

TRMM Version 7 Level 3 Gridded Monthly Accumulations of GPROF Precipitation Retrievals

E. F. Stocker (1) and O. A. Kelley (2,3)

(1) NASA/GSFC, Code 610.2, Greenbelt, United States (erich.f.stocker@nasa.gov, 301 614 5269), (2) PPS, Code 610,

(3) George Mason University, Fairfax VA

Presented at the April 2012 General Assembly of the European Geosciences Union (EGU)

Abstract: *In July 2011, improved versions of the retrieval algorithms were approved for TRMM. All data starting with June 2011 are produced only with the version 7 code. At the same time, version 7 reprocessing of all TRMM mission data was started. By the end of August 2011, the 14+ years of the reprocessed mission data became available online to users. This reprocessing provided the opportunity to redo and enhance upon an analysis of V7 impacts on L3 data accumulations that was presented at the 2010 EGU General Assembly. This paper will discuss the impact of algorithm changes made in the GPROF retrieval on the Level 2 swath products. Perhaps the most important change in that retrieval was to replacement of a model based a priori database with one created from Precipitation Radar (PR) and TMI brightness temperature (Tb) data. The radar plays a major role in the V7 GPROF (GPROF2010) in determining existence of rain. The level 2 retrieval algorithm also introduced a field providing the probability of rain. This combined use of the PR has some impact on the retrievals and created areas, particularly over ocean, where many areas of low-probability precipitation are retrieved whereas in version 6, these areas contained zero rain rates. This paper will discuss how these impacts get translated to the space/time averaged monthly products that use the GPROF retrievals. The level 3 products discussed are the gridded text product 3G68 and the standard 3A12 and 3B31 products. The paper provides an overview of the changes and explanation of how the level 3 products dealt with the change in the retrieval approach. Using the .25 deg x .25 degree grid, the paper will show that agreement between the swath product and the level 3 remains very high. It will also present comparisons of V6 and V7 GPROF retrievals as seen both at the swath level and the level 3 time/space gridded accumulations. It will show that the various L3 products based on GPROF level 2 retrievals are in close agreement. The paper concludes by outlining some of the challenges of the TRMM version 7 level 3 products.*

1. Introduction

The Tropical Rainfall Measuring Mission (TRMM) observatory was launched from Tanegashima Space Center, Japan on November 27/28, 1997. The observatory carries 5 instruments: TRMM Microwave Imager (TMI), JAXA-provided Precipitation Radar (PR), Visible and Infrared Scanner (VIRS), Earth Observing System (EOS) provided Lightning Imaging Sensor (LIS), and EOS-provided Clouds and the Earth Radiant Energy System (CERES) [1].

A key aspect of the TRMM mission is the frequent reprocessing of the entire mission data when the characteristics of the instrument (e.g. calibration) change or when improvements in the retrieval algorithms can be incorporated. This paper analyzes the impact that V7 changes in the L1B brightness temperature (Tb) product and the Goddard Profiling (GPROF) level 2

precipitation-retrieval algorithm had on the level 3 time/space averaged products, both monthly and daily. It was discovered that the Tb from TMI (V6 1B11) had an orbital position bias [2]. The version 7 1B11 algorithm applies a Tb bias correction to remove most of the effect of this heating-induced bias in the warm load.

The most significant impact on the L3 accumulations came as a result of the changes in the GPROF retrieval described below, which was clear during the algorithm testing prior to the start of V7 processing [3]. In May of 2011, the Joint Precipitation Measurement Missions (PMM) Science Team (JPST) approved the beginning of V7 reprocessing with 1 July 2011 data. Reprocessing is carried out both at the Precipitation Processing System (PPS) and at JAXA at the Tsukuba Space Center, Japan. PPS completed reprocessing by 19 of August 2011.

2. Goddard Profiling (GPROF) Precipitation Retrieval

V6 GPROF and previous versions of GPROF relied on a set of cloud resolving models along with computed brightness temperatures in the a-priori database. In version 7, this database was changed to one constructed by first taking the TRMM PR precipitation product and computing the corresponding brightness temperatures. Where there are differences between computed and observed brightness temperatures, the initial hydrometers were modified so that full agreement of the PR reflectivities and TMI brightness temperatures was achieved [4].

GPROF V6 and previous versions of GPROF all used precipitation/no-precipitation thresholds that were needed because the cloud resolving models did not have representative ratios of precipitating and non-precipitating clouds. With the proper ratio of precipitating and non-precipitating pixels represented in the V7 database, it was no longer necessary to determine whether or not a pixel is precipitating before applying the Bayesian scheme. GPROF V7 still reports the unconditional precipitation rate, but because pixels can be consistent with both precipitation and zero-precipitation database entries, GPROF V7 now also reports the probability that a specific pixel is precipitating.

GPROF V6 and previous versions explicitly reported at each vertical layer the concentration of cloud water, precipitation water, cloud ice, and precipitating ice and the latent heating rate. Version 7 reduces the output volume by approximating the profile for each hydrometeor species with a linearly-scaled version of one of the 100 reference profiles stored in the file metadata [5].

The GPROF algorithm contains three relatively distinct retrieval modes for land, coast, and ocean. Retrievals of the ocean are physically based using the a-priori database. The retrievals over land and coast are essentially empirically grounded retrievals. Land and coast retrievals used PR data to help establish the retrieval limitations, but PR observational data is not used dynamically during individual land or coast retrievals.

