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Joint Polar Satellite System (JPSS) Operational Algorithm Description (OAD) Document for VIIRS Cloud Mask (VCM) Intermediate Product (IP) Software

For Public Release

Goddard Space Flight Center
Greenbelt, Maryland

National Aeronautics and
Space Administration

Joint Polar Satellite System (JPSS) Operational Algorithm Description (OAD) Document for VIIRS Cloud Mask (VCM) Intermediate Product (IP) Software

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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:

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Change History Log

Revision	Effective Date	Description of Changes (Reference the CCR & CCB/ERB Approve Date)
Original	07/31/2011	This version incorporates **474-CCR-11-0078**: (This version baselines D39539, Rev B dated 07/07/2010. 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.) to create JPSS version, Rev-. This was approved by the JPSS Ground Algorithm ERB on July 31, 2011.
Revision A	01/18/2012	**474-CCR-11-0269:** This version baselines 474-00062, Joint Polar Satellite System (JPSS) Operational Algorithm Description (OAD) Document for VIIRS Cloud Mask (VCM) 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	10/09/2012	**474-CCR-12-0627:** This version authorizes 474-00062, Joint Polar Satellite System (JPSS) Operational Algorithm Description (OAD) Document for VIIRS Cloud Mask (VCM) Intermediate Product (IP) Software, for the Mx 6.1 – 6.3 IDPS releases. Includes: **ECR-ALG-0035** which contains Raytheon PCR030368; OAD: Implement 474-CCR-12-0376 (VCM snow_night sign error) (ADR 4639), updated text on page 49. Raytheon PCR030550; OAD: Implement 474-CCR-12-0400 (Update to VCM Snow/Ice Preprocessor (DR 4577)), updated Figure 5 and pg 25. Raytheon PCR031556, OAD: PRO: Implement 474-CCR-12-0476 VIIRS Cloud Mask M7 Scattering Angle Correction (ADR 4793) updated Tables 28 & 50 and corrected various references within the OAD.

NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM (NPOESS)

OPERATIONAL ALGORITHM DESCRIPTION (OAD) DOCUMENT FOR VIIRS CLOUD MASK (VCM) INTERMEDIATE PRODUCT (IP)

SDRL No. S141
SYSTEM SPECIFICATION SS22-0096

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

IAW DFAR 252.227-7036, Raytheon hereby declares that, to the best of its knowledge and belief, the technical data delivered under Subcontract No. 7600002744 is complete, accurate, and complies with all requirements of the Subcontract.

TITLE: NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM (NPOESS) OPERATIONAL ALGORITHM DESCRIPTION DOCUMENT FOR VIIRS CLOUD MASK (VCM) INTERMEDIATE PRODUCT (IP)

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Engineering & Manufacturing Development (EMD) Phase
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Operational Algorithm Description
VIIRS Cloud Mask Intermediate Product (VCM IP)

Document Number: D36816
Document Date: Jun 29, 2011
Revision: C3

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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	NORTHROP GRUMMAN Raytheon

Revision/Change Record	**Document Number**	**D36816**

Revision	Document Date	Revision/Change Description	Pages Affected
---	3-13-03	Initial Release.	All
A1	4-25-03	Revision A.	Title Page, Pages i, 4, 6, 9, 11, 12, 14, 16, 28
A2	8-14-03	Updated Algorithm description to reflect its inclusion to the IPO model.	All
A3	12-11-03	Finalized for ACCB Review.	All
A4	2-5-04	Updated to list units in input and output tables, ERB updates.	All
A5	12-3-04	Update code changes.	All
A6	4-12-06	03Oct05 - Reflects Raytheon-Omaha edits to insert 04Mar05 Tech Memo and 11Mar05 Tech Memo information. 07Dec05 – Updated per comments from 2Dec05 follow-on I-P-O CUT peer review, specifically reinserting Section 2.2.3 I/O Timeliness Requirements, etc. 02Mar06 – Began updating per the 24Oct05 66 page Tech Memo titled "Updates to VIIRS Cloud Mask IP OAD for NGST Drop 1.0.5". 06 & 07-Mar06 – Continued updating per the 24Oct05 Tech Memo. 13Mar06 – Inserted more Section 5.2 tables, therefore had to renumber some, and update the List of Tables. Inserted new Unit Test and had to update Table of Contents, page numbering for List of Tables. 27Mar06 – Per CUTPR 3-17-06 follow- on comments replaced Figure 2 with latest "IPO Model Interface to INF & DMS" diagram, removed Table 1 and Table 4 at PRO SW engineer's suggestion and renumbered the updated the List of Tables. 07Apr06 – Per 7Apr06 Follow-on DDPR comments, reversed borders in tables so when OAD is printed they appear. Added a border around Figures. Removed all "Notes" marked as red. Reworded Table 4 Byte 2 Bit 6 to distinguish between RM7 and RM1 tests. Inserted suggested paragraph under Section 4.2 Error Handling for clarification. Updated Table 13 superscript corrections. Made other minor spacing/format changes. 11Apr06 – Added a new Section 2.5, Cross Granule Processing and updated Table of Contents to incorporate it. 12Apr06 – Did spacing/format edits. Replaced the 3/10/2006 Unit Test with the MODIS size 4/10/2006 Unit Test.	All

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A7	12-3-07	Updated Snow / Ice Logic Enhanced Clouds / Heavy Aerosol Discrimination Updated Cloud Adjacency Logic Removed two of the Imagery Resolution Cloud Tests and Flags Added new dust, smoke and volcanic ash / dust flags.	All
A8	3-12-08	Updated to calculate using IET time instead of Julian Day Updated the reference table Added details of common adjacency.	2, 8, 15, 16, 83
A9	9-4-08	Update Graceful Degradation.	84, 85
A10	9-18-08	Update Cloud Shadow Logic and Cloud Shadow Cross Granule Processing. Implemented Tech Memo NP-EMD.2008.510.0011.	All
A11	10-17-08	Updated comments with respect to CCPR of Cloud Shadow. Tech Memos NP-EMD.2007.510.0048, NP-EMD.2004.510.0061, NP-EMD.2005.510.0031, NP-EMD.2005.510.0083, NP-EMD.2005.510.0138, NP-EMD.2008.510.0011 and NP-EMD.2008.510.0047, have been implemented. Prepared for delivery to NGST.	All
A12	3-18-09	Updated for SDRL comments. Prepared OAD for TIM.	All
A13	4-15-09 5-04-09 5-06-09 5-20-09	Incorporated TIM comments. Prepared for ARB/ACCB. Incorporated ARB comments and prepared for resubmittal to ARB/ACCB Incorporated RFA #547 as requested by ARB. Incorporated additional ARB comments from 5-20-09.	All All Table 44 17, 37, 55, 69, & 89
A	5-20-09	Approved at ACCB	All
B1	6-17-09	Added D48316_---_CmnAdjacency_OAD.doc to Reference Table.	1 - 3
B2	8-10-09	Updated based on NP-EMD.2008.510.0065	All
B3	10-7-09	Incorporated VIIRS Science Algorithms 4.16 Delivery and Code and Unit Test Peer review comments	All
B4	11-04-09	Updated for SDRL delivery	All

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Revision/Change Record

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B5	12-15-09	Updated VCM IP Constants and Tunable Parameter tables; replaced hard-coded values in text with tunable parameter names; corrected M9 test description; rewrote Cloud Phase algorithm description; updated Cloud Phase algorithm, water/day and water/night description and Heavy Aerosol flowcharts with latest mods; various formatting corrections; added in mods missed from previous Tech Memo; added automatic caption numbering and cross references	All
B6	5-05-10	Updated with drop 4.20 and 4.25 (TM 2010.510.0035)	All
B	7-07-10	Prepared for TIM/ARB/ACCB	All
C1	9-15-10	Fixed tab formats in "Steps for Performing the BTM15 – BTM12 Emission Difference Test" Correct Document Number in Revision/Change Record Made mods in response to RFA ID_012 and/or RFA_ID_011 • Updated Figures 1 and 2 with Active Fire IP • Updated Table 4 by adding Active Fire IP as source for Fire Mask in Description column, and other minor formatting nits • Added a note about reverse naming convention of I/O, thresholds, local variables for the M7/M5 ratio spectral test • Added note about differences between GEMI equation in OAD versus ATBD • Added further detail re interpolation of Table 36 in M15 – M16 BT Difference Test discussion • Updated Figure 23 title	46-48 this section 5 and12, 9, 60, 61, 65, 88
C2	10-20-10	Incorporated TM 2010.510.0076 and other convergence related updates	All
C3	06-29-11	Updated due to ECR-ALG-0006 VIIRS Cloud Mask_Drop 4.25.1 & Tm 2010.510.0100	All

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1.0 INTRODUCTION

1.1 Objective

The purpose of the Operational Algorithm Description (OAD) document is to express, in computer-science terms, the remote sensing algorithms that produce the National Polar-Orbiting Operational Environmental Satellite System (NPOESS) 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 Data Processing Element (DPE).

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 Cloud Mask IP. The theoretical basis for this algorithm is described in Section 3.4 of the VIIRS Cloud Mask (VCM) Algorithm Theoretical Basis Document ATBD, 474-00033.

1.3 References

The primary software detailed design publications listed here include science software documents, NPOESS program documents, plus science source code and test data 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 Mask (VCM) Algorithm Theoretical Basis Document ATBD	474-00033	22 Apr 2011
Cloud Mask IP Component Level Detailed Design	Y2491 Ver. 5 Rev. 5	Apr 2003
Cloud Mask IP Comp. Level Software Architecture	Y3244 Ver. 5 Rev. 8	Dec 2002
Cloud Mask IP Comp. Level Data Dictionary	Y3265 Ver. 5 Rev. 4	Mar 2003
VIIRS Cloud Mask Interface Control Document	Y0010879 Ver. 5 Rev. 5	Mar 2003
VIIRS Algorithm Verification Status Report	D36812 Ver. 1	31 Mar 2003

Document Title	Document Number/Revision	Revision Date
Operational Algorithm Description Document for VIIRS Active Fires Application Related Product (ARP)	474-00064, Rev A	27 Jan 2012
Operational Algorithm Description Document for Gridding/Granulation (G/G) and VIIRS Gridded Intermediate Products (GIP)	474-00075, Rev A	27 Jan 2012
Operational Algorithm Description Document for the Granulate Ancillary Software	474-00089, Rev A	27 Jan 2012
Operational Algorithm Description Document for VIIRS Geolocation (GEO) Sensor Data Record (SDR) and Calibration (CAL) SDR	474-00090, Rev A	27 Jan 2012
Hutchison, K.D., Roskovensky, J.K., Jackson, J.M., Heidinger, A.K., Kopp, T. J., Pavolonis, M.J, and R. Frey, 2005: “Automated Cloud Detection and Typing of Data Collected by the Visible Infrared Imager Radiometer Suite (VIIRS),” *International Journal of Remote Sensing*, 20, 4681 – 4706.	NA	2005
Hutchison, K. D., Iisager, B. D., Kopp, T, J., Jackson, J. M, Distinguishing Aerosols from Clouds in Global, Multispectral Satellite Data with Automated Cloud Classification Algorithms, *Journal of Atmospheric and Oceanic Technology*, 2008.	NA	NA
Inoue, T., 1985: On the Temperature and effective emissivity determination of semi-transparent cirrus clouds by bi-spectral measurements in the 10-μm window region, *J. Meteorological Society of Japan*, 63, 88-99.	NA	1985
Martins, J.V., D. Tanré, L.A. Remer, Y.J. Kaufman, Mattoo, S., and R. Levy, 2002: MODIS Cloud screening for remote sensing of aerosol over oceans using spatial variability. *Geophysical Research Letters*, 29, 10.1029/2001GL013252.	NA	2002
Pavolonis, M. J.; Feltz, W. F.; Heidinger, A. K., and G. M. Gallina, 2006: A daytime complement to the reverse absorption technique for improved automated detection of volcanic ash, *J. Atmos. Ocea. Technol*., 23, 1422-1444	NA	2006
Prata, A. J.,1989a: Observations of volcanic ash clouds in the 10-12-micron window using AVHRR/2 data, *International Journal of Remote Sensing*, 10, 751-761.	NA	1989
Prata, A. J., 1989b: Radiative transfer calculations for volcanic ash clouds, *Geophysical Research Letters*, 16, 1293-1296	NA	1988
Prata, A. J., Bluth, G., Rose, B., Schneider, D., and A. Tupper, 2001: Failures in detecting volcanic ash from a satellite-based technique – Comments, *Remote Sensing of the Environment*, 78, 341-346.	NA	NA
JPSS Environmental Data Record (EDR) Production Report for NPP	474-00012 Rev. A	09 Feb 2011
JPSS Environmental Data Record (EDR) Interdependency Report (IR) for NPP	474-0007 Rev. A	09 Feb 2011
JPSS Common Data Format Control Book - External - Volume I - Overview	474-00001-01, Rev-	10-Dec-10
JPSS Common Data Format Control Book - External - Volume II - RDR Formats	474-00001-02, Rev-	10-Dec-10
JPSS Common Data Format Control Book - External - Volume III - SDR/TDR Formats	474-00001-03, Rev-	16-Feb-11
JPSS Common Data Format Control Book - External - Volume IV - Part I - IPs, ARPs, and Geolocation Data	474-00001-04-01, Rev-	10-Dec-10
JPSS CDFCB - External - Volume IV - Part II - Imagery, Atmospheric, and Cloud EDRs	474-00001-04-02, Rev-	10-Dec-10
JPSS Common Data Format Control Book - External - Volume IV - Part III - Land and Ocean/Water EDRs	474-00001-04-03, Rev-	10-Dec-10
JPSS Common Data Format Control Book - External - Volume IV - Part IV - Earth Radiation Budget and Space EDRs	474-00001-04-04, Rev-	18-Feb-11

Document Title	Document Number/Revision	Revision Date
JPSS Common Data Format Control Book - External - Volume V - Metadata	474-00001-05, Rev-	16-Feb-11
JPSS CDFCB - External - Volume VI - Ancillary Data, Auxiliary Data, Messages, and Reports	474-00001-06, Rev-	10-Dec-10
JPSS Common Data Format Control Book - External - Volume VII - Part I - JPSS Downlink Data Formats	474-00001-07-01, Rev-	16-Feb-11
JPSS CDFCB - External - Volume VII - Part 2 - JPSS Downlink Data Formats - CrIS	474-00001-07-02, Rev-	16-Feb-11
JPSS CDFCB - External - Volume VII - Part 3 - JPSS Downlink Data Formats - OMPS	474-00001-07-03, Rev-	16-Feb-11
JPSS CDFCB - External - Volume VII - Part 4 - JPSS Downlink Data Formats - ATMS	474-00001-07-04, Rev-	16-Feb-11
JPSS CDFCB - External - Volume VII - Part 5 - JPSS Downlink Data Formats - VIIRS	474-00001-07-05, Rev -	16-Feb-11
JPSS Common Data Format Control Book - External - Volume VIII - Look Up Table Formats	474-00001-08, Rev -	10-Dec-10
NPP Mission Data Format Control Book and App A (MDFCB)	472-REF-00057	06 Jan 2011
NPP Command and Telemetry (C&T) Handbook	D568423 Rev. C	30 Sep 2008
JPSS CGS Data Processor Inter-subsystem Interface Control Document (DPIS ICD) Vol I – IV	IC60917-IDP-002, Rev C	29-Sep-11
JPSS CGS Acronyms and Glossary	LI60917-GND-005, Rev -	17-Oct-11
NGST/SE technical memo – VCM_OADUpdatesForDrop4.7_TechMemo	NP-EMD-2007.510.0048	22 Aug 2007
NGST/SE technical memo – VCM_vs_VFM_Memo	NP-EMD.2004.510.0061	20 Dec 2004
NGST/SE technical memo – VCM_OAD_tech_memo_03-09-05	NP-EMD.2005.510.0031	3 Nov 2005
NGST/SE technical memo – VIIRS_CM_QF_thin_cirrus	NP-EMD.2005.510.0083	4 Mar 2005
NGST/SE technical memo – VCM_Drop_1.0.5_EngMemo	NP-EMD.2005.510.0138	24 Oct 2005
NGST/SE technical memo – VCM_OADUpdatesForDrop4.8_TechMemo	NP-EMD.2008.510.0011	25 Mar 2008
NGST/SE technical memo – VCM_OADUpdate_for_CloudShadow_xGran_Processing	NP-EMD.2008.510.0047	19 Aug 2008
PRO User's Manual (for Cross Granule Processing and the Bow-Tie Trim Table)	UG60822-IDP-026 IDPS PRO SW Users Manual Part 2 App A Com. IO Design	24 Sep 2008
Operational Algorithm Description Document for Common Adjacency	474-00097	02 Dec 2011
NGST/SE technical memo – VCM OAD Updates for Drop ISTN_VIIRS_NGST_4.13	NP-EMD.2008.510.0065	17 Dec 2008
VIIRS Science Algorithms 4.16 Delivery to IDPS Package Version Description	D52873 Rev ---	02 Jul 2009
NGAS/SE technical memo – VCM OAD Updates for Drop ISTN_VIIRS_NGST_4.20	NP-EMD.2009.510.0065 Rev B	05 Jan 2010
VIIRS Science Algorithms 4.20 Delivery to IDPS Package Version Description	D54423 Rev ---	13 Jan 2010
NGAS/SE technical memo – VCM_UpdatesForDrop4.25	NP-EMD-2010.510.0035	05 May 2010
NGST/SE technical memo VIIRS_VCM_OAD_RFA_redline	NP-EMD.2010.510.0076	16 Sep 2010
NGST/SE technical memo VIIRS_VCM_DaytimeTuning_Drop4.25.1	NP-EMD.2010.510.0100	22 Dec 2010

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
ISTN_VIIRS_NGST_1.0 (baseline)	(OAD Rev ---)	--
ISTN_VIIRS_NGST_1.0.1	--	--
Operational Software	Build 1.2 (OAD Rev A2)	14 Aug 2003
ISTN_VIIRS_NGST_1.0.2	--	16 Dec 2004
Operational Software	Build 1.3 (OAD Rev A5)	03 Dec 2004
ISTN_VIIRS_NGST_1.0.3	(ECR-A047)	30 Mar 2005
ISTN_VIIRS_NGST_1.0.5	(ECR A079A)	30 Nov 2005
Operational Software	Build 1.4 (OAD Rev A6)	12 Apr 2006
ISTN_VIIRS_NGST_4.7	(ECR-A131B)	7 Nov 2007
Operational Software	Build 1.5 (OAD Rev A7)	03 Dec 2007
ISTN_VIIRS_NGST_4.8	(ECR-A142)	16 Apr 2008
ISTN_VIIRS_NGST_4.8.1	--	12 Dec 2008
Operational Software	Build 1.5.x.1 (OAD Revs A8 - A12)	18 Mar 2009
ISTN_VIIRS_NGST_4.13	(ECR-A185)	23 Jan 2009
ACCB	ECR-A231B (OAD Rev-A)	20 May 2009
Operational Software	Build Sensor Characterization (SC)-1 (OAD Rev B2)	10 Aug 2009
ISTN_VIIRS_NGST_4.16	(ECR-A245)	02 Jul 2009
Operational Software	Build Sensor Characterization (SC)-4 (OAD Rev B3)	07 Oct 2009
SDRL	OAD Rev B4	04 Nov 2009
ISTN_VIIRS_NGST_4.20	(ECR-A262) (OAD Rev B5)	09 Dec 2009
ISTN_VIIRS_NGST_4.25	(ECR-A298) (OAD Rev B6)	05 May 2010
Operational Software	Build Sensor Characterization (SC)-11 (OAD Rev B6)	28 Jun 2010
ACCB	OAD Rev B	07 Jul 2010
Implement Tech Memo 2010.510.0076 (PCR024739)	OAD Rev C1	20 Oct 2010
Convergence Update (No code update)	OAD Rev C2	20 Oct 2010
ISTN_VIIRS_NGST_4.25.1 includes TM 2010.510.0100	(ECR-A0006	13 Jan 2011
Operational Software (PCRs 025914 & 026164)	Maintenance Build 1.5.05.00.01 (OAD Rev C3)	11 Mar 2011 & 29 Jun 2011 (OAD)

2.0 ALGORITHM OVERVIEW

This document describes the as-built IDPS implementation for the VCM algorithm. The VCM technique incorporates a number of cloud detection tests that determine whether a cloud obstructs a pixel. If a cloud is detected, the VCM indicates whether its phase is water, ice, mixed or overlapping water and ice clouds. Additionally, the VCM specifies whether aerosols, fire, or shadows are detected within the pixel field of view (FOV). Based on the results of the cloud detection tests, VCM assigns one of four cloud ‘confidences’: (1) confidently cloudy, (2) probably cloudy, (3) probably clear, and (4) confidently clear. Different thresholds for the tests are applied based on surface type (e.g. land versus water) and solar illumination (i.e. day versus night). The cloud detection tests are divided into five groups: (1) simple IR threshold tests, (2) brightness temperature difference tests, (3) solar reflectance tests, (4) NIR thin cirrus test, and (5) IR thin cirrus tests. The tests are grouped so that independence between them is maximized. When all tests within a group have been performed, the minimum resulting confidence from among them is taken to be representative of that group. A final step is to combine the group confidences, assumed to be independent, by multiplying them together and taking the Nth root. Figure 1 below depicts the VCM processing chain. The VCM is the first to be executed in the VIIRS EDR chain as it provides input to a number of other EDRs.

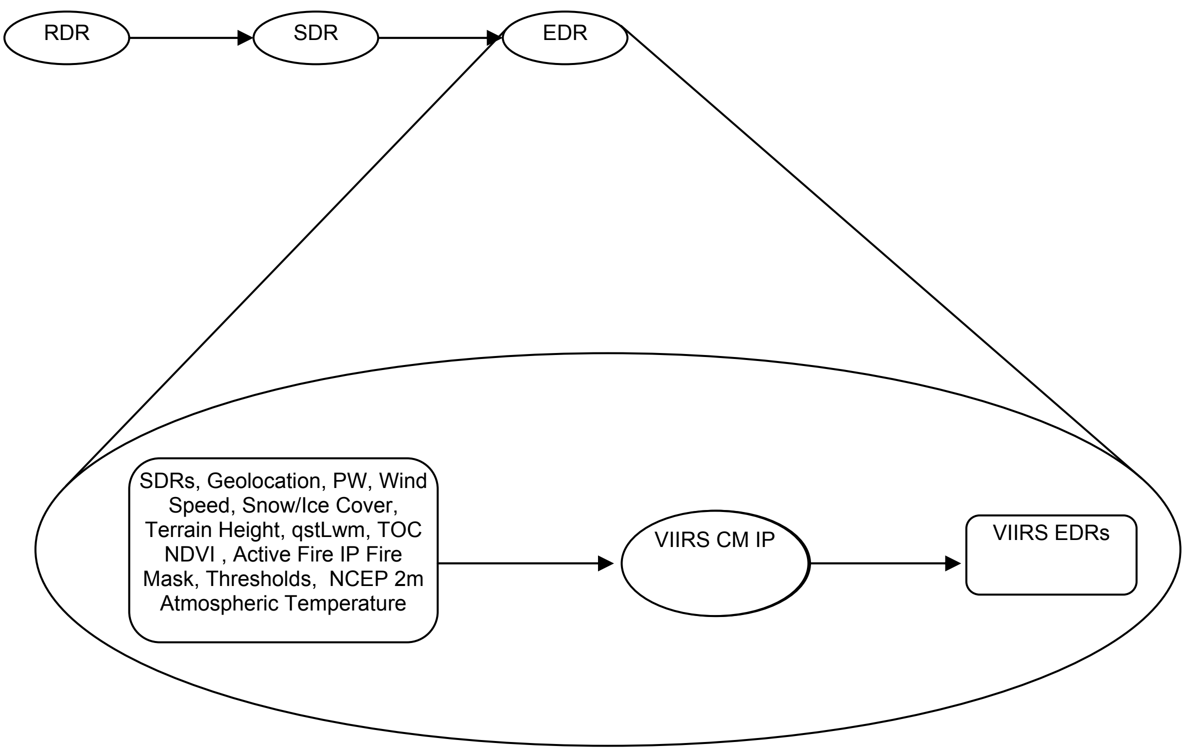


Figure 1. Processing Chain Associated with VCM IP

2.1 VCM IP Description

2.1.1 Interfaces

The VCM algorithm is initiated by the controller algorithm, ViirsMasksController, which executes both VIIRS Active Fires and VIIRS Cloud Mask Algorithms.

Table 3 lists all the constants used in the VCM algorithm. These constants are contained in the ProEdrViirsCMConstants.h include file. Note also that the software requires many tunable input parameters. These parameters are listed in Table 50, VCM IP Tunable Parameters.

Table 3. VCM IP Constants

Input	Type	Description/Source	Units/Valid Range
TRUE	uint	flag indicating a “true” outcome	1
FALSE	uint	flag indicating a “false” outcome	0
CP_BAD	float	float for bad threshold data in Cloud_Phase()	9999.0
CP_BAD_TOL	float	tolerance constant used in testing for an unusable cloud phase threshold flagged as CP_BAD	1.0
CP_TRUE	uint	flag indicating a “true” outcome in Cloud_Phase()	1
CP_FALSE	uint	flag indicating a “false” outcome in Cloud_Phase()	0
BAD_ANGLE	float	flag indicating invalid angle	–180.0 degrees
FLOAT32_FILL_TEST	float	fill value indicating bad or invalid data	–999.0
INT_FILL	int	integer fill flag	255
INIT_INT	int	integer initialization value	0
INIT_FLOAT	float	float initialization value	0.0
MAX_LAT	float	maximum global latitude	90 degrees
NUM_DAYS_IN_YEAR	int	number of days in a year	365 days
M_PI	double	UNIX standard math library value for π, found in math.h	3.14159265358979323846
TWO_PI	double	2π	2*M_PI
SPEED_LIGHT_M_S	float	speed of light in a vacuum	2.99792458e+08 m/s
PLANCK	float	Planck's constant	6.6262e-34 W sec^2
BOLTZMANN	float	Boltzmann's constant	1.3807e-23 W sec / K
M_PER_MICRON	float	conversion factor for microns to meters	1.0e-06 m/μm
ERAD_KM	float	Earth equatorial radius in kilometers	6378.137 km
VFM_LOW_FIRE_CONF	int	Active Fire flag value for “low confidence” of fire	7
VFM_HIGH_FIRE_CONF	int	Active Fire flag value for “high confidence” of fire	9
NVZA	int	number of satellite zenith angles for Cloud Phase coefficient table	7
NSZA	int	number of solar zenith angles for Cloud Phase coefficient table	8
NSCT	int	number of scattering angles for Cloud Phase coefficient table	18
VIIRS_MAX_SENZEN_ANGLE	float	maximum sensor zenith angle	70.0 degrees
VCM_DEFAULT_TPW_SLANT_PATH_FACTOR	float	Default setting of the secant of the sensor zenith angle when the sensor zenith angle is outside the range of 0.0 and 90.0 degrees	1.0

Input	Type	Description/Source	Units/Valid Range
NSZ	int	number of elements solar zenith array; array ranges between 0.0 and 80.0 degrees, inclusive; array used in Imagery Band calculations	9
NVZ	int	number of elements satellite zenith array; array ranges between 0.0 and 80.0 degrees, inclusive; array used in Imagery Band calculations	9
NRAZ	int	number of elements azimuth array; array ranges between 0.0 and 180.0 degrees, inclusive; array used in Imagery Band calculations	19
sol_arr{NSZ]	float * NSZ	array of solar zenith angles ranging between 0.0 and 80.0 degrees at 10 degree increments	0.0, 10.0, … 80.0 degrees
sat_arr[NVZ]	float * NVZ	array of satellite zenith angles ranging between 0.0 and 80.0 degrees at 10 degree increments	0.0, 10.0, … 80.0 degrees
azi_arr[NRAZ]	float * NRAZ	array of azimuth angles ranging between 0.0 and 180.0 degrees at 10 degree increments	0.0, 10.0, … 180.0 degrees
Sun Glint Calculation Constants			
SUNGLINT_COX_MUNK_C1	float	0^{th} order constant in variance (σ^2) calculation for the calculation for the probability of sun glint Refer to Eqn 2.	0.003
SUNGLINT_COX_MUNK_C2	float	1^{st} order constant in variance (σ^2) variable for the calculation for the probability of sun glint Refer to Eqn 2.	0.00512
RAD_SUNGLINT_COX_MUNK_PROB_VAR_LIMIT	float	max limit of variable Θ_N in probability equation for sun glint Refer to Eqn 2.	89.0 * DEG2RAD radians
RAD_THETA_N_MAX	float	discontinuity check variable for variable Θ_N in probability equation for sun glint Refer to Eqn 2	90.0 * DEG2RAD radians
Earth to Sun Distance Calculations Constants for M12 Reflectance Calculation in Heavy Aerosol			
EARTH_TO_SUN_CONST	float	Earth to Sun distance constant. Refer to Eqn 1.	1.00011
EARTH_TO_SUN_COSPHI_FACTOR	float	Earth to Sun distance cos(phi) factor. Refer to Eqn 1.	0.034221
EARTH_TO_SUN_SINPHI_FACTOR	float	Earth to Sun distance sin(phi) factor. Refer to Eqn 1.	0.00128
EARTH_TO_SUN_COS2PHI_FACTOR	float	Earth to Sun distance cos(2phi) factor. Refer to Eqn 1.	0.000719
EARTH_TO_SUN_SIN2PHI_FACTOR	float	Earth to Sun distance sin(2phi) factor. Refer to Eqn 1.	0.000077
NUM MICROSEC_IN_YEAR	long	Number of microseconds in a year	1000000 * 31556926 μsec
NUM_MICROSEC_IN_DAY	int	Number of microseconds in a day	1000000 * 86400 μsec

Input	Type	Description/Source	Units/Valid Range
RECI_DAYS_PER_YEAR	double	The reciprocal of days per year	1.0 / 365.242199 $days^{-1}$
M5M1 Test Constants			
DELTA_NDVI_CLASS	float	Bin width for TOC NDVI categorization used in land/day and coast/day M5 (M1) reflectance tests	0.1
MIN_NDVI_CLASS	float	Minimum bin center for TOC NDVI categorization used in land/day and coast/day M5 (M1) reflectance tests	0.05
NUM_NDVI_BINS	int	Total number of TOC NDVI bins used in land/day and coast/day M5 (M1) reflectance tests	10
MAX_NUM_M1_NDVI_BINS	int	number of TOC NDVI bins for M1 coefficient table, M1_ndvi_coef (must be less than NUM_NDVI_BINS)	3
NCOEFS	int	Number of NDVI coeffs used for threshold calculations for the M5M1 reflectance test	4
NTHRESH	int	Number of thresholds calculated for the M5M1 reflectance test	3
VCM_AERO_MOD_WINSIZE	int	number of moderate resolution pixels used along track and along scan for the heavy aerosol dust/smoke spatial test	2

2.1.1.1 Inputs

The VCM IP requires several types of input data. They are summarized in Table 4 below. Some of the input data can originate from multiple sources. For these situations, a hierarchy is established for order of preference (for additional information, see Section 2.1.3, Graceful Degradation). Refer to the CDFCB-X, 474-00001, for a detailed description of the inputs.

Table 4. VCM IP Inputs

Name	Type	Description	Units / Valid Range
VIIRS Radiance SDRs for moderate band M12	Float32	VIIRS calibrated top of the atmosphere (TOA) radiance	$W/(m^2\text{-sr-}\mu m)$ / Refer to CDFCB-X, Vol III, VIIRS SDR Format, sect. 2.16
VIIRS Brightness temperature SDRs for moderate bands M12, M13, M14, M15 and M16	Float32	VIIRS calibrated top of the atmosphere (TOA) brightness temperatures	K / Refer to CDFCB-X, Vol III, VIIRS SDR Format, sect. 2.16
VIIRS Brightness temperature SDRs for Imagery bands I4 and I5.	Float32	VIIRS calibrated top of the atmosphere (TOA) brightness temperatures	K / Refer to CDFCB-X, Vol III, VIIRS SDR Format, sect. 2.17
VIIRS Reflectance for moderate bands M1, M4, M5, M7, M9, M10, and M11	Float32	VIIRS calibrated top of the atmosphere (TOA) reflectance	N/A / Refer to CDFCB-X, Vol III, VIIRS SDR Format, sect. 2.16

Name	Type	Description	Units / Valid Range
VIIRS Reflectance for imagery bands I1 and I2	Float32	VIIRS calibrated top of the atmosphere (TOA) reflectance	N/A / Refer to CDFCB-X, Vol III, VIIRS SDR Format, sect. 2.17
VIIRS Moderate Band Geolocation File for latitude, longitude, sensor azimuth angle, sensor zenith angle, solar azimuth angle and solar zenith angle.	Float32	Earth location for each satellite view point as well as solar, sensor angles and view geometry	Degrees or radians (but converted to radians internally) / See VIIRS SDR OAD, 474-00090 (Geo outputs)
scanStartTime	Int64	Scan Start Time in IET time format	Microseconds $0 \le$ scanStartTime $\le$ 1.00E+38
Terrain Height	Int16	Digital terrain elevation	gpm / -1000 – 9000
Snow/Ice Cover	Int8	Snow/Ice Mask	Unitless / 0-1
Land / Water Quarterly Surface Type Map	Int8	Classification of pixel surface type, granulated for 750 m resolution pixels	Unitless / 1 to 20
Wind Speed	Float32	Sea Surface wind speed	m/s / refer to 474-00089,Gran ANC OAD
TOC NDVI	Float32	Ratio of RM7 – RM5 to RM7 + RM5 (unitless)	Unitless / Refer to 474-00075, G-G-VIIRS GIP OAD
Precipitable Water (PW)	Float32	Total column precipitable water	cm / 0-130
Surface Temperature	Float32	Temperature	K / 183 -328
Fire Mask	UInt8	Flag indicating confidence of fire in moderate resolution pixel from VIIRS Active Fire IP	Refer to VIIRS Active Fire ARP OAD, 474-00064
Cloud Mask Thresholds		Threshold values to calculate VIIRS Cloud Mask, see Table 50, VCM IP Tunable Parameters	various, refer to Table 50
Configuration File		File containing values for adjustable parameters used to execute the software	N/A

2.1.1.2 Outputs

The VCM algorithm primary output, as shown in Table 5 below, are 6 bytes (48 bits) for each moderate resolution pixel. The 6 bytes contain an overall cloud confidence flag, processing path flags, cloud detection test flags (at moderate resolution), and quality flags. To allow for the imprecise measurement of the real world and to accommodate a wide variety of applications, the mask is more than a simple yes/no decision. The VCM includes 4 levels of ‘confidence’ with regard to whether a pixel is thought to be clear, as well as the results from different spectral tests. Refer to the CDFCB-X, 474-00001, for a detailed description of the outputs. Table 6 lists VCM IP output quality flag bits and descriptions.

Table 5. VCM IP Output File Content Table

Output	Type	Description	Units / Valid Range
VCM IP	UInt8	A 48-bit word (6 bytes) for each moderate resolution pixel that includes information about whether the view of the surface is obstructed by clouds and specifies the processing path the algorithm took. See Table 6 for the complete listing of VCM flags.	Refer to Table 6 for the complete listing of the VCM flags.
ScanAllOcean	UInt8	Identifies whether the scan is composed of all ocean pixels.	Unitless
ScanNoOcean	UInt8	Identifies whether the scan contains no ocean pixels.	Unitless
GranuleAllOcean	UInt8	Identifies whether the granule is composed of all ocean pixels.	Unitless
GranuleNoOcean	UInt8	Identifies whether the granule contains no ocean pixels.	Unitless

Table 6. VCM IP Output Quality Flag Bits and Description

Byte	Bit	Flag Description Key	Results
0	0-1	Cloud Mask Quality	00=Poor 01=Low 10=Medium 11=High
	2-3	Cloud Detection Results & Confidence Indicator	11=Confident Cloudy 10=Probably Cloudy 00=Confident Clear 01=Probably Clear
	4	Day / Night	0=Night 1=Day
	5	Snow / Ice Surface	1=Snow/Ice 0=No Snow
	6-7	Sun Glint	00=None 01=Geometry Based 10=Wind Speed Based 11=Geometry and Wind
1	0-2	Land / Water Background	000=Land & Desert 001=Land no Desert 010=Inland Water 011=Sea Water 101=Coastal
	3	Shadow Detected	1=Yes 0=No
	4	Non Cloud Obstruction (Heavy Aerosol)	1=Yes 0=No
	5	Fire Detected	1=Yes 0=No
	6	Cirrus Detection (Solar) (RM9)	1=Cloud 0=No Cloud
	7	Cirrus Detection (IR) (BTM15-BTM16)	1=Cloud 0=No Cloud

Byte	Bit	Flag Description Key	Results
2	0	IR Threshold Cloud Test (BTM15)	1=Cloud 0=No Cloud
	1	High Cloud (BTM12-BTM16) Test	1=Cloud 0=No Cloud
	2	IR Temperature Difference Test (BTM14 – BTM15 & BTM15 – BTM16)	1=Cloud 0=No Cloud
	3	Temperature Difference Test (BTM15 – BTM12)	1=Cloud 0=No Cloud
	4	Temperature Difference Test (BTM12 – BTM13)	1=Cloud 0=No Cloud
	5	Visible Reflectance Test (RM5)	1=Cloud 0=No Cloud
	6	Visible Reflectance Test (RM7), also Visible Reflectance Test (RM1)	1=Cloud 0=No Cloud
	7	Visible Ratio Test (RM7 / RM5)	1=Cloud 0=No Cloud
3	0-1	Adjacent Pixel Cloud Confident Value	11=Confident Cloudy 10=Probably Cloudy 00=Confident Clear 01=Probably Clear
	2	Conifer Boreal Forest	1=Yes 0=No
	3	Spatial Uniformity	1=Yes 0=No
	4	Dust candidate	1=Yes 0=No
	5	Smoke candidate	1=Yes 0=No
	6	Dust / Volcanic Ash	1=Yes 0=No
	7	Spare	
4	0-7	Spare	
5	0-2	Cloud Phase	000 = Not Executed 001 = Clear 010 = Partly Cloudy 011 = Water Cloud 100 = Supercooled Water/Mixed 101 = Opaque Ice Cloud 110 = Cirrus Cloud 111 = Cloud Overlap
	3	Thin Cirrus Flag	1=Yes 0=No
	4	Ephemeral Water Flag	1=Yes 0=No
	5	Degraded TOC NDVI Flag	1=Yes 0=No
	6	Degraded Sun Glint Flag	1=Yes 0=No
	7	Degraded Polar Night Flag	1=Yes 0=No

2.1.2 Algorithm Processing

The purpose of the VCM unit is to create VCM IP for each moderate resolution pixel.

The VCM IP production centers around a core set of reflectance and brightness temperature threshold tests combined with tests for identifying background conditions. A top level data flow diagram is shown in Figure 2. A top-level logic flow diagram is shown in Figure 3. The core logic for each of the blocks shown is discussed in detail in the sections that follow.

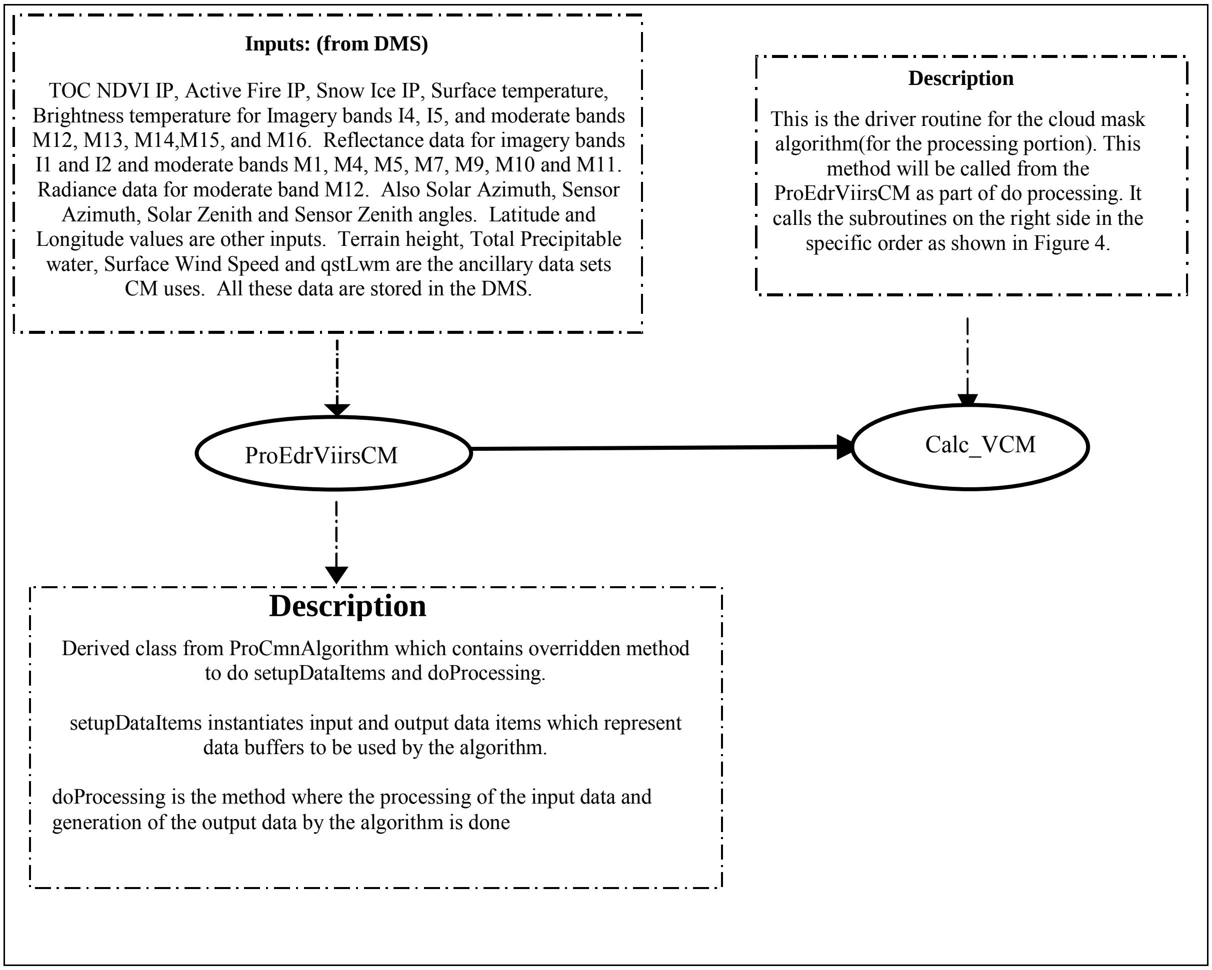


Figure 2. Level 1 Data Flow Diagram to Calculate VCM IP

2.1.2.1 Main Module - ProEdrViirsCM.cpp

This is the derived class from the base PRO Common Algorithm Class. The VCM Algorithm Class (1) gets the tasking from INF, (2) retrieves the input data to be used by VCM, (3) processes the data to create the VCM IP, and (4) sends output to DMS.

