

**GSFC JPSS CMO
April 24, 2017
Released**

**Joint Polar Satellite System (JPSS) Ground Project
Code 474
474-00084**

**Joint Polar Satellite System (JPSS)
Operational Algorithm Description
(OAD)
Document for VIIRS Cloud Base
Height Intermediate Product (IP)
Software**

For Public Release

The information provided herein does not contain technical data as defined in the International Traffic in Arms Regulations (ITAR) 22 CFC 120.10. This document has been approved For Public Release to the NOAA Comprehensive Large Array-data Stewardship System (CLASS).



**Goddard Space Flight Center
Greenbelt, Maryland**

National Aeronautics and
Space Administration

**Joint Polar Satellite System (JPSS)
Operational Algorithm Description (OAD) Document for
VIIRS Cloud Base Height Intermediate Product (IP)
Software
JPSS Electronic Signature Page**

Prepared By:

Ray Godin
JPSS Data Products and Algorithms EDR Lead
(Electronic Approvals available online at (https://jpssmis.gsfc.nasa.gov/mainmenu_dsp.cfm))

Approved By:

Gilberto Vicente
JPSS Ground Project Algorithm Integration Team (AIT) Manager
(Electronic Approvals available online at (https://jpssmis.gsfc.nasa.gov/mainmenu_dsp.cfm))

**Goddard Space Flight Center
Greenbelt, Maryland**

Preface

This document is under JPSS Ground Algorithm ERB configuration control. Once this document is approved, JPSS approved changes are handled in accordance with Class I and Class II change control requirements as described in the JPSS Configuration Management Procedures, and changes to this document shall be made by complete revision.

Any questions should be addressed to:

JPSS Configuration Management Office
NASA/GSFC
Code 474
Greenbelt, MD 20771

Change History Log

Revision	Effective Date	Description of Changes (Reference the CCR & CCB/ERB Approve Date)
Original	12/02/2011	474-CCR-11-0099: This version baselines D39589, Rev B2 dated 27 Sep 2011. This is the version that was approved for NPP launch. Per NPOESS CDFCB - External, Volume V – Metadata, doc number D34862-05, this has been approved for Public Release into CLASS.
Revision A	01/18/2012	474-CCR-11-0276: This version baselines 474-00084, Joint Polar Satellite System (JPSS) Operational Algorithm Description (OAD) Document for VIIRS Cloud Base Height Intermediate Product (IP) Software, for the Mx 6 IDPS release. This CCR was approved by the JPSS Algorithm ERB on January 18, 2012.
Revision B	05/14/2013	474-CCR-13-0948: This version authorizes 474-00084, JPSS OAD Document for VIIRS CBH IP Software, for the Mx 7.0 IDPS release. Includes Raytheon PCR032720; 474-CCR-13-0916/ECR-ALG-0037: Update applicable OAD filenames/template/Rev/etc. for Mx7 Release.
Revision C	03/13/2017	474-CCR-17-3243 (ECR-CGS-0734): This version authorizes 474-00084, JPSS OAD Document for VIIRS CBH IP Software, for the Block 2.0 IDPS release. Includes Raytheon PCR045678: Block 2.0: PRO: OAD: CCR: 474-CCR-15-2444: General OAD Clean-up CCR/PCR, affects all 35/37 OADs. All sections and tables may be affected.



**NATIONAL POLAR-ORBITING
OPERATIONAL ENVIRONMENTAL
SATELLITE SYSTEM (NPOESS)
OPERATIONAL ALGORITHM DESCRIPTION
DOCUMENT FOR VIIRS CLOUD
BASE HEIGHT (CBH)**

**SDRL No. S141
SYSTEM SPECIFICATION SS22-0096**

**RAYTHEON COMPANY
INTELLIGENCE AND INFORMATION SYSTEMS (IIS)
NPOESS PROGRAM
OMAHA, NEBRASKA**

**Copyright © 2005-2010
Raytheon Company
Unpublished Work
ALL RIGHTS RESERVED**

Portions of this work are the copyrighted work of Raytheon. However, other entities may own copyrights in this work. Therefore, the recipient should not imply that Raytheon is the only copyright owner in this work.

This data was developed pursuant to Contract Number F04701-02-C-0502 with the US Government under subcontract number 7600002744. The US Government's rights in and to this copyrighted data are as specified in DFAR 252.227-7013, which was made part of the above contract.

Northrop Grumman Space & Mission Systems Corp.
Space Technology
One Space Park
Redondo Beach, CA 90278



**Engineering & Manufacturing Development (EMD) Phase
Acquisitions & Operations Contract**

CAGE NO. 11982

**Operational Algorithm Description Document for the
VIIRS Cloud Base Height (CBH) Software**

Document Date: Sep 27, 2011

**Document Number: D39589
Revision: B2**

PREPARED BY:

Eric Wong *Date*
AM & S Algorithm Lead

Paul D. Siebels *Date*
IDPS PRO SW Manager

ELECTRONIC APPROVAL SIGNATURES:

Roy Tsugawa *Date*
A&DP Lead & ACCB Chair

Stephen E. Ellefson *Date*
IDPS Processing SI Lead

Bob Hughes *Date*
A&DP Deputy & ARB Chair

Prepared by
Northrop Grumman Space Technology
One Space Park
Redondo Beach, CA 90278

Prepared for
Department of the Air Force
NPOESS Integrated Program Office
C/O SMC/CIK
2420 Vela Way, Suite 1467-A8
Los Angeles AFB, CA 90245-4659

Under
Contract No. F04701-02-C-0502

This document has been identified per the NPOESS Common Data Format Control Book – External Volume 5 Metadata, D34862-05, Appendix B as a document to be provided to the NOAA Comprehensive Large Array-data Stewardship System (CLASS) via the delivery of NPOESS Document Release Packages to CLASS.