3. Analysis

TRMM produces three level-3 (space-time gridded) products that aggregate the level-2 swath based GPROF retrieval. The first of these products is a monthly product with a .5 x .5 degree grid (3A12-TRMM designation) that is a direct accumulation of TMI GPROF (2A12-TRMM designation). The second product is also monthly with a .5 x .5 degree grid and contains the combined PR-TMI accumulations and the TMI GPROF full-swath accumulations (3B31-TRMM designation). Both of these products are stored in HDF4. The last level 3 product using GPROF retrievals is a gridded text product (3G68-TRMM designation)[6]. This product is

produced at three grid resolutions (.5, .25, and .1 degree) and two time resolutions (daily and monthly). All the daily 3G products contain a separate average for each hour of the day in UTC time. Monthly summations of these daily files are produced only at .5 x .5 and .25 x .25 degree resolution. Each line of a 3G68 file records the information for a single grid box, specifically the summary of the precipitation retrieval from GPROF (2A12), and if available, PR (2A25) and Combined (2B31).

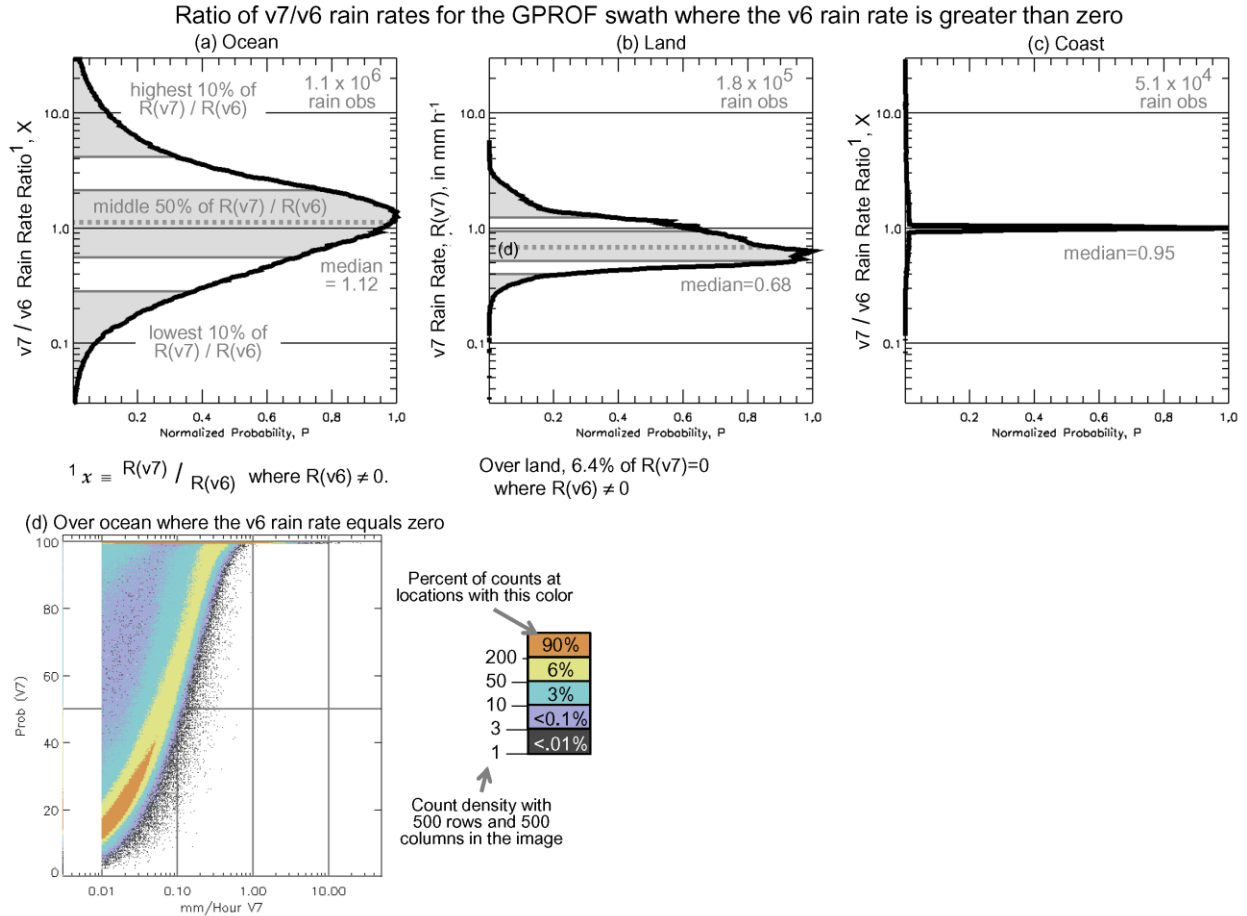


Figure 1

A detailed analysis of the differences between TMI GPROF V7 and V6 is beyond the scope of this paper and is being done by others [4]. Figure 1 presents a high-level statistical summary of three days of GPROF swath retrievals comparing version 6 and 7 that hints at some of the differences between the two versions. The data were collected on 1-2 January 2009 and 1 June 2009. The first three panels of figure 1 display a probability density function (PDF) normalized to a maximum value of 1. Near the peak, the middle 50% of the distribution is indicated with gray shading and the median is indicated with a gray dotted line. Figure 1a summarizes TMI GPROF data over ocean where the V6 precipitation rate is greater than zero. The ratio of V7 to V6 precipitation rates has a median value of 1.12, and the middle 50% of the data has a ratio between 0.5 and 2. This indicates that V7 provides slightly more precipitation over ocean than V6 did. Figure 1b presents the summary over land where the V6 precipitation rate is greater than zero. V7 precipitation rates are often lower than the V6 precipitation rate at the same location.

