Changes in the TRMM version 7 space/time averaged level 3 data products based on GPROF TMI swath-based precipitation retrievals

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Abstract

TRMM has three level 3 (space/time averaged) data products that aggregate level 2 TRMM Microwave Imager (TMI) GPROF precipitation retrievals. These three products are TRMM 3A12, which is a monthly accumulation of 2A12 the GPROF swath retrieval product; TRMM 3B31, which is a monthly accumulation of 2A12 and 2B31 the combined retrieval product that uses both Precipitation Radar (PR) and TMI data; and 3G68 and its variants, which provide hourly retrievals for TMI, PR and combined. The 3G68 products are packaged as daily files but provide hourly information at 0.5° x 0.5° resolution globally, 0.25° x 0.25° globally, or 0.1° x 0.1° over Africa, Australia and South America. This paper will present early information of the changes in the v7 TMI GPROF level 2 retrievals that have an impact on the level 3 accumulations. This paper provides an analysis of the effect the 2A12 GPROF changes have on 3G68 products. In addition, it provides a comparison between the TRMM level 3 products that use the TMI GPROF swath retrievals.

1. Introduction

In space since 1997, the Tropical Rainfall Measuring Mission (TRMM) satellite is the first satellite to carry both passive microwave and radar for observing the detailed three-dimensional structure of precipitation. In 2010, algorithms are being tested for the version 7 (v7) reprocessing of TRMM data. To a greater degree than ever before, the v7 algorithms will take advantage of the possible synergies between active and passive precipitation sensors. This new version of the algorithms introduces techniques that may be used by the at-launch algorithms of the Global Precipitation Measurement (GPM) mission. The core GPM satellite is scheduled for a 2013 launch, so the version 7 algorithms currently being tested may be the last reprocessing cycle prior to the GPM launch.

The Precipitation Processing System (PPS) at NASA Goddard generates three levels of TRMM standard data products. The level 1 products report values at the instrument field of view (IFOV): brightness temperature for the radiometer and returned power and radar reflectivity for the Precipitation Radar (PR). Level 2 products contain the swath-oriented geophysical precipitation retrievals at the same IFOV as the Level 1 products. Level 3 products contain time/space accumulations or averages for various horizontal resolutions and for accumulation periods of varying durations.

This paper describes TRMM v7 changes in the TMI level 2 product that have an impact on the level 3 time/space averaged data products. It concentrates particularly on the daily level 3 product with the TRMM designation 3G68. A description of the 3G68 format is available on the trmmopen FTP site [1] and the formats of other TRMM standard products are available on the PPS web site [2]. The paper also compares the current test v7 implementation of 3G68 with the other level 3 products that average the TRMM Microwave Imager (TMI) precipitation retrievals on monthly basis.

Of particular importance to this analysis are the v7 changes in the GPROF precipitation retrievals from TMI observations. Versions 5 and 6 of GPROF have been described elsewhere [3,4]. In the context of TRMM, GPROF is referred to as the TRMM 2A12 algorithm.

The V7 GPROF uses a substantially improved *a priori* database over oceans compared to previous versions. Specifically, previous versions used only cloud resolving models to construct the *a priori* databases while V7 uses PR observations along with physical adjustments to make the profiles consistent with both PR and TMI observations [5].

While this new database is believed to improve GPROF's surface precipitation estimates, the new database cannot overcome the limited sensitivity of the PR that prevents PR from detecting very light precipitation. This detection limit means that TMI ocean observations based on the v7 GPROF database, cannot distinguish between light precipitation and no precipitation.

Unlike v6 GPROF, the v7 GPROF database contains profiles with zero surface precipitation because v7 GPROF is observationally based. The surface precipitation rate that v7 GPROF reports at a pixel is the average of the surface precipitation rate in all of the precipitating and non-precipitating profiles that match the observed TMI brightness temperature at this pixel. As a diagnostic variable, v7 GPROF algorithm also reports a precipitation probability. This probability is simply calculated as the percent of matching database profiles that have a non-zero surface precipitation rate. For example, if ten profiles in the database matched the observed brightness temperature at a pixel and only five of them had non-zero surface precipitation, then the reported precipitation probability would be 50%.

This new approach is a significant change from the historic rain/no-rain decisions based on empirical thresholds. Specifically, almost all pixels now contain some small probability of rain in the new scheme. The low-probability pixels, while easily filtered from the instantaneous precipitation, should not be filtered before monthly averages are calculated, or the monthly averages will lose some of the information in the instantaneous values. The issue of whether to filter, when to filter, and which variables to filter offers challenges to any level 3 algorithm based on v7 GPROF swath retrievals.