This module also allocates memory for internally created parameters and frees up memory when the process is completed.

PDL for ProEdRViirsCM

Initialize the values for the base class
Set the Routine to ProEdrViirsCM
Set up the data item needed for input and output.
Allocate memory for the data pointers and also for the VCM flags.
doProcessing does the processing of the input data and the generation of the output data.
Invoke the calc_vcm to calculate the VIIRS cloud mask IP

2.1.2.2 Calculate VCM IP

This is the driver routine for calculating the cloud mask IP. The functional flow is shown in Figure 3.

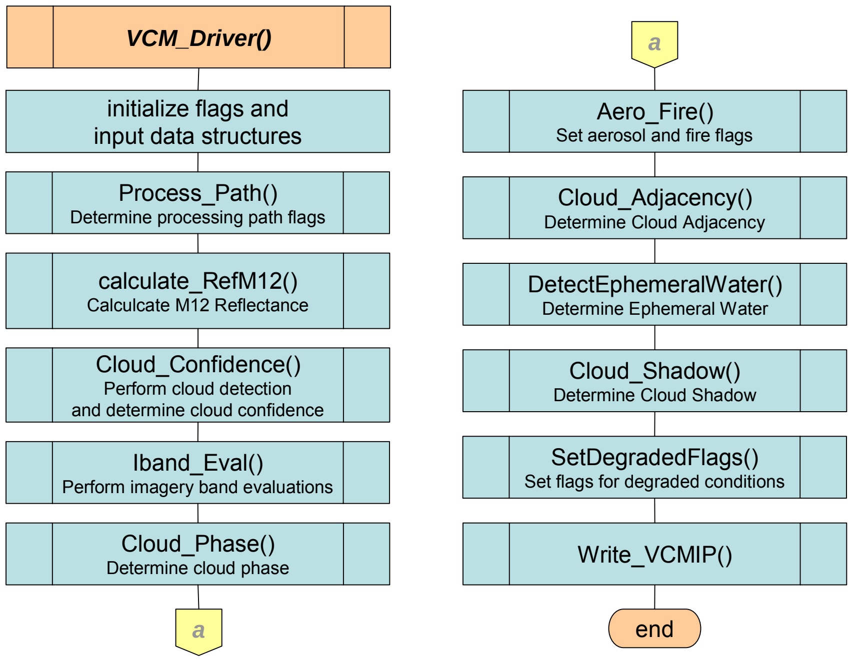


Figure 3. Top Level Processing for VCM IP Production

PDL For calc_VCM

```
VCM (VCM_DATA_TYPE, VCM_FLAGS, VCM_METADATA)

        CALL  initLowNDVIswitchParms(NDVI Switch Parameters)

        CALL init_vcm_flags(VCM_FLAGS, VCM_METADATA)

        CALL Process_Path (VCM_DATA_TYPE, VCM_FLAGS, VCM_METADATA )

        CALL calculate_RefM12(VCM_DATA_TYPE, VCM_FLAGS, VCM_METADATA)

        CALL Cloud_Confidence (VCM_DATA_TYPE, VCM_FLAGS)

        CALL Iband_Eval (VCM_DATA_TYPE, VCM_FLAGS )

        CALL Cloud_Phase (VCM_DATA_TYPE, VCM_FLAGS)

        CALL Aero_Fire (VCM_DATA_TYPE, VCM_FLAGS)

        CALL Cloud_Adjacency (VCM_FLAGS)

        CALL DetectEphemeralWater(VCM_DATA_TYPE, VCM_FLAGS)

        CALL Cloud_Shadow (VCM_DATA_TYPE, VCM_FLAGS)

        CALL SetDegradedFlags(VCM_DATA_TYPE, VCM_FLAGS)

        CALL Write_VCMIP (VCM_DATA_TYPE, VCM_FLAGS, VCM_METADATA)
```

2.1.2.3 Initialization of VCM

2.1.2.3.1 Initialize the VCM flags (init_vcm_flags.cpp)

This process initializes all the VCM flags to a default value.

PDL For init_VCM_Flags
Initialize VCM flags to the right default values.

2.1.2.3.2 Validation of User Input

MAX_LOW_TOC_NDVI and MAX_NUM_M1_NDVI_Bins. For the M5M1 cloud detection test over daytime land and coastal surfaces (where band M1 is used for low TOC NDVI conditions), cloud detection thresholds are derived using coefficients tabulated for a range of TOC NDVI values. Operationally, these coefficients are defined for TOC NDVI bins with width DELTA_NDVI_CLASS. The first bin has a bin center of MIN_NDVI_CLASS. For the M5 band, 10 TOC NDVI bins (0 – 0.1, 0.1 – 0.2, …, 0.9 – 1) are specified by the constant NUM_NDVI_BINS. For the M1 band, since it is used under low TOC NDVI conditions, a smaller bin range is needed and is specified by the user through the constant MAX_NUM_M1_NDVI_BINS. Constants NUM_NDVI_BINS and MAX_NUM_M1_NDVI_BINS also dictate the number of sets of M5 and M1 TOC NDVI bin coefficients, respectively, required by the software.

The TOC NDVI value at which the use of the M1 band ceases and the M5 band takes over is dictated by the user-input value, MAX_LOW_TOC_NDVI. For the current implementation, there is no requirement on the user to specify a bin center or boundary, so the value is adjusted by the software during VCM initialization to coincide with the nearest bin maximum. This adjusted value is stored as parameter low_toc_ndvi_max_bin_value. In order to allow threshold interpolation at the M1-M5 bin transition, a check is performed, also at VCM initialization, to ensure that the MAX_LOW_TOC_NDVI is within the M1 bin range and that at least one additional bin is to the right of the bin containing the low TOC NDVI switch bin value.

Aerosol Spatial Variability Test Parameters. The aerosol detection logic uses an nxn moderate resolution window in order to perform spatial variability tests that further refine the detection of dust and smoke laden pixels. In software, the one-dimensional size n is specified by the constant parameter VCM_AERO_MOD_WINSIZE. In order for the nxn moderate window to hop across the entire granule with no pixels being left uncovered, the window size in both the track and scan dimension is restricted to a multiple of both the number of scan and number of track pixels. In other words, a valid VCM_AERO_MOD_WINSIZE must satisfy the condition

```
((VCM_AERO_MOD_WINSIZE > 0) &&
 (number of scan pixels % VCM_AERO_MOD_WINSIZE == 0) &&
 (number of track lines % VCM_AERO_MOD_WINSIZE == 0)),
```

otherwise, the software aborts with an error message stating the requirement. If this restriction were lifted in a future modification of the software, the window-stepping logic should be upgraded to cover the pixels that would be excluded should the window size not be a multiple of the scan or track dimension. The logic upgrade would simply step the window back the required number of pixels such that the granule edge is covered.

If this restriction were lifted in a future modification of the software, the window-stepping logic should be upgraded to cover the pixels that would be excluded should the window size not be a multiple of the scan or track dimension. The logic upgrade would simply step the window back the required number of pixels such that the granule edge is covered.

The aerosol spatial variability tests are triggered only when at least a minimum number of aerosol-candidate pixels are detected by the upper tier aerosol tests. This setting is user-settable by the parameter, VCM_AERO_NUM_MOD_WIN_CANDS_THRESH, and must be greater than 0 but cannot exceed the number of moderate resolution window pixels, VCM_AERO_MOD_WINSIZE x VCM_AERO_MOD_WINSIZE:

$$0 \le \text{VCM\_AERO\_NUM\_MOD\_WIN\_CANDS\_THRESH} \le \text{VCM\_AERO\_MOD\_WINSIZE}^2$$

The spatial variability test is, in essence, a standard deviation threshold test for the imagery resolution I1 reflectance data nested within each candidate moderate resolution pixel. The user-settable parameter, VCM_AERO_NUM_IMG_SAMPS_STDDEV_THRESH, dictates the minimum number of valid (i.e., non-filled) I1 reflectance samples that must be present in order to perform the standard deviation threshold test. Valid parameter settings must satisfy the constraint below

((VCM_AERO_NUM_IMG_SAMPS_STDDEV_THRESH > 1) &&
(VCM_AERO_NUM_IMG_SAMPS_STDDEV_THRESH ≤ max_img_samps)),

where max_img_samps is the maximum number of image samples and is related to the number of moderate resolution window samples by 4*(VCM_AERO_MOD_WINSIZE^2).

As in the case of the first constraint, if any of the user-settings violate the constraints defined above, the software aborts with an error message stating the offense.

2.1.2.4 Calculate M12 Reflectance (calculate_RefM12.cpp)

The M12 reflectance is a derived quantity used in the volcanic ash detection over land and cloud phase algorithms. Since this calculated value is needed more than once, the data is precalculated and stored. The calculation is based on the following equation:

$$\rho_{M12} = \frac{\pi \left(L_{M12,sens} - L_{M12,calc,emiss} \big|_{T=BTM15} \right)}{\frac{H_{M12} \cos \theta_{solzen}}{R^2_{earth-sun}}},$$

where

$L_{M12,sens}$ is the sensor retrieved M12 radiance,

$L_{M12,calc,\ emiss}$ is the calculated M12 radiance due to thermal emission which is directly calculated using Planck's Law with the M15 brightness temperature substituted for the blackbody temperature, i.e.,

$$L_{M12,\ calc,emiss} \big|_{T=BTM15} = \frac{2hc^2}{\lambda^5_{M12}} \frac{1}{e^{hc/\lambda_{M12} kT_{M15}} - 1},$$

H_{M12} is the extraterrestrial radiation (TOA irradiance) at mean sun-earth distance, which is derived from solar irradiance spectral data, convolved with the sensor response function over the M12 spectral bandpass and normalized by the sensor responsivity. The preoperational value used is 10.7813 W m^{-2} µm^{-1} and is expected to change with sensor characterization.

λ_{M12} is the response-weighted M12 band center in meters,

θ_{solzen} = solar zenith angle,

$R_{earth\text{-}sun}$ is the earth to sun ratio based on IET time calculated by

phi = 2.0*PI*(Float32)((scanStartTime[0] % NUM_MICROSEC_IN_YEAR) / NUM_MICROSEC_IN_DAY) * RECI_DAYS_PER_YEAR

$R_{earth\text{-}sun}$ = 1.0/sqrt(EARTH_TO_SUN_CONST +
EARTH_TO_SUN_COSPHI_FACTOR * cos(phi) +
EARTH_TO_SUN_SINPHI_FACTOR * sin(phi) +
EARTH_TO_SUN_COS2PHI_FACTOR * cos(2*phi) +
EARTH_TO_SUN_SIN2PHI_FACTOR * sin(2*phi)).   **Eqn 1**

Steps for Calculating M12 Reflectance

Initial conditions:

M12 radiance has been read in and stored
M12 reflectance has been initialized to fill value, FLOAT32_FILL
scanStartTime[0] is the start time of the current scan of data in microseconds
Physical and System Constants have been defined (see Table 3)

SPEED_LIGHT_M_PER_S = speed of light in m/s,,
PLANCK = Planck's constant in W sec^2,
BOLTZMANN = Boltzmann's constant in W sec/K,
M_PER_MICRON = meters to micron conversion factor,
LAMBDA_M12 = M12 band average weighted by sensor responsivity in meters.
M12_MEAN_TOA_SOL_IRRAD = mean top of atmosphere solar irradiance in the M12 band, weighted with sensor responsivity in W/(m^2 μm),
EARTH_TO_SUN = parameters as stated in the $R_{earth\text{-}sun}$ factor equation above
NUM_MICROSEC_IN_YEAR = Number of microseconds in a year
NUM_MICROSEC_IN_DAY = Number of microseconds in a day
RECI_DAYS_PER_YEAR = The reciprocal of days per year

1. Calculate derived constants:
   a. M12 band average weighted by sensor responsivity raised to the 5^{th} power
      wvl_M12_5 = (LAMBDA_M12)^5,
      where LAMBDA_M12 is the M12 band average weighted by sensor responsivity.
   b. First radiation constant / wvl_M12_5
      RAD_CONST1_OVER_LAMBDA_M12_5 = 2.0 * PI * (PLANCK/wvl_M12_5) * SPEED_LIGHT_M_PER_S * SPEED_LIGHT_M_PER_S
   c. Second radiation constant / LAMBDA_M12
      RAD_CONST2_OVER_LAMBDA_M12 = (PLANCK / (BOLTZMANN * LAMBDA_M12)) * SPEED_LIGHT_M_PER_S
2. Calculate processing constants
   a. Earth-sun distance factor, rESfactor, as a function of IET Time
      phi = 2.0*PI*(Float32)((scanStartTime[0] % NUM_MICROSEC_IN_YEAR) / NUM_MICROSEC_IN_DAY) * RECI_DAYS_PER_YEAR
      rESfactor =
      1.0/sqrt(EARTH_TO_SUN_CONST + EARTH_TO_SUN_COSPHI_FACTOR * cos(phi) + EARTH_TO_SUN_SINPHI_FACTOR * sin(phi) + EARTH_TO_SUN_COS2PHI_FACTOR * cos(2*phi) + EARTH_TO_SUN_SIN2PHI_FACTOR * sin(2*phi))
   b. M12 top of atmosphere solar irradiance for given IET Time
      TOA_SOL_IRRAD = M12_MEAN_TOA_SOL_IRRAD/(rESfactor*rESfactor)
3. Calculate M12 reflectance for each moderate resolution pixel. The input M12 radiance is used to calculate the M12 total emittance, while Planck's law using the input M15 brightness

temperature is used to estimate the emissive component of the total M12 radiance. The reflective component is simply the difference of the two terms. The M12 reflectance is the ratio of this reflective component normalized by the M12 solar irradiance that has been corrected for the solar incidence angle. M12 reflectance is not calculated for nighttime pixels or when required input parameters are invalid. For this situation, the M12 reflectance maintains its initialized fill value.

```
FOR each moderate resolution pixel
    IF (BTM12 is valid AND BTM15 is valid AND
        MBSolZen is valid AND day_night_flag is "Day") THEN
           x_M15 = RAD_CONST2_OVER_LAMBDA_M12 / BTM15
           m12TotEmittance = PI * RadM12
           m12EmisEmittance =
                  (RAD_CONST1_OVER_LAMBDA_M12_5) * (1.0/((exp(x_M15)) - 1.0)) *
                  M_PER_MICRON;

           m12ReflEmittance = m12TotEmittance - m12EmisEmittance;

           IF (m12ReflEmittance < 0.0) THEN
             Warn that the m12ReflEmittance value < 0.0 and that RefM12 will be set to 0.0.
             RefM12  = 0.0;
           ELSE
             rSolZen=DEGREES_TO_RADIANS(MBSolZen)
             RefM12 = m12ReflEmittance / (M12_TOA_SOL_IRRAD * cos(rSolZen))
           END IF
    ENDIF
END FOR
```

2.1.2.5 Determine Process Path (Process_Path.cpp)

This process is the driver for determining the processing path that the pixel follows. It calls four other components shown in Figure 4 below. Each component conducts tests to determine surface background conditions and light conditions in the atmosphere. This process creates the day-night flag, land-water flag, sun glint flag, and snow ice flag.

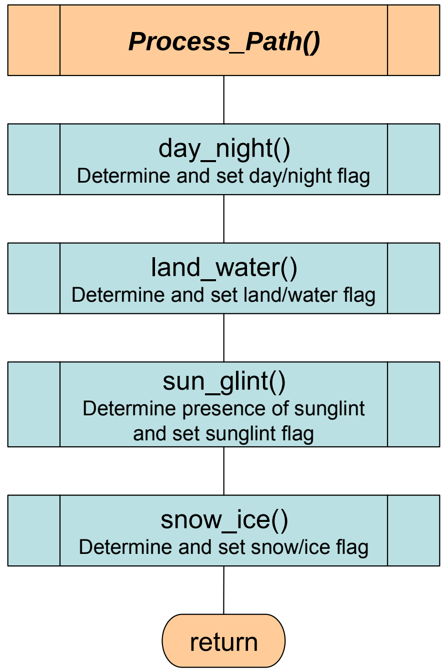


Figure 4. Top Level Functional Flow for Determining Pixel Processing Path Flags

PDL For Process_Path

Process_Path (VCM_DATA_TYPE, VCM_FLAGS, VCM_METADATA)

CALL day_night (VCM_DATA_TYPE , *day_night_flag*)

CALL land_water (*land_water_flag, CBforest_flag, scan_all_ocean, scan_no_ocean,* eco_class, *terrain height*, VCM_METADATA)

CALL sun_glint (VCM_DATA_TYPE, VCM_FLAGS)

CALL snow_ice (VCM_DATA_TYPE, VCM_FLAGS)

2.1.2.5.1 Day Night Determination (day_night.cpp)

Given the solar zenith angle, this process determines whether the daytime or nighttime processing path will be used for a given pixel.

PDL for day_night

```
day_night (VCM_DATA_TYPE , day_night_flag )
        Initialize Integer  day_night_flag DAY

                FOR every pixel in the granule
                IF ( (*(vcmData->geoData->MBSolZen ) >= maxSolarZenith) or
                    (*(vcmData->geoData->MBSolZen ) <= Fill Data ) )THEN
                        Set day_night_flag to NIGHT
                ENDIF
```

2.1.2.5.2 Determine Land/Water Background (land_water.cpp)

This procedure assigns one of five land-use categories—land, desert, coast, inland water, or seawater—to each pixel based upon an input Quarterly Surface Type/Land Water Mask (QST/LWM). The mapping between the QST/LWM input and the VCM land type flags are specified in Table 7 below. When the QST/LWM indicates an "Evergreen Needle Forest", the VCM output conifer boreal flag is also set. This procedure also sets a scan-wide flag and a granule-wide flag noting whether that scan or granule is entirely ocean or no ocean. Table 8 lists the Land/Water I/O for this process. The process steps are provided below.

Table 7. Mapping of QST/LWM Ecosystem Flags to VCM Land/Water Flag

Granulated Merged Land/Water Quarterly Surface Type		VCM Land Water Flag Setting *
Description	Value	
Evergreen Needle Forest	1	Land no Desert
Evergreen Broadleaf Forest	2	
Deciduous Needle Forest	3	
Deciduous Broadleaf Forest	4	
Mixed Forest	5	
Closed Shrubs	6	
Open Shrubs	7	
Woody Savannas	8	
Savannas	9	
Grasslands	10	
Permanent Wetlands	11	
Croplands	12	
Urban	13	
Crop and Natural Mosaic	14	
Perennial Snow and Ice	15	
Barren or Sparsely Vegetated	16	Land & Desert
Ocean/Sea	17	Sea Water
Inland Water	18	Inland Water
Coastal Water	19	Coastal
Unclassified Land	20	Land no Desert
Fill Value	255	Coastal

* See. VCM IP Output Quality Flag Bits and Description table for values

Table 8. Land/Water I/O

	Variable	Description
Input	eco_class	Pixel background flag from QST/LWM input file. See Table 7 for flag values.
Output	land_water_flag	Pixel background flag from QST/LWM input file. See Table 7 for mapping of eco_class flags to land_water_flag.
	CBforest_flag	Conifer Boreal Forest flag. See VCM IP output Table 6, for settings.
	scan_all_ocean	Flag indicating if all pixels in the scan are ocean pixels. See VCM IP output Table 6, for settings.
	scan_no_ocean	Flag indicating if all pixels in the scan are non-ocean pixels. See VCM IP output Table 6, for settings.

	Variable	Description
	granule_all_ocean	Flag indicating if all pixels in the granule are ocean pixels. See VCM IP output Table 6, for settings.
	granule_no_ocean	Flag indicating if all pixels in the granule are non-ocean pixels. See VCM IP output Table 6, for settings.

Steps for Determination of Land/Water Background Flag and Swath and Granule Flags

1. Initialize scan and granule flags
```
scan_all_ocean = TRUE
scan_no_ocean = TRUE
granule_all_ocean = TRUE
granule_no_ocean = TRUE
```

2. Determine land water flag
```
FOR every pixel in the scan
    Given eco_class type given in Table 7, set VCM land_water_flag to the appropriate
    mapped value
    IF (land_water_flag = Evergreen Needle Forest) THEN
            Set CBforest_flag to Yes
    ELSE
            SetCBforest_flag to No (no action necessary if default is No)
    ENDIF
END FOR
```

3. Determine swath flags, all ocean and no ocean, and granule flags all ocean and no ocean.
```
FOR all pixels in the swath
    IF (land_water_flag = Land & Desert .OR.
       land_water_flag = Land no Desert .OR.
       land_water_flag = Inland Water .OR.
       land_water_flag = Coastal) THEN
            Set scan_all_ocean to FALSE
    ELSEIF (land_water_flag = Sea Water) THEN
            Set scan_no_ocean to FALSE
    ENDIF

    FOR every scan in the granule
        IF (scan_all_ocean = FALSE) THEN
            Set granule_all_ocean FALSE
        ENDIF
        IF (scan_no_ocean = FALSE) THEN
            Set granule_no_ocean FALSE
        ENDIF
    END FOR every scan in granule
END FOR all pixels in swath
```

2.1.2.5.3 Determine Sun Glint (sun_glint.cpp)

The presence of sun glint can degrade the ability of the cloud mask to correctly detect clouds. Sun glint is considered over both land and water. Land regions are included because spatially unresolved water bodies, snow, or recent rainfall can also cause sun glint. Given the presence of glint, alternative threshold values can be used in the reflective spectral tests to adjust for sun glint contaminated paths.

The test for sun glint is performed when the solar zenith angle is less than the tunable parameter VCM_SUNGLINT_MAX_SOLZEN, which is nominally 89º. (Note that this parameter is not restricted to be less than or equal to the day/night tunable solar zenith threshold of maxSolarZenith.) The VCM flags in its output moderate resolution pixels that are glint contaminated and indicates whether the glint was detected through a geometric determination, a wind-based determination or through both.

The wind-based determination is performed only over water where wind speeds are non-zero. The wind-based flag is set when the probability that the pixel is contaminated by sun glint due to sea surface wind speed (McCain and Yeh, 1994) exceeds a tunable proability threshold PROB_THRESH. This probability is calculated by the following equation:

$$P = (1/\pi\sigma^2)\exp[-\tan^2\theta_N/\sigma^2] \qquad \textbf{Eqn 2}$$

where

P represents the probability,

$\sigma^2 = SUNGLINT\_COX\_MUNK\_C1 + SUNGLINT\_COX\_MUNK\_C2 \cdot (windspeed\,(m/s))$,

$\theta_N = \cos^{-1}[(\cos\theta + \cos\theta_o)/2\cos\omega]$,

$\cos 2\omega = \cos\theta\cos\theta_o + \sin\theta\sin\theta_o\cos(\phi - \phi_o)$,

θ = satellite zenith angle,

φ = satellite azimuth angle,

θ_o = solar zenith angle,

φ_o = solar azimuth angle, and

SUNGLINT_COX_MUNK_C1 and SUNGLINT_COX_MUNK_C2 are constants.

Note, that the above equation for cos (2ω) is simply the dot product between the satellite unit vector and the solar unit vector.

The geometric determination is made through the evaluation of the reflected sun angle, θ_r, where

$$\cos\theta_r = \cos\theta\cos\theta_o + \sin\theta\sin\theta_o\cos(180 - (\phi - \phi_o)).$$

Note that 180º is introduced in the azimuth angle term because the solar azimuth angle is defined, in this convention, as the extension of the incident solar beam projected onto the xy-plane. If the reflected angle is within a given range, (i.e., between 0 and the tunable parameter VCM_SUNGLINT_MAX_REFANGLE_FOR_GEO), glint is geometry-based.

Once the outcome of the wind-speed and geometry-based determinations are known the sun glint flag is set to geometry only, wind-based only, both geometry and wind-based or the default value of none.

Operationally, the refinements to the above cosine equations are optimized as follows:

cos (2ω) = 0.5 * ((cosMinus + cosPlus) + ((cosMinus - cosPlus) * cos (φ-φ_o)))

cos (θ_r) = 0.5 * ((cosMinus + cosPlus) + ((cosMinus - cosPlus) * cos (PI-(φ-φ_o)))

where

cosMinus = cos(θ_o - θ)
cosPlus = cos(θ_o + θ).

The PDL for the sun glint algorithm is shown below. Table 3 provides the definitions and values for the following constants used:

SUNGLINT_COX_MUNK_C1
SUNGLINT_COX_MUNK_C2
RAD_SUNGLINT_COX_MUNK_PROB_VAR_LIMIT
RAD_THETA_N_MAX

Table 50 provides the definitions for the following tunable parameters used:

VCM_SUNGLINT_MAX_SOLZEN
VCM_SUNGLINT_MAX_REFANG_FOR_GEO
Note that these settings are converted to radians during initialization in order to optimize the software.

PDL for Sun_glint

```
sun_glint (VCM_DATA_TYPE,  VCM_FLAGS)

        Initialize Integer  sun_glint_flag NO GLINT
                            sun_glint_geo_flag NO GEO GLINT
                            sun_glint_wind_flag NO WIND GLINT
        Initialize Float    wind_exe 0
                            prob = 0.0

        Convert user-setable parameters from degrees to radians
        RAD_VCM_SUNGLINT_MAX_SOLZEN =
            VCM_SUNGLINT_MAX_SOLZEN * DEG2RAD;

        COSINE_MAX_REL_ANGLE  =
            cos(VCM_SUNGLINT_MAX_REFANG_FOR_GEO * DEG2RAD);

        FOR every pixel in the granule

            IF SunZen  <= RAD_VCM_SUNGLINT_MAX_SOLZEN) THEN
           {
             /* Read in viewing geometry data */
             rSenAzi= SatAzi;
             rSenZen= SatZen
             rSolAzi= SunAzm
             rSolZen= SunZen

             /* Check for FILL values */
             IF (( rSenAzi > FLOAT32_FILL_TEST) &&
                 ( rSenZen > FLOAT32_FILL_TEST) &&
                 ( rSolAzi > FLOAT32_FILL_TEST) &&
                 ( rSolZen > FLOAT32_FILL_TEST) ) THEN
             {
              cosMinus = cos(rSolZen - rSenZen);
              cosPlus  = cos(rSolZen + rSenZen);

              IF( WIND SPEED  >= 0) &&
                 (LAND WATER ==CM_IN_WATER) ||
                  (LAND WATER==CM_SEA_WATER)))
              {
                 wind_exe=CM_YES;

                /*Compute the Cox & Munk Sun Glint Eq.*/
```

```
  sigma_squared = (WIND SPEED* SUNGLINT_COX_MUNK_C2) + SUNGLINT_COX_MUNK_C1;
  invSigma_squared = 1.0 / sigma_squared;

  cosRSolZen = cos(rSolZen);
  cosRSenZen = cos(rSenZen);

  cosRelativeAzi = cos((rSenAzi - rSolAzi));

  cos_two_omega =0 .5 * ( (cosMinus + cosPlus) +
                 ((cosMinus - cosPlus) * cosRelativeAzi));
  omega = 0.5 * (acos(cos_two_omega));
  theta_N = acos(0.5 *
               (cosRSenZen + cosRSolZen)/(cos(omega)));
  if(theta_N >=  RAD_THETA_N_MAX)
  {
      theta_N = RAD_SUNGLINT_COX_MUNK_PROB_VAR_LIMIT;
  }
  tanTheta_N = tan(theta_N);
  prob = (M_1_PI) * invSigma_squared *
          exp( -(tanTheta_N * tanTheta_N) * invSigma_squared );

  if(prob > PROB_THRESH)
  {
    sun_glint_wind_flag=CM_YES;
  }
  else
  {
    sun_glint_wind_flag=CM_NO;
  }
}
else
{
  wind_exe=CM_NO;
}

/* Always Perform the following geometry based sun glint test,
 regardless of land type */
 cos_rel_angle =  0.5 * ( (cosMinus + cosPlus) +
               ((cosMinus - cosPlus) *
               cos(M_PI-(rSenAzi-rSolAzi))));

   /* Checking the cosine of rel angle is in the range where
     COSINE_MAX_REL_ANGLE is cosine of 36 degress in radians */
   if (cos_rel_angle >  COSINE_MAX_REL_ANGLE)          {
  sun_glint_geo_flag=CM_YES;
}
else
{
  sun_glint_geo_flag=CM_NO;
}

if ((wind_exe==CM_YES) && (sun_glint_wind_flag==CM_YES) &&
    (sun_glint_geo_flag==CM_YES))
{
 sun_glint_flagI = CM_GEO_AND_WIND;
}
else if((wind_exe==CM_YES) &&
      (sun_glint_wind_flag==CM_YES))
{
```

```
          sun_glint_flag = CM_WIND_SPD_BASED;
        }
        else if(sun_glint_geo_flag==CM_YES)
        {
          sun_glint_flag = CM_GEOMETRY_BASED;
        }
        else
        {
          sun_glint_flag = CM_NONE;
        }
      } /*END IF GOOD ANGLE */
    } /* END IF Solar Zenith <= VCM_SUNGLINT_MAX_SOLZEN */
  }  /* END FOR */
```

2.1.2.5.4 Determine Snow/Ice Surface (snow_ice.cpp)

This procedure determines if the pixel is over snow or ice and populates a snow-ice flag when snow-ice is present. For VCM, this processing path flag takes precedence over any of the other land type processing paths (i.e., coast, land, desert, water). Ideally, VCM tries to use the current brightness temperatures and reflectance data to determine the presence of snow and ice. However, under conditions where the VCM's own logic cannot be performed or the tests yield an indeterminable result, the fallback VIIRS gridded Snow Cover IP is used. The logic flow is indicated in Figure 5 below. The fallback value for a given moderate resolution pixel is stored in parameter, `init_snow_ice_flag`. The outcome of the VCM snow/ice detection logic is stored in parameter `sec_snow_ice_flag`.

The logic shows that VCM falls back to the VIIRS Gridded Snow Cover IP under nighttime conditions. Under daytime conditions, VCM first examines the M15 brightness temperature to determine if the surface temperature is too warm (as decided by an M15 brightness temperature snow threshold) to support the presence of snow. If the temperature threshold is exceeded, no snow is declared; otherwise a normalized difference snow index (NDSI) test, in conjunction with a moderate resolution reflection threshold test, is performed to determine the potential presence of snow. Again, if snow is not indicated, no snow is declared; otherwise, additional tests are performed to eliminate the conditions that may bring about a "false positive" snow/ice setting (i.e., presence of thin cirrus or sun-glint contaminated water pixels).

Table 9 shows the process I/O.

Table 9. Snow/Ice Determination I/O

	Variable	Description
Input	snow_ice_flag	snow ice data from 1-km gridded product "VIIRS-GridIP-VIIRS-Snow-Ice-Cover-Mod-Gran
	day_night_flag	flag indicating day or night condition
	land_water_flag	flag indicating pixel surface type
	terrainHt	terrain height
	RefM4, RefM7, RefM9, RefM10	Moderate resolution reflectances for bands M4, M7, M9 and M10
	BTM12, BTM14, BTM15	Moderate resolution brightness temperatures for bands M12, M14, and M15
Output	snow_ice_flag	final determination of snow/ice setting, dependent on input snow/ice flag and VCM determination

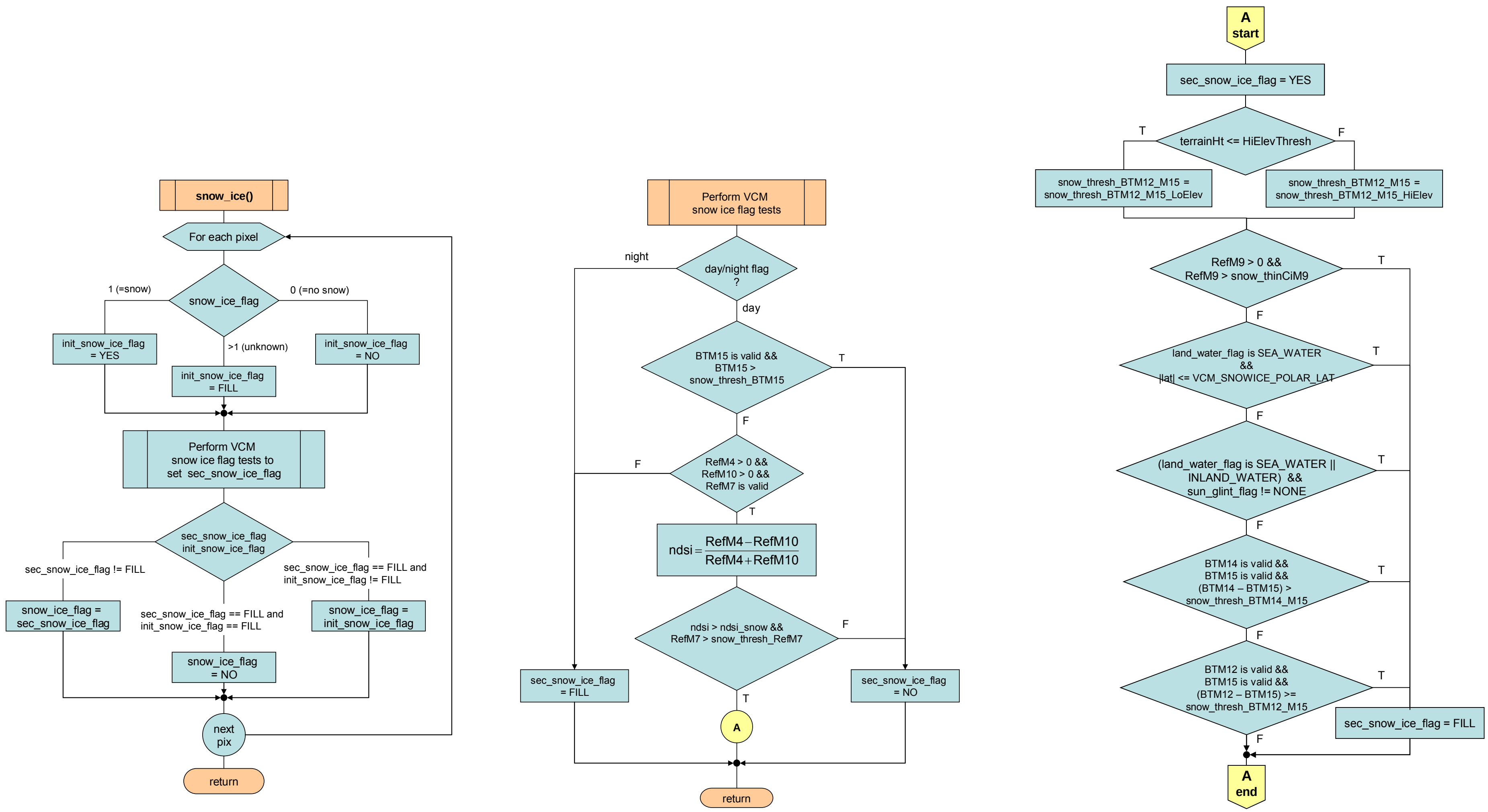


Figure 5. Snow/Ice Logic Flow

2.1.2.6 Perform Cloud Confidence Determination

This process controls the flow for executing cloud detection tests. Two categories of tests are performed: one specifically designed for thin cirrus cloud detection, and a second for general cloud detection. The thin cirrus detection test outputs its "Cloud/No Cloud" result in a thin cirrus flag. The general cloud detection category, comprised of a series of tests specifically designed for a given pixel surface type and day/night scenario, outputs a cloud detection confidence and a cloud detection quality. Both the thin cirrus test and the cloud detection tests are performed for moderate resolution pixels and produce results that are independent of one another. The top level logic flow is provided in Figure 6 below. The list of input/output follows in Table 10. The thin cirrus detection test, the processing-path-specific cloud detection tests, and the logic to determine cloud confidence and quality are discussed in following sections.

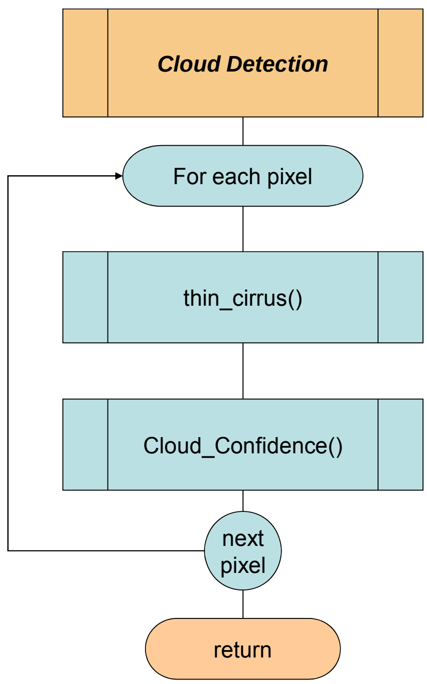


Figure 6. Top Level Functional Flow for Cloud Detection

Table 10. Cloud Detection and Cloud Confidence Determination I/O

	Variable	Description
Input	BTM12 through BTM16	Moderate resolution brightness temperatures for bands M12 through M16
	RefM1, RefM5, RefM7, RefM9, RefM10, RefM11	Moderate resolution reflectances for bands M1, M5, M7, M9, M10 and M11
	MBSolZen	Solar Zenith Angle
	MBSolAz	Solar Azimuth Angle
	MBSenZen	Sensor Zenith Angle
	MBSenAz	Sensor Azimuth Angle
	tpw	total precipitable water

	Variable	Description
	toc_ndvi	top of canopy normalized difference vegetation index (TOC NDVI)
	terrainHt	terrain height
	sfc_temp	surface temperature
	latitude	pixel latitude
	day_night_flag land_water_flag snow_ice_flag	pixel processing path
Output	thin_cirrus_test_flag	flag indicating presence of thin cirrus
	cloud_confidence	cloud confidence *
	cc_qual	cloud confidence quality
	<test>_Test_Result	cloud test results (cloud vs. no cloud) for each of the tests performed for the given processing path

*Note that under certain scenarios, the Cloud Confidence output will be modified in a downstream spatial variability test

2.1.2.6.1 Determine Thin Cirrus Flag (thin_cirrus.cpp)

This process executes a single thin cirrus test for the day or night condition. The tests consist of a brightness temperature difference threshold test in M15 – M16 at night and a reflectance threshold tests using band M9 in the daytime. The brightness temperatures are in Kelvin.

See Table 50 under the section “Thin Cirrus Detection Parameters” for the thresholds associated with this process. These thresholds are accessed from Cloud Mask Ingest Coefficient File.

