Precipitation Processing System (PPS)

Algorithm Theoretical Basis Document (ATBD)

NASA Global Precipitation Measurement (GPM) Level 1C Algorithms

Version 1.6

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REVISION HISTORY

Mod. #	Mod. Date	Description	Section Affected
1 (V1.3)	5/2014	Added two generic quality flags (-7 and -10).	Section 4
2 (V1.3)	5/2014	Added new section L1C-R GMI.	Appendix B
3 (V1.4)	3/2015	Added along-scan correction for GMI in Section A.3.1 and RFI warning check in Section A.4.1.	Appendix A
4 (V1.4)	3/2015	Added information for SSMI/S F19 in Sections D.3.1.2, D.3.1.3, D.3.1.6, and Table D-1.	Appendix D
5 (V1.4)	3/2015	Updated the intercalibration table for AMSR2 to 1C.GCOMW1.AMSR2.XCAL2014a-V.tbl in Section E.3 and Table E-1.	Appendix E
6 (V1.5)	2/2016	Added Tb to GMIBASE in Section A.1.1; removed Ta to Tb conversion from Section A.3.	Appendix A
7 (V1.5)	2/2016	Added Tb to TMIBASE in Section C.1.1, removed Ta to Tb conversion from Section C.3, and implemented the satellite intercalibration table XCAL2015-V in Section C.3.	Appendix C
8 (V1.5)	2/2016	Moved SSMI/S corrections performed by CSU from Section D.3 to section D.2, updated the intercalibration table version to XCAL2015-V in Section D.3 and Table D-1, and added SSMI/S sensor quality flag -126 in Section D.4.2.	Appendix D
9 (V1.5)	2/2016	Added incidence angles for each low-frequency channel to the AMSR2BASE file in Section E.2; updated the intercalibration table version to XCAL2015-V in Section E.3 and Table E-1.	Appendix E
10 (V1.5)	2/2016	Corrected ATMS channel frequencies and number of swaths in Section F.1.2; updated the intercalibration table version to XCAL2015-V in Section F.3 and Table F-1.	Appendix F
11 (V1.5)	2/2016	Updated the SAPHIR intercalibration table version to XCAL2015-V in Section G.3 and Table G-1; added checks for geolocation quality in Section G.4.1.	Appendix G
12 (V1.5)	2/2016	Corrected MHS channel frequencies in Section H.1.2, moved Ta to Tb conversion from Section H.3 to Section H.2, and updated the intercalibration table version to XCAL2015-V in Section H.3 and Table H-1.	Appendix H
12 (V1.5)	2/2016	Added new Appendix I.	Appendix I
13 (V1.6)	4/2016	Added -127 Error in Section D.4.2.	Appendix D

Notes: Version 1.4 changes apply to L1C product versions V03C (GMI, AMSR2), V02B (TMI, MHS, ATMS), V02C (SSMI/S F16, F17, F18) and V03A (SSMI/S F19). Version 1.5 and 1.6 changes apply to L1C product version V04 (GMI, TMI, SSMI/S, AMSR2, ATMS, SAPHIR, and MHS).

1. INTRODUCTION

The Level 1C (L1C) algorithms are a collection of algorithms that produce common calibrated brightness temperature products for the Global Precipitation Measurement (GPM) Core and Constellation satellites.

1.1 OBJECTIVE

This document describes the GPM Level 1C algorithms. It consists of physical and mathematical bases for orbitization, satellite intercalibration, and quality control (QC), as well as the software architecture and implementation for the Level 1C algorithms.

1.2 L1C ALGORITHMS OVERVIEW

The Level 1C algorithms transform equivalent Level 1B radiance data into Level 1C products. The input source data are geolocated and radiometric calibrated antenna temperature (Ta) or brightness temperature (Tb). The output Level 1C products are common intercalibrated brightness temperature (Tc) products using the GPM Microwave Imager (GMI) as the reference standard.

The Level 1C algorithms contain the following major components:

- Orbitization.
- Satellite intercalibration.
- Quality control.
- Ancillary data calculations.

The detail of L1C algorithms and implementation depends on the details of each sensor. In this document, the Level 1C algorithms are described in a general sense. Individual sensor-specific details are provided separately in Appendices A through H: A) GMI, B) LIC-R GMI, C) Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI), D) Special Sensor Microwave Imager/Sounder (SSMI/S), E) Advanced Microwave Scanning Radiometer 2 (AMSR2), F) Advanced Technology Microwave Sounder (ATMS), G) Sondeur Atmospherique du Profil d'Humidite Intertropicale par Radiometrie (SAPHIR), and H) Microwave Humidity Sounder (MHS).

1.3 L1C INPUT DATA DESCRIPTION

The input data to the Level 1C process are equivalent Level 1B radiance data. The input source to the L1C process is different for each sensor. Input data are geolocated, and radiometric calibrated antenna temperature (Ta) or brightness temperature (Tb) depending on the data availability from each sensor. An input data file could be an orbit with an arbitrary starting point or any arbitrary length. The input data format could be in binary, Network Common Data Form (NetCDF), or Hierarchical Data Format (HDF), etc.

Detailed information on the L1C input data description for each sensor is included in the Appendices.

1.4 L1C PRODUCTS DESCRIPTION

The standard Level 1C products are the intercalibrated microwave brightness temperatures. All L1C products have a common format and are in HDF5. The format is designed to be simple and generic. One or more swaths are included in a product; a swath is defined as scan time, latitude, longitude, and data that match the latitude and longitude (lat/lon). Each swath includes scan time, latitude, longitude, scan status, quality, incidence angle, Sun glint angle, and the intercalibrated brightness temperature (Tc). The granule size is one orbit, which begins and ends at the southernmost point. There is no overlap scan in the standard L1C products.

A more detailed L1C product description for each sensor is included in the Appendices.

2. <u>ORBITIZATION</u>

The orbitization process reorbitizes and reformats multiple input files into an intermediate base file. The base file is a GPM standard orbital file that begins and ends at the southernmost point. It is written in a base format that preserves all of the information from the input but is written out in HDF5.

The purpose of orbitization is to prepare a standard orbital file in the same format for the succeeding L1C intercalibration process. The use of the base file allows the Intercalibration Working Group (X-CAL) to experiment with different intercalibration algorithms without having to read the inputs in several different formats and without having to reorbitize the data.

The orbitization process is needed only when the input files do not conform to the GPM standard orbit format. L1C GMI and L1C TMI processes do not need the orbitization process because their input source files (GMIBASE and TMIBASE, respectively) are already GPM standard orbital files. The major components in the orbitization process include orbit boundary derivation and data reorbitization.

2.1 ORBIT BOUNDARY DERIVATION

The orbit start (and end) point is the beginning of scan nearest the instant in time when the satellite reaches the southernmost point in its orbit, independent of where each instrument happens to be pointing at that instant. The southernmost point in orbit was chosen to avoid the undesirable granule boundaries in the tropics, over Japan, and over ground validation (GV) sites (most of which are in the northern hemisphere). The North American Aerospace Defense Command (NORAD) two-line element (TLE) and a simplified General Perturbations Satellite Orbit Model 4 (SGP4) orbital model were used in the L1C process to derive the orbit boundaries [Hoots and Roehrich, 1980].

2.1.1 <u>Two-Line Element (TLE)</u>

A two-line element set is a set of orbital elements that describe the orbit of an Earth satellite. The TLE is in a format specified by NORAD and used by NORAD and the National Aeronautics and Space Administration (NASA). The TLE can be used directly by the SGP4 model to compute the precise position of a satellite at a particular time.

The following is an example of a TLE:

1 25544U 98067A   08264.51782528 -.00002182 00000-0 -11606-4 0 2927
2 25544   51.6416 247.4627 0006703 130.5360 325.0288 15.72125391563537

The meaning of these data is as follows:

LINE 1

Field	**Columns**	**Content**	**Example**
1	01-01	Line number	1
2	03-07	Satellite number	25544
3	08-08	Classification (U=Unclassified)	U
4	10-11	International designator (last two digits of launch year)	98
5	12-14	International designator (launch number of the year)	067
6	15-17	International designator (piece of the launch)	A
7	19-20	Epoch year (last two digits of the year)	08
8	21-32	Epoch (day of the year and fractional portion of the day)	264.51782528
9	34-43	First time derivative of the mean motion divided by two	-.00002182
10	45-52	Second time derivative of mean motion divided by six (decimal point assumed)	00000-0
11	54-61	B-Star drag term (decimal point assumed)	-11606-4
12	63-63	The number 0 (originally this should have been "ephemeris type")	0
13	65-68	Element number	292
14	69-69	Checksum (Modulo 10)	7

LINE 2

Field	**Columns**	**Content**	**Example**
1	01-01	Line number	2
2	03-07	Satellite number	25544
3	09-16	Inclination (degrees)	51.6416
4	18-25	Right ascension of the ascending node (degrees)	247.4627
5	27-33	Eccentricity (decimal point assumed)	0006703
6	35-42	Argument of perigee (degrees)	130.5360
7	44-51	Mean anomaly (degrees)	325.0288
8	53-63	Mean motion (revolutions per day)	15.72125391
9	64-68	Revolution number at epoch (revolutions)	56353
10	69-69	Checksum (Modulo 10)	7

2.1.2 SGP4

The Simplified General Perturbations Satellite Orbit Model 4 (SGP4) is a NASA/NORAD algorithm that calculates the orbital state vectors of near-Earth satellites relative to the Earth Centered Inertial coordinate system. TLE data should be used as the input for the SGP4 algorithm. The accuracy of SGP4 is typically about 1 km in position. More details about TLE and SGP4 can be found in Spacetrack Report No. 3 [Hoots and Roehrich, 1980].

2.1.3 Daily Orbit Start/Stop Times Generation

Each day, TLEs for satellites of interest (e.g., F16, F17, F18, NOAA-18, METOP-A, etc.) are obtained automatically from the Spacetrack site and the U.S. Army STRATCOM message system, and the TLE data are stored in the PPS database. The ostFinderTLE algorithm, which utilizes the SGP4 model, then is run using these TLE data. The algorithm computes the satellite positions throughout the day and identifies the orbit start/stop times (orbit definition) by searching the times when the satellite reaches the lowest position (in Z component). It then outputs these orbit start/stop times and orbit numbers to an orbit definition file for each orbit identified during the day. These orbit definition data are then registered in the database and can be used in the succeeding data reorbitization process.

The very first orbit definition is created manually by assigning an initial orbit number. After that, the ostFinderTLE will automatically increment the orbit number by one from the previous orbit definition. This process is done only once per day. Once the orbit definition data are created during the initial processing, they will not change during the reprocessing.

2.2 DATA REORBITIZATION

In most cases, it takes two or three input files to create one GPM standard orbit file. This process is done by the L1CBASE algorithms. The inputs to L1CBASE are: Input filenames, orbitNumber, orbitStartDate, orbitStartTime, orbitStopDate, and orbitStopTime. The output is a standard base file; it is standard in the sense that it has been reorbitized to a GPM standard orbit and reformatted into a common HDF5 format. The base file preserves all information from the input and is used as the input to the succeeding L1C intercalibration algorithms.

The L1CBASE algorithms read multiple input files. For each sensor, the input is in a specific format (binary, NetCDF, HDF, etc.), and therefore different code applying to each format is used to read the input files. The scan time is used to check whether the current scan data fall within the desired L1C orbit boundary and determine whether they should be written to the output file. The algorithm also checks for missing scans and fills in missing data if found. In the case of antenna temperature (Ta) being provided in the input data, the antenna pattern correction (APC) coefficients are applied to convert Ta to brightness temperature (Tb). The APC coefficients and conversion code used are provided from the data source. An empty granule is generated if no scan was extracted from the input files. Scan data are reformatted into the base file format and written to the output base file using the PPS Science Algorithm Input/Output Toolkit (TKIO).

A minimum of processing, other than reorbitizing, reformatting, and Ta to Tb conversion is done in the L1CBASE algorithm. This algorithm simply preserves all information from the input data and creates a uniform, standard base file for further L1C processing. Some additional parameters such as incidence angle, Sun glint angle, solar beta angle, etc. may be computed and output to the base file to support the X-CAL Working Group's intercalibration analysis.

