Integrated Multi-satellitE Retrievals for GPM (IMERG) Technical Documentation

George J. Huffman (1), David T. Bolvin (1,2), Eric J. Nelkin (1,2)

(1) Mesoscale Atmospheric Processes Laboratory, NASA Goddard Space Flight Center
(2) Science Systems and Applications, Inc.

19 June 2015

"Recent" News

28 April 2015 NOAA reprocessed the global IR data for 10 UTC 26 April through 14 UTC 27 April due to dropped images, however there is no straightforward way to re-do the Early and Late Runs, so that period should display somewhat lower quality in the regions that lack IR input.
17 April 2015 IMERG Early and Late Runs ceased when CPC Global 4 km Merged IR data dropped out, starting 17 UTC 14 April due to processing issues at NOAA, and were caught up after the data returned around 11 UTC 17 April.
8 April 2015 End of TMI data
1 April 2015 Initial release of IMERG Late Run (V03D); beta release of Day-1 IMERG Early Run.
13 March 2015 Beta release of Day-1 IMERG Late Run.
20 January 2015 Revised release of IMERG Final Run (V03D).
16 January 2015 Initial release retracted due to minor inconsistencies in "missing" values.
15 January 2015 Initial release of IMERG Final Run (V03D).
4 December 2014 Beta release of Day-1 IMERG Final Run for Early Adopters.

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README Summary

The Integrated Multi-satelliE Retrievals for GPM (*IMERG*) is the unified U.S. algorithm that provides the Day-1 multi-satellite precipitation product for the U.S. GPM team. The precipitation estimates from the various precipitation-relevant satellite passive microwave (PMW) sensors comprising the GPM constellation are computed using the 2014 version of the Goddard Profiling Algorithm (GPROF2014), then gridded, intercalibrated to the GPM Combined Instrument product, and combined into half-hourly 0.1°x0.1° fields. These are provided to both the Climate Prediction Center (CPC) Morphing-Kalman Filter (CMORPH-KF) Lagrangian time interpolation scheme and the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks – Cloud Classification System (PERSIANN-CCS) re-calibration scheme. In parallel, CPC assembles the zenith-angle-corrected, intercalibrated “even-odd” geo-IR fields and forward them to PPS for use in the CMORPH-KF Lagrangian time interpolation scheme and the PERSIANN-CCS computation routines. The PERSIANN-CCS estimates are computed (supported by an asynchronous re-calibration cycle) and sent to the CMORPH-KF Lagrangian time interpolation scheme. The CMORPH-KF Lagrangian time interpolation (supported by an asynchronous KF weights updating cycle) uses the PMW and IR estimates to create half-hourly estimates. The IMERG system is run twice in near-real time

- “Early” multi-satellite product ~4 hr after observation time and

- "Late" multi-satellite product ~12 hr after observation time,

and once after the monthly gauge analysis is received

- "Final" satellite-gauge product ~2 months after the observation month.

The baseline is for the (near-)real-time Early and Late half-hour estimates to be calibrated with climatological coefficients that vary by month and location, while in the Final post-real-time run the multi-satellite half-hour estimates are adjusted so that they sum to a monthly satellite-gauge combination. In all cases the output contains multiple fields that provide information on the input data, selected intermediate fields, and estimation quality.

The current standard reference is the IMERG ATBD, posted at

http://pmm.nasa.gov/sites/default/files/document_files/IMERG_ATBD_V4.4.pdf .

Note: **gray shaded text** denotes information that pertains to the TRMM era. This information is not germane to the Day-1 IMERG data sets, but is included in anticipation of the retrospective processing that is planned for early 2017 (which is later than previously planned). Other shading denotes information that is still being finalized. **yellow shaded text** denotes information that is not yet finalized.

1. Data Set Names and General Content

The formal **data set name** is the Integrated Multi-satelliE Retrievals for GPM (IMERG). Note that there are other products in the general GPM data inventory, so it is important to be specific about the product being used.

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The **contents of the IMERG output** are as follows:

The IMERG system is run twice in near-real time

- "Early" multi-satellite product ~6 hr after observation time (goal of 4) and
- "Late" multi-satellite product ~18 hr after observation time (goal of 12),

and once after the monthly gauge analysis is received

- "Final" satellite-gauge product ~3 months after the observation month.

All three runs create half-hourly 0.1°x0.1° products (3IMERGHH), while the Final post-real-time run additionally provides a monthly 0.1°x0.1° satellite-gauge combination data set (3IMERGM). In all cases the output contains multiple fields that provide information on the input data, selected intermediate fields, and estimation quality. See "multiple runs, source, and formats" for more information.

Initially, GPM data sets are being computed for the GPM era, starting in March 2014. [However, the actual start date is the middle of the month, so we suggest ignoring data before April.] It is planned that the GPM data sets will use TRMM as a calibrator for the period from the start of TRMM observations to the launch of the GPM Core Observatory. The reprocessing necessary to effect this plan will occur in early 2016 for IMERG (and mid-2015 for GPM sensor products). The GPM home page is located at *http://pmm.nasa.gov/GPM/* .

The current standard reference is the IMERG ATBD, posted at

http://pmm.nasa.gov/sites/default/files/document_files/IMERG_ATBD_V4.4.pdf .
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2. Related Projects, Data Networks, and Data Sets

The **data set creators** are G.J. Huffman, D.T. Bolvin, and E.J. Nelkin, working in the Mesoscale Atmospheric Processes Laboratory, NASA Goddard Space Flight Center, Code 612, Greenbelt, Maryland; E.F. Stocker, working in the Precipitation Processing System (PPS), NASA Goddard Space Flight Center, Code 610.2, Greenbelt, Maryland; and the other members of the GPM Multi-Satellite Team: Dan Braithwaite (Univ. of Calif. Irvine), Kuolin Hsu (Univ. of Calif. Irvine), Robert Joyce (Inovim; NOAA/NWS/CPC), Christopher Kidd (Univ. of Maryland College Park; NASA/GSFC 612), and Pingping Xie (NOAA/NWS/CPC).
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The work is being carried out as part of the Global Precipitation Measurement (**GPM**) mission, an international project of NASA and JAXA designed to provide improved estimates of precipitation over most of the globe, following the highly successful Tropical Rainfall Measuring Mission (see "TRMM"). GPM has four key components: the Core Observatory, the GPM Constellation, the Precipitation Processing System (PPS), and GPM Ground Validation (GV) team. See each topic for more details.
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The **GPM Core Observatory** was launched on 27 February 2014 (UTC) into an (83-day) precessing orbit with a 65° inclination, a period of about 95 min., and an altitude of 407 km. This orbit allows GPM to build up a complete view of the climatological diurnal cycle, as well as providing calibration for other precipitation-relevant sensors in Sun-synchronous orbits in the GPM constellation. The calibrations are based on data from the GMI, a passive microwave sensor provided by NASA, and the GPM DPR, a Ku- and Ka-band electronically scanning radar provided by JAXA.
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The **GPM constellation** is a virtual constellation of satellites carrying precipitation-relevant sensors. The satellites are "of opportunity", with no coordination of function or orbit other than providing data to GPM as quickly as possible. The GPM constellation has been designated as an official CEOS Virtual Constellation. The constellation members are listed in the "sensors contributing to GPM" section.
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The Precipitation Processing Sy*stem *PPS** is responsible for working with the GPM Science Team algorithm developers to create an end-to-end processing system that ingests raw satellite data and ancillary data, then computes finished precipitation and related products.

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The GPM Ground Validation **GV** team is responsible for assembling the necessary data and computing validation and error statistical products. In some cases this includes organizing or participating in field experiments to collect high-quality data that are not otherwise available for particular climatic zones.

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The Tropical Rainfall Measuring Mission (**TRMM**) is an international project of NASA and JAXA designed to provide improved estimates of precipitation in the Tropics, where the bulk of the Earth's rainfall occurs. TRMM began recording data in December 1997 in a (46-day) precessing orbit at a 35° inclination with a period of about 91.5 min. This orbit allows TRMM to build up a complete view of the climatological diurnal cycle, as well as providing calibration for other precipitation-relevant sensors in Sun-synchronous orbits. TRMM exhausted its station-keeping fuel in July 2014 and began to descend (due to atmospheric drag), with passivation (shutdown) in April 2015 and a predicted reentry date in June 2015. The TRMM home page is located at *http://pmm.nasa.gov/TRMM/.*

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Precipitation Measurement Missions (**PMM**) is the umbrella organization within NASA to pursue satellite projects that advance precipitation science. To date, the two such projects are TRMM and GPM. The PMM home page is located at *http://pmm.nasa.gov/* .

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IMERG draws on data from several **data providers**:

1. NASA/GSFC Level 1 GMI Tb's;
2. NASA/GSFC Level 2 GPM Combined Instrument (DPR-GMI) precipitation;
3. NASA/GSFC Level 1 TMI Tb's;
4. NASA/GSFC Level 2 TRMM Combined Instrument (PR-TMI) precipitation;
5. NSIDC Level 1 AMSR-E Tb’s;
6. NSIDC Level 1 AMSR2 Tb’s;
7. NOAA/NCDC CLASS Level 1 SSMI Tb's;
8. NOAA/NCDC CLASS Level 1 SSMIS Tb’s;
9. NOAA/NCDC CLASS Level 1 (NOAA-series) AMSU-B Tb’s;
10. NOAA/NCDC CLASS Level 1 (NOAA- and MetOp-series) MHS Tb’s;
11. CNES ICARE (alternatively ISRO MOSDAC) Level 1 SAPHIR Tb’s;
12. NESDIS Level 1 ATMS Tb’s;
13. NOAA/NWS/CPC Level 3 Merged 4-Km Geostationary Satellite IR Tb Data; and
14. GPCC Level 3 Full and Monitoring Precipitation Gauge Analyses.

See “sensors contributing to GPM” for more details.

Some of these data sets extend beyond the TMPA and GPM periods in their original archival locations.

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There are numerous **similar data sets*, although no other quite matches all the attributes of being routinely produced for multiple latencies, publicly available, fine-scale in space and time, quasi-global, available from January 1998 onwards (planned for Spring 2016; currently starting March 2014), intercalibrated, and formed by combining multiple data sources including precipitation gauges. The IPWG data set tables at *http://www.isac.cnr.it/~ipwg/data/datasets.html* provide a good listing of other precipitation data sets. The closest include the set of estimates based on:

1. Huffman et al. (2007a, 2007b, 2010): the legacy Version 7 TMPA and TMPA-RT estimates;
2. Turk (1999): individual SSMI overpasses calibrate geo-IR precipitation estimates;
3. Sorooshian et al. (2000): the PERSIANN neural network calibrates IR with microwave;
4. Joyce et al. (2004): the CMORPH morphing scheme time-interpolates microwave patterns with IR-based motion vectors; and
5. Kubota et al. (2007): the GSMaP system applies a Lagrangian time-interpolation scheme similar to CMORPH.

Several SSMI/SSMIS-based data sets are available as gridded single-sensor data sets with significant data voids in cold-land, snow-covered, and ice-covered areas, including those computed with the GPROF 6.0, 2004a, and 2010 algorithms (based on Kummerow et al. 1996); and the NOAA Scattering algorithm (Grody 1991) among others. Other daily, single-sensor data sets are available for open-water regions based on SSMI/SSMIS data (RSS, Wentz and Spencer 1998; HOAPS, Andersson et al. 2010), MSU data (Spencer 1993), AMSR-E, and AMSU-B/MHS data. Several daily single-sensor or combination data sets are available at the regional scale, but are not really "similar." At the monthly scale over open-water regions, SSMI/SSMIS data are used in the Chang/Chiu/Wilheit emission algorithm (Wilheit et al. 1991, Chiu and Chokngamwong 2010).

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The **transition from TMPA to IMERG** is planned as

1. initial production of IMERG for the GPM era,
2. extension of IMERG to the TRMM era at the first GPM reprocessing in early 2017, and
3. continued production of the Version 7 TRMM 3B42/43 and 3B42RT until IMERG is considered stable, likely in mid-2017.

The 2017 dates are a change from previous plans. An extended discussion of this topic, with current details is contained in the document *The Transition in Multi-Satellite Products from TRMM to GPM (TMPA to IMERG)*, which is available at *http://pmm.nasa.gov/sites/default/files/document_files/TMPA-to-IMERG_transition.pdf* . In particular, users should note the scenarios under which a less graceful transition might become necessary. These include difficulties in creating a consistent calibration for 3B42 or changes in the input data streams.

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The Version 7 TRMM product **3B42** is being computed with the TMPA after real time, and constitutes the research-grade archive of TMPA estimates. Note that the version numbering for the TMPA-RT and official TRMM products are not necessarily related, although both are currently numbered 7. The post-real time computation allows several improvements in 3B42 compared to 3B42RT:

1. Data are processed starting with the first full month of TRMM data, which begins 1 January 1998.
2. The IR calibration period is the calendar month in which the observation time falls, rather than a trailing 30-day accumulation.
3. The TRMM Combined Instrument product (2B31) is used as the calibrating standard month-to-month, which should give better estimates than the climatological calibration used in the TMPA-RT.
4. For each grid box, the individual 3B42 3-hourly precipitation values are scaled to sum to a combination of monthly 3B42 and gauge analysis, which is TRMM product 3B43.

