit boost.

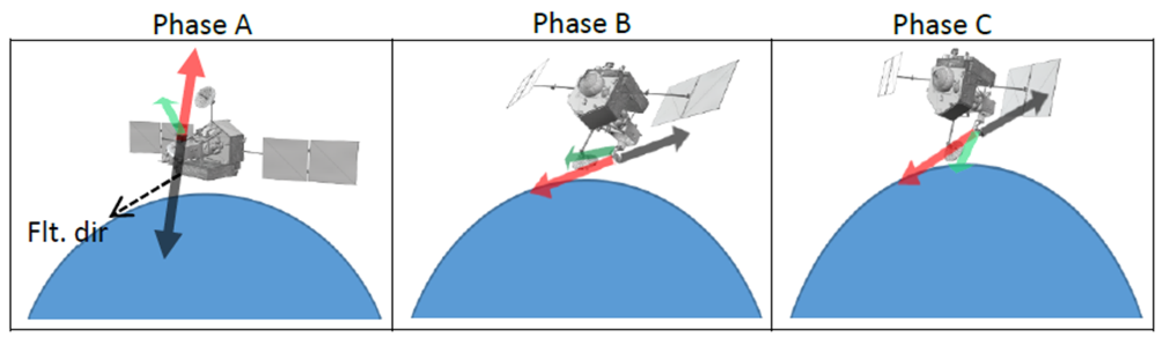

Figure 2: Schematic diagram of the 1998 Deep Space Calibration (DSC) maneuver.

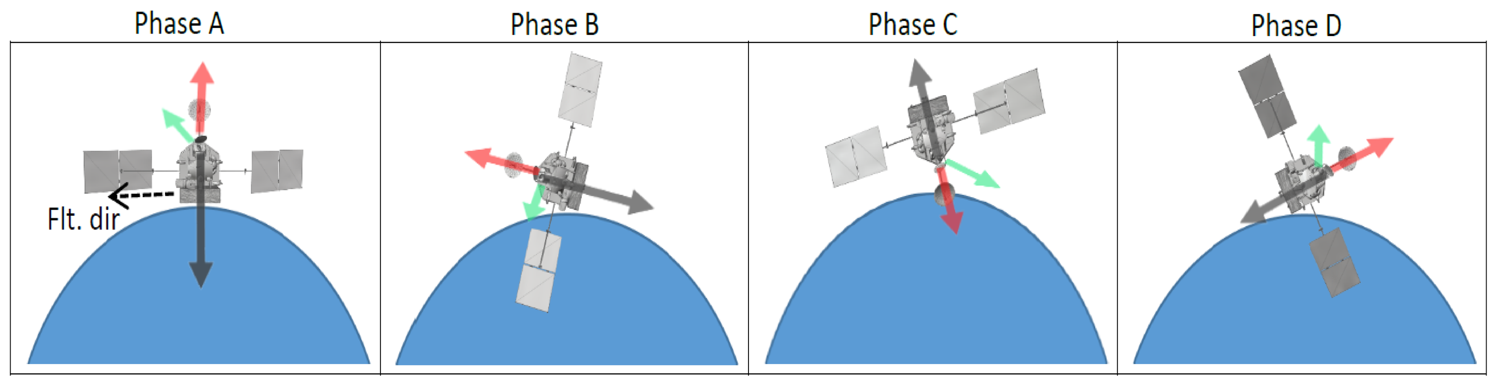

Figure 3: Schematic diagram of the 2015 Deep Space Calibration (DSC) maneuver.

The onboard attitude-control characteristics were different for the pre-boost and post-boost periods, as illustrated in the plots shown for sample orbits. In the pre-boost period, the control used Earth-horizon sensors to control pitch and roll. These sensors were susceptible to seasonal horizon radiance errors in the tenth of a degree range and occasional to errors from sun interference which caused errors as large as 0.4°. Yaw was updated using the Sun-sensor data twice each orbit and propagated with Gyro data, yet calibration issues caused errors to remain as large as 0.2° on many occasions. Real spacecraft motions due to errors and discontinuities in the onboard-calculated attitude are now tracked with the ground reprocessing.