3. SATELLITE INTERCALIBRATION ALGORITHMS

Producing intercalibrated brightness temperature data from different satellites depends on the details of each sensor. The GPM L1C implementation uses GMI as the reference standard.

The physical and mathematical bases of satellite intercalibration are provided separately for each individual sensor in the Appendices by the X-CAL Working Group.

For each sensor and satellite, an intercalibration table provided by the X-CAL team is implemented in the L1CXCAL algorithm to produce the intercalibrated brightness temperature (Tc). The intercalibration table consists of a series of tie points and offsets for each channel. The table has a generic format: It contains two lines of information for each channel. The first column contains the channel number from 1 to N, and the second column contains the number of tie points for that channel. The remaining values in the first line consist of the temperature values in Kelvin for each tie point, and the second line contains the calibration offset values in Kelvin for each tie point. For a particular channel, the first offset value is used for pixels with Tb less than the first tie point. For pixels with Tb larger than the last tie point, the last offset value is used. And for pixels with Tb between two tie points, an interpolated value from the two corresponding offsets is used. Note that the resulting offset values are added to the Tb so the final intercalibrated brightness temperature is Tc= Tb + offset.

4. QUALITY CONTROL

To ensure the consistency among all L1C algorithms, all data are checked and quality flags (QFs) are assigned. L1C quality flags contain two sets of flags. The first set is the generic flags that apply to all sensors, and the second set is the sensor-specific flags that vary from sensor to sensor.

The general specification is as follows:

0	Good data.	
-99	Missing values (no quality information available).	
Positive value	Cautionary warning flags; brightness temperatures are retained.	
	1 – 99	Generic flags for all sensors.
	100 – 127	Sensor-specific flags.
Negative value	Major error flags; brightness temperatures are set to missing values.	
	(-1) – (-98)	Generic flags for all sensors.
	(-100) – (-127)	Sensor-specific flags.

The following generic quality flags are set for data of questionable quality. The corresponding brightness temperatures are retained; however, it is advised to use caution with these values.

0 Good.
1 Possible Sun glint, 0 <= sunGlintAngle < 20 degrees.
2 Possible radio frequency interference.
3 Degraded geolocation data.
4 Data corrected for warm load intrusion.

The following generic quality flags are set for failing catastrophic tests. As a result, in each of these cases the resulting brightness temperatures are set to missing values.

-1 Data are missing from file or are unreadable.
-2 Invalid Tb or nonphysical brightness temperature (Tb < 50K or Tb > 350K).
-3 Error in geolocation data.
-4 Data are missing in one channel.
-5 Data are missing in multiple channels.
-6 Latitude/longitude values are out of range.
-7 Non-normal status modes.
-10 Distance to corresponding LF pixel > 7 km (used in L1C-R product only).

The missing values used in L1C algorithms are as follows:

MISSING_FLOAT	-9999.9
MISSING_DOUBLE	-9999.9
MISSING_INT	-9999
MISSING_SHORT	-9999
MISSING_BYTE	-99

Detailed quality control procedures and sensor-specific quality flags for each radiometer are discussed in the Appendices.

5. ANCILLARY DATA CALCULATIONS

Various geometric ancillary data such as solar beta angle, Earth incidence angle, and Sun glint angle are calculated during the L1C process if the input source does not contain such data. The details can be obtained from the PPS GPM Geolocation Toolkit Algorithm Theoretical Basis Document (ATBD).

6. LEVEL 1C PROCESSING

This section documents the software architecture overview and details for Level 1C processing. Level 1C processing is further divided into three steps: 1) orbit boundaries derivation, 2) data reorbitization, and 3) satellite intercalibration.

Not all sensors require all three steps in their L1C processing. For sensors such as GMI and TMI, the input file is already in GPM standard orbital base file format; therefore, processing steps one and two can be omitted.

6.1 ORBIT BOUNDARIES DERIVATION PROCESSING

Orbit boundaries derivation processing uses the ostFinderTLE algorithm. It generates the daily orbit definition file (also called orbit start/stop times [OST] file) for a given date and satellite. Each orbit definition file contains the start time, stop time, and orbit number information for all orbits in one day. Orbit definition data are then registered in the database and to be used in succeeding data reorbitization processing. This processing is done only once per day for each satellite of interest.

6.1.1 Activation

The scheduler spawns the ostFinderTLE executable once per day for each of the partner satellites. Command line usage:

ostFinderTLE   jobName   inputParameterFile

jobName – A given string assigned to this job.
inputParameterFile – A text file that lists all the input parameters using “key=value” format.

The following is an example of the inputParameterFile:

```
platform=MT1
date=2012-09-10
preorbitnumber=4715
preorbittaistop=810772044.7
outfilename=~jchou/ostXML/MT1/MT1.20120910.V01A.ORBDEF.xml
maxmissingdays=5
outtype=XML
tle1=1 37838U 11058A   12253.88247965 +.00000263 +00000-0 +00000-0 0 0239
tle2=2 37838 019.9744 213.1232 0009138 044.0573 316.0558 14.0969828604711
```

Input parameters:

platform – Satellite ID.
date – Date in YYYY-MM-DD format.
tle1 – Line 1 of the nearest TLE.
tle2 – Line 2 of the nearest TLE.
preorbitnumber – Previous orbit number.
preorbittaistop – Stop time of the previous orbit in TAI format.
outfilename –The output daily orbit definition filename.
maxmissingdays – The number of days allowed for missing TLEs.
outtype – Output type (text or Extensible Markup Language [XML]).

Output files:

The output of ostFinderTLE is the orbit definition file containing all of the orbits found during the given date. Orbit definition file is in XML format and is to be used for registering orbit information in the database. The following is an example of the daily orbit definition file (MT1.20131201.V01A.ORBDEF.xml):


```
<?xml version="1.0" encoding="UTF-8"?>

<!--
This is the XML version of the orbit start times file for 2013-12-01.
-->

<ost:orbitStartTimes
 xmlns:ost="ost"
 xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
 xsi:schemaLocation="OST.xsd">

   <orbit platform="MT1" number="11031" action="insert">
     <startTime format="tai">849393336.300000</startTime>
     <stopTime format="tai">849399452.300000</stopTime>
     <longOfMaxLat>63.823701</longOfMaxLat>
     <timeEventFlag>0</timeEventFlag>
     <ephemQualityFlag>0</ephemQualityFlag>
     <meanSolarBetaAngle>-9.997960</meanSolarBetaAngle>
     <longitudeOnEquator>-19.677301</longitudeOnEquator>
     <timeOnEquator format="tai">849394864.219631</timeOnEquator>
     <timeOnEquator format="utc">2013-11-30 23:00:52.219</timeOnEquator>
     <startTimeAdjusted>2013-11-30 22:35:24</startTimeAdjusted>
     <stopTimeAdjusted>2013-12-01 00:17:19</stopTimeAdjusted>
     <dailyNumber>1</dailyNumber>
   </orbit>
   <orbit platform="MT1" number="11032" action="insert">
     <startTime format="tai">849399452.300000</startTime>
     <stopTime format="tai">849405568.300000</stopTime>
     <longOfMaxLat>37.857946</longOfMaxLat>
     <timeEventFlag>0</timeEventFlag>
     <ephemQualityFlag>0</ephemQualityFlag>
     <meanSolarBetaAngle>-9.876040</meanSolarBetaAngle>
     <longitudeOnEquator>-45.656330</longitudeOnEquator>
     <timeOnEquator format="tai">849400980.018973</timeOnEquator>
     <timeOnEquator format="utc">2013-12-01 00:42:48.018</timeOnEquator>
     <startTimeAdjusted>2013-12-01 00:17:20</startTimeAdjusted>
     <stopTimeAdjusted>2013-12-01 01:59:15</stopTimeAdjusted>
     <dailyNumber>2</dailyNumber>
   </orbit>
   <orbit platform="MT1" number="11033" action="insert">
```

```
    <startTime format="tai">849405568.300000</startTime>
    <stopTime format="tai">849411684.300000</stopTime>
    <longOfMaxLat>11.892200</longOfMaxLat>
    <timeEventFlag>0</timeEventFlag>
    <ephemQualityFlag>0</ephemQualityFlag>
    <meanSolarBetaAngle>-9.754979</meanSolarBetaAngle>
    <longitudeOnEquator>-71.635359</longitudeOnEquator>
    <timeOnEquator format="tai">849407095.818508</timeOnEquator>
    <timeOnEquator format="utc">2013-12-01 02:24:43.818</timeOnEquator>
    <startTimeAdjusted>2013-12-01 01:59:16</startTimeAdjusted>
    <stopTimeAdjusted>2013-12-01 03:41:11</stopTimeAdjusted>
    <dailyNumber>3</dailyNumber>
  </orbit>
  <orbit platform="MT1" number="11034" action="insert">
    <startTime format="tai">849411684.300000</startTime>
    <stopTime format="tai">849417799.300000</stopTime>
    <longOfMaxLat>-14.131845</longOfMaxLat>
    <timeEventFlag>0</timeEventFlag>
    <ephemQualityFlag>0</ephemQualityFlag>
    <meanSolarBetaAngle>-9.634772</meanSolarBetaAngle>
    <longitudeOnEquator>-97.614389</longitudeOnEquator>
    <timeOnEquator format="tai">849413211.618235</timeOnEquator>
    <timeOnEquator format="utc">2013-12-01 04:06:39.618</timeOnEquator>
    <startTimeAdjusted>2013-12-01 03:41:12</startTimeAdjusted>
    <stopTimeAdjusted>2013-12-01 05:23:06</stopTimeAdjusted>
    <dailyNumber>4</dailyNumber>
  </orbit>
  <orbit platform="MT1" number="11035" action="insert">
    <startTime format="tai">849417799.300000</startTime>
    <stopTime format="tai">849423915.300000</stopTime>
    <longOfMaxLat>-40.097575</longOfMaxLat>
    <timeEventFlag>0</timeEventFlag>
    <ephemQualityFlag>0</ephemQualityFlag>
    <meanSolarBetaAngle>-9.515421</meanSolarBetaAngle>
    <longitudeOnEquator>-123.593420</longitudeOnEquator>
    <timeOnEquator format="tai">849419327.418155</timeOnEquator>
    <timeOnEquator format="utc">2013-12-01 05:48:35.418</timeOnEquator>
    <startTimeAdjusted>2013-12-01 05:23:07</startTimeAdjusted>
    <stopTimeAdjusted>2013-12-01 07:05:02</stopTimeAdjusted>
    <dailyNumber>5</dailyNumber>
  </orbit>
  :
  :
</ost:orbitStartTimes>
```

6.1.2 Execution

The flow chart for executing the ostFinderTLE program is shown in Figure 1.

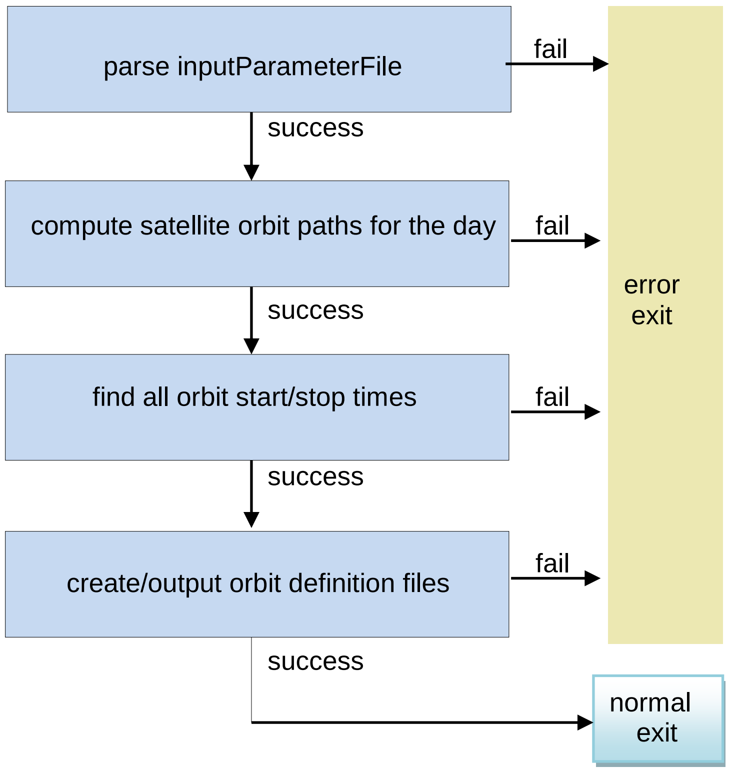

Figure 1. Flow Chart for Executing the ostFinderTLE Program

6.1.3 Termination

When ostFinderTLE finishes execution, successfully or otherwise, it passes a return code to the scheduler and stops. The return code tells the scheduler the reason for termination. The following return states are defined:

- 1 Problem reading input (i.e., no orbit definition file created).
- 2 Problem creating output (i.e., no orbit definition file created).
- 0 Normal termination (i.e., orbit definition files created).