<u>PDL for thin_cirrus</u>

```
thin_cirrus (VCMthresholdvalues, day_night_flag, snow_ice_flag, land_water_flag,
        VIIRS_MOD_Data [BTM15, BTM16, MBSenZen, mTerrainHeight, mTPW, RefM9];
        Thin_Cirrus_Test_Result)

Initialize Integer Thin_Cirrus_Test_Result NO CLOUD

Initialize Float   diff_m15_m16 0.0
                   diftemp 0.0
                   M15_M16_Mid 0.0
                   M15_M16_thin_cirrus_thres 0.0
                   M9_Mid 0.0
                   M9_thin_cirrus_thres 0.0
                   tpiwv 0.0

tpiwv = mTPW/cos(MBSenZen*M_PI/180.0)

IF (day_night_flag is NIGHT) THEN
       /* Perform Thin Cirrus Test at Night )*/
       IF (BTM15, BTM16, MBSenZen is good quality) THEN
              /********************
              Interpolate lookup table values of 11 - 12 micron BT
              difference thresholds. This is a function of the
              satellite zenith and BTM15.
              Value produced stored in M15_M16_Mid
              **********************/
```

```
            M15_M16_thin_cirrus_thres =
               M15_M16_Mid + M15_M16_THIN_CIRRUS_MID_CORR

            diff_m15_m16=BTM15- BTM16
            IF (diff_m15_m16>M15_M16_thin_cirrus_thres .AND.
                      diff_m15_m16 < M15_M16_Mid) THEN
                      thin_cirrus_test_result=CLOUD
            ELSE
                      thin_cirrus_test_result=NO_CLOUD
            ENDIF
   ENDIF
   ELSE
            /* Perform Thin Cirrus Test in the Daytime)*/

            IF (RefM9 is good quality .AND. tpiwv > DD_M9_TPIWV_cutoff) THEN
                      IF (snow_ice_flag is SNOW) THEN
                                M9_Mid=SD_M9_Mid
                                M9_thin_cirrus_thres=SD_M9_thin_cirrus
                      ELSE IF (land_water_flag is water) THEN
                                M9_Mid=WD_M9_Mid
                                M9_thin_cirrus_thres=WD_M9_thin_cirrus
                      ELSE IF (land_water_flag is desert) THEN
                                M9_Mid=DD_M9_Mid
                                M9_thin_cirrus_thres=DD_M9_thin_cirrus
                      ELSE IF (land_water_flag is coastal) THEN
                                M9_Mid=CD_M9_Mid
                                IF (tpiwv >= high_tpw_value) .OR>
                                   (high_tpw_value <= DD_M9_TPIWV_cutoff) THEN
                                          M9_thin_cirrus_thres=CD_M9_thin_cirrus
                                ELSE
                                          M9_thin_cirrus_thres=CD_M9_thin_cirrus +
                                                    (((high_tpw_value-tpiwv)/
                                                    (high_tpw_value-DD_M9_TPIWV_cutoff))
                                                    *(DD_M9_thin_cirrus-CD_M9_thin_cirrus))
                                ENDIF
                      ELSE
                                M9_Mid=LD_M9_Mid
                                IF ((tpiwv >= high_tpw_value) .OR.
                                          (high_tpw_value <= DD_M9_TPIWV_cutoff)) THEN
                                          M9_thin_cirrus_thres=LD_M9_thin_cirrus
                                ELSE
                                          M9_thin_cirrus_thres=LD_M9_thin_cirrus +
                                                    (((high_tpw_value-tpiwv)/
                                                    (high_tpw_value-DD_M9_TPIWV_cutoff))
                                                    *(DD_M9_thin_cirrus-LD_M9_thin_cirrus))
                                ENDIF
                      ENDIF
                      IF (RefM9 >= M9_thin_cirrus_thres .AND. RefM9 < M9_Mid) THEN
                                thin_cirrus_test_result=CLOUD
                      ELSE
                                thin_cirrus_test_result=NO_CLOUD
                      ENDIF
            ENDIF
   ENDIF
```

2.1.2.6.2 Surface Type-Dependent Cloud Detection and Cloud Confidence Determination

The general cloud detection process is comprised of a set of processing path dependent functions: snow/day, coast/day, land/day, water/day, desert/day, snow/night, land/night and water/night. Within each processing path are groups of tests whose outcomes are combined to express a composite "cloud" versus "no cloud" confidence flag—Confidently Cloudy, Probably Cloudy, Probably Clear and Confidently Clear. The total number of tests performed for a given processing path is compared against the maximum possible number of tests performed for that path to produce a cloud mask quality output of Poor, Low, Medium and High. A top-level functional flow is shown in Figure 7. Further details for the individual process boxes shown in this figure are provided in subsections that follow.

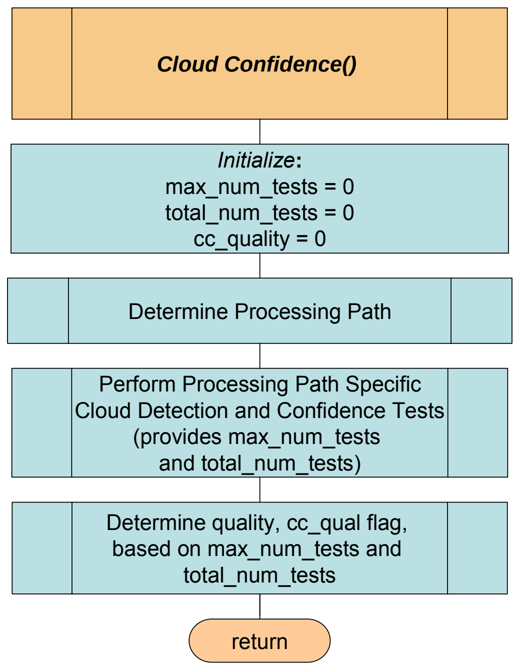


Figure 7. Logic Flow for General Cloud Detection

2.1.2.6.2.1 Determination of Cloud Confidence Pixel Processing Path

The logic for determining a pixel's processing path is shown in Figure 8. Note that pixels containing snow or ice, as indicated by the snow/ice flag, take precedence over any other surface background. Also, during nighttime conditions, desert, coast and land pixels are processed by the land/night process. (Land_night includes desert and coasts.)

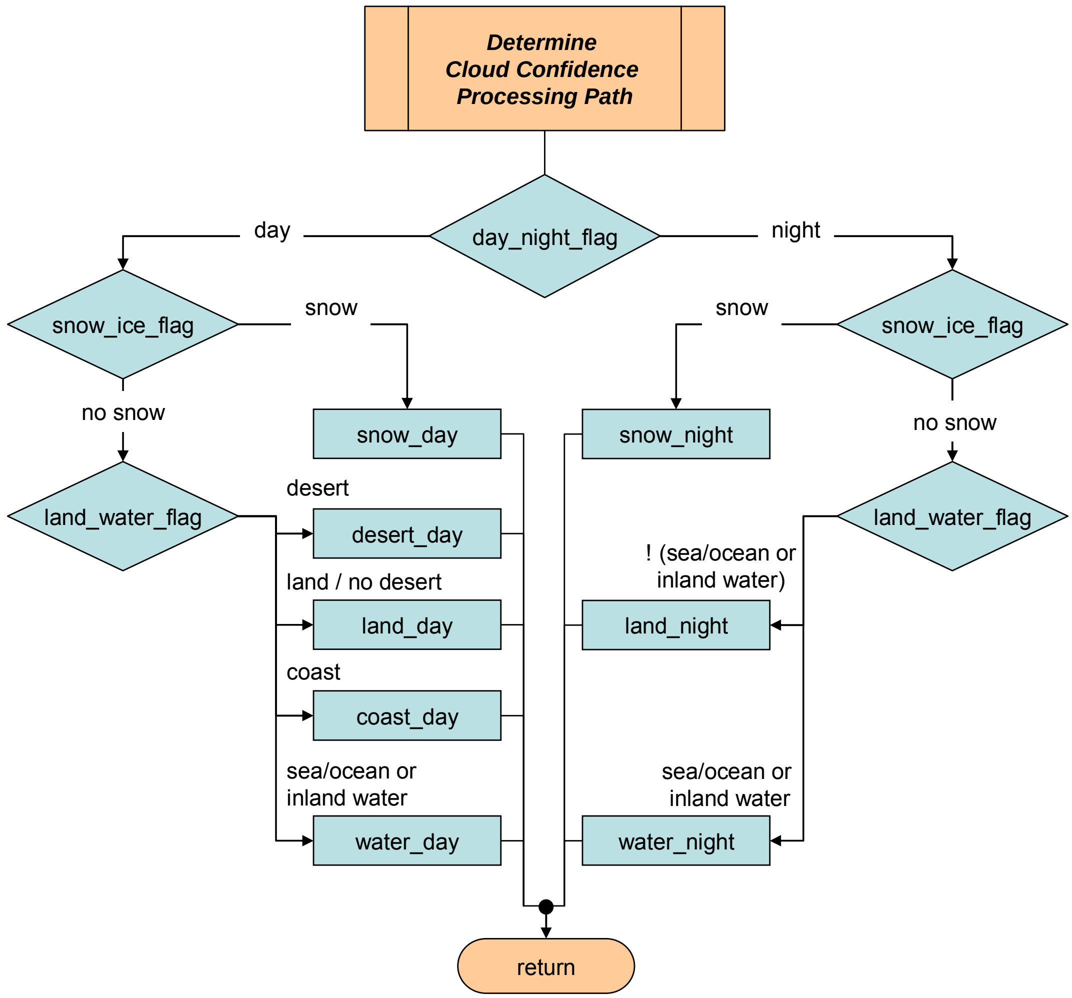


Figure 8. Determining Cloud Confidence Pixel Processing Path Logic

2.1.2.6.2.2 Generic Processing for Cloud Confidence Determination

Figure 9 describes the generic functional flow for each of the surface type-day/night paths shown in Figure 8. As shown, each path is comprised of one or more groups of tests. These test groups are categorized as 1) Emission Threshold Tests, 2) Emission Difference Tests, 3) Reflectance Threshold Tests, 4) Reflectance Cirrus Tests and 5) Emission Cirrus Tests. Within each test group are a series of one or more tests targeted for various cloud types against the given pixel surface type and day/night condition. The number of test groups and the number of tests within a specific group varies between the different processing paths. However all tests, when executed, produce two results: 1) a cloud/no cloud decision based on a comparison between the observation (e.g., reflectance, brightness temperature difference) and a clear/cloudy threshold, and 2) an individual confidence level based on the clear/cloudy threshold and additionally, confident clear and confident cloudy thresholds. The individual confidences range from 0 (a low clear sky confidence or high confidence that the pixel is cloudy) to 1 (high confidence that the pixel is clear) and are combined to produce a final Cloud Confidence flag that is written to the VCM output.

The algorithms for the individual confidence level determination and final cloud confidence determination are discussed further in the following subsections. After this discussion, the specific detection tests used for each pixel processing path and the groups to which these tests belong are listed. Finally, the tests within each test group category are described.

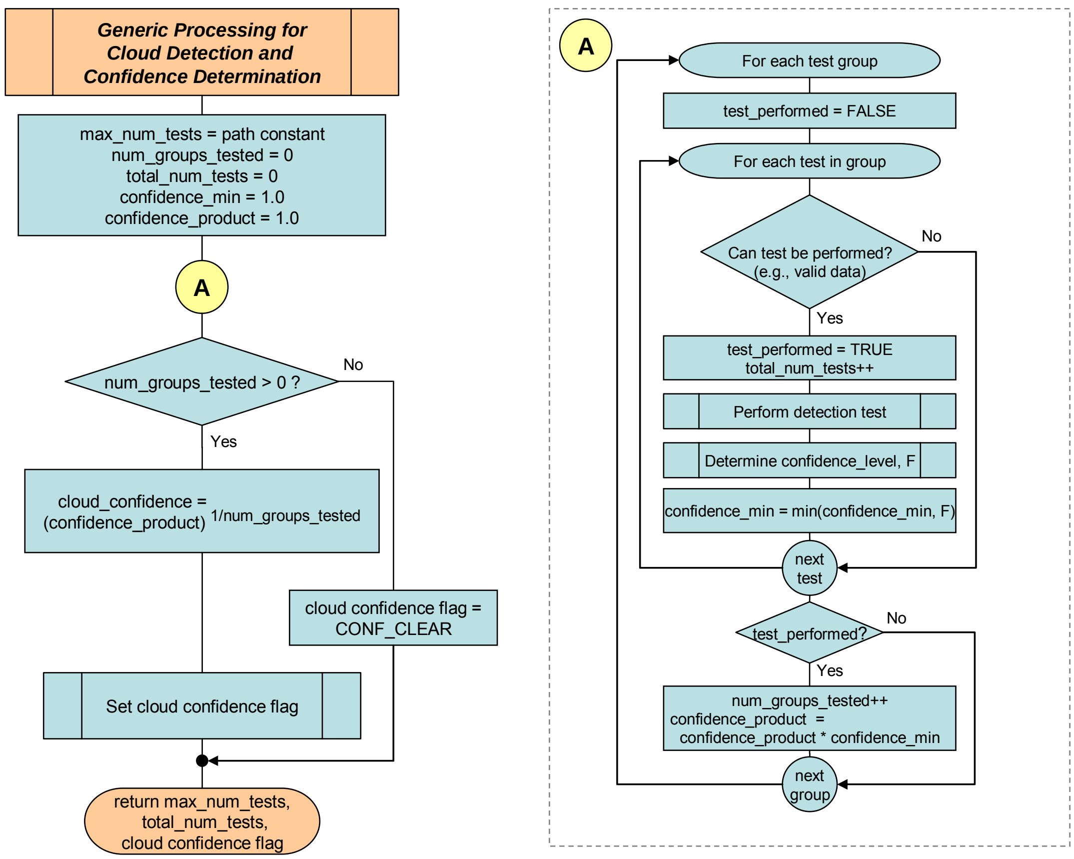


Figure 9. Generic Cloud Confidence Processing

2.1.2.6.2.3 Calculation of Individual Confidence Levels

The individual confidence levels indicate the strength in conviction in the outcome of a detection test's cloud/no cloud decision. The confidence is based on the observation's proximity to a confident clear or confident cloudy threshold value. The threshold values are either predetermined from observations and/or theoretical simulations or derived in real-time based on given geophysical and/or viewing conditions. Each test has a minimum of three thresholds values—confident clear, clear/cloudy and confident cloudy; however, one test, namely the visible ratio test, identifies a cloud if the observations falls within a given range (e.g., $0.9 < Ref_{M7}/Ref_{M5} < 1.1$). For these range tests there are six thresholds. Process confidence_test() produces confidence levels for detection tests using single-valued threshold sets while process confidence_test_2val() produces the levels for range thresholds.

Both schemes apply a linear interpolation approach. The implementation for the single-value threshold approach is depicted in Figure 10. The abscissa represents the observation and the ordinate the clear-sky confidence level. The β value is the clear/cloudy (pass/fail) threshold for a given test and is assigned a confidence level of 0.5. The confident clear threshold is assigned a confidence level of 1.0 and the confident cloudy threshold, a level of 0.0. Values γ and α correspond to the largest and smallest threshold *magnitudes*, respectively, which for the upper diagram of Figure 10, are the confident clear and confident cloudy thresholds. In this scenario, observations greater than the confident clear threshold receive a confidence level of 1.0; values less than the confident cloudy threshold receive a confidence level of 0.0. Note that although the clear/cloudy threshold is assigned a midpoint confidence level of 0.5, one cannot assume that the threshold itself is the exact midpoint of the threshold range. As shown, two different slopes lie to either side of the clear/cloudy threshold. Therefore, a correct interpolation must first consider the proximity of the observation with respect to the clear/cloudy threshold and use this threshold as one of its reference points. Note also that the confident clear threshold is not always greater than the confident cloudy threshold; therefore the general slopes of the curve can be reversed as depicted in the lower diagram of Figure 10. Likewise, the logical comparisons become reversed. In this lower scenario, a confidence level of 1.0 is now assigned to observations *less than* the confident clear threshold and a confidence level of 0.0 is now assigned to observations *greater than* the confident cloudy threshold.

Figure 11 shows the approach used for threshold ranges and the scenarios encountered. Note that the definitions for α and γ differ from the above definitions. In this implementation, α always refers to the low clear sky confidence threshold (confident cloudy threshold) while γ refers to the high clear sky confidence threshold (confident clear threshold). As before, β refers to the clear/cloudy threshold (midpoint confidence threshold).

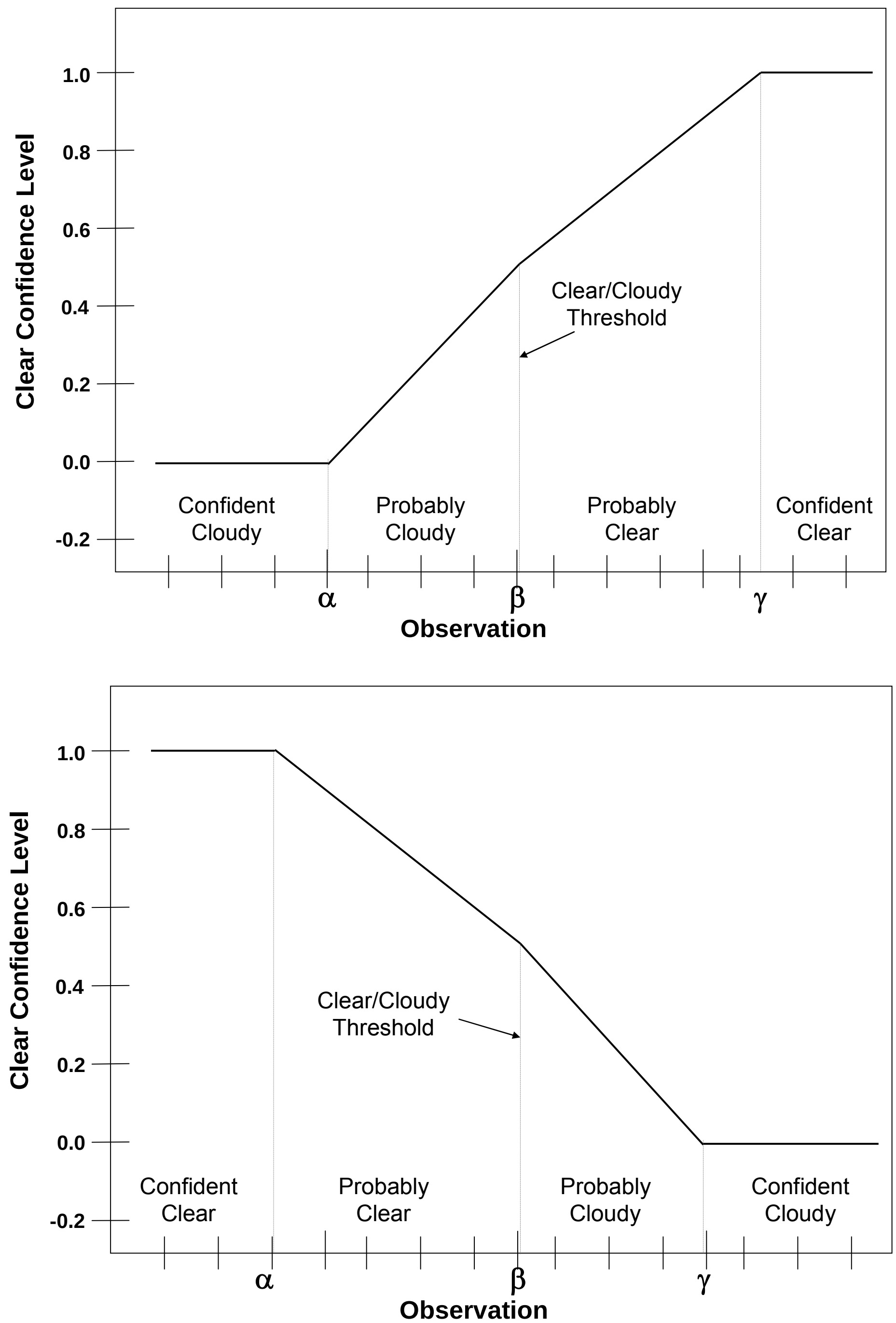


Figure 10. Graphical Depiction of Three Thresholds Used in Cloud Screening.
Upper – Confident Clear Threshold> Clear/Cloudy Threshold
Lower – Confident Clear Threshold> Clear/Cloudy Threshold

Table 11 shows the I/O for calculating confidences using single-valued thresholds. The steps for this process follow.

Table 11. Confidence Level I/O for Single-Valued Threshold Tests

	Variable	Description
Input	value	observation (test value) from detection test
	ccldy_thresh	low clear sky confidence threshold value (aka, confident cloudy threshold)
	cclr_thresh	high clear sky confidence threshold value (aka, confident clear threshold)
	clr_cldy_thresh	clear/cloudy threshold value
Output	confidence_value	confidence level ranging from 0 to 1, with 1 indicating confident clear and 0 indicating confident cloudy

<u>Steps for calculating individual confidence levels using single-valued thresholds – confidence_test()</u>

1. Determine the largest and smallest magnitude threshold values. Store the largest value in variable gamma, the smallest in variable alpha and the clear/cloudy threshold in variable beta. Set a flag, variable switched, to indicate the slope condition.

```
IF (cclr_thresh > ccldy_thresh) THEN
        gamma = cclr_thresh
        alpha = ccldy_thresh
        switched = FALSE
ELSE
        gamma = ccldy_thresh
        alpha = cclr_thresh
        switched = TRUE
END IF
beta = clr_cldy_thresh
```

2. Set confidence level if the test value is out of range and return

```
IF ((switched is FALSE .AND. value > gamma) .OR.
    (switched is TRUE .AND. value < alpha)) THEN
        confidence_value = 1.0
        return with confidence_value
ELSE IF ((switched is FALSE .AND. value < alpha) .OR.
           (switched is TRUE .AND. value > gamma)) THEN
        confidence_value = 0.0
        return with confidence_value
END IF
```

3. Value lies between the confident clear and confident cloudy threshold. Perform linear interpolation to determine the confidence value.

```
IF (value <= beta) THEN
        conf_delta = 0.5 * (value – alpha) / (beta – alpha)
        IF (switched is FALSE) THEN
                confidence_value = conf_delta
        ELSE
                confidence_value = 1.0 – conf_delta
        END IF
ELSE
        conf_delta = 0.5 * (value – gamma) / (beta – gamma)
        IF (switched is FALSE) THEN
```

confidence_value = 1.0 – conf_delta
ELSE
confidence_value = conf_delta
END IF
END IF

4. Correct for machine precision error. Confidence level should always be between 0 and 1.
IF (confidence_value > 1.0) THEN
confidence_value = 1.0
ELSE IF (confidence_value < 0.0) THEN
confidence_value = 0.0
END IF

5. Return with confidence_value

<u>Steps for calculating confidence level using threshold ranges – confidence_test_2val()</u>

For this logic, variable alpha represents the low clear sky confidence threshold (confident cloudy threshold), variable beta represents the clear/cloudy threshold, and variable gamma represents the high clear sky confidence threshold (confident clear threshold).

For the configuration where the threshold ranges do not overlap, alpha2 >= alpha1 (Figure 11a), the following logic applies:

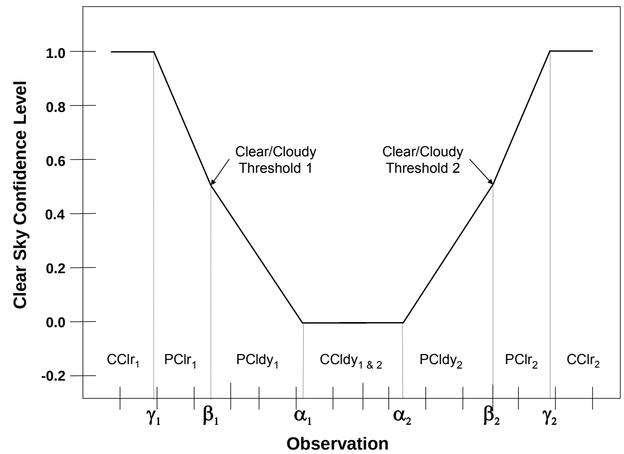
IF (value lies within the region marked CCldy) THEN
confidence_value = 0.0
ELSE IF (value lies within $CClr_1$ or $CClr_2$ regions) THEN
confidence_value = 1.0
ELSE IF (value lies within $PCldy_1$ region) THEN
confidence_value = 0.5 *(value – alpha1) / (beta1 – alpha1)
ELSE IF (value lies within $PClr_1$ region) THEN
confidence_value = 1.0 – (0.5 * (value – gamma1) / (beta1 – gamma1))
ELSE IF (value lies within $PCldy_2$ region) THEN
confidence_value = 0.5 *(value – alpha2) / (beta2 – alpha2)
ELSE IF (value lies within $PClr_2$ region) THEN
confidence_value = 1.0 – (0.5 * (value – gamma2) / (beta2 – gamma2))
END IF

For the configuration where the threshold ranges overlap, alpha2 < alpha1, the following logic applies:

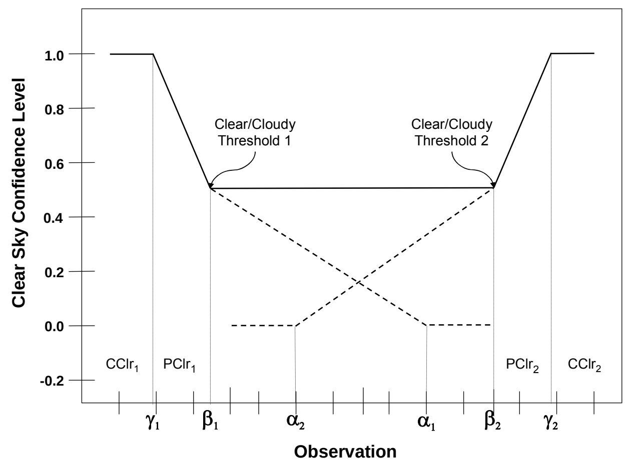
IF (value lies within $CClr_1$ or $CClr_2$ regions) THEN
confidence_value = 1.0
ELSE IF (beta2 – beta1 > 0.0) THEN (Figure 11b)
IF (beta2 > value > beta1) THEN
confidence_value = 0.5
ELSE IF (value is in the $PClr_1$ region) THEN
confidence_value = 1.0 – (0.5 * (value – gamma1) / (beta1 – gamma1))
ELSE (value is in the $PClr_2$ region)
confidence_value = 1.0 – (0.5 * (value – gamma2) / (beta2 – gamma2))
END IF
ELSE IF (value <= beta1) THEN (Figure 11c).
confidence_value = 1.0 – (0.5 * (value – gamma1) / (beta1 – gamma1))
ELSE
confidence_value = 1.0 – (0.5 * (value – gamma2) / (beta1 – gamma2))
END IF

Correct confidence_value for machine precision error:

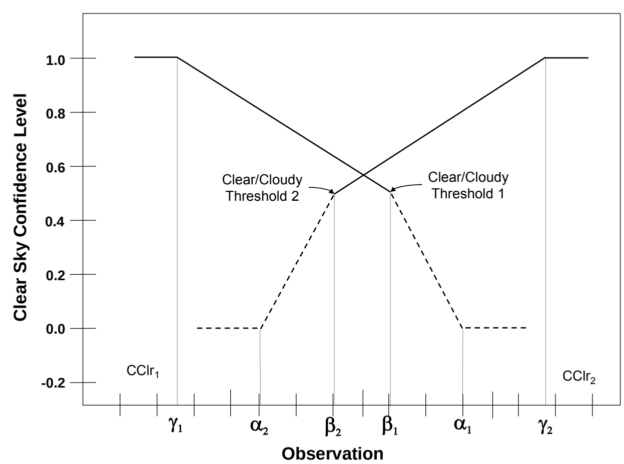
```
IF (confidence_value > 1.0) THEN
    confidence_value = 1.0
ELSE IF (confidence_value < 0.0) THEN
    confidence_value = 0.0
END IF
```



a) No overlap between Confident Cloudy Thresholds ($\alpha_2 \geq \alpha_1$)



b) Overlap between threshold ranges ($\alpha_2 < \alpha_1$ and $\beta_2 > \beta_1$)



c) Overlap between threshold ranges ($\alpha_2 < \alpha_1$ and $\beta_2 < \beta_1$)

Figure 11. Confidence Level Calculation Using Threshold Ranges

2.1.2.6.2.4 Calculation of Final Cloud Confidence

A composite cloud confidence for a given surface type/illumination path is determined using the confidence levels obtained from the individual detection tests from each detection group. Figure

12 shows the general data flow. The specific calculations are shown below. Note that the current implementation uses a more stringent "Confidently Clear" threshold for snow/night and water/night conditions.

Steps for Calculation of Cloud Confidence

A Cloud Confidence is calculated by the instructions below:

1. Determine a minimum confidence level for each group in which at least one test within that group has been performed:

$$\texttt{minimum\_confidence\_level}_{igroup} = \texttt{min}(\texttt{F}_{igroup,\ itest}),$$

where

itest = 1, $ntest_{igroup}$, ntest is the number of tests executed in a given group *igroup*, *igroup* = 1, ngroup, and ngroup is the number of groups for a given processing path.

2. Calculate a composite "analog" cloud confidence by finding the Nth root of the product of the minimum confidence levels:

$$\texttt{cloud\_confidence} = \sqrt[N]{\prod_{igroup}^{N} \left(\texttt{minimum\_confidence\_level}_{\texttt{igroup}}\right)}$$

where

N is the total number of groups actually executed and excludes in its total count any groups where exactly no tests could be executed.

3. Quantize the "analog" cloud confidence into the 4-valued cloud confidence flag by the following rules:

if $\texttt{cloud\_confidence} \geq \texttt{VCM\_CONFIDENCE\_HIGH}$ or no tests were performed (N=0)
    $\texttt{cloud\_confidence\_flag}$ = "Confidently Clear" (0)

if $\texttt{VCM\_CONFIDENCE\_MED} \leq \texttt{cloud\_confidence} < \texttt{VCM\_CONFIDENCE\_HIGH}$
    $\texttt{cloud\_confidence\_flag}$ = "Probably Clear" (1)

if $\texttt{VCM\_CONFIDENCE\_LOW} < \texttt{cloud\_confidence} < \texttt{VCM\_CONFIDENCE\_MED}$
    $\texttt{cloud\_confidence\_flag}$ = "Probably Cloudy" (2)

if $\texttt{cloud\_confidence} = \texttt{VCM\_CONFIDENCE\_LOW}$
    $\texttt{cloud\_confidence\_flag}$ = "Confidently Cloudy" (3)

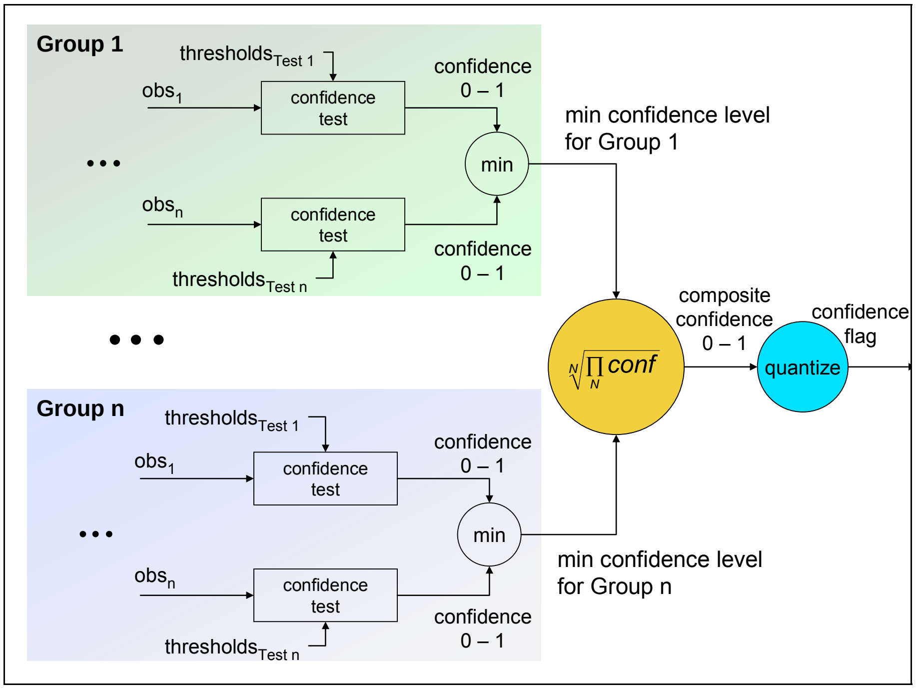


Figure 12. Data Flow for the Calculation of Cloud Confidence

2.1.2.6.2.5 Path Specific Cloud Detection

Table 12 shows a listing of the test groups and the specific detection tests belonging to each group. Table 13 gives a summary of when each cloud test is applied according to the five defined surface types for both day and night. The "X" represents the application of a specific test. Specific conditions, if present, are marked with superscripts and explained below the table. Please refer to Table 50, VCM IP Tunable Parameters for specific values that limit the execution of the tests. The processing steps provided below for each surface type/illumination path are essentially a more explicit reiteration of Table 13 but also shows the order in which the tests are executed and the settings for the constant max_num_tests. A generalized I/O table is also provided in Table 14. The specific processing details of each detection test follow in Section 2.1.2.6.2.6, Spectral Cloud Detection Test Descriptions.

Table 12. Test Groups Versus Spectral Cloud Detection Tests

Group #	Test Group	Tests
I	Emission Threshold	BT_{M15}
II	Emission Difference	BT_{M12}-BT_{M13} BT_{M15}-BT_{M12} BT_{M14}-BT_{M15} & BT_{M15}-BT_{M16} (trispectral test)
III	Reflectance Threshold	Ref_{M1} Ref_{M5} Ref_{M7} Ref_{M7}/Ref_{M5}
IV	Reflectance Thin Cirrus	Ref_{M9}
V	Emission Thin Cirrus	BT_{M15}-BT_{M16} BT_{M12}-BT_{M16}

Table 13. Cloud Test Checklist According to Processing Path

<table>
<tr><th colspan="2"></th><th colspan="5">Day</th><th colspan="5">Night</th></tr>
<tr><th>Group</th><th>Cloud Test</th><th>Snow / Ice</th><th>Water</th><th>Land</th><th>Desert</th><th>Coast</th><th>Snow / Ice</th><th>Water</th><th>Land</th><th>Desert</th><th>Coast</th></tr>
<tr><td>I</td><td>BT_{M15}</td><td></td><td></td><td></td><td></td><td></td><td>X</td><td>X</td><td colspan="3">X</td></tr>
<tr><td rowspan="3">II</td><td>BT_{M15}-BT_{M12}</td><td>X</td><td>X[3]</td><td>X[7]</td><td>X[5]</td><td>X[3,7]</td><td>X[6,11]</td><td>X</td><td colspan="3">X[9,11]</td></tr>
<tr><td>BT_{M12}-BT_{M13}</td><td>X[4]</td><td>X[3,4]</td><td>X[4,8]</td><td></td><td></td><td></td><td></td><td colspan="3"></td></tr>
<tr><td>Tri-Spectral</td><td></td><td>X</td><td></td><td></td><td></td><td></td><td>X</td><td colspan="3"></td></tr>
<tr><td rowspan="4">III</td><td>Ref_{M1}</td><td></td><td></td><td></td><td>X[4]</td><td></td><td></td><td></td><td colspan="3"></td></tr>
<tr><td>Ref_{M5}</td><td></td><td></td><td>X[2]</td><td></td><td>X[2]</td><td></td><td></td><td colspan="3"></td></tr>
<tr><td>Ref_{M7}</td><td></td><td>X</td><td></td><td></td><td></td><td></td><td></td><td colspan="3"></td></tr>
<tr><td>Ref_{M7}/Ref_{M5}</td><td></td><td>X</td><td>X[10]</td><td></td><td></td><td></td><td></td><td colspan="3"></td></tr>
<tr><td>IV</td><td>Ref_{M9}</td><td>X</td><td>X</td><td>X</td><td>X[1]</td><td>X</td><td></td><td></td><td colspan="3"></td></tr>
<tr><td rowspan="2">V</td><td>BT_{M15}-BT_{M16}</td><td></td><td>X</td><td>X</td><td>X</td><td>X</td><td></td><td>X</td><td colspan="3">X</td></tr>
<tr><td>BT_{M12}-BT_{M16}</td><td></td><td></td><td></td><td></td><td></td><td>X[6,11]</td><td></td><td colspan="3">X[11]</td></tr>
</table>

1 If TPW > DD_M9_TPIWV_cutoff .
2 Ref_{M1} is used if TOC NDVI < MAX_LOW_TOC_NDVI.
3 If no sun glint.
4 If between lowLat and highLat, i.e., outside polar latitudes.
5 If poleward of DD_MIN_POLAR_LAT.
6 If terrain height is less than HiElevThresh, then $BT_{M15} – BT_{M12}$ is used; otherwise, $BT_{M12} – BT_{M16}$ is used.
7 If TOC NDVI > VCM_M15M12DIFF_MIN_TOCNDVI.
8 If TOC NDVI > VCM_M12M13DIFF_MIN_TOCNDVI.
9 If TOC NDVI > VCM_NIGHT_MIN_TOCNDVI.
10 Test is performed only if $Ref_{M5} \geq$ LD_M5_GEMI_THRESH.
11 Test is performed only if BT_{M12} > BTM12_limit.

Table 14. Surface Type/Illumination Path I/O

<table>
<tr><th></th><th>Variable</th><th>Description</th></tr>
<tr><td>Input</td><td colspan="2">Please refer to the input table for each detection test used by the specific pixel path.</td></tr>
<tr><td rowspan="4">Output</td><td>*_Test_Result</td><td>Binary cloud/no cloud test result for each detection test performed, where * refers to a specific cloud/no cloud spectral test result.</td></tr>
<tr><td>cc</td><td>composite cloud confidence level ranging between 0 and 1.</td></tr>
<tr><td>cc_quality</td><td>Cloud Mask quality. Please see VCM IP output table, Table 6.</td></tr>
<tr><td>trispectral_only_flag</td><td>flag indicating that only the trispectral test yielded a “Cloud” (“Yes”) versus a “No Cloud” (“No”) result; flag used later for Cloud Phase determination</td></tr>
</table>

Perform Snow/Day Processing

max_num_tests = 3

1. Perform the Emission Difference Test Group (Group II) tests listed below
   - BTM12 – BTM13 Difference Test for latitudes outside the polar regions (i.e., between lowLat and highLat,).
   - BTM15 – BTM12 Difference Test
2. Perform the Reflectance Cirrus Test Group (Group IV) test listed below:
   - RefM9 Test

Perform Coast/Day Processing

max_num_tests = 4

1. Perform the Emission Thin Cirrus Test Group (Group V) tests listed below
   - BTM15 – BTM16 Difference Test
2. Perform the Emission Difference Test Group (Group II) tests listed below
   - BTM15 – BTM12 Difference Test for TOC NDVI > VCM_M15M12DIFF_MIN_TOCNDVI and no sun glint
3. Perform the Reflectance Threshold Test Group (Group III) test listed below:
   - RefM5 Test
4. Perform the Reflectance Thin Cirrus Test Group (Group IV) test listed below:
   - RefM9 Test

Perform Desert/Day Processing

max_num_tests = 4

1. Perform the Emission Thin Cirrus Test Group (Group V) tests listed below
   - BTM15 – BTM16 Difference Test
2. Perform the Emission Difference Test Group (Group II) tests listed below
   - BTM15 – BTM12 Difference Test for poleward latitudes starting at 60^o
3. Perform the Reflectance Threshold Test Group (Group III) test listed below:
   - RefM1 Test for latitudes between 60^o S and 60^o N
4. Perform the Reflectance Thin Cirrus Test Group (Group IV) test listed below:
   - RefM9 Test for TPIWV > DD_M9_TPIWV_cutoff

Perform Water/Day Processing

max_num_tests = 7

1. Perform the Emission Thin Cirrus Test Group (Group V) tests listed below
   - BTM15 – BTM16 Difference Test
2. Perform the Emission Difference Test Group (Group II) tests listed below
   - BTM12 – BTM13 Difference Test for latitudes outside the polar regions (i.e., between lowLat and highLat) and with no sun glint
   - BTM15 – BTM12 Difference Test with no sun glint
   - Tri-spectral Test
3. Perform the Reflectance Threshold Test Group (Group III) test listed below:
   - RefM7 Test
   - RefM7/RefM5 RatioTest
4. Perform the Reflectance Thin Cirrus Test Group (Group IV) test listed below:
   - RefM9 Test
5. Set the trispectral_only_flag to "Yes" when only the trispectral test detects a cloud

Perform Land/Day Processing

max_num_tests = 6

1. Perform the Emission Thin Cirrus Test Group (Group V) tests listed below
   - BTM15 – BTM16 Difference Test
2. Perform the Emission Difference Test Group (Group II) tests listed below
   - BTM12 – BTM13 Difference Test for latitudes outside the polar regions (i.e., between lowLat and highLat and TOC NDVI > VCM_M12M13DIFF_MIN_TOCNDVI
   - BTM15 – BTM12 Difference Test for TOC NDVI > VCM_M15M12DIFF_MIN_TOCNDVI
3. Perform the Reflectance Threshold Test Group (Group III) test listed below:
   - RefM5 Test
   - RefM7/RefM5 ratio test for RefM5 ≥ LD_M5_GEMI_THRESH

4. Perform the Reflectance Thin Cirrus Test Group (Group IV) test listed below:
   - RefM9 Test

Perform Water/Night Processing

max_num_tests = 4

1. Perform the Emission Thin Cirrus Test Group (Group V) tests listed below:
   - BTM15 – BTM16 Difference Test
2. Perform the Emission Threshold Test Group (Group 1) tests listed below:
   - BTM15 Threshold Test
3. Perform the Emission Difference Test Group (Group II) tests listed below
   - BTM15 – BTM12 Difference Test for BTM12 > BTM12_limit
   - Tri-spectral Test
4. Set the trispectral_only_flag to "Yes" when only the trispectral test detects a cloud

Perform Snow/Night Processing

max_num_tests = 3

IF (terrainHt > HiElevThresh) THEN

1. Perform the Emission Thin Cirrus Test Group (Group V) tests listed below:
   - BTM12 – BTM16 Difference Test for BTM12 > BTM12_limit

ELSE

2. Perform the Emission Difference Test Group (Group II) tests listed below
   - BTM15 – BTM12 Difference Test for BTM12 > BTM12_limit

ENDIF

3. Perform the Emission Threshold Test Group (Group 1) tests listed below:
   - BTM15 Threshold Test

Perform Land/Night Processing

max_num_tests = 4

1. Perform the Emission Thin Cirrus Test Group (Group V) tests listed below:
   - BTM15 – BTM16 Difference Test
   - BTM12 – BTM16 Difference Test for BTM12 > BTM12_limit
2. Perform the Emission Difference Test Group (Group II) tests listed below
   - BTM15 – BTM12 Difference Test for and TOC NDVI > VCM_NIGHT_MIN_TOCNDVI and BTM12 > BTM12_limit
3. Perform the Emission Threshold Test Group (Group 1) tests listed below:
   - BTM15 Threshold Test

2.1.2.6.2.6 Spectral Cloud Detection Test Descriptions

The details of the spectral cloud detection tests listed in and used by the various surface type/illumination paths discussed in Section 2.1.2.6.2.5, Path Specific Cloud Detection, are described below. I/O Tables are provided for each test.