The first set of reprocessed data for Version 7 was posted in May 2012, while the second was posted in December 2012. Product 3B42RT continues to march forward in real time, and 3B42 estimates are considered to supersede the 3B42RT estimates as each month of 3B42 is computed. The 3B42 processing is designed to maximize data quality, so 3B42 is strongly recommended for any research work not specifically focused on real-time applications.

With the end of routine TRMM PR precipitation estimates on 7 October 2014 (see "TRMM end of mission issues"), the last month that fully conforms to the processing described above is September 2014. Thereafter a climatological calibration has been developed that minimizes the data discontinuity. It is planned that both the production and RT TMPA systems will be superseded by IMERG, although they will continue to be computed until IMERG is considered operational (expected in Spring 2017). See "transition from TMPA to IMERG" for more details.

See *ftp://meso-a.gsfc.nasa.gov/pub/trmmdocs/3B42_3B43_doc.pdf* for more details on 3B42.
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The Version 7 Real-Time TRMM product **3B42RT** is being computed with the TMPA in near-real time, and constitutes the most timely source of TMPA estimates. The near-real time computation requires several simplifications in 3B42RT compared to 3B42:

1. The complete 3B42RT data record is not reprocessed as upgrades are made to the procedure – its main focus is timeliness.
2. The IR calibration period is a trailing approximately 30-day accumulation, rather than the calendar month in which the observation time falls.
3. A real-time version of the GPROF-TMI is used as the calibrating standard because the TRMM Combined Instrument product (2B31) is not available in real time.
4. In near-real time it is not possible to apply precipitation gauge data. Rather, a climatological correction to the Version 7 production 3B42 is applied that varies by month and location to approximately account for the different calibrators and the use of precipitation gauge data in 3B42.

Note that 3B42 estimates are considered to supersede the 3B42RT estimates as each month of 3B42 is computed. The 3B42 processing is designed to maximize data quality, so 3B42 is strongly recommended for any research work not specifically focused on real-time applications.

The first set of retrospectively processed data for Version 7 3B42RT was released in June 2012 using the Version 7 3B42 for calibration, while the second set was posted in December 2012. This version includes the following:

1. SSMIS data are introduced based on interim calibration developed in conjunction with D. Vila (ESSIC).
2. The RT system is retrospectively processed back to 1 March 2000 using the full satellite data sets available in the Version 7 production system. The main difference from true RT processing is that the production data records are somewhat more complete than those available in real time. The start date is driven by the start date of the CPC Merged 4 Km IR data record. It continues to be the case that, despite the long RT record, it is strongly recommended that the production dataset (3B42) be used for all research not specifically focused on RT applications. It is planned that both the production and RT TMPA systems will be superseded by IMERG, although they will continue to be computed until IMERG is considered operational (expected in Spring 2017). See "transition from TMPA to IMERG" for more details.

See *ftp://meso-a.gsfc.nasa.gov/pub/trmmdocs/rt/3B4XRT_doc.pdf* for more details on 3B42RT.
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3. Data Archive Information

Production and updates for IMERG are a joint activity of the precipitation research group in NASA Goddard Space Flight Center in the Mesoscale Atmospheric Processes Laboratory and PPS.

The latency of the various IMERG runs is governed by the latency of the individual input products. See "multiple runs, sources, and formats" for more details.

Updates will be released to (1) extend the data record, (2) take advantage of improved combination techniques, or (3) correct errors. Updates resulting from the last two cases will be given new version numbers.

> NOTE: The changes described in this section are typical of the changes that are required to keep IMERG abreast of current requirements and science. Users are strongly encouraged to check back routinely for additional upgrades and to refer other users to this site rather than redistributing data that are potentially out of date.

In some cases, such as the failure of AMSR-E, the end of a data record is clear. In other cases, such as the gradual failure of the NOAA-16 AMSU-B during 2010, the point at which to end use of the data is a matter of judgment. In the latter case we chose 30 April 2010 despite continued operation into early 2011 based on apparent issues caused by these data in the TRMM 3B42RT.

In the future, we expect to expand all products to a fully global domain and to provide more advanced error estimates. For more details, refer to the sections “Pre-Planned Product Improvements” and “Options for Processing” in the IMERG ATBD.

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Several **TRMM end of mission issues** impact the IMERG system:

1. On 7 October 2014, routine production ended for the TRMM PR precipitation estimates due to the ongoing descent and ultimate decommissioning of the TRMM satellite (PMM, 2014). [PR data were briefly available from 12 February to 1 April 2015 as TRMM descended past its original altitude of 350 km.] Estimates from the TMI continued to be produced until it was turned off on 8 April 2015 as part of the TRMM decommissioning.
2. TMI continued to be included as one of the input data sets until it was ended on 8 April 2015 as part of the TRMM decommissioning activities.
3. Despite the end of TRMM operations, IMERG will not be a complete replacement for the TMPA products until retrospective processing is carried out in early 2017. Giving a decent interval for users to make the transition argues for continuing TMPA production until mid-2017.

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The **archive and distribution sites** for the official release of IMERG (and all other GPM products) are listed on the GPM data access pages

http://pmm.nasa.gov/data-access/downloads/gpm

Note that users are required to complete a simple, free, and automatic on-line registration in order to access the data PPS. This is required by data security considerations.

The responsible archive organizations are:

Precipitation Processing System
NASA Goddard Space Flight Center
Code 610.2
Greenbelt, MD 20771 USA
Internet: *helpdesk@pps-mail.nascom.nasa.gov*
Web site: *http://pps.gsfc.nasa.gov*

Goddard Earth Sciences Data and Information Services Center
NASA Goddard Space Flight Center
Code 610.2
Greenbelt, MD 20771 USA
Phone: +1-301-614-5224
Fax: +1-301-614-5268
Internet: gsfc-help-disc@lists.nasa.gov
Web site: *http://disc.gsfc.nasa.gov*

The Level 1C and 2 input satellite data sets are available in the PPS archive. The other input data, as well as the original (i.e., non-NASA input data) are available in independent archive and distribution sites, and contact information may be obtained through PPS.

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The official **data set archive** consists of Version 5 Hierarchical Data Format (HDF5) files. Each half-hour dataset (3IMERGHH) or monthly dataset (3IMERGM) is contained in a separate file with standard self-documenting HDF5 metadata. The data are distributed via the Internet. Each 3IMERGHH file is approximately 2 MB (with internal compression), while the 3IMERGM files are each about 30 MB (with internal compression).

The full collection of IMERG Final Run files are provided and archived by PPS at *https://storm-pps.gsfc.nasa.gov/storm* and by GES DISC at the DOI (see the DOI topic for the correct value). IMERG Early and Late Run files are available at PPS. Secondary archives of these data files exist outside of PPS and GES DISC, but users are responsible for gaining a clear understanding of the provenance of those data to assure that they are working with current, clean data.

In addition, PPS and GES DISC provide a variety of value-added products, which are listed on the GPM data access pages

http://pmm.nasa.gov/data-access/downloads/gpm .

Finally, quick-look imagery can be created using the THOR application, while interactive Web-based analysis for selected IMERG precipitation estimates and related fields is provided through GIOVANNI. See the respective topics for details.

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The **DOI** list for the original IMERG Final Run HDF5 files is

half-hourly	10.5067/GPM/IMERG/HH/3B
monthly	10.5067/GPM/IMERG/MONTH/3B

DOI's are not currently assigned for the IMERG Early and Late Run files.

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Known data set access issues include:

1. Besides the primary data sites (see "data set archive"), several "mirror" and value-added archive sites outside of PPS and GES DISC provide the IMERG data sets and/or value-added products in their holdings. Users availing themselves of these sites should work with the personnel in charge of those sites to work out access problems. Also, users are responsible for gaining a clear understanding of the provenance of those data to assure that they are working with current, clean data.
2. FTP access is sometimes regulated by the ISP or institution providing Internet connectivity. Specifically, many ISP's and institutions only permit the FTP software on user machines ("clients") to make "passive" FTP connections. At least some Macintosh and Windows native FTP applications default to "active". Users having trouble with FTP access should consult with their computer system support personnel to determine whether this is an issue, and if so, whether shifting to a third-party FTP package is necessary to allow "passive" operation.
3. The IMERG data sets are in IEEE "little-endian" floating-point format. Some Unix-based computers run in "big-endian", meaning the data must be "byte-swapped" to be useful. This

is the opposite of the convention in the 3B42, 3B43, and 3B42RT data sets, which are in big-endian format.

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The **data set inventory** may be obtained by accessing the IMERG product listings on the GPM data access pages

http://pmm.nasa.gov/data-access/downloads/gpm

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Users interested in **obtaining data** can follow the links on the GPM data access pages

http://pmm.nasa.gov/data-access/downloads/gpm

to determine the correct run/format/service for their particular needs and then navigate to the correct data site. Note that users are required to complete a simple, free, and automatic on-line registration in order to access the data at PPS. This is dictated by data security considerations.

It is possible to subset some of the data sets by parameter and/or space, as well as acquiring only the data files that correspond to the user's time period of interest. See the documentation for the individual dataset formats/services to determine what parameter/space subsetting is supported.

As well, Web-based interactive access to the IMERG and related data is provided by GIOVANNI; see that topic for details.

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The **data access policy** is "freely available" with three common-sense caveats:

1. It is an emerging best practice that the data set source should be referenced when the data are used. A formal reference of the form

   Huffman, G.J., E.F. Stocker, D.T. Bolvin, E.J. Nelkin, 2014, last updated 2014: *<dataset identifier> Data Sets*. NASA/GSFC, Greenbelt, MD, USA, <archive site – PPS or GES DISC>, Accessed <enter user data access date>, [doi:*<doi>* or at *<data landing page URL>*].

   is suggested following the AMS policy statement at

   http://www2.ametsoc.org/ams/index.cfm/publications/authors/journal-and-bams-authors/journal-and-bams-authors-guide/data-archiving-and-citation/.

   Note that the AMS policy states that this dataset reference should be in addition to reference to the relevant papers on constructing the data set. This approach allows readers to find both the technical literature and the data archive.
2. New users are urged to obtain their own current, clean copy from an official archive, rather than taking a version from a third party that might be damaged or out of date.
3. Errors and difficulties in the original datasets should be reported to the dataset creators or archive sites (depending on the nature of the issue). Access and format issues at third-party sites should be directed to their contacts.

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The Tool for High-resolution Observation Review (**THOR**) is created and supported by PPS. THOR is a point-and-click program written in IDL that runs on Linux, Mac OS X, and Windows. This viewer enables you to display TRMM and GPM observations on a map of the Earth at the full instrument resolution. You install it on your own computer; instructions for downloading and installing the current Version 2 of THOR are located at

http://pmm.nasa.gov/node/1189 .

As well, THOR is accessible within the PPS STORM (without downloading the application) to quickly visualize data fields.

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The Geospatial Interactive Online Visualization ANd aNalysis Infrastructure (**GIOVANNI**) is created and supported by GES DISC. It provides a web-based resource for accessing many Earth science data sets, including IMERG Final Run. It performs a variety of basic subsetting, time- and space-averaging, and output of results in plots, time series, animations, or ASCII text. The current Version 4 of Giovanni is located at

http://giovanni.gsfc.nasa.gov/ .

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4. Data Set Information

Advice for new users: The variety of products that provide IMERG data can be daunting to a new user. These different products serve different needs, as outlined in "multiple runs, sources, and formats", which each user must map into their particular needs, level of computing skills, and computing tools. As well, first-time users are required to complete a simple, free, and automatic on-line registration in order to access the data, as dictated by data security considerations. Once a user has acquired an example dataset, it is strongly suggested that they use GIOVANNI (which topic see) to verify that they are correctly accessing the data set. The various IMERG dataset formats have been developed to work nicely with a range of off-the-shelf application software packages. If this is not successful, the user should contact the archive site for more information. Questions about the scientific basis for IMERG that are not answered in this technical document or the ATBD should be referred to the algorithm developers.

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IMERG output is available in **multiple runs, sources, and formats**, which can lead to confusion among users. The IMERG system is run twice in near-real time

- "Early" multi-satellite product ~4 hr after observation time and
- "Late" multi-satellite product ~12 hr after observation time,

and once after the monthly gauge analysis is received

- "Final" satellite-gauge product ~2 months after the observation month.

All three runs create half-hourly 0.1°x0.1° products (3IMERGHH), while the Final post-real-time run additionally provides a monthly 0.1°x0.1° satellite-gauge combination data set

(3IMERGM). In all cases the output contains multiple fields that provide information on the input data, selected intermediate fields, and estimation quality.

These multiple runs are computed because of the competing demands for timeliness and completeness of data. The Early run can only employ forward morphing, but provides relatively quick results for flood analysis and other short-fuse applications. The Late run employs both forward and backward morphing with later data, and is appropriate for daily and longer applications, such as crop forecasting. The Final run introduces monthly precipitation gauge analyses, providing more accurate results in regions with gauge information. The Final run is considered the research-grade product.

Once computed, the IMERG data sets are hosted on both PPS and GES DISC, with each site providing value-added products based on the basic IMERG data sets, such as daily averages, GeoTIFF-format files, and WMS servers. A complete list of datasets provided by PPS and GES DISC is given on the GPM data access pages (*http://pmm.nasa.gov/data-access/downloads/gpm*).

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The identifier **3IMERGHH** denotes the half-hourly output from any run of IMERG.

....

The identifier **3IMERGM** denotes the monthly output, only computed by the Final run of IMERG.

