Precipitation Processing System (PPS)

Introduction to GPM Data Products

Version 1.1

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1. INTRODUCTION

This guide is intended to introduce graduate students and researchers to the data products of NASA's Global Precipitation Measurement (GPM) mission. The GPM core satellite has been in Earth orbit since 2014. Some GPM data products are available for observations made before the launch of the core satellite, using other satellites for periods beginning in the 1990s (e.g., passive microwave data products) or in 2000 (i.e., the IMERG data product).

This guide describes the purpose, caveats, and limitations of GPM data products in order to assist new users in selecting a data product that meets their needs. For example, if one is interested in precipitation at the Earth's surface (not 3D precipitation) and one requires uniform coverage in space and time, then the best data product may be IMERG. IMERG is described in Section 12 of the present document. If one needs high-resolution 3D precipitation estimates and one can tolerate a revisit time of several days for a particular location, then one may prefer the 2ADPR data product. 2ADPR is described in Section 5.

The data-product descriptions in the present document are summaries of information in the PPS file-specification document and various Algorithm Theoretical Basis Documents (ATBDs). Figure 1 shows the dependency of the data products for the GPM core satellite. A dependency means that a data product is an input for generating another data product.

While Figure 1 shows data products specifically for the GPM core satellite, PPS also generates some of these data products for other satellites. For example, PPS generated and distributes data products for the GPM core satellite's predecessor, the Tropical Rainfall Measuring Mission (TRMM) satellite. PPS also produces data products for a constellation of polar-orbiting satellites. For the constellation satellites that carry passive microwave radiometers or imagers, PPS generates data products analogous to the GMI 1C, 2AGPROF, and 3GPROF data products shown in Figure 1. PPS also generates value-added products that are derived from the GPM products described here. For example, PPS generates 3-hour to 7-day IMERG accumulations that are written in the GeoTIFF file format for display in Geographic Information Systems (GIS).

The level of a product indicates the degree to which the data have been processed. Some Level 1 products contain instrument-independent physical variables such as radar reflectivity or microwave brightness temperature in the original observation geometry of the instrument (i.e., the satellite's data swath). Other Level 1 products contain engineering variables, such as radar returned power, that are instrument dependent. Level 2 products have been further processed so that they contain geophysical variables such as precipitation rate. Generally, Level 2 products have the same observation geometry as the corresponding Level 1 product. Level 3 products contain time-averaged and space-averaged data, such as monthly average precipitation rate in a rectangular latitude/longitude grid.

For Level 1 and some Level 2 products, the designation A, B, or C expresses the product's position in the sequence of products generated at Level 1: e.g., 1AGMI, 1BGMI, or 1CGMI. For some Level 2 products, an A means that the product contains data from one instrument (e.g., 2AKu, 2AKa, and 2ADPR) while a B indicates that the product is generated with input from multiple instruments (e.g., DPR and GMI for 2BCMB).

Data products described in the present document may be downloaded from the PPS STORM data-ordering system (https://storm.pps.eosdis.nasa.gov/) and from the PPS online archive (https://arthurhouhttps.pps.eosdis.nasa.gov/ and https://jsimpsonhttps.pps.eosdis.nasa.gov/). Before using either of these download methods, register your email address with PPS (https://registration.pps.eosdis.nasa.gov). GPM data products may also be downloaded from the Goddard Earth Sciences Data and Information Services Center (GES DISC), formerly known as the Goddard DAAC (https://disc.gsfc.nasa.gov/).

Most GPM products are written in the HDF5 format. Researchers may read these products with any software that can read HDF5, including Python, Matlab, IDL, C, and FORTRAN. PPS also distributes and maintains the Orbit Viewer THOR application, which is a desktop application to interactively visualize PPS-generated HDF5 files.

Some aspects of the data products are not described in the present document in order to keep it concise. For example, visit the PPS web site (https://arthurhou.pps.eosdis.nasa.gov/) for information about distinguishing between near real-time versions and research-quality versions of these data products. A separate consideration is that every few years, PPS reprocesses GPM observations with upgraded science algorithms. In general, researchers should use the most recent version of any data product. For additional information, please consult the following list of online resources. Alternatively send questions to the PPS Helpdesk (helpdesk@mail.pps.eosdis.nasa.gov) or to the contact form on the GPM science-team web site (https://gpm.nasa.gov/contact).

The PPS web site, https://arthurhou.pps.eosdis.nasa.gov/ formerly https://pps.gsfc.nasa.gov/.

PPS STORM User Guide, https://storm.pps.eosdis.nasa.gov/storm/STORMUserGuide.pdf.

Algorithm Theoretical Basis Document (ATBD) for the PPS Toolkit and various algorithms, https://arthurhou.eosdis.nasa.gov/.

Hou, A. Y., R. K. Kakar, S. Neeck, A. Azarbarzin, C. D. Kummerow, M. Kojima, R. Oki, K. Nakamura, and T. Iguchi, 2014: The Global Precipitation Measurement (GPM) mission. *Bulletin of the American Meteorological Society*, **95**, 701–722, https://doi.org/10.1175/BAMS-D-13-00164.1.

Kelley, O. A., 2022: The IMERG multi-satellite precipitation estimates reformatted as 2-byte TIFF files for display in Geographic Information Systems (GIS), https://arthurhou.pps.eosdis.nasa.gov/Documents/README.GIS.pdf.

Kelley, O. A., 2021: *The Orbit Viewer THOR Tutorial*. https://gpmweb2https.pps.eosdis.nasa.gov/pub/THOR/version_2.2/tutorial.pdf.

Kummerow, C., W. Barnes, T. Kozu, J. Shue, and J. Simpson, 1998: The Tropical Rainfall Measuring Mission. *J. Atmospheric and Oceanic Technology*, **15**, 809–817.

PPS File Specification, https://arthurhou.eosdis.nasa.gov/.