Group I – Emission Threshold

M15 Threshold Test – This test is performed over all surface types during nighttime only. The M15 brightness temperature is compared to ancillary surface temperature to determine the existence of clouds. The I/O for this test is shown in Table 15 below.

Table 15. M15 Threshold Test I/O

	Variable	Description
Input	BTM15	M15 brightness temperature
	BTM16	M16 brightness temperature
	MBSenZen	sensor zenith angle, moderate resolution
	sfc_temp	surface temperature, K
	land_water_flag	land/water background flag for distinguishing water and land surface types in water_night and land_night, respectively
Output	M15_Test_Result	Binary cloud/no cloud test result
	M15_test_cc	confidence level from confidence_test ranging from 0 (confident cloudy) to 1 (confident clear)

The base clear/cloudy thresholds used in this test in Table 16 are dependent on pixel surface type:

Table 16. M15 Test Thresholds

Subroutine	Pixel Surface Type	Clear/Cloudy Variable
snow_night	snow	lst_snow_thres
water_night	inland water	sst_in_water_thres
	ocean	sst_thres
land_night	desert	lst_desert_thres
	land (no desert)	lst_thres
	coast	

Steps for performing the BT_{M15} Emission Threshold Test

1. Check the validity of input values, BTM15, BTM16 and Sensor Zenith Angle, MBSenZen. Also check that the surface temperature is within range between sfc_temp_Lo and sfc_temp_Hi. This test is not performed if any of these conditions are not satisfied.

```
IF (BTM15 & BTM16 & MBSenZen = Good Quality .AND.
sfc_temp > sfc_temp_Lo .AND. sfc_temp < sfc_temp_Hi) THEN
    proceed with test steps below
END IF
```

2. Set the clear/cloudy threshold, mid_pt, according to pixel surface type condition shown in the table above.

   mid_pt = value dependent on surface type listed above

   a. *Snow/Night Variation*

      , mid_pt = lst_snow_thres

   b. *Water/Night Variation*,

```
IF (land_water_flag = “Inland Water”) THEN
    mid_pt = sst_in_water_thres
ELSE
    mid_pt = sst_thres
ENDIF
```

c. *Land/Night Variation*,

```
IF (land_water_flag = "Desert") THEN
    mid_pt = lst_desert_thres
ELSE
    mid_pt = lst_thres
ENDIF
```

3. Correct the clear/cloudy threshold for water vapor concentration based on M15-M16 brightness temperature difference, btd, and sensor zenith angle.

```
btd = BTM15 – BTM16
IF (btd >= M15_M16_WV_CORR_THRESH) THEN
    mid_pt = mid_pt + (M15_MIDPT_WV_CORR_FACTOR  * int(btd))
ENDIF
a = MBSenZen / VIIRS_MAX_SENZEN_ANGLE
corr = (a**4)* M15_ATM_SLANT_WV_CORR_FACTOR
mid_pt = mid_pt + corr
```

4. Calculate the confident cloudy and confident clear thresholds, lo_conf and hi_conf respectively.

```
lo_conf = mid_pt + LN_M15_LO_CORR
hi_conf = mid_pt + LN_M15_HI_CORR
```

5. Calculate the surface temperature difference, sfcdif

```
sfcdif = sfc_temp - BTM15
```

6. Set the M15 binary test result to Cloud/No Cloud based on the observed value of the surface temperature difference.

```
IF (sfcdif greater than or equal to mid_pt) THEN
    Set M15_Test_Result to "Cloud"
ELSE
    Set M15_Test_Result to "No Cloud"
ENDIF
```

7. Calculate a confidence level, M15_test_cc based on the test value, sfcdif, and the confident cloudy, confident clear and clear/cloudy thresholds by calling subroutine confidence_test() described in Section 2.1.2.6.2.3, Calculation of Individual Confidence Levels.

```
CALL Confidence_Test (sfcdif, lo_conf, hi_conf, mid_pt; M15_test_cc)
```

Group II – Emission Difference

M15 – M12 BT Difference Test – This test is performed for all surface types, both day and night, with certain exceptions as outlined in Table 13. These differences will be shown as test variations on test in the instructions that follow. The I/O for this test is shown in Table 17 below.

Table 17. M15 – M12 BT Difference Test

	Surface Type / Illumination	Variable	Description
Input	all	BTM15	M15 brightness temperature
	all	BTM12	M12 brightness temperature
	snow/day	terrainHt	terrain height
	water/day	sun_glint_flag	flag indicating presence of sun glint
	land/day	toc_ndvi	top-of-canopy NDVI
	desert/day	mLat	pixel latitude

	Surface Type / Illumination	Variable	Description
		tpiwv	total path integrated water vapor
	coast/day	sun_glint_flag	flag indicating presence of sun glint
		toc_ndvi	top-of-canopy NDVI
	snow/night	terrainHt	terrain height
	water/night	MBSenZen	sensor zenith angle, moderate resolution
		tpw	total precipitable water
	land/night	toc_ndvi	top-of-canopy NDVI
		tpw	total precipitable water
Output	all	M15_M12_Test_Result	Binary cloud/no cloud test result
	all	M15_M12_test_cc	confidence level from confidence_test ranging from 0 (confident cloudy) to 1 (confident clear)

The clear/cloudy threshold and the confident clear (high clear sky confidence) and confident cloudy (low clear sky confidence) thresholds used in this test are summarized in Table 18.

Table 18. M15 – M12 BT Difference Test Thresholds

Pixel Surface Type Processing Path	Threshold Dependencies	M15_M12_Mid Clear/Cloudy Threshold Variable Name	M15_M12_Hi Confident Clear Threshold Variable Name	M15_M12_Lo Confident Cloudy Threshold Variable Name
snow/day	high elevations	SD_M12_M15_MidHiElev	SD_M12_M15_HiHiElev	SD_M12_M15_LoHiElev
	all other elevations	SD_M12_M15_Mid	SD_M12_M15_Hi	SD_M12_M15_Lo
water/day	-	WD_M15_M12_Mid	WD_M15_M12_Hi	WD_M15_M12_Lo
land/day	-	LD_M15_M12_Mid	LD_M15_M12_Hi	LD_M15_M12_Lo
desert/day	tpiwv	dynamic linear dependency on tpiwv	M15_M12_Mid (dynamic) + correction	M15_M12_Mid (dynamic) + correction
coast/day	-	CD_M15_M12_Mid	CD_M15_M12_Hi	CD_M15_M12_Lo
snow/night	-	SN_M15_M12_Mid	SN_M15_M12_Hi	SN_M15_M12_Lo
water/night	corrected for tpw	dynamic WN_M15_M12_Mid + correction	dynamic WN_M15_M12_Hi + correction	dynamic WN_M15_M12_Lo + correction
land/night	corrected for tpw	dynamic LN_M15_M12_Mid + correction	dynamic LN_M15_M12_Hi + correction	dynamic LN_M15_M12_Lo + correction

Steps for performing the BT_{M15} – BT_{M12} Emission Difference Test

1. Check the validity of input values BTM15 and BTM12 and the satisfaction of any additional restrictive conditions imposed on this test as dictated by the pixel surface type/illumination variation noted below. The test is not performed if any of these conditions are not satisfied.

   a. *Snow/Day Variation*

      IF (BTM15 & BTM12 = Good) THEN

      proceed with test steps below

```
END IF
```

b. *Water/Day Variation – no sun glint*

```
IF (BTM15 & BTM12 = Good AND sun_glint_flag = "None") THEN
        proceed with test steps below
END IF
```

c. *Land/Day Variation – toc_ndvi > VCM_M15M12DIFF_MIN_TOCNDVI*

```
IF (BTM15 & BTM12 = Good AND
      toc_ndvi > VCM_M15M12DIFF_MIN_TOCNDVI) THEN
         proceed with test steps below
END IF
```

d. *Desert/Day Variation – poleward latitudes from +/- DD_MIN_POLAR_LAT*

```
polar = (fabs(mLat) >= DD_MIN_POLAR_LAT) &&
            (fabs(mLat) <= DD_MAX_POLAR_LAT)
IF (BTM15 & BTM12 = Good AND polar) THEN
        proceed with test steps below
END IF
```

e. *Coast/Day Variation – no sun glint AND toc_ndvi > VCM_M15M12DIFF_MIN_TOCNDVI*

```
IF (BTM15 & BTM12 = Good AND
      toc_ndvi > VCM_M15M12DIFF_MIN_TOCNDVI AND
      sun_glint_flag = "None") THEN
           proceed with test steps below
END IF
```

f. *Snow/Night Variation – terrain height ≦ HiElevThresh AND BTM12 > BTM12_limit*

```
IF (BTM15 & BTM12 = Good AND
      terrainHt <= HiElevThresh AND
      BTM12 > BTM12_limit) THEN
           proceed with test steps below
END IF
```

g. *Water/Night Variation – BTM12 > BTM12_limit*

```
IF (BTM15 & BTM12 = Good AND
     BTM12 > BTM12_limit) THEN
           proceed with test steps below
END IF
```

h. *Land/Night Variation – BTM12 > BTM12_limit AND toc_ndvi > VCM_NIGHT_MIN_TOCNDVI*

```
IF (BTM15 & BTM12 = Good AND
     BTM12 > BTM12_limit AND
     toc_ndvi > VCM_NIGHT_MIN_TOCNDVI) THEN
           proceed with test steps below
END IF
```

2. Calculate the brightness temperature difference, btd

   a. *Snow/Day Variation*

```
btd = BTM12 – BTM15
```

   b. *Water/Day Variation*
      Land/Day Variation
      Desert/Day Variation

Coast/Day Variation
Snow/Night Variation
Water/Night Variation
Land/Night Variation
btd = BTM15 – BTM12

3. Establish the confident clear, clear/cloudy, and confident cloudy thresholds—M15_M12_Hi, M15_M12_Mid, M15_M12_Lo—according to the surface type/illumination.

   a. *Snow/Day Variation – thresholds are dependent on terrain height*

```
IF (terrainHt > HiElevThresh) THEN
      M15_M12_Mid = SD_M12_M15_MidHiElev
      M15_M12_Hi = SD_M12_M15_HiHiElev
      M15_M12_Lo = SD_M12_M15_LoHiElev
ELSE
      M15_M12_Mid = SD_M12_M15_Mid
      M15_M12_Hi = SD_M12_M15_Hi
      M15_M12_Lo = SD_M12_M15_Lo
END IF
```

   b. *Water/Day Variation*

```
M15_M12_Mid = WD_M15_M12_Mid
M15_M12_Hi = WD_M15_M12_Hi
M15_M12_Lo = WD_M15_M12_Lo
```

   c. *Land/Day Variation*

```
M15_M12_Mid = LD_M15_M12_Mid
M15_M12_Hi = LD_M15_M12_Hi
M15_M12_Lo = LD_M15_M12_Lo
```

   d. *Desert/Day Variation – thresholds are a function of total path integrated water vapor content*

```
IF (tpiwv <= DD_M15_M12_TPIWV_switch) THEN
      A = DD_M15_M12_A1
      B = DD_M15_M12_B1
ELSE
      A = DD_M15_M12_A2
      B = DD_M15_M12_B2
END IF
M15_M12_Mid = A*tpiwv + B
M15_M12_Hi = M15_M12_Mid + DD_M15_M12_HI_CORR
M15_M12_Lo = M15_M12_Mid + DD_M15_M12_LO_CORR
```

   e. *Coast/Day Variation*

```
M15_M12_Mid = CD_M15_M12_Mid
M15_M12_Hi = CD_M15_M12_Hi
M15_M12_Lo = CD_M15_M12_Lo
```

   f. *Snow/Night Variation*

```
M15_M12_Mid = SN_M15_M12_Mid
M15_M12_Hi = SN_M15_M12_Hi
M15_M12_Lo = SN_M15_M12_Lo
```

   g. *Water/Night Variation – thresholds adjusted for total path total precipitable water*

```
secSenZen = 1.0
IF (0 < MBSenZen < 90.0) THEN
       cosSenZen=cos(DEGREES_TO_RADIANS(MBSenZen))
```

```
        IF (fabs(cosSenZen) > VCM_MIN_COS_SENZEN_TOL) THEN
            secSenZen = (1.0/cosSenZen)
        END IF
END IF

IF (tpw < VCM_MIN_PTPW) THEN
        ptpw = VCM_MIN_PTPW
ELSE IF (tpw * secSenZen > WN_M15_M12_MAX_PTPW)
        ptpw = WN_M15_M12_MAX_PTPW
ELSE
        ptpw = (*(tpw))*secSenZen
END IF

M15_M12_Mid = WN_M15_M12_Mid – (ptpw * WN_MID_PTPW_FACTOR)
M15_M12_Hi = WN_M15_M12_Hi – (ptpw * WN_HI_PTPW_FACTOR)
M15_M12_Lo = WN_M15_M12_Lo – (ptpw * WN_LO_PTPW_FACTOR)
```

h. *Land/Night Variation – thresholds adjusted for total path total precipitable water*

```
secSenZen = 1.0
IF (0 < MBSenZen < 90.0) THEN
        cosSenZen=cos(DEGREES_TO_RADIANS(MBSenZen))
        IF (fabs(cosSenZen) > VCM_MIN_COS_SENZEN_TOL) THEN
            secSenZen=(1.0/cosSenZen)
        END IF
END IF

IF (tpw < VCM_MIN_PTPW) THEN
        ptpw = VCM_MIN_PTPW
ELSE IF (tpw * secSenZen > LN_M15_M12_MAX_PTPW)
        ptpw = LN_M15_M12_MAX_PTPW
ELSE
        ptpw = (*(tpw))*secSenZen
END IF

M15_M12_Mid = LN_M15_M12_Mid – (ptpw * LN_MID_PTPW_FACTOR)
M15_M12_Hi = LN_M15_M12_Hi – (ptpw * LN_HI_PTPW_FACTOR)
M15_M12_Lo = LN_M15_M12_Lo – (ptpw * LN_LO_PTPW_FACTOR)
```

4. Set the M15_M12 binary test result to Cloud/No Cloud based on the value of the brightness temperature difference.

   a. *Snow/Day Variation*

```
IF (btd >= M15_M12_Mid) THEN
      Set M15_M12_Test_Result to “Cloud”
ELSE
      Set M15_M12_Test_Result to “No Cloud”
ENDIF
```

   b. *Water/Day Variation*
      Land/Day Variation

```
IF (btd < M15_M12_Mid) THEN
      Set M15_M12_Test_Result to “Cloud”
ELSE
      Set M15_M12_Test_Result to “No Cloud”
ENDIF
```

c. *Desert/Day Variation*
Coast/Day Variation

```
IF (btd <= M15_M12_Mid) THEN
        Set M15_M12_Test_Result to "Cloud"
ELSE
        Set M15_M12_Test_Result to "No Cloud"
ENDIF
```

d. *Water/Night Variation*
Snow/Night Variation

```
IF (btd > M15_M12_Mid) THEN
        Set M15_M12_Test_Result to "Cloud"
ELSE
        Set M15_M12_Test_Result to "No Cloud"
ENDIF
```

5. Calculate a confidence level, M15_M12_test_cc based on the observation, btd, and the confident cloudy, confident clear and clear/cloudy thresholds by calling subroutine confidence_test() described in Section 2.1.2.6.2.3, Calculation of Individual Confidence Levels.

```
CALL Confidence_Test (btd, M15_M12_Lo, M15_M12_Hi,
                      M15_M12_Mid; M15_M12_test_cc)
```

M12 – M13 BT Difference Test – This test is not performed in areas with bright surfaces such as polar regions, land and coastal areas where TOC NDVI is less than a specified value, and under conditions of sun glint. See Table 13 for the surface type/illumination pixels that use this test and the variations associated with it. The I/O for this difference test is shown in Table 19 below.

Table 19. M12 – M13 BT Difference Test I/O

	Variable	Description
Input	BTM12	M12 brightness temperature
	BTM13	M13 brightness temperature
	mLat	pixel latitude
	sun_glint_flag	flag indicating presence of sun glint; used for water_day() only
	toc_ndvi	top-of-canopy NDVI; used for land_day() only
Output	M12_M13_Test_Result	Binary cloud/no cloud test result
	M12_M13_test_cc	confidence level from confidence_test ranging from 0 (confident cloudy) to 1 (confident clear)

The clear/cloudy threshold and the confident clear (high clear sky confidence) and confident cloudy (low clear sky confidence) thresholds used in this test are listed in Table 20.

Table 20. M12 – M13 Difference Test Thresholds

Pixel Surface Type Processing Path	M12_M13_Mid Clear/Cloudy Threshold Variable Name	M12_M13_Hi Confident Clear Threshold Variable Name	M12_M13_Lo Confident Cloudy Threshold Variable Name
snow/day	SD_M12_M13_Mid	SD_M12_M13_Hi	SD_M12_M13_Lo
water/day	WD_M12_M13_Mid	WD_M12_M13_Hi	WD_M12_M13_Lo
land/day	LD_M12_M13_Mid	LD_M12_M13_Hi	LD_M12_M13_Lo

Steps for performing the $BT_{M12} – BT_{M13}$ Emission Difference Test

1. Check the validity of input values BTM12 and BTM13, that the pixel latitude is outside the polar bounds, highLat and lowLat, and the satisfaction of any additional restrictive conditions imposed on this test as dictated by the pixel surface type/illumination variation noted below. The test is not performed if any of these conditions are not satisfied.

   a. *Snow/Day Variation*

   ```
   IF (BTM12 & BTM13 = Good .AND.
       mLat < highLat .AND. mLat > lowLat) THEN
         proceed with test steps below
   END IF
   ```

   b. *Water/Day Variation – no sun glint*

   ```
   IF (BTM12 & BTM13 = Good .AND.
       mLat < highLat .AND. mLat > lowLat .AND.
       sun_glint_flag = "None") THEN
         proceed with test steps below
   END IF
   ```

   c. *Land/Day Variation – toc_ndvi > VCM_M12M13DIFF_MIN_TOCNDVI*

   ```
   IF (BTM12 & BTM13 = Good .AND.
       mLat < highLat .AND. mLat > lowLat .AND.
       toc_ndvi > VCM_M12M13DIFF_MIN_TOCNDVI) THEN
         proceed with test steps below
   END IF
   ```

2. Calculate the brightness temperature difference, btd
   btd = BTM12 – BTM13

3. Establish the clear/cloudy, confident clear, and confident cloudy thresholds—M12_M13_Mid, M12_M13_Hi, M12_M13_Lo—according to the surface type/illumination (see table above)

4. Set the M12_M13 binary test result to Cloud/No Cloud based on the observed value of the brightness temperature difference.

   a. *Snow/Day Variation*
      Land/Day Variation

   ```
   IF (btd >= M12_M13_Mid) THEN
         Set M12_M13_Test_Result to "Cloud"
   ELSE
         Set M12_M13_Test_Result to "No Cloud"
   ENDIF
   ```

b. *Water/Day Variation*

    IF (btd > M12_M13_Mid) THEN
        Set M12_M13_Test_Result to "Cloud"
    ELSE
        Set M12_M13_Test_Result to "No Cloud"
    ENDIF

5. Calculate a confidence level, M12_M13_test_cc based on the observation, btd, and the confident cloudy, confident clear and clear/cloudy thresholds by calling subroutine confidence_test() described in Section 2.1.2.6.2.3, Calculation of Individual Confidence Levels.

    CALL Confidence_Test (btd, M12_M13_Lo, M12_M13_Hi,
        M12_M13_Mid; M12_M13_test_cc)

Tri-spectral (BTM14, BTM15, BTM16) Test – This test uses brightness temperature differences BTM14 – BTM15 and BTM15 – BTM16 and is performed only over water. The I/O for this test is shown in Table 21 below.

Table 21. Trispectral Test I/O

	Variable	Description
Input	BTM14	M14 brightness temperature
	BTM15	M15 brightness temperature
	BTM16	M16 brightness temperature
Output	M14_M15_M16_Test_Result	Binary cloud/no cloud test result
	M14_M15_M16_test_cc	confidence level from confidence_test ranging from 0 (confident cloudy) to 1 (confident clear)

The threshold calculations are summarized in Table 22.

Table 22. Trispectral Test Thresholds

Pixel Surface Type Processing Path	Threshold Dependency	M14_M15_M16_Mid Clear/Cloudy Threshold	M14_M15_M16_Hi Confident Clear Threshold	M14_M15_M16_Lo Confident Cloudy Threshold
water/day	BTM15 – BTM16	dynamic 3-degree polynomial, M14_M15_M16_Mid	M14_M15_M16_Mid + WD_M14_M15_M16_HI_CORR	M14_M15_M16_Mid + WD_M14_M15_M16_LO_CORR
water/night			M14_M15_M16_Mid + WN_M14_M15_M16_HI_CORR	M14_M15_M16_Mid + WN_M14_M15_M16_LO_CORR

<u>**Steps for performing the Tri-spectral Emission Difference Test**</u>

1. Check the validity of input values BTM14, BTM15 and BTM16. The test is not performed if any of these conditions are not met.

    IF (BTM14, BTM15 & BTM16 = Good) THEN
        proceed with test steps below
    ENDIF

2. Calculate the brightness temperature differences BTM14 – BTM15 and BTM15 – BTM16

    diff_m14_m15 = BTM14 – BTM15
    diff_m15_m16 = BTM15 – BTM16

3. Determine clear/cloudy threshold, M14_M15_M16_Mid, using a 3-degree polynomial as a function of the BTM15 – BTM16 temperature difference, diff_m15_m16
   M14_M15_M16_Mid = VCM_TRISPEC_C0 + (VCM_TRISPEC_C1 * T) + (VCM_TRISPEC_C2 * T^2) + (VCM_TRISPEC_C3 * T^3),
   where
   T = diff_m15_m16, and
   VCM_TRISPEC_C* are tunable parameters.

4. Set the M14_M15_M16 binary test result to Cloud/No Cloud based on the BTM14 – BTM15 brightness temperature difference.

   a. *Water/Day Variation*
```
IF (diff_m14_m15 >= M14_M15_M16_Mid) THEN
      Set M14_M15_M16_Test_Result to "Cloud"
ELSE
      Set M14_M15_M16_Test_Result to "No Cloud"
ENDIF
```
   b. *Water/Night Variation*
```
IF (diff_m14_m15 > M14_M15_M16_Mid) THEN
      Set M14_M15_M16_Test_Result to "Cloud"
ELSE
      Set M14_M15_M16_Test_Result to "No Cloud"
ENDIF
```

5. Establish the clear/cloudy threshold and the confident clear and confident cloudy thresholds— M14_M15_M16_Lo and M14_M15_M16_Hi (see table above).

6. Calculate a confidence level, M14_M15_M16_test_cc based on the BTM14 – BTM15 brightness temperature difference, diff_m14_m15, and the confident cloudy, confident clear and clear/cloudy thresholds by calling subroutine confidence_test() described in Section 2.1.2.6.2.3, Calculation of Individual Confidence Levels.
```
CALL Confidence_Test (diff_m14_m15, M14_M15_M16_Lo,
                      M14_M15_M16_Hi, M14_M15_M16_Mid,
                      M14_M15_M16_test_cc)
```

Group III – Reflectance Threshold

M1 Reflectance Threshold Test – This test is used for non-polar desert and semi-arid ecosystems. Note that since the execution of this test and the M7 reflectance threshold test are exclusive of each other, the binary cloud/no cloud output result for M1 and M7 share the same storage bit field in the VCM IP output. The I/O for this test is listed in Table 23 below.

Table 23. M1 Reflectance Threshold Test I/O

	Variable	Description
Input	refm1	M1 reflectance
	lat	pixel latitude
Output	M1_Test_Result *	binary cloud/no cloud test result
	M1_test_cc	confidence level from confidence_test ranging from 0 (confident cloudy) to 1 (confident clear)

* Note the M1_Test_Result is currently stored in the M7_Test_Result bit

The clear/cloudy threshold and the confident clear (high clear sky confidence) and confident cloudy (low clear sky confidence) thresholds used in this test are listed in Table 24.

Table 24. M1 Reflectance Test Thresholds

Pixel Surface Type Processing Path	M1_Mid Clear/Cloudy Threshold Variable Name	M1_Hi Confident Clear Threshold Variable Name	M1_Lo Confident Cloudy Threshold Variable Name
desert/day	DD_M1_Mid	DD_M1_Hi	DD_M1_Lo

Steps for performing the M_1 Reflectance Threshold Test

1. Check the validity of input M1 band, refm1. The test is not performed if these conditions are not met.
   polar = (fabs(lat) >= DD_MIN_POLAR_LAT) AND
   (fabs(lat) <= DD_MAX_POLAR_LAT)
   IF (refm1 = Good .AND. !polar)
   proceed with test steps below
   ENDIF
2. Establish the clear/cloudy threshold and the confident clear and confident cloudy thresholds—M1_Mid, M1_Hi, M1_Lo (see table above).
3. Set the M1 Cloud/No Cloud test result, M1_Test_Result*, based on the observed M1 reflectance and the clear/cloudy threshold.
   * Note that the M1 Test Result is currently stored in the M7 Test Result!
   IF (refm1 > M1_Mid) THEN
   Set M1_Test_Result to "Cloud"
   ELSE
   Set M1_Test_Result to "No Cloud"
   ENDIF
4. Calculate a confidence level, M1_test_cc based on the M1 reflectance, refm1, and the confident cloudy, confident clear and clear/cloudy thresholds by calling subroutine confidence_test() described in Section 2.1.2.6.2.3, Calculation of Individual Confidence Levels.
   CALL Confidence_Test (refm1, M1_Lo, M1_Hi, M1_Mid, M1_test_cc)

M5 (M1) Reflectance Threshold Test – This reflectance test is used over non-desert, non-snow land surfaces and coastal regions. The thresholds are derived using the scattering angle and TOC NDVI. For backgrounds having a low TOC NDVI, the M1 band is used. The I/O for this test is shown Table 25. Further discussion on the TOC NDVI bin configuration and the computation of the thresholds follows.

Table 25. M5 (M1) Reflectance Threshold Test I/O

	Variable	Description
Input	RefM1	M1 reflectance
	RefM5	M5 reflectance
	MBSenZen	Sensor zenith angle, moderate resolution
	MBSenAzi	Sensor azimuth angle, moderate resolution
	MBSolZen	Solar zenith angle, moderate resolution

	Variable	Description
	MBSolAzi	Solar azimuth angle, moderate resolution
	toc_ndvi	Top of canopy NDVI
	low_toc_ndvi_bin_value	Maximum top of canopy NDVI bin value indicating low toc NDVI condition, derived from tunable parameter MAX_LOW_TOC_NDVI, and constants MIN_NDVI_CLASS, and DELTA_NDVI_CLASS. See Section 2.1.2.3.2, Validation of User Input and discussion in *Computation of NDVI Dependent Thresholds* below
	tunable parameters	See Table 50, TOC NDVI Test Thresholds
	constants	See Table 3, M5M1 Test Constants
Output	M5_Test_Result	Binary cloud/no cloud test result
	M5_M1_test_cc	Confidence level from confidence_test ranging from 0 (confident cloudy) to 1 (confident clear)

Steps for performing the Ref_{M5} Threshold Test

1. Determine if low TOC NDVI conditions exist to determine which band, M1 or M5 to use. Note, the appropriate band reflectance is stored in variable ref_m5m1.
```
IF (toc_ndvi < low_toc_ndvi_bin_value) THEN
      low_ndvi = "True"
      ref_m5m1 = RefM1
ELSE
      low_ndvi = "False"
      ref_m5m1 = RefM5
END IF
```
2. Check the validity of input values, MBSolZen, MBSolAzi, MBSenZen, MBSenAzi and band reflectance, ref_m5m1, for the given TOC NDVI condition. This test is not performed if any of these conditions are not satisfied.
```
IF (ref_m5m1 = Good Quality .AND.
    MBSolZen > BAD_ANGLE .AND.
    MBSenZen > BAD_ANGLE .AND.
    MBSolAzi >= BAD_ANGLE .AND.
    MBSenAzi >= BAD_ANGLE) THEN
      proceed with test steps below
END IF
```
3. Calculate the relative reflected angle, where the solar and sensor azimuth and zenith angles are converted to radians from degrees
```
rel_angle = ((cos(solZen) * cos(satZen)) +
              (sin(solZen) * sin(satZen) * cos(satAzi – solAzi)))
```
4. Calculate the scattering angle in degrees.
```
deg_scat_angle = (Π – acos(rel_angle)) * RADIANS_TO_DEGREES
```
5. If the scattering angle is less than a threshold minimum scattering angle, reset the scattering angle to the threshold minimum.
```
IF (toc_ndvi ≥ M5_TEST_HI_NDVI_THRESH AND
    deg_scat_angle < M5_TEST_HI_NDVI_MIN_SCAT_ANGLE) THEN
      deg_scat_angle = M5_TEST_HI_NDVI_MIN_SCAT_ANGLE
ENDIF
```
6. Compute the confident clear, clear/cloudy and confident cloudy NDVI-based thresholds—M5M1_Hi, M5M1_Mid, M5M1_Lo, respectively—based on TOC NDVI and

scattering angle. See the discussion on NDVI-based threshold computation at the completion of these steps.

CALL computeNDVIbasedThresholds(toc_ndvi, deg_scat_angle, M5M1_Hi, M5M1_Mid, M5M1_Lo, low_ndvi)

7. Set the M5 binary test result to Cloud/No Cloud based on the value of the band reflectance, ref_m5m1, and the clear/cloudy threshold.

```
IF (ref_m5m1 > M5M1_Mid) THEN
    Set M5_Test_Result to "Cloud"
ELSE
    Set M5_Test_Result to "No Cloud"
ENDIF
```

8. Calculate a confidence level, M5_test_cc based on the test value, ref_m5m1, and the confident cloudy, confident clear and clear/cloudy thresholds by calling subroutine confidence_test() described in Section 2.1.2.6.2.3, Calculation of Individual Confidence Levels.

```
CALL Confidence_Test (ref_m5m1, M5M1_Lo, M5M1_Hi, M5M1_Mid;
                      M5_M1_test_cc)
```

Computation of NDVI Dependent Thresholds (computeNDVIbasedThresholds())

For the M5 band, 10 TOC NDVI bins (0 – 0.1, 0.1 – 0.2, …, 0.9 – 1) are defined specified by the constant NUM_NDVI_BINS. For the M1 band, since it is used under low TOC NDVI conditions, a smaller bin range is needed, and is specified by the user in the constant MAX_NUM_M1_NDVI_BINS. Both bin tables have the same bin width of DELTA_NDVI_CLASS and a starting bin center of MIN_NDVI_CLASS.

The TOC NDVI value at which the use of the M1 band ceases is dictated by the user-input value, MAX_LOW_TOC_NDVI. For the current implementation, there is no requirement on the user to specify a bin center or boundary, so the value is adjusted by the software during VCM initialization to coincide with the nearest bin maximum. This adjusted value is stored as parameter low_toc_ndvi_max_bin_value. Also during VCM initialization, a check is performed to ensure that the MAX_LOW_TOC_NDVI is within the M1 bin range and that at least one additional bin is to the right of the bin containing the maximum low TOC NDVI bin value so that threshold interpolation is allowed at the M1-M5 bin transition.

The thresholds are calculated using a 3-degree polynomial as a function of scattering angle for each of the TOC NDVI bins defined in the software. The coefficients used for each band are stored in arrays

M5_ndvi_coef[NTHRESH][NUM_NDVI_BINS][NCOEFFS] and
M1_ndvi_coef[NTHRESH][MAX_NUM_M1_NDVI_BINS][NCOEFS],

where

NTHRESH is the number of thresholds, with indices 0 through 2 representing the confident clear, clear/cloudy and confident cloudy thresholds, respectively,
NUM_NDVI_BINS is the total number of M5 bins,
MAX_NUM_M1_NDVI_BINS is the total number of M1 bins, and
NCOEFS is the number of coefficients, with indices 0 through 3 representing the 3^{rd} order to the 0^{th} order coefficient, respectively.

For example, the RM5 thresholds for the TOC NDVI bin defined by TOC NDVI values between

0.2 – 0.3 (bin index=2) are determined by the polynomials listed below. Please refer to Table 50 for the coefficientsRM5 Confident Clear Threshold
= M5_ndvi_coef[0][2][3] x^3 + M5_ndvi_coef[0][2][2] x^2 + M5_ndvi_coef[0][2][1] x + M5_ndvi_coef[0][2][0]

RM5 Clear/Cloudy Threshold
= M5_ndvi_coef[1][2][3] x^3 + M5_ndvi_coef[1][2][2] x^2 + M5_ndvi_coef[1][2][1] x + M5_ndvi_coef[1][2][0]

RM5 Confident Cloudy Threshold
= M5_ndvi_coef[2][2][3] x^3 + M5_ndvi_coef[2][2][2] x^2 + M5_ndvi_coef[2][2][1] x + M5_ndvi_coef[2][2][0]

where x is the scattering angle in degrees.

Final thresholds are determined by linearly interpolating between values from the nearest two TOC NDVI bins. For TOC NDVI values residing in the first bin and less than bin center, and for TOC NDVI values residing in the last bin and greater than bin center, interpolation cannot be performed; therefore thresholds are calculated directly from the coefficients of the current bin only. The I/O for computing these variable NDVI thresholds is listed in Table 26 below.

Table 26. Computation of NDVI Dependent Thresholds I/O

	Variable	Description
Input	toc_ndvi	Top of canopy NDVI
	deg_scat_angle	Scattering angle in degrees
	low_ndvi	Flag indicating low TOC NDVI condition
	M5_ndvi_coef, M1_ndvi_coef	TOC NDVI coefficients for M1 and M5, see Table 50, TOC NDVI Test Thresholds Section
	Mx_*_THRES_ADJUST	M1 and M5 high, mid and low threshold adjustments, see Table 50, TOC NDVI Test Thresholds Section
	constants	See Table 3, M5M1 Test Constants
Output	thres_Hi	Confident clear threshold
	thres_Mid	Clear/cloudy threshold
	thres_Lo	Confident cloudy threshold

Steps for computing NDVI-based thresholds

1. Using the low_ndvi flag, initialize the M1 or M5-dependent parameters (e.g., point to the appropriate coefficient table)

```
IF (low_ndvi) THEN
    coef_table = &M1_ndvi_coef[0][0][0]
    thres_hi_adjust = M1_HI_THRES_ADJUST
    thres_mid_adjust = M1_MID_THRES_ADJUST
    thres_lo_adjust = M1_LO_THRES_ADJUST
    numBins = MAX_NUM_M1_NDVI_BINS
ELSE
    coef_table = &M5_ndvi_coef[0][0][0]
    thres_hi_adjust = M5_HI_THRES_ADJUST
    thres_mid_adjust = M5_MID_THRES_ADJUST
    thres_lo_adjust = M5_LO_THRES_ADJUST
    numBins = NUM_NDVI_BINS
ENDIF
```

2. Determine the bin index, indvi, in which the TOC NDVI value, toc_ndvi, falls
   indvi = (toc_ndvi – MIN_NDVI_CLASS) / DELTA_NDVI_CLASS

3. Determine location of toc_ndvi value within bin by computing the fractional distance, frac_ndvi, between the toc_ndvi and the "indvi" bin center. Correct for machine precision error.

```
frac_ndvi = toc_ndvi – (MIN_NDVI_CLASS + (indvi * DELTA_NDVI_CLASS)
IF (fabs(frac_ndvi) < 1.0e-6) THEN
      frac_ndvi = 0.0
ENDIF
```

4. Compute the M5 or M1 thresholds based on bin index and toc_ndvi position with respect to the bin center

   a. If value is in the 0th bin and left of bin center, or if the value is in the last bin and equal to or right of bin center, no interpolation is performed. Use the current bin center coefficients for the threshold calculation. Index into the coefficient table, coef_table, to extract the coefficients for each "ith" threshold of the indvith bin.

```
IF ((( indvi = 0) AND (frac_ndvi < 0.0)) OR
   ((indvi = NUM_NDVI_BINS-1) AND (frac_ndvi >= 0.0))) THEN
    FOR (ith = 0;  ith < NTHRESH; ith++)
        coef_ptr = coef_table + (ith*numBins*NCOEFS) + (indvi*NCOEFS)
        thres[ith] =
            VCM_POLY3(coef_ptr[3], coef_ptr[2], coef_ptr[1],
                              coef_ptr[0], deg_scat_angle) * 0.01
    END FOR
ENDIF
```

   b. Otherwise, interpolate thresholds using nearest neighbor bins. If left of bin center, calculate the current and previous bin thresholds. If right of bin center, calculate the current and the next bin thresholds. Index into the coefficient table, coef_table, to extract the coefficients for each ith threshold of the indvith bin.

```
ELSE IF (frac_ndvi < 0.0) THEN
    FOR (ith = 0; ith < NTHRESH; ith++)
        coef_ptr = coef_table + (ith*numBins*NCOEFS) + (indvi*NCOEFS)
        curBinTh =
           VCM_POLY3(coef_ptr[3], coef_ptr[2], coef_ptr[1],
                              coef_ptr[0], deg_scat_angle);

        coef_ptr =
          coef_table + (ith*numBins*NCOEFS) + ((indvi-1)*NCOEFS)
        adjBinTh =
          VCM_POLY3(coef_ptr[3], coef_ptr[2], coef_ptr[1],
                             coef_ptr[0], deg_scat_angle);

        thres[ith] = (curBinTh –
             ((adjBinTh – curBinTh)*(frac_ndvi/DELTA_NDVI_CLASS)))*0.01
    END FOR
ELSE
    FOR (ith = 0; ith < NTHRESH; ith++)
        coef_ptr = coef_table + (ith*numBins*NCOEFS) + (indvi*NCOEFS)
        curBinTh =
           VCM_POLY3(coef_ptr[3], coef_ptr[2], coef_ptr[1],
                             coef_ptr[0], deg_scat_angle);
```

```
        coef_ptr =
          coef_table + (ith*numBins*NCOEFS) + ((indvi+1)*NCOEFS)
        adjBinTh =
          VCM_POLY3(coef_ptr[3], coef_ptr[2], coef_ptr[1],
                         coef_ptr[0], deg_scat_angle);

        thres[ith] = (curBinTh –
            ((curBinTh – adjBinTh)*(frac_ndvi/DELTA_NDVI_CLASS)))*0.01
      END FOR
    ENDIF
```

5. Adjust the high, mid and low thresholds by their respective adjustment values. Store each threshold into its appropriate variable; indices 0 through 2 into confident clear, clear/cloudy and confident cloudy thresholds, respectively and return final threshold values.

```
thres_Hi = thres[0] + thres_hi_adjust
thres_Mid = thres[1] + thres_mid_adjust
thres_Lo = thres[2] + thres_lo_adjust
```

M7 Reflectance Threshold Test – This test is used over water with separate thresholds applied to sun glint and no sun glint regions. Note that sun glint thresholds are applied to inland water regions. Also, note that since the execution of this test and the M1 reflectance threshold test are exclusive of each other, the binary cloud/no cloud output result for M1 and M7 share the same storage bit field in the VCM IP output. The I/O for this test is shown in Table 27.

Table 27. M7 Reflectance Threshold Test I/O

	Variable	Description
Input	refm7	M7 reflectance
	sun_glint_flag	flag indicating presence of sun glint
Output	M7_Test_Result	Binary cloud/no cloud test result
	M7_test_cc	confidence level from confidence_test ranging from 0 (confident cloudy) to 1 (confident clear)

The clear/cloudy threshold and the confident clear (high clear sky confidence) and confident cloudy (low clear sky confidence) thresholds used in this test are listed in Table 28.