Northrop Grumman Space & Mission Systems Corp. Space Technology One Space Park Redondo Beach, CA 90278		 	
Revision/Change Record		Document Number	D39589
Revision	Document Date	Revision/Change Description	Pages Affected
---	1-21-05	Initial PCIM Release, ECR A046.	All
A1	9-21-05	Reflects Raytheon-Omaha's initial edits for Science To Operational (Sci2Ops) Code Conversion Process, adding Raytheon coversheet, title/signature page, etc.	All
A2	2-23-07	Update per EH DQ OPT GD design peer review.	15,17
A3	3-4-07	Update per EH DQ OPT GD design peer review.	All
A4	3-10-07	Update per EH DQ OPT GD CUT CC peer review.	5
A5	3-26-07	Convert OAD to new template.	All
A6	4-27-07	Reflects updates pertaining to Tech Memo NP-EMD.2005.510.0080. Delivered to NGST.	All
A7	8-9-07	TM EMD.2007.510.0038 is implemented in B1.5.	All
A8	10-24-07	Minor update to Figure 1 per NGST. Delivered to NGST.	All
A9	7-23-08	Prepared for delivery to ACCB. Updated Acronym list and references. Implemented new cover sheet from NGST.	All
A	9-2-08	ECR A-166. Incorporated interim changes and addressed TIM comments.	All
B1	10-11-10	Updated due to document convergence including TM 2010.510.0014	All
B2	09-27-11	Updated OAD for PCR026627.	2, 6

Table of Contents

1.0 INTRODUCTION..... 1

 1.1 Objective..... 1

 1.2 Scope 1

 1.3 References 1

 1.3.1 Document References 1

 1.3.2 Source Code References 2

2.0 ALGORITHM OVERVIEW 4

 2.1 VIIRS Cloud Module Description 4

 2.1.1 Interfaces 5

 2.1.1.1 Inputs 7

 2.1.1.2 Outputs 7

 2.1.2 Algorithm Processing 8

 2.1.2.1 Main Module – CBH_main()..... 8

 2.1.2.2 Submodule CalculateCbh()..... 8

 2.1.2.3 Submodule CalculateWaterCbh() 10

 2.1.2.4 Submodule CalculateMixedCbh() 12

 2.1.3 Graceful Degradation..... 14

 2.1.4 Exception Handling 14

 2.1.5 Data Quality Monitoring 15

 2.1.6 Computational Precision Requirements 15

 2.1.7 Algorithm Support Considerations 15

 2.1.8 Assumptions and Limitations 15

3.0 GLOSSARY/ACRONYM LIST 16

 3.1 Glossary 16

 3.2 Acronyms..... 18

4.0 OPEN ISSUES 20

List of Figures

Figure 1. CBH Algorithm Overview 4
 Figure 2. Cloud Module Data Flow 5
 Figure 3. Cloud Base Height Overall Flow Diagram 6
 Figure 4. CalculateCbh() Logic Flow..... 10
 Figure 6. CalculateMixedCbh() Logic Flow 14

List of Tables

Table 1. Reference Documents 1
 Table 2. Source Code References..... 2
 Table 3. Fill Values 6
 Table 4. CBH Inputs..... 7
 Table 5. Glossary 16
 Table 6. Acronyms 18
 Table 7. TBXs 20

1.0 INTRODUCTION

1.1 Objective

The purpose of the Operational Algorithm Description Document (OAD) is to express, in computer-science terms, the remote sensing algorithms that produce the Joint Polar Satellite System (JPSS) end-user data products. These products are individually known as Raw Data Records (RDRs), Temperature Data Records (TDRs), Sensor Data Records (SDRs) and Environmental Data Records (EDRs). In addition, any Intermediate Products (IPs) produced in the process are also described in the OAD.

The science basis of an algorithm is described in a corresponding Algorithm Theoretical Basis Document (ATBD). The OAD provides a software description of that science as implemented in the operational ground system.

The purpose of an OAD is two-fold:

1. Provide initial implementation design guidance to the operational software developer.
2. Capture the “as-built” operational implementation of the algorithm reflecting any changes needed to meet operational performance/design requirements.

An individual OAD document describes one or more algorithms used in the production of one or more data products. There is a general, but not strict, one-to-one correspondence between OAD and ATBD documents.

1.2 Scope

The scope of this document is limited to the description of the core operational algorithm(s) required to create the VIIRS CBH IP. The theoretical basis for these algorithms is described in Section 3.3 of the VIIRS Cloud Base Height Algorithm Theoretical Basis Document (ATBD), D0001-M01-S01-015.

1.3 References

1.3.1 Document References

The science and system engineering documents relevant to the algorithms described in this OAD are listed in Table 1.

Table 1. Reference Documents

Document Title	Document Number/Revision	Revision Date
VIIRS Cloud Base Height Algorithm Theoretical Basis Document (ATBD)	D0001-M01-S01-015	Latest
Joint Polar Satellite System (JPSS) Algorithm Specification Part 16	474-00448-01-16_JPSS-SRS-Vol-I-Part-16	Latest
	474-00448-02-16_JPSS-DD-Vol-II-Part-16	
	474-00448-03-16_JPSS-OAD-Vol-III-Part-16	

Document Title	Document Number/Revision	Revision Date
	474-00448-04-16_JPSS-SRSPF-Vol-IV-Part-16	
Joint Polar Satellite System (JPSS) Program Lexicon	470-00041	Latest
Operational Algorithm Description Document for VIIRS Cloud Optical Properties (COP) Software	474-00074	Latest
Operational Algorithm Description Document for VIIRS Cloud Top Parameters (CTP) Environmental Data Record (EDR)	474-00083	Latest
Operational Algorithm Description Document for VIIRS Cloud Mask Intermediate Product (VCM EDR)	474-00062	Latest
Operational Algorithm Description Document for VIIRS Geolocation (GEO) Sensor Data Record (SDR) and Calibration (CAL) SDR	474-00090	Latest
Operational Algorithm Description Document for VIIRS Cloud Cover/Layers (CCL) and Generate Cloud EDR (GCE) Software	474-00085	Latest
Operational Algorithm Description Document for VIIRS Perform Parallax Correction (PPC) Software	474-00088	Latest
NGST/SE technical memo – MS Engineering Memo_CBH OAD Update	NP-EMD.2006.510.0080	07 Jul 2005
NGST/SE technical memo – NPP_VIIRS_CBH_bug_fixes_RevA	NP-EMD.2007.510.0038 Rev. A	08 Jun 2007
NGST/SE technical memo – VIIRS Cloud Mask (VCM) OAD Update	NP-EMD.2004.510.0050	03 Dec 2004
NGST/SE technical memo – PC_Format_Corrections	NPOESS GJM-2010.510.0014	22 Sep 2010
Joint Polar Satellite System (JPSS) Common Ground System (CGS) IDPS PRO Software User's Manual Part 2	UG60917-IDP-1005	Latest
JPSS Algorithm Specification Volume II Data Dictionary for the Cloud Physical Properties - Block 2.0.0	474-00448-02-16	Latest
JPSS Algorithm Specification Volume II Data Dictionary for the VIIRS RDR/SDR- Block 2.0.0	474-00448-02-06	Latest
JPSS Algorithm Specification Volume II Data Dictionary for the Ancillary Data Handling Gridding and Granulation-Block 2.0.0	474-00448-02-07	Latest

1.3.2 Source Code References

The science and operational code and associated documentation relevant to the algorithms described in this OAD are listed in Table 2.