The median ratio is 0.68. The middle 50% of the data have a ratio between 0.5 and 0.9. Over coast, Fig.1c shows that, where the V7 precipitation rate is not zero, it tends to remain very close to the V6 precipitation rate. Specifically, 41% of coastal V7 precipitation rates are within 5% of the V6 precipitation rate (i.e., the V7/V6 ratio is 0.95 to 1.05). In addition, 44% of coastal V7 precipitation rates are zero where V6 precipitation rates are non-zero (not shown in plot). Figure 1, panel d, provides a two-dimensional summary of the swath where V6 ocean precipitation retrievals are zero. The precipitation rate is plotted against the probability that precipitation is occurring. This data had to be excluded from figure 1a to avoid division by zero. As can be seen, the majority of the precipitation rates are below .1 mm/hr and have an occurrence probability of less than 50%.

Having provided a high-level summary of the differences between the V7 and V6 TMI GPROF retrievals, the next step is to look at how these alter the level 3 accumulations. The accuracy of the summing process is suggested by the single overflight of the Atlantic Ocean shown in figure 2. In this figure, V6 and V7 GPROF are compared with the single-hour 0.25-degree grid of V7 3G68. The close match of V7 GPROF and V7 3G68 occurs because the 0.25-degree resolution of 3G68 is close to the TMI instrument's footprint.

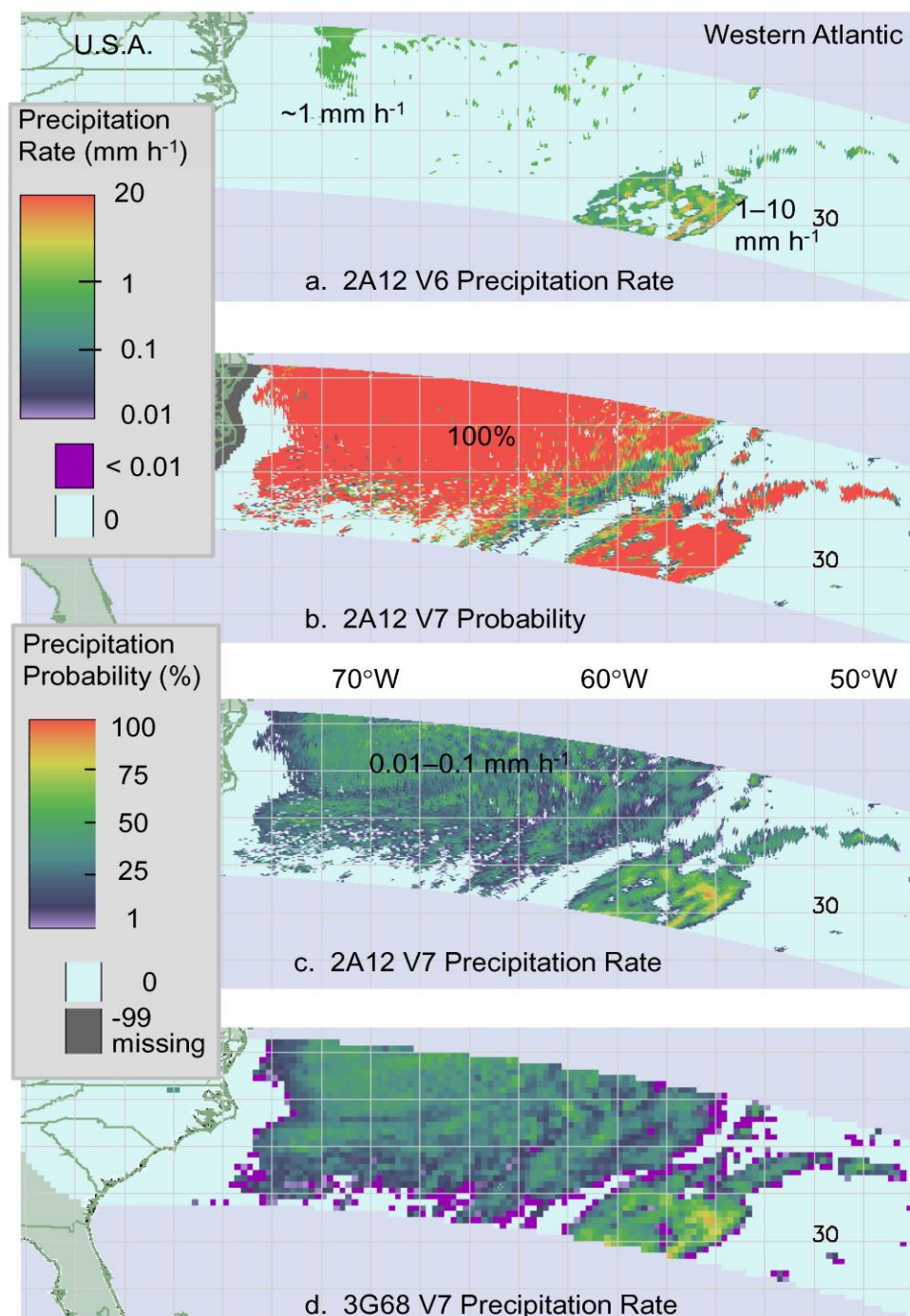


Figure 2

The single overflight of oceanic precipitation in figure 2 illustrates the broad conclusion of the statistical summary of three days of oceanic retrievals in figure 1a. Specifically, where V6 GPROF detected precipitation, the precipitation rates in V7 are similar. Over the three-day period used to generate figure 1, 28% of the oceanic locations with zero precipitation in V6 have greater than zero precipitation in V7. This "new" precipitation in V7 is typically light, with only 7% of the zero-precipitation V6 locations having precipitation rates in excess of 0.1 mm/hr in