Table 28. M7 Reflectance Test Thresholds

Pixel Surface Type Processing Path	Threshold Dependencies	M7_Mid Clear/Cloudy Threshold Variable Name	M7_Hi Confident Clear Threshold Variable Name	M7_Lo Confident Cloudy Threshold Variable Name
water/day	no sun glint	WD_M7_MID_POLY_COEFS + WD_M7_MID_CORR	WD_M7_HI_POLY_COEFS + WD_M7_HI_CORR	WD_M7_LO_POLY_COEFS + WD_M7_LO_CORR
	with sun glint or inland water	WD_M7_SNGLNT_MID_POLY_COEFS + WD_M7_SNGLNT_MID_CORR	WD_M7_SNGLNT_HI_POLY_COEFS + WD_M7_SNGLNT_HI_CORR	WD_M7_SNGLNT_LO_POLY_COEFS + WD_M7_SNGLNT_LO_CORR

Steps for performing the M_7 Reflectance Threshold Test

1. Check the validity of input M7 band, refm7. The test is not performed if this condition is not met.
```
IF (refm7 = Good Quality) THEN
    proceed with test steps below
ENDIF
```
2. Prevent the execution of this test over any pixels misclassified as "inland water" by the land/water mask since this misclassification will produce false alarms. To test for a possible misclassification, calculate the pixel's TOA NDVI using the M5 and M7 bands. If the value exceeds a given minimum tunable value, the pixel is most likely land, and the M7 test must not proceed.
```
toa_ndvi = -1.0
prob_land = FALSE
IF ((land_water_flag = "Inland Water") AND
   RefM5 > FLOAT32_FILL_TEST)) THEN
    toa_ndvi = (RefM7 – RefM5) / (RefM7 + RefM5)
    IF (toa_ndvi > VCM_M7_TOA_NDVI_THRESH) THEN
        Set prob_land to TRUE
    ENDIF
ENDIF

IF (prob_land = FALSE) THEN
    proceed with test steps below
ENDIF
```
3. Establish the clear/cloudy threshold and the confident clear and confident cloudy thresholds—M7_Mid, M7_Hi, M7_Lo—based on the presence or absence of sun glint or inland water (see table above).
4. Set the M7 Cloud/No Cloud test result, M7_Test_Result, based on the M7 reflectance and the clear/cloudy threshold.
```
IF (refm7 > M7_Mid) THEN
    Set M7_Test_Result to "Cloud"
ELSE
    Set M7_Test_Result to "No Cloud"
ENDIF
```
5. Calculate a confidence level, M7_test_cc based on the M7 reflectance, refm7, and the confident cloudy, confident clear and clear/cloudy thresholds by calling subroutine confidence_test() described in Section 2.1.2.6.2.3, Calculation of Individual Confidence Levels.
```
CALL Confidence_Test (refm7, M7_Lo, M7_Hi, M7_Mid, M7_test_cc)
```

M7/M5 Reflectance Ratio Threshold Test– This test is performed over daytime water and land pixels. Note that variations in how the ratio is calculated and how the confidence test is applied are dependent on the pixel surface type classification.

For the case of water, a direct ratio, M7/M5 is calculated. However, the confident cloudy, confident clear and clear/cloudy thresholds are ranges, rather than single values encountered in the other tests. Since the threshold is now a range of numbers, there are six thresholds for this test over water. Furthermore, two separate sets of six thresholds are defined—one set used within the sun glint region, the other set used outside sun glint.

Over land, a pseudo GEMI Index, developed for the MODIS Airborne Simulator, is used in place of the M7/M5 ratio. In addition, the M5 reflectance must exceed a given threshold for the test to run. The confident cloudy, confident clear and clear/cloudy thresholds are as in all the other tests, single-valued.

The I/O for this test is shown in Table 29 below. Note that while this test, in fact, calculates a M7/M5 Ratio test, the input, output, thresholds and local variables are named with a reverse naming convention, as if an M5/M7 ratio is being calculated. For clarification, this is not the case. This naming convention was left "*as is*" due to its pervasiveness throughout the software and associated documentation.

Table 29. M7/M5 Reflectance Ratio Threshold Test I/O

	Variable	Description
Input	refm7	M7 reflectance
	refm5	M5 reflectance
	sun_glint_flag	flag indicating presence of sun glint for water/day
Output	M5_M7_Test_Result	Binary cloud/no cloud test result
	M5_M7_test_cc	confidence level from confidence_test ranging from 0 (confident cloudy) to 1 (confident clear)

The clear/cloudy threshold and the confident clear (high clear sky confidence) and confident cloudy (low clear sky confidence) thresholds used in this test are listed in Table 30.

Table 30. M7/M5 Reflectance Ratio Test Thresholds

Pixel Surface Type Processing Path	Threshold Dependencies	M5_M7_Mid Clear/Cloudy Threshold Variable Name	M5_M7_Hi Confident Clear Threshold Variable Name	M5_M7_Lo Confident Cloudy Threshold Variable Name
water/day	no sun glint	WD_M5_M7_Mid1 WD_M5_M7_Mid2	WD_M5_M7_Hi1 WD_M5_M7_Hi2	WD_M5_M7_Lo1 WD_M5_M7_Lo2
	with sun glint	snglntRatio_Mid1 snglntRatio_Mid2	snglntRatio_Hi1 snglntRatio_Hi2	snglntRatio_Lo1 snglntRatio_Lo2
land/day	–	LD_M5_M7_Mid	LD_M5_M7_Hi	LD_M5_M7_Lo

Steps for performing the M_7/M_5 Reflectance Ratio Threshold Test

1. Check the validity of input values, RefM5 and RefM7. For land/day, test that the M5 reflectance exceeds the threshold, LD_M5_GEMI_THRESH. This test is not performed if any of these conditions are not met.

   a. *Water/Day Variation*

      IF (RefM5 & RefM7 = Good) THEN
         proceed with test steps below
      ENDIF

   b. *Land/Day Variation*

      IF (RefM5 & RefM7 = Good .AND.
         RefM5 >= LD_M5_GEMI_THRESH) THEN
         proceed with test steps below
      ENDIF

2. Calculate the M7/M5 ratio, ratio_m5_m7

   a. *Water/Day Variation*
      ratio_m5_m7 = RefM7 / RefM5

   b. *Land/Day Variation*

$$ratio\_c1 = GEMI\_RATIO1\_CONST\_1(RefM7 - RefM5) + GEMI\_RATIO1\_CONST\_2(RefM7) + GEMI\_RATIO1\_CONST\_3(RefM5)$$

$$ratio\_c2 = RefM7 + RefM5 + GEMI\_RATIO\_CONST2\_1$$

$$ratio\_c3 = \frac{ratio\_c1}{ratio\_c2}$$

$$ratio\_m5\_m7 = ratio\_c3 * (GEMI\_EQU\_CONST\_1 - GEMI\_EQU\_CONST\_2 \cdot ratio\_c3) - \frac{RefM5 - GEMI\_EQU\_CONST\_3}{GEMI\_EQU\_CONST\_4 - RefM5} \quad \textbf{Eqn 3}$$

   Note that the operational form of this equation varies from that shown in the ATBD. Here, for computational optimization purposes, all the coefficients except GEMI_EQU_CONST_1 and GEMI_EQU_CONST_2 have been scaled by a factor of 100. Please refer to Table 50 for the correct values of these parameters.

3. Establish the clear/cloudy threshold and the confident clear and confident cloudy thresholds.

   a. *Water/Day Variation*

```
IF (sun_glint_flag != "None") THEN
    M5_M7_Mid1 = snglntRatio_Mid1
    M5_M7_Mid2 = snglntRatio_Mid2
    M5_M7_Hi1 = snglntRatio_Hi1
    M5_M7_Hi2 = snglntRatio_Hi2
    M5_M7_Lo1 = snglntRatio_Lo1
    M5_M7_Lo2 = snglntRatio_Lo2
ELSE
    M5_M7_Mid1 = WD_M5_M7_Mid1
    M5_M7_Mid2 = WD_M5_M7_Mid2
    M5_M7_Hi1 = WD_M5_M7_Hi1
    M5_M7_Hi2 = WD_M5_M7_Hi2
    M5_M7_Lo1 = WD_M5_M7_Lo1
    M5_M7_Lo2 = WD_M5_M7_Lo2
ENDIF
```

   b. *Land/Day Variation*

```
M5_M7_Mid = LD_M5_M7_Mid
M5_M7_Hi = LD_M5_M7_Hi
M5_M7_Lo = LD_M5_M7_Lo
```

4. Set the M5_M7 Cloud/No Cloud test result, M5_M7_Test_Result, based on the reflectance ratio, ratio_m5_m7, and the clear/cloudy threshold.

a. *Water/Day Variation*

```
IF (M5_M7_Mid1 <= ratio_m5_m7 <= M5_M7_Mid2) THEN
    Set M5_M7_Test_Result to "Cloud"
ELSE
    Set M5_M7_Test_Result to "No Cloud"
ENDIF
```

b. *Land/Day Variation*

```
IF (ratio_m5_m7 <= M5_M7_Mid) THEN
    Set M5_M7_Test_Result to "Cloud"
ELSE
    Set M5_M7_Test_Result to "No Cloud"
ENDIF
```

5. Calculate a confidence level, M5_M7_test_cc based on the reflectance ratio, ratio_m5_m7, and the confident cloudy, confident clear and clear/cloudy thresholds by calling confidence_test_2val() for water/day and confidence_test() for land/day. (See calling subroutine confidence_test() described in Section 2.1.2.6.2.3, Calculation of Individual Confidence Levels for further details.)

a. *Water/Day Variation*

```
CALL Confidence_Test (ratio_m5_m7, M5_M7_Lo1, M5_M7_Lo2,
                      M5_M7_Hi1, M5_M7_Hi2,
                      M5_M7_Mid1, M5_M7_Mid2, 2,
                      M5_M7_test_cc)
```

b. *Land/Day Variation*

```
CALL Confidence_Test (ratio_m5_m7, M5_M7_Lo, M5_M7_Hi,
                      M5_M7_Mid, M5_M7_test_cc)
```

Group IV – Reflectance Thin Cirrus

M9 Thin Cirrus Reflectance Test – This test is performed for all daytime pixels with the additional condition that over deserts, it is bypassed for low values of TPIWV (total path integrated water vapor). The I/O for this test is shown in Table 31 below.

Table 31. M9 Thin Cirrus Reflectance Test I/O.

	Variable	Description
Input	refm9	M9 reflectance
	tpiwv	total path integrated water vapor, used for desert/day pixels only
Output	M9_Test_Result	binary cloud/no cloud test result
	M9_test_cc	confidence level from confidence_test ranging from 0 (confident cloudy) to 1 (confident clear)

The clear/cloudy threshold and the confident clear (high clear sky confidence) and confident cloudy (low clear sky confidence) thresholds used in this test are listed in Table 32.

Table 32. M9 Thin Cirrus Reflectance Test Thresholds

Pixel Surface Type Processing Path	M9_Mid Clear/Cloudy Threshold Variable Name	M9_Hi Confident Clear Threshold Variable Name	M9_Lo Confident Cloudy Threshold Variable Name
land/day	LD_M9_Mid	LD_M9_Hi	LD_M9_Lo
desert/day	DD_M9_Mid	DD_M9_Hi	DD_M9_Lo
coast/day	CD_M9_Mid	CD_M9_Hi	CD_M9_Lo
water/day	WD_M9_Mid	WD_M9_Hi	WD_M9_Lo
snow/day	SD_M9_Mid	SD_M9_Hi	SD_M9_Lo

Steps for performing the M_9 Thin Cirrus Reflectance Test

1. Check the validity of input M9 band, refm9. For desert/day conditions, also check that the total path integrated water vapor, tpiwv, exceeds the cutoff value, DD_M9_TPIWV_cutoff. The test is not performed if these conditions are not met.

   a. *Land/Day Variation*
   Coast/Day Variation
   Water/Day Variation
   Snow/Day Variation

   ```
   IF (RefM9 = Good) .AND.
       proceed with test steps below
   END IF
   ```

   b. *Desert/Day Variation – total precipitable water dependency > cutoff value*

   ```
   IF (refm9 = Good .AND. tpiwv > DD_M9_TPIWV_cutoff) THEN
        proceed with test steps below
   ENDIF
   ```

2. Establish the clear/cloudy threshold and the confident clear and confident cloudy thresholds—M9_Mid, M9_Hi, M9_Lo (see table above).

3. Set the M9 Cloud/No Cloud test result, M9_Test_Result, based on the M9 reflectance and the clear/cloudy threshold.

   ```
   IF (refm9 >= M9_Mid) THEN
        Set M9_Test_Result to "Cloud"
   ELSE
        Set M9_Test_Result to "No Cloud"
   ENDIF
   ```

4. Calculate a confidence level, M9_test_cc based on the M9 reflectance, refm9, and the confident cloudy, confident clear and clear/cloudy thresholds by calling subroutine confidence_test() described in Section 2.1.2.6.2.3, Calculation of Individual Confidence Levels.

   ```
   CALL Confidence_Test (refm9, M9_Lo, M9_Hi, M9_Mid, M9_test_cc)
   ```

Group V – Emission Thin Cirrus

M12 – M16 BT Difference Test – This test is applied during the nighttime over all surface types except water. It is not applied if BTM12 is less than a specified value due to calibration uncertainties in the M12 band. The I/O for this test is shown in Table 33 below.

Table 33. M12 – M16 BT Different Test I/O

Variable		Description
Input	BTM12	M12 brightness temperature
	BTM16	M16 brightness temperature
	terrainHt	terrain height used for snow/night condition
Output	M12_M16_Test_Result	binary cloud/no cloud test result
	M12_M16_test_cc	confidence level from confidence_test ranging from 0 (confident cloudy) to 1 (confident clear)

The clear/cloudy threshold and the confident clear (high clear sky confidence) and confident cloudy (low clear sky confidence) thresholds used in this test are listed in Table 34.

Table 34. M12 – M16 BT Difference Test Thresholds

Pixel Surface Type Processing Path	M12_M16_Mid Clear/Cloudy Threshold Variable Name	M12_M16_Hi Confident Clear Threshold Variable Name	M12_M16_Lo Confident Cloudy Threshold Variable Name
snow/night	SN_M12_M16_Mid	SN_M12_M16_Hi	SN_M12_M16_Lo
land/night	LN_M12_M16_Mid	LN_M12_M16_Hi	LN_M12_M16_Lo

<u>Steps for performing the $BT_{M12} - BT_{M16}$ Emission Thin Cirrus Difference Test</u>

1. Check the validity of input values, BTM12 and BTM16. Also check that the BTM12 exceeds the limit, BTM12_limit. For snow/night, test that the terrain height exceeds the threshold, HiElevThres. This test is not performed if any of these conditions are not met.

   a. *Land/Night Variation*
   ```
   IF (BTM12 & BTM16 = Good .AND. BTM12 > BTM12_limit) THEN
       proceed with test steps below
   ENDIF
   ```

   b. *SnowNight Variation*
   ```
   IF (terrainHt > HiElevThresh) THEN
       IF (BTM12 & BTM16 = Good .AND. BTM12 > BTM12_limit) THEN
           proceed with test steps below
       ENDIF
   ENDIF
   ```

2. Calculate the brightness temperature difference, diff_m12_m16
   diff_m12_m16 = BTM12 – BTM16

3. Establish the clear/cloudy, confident clear, and confident cloudy thresholds—M12_M16_Mid, M12_M16_Hi, M12_M16_Lo—according to the surface type/illumination (see table above)

4. Set the M12_M16 Cloud/No Cloud test result, M12_M16_Test_Result, based on the brightness temperature difference and the clear/cloudy threshold.
   ```
   IF (diff_m12_m16 > M12_M16_Mid) THEN
       Set M12_M16_Test_Result to “Cloud”
   ELSE
       Set M12_M16_Test_Result to “No Cloud”
   ENDIF
   ```

5. Calculate a confidence level, M12_M16_test_cc based on the M12 – M16 brightness temperature difference, diff_m12_m16, and the confident cloudy, confident clear and clear/cloudy thresholds by calling subroutine confidence_test() described in Section 2.1.2.6.2.3, Calculation of Individual Confidence Levels.
   CALL Confidence_Test (diff_m12_m16, M12_M16_Lo, M12_M16_Hi,
   M12_M16_Mid, M12_M16_test_cc)

M15 – M16 BT Difference Test – This difference test is used to detect cirrus clouds during the day and night over all surface types except that of snow/ice. The I/O for this test is shown in Table 35 below.

Table 35. M15 – M16 BT Difference Test I/O

Variable		Description
Input	BTM15	M15 brightness temperature
	BTM16	M16 brightness temperature
	MBSenZen	sensor zenith angle, moderate resolution
Output	M15_M16_Test_Result	binary cloud/no cloud test result
	M15_M16_test_cc	confidence level from confidence_test ranging from 0 (confident cloudy) to 1 (confident clear)

The thresholds are dependent on the satellite zenith angle and BT_{M15}. Table 36 lists the clear/cloudy threshold table for this test at mid-latitudes. To obtain the clear/cloudy threshold for this test, a two-dimensional linear interpolation of values in Table 36 is performed. Currently, if the input BT_{M15} exceeds the range of values shown in the table, the BT_{M15} is set to the minimum or maximum range value. In addition, if the input secant of the satellite zenith angle is outside the range shown in the table, it too will be set to the lower or upper limit of the range. A default clear/cloudy threshold is used for long line-of-sight paths (i.e., when the sensor zenith angle approaches the secant discontinuity at 90^{o}) or when the interpolated clear/cloudy temperature difference threshold is less than VCM_M15_M16_MIN_DIFTEMP.

Table 36. Clear/Cloudy Temperature Thresholds in Kelvin for BT_{M15}-BT_{M16} Cloud Detection Test at Mid-latitudes.

BT_{M15}	secant(sensor zenith angle)				
	1.0	**1.25**	**1.50**	**1.75**	**2.0**
260K	0.55	0.60	0.65	0.90	1.10
270K	0.58	0.63	0.81	1.03	1.13
280K	1.30	1.61	1.88	2.14	2.30
290K	3.06	3.72	3.95	4.27	4.73
300K	5.77	6.92	7.00	7.42	8.43
310K	9.41	10.74	11.03	11.60	13.39

The confident cloudy and confident clear thresholds for this spectral test are found by adding an incremental quantity to the clear/cloudy threshold. The default thresholds and incremental quantity parameter names are provided in Table 37 for each of the pixel surface types and day/night scenario using this test.

Table 37. M15 – M16 BT Difference Test Thresholds

Pixel Surface Type Processing Path	Default Clear/Cloudy Threshold Variable Name	M15_M16_Mid Clear/Cloudy Threshold, K (Mid Threshold)	M15_M16_Hi Confident Clear Threshold, K	M15_M16_Lo Confident Cloudy Threshold, K
water/day	WD_M15_M16_Mid	bilinear interpolation using BT_{M15}, sensor zenith angle and Table 36	M15_M16_Mid + WD_M15_M16_HI_CORR	M15_M16_Mid + WD_M15_M16_LO_CORR
land/day	LD_M15_M16_Mid		M15_M16_Mid + LD_M15_M16_HI_CORR	M15_M16_Mid + LD_M15_M16_LO_CORR
desert/day	DD_M15_M16_Mid		M15_M16_Mid + DD_M15_M16_HI_CORR	M15_M16_Mid + DD_M15_M16_LO_CORR
coast/day	CD_M15_M16_Mid		M15_M16_Mid + CD_M15_M16_HI_CORR	M15_M16_Mid + CD_M15_M16_LO_CORR
water/night	WN_M15_M16_Mid		M15_M16_Mid + WN_M15_M16_HI_CORR	M15_M16_Mid + WN_M15_M16_LO_CORR
land/night	LN_M15_M16_Mid		M15_M16_Mid + LN_M15_M16_HI_CORR	M15_M16_Mid + LN_M15_M16_LO_CORR

Steps for performing the BT_{M15} – BT_{M16} Emission Thin Cirrus Difference Test

1. Check the validity of input values, BTM15, BTM16 and Sensor Zenith Angle, MBSenZen. This test is not performed if any of these values are invalid.
2. Set the default M15_M16_Mid threshold, M15_M16_Mid.
3. Calculate cosSenZen = cos(MBSenZen), where MBSenZen is converted to radians from degrees.
4. Determine a dynamic M15_M16_Mid threshold by performing a bilinear interpolation with input BTM15 and the secant of the sensor zenith angle. The determination is only performed for non-grazing sensor line-of-sights (i.e., cosSenZen does not approach zero), and the interpolated value is used as the clear/cloudy threshold only if it exceeds a given minimum value, VCM_M15_M16_MIN_DIFTEMP. Otherwise, the default M15_M16_Mid threshold is used.
```
IF (fabs(cosSenZen) > VCM_MIN_COS_SENZEN_TOL) THEN
    secSenZen = 1/cosSenZen
    Determine a temperature difference, diftemp, by performing a bilinear interpolation
    with input BTM15 and secSenZen. (See Table 36.)
    IF (diftemp ≥ VCM_M15_M16_MIN_DIFTEMP) THEN
        M15_M16_Mid = diftemp
    ENDIF
END IF
```
5. Perform M15 – M16 brightness temperature difference.
```
diff_m15_m16= BTM15 – BTM16
```
6. Set the M15 M16 binary test result to Cloud/No Cloud based on the value of the brightness temperature difference.
```
IF (diff_m15_m16 > M15_M16_Mid) THEN
    M15_M16_Test_Result = "Cloud"
ELSE
    M15_M16_Test_Result = "No Cloud"
ENDIF
```

7. Establish the clear/cloudy threshold and the confident clear and confident cloudy thresholds — M15_M16_Lo and M15_M16_Hi (see table above).
8. Calculate a confidence level, M15_M16_test_cc, based on the test value, diff_m15_m16, and the confident cloudy, confident clear and clear/cloudy thresholds by calling subroutine confidence_test() described in Section 2.1.2.6.2.3, Calculation of Individual Confidence Levels.

   CALL Confidence_Test (diff_m15_m16, M15_M16_Lo, M15_M16_Hi,
   M15_M16_Mid; M15_M16_test_cc)

2.1.2.6.2.7 Cloud Mask Quality

The quality of the cloud confidence is a measure of the number of tests executed for a given processing path relative to the maximum number of tests available for that path. The maximum number of tests available is a constant for the particular processing path. The number of tests executed for a given pixel should nominally be equal to the maximum number of tests available for its particular processing path, but can be reduced by the pixel's latitude or vegetation index or by invalid reflectances and brightness temperatures.

The cloud mask quality is stored in a 2-bit field of the VCM IP output with the possible values of Poor (=0), Low (=1), Medium (=2), or High (=3). These quality values have the following meaning:

Poor = No tests were executed for this pixel; therefore, DO NOT RELY ON THIS VCM.
Low = Less than 1/2 of maximum number of tests were executed for pixel.
Med = Either exactly 1/2 or more than half (but not all) tests were executed for pixel.
High = Maximum number of tests were executed for pixel.

The I/O used in the computation of this parameter is shown in Table 38 below.

Table 38. I/O for Cloud mask Quality Computation

	Variable	Description
Input	max_num_tests	maximum number of tests available for a given pixel background (e.g., land/day, snow/night, etc.)
	total_num_tests	total number of tests actually executed for a given pixel background
	q_tol	tolerance value applied to calculation of cloud mask quality
Output	cc_quality_flag	flag indicating cloud mask quality

Calculation of Cloud Mask Quality

Given the following parameters types

```
integer max_num_tests
integer total_num_tests
float q_tol = 1e-4
float q_val

IF ((max_num_tests == 0) OR (total_num_tests==0)) THEN
    cc_quality flag = "Poor"
ELSE IF (total_num_tests == max_num_tests) THEN
    cc_quality flag = "High"
```

```
ELSE
    q_val = (float)total_num_tests/(float)max_num_tests
    IF (q_val + q_tol >= 0.5) THEN
        cc_quality flag = "Medium"
    ELSE
        cc_quality flag = "Low"
    END IF
END IF
```

2.1.2.7 Conduct Imagery Band Evaluations (Iband_Eval.cpp)

An imagery band spatial uniformity test using imbedded 2x2 pixel groups is performed on all moderate resolution, non-sea ice, water surface pixels that are defined as confident or probably clear in order to further refine the VCM Cloud Confidence determination. During the daytime, the test is made on both the I2 and I5 bands, while the I4 and I5 are used at night. If the difference between the minimum and maximum values of the 4-pixel group is greater than a specified threshold in any band, then high variance suggests the presence of a cloud.

The BT thresholds used for the I4 and I5 bands are tunable parameters I4varthres and I5varthres, respectively (e.g., pre calibration/validation value of 0.5 K for both). The I2 reflectance threshold is given as a function of viewing angle based on theoretical reflectance calculations made for the AVHRR channel 1 (0.63 um) band (Heidinger, A., CLAVR-x Cloud Mask Algorithm Theoretical Basis Document (Rough Draft), Version 0.1, March 1, 2004).

A second test is performed using the mean of the 4-pixel group and the average of the maximum and minimum pixels. If the 4-pixel mean is greater than (less than) the second average for I2 reflectance (I4 and I5 brightness temperature) then this test is thought to further indicate the presence of a cloud. For conditions where both tests are met, the cloud confidence is changed to Probably Cloudy and the spatial_var_flag is set to “Yes”. Confident Clear pixels are re-classified as Probably Clear if only the spatial uniformity test is passed and the spatial_var_flag is set to “Yes”. Originally Probably Clear pixels remain as is if only the spatial uniformity test is passed and the spatial_var_flag is set to NO. If there is no change to the cloud confidence, then the spatial_var_flag is set to NO.

The I/O of this process is listed in Table 39.

Table 39. Imagery Band Evaluation I/O

	Variable	Description
Input	ReflI2	Imagery resolution reflectance for band I2
	BTI4, BTI5	Imagery resolution brightness temperatures for bands I4 and I5
	MBSolZen, MBSolAzi	Moderate resolution solar zenith and azimuth angles
	MBSenZen, MBSenAzi	Moderate resolution sensor zenith and azimuth angles
	cloud_confidence	Cloud Confidence flag See VCM IP output, Table 6
	day_night_flag	Flag indicating day or nighttime illumination See VCM IP output, Table 6 for values
	land_water_flag	Flag indicating pixel surface type See VCM IP output, Table 6 for values
	snow_ice_flag	Flag indicating presence of snow or ice in pixel See VCM IP output, Table 6 for values

	Variable	Description
	vis2_ref_arr[NSZ][NVZ][NRAZ]	theoretical I2 reflectance thresholds as a function of viewing geometry, tunable setting; see Table 50, Imagery Band Test Parameters section
	I4varthres, I5varthresh	I4 and I5 spatial variability brightness temperature thresholds, tunable setting; see Table 50, Imagery Band Test Parameters section
	BTI4_limit	minimum I4 brightness temperature at which nighttime spatial variability tests can be performed, tunable setting; see Table 50, Imagery Band Test Parameters section
Output	spatial_var_flag	Spatial uniformity flag

PDL for Iband_Eval

```
Iband_Eval (VCM_DATA_TYPE, VCM_FLAGS)
    Initialize Integer  spatial_uniformity NO
    FOR every Moderate Resolution pixel in the granule
      FOR every Imagery Resolution pixel within the Moderate Resolution Pixel
        IF ((cloud_confidence_flag = Confident Clear.OR.
            cloud_confidence_flag = Probably Clear).AND.
           (land_water_flag = sea water.OR.
            land_water_flag = inland water)).AND.
            (snow_ice_flag = No snow)) THEN
            IF (day_night_flag = day) THEN
                IF (RefI2 & BTI5 = Good Quality) THEN
                    diff_RefI2 = max(RefI2) – min(RefI2)
                    diff_BTI5 = max(BTI5) – min(BTI5)
                    I2varthres = MIN(VCM_I2_MAX_VAR_THRESH,
                                 MAX(VCM_I2_MIN_VAR_THRESH,
                                     function of vis2_ref_arr));
                    IF (diff_RefI2 > I2_var_thresh.OR.
                        diff_BTI5 > I5-var_thresh) THEN
                            mean_RefI2 = sum(RefI2)/4
                            mean_BTI5 = sum(BTI5)/4
                            mid_diff_RefI2 = (max(RefI2) + min(RefI2))/2
                            mid_diff_BTI5 = (max(BTI5) + min(BTI5))/2
                            IF ((mean_RefI2 > mid_diff_RefI2.AND.
                                diff_RefI2 > I2_var_thresh).OR.
                                (mean_BTI5 < mid_diff_BTI5.AND.
                                diff_BTI5 > I5_var_thresh))
                                    Cloud_Confidence_flag = Probably Cloudy
                                    spatial_uniformity = “Yes”
                            ELSE IF (Cloud_Confidence_flag = Confident Clear)
                            THEN
                                    Cloud_Confidence_flag = Probably Clear
                                    spatial_uniformity = “Yes”
                            ENDIF
                    ENDIF
                ENDIF
            ELSE
                IF (BTI4 & BTI5 = Good Quality).AND.BT14 > BT14_limit) THEN
                    diff_BTI4 = max(BTI4) – min(BTI4)
                    diff_BTI5 = max(BTI5) – min(BTI5)
                    IF (diff_BTI4 > I4_var_thresh.OR.
                        diff_BTI5 > I5_var_thresh) THEN
                            mean_BTI4 = sum(BTI4)/4
                            mean_BTI5 = sum(BTI5)/4
                            mid_diff_BTI4 = (max(BTI4) + min(BTI4))/2
                            mid_diff_BTI5 = (max(BTI5) + min(BTI5))/2
```

```
                        IF ((mean_BTI4 < mid_diff_BTI4.AND.
                          diff_BTI4 > I4_var_thresh).OR.
                          (mean_BTI5 < mid_diff_BTI5.AND.
                          diff_BTI5 > I5_var_thresh))
                              Cloud_Confidence_flag = Probably Cloudy
                              spatial_uniformity = "Yes"
                        ELSE IF (Cloud_Confidence_flag = Confident Clear)
                        THEN
                              Cloud_Confidence_flag = Probably Clear
                              spatial_uniformity = "Yes"
                        ENDIF
                    ENDIF
                ENDIF
            ENDIF
        ENDIF
```

2.1.2.8 Determine the Cloud Phase (Cloud_Phase.cpp)

VCM determines cloud phase for pixels classified as "Confidently Cloudy" or "Probably Cloudy". Possible cloud phase outcomes include one of the following five cloud phase categories—water, mixed phase, opaque ice, cirrus, or overlap. The following definitions are given for each category.

- Water: Single cloud layer composed completely of water droplets.
- Mixed Phase: Single cloud layer composed of a mixture of water and ice particles or of supercooled water.
- Opaque Ice: Optically thick cloud with cloud top composed of ice crystals as determined by low M15 brightness temperature and lack of cloud overlap signature.
- Cirrus: Non-opaque, single-layer ice cloud.
- Overlap: At least two distinctive cloud layers defined as an ice cloud above a cloud predominantly of water phase.

Additional classifications are given to pixels when cloud phase is not determined or executed:

- Clear: Pixels possessing a cloud confidence classification of "Confidently Clear",
- Partly Cloudy: Pixels possessing a cloud confidence classification of "Probably Clear",
- Not Executed: Pixels in which the cloud phase algorithm could not be executed due to bad or missing data.

An accurate cloud phase classification is important because it establishes the processing path for the suite of downstream cloud algorithms (e.g., Cloud Optical Properties, Cloud Top Parameters). Misclassifications between "Opaque Ice" and "Water" have the potential to introduce large downstream errors, and because the theoretical basis of the cloud algorithms assume a single layer cloud in each pixel, an "Overlap" classification identifies pixels where poorer cloud EDR performance is expected.

The process I/O is shown in Table 40. Note that the many of the thresholds for this algorithm are dynamic thresholds based on tunable parameters listed in the Cloud Phase section of Table 50. The logic for setting these thresholds is given inTable 41 for water pixels, Table 42 for desert pixels and Table 43 for land, coast and snow pixels. The equations associated with the definitions of these thresholds follow in Table 44. Note that thresholds can be flagged as "unusable" with the floating point constant CP_BAD. A valid floating point threshold is defined as a threshold outside the tolerance range defined by CP_BAD_TOL.

Table 40. Cloud Phase Process I/O

Input	cloud_confidence	Cloud Confidence flag
	day_night_flag	flag indicating day or night illumination; See VCM IP output, Table 6 for values
	land_water_flag	flag indicating pixel surface type; See VCM IP output, Table 6 for values
	trispectral_only_flag	flag indicating that only the trispectral test yielded a “Cloud” (“Yes”) versus a “No Cloud” (“No”) result; flag used later for Cloud Phase determination
	RefM1, RefM9, RefM10	moderate resolution reflectances for bands M1, M9, and M10
	BTM12, BTM14, BTM15, BTM16	moderate resolution brightness temperatures for bands M12, M14, M15 and M16
	mTerrainHeight	terrain height
	mLat, mLon	moderate resolution latitude/longitude
	MBSolZen, MBSolAzi	moderate resolution solar zenith and azimuth angles
	MBSenZen, MBSenAzi	moderate resolution sensor zenith and azimuth angles
	various thresholds and coefficients	See Table 50, Cloud Phase section
Output	cloud_phase_flag	flag indicating phase of cloud, See VCM IP output, Table 6 for values

The cloud phase top level flow diagram, shown in Figure 13 and Figure 14, shows that the algorithm can be decomposed conceptually into four major logical blocks: 1) the decision to execute the Cloud Phase process, based primarily on the value of the cloud confidence flag, 2) initialization of Cloud Phase thresholds when the cloud confidence states a pixel is probably or confidently cloudy, 3) initial cloud phase typing based on the M15 brightness temperature, and 4) cloud phase typing. Cloud phase typing for daytime and nighttime pixels can be further deconstructed into three categories: 1) tests for cloud overlap, 2) tests for cirrus clouds for pixels where cloud overlap is not found, and 3) reclassification of cloud phase settings for pixels where there is neither overlap or cirrus clouds. Figure 15 shows the top level flow for daytime cloud typing with the detail for the specific cloud tests shown in Figure 16 through Figure 18. Figure 19 shows the top level flow for nighttime cloud typing followed by the detailed cloud tests in Figure 20 through Figure 22.

Note that the daytime cloud typing, Figure 15, requires the calculation of an M12 reflectance, ref_M12. Similarly, the nighttime cloud typing, Figure 19, requires the calculation of a simple emissivity, EMSM12. Currently, these values are calculated internally to the Cloud Phase routine:

Calculation of Cloud Phase M12 Reflectance and M12 Simple Emissivity

For daytime cloud phase typing, the equation for M12 reflectance is

$$\rho_{M12} = \frac{\pi \left(L_{M12,calc} - L_{M12,calc,emiss}\big|_{T=BTM15} \right)}{\dfrac{H_{M12}\cos\theta_{solzen}}{R^2_{earth-sun}} - \pi L_{M12,calc,emiss}\big|_{T=BTM15}},$$

and for nighttime cloud typing, the equation for the M12 simple emissivity is

$$\varepsilon_{M12,\,simple} = \frac{L_{M12,\,calc}}{L_{M12,\,calc,emiss}\big|_{T=BTM15}},$$

where

$L_{M12,\,calc}$ = total M12 blackbody radiance within the M12 waveband calculated with Planck's Law (as opposed to using the retrieved radiance from the SDR),

$L_{M12,\,calc,\,emiss}$ = total emissive blackbody radiance within the M12 waveband approximated by calculating the radiance at the M15 brightness temperature using Planck's Law (as opposed to using the retrieved radiance from the SDR),

$\Delta\lambda_{M12}$ = M12 band center,

H_{M12} = mean top of atmosphere solar irradiance within the M12 band,

θ_{solzen} = solar zenith angle,

$R_{earth\text{-}sun}$ = earth to sun distance.

The numerator in the M12 reflectance calculation represents the reflected portion of the radiation leaving the surface while the denominator represents the radiation incident on the pixel surface reduced by the amount of energy emitted by it.

The equations for the total M12 radiance and the approximate M12 emissive radiance using the M15 brightness temperature are, following Planck's Law,

$$L_{M12,\,calc} = \frac{2hc^2}{\lambda_{M12}^{5}} \frac{1}{e^{hc/\lambda_{M12}kT_{M12}} - 1} \Delta\lambda_{M12}, \text{ and}$$

$$L_{M12,\,calc,emiss}\big|_{T=BTM15} = \frac{2hc^2}{\lambda_{M12}^{5}} \frac{1}{e^{hc/\lambda_{M12}kT_{M15}} - 1} \Delta\lambda_{M12},$$

where

h is Planck's constant,

c is the speed of light,

k is Boltzmann's constant,

T_{Mx} is the brightness temperature of band Mx,

λ is the M12 band center,

$\Delta\lambda_{M12}$ is the M12 bandwidth.

The software implementation is as follows:

```
wvl_M12_5 = CP_LAMBDA_M12 * CP_LAMBDA_M12 * CP_LAMBDA_M12 *
    CP_LAMBDA_M12 * CP_LAMBDA_M12

x_M12 = (PLANCK * SPEED_LIGHT_M_PER_S) / (CP_LAMBDA_M12 * BOLTZMANN * BTM12)

x_M15 = (PLANCK * SPEED_LIGHT_M_PER_S) / (CP_LAMBDA_M12 * BOLTZMANN * BTM15)

L_M12 = (2.0 * PLANCK * SPEED_LIGHT_M_PER_S*SPEED_LIGHT_M_PER_S / wvl_M12_5) *
    (1.0/((exp(x_M12)) - 1))*CP_M12_BW_METERS

L_M15 = (2.0 * PLANCK * SPEED_LIGHT_M_PER_S*SPEED_LIGHT_M_PER_S / wvl_M12_5) *
    (1.0/((exp(x_M15)) - 1))*CP_M12_BW_METERS

ref_m12 = M_PI*(L_M12-L_M15) / (CP_M12_MEAN_TOA_SOL_IRRAD*CP_M12_BW_MICRONS *
    ((cos(rSolZen))/(CP_EARTHSUNRATIO*CP_EARTHSUNRATIO)) - (M_PI*L_M15))

EMSM12 = L_M12/L_M15
```

where

PLANCK, SPEED_LIGHT_M_PER_S, and BOLTZMANN are physical constants (see Table 3), and
CP_LAMBDA_M12, CP_M12_BW_METERS, CP_M12_MEAN_TOA_SOL_IRRAD, CP_M12_BW_MICRONS, and CP_EARTHSUNRATIO are tunable parameters (see Table 50).

The basis of the cloud phase algorithm originates from:

Pavolonis, M. J., A. K. Heidinger, 2004: Daytime Cloud Overlap Detection from AVHRR and VIIRS. J. Appl. Meteor., 43, Number 5, pages 762-778.

Pavolonis, M. J., A. K. Heidinger and T. Uttal, 2004: Daytime Global Cloud Typing from AVHRR and VIIRS: Algorithm Description, Validation, and Comparisons; submitted to Journal of Applied Meteorology, May 2004,

Further detail, including a derivation for the various coefficient curves for the spectral tests, is provided in the Cloud Mask ATBD.

Table 41. Cloud Phase Dynamic Thresholds and Logic for Water Surface Type

Threshold	Inland Water Sea Water
CIRRUS_THRES	Independent of surface type. See Table 44, Eqn 6 below.
M14_M15_THRES	Independent of surface type. See Table 44, Eqn 8 below.
WIN_OVER_THRESH	See Table 44, Eqn 10 below.
NIR_OVERLAP_THRES	CP_BAD if (CP_MAX_M9_OVER ≤ RefM9) $f_{w,NOT}(RefM9, ScatAngle)$ + CP_NIR_OVERLAP_WATER_CORRECTION otherwise. See Table 44, Eqn 4 for $f_{w,NOT}$ below.
M9_WIN_CHECK_THRES	CP_M9_WIN_CHECK_THRES_LAND if (RefM9 ≥ CP_MAX_M9_OVER) CP_M9_WIN_CHECK_THRES_WATER otherwise
NIR_CIRRUS_THRES_M12	CP_NIR_CIRRUS_THRES_WATER_M12
MIN_M9_OVER	CP_MIN_M9_OVER_WATER_HIGH if pixel lat is within the M9 water polar latitude region defined by (latitude ≥ CP_M9_WATER_HI_LAT_N or latitude ≤ CP_M9_WATER_HI_LAT_S) CP_MIN_M9_OVER_WATER_LOW otherwise
M15_M16_N_OVER_L	CP_M15_M16_N_OVER_L_TROPWATER if pixel lat is within tropic latitude region defined by (latitude > CP_IR_WATER_TROPIC_LAT_S or latitude < CP_IR_WATER_TROPIC_LAT_N) CP_M15_M16_N_OVER_L_MIDWATER otherwise
M15_M16_N_OVER_H	CP_M15_M16_N_OVER_H_TROPWATER if pixel lat is within tropic latitude region defined by (latitude > CP_IR_WATER_TROPIC_LAT_S or latitude < CP_IR_WATER_TROPIC_LAT_N) CP_M15_M16_N_OVER_H_MIDWATER otherwise
EMSM12_N_OVER_L	CP_M12_N_OVER_L_TROPWATER if pixel lat is within tropic latitude region defined by (latitude > CP_IR_WATER_TROPIC_LAT_S or latitude < CP_IR_WATER_TROPIC_LAT_N) CP_M12_N_OVER_L_MIDWATER otherwise
EMSM12_N_OVER_H	CP_M12_N_OVER_H_TROPWATER if pixel lat is within tropic latitude region defined by (latitude > CP_IR_WATER_TROPIC_LAT_S or latitude < CP_IR_WATER_TROPIC_LAT_N) CP_M12_N_OVER_H_MIDWATER otherwise
SNOW_M10_THRES	Independent of surface type. See Table 44, Eqn 13 below.