....

The **file date/time** is the UTC year, month, day, and then starting and ending hour, minute, second for both the 3IMERGHH and 3IMERGM data sets. The single date provided is the first day of the month for 3IMERGM; basically everything after year and month in its name is filled with nominal values. The date, start time and end time are provided in both the metadata and file name. Within the name, start and end times are denoted by “S” and “E”. All dates and times are UTC.

....

The template for **data set file names** for the original IMERG HDF5 files is given in

http://pps.gsfc.nasa.gov/Documents/FileNamingConventionForPrecipitationProductsForGPMMissionV1.4.pdf

Examples are:

3IMERGHH from the Early run starting at 10UTC on 4 November 2014:
3B-HHR-E.MS.MRG.3IMERG.20141104-S100000-E102959.0600.V00Z.HDF5

3IMERGM (always the Final run) for November 2014:
3B-MO.MS.MRG.3IMERG.20141101-S000000-E235959.11.V00Z.HDF5

The prefixes for the different runs are:

- 3B-HHR-E – half-hourly, Early Run

- 3B-HHR-M – half-hourly, Middle (or Late) Run
- 3B-HHR – half-hourly, Final Run
- 3B-MO – monthly, Final Run

The standard approach to version numbering in GPM is to give all "down-stream" products the same version as the inputs. Given that IMERG has numerous inputs, we choose to use the calibrator, 2BCMB, to set the version for IMERG products. Thus, whenever 2BCMB has a version update, either major or minor (i.e., number or letter), then IMERG products will be updated as well. It also means that, if IMERG products are updated with a minor change (letter), then should 2BCMB be updated afterwards, the IMERG version will be updated once again and have a greater letter than 2BCMB. The initial 2BCMB product version is V03D. For example:

2BCMB V03D IMERG V03D
IMERG updates ...
2BCMB V03D IMERG V03E
2BCMB updates ...
2BCMB V03E IMERG V03F

....

The **temporal resolution* of the products is:

- 3IMERGHH: half hour (with "-E", "-M", and "" for the Early, Middle, and Final Runs)
- 3IMERGM: month

The half-hour period for the 3IMERGHH is driven by the basic observational interval for the geo-IR data. Note that both the microwave and IR input data are snapshots. In those small regions in which two (or more) overlapping microwave scenes occur in a grid box, the imager closest to the mid-point of the half hour is taken, or lacking any imagers, the sounder closest to the mid-point. [To be explicit, when both an imager and a sounder are available, the imager is chosen even if it's further from the mid-point than the sounder.] This restriction to one snapshot makes the statistics of the data sets as comparable as possible, since the collect of two-snapshot averages of precipitation rates has a rather different PDF than single-shot averages. These snapshots might be thought of as an average rate, valid at the nominal observation time, since Villarini and Krajewski (2007) showed that the (snapshot-based) TRMM 3B42 is best correlated with radar data averaged over 60-90 minutes, not always centered on the nominal overpass time.

The monthly period for 3IMERGM is driven by the typical calendar monthly period of precipitation gauge analyses, although it is also a typical period requested by many users. The precipitation value is an average over the calendar month.

Because the data are provided at nominal UTC half-hour intervals, each 3IMERGHH data set represents a nominal 30-minute span starting on the hour or half-hour. Thus, the first image of the day includes data for 00:00:000–00:29:59 UTC. The metadata and dataset name contain the date and start and end times.

....

The *period of record* for IMERG Final Run is mid-March 2014 through the present. [The lack of input for the first part of March leads us to suggest ignoring data before the start of April 2014.] For IMERG Late Run, the record starts 7 March 2015, while for IMERG Early Run it starts 1 April 2015. There is a delay (latency) of 6 hours, 18 hours, and about 3 months after the end of the month for the Early, Late, and Final runs. [We have a goal of reducing the Early and Late Run latencies to 4 and 12 hours, respectively.] The start is based on the first full month of GPM DPR data. In the first GPM reprocessing, expected in early 2017, IMERG will incorporate TRMM data as a calibrator, enabling a start date of January 1998.

....

The **grid** on which each field of values is presented is a 0.1°x0.1° lat./lon. (Cylindrical Equal Distance) global array of points. It is size 3600x1800, with X (longitude) incrementing most rapidly West to East from the Dateline, and then Y (latitude) incrementing South to North from the southern edge as detailed in the metadata. Tenth-degree latitude and longitude values are at grid edges:

First point center	(89.95°S,179.95°W)
Second point center	(89.95°S,179.85°W)
Last point center	(89.95°N,179.95°E)

The reference datum is WGS84.

Note that the Day-1 IMERG precipitation estimates are filled with "missing" values outside the latitude band 60°N-S, while some of the additional data fields have values at the higher latitudes.

....

The **spatial resolution** of IMERG is 0.1°x0.1° lat/lon.

....

The **spatial coverage** of the Day-1 IMERG precipitation estimates is the latitude band 60°N-S. Some of the additional data fields have values at the higher latitudes.

....

The **data file layout** for the original IMERG HDF5 files can be accessed at *ftp://gpmweb2.pps.eosdis.nasa.gov/pub/GPMfilespec/filespec.GPM.V1.pdf* , which includes a significant quantity of metadata intended to make the files recognizable by many standard off-the-shelf applications (see *ftp://gpmweb2.pps.eosdis.nasa.gov/pub/GPMfilespec/filespecMeta. GPM.V1.pdf*).

....

It is possible to **read a file of data** with many standard off-the-shelf applications; any tool that reads the standard HDF5 file can be used to process IMERG files. As well, PPS provides a toolkit with C and FORTRAN versions that allow users to write custom programs. See *ftp://gpmweb2.pps.eosdis.nasa.gov/pub/PPStoolkit/GPM* for more details. The toolkit is at TK version 3.70.1 as of 4 February 2015. Documentation for the value-added file formats listed in the GPM data access pages at *http://pmm.nasa.gov/data-access/downloads/gpm* should be consulted to determine the best way to read these files. Some of these formats are intended for specific functions, such as the GIS-oriented GeoTIFF files. For users of the R programming language, a package to read HDF5, called ‘h5’, is located at *http://cran.r-project.org/web/packages/h5/index.html.*

....

The **3IMERGHH data fields** provide a variety of data fields for users and data developers.

Table 1. List of data fields, their variable names (in the data structure), and the data units for 3IMERGHH data files.

Data field	*Variable name*	*Units*
snapshot precipitation – calibrated	precipitationCal	mm/hr
snapshot precipitation – uncalibrated	precipitationUncal	mm/hr
calibrated-precipitation random error	randomError	mm/hr
merged PMW precipitation	HQprecipitation	mm/hr
PMW source sensor identifier	HQprecipSource	index values
PMW source time	HQobservationTime	min. into half hour
IR precipitation	IRprecipitation	mm/hr
Kalman filter weight for IR	IRkalmanFilterWeight	percent
probability of liquid precipitation phase	*probabilityLiquidPrecipitation*	percent

The index values for HQprecipSource are:

0 = no observation	1 = TMI	2 = (unused)
3 = AMSR	4 = SSMI	5 = SSMIS
6 = AMSU	7 = MHS	8 = SAPHIR
9 = GMI	10 = (unused)	11 = ATMS
12 = AIRS	13 = TOVS	14 = CRIS
15 = Spare scanner 1	16 = Spare scanner 2	17 = Spare scanner 3
18 = Spare scanner 4	19 = Spare scanner 5	20 = Spare sounder 1
21 = Spare sounder 2	22 = Spare sounder 3	23 = Spare sounder 4
24 = Spare sounder 5		

The time span for each 3IMERGHH field is the half hour (in UTC) stated in the file name and metadata.

....

The **3IMERGM data fields** provide a variety of data fields for users and data developers.

Table 2. List of data fields, their variable names (in the data structure), and the data units for 3IMERGM data files.

Data field	*Variable name*	*Units*
satellite-gauge precipitation	precipitation	mm/hr
satellite-precipitation random error	randomError	mm/hr
gauge relative weighting	gaugeRelativeWeight	percent
accumulation-weighted probability of liquid precipitation phase	*probabilityLiquidPrecipitation*	percent

The time span for each 3IMERGM field is the month stated in the file name and metadata.
....

5. Sensors

Some **PMW satellite overpass times** experienced significant drifting during the satellite's period of service (see *http://precip.gsfc.nasa.gov/times_allsat.jpg* for a current time-series plot). There is no direct effect on the accuracy of the precipitation estimates, but it is possible that the systematic change in sampling time could introduce subtle shifts in the resulting collection of precipitation estimates. The plot shows that the 00/12 UTC slot entirely lacks coverage for three or more hours over the entire record. Meanwhile, the uncoordinated satellite operations end up giving a slowly varying pattern of near-duplicate data in some time slots, and totally absent coverage in others. Finally, it is routinely the case that the precessing satellites (TRMM, GPM, Megha-Tropiques) create a complicated pattern of overlap and fill-in for the observations and gaps in the sun-synchronous satellites.
....

The GPM Dual-frequency Precipitation Radar (**DPR**) is a pair of flat-panel phased-array weather radars, based on the very successful TRMM PR. The horizontal and vertical resolutions for the Ku-band unit are 5 km and 250 m, respectively, over a 245 km swath to a height above sea level of 19 km. The minimum detectable rainrate is 0.5 mm/hr. The Ka-band unit has two modes. In the standard mode, the horizontal and vertical resolutions are 5 km and 250 m, respectively, over a 125 km swath to a height above sea level of 19 km, with a minimum detectable rainrate of 0.2 mm/hr. In high-resolution mode, the horizontal and vertical resolutions are 2.5 km and 250 m, respectively, over a 110 km swath to a height above sea level of 20 km.

The DPR is an operational sensor, so the data record suffers the usual gaps in the record due to processing errors, down time on receivers, etc.

The 65° inclination provides nominal coverage over the latitudes 67°N-S for the Ku-band unit, and to 66°N-S for the Ka-band unit.

Further details are available in Iguchi et al. (2010).
....

The GPM Microwave Imager (**GMI**) is a multi-channel passive microwave radiometer. The GMI provides vertical and horizontal polarization values for 10.7, 18.7, 23.8, 36.5, 89.0, 165.5, 183.3 ± 3, and 183.3 ± 7 GHz frequencies (except only vertical at 23 and the 183's) with conical scanning, similar to the SSMIS. The channels have effective fields of view that vary from 4x7 km for the 89 GHz (oval due to the slanted viewing angle intersecting the surface at 51°) to 19x32 km for the 10 GHz. Channels above 89 GHz are resolved at the 89 GHz footprint size. For practical reasons, as with SSMIS, two separate feed horns collect the lower-frequency channels (36.5 and below) and the remaining higher-frequency channels. As a result, each set of channels has a separate navigation, and the footprints are not collocated. At Level 1C PPS provides both the original, separately navigated channels and a special product in which the high-frequency channels are remapped to the low-frequency footprint locations. The 89 GHz and higher frequency channels are undersampled near nadir, and the lower-frequency channels are more or less oversampled (see *http://mirs.nesdis.noaa.gov/gpmgmi.php*). At the swath edge even the higher-frequency channels are oversampled.

The GMI is an operational sensor, so the data record suffers the usual gaps in the record due to processing errors, down time on receivers, etc.

The 65° inclination provides nominal coverage over the latitude band 70°N-S, although limitations in retrieval techniques limit the accuracy, or even availability, of precipitation estimates in cases of cold land or sea ice.

Further details are available at *http://pmm.nasa.gov/sites/default/files/document_files/GMIL1B_ATBD.pdf* .
....

The TRMM Precipitation Radar (**PR**) is a flat-panel phased-array weather radar, the first flown in space. The horizontal and vertical resolutions are 4 km and 250 m, respectively, over a 220 km swath to a height above sea level of 20 km. The minimum detectable signal is 17 (18) dBZ before (after) the TRMM orbit boost in August 2001.

The PR is an operational sensor, so the data record suffers the usual gaps in the record due to processing errors, down time on receivers, etc. There were outages for an operational anomaly in May 2000, and the boost to a higher orbit during the first part of August 2001. The PR suffered an electronics failure on 29 May 2009. Data were lost until the "B-side" electronics were activated until 19 June 2009. Some residual differences are noticeable. The descent of TRMM following fuel exhaustion in July 2014 prevented useful retrievals after 7 October 2014, except for a short period in 2015 from 12 February to 1 April as TRMM descended past its original at-launch altitude of 350 km.

The 35° inclination provides nominal coverage over the latitudes 37°N-S.

Further details are available in Kummerow et al. (1998).
....

The TRMM Microwave Imager (**TMI**) is a multi-channel passive microwave radiometer that flies on TRMM. The TMI provides vertical and horizontal polarization values for 10.65, 19.35 21.3, 37.0, and 85.5 GHz frequencies (except only vertical at 21) with conical scanning, similar to the SSMI. The channels have effective fields of view that vary from 4.6x6.9 km for the 85 GHz (oval due to the slanted viewing angle intersecting the surface at 51°) to 29.1x55.2 km for the 10 GHz. Consequently, the 85 GHz is undersampled near nadir, and all other channels are more or less oversampled. At the swath edge even the 85.5 GHz is oversampled.