Table 2. Source Code References

Reference Title	Reference Tag/Revision	Revision Date
VIIRS Cloud Base Height --- science grade software	20050812_ISTN_VIIRS_NGST_3.5	12 Aug 2005
VIIRS Cloud Base Height --- operational software	/PRO/EDR/VIIRS/clouds/cbh/ B1.5, Vers. D.1.1.6	06 Apr 2007
ACCB	OAD Rev A	02 Sep 2008
Convergence update (No code updates)	(OAD Rev B1)	11 Oct-2010

Reference Title	Reference Tag/Revision	Revision Date
PCR06627 (OAD update for ADL)	(OAD Rev B2)	27 Sep-2011
OAD transitioned to JPSS Program – this table is no longer updated.		

2.0 ALGORITHM OVERVIEW

For this section, the definition of an algorithm is a logical grouping of operational algorithm modules for which there is a single Input-Processing-Output (I-P-O) architecture with a single defined set of external inputs and outputs (e.g., IPs or xDRs).

The Cloud Base Height (CBH) algorithm is executed during IP/EDR processing and requires SDR, IP, Ancillary (ANC), and Look-Up Table (LUT) inputs to produce an IP output. A top-level diagram for the CBH algorithm is shown in Figure 1.



Figure 1. CBH Algorithm Overview

2.1 VIIRS Cloud Module Description

A dataflow diagram for the VIIRS Clouds Module, of which the CBH Module is a member, is shown in Figure 2. Each circle represents a stand-alone unit of the VIIRS Cloud Module. Processing order is indicated by the number in each circle. The CBH algorithm produces the CBH IP which is used by the GCE algorithm to produce the CBH EDR.

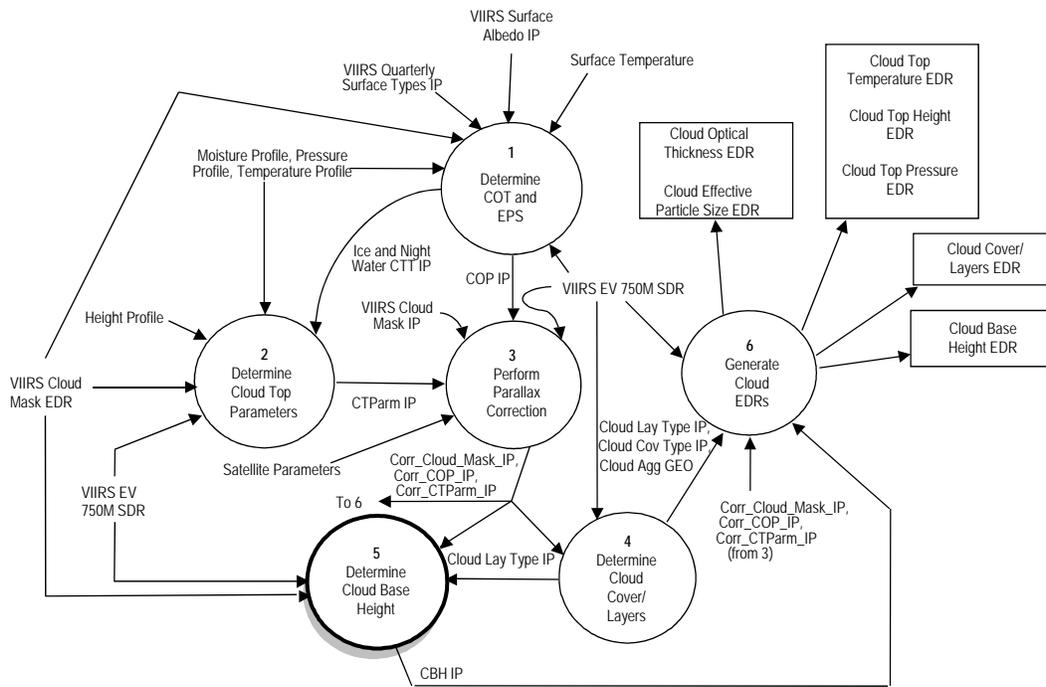


Figure 2. Cloud Module Data Flow

2.1.1 Interfaces

CBH consists of derived and core algorithm modules. The derived algorithm module ProEdrViirsCbh functions as a wrapper for the core algorithm module and handles the I-O stages in the I-P-O architecture. ProEdrViirsCbh initiates the core algorithm module Cloud Base Height which makes up the P stage.

The main flow of the operational CBH algorithm is shown in Figure 3 below. The CBH algorithm gets all required input data from the Data Management System (DMS). When all input data needed for processing is available, the core algorithm CloudBaseHeight is called to determine cloud base height. All inputs from and outputs to DMS are in binary format.

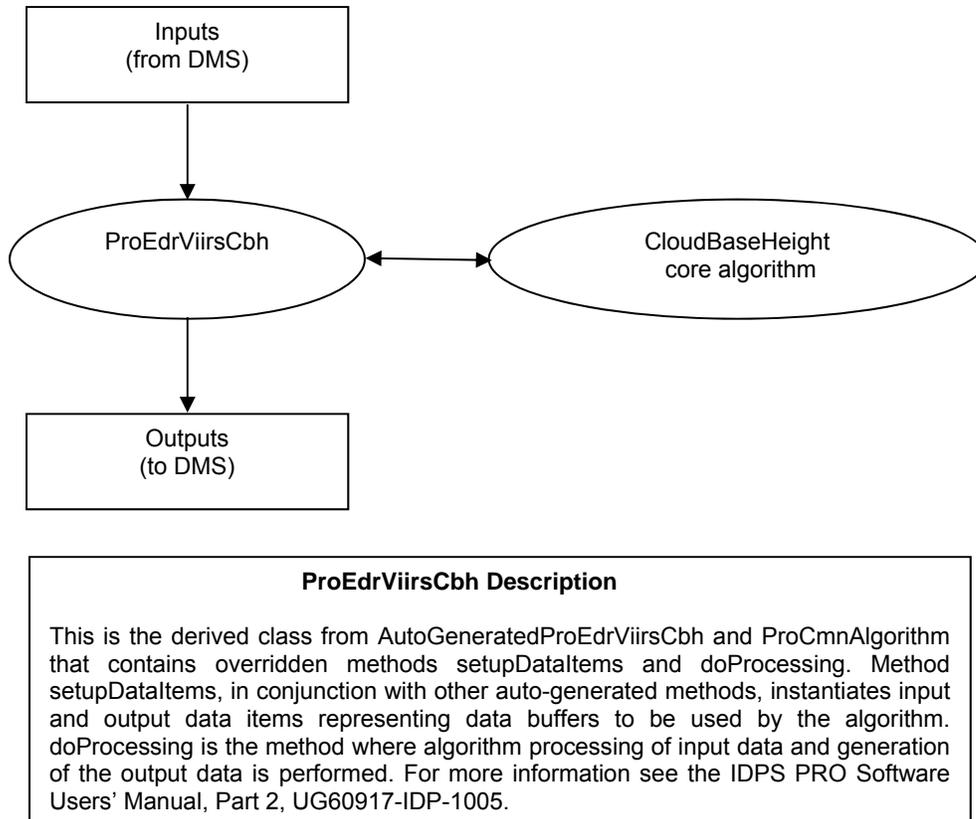


Figure 3. Cloud Base Height Overall Flow Diagram

The CBH Module requires VIIRS Moderate Geolocation (GEO), VIIRS Moderate Surface Height Granulated ANC, VIIRS Parallax Corrected Cloud Mask (CM) IP, VIIRS Parallax Corrected Cloud Optical Properties (COP) IP, VIIRS Cloud Layer Type IP, VIIRS CBH Liquid Water Content (LWC) LUT, and VIIRS CBH IP Algorithm Coefficients as inputs to produce the VIIRS CBH IP. A detailed itemization of the inputs and outputs for the CBH Module is provided below.

