Earth Observation Research Center (EORC), Japan Aerospace Exploration Agency (JAXA)

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USER'S GUIDE FOR
Global Satellite Mapping of Precipitation Microwave-IR Combined Product (GSMaP_MVK), Gauge-calibrated Rainfall Product (GSMaP_Gauge) Version 8

1. Introduction

We offer hourly global rainfall maps, which is reanalysis version of JAXA/EORC Global Rainfall Map in Near-Real-Rime by JAXA Global Rainfall Watch (GSMaP_NRT), for meteorological and climate studies. The algorithms are developed for the Global Precipitation Measurement (GPM) mission, and products called as Microwave-IR Combined Product (GSMaP_MVK), and Gauge-calibrated Rainfall Product (GSMaP_Gauge).

The newly developed algorithm for the Global Precipitation Measurement (GPM) mission (GPM-GSMaP Ver.8) is used to retrieve rain rate, and rainfall product is the same to the GPM Global Rainfall Map product distributed from the JAXA G-Portal (https://www.gportal.jaxa.jp). GPM-GSMaP Ver.8 is the latest algorithm developed by the Global Satellite Mapping of Precipitation (GSMaP) project. The main feature of the GSMaP algorithm is utilization of various attributes derived from the spaceborne precipitation radars, such as TRMM Precipitation Radar (PR) and GPM Core Observatory Dual-frequency Precipitation Radar (DPR).

2. Description of rainfall data

Table 1 summarizes major specification of rainfall data.

Table 1 Description of rainfall data

Variable	Rainfall rate (mm/h), Gauge-calibrated rain rate (mm/h), Satellite Information Flag, Observation Time Flag, Reliability Flag
Domain	Global (60N - 60S)
Grid resolution	0.1 degree latitude/longitude
Temporal resolution	1 hour (averaged from 00 minutes to 59 minutes)
Data Delay	About 3-day after observation for GSMaP_MVK and GSMaP_Gauge

3. Algorithms

For details of the GPM-GSMaP algorithm Ver.8, please see "Global Satellite Mapping of Precipitation (GSMaP) for GPM: Algorithm Theoretical Basis Document (ATBD)" (https://sharaku.eorc.jaxa.jp/GSMaP/faq/GSMaP_faq15.html).

1) Microwave Imager Algorithm

GSMaP microwave imager (MWI) algorithm retrieves global precipitation rates from satellite microwave imager (TMI, GMI, AMSR, AMSRE, AMSR2, SSM/I) bright temperatures (TBs). To develop this algorithm, we improved that of Aonashi et al. (2009) by introducing the orographic rain adjustment method etc..

The basic idea of the MWI algorithm is to find precipitation rates that give radiative transfer model (RTM)-calculated TBs that best fit with TMI TBs. The MWI algorithm employs polarization corrected temperatures (PCTs) at higher frequencies (37 and 85 GHz for TMI) over land and coast, TBs with vertical polarization at lower frequencies (10, 19, and 37 GHz for TMI) in addition to the higher frequency PCTs over ocean. (For SSM/I, this algorithm employs TB polarization differences at 19 GHz instead of TBs at 10GHz.)

The MWI algorithm consists of the forward calculation part to calculate the LUTs, and the retrieval part to estimate precipitation rates from the observed TBs using the LUTs.

In the forward calculation part, we calculate LUTs for homogeneous precipitation by incorporating atmospheric and surface variables of the Japan Meteorological Agency (JMA) global analyses or forecasts and precipitating cloud models based on TRMM observation etc. (Takayabu, 2008; Takahashi and Awaka, 2005) into the RTM program of Liu (1998). We also calculate LUTs for orographic precipitation, following Shige *et al.* (2013) and Taniguchi *et al.* (2013). We then derive LUTs for inhomogeneous precipitation from the above LUTs using the approximation of Aonashi and Liu (2000).

The retrieval part performs a detection of precipitation, a retrieval using scattering signals, and an over-ocean retrieval using emission signals. For the detection of precipitation, we adopt the methods of Seto *et al.* (2005), Kubota *et al.* (2007), and Kida *et al.* (2009) over land, coastal areas, and ocean, respectively. In the retrieval using scattering signals, we employ dual frequency PCTs (at 37 and 85 GHz for TMI). We introduce an adjustment method using indices of frozen precipitation depth and surface temperature. In addition, we detect orographic precipitation areas where we use LUTs for orographic precipitation (Yamamoto and Shige, 2014). In the over-ocean retrieval using emission signals, we derive precipitation rate by minimizing a cost function for lower frequency, vertically-polarized TBs (10, 19, and 37 GHz for TMI) with the scattering retrievals as the first guess.