6.2 DATA REORBITIZATION PROCESSING

Data reorbitization processing processes the L1CBASE algorithms. It reorbitizes and reformats multiple input files into one standard GPM base file for each radiometer of interest in the GPM Constellation. Each radiometer has a different executable for the reorbitization processing. Current L1CBASE algorithms include L1CBASEssmis, L1CBASEamsr2, L1CBASEsaphir, L1CBASEatms, and L1CBASEmhs. More will be added when more satellites join the constellation. However, all L1CBASE algorithms follow the same procedure and have the same command line usage.

6.2.1 Activation

The scheduler spawns the L1CBASE program, for example L1CBASEssmis for the SSMI/S sensor, as an autonomous process upon the availability of input granules.

Command line usage:

L1CBASEssmis   jobName   inputParameterFile

jobName – A given string assigned to this job.
inputParameterFile – A text file that lists all the input parameters using "key=value" format.

The following is an example of the inputParameterFile:

```
infile=/SSMIS_TDR/US058SORBRAWspp.tdris_f16_d20121102_s070600_e082800_r46653_c
fnoc.raw
infile=/SSMIS_TDR/US058SORBRAWspp.tdris_f16_d20121102_s082400_e104100_r46654_c
fnoc.raw
infile=.... (as many as needed to fill an orbit)
outfile=/data/L1Cdata/1Base.F16.SSMIS.TB2014.20121102-S080250-
E094445.046652.V00A.HDF5
orbitNumber=46652
platform=F16
ostfile=/ostXML/F16/F16.20121102.V01A.ORBDEF.xml
tle1=1 28054U 03048  A 12307.21145571  .00000105  00000-0  00000+0 0  4386
tle2=2 28054  98.6112 306.6220 0006951 231.8098 128.2996 14.13456952466518
dataPath=/1cXcal/staticFiles/SSMIS/
```

Input parameters:

infile – Input SSMI/S Temperature Data Record (TDR) binary filename.
outfile – Output SSMIBASE HDF5 filename.
orbitNumber – Orbit number.
platform – Satellite ID.
ostfile – Daily orbit definition file.
tle1 – Nearest TLE line 1 data.
tle2 – Nearest TLE line 2 data.
datapath – The directory path containing static data needed during processing for SSMI/S.

6.2.2 Execution

The flow chart for executing the L1CBASE program is shown in Figure 2.

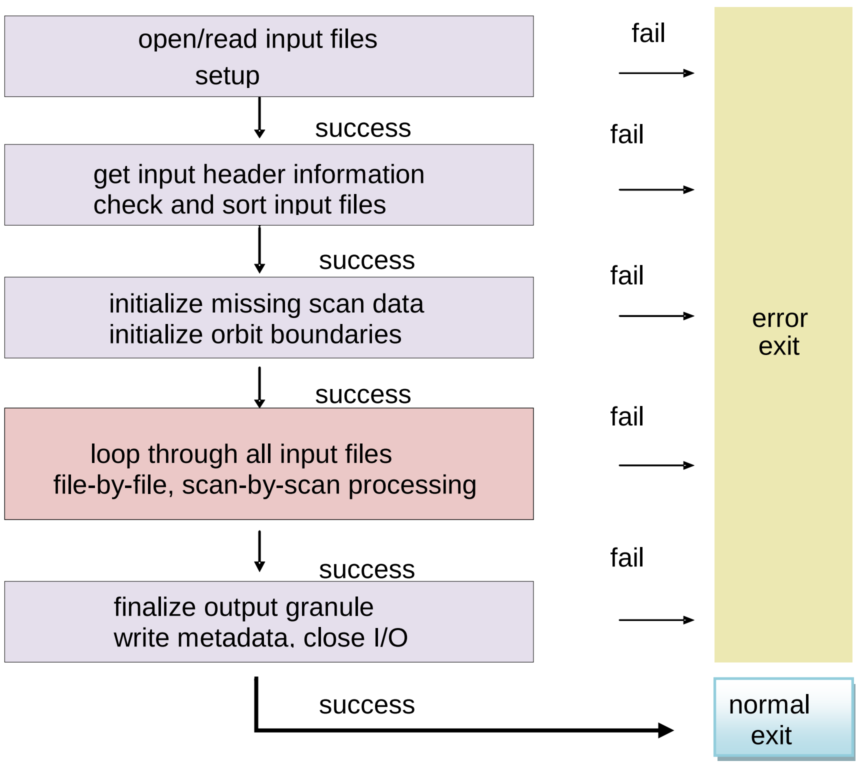

Figure 2. Flow Chart for Executing the L1CBASE Program

The flow chart for executing the file-by-file, scan-by-scan process is shown in Figure 3. If unsuccessful, the program exits with an error report.

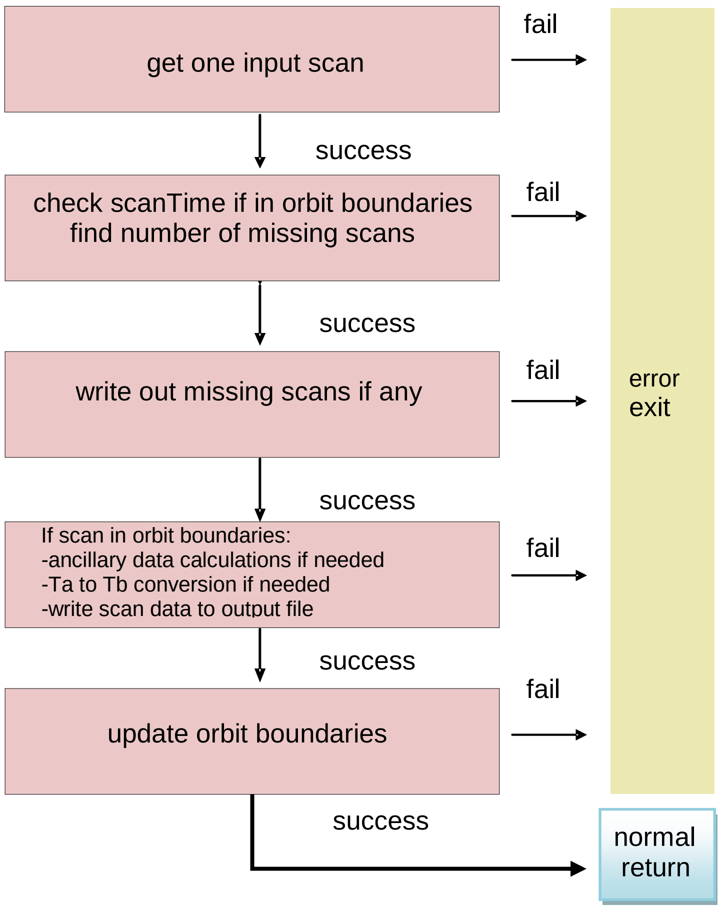

Figure 3. Flow Chart for Executing the L1CBASE File-by-File, Scan-by-Scan Processing

6.2.3 <u>Termination</u>

When L1CBASE finishes execution, successfully or otherwise, it passes a return code to the scheduler and stops. The return code tells the scheduler the reason for termination. The following return states are defined as follows:

0	Normal termination (i.e., L1CBASE created).
99	Empty granule created (i.e., L1CBASE created, but it is an empty granule).
Others	Error termination, program failed.

6.3 INTERCALIBRATION PROCESSING

Intercalibration processing processes the L1CXCAL algorithms. It performs satellite intercalibration and quality control and creates the L1C products for the GPM Core and Constellation satellites. Each sensor has a different executable for the L1C intercalibration processing. Current L1C includes L1CXCALgmi, L1CXCALtmi, L1CXCALssmis, L1CXCALamsr2, L1CXCALsaphir, L1CXCALatms, and L1CXCALmhs. However, all L1CXCAL algorithms follow the same procedure and have the same command usage.

6.3.1 Activation

The scheduler spawns the L1CXCAL program, for example L1CXCALgmi for GMI, as an autonomous process upon the availability of the input GMIBASE granule.

Command line usage:

```
L1CXCALgmi  jobName  inputParameterFilename
```

Example of inputParameterFile:

```
infile=1Base.GPM.GMI.TA2014.20140412-S080250-E094445.000652.V00A.HDF5
outfile=1C.GPM.GMI.XCAL2014-N.20140412-S080250-E094445.000652.V00A.HDF5
dataPath=/1cXcal/staticFiles/GMI/
```

Input parameters:

infile – Granule ID of the input base granule.
outfile – Granule ID of the L1C granule that is to contain the output data.
dataPath – Directory path to the static data files needed during processing.

6.3.2 Execution

The flow chart for executing the L1CXCAL program is shown in Figure 4.

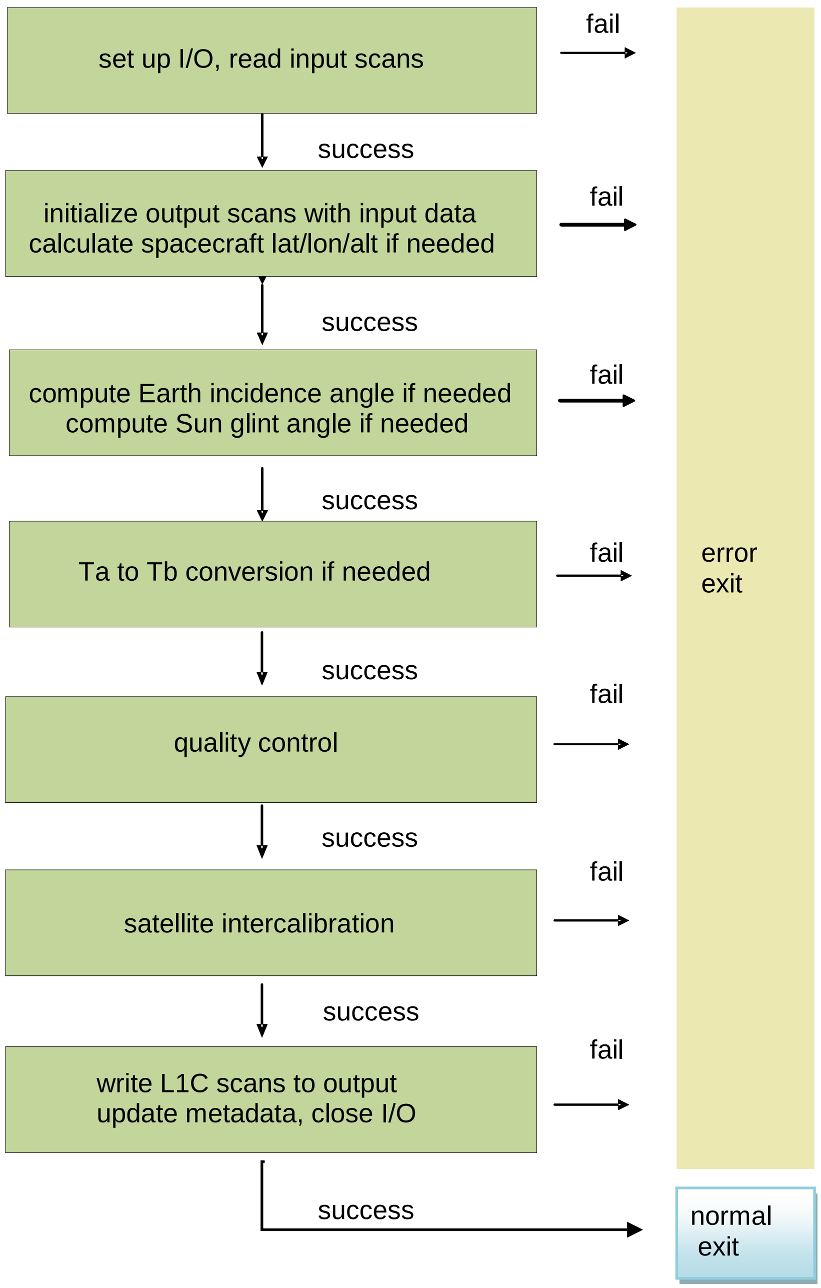

Figure 4. Flow Chart for Executing the L1CXCAL Program

6.3.3 Termination

When L1CXCAL finishes execution, successfully or otherwise, it passes a return code to the scheduler and stops (ceasing to exist as a spawned process). The return code specifies the reason for termination to the scheduler. The following return states are defined:

0	Normal termination (i.e., L1C created).
99	Empty granule created (i.e., L1C created, but it is an empty granule).
Others	Error termination, program failed.