Note: For Sections 2.1.1.1 and 2.1.1.2 below, the following applies:

- Fill values corresponding to the individual pixels in each product that do not contain valid data are dictated by the datatype (see Table 3). Exception: bitwise flags (i.e. cloud mask data, quality flags) are filled with zeros.
- For detailed descriptions of the quality flags in the tables below, refer to the applicable I-P-O algorithm OAD (CM, COP, or CTP).
- M_VIIRS_SDR_ROWS = NUMBER of SCANS PER GRANULE X NUMBER of MODERATE DETECTORS
- M_VIIRS_SDR_COLS = 3200

Table 3. Fill Values

Input	Type	Description	Units/Valid Range
NA_FLOAT32_FILL	Float32	Float32 not applicable fill value	Unitless / -999.9
MISS_FLOAT32_FILL	Float32	Float32 missing fill value	Unitless / -999.8
ONBOARD_PT_FLOAT32_FILL	Float32	Float32 onboard pixel trim fill value	Unitless / -999.7
ONGROUND_PT_FLOAT32_FILL	Float32	Float32 on ground pixel trim fill value	Unitless / -999.6

Input	Type	Description	Units/Valid Range
ERR_FLOAT32_FILL	Float32	Float32 error fill value	Unitless / -999.5
NA_UINT8_FILL	UInt8	UInt8 not applicable fill value	Unitless / 255
MISS_UINT8_FILL	UInt8	UInt8 missing fill value	Unitless / 254
ONBOARD_PT_UINT8_FILL	UInt8	UInt8 onboard pixel trim fill value	Unitless / 253
ONGROUND_PT_UINT8_FILL	UInt8	UInt8 on ground pixel trim fill value	Unitless / 252
ERR_UINT8_FILL	UInt8	UInt8 error fill value	Unitless/ 251

2.1.1.1 Inputs

The CBH algorithm requires several types of input data (see the Table 4 below); they are summarized in 474-00448-01-16_JPSS-SRS-Vol-I-Part-16.

Table 4. CBH Inputs

Input	Description	Reference Document
VIIRS-MOD-GEO	VIIRS Moderate Geolocation	474-00448-02-06_JPSS-DD-Vol-II-Part-06, Section 6.2.66
VIIRS-Parx-Corr-CM-IP	VIIRS Parallax Corrected Cloud Mask IP	474-00448-02-16_JPSS-DD-Vol-II-Part-16, Section 4.5
VIIRS-Parx-Corr-Cd-Top-Param-IP	VIIRS Parallax Corrected Cloud Top Parameter	474-00448-02-16_JPSS-DD-Vol-II-Part-16, Section 4.7
VIIRS-Parx-Corr-Cd-Opt-Prop-IP	VIIRS Parallax Corrected Cloud Optical Properties	474-00448-02-16_JPSS-DD-Vol-II-Part-16, Section 4.6
VIIRS-Cd-Layer-Type-IP	VIIRS Cloud Layer Type IP	474-00448-02-16_JPSS-DD-Vol-II-Part-16, Section 4.2
VIIRS-ANC-Surf-Ht-Mod-Gran	VIIRS Moderate Surface Height Granulated Ancillary data	474-00448-02-07_JPSS-DD-Vol-II-Part-07, Section 6.1.3
VIIRS-CBH-LWC-LUT	VIIRS CBH Liquid Water Content LUT	474-00448-02-16_JPSS-DD-Vol-II-Part-16, Section 7.2.2
VIIRS-CBH-IP-AC	VIIRS CBH IP Algorithm Coefficients	474-00448-02-16_JPSS-DD-Vol-II-Part-16, Section 7.2.2

Note that none of the inputs are scaled and that all input files must be spatially and temporally consistent with each other.

2.1.1.2 Outputs

CBH algorithm outputs are found in 474-00448-01-16_JPSS-SRS-Vol-I-Part-16, Table 3-1 (third row from end of table) and details are defined in 474-00448-02-16_JPSS-DD-Vol-II-Part-16, Tables 4.1.1 through 4.1.5.

2.1.2 Algorithm Processing

The purpose of the CBH IP algorithm is to retrieve cloud base heights for each confidently cloudy pixel in a VIIRS moderate resolution (750 m) granule. CBH, defined as the height above sea level where cloud bases occur, is calculated by determining the cloud thickness and subtracting it from cloud top height (CTH). Since CTH is obtained from a parallax-corrected version of the CTH IP, the processing focuses on the calculation of the cloud thickness. Briefly, cloud thickness is calculated by dividing the liquid (or ice) water path with liquid (or ice) water content. Both liquid water path and ice water path are determined based on a correlation equation in terms of cloud optical depth and effective particle size (EPS). Ice water content is also determined from a parameterization equation in terms of cloud top temperature (CTT). For liquid water content, however, constant values are used for each water cloud type.

Cloud thickness must be calculated and is dependent on cloud-phase. The CBH retrieval is performed by one of two algorithms:

- 1) a liquid-water algorithm for water-phase clouds,
- 2) a mixed-phase algorithm for opaque ice-phase, cirrus-phase, mixed-phase, or overlap-phase clouds.

The retrieval is performed for confidently cloudy pixels only.

Quality assessment flags for each pixel are stored in the CBH Quality Flag (QF) output.

2.1.2.1 Main Module – CBH_main()

The CBH_main() module performs four main tasks: 1) initialize output buffers, 2) associate pointers returned from DMS with local variables, 3) perform basic error handling, and 4) call CalculateCbh().

The CBH algorithm outputs two pieces of data: cloud base height and quality flags. CBH is initialized to ONGROUND_PT_FLOAT32_FILL and quality flags are initialized to zero.

Pointers to CBH inputs retrieved from DMS in ProEdrViirsCbh() are assigned to a class variable (a structure) that is passed throughout the CBH algorithm.