V7. V7 GPROF's improved ability to detect moderately light precipitation comes from V7 GPROF's use of TRMM Precipitation Radar data to make precipitation/no-precipitation determinations and to estimate the profile of the light precipitation. Where GPROF believes there may be very light precipitation that falls below the sensitivity of the TRMM radar, then GPROF assigns a low probability to the precipitation, as shown in figure 2b.

The decision was made that all level 3 products should accumulate all TMI GPROF precipitation-rates regardless of the probability of occurrence that the retrieval assigns to them. This decision was based on the need for level 3 algorithms not to filter very low-rate, very low-probability data as this might have major impacts on the accumulations. While both 3A12 and 3G68 count a TMI GPROF precipitation pixel with very low precipitation rate and very low probability in the total-pixel count, neither algorithm adds such a pixel to the precipitation-pixel count. As level 3 contains unconditioned precipitation-rate, this approach ensures that GPROF data is not lost when accumulating the month grid from the hourly grids.

In the 3G series of products, additional information can be inferred where the precipitation rate is greater than zero and there are no precipitation counts. In such a case, all of the precipitation can be attributed to precipitation rates with a probability of occurrence under 50%. This can occur only when all the pixels in the grid are over ocean.

The equivalent area of 3G68 quarter degree data is presented in figure 2d. Visually comparing this with TMI GPROF data in figure 2c, it is easy to see that it faithfully represents the TMI GPROF data. However, the resolution of 3G68 quarter degree is coarser than the TMI GPROF. This can be seen in the smearing of detail and also the coarser edges where the very light precipitation rates are more visually apparent than in figure 2c. Second, 3G68 maintains only 4 decimal places of accuracy for the precipitation rates while GPROF outputs floating-point values.

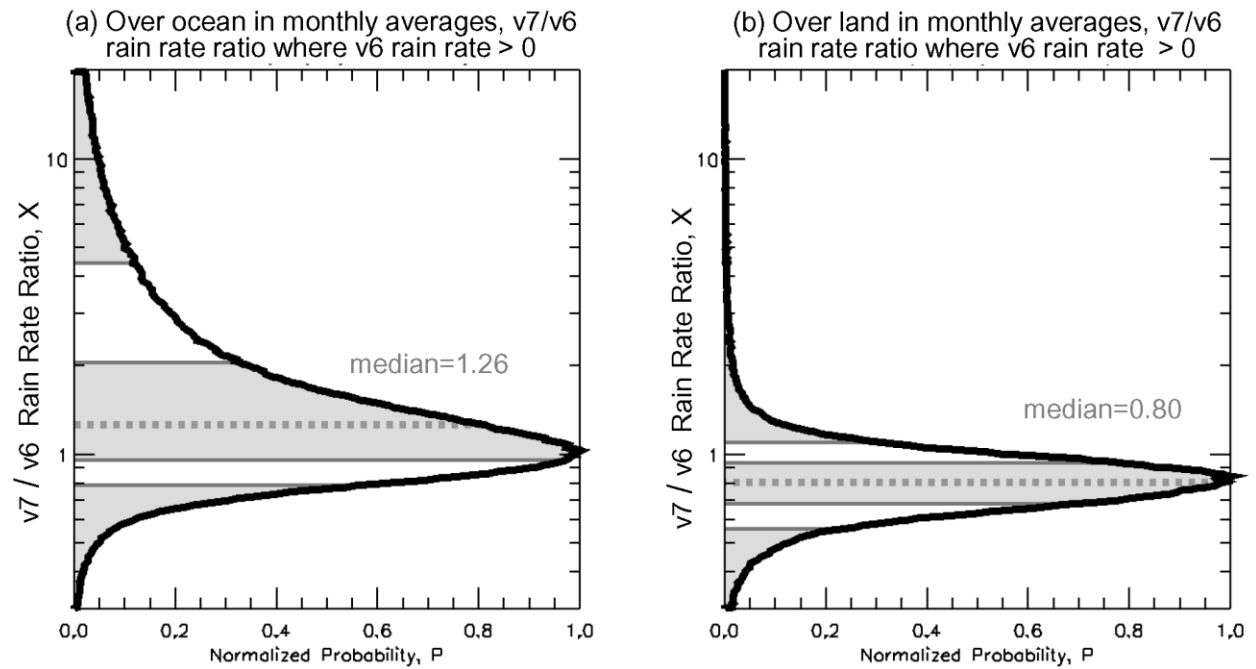


Figure 3

Having demonstrated that the hourly 3G68 grid accurately tracks the single-swath GPROF retrievals, the next step is to compare the monthly summarizes of hourly 3G68 grids to the direct monthly accumulations of GPROF swaths. Figure 3 presents a statistical summary of 2007's twelve monthly 3G68 0.5 degree wide-swath grids. Figure 3a provides information over ocean and figure 3b over land, and it shows the same trends noted at the instantaneous level in figure 1: V7 is slightly higher than V6 over ocean and slightly lower over land.