The TMI is an operational sensor, so the data record suffers the usual gaps in the record due to processing errors, down time on receivers, etc. There were outages for an operational anomaly in May 2000 and the boost to a higher orbit during the first part of August 2001. The TMI continues to be operated during the descent of TRMM following fuel exhaustion in July 2014, until passivation (shutdown of the satellite) in April 2015. There is some effect due to a gradually changing Earth Incidence Angle (EIA) of the sensor, but to date the retrievals are considered useful.

The 35° inclination provides nominal coverage over the latitudes 40°N-S, although limitations in retrieval techniques limit the accuracy, or even availability, of precipitation estimates in cases of cold land or sea ice (which is unlikely in this latitude range).

Further details are available in Kummerow et al. (1998).
....

The Advanced Microwave Scanning Radiometer Version 2 (*AMSR2*) is a multi-channel passive microwave radiometer provided by the Japan Aerospace Exploration Agency that has flown on GCOM-W since mid-2012. GCOM-W is placed in a sun-synchronous polar orbit with a period of about 102 min. The AMSR2 provides vertical and horizontal polarization values for 6.9, 10.65, 18.7, 23.8, 36.5, and 89.0 GHz frequencies (except only vertical at 23.8) with conical scanning, similar to the SSMI. Pixels and scans are spaced 10 km apart at the suborbital point, except the 89-GHz channels are collected at 5 km spacing. Every other high-frequency pixel was co-located with the low-frequency pixels, starting with the first pixel in the scan and the first scan in a pair of scans. The channels had resolutions that vary from 3x5 km for the 89 GHz (oval due to the slanted viewing angle) to 35x62 km for the 6 GHz.

The polar orbit provides nominal coverage over the latitudes 85°N-S, although limitations in retrieval techniques limit the accuracy, or even availability, of precipitation estimates in cases of cold land or sea ice.

The AMSR2 is an operational sensor, so the data record suffers the usual gaps in the record due to processing errors, down time on receivers, etc.

Further details are available at *http://suzaku.eorc.jaxa.jp/GCOM_W/w_amsr2/whats_amsr2.html*.
....

The Advanced Microwave Scanning Radiometer for the Earth Observing System (*AMSR-E*) is a multi-channel passive microwave radiometer provided by the Japan Aerospace Exploration Agency that flew on Aqua from mid-2002 until it failed in late 2011. Data use in 3B42/43 cover 19 June 2002 – 3 October 2011. Aqua is placed in a sun-synchronous polar orbit with a period of about 102 min. The AMSR-E provided vertical and horizontal polarization values for 6, 10, 18, 23, 36, and 89 GHz frequencies (except only vertical at 23) with conical scanning, similar to the SSMI. Pixels and scans were spaced 10 km apart at the suborbital point, except the 89-GHz channels were collected at 5 km spacing. However, the B-scan sensor, which provides the 89 GHz scan between the lower-frequency scans, failed around 4 November 2004. Every other high-frequency pixel was co-located with the low-frequency pixels, starting with the first pixel in the scan and the first scan in a pair of scans. The channels had resolutions that vary from 4x6 km for the 89 GHz (oval due to the slanted viewing angle) to 43x74 km for the 6 GHz.

The polar orbit provides nominal coverage over the latitudes 85°N-S, although limitations in retrieval techniques limit the accuracy, or even availability, of precipitation estimates in cases of cold land or sea ice.

The AMSR-E was an operational sensor, so the data record suffered the usual gaps in the record due to processing errors, down time on receivers, etc. Over time the coverage improved as the operational system matured. As noted above, the B-scan sensor failed around 4 November 2004.

Further details are available at *http://www.ghcc.msfc.nasa.gov/AMSR/*.
....

The Special Sensor Microwave Imager/Sounder (**SSMIS*) is a multi-channel passive microwave radiometer that has flown on selected Defense Meteorological Satellite Program (DMSP) platforms since late 2003. The DMSP is placed in a sun-synchronous polar orbit with a period of about 102 min. The SSMIS provides vertical and horizontal polarization values for the SSMI-like 19, 22, 37, and 91 GHz frequencies (except only vertical at 22) with conical scanning, as well as other channels with a heritage in the Special Sensor Microwave/Temperature 2 (SSM/T2) sensor: 150, 183±1, 183±3, and 183±7 GHz. Unlike SSMI, every SSMIS scan observes at all channels: pixels and scans are respectively spaced 25 and 12.5 km apart at the suborbital point for channels below 91 GHz, 12.5 km for both pixel and scans for 91 GHz. Thus, the high-frequency channels have twice as many footprints per scan as the lower-frequency channels. For practical reasons, as with GMI, multiple separate feed horns are used to collect sets of channels. As a result, each set of channels has a separate navigation, and the footprints are not collocated. The SSMI-like channels have the resolutions

42.4x70.1 km (19, 22 GHz)
27.5x44.2 km (37 GHz)
13.1x14.4 km (91 GHz)

while the "sounding" channels have the resolutions

13.1x14.4 km (150 GHz)
13.1x14.4 km (183±1, 183±3, 183±7 GHz)

with the slanted viewing angle and in-line processing determining the oval shape.

Operational and design problems early in the program raised serious obstacles to use of the data. Accordingly, the useful periods of record (below) start relatively long after launch. These dates are based on the start of the first publicly available SSMIS as determined by NRL/FNMOC through the Shared Processing Program with NESDIS.

The polar orbit provides nominal coverage over the latitudes 85ºN-S, although limitations in retrieval techniques limit the accuracy, or even availability, of precipitation estimates in cases of cold land or sea ice.

The SSMIS is an operational sensor, so the data record suffers the usual gaps in the record due to processing errors, down time on receivers, etc. Over time the coverage has improved as the operational system has matured.

Further details are available in Northrup Grumman (2002) and at *http://nsidc.org/data/docs/daac/ssmis_instrument/* . Note that the acronym was originally "SSMI/S", but "SSMIS" has since come into common use.

Table 3. The inventory of SSMIS data used in IMERG, period of record, and sensor status.

DMSP	*Period of Record*	*Status*
F16	20 November 2005 - ongoing	active
F17	19 March 2008 - ongoing	active
F18	8 March 2010 - ongoing	active
F19	1 December 2014 - ongoing	active

....

The Special Sensor Microwave/Imager (**SSMI**) is a multi-channel passive microwave radiometer that began flying on selected Defense Meteorological Satellite Program (DMSP) platforms in mid-1987. The DMSP is placed in a sun-synchronous polar orbit with a period of about 102 min. The SSMI provides vertical and horizontal polarization values for 19, 22, 37, and 85 GHz frequencies (except only vertical at 22) with conical scanning. Pixels and scans are spaced 25 km apart at the suborbital point, except the 85-GHz channels are collected at 12.5 km spacing. Every other high-frequency pixel is co-located with the low-frequency pixels, starting with the first pixel in the scan and the first scan in a pair of scans. The channels have resolutions that vary from 12.5x15 km for the 85 GHz (oval due to the slanted viewing angle) to 60x75 km for the 19 GHz.

The polar orbit provides nominal coverage over the latitudes 85°N-S, although limitations in retrieval techniques limit the accuracy, or even availability, of precipitation estimates in cases of cold land or sea ice.

The SSMI is an operational sensor, so the data record suffers the usual gaps in the record due to processing errors, down time on receivers, etc. Over time the coverage has improved as the operational system has matured. As well, the first 85 GHz sensor to fly degraded quickly due to inadequate solar shielding. After launch in mid-1987, the 85.5 GHz vertical- and horizontal-polarization channels became unusable in 1989 and 1990, respectively. Another issue arose on 14 August 2006: DoD activated the RADCAL beacon on the F15 DMSP, which interfered with the 22V and 85.5V channels and prevented reliable estimates using then-current GPROF code. Subsequently, calibration work has been done that should allow F15 to be used in a future reprocessing.

Further details are available in Hollinger et al. (1987, 1990). Note that the acronym was originally "SSM/I", but "SSMI" has since come into common use.

Table 4. The inventory of SSMI data used in IMERG, period of record, and sensor status.

DMSP	*Period of Record*	*Status*
F13	1 January 1998 - 31 July 2009	inactive
F14	1 January 1998 - 23 August 2008	inactive

F15	23 February 2000 - 14 August 2006	active, but unusable

....

The Sounder for Atmospheric Profiling of Humidity in the Intertropics by Radiometry (*SAPHIR*) is a multi-channel passive microwave radiometer that has flown on the Megha-Tropiques platform since 12 October 2011. The satellites are placed in an orbit with an inclination of 20° and a period of about 102 min. SAPHIR contains 6 channels, around 183 GHz, with cross-track scanning. Pixels and scans are spaced 10 km apart at nadir, with the pixels increasing in size and changing from circular to elongated in the cross-track direction as one moves away from nadir.

The 20° inclined orbit provides excellent coverage over the deep tropics.

SAPHIR is an operational sensor, so the data record suffers the usual gaps in the record due to processing errors, down time on receivers, etc. Over time the coverage has improved as the operational system has matured.

Further details are available at *http://meghatropiques.ipsl.polytechnique.fr/instruments.html* .

Table 5. Inventory of SAPHIR data used in IMERG, period of record, and sensor status.

Satellite	*Period of Record*	*Status*
Megha-Tropiques	13 October 2011 – current	active, but not yet in use

....

The Advanced Temperature and Moisture Sounder (*ATMS*) is a multi-channel passive microwave radiometer that has flown on the Suomi National Polar-orbiting Partnership platform since 28 October 2011. The satellite is placed in a sun-synchronous polar orbit with a period of about 102 min. ATMS contains 22 channels, some being similar to AMSU-B. These channels cover the frequencies 89.0, 157.0, 183.311±1 and 3, and 190.311, all in GHz, with cross-track scanning. Pixels and scans are spaced 16.3 km apart at nadir, with the pixels increasing in size and changing from circular to elongated in the cross-track direction as one moves away from nadir.

The polar orbit provides nominal coverage over the entire globe, although limitations in retrieval techniques limit the accuracy, or even availability, of precipitation estimates in cases of cold land or sea ice.

The ATMS is an operational sensor, so the data record suffers the usual gaps in the record due to processing errors, down time on receivers, etc. Over time the coverage has improved as the operational system has matured.

Further details are available at *http://mirs.nesdis.noaa.gov/snppatms.php* .

Table 6. Inventory of ATMS data used in IMERG, period of record, and sensor status.

Satellite	*Period of Record*	*Status*

SNPP	10 December 2011 – current	active, but not yet in use

....

The Microwave Humidity Sounder (*MHS*) is a multi-channel passive microwave radiometer that has flown on selected NOAA platforms since mid-2005 as a follow-on to AMSU-B and on the EUMETSAT MetOp-A since late 2006, and MetOp-B since mid-2013. The satellites are placed in sun-synchronous polar orbits with periods of about 102 min. The MHS contains 5 channels, similar to AMSU-B. These channels cover the frequencies 89.0, 157.0, 183.311±1 and 3, and 190.311, all in GHz, with cross-track scanning. Pixels and scans are spaced 16.3 km apart at nadir, with the pixels increasing in size and changing from circular to elongated in the cross-track direction as one moves away from nadir.

The polar orbit provides nominal coverage over the entire globe, although limitations in retrieval techniques limit the accuracy, or even availability, of precipitation estimates in cases of cold land or sea ice.

The MHS is an operational sensor, so the data record suffers the usual gaps in the record due to processing errors, down time on receivers, etc. Over time the coverage has improved as the operational system has matured.

Further details are available in the NOAA KLM User's Guide (September 2000 revision) at *http://www2.ncdc.noaa.gov/docs/klm/index.htm*, specifically at *http://www2.ncdc.noaa.gov/docs/klm/html/c3/sec3-9.htm*.

Table 7. Inventory of MHS data used in IMERG, period of record, and sensor status.

Satellite	*Period of Record*	*Status*
NOAA-18	25 May 2005 – current	active
NOAA-19	25 February 2009 – current	active
MetOp-A	5 December 2006 – current	active
MetOp-B	24 September 2012 – current	active

....

The Advanced Microwave Sounding Unit B (*AMSU-B*) is a multi-channel passive microwave radiometer that flew on selected National Oceanic and Atmospheric Administration (NOAA) platforms from early 2000 to 2011. The NOAA satellites are placed in sun-synchronous polar orbits with periods of about 102 min. The complete AMSU contained 20 channels, the first 15 referred to as AMSU-A, and the last 5 as AMSU-B. These channels (identified as 16 through 20) covered the frequencies 89.0±0.9, 150.0±0.9, and 183.31±1, 3, and 7, all in GHz, with cross-track scanning. Pixels and scans were spaced 16.3 km apart at nadir, with the pixels increasing in size and changing from circular to elongated in the cross-track direction as one moves away from nadir.

The polar orbit provided nominal coverage over the entire globe, although limitations in current retrieval techniques prevent useful precipitation estimates in cases of cold land or sea ice.

The AMSU-B was an operational sensor, so the data record suffered the usual gaps in the record due to processing errors, down time on receivers, etc. Over time the coverage improved as the operational system matured. As well, the NOAA-17 50-GHz channel failed in late October 2003, apparently due to solar flare activity. Finally, NOAA-16 gradually failed during 2010, and eventually it was determined that the Version 7 TMPA should stop using the data at the end of April 2010.

Further details are available in the NOAA KLM User's Guide (September 2000 revision) at *http://www2.ncdc.noaa.gov/docs/klm/index.htm*, specifically at *http://www2.ncdc.noaa.gov/docs/klm/html/c3/sec3-4.htm* .