A small amount of error handling is performed in CBH_main() at the granule level to ensure there are valid scans to process and that selected coefficients (used later as divisors) do not cause divide-by-0 errors.

CBH_main() calls CalculateCbh() which in turn calculates CBH and quality flags for the entire granule.

2.1.2.2 Submodule CalculateCbh()

The logic flow of the CBH IP retrieval algorithm is provided in Figures 4 through 6. Duties of the module CalculateCbh() are: 1) establish whether or not a pixel should be processed, 2) determine the retrieval quality, 3) determine the retrieval algorithm for pixels that are processed, and 4) adjust for terrain height if necessary.

CBH is not retrieved if any of the following conditions occur:

- The pixel is not confidently cloudy (as specified by the VIIRS CM).
- Cloud phase is specified as something other than water-phase, opaque-ice-phase, cirrus-phase, mixed-phase, or overlap-phase.
- Cloud type is outside the CBH definition range of stratus, altocumulus/altostratus, cumulus, cirrus, or cirrocumulus.
- Cloud layer is outside a defined range.
- The pixel is determined to be in an area affected by the VIIRS “bow tie” effect.
- COT, EPS, or CTH contains Fill values.

Further retrieval restrictions apply for ice-phase (opaque-ice, cirrus), mixed-phase, or overlap-phase clouds:

- CTT contains Fill values.

For pixels that are processed, CBH is retrieved by either a water-phase algorithm for water-phase clouds or by a mixed-phase algorithm for ice-phase, mixed-phase, or overlap-phase clouds. A false retrieval occurs if cloud base height for a given pixel is greater than the pixel's CTH. In this scenario, the CBH is filled with ERR_FLOAT32_FILL.

For valid CBH retrievals where CBH is less than the terrain height, CBH is adjusted to terrain height.

CBH retrieval quality is checked and flagged for sun glint, cloud confidence of probably or confidently clear, and out-of range values.

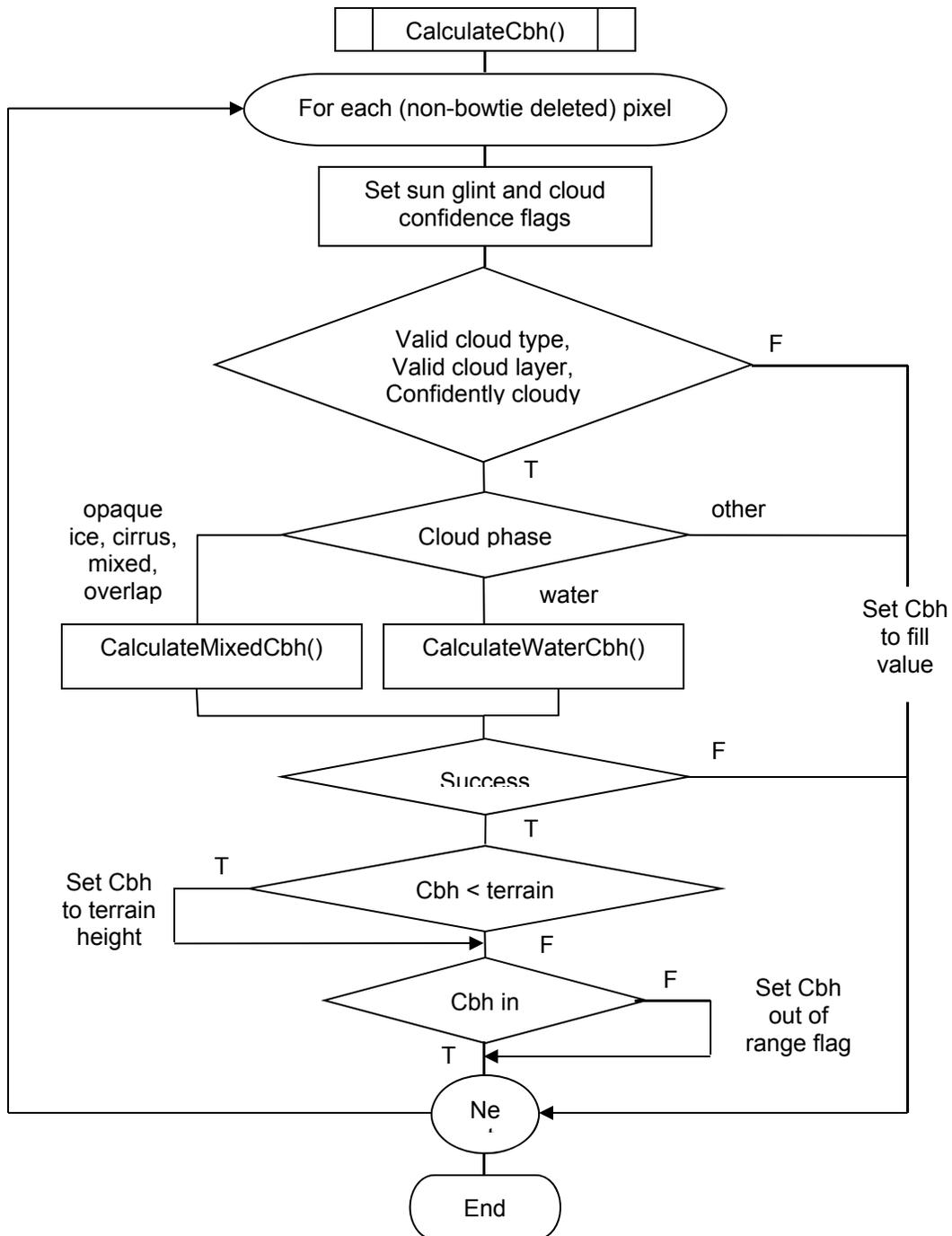


Figure 4. CalculateCbh() Logic Flow

2.1.2.3 Submodule CalculateWaterCbh()

For water-phase clouds, CBH is calculated according to the following algorithm (see Figure 5 for logic flow):

Calculate Liquid Water Path (LWP).

$$LWP = \frac{d_0 \cdot Cot \cdot r_{eff}}{d_3}$$

where

LWP is in g/m²,
d₀ and d₃ are cloud LWP constants,
Cot is the unitless COT, and
r_{eff} is the effective particle radius in μm, (also denoted by variable Eps).

Calculate CBH, Cbh in m and convert to km.

$$C_{bh} = C_{th} - \text{cloud thickness} = C_{th} - \left(\frac{LWP}{LWC_{Ct}} \right) \cdot METERS_TO_KM$$

where

C_{th} is the CTH in km,
LWC_{C_t} is the liquid water concentration lookup value in g/m³ for a specified
cloud type, C_t, and
METERS_TO_KM is the conversion from m to km.