The approach adopted by the three major level 3 products that use the GPROF retrievals for their accumulation and averaging is described in the following paragraphs. Two other TRMM level 3 algorithms are not included in this study (3B42 and 3B43) because, while they read GPROF swath data, these algorithms do not output GPROF-only averages. Another TRMM level 3 algorithm is excluded from this study because it reads 1B11 instead of 2A12 and its grid is much coarser than the 3G68 grid, i.e., the TRMM 3A11 algorithm has a 5° x 5° grid. The three algorithms are included in this study are designated TRMM 3A12, 3B31, and 3G68.

3A12 is a monthly 0.5° x 0.5° gridded average of 2A12 parameters. In discussions with the GPROF developers, the decision was made not to filter low-probability precipitation rates from the 3A12 averages over the ocean. Had 3A12 omitted instantaneous surface precipitation rates that had probabilities of 50% or less, it would have resulted in an underestimation of the monthly-average precipitation rate. In the calculation of the number of precipitation pixels, 3A12 does not count instantaneous precipitation rates with a 50% or lower probability.

3B31 is the monthly gridded accumulation of the combined radar/radiometer swath product 2B31. In v7, 3B31 is still a straight accumulation of 2A12 and 2B31 parameters but now at a 0.5° x 0.5° resolution rather than the former 5° x 5° resolution. Of interest in this study are the "wide swath" accumulations of the 3B31 product which include all data in the wide swath of the TMI instrument. 3B31 does no filtering of instantaneous precipitation rates. As in 3A12, 3B31 does not provide a precipitation pixel count or total pixel count in the grid box.

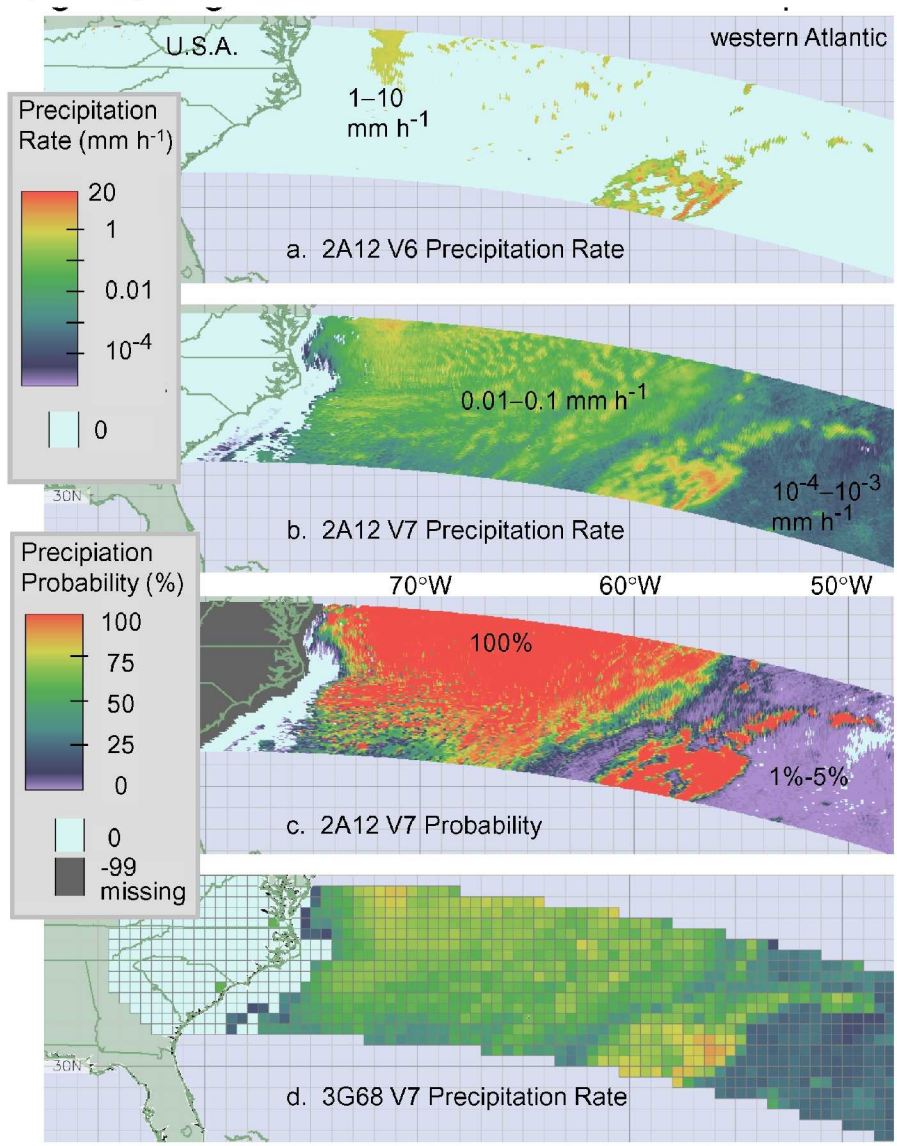
3G68 is an ASCII text product that contains average surface precipitation rates in hourly grids packaged as a daily product. The 3G68 daily product is versatile because it can be used to determine diurnal variation in average precipitation rate over months, seasons, years, or decades. Alternatively, climatologies of precipitation rate can be calculated from 3G68 daily files for arbitrary start and end dates. Despite this flexibility, it is important that the 3G68 product give the same monthly-average precipitation rates as the other level 3 TRMM products when the same GPROF level 2 data are used as input. Care was taken to minimize any variability in 3G68 that is due to deviations between the averaging algorithm of 3G68 and the other level 3 TRMM algorithms.