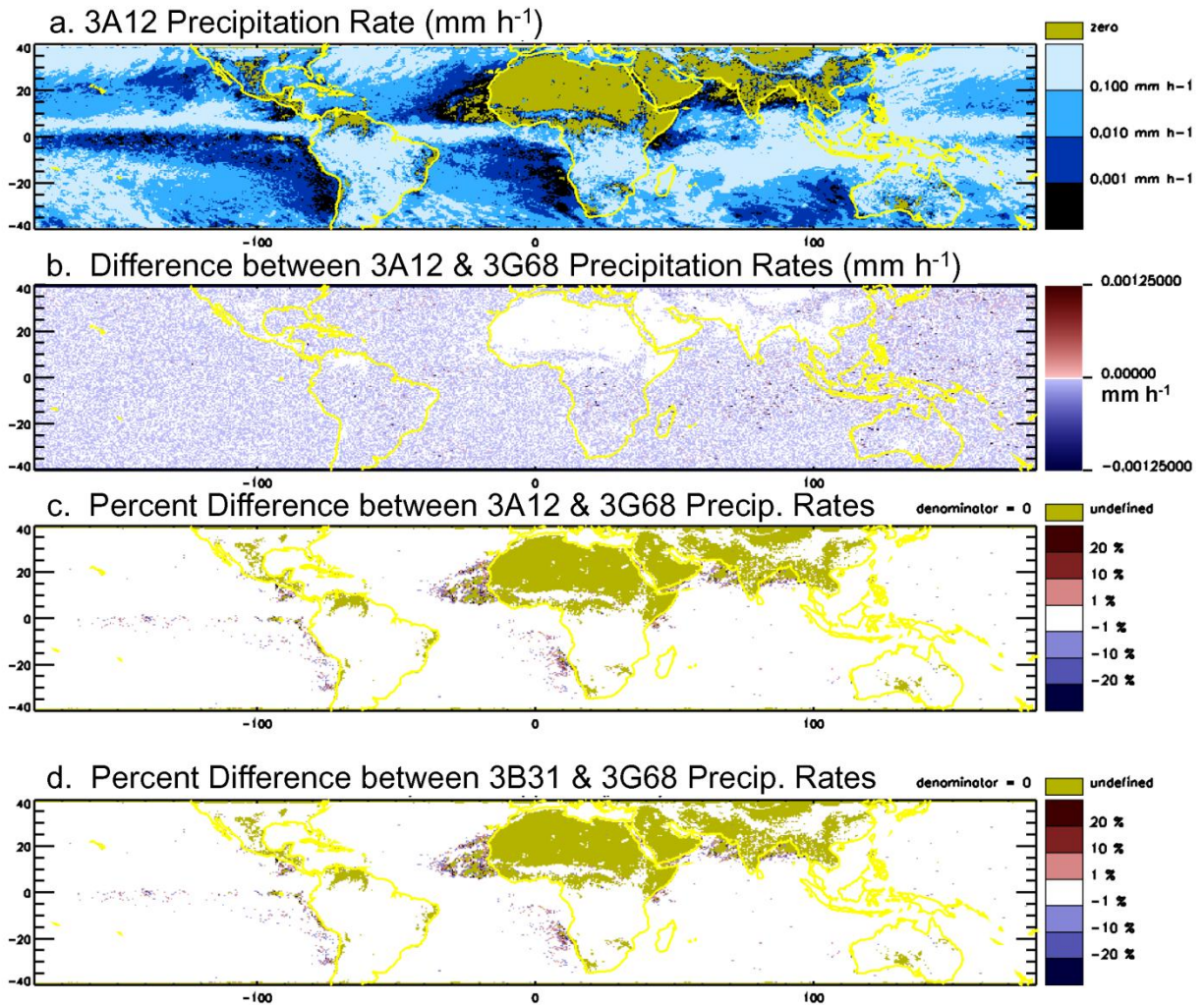


Figure 4.

Having shown that 3G68 tracks the TMI GPROF retrieval with fidelity, the next step is to show that the other TRMM level 3 products also do so. Figure 4 provides a comparison among 3G68, 3A12, and 3B31 over one month and at a .5 degree grid resolution. Figure 4b shows that the differences in precipitation rates between 3A12 and 3G68 are very small, falling into the range of $\pm 0.00125 \text{ mm/hr}$. Such differences derive from the fact that 3G68 monthly accumulations are 4 decimal digit additions with the mean being calculated to 5 decimal digit accuracy. Both 3A12 and 3B31 accumulate direct floating point values.