Note that all calculations are carried out in floating point arithmetic. The theoretical basis of this algorithm is presented in Section 3.3.2 of the VIIRS Cloud Base Height Algorithm Theoretical Basis Document (ATBD), D0001-M01-S01-015.

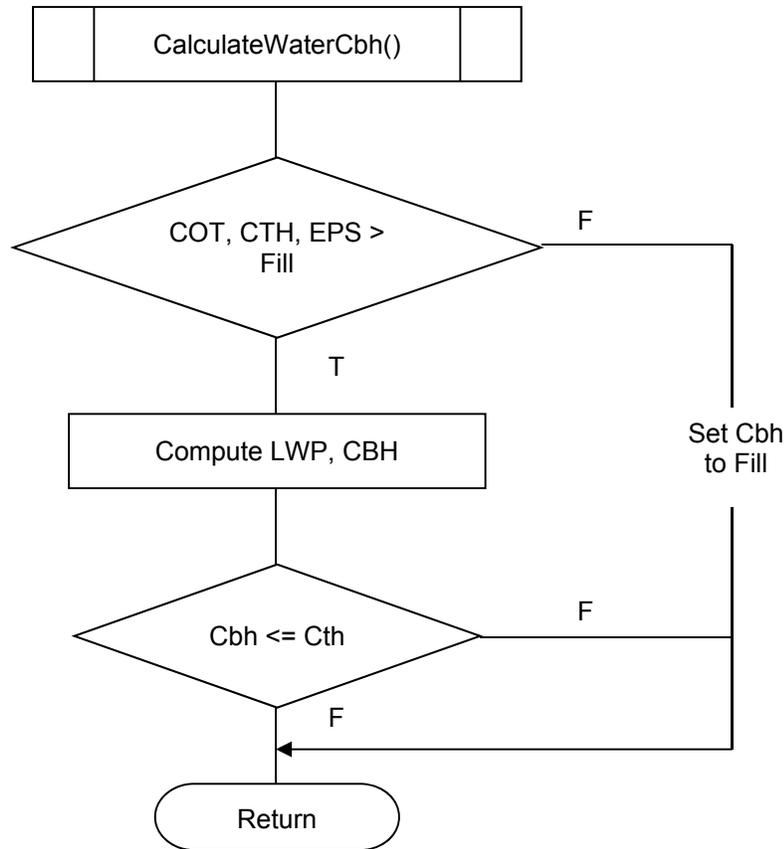


Figure 5. CalculateWaterCbh() Logic Flow

2.1.2.4 Submodule CalculateMixedCbh()

For ice-phase and mixed-phase clouds, CBH is calculated according to the following algorithm (see Figure 6 for logic flow):

Calculate Ice Water Path (IWP).

$$IWP = \frac{Cot}{c_0 + \frac{c_1}{2r_{eff}}}$$

where

- IWP is in g/m²,
- c₀ and c₁ are cloud IWP constants,
- Cot is the unitless COT, and
- r_{eff} is the effective particle radius in μm, (also denoted by variable Eps).

Calculate Cloud Mean Temperature (CMT), from CTT, Ctt

- Convert CTT, Ctt from Kelvin to Centigrade

$$Ctt = Ctt - 273.15$$

- Reset temperature to -60°C if it is below -60°C .
 Add delta temperature correction ($Cot * 20.0/6.0$).
 Reset temperature to -20°C if it is warmer than -20°C

$$CMT = \min((\max(-60, Ctt) + (20.0/6.0) * Cot), - 20) .$$

Calculate Ice Water Path, IWC.

- Since IWP equation is valid for $|CMT| > 20^{\circ}\text{C}$, ensure that this condition is met.

$$absCMT = \max(|CMT|, 20.000001)$$

- Use absCMT to calculate IWC.

$$\ln(IWC) = c_6 + c_7 \cdot e^{term}$$

$$term = c_4 \cdot c_5 \cdot (absCMT - c_2)^{c_3}$$

where

IWC is the Ice Water Path in g/m^3 , and
 c_2 to c_7 are the IWC constants.

Calculate CBH, Cbh in m and convert to km.

$$Cbh = Cth - \text{cloud thickness} = Cth - \left(\frac{IWP}{IWC} \right) \cdot METERS_TO_KM$$

where

Cth is the CTH in km, and
 METERS_TO_KM is the conversion from m to km.

Note that all calculations are carried out in floating point arithmetic. The theoretical basis of this algorithm is presented in Section 3.3.2 of the VIIRS Cloud Base Height Algorithm Theoretical Basis Document (ATBD), D0001-M01-S01-015.