6.3.4 Static Data Files

Various algorithms within the Level 1C intercalibration processing require some parameters. The values are set manually to some initial values (during prelaunch software development) and will possibly be changed by scientists throughout the mission depending on observation of the algorithm performance and external physical changes. A list of these static data files can be obtained in the Appendices for each sensor.

7. REFERENCES

1. Hoots, F. R., and R. L. Roehrich, 1980: Spacetrack Report No. 3, Models for Propagation of NORAD Element Sets, December 1980.

APPENDIX A. L1C GMI

A.1 INTRODUCTION

This document describes sensor-specific information for the GPM Level 1C GMI algorithm.

A.1.1 L1C GMI Input Data Description

The GPM Microwave Imager L1C product is derived from GPM GMIBASE data. GMIBASE contains GMI brightness temperatures (Tb) and is in HDF format. Details about the data content and format can be obtained from the GPM PPS GMIBASE File Specification Document. Details of GMI calibration and corrections are documented in the PPS GMI L1B Algorithm Theoretical Basis Document (ATBD).

A.1.2 L1C GMI Product Description

L1CGMI contains common calibrated brightness temperatures from the GMI passive microwave instrument flown on the GPM satellite. L1CGMI has two swaths. Swath S1 has nine channels that are similar to TRMM TMI (10V, 10H, 19V, 19H, 23V, 37V, 37H, 89V, and 89H). Swath S2 has four channels similar to the Advanced Microwave Sounding Unit – B (AMSU-B) (166V, 166H, 183+/-3V, and 183+/-7V). Data for both swaths are observed in the same revolution of the instrument.

Relation between the swaths: Swath S2 has the same number of scans and the same number of pixels as swath S1. Each S1 scan contains nine channels sampled 221 times along the scan. Each S2 scan contains four channels sampled 221 times along the scan. Since the incidence angle of swath S1 is different than swath S2, the geolocations of the pixel centers are different.

Details about the data content and format can be obtained from the GPM PPS L1C GMI File Specification Document.

A.2 ORBITIZATION

No orbitization process was done to the input source (GMIBASE) since it is already a GPM orbital base file and contains all the information needed for the satellite intercalibration process.

A.3 SATELLITE INTERCALIBRATION

The GPM GMI brightness temperatures have been defined as the calibration reference for the GPM constellation. As a result, no changes were made to the GMI brightness temperature (Tb).

A.4 QUALITY CONTROL

A.4.1 Quality Control Procedures

The following quality control procedures were implemented for GMI.

Scan-level checking:

1. Scan check for missing scan: Missing scans are flagged, and all parameter values except scanTime are set to missing.
2. Scan check for bad data quality: Scans with dataQuality not equal to 0 are flagged accordingly, and all pixel Tc values are set to missing.

Pixel-level checking:

1. Pixel check for missing Tc: Pixels with missing Tc are flagged, and Tc values are set to missing for that channel.
2. Pixel check for nonphysical Tc: Pixels with brightness temperature values outside the physical limits (currently 50K to 350K) are flagged, and Tc is set to missing for that channel.
3. Pixel check for out-of-range latitude/longitude values: Pixels with latitude/longitude values outside of range (-75 to 75 and -180 to 180) are flagged, and latitude, longitude, and Tc are set to missing.
4. Pixel check for possible Radio Frequency Interference (RFI): Pixels with RFIFlag greater than 0 are flagged as possible RFI warning.
5. Pixel check for possible Sun glint: Pixels with Sun glint angle values greater than or equal to 0 and less than 20.0 degrees are flagged as possible Sun glint warning.
6. Pixel check for blanking: Pixels with sampleHeader.blanking=1 are flagged as blinking warning.

A.4.2 <u>Quality Flag Values and Definition</u>

Generic quality flags:

0 Good.
1 Warning – Possible Sun glint, 0 <= sunGlintAngle < 20 degrees.
2 Warning – Possible radio frequency interference.
3 Warning – Degraded geolocation data.
4 Warning – Data corrected for warm load intrusion.
-1 Error – Data are missing from file or are unreadable.
-2 Error – Invalid Tb or nonphysical brightness temperature (Tb < 50K or Tb > 350K).
-3 Error – Error in geolocation data.
-4 Error – Data are missing in one channel.
-5 Error – Data are missing in multiple channels.
-6 Error – Latitude/longitude values are out of range.
-7 Error – Non-normal status modes.
-10 Distance to corresponding low-frequency (LF) pixel > 7 km (used in L1C-R product only).

Sensor-specific quality flags:

100 Warning – Scan blanking is on.

A.5 STATIC DATA FILES

Table A-1 summarizes the current list of static data files used in the L1CXCALgmi algorithm.

Table A-1. List of Static Data Files for L1C GMI

File Name	Description
1C.GPM.GMI.XCAL2015-C.tbl	Intercalibration Tb offset table

A.6 REFERENCES

1. PPS GPM GMIBASE File Specification.
2. PPS GPM L1CGMI File Specification.
3. PPS GPM GMI L1B Algorithm Theoretical Basis Document (ATBD).

APPENDIX B. L1C-R GMI

B.1 INTRODUCTION

This document describes the GPM Level 1C-R GMI algorithm.

B.1.1 L1C-R GMI Input Data Description

The GPM Microwave Imager L1C-R product is derived from GPM L1C GMI data. L1C GMI contains common calibrated brightness temperatures. Details are described in Appendix A.

Two L1C GMI orbits are required to create a L1C-R orbit: A main L1C GMI orbit and its previous or next orbit, depending on the instrument viewing direction.

B.1.2 L1C-R GMI Product Description

L1C-R GMI is a re-mapped/co-registered version of L1C GMI. Its data format is identical to L1C GMI.

L1C-R is the input for the Goddard Profiling Algorithm (GPROF). The L1C-R Swath S1 (Low-Frequency channels) is the same as the L1C Swath S1. However, the L1C-R Swath S2 (High-Frequency [HF] channels) consists of pixels selected from L1C Swath S2 to be as close as possible to the S1 pixels. The L1C-R S2 pixels will often be observed at a different scantime and sometimes from a different orbit than the corresponding S1 pixels. Since L1C S2 is narrower than L1C S1, L1C-R S2 has missing pixels on both edges of the swath.

B.2 CO-REGISTRATION

The L1C GMI Swath S2 (HF channels) scan does not quite match the Swath S1 (LF channels) scan geometry, and the view angle is off by almost 4 degrees. To address this issue, the L1CRgmi algorithm co-registers/collocates the L1C GMI HF field-of-view (FOV) position to bring it as close to the corresponding LF FOV position as possible using the nearest-neighbor matching approach.

Figure B-1 shows the L1C GMI Swath S1 Low-Frequency scan (in color black) and the corresponding Swath S2 High-Frequency scan (in color blue) positions, as well as the resulting matched L1C-R GMI Swath S2 High-Frequency scan (in color red). After the co-registration, the GMI L1C-R HF scan stays close to the corresponding LF scan.

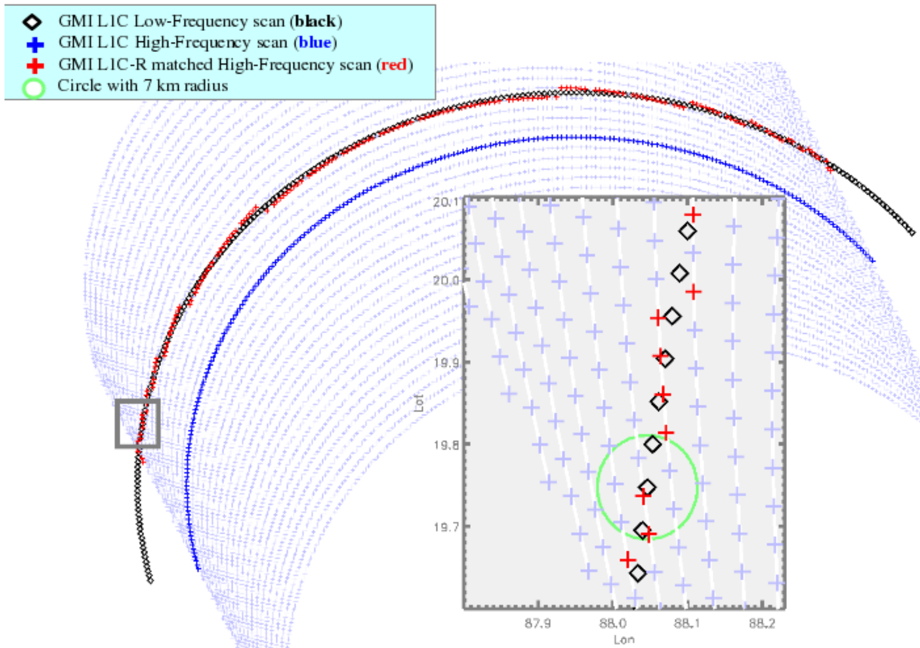

Figure B-1. L1C GMI and L1C-R GMI Swath S1 and S2 Scan Positions

B.2.1 Initial Matching Position

A mean pix/scan offsets table (a function of LF pixel indices) was pre-constructed and used to obtain the initial S2 HF pixel matching position. (This table was provided by Wesley Berg, Colorado State University [CSU].)

For example, a LF pixel at position (pixel, scan)=(p,s), the initial HF matching position (pix0, scan0) will be:

pix0 = p + mean_pixel_offset(p)

scan0 = s + mean_scan_offset(p) if SCorientation=0 (looking forward)

scan0 = s - mean_scan_offset(p) if SCorientation=180 (looking backward)

B.2.2 Nearest-Neighbor Search

For each L1C GMI Swath S1 LF pixel, a nearest-neighbor search is applied on the Swath S2 HF pixels to find its closest match. The searching box is 21 pixels x 11 scans centered at the initial HF matching position obtained from the mean pix/scan offsets table.

Depending on the instrument viewing direction (forward or backward), the searching box may contain HF scans from the next or previous L1C GMI orbit.

If the distance between the LF pixel and the nearest HF pixel found is less than 7km, the nearest HF pixel is selected and its data (Tc, Latitude, Longitude, sunGlintAngle, incidenceAngle, Quality) are used for the L1C-R Swath S2 HF pixel; otherwise, the HF pixel is flagged (S2.Quality=-10 meaning distance to its corresponding LF pixel > 7km) and missing values are output for the L1C-R S2 pixel.

B.3 STATIC DATA FILES

Table B-1 summarizes the current list of static data files used in the L1C-R GMI algorithm.

Table B-1. List of Static Data Files for L1C-R GMI

File Name	Description
indices.list	Mean pix/scan offsets table

B.4 REFERENCE

1. PPS GPM L1CGMI File Specification.

APPENDIX C. L1C TMI

C.1 INTRODUCTION

This document describes sensor-specific information for the GPM Level 1C TMI algorithm.