Table 8. The inventory of AMSU-B data used in IMERG, period of record, and sensor status.

Satellite	*Period of Record*	*Status*
NOAA-15	1 January 2000 - 14 September 2010	inactive
NOAA-16	4 October 2000 - 16 February 2011 (last used for 30 April 2010)	inactive
NOAA-17	28 June 2002 - 17 December 2009	inactive

....

The infrared (*IR*) data are collected from a variety of sensors flying on the international constellation of geosynchronous-orbit meteorological satellites – the Geosynchronous Operational Environmental Satellites (GOES, United States); the Geosynchronous Meteorological Satellite (GMS, Japan), subsequently Multi-functional Transport Satellite, (MTSat, Japan), to be followed by Himawari (Japan); and the Meteorological Satellite (Meteosat, European Community). There are usually two GOES platforms active covering the eastern and western regions of the Americas, two Meteosats covering the Europe/Africa and Indian Ocean sectors, and the Japanese series over east Asia. The geosynchronous IR data are collected by scanning (parts of) the earth's disk. By international agreement, all satellite operators collect full-disk images at the synoptic observing times (00, 03, ..., 21 UTC) at a minimum. Most of the time the operators provide substantially complete coverage for their respective regions every half hour, but the Japanese satellite tends to provide Southern Hemisphere data every hour, and GOES-W tends to cut off the higher latitudes over the South Pacific Ocean.

Subsequent processing is described in "Merged 4-Km IR Tb data set".

The various IR instruments are operational sensors, so the data record suffers the usual gaps in the record due to processing errors, down time on receivers, sensor failures, etc., as well as choices by the operators on observing strategies. Most notably, there was no geo-IR coverage in the Indian Ocean sector until 06 UTC 16 June 1998, although high-zenith-angle observations from adjacent geo-satellites are used to largely cover the gap. As well, GMS-5 was replaced by GOES-9 starting 01 UTC 22 May 2003, which introduced slightly different instrument characteristics. MTSat-1R went operational starting 19 UTC 17 November 2005, and was replaced by MTSat-2 on 1 July 2010. Himawari 8 is scheduled to take over on 7 July 2015.

Further details are available in Janowiak and Arkin (1991).
....

The *precipitation gauge analysis* that is used in IMERG is produced by the Global Precipitation Climatology Centre (GPCC) under the direction of Andreas Becker and Udo Schneider, located in the Deutscher Wetterdienst, Offenbach a.M., Germany (Schneider et al. 2010). [Note: Throughout, we are clearly dealing with all forms of precipitation, but we follow the customary practice here of referring to precipitation gauges as “rain gauges”.] Rain gauge reports are archived from a time-varying collection of over 70,000 stations around the globe, both from Global Telecommunications System (GTS) reports and from other world-wide or national data collections. An extensive quality-control system is run, featuring an automated screening and then a manual step designed to retain legitimate extreme events that characterize precipitation. This long-term data collection and preparation activity feeds into an analysis that is done in two steps. First, a long-term climatology is assembled from all available gauge data, focusing on the period 1951-2000. The lack of complete consistency in period of record for individual stations has been shown to be less important than the gain in detail, particularly in complex terrain. Then for each month, the individual gauge reports are converted to deviations from climatology, and are analyzed into gridded values using a variant of the SPHEREMAP spatial interpolation routine (Willmott et al. 1985). Finally, the month’s analysis is produced by superimposing the anomaly analysis on the month’s climatology.

The GPCC creates multiple products, and two are used in IMERG. The Full Data Reanalysis (currently Version 6) is a retrospective analysis that covers the period 1901-2010, and it is used in the TMPA for the span 1998-2010. Thereafter we use the GPCC Monitoring Product (currently Version 4), which has a similar quality control and the same analysis scheme as the Full Data Reanalysis, but whose data source is limited to GTS reports. When the Full Data Reanalysis is updated to a longer record we hope to reprocess the IMERG datasets to take advantage of the improved data. We continue our long-standing practice of correcting all gauge analysis values for climatological estimates of systematic error due to wind effects, side-wetting, evaporation, etc., following Legates (1987). We hope to develop a more modern and detailed correction for these effects in subsequent versions.
....

The inventory of *sensors contributing to IMERG* is summarized here for convenience; refer to the individual sensor descriptions for additional details.

Table 9. Alphabetized lists of contributing data sets for IMERG, broken out by sensor type. Data sets with start dates of Jan 98 extend before that time, but these data are not relevant to IMERG. Square brackets ([ ]) indicate an estimated date. “M-T” stands for Megha-Tropiques. The M-T MADRAS instrument is not included on this list because of its short, gappy record. It is planned that the geosynchronous IR data will be processed into “even-odd” files at NESDIS. All data are computed to Level 2 (scan/pixel) precipitation from Level 1 data by PPS, except for the precipitation gauge analyses (Level 3) and IR data (Level 1).

Merged Radar – Passive Microwave Imager Products	
Product	*Period of Record*

GPM DPR-GMI	Mar 14 - [Feb 24]
TRMM PR-TMI	Jan 98 - Sep 14

Conically-Scanning Passive Microwave Imagers and Imager/Sounders		
Sensor	*Period of Record*	*Agency*
Aqua AMSR-E	Jun 02 - Oct 11	JAXA
DMSP F13 SSMI	Jan 98 - Jul 09	U.S. DoD
DMSP F14 SSMI	Jan 98 - Aug 08	U.S. DoD
DMSP F15 SSMI	Feb 00 - Aug 06	U.S. DoD
DMSP F16 SSMIS	Nov 05 - [Nov 15]	U.S. DoD
DMSP F17 SSMIS	Mar 08 - [Nov 18]	U.S. DoD
DMSP F18 SSMIS	Mar 10 - [Mar 20]	U.S. DoD
DMSP F19 SSMIS	Dec 14 - [Jan 24]	U.S. DoD
DMSP F20 SSMIS	[Jul 20] - [Jan 30]	U.S. DoD
GCOMW1 AMSR2	Jun 02 - [May 22]	JAXA
GCOMW2 AMSR2	[Feb 16] - [Jan 26]	JAXA
GCOMW3 AMSR2	[May 20] - [May 30]	JAXA
GPM GMI	Mar 14 - [Feb 24]	NASA
TRMM TMI	Jan 98 - Apr 15	NASA

Cross-Track-Scanning Passive Microwave Sounders		
Sensor	*Period of Record*	*Agency*
JPSS-1 ATMS	[Jun 16] - [Jun 21]	NOAA
METOP-2/A MHS	Dec 06 - [Aug 18]	EUMETSAT
METOP-1/B MHS	Sep 12 - [Aug 22]	EUMETSAT
METOP-3/C MHS	[Apr 18] - [Apr 28]	EUMETSAT
M-T SAPHIR *	[Oct 11] - [Jan 15]	CNES
NOAA-15 AMSU	Jan 00 - Sep 10	NOAA
NOAA-16 AMSU	Oct 00 - Apr 10	NOAA
NOAA-17 AMSU	Jun 02 - Dec 09	NOAA
NOAA-18 MHS	May 05 - [Dec 16]	NOAA
NOAA-19 MHS	Feb 09 - [Apr 19]	NOAA
SNPP ATMS	Dec 11 - [Nov 21]	NOAA

* Parts of the SAPHIR record suffer drop-outs.

Geosynchronous Infrared Imagers		
Satellite	*Sub-sat. Lon.*	*Agency*
GMS, MTSat, Himawari series	140E	JMA
GOES-E series	75W	NESDIS
GOES-W series	135W	NESDIS
Meteosat prime series	0E	EUMETSAT
Meteosat repositioned series	63E	EUMETSAT

IR/Passive Microwave Sounders

Sensor	Period of Record	Institution
Aqua AIRS	Sep 02 - [Sep 15]	NASA/GSFC DISC
NOAA-14 TOVS	Jan 98 - April 05	Colo. State Univ.; NOAA/NCDC
SNPP CrIS	Dec 11 - [Nov 21]	NASA/GSFC DISC

Precipitation Gauge Analyses		
Analysis	*Period of Record*	*Institution*
Full Version 6	Jan 98 – Dec 10	DWD/GPCC
Monitoring Version 4	Jan 11 - ongoing	DWD/GPCC

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6. Definitions and Defining Algorithms

The **precipitation variable** is computed as described under the individual product headings. All precipitation products have been converted from their original units to mm/hr. Throughout this document, "precipitation" refers to all forms of precipitation, including rain, drizzle, snow, graupel, and hail (see "precipitation phase").
....

The **time zone** for these data sets is Universal Coordinated Time (UTC, also as GMT or Z).
....

The Goddard Profiling Algorithm (**GPROF**) is based on Kummerow et al. (1996), Olson et al. (1999), and Kummerow et al. (2001), Passive Microwave Algorithm Team Facility (2010). GPROF is a multi-channel physical approach for retrieving rainfall and vertical structure information from satellite-based passive microwave observations, both conical-scan images and imagers/sounders (AMSR-E, AMSR2, GMI, SSMI, SSMIS, TMI) and cross-track-scan sounders (AMSU, ATMS, MHS, SAPHIR). GPROF applies a Bayesian inversion method to the observed microwave brightness temperatures using an extensive library of profiles relating hydrometeor profiles, microwave brightness temperatures, and surface precipitation rates. For the Day-1 IMERG, the GPROF2014 library for the conical-scan imagers depends on TRMM PR over ocean, NOAA MRMS calibrated radar data at lower latitudes over land, and joint CloudSat/AMSR-E data at higher latitudes over land. In contrast, the GPROF2014 library for the cross-track sounders depends on Goddard Multiscale Modeling Framework Model cloud model computations. In the first reprocessing, GPROF will be upgraded to GPROF2015, whose libraries will shift to compilations of GPM Combined Instrument data for all satellites. GPROF includes a procedure that accounts for inhomogeneities of the rainfall within the satellite field of view. Over land and coastal surface areas the conical-scan imager library reduces to a scattering-type procedure using only the higher-frequency channels. This loss of information arises from the physics of the emission signal in the lower frequencies when the underlying surface is other than entirely water.
....

The Version 1 PPS datasets for **GMI, TMI, and constellation sensor Level 2 precipitation datasets** contain Level 2 (scan-pixel) GPROF2014 estimates of precipitation based on the sensor named in each dataset. These are provided by PPS. Each file contains an orbit of estimates, except the real-time 2GPROFGMI is in nominally 5-minute granules as down-linked from the Core Observatory. The data have had some quality control, and are converted from sensor units to Ta, then to Tb, then to precipitation.

These data are used as input to IMERG processing.
....

The GPM Combined Radar-Radiometer Algorithm (**GPM Combined Instrument**) provides, in principle, the most accurate, high resolution estimates of surface rainfall rate and precipitation vertical precipitation distributions that can be achieved with the GPM Core Observatory's GMI and DPR instruments. The Combined algorithm is based upon a hybrid ensemble Kalman filtering / variational approach for inverting the DPR reflectivities and GMI brightness temperatures to estimates of precipitation profiles (Olson et al. 2010). This architecture is largely consistent with the successful TCI algorithm design, but it has been updated and modularized to take advantage of improvements in the representation of physics, new climatological background information, and model-based analyses that may become available during the GPM mission.
....

PPS dataset **2BCMB** contains Level 2 (scan-pixel) output from the Version 1 GPM Combined Instrument algorithm, computed at PPS. Each file contains an orbit of GPM Combined Instrument rain rate and path-integrated attenuation at 5 km horizontal and 250 m vertical resolutions over a 250 km swath. More information is available at

http://pps.gsfc.nasa.gov/Documents/GPM2011CombinedL2ATBD.pdf

and Olson et al. (2010).

These Level 2 data are used as input to IMERG processing.
....

The **random error field**, data field randomError, is computed for both the half-hourly (3IMERGHH) and monthly (3IMERGM) datasets. The units are mm/hr.

The monthly random error is computed as in Huffman (1997), with appropriate adjustments for the difference in gridbox size. The half-hour random error is similarly computed, even though the approach is not entirely consistent for such fine scales. [The Huffman (1997) approach assumes that the various input data are statistically independent.] As a partial compensation, the half-hour random errors are approximately scaled to aggregate to the monthly random error, assuming that the half-hour values are statistically independent. This is also not strictly true, but the overall result appeared useful.

Work is currently underway with NASA funding to develop more-appropriate estimators for random error, and to introduce estimates of bias error. In particular, Maggioni et al. (2014) seems to provide a useful framework.

....