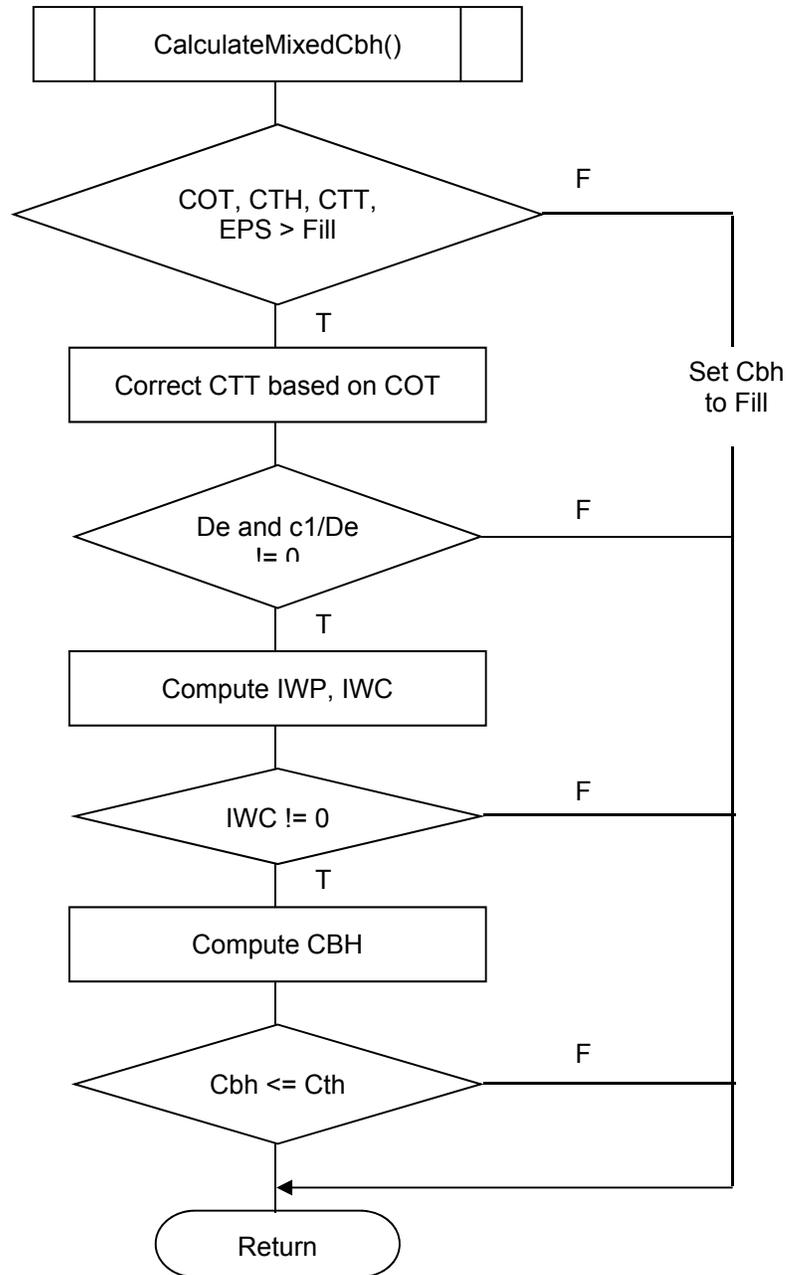


Figure 6. CalculateMixedCbh() Logic Flow

2.1.3 Graceful Degradation

None.

2.1.4 Exception Handling

A mechanism for external termination of the algorithm, called a stop callback, has been implemented. If a stop callback is issued, processing is terminated and no outputs are produced.

Error-handling in the Input (I) and Output (O) stages of the I-P-O algorithm addresses errors associated with reading/writing of databases. If an error occurs, the error is reported, the process is terminated and no outputs are produced.

Error-handling in the Processing (P) stage involves granule level and pixel level errors. For granule level errors, i.e. bad LUT values or an invalid number of scans, the error is reported, the process is terminated and no outputs are produced.

At initialization, cbh outputs are set to ONGROUND_PT_FLOAT32_FILL (i.e. pixel-trim fill) so they are already set for bow tie deletion and quality flag outputs are set to zero. Only pixels that are not in the bow-tie deletion region are processed. During processing, pixel level errors (i.e. divide by zero, $cbh > cth$), are reported, the pixels are filled with ERR_FLOAT32_FILL, and processing continues with the next pixel. Pixels not applicable for cloud base height processing (i.e. invalid cloud layer or type; not water, ice, mixed, or overlap phase; filled COT, CTH, CTT, or EPS) are filled with NA_FLOAT32_FILL and processing continues with the next pixel.

2.1.5 Data Quality Monitoring

CBH quality assessments consist of quality flags for sun glint, cloud confidence (confidently/probably clear), and out-of-range (see 474-00448-02-16_JPSS-DD-Vol-II-Part-16, Table 4.1.2) in the output IP.

Any Data Quality Threshold Tables (DQTTs) or Data Quality Notifications (DQNs) relevant to CBH are handled downstream during EDR processing by the Generate Cloud EDRs (GCE) module.

2.1.6 Computational Precision Requirements

Floating-point calculations are carried out in single-precision and double-precision arithmetic.

2.1.7 Algorithm Support Considerations

Sufficient research observations have been made to characterize cloud optical properties (e.g., LWC and IWC), and these values are relatively constant over global conditions.

2.1.8 Assumptions and Limitations

Assumptions and limitations based on theory are contained in the VIIRS Cloud Base Height Algorithm Theoretical Basis Document (ATBD), D0001-M01-S01-015.

3.0 GLOSSARY/ACRONYM LIST

3.1 Glossary

Table 5 contains terms most applicable for this OAD.

Table 5. Glossary

Term	Description
Algorithm	A formula or set of steps for solving a particular problem. Algorithms can be expressed in any language, from natural languages like English to mathematical expressions to programming languages like FORTRAN. On NPOESS, an algorithm consists of: <ol style="list-style-type: none"> 1. A theoretical description (i.e., science/mathematical basis) 2. A computer implementation description (i.e., method of solution) 3. A computer implementation (i.e., code)
Algorithm Engineering Review Board (AERB)	Interdisciplinary board of scientific and engineering personnel responsible for the approval and disposition of algorithm acceptance, verification, development and testing transitions. Chaired by the Data Process Algorithm Lead, members include representatives from STAR, DPES, IDPS, and Raytheon..
Algorithm Verification	Science-grade software delivered by an algorithm provider is verified for compliance with data quality and timeliness requirements by Algorithm Team science personnel. This activity is nominally performed at the GRAVITE facility. Delivered code is executed on compatible GRAVITE computing platforms. Minor hosting modifications may be made to allow code execution. Optionally, verification may be performed at the Algorithm Provider's facility if warranted due to technical, schedule or cost considerations.
Ancillary Data	Any data which is not produced by the JPSS System, but which is acquired from external providers and used by the JPSS system in the production of JPSS data products.
Auxiliary Data	Auxiliary Data is defined as data, other than data included in the sensor application packets, which is produced internally by the JPSS system, and used to produce the JPSS deliverable data products.
EDR Algorithm	Scientific description and corresponding software and test data necessary to produce one or more environmental data records. The scientific computational basis for the production of each data record is described in an ATBD. At a minimum, implemented software is science-grade and includes test data demonstrating data quality compliance.
Environmental Data Record (EDR)	<p><i>[IORD Definition]</i> Data record produced when an algorithm is used to convert Raw Data Records (RDRs) to geophysical parameters (including ancillary parameters, e.g., cloud clear radiation, etc.).</p> <p><i>[Supplementary Definition]</i> An Environmental Data Record (EDR) represents the state of the environment, and the related information needed to access and understand the record. Specifically, it is a set of related data items that describe one or more related estimated environmental parameters over a limited time-space range. The parameters are located by time and Earth coordinates. EDRs may have been resampled if they are created from multiple data sources with different sampling patterns. An EDR is created from one or more JPSS SDRs or EDRs, plus ancillary environmental data provided by others. EDR metadata contains references to its processing history, spatial and temporal coverage, and quality.</p>
Operational Code	Verified science-grade software, delivered by an algorithm provider and verified by GRAVITE, is developed into operational-grade code by the IDPS IPT.
Operational-Grade Software	Code that produces data records compliant with the System Specification requirements for data quality and IDPS timeliness and operational infrastructure. The software is modular relative to the IDPS infrastructure and compliant with IDPS application programming interfaces (APIs) as specified for TDR/SDR or EDR code.