C.1.1 L1C TMI Input Data Description

The TMI L1C product is derived from the TRMM TMIBASE data. TMIBASE contains TMI radiometric calibrated brightness temperatures (Tb) and is in HDF5 format. Details about the data content and format can be obtained from the GPM PPS TMIBASE File Specification Document. Details of TMI calibration and corrections are documented in the TRMM TMI L1B Algorithm Theoretical Basis Document (ATBD).

C.1.2 L1C Product Description

L1CTMI contains two swaths of common calibrated brightness temperatures from the TMI passive microwave instrument flown on the TRMM satellite. Swath S1 has seven low-resolution channels (10V, 10H, 19V, 19H, 21V, 37V, and 37H). Swath S2 has two high-resolution channels (85V and 85H).

Relation between the swaths: Swath S2 has the same number of scans but twice as many pixels as swath S1. Each S1 scan contains low-frequency channels sampled 104 times along the scan. Each S2 scan contains high-frequency channels sampled 208 times along the scan. S1 and S2 scans are repeated every 1.9s. Along an S1 scan, every other center of an S2 pixel coincides with the center of an S1 pixel.

Details about the data content and format can be obtained from the GPM PPS L1CTMI File Specification Document.

C.2 ORBITIZATION

No orbitization process was done to the input source (TMIBASE) since it is already a GPM orbital base file and contains all the information needed for the satellite intercalibration process.

C.3 SATELLITE INTERCALIBRATION

The calibration adjustments are implemented via piece-wise linear functions with the anchor points contained in 1C.TRMM.TMI.XCAL2015-V.tbl. In most cases, two points are specified so the adjustment is a linear function of the input Tbs. Any positive number of points is possible. If the input Tb is above (below) the highest (lowest) point in the table, then the adjustment for the highest (lowest) point is used. If only one anchor point is given, the adjustment is constant for all Tbs.

C.4 QUALITY CONTROL

C.4.1 Quality Control Procedures

The following quality control procedures were implemented for TMI.

Scan-level checking:

1. Scan check for missing scan: Missing scans are flagged, and all parameter values except scanTime are set to missing.
2. Scan check for bad geolocation quality: Scans with dataQuality not equal to 0 are flagged, and all pixel Tc values are set to missing.

Pixel-level checking:

1. Pixel check for missing Tc: Pixels with missing Tc are flagged, and Tc is set to missing for that channel.
2. Pixel check for nonphysical Tc: Pixels with brightness temperature values outside the physical limits (currently 50K to 350K) are flagged, and Tc is set to missing for that channel.
3. Pixel check for out-of-range latitude/longitude values: Pixels with latitude/longitude values outside of range (-45 to 45 and -180 to 180) are flagged, and latitude, longitude, and Tc are set to missing.
4. Pixel check for possible Sun glint: Pixels with Sun glint angle values greater than or equal to 0 and less than 20.0 degrees are flagged as possible Sun glint warning.

C.4.2 Quality Flag Values and Definition

Generic quality flags:

0	Good.
1	Warning – Possible Sun glint, 0 <= sunGlintAngle < 20 degrees.
2	Warning – Possible radio frequency interference.
3	Warning – Degraded geolocation data.
4	Warning – Data corrected for warm load intrusion.
-1	Error – Data are missing from file or are unreadable.
-2	Error – Invalid Tb or nonphysical brightness temperature (Tb < 50K or Tb > 350K).
-3	Error – Error in geolocation data.
-4	Error – Data are missing in one channel.
-5	Error – Data are missing in multiple channels.
-6	Error – Latitude/longitude values are out of range.
-7	Error – Non-normal status modes.

Sensor-specific quality flags:

None.

C.5 STATIC DATA FILES

Table C-1 summarizes the current list of static data files used in L1CXCALtmi algorithm.

Table C-1. List of Static Data Files for L1C TMI

File Name	Description
1C.TRMM.TMI.XCAL2015-V.tbl	Intercalibration Tb offset table

C.6 REFERENCES

1. PPS GPM TMIBASE File Specification.
2. PPS GPM L1CTMI File Specification.
3. PPS TRMM TMI L1B Algorithm Theoretical Basis Document (ATBD).

APPENDIX D. L1C SSMI/S

D.1 INTRODUCTION

This document describes sensor-specific information for the GPM Level 1C SSMI/S algorithm.

D.1.1 L1C SSMI/S Input Data Description

The source for the Special Sensor Microwave Imager/Sounder (SSMI/S) L1C data is the Temperature Data Record (TDR) data produced by the Navy's Fleet Numerical Meteorology and Oceanography Center (FNMOC). The TDR data are archived and publicly available from NOAA's Comprehensive Large Array-Data Stewardship System (CLASS). The TDR data contain antenna temperatures (Ta) and are in binary format. Details about the data content and format can be obtained from the Interface Design Document for the Special Sensor Microwave Imager/Sounder (SSMI/S) Ground Processing Software.

D.1.2 L1C SSMI/S Product Description

L1CSSMIS contains common calibrated brightness temperature from the SSMI/S passive microwave instruments flown on the Defense Meteorological Satellite Program (DMSP) satellites.

Swath S1 has three low-frequency channels (19V, 19H, and 22V). Swath S2 has two low-frequency channels (37V and 37H). Swath S3 has four high-frequency channels (150H, 183+/-1H, 183+/-3H, and 183+/-7H). S4 has two high-frequency channels (91V and 91H). All the above frequencies are in GHz.

Relationships among the swaths: Each S1 and S2 scan contains low-frequency channels sampled 90 times along the scan. Each S3 and S4 scan contains high-frequency channels sampled 180 times along the scan. All four swaths have exactly the same number of scans. All four swaths repeat scans every 1.9s. The Earth positions of S1 are very close to those of S2. The Earth positions of S3 are very close to those of S4. The Earth positions of S1 and S2 alternate with those of S3 and S4 along the satellite track. The positions of the S1 and S2 pixels do not match the positions of the S3 and S4 pixels.

Details about the product content and data format can be obtained from the GPM PPS L1CSSMIS File Specification Document.

D.2 ORBITIZATION

D.2.1 Data Reorbitization

Orbitization processing was first done to the input SSMI/S TDR files to reorbitize and reformat them into the GPM standard orbital base file (SSMISBASE). Extra ancillary data computed and added to the base file include: solarBetaAngle; timeSinceEclipseEntry; spacecraft latitude, longitude, and altitude; sunGlintAngle; and incidenceAngle. These data are computed based on TLE-derived spacecraft position and velocity.

D.2.2 Corrections Performed by CSU

In this section, all information was provided by Christian Kummerow and Wesley Berg of the Colorado State University. The Fundamental Climate Data Record (FCDR) stewardship code provided by CSU was used to perform SSMI/S geolocation, Ta, and Tb corrections. Additional details can be obtained from the SSMI/S Climate Algorithm Theoretical Basis Document (C-ATBD) and the CSU technical report on Corrections and APC for SSMI/S Ta to Tb [Berg and Sapiano, 2013].

D.2.2.1 Geolocation

The original SSMI/S pixel geolocation is based on predicted spacecraft ephemeris. In L1CSSMIS, the spacecraft ephemeris is recomputed using orbital element information contained in two-line element (TLE) files produced by the North American Aerospace Defense Command (NORAD). Then this updated spacecraft ephemeris is used along with software to re-compute the pixel geolocation based on the geometry of the sensor. Using a previously developed coastline analysis technique, estimates of changes in the spacecraft attitude including deviations in roll, pitch, and yaw have been computed for the life of each of the SSMI/S sensors. Applying these corrections results in an improved pixel geolocation, but more importantly provides accurate estimates of the Earth Incidence Angle (EIA) across the scan and throughout each orbit.

More details on geolocation can be found at the CSU FCDR home page (rain.atmos.colostate.edu/FCDR/index.html) and in the SSMI and SSMI/S Stewardship Code Geolocation Algorithm Theoretical Basis Technical Report [Sapiano, Bilanow, and Berg, 2010].

D.2.2.2 Solar and Lunar Intrusion Correction

Corrections are applied to the Ta to account for solar and lunar intrusions into the warm load and cold-sky mirror. The corrections are based on those applied in the SSMI/S Ground Processing Software Revision 9 (GPSr9) of July 2010.

No solar or lunar intrusion correction is applied to F19 Ta.

D.2.2.3 Cross-Track Bias Correction

The cross-track bias correction is applied to adjust for nonphysical end-of-scan falloff in Ta. An analysis of clear-sky scenes was done for each satellite and channel to determine the magnitude of this falloff. Based on this analysis, a scale factor was computed for each pixel position along the scan, with the center pixel defined as having a multiplier of 1.0. These scale factors are stored in files and used to remove the cross-track biases from the Ta.

For F19 data, the cross-track bias correction is applied to Tb (after the Ta to Tb conversion) instead of Ta.

D.2.2.4 Ta to Tb Conversion

The SSMI/S equivalent channels (19, 22, 37, and 91 GHz channels) have both a cross-polarization and spillover correction applied. For the remaining channels, only the spillover correction is applied.

D.2.2.5 Sun-Angle Correction

A Sun-angle-dependent correction is applied to account for emissive reflector and residual heating issues. Using a double-difference approach, Berg and Sapiano [5] solve for Tb biases as a function of the Sun angle relative to the direction of motion of the spacecraft. Correction maps, or Tb offsets, as a function of Sun azimuth and elevation angles were computed based on matchups with TRMM TMI over the entire available time series for each SSMI/S sensor.

The corrected antenna temperatures (Ta) and brightness temperatures (Tb) are both output to the base file. The resulting SSMISBASE file is then used as input to the satellite intercalibration process.

D.3 SATELLITE INTERCALIBRATION

The calibration adjustments are implemented via piece-wise linear functions with the anchor points contained in 1C.DMSP-F*.SSMIS.XCAL2015-V.tbl (* is the F number of the satellite, for example, 18). In most cases, two points are specified so the adjustment is a linear function of the input Tbs. Any positive number of points is possible. If the input Tb is above (below) the highest (lowest) point in the table, then the adjustment for the highest (lowest) point is used. If only one anchor point is given, the adjustment is constant for all Tbs. For the channels at frequencies of 91 GHz and below, two anchor points are used, and for the water vapor sounding channels only a single anchor point is used.

D.4 QUALITY CONTROL

D.4.1 Quality Control Procedures

The following quality control procedures were implemented for SSMI/S. The quality control routines in the CSU FCDR code were used to perform quality control in L1CSSMIS.

1. Check for erroneous pixel geolocation and large variance from climatology for multiple data scans: Affected pixels are flagged, and Ta values are set to missing.
2. Check for known sensor issues: Data are flagged, and Ta is set to missing for known sensor issues as determined from documented issues and data monitoring.
3. Check for nonphysical values: Pixels with Ta outside the physical limits (50K to 350K) are flagged, and Ta is set to missing for that channel.
4. Environmental sensor channels check: For scans where the fraction of pixels with Ta that differ from the mean by more than three standard deviations exceeds a threshold, the data are flagged as having a climatology issue. A warning flag is set for scans near the threshold (within 5%). An error flag is set, and Ta is set to missing for scans exceeding the threshold. Anomalous jumps between adjacent scans are also flagged.

5. Imager channels check: The same check used for environmental sensor channels (19, 22, and 37 GHz) is also applied to the 91 GHz channels.
6. Check for missing scan: Missing scans are flagged, and all parameter values except scanTime are set to missing.
7. Pixel check for out-of-range latitude/longitude values: Pixels with latitude/longitude values outside of range (-90 to 90 and -180 to 180) are flagged, and latitude, longitude, and Tc are set to missing.
8. Check for possible Sun glint: Pixels with Sun glint angle values greater or equal to 0 and less than 20.0 degrees are flagged as possible Sun glint warning.

Additional details are available in the CSU technical report on SSMI and SSMI/S Quality Control [Berg and Rodriguez-Alvarez, 2013].