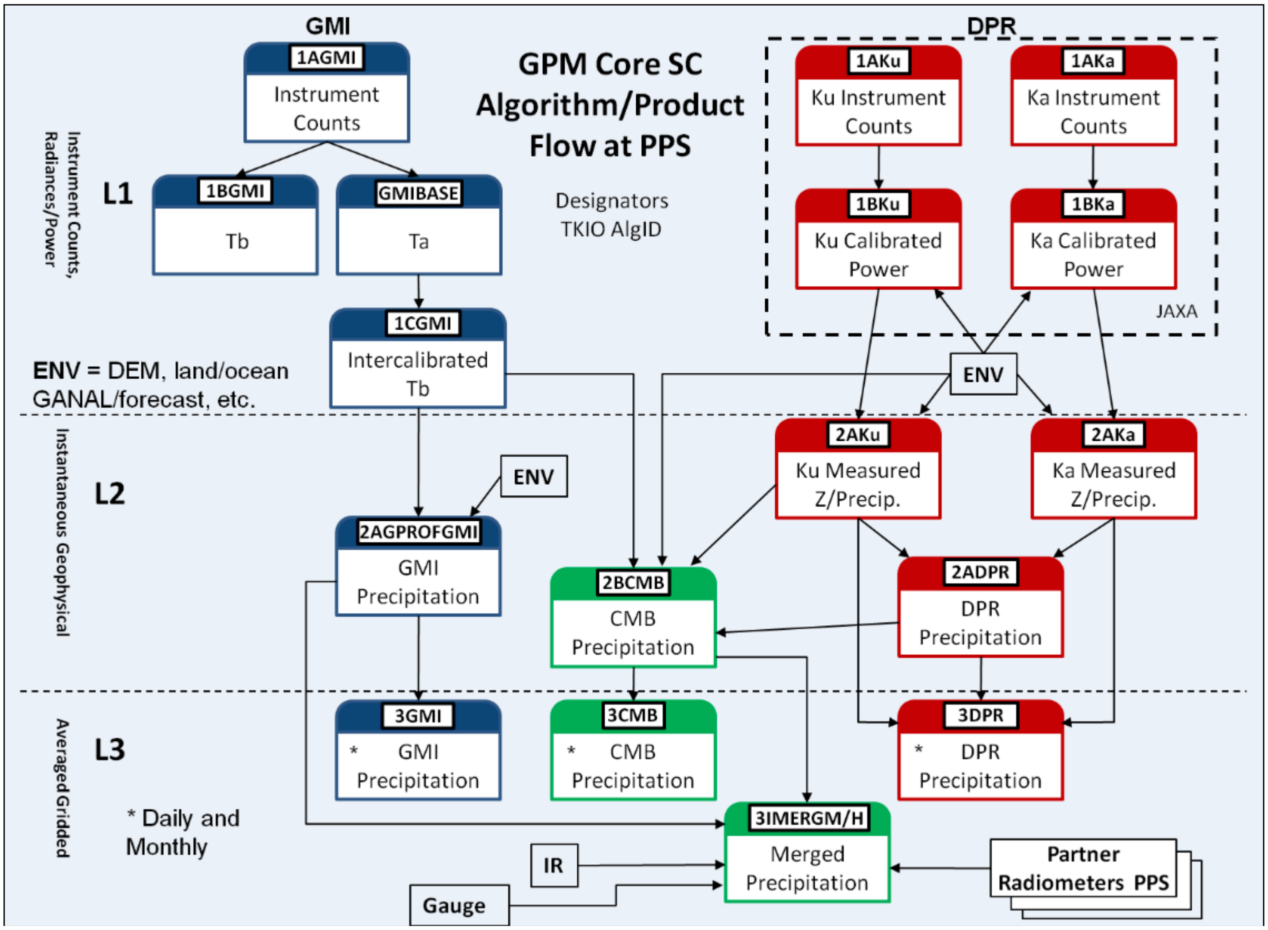

Figure 1. Data-product Dependencies

Key:

CMB	Combined
DEM	Digital Elevation Model
DPR	Dual-Frequency Precipitation Radar
ENV	Environment
GANAL	Gridded Dataset of Global Analysis
GMI	GPM Microwave Imager
GPROF	GPM Profiling Algorithm
IMERG	Integrated Multi-SatellitE Retrievals for GPM
IR	Infrared
JAXA	Japan Aerospace Exploration Agency
KaPR/KuPR	Ka-band Precipitation Radar/Ku-band Precipitation Radar
L1A, L1B	Level 1A, Level 1B
PPS	Precipitation Processing System
SC	Spacecraft
Ta, Tb	Antenna Temperature, Brightness Temperature
TKIO	PPS Science Algorithm Input/Output Toolkit
Z	Reflectivity

2. 1AGMI

2.1 PURPOSE

The 1AGMI product has two purposes: To repackage the raw satellite data from binary Consultative Committee for Space Data Systems (CCSDS) packets to Hierarchical Data Format (HDF), and to geolocate the sample data. The counts in the 1AGMI product are the raw counts taken directly from the packets created by the GPM Microwave Imager (GMI) instrument. There is no calibration or interpretation performed at the 1AGMI level. There are five swaths in the 1AGMI product:

1. Earth-view, hot-load, and cold-sky samples for low-frequency channels
2. Earth-view, hot-load, and cold-sky samples for high-frequency channels
3. Scan housekeeping data provided by instrument
4. All samples for low-frequency channels
5. All samples for high-frequency channels

Swaths S1 and S2 are subsets of swaths S4 and S5, respectively. The samples to subset are noted in the 1AGMI product in the gmi1aHeader/sampleRangeFile table. This is a table that was determined during testing and the Launch and Early Orbit phase of the Global Precipitation Measurement (GPM) Mission. Geolocation is performed on the samples using the PPS Geolocation Toolkit. The details on GMI geolocation can be found in the GMI Calibration Data Book.