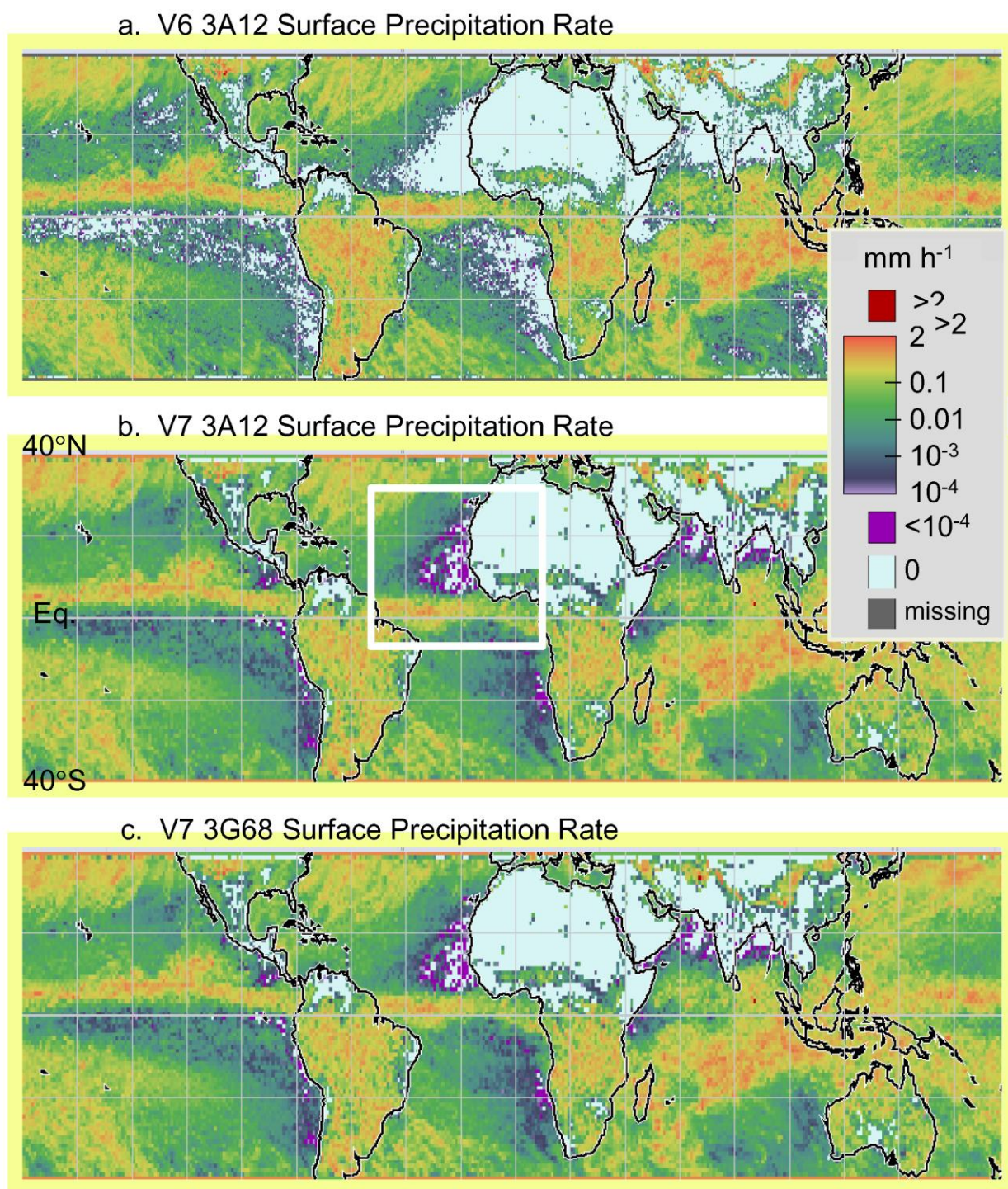


Figure 5

Figure 5 contains plots for January, 2001. Figures 5a and 5b present V6 and V7 surface precipitation rate as reported in TRMM 3A12. V7 shows light precipitation in ocean locations where V6 reported zero precipitation. For example, the white box highlights where this occurs

over the ocean just off the western coast of Africa. Figure 5c presents the 3G68 surface precipitation rate. V7 3A12 and 3G68 monthly products appears indistinguishable.

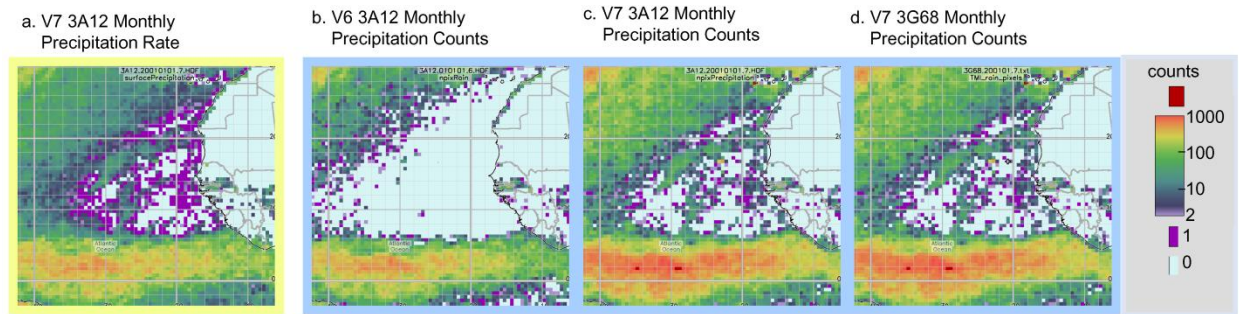


Figure 6

Figure 6 graphs precipitation counts off the west coast of Africa. Figure 6a presents a zoomed image of the precipitation rate shown in the white box of panel 5b. Plot 6b provides the counts in V6 3A12. Plot 6c provides the counts for V7 3A12, which shows precipitation counts in locations where V6 had none. As level 3 provides accumulations, there is no way to know how many of such new counts came from very low probability precipitation-rate pixels. Providing further evidence of the “sameness” of the level 3 products, plot 6d provides the counts in V7 3G68 and these appear indistinguishable from V7 3A12.