D.4.2 Quality Flag Values and Definition

Generic quality flags:

0 Good.
1 Warning – Possible Sun glint, 0 <= sunGlintAngle < 20 degrees.
2 Warning – Possible radio frequency interference.
3 Warning – Degraded geolocation data.
4 Warning – Data corrected for warm load intrusion.
-1 Error – Data are missing from file or are unreadable.
-2 Error – Invalid Tb or nonphysical brightness temperature (Tb < 50K or Tb > 350K).
-3 Error – Error in geolocation data.
-4 Error – Data are missing in one channel.
-5 Error – Data are missing in multiple channels.
-6 Error – Latitude/longitude values are out of range.
-7 Error – Non-normal status modes.

Sensor-specific quality flags:

-102 Error – Climatology check flagged in base file.
-110 Error – Climatology check failure (19V channel).
-111 Error – Climatology check failure (19H channel).
-112 Error – Climatology check failure (22V channel).
-113 Error – Climatology check failure (37V channel).
-114 Error – Climatology check failure (37H channel).
-115 Error– Climatology check failure (91V channel).
-116 Error – Climatology check failure (91H channel).
-117 Error – Climatology check failure (150H channel).
-118 Error – Climatology check failure (183+/-1 channel).
-119 Error– Climatology check failure (183+/-3 channel).
-120 Error – Climatology check failure (183+/-7 channel).
-121 Error – Climatology check failure (multiple environment sensor channels).
-122 Error – Climatology check failure (multiple imager sensor channels).
-123 Error – Climatology check failure (one or more Lower Atmosphere Sounding [LAS] channels).

-124	Error – Climatology check failure (one or more Upper Atmosphere Sounding [UAS] channels).
-125	Error – Failure of 150H channel.
-126	Error – Failure of one or more imager sensor channels.
-127	Error - Failure of one or more environment sensor channels.
102	Warning – Climatology check warning (19V channel).
103	Warning – Climatology check warning (19H channel).
104	Warning – Climatology check warning (22V channel).
105	Warning – Climatology check warning (37V channel).
106	Warning – Climatology check warning (37H channel).
107	Warning – Climatology check warning (91V channel).
108	Warning – Climatology check warning (91H channel).
109	Warning – Climatology check warning (150H channel).
110	Warning – Climatology check warning (183+/-1 channel).
111	Warning – Climatology check warning (183+/-3 channel).
112	Warning – Climatology check warning (183+/-7 channel).
113	Warning – Climatology check warning (multiple environment sensor channels).
114	Warning – Climatology check warning (multiple imager sensor channels).
115	Warning – Climatology check warning (one or more LAS channels).
116	Warning – Climatology check warning (one or more UAS channels).
117	Warning – Correction for lunar intrusion into cold-sky mirror.
118	Warning – Correction for solar intrusion into warm load.

D.5 STATIC DATA FILES

Table D-1 summarizes the current list of static data files used in L1CXCALssmis algorithm.

Table D-1. List of Static Data Files for L1C SSMI/S

File Name	Description
CLIM01.grd	Tb climatology file for Jan
CLIM02.grd	Tb climatology file for Feb
CLIM03.grd	Tb climatology file for Mar
CLIM04.grd	Tb climatology file for Apr
CLIM05.grd	Tb climatology file for May
CLIM06.grd	Tb climatology file for June
CLIM07.grd	Tb climatology file for July
CLIM08.grd	Tb climatology file for Aug
CLIM09.grd	Tb climatology file for Sep
CLIM10.grd	Tb climatology file for Oct
CLIM11.grd	Tb climatology file for Nov
CLIM12.grd	Tb climatology file for Dec
geo_LeapSecs.dat	Leap-seconds data
surftag.bin	Surface tag database
Tarm_Template_UPPv3.dat	Emissive antenna correction data
CorCoefs_SSMIS_F16.dat	Spillover and cross-pol coefficients for F16
CorCoefs_SSMIS_F17.dat	Spillover and cross-pol coefficients for F17
CorCoefs_SSMIS_F18.dat	Spillover and cross-pol coefficients for F18
CorCoefs_SSMIS_F19.dat	Spillover and cross-pol coefficients for F19
F16_ctb_may12.dat	Cross-track bias correction coefficients for F16
F17_ctb_may12.dat	Cross-track bias correction coefficients for F17
F18_ctb_may12.dat	Cross-track bias correction coefficients for F18
F19_ctb_feb15.dat	Cross-track bias correction coefficients for F19
F16cal_tsun.dat	Sun correction offsets for F16
F17cal_tsun.dat	Sun correction offsets for F17
F18cal_tsun.dat	Sun correction offsets for F18
F19cal_tsun.dat	Sun correction offsets for F19
geo_ssmis_F16.dat	Geolocation sensor data for F16
geo_ssmis_F17.dat	Geolocation sensor data for F17
geo_ssmis_F18.dat	Geolocation sensor data for F18
geo_ssmis_F19.dat	Geolocation sensor data for F19
Geo_ssmis_F16_rpy.dat	Sensor roll, pitch, yaw data for F16
Geo_ssmis_F17_rpy.dat	Sensor roll, pitch, yaw data for F17
Geo_ssmis_F18_rpy.dat	Sensor roll, pitch, yaw data for F18
Geo_ssmis_F19_rpy.dat	Sensor roll, pitch, yaw data for F19
1C.DMSP-F16.SSMIS.XCAL2015-V.tbl	Intercalibration Tb offset table for F16
1C.DMSP-F17.SSMIS.XCAL2015-V.tbl	Intercalibration Tb offset table for F17
1C.DMSP-F18.SSMIS.XCAL2015-V.tbl	Intercalibration Tb offset table for F18

File Name	Description
1C.DMSP-F19.SSMIS.XCAL2015-V.tbl	Intercalibration Tb offset table for F19

D.6 REFERENCES

1. Interface Design Document for the Special Sensor Microwave Imager/Sounder (SSMI/S) Ground Processing Software.
2. PPS GPM SSMISBASE File Specification.
3. PPS GPM L1CSSMIS File Specification.
4. Sapiano, M. R. P., S. Bilanow, and W. Berg, 2010: SSMI and SSMI/S Stewardship Code Geolocation Algorithm Theoretical Basis, Technical Report, Colorado State University.
5. Berg, W., and M. R. P. Sapiano, 2013: Corrections and APC for SSMI/S, Technical Report, Colorado State University.
6. Sapiano, M. R. P., and W. Berg, 2013: Intercalibration of SSMI and SSMI/S for the CSU FCDR, Technical Report, Colorado State University.
7. Berg, W. K., and N. Rodriguez-Alvarez, 2013: SSMI and SSMI/S Quality Control, Technical Report, Colorado State University.
8. SSMI/S Climate Algorithm Theoretical Basis Document (C-ATBD).

APPENDIX E. L1C AMSR2

E.1 INTRODUCTION

This document describes sensor-specific information for the GPM Level 1C AMSR2 algorithm.

E.1.1 L1C AMSR2 Input Data Description

The source for the Advanced Microwave Scanning Radiometer 2 (AMSR2) L1C product is the AMSR2 Level 1B data produced by the Japan Aerospace Exploration Agency (JAXA). The data contain brightness temperatures and are in HDF5 format. Details about the data content and format can be obtained from the AMSR2 Level 1 Product Format Specification Document.

E.1.2 L1C AMSR2 Product Description

L1CAMSR2 contains common calibrated brightness temperature from the AMSR2 passive microwave instrument flown on the Global Change Observation Mission (GCOM-W1) satellite. This product contains six swaths. Swath 1 has channels 10.65V and 10.65H. Swath 2 has channels 18.7V and 18.7H. Swath 3 has channels 23.8V and 23.8H. Swath 4 has channels 36.5V and 36.5H. Swath S5 has two high-frequency A channels (89V and 89H). Swath S6 has two high-frequency B channels (89V and 89H). Data for all six swaths are observed in the same revolution of the instrument. High-frequency A data and high-frequency B data are observed in separate feedhorns.

Relation between the swaths: Each S1 scan contains 10 GHz channels sampled 243 times along the scan. S2, S3, and S4 are sampled nominally at the same position as the S1 samples, but differ by small distances. Each S5 scan contains high-frequency A channels sampled 486 times along the scan. Each S6 scan contains high-frequency B channels sampled 486 times along the scan. Both swath S5 and swath S6 have exactly twice as many pixels as swath S1. S1 pixels 1, 2, 3, ... coincide with S5 pixels 1, 3, 5, ... Scans of all swaths are repeated every 1.5s, and the scans of one swath are about 10km apart along the direction of the satellite track. Along an S1 scan, every other center of an S5 pixel coincides with the center of an S1 pixel, but the S6 pixels are offset from S1 and S2 pixels by nominally 15km in the direction normal to the scan direction on the aft side; in other words, S6 pixels are nominally 15km behind the S1 and S5 pixels for the same scan. Details about the product content and data format can be obtained from the GPM PPS L1CAMSR2 File Specification Document.

E.2 ORBITIZATION

E.2.1 Data Reorbitization

Orbitization processing was first done to the input AMSR2 L1B files to reorbitize and reformat them into the GPM standard orbital base file (AMSR2BASE). Extra ancillary data computed and added to the base file include: solarBetaAngle; timeSinceEclipseEntry; spacecraft latitude, longitude, and altitude; and sunGlintAngle. Sun glint angle is computed from the input data: Sun_Elevation, Sun_Azimuth, and Earth_Incidence.

E.2.2 Co-registration

During this process, the co-registration parameters are applied to 89 A latitude/longitude values to compute the latitude/longitude for each low-frequency channel using equations documented in the AMSR2 Level 1 Product Format Specification Document 4.1 (57). The computed low-frequency latitude/longitude values are added to the base file. Earth incidence angles for each channel are then computed using each channel's geolocation and added to the base file as well.

The resulting AMSR2BASE file is then used as input to the satellite intercalibration process.

E.3 SATELLITE INTERCALIBRATION

The calibration adjustments are implemented via piece-wise linear functions with the anchor points contained in 1C.GCOMW1.AMSR2.XCAL2015-V.tbl. In most cases, two points are specified so the adjustment is a linear function of the input Tbs. Any positive number of points is possible. If the input Tb is above (below) the highest (lowest) point in the table, then the adjustment for the highest (lowest) point is used. If only one anchor point is given, the adjustment is constant for all Tbs.

E.4 QUALITY CONTROL

E.4.1 Quality Control Procedures

The following quality control procedures were implemented for AMSR2.

Scan-level checking:

1. Scan check for missing scan: Missing scans are flagged, and all parameter values except scanTime are set to missing.

Pixel-level checking:

1. Pixel check for missing Tc: Pixels with missing Tc are flagged, and Tc values are set to missing for that channel.
2. Pixel check for nonphysical Tc: Pixels with brightness temperature values outside the physical limits (currently 50K to 350K) are flagged, and Tc is set to missing for that channel.
3. Pixel check for out-of-range latitude/longitude values: Pixels with latitude/longitude values outside of range (-90 to 90 and -180 to 180) are flagged, and latitude, longitude, and Tc are set to missing.
4. Pixel check for possible Sun glint: Pixels with Sun glint angle values greater or equal to 0 and less than 20.0 degrees are flagged as possible Sun glint warning.

E.4.2 Quality Flag Values and Definition

Generic quality flags:

0 Good.
1 Warning – Possible Sun glint, 0 <= sunGlintAngle < 20 degrees.
2 Warning – Possible radio frequency interference.
3 Warning – Degraded geolocation data.
4 Warning – Data corrected for warm load intrusion.
-1 Error – Data are missing from file or are unreadable.
-2 Error – Invalid Tb or nonphysical brightness temperature (Tb < 50K or Tb > 350K).
-3 Error – Error in geolocation data.
-4 Error – Data are missing in one channel.
-5 Error – Data are missing in multiple channels.
-6 Error – Latitude/longitude values are out of range.
-7 Error – Non-normal status modes.

Sensor-specific quality flags:

None.

E.5 STATIC DATA FILES

Table E-1. List of Static Data Files for L1C AMSR2

File Name	Description
1C.GCOMW1.AMSR2.XCAL2015-V.tbl	Intercalibration Tb offset table

E.6 REFERENCES

1. AMSR2 Level 1 Product Format Specification.
2. PPS GPM AMSR2BASE File Specification.
3. PPS GPM L1CAMSR2 File Specification.