2) Microwave Sounder Algorithm

The GSMaP over-ocean rainfall retrieval algorithm for microwave sounders (MWS) was developed by Shige *et al.* (2009) based on the GSMaP algorithm for microwave imagers (MWI). This algorithm combines an emission-based estimate from brightness temperature (Tb) at 23 GHz and a scattering-based estimate from Tb at 89 GHz. Precipitation inhomogeneities are also taken into account. Improvements of rain/no-rain classification method over coast and mitigation of underestimation in mountainous areas (Shige et al., 2013, Taniguchi et al., 2013) have been done.

The GSMaP over-land rainfall retrieval algorithm for MWS is a scattering algorithm that mainly relies on Tb data at 89 GHz and its rain/no-rain classification method has been developed utilizing Tb data at 150 GHz and 180 GHz (Kida et al. 2012).

In the MWS algorithm, LUT is fitted by a five degree polynomial function of incident angle number. The MWS algorithm saves coefficients of the regression function. The LUT is reconstructed from the regression coefficients in the retrieval algorithm for MWS.

3) Microwave Imager/Sounder Algorithm

The GSMaP rainfall retrieval algorithm for microwave imager/sounders (MWIS) was developed by Kubota *et al.* (2011) based on the GSMaP algorithm for microwave imagers (MWI). SSMIS does not have 10 GHz channels same as SSM/I, the algorithm combines emission-based estimates using TB polarization differences at 19 GHz, in addition to emission-based estimates using TB at 19 GHz vertical polarization and scattering-based estimates using TB at 89 GHz, over the ocean. Precipitation inhomogeneities are also taken into account. See Kubota *et al.* (2011) for more details.

The GSMaP over-land rainfall retrieval algorithm for MWIS was developed based on the GSMaP algorithm for microwave imagers (MWI).

4) Microwave-IR Combined Algorithm

GSMaP_MVK is a product that integrates passive microwave radiometer data with infrared radiometer data in order to have high temporal (1 hour) and spatial (0.1 degree) resolution global precipitation estimates. The product (GSMaP_MVK) is produced based on a Kalman filter model that refines the precipitation rate propagated based on the atmospheric moving vector derived from two successive IR images. The detail of the algorithm can be found in Ushio *et al.* (2009).

And using the Japanese 55-year Reanalysis (JRA-55) data (6-hourly, model grid (TL319L60)) as ancillary data instead of the Japan Meteorological Agency (JMA) Global Analysis (GANAL) data to produce continuous and homogeneous dataset for the past period from January 1998 to November 2021.

5) Gauge-Calibrated Rainfall Algorithm

Gauge calibrated rainfall algorithm (GSMaP_Gauge) is a product that adjust the GSMaP_MVK estimate with global gauge analysis (CPC Unified Gauge-Based Analysis of Global Daily Precipitation) supplied by NOAA. The product also has the same spatial and temporal resolution with GSMaP_MVK and GSMaP_NRT, which is 0.1 degree and 1 hour. The adjustment is applied to the estimation only over land. The rain rate of GSMaP_Gauge is calculated based on the optimal theory which adjusts the GSMaP_Gauge hourly rain rate so that the sum of the 24 hour GSMaP_Gauge rain rate is roughly same as the gauge measurement (Ushio *et al.*, 2013, Mega et al. 2019).

4. Algorithm inputs

1) Geostationary satellite data

Globally-merged, full-resolution (~4km) IR Data, which is merged from the ~11 micron IR channels aboard the MTSAT (operated by Japan Meteorological Agency), METSOSAT-7/-8 (operated by EUMETSAT), and GOES-11/-12 (operated by NOAA), provided by NOAA Climate Prediction Center (CPC) is used for GSMaP_MVK as inputs for microwave-IR combined algorithm. Moreover, before February 8, 2000, NOAA's GridSat-B1 was used. Please see here for more detailed instructions and notes.

2) Low Earth Orbit satellite data

Following microwave imager and/or sounder data are used for GSMaP_MVK as inputs for rainfall retrieval.