While this study uses the standard 3G68 product on the 0.5° x 0.5° grid, there is actually a family of related products with finer resolution [6]: 3G68.25 has 0.25° resolution and 3G68Land has 0.1° resolution for South America, Africa, and Australia. For each hour, all 3G68 variants calculate the average, unconditioned, mean precipitation rate from TMI

GPROF swath data (2A12), the TRMM Precipitation Radar (2A25), and the combined radiometer/radar algorithm (2B31). 3G68 also provides precipitation pixel counts, total counts, and the percent of the precipitation that is falling as convective rather than stratiform precipitation. The recently-implemented refinements to 3G68 to accommodate v7 input data form the basis of this paper and of the present analysis of the impact of v7 TMI precipitation retrieval changes over the ocean.

Initially, it was thought that, because 3G68 is designed to be a simple product, low-probability precipitation over the ocean (when the GPROF probability for the instantaneous precipitation rate is less than 50%) would be set to zero inside 3G68. However, this plan was changed when analysis showed

Fig 1. Single-orbit GPROF Precipitation



A comparison of v6 and v7 2A12 and v7 3G68. **(a)** In v6 of the TRMM 2A12 algorithm, most of the surface precipitation rate over most of the ocean is zero. Where it is precipitating, the precipitation rate is general between 0.1 and 10 mm h^{-1}. The data were collected on 1 January 2001 **(b)** In v7 TRMM 2A12, the frequency of precipitation over land has changed little, but over ocean, the algorithm estimates that it is nearly always precipitating. **(c)** v7 2A12 gives some of the "new" ocean precipitation a 100% probability. Probability in this context refers to the fraction of GPROF database profiles with non-zero surface precipitation out of the set of GPROF database profiles that match the TMI observed brightness temperatures. **(d)** A single-hour 3G68 grid that was generated from v7 2A12 with no filtering on precipitation rates. Essentially the same precipitation rates are obtained as in v7 2A12.