APPENDIX F. L1C ATMS

F.1 INTRODUCTION

This document describes sensor-specific information for the GPM Level 1C ATMS algorithm.

F.1.1 L1C ATMS Input Data Description

The source for the Advanced Technology Microwave Sounder (ATMS) L1C product is the ATMS Sensor Data Record (SDR) data. The SDR data are archived and publicly available from NOAA's Comprehensive Large Array-Data Stewardship System (CLASS). The data contain brightness temperatures and are in HDF5 format. Details about the data content and format can be obtained from the Joint Polar Satellite System (JPSS) Common Data Format Control Book – External (CDFCD-X) Volume III SDR/TDR Formats.

F.1.2 L1C ATMS Product Description

L1CATMS contains common calibrated brightness temperature from the ATMS passive microwave instrument flown on the Suomi National Polar-orbiting Partnership (NPP) satellite and JPSS satellites. ATMS is approximately a combination of the AMSU-A channels and the MHS channels. ATMS rotates three scans per 8 seconds. ATMS has 22 channels. L1CATMS contains four swaths, one for each band K, A(Ka), W, and G. Swath 1 has channel 23.8QV. Swath 2 has channel 31.4QV. Swath 3 has channel 88.2QV. Swath 4 has six channels (165.5 QH, 183.31+/-7 QH, 183.31+/-4.5 QH, 183.31+/-3 QH, 183.31+/-1.8 QH, and 183.31+/-1 QH). QV means quasi-vertical; the polarization vector is parallel to the scan plane at nadir. QH means quasi-horizontal polarization.

Relationship among the swaths: All four swaths contain observations sampled 96 times along the scan.

Details about the product content and data format can be obtained from the GPM PPS L1CATMS File Specification Document.

F.2 ORBITIZATION

Orbitization processing was first done to the input ATMS SDR files to reorbitize and reformat them into the GPM standard orbital base file (ATMSBASE). Extra ancillary data computed and added to the base file include: solarBetaAngle; timeSinceEclipseEntry; spacecraft latitude, longitude, and altitude; and sunGlintAngle. SunGlintAngle is computed from input SatelliteAzimuthAngle, SatelliteZenithAngle, SolarAzimuthAngle, and SolarZenithAngle data. Earth incidence angles for each band are also computed and added to the base file. The resulting ATMSBASE file is then used as input to the satellite intercalibration process.

F.3 SATELLITE INTERCALIBRATION

The calibration adjustments are implemented via piece-wise linear functions with the anchor points contained in 1C.NOAA-NPP.ATMS.XCAL2015-V.tbl. In most cases, two points are specified so the adjustment is a linear function of the input Tbs. Any positive number of points is possible. If the input Tb is above (below) the highest (lowest) point, then the adjustment for the highest (lowest) point is used. If only one anchor point is given, the adjustment is constant for all Tbs. For each of the ATMS channels only a single anchor point recalibration is used, i.e., a constant offset.

F.4 QUALITY CONTROL

F.4.1 Quality Control Procedures

The following quality control procedures were implemented for ATMS:

Scan-level checking:

1. Scan check for missing scan: Missing scans are flagged, and all parameter values except scanTime are set to missing.
2. Scan check for time sequence error: Scans with QF19_SCAN_ATMSSDR bit0=1 are flagged, and Tc values are set to missing.
3. Scan check for space view antenna position error: Scans with QF19_SCAN_ATMSSDR bit4=1 are flagged, and Tc values are set to missing.
4. Scan check for blackbody view antenna position error: Scans with QF19_SCAN_ATMSSDR bit5=1 are flagged, and Tc values are set to missing.
5. Scan check for K, Ka, and V bands (KAV) Precision Resistance Thermometer (PRT) error: Scans with QF19_SCAN_ATMSSDR bit2=1 are flagged, and Tc values are set to missing for swaths 1, 2, and 3 (K, A, and V bands).
6. Scan check for W and G bands (WG) PRT error: Scans with QF19_SCAN_ATMSSDR bit3=1 are flagged, and Tc values are set to missing for swaths 4 and 5 (W and G bands).

Pixel-level checking:

1. Pixel check for missing Tc: Pixels with missing Tc are flagged, and Tc values are set to missing for that channel.
2. Pixel check for nonphysical Tc: Pixels with brightness temperature values outside the physical limits (currently 50K to 350K) are flagged, and Tc is set to missing for that channel.
3. Pixel check for out-of-range latitude/longitude values: Pixels with latitude/longitude values outside of range (-90 to 90 and -180 to 180) are flagged, and latitude, longitude, and Tc are set to missing.
4. Pixel check for possible Sun glint: Pixels with Sun glint angle values greater or equal to 0 and less than 20.0 degrees are flagged as possible Sun glint warning.

F.4.2 Quality Flag Values and Definition

Generic quality flags:

0 Good.
1 Warning – Possible Sun glint, 0 <= sunGlintAngle < 20 degrees.
2 Warning – Possible radio frequency interference.
3 Warning – Degraded geolocation data.
4 Warning – Data corrected for warm load intrusion.
-1 Error – Data are missing from file or are unreadable.
-2 Error – Invalid Tb or nonphysical brightness temperature (Tb < 50K or Tb > 350K).
-3 Error – Error in geolocation data.
-4 Error – Data are missing in one channel.
-5 Error – Data are missing in multiple channels.
-6 Error – Latitude/longitude values are out of range.
-7 Error – Non-normal status modes.

Sensor-specific quality flags:

-100 Error – Missing scans indicated by QF19_SCAN_ATMSSDR flag.
-101 Error – Time sequence error.
-102 Error – Insufficient KAV PRT data.
-103 Error – Insufficient WG PRT data.
-104 Error – Space view antenna position error.
-105 Error – Blackbody view antenna position error.

F.5 STATIC DATA FILES

Table F-1. List of Static Data Files for L1C ATMS

File Name	Description
1C.NOAA-NPP.ATMS.XCAL2015-V.tbl	Intercalibration Tb offset table

F.6 REFERENCES

1. Joint Polar Satellite System (JPSS) Common Data Format Control Book – External (CDFCD-X) Volume III SDR/TDR Formats.
2. PPS GPM ATMSBASE File Specification.
3. PPS GPM L1CATMS File Specification.

APPENDIX G. L1C SAPHIR

G.1 INTRODUCTION

This document describes sensor-specific information for the GPM Level 1C SAPHIR algorithm.

G.1.1 L1C SAPHIR Input Data Description

The source for the SAPHIR (Sondeur Atmospherique du Profil d'Humidite Intertropicale par Radiometrie) L1C product is the SAPHIR L1A data. The data are archived and publicly available from Cloud-Aerosol-Water-Radiation Interactions (ICARE). The L1A data contain brightness temperatures and are in HDF5 format. Details about the data content and format can be obtained from the Megha-Tropiques Level 1 Product Definition Document.

G.1.2 L1C SAPHIR Product Description

1CSAPHIR contains common calibrated brightness temperature from the SAPHIR passive microwave instrument flown on the Megha-Tropiques satellite. Swath S1 is the only swath, and it has six channels (S1, S2, S3, S4, S5, and S6). The channels are 183.31 +/- delta GHz, where delta = 0.2, 1.1, 2.8, 4.2, 6.8, and 11.0.

Relation between the swaths: S1 is the only swath, containing observations sampled 182 times along the scan.

Details about the product content and data format can be obtained from the GPM PPS L1CSAPHIR File Specification Document.

G.2 ORBITIZATION

Orbitization processing was first done to the input SAPHIR L1A files to reorbitize and reformat them into the GPM standard orbital base file (SAPHIRBASE). Extra ancillary data computed and added to the base file include: solarBetaAngle, timeSinceEclipseEntry, spacecraft altitude, and sunGlintAngle. These data are computed based on TLE-derived spacecraft position and velocity. The resulting SAPHIRBASE file is then used as input to the satellite intercalibration process.

G.3 SATELLITE INTERCALIBRATION

The calibration adjustments are implemented via piece-wise linear functions with the anchor points contained in 1C.MT1.SAPHIR.XCAL2015-V.tbl. In most cases, two points are specified so the adjustment is a linear function of the input Tbs. Any positive number of points is possible. If the input Tb is above (below) the highest (lowest) point, then the adjustment for the highest (lowest) point is used. If only one anchor point is given, the adjustment is constant for all Tbs. For each of the SAPHIR channels only a single anchor point recalibration is used, i.e., a constant offset.

G.4 QUALITY CONTROL

G.4.1 Quality Control Procedures

The following quality control procedures were implemented for SAPHIR.

Scan-level checking:

1. Scan check for missing scan: Missing scans are flagged, and all parameter values except scanTime are set to missing.
2. Scan check for invalid scan: Scans with SAPHIR_QF_SCAN bit15=1 are flagged, and Tc values are set to missing.
3. Scan check for scan error: Scans with SAPHIR_QF_SCAN bit12=1 are flagged, and Tc values are set to missing.
4. Scan check for time error: Scans with SAPHIR_QF_SCAN bit11=1 are flagged, and Tc values are set to missing.
5. Scan check for PRT error: Scans with SAPHIR_QF_SCAN bit10=1 are flagged, and Tc values are set to missing.
6. Scan check for CRC error: Scans with SAPHIR_QF_SCAN bit7=1 are flagged, and Tc values are set to missing.
7. Scan check for payload mode not nominal: Scans with SAPHIR_QF_SCAN bit5=1 or bit4=1 or bit3=1 are flagged, and Tc values are set to missing.
8. Scan check for bad nadir incidence angle: Scans with nadir incidence angle > 1.0 are flagged and Tc values are set to missing.

Pixel-level checking:

1. Pixel check for geolocation error: Pixels with channel QF_samples bit8=1 are flagged, and Tc values are set to missing for all channels.
2. Pixel check for out-of-range latitude/longitude values: Pixels with latitude/longitude values outside of range (-30 to 30 and -180 to 180) are flagged, and latitude, longitude, and Tc are set to missing.
3. Pixel check for channel off: Pixels with channel QF_samples bit11=1 are flagged, and Tc values are set to missing for that channel.
4. Pixel check for invalid or nonphysical Tc: Pixels with brightness temperature values outside the physical limits (currently 50K to 350K) or channel QF_samples bit15=1 are flagged, and Tc is set to missing for that channel.
5. Pixel check for poor L0 count: Pixels with channel QF_samples bit9=1 and bit10=1 are flagged, and Tc values are set to missing for that channel.
6. Pixel check for hot/cold count error: Pixels with channel QF_samples bit4=1 and bit5=1 are flagged, and Tc values are set to missing for that channel.
7. Pixel check for calibration error: Pixels with channel QF_samples bit6=1 or bit7=1 are flagged, and Tc values are set to missing for that channel.
8. Pixel check for possible Sun glint: Pixels with Sun glint angle values greater or equal to 0 and less than 20.0 degrees are flagged as possible Sun glint warning.
9. Pixel check for backward scanning: Pixels with SAPHIR_QF_scan bit3=1 are flagged as backward scanning warning.

G.4.2 Quality Flag Values and Definition

Generic quality flags:

0 Good.
1 Warning – Possible Sun glint, 0 <= sunGlintAngle < 20 degrees.
2 Warning – Possible radio frequency interference.
3 Warning – Degraded geolocation data.
4 Warning – Data corrected for warm load intrusion.
-1 Error – Data are missing from file or are unreadable.
-2 Error – Invalid Tb or nonphysical brightness temperature (Tb < 50K or Tb > 350K).
-3 Error – Error in geolocation data.
-4 Error – Data are missing in one channel.
-5 Error – Data are missing in multiple channels.
-6 Error – Latitude/longitude values are out of range.
-7 Error – Non-normal status modes.

Sensor-specific quality flags:

101 Warning – Backward scanning.
-100 Error – Invalid scan.
-101 Error – Scan error.
-102 Error – Date/time error.
-103 Error – PRT error.
-104 Error – CRC error.
-105 Error – Payload mode not nominal.
-110 Error – Channel is off.
-111 Error – Poor or saturated L0 count.
-112 Error – Hot/cold count not available or error.
-113 Error – Calibration error.