2.2 DATASET

The 1AGMI product contains unaltered data straight from the satellite. This product can be used to show exactly what was recorded by the GMI instrument. The 1AGMI product also contains all of the data sent down by the satellite. If there is enough bandwidth, the entire circle of GMI samples will be sent down. The 1AGMI product's swaths 4 and 5 contain all of the samples that are sent down. Later products only use the subset of these data that contains the Earth-view, hot-load, and cold-sky samples.

2.3 CAVEATS/LIMITATIONS

The data in the 1AGMI file are not calibrated. Do not use these data unless they can be correctly calibrated and interpreted.

2.4 REFERENCES

The following documents are available on the PPS web site, https://arthurhou.eosdis.nasa.gov/:

- GMI Calibration Data Book.
- GPM Geolocation Toolkit Algorithm Theoretical Basis Document (ATBD).
- GPM/PPS File Specification.
- PPS Geolocation Toolkit.

3. 1BGMI

3.1 PURPOSE

The 1BGMI data product and software transform Level 0 counts into geolocated and calibrated brightness temperature (Tb) for the 13 GMI channels.

3.2 DATASET

The 1BGMI data product uses a non-linear three-point in-flight calibration to derive antenna temperature (Ta) and convert Ta to Tb using GMI antenna pattern corrections. The four-point calibration, which utilizes noise-diode measurements, is used to monitor the sensor's non-linearity. The noise-diode measurements also provide a hot-load back-up calibration in case the hot-load measurements are lost. Details are found in the GMI ATBD.

3.3 CAVEATS/LIMITATIONS

The Tb calibration error is normally < 0.5 K. The Noise-Equivalent Differential Temperature results, with worst-case on-orbit corrections, are given in the following table:

			Receiver Temperature				Low Gain				Nominal Gain				High Gain			
Frequency (GHz)	pol	Blanking	Cold	Nom	Hot	Gain Setting	Cold	Nom	Hot	Gain Setting	Cold	Nom	Hot	Gain Setting	Cold	Nom	Hot	REQUIREMENT
10.65	vpol	Off	2.7	20.4	39.2	6	0.79	0.83	0.85	4	0.79	0.81	0.85	2	0.78	0.83	0.84	0.96
10.65	hpol	Off	2.7	20.4	39.2	6	0.80	0.82	0.85	4	0.79	0.81	0.86	2	0.78	0.82	0.84	0.96
18.7	vpol	Off	1.6	25.3	43.8	6	0.65	0.68	0.70	4	0.64	0.68	0.72	2	0.65	0.67	0.70	0.84
18.7	hpol	Off	1.6	25.3	43.8	6	0.62	0.64	0.68	4	0.61	0.64	0.66	2	0.61	0.64	0.67	0.84
23.8	vpol	Off	1.0	24.8	43.3	6	0.53	0.57	0.62	4	0.52	0.56	0.60	2	0.53	0.55	0.58	1.05
36.64	vpol	Off	-0.4	24.4	42.7	6	0.43	0.45	0.47	4	0.43	0.46	0.47	2	0.43	0.45	0.47	0.65
36.64	vpol	Dur=8	-0.4	24.4	42.7	6	0.60	0.77	0.95	4	0.45	0.53	0.64	2	0.44	0.45	0.50	N/A
36.64	vpol	Dur=20	-0.4	24.4	42.7	6	1.11	1.63	2.20	4	0.56	0.83	1.19	2	0.49	0.47	0.56	N/A
36.64	vpol	Dur=32	-0.4	24.4	42.7	6	1.73	2.54	3.41	4	0.68	1.19	1.83	2	0.55	0.48	0.67	N/A
36.64	hpol	Off	-0.4	24.4	42.7	6	0.45	0.46	0.50	4	0.45	0.46	0.48	2	0.45	0.47	0.49	0.65
36.64	hpol	Dur=8	-0.4	24.4	42.7	6	0.68	0.81	1.06	4	0.49	0.55	0.68	2	0.46	0.47	0.50	N/A
36.64	hpol	Dur=20	-0.4	24.4	42.7	6	1.42	1.75	2.42	4	0.67	0.87	1.34	2	0.48	0.48	0.60	N/A
36.64	hpol	Dur=32	-0.4	24.4	42.7	6	2.19	2.71	3.90	4	0.91	1.28	2.01	2	0.52	0.49	0.74	N/A
89	vpol	Off	3.6	27.0	45.6	6	0.34	0.36	0.38	4	0.33	0.35	0.37	2	0.33	0.35	0.38	0.57
89	hpol	Off	3.6	27.0	45.6	6	0.31	0.33	0.34	4	0.30	0.33	0.34	2	0.31	0.32	0.34	0.57
166	vpol	Off	2.0	14.1	35.0	4	0.69	0.71	0.74	2	0.69	0.70	0.74	1	0.70	0.71	0.74	1.50
166	hpol	Off	-0.1	13.7	34.5	4	0.64	0.65	0.69	2	0.64	0.67	0.69	1	0.64	0.67	0.69	1.50
183.31±3	vpol	Off	2.3	15.3	36.2	5	0.55	0.57	0.63	4	0.55	0.57	0.62	3	0.55	0.57	0.62	1.50
183.31±7	vpol	Off	2.3	15.3	36.2	5	0.48	0.50	0.53	4	0.48	0.49	0.53	3	0.48	0.50	0.52	1.50

3.4 REFERENCES

The following documents are available on the PPS web site, https://arthurhou.eosdis.nasa.gov/:

- GPM Microwave Imager (GMI) Level 1B ATBD.
- GPM/PPS File Specification 1BGMI.
- Wentz, F. J., and M. Thomas, 2008: GMI Calibration ATBD.