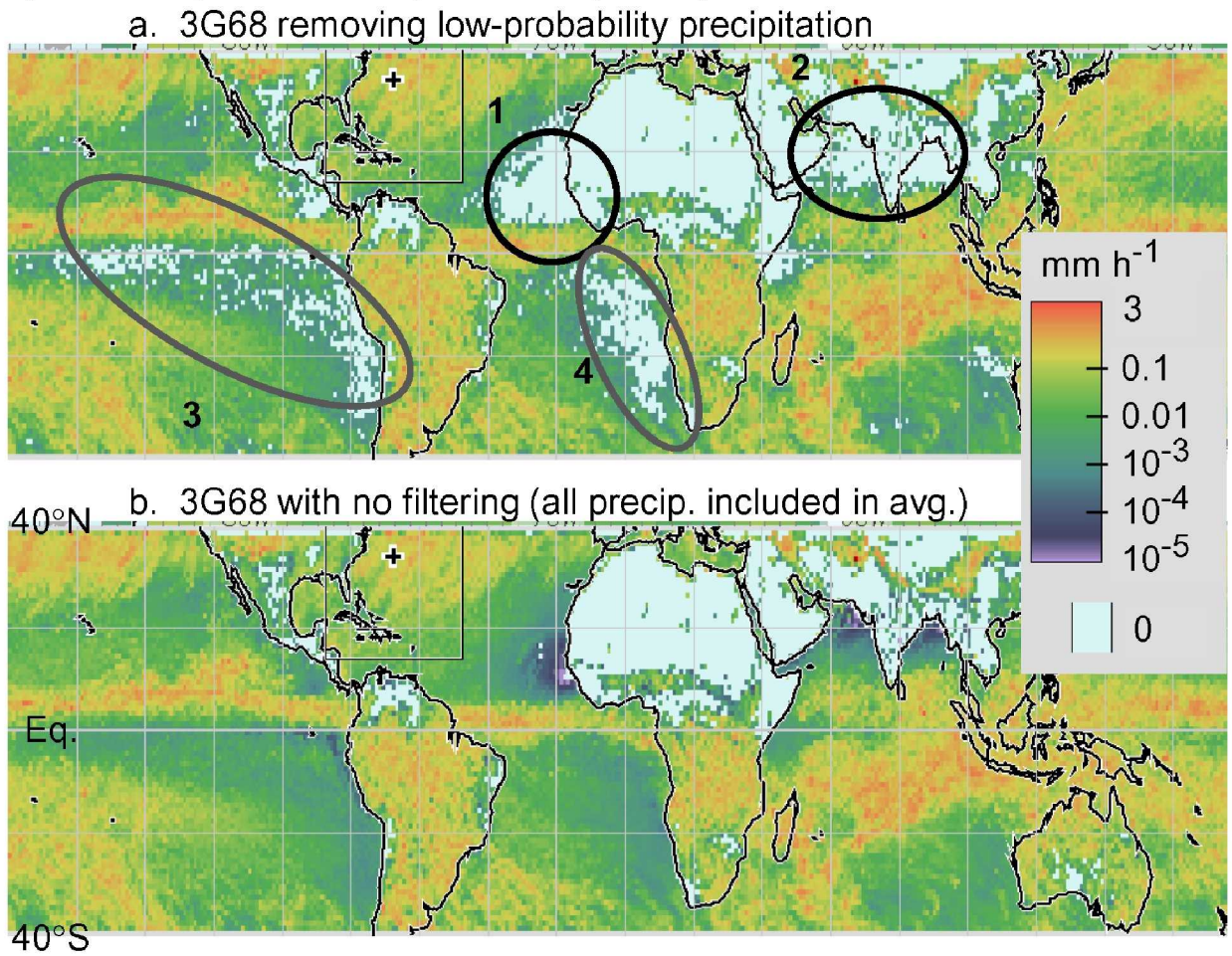
that the original plan would have led to the loss of approximately 3.5% of the global total precipitation accumulation during a month. In the tropical subsidence regions, the monthly-average precipitation rate would be lowered by 15%, and in a few small regions of the ocean with extremely low average precipitation rates, the monthly-average precipitation rate would be lowered by over 50%.

2. Analysis

When the abstract of this paper was originally submitted, the figures were to show data from the official version 7 algorithms. This plan had to be changed due to continued testing of the version 7 algorithms that is leading to a later start to the version 7 reprocessing cycle. For this reason, the figures in this paper are generated with a test version of v7 data. These test data are believed to be close enough to the eventual official v7 data products to validate the v7 3G68 algorithm.

Based on brightness temperature and because of limitations in the detectability threshold of the radar

Fig. 2. Filtering vs. No Filtering in a Monthly average Precipitation Rate



A comparison of monthly-average v7 3G68 precipitation rates when low probability precipitation is filtered out or included in the calculation. Both 3G68 files are calculated from v7 2A12 files for January 2001. **(a)** Filtering: Instantaneous precipitation with a probability of 50% or less is set to zero and counted as non-precipitating. The four numbered regions are defined in the text. **(b)** No filtering: All instantaneous precipitation measurements are averaged to obtain the monthly-average precipitation rates.

which is inherent in the *a priori* database, GPROF version 6 or 7 cannot definitively distinguish between light precipitation and no precipitation. In v6, GPROF simply reported zero precipitation over most of the ocean where precipitation was possible but not certain. In v7, GPROF reports a small but non-zero precipitation rate and an associated probability almost everywhere over the ocean, with zero precipitation almost never reported over ocean. This extra information in the v7 GPROF enables end users to choose an appropriate threshold for screening out uncertain precipitation based on how they intend on using the GPROF output.

To illustrate this difference between v6 and v7 GPROF, Figure 1 shows a portion of TRMM orbit #17821 that observed the western Atlantic early on January 1, 2001. Figure 1a shows that, in v6 GPROF, most of the non-zero precipitation rates in are light to moderate (1 to 10 mm h^{-1}), shown in shades of yellow-orange. In v7 GPROF, Figures 1b and 1c show that the western portion of the scene is filled with 0.01 to 0.1 mm h^{-1} precipitation rates shown in yellow-green that are assigned 100% probability, while the eastern portion of the scene is filled with even lighter precipitation (10^{-4} to 10^{-3} mm h^{-1}) in blue-green that is assigned low probability of 1–4%.