In the post-boost period, the onboard control used Sun-sensor and magnetometer data along with gyro data in a Kalman filter. After tuning in the immediate post-boost period, the attitude control was generally smoother and met requirements (0.2°). Errors in roll and yaw had orbit-period characteristics due to magnetic-field modeling errors that affected the gyro-propagated attitudes. Pitch was dependent on onboard ephemeris, showing discontinuities at daily uplinks and systematic errors coupled with roll and yaw that were typically in the one or two tenths of a degree range.

These just-described corrections generally improve the accuracy of the attitude from the tenths of a degree range to the hundredths of a degree range. Errors in the attitude tracking are particularly improved during various anomalous periods. These new attitude estimates make use of the onboard gyroscope data, Sun-sensor data, and Precipitation Radar science data for measuring roll.

V8 Changes in VIRS

The VIRS instrument products will have the least changes of all the TRMM sensors. File names and formats will be changed. Obviously, the geolocation, both ground position and attitude will be improved because of the geolocation changes summarized above.

In TRMM V7, VIRS level 1A files were binary files containing packed CCSDS packets as received from the spacecraft. In TRMM V8, the VIRS level 1A files will be unpacked data that contain geolocated counts stored in the HDF5 format. This conversion to HDF5 will make it easier for researchers to use the count data should they wish it.

In TRMM V8, the VIRS 1B data product will continue to provide geolocated radiances. As time permits, some updates will be made to the radiance calibration in this product.

V8 Changes in Precipitation Radar (PR)

Major changes will be undertaken for Ku products from the TRMM PR. In TRMM V8, the level 1A products will remain packed-orbital CCSDS packets, but they will be stored in the HDF5 format.

In TRMM V8, the level TRMM PR 1B "radar power" products will use a format almost identical to the GPM V05 Ku-radar level-1B products. The Japan Aerospace Exploration Agency (JAXA) is committed to ensuring consistent Ku-band radar-reflectivity calibration between the TRMM PR and the GPM Ku instrument. To achieve this calibration, JAXA will use the overlap period when both TRMM and GPM were on orbit. It is anticipated that some PR calibration changes will occur for the TRMM V8 reprocessing.

The data product suite up to TRMM V7 included a radar-reflectivity product at level 1C and three level 2 swath products (sigma0-2A21, rain type-2A23, and rain retrieval-2A25). In TRMM V8, the GPM V05 Ku algorithm will be used to generate a single level 2 product for TRMM just as it is done for the GPM satellite. Indeed, the format for the TRMM V8 PR level 2 data product will be the same as that of the GPM V05. The important thing to note is that the TRMM V8 level 2 algorithm is based on the GPM V05 Ku algorithm.

In TRMM V8, the level 3 PR products will be like those of GPM V05 Ku. In other words, there will be daily and monthly files containing 0.25° and 5° grids. The format for these TRMM V8 level 3 products will be the same as for GPM V05 Ku level 3 products.

V8 Changes in TMI

In TRMM V8, TMI level 1A data products will include four data swaths. Swath S1 stores 10V and 10H GHz observations with separate incidence angles. Swath S2 stores 19V+H, 21V, and 37V+H GHz observations. Swath S3 stores 85V and 85H GHz observations. And last, Swath S4 stores housekeeping data. The TMI level 1A product will be changed from a binary orbital file containing packed CCSDS packets to containing geolocated counts for each swath type stored in HDF5. This way of handling the 1A data is analogous to what is done for GMI. Storing 1A data in the HDF5 format will make it much easier for researchers to use the count data.

Substantial efforts are ongoing to improve the calibration of the TMI sensor in the level 1B brightness temperature product. Some of the effects seen as part of the GMI calibration will be examined as part of the TMI calibration. These include but are not limited to RFI, moon intrusion, Earth-scene intrusion, and magnetic-field interference. As in done in GMI, the TMI data will be averaged across nine scans to improve the consistency and accuracy of the calibration (four scans backward, the current scan, and four scans forward). Such averaging increases the stability of the calibration and reduces cross-scan noise.