Table 2 Summary of input low Earth orbit data

Satellite	Height (km)	Instrument	Category	frequency (GHz)	Note
GPM Core	407	GMI	imager	10.7, 19.4, 21.3, 37, 85.5, 166, 183.31±3, 183.31±7	Introduced into GSMaP_NRT system since 3 Sep. 2014
TRMM	402	TMI	imager	10, 19, 21, 37, 85	Not operational since 9 Apr. 2015
ADEOS-II	803	AMSR	imager	7, 10, 19, 24, 37, 89	Not operational since 25 Oct. 2003
AQUA	705	AMSR-E	imager	7, 10, 19, 24, 37, 89	Not operational since 4 Oct. 2011
GCOM-W	705	AMSR2	imager	7, 10, 19, 24, 37, 89	Mar. 2014 – present
DMSP-F11	833	SSM/I	imager	19, 22, 37, 85	Not operational since 17 May. 2000
DMSP-F13	833				Not operational since 18 Nov. 2009
DMSP-F14	833				Not operational since 24 Aug. 2008
DMSP-F15	833				Only rain over the ocean has been used since Aug. 2006. Not used since 3 Sep. 2014
DMSP-F16	833	SSMIS	imager/ sounder	19.4, 22.2, 37, 91.7, 60-63, 50-59, 150, 183.31±1, 183.31±3, 183.31±7	Introduced into GSMaP_NRT system since 11 Jun. 2010
DMSP-F17	850				Mar. 2014 – Dec. 2017
DMSP-F18	850				Introduced into GSMaP_NRT system since 1 Jul. 2013
DMSP-F19	850				Introduced into GSMaP_NRT system since 25 Mar, 2015 Not operational since 11 Feb. 2016
NOAA-N15	833	AMSU-A/ B	imager/ sounder	23.8-89.0 (AMSU-A), 89,150, 183.31±1,	Not operational since 01 Oct. 2010

NOAA-N16	833			183.31±3, 183.31±7 (AMSU-B)	Not operational since 01 Jan. 2008
NOAA-N17	833				Not operational since 01 Jan. 2010
NOAA-N18	870	AMSU-A/ MHS	sounder	23.8-89.1 (AMSU-A), 89, 157, 183.311±3, 183.311±5, 190.311 (MHS)	Introduced into GSMaP_NRT system since 3 Sep. 2014
NOAA-N19					Introduced into GSMaP_NRT system since 1 Aug. 2011
MetOp-A	817				
MetOp-B					Introduced into GSMaP_NRT system since 3 Sep. 2014
MetOp-C					Introduced into GSMaP_NRT system since 17 Sep. 2020
NPP	824	ATMS	sounder	23.8-183.31±1	Introduced into GSMaP_NRT system since 1 Dec. 2021
JPSS-1					

3) Ancillary Data

Following data sets are used as ancillary data for calculating look-up tables, which are referred by the GSMaP microwave imager and sounder algorithms.

- Japan Meteorological Agency (JMA) Global Analysis (GANAL), 6-hourly, 0.5 degree grid box for GSMaP_MVK and GSMaP_Gauge. For the past period from January 1998 to November 2021, Japanese 55-year Reanalysis (JRA-55) data (6-hourly, model grid (TL319L60)) is used.
- JMA Merged satellite and in situ data Global Daily Sea Surface Temperatures (MGDSST), daily, 1.0 degree grid box.
- NOAA CPC Unified Gauge-Based Analysis of Global Daily Precipitation, daily, 0.5 degree grid box.

5. Differences from previous GSMaP rainfall products (V7.3112)

Following improvements in the algorithm was implemented in Ver.8.

A. Passive microwave (PMW) algorithm

1. Improvement of PMW retrieval technique
   - Adding MHS (Metop-C) and ATMS (Suomi-NPP/ATMS, NOAA-20/ATMS)
   - Update L1 data (TMI, AMSR-E) and decoding tool (AAPP)
   - Retrievals extended to the pole-to-pole (PMW only)
   - Application of dynamic land/ocean classification for all PMW sensors
   - PMW retrieval algorithm considering frozen precipitation depth and static stability in

low-level troposphere
- PMW retrieval for low temperature conditions using scattering signature
- Implementation of fake precipitation screening due to sea ice, snow etc. over Greenland and Hudson Bay
- Improvement of snowfall retrievals
- Improvement of MWS algorithms (Precipitation detection for coastal region etc.)
- Improvement of rainfall detection method over ocean (implementation of correction method for brightness temperature for rain-free areas)