Originally, it was thought that 3G68 should filter out the low-probability precipitation when generating a single-hour grid. Such filtering in the single-hour grid would mean that all low-probability precipitation would also be excluded from any monthly or longer-duration 3G68 average that were generated from the single-hour grid. To implement this plan, a filter was constructed that checked if a pixel was over the ocean, had non-zero precipitation, and had a probability of less than or equal to 50%. When this filter was satisfied, the precipitation rate was set to zero and the pixel was counted as a non-precipitating pixel in the 3G68 pixel count. Using this filter always lowers the average precipitation rate to some degree.

Figure 2a shows the January 2001 monthly-average precipitation rates in 3G68 when this filter is used. Figure 2b shows the same month of data when no filtering is used. In regions where precipitation is moderate to heavy, there is little visible difference in the filtered and unfiltered image. However, the regions of light precipitation show larger differences. More specifically, just west of equatorial Africa, in the Arabian Sea, and in the Bay of Bengal (regions 1 and 2), the monthly-average precipitation rates are consistently zero (shown in cyan) when filtering is done and 10^{-5} to 10^{-4} mm h^{-1} (blue-purple in Figure 2b) when no filtering is done. Similarly, in the ocean "deserts" downwind of continents (regions 3 and 4), there is a scattering of zero precipitation rates when filtering is done and heaver precipitation rates of 0.1 mm h^{-1} (blue-green in Figure 2b) when no filtering is done.

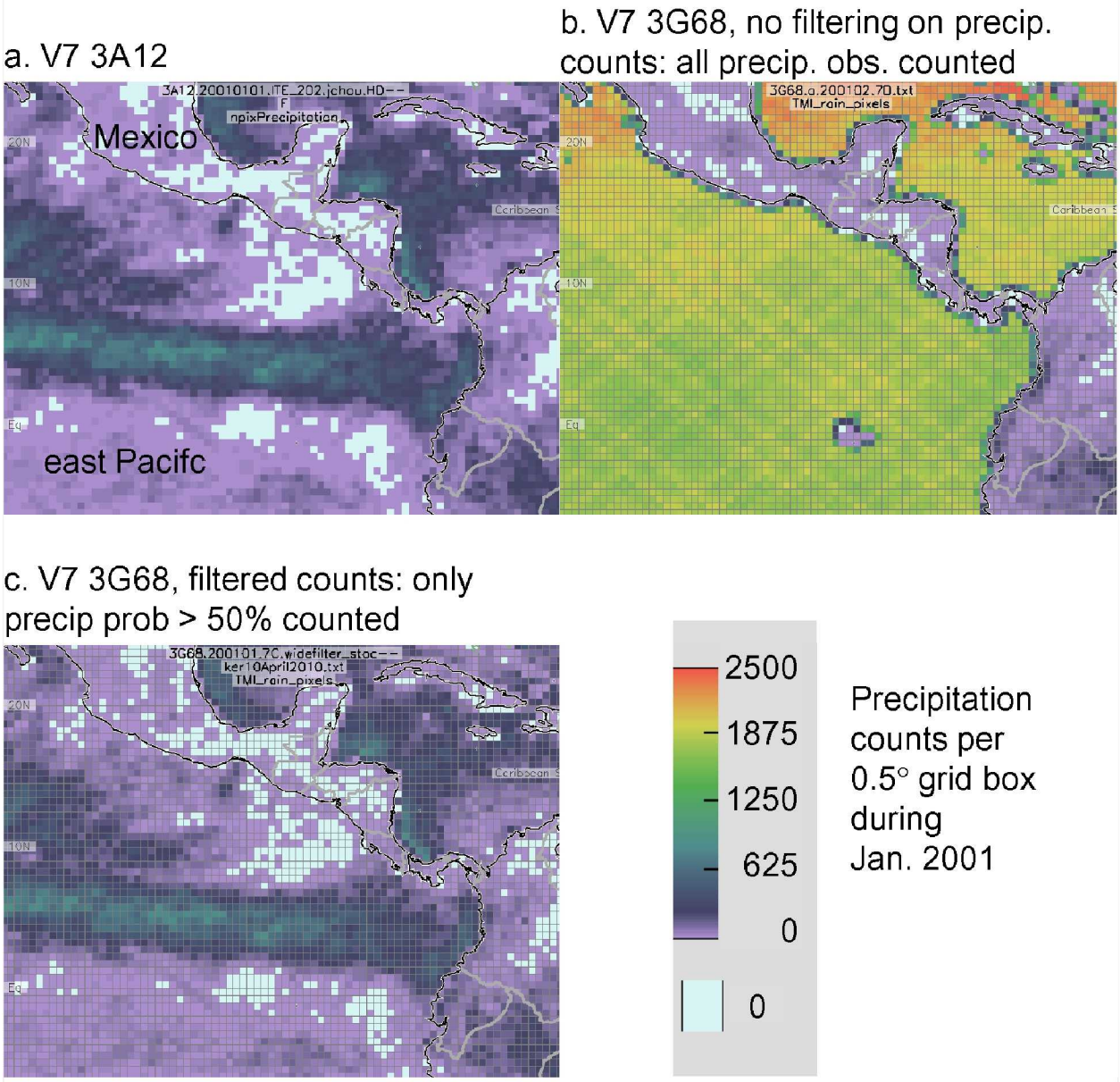
Despite the initial plan, analysis showed that, with the filtering, the 3G68 product no longer matched the monthly retrievals stored in the TRMM 3A12 product. For this reason, the filtering on precipitation rate was removed from the v7 3G68 software. Just as for 3A12, 3G68 now includes all precipitation observations when calculating average precipitation and, also as 3A12 does, 3G68 now excludes low-probability precipitation when calculating precipitation counts.