Table 42. Cloud Phase Dynamic Thresholds and Logic for Desert Surface Type

Threshold	Desert
CIRRUS_THRES	Independent of surface type. See Table 44, Eqn 6 below.
M14_M15_THRES	Independent of surface type. See Table 44, Eqn 8 below.
WIN_OVER_THRESH	CP_BAD if (RefM1 < CP_MIN_M1_OVER See Table 44, Eqn 10 otherwise.
NIR_OVERLAP_THRES	CP_BAD
M9_WIN_CHECK_THRES	CP_M9_WIN_CHECK_THRES_LAND
NIR_CIRRUS_THRES_M12	CP_NIR_CIRRUS_THRES_DESERT_M12 if pixel lat/lon is within the desert exclusion region defined by (CP_M12_DESERT _EXCLREG1_LAT_LO < latitude < CP_M12_DESERT _EXCLREG1_LAT_HI and CP_M12_DESERT_EXCLREG1_LON_LF < longitude < CP_M12_DESERT_EXCLREG1_LON_RT) CP_NIR_CIRRUS_THRES_WATER_M12 if pixel lat is within the M12 water polar latitude regions defined by (latitude ≥ CP_M12_WATER_HI_LAT_N or latitude ≤ CP_M12_WATER_HI_LAT_S) CP_NIR_CIRRUS_THRES_LAND_M12 otherwise
MIN_M9_OVER	CP_MIN_M9_OVER_LAND_HIGH if pixel lat is within the M9 desert polar latitude region defined by (latitude ≥ CP_M9_DESERT_HI_LAT_N or latitude ≤ CP_M9_DESERT_HI_LAT_S) CP_MIN_M9_OVER_LAND_LOW otherwise
M15_M16_N_OVER_L	CP_BAD if pixel lat/lon is within the desert exclusion region defined by (CP_M12_DESERT _EXCLREG1_LAT_LO < latitude < CP_M12_DESERT _EXCLREG1_LAT_HI and CP_M12_DESERT_EXCLREG1_LON_LF < longitude < CP_M12_DESERT_EXCLREG1_LON_RT) CP_M15_M16_N_OVER_L_LAND otherwise
M15_M16_N_OVER_H	CP_BAD if pixel lat/lon is within the desert exclusion region defined by (CP_M12_DESERT _EXCLREG1_LAT_LO < latitude < CP_M12_DESERT _EXCLREG1_LAT_HI and CP_M12_DESERT_EXCLREG1_LON_LF < longitude < CP_M12_DESERT_EXCLREG1_LON_RT) CP_M15_M16_N_OVER_H_LAND otherwise
EMSM12_N_OVER_L	CP_BAD if pixel lat/lon is within the desert exclusion region defined by (CP_M12_DESERT _EXCLREG1_LAT_LO < latitude < CP_M12_DESERT _EXCLREG1_LAT_HI and CP_M12_DESERT_EXCLREG1_LON_LF < longitude < CP_M12_DESERT_EXCLREG1_LON_RT) CP_M12_N_OVER_L_LAND otherwise
EMSM12_N_OVER_H	CP_BAD if pixel lat/lon is within the desert exclusion region defined by (CP_M12_DESERT _EXCLREG1_LAT_LO < latitude < CP_M12_DESERT _EXCLREG1_LAT_HI and CP_M12_DESERT_EXCLREG1_LON_LF < longitude < CP_M12_DESERT_EXCLREG1_LON_RT) CP_M12_N_OVER_H_LAND otherwise
SNOW_M10_THRES	Independent of surface type. See Table 44, Eqn 13 below.

Table 43. Cloud Phase Dynamic Thresholds and Logic for Land, Coast and Snow Surface Types

Threshold	Land/Coast/Snow
CIRRUS_THRES	Independent of surface type. See Table 44, Eqn 6 below.
M14_M15_THRES	Independent of surface type. See Table 44, Eqn 8 below.
WIN_OVER_THRESH	See Table 44, Eqn 10 below.

NIR_OVERLAP_THRES	CP_BAD if (CP_MAX_M9_OVER ≤ RefM9)
	$f_{I,NOT}(RefM9, ScatAngle)$ + CP_NIR_OVERLAP_LAND_CORRECTION,
	if (CP_NIR_OVERLAP_LAND_MAX_POLY < $f_{I,NOT}$)
	CP_NIR_OVERLAP_LAND_MAX_POLY + CP_NIR_OVERLAP_LAND_CORRECTION,
	if (CP_NIR_OVERLAP_LAND_MAX_POLY ≥ $f_{I,NOT}$)
	See Table 44, Eqn 5 for $f_{I,NOT}$ below.

M9_WIN_CHECK_THRES	CP_M9_WIN_CHECK_THRES_LAND
NIR_CIRRUS_THRES_M12	CP_NIR_CIRRUS_THRES_WATER_M12 if pixel lat is within the M12 water polar latitude region defined by (latitude ≥ CP_M12_WATER_HI_LAT_N or latitude ≤ CP_M12_WATER_HI_LAT_S) CP_NIR_CIRRUS_THRES_LAND_M12 otherwise
MIN_M9_OVER	CP_MIN_M9_OVER_LAND_HIGH if pixel lat is within the M9 land polar latitude region defined by (latitude ≥ CP_M9_LAND_HI_LAT_N or latitude ≤ CP_M9_LAND_HI_LAT_S) CP_MIN_M9_OVER_LAND_LOW otherwise
M15_M16_N_OVER_L	CP_M15_M16_N_OVER_L_LAND
M15_M16_N_OVER_H	CP_M15_M16_N_OVER_H_LAND
EMSM12_N_OVER_L	CP_M12_N_OVER_L_LAND
EMSM12_N_OVER_H	CP_M12_N_OVER_H_LAND
SNOW_M10_THRES	Independent of surface type. See Table 44, Eqn 13 below.

Table 44. Cloud Phase Threshold Equations

Equation Definitions	
$i = Satellite\ Zenith Angle\ bin\ index = \text{int}(SatZenAngle/10.0),$ $0 \le i \le\ Number\ of\ Satellite\ Zenith\ Bins - 1$ $j = Solar\ Zenith\ Angle\ bin\ index = \text{int}(SolZenAngle/10.0),$ $0 \le j \le Number\ of\ Solar\ Zenith\ Bins - 1$ $k = Scattering\ Angle\ bin\ index = \text{int}(ScatAngle/10.0),$ $0 \le k \le Number\ of\ Scattering\ Angle\ Bins - 1$	
NIR_OVERLAP_THRES polynomials for water and land: $f_{w,NOT}(RefM9, ScatAngle) = A\_nir\_over\_water_k(RefM9)^4 + B\_nir\_over\_water_k(RefM9)^3 + C\_nir\_over\_water_k(RefM9)^2 + D\_nir\_over\_water_k(RefM9) + E\_nir\_over\_water_k$	**Eqn 4**
$f_{l,NOT}(RefM9, ScatAngle) = A\_nir\_over\_land_k(RefM9)^4 + B\_nir\_over\_land_k(RefM9)^3 + C\_nir\_over\_land_k(RefM9)^2 + D\_nir\_over\_land_k(RefM9) + E\_nir\_over\_land_k$	**Eqn 5**
$CIRRUS\_THRES = \begin{cases} f_{cirrus}(BTM15,\ SatZenithAngle), \\ \quad if\ CP\_MIN\_CIRRUS < f_{cirrus}(BTM15,\ SatZenithAngle) < CP\_MAX\_CIRRUS \\ CP\_MIN\_CIRRUS, \quad if\ f_{cirrus}(BTM15,\ SatZenithAngle) < CP\_MIN\_CIRRUS \\ CP\_MAX\_CIRRUS, \quad if\ f_{cirrus}(BTM15,\ SatZenithAngle) > CP\_MAX\_CIRRUS \end{cases}$	**Eqn 6**
where $f_{cirrus}(BTM15, SatZenithAngle) = A\_cirrus_i(BTM15)^4 + B\_cirrus_i(BTM15)^3 + C\_cirrus_i(BTM15)^2 + D\_cirrus_i(BTM15) + E\_cirrus_i$	**Eqn 7**
$M14\_M15\_THRES = \begin{cases} f_{M14M15}(BTM15,\ SatZenithAngle), \quad if\ BTM15 \le CP\_M14M15\_BTM15\_LIMIT \\ CP\_BAD, \quad otherwise \end{cases}$	**Eqn 8**
where $f_{M14M15}(BTM15,\ SatZenithAngle) = A\_M14\_M15_i(BTM15)^4 + B\_\_M14\_M15_i(BTM15)^3 + C\_\_M14\_M15_i(BTM15)^2 + D\_\_M14\_M15_i(BTM15) + E\_\_M14\_M15_i$	**Eqn 9**

Equation Definitions

$$WIN\_OVER\_THRESH = \begin{cases} f_{1,WOT}(RefM5, SatZenithAngle, SolZenAngle) - CP\_WIN\_OVER\_CORRECTION, \\ \quad if\ ((CP\_MIN\_M5\_OVER \le RefM5 \le CP\_MID\_M5\_OVER)\ and\ (f_{1,WOT} > f_{2,WOT})) \\ f_{2,WOT}(SatZenithAngle, SolZenAngle) - CP\_WIN\_OVER\_CORRECTION, \\ \quad if\ ((CP\_MIN\_M5\_OVER \le RefM5 \le CP\_MID\_M5\_OVER)\ and\ (f_{1,WOT} \le f_{2,WOT})) \\ f_{2,WOT}(SatZenithAngle, SolZenAngle) - CP\_WIN\_OVER\_CORRECTION, \\ \quad if\ (CP\_MID\_M5\_OVER < RefM5 \le CP\_MAX\_M5\_OVER) \\ CP\_BAD,\ otherwise \end{cases}$$ **Eqn 10**

where

$$f_{1,WOT}(RefM5,\ SatZenithAngle,\ SolZenAngle) = A\_win\_over_{j,i}(RefM5)^4 + B\_win\_over_{j,i}(RefM5)^3 + C\_win\_over_{j,i}(RefM5)^2 + D\_win\_over_{j,i}(RefM5) + E\_win\_over_{j,i}$$ **Eqn 11**

$$f_{2,WOT}(SatZenithAngle,\ SolZenAngle) = MIN\_win\_over_{j,i}$$ **Eqn 12**

$$SNOW\_M10\_THRES = \begin{cases} CP\_SNOW\_M10\_THRES\_HIGH, \\ \quad if\ (pixel\ latitude\ is\ within\ "polar\ snow\ latitudes")\ where\ the \\ \quad "polar\ snow\ latitudes"\ are\ defined\ as \\ \quad (latitude \ge CP\_M10\_SNOW\_HI\_LAT\_N\ or \\ \quad latitude \le CP\_M10\_SNOW\_HI\_LAT\_S) \\ CP\_SNOW\_M10\_THRES\_LOW,\quad otherwise \end{cases}$$ **Eqn 13**

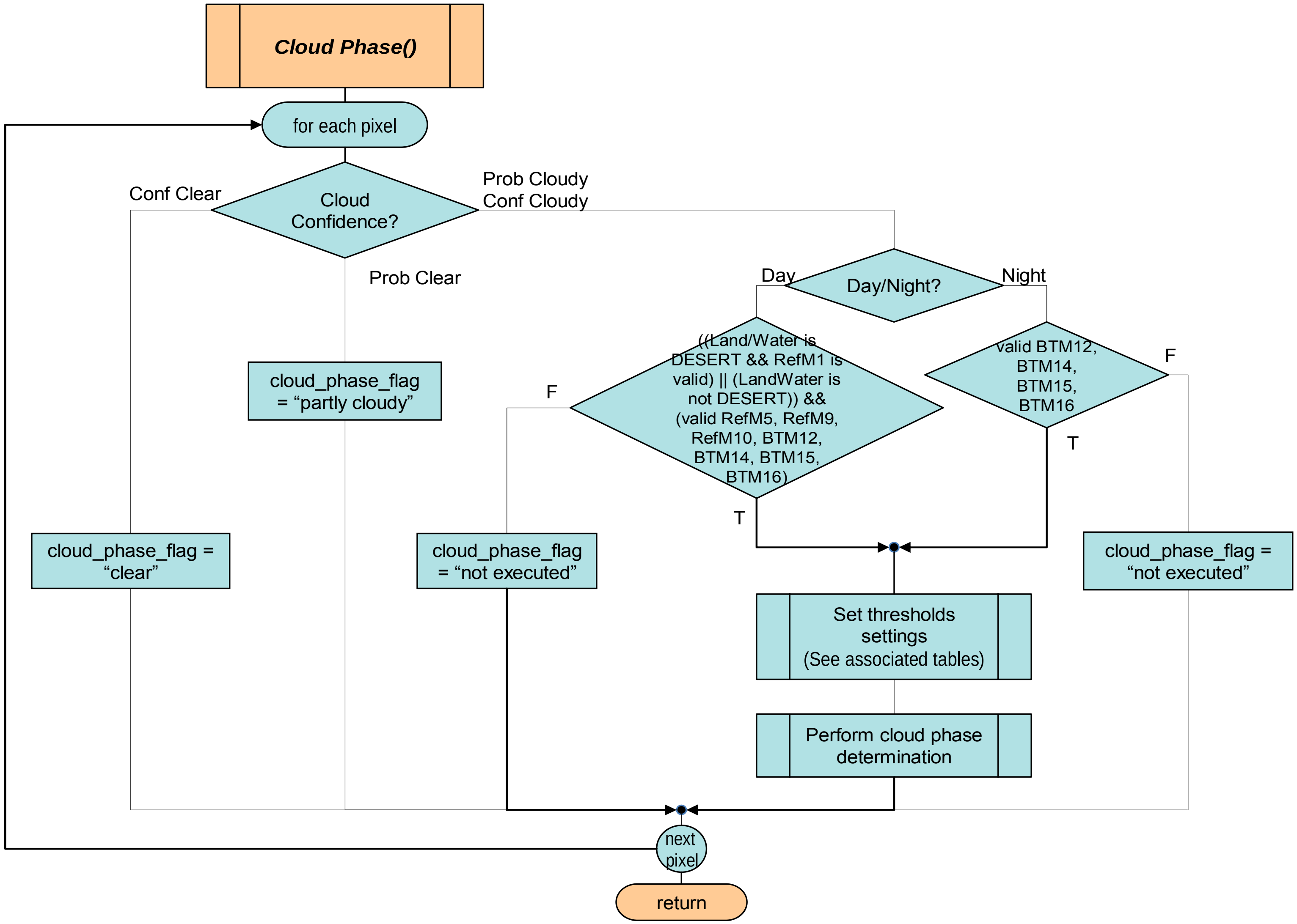


Figure 13. Top Level Functional Flow for Cloud Phase Determination – Part 1

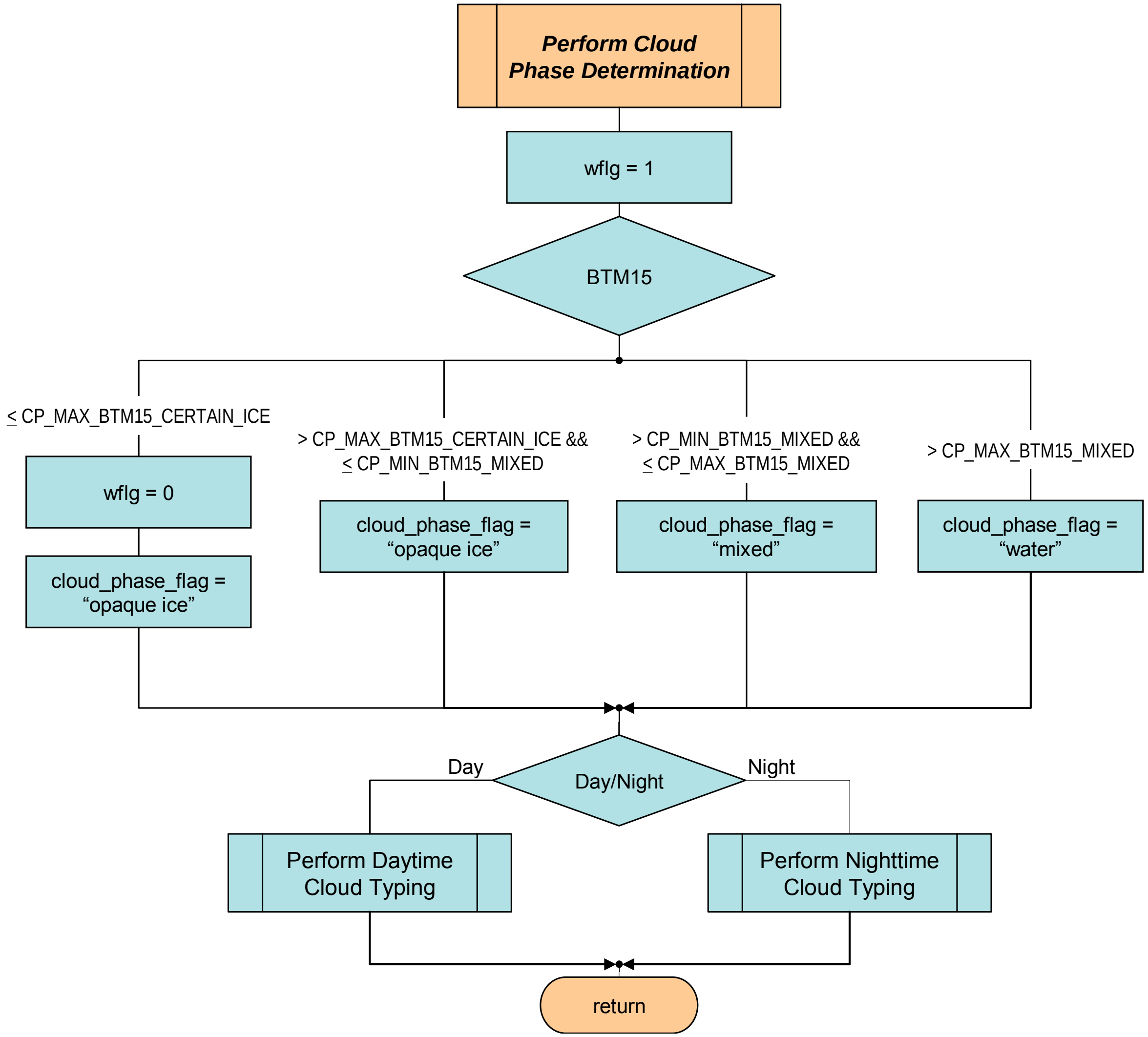


Figure 14. Top Level Functional Flow for Cloud Phase Determination – Part 2

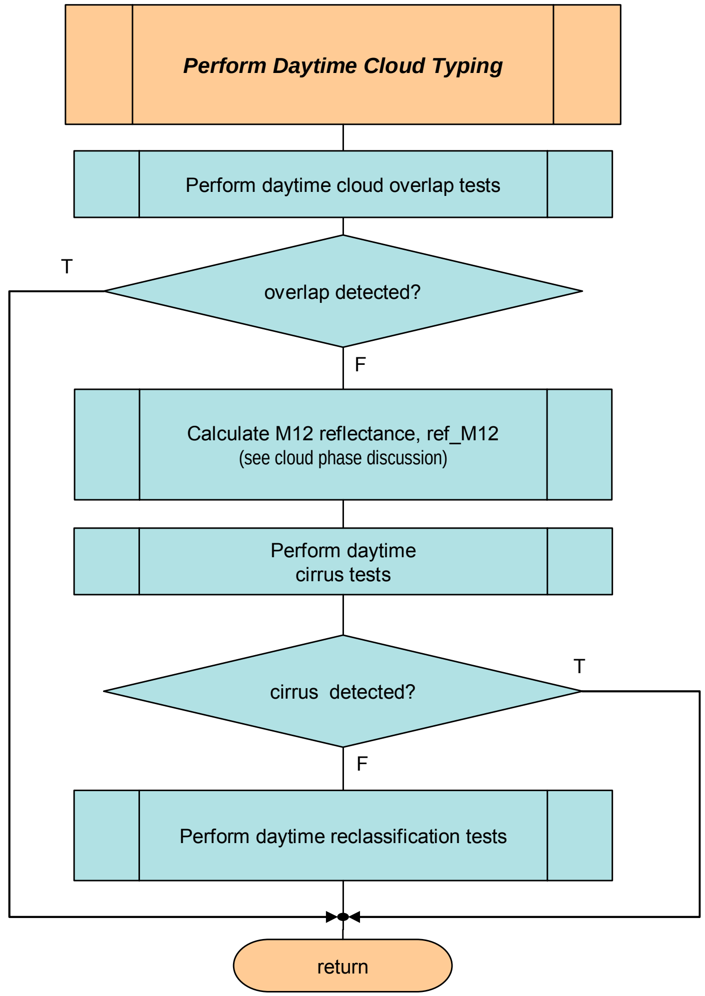


Figure 15. Cloud Phase Functional Flow – Top Level Flow for Daytime Cloud Typing

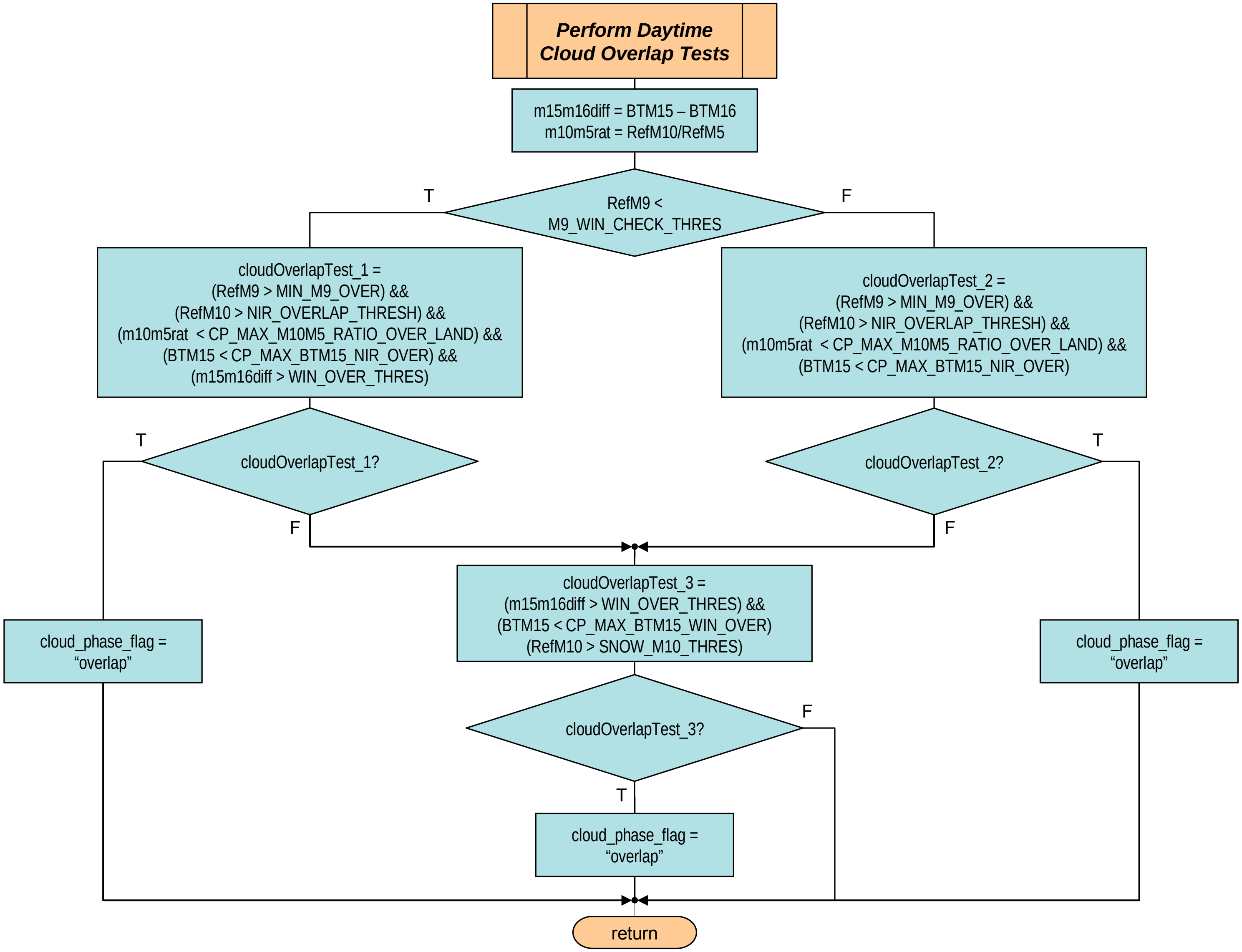


Figure 16. Cloud Phase Functional Flow – Cloud Overlap Tests for Daytime Pixels

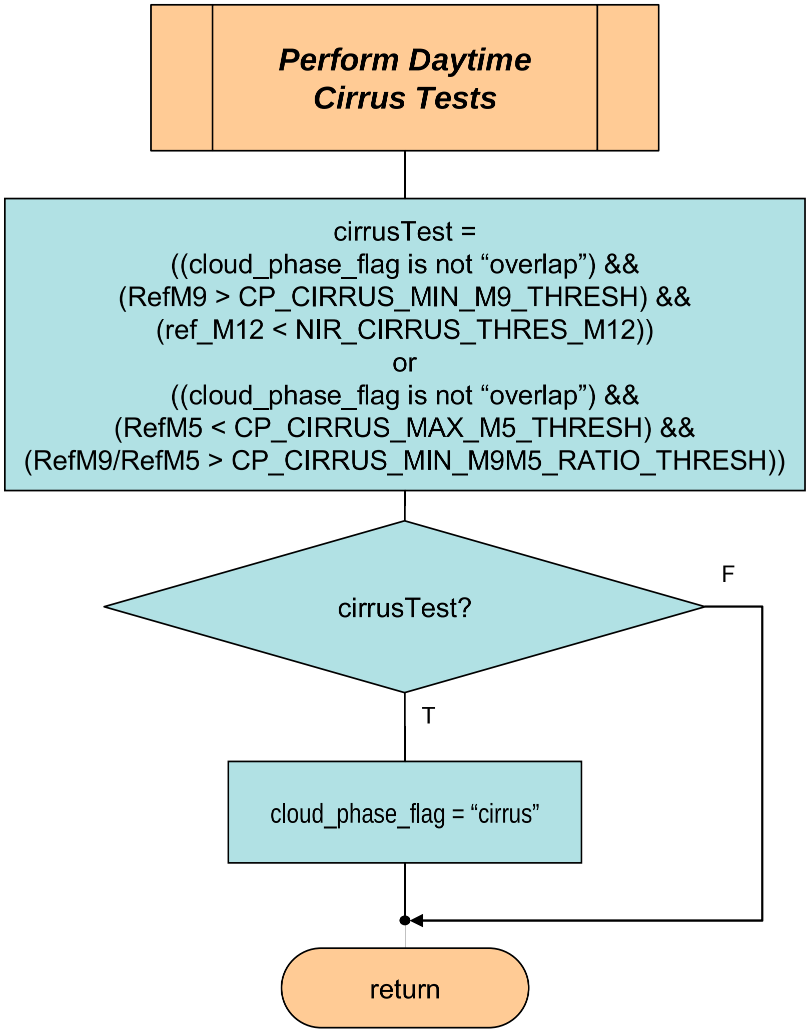


Figure 17. Cloud Phase Functional Flow – Cirrus Tests for Daytime Pixels

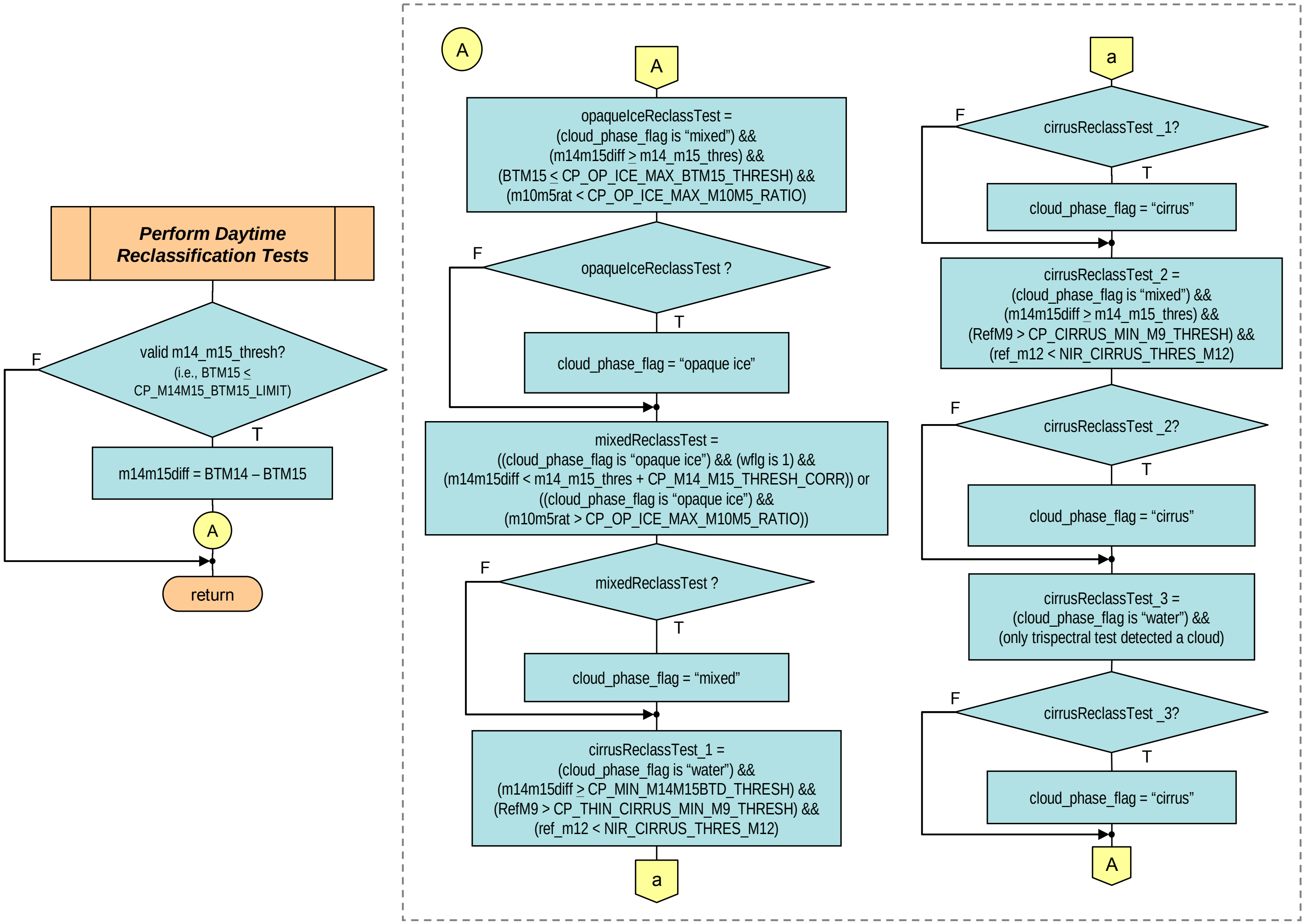


Figure 18. Cloud Phase Functional Flow – Cloud Reclassification Tests for Daytime Pixels

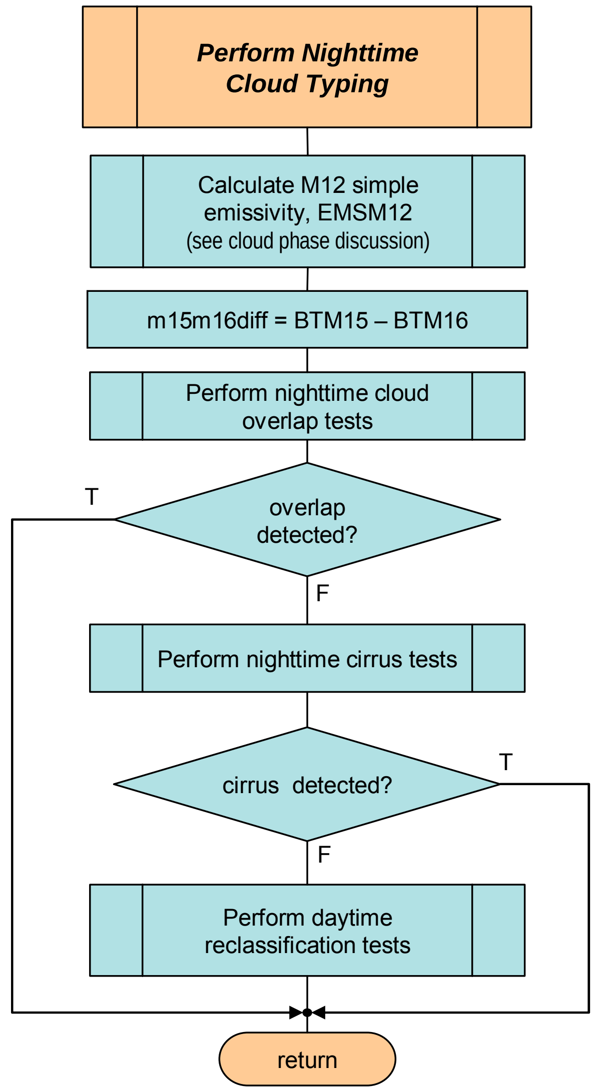


Figure 19. Cloud Phase Functional Flow – Top Level Flow for Nighttime Cloud Typing

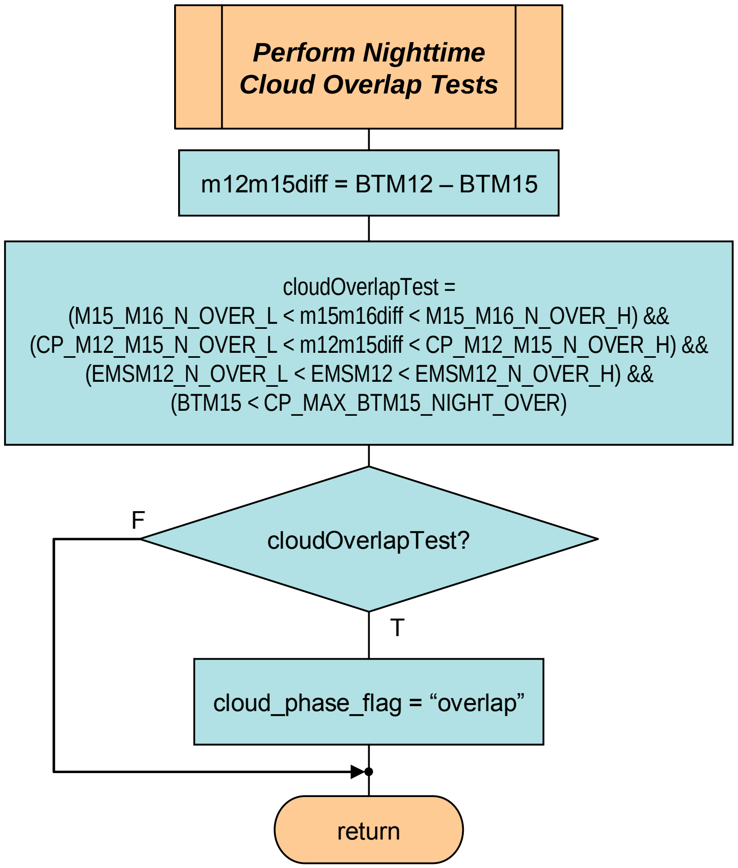


Figure 20. Cloud Phase Functional Flow – Cloud Overlap Tests for Nighttime Pixels

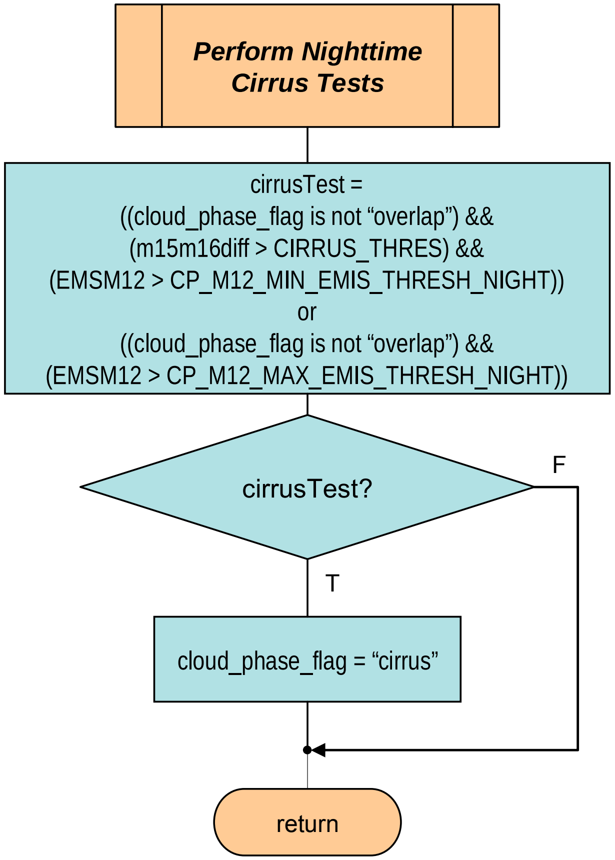


Figure 21. Cloud Phase Functional Flow – Cirrus Tests for Nighttime Pixels

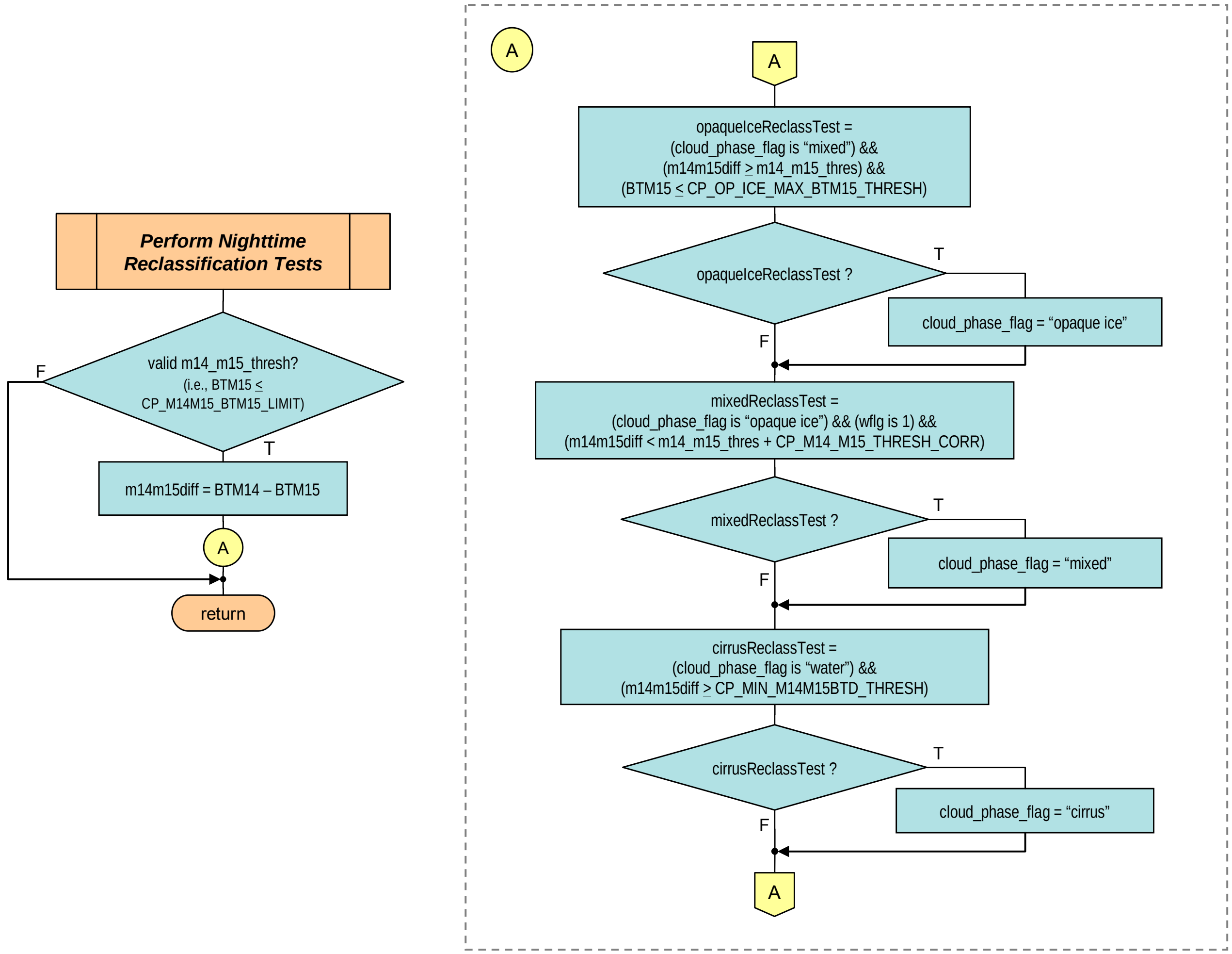


Figure 22. Cloud Phase Functional Flow – Cloud Reclassification Tests for Nighttime Pixels

2.1.2.9 Determine Aerosol and Fire

As inferred by the process name, this routine focuses on the detection of fires and aerosols in each moderate resolution pixel. The top level logical flow is shown in Figure 23. The I/O for each entity (i.e., aerosol, fire) of this process is shown in Table 45. The detection logic for is discussed in the following subsections.