2. Improvement of heavy orographic rainfall retrievals considering static stability in low-level troposphere
3. Update of Database
   - Precipitation profile database (5-year DPR(MS) 06A, algorithm update)
   - Precipitation/no-precipitation classification (5-year KuPR & GMI combined)
   - Surface emissivity (adding TELSEM database outside of PR observation)
   - Change AUTOSNOW format

B. Implementation of Normalization module for PMW retrievals

C. PMW-IR Combined algorithm
1. Improvement of MVK algorithm
2. Implementation of histogram matching method

D. Gauge-adjustment algorithm
1. Improvement of the gauge-calibrated method
2. Mitigation of artificial patterns appeared in V04

E. Data format

Adding new variables

3GSMAPH: reliability flag, surface type, and orographic rain flag

3GSMAPM: orographic rain ratio

F. Others

Minor bug fix

6. Some caveats for data users

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Please refer to the following example for indication of the credit of the product.
"GSMaP data by the Japan Aerospace Exploration Agency (JAXA) ."

・ Anyone wishing to publish any results using the data from the JAXA/EORC GSMaP System should clearly acknowledge the ownership of the data in the publication (for example, “GPM Global Rainfall Map (GPM-GSMaP) Ver.8”, “GPM-GSMaP Microwave-IR Combined Product (GSMaP_MVK) Ver.8”, “GPM-GSMaP Gauge-calibrated Rainfall Product (GSMaP_Gauge) Ver.8” was produced and distributed by the Earth Observation Research Center, Japan Aerospace Exploration Agency). If you have benefited from GSMaP rainfall products, please cite the major papers listed in Section 7 that you have benefited from.

- We would appreciate receiving a preprint and/or reprint of publications in which you utilize our data. Relevant publications should be sent to:

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- Please contact us at the TRMM Realtime office (Z-trmm_real@ml.jaxa.jp) if you have any questions.

7. Papers describing the GSMaP project

Please refer the following paper:

- Kubota, T., K. Aonashi, T. Ushio, S. Shige, Y. N. Takayabu, M. Kachi, Y. Arai, T. Tashima, T. Masaki, N. Kawamoto, T. Mega, M. K. Yamamoto, A. Hamada, M. Yamaji, G. Liu and R. Oki 2020: Global Satellite Mapping of Precipitation (GSMaP) products in the GPM era, Satellite precipitation measurement, Springer, https://doi.org/10.1007/978-3-030-24568-9_20.

(Major papers related to GSMaP algorithms)

- Kubota, T., S. Shige, H. Hashizume, K. Aonashi, N. Takahashi, S. Seto, M. Hirose, Y. N. Takayabu, K. Nakagawa, K. Iwanami, T. Ushio, M. Kachi, and K. Okamoto, 2007: Global Precipitation Map using Satelliteborne Microwave Radiometers by the GSMaP Project : Production and Validation, *IEEE Trans. Geosci. Remote Sens.*, **45**, No. 7, 2259-2275, https://doi.org/10.1109/TGRS.2007.895337.

- Aonashi, K., J. Awaka, M. Hirose, T. Kozu, T. Kubota, G. Liu, S. Shige, S., Kida, S. Seto, N.Takahashi, and Y. N. Takayabu, 2009: GSMaP passive, microwave precipitation retrieval algorithm: Algorithm description and validation. *J. Meteor. Soc. Japan*, **87A**, 119-136, https://doi.org/10.2151/jmsj.87A.119.

- T. Ushio, T. Kubota, S. Shige, K. Okamoto, K. Aonashi, T. Inoue, N., Takahashi, T. Iguchi, M.Kachi, R. Oki, T. Morimoto, and Z. Kawasaki, 2009: A Kalman filter approach to the Global Satellite Mapping of Precipitation (GSMaP) from combined passive microwave and infrared radiometric data. *J. Meteor. Soc. Japan*, **87A**, 137-151, https://doi.org/10.2151/jmsj.87A.137.

- Mega, T., T. Ushio, M. T. Matsuda, T. Kubota, M. Kachi, and R. Oki, 2019: Gauge-adjusted global satellite mapping of precipitation. *IEEE Trans. Geosci. Remote Sens.*, **57.4**, 1928-1935, https://doi.org/10.1109/TGRS.2018.2870199.

8. Acknowledgments

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