The *merged PMW precipitation* estimate, data field HQprecipitation in 3IMERGHH data files, sometimes referred to as "High Quality" (HQ), provides a global Level 3 (0.1°x0.1°-gridded) half-hourly combination of all currently available GMI, TMI, SSMI, SSMIS, AMSR-E, AMSR2, AMSU-B, MHS, ATMS, and SAPHIR precipitation estimates as a field in the 3IMERGHH files:

1. Offline, the GPROF-TMI, -SSMI, -SSMIS, -AMSR-E, -AMSR2, -AMSU-B, -MHS, -ATMS, and -SAPHIR precipitation estimates have been climatologically probability-matched to 2GPROFGMI. The calibrations have one set of coefficients for each sensor type for land and 22 sets for ocean. The ocean latitude bands are 15° overlapping latitude bands centered on the 5° bands >50°S, 50-45°S, 45-40°S, …, 40-45°N, 45-50°N, and >50°N. The outermost bands are used in their respective hemispheres for all higher-latitude calibrations due to the lack of GMI data beyond about 68°. Each type of satellite is given its own calibration set. The coefficients are initially computed for the period April–September 2014, but will later be computed separately for each season. Finally, a volume adjustment factor is computed for each set to ensure that total GMI precipitation is preserved in these transformations.
2. These radiometer estimates and 2BCMB are gridded to a 0.1°x0.1° grid for a half-hour period starting at full and half hours, UTC.
3. The gridded radiometer estimates are climatologically calibrated to 2GPROFGMI. [This is only done for sounders in Day-1.]
4. The gridded 2GPROFGMI is calibrated to the gridded 2BCMB using a matched histogram correction computed afresh for a 45-day period once a pentad. In the Early and Late runs this period is necessarily trailing, but for the Final we take advantage of the delay in waiting for the gauge analysis and use a centered 45-day period updated once a pentad. The correction is computed and applied on 1° blocks since the 2GPROFGMI and 2BCMB estimates vary significantly by region and time of year.
5. The (climatologically) 2GPROFGMI-calibrated radiometer estimates are calibrated to 2BCMB using the 2GPROFGMI/2BCMB adjustment coefficients.
6. The rain rate in each grid box is the calibrated conical-scan microwave radiometer estimate (i.e., GMI, TMI, SSMI, SSMIS, AMSR-E, AMSR2) contributing during the half hour, or the cross-track microwave sounder estimate (i.e., AMSU-B, MHS, ATMS, SAPHIR) if a conical-scanner isn't available. Most of the time, during the dataset's half-hour window there's only one overpass of whatever the "best" type of sensor is; when more than one of that type is available, the one closest to the center of the period (15 or 45 minutes into the hour) is used. This selection is made because the histogram of rain rates is sensitive to averaging one, two, or three overpasses in a half-hour period.
7. Additional fields in the intermediate data file include the number of pixels, the number of pixels with non-zero rain, the number of pixels for which the estimate is "ambiguous," or highly uncertain, the instrument type producing the estimate, the time of the instrument's overpass, and the probability of liquid precipitation.
8. All of the merged PMW estimates are less accurate, or totally absent, in regions with frozen or icy surfaces.

....

The **Merged 4-Km IR Tb data set** is produced by the Climate Prediction Center (CPC), NOAA National Centers for Environmental Prediction, Washington, DC under the direction of P. Xie. Each cooperating geostationary (geo) satellite operator (the Geosynchronous Operational Environmental Satellites [GOES], United States; the Geosynchronous Meteorological Satellite [GMS], followed by the Multi-functional Transport Satellite [MTSat] and then Himawari, Japan; and the Meteorological Satellite [Meteosat], European Community) forwards infrared (IR) imagery to CPC. Then global geo-IR are zenith-angle corrected (Joyce et al. 2001), re-navigated for parallax, and merged on a global grid. In the event of duplicate data in a grid box, the value with the smaller zenith angle is taken. The data are provided on a 4-km-equivalent latitude/longitude grid over the latitude band 60°N-S, with a total grid size of 9896x3298.

The data set was first produced in late 1999, but the current uniformly processed record is available starting 17 February 2000. CPC is working to extend the record back to January 1998.

All 5 geo-IR satellites are used, with essentially continuous coverage. GMS-5 was replaced by GOES-9 starting 01 UTC 22 May 2003, which introduced slightly different instrument characteristics. Then starting 19 UTC 17 November 2005 the new Japanese MTSat-1R took over, followed by MTSat-2 on 1 July 2010. The next satellite will be Himawari 8, scheduled for 2015. Data from adjacent geo-IR satellites partially fills this shortfall.

Each UTC hour file contains 2 data fields. All geo-IR images with start times within 15 minutes of the UTC hour are accumulated in the "on-hour" field. Images with start times within 15 minutes of the UTC hour plus 30 minutes are accumulated in the "half-hour" field. The nominal image start times for the various satellites and their assignment to half-hour fields are shown in Table 10.

Table 10. Nominal sub-satellite longitude (in degrees longitude) and image start time (in minutes past the hour) for the various geosynchronous satellites. The start times are displayed according to their assignment to either the on-hour or half-hour fields in the CPC Merged 4-Km IR Tb data set. Full-disc views are guaranteed only at 00, 03, ..., 21 UTC. These appear in the on-hour field except MTSat appears in the previous half-hour for all hours. For images not at these times, a satellite's "image" may be assembled from various operator-specified regional sectors. MTSat provides N. Hemisphere sectors (only) on-hour, except S. Hemisphere sectors (only) at 00, 06, 12, 18 UTC.

Satellite	*Sub-sat. Lon.*	*on-hour*	*half-hour*
MTSat-2 (formerly 1R, GMS)	140E	00	30
GOES-E (8, 12, now 13)	75W	45	15
GOES-W (10, 11, now 15)	135W	00	30
Meteosat-9 (formerly 5, 7, 8)	0E	00	30
Meteosat-7 (formerly 5)	63E	00	30

These data are used as input to IMERG processing.
....

The Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks – Cloud Classification System (**PERSIANN-CCS**; Hong et al., 2004) is used to

convert geo-IR Tb to precipitation rates that are merged-PMW-calibrated locally in time and space. The latitude belt 60°N-S is subsetted into 24 overlapping sub-regions (six in longitude by four in latitude) to allow for regional training and parallel processing. For each sub-region, the full-resolution (4-km Merged Global) IR Tb field is segmented into separable cloud patches using a watershed algorithm. Cloud patch features are extracted at three separate temperature levels: 220K, 235K, and 253K, which are chosen to demonstrate the existence of the cloud patches at different altitudes in the atmosphere. An unsupervised clustering analysis (Self-Organizing Feature Map) is used to classify cloud patches into a number of cloud patch groups based on the similarities of patch features. Precipitation is assigned to each classified cloud patch group based on an off-line training set of leo-PMW precipitation samples. These initial precipitation estimates are then adjusted using coefficients based on a two years of accumulated monthly matched HQ leo-PMW precipitation and cloud-patch precipitation. The backlog is sized to ensure sufficient sampling to generate a stable estimate.
....

The **IR precipitation field**, data field IRprecipitation in 3IMERGHH data files, provides a global Level 3 (0.1°x0.1°-gridded) half-hourly IR estimate computed with PERSIANN-CCS. The units are mm/hr.

For the period 1 January 1998 - 03 UTC 16 June 1998 geo-IR data were not available in the Indian Ocean sector, but high-zenith-angle data from adjacent geo-satellites are generally sufficient for fill-in.
....

The **precipitation phase**, namely whether it is liquid, solid, or mixed, is not currently provided as a satellite-based calculation by the standard PMW precipitation algorithms, so we must use ancillary data sets to create the estimate. [Note: the DPR does estimate phase using the radar data.] Formally, there should be separate estimates for each phase. However, mixed-phase cases tend to be a small fraction of all cases, and we consider the estimation schemes to be sufficiently simplistic that estimating mixed phase as a separate class seems unnecessary. Some users need information on the occurrence of the solid phase, both due to the delays it introduces in moving precipitation water mass through hydrological systems, and due to the hazardous surface conditions that snow and ice create. Accordingly, we lump together liquid and mixed as "liquid" and compute a simple probability of liquid phase.

For the half-hourly data, we adopt the Liu scheme (personal communication, 2013), which is under development for the Radiometer Team. The present (experimental) form is a simple look-up table for probability of liquid precipitation as a function of wet-bulb temperature, with separate curves for land and ocean. This is a current area of research, so we anticipate changes as research results are reported. Since this diagnostic is independent of the estimated precipitation, we choose to report the probability of liquid phase for all grid boxes, including those with zero estimated precipitation. The surface temperature, humidity, and pressure information needed to compute the surface wet-bulb temperature are taken from the JMA NWP forecast for the Early and Late runs, and the JMA GANAL reanalysis for the Final run. These forecast and reanalysis fields are retrieved and reformatted by PPS.

GPROF2014 retrieves total hydrometeor mass in the atmospheric column (except the conical-scan imager PMW retrievals only consider total solid hydrometeor mass over land and coast and then implicitly correlate it to surface precipitation in any phase). Given these facts, the "precipitation" reported in this document refers to all forms of precipitation, including rain, drizzle, snow, graupel, and hail. The IR retrievals are calibrated to the passive microwave retrievals, again, without reference to precipitation phase. These IR calibrations are in-filled from surrounding areas in the snowy/icy-surface areas where PMW cannot provide estimates.

At the monthly scale the probability could either be the fraction of the time that the precipitation is liquid or the fraction of the monthly accumulation that fell as liquid. The latter seems to be what most users will want, so this is the parameter computed. The monthly probability of liquid is the precipitation-rate-weighted average of all half-hourly probabilities in the month, except for grid boxes where zero precipitation is estimated for the month, in which case it is the simple average of all available probabilities in the month.
....

The **probability of liquid phase precipitation field**, data field probabilityLiquidPrecipitation, provides a global Level 3 (0.1°x0.1°-gridded) half-hourly estimate in 3IMERGHH data files based on the implementation of the Liu wet-bulb temperature diagnostic discussed in "precipitation phase". For the 3IMERGM data files, this field provides the precipitation-rate-weighted average of all half-hourly probabilities in the month, except for grid boxes where zero precipitation is estimated for the month, in which case it is the simple average of all available probabilities in the month. See "precipitation phase" for more discussion of the monthly fields. In both cases, the field is globally complete as long as the input ancillary forecast/reanalysis data are complete.
....

Under the **Kalman Smoother framework** as developed in CMORPH-KF and applied here, the precipitation analysis for a grid box is defined in three steps (Joyce et al. 2011). First, the half-hourly PMW precipitation estimates closest to the target analysis time in both the forward and backward directions are propagated from their observation times to the analysis time using the cloud motion vectors computed from the geo-IR images (see next paragraph). The "prediction" of the precipitation analysis is then defined by compositing the forward- and backward-propagated PMW estimates with weights inversely proportional to their error variance. If the gap between the two PMW observations is longer than 90 minutes, the final "analysis" is defined by updating the forecast with IR-based precipitation observations with weights inversely proportional to the observation error variance. This 90-minute threshold is due both to the natural timescale of precipitation at these fine scales and to the retrieval errors in the microwave algorithms.

The cloud motion vectors used to propagate the PMW estimates are calculated by computing the pattern correlation between spatially lagged geo-IR Tb arrays from two consecutive images. The spatial displacement with the highest correlation is used to define the cloud motion vector. The cloud motion vectors are defined for each 2.5° lat/lon grid box using IR data over a 5° lat/lon domain centered on the target grid box. Over mid-latitudes, precipitation systems present slightly different movements than the cloud systems that we are tracing with the geo-IR Tb. To account for the differences, the PDFs of the zonal and meridional components of the cloud motion vectors were compared against those of the precipitation systems observed by the Stage II radar over the contiguous U.S. (CONUS). A static correction table was then established for adjusting the geo-IR-based cloud motion vectors in both hemispheres' mid-latitudes to better represent precipitation motion. Interpolation in time, and then space is used to provide spatially complete propagation fields.

Errors for the individual satellite estimates are calculated by comparison against TMI/GMI estimates in the TMI/GMI eras, with all imagers lumped into one correlation table and all sounders lumped into another. Because of the simple form used (see following), the error table for the TMI is the lumped imager table in the TRMM era. During the GPM era, the TMI is treated as "just" another imager and included in computing the lumped imager error table (against GMI), and the lumped imager error table is taken as representative of GMI. Expressed in the form of correlation, the errors for the propagated PMW estimates are defined as regionally dependent and seasonally changing functions of sensor type (imager, sounder, IR) and the length of propagation time. Over land, the error functions are computed for each 10° latitude band using data collected over a 30°-wide latitude band centered on the target band. No zonal differences in the error are considered due to the limited sampling of the data. Over ocean, the error functions are defined for each 20°x20° lat/lon box using data over a 40°x40° lat/lon region centered on the target box. Over both land and ocean, the error functions are calculated for each month using data over a three-month period, trailing for Early and Late, and centered on the target month for Final, to account for the seasonal variations. The comparisons against TMI/GMI are updated monthly.

These data are computed as part of IMERG processing.
....

The **Kalman filter weight for IR field**, data field IRkalmanFilterWeight in 3IMERGHH data files, provides a global Level 3 (0.1°x0.1°-gridded) half-hourly listing of the weight (in percent) that the IR data get in the Kalman filter step described in "Kalman Smoother framework".
....

The monthly satellite-gauge, or **SG combination**, is computed as follows, following the TMPA approach for infusing monthly gauge information into the fine-scale precipitation estimates (Huffman et al. 2007a, 2007b, 2010):

1. The original (i.e., before the scaling step) half-hourly morphed and KF-filtered estimates are summed for the calendar month.
2. The monthly precipitation gauge analysis is used to create a large-scale (31x31 0.1° grid boxes) bias adjustment to these satellite-only estimates in regions where the gauge stations are available, mostly land. Note that analysis values distant from any gauges are not used.
3. The monthly gauge-adjusted satellite-only estimate is combined directly with the precipitation gauge analysis using inverse error variance weighting.

The monthly random error is also computed at this point as a separate field following Huffman (1997). See "random error" for a summary.

These data are computed in the Final run alone.
....