After removing the filter in the precipitation-rate calculation, the 3G68 hourly grid was checked against the instantaneous 2A12 swath. It was important to substantiate that the 3G68 hourly grid was properly capturing the instantaneous precipitation rate. Figure 1b presents a precipitation feature in an orbit of v7 2A12. Figure 1d shows this same feature in the appropriate hour of a daily 3G68 file. This example suggests that the 3G68 algorithm is correctly capturing the instantaneous precipitation rates in the 2A12 swath.

A next step was to compare the number of precipitation pixels that 3A12 and 3G68 find in a month in each 0.5° by 0.5° grid box. The goal of this comparison was to ensure that the two level 3 products are consistent. Figure 3a shows the count of precipitating pixels from v7 3A12 for January 2001 observations. Figure 3b shows what the precipitating pixel count would be in 3G68 if all of the non-zero 2A12 precipitation were counted as precipitating pixels. Clearly, there is a mismatch between 3G68 and 3A12 when this is done because there are large difference in Figures 3a and 3b. Figure 3c shows the v7 3G68 precipitation pixel count when low-probability precipitation is excluded. Comparing Figures 3a and 3c suggests that 3G68 now arrives at the same answer as 3A12 in terms of the number of precipitating pixels.

At the end of this study, 3G68 applies no filter when calculating average precipitation rate but does apply a filter when calculating the total number of precipitation observations. An advantage of this approach is that it provides the researcher with a "filtering" technique. Specifically, the researcher can

Fig 3. Monthly Precipitation Counts



The number of precipitation observations in each half degree grid box for the ITE202 test of TRMM v7 for January 2001. (a) In v7 3A12, the precipitation count includes only the pixels that have a probability of precipitation greater than 50%. This means that although almost all ocean observations are used to calculate the monthly-average surface precipitation rate, many of these ocean observations are not included in the official count of precipitation observations. (b) If v7 3G68 were to include in precipitation counts all of the observations included in the monthly-average precipitation-rate calculation, then v7 3G68 would report a much higher precipitation count than does v7 3A12. (c) When v7 3G68 uses the same threshold as v7 3A12, v7 3G68 calculates essentially the same value for precipitation counts.

filter out grid boxes that only contain low-probability precipitation by ignoring grid boxes that have non-zero precipitation and zero precipitation pixels. Such a combination of values in a monthly 3G68 grid box indicates that all of the precipitation observations that went into that grid box were low-probability observations.

The last step in this study was to look for any small differences in the monthly-average GPROF surface precipitation estimates calculated by 3A12, 3B31, and 3G68 (Figure 4). All three of these algorithms use the same basic method to calculate monthly averages so only small differences should exist in the results. The comparison is performed for the January 2001 version 7 monthly TMI precipitation rate. Figure 4a shows that the monthly-average precipitation rate in the 3A12 product is typically about 0.1 mm h^{-1}. Figure 4a also shows that the monthly-average precipitation rate is less than 10^{-3} mm h^{-1} in only a few locations: west of equatorial Africa, in the Arabian Sea, and in the Bay of Bengal.