4. 1C PRODUCTS

4.1 PURPOSE

The purpose of the Level 1C algorithms is to provide common intercalibrated microwave brightness temperature (Tc) products for GPM core and constellation satellites. The 1C algorithms all use the GPM Microwave Imager (GMI) as the reference standard to ensure the consistency among the various satellites' precipitation retrievals. The set of satellites contributing data to the constellation varies depending on the year, including those satellites listed in the following table, which was compiled in 2021. For constellation satellites that provided data only prior to the launch of GPM, a multi-step calibration procedure is followed. The multi-step process consists in some cases of calibrating first to the TRMM Microwave Imager (TMI), which itself is calibrated to GMI using the TRMM/GPM overlap period that occurred 2014.

Table 4-1. Microwave Imagers in the GPM Constellation

Instrument	Satellite	Data Period	Calibration
TMI	TRMM	1997-2015	GMI
SSMI	F08	1987-1991	F10 > F11 > TMI > GMI
	F10	1990-1997	F11 > TMI > GMI
	F11	1991-2000	TMI > GMI
	F13	1995-2009	TMI > GMI
	F14	1997-2008	TMI > GMI
	F15	2000-2006	TMI > GMI
SSMIS	F16	2005-present	GMI
	F17	2008-present	GMI
	F18	2010-present	GMI
	F19	2014-2016	GMI
GMI	GPM	2014-present	not applicable
AMSRE	AQUA	2002-2011	TMI > GMI
AMSR2	GCOM-W1	2012-present	GMI

Table 4-2. Microwave Sounders in the GPM Constellation

Instrument	Satellite	Data Period	Calibration
SAPHIR	MT1	2011-present	GMI
AMSUB	NOAA-15	2000-2010	MHS > GMI
	NOAA-16	2002-2009	MHS > GMI
	NOAA-17	2000-2010	MHS > GMI
MHS	NOAA-18	2005-2018	GMI
	NOAA-19	2009-present	GMI
	METOP-A	2006-2019	GMI
	METOP-B	2012-present	GMI
	METOP-C	2018-present	GMI
ATMS	NPP	2011-present	GMI
	NOAA-20	2017-present	GMI

4.2 DATASET

All 1C products have a common L1C data structure that is simple and generic. Each L1C swath includes scan time, latitude, longitude, scan status, quality, incidence angle, Sun glint angle, and the intercalibrated brightness temperature (Tc). One or more swaths are included in a product. The radiometer data are recalibrated to a common basis so that precipitation products derived from them are consistent.

4.3 CAVEATS/LIMITATIONS

The L1C products contain brightness temperatures that have been intercalibrated. L1C products omit channels not relevant to precipitation retrievals.

The intercalibration for most radiometers is a simple 2-point linear adjustment. For the water-vapor sounding channels, the intercalibration is a simple offset. In the case of AMSR2, the adjustment is piecewise linear with more than two points to approximate the non-linear nature of that instrument's calibration.

The goal of intercalibration is to make the brightness temperature of different instruments consistent to 0.1 K. This is not to say the calibration is accurate to this level; there are no suitable standards to assure absolute accuracy. The 0.1 K level of consistency has been achieved in most cases, but in the case of the channels near 90 GHz, the uncertainty is somewhat greater. Also, some radiometers are not stable enough to permit this level of consistency.

4.4 REFERENCES

GPM Level 1C Algorithms (L1C) Algorithm Theoretical Basis Document (ATBD), https://arthurhou.eosdis.nasa.gov/.

GPM/PPS File Specification, https://arthurhou.eosdis.nasa.gov/.

Biswas, S. K., S. Farrar, K. Gopalan, A. Santos-Garcia, W. L. Jones, and S. Bilanow, 2013: Intercalibration of Microwave Radiometer Brightness Temperatures for the Global Precipitation Measurement Mission. *IEEE Trans. on Geoscience and Remote Sensing*, **51**, 1465–1477.

Sapiano, M. R. P., W. K. Berg, D. S. McKague, and C. D. Kummerow, 2013: Toward an Intercalibrated Fundamental Climate Data Record of the SSM/I Sensors. *IEEE Trans. on Geoscience and Remote Sensing*, **51**, 1492–1503.

Wilheit, T. T., 2013: Comparing Calibrations of Similar Conically Scanning Window-Channel Microwave Radiometers. *IEEE Trans. on Geoscience and Remote Sensing*, **51**, 1453–1464.

5. 2ADPR, 2AKU, 2AKA

5.1 PURPOSE

Three data products provide single- and dual-frequency-derived precipitation estimates from the Ku-band and Ka-band radars of the Dual-Frequency Precipitation Radar (DPR) on the core GPM spacecraft. The estimates are calculated for each radar range bin along the slant path of the radar instrument field of view.

The three data products are called 2ADPR, 2AKu, and 2AKa. The 2ADPR data product contains three kinds of precipitation estimates: those derived from the Ku-band frequency only, those derived from the Ka-band frequency only, and those derived from the dual-frequency data. In contrast, the 2AKu data product contains only Ku-band precipitation estimates. The 2AKa data product contains only Ka-band precipitation estimates.

In these products, there are two kinds of Ka-band estimates: standard and high-sensitivity. In the Ka-band's standard-sensitivity mode, data are collected for the fields of view within the middle portion of the Ku-band swath, which is known as the "inner swath."

A major change in the Ka-band's high-sensitivity mode occurred on 21 May 2018. Prior to that date (2014–2018), the high-sensitivity mode collected data approximately in the same "inner swath" location where the Ka-band's standard-sensitivity mode. After that date (2018–present), the Ka-band's high-sensitivity mode collects data outside the inner swath and approximately co-located with the Ku-band fields of view along the edges of the Ku-band swath. The motivation for the change in the Ka-band's observation geometry was to enable dual-frequency Ku-Ka precipitation retrievals across the entire wide-swath of the Ku-band data. Such retrievals are only possible after the 21 May 2018 configuration change.