During TRMM V7 for the first time, a correction was made to account for the emissiveness of the TMI antenna. This correction went a long way toward ensuring that the brightness temperatures were accurate. While the correction was quite good, the GPM intercalibration working (XCAL) group believes a more-focused and physically-based correction can be applied to the TRMM V8 reprocessing.

The first step in this calibration process is to review the data from deep-space calibration (DSC) events as this data provides a physical benchmark for what TMI is actually measuring. In 1998, several DSC maneuvers were performed. The TRMM pitch attitude completed 360° rotation during one orbit causing the TMI antenna to view "cold space" (brightness temperature = 2.73 K). The TMI antenna system is comprised of three beams: the Main Beam (MB) black vector, the Spill-Over (SO) red vector, and the Cold Sky Mirror (CSM) green vector.

The optimum condition is for all beams to view space simultaneously, which was not possible for the 1998 DSC maneuvers (Figure 2). So these maneuvers by themselves were not enough to deal with the emissive-antenna issue.

In TRMM V7, the TMI 1B11 brightness temperature included several ad-hoc adjustments to improve the radiometric calibration. For TRMM V8, the University of Central Florida (UCF) team within XCAL has developed an improved radiative transfer model to calculate Tb from radiometer counts using physical principles and reanalysis of on-orbit DSC maneuvers. In 2015, prior to end of the TRMM mission, a new DSC was conducted by performing a spacecraft maneuver of yaw = 90° followed by a 360° roll (Figure 3). This maneuver allowed the three antenna beams to simultaneously view space and thereby correct the effects of an emissive main reflector. Analysis of these data forms the basis of the TRMM V8 1B11 emissive-antenna correction (Figure 4).