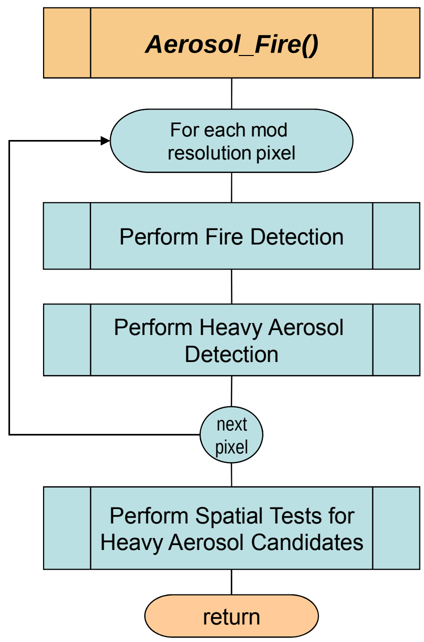


Figure 23. Top Level Functional Flow for Aerosol/Fire Detection

Table 45. Aerosol/Fire Process I/O

	Variable	Description
Fire		
Input	fire_mask	Fire mask field of ancillary input Active Fires IP
Output	fire_flag	Flag indicating presence of fire See VCM IP output, Table 6
Heavy Aerosol		
Input	day_night_flag	Flag indicating day or nighttime illumination See VCM IP output, Table 6 for values
	land_water_flag	Flag indicating pixel surface type See VCM IP output, Table 6 for values
	snow_ice_flag	Flag indicating presence of snow or ice in pixel See VCM IP output, Table 6 for values
	sun_glint_flag	Flag indicating presence of sun glint. See VCM IP output, Table 6 for values
	cloud_phase_flag	Flag indicating cloud phase detected by the VCM cloud phase algorithm. See VCM IP output, Table 6 for values
	MBSenZen	Moderate resolution sensor zenith angle

	Variable	Description
	MBSolZen	Moderate resolution solar zenith angle
	mLon, mLat	Longitude/Latitude of moderate resolution pixel
	toc_ndvi	top of canopy NDVI
	RefM1, RefM5, RefM11	Moderate resolution reflectances for bands M1, M5, and M11
	RefM12	Moderate resolution M12 reflectance derived from M12 Radiance
	BTM15, BTM16	Moderate resolution brightness temperatures for bands M15 and M16
	various thresholds	See Table 50, Aerosol and Fire Parameters section
Output	heavy_aerosol_flag	Flag indicating presence of heavy aerosol See VCM IP output, Table 6
	dustCand	Flag indicating potential dust contaminated pixel See VCM IP output, Table 6
	smokeCand	Flag indicating potential smoke contaminated pixel See VCM IP output, Table 6
	dustVolcAsh	Flag indicating presence of dust or volcanic ash

2.1.2.9.1 Fire Detection

VCM uses the Active Fire IP Fire Mask field to set its fire flag. Specifically, VCM keys in on the fire confidence setting of the Fire Mask.

Setting of Fire Flag
Given the following parameters:
initial fire_flag setting of "NO"

```
IF ((Active Fire IP Fire Mask confidence flag ≥ low confidence fire) AND
   (Active Fire IP Fire Mask confidence flag ≤ high confidence fire)) THEN
       VCM Fire Flag = "Yes"
ENDIF
```

2.1.2.9.2 Heavy Aerosol Detection

A new approach, different from the MODIS heritage algorithms, was developed at NGST to identify heavy aerosols in pixels classified as confidently cloudy by the VCM. This approach exploits the differences in spectral and textural signatures between clouds and heavy aerosols to identify “candidate” pixels that might contain heavy aerosols, including dust, smoke, volcanic ash, and industrial pollution. The term candidate is used to emphasize that these highly accurate, new spectral tests, developed to detect heavy aerosols over water surfaces using the M1 (0.412 μm) band, also detect some cloud edges. Therefore, these heavy aerosol candidates are analyzed using spatial tests to differentiate between water clouds and heavy aerosols, which normally have more homogeneous signatures. Over land, variations in surface reflectance can impact the spatial test when clouds are optically thin or aerosols are present. Therefore, the spectral tests have limited value, and all water clouds are considered “candidate” heavy aerosols and are examined with the spatial tests. Similarly, in sun glint regions, all water clouds are considered heavy aerosol candidates. In addition, new procedures are used to detect volcanic ash.

A top level flow of the heavy aerosol detection routine is shown in Figure 24. The heavy aerosol detection routines over water and land and the spatial tests for aerosol candidates are discussed in more detail in the following paragraphs. Although the detection of volcanic ash over water and land is discussed in its separate section, the calls to the volcanic ash detection routine are performed in the heavy aerosol detection processes.

As mentioned above, the heavy aerosol detection routines are executed for confidently cloudy pixels only. VCM does not attempt to detect heavy aerosol in pixels classified as clear since its intent is to flag those pixels that were misclassified as cloudy due to heavy aerosol content. Downstream algorithms can use the heavy aerosol and cloud confidence flag settings to determine if a given pixel should be treated as cloudy or clear.

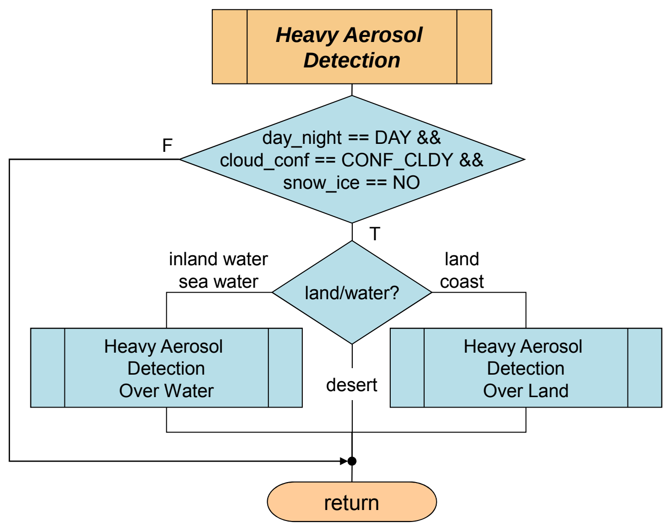


Figure 24. Top Level Flow for Heavy Aerosol Detection

2.1.2.9.2.1 Heavy Aerosols Over Water Surfaces

Different spectral tests are used to identify candidates believed to contain dust and smoke over water surfaces. The M1/M5 reflectance ratio and M1 reflectance tests are used to detect dust since heavy dust has its minimum reflectance in the M1 VIIRS band while both ice and water clouds are highly reflective in both bands. The thresholds established for these tests are based upon the principles of radiative transfer. Under cloudy conditions, the ratio between VIIRS M1 and M5 bands is nearly unity for ice clouds. For water clouds, this ratio is roughly proportional to the ratio of extinction coefficients in the M1 and M5 bands, i.e. 2.1042 / 2.1431 or 0.98 for droplets with a particle radius of 6 μm. However, in cloud-free regions, the ratio of the extinction coefficients is inversely proportional to the 4th power of the wavelength ratio, i.e. [(0.65/0.412)**4] or ~6.3. Since airborne dust and blowing sand often occur at altitudes relatively near the Earth's surface, it is expected that a significant number of air molecules are present above these non-cloud obscurations at higher levels in the atmosphere. Therefore, the threshold, VCM_AERO_DUST_M1M5_REFLRATIO_THRESH, is initially set to 2.0. As a result, the threshold for the M1 reflectance test, VCM_AERO_DUST_M1_REFL_THRESH, is set relatively low, i.e. to 0.3, in an attempt to avoid identifying pixels as heavy aerosols when they contain sub-pixel clouds. These procedures are more fully described by Hutchison et al., (2008).

To detect smoke over water surfaces, the VCM now employs the M11/M1 (2.1 μm/0.412 μm) reflectance ratio test, since this ratio is nearly one for water clouds but very low in pixels containing smoke, e.g. ~ 0.1. However, this test can also detect ice clouds since reflection for ice is smaller in the larger wavelength, and reflectance in the M1 band is strongly affected by Rayleigh scattering. Thus, the test is only applied to pixels classified as water clouds in the VCM cloud phase analyses, and the thresholds for this test, VCM_AERO_SMOKE_CONF_M11M1_REFLRATIO_THRESH and VCM_AERO_SMOKE_CAND_M11M1_REFLRATIO_THRESH vary with scan angle to compensate for Rayleigh scattering.

Again, since the M11/M1 reflectance ratio test was found to accurately detect smoke but also misclassified water cloud edges, pixels detected by this spectral test are also considered heavy aerosol “candidates” and further tested with the spatial tests along with candidates identified by the dust test. Note that if the results of the M11/M1 reflectance ratio are less than VCM_AERO_SMOKE_CONF_M11M1_REFLRATIO_THRESH (nadir, pre-calibration/validation value of 0.1), the pixel is classified as heavy aerosol and this classification is not changed by results from the spatial test. This is done to avoid misclassification of the heaviest aerosols which may have texture, e.g., dense smoke near the source of a fire. Subsequently, for ratios larger than this value but less than VCM_AERO_SMOKE_CAND_M11M1_REFLRATIO_THRESH, the pixel is flagged as a candidate heavy aerosol and is further evaluated by the spatial test.

The logic flow for heavy aerosol detection over water surfaces is shown in Figure 25.

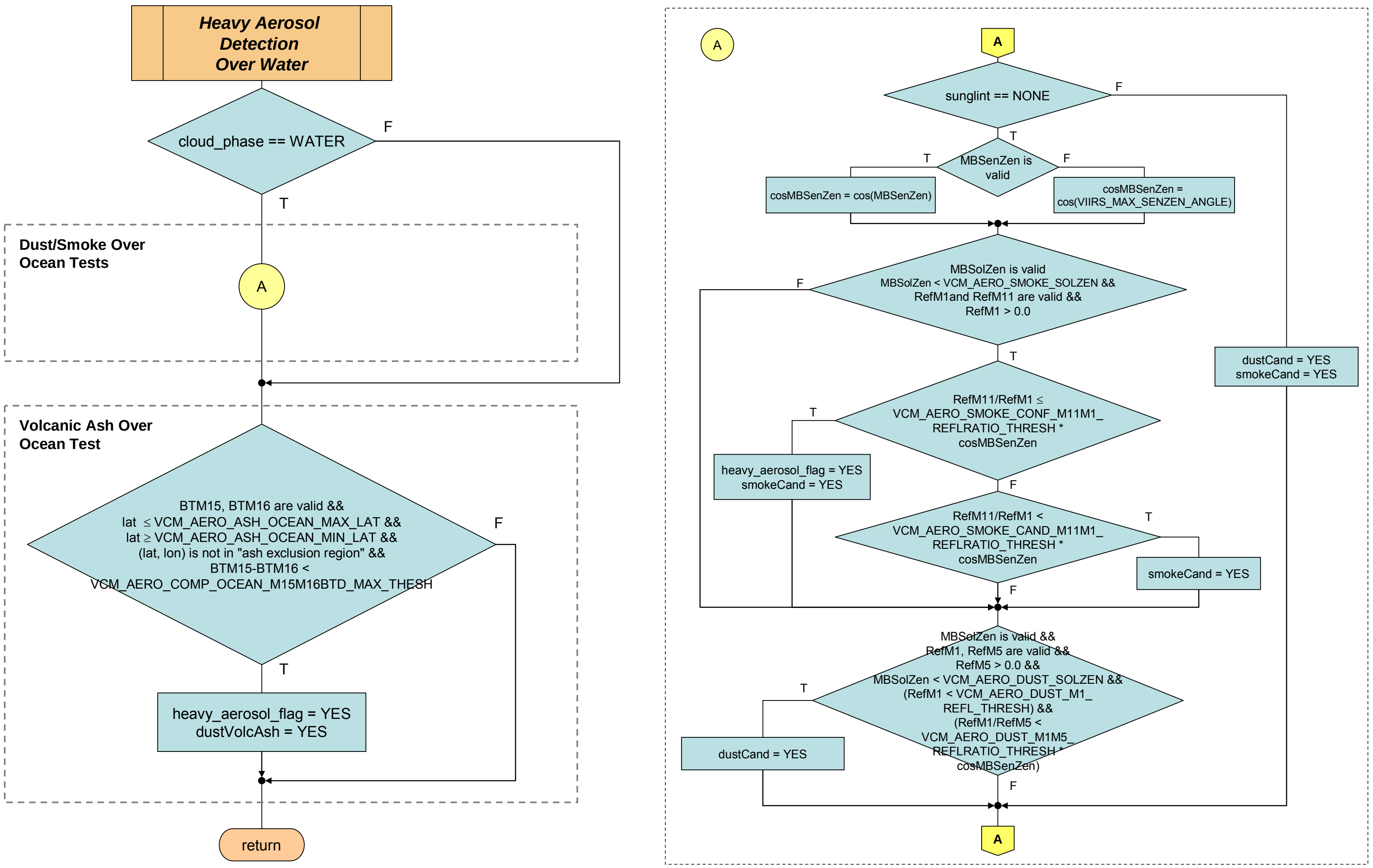


Figure 25. Functional Logic Flow for Heavy Aerosol Detection Over Water

2.1.2.9.2.2 Heavy Aerosols Over Land Surfaces

While spectral tests can be applied to identify heavy aerosol candidates over water backgrounds, variations in cloud-free surface reflectance negate using similar tests over land backgrounds. Therefore, all water clouds over land surfaces are considered heavy aerosol candidates and are evaluated with the spatial tests alluded to in previous sections. The logic flow is shown below in Figure 26.

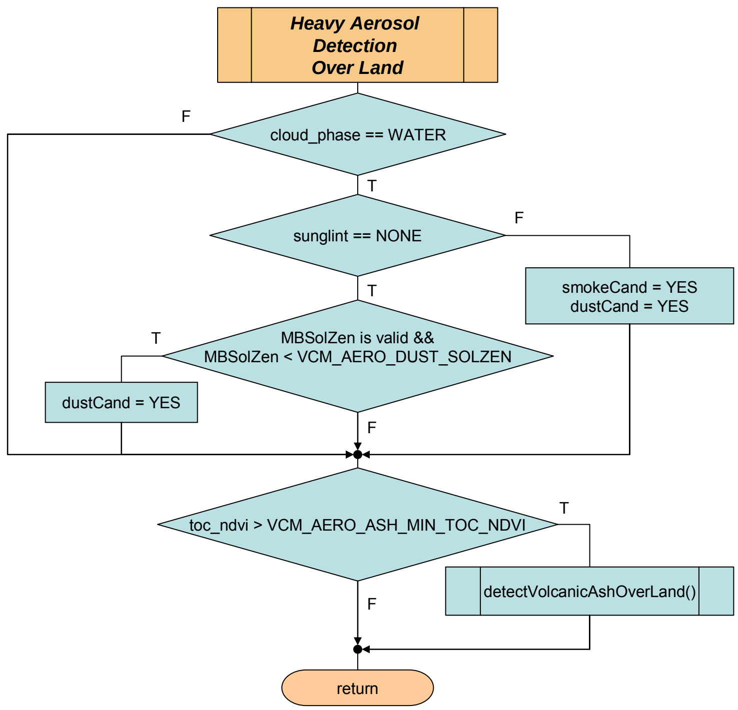


Figure 26. Functional Logic Flow for Heavy Aerosol Detection Over Land

2.1.2.9.2.3 Spatial Tests for Heavy Aerosol Candidates

The spatial test uses the 0.65 µm imagery (375-m) resolution band, I1, with a hopping window composed of all heavy aerosol candidates to distinguish between water clouds and aerosols.

All candidates from the spectral tests discussed in Section 2.1.2.9.2.1, Heavy Aerosols Over Water Surfaces, are integrated with all pixels over land classified by the VCM as confidently cloudy and containing water cloud phase. This composite of heavy aerosol candidates is then examined using a spatial test based upon the 0.65 µm imagery resolution (375-m) reflectance, I1, contained within a VCM_AERO_MOD_WINSIZE x VCM_AERO_MOD_WINSIZE array of moderate resolution pixels which extends across a nominal 1.5-km x 1.5-km analysis area. The standard deviation for all candidates with this moderate resolution pixel array is calculated using a hopping window, as opposed to a sliding window, as follows:

- If only one candidate exists within the moderate resolution window, it is assumed to be a cloud edge.
- Over water backgrounds, if at least two candidates exist in the moderate resolution window, the standard deviation is calculated using all imagery resolution pixels within

these candidates. At least 8 but as many as 16 imagery resolution pixels are used in this calculation.

- If the standard deviation > VCM_AERO_WATER_STDDEV_THRESH, all candidates are classified as water clouds. No heavy aerosol flag is set.
- If the standard deviation is ≤ VCM_AERO_WATER_STDDEV_THRESH, all moderate resolution pixels are defined to contain heavy aerosols.

- Over land backgrounds, if at least two candidates exist in the moderate resolution window and the TOC NDVI > VCM_AERO_COMP_TOCNDVI_THRESH, the standard deviation is calculated.
  - If the standard deviation > VCM_AERO_LAND_STDDEV_THRESH, all candidates are classified as water clouds. No heavy aerosol flag is set.
  - If the standard deviation is ≤ VCM_AERO_LAND_STDDEV_THRESH, all moderate resolution pixels are defined to contain heavy aerosols.

The thresholds used to define whether candidates contain cloud edges or heavy aerosols are larger than those used in the MODIS aerosol algorithm. The algorithm used to create the MOD04 product employs a threshold of 0.25% in a 3x3 array of MODIS 500-m pixels collected in the 0.55 μm band (Martins et al., 2002). The threshold used in the VIIRS cloud mask are quadrupled because the VCM provides a cloud mask that accurately defines cloudy pixels, including those with sub-pixel clouds (Hutchison et al., 2005), while the algorithm used to generate the MOD04 product must differentiate between clouds and cloud-free features including aerosols with this spatial test. There is no requirement for the VIIRS cloud mask to identify aerosol. The requirement is only for it *not* to classify as cloudy those pixels which contain heavy aerosols. Since candidates with water clouds have much larger standard deviations across the moderate resolution detection window, the heavy aerosol threshold can be larger while still remaining highly effective.

The top level logic flow for the spatial tests is shown in Figure 27. The detailed logic for deciding whether the spatial tests should be performed, contained in process candidateAeroFlagSet(), and the logic for the application of the aerosol spatial test, process applyAeroSpatialTest(), are shown in Figure 28 and Figure 29, respectively. The decision to perform the spatial test is based on the number of candidates found within the search window. If the heavy aerosol flag is already set for all the candidates, which is possible as seen from the discussion of heavy aerosols over land and water, then executing the spatial test, which has the purpose of setting the heavy aerosol flag, is unnecessary. In addition to returning the number of candidates found in the search window, candidateAeroFlagSet() also returns the moderate resolution pixel index of each candidate. This array is later recalled in applyAeroSpatialTest() in order to retrieve the I1 reflectances of the imagery resolution pixels nested within the candidates of the search window. The standard deviation is calculated for the imagery resolution pixels of the moderate resolution candidates only.

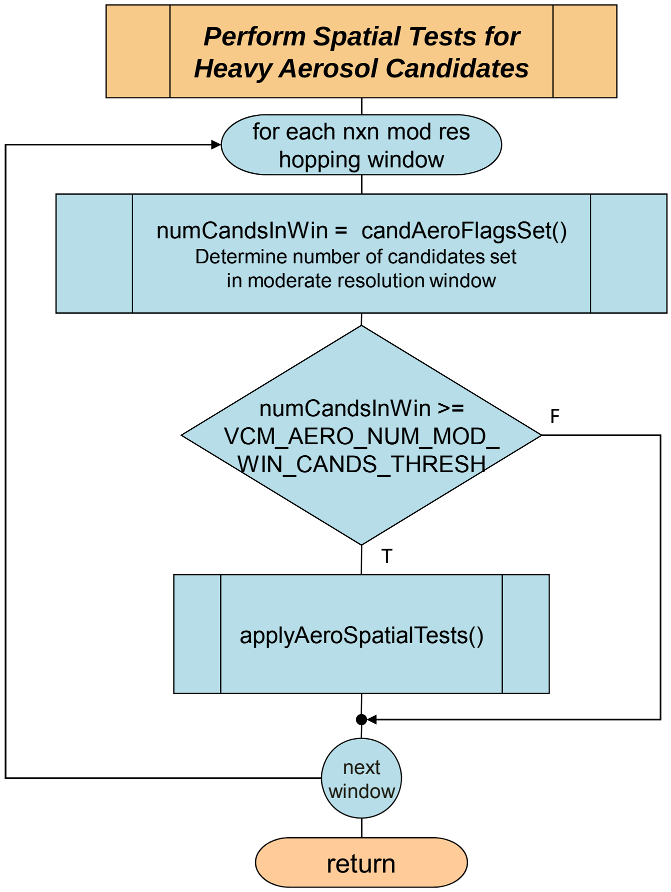


Figure 27. Top Level Logic Flow for the Heavy Aerosol Spatial Tests

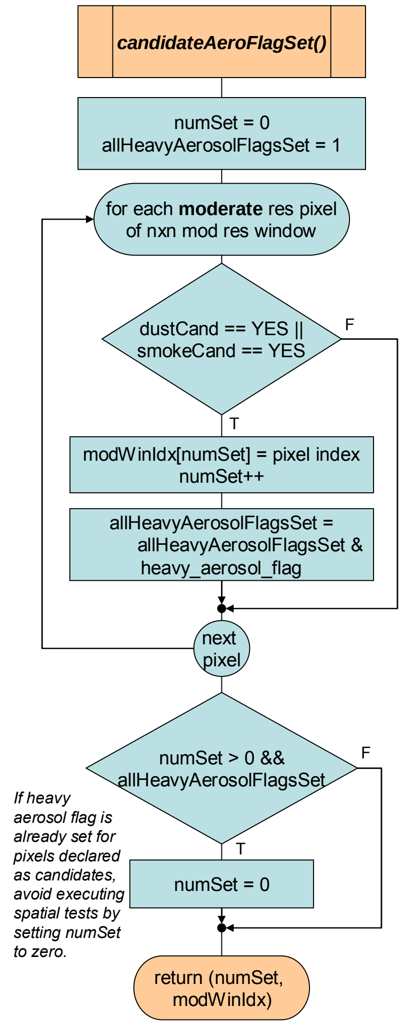


Figure 28. Logic Flow for Testing Presence of Aerosol Candidates in Moderate Resolution Search Window

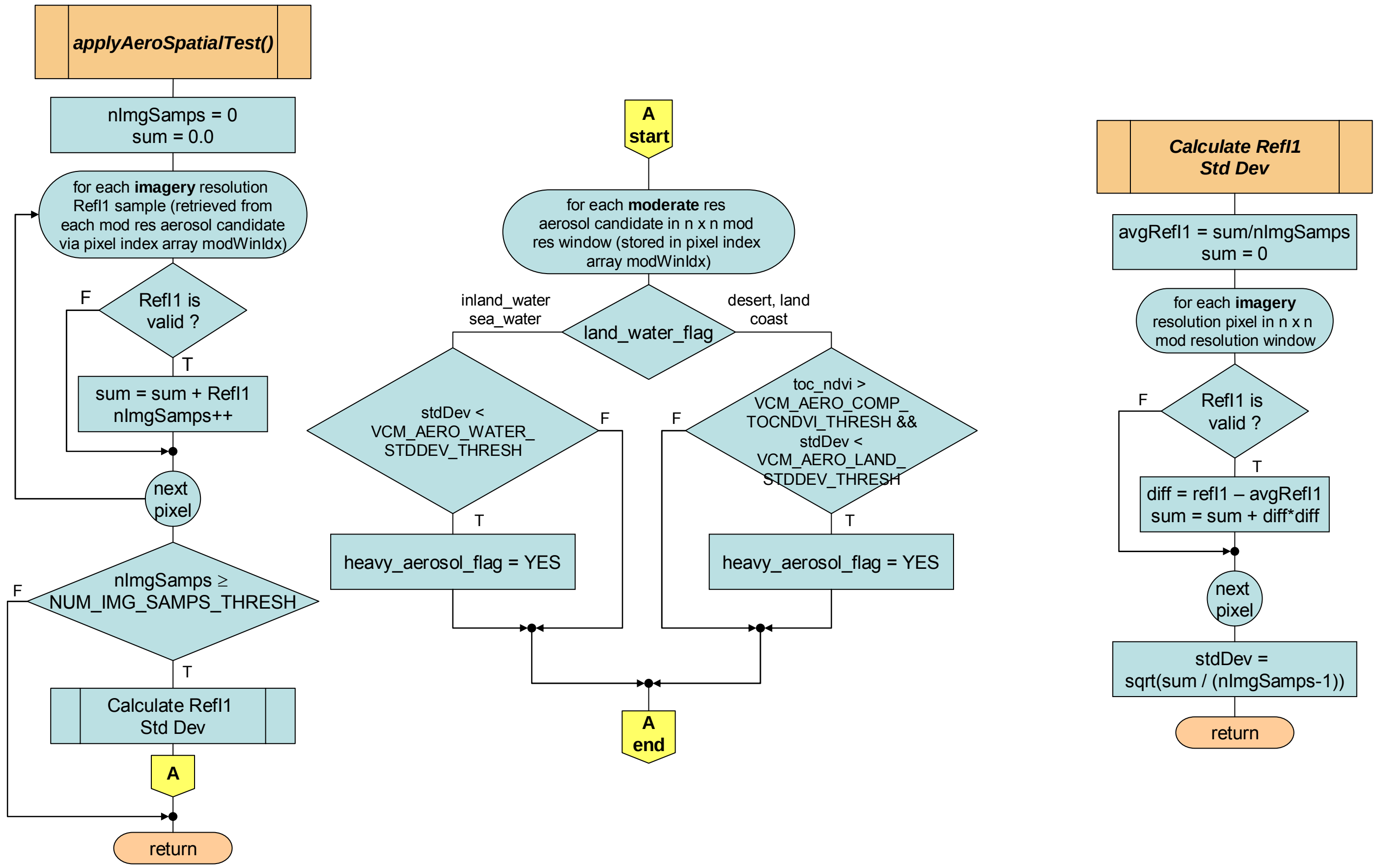


Figure 29. Functional Flow for Application of Aerosol Spatial Test

2.1.2.9.2.4 Volcanic Ash

Detection of aerosols composed of volcanic ash follows a modification of the approaches developed by Prata (1989a; 1989b) and Pavolonis et al. (2006). The VCM volcanic ash test is applied only to daytime non-snow/ice-covered ocean and land surfaces classified as confidently cloudy. Positive detection of volcanic ash results in a “Yes”-setting of the dustVolcAsh and heavy aerosol flags.

2.1.2.9.2.4.1. Volcanic Ash Over Ocean

The "reverse absorption" method, based on the M15 – M16 (T_{11} - T_{12}) BTD feature, is the only spectral test used to detect volcanic ash over ocean and is applied only to pixels classified as confidently cloudy (see Figure 25 for implementation). The threshold of the reverse absorption technique has also been modified. Originally, Prata recommended the threshold be set to 0.0 K but this leads to large numbers of false alarms, especially over desert regions and areas with persistent stratocumulus clouds as shown in Figure 30, which comes from Figure 10 of Pavolonis et al., (2006). For this reason, the test is restricted to perform within a user-settable latitude range but outside the regions of persistent stratocumulus clouds. The recommended regions, currently limited to 3 regions, are shown in Table 46 and are marked in Figure 30. The test was originally applied in the VCM with a threshold of -1.0 K but this conservative threshold detected little volcanic ash. Subsequently, NGST modified the threshold, originally set to -1.0 K with little volcanic ash detection, to -0.25 K. This threshold was found to allow maximum detection of volcanic ash.

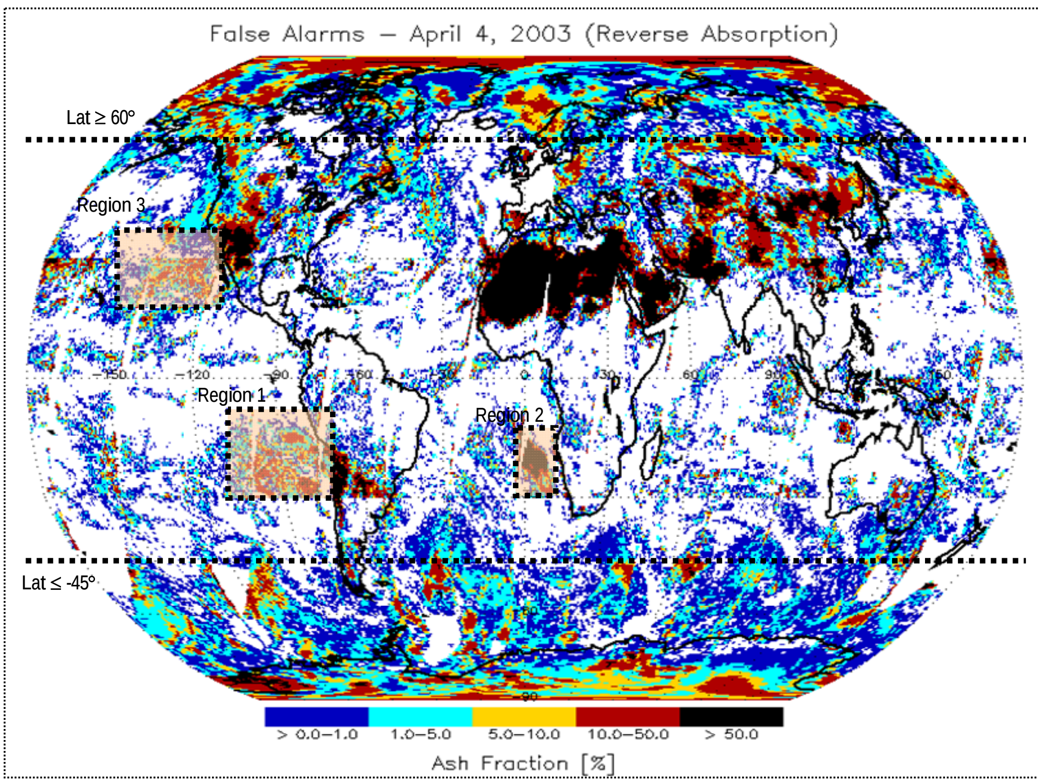


Figure 30. Frequency of Occurrence for False Alarms

Table 46. Volcanic Ash Over Ocean Exclusion Region

Exclusion Region	Upper Latitude	Lower Latitude	Left Longitude	Right Longitude
1	-5.0	-30.0	-105.0	-70.0
2	-15.0	-30.0	0.0	15.0
3	30.0	15.0	-150.0	-120.0
All latitudes ≥ 60.0° and latitudes ≤ -45.0°				

2.1.2.9.2.4.2. Volcanic Ash Over Land

Over land surfaces, the VCM employs Tier I and Tier II tests described by Pavolonis, et al. (2006). These tests provide useful detection of volcanic ash with minimum false alarms. The tests employ several logical combinations of spectral threshold tests. The spectral tests are, in general, dependent on

- an M15 brightness temperature
- an M15-M16 brightness temperature difference,
- an M12 reflectance, and
- an M12/M5 reflectance ratio.

The thresholds for these tests are in general dependent on the tropic, midlatitude and polar latitudinal regions.

The tests for volcanic ash detection over land are presented below. All thresholds are user-settable, and each set of tests are only performed if the parameters (i.e., spectral test parameters, latitude, solar zenith angle) used in testing are valid.

For all latitudes, the following test is performed.

```
IF ((refM12 > VCM_AERO_ASH_REFM12_MIN_THRESH_1) AND
    (btM15 < VCM_AERO_ASH_BTM15_MAX_THRESH_1) AND
    (refM5 < VCM_AERO_ASH_REFM5_MAX_THRESH_1)) THEN
      Set heavy aerosol flag to "Yes"

      Set dustVolcAsh flag to "Yes"

ENDIF
```

If, and only if, the above test fails, the following latitude-dependent tests are performed:

```
IF ((latitude is in tropical latitude) THEN
    IF (((btM15 < VCM_AERO_ASH_BTM15_TROPIC_MAX_THRESH_1) AND
         (m12m5refRatio > VCM_AERO_ASH_M12M5REFRAT_TROPIC_MIN_THRESH_1) AND
         (m15m16Diff < VCM_AERO_ASH_M15M16BTDIFF_TROPIC_MAX_THRESH_1))
    OR
          ((btM15 < VCM_AERO_ASH_BTM15_TROPIC_MAX_THRESH_2) AND
           (m12m5refRatio > VCM_AERO_ASH_M12M5REFRAT_TROPIC_MIN_THRESH_2) AND
           (m15m16Diff < VCM_AERO_ASH_M15M16BTDIFF_TROPIC_MAX_THRESH_2))
    OR
           ((btM15 < VCM_AERO_ASH_BTM15_TROPIC_MAX_THRESH_3) AND
            (m12m5refRatio > VCM_AERO_ASH_M12M5REFRAT_TROPIC_MIN_THRESH_3) AND
            (m15m16Diff < VCM_AERO_ASH_M15M16BTDIFF_TROPIC_MAX_THRESH_3))
    OR
```

```
            ((btM15 < VCM_AERO_ASH_BTM15_TROPIC_MAX_THRESH_4) AND
             (refM12 > VCM_AERO_ASH_REFM12_TROPIC_MIN_THRESH_4) AND
             (refM5 < VCM_AERO_ASH_REFM5_TROPIC_MAX_THRESH_4) AND
             (landWater != "Desert"))))
        THEN
             Set heavy aerosol flag to "Yes"
             Set dustVolcAsh flag to "Yes"
    ELSE IF ((latitude is in Mid-latitude region)
        IF (((btM15 < VCM_AERO_ASH_BTM15_MIDLAT_MAX_THRESH_1) AND
           (m12m5refRatio > VCM_AERO_ASH_M12M5REFRAT_MIDLAT_MIN_THRESH_1) AND
           (m15m16Diff < VCM_AERO_ASH_M15M16BTDIFF_MIDLAT_MAX_THRESH_1) AND
           (landWater != "Desert"))
        OR
          ((btM15 < VCM_AERO_ASH_BTM15_MIDLAT_MAX_THRESH_2) AND
           (m12m5refRatio > VCM_AERO_ASH_M12M5REFRAT_MIDLAT_MIN_THRESH_2) AND
           (m15m16Diff < VCM_AERO_ASH_M15M16BTDIFF_MIDLAT_MAX_THRESH_2) AND
           (landWater != "Desert"))
        OR
          ((btM15 < VCM_AERO_ASH_BTM15_MIDLAT_MAX_THRESH_3) AND
           (m12m5refRatio > VCM_AERO_ASH_M12M5REFRAT_MIDLAT_MIN_THRESH_3) AND
           (m15m16Diff < VCM_AERO_ASH_M15M16BTDIFF_MIDLAT_MAX_THRESH_3))
        OR
          ((btM15 < VCM_AERO_ASH_BTM15_MIDLAT_MAX_THRESH_4) AND
           (refM12 > VCM_AERO_ASH_REFM12_MIDLAT_MIN_THRESH_4) AND
           (refM5 < VCM_AERO_ASH_REFM5_MIDLAT_MAX_THRESH_4) AND
           (llandWater != "Desert"))))
        THEN
             Set heavy aerosol flag to "Yes"
             Set dustVolcAsh flag to "Yes"
    ELSE IF ((latitude is in Polar region)
        IF (((btM15 < VCM_AERO_ASH_BTM15_POLAR_MAX_THRESH_1) AND
          (m15m16Diff < VCM_AERO_ASH_M15M16BTDIFF_POLAR_MAX_THRESH_1))
        OR
         ((solZen < VCM_AERO_ASH_SOLZEN) AND
          (btM15 < VCM_AERO_ASH_BTM15_POLAR_MAX_THRESH_2) AND
          (m12m5refRatio > VCM_AERO_ASH_M12M5REFRAT_POLAR_MIN_THRESH_2) AND
          (m15m16Diff < VCM_AERO_ASH_M15M16BTDIFF_POLAR_MAX_THRESH_2))
        OR
         ((solZen < VCM_AERO_ASH_SOLZEN) AND
          (btM15 < VCM_AERO_ASH_BTM15_POLAR_MAX_THRESH_3) AND
          (m15m16Diff < VCM_AERO_ASH_M15M16BTDIFF_POLAR_MAX_THRESH_3) AND
          (refM12 > VCM_AERO_ASH_REFM12_POLAR_MIN_THRESH_3))
        OR
          ((solZen < VCM_AERO_ASH_SOLZEN) &&
           (btM15 < VCM_AERO_ASH_BTM15_POLAR_MAX_THRESH_4) AND
           (refM5 < VCM_AERO_ASH_REFM5_POLAR_MAX_THRESH_4) AND
           (refM12 > VCM_AERO_ASH_REFM12_POLAR_MIN_THRESH_4))))
        THEN
             Set heavy aerosol flag to "Yes"
             Set dustVolcAsh flag to "Yes"
        ENDIF
    ENDIF
```

2.1.2.10 Determine Cloud Adjacency

The Cloud Adjacency algorithm slides a 3x3 moderate resolution window across the granule and examines the Cloud Confidence of the pixels surrounding the center pixel. For each moderate resolution pixel, the stored cloud confidence of all eight adjacent pixels, determined as a function of distance between pixel centers through the common adjacency process, is evaluated and the most extreme value (from confident cloudy to confidently clear) of the adjacent pixels is reported. This input data required for this process are the granule and swath metadata, latitude, longitude, and the stored Cloud Confidence of each pixel in the granule.

PDL for Cloud_Adjacency

```
Cloud_ Adjacency (VCM_DATA_TYPE)
    Initialize Integer  cloud_adjacency  CONFIDENT CLEAR

    FOR every pixel in the granule
       /* Check pixel position with the granule to see if pixel is on the edge of scan */
       /* Evaluate surrounding pixels' cloud_confidence value and set the cloud_adjacency to the
       "worse case" pixels' cloud_confidence (confident cloudy being worse case, then probably
       cloudy, probably clear, and finally confidently clear) */
       IF (adjacent pixel cloud_confidence = Confident Cloudy) THEN
            Set cloud_adjacency to CONFIDENT CLOUDY
       ELSE IF (adjacent pixel cloud_confidence = Probably Cloudy) THEN
            Set cloud_adjacency to PROBABLY CLOUDY
       ELSE IF (adjacent pixel cloud_confidence = Probably Clear) THEN
            Set cloud_adjacency to PROBABLY CLEAR
       ELSE
            Set cloud_adjacency to CONFIDENT CLEAR
       ENDIF
```

2.1.2.11 Ephemeral Water Detection – DetectEphemeralWater()

An ephemeral water detection routine is performed for the benefit of downstream aerosol and land algorithms (e.g., surface temperature, surface reflectance) which are impacted by the presence of surface water. This routine aims to detect both transient water and water regions averaged out by the relatively coarse resolution of the Land/Water Mask – Quarterly Surface Type database.

The ephemeral detection test is performed on the 2x2 imagery resolution pixels contained within each moderate resolution pixel, and is only performed for confidently clear, daytime, moderate resolution pixels classified as land (non-desert) and containing no snow. The moderate resolution pixel is said to contain ephemeral water if any of its imagery resolution pixels have a top-of-atmosphere NDVI (TOA NDVI) value less than a specified threshold, VCM_TOA_NDVI_THRESH. If ephemeral water is detected, an ephemeral water bit is set and the VCM Land/Water Background flag is reset to "Inland Water".

Note that the ephemeral water detection process is applied after all VCM processes are complete. Note also that cloud leakage will be falsely identified as inland water.

The I/O for this process is listed in Table 47. The steps for performing the process follow.

Table 47. Ephemeral Water Detection I/O

	Variable	Description
Input	day_night_flag	Flag indicating day or nighttime illumination See VCM IP output, Table 6 for values
	snow_ice_flag	Flag indicating presence of snow or ice in pixel See VCM IP output, Table 6 for values

	Variable	Description
	land_water_flag	Flag indicating pixel surface type. See VCM IP output, Table 6 for values
	cloud_confidence_flag	Cloud Confidence flag See VCM IP output, Table 6
	RefI1, RefI2	Imagery resolution reflectances for bands I1 and I2
Output	land_water_flag	land (no desert) flag reset to inland water if ephemeral water is detected
	ephemeral_water_flag	Flag indicating presence of ephemeral water See VCM IP output, Table 6 for values

Steps for Ephemeral Water Determination

Note: The process below assumes that the ephemeral water flag has been initialized to "No": ephemeral_water_flag = "No"

1. For each moderate resolution pixel, determine if the ephemeral water test should be performed.

```
FOR each moderate resolution pixel
    IF (cloud_confidence = "Confidently Clear")
        day_night_flag = "Day" AND
        land_water_flag = "Land" (no Desert) AND
        snow_ice_flag = "No Snow") THEN
            proceed with remaining steps
    END IF
END FOR each moderate resolution pixel
```

2. Extract the imagery resolution reflectances, RefI1 and RefI2, for bands I1 and I2.

3. For each imagery resolution pixel, calculate a TOA NDVI. Reset the Land/Water flag and set the Ephemeral Water bit if ephemeral water is detected.

```
FOR each imagery resolution pixel within the moderate resolution pixel
    IF (RefI1 is valid AND RefI2 is valid) THEN
      toa_ndvi = (RefI2 – RefI1)/(RefI2 + RefI1)
      IF (toa_ndvi < VCM_TOA_NDVI_THRESH) THEN
            land_water_flag = "Inland Water"
            ephemeral_water_flag = "Yes"
            break out of imagery loop and proceed to next moderate resolution pixel
      END IF toa_ndvi test
    END IF valid imagery reflectances
END FOR each imagery resolution pixel
```

2.1.2.12 Cloud Shadow Detection – Cloud_Shadow()

Shadows tests are executed under daytime conditions for confidently cloudy pixels casting shadows on to confidently clear and probably clear pixels based on sun to cloud geometry computations. M15 derived brightness temperatures are used to assign cloud top temperatures. Also computed are clear-sky mean NCEP surface air temperatures for mxm hopping windows, where m is defined by the tunable parameter VCM_SHADOW_GRIDCELL_SIZE, and a mask indicating whether at least one confidently clear pixel-exists in the mxm grid cell. Cloud heights and bases are determined using an assumed lapse rate and the difference between the mean clear sky surface air temperature and the cloud top temperature. The minimum and maximum cloud height levels are constrained by tunable parameters. The algorithm iterates over cloud height intervals to compute line of sight cloud shadow geometries for each height iteration. The shadow flag is set for pixels within an nxn neighborhood of the computed shadow target location if the neighborhood pixels are confidently clear or probably clear. This nxn neighborhood is defined by a window-halfsize tunable parameter, VCM_SHADOW_CLDCONF_CHECK_WINDOW, where a value of 1 produces a 3x3 neighborhood. Note that an optional run mode (i.e., an input “shadow cast switch”) can be set to include probably cloudy pixels in the determination of cloud shadows; however, this option is not currently used due to the increase in latency. A flow chart of the logic is shown in Figure 31.