5.2 DATASET

The dual-frequency retrieval in the 2ADPR product benefits from having co-aligned measurements at Ku- and Ka-bands. The GPM core satellite is the first satellite whose observations can be used to make dual-frequency radar-based precipitation estimates. Previously, this capability was only available in some ground-based and aircraft-based radars.

DPR observations are used to infer properties of the particle-size distribution, which are expected to lead to improved estimates of precipitation rate, precipitation phase, and equivalent liquid water content. Dual-frequency data are expected to improve the capability to discriminate among water, ice, and mixed-phase hydrometeors as a function of height. This capability is particularly important in a convective storm where a bright-band signature, associated with mixed-phase hydrometeors, is often absent. In addition, the different attenuation rates of the Ku-band and Ka-band allow differential attenuation techniques to be used to estimate the path integrated attenuation. The high-sensitivity Ka-band channel is expected to have a 6-dB greater sensitivity than the Ku-band and standard-sensitivity Ka-band. For this reason, the high-sensitivity Ka-band is better able to estimate light precipitation.

5.3 CAVEATS/LIMITATIONS

The 2AKu data product contains less reliable precipitation estimates than the 2ADPR dual-frequency data product, but the 2AKu product has the advantage that it would not be impacted by any operational issues with the Ka-band radar. Similarly, the 2AKa data product contains less reliable precipitation estimates than the 2ADPR dual-frequency data product, but the 2AKa product has the advantage that it would not be impacted by any operational issues with the Ku-band radar.

For all three of the Level 2 DPR data products, the presence of changing topography (ex.: mountains) presents challenges to the ability of the algorithm to distinguish between precipitation echo and surface clutter. The Ka band undergoes larger extinction through precipitation, and the dual-frequency retrieval may be limited to low-to-moderate precipitation rates. Major sources of error include surface-clutter contamination of near-surface echoes, incorrect identification of precipitation type (convective/stratiform), and severe attenuation of the Ka-band data due to heavy precipitation.

5.4 REFERENCES

The following documents are available on the PPS web site, https://arthurhou.eosdis.nasa.gov/, on the ATBD or Document web pages:

- GPM/DPR Level 2 Algorithm Theoretical Basis Document.
- GPM/PPS File Specification.

6. 2AGPROF

6.1 PURPOSE

The 2AGPROF algorithm retrieves consistent precipitation and related variables from the GPM Microwave Imager (GMI) and passive-microwave sensors on most of the other satellites in the GPM constellation. The 2AGPROF data product is available for all sensors listed in Section 4.1 of the present document except the SAPHIR instrument, which has its precipitation estimated by the GPM Precipitation Retrieval and Profiling Scheme (PRPS) algorithm.

The sensors processed to generate the 2AGPROF data product provide the bulk of the 3-hour coverage achieved by GPM. For each sensor, there are near real-time (NRT) products, standard products, and climate products. These products differ in their latency, i.e., whether one must wait approximately 3 hours, 48 hours, or 3 months after data collection for the data product to be available. The variables in the 2AGPROF HDF5 files are identical regardless of the latency, although the accuracy of the precipitation estimates is expected to be higher with the products with higher latency. NRT 2AGPROF uses Japan Meteorological Agency (JMA) forecast data as input. Standard 2AGPROF uses GANAL analysis and JMA forecast data as input, while the climate 2AGPROF uses ECMWF reanalysis as input. The climate 2AGPROF uses ECMWF as input so that its precipitation estimates are consistent with those of earlier satellite instruments.

6.2 DATASET

GPROF is a Bayesian-type algorithm. The algorithm searches an a-priori database of potential rain profiles and retrieves a weighted average of these entries based upon the proximity of the observed brightness temperature (Tb) to the simulated Tb corresponding to each rain profile. By using the same a-priori database of rain profiles, with appropriate simulated Tb for each constellation sensor, the Bayesian method is completely parametric and thus well suited for GPM's constellation approach. The a-priori information is supplied by the Combined algorithm. The solution provides a mean rain rate as well as the vertical structure of cloud and precipitation hydrometeors and their uncertainty.

6.3 CAVEATS/LIMITATIONS

The major sources of systematic errors in these data products are the a-priori database and the Bayesian model. Some error can also be introduced by the ancillary information (surface type, surface temperature, and total precipitable water) used to subset the a-priori database in the algorithm.

Because passive microwave signatures at the pixel level represent primarily integrated quantities, neither the vertical structure nor the near-surface precipitation from radiometers are typically as good as their radar counterparts. Solutions are also smoothed by the Bayesian scheme, leading to fewer extremely high precipitation-rate pixels relative to the frequency of extremely high precipitation-rate pixels in dual-frequency precipitation radar data.

6.4 REFERENCES

The following documents are available on the PPS web site, https://arthurhou.eosdis.nasa.gov/, or on the relevant journal's web site:

GPM GPROF (Level 2) Algorithm Theoretical Basis Document.

GPM/PPS File Specification.

Kummerow, C., W. S. Olson, and L. Giglio, 1996: A Simplified Scheme for Obtaining Precipitation and Vertical Hydrometeor Profiles from Passive Microwave Sensors. *IEEE Trans. on Geoscience and Remote Sensing*, **34**, 1213-1232, doi: 10.1109/36.536538.

PRPS (Level 2) Algorithm Theoretical Basis Document.

7. 2BCMB

7.1 PURPOSE

The 2BCMB product uses data from the Dual-Frequency Precipitation Radar and GMI data to estimate precipitation rate and phase for one orbit-worth of data. The product is written as a two-swath structure.

In Version 6 of 2BCMB, the two swaths are called NS and MS. The first swath, NS (normal scan), contains 49 rays per scan that match the Ku-band radar rays. The precipitation estimates in the NS swath are calculated from the Ku-band radar and GMI data. The second swath, MS (matched scan), contains 25 rays per scan that match the 25 KaPR rays. It is calculated from the KuPR, KaPR, and GMI data.