Term	Description
Raw Data Record (RDR)	<p><i>[IORD Definition]</i> Full resolution digital sensor data, time referenced and earth located, with absolute radiometric and geometric calibration coefficients appended, but not applied, to the data. Aggregates (sums or weighted averages) of detector samples are considered to be full resolution data if the aggregation is normally performed to meet resolution and other requirements. Sensor data shall be unprocessed with the following exceptions: time delay and integration (TDI), detector array non-uniformity correction (i.e., offset and responsivity equalization), and data compression are allowed. Lossy data compression is allowed only if the total measurement error is dominated by error sources other than the data compression algorithm. All calibration data will be retained and communicated to the ground without lossy compression.</p> <p><i>[Supplementary Definition]</i> A Raw Data Record (RDR) is a logical grouping of raw data output by a sensor, and related information needed to process the record into an SDR or TDR. Specifically, it is a set of unmodified raw data (mission and housekeeping) produced by a sensor suite, one sensor, or a reasonable subset of a sensor (e.g., channel or channel group), over a specified, limited time range. Along with the sensor data, the RDR includes auxiliary data from other portions of JPSS (space or ground) needed to recreate the sensor measurement, to correct the measurement for known distortions, and to locate the measurement in time and space, through subsequent processing. Metadata is associated with the sensor and auxiliary data to permit its effective use.</p>
Retrieval Algorithm	A science-based algorithm used to ‘retrieve’ a set of environmental/geophysical parameters (EDR) from calibrated and geolocated sensor data (SDR). Synonym for EDR processing.
Science Algorithm	The theoretical description and a corresponding software implementation needed to produce an NPP/JPSS data product (TDR, SDR or EDR). The former is described in an ATBD. The latter is typically developed for a research setting and characterized as “science-grade”.
Science Algorithm Provider	Organization responsible for development and/or delivery of TDR/SDR or EDR algorithms associated with a given sensor.
Science-Grade Software	Code that produces data records in accordance with the science algorithm data quality requirements. This code, typically, has no software requirements for implementation language, targeted operating system, modularity, input and output data format or any other design discipline or assumed infrastructure.
SDR/TDR Algorithm	Scientific description and corresponding software and test data necessary to produce a Temperature Data Record and/or Sensor Data Record given a sensor’s Raw Data Record. The scientific computational basis for the production of each data record is described in an Algorithm Theoretical Basis Document (ATBD). At a minimum, implemented software is science-grade and includes test data demonstrating data quality compliance.
Sensor Data Record (SDR)	<p><i>[IORD Definition]</i> Data record produced when an algorithm is used to convert Raw Data Records (RDRs) to calibrated brightness temperatures with associated ephemeris data. The existence of the SDRs provides reversible data tracking back from the EDRs to the Raw data.</p> <p><i>[Supplementary Definition]</i> A Sensor Data Record (SDR) is the recreated input to a sensor, and the related information needed to access and understand the record. Specifically, it is a set of incident flux estimates made by a sensor, over a limited time interval, with annotations that permit its effective use. The environmental flux estimates at the sensor aperture are corrected for sensor effects. The estimates are reported in physically meaningful units, usually in terms of an angular or spatial and temporal distribution at the sensor location, as a function of spectrum, polarization, or delay, and always at full resolution. When meaningful, the flux is also associated with the point on the Earth geoid from which it apparently originated. Also, when meaningful, the sensor flux is converted to an equivalent top-of-atmosphere (TOA) brightness. The associated metadata includes a record of the processing and sources from which the SDR was created, and other information needed to understand the data.</p>

Term	Description
Temperature Data Record (TDR)	<p><i>[IORD Definition]</i> Temperature Data Records (TDRs) are geolocated, antenna temperatures with all relevant calibration data counts and ephemeris data to revert from T-sub-a into counts.</p> <p><i>[Supplementary Definition]</i> A Temperature Data Record (TDR) is the brightness temperature value measured by a microwave sensor, and the related information needed to access and understand the record. Specifically, it is a set of the corrected radiometric measurements made by an imaging microwave sensor, over a limited time range, with annotation that permits its effective use. A TDR is a partially-processed variant of an SDR. Instead of reporting the estimated microwave flux from a specified direction, it reports the observed antenna brightness temperature in that direction.</p>
Model Validation	The process of determining the degree to which a model is an accurate representation of the real-world from the perspective of the intended uses of the model.
Model Verification	The process of determining that a model implementation accurately represents the developer's conceptual description and specifications.

3.2 Acronyms

Table 6 contains terms most applicable for this OAD.

Table 6. Acronyms

Acronym	Description
ACO	Atmospheric Correction over Ocean
ADCS	Advanced Data Collection System
AFM	Airborne Fluxes and Meteorology Group
AOS	Acquisition of Signal
CBH	Cloud Base Height
CCL	Cloud Cover\Layers
CDA	Command and Data Acquisition
CDR	Climate Data Records
CI	Configured Item
CM	Cloud Mask
CMT	Cloud Mean Temperature
COMSAT	Communications Satellite
COP	Cloud Optical Properties
COT	Cloud Optical Thickness
CTH	Cloud Top Height
CTP	Cloud Top Parameters
CTT	Cloud Top Temperature
DES	Digital Encryption System
DHN	Data Handling Node
EOS	Earth Observing System
EPS	Effective Particle Size
ERBS	Earth Radiation Budget Suite
ESD	Electrostatic Discharge
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FMH	Federal Meteorological Handbook
GPS	Global Positioning System
GSE	Ground Support Equipment
HRD	High Rate Data

Acronym	Description
IGS	International GPS Service
IJPS	Initial Joint Polar System
IOC	Initial Operational Capability
IP	Intermediate Product
IWP	Ice Water Path
LEO&A	Launch, Early Orbit, & Anomaly Resolution
LOS	Loss of Signal
LRD	Low Rate Data
LST	Local Solar Time
LUT	Look-Up Table or Local User Terminal
LWP	Liquid Water Path
Metop	Meteorological Operational Program
MSS	Mission System Simulator
NA	Non-Applicable
NCA	National Command Authority
NDT	Nitrate-Depletion Temperature
OC/C	Ocean Color/Chlorophyll
PIP	Program Implementation Plan
PMT	Portable Mission Terminal
POD	Precise Orbit Determination
QF	Quality Flag
RSR	Remote Sensing Reflectance
S&R	Search and Rescue
SCA	Satellite Control Authority
SDE	Selective Data Encryption
SDP	Software Development Plan
SDR	Sensor Data Records
SDS	Science Data Segment
SGI®	Silicon Graphics, Inc.
SI	International System of Units
SN	NASA Space Network
SOC	Satellite Operations Center
SRD	Sensor Requirements Documents
SS	Space Segment
SST	Sea Surface Temperature
TBD	To Be Determined
TBR	To Be Resolved
TBS	To Be Supplied
TEMPEST	Telecommunications Electronics Material Protected from Emanating Spurious Transmissions
TOA	Top of the Atmosphere
USB	Unified S-band
UTC	Universal Time Coordinated

4.0 OPEN ISSUES

Table 7. TBXs

TBX ID	Title/Description	Resolution Date
None		