Figure 4b shows that the absolute difference between 3A12 and 3G68 is generally on the order of 10^{-3} mm h^{-1}, which is small compared with the typical monthly-average oceanic surface precipitation rate of 0.1 mm h^{-1}. Figure 4c shows that the difference between 3A12 and 3G68 is under 1% in most of the tropics (the white regions of the figure). The percent difference in Figure 4c exceeds 20% only in the three above-mentioned regions of the ocean where the average precipitation rate is extremely low, i.e., under 10^{-3} mm h^{-1} in Figure 4a. The reason for the large percent differences in Figure 4c in these three small regions is that the hourly 3G68 grids stored precipitation rate only to the nearest 10^{-4} mm h^{-1}, which introduces a considerable round-off error only in regions where the typical rate rates are 10^{-3} mm h^{-1} as they are in these three small regions.

Figure 4d shows that the percent difference between 3B31 and 3G68 is under 1% in most locations in the ocean. The only places where it is consistently greater than 1% is the same three places noted above where 3A12 and 3G68 differ by more than 1%. The 3B31 product actually stores monthly accumulated precipitation in units of millimeters per month. To generate Figure 4d, these units were converted into monthly-average precipitation rates by dividing by the monthly accumulation by the number of hours in the month. After this unit conversion, it is possible to compare 3B31 and 3G68 precipitation values.

It might be possible to eliminate the above-mentioned three small regions of the ocean where 3G68 has a ≥20% difference in average surface precipitation rate relative to 3A12 and 3B31, but that would require adding additional decimal places in the 3G68 format beyond the v7 increased 4 decimal places stored in the hourly 3G68 files and v7 increased 5 decimal places stored in the monthly 3G68 files. At this time, it has been decided that the increase in the 3G68 file size that would result from storing extra decimal places outweighs the advantage of closer agreement between 3G68 and the other level 3 algorithms.

3. Conclusion

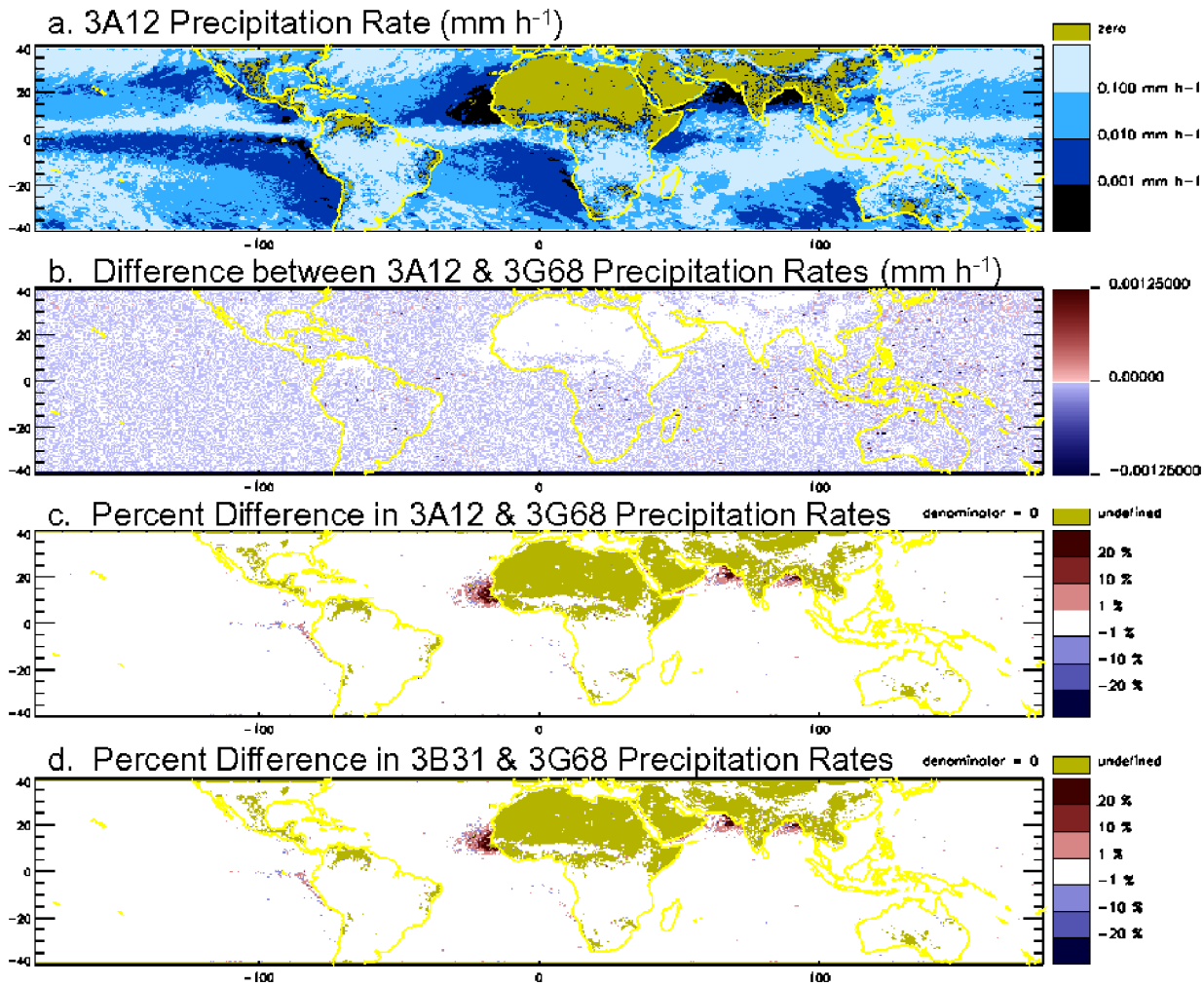
Filtering out low precipitation rates with low probability leads to an underestimation of the global average precipitation rate by 3.5%. In some areas, the underestimation could be 20% or more where the oceanic precipitation rate is low.