In Version 7 of 2BCMB, the two swaths are called KuGMI and KuKaGMI. Both swaths contain 49 rays per scan. As the name suggests, the KuGMI swath contains estimates of precipitation calculated from Ku-band radar and GMI data. The KuKaGMI swath contains estimates of precipitation calculated from Ku-band and Ka-band radar data and GMI data.

The swaths contain the following physical measurements of general interest, among others:

- Surface air pressure (hPa)
- Surface air temperature (K)
- Surface water vapor density (g/m^3)
- Earth's surface temperature
- Air pressure (hPa) at 10 vertical levels
- Air temperature (K) at 10 vertical levels
- Water vapor density (g/m^3) at 10 vertical levels
- Cloud liquid water content (g/m^3) at 88 vertical levels
- Cloud ice water content (g/m^3) at 88 vertical levels
- Total precipitation liquid water content (g/m^3) at 88 vertical levels
- Precipitation rate (mm/h) at 88 vertical levels
- Mass fraction precipitation that is liquid in phase transition region at 10 vertical level
- Fraction of precipitation rate that is liquid in phase transition region at 10 vertical levels
- Surface precipitation rate (mm/h)
- Uncertainty of the surface precipitation rate (mm/h)
- Fraction of surface precipitation that is liquid
- Wind speed magnitude (m/s) at 10-meter altitude

7.2 DATASET

There are uncertainties in the interpretation of data from any one of the instruments (Ku-band radar, Ka-band radar, and GMI). Using data from multiple instruments constrains the retrieval of precipitation rate.

7.3 REFERENCES

The following documents are available on the PPS web site, https://arthurhou.eosdis.nasa.gov/:

File Specification for GPM Products, Version 1.01, TKIO 3.60.0, March 11, 2014.

Olson, W. S., H. Masunaga, and the GPM Combined Radar-Radiometer Algorithm Team: GPM Combined Radar-Radiometer Precipitation ATBD (Version 2).

8. <u>3CMB</u>

8.1 PURPOSE

The 3CMB data product contains either a daily or monthly accumulation of the 2BCMB orbital precipitation product. Regardless of the accumulation period, the 3CMB product contains variables at resolutions: 5×5 degrees in grid G1 and 0.25×0.25 degrees in grid G2. Below are listed some of the variables in grid G1.

Grid G2 contains the same variables but binned without the surface type dimension (dimension "st") and without histograms (variables called "hist").

In the list below, variables described as "conditional" represent means calculated with data points in which the precipitation rate was non-zero, while "unconditional" variables are calculated from all data points including both precipitating and non-precipitating areas. Variables that express probabilities are calculated as the number of precipitating observations divided by the total number of precipitating and non-precipitating observations.

<u>Conditional variables</u>

- Group precipTotRate sums all precipitation phases (ice, liquid, mixed-phase) but only pixels with non-zero precipitation rate. The variables in the group are: count, mean, standard deviation for monthly product and mean of squares for daily product (stdev), and histogram (hist). The variables in this group have dimensions of swath (ns), altitude (ght), rain type (rt), and Earth surface type (st).
- Group precipLiqRate is calculated using only pixels with a non-zero liquid precipitation rate. The variables and dimensions are the same as for precipTotRate.
- Group precipTotWaterContent is calculated using only pixels with a non-zero water content of any phase. The variables and dimensions are the same as for precipTotRate.
- Group precipLiqWaterContent is calculated using only pixels with a non-zero liquid water content. The variables and dimensions are the same as for precipTotRate.
- Group precipTotDm is calculated using only pixels with a non-zero mass-weighted mean particle diameter. The variables and dimensions are the same as for precipTotRate.
- Group precipTotRateDiurnal is calculated using only pixels with a non-zero precipitation rate of any phase. The variables are the same as for precipTotRate, but the variable's dimensions are different in one respect. Instead of an Earth surface type (st) dimension, there is a local time (tim) dimension.
- Group surfPrecipTotRateDiurnalAllObs is calculated the same as precipTotRateDiurnal except that it provides values at the Earth's surface, and therefore lacks an altitude (hgt) dimension.

<u>Unconditional variables</u>

- surfPrecipTotRateUn is the average unconditional surface total precipitation rate (mm/h) including all phases with a dimension for surface type. To obtain rate conditioned on precipitation, divide by the probability of precipitation occurring, surfPrecipTotRateProb.

- surfPrecipLiqRateUn is calculated the same way as surfPrecipTotRateUn except only with data with non-zero liquid precipitation rate. To obtain rate conditioned on liquid precipitation, divide by the probability of liquid precipitation occurring, surfPrecipLiqRateProb.
- surfPrecipTotRateProb is the probability of non-zero precipitation.
- surfPrecipLiqRateProb is the probability of non-zero liquid precipitation.

The dimensions of these variables include the following:

- **ns** has 2 elements, represents the number of swaths: Ku+microwave or Ku+Ka+microwave.
- **hgt** has 16 elements, represents altitude ranges. Index 0 is for near surface and indices 1 through 10 are for a 1-km deep height bin whose lower bound is 1 km times the index. Indices 11 to 15 are for a 2-km deep height bin whose lower bound is 10 km plus 2.0 km times (index-10).
- **tim** has 24 elements representing hourly local-time bins.
- **rt** has 3 elements, representing precipitation type: stratiform, convective, or all.
- **st** has 3 elements, representing Earth surface type: ocean, land, or all.
- **bin** has 30 elements, representing bins in the histogram, which varies with the units of the variable being summarized.

8.2 DATASET

There are uncertainties in the interpretation of data from any one of the instruments (KuPR, KaPR, and GMI). By using data from multiple instruments, further constraints on the solution of precipitation structure improve the final product.

8.3 REFERENCES

The following documents are available on the PPS web site, https://arthurhou.eosdis.nasa.gov/:

File Specification for GPM Products.