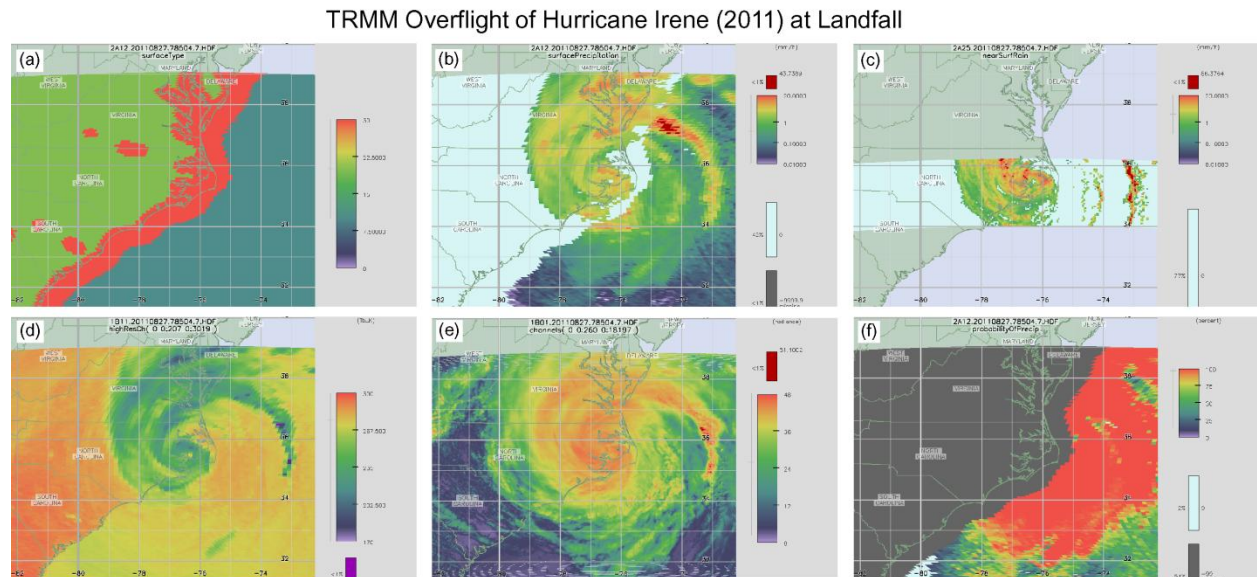


Figure 7.

As a final analysis aspect, the authors looked at the impact of the more conservative coast retrieval within the TMI GPROF algorithm. Figure 7 shows TRMM observations of Hurricane Irene making landfall in North Carolina on 27 August 2011 in TRMM Orbit #78504. Plot 7a shows which retrieval mode is being used: land (light green), coast (red), or ocean (dark green). Plot 7b presents the TMI GPROF surface precipitation retrieval, in which the precipitation shield

of Hurricane Irene appears circular over land, discontinuous over coast, and very large over ocean. This indicates the more conservative retrievals made by the land and coast mode. Plot 7c shows a TRMM PR precipitation retrieval over Irene. One can see there is a generally good match between the land and the ocean retrievals of GPROF but suggests that GPROF may be under-reporting the area covered by precipitation over some coastal waters. The visual discontinuity occurs because of the conservative approach taken by the GPROF coastal mode retrieval. In making such a comparison, one must temper these observations with the fact that the radar has a limited swath width. Plot 7d shows that the TRMM Microwave Imager (TMI) reports cold 85 GHz brightness temperature (level 1b TMI product). This indicates significant ice scattering in locations where the radar sees precipitation and some coastal locations where GPROF reported no precipitation. Scientists using GPROF in coastal regions should be aware of these properties of the V7 coastal retrievals although this present analysis does not claim to be a definitive guide to the coast mode of the GPROF algorithm. In plot 7e, the TRMM Visible and Infrared Scanner (VIRS) reports cold brightness temperatures, indicating tall clouds, in locations where the TRMM radar observes coastal precipitation and GPROF reports no coastal precipitation. Plot 7f reports V7 GPROF retrievals with 100% probability of precipitation over open ocean up to the boundary of open-ocean and coastal waters. Unfortunately, the probability of precipitation occurrence is not calculated by the land and coast modes of the GPROF algorithm.

4. Online Access to 3G68 Products

PPS provides anonymous FTP access to 3G products at <ftp://trmmopen.gsfc.nasa.gov/pub>. The data may also be viewed online through a early version of a tool for GPM data that was made available for viewing these products. The URL for this tool is <http://pps.gsfc.nasa.gov/3GRetrieve/>. Figure 8 shows screen captures from the navigation process of this online 3G68 search-and-display tool.