IMERG ends with a **final post-processing** that introduces gauge information into the half-hourly files. In the case of the Early and Late runs, a climatological calibration is performed using monthly climatological maps of calibration that are computed off-line. The climatological calibration is intended to make the real-time products as consistent as possible with the Final product. One important simplification compared to the TMPA is that both the DPR and 2BCMB are computed in real time for GPM. This contrasts to the situation in TRMM where the PR and TCI were not computed in real time and we have had to substitute TMI as the RT calibrator. Accordingly, in GPM only a straightforward calibration to the Final product will be computed with a climatological 2BCMB calibration.

For the Final run, the field of ratios between the monthly accumulation of uncalibrated multi-satellite data and the monthly satellite-gauge field is computed, then each half-hourly field of uncalibrated precipitation estimates in the month is multiplied by the ratio field to create the final calibrated IMERG precipitation estimates.

The half-hourly random error is also computed at this point as a separate field following Huffman (1997). See “random error” for a summary.
....

The **uncalibrated precipitation field**, data field precipitationUncal, provides a global Level 3 (0.1°x0.1°-gridded) half-hourly listing in 3IMERGHH data files of the morphed and KF-combined estimates computed in the Kalman filter step described in “Kalman Smoother framework”, which is recorded before the “final post-processing” step. For the Early and Late Runs, this means the climatological calibrations have not yet been applied, while for the Final Run it is the ratio field for the month. In 3IMERGM data files it provides the global Level 3 (0.1°x0.1°-gridded) monthly accumulation of uncalibrated 3IMERGHH data described in “final post-processing”.
....

The **calibrated precipitation field**, data field precipitationCal, provides global Level 3 (0.1°x0.1°-gridded) half-hourly listing in 3IMERGHH data files of the calibrated data described in “final post-processing”. In 3IMERGM data files it provides the global Level 3 (0.1°x0.1°-gridded) monthly SG combination data described in “SG combination”.
....

The **units of the IMERG estimates** are listed in the tables in “*3IMERGHH data fields*” and “*3IMERGM data fields*”. Recall that the half-hourly data are best thought of as snapshots, valid during the stated half hour, since Villarini and Krajewski (2007) showed that the (snapshot-based) TRMM 3B42 is best correlated with radar data averaged over 60-90 minutes, not always centered on the nominal overpass time. The monthly values are averages over the month, although the probability of liquid precipitation phase is weighted by the precipitation rate accompanying each half hour’s probability.

....

7. Error Detection and Correction

Even before launch GPM instituted the GPM Working Group (*X-Cal Working Group*), which was charged with developing a consistent "Level 1C" calibration of all constellation radiometers to the GMI. Their work identified a range of problems and developed very careful radiometric calibrations for use in GPM (and the community at large). See PPS et al. (2010) for details.
....

DPR and PR error detection/correction has several parts. The performance of the various radar components, including transmit power and Low Noise Amplifiers, are monitored. An active ground calibration target is episodically viewed, and surface Zo is routinely monitored. See *http://pps.gsfc.nasa.gov/tsdis/Documents/PR_Manual_JAXA_V6.pdf* for more information about PR.

Accuracies in the radar data are within the uncertainties of the precipitation estimation techniques.

The satellite altitude change in August 2001 introduced some changes in detectability for which the algorithms are supposed to approximately account. The TRMM PR electronics failure on 29 May 2009 resulted in a switch to the "B-side" electronics. Some residual differences are noticeable despite careful work to harmonize the record.
....

GMI, TMI, and constellation sensor error detection/correction has several parts. The SSMI is typical: built-in hot- and cold-load calibration checks are used to convert counts to antenna temperature (Ta). An algorithm has been developed to convert Ta to brightness temperature (Tb) for the various channels (eliminating cross-channel leakage). Differences between the Ta-to-Tb conversions employed by the various data providers imply that uncertainties in the Ta-to-Tb conversion are much larger than any other known uncertainty. Consequently, GPM developed the concept of a Level 1C, which applies radiometric corrections for all constellation sensors to GMI. See "X-Cal Working Group" for more information on this intercalibration.

Accuracies in the Tb's are within the uncertainties of the precipitation estimation techniques.

Among the sensor groups, the NOAA-17 50-GHz channel failed, decreasing the accuracy of its retrievals. More generally, trending data are tracked for individual satellites, particularly near their end of life to determine whether sensor degradation is introducing unacceptable error.

GPM, TRMM, and Megha-Tropiques are designed to precess over 83-, 46-, and 51-day periods, respectively. There is no direct effect on the accuracy of their sensor data, but the continually changing diurnal sampling causes significant systematic fluctuations in the resulting GMI-, TMI-, and SAPHIR-only precipitation estimates.

Some constellation satellites experienced significant drifting of their (nominally) sun-synchronous overpass time during their period of service (see *http://precip.gsfc.nasa.gov /times_allsat.jpg* for a current time-series plot). There is no direct effect on the accuracy of the precipitation estimates, but it is possible that the systematic change in sampling time could introduce subtle shifts in the resulting collection of precipitation estimates.

One important test for artifacts is screening the data for "excessive" numbers of "ambiguous pixels"; see that topic for an explanation.

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In common with some other microwave algorithms, GPROF flags pixels with certain ranges of Tb values as **ambiguous pixels** because such ranges are associated with both real precipitation and artifacts, compared to coincident weather observations. In this approach, the algorithm makes an estimate, but flags it as a possible artifact. GPROF leaves it to the user to evaluate such pixels for use or deletion. Experience shows that if an artifact due to surface effects <u>is</u> responsible, it tends to trigger ambiguous values in the same place repeatedly, and one can capture this by seeing how many of the pixels in the area are flagged. The threshold of "too many" ambiguous pixels is somewhat subjectively chosen to balance dropping good data and including artifacts. In the TMPA the ambiguous pixels are handled as follows:

1. In the HQ, preliminary results indicate that when the fraction of ambiguous (FA) exceeds 40% for a 3x3-grid box average or the 13x13-grid box average FA exceeds 0.5%, the precipitation value is likely an artifact. Currently all GPROF2014 estimates have ambiguous flagging disabled, so it is likely the above screening scheme will be modified when screening is re-enabled.
2. In the combination of HQ and PERSIANN-CCS, the HQ values previously judged to be suspect are set to missing before combination with PERSIANN-CCS.

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The dominant **IR data correction** is for slanted paths through the atmosphere. Referred to as "limb darkening correction" in polar-orbit data, or "zenith-angle correction" (Joyce et al. 2001) in geosynchronous-orbit data, this correction accounts for the fact that a slanted path through the atmosphere increases the chances that (cold) cloud sides will be viewed, rather than (warm) surface, and raises the altitude dominating the atmospheric emission signal (almost always lowering the equivalent Tb). The slant path also creates an offset to the geolocation of the IR pixel due to parallax. That is, the elevated cloud top, viewed from an angle, is located closer to the satellite than where the line of sight intersects the Earth's surface. Pixels are moved according to a standard height-Tb-zenith angle profile, at the price of holes created when tall clouds are moved farther than shallow clouds behind them. In addition, the various sensors have a variety of sensitivities to the IR spectrum, usually including the 10-11 micron band. Inter-satellite calibration is computed with GOES-E as the standard. The satellite operators are responsible for detecting and eliminating navigation and telemetry errors.

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A number of **known errors and anomalies** are contained in part or all of the current IMERG archive. They have been uncovered by visual inspection and other diagnostics. In some cases correction will be applied in the next reprocessing, while for others no satisfactory correction is possible. Other items will be included in future re-processing cycles as possible. For ease of document maintenance, some of the following items imply the known error by stating what upgrade was applied.

General

1. In general, GPROF2014 has excessive coverage by light precipitation, even considering that the estimates are made on the scale of the ~23 GHz channel, yet at the monthly scale the correct accumulation appears to be given by including this unrealistic drizzle. At present IMERG performs thresholding at 0.1 mm/hr on individual footprints, then rescales the data to approximate the monthly accumulation. In most locations this rescale is a small change from the original values.
2. GPROF2014 estimates have a variety of artifacts associated with coastal regions that are sensor- and scene-dependent. For conical-scan imagers, inland water bodies in the Southeastern U.S. (Tian and Peters-Lidard 2007), Lake Nasser in Egypt, and desert coastal regions show anomalous high precipitation, while oceanic coastal regions in a variety of rainy situations tend to be deficient in precipitation. For cross-track sounders the land/water interface in coasts provokes high estimates in the Day-1 version, although this is largely controlled inside the algorithm itself.
3. The current satellite-gauge combination scheme allows coastal gauge data to "bleed" into coastal waters, up to 1° away from the coast. This is particularly noticeable where there is heavy precipitation in the gauge analysis, but modest values off-shore.
4. The Day-1 GPROF retrievals, and the subsequent IMERG calibrations for them, are not entirely consistent between sensors. Accordingly, users will observe "flashing" in the precipitation fields as successive overpasses in a particular location are populated by different sensors.
5. The IR estimates sometimes exhibit "flashing" because successive images in a given region are successively populated with data from different geo-IR satellites, usually with one having a near-nadir view, but then dropping out and being replaced by high-zenith-angle data from an adjacent geo-IRsatellite.
6. The mix of satellites has changed over time, which affects the overall performance of the algorithm in two ways. First, the relative weighting of conical-scan imagers versus cross-track sounders shifts, and second, the relative proportion of IR-based estimates changes. The PMW sensor inventory is shown in "sensors contributing to IMERG". See Behrangi et al. (2014) for more discussion of sensor performance for legacy algorithms.

Specific

7. For the period 1 January 1998 - 03 UTC 16 June 1998 there were no geo-IR data available in the Indian Ocean Sector. High-zenith-angle observations from adjacent satellites are used for fill-in as available.
8. GMS data are missing for 21 UTC 4 January 1998 – 21 UTC 8 January 1998. Since the Meteosat data over the Indian Ocean sector do not begin until mid-1998, this results in a lack of IR data over the East Asia sector.
9. The TRMM orbital altitude was raised from 350 to 401.5 km in August 2001 to extend the life of the mission by reducing the amount of fuel needed to maintain the orbit. This caused small changes in footprint size and minimum detectable precipitation rates. The

GPROF2014 algorithm is supposed to account for these changes, but tests show small unavoidable differences that are still being researched.

10. The TRMM PR suffered an electronics failure on 29 May 2009. Data were lost until the "B-side" electronics were activated on 19 June 2009. Small residual differences remain between A-side and B-side data.
11. At 2045 UTC on 21 March 2012 GOES-15 (WEST) suffered a "bad momentum unload" and ceased recording data. Imaging was restored at 1722 UTC on 23 March 2012. In the interim GOES-13 (EAST) was shifted to recording full-disk images. Use of higher-zenith-angle GOES-13 and MTSat-1 data largely covers the gap caused by the GOES-15 drop-outs.
12. In previous versions, and not yet checked for GPROF2014, F17 SSMIS has anomalously high precip values for a few scans over Brazil in the 21Z 26 April 2013 3B42 HQ and multi-satellite precip fields.
13. A TRMM spacecraft anomaly resulted in the loss of most TRMM sensor data for the period 02-14 UTC on 12 November 2013, and additional issues resulted in data gaps during the period 20-23:30 UTC. This reduces the data content in IMERG somewhat, but is not a serious issue overall.
14. Snow accumulation on the receiving antenna prevented reception of MTSAT-2 data from 1832 UTC on 14 February 2014 to 1232 UTC on 15 February 2014. The data were lost.
15. Metop-A experienced an anomaly that prevented data collection for 1400 UTC 27 March 2014–0746 UTC 21 May 2014.
16. The GMI instrument on the GPM Core Observatory went into safe mode on 22 October 2014. It was returned to operations on 24 October 2014 after determining that the cause was a faulty thermistor that provides information on the GMI's environment, but is not critical to its operation. Subsequently, non-critical thermistors have been removed from the Core Observatory's spacecraft health and safety alarm conditions.

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8. Missing Value Estimation and Codes

There is generally no effort to *estimate missing values* in the single-source input data sets.

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All products in IMERG use the *standard missing value* "-9999.9" or "-9999" for 4-byte floats or 2-byte integers, respectively. These values are carried in the metadata.

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All *completely missing fields* of a product result from completely absent input data for the given time. If the input file(s) is(are) available, the product file is created, even if it lacks any valid data.

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9. Quality and Confidence Estimates

The *accuracy* of the precipitation products can be broken into systematic departures from the true answer (bias) and random fluctuations about the true answer (sampling), as discussed in Huffman (1997). The former are the biggest problem for climatological averages, since they will not average out. However, for short averaging periods the low number of samples and/or algorithmic inaccuracies tend to present a more serious problem for individual microwave data sets. That is, the sampling is spotty enough that the collection of values over, say, one day may not be representative of the true distribution of precipitation over the day. For the IR estimates, the sampling is good, but the algorithm likely has substantial RMS error due to the weak physical connection between IR Tb's and precipitation.

Accordingly, the "random error" is assumed to be dominant, and estimates could be computed as discussed in Huffman (1997). Random error cannot be corrected.

The "bias error" is likely smaller, or at least contained. This is less true over land, where the lower-frequency microwave channels are not useful for precipitation estimation with our current state of knowledge. The state of the art at the monthly scale is reflected in the study by Smith et al. (2006) and Adler et al. (2012). One study of the sub-monthly bias is provided by Tian et al. (2009).
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The IMERG **intercomparison results** are just starting to be developed. The time series of the global images shows good continuity in time and space. Overall, the analysis approach appears to be working as expected. Some preliminary results are discussed in the release notes document, available at *http://pmm.nasa.gov/sites/default/files/document_files/IMERG_FinalRun_Day1_release_notes.pdf* .