G.5 STATIC DATA FILES

Table G-1. List of Static Data Files for L1C SAPHIR

File Name	Description
1C.MT1.SAPHIR.XCAL2015-V.tbl	Intercalibration Tb offset table

G.6 REFERENCES

1. Megha-Tropiques Level 1 Product Definition Document.
2. PPS GPM SAPHIRBASE File Specification.
3. PPS GPM L1CSAPHIR File Specification.

APPENDIX H. L1C MHS

H.1 INTRODUCTION

This document describes sensor-specific information for the GPM Level 1C MHS algorithm.

H.1.1 L1C MHS Input Data Description

The MHS L1C product is derived from the Microwave Surface and Precipitation Products System (MSPPS) Level-2 MHS orbital products. The data are archived and publicly available from NOAA's Comprehensive Large Array-Data Stewardship System (CLASS). The data contain antenna temperatures (Ta) and are in HDF-EOS format. Details about the data content and format can be obtained from the Microwave Surface and Precipitation Products System (MSPPS) Users' Manual (UM).

H.1.2 L1C Product Description

1CMHS contains common calibrated brightness temperature from the MHS passive microwave instrument flown on the NOAA and METOP satellites. Swath S1 is the only swath and has five channels (89V, 157V, 183.31+/-1H, 183.31+/-3H, and 190.31V). MHS is very similar to AMSU-B. The scan period is 2.667s.

Relation between the swaths: S1 is the only swath, containing observations sampled 90 times along the scan.

Details about the data content and format can be obtained from the GPM PPS L1CMHS File Specification Document.

H.2 ORBITIZATION

H.2.1 Data Reorbitization

Orbitization processing was first done to the input MSPPS Level-2 MHS files to reorbitize and reformat them into the GPM standard orbital base file (MHSBASE). Extra ancillary data computed and added to the base file include: solarBetaAngle; timeSinceEclipseEntry; spacecraft latitude, longitude, and altitude; and sunGlintAngle. These data are computed based on TLE-derived spacecraft position and velocity.

H.2.2 Ta to Tb Conversion

The antenna pattern correction (APC) is based on the AAPP (ATOVS and AVHRR Processing Package) scan-dependent correction algorithm. The algorithm corrects the error due to non-unity antenna reflectivity described in AAPP Documentation Scientific Description (Doc ID: NWPSAF-MF-UD-001, Version: 6.0, Date: June 2006).

The software and look-up tables were provided by the MSPPS group at the NOAA Center for Satellite Applications and Research (STAR). The correction is a linear correction on radiance R.

Rcorr [j][chan] = A[j][chan] *R[j][chan] +B[j][chan]

Where j is the sample number of a scan and chan is the number of channels. A[j][chan] and B[j][chan] are derived from different look-up tables for AMSU-B and MHS sensors onboard NOAA 15-19 and METOP.

Each look-up table contains 270 (90 *3) lines, and each line has five (channels) values (accf[j][chan] for this example).

A[j]=1.0/(accf[j][chan] + accf[90+j][chan]);
B[j][chan]=(-1.0)*(accf[180+j][chan]*Bspace[chan])/(accf[j][chan] + accf[90+j][chan]);

Bspace[chan] are constant fields depending only on channels. Both look-up tables (accf) and values of Bspace are recorded in the base product.

Since the input data contains antenna temperature (Ta) rather than radiance, the correction procedure first converts Ta into radiance using the Planck function, and then applies the correction to the radiance. Last, the code converts the corrected radiance to the brightness temperature (Tb), again using the Planck function. The computed brightness temperature (Tb) values are output to the base file.

The resulting MHSBASE file is then used as input to the satellite intercalibration process.

H.3 SATELLITE INTERCALIBRATION

The calibration adjustments are implemented via piece-wise linear functions with the anchor points contained in 1C.*.MHS.XCAL2015-V.tbl (where * indicates NOAA-18, NOAA-19, METOP-A, or METOP-B). In most cases, two points are specified so the adjustment is a linear function of the input Tbs. Any positive number of points is possible. If the input Tb is above (below) the highest (lowest) point, then the adjustment for the highest (lowest) point is used. If only one anchor point is given, the adjustment is constant for all Tbs. For each of the MHS channels only a single anchor point recalibration is used, i.e., a constant offset.

H.4 QUALITY CONTROL

H.4.1 Quality Control Procedures

The following quality control procedures were implemented for MHS.

Scan-level checking:

1. Scan check for missing scan: Missing scans are flagged, and all parameter values except scanTime are set to missing.

Pixel-level checking:

1. Pixel check for missing Tc: Pixels with missing Tc are flagged, and Tc is set to missing for that channel.
2. Pixel check for nonphysical Tc: Pixels with brightness temperature values outside the physical limits (currently 50K to 350K) are flagged, and Tc is set to missing for that channel.
3. Pixel check for out-of-range latitude/longitude values: Pixels with latitude/longitude values outside of range (-90 to 90 and -180 to 180) are flagged, and latitude, longitude, and Tc are set to missing.
4. Pixel check for possible Sun glint: Pixels with Sun glint angle values greater or equal to 0 and less than 20.0 degrees are flagged as possible Sun glint warning.

H.4.2 Quality Flag Values and Definition

Generic quality flags:

0	Good.
1	Warning – Possible Sun glint, 0 <= sunGlintAngle < 20 degrees.
2	Warning – Possible radio frequency interference.
3	Warning – Degraded geolocation data.
4	Warning – Data corrected for warm load intrusion.
-1	Error – Data are missing from file or are unreadable.
-2	Error – Invalid Tb or nonphysical brightness temperature (Tb < 50K or Tb > 350K).
-3	Error – Error in geolocation data.
-4	Error – Data are missing in one channel.
-5	Error – Data are missing in multiple channels.
-6	Error – Latitude/longitude values are out of range.
-7	Error – Non-normal status modes.

Sensor-specific quality flags:

None.

H.5 STATIC DATA FILES

Table H-1 summarizes the current list of static data files used in L1CXCALmhs algorithm.

Table H-1. List of Static Data Files for L1C MHS

File Name	Description
noaa18ac.dat	MHS antenna correction coefficients for NOAA-18
noaa19ac.dat	MHS antenna correction coefficients for NOAA-19
metopAac.dat	MHS antenna correction coefficients for METOP-A
metopBac.dat	MHS antenna correction coefficients for METOP-B
1C.NOAA18.MHS.XCAL2015-V.tbl	Intercalibration Tb offset table for NOAA-18
1C.NOAA19.MHS.XCAL2015-V.tbl	Intercalibration Tb offset table for NOAA-19
1C.METOPA.MHS.XCAL2015-V.tbl	Intercalibration Tb offset table for METOP-A
1C.METOPB.MHS.XCAL2015-V.tbl	Intercalibration Tb offset table for METOP-B

H.6 REFERENCES

1. PPS GPM MHSBASE File Specification.
2. PPS GPM L1CMHS File Specification.
3. PPS TRMM TMI L1B Algorithm Theoretical Basis Document (ATBD).

APPENDIX I. CHANGES FROM VERSION 03 TO VERSION 04

This Version 04 (V04) release involves the following significant changes from the previous release in the calibration of the GPM radiometer constellation.

1. The Level 1C brightness temperature (Tb) data for all of the constellation radiometers has been intercalibrated to be consistent with the Tb from GMI onboard the GPM core satellite. Note that the GMI V04 calibration differs from V03 by up to 2-3 K (based on mean Tb values) for some channels due to updated spillover corrections derived from on-orbit calibration maneuvers.

   V04 Tb changes vary from channel to channel and are functions of brightness temperatures. For channels 1-5, Tb reduced ~3-6 K at their maximums. For channels 10-13, Tb increased ~2-4 K at their maximums. For channels 6-9, Tb increased ~0.1 K at their maximums. Please see the latest GMIL1B ATBD for more details on the GMI V04 calibration updates.

   Comparisons with other well-calibrated radiometers and with radiative transfer simulations indicate that GMI is extremely well calibrated and stable with an absolute calibration accuracy of well within 1 K for all channels.

2. For the constellation radiometers, V04 moves from the use of TRMM TMI and METOP-A MHS as the calibration reference for the window and sounder channels, respectively, to GPM GMI as the reference for all channels. This results in changes to the Level 1C Tb by up to 2.5 K depending on the channel, but with significantly improved consistency between channels and with radiative transfer models. In addition, a number of calibration biases and artifacts have been identified and removed from the Level 1C Tb for the constellation radiometers. These include, but are not limited to, issues such as emissive reflectors, solar and lunar intrusions, and biases across the scan.

3. A bug fix that affects sunGlintAngle calculation was implemented in December 2014 for V03C processing. V03 data generated prior to December 2014 may have sunGlintAngle error up to 6 degrees.

ACRONYMS USED IN THIS DOCUMENT AND ITS APPENDICES

AAPP	ATOVS and AVHRR Processing Package
AMSR2	Advanced Microwave Scanning Radiometer 2
AMSU-A	Advanced Microwave Sounding Unit – A
AMSU-B	Advanced Microwave Sounding Unit – B
APC	Antenna Pattern Correction
ATBD	Algorithm Theoretical Basis Document
ATMS	Advanced Technology Microwave Sounder
ATOVS	Advanced TIROS Operational Vertical Sounder
AVHRR	Advanced Very High Resolution Radiometer
CLASS	NOAA’s Comprehensive Large Array-Data Stewardship System
CSU	Colorado State University
DMSP	Defense Meteorological Satellite Program
ECMWF	European Centre for Medium-Range Weather Forecasts
EIA	Earth Incidence Angle
FCDR	Fundamental Climate Data Record
FNMOC	Fleet Numerical Meteorology and Oceanography Center
FOV	Field of View
GCOM-W1	Global Change Observation Mission
GHz	Gigahertz
GMI	GPM Microwave Imager
GPM	Global Precipitation Measurement
GPROF	Goddard Profiling Algorithm
GSFC	Goddard Space Flight Center
GV	Ground Validation
H	Horizontal
HDF	Hierarchical Data Format
HDF-EOS	Hierarchical Data Format-Earth Observing System
HF	High Frequency
I/O	Input/Output
ICARE	Cloud-Aerosol-Water-Radiation Interactions
JAXA	Japan Aerospace Exploration Agency
JPSS	Joint Polar Satellite System
KAV	K, Ka, and V Bands
L1C	Level 1C
LAS	Lower Atmosphere Sounding
lat/lon	Latitude/Longitude
LF	Low Frequency
METOP	(European) Meteorological Operational (Spacecraft)
MHS	Microwave Humidity Sounder
MSSPS	Microwave Surface and Precipitation Products System
NASA	National Aeronautics and Space Administration
NetCDF	Network Common Data Form
NOAA	National Oceanic and Atmospheric Administration
NORAD	North American Aerospace Defense Command
NPP	Suomi National Polar-orbiting Partnership

OST	Orbit Start/Stop Times
PPS	Precipitation Processing System
PRT	Precision Resistance Thermometer
QC	Quality Control
QF	Quality Flag
QH	Quasi-Horizontal
QV	Quasi-Vertical
RFI	Radio Frequency Interference
SAPHIR	Sondeur Atmospherique du Profil d'Humidite Intertropicale par Radiometrie
SDR	Sensor Data Record
SGP4	Simplified General Perturbations Satellite Orbit Model 4
SSMI	Special Sensor Microwave Imager
SSMI/S	Special Sensor Microwave Imager/Sounder
STAR	NOAA Center for Satellite Applications and Research
Ta	Antenna Temperature
TAI	International Atomic Time
Tb	Brightness Temperature
Tc	Common Intercalibrated Brightness Temperature
TDR	Temperature Data Record
TIROS	Television Infrared Observation Satellites
TKIO	PPS Science Algorithm Input/Output Toolkit
TLE	Two-Line Element
TMI	TRMM Microwave Imager
TRMM	Tropical Rainfall Measuring Mission
UAS	Upper Atmosphere Sounding
UM	Users' Manual
V	Vertical (lower-case v stands for vector)
V03, 04	Version 03, Version 04
WG	W and G Bands
X-CAL	Intercalibration Working Group (GPM)
XML	Extensible Markup Language