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9. 3DPR, 3DPRD

9.1 PURPOSE

The Level 3 DPR data product contains instantaneous precipitation estimates generated by converting the Level 2 DPR data products into grids covering either a day and/or month. For 3DPR data products of either time resolution, there are two grid resolutions: 5.0 degrees and 0.25 degrees. For each grid box, statistics calculated are the number of DPR fields of view, the mean of the observations, and the standard deviation of the observations. Most variables are also conditioned on surface type and precipitation type with other three-dimensional fields adding the height above the ellipsoid. Unless otherwise specified, the means are conditioned on precipitation being present (rain rate > 0). For the daily product, the mean square statistic is saved rather than the standard deviation.

The standard daily and monthly products are designated as 3DPR, while a simplified daily product that contains a subset of the variables is designated 3DPRD.

9.2 DATASET

The Level 3 DPR products present the user with summary information over daily or monthly time periods. These gridded products are in a convenient gridded form and can be used easily in comparisons with other satellite and ground data.

9.3 CAVEATS/LIMITATIONS

The results presented in the Level 3 product are simple conditioned statistics of the Level 2 retrievals. Any errors/limitations are inherent to the Level 2 retrieval issues already presented.

Issues with sampling must be considered when using these data. For the daily products, the number of measurements in each 0.25-degree box is very limited. While this is a convenient resolution that can be used to create larger grids, the values at the 0.25-degree resolution should be used with caution. The standard deviation is not computed at the daily level because of the limited sample size.

9.4 REFERENCES

The following documents are available on the PPS web site, https://arthurhou.eosdis.nasa.gov/:

- GPM/PPS File Specification.
- GPM/DPR Level-3 for V07 Algorithm Theoretical Basis Document.

10. 3GPROF

10.1 PURPOSE

The purpose of the 3GPROF data product is to provide monthly and daily mean precipitation and related retrieved parameters from the Level 2 GPROF precipitation profiling data product for the GPM core and constellation satellites. Each 3GPROF product contains global 0.25×0.25 degree gridded monthly or daily means. Because this product is an accumulation of the Level 2 retrieval products, much more information is available via the GPROF Level 2 documentation. The 3GPROF data product is generated for satellite instruments for which 2AGPROF files can be generated.

10.2 DATASET

3GPROF products provide global gridded monthly or daily precipitation averages from multiple satellites that can be used for climate studies. The 3GPROF products are based on retrievals from high-quality microwave sensors, which are sensitive to liquid and ice-phase precipitation hydrometeors in the atmosphere.

10.3 CAVEATS/LIMITATIONS

The primary limitation of the 3GPROF product is the reliance on a single sensor for each output file, thus limiting the available sampling to two times a day or less, except at high latitudes. In addition, with the exception of the GMI, TMI, and SAPHIR sensors, all of the other sensors are in Sun-synchronous orbits, meaning that they observe a given point on the Earth's surface at the same local times each day. Over land regions in particular, this limited sampling of the diurnal cycle can lead to large errors in the 3GPROF estimated average precipitation rate for that day or month. The sampling errors are largest over land regions that are characterized by large diurnal cycles in precipitation.

Other sources of error that can significantly impact the 3GPROF products include difficulties over certain surface types (e.g., sea ice, snow, frozen ground, and deserts) and limited sensitivity of the sounder instruments (in particular in light precipitation or shallow warm rain systems). A list of sounders and imagers is provided in the discussion of the 2AGPROF data product earlier in the present document.

10.4 REFERENCES

Aires, F., C. Prigent, F. Bernardo, C. Jiménez, R. Saunders, and P. Brunel, 2011: A Tool to Estimate Land-Surface Emissivities at Microwave Frequencies (TELSEM) for Use in Numerical Weather Prediction. *Q. J. of the Roy. Meteorol. Soc.*, **137**: 690–699, doi: 10.1002/qj.803.

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11. IMERG

11.1 PURPOSE

The Integrated Multi-satellitE Retrievals for GPM (IMERG) data product contains estimates of surface precipitation generated from a constellation of passive-microwave satellite instruments, infrared satellite instruments, and various calibration data sets. IMERG also provides some information about the phase of the surface precipitation. The data product is available in files that cover periods whose duration is either 30 minutes or 1 month.

The IMERG data product is intended to be the best estimate for the period covered by each file, meaning that it is not guaranteed to have a decade-long consistent calibration. IMERG is not a climate data record in the way that the 2.5°×2.5° latitude-longitude monthly files of the Global Precipitation Climatology Project (GPCP) are a climate data record. Nonetheless, the IMERG development team has made an effort to make the IMERG data product as homogenous a record as possible.

PPS runs two simplified configurations of the IMERG algorithm in near real-time, and the resulting data products are called Early and Late IMERG. PPS runs a third configuration of IMERG several months after the satellite observations are made, and the resulting data product is called Final IMERG. Generally speaking, Final IMERG is more accurate than near real-time estimates and therefore should be used whenever it is available.

11.2 DATASET

Variables in the IMERG data product are globe-covering grids (90°S to 90°N, 180°W to 180°E) with 0.1-degree resolution. IMERG's relatively high spatial resolution and broad spatial coverage makes it well suited for a range of uses. In addition, IMERG may be the best data product for users who are new to satellite-based precipitation estimates. The exceptions are users who have requirements that would not be met by IMERG, such as needing three-dimensional precipitation or high-resolution Level 2 footprints from individual satellites.

Version 6 IMERG is available from June 2000 through the present. In 2022, it is expected that the Precipitation Processing System (PPS) will begin generating Version 7 IMERG, which will replace Version 6 for the entire data period, June 2000 to the present.