For this reason, the decision has been made not to filter precipitation rates during the calculation of TMI monthly-average precipitation rates in the TRMM 3A12, 3B31, and 3G68 algorithms. These algorithms will, however, filter out low-probability rain in the calculation of the monthly count of precipitating pixels. It is felt that the end-user of these data products are in a better position to make the appropriate determination of if, and if so, how to filter out low-probability precipitation or very light precipitation.

The level 3 monthly accumulations are consistent with one another in how they treat precipitation rates and the precipitation pixel counts.

Acknowledgements

Fig. 4. Monthly Average Surface Precipitation: V7 3G68 vs. V7 3A12 and V7 3B31



When 3G68, 3A12, and 3B31 use the same method to calculate monthly-average surface precipitation rate, the three algorithms obtain nearly the same result. These images show data from the ITE202 test of TRMM Version 7 for observations from January 2001. **(a)** 3A12 surface precipitation rate. **(b)** 3G68 and 3A12 differ generally by less than 0.001 mm h^{-1}. **(c)** As the percent of the 3G68 monthly average, the difference between 3A12 and 3G68 over the ocean is less than 1% everywhere except in a few small regions where the precipitation rate is very low. At these locations, some round-off error is to be expected because the monthly average precipitation rate there is near 10^{-4} mm h^{-1}, which is the precision of 3G68 hourly grids. **(d)** The same except comparing 3B31 to 3G68.

Dave Randel provided helpful information about how version 7 GPROF works and recommendations on how to use GPROF output in level 3 products. John Kwiatkowski helped the authors develop some of the ideas in this study, particularly with regard to rainy pixel counts. The PPS Team ran multiple versions of 3G68 and other version 7 algorithms in an expeditious fashion so that the analysis for this study could be completed in time. Special thanks to the co-author Owen Kelley for generating the figures in the paper and doing the detailed analysis for many of the issues.

References

[1] Stocker, E., 2000. Summary Information about 3G68, NASA Goddard, Greenbelt. Available online at ftp://trmmopen.gsfc.nasa.gov/pub/README.3G68.

[2] PPS, 2007. PPS Interface Control Specification, Volume 4: Levels 2 and 3 File Specification, NASA Goddard, Greenbelt. Available online at http://pps.gsfc.nasa.gov/.

[3] Kummerow, C., Y. Hong, W.S. Olson, S. Yang, R.F. Adler, J. McCollum, R. Ferraro, G. Petty, D.B. Shin, and T.T. Wilheit, 2001. The evolution of the Goddard Profiling Algorithm (GPROF) for rainfall estimation from passive Microwave Sensors. *J. Appl. Meteor.*, **40**, 1801–1820. [Describes GPROF version 5]

[4] Olson, William S., and co-authors, 2006. Precipitation and latent heating distributions from satellite passive microwave radiometry. Part I: Improved method and uncertainties, *J. Appl. Meteor. and Climate*, **45**, 702–720. [Describes GPROF version 6]

[5] Kummerow, C. D., S. Ringerud, J. Crook, D. Randel and W. Berg, 2010. An observationally generated A-Priori database for microwave rainfall retrievals, *J. Atmos. Oceanic Tech.*, in review. [Describes GPROF version 7].

[6] Stocker, E. F., J. Kwiatkowski, and O. Kelley, 2001. Gridded hourly text product: A TRMM data reduction approach, IGARSS, Australia.