Some validation studies will be conducted under the auspices of the International Precipitation Working Group (IPWG) in Australia, the continental U.S., western Europe, parts of South America, and Japan (Ebert et al. 2007). Respectively, the web sites for these activities are:

http://cawcr.gov.au/projects/SatRainVal/validation-intercomparison.html
http://cics.umd.edu/ipwg/us_web.html
http://meso-a.gsfc.nasa.gov/ipwg/ipwgeu_home.html
http://cics.umd.edu/~dvila/web/SatRainVal/dailyval.html (currently inactive)
http://www-ipwg.kugi.kyoto-u.ac.jp/IPWG/sat_val_Japan.html
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The **diurnal cycle** depicted in IMERG is affected by the particular mix of satellite sensors at any given time and place, in common with all other such satellite-based precipitation estimation systems. The diurnal cycle phase produced by IR estimates, which respond to cloud tops, is known to lag the phase of surface observations in many locations. The lag is highly variable, but frequently reported as up to 3 hours. The passive microwave estimates over land depend on the solid hydrometeors, which typically are confined to the upper reaches of clouds. This dependence also leads to lags compared to surface observations, up to about 1.5 hours. Over ocean the passive microwave estimates are driven by the full vertical profile of precipitation for imagers, but primarily by solid hydrometeors for sounders. Thus, there is a mix of typical lags, minimal for imagers and up to 1.5 hours for sounders. When you consider the regional variability in the lags of the individual sensor types and the variable mix of sensors contributing to the diurnal cycle during different epochs of satellite coverage, the general statement is that lags are more likely early in the dataset, before many passive microwave satellites were available, and are more likely over land. The GPM DPR and TRMM PR, being radars, give relatively unbiased estimates of the diurnal cycle, but their sampling is so sparse that it takes several years of data to allow a reasonable estimate to appear out of the sampling noise. See Kikuchi and Wang (2008), although their study with Version 6 TMPA has larger lags due to concentrating early in the record and having fewer passive microwave satellites than Version 7 TMPA has for the bulk of their study period

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Research shows **interannual differences driven by data set calibrators** in various legacy datasets, and the same should be true for IMERG. That is, all of the global precipitation data sets have some calibrating data source, which is necessary to control bias differences between contributing satellites. Otherwise, shifts in the contributing set of satellites at any given time can cause unphysical shifts in the behavior of the precipitation estimates. However, this calibration plays a large role in determining the interannual variation that the various data sets display. This is a current area of research. At present, it appears that a calibrator that depends on PR, even in part, tends to have a smaller interannual variation, and to have peaks and valleys that occur a couple of months sooner than data sets whose calibrator is computed from PMW data. This result is somewhat insensitive to the source and algorithm of the PMW data.

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10. Documentation

The **documentation creator** is:

Dr. George J. Huffman
Code 612
NASA Goddard Space Flight Center
Greenbelt, MD 20771 USA
Phone: +1-301-614-6308
Fax: +1-301-614-5492
Internet: *george.j.huffman@nasa.gov*
MAPL Precipitation Page: *http://precip.gsfc.nasa.gov/*

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Documentation revision history:

4 December 2014	Version 1	by GJH, DTB, EJN
15 January 2015	Version 1.1	by GJH, DTB, EJN; revisions for first Final Run release
20 January 2015	Version 1.2	by GJH; re-release due to “missing” definition
9 April 2015	Version 1.3	by GJH; more-uniform reference to Runs; retrospective processing in 2017; end of TRMM
19 June 2015	Version 1.4	by DTB; reading HDF5 using the R language

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Web resources:

2BCMB ATBD: *http://pmm.nasa.gov/sites/default/files/document_files/Combined_algorithm_ATBD.EnKF_.pdf*

AMS data citation policy: *http://www2.ametsoc.org/ams/index.cfm/publications/authors/journal-and-bams-authors/journal-and-bams-authors-guide/data-archiving-and-citation/*
AMSR-E instrument: *http://www.ghcc.msfc.nasa.gov/AMSR/*
AMSR2 instrument: *http://suzaku.eorc.jaxa.jp/GCOM_W/w_amsr2/whats_amsr2.html*
AMSU-B instrument: *http://www2.ncdc.noaa.gov/docs/klm/html/c3/sec3-4.htm* in the NOAA KLM User's Guide (September 2000 revision): *http://www2.ncdc.noaa.gov/docs/klm/index.htm*
ATMS: *http://mirs.nesdis.noaa.gov/snppatms.php*
FAQ: *http://disc.sci.gsfc.nasa.gov/additional/faq/precipitation_faq.shtml*
Giovanni: *http://giovanni.gsfc.nasa.gov/*
GMI channel and Level 1B processing: *http://pmm.nasa.gov/sites/default/files/document_files/GMIL1B_ATBD.pdf*
GMI scanning basics: *http://mirs.nesdis.noaa.gov/gpmgmi.php*
GPM data access: *http://pmm.nasa.gov/data-access/downloads/gpm*
GPM data file naming: *http://pps.gsfc.nasa.gov/Documents/FileNamingConventionForPrecipitationProductsForGPMMissionV1.4.pdf*
GPM home: *http://gpm.gsfc.nasa.gov/*
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IMERG ATBD: *http://pmm.nasa.gov/sites/default/files/document_files/IMERG_ATBD_V4.4.pdf*
IMERG HDF5 file layout: *ftp://gpmweb2.pps.eosdis.nasa.gov/pub/GPMfilespec/filespec.GPM.V1.pdf*
IMERG HDF5 metadata: *ftp://gpmweb2.pps.eosdis.nasa.gov/pub/GPMfilespec/filespecMeta.GPM.V1.pdf*
IPWG data set tables: *http://www.isac.cnr.it/~ipwg/data/datasets.html*
IPWG Validation for Australia: http://cawcr.gov.au/projects/SatRainVal/validation-intercomparison.html
IPWG Validation for U.S.: http://cics.umd.edu/ipwg/us_web.html
IPWG Validation for western Europe: http://meso-a.gsfc.nasa.gov/ipwg/ipwgeu_home.html
IPWG Validation for South America: http://cics.umd.edu/~dvila/web/SatRainVal/dailyval.html (inactive)
IPWG Validation for Japan: http://www-ipwg.kugi.kyoto-u.ac.jp/IPWG/sat_val_Japan.html
MAPL Precipitation Page: *http://precip.gsfc.nasa.gov/*
MHS instrument: *http://www2.ncdc.noaa.gov/docs/klm/html/c3/sec3-9.htm* in the NOAA KLM User's Guide (September 2000 revision): *http://www2.ncdc.noaa.gov/docs/klm/index.htm*
PPS home: *http://pps.gsfc.nasa.gov*
PR Manual: *http://pps.gsfc.nasa.gov/tsdis/Documents/PR_Manual_JAXA_V6.pdf*
Release notes for Final Run: *http://pmm.nasa.gov/sites/default/files/document_files/IMERG_LateRun_Day1_release_notes.pdf*
Release notes for Late Run: *http://pmm.nasa.gov/sites/default/files/document_files/IMERG_FinalRun_Day1_release_notes.pdf*
SAPHIR: *http://meghatropiques.ipsl.polytechnique.fr/instruments.html*
Satellite overpass times graphic: *http://precip.gsfc.nasa.gov/times_allsat.jpg*
SSMIS description: *http://nsidc.org/data/docs/daac/ssmis_instrument/*
THOR download site: *http://pmm.nasa.gov/node/1189*

TRMM home page: *http://pmm.nasa.gov/TRMM/*

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**Acronyms*:*

2BCMB	GPM Combined Instrument data set
2B31	TRMM Combined Instrument data set
2GPROFGMI	GPM GPROF2014 precipitation estimates using GMI
3B42	production 3-hourly TMPA data set
3B42RT	real-time 3-hourly TMPA data set
3B43	production monthly TMPA data set
3IMERGHH	half-hourly GPM IMERG data set
3IMERGM	monthly GPM IMERG data set
ASCII	American Standard Code for Information Interchange (i.e., text)
AIRS	Atmospheric Infrared Sounder
AMSR2	Advanced Microwave Scanning Radiometer model 2
AMSR-E	Advanced Microwave Scanning Radiometer for Earth Observing System
AMSU	Advanced Microwave Sounding Unit
Aqua	satellite
ATBD	Algorithm Theoretical Basis Document
ATMS	Advanced Technology Microwave Sounder
C	programming language
CEOS	Committee on Earth Observation Satellites
CMORPH	CPC MORPHing algorithm
CMORPH-KF	Kalman Filter version of CMORPH
CNES	Centre National d'Etudes Spatiales
CONUS	Contiguous U.S.
CPC	Climate Prediction Center
CrIS	Cross-track Infrared Sounder
dBZ	decibels of reflectivity factor
DMSP	Defense Meteorological Satellite Program
DOI	Digital Object Identifier
DWD	Deutscher Wetterdienst
DPR	(GPM) Dual-frequency Precipitation Radar
ESSIC	(University of Maryland College Park) Earth System Science Interdisciplinary Center
EUMETSAT	EUropean organization for the exploitation of Meteorological Satellites
FAQ	Frequently Asked Questions
FORTRAN	programming language
FTP	File Transfer Protocol
GANAL	Global Analysis
GeoTIFF	Georeferenced Tagged Image File Format
GES DISC	Goddard Earth Sciences Data and Information Services Center
GHz	Gigahertz
GIOVANNI	Geospatial Interactive Online Visualization ANd aNalysis Infrastructure
GIS	Geographical Information System
GMI	GPM Microwave Imager

GMS	Geosynchronous Meteorological Satellite
GOES	Geosynchronous Operational Environmental Satellites
GPCC	Global Precipitation Climatology Centre
GPM	Global Precipitation Measurement mission
GPROF	Goddard Profiling algorithm
GSFC	Goddard Space Flight Center
GSMaP	Global Satellite Map of Precipitation
GTS	Global Telecommunications System
GV	Ground Validation
HDF	Hierarchical Data Format
HOAPS	Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite data set
HQ	High Quality (microwave precipitation)
ICARE	Interactions Clouds Aerosols Radiations Etc. (or in more exact English, Cloud-Aerosol-Water-Radiation Interactions)
IDL	Interactive Data Language
IEEE	Institute of Electrical and Electronics Engineers
IMERG	Integrated Multi-satellitE Retrievals for GPM
IPWG	International Precipitation Working Group
IR	Infrared
ISRO	Indian Space Research Organisation
JAXA	Japan Aerospace Exploration Agency
JMA	Japan Meteorological Agency
Ka	microwave band; 26.5–40 GHz
KF	Kalman Filter
Ku	microwave band; 12–18 GHz
lat/lon	latitude/longitude
leo	Low Earth orbit
MAPL	Mesoscale Atmospheric Processes Laboratory
MB	megabytes
Meteosat	Meteorological Satellite
MetOp	Operational Meteorological satellite
MHS	Microwave Humidity Sounder
MOSDAC	Meteorological and Oceanographic Satellite Data Archival Centre
MRMS	Multi-Radar Multi-Sensor
MSU	Microwave Sounding Unit
MTSat	Multifunctional Transport Satellite
NASA	National Aeronautics and Space Administration
NESDIS	National Environmental Satellite Data and Information Service
NRL/FNMOC	Naval Research Laboratory / Fleet Numerical Meteorological and Oceanographic Center
NOAA	National Oceanic and Atmospheric Administration; also a leo-satellite series
NWP	Numerical Weather Prediction
NWS	National Weather Service
PDF	Probability Density Function
PERSIANN	Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks

PERSIANN-CCS	
	PERSIANN with Cloud Classification System
PMM	Precipitation Measurement Missions
PMW	Passive Microwave
PPS	Precipitation Processing System
PR	(TRMM) Precipitation Radar
RMS	Root Mean Square
SAPHIR	Sounder for Atmospheric Profiling of Humidity in the Intertropics by Radiometry
SG	Satellite-Gauge combined data set
SNPP	Suomi National Polar Partnership satellite
SSMI	Special Sensor Microwave/Imager
SSMIS	Special Sensor Microwave Imager-Sounder
SSM/T2	Special Sensor Microwave/Temperature 2
Ta	Antenna Temperature
Tb	Brightness Temperature
TCI	TRMM Combined Instrument algorithm (2B31)
THOR	Tool for High-resolution Observation Review
TMI	TRMM Microwave Imager
TMPA	TRMM Multi-satellite Precipitation Algorithm
TMPA-RT	Real-Time TMPA
TRMM	Tropical Rainfall Measuring Mission
UTC	Universal Coordinated Time (same as GMT, Z)
V7	Version 7
WMS	Web Map Service
X-Cal	Intersatellite Calibration (working group)
Zo	Surface reflectivity

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A **Frequently Asked Questions (FAQ)** list is being assembled and maintained by the Goddard Earth Science Data and Information Services Center (GESDISC). It is posted at:

http://disc.sci.gsfc.nasa.gov/additional/faq/precipitation_faq.shtml.

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The **GPM data access pages** provide a one-stop shop for data and documentation:

http://pmm.nasa.gov/data-access/downloads/gpm

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