11.3 CAVEATS/LIMITATIONS

The following cautions are due to the computational steps within the IMERG algorithm:

- IMERG generally provides complete data only between 60°N and 60°S latitude due to limitations of the satellite observations. In this latitude band only, precipitation estimates from geosynchronous infrared satellite instruments are available to fill in the gaps in the precipitation estimates from polar-orbiting passive-microwave satellite instruments and morphed polar-orbiting satellite data. Future work on the IMERG algorithm will attempt to bring it closer to providing complete global coverage, including near the poles.

- The calibration built into the IMERG algorithm is generally performed over full-month or longer periods to increase the stability of the retrievals. Such long-term calibration methods mean that fast-changing weather patterns might introduce spurious variations that such calibrations cannot correct.
- The morphing scheme that IMERG uses to time-interpolate between microwave sensor overpasses is linear interpolation, to a first approximation. When the time between overpasses exceeds about two hours, the morphed and actual evolution of a precipitation system may differ significantly.
- The displacement vectors used in morphing are computed from analyses of vertically integrated water vapor. Motion errors are largest at scales below about 2.5° of latitude/longitude or in regions with sharp surface-elevation variation.
- Morphing will propagate the error in a microwave retrieval along with the good precipitation signal, creating correlated error at nearby time periods.
- Short-term infrared-based precipitation estimates are less reliable than passive microwave estimates, and in places where the infrared precipitation estimate must be used, the IMERG values are therefore less reliable.

The following cautions are due to the input data used by the IMERG algorithm:

- Single-satellite passive-microwave algorithms, such as GPROF, work best over tropical ocean and progressively less well over mid-latitude ocean, tropical land, mid-latitude land, complex topography, or frozen surfaces (sea ice or snow- and ice-covered land).
- Over land, the emission signal in the low-frequency passive-microwave channels cannot be used by single-satellite precipitation-estimation algorithms, reducing the accuracy of such estimates.
- In high-frequency passive-microwave channels, the emission from frozen land surfaces is similar to a precipitation-scattering signal, causing large errors in passive microwave precipitation retrievals over snow-covered or ice-covered surfaces.
- In regions of complex terrain, high-frequency channels can be used, but will result in a variable amount of overestimation or underestimation of liquid-phase precipitation.
- Looking more broadly, each satellite instrument has its own viewing geometry and observing frequencies. Any retrieval algorithm that combines multiple instruments, by necessity, represents a compromise between precision, completeness, and computational practicality. Subject to such constraints, IMERG is designed to emphasize strengths of and compensate for weaknesses in the input data. In many cases, the errors in the input data are, nonetheless, passed through to the IMERG output fields.

The error estimates contained in the IMERG datasets are first approximations and should be used with caution, including the random-error (mm/h) variable and the quality-index variable (a unitless number between 0 and 1).

The validation statistics for IMERG are relatively modest at the 0.1-degree resolution of the variables in the IMERG files. Nonetheless, IMERG's validation statistics are competitive with those of other satellite-based global precipitation data products with similar space and time resolution. The end user can reduce random error by averaging IMERG grid boxes onto a coarser grid or onto a larger region such as drainage basin.

11.4 REFERENCES

The following three references are good starting places for information about IMERG:

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George J. Huffman (1), David T. Bolvin (1,2), Eric J. Nelkin (1,2), and Jackson Tan (1,3), 2019: Integrated Multi-satellitE Retrievals for GPM (IMERG) Technical Documentation. 71 pp., https://arthurhou.pps.eosdis.nasa.gov/Documents/IMERG_doc_190604.pdf.

GPM/PPS File Specifications, PPS web site (https://arthurhou.eosdis.nasa.gov/).

Among the many papers related to IMERG and global satellite-based precipitation estimation in general, here are a few that may be useful starting places:

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ACRONYMS AND ABBREVIATIONS

AMSR2	Advanced Microwave Scanning Radiometer 2
AMSRE	AMSR Earth Observing System
AMSUB	Advanced Microwave Sounding Unit – B
ATBD	Algorithm Theoretical Basis Document
ATMS	Advanced Technology Microwave Sounder
CCSDS	Consultative Committee for Space Data Systems
CMB	Combined
DPR	Dual-Frequency Precipitation Radar
ECMWF	European Centre for Medium-Range Weather Forecasts
GANAL	Gridded Dataset of Global Analysis
GCOM-W1	Global Change Observation Mission – Water Satellite 1
GES DISC	Goddard Earth Sciences Data and Information Services Center
GIS	Geographic Information Systems
GMI	GPM Microwave Imager
GPCP	Global Precipitation Climatology Project
GPM	Global Precipitation Measurement
GPROF	GPM Profiling Algorithm
HDF	Hierarchical Data Format
IDL	Interactive Data Language
IMERG	Integrated Multi-SatellitE Retrievals for GPM
JAXA	Japan Aerospace Exploration Agency
JMA	Japan Meteorological Agency
KaPR/KuPR	Ka-band Precipitation Radar/Ku-band Precipitation Radar
L1A, L1B	Level 1A, Level 1B
METOP	(European) Meteorological Operational (Spacecraft)
MHS	Microwave Humidity Sounder
MS	Matched Scan
NOAA	National Oceanic and Atmospheric Administration
NPP	National Polar-Orbiting Operational Environment Satellite (NPOESS) Preparatory Project
NRT	Near Real-time
NS	Normal Scan
PPS	Precipitation Processing System
PRPS	GPM Precipitation Retrieval and Profiling Scheme (Algorithm)
SAPHIR	Sondeur Atmospherique du Profil d'Humidite Intertropicale par Radiometrie
SSMI	Special Sensor for Microwave Imager
SSMIS	Special Sensor Microwave Imager/Sounder
Ta	Antenna Temperature
Tb	Brightness Temperature
Tc	Intercalibrated Brightness Temperature
TKIO	PPS Science Algorithm Input/Output Toolkit
TMI	TRMM Microwave Imager
TRMM	Tropical Rainfall Measuring Mission