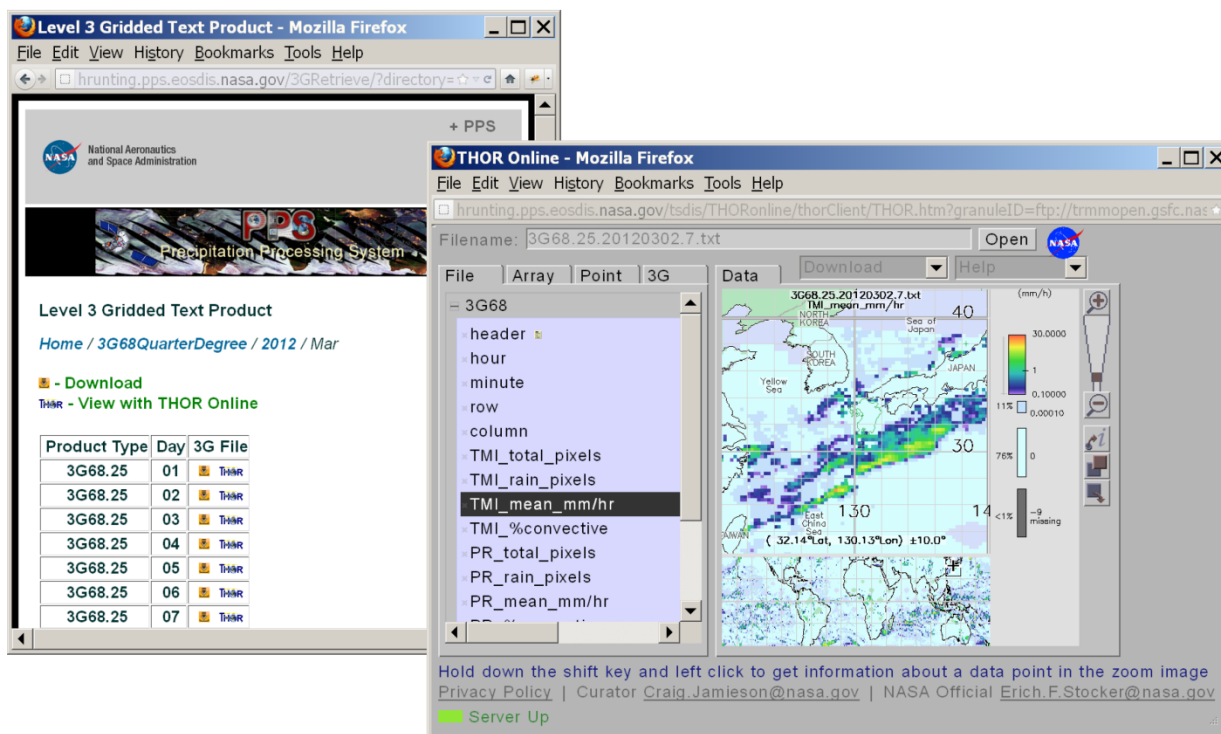


Figure 8

5. Conclusions

This paper has demonstrated that there are improvements in precipitation retrieval by GPROF in V7 over V6. This is especially true over the ocean where the physically based (PR and TMI) a-priori database is used. V7 GPROF and PR retrievals over the ocean generally match extremely well. However, we have seen there are differences in the retrievals for land and coast. The discontinuities over coast that can appear during extreme events need to be investigated further and much more data needs to be included in the analysis. The paper also verified that the level 3 time/space accumulations of the TMI GPROF swath retrievals are faithful to the original and do not add statistical artifacts or noise. It was also demonstrated that all the level 3 products that are accumulating TMI GPROF are doing so virtually identically. This ensures that whatever level 3 radiometer product a user selects is faithful to the level 2 GPROF retrieval. Some preliminary work seemed to indicate that V7 radiometer precipitation retrievals were slightly higher over the ocean when compared to V6 but lower over land. Once again, considerable more data (perhaps over the entire mission) should be used to finalize such a comparison.

Acknowledgements: Special thanks are due to Christian Kummerow and David Randel of the School of Atmospheric Sciences at Colorado State University who provided detailed information about the GPROF algorithm. Kummerow also provided input about GPROF changes from V6 to V7 and contributed valuable editing of the paper content. W. Berg and J. Chou contributed to the GPROF 3A12 algorithm, and L. Woltz contributed to the combined monthly 3B31 algorithm. The efforts of this paper's co-author in generating the graphics and formatting the poster needs to be separately acknowledged.

References

- [1] Simpson, J., C. Kummerow, W.-K. Tao, and R. F. Adler, 1996. On the Tropical Rainfall Measuring Mission (TRMM). *Meteorol. Atmos. Phys.*, 60, 19-36.
- [2] Biswas, S. K., K. Gopalan, W. Linwood Jones, and S. Bilanow, 2010. Correction of time-varying radiometric errors in TRMM microwave imager calibrated brightness temperature products. *GeoScience and Remote Sensing Letters*, 7, 851-855.
- [3] Stocker et al., 2010. Changes in the TRMM Version 7 Space/Time Averaged Level 3 Data Products Based on GPROF TMI Swath-based Precipitation Retrieval. Poster paper. EGU General Assembly, Vienna, Austria. (egu_2010_FinalL3Paper.pdf available anonymous ftp from <ftp://trmmopen.gsfc.nasa.gov/pub/trmmpapers>)
- [4] Christian D. Kummerow, Sarah Ringerud, Jody Crook, David Randel, Wesley Berg, 2011. An Observationally Generated A Priori Database for Microwave Rainfall Retrievals. *Journal Atmospheric and Oceanic Technology*, 28, 113-130.
- [5] PPS, 2012. File Specification for TRMM Products: Version 7.001. NASA Goddard, 327 pp.
- [6] Erich F. Stocker, 2012. <ftp://trmmopen.gsfc.nasa.gov/pub/README.3G68>,
<ftp://trmmopen.gsfc.nasa.gov/pub/README.3G68.QuarterDegree>,
<ftp://trmmopen.gsfc.nasa.gov/pub/README.3G68Land>.