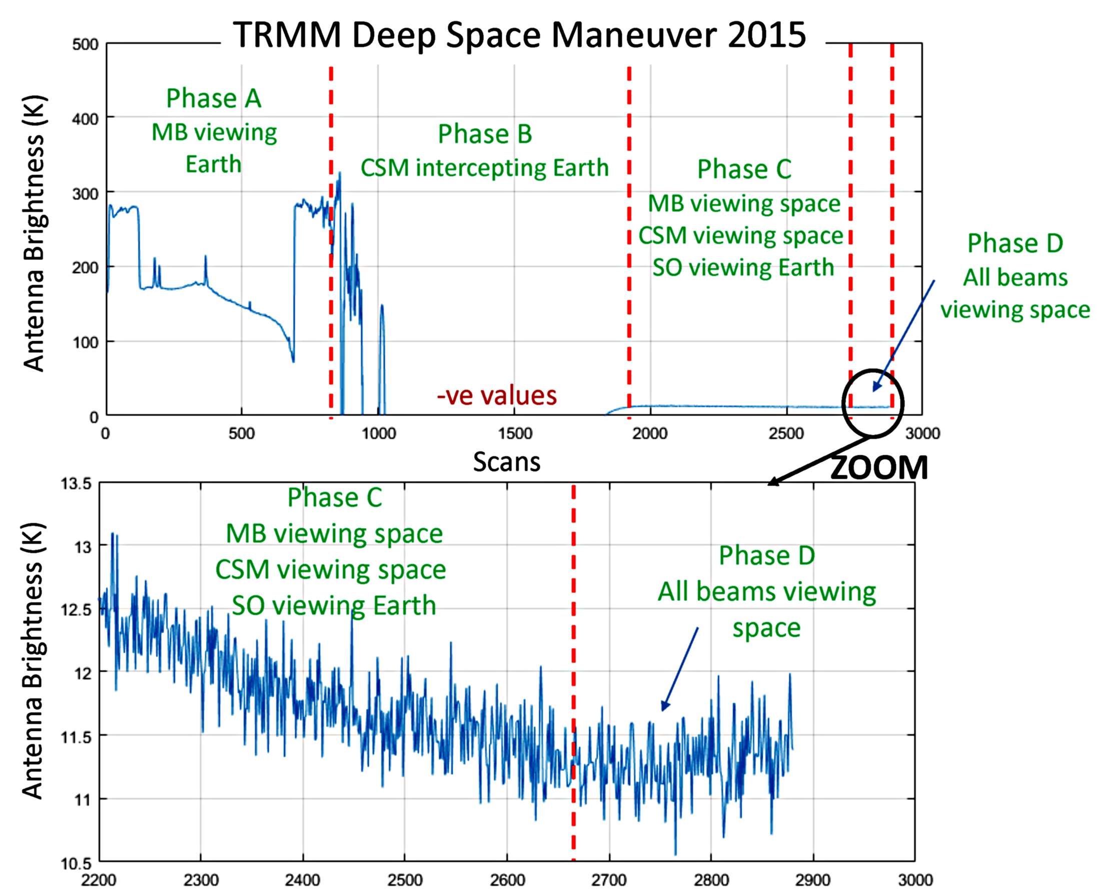

Figure 4: Data from the 2015 Deep Space Maneuver.

As part of the integration of the TRMM satellite into the GPM constellation of satellites, TMI will have a 1C product in which the brightness temperatures for TMI will be corrected based upon the GPM reference standard which is GMI. The TMI 1C calibrated brightness temperature (designated Tc) will be intercalibrated using GMI. This correction will then be used to intercalibrate the entire TRMM historical record. Once the TMI Tc data are available, these Tc values can be used to extend the GMI intercalibration to the remaining historical sensors that operated only prior to the launch of the GPM satellite (e.g., AMSRE, SSMIS, AMSU-B, etc).

The TRMM V7 TMI GPROF rainfall retrieval (aka TRMM 2A12) will be changed to use the GPM V05 GPROF algorithm. The file format and parameters of the TRMM V8 TMI GPROF data product will be the same as in GPROF V05 for all other radiometers. For more information, see IPWG2016 poster P1.20, *Results from GPROF V4 and Improvements Planned for V5* by Kummerow, Randel, and Petkovic. TMI level 3 products will have daily and monthly 0.25° x 0.25° grids.

V8 Combined (PR/TMI)

The combined data product, which was generated by the 2B31 algorithm in TRMM V7, will instead be generated with the GPM V05 combined algorithm in TRMM V8. In addition, the content of the TRMM combined product will include similar variables to the GPM-satellite combined data product. Obviously only Ku, not Ka, radar information will be used in the TRMM V8 combined algorithm. This new TRMM product will be consistent with the GPM product and will extend this consistently back to the beginning of TRMM.

V8 TMPA and IMERG

A major change occurs with the multiple-satellite precipitation product. Since TRMM V5, the TRMM Multi-satellite Precipitation Analysis (TMPA) has been the basis of a level 3 multi-satellite product. The product is computed for three-hour periods on a 0.25° x 0.25° grid covering 50°S to 50°N latitude. In addition, there is a monthly product. To summarize at a high-level, this product statistically "inter-calibrates" radiometers and IR precipitation products before merging them. These merged estimates are then adjusted to analyses of observations from precipitation gauges.

Beginning with TRMM V8, TMPA will no longer be produced. In its place the GPM IMERG algorithm will be used to create the merged satellite product. IMERG is a much more complex algorithm, combining the TMPA "statistical" calibration, morphing for time interpolation, and neural net precipitation estimates from IR data. This yields a highly robust and potentially more consistent merger over the TRMM time period.

IMERG is produced for half-hour periods on a 0.1° x 0.1° grid covering 60°S to 60°N latitude. In addition, a monthly product is produced at the same resolution. The final research product is gauge adjusted.

Acknowledgements

Stephen Bilanow developed the gyro data analysis technique and provided the figures to illustrate this technique. Dr. Linwood Jones and Faisal Alquaied of the University of Central Florida provided the DCS analysis and figures.