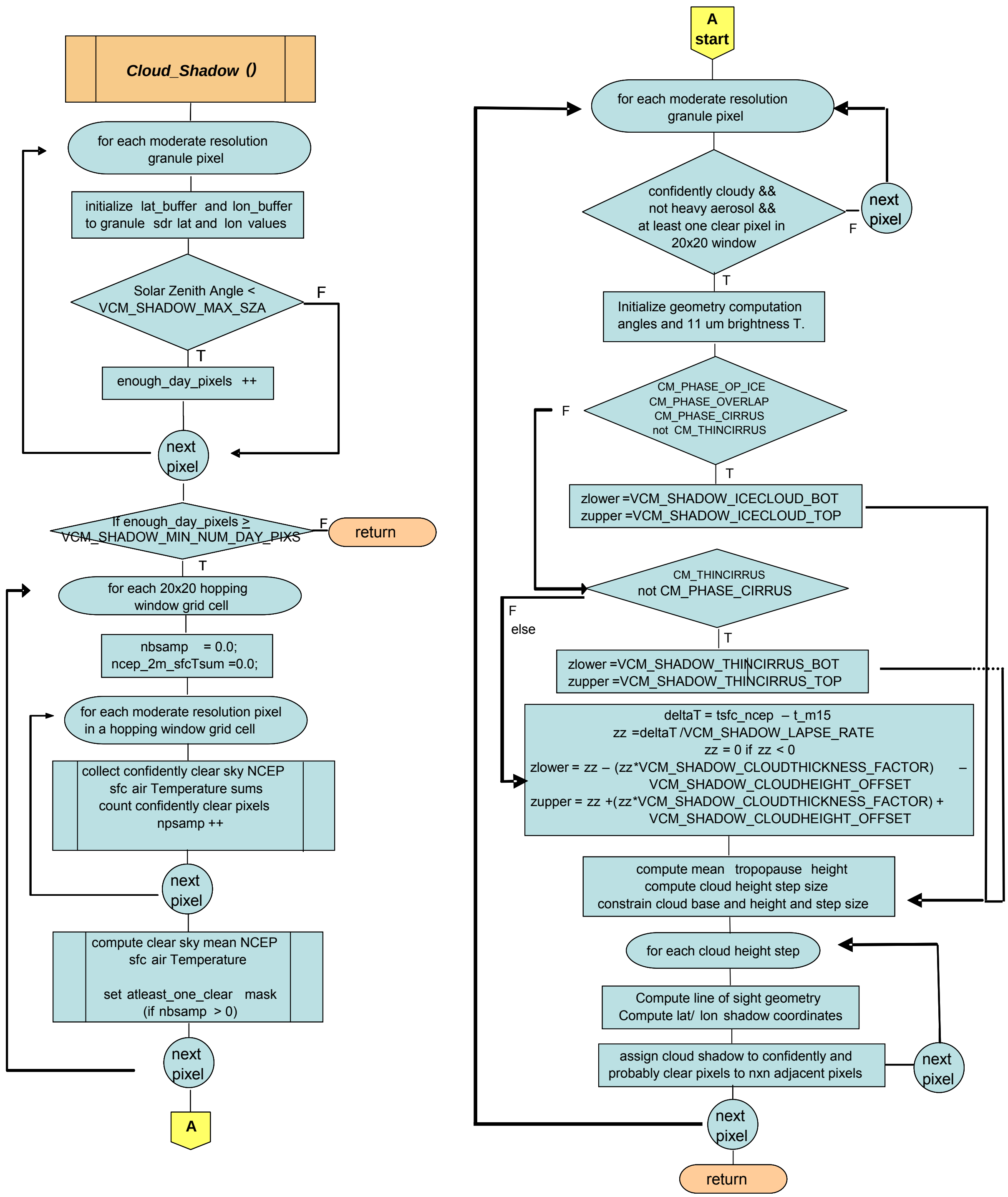


Figure 31. Cloud Shadow Logic

[1] Note: An optional run mode switch "ShadowCastSwitch" set to a value of 1 allows shadows to be cast from confidently cloudy and probably cloudy pixels. The ShadowCastSwitch set to 0 (default operational run mode setting) will cast shadows from confidently cloudy pixels only.

A number of tunable parameters are used in the cloud shadow logic to allow for correction of biases in the computed shadow extents as well as for the controlling algorithm latency associated with the computation of geometry based cloud shadows. The cloud shadow tunable parameters are further described in Table 50, VCM IP Tunable Parameters, under the Cloud Shadows subheading.

2.1.2.13 Set Degraded Flags – SetDegradedFlags()

Excluded/degraded conditions for VCM are defined by the NPOESS System Specification, Rev N. Process SetDegradedFlags() contains the logic to set moderate resolution flags for these conditions. Note that the System Specification also includes clouds with optical thickness < 1.0 in the specification of the degraded conditions but this cannot be flagged in the VCM since the optical thickness EDR is generated after the VCM execution is complete. The I/O for this process is shown in Table 48. Tunable parameters used for this process are listed in Table 50 under the Degraded Flags section.

Table 48. Set Degraded Flags I/O

	Variable	Description
Input	day_night_flag	Flag indicating day or nighttime illumination See VCM IP output, Table 6 for values
	sun_glint_flag	Flag indicating presence of sun glint in pixel See VCM IP output, Table 6 for values
	toc_ndvi	Top of Canopy NDVI from ancillary data
	mLat	Latitude of the moderate resolution pixel
Output	degraded_toc_ndvi_flag	Flag indicating degraded conditions due to a specified range of TOC NDVIs See VCM IP output, Table 6 for value of flag
	degraded_sunglint_flag	Flag indicating degraded conditions due to presence of sun glint See VCM IP output, Table 6 for values
	degraded_polar_night_flag	Flag indicating degraded conditions due to nighttime illumination at polar latitudes See VCM IP output, Table 6 for values

During the VCM initialization process, all degraded condition flags are initialized to NO. The flags are set according to the logic below.

<u>**Steps for Setting Degraded/Excluded Flag Conditions**</u>
Note: The process below assumes that the degraded flags have been pre-initialized to “No”:

```
FOR each moderate resolution pixel
    IF (sun_glint_flag != “None”) THEN
        degraded_sun_glint flag = "Yes"
    ENDIF

    IF ((toc_ndvi > VCM_MIN_DEGRAD_TOC_NDVI) AND
       (toc_ndvi < VCM_MAX_DEGRAD_TOC_NDVI))  THEN
        degraded_toc_ndvi flag = "Yes"
    ENDIF

    IF ((day_night_flag  = NIGHT) AND
       (abs(lat) >= VCM_POLAR_LAT) AND
       (abs(lat) <= VCM_MAX_LAT)) THEN
        degraded_polar_night_flag = "Yes"
```

```
    END IF
END FOR each moderate resolution pixel
```

2.1.2.14 Cross Granule Processing

Cross granule processing is required when the value of a pixel depends on the values of an nxn neighborhood of surrounding pixels, that is, when scan lines from one granule are needed in the analysis of an adjoining granule. Due to Earth's curvature, the projection of the sensor FOV onto the earth as the sensor line-of-sight moves away from nadir expands in a bow-tie-like pattern. As a result, some pixels are imaged more than once, and the determination of a pixel neighborhood in sensor space becomes more complex. In order to get the true neighborhood of a pixel in "sensor space", these redundant pixels must be removed, i.e., the bow-tie region must be trimmed. The pixels to be trimmed are specified by the ProCmnViirsTrimTable which is implemented in the PRO SI common code. This table specifies the column range that defines the extended bow-tie deletion boundaries for each row. Pixels that are marked as "trimmed" or redundant are not processed.

Cross granule processing is required in Cloud Mask for the Cloud Shadow and Adjacent Pixel Cloud Confidence logic. As discussed in Section 2.1.2.10, the Cloud Adjacency algorithm requires a 3x3 pixel neighborhood of adjacent pixels and therefore, cross granule processing is required for pixels above and below the pixel of interest.

Cross granule processing associated with the VCM cloud shadow algorithm requires buffering of five 16 scan or two 48 scan granules from the previous and next granules. Cloud shadows may be projected into the granule being processed from cloudy pixels located approximately 60 km beyond the granule boundary for shadows cast from high clouds under high solar zenith conditions. The computation NCEP clear sky, 2 meter surface air temperature and an "at-least one confidently clear pixel" mask is performed for each 20 x 20 hopping window. The 20 x 20 hopping windows must extend into the previous and next granules such that the windows extend at least 60 pixels into the buffered regions. The shadows must be computed from pixels residing within the buffered regions into the current processing granule. The 3x3 pixel "shadow cast" windows that are centered on each computed line of sight shadow pixel may also overlap granule boundaries; however, the amount of overlap is limited to approximately one to two pixels.

2.1.3 Graceful Degradation

A product is marked as "gracefully degraded" when backup or inferior data must be used to produce the output. The VIIRS Cloud Mask product has the potential to become gracefully degraded if one of its inputs is also gracefully degraded. If any of the three input data, Sea Surface Wind Speed and Direction, Total Column Precipitable Water or Surface Air Temperature is marked as degraded (i.e., the N_Graceful_Degradation metadata field set to “Yes”), the VIIRS Cloud Mask product will also be marked as degraded.

2.1.3.1 Graceful Degradation Inputs

There is one case where input graceful degradation is indicated in the VIIRS Cloud Mask.

1. If one of the listed inputs shaded grey in the Table 49 retrieved for the algorithm had its N_Graceful_Degradation metadata field set to “Yes” (propagation).

Table 49 details the instance of this one case. Note that the shaded cells indicate that the graceful degradation was done upstream at product production.

Table 49. Graceful Degradation

Input Data Description	Baseline Data Source	Primary Backup Data Source	Secondary Backup Data Source	Tertiary Backup Data Source	Graceful Degradation Done Upstream
Global Ice Concentration & Snow Extent	VIIRS_GD_08.4.1 VIIRS	N/A	N/A	N/A	N/A
Sea Surface Wind Speed and Direction	VIIRS_GD_09.4.2 NCEP	VIIRS_GD_09.4.2 NCEP (Extended Forecast)	N/A	N/A	Yes
Total Column Precipitable Water	VIIRS_GD_09.4.11 NCEP	VIIRS_GD_09.4.11 NCEP (Extended Forecast)	N/A	N/A	Yes
Surface Air Temperature	VIIRS_GD_09.4.10 NCEP	VIIRS_GD_09.4.10 NCEP (Extended Forecast)	N/A	N/A	Yes
Global NBAR NDVI	VIIRS_GD_08.4.6 Global 5-km NBAR NDVI IP	N/A	N/A	N/A	N/A
Surface Type	VIIRS_GD_08.4.3 VIIRS	N/A	N/A	N/A	N/A
Land-Water Mask	VIIRS_GD_27.4.1 MODIS Land-Water Mask	N/A	N/A	N/A	N/A

2.1.3.2 Graceful Degradation Processing

None.

2.1.3.3 Graceful Degradation Outputs

None.

2.1.4 Exception Handling

VIIRS produces a cloud mask under all circumstances. If a band is bad, the tests using that band are not used. This degradation is reflected in the cloud mask quality flag.

In order to prevent a software failure during processing, VCM performs consistency checks for user-input settings. The user constraints are discussed in Section 2.1.2.3.2, Validation of User Input. If any of the conditions are violated, VCM reports the error and exits with a failure.

If the QST/LWM (Land Water Mask) does not provide a valid surface type, the VCM shall report "Coastal" in the Land/Water Background Flag.

No exception handling is required in the process portion of the code since VIIRS produces a cloud mask under all circumstances. Error checking and exception handling is done in the derived algorithm class (ProEdrViirsCM.cpp) when receiving tasks from INF, getting input data from DMS and sending VCM output to DMS. If a failure occurs within any of its processes, VCM reports an error to INF and ProEdrViirsCM terminates the process. Also debug information is provided for each function (in the beginning of the function InfUtil_DbgFunctionEnter ("Function Name") and InfUtil_DbgFunctionExit() upon exit).

2.1.5 Data Quality Monitoring

Each algorithm uses specific criteria contained in a Data Quality Threshold Table (DQTT) to determine when a Data Quality Notification (DQN) is produced. The DQTT contains the threshold used to trigger the DQN as well as the text contained in the DQN. If a threshold is met, the algorithm stores a DQN in DMS indicating the test(s) that failed and the value of the DQN attribute. For more algorithm specific detail refer to the CDFCB-X, 474-00001.

2.1.6 Computational Precision Requirements

The current implementation of the VCM IP algorithm does computations in 32-bit precision float. The output flags are byte flags and precision requirements are not applicable.

2.1.6.1 Numerical Computation Considerations

Bispectral cloud detection tests are computationally inexpensive. All possible cloud detection tests are applied for a given pixel. Tests for aerosols, shadows, and fire are made only after all cloud tests have been applied and pixels identified as cloud-contaminated have been flagged. Overall, VCM does not pose any serious problems for meeting timeliness requirements. The latency associated with computation of geometry based cloud shadows is controlled by the turnable parameters defined in Table 50. An optional run time mode switch "ShadowCastSwitch" which is defined as an Integer32 parameter may be set to allow the VCM to cast shadows from confidently cloudy and probably cloudy pixels. The definition of the switch is as follows:

ShadowCastSwitch = 0	Cast shadow only from confidently cloudy pixels (default operation run mode setting)
ShadowCastSwitch = 1	Cast shadows from confidently cloudy and probably cloudy pixels

2.1.7 Algorithm Support Considerations

2.1.7.1 Software Environment Considerations

- DMS should be up and running. All the data (primary or secondary) needed for the VCM calculations must be available in the DMS for the successful completion of the process.
- INF must be up and running, so the process can retrieve the task from INF and also send messages to INF upon successful completion or failure to complete the process.
- A C ++ compiler is necessary to compile the VCM source code.
- The PRO Common library is available.
- The imake files can create the Makefile used to compile the VCM.

2.1.7.2 Science Enhancement Opportunities

While great performance has been made in the enhancement of the VCM, some additional science enhancement may be warranted in the future. Those include

- Modifying single-valued thresholds with variable, threshold functions,
- Generating a common approach to calculate M12 reflectance,
- Any coding errors that remain.

While many thresholds have been changed to functions during the past few years, several single-valued thresholds remain in the VCM algorithm. It is clear that migrating from these single-values to functions could further improve VCM performance. For example, during chain testing, it was found that the M12-M16 cloud test employs a single-valued threshold of 4K and cites a reference by Hutchison et al., 1995 as the source of this threshold. However, the reference noted specifically shows that 4K represents a specific amount of humidity in the atmosphere. Using this threshold under cloud-free conditions, pixels with more humidity will be misclassified as cloudy, as was found to occur in the nighttime VCM with synthetic data. Cirrus clouds which are present in less humid atmospheres may also not be detected. Replacing this single threshold with a threshold function will improve VCM performance with nighttime data which currently is poorer than daytime performance.

The VCM currently uses two approaches to calculate M12 reflectance. One approach was used in the cloud phase algorithm; the second approach is used in tests for volcanic ash. The logic used for the cloud phase was hosted in the VCM in 1995 and was developed by the Cooperative Institute for Meteorological Satellite Studies (CIMSS). NGST hosted this large amount of code without modification. More recently, the procedure used to generate the M12 reflectance in this code was questioned by the NGST staff and while scientists at CIMSS explained their assumptions, NGST concluded these were too simplistic and developed a different approach that more correctly calculates the reflective component of the M12 band. However, to avoid changes to the thresholds in the more complicated M12 band, NGST did not modify the calculation in the cloud phase algorithm but left it for a future exercise.

2.1.7.3 Operational Code - Adaptation, Deviation or Limitations

Currently, two approaches—one used in the cloud phase determination and one used in the volcanic ash detection routine—are used to calculate M12 reflectances. Ideally, one routine should be used. However, currently the two approaches yield different results. Further study has to be performed to determine a consistent mathematical form that satisfies the requirements of the two routines. Once this is decided, code modifications will be necessary to use a common M12 calculation routine.

Although many tunable parameters and constants are already specified, some still exist as either hard-coded constants or embedded variables in the source code. Once these parameters are identified, minor modifications may be warranted.

2.1.7.4 Program Parameters for continuous monitoring

Tunable parameters used in the operational code for the VCM are listed in Table 50 below. These are the run time configurable parameters used in the cloud mask algorithm.

Table 50. VCM IP Tunable Parameters

Name	Type	Description	Units	Sug Value
Processing Path Determination				
snow_thresh_BTM15	float	maximum M15 brightness temperature at which snow/ice may exist	Kelvin	280

Name	Type	Description	Units	Sug Value
snow_thresh_RM7	float	minimum M7 reflectance for which snow/ice can be present	unitless	0.11
ndsi_snow	float	minimum normalized difference snow index for snow/ice to be present	unitless	0.4
snow_thinCiM9	float	minimum M9 reflectance for snow/ice to be present rather than thin cirrus	unitless	0.0525
VCM_SNOWICE_POLAR_LAT	float	Minimum latitude at which the VCM snow/ice routine is used over open ocean; for lower latitudes, the snow/ice ancillary product is used	degrees	60.0
snow_thresh_BTM14_M15	float	maximum M14 – M15 BTD for snow/ice to be present rather than thin cirrus	Kelvin	0.5
snow_thresh_BTM12_M15_LoElev	float	minimum M12 – M15 BTD for snow/ice to exist rather than thin cirrus; threshold used for elevations less than or equal to HiElevThresh	Kelvin	9.0
snow_thresh_BTM12_M15_HiElev	float	minimum M12 – M15 BTD for snow/ice to exist rather than thin cirrus; threshold used for elevations greater than HiElevThresh	Kelvin	10.0
maxSolarZenith	float	maximum solar zenith angle for daytime classification	degrees	85.0
VCM_DAYNIGHT_TOL	float	tolerance on maxSolarZenith	degrees	0.0
Sun Glint Parameters				
VCM_SUNGLINT_MAX_SOLZEN	float	maximum solar zenith angle for determining sun glint	degrees	89.0
VCM_SUNGLINT_MAX_REFANG_FOR_GEO	float	maximum reflection angle for sun glint to be geometry based	degrees	36.0
PROB_THRESH	float	probability threshold for sun glint	unitless	1.5
M12 Reflectance Calculation				
LAMBDA_M12	float	response-weighted M12 band center	meters	3.78e-06
M12_MEAN_TOA_SOL_IRRAD	float	average extra-terrestrial solar irradiance in M12 band corrected for sensor responsivity	W/m^2 µm	10.78125
Aerosol and Fire Parameters				
VCM_AERO_NUM_MOD_WIN_CANDS_THRESH	uint	minimum number of moderate resolution pixels containing heavy aerosol candidates for heavy aerosol spatial test to be performed	unitless	2
VCM_AERO_NUM_IMG_SAMPS_STDDEV_THRESH	uint	minimum number of imagery resolution pixels required to compute standard deviation for heavy aerosol spatial test	unitless	8
VCM_AERO_ASH_POLAR_LAT	float	lower bound latitude for using volcanic ash detection in polar regions	degrees	60.0
VCM_AERO_ASH_TROPIC_LAT	float	lower bound latitude for using volcanic ash detection in tropic regions	degrees	30.0
VCM_AERO_DUST_SOLZEN	float	maximum solar zenith angle allowed for dust detection	degrees	75.0
VCM_AERO_SMOKE_SOLZEN	float	maximum solar zenith angle allowed for smoke detection	degrees	75.0
VCM_AERO_ASH_SOLZEN	float	maximum solar zenith angle allowed for volcanic ash detection	degrees	70.0
VCM_AERO_SMOKE_CONF_M11M1_REFLRATIO_THRESH	float	maximum M11/M1 reflectance ratio at nadir for confident heavy aerosol detection; smoke candidate flag also set; value corrected for sensor zenith angle	unitless	0.1

Name	Type	Description	Units	Sug Value
VCM_AERO_SMOKE_CAND_M11M1_REFLRATIO_THRESH	float	maximum M11/M1 reflectance ratio at nadir for possible presence of smoke; value corrected for sensor zenith angle	unitless	0.25
VCM_AERO_DUST_M1_REFL_THRESH	float	maximum M1 reflectance for possible presence of dust;	unitless	0.3
VCM_AERO_DUST_M1M5_REFLRATIO_THRESH	float	maximum M1/M5 reflectance ratio at nadir for possible presence of dust; value corrected for sensor zenith angle	unitless	2.0
VCM_AERO_COMP_OCEAN_M15M16BTD_MAX_THRESH	float	maximum M15 – M16 BTD threshold for volcanic ash detection	Kelvin	-0.25
VCM_AERO_ASH_OCEAN_MAX_LAT	float	maximum latitude for applying volcanic ash detection over water	degrees	60.0
VCM_AERO_ASH_OCEAN_MIN_LAT	float	minimum latitude for applying volcanic ash detection over water	degrees	-45.0
VCM_AERO_ASH_MIN_TOC_NDVI	float	minimum TOC NDVI for which volcanic ash detection over land should be performed	unitless	0.7
VCM_AERO_ASH_EXCLREG1_LAT_UP	float	boundaries of 1st exclusion region where volcanic ash detection over water is not performed in order to eliminate regions of high false alarms	degrees	-5.0
VCM_AERO_ASH_EXCLREG1_LAT_LO	float		degrees	-30.0
VCM_AERO_ASH_EXCLREG1_LON_LF	float		degrees	-105.0
VCM_AERO_ASH_EXCLREG1_LON_RT	float		degrees	-70.0
VCM_AERO_ASH_EXCLREG2_LAT_UP	float	boundaries of 2nd exclusion region where volcanic ash detection over water is not performed in order to eliminate regions of high false alarms	degrees	-15.0
VCM_AERO_ASH_EXCLREG2_LAT_LO	float		degrees	-30.0
VCM_AERO_ASH_EXCLREG2_LON_LF	float		degrees	0.0
VCM_AERO_ASH_EXCLREG2_LON_RT	float		degrees	15.0
VCM_AERO_ASH_EXCLREG3_LAT_UP	float	boundaries of 3rd exclusion region where volcanic ash detection over water is not performed in order to eliminate regions of high false alarms	degrees	30.0
VCM_AERO_ASH_EXCLREG3_LAT_LO	float		degrees	15.0
VCM_AERO_ASH_EXCLREG3_LON_LF	float		degrees	-150.0
VCM_AERO_ASH_EXCLREG3_LON_RT	float		degrees	-120.0
VCM_AERO_ASH_REFM12_MIN_THRESH_1	float	first minimum M12 reflectance for volcanic ash detection over land	unitless	0.08
VCM_AERO_ASH_BTM15_MAX_THRESH_1	float	first maximum M15 BT threshold for detection of volcanic ash over land	Kelvin	210.0
VCM_AERO_ASH_REFM5_MAX_THRESH_1	float	first maximum M5 reflectance threshold for detection of volcanic ash over land	unitless	0.4
VCM_AERO_ASH_BTM15_TROPIC_MAX_THRESH_1	float	1st set of spectral discriminators for volcanic ash detection over land at tropical latitudes: • maximum M15 BT, • minimum M12/M5 reflectance ratio, • maximum M15 – M16 BTD, respectively	Kelvin	280.0
VCM_AERO_ASH_M12M5REFRAT_TROPIC_MIN_THRESH_1	float		unitless	1.0
VCM_AERO_ASH_M15M16BTDIFF_TROPIC_MAX_THRESH_1	float		Kelvin	0.0

Name	Type	Description	Units	Sug Value
VCM_AERO_ASH_BTM15_TROPIC_MAX_THRESH_2	float	2nd set of spectral discriminators for volcanic ash detection over land at tropical latitudes: • maximum M15 BT, • minimum M12/M5 reflectance ratio, • maximum M15 – M16 BTD, respectively	Kelvin	285.0
VCM_AERO_ASH_M12M5REFRAT_TROPIC_MIN_THRESH_2	float		unitless	1.0
VCM_AERO_ASH_M15M16BTDIFF_TROPIC_MAX_THRESH_2	float		Kelvin	-1.0
VCM_AERO_ASH_BTM15_TROPIC_MAX_THRESH_3	float	3rd set of spectral discriminators for volcanic ash detection over land at tropical latitudes: • maximum M15 BT, • minimum M12/M5 reflectance ratio, • maximum M15 – M16 BTD, respectively	Kelvin	277.0
VCM_AERO_ASH_M12M5REFRAT_TROPIC_MIN_THRESH_3	float		unitless	0.7
VCM_AERO_ASH_M15M16BTDIFF_TROPIC_MAX_THRESH_3	float		Kelvin	-2.0
VCM_AERO_ASH_BTM15_TROPIC_MAX_THRESH_4	float	4th set of spectral discriminators for volcanic ash detection over land at tropical latitudes: • maximum M15 BT, • maximum M5 reflectance, • minimum M12 reflectance, respectively	Kelvin	233.0
VCM_AERO_ASH_REFM5_TROPIC_MAX_THRESH_4	float		unitless	0.6
VCM_AERO_ASH_REFM12_TROPIC_MIN_THRESH_4	float		unitless	0.2
VCM_AERO_ASH_BTM15_MIDLAT_MAX_THRESH_1	float	1st set of spectral discriminators for volcanic ash detection over land at mid latitudes: • maximum M15 BT, • minimum M12/M5 reflectance ratio, • maximum M15 – M16 BTD, respectively	Kelvin	270.0
VCM_AERO_ASH_M12M5REFRAT_MIDLAT_MIN_THRESH_1	float		unitless	1.0
VCM_AERO_ASH_M15M16BTDIFF_MIDLAT_MAX_THRESH_1	float		Kelvin	-0.5
VCM_AERO_ASH_BTM15_MIDLAT_MAX_THRESH_2	float	2nd set of spectral discriminators for volcanic ash detection over land at mid latitudes: • maximum M15 BT, • minimum M12/M5 reflectance ratio, • maximum M15 – M16 BTD, respectively	Kelvin	270.0
VCM_AERO_ASH_M12M5REFRAT_MIDLAT_MIN_THRESH_2	float		unitless	0.7
VCM_AERO_ASH_M15M16BTDIFF_MIDLAT_MAX_THRESH_2	float		Kelvin	-1.0
VCM_AERO_ASH_BTM15_MIDLAT_MAX_THRESH_3	float	3rd set of spectral discriminators for volcanic ash detection over land at mid latitudes: • maximum M15 BT, • minimum M12/M5 reflectance ratio, • maximum M15 – M16 BTD, respectively	Kelvin	277.0
VCM_AERO_ASH_M12M5REFRAT_MIDLAT_MIN_THRESH_3	float		unitless	0.7
VCM_AERO_ASH_M15M16BTDIFF_MIDLAT_MAX_THRESH_3	float		Kelvin	-2.0
VCM_AERO_ASH_BTM15_MIDLAT_MAX_THRESH_4	float	4th set of spectral discriminators for volcanic ash detection over land at mid latitudes: • maximum M15 BT, • maximum M5 reflectance, • minimum M12 reflectance, respectively	Kelvin	235.0
VCM_AERO_ASH_REFM5_MIDLAT_MAX_THRESH_4	float		unitless	0.6
VCM_AERO_ASH_REFM12_MIDLAT_MIN_THRESH_4	float		unitless	0.2
VCM_AERO_ASH_BTM15_POLAR_MAX_THRESH_1	float	1st set of spectral discriminators for volcanic ash detection over land at polar latitudes: • maximum M15 BT, • maximum M15 – M16 BTD, respectively	Kelvin	277.0
VCM_AERO_ASH_M15M16BTDIFF_POLAR_MAX_THRESH_1	float		Kelvin	-3.0

Name	Type	Description	Units	Sug Value
VCM_AERO_ASH_BTM15_POLAR_MAX_THRESH_2	float	2nd set of spectral discriminators for volcanic ash detection over land at polar latitudes: • maximum M15 BT, • maximum M15 – M16 BTD, • minimum M12/M5 reflectance ratio, respectively	Kelvin	270.0
VCM_AERO_ASH_M15M16BTDIFF_POLAR_MAX_THRESH_2	float		Kelvin	-0.5
VCM_AERO_ASH_M12M5REFRAT_POLAR_MIN_THRESH_2	float		unitless	1.1
VCM_AERO_ASH_BTM15_POLAR_MAX_THRESH_3	float	3rd set of spectral discriminators for volcanic ash detection over land at polar latitudes: • maximum M15 BT, • maximum M15 – M16 BTD, • minimum M12 reflectance, respectively	Kelvin	245.0
VCM_AERO_ASH_M15M16BTDIFF_POLAR_MAX_THRESH_3	float		Kelvin	-0.5
VCM_AERO_ASH_REFM12_POLAR_MIN_THRESH_3	float		unitless	0.1
VCM_AERO_ASH_BTM15_POLAR_MAX_THRESH_4	float	4th set of spectral discriminators for volcanic ash detection over land at polar latitudes: • maximum M15 BT, • minimum M12 reflectance, • maximum M5 reflectance, respectively	Kelvin	240.0
VCM_AERO_ASH_REFM12_POLAR_MIN_THRESH_4	float		unitless	0.2
VCM_AERO_ASH_REFM5_POLAR_MAX_THRESH_4	float		unitless	0.8
VCM_AERO_WATER_STDDEV_THRESH	float	maximum standard deviation for heavy aerosol detection over ocean and inland water using spatial test	unitless	0.01
VCM_AERO_LAND_STDDEV_THRESH	float	maximum standard deviation for heavy aerosol detection over land, desert and coast using spatial test	unitless	0.02
VCM_AERO_COMP_TOCNDVI_THRESH	float	minimum TOC_NDVI for heavy aerosol detection over desert, land, and coast using spatial test	unitless	0.3
Imagery Band Test Parameters				
BTI4_limit	float	minimum I4 BT for performing imagery band spatial uniformity test at night	Kelvin	270.0
VCM_I2_MAX_VAR_THRESH	float	maximum I2 reflectance variance threshold for spatial uniformity test over non-cloudy water pixels during the day	unitless	0.010
VCM_I2_MIN_VAR_THRESH	float	minimum I2 reflectance variance threshold for spatial uniformity test over non-cloudy water pixels during the day	unitless	0.003
I4varthres	float	minimum I4 variance threshold for spatial uniformity test over nighttime pixels	Kelvin	0.50
I5varthres	float	minimum I5 variance threshold for spatial uniformity test over nighttime pixels	Kelvin	0.50
vis2_ref_arr[NSZ][NVZ][NRAZ]	float * NSZ * NVZ * NRAZ	I2 reflectance array	unitless	

Name	Type	Description	Units	Sug Value
Cloud Confidence Parameters				
VCM_CONFIDENCE_HIGH	float	maximum composite cloud confidence threshold for classifying a pixel as “Confidently Clear”	unitless	0.90
VCM_CONFIDENCE_MED	float	maximum composite cloud confidence threshold for classifying a pixel as “Probably Clear”	unitless	0.5
VCM_CONFIDENCE_LOW	float	maximum composite cloud confidence threshold for classifying a pixel as “Probably Cloudy”; a pixel is classified as “Confidently Cloudy” when the composite cloud confidence value is exactly the value of this parameter	unitless	0.0
VCM_M7_TOA_NDVI_THRESH	float	maximum TOA NDVI allowable for execution of the water/day M7 reflectance test for pixels classified as inland water	unitless	0.10
VCM_MIN_PTPW	float	minimum path total precipitable water limit used in the execution of the M15-M12 BTD test for nighttime pixels	cm	0.0
VCM_MIN_COS_SENZEN_TOL	float	minimum allowable value for the cosine of the moderate band sensor zenith angle in order to avoid a singularity (1/0) result when the secant of the angle is determined	unitless	0.00001
VCM_M15_M16_MIN_DIFTEMP	float	minimum M15 – M16 BTD allowed before the default M15 – M16 BTD is used	Kelvin	0.1
CD_M15_M12_Hi	float	confident clear threshold used in the coast/day M15 – M12 emission difference test	Kelvin	-10.000
CD_M15_M12_Mid	float	clear/cloudy threshold used in the coast/day M15 – M12 emission difference test	Kelvin	-12.000
CD_M15_M12_Lo	float	confident cloudy threshold used in the coast/day M15 – M12 emission difference test	Kelvin	-14.000
CD_M15_M16_Mid	float	clear/cloudy default threshold used in the coast/day M15 – M16 emission thin cirrus test	Kelvin	3.0
CD_M15_M16_LO_CORR	float	correction added to the coast/day M15-M16 clear/cloudy threshold (derived or default CD_M15_M16_Mid) to define the confident cloudy threshold for the M15 – M16 emission thin cirrus test	Kelvin	0.5
CD_M15_M16_HI_CORR	float	correction applied to the coast/day M15-M16 clear/cloudy threshold (derived or default CD_M15_M16_Mid) to define the confident clear threshold for the M15 – M16 emission thin cirrus test	Kelvin	-0.25
CD_M9_Hi	float	confident clear threshold used in the coast/day M9 thin cirrus reflectance test	unitless	0.030
CD_M9_Mid	float	clear/cloudy threshold used in the coast/day M9 thin cirrus reflectance test	unitless	0.035
CD_M9_Lo	float	confident cloudy threshold used in the coast/day M9 thin cirrus reflectance test	unitless	0.040
DD_MIN_POLAR_LAT	float	absolute value of the minimum latitude defining the boundary of the polar latitude region for desert/day tests	degrees	60.0
DD_MAX_POLAR_LAT	float	absolute value of the maximum latitude defining the boundary of the polar latitude region for desert/day tests	degrees	MAX_LAT

Name	Type	Description	Units	Sug Value
DD_M15_M12_A1	float	first degree coefficient used in desert/day M15 – M12 threshold determination under low total path integrated water vapor (tpiwv) conditions according to equation threshold = A*tpiwv + B	Kelvin/cm	5.0
DD_M15_M12_B1	float	zeroth degree coefficient used in desert/day M15 – M12 threshold determination under low total path integrated water vapor (tpiwv) conditions according to equation threshold = A*tpiwv + B	Kelvin	-30.0
DD_M15_M12_A2	float	first degree coefficient used in desert/day M15 – M12 threshold determination under high total path integrated water vapor (tpiwv) conditions according to equation threshold = A*tpiwv + B	Kelvin/cm	0.5
DD_M15_M12_B2	float	zeroth degree coefficient used in desert/day M15 – M12 threshold determination under high total path integrated water vapor (tpiwv) conditions according to equation threshold = A*tpiwv + B	Kelvin	-21.0
DD_M15_M12_TPIWV_switch	float	total path integrated water vapor (tpiwv) switch value used for classifying low versus high tpiwv conditions in the desert/day M15 – M12 emission difference test	cm	2.0
DD_M15_M12_LO_CORR	float	correction added to the derived desert/day M15-M12 clear/cloudy threshold to define the confident cloudy threshold for the M15 – M12 emission thin cirrus test	Kelvin	-1.0
DD_M15_M12_HI_CORR	float	correction added to the derived desert/day M15-M12 clear/cloudy threshold to define the confident clear threshold for the M15 – M12 emission thin cirrus test	Kelvin	1.0
DD_M15_M16_Mid	float	clear/cloudy default threshold used in the desert/day M15 – M16 emission thin cirrus test	Kelvin	3.0
DD_M15_M16_LO_CORR	float	correction added to the desert/day M15-M16 clear/cloudy threshold (derived or default DD_M15_M16_Mid) to define the confident cloudy threshold for the M15 – M16 emission thin cirrus test	Kelvin	0.50
DD_M15_M16_HI_CORR	float	correction added to the desert/day M15-M16 clear/cloudy threshold (derived or default DD_M15_M16_Mid) to define the confident clear threshold for the M15 – M16 emission thin cirrus test	Kelvin	-0.25
DD_M1_Hi	float	confident clear threshold used in the desert/day M1 reflectance threshold test	unitless	0.40
DD_M1_Mid	float	clear/cloudy threshold used in the desert/day M1 reflectance threshold test	unitless	0.45
DD_M1_Lo	float	confident cloudy threshold used in the desert/day M1 reflectance threshold test	unitless	0.50
DD_M9_TPIWV_cutoff	float	minimum total path integrated water vapor value required for conducting desert/day M9 reflectance threshold test and thin cirrus test; also used in thin cirrus to set threshold over coast/day pixels	cm	0.25

Name	Type	Description	Units	Sug Value
DD_M9_Hi	float	confident clear threshold used in the desert/day M9 reflectance threshold test	unitless	0.030
DD_M9_Mid	float	clear/cloudy threshold used in the desert/day M9 reflectance threshold test	unitless	0.035
DD_M9_Lo	float	confident cloudy threshold used in the desert/day M9 reflectance threshold test	unitless	0.040
LD_M12_M13_Hi	float	confident clear threshold used in the land/day M12 – M13 emission difference test	Kelvin	12.0
LD_M12_M13_Mid	float	clear/cloudy threshold used in the land/day M12 – M13 emission difference test	Kelvin	13.75
LD_M12_M13_Lo	float	confident cloudy threshold used in the land/day M12 – M13 emission difference test	Kelvin	15.50
LD_M15_M12_Hi	float	confident clear threshold used in the land/day M15 – M12 emission difference test	Kelvin	-16.000
LD_M15_M12_Mid	float	clear/cloudy threshold used in the land/day M15 – M12 emission difference test	Kelvin	-18.000
LD_M15_M12_Lo	float	confident cloudy threshold used in the land/day M15 – M12 emission difference test	Kelvin	-20.000
LD_M15_M16_Mid	float	clear/cloudy default threshold used in the land/day M15 – M16 emission thin cirrus test	Kelvin	3.0
LD_M15_M16_LO_CORR	float	correction added to the land/day M15-M16 clear/cloudy threshold (derived or default LD_M15_M16_Mid) to define the confident cloudy threshold for the M15 – M16 emission thin cirrus test	Kelvin	0.50
LD_M15_M16_HI_CORR	float	correction added to the land/day M15-M16 clear/cloudy threshold (derived or default LD_M15_M16_Mid) to define the confident clear threshold for the M15 – M16 emission thin cirrus test	Kelvin	-0.25
LD_M5_M7_Hi	float	confident clear threshold used in the land/day M7/M5 reflectance threshold test	unitless	1.87
LD_M5_M7_Mid	float	clear/cloudy threshold used in the land/day M7/M5 reflectance threshold test	unitless	1.82
LD_M5_M7_Lo	float	confident cloudy threshold used in the land/day M7/M5 reflectance threshold test	unitless	1.78
LD_M5_GEMI_THRESH	float	minimum M5 reflectance required to perform the land/day M7/M5 reflectance threshold test	unitless	0.1
LD_M9_Hi	float	confident clear threshold used in the land/day M9 thin cirrus reflectance test	unitless	0.030
LD_M9_Mid	float	clear/cloudy threshold used in the land/day M9 thin cirrus reflectance test	unitless	0.035
LD_M9_Lo	float	confident cloudy threshold used in the land/day M9 thin cirrus reflectance test	unitless	0.040
LN_M12_M16_Hi	float	confident clear threshold used in the land/night M12 – M16 emission difference test	Kelvin	3.500
LN_M12_M16_Mid	float	clear/cloudy threshold used in the land/night M12 – M16 emission difference test	Kelvin	4.000
LN_M12_M16_Lo	float	confident cloudy threshold used in the land/night M12 – M16 emission difference test	Kelvin	4.500
LN_M15_M12_Hi	float	confident clear threshold used in the land/night M15 – M12 emission difference test	Kelvin	2.000

Name	Type	Description	Units	Sug Value
LN_M15_M12_Mid	float	clear/cloudy threshold used in the land/night M15 – M12 emission difference test	Kelvin	2.500
LN_M15_M12_Lo	float	confident cloudy threshold used in the land/night M15 – M12 emission difference test	Kelvin	3.000
LN_M15_M12_MAX_PTPW	float	maximum slant-path-corrected total precipitable water limit for the land/night M15 – M12 BTD emission test	cm	5.0
LN_HI_PTPW_FACTOR	float	slant path total precipitable water factor used for adjusting the M15 – M12 confident clear sky threshold LN_M15_M12_Hi, see above	Kelvin/cm	0.6
LN_MID_PTPW_FACTOR	float	slant path total precipitable water factor used for adjusting the M15 – M12 clear/cloudy threshold LN_M15_M12_Mid, see above	Kelvin/cm	0.5
LN_LO_PTPW_FACTOR	float	slant path total precipitable water factor used for adjusting the M15 – M12 confident cloudy threshold LN_M15_M12_Lo, see above	Kelvin/cm	0.4
LN_M15_M16_Mid	float	clear/cloudy default threshold used in the land/night M15 – M16 emission thin cirrus test	Kelvin	3.0
LN_M15_M16_LO_CORR	float	correction added to the land/night M15-M16 clear/cloudy threshold (derived or default LN_M15_M16_Mid) to define the confident cloudy threshold for the M15 – M16 emission thin cirrus test	Kelvin	0.50
LN_M15_M16_HI_CORR	float	correction added to the land/night M15-M16 clear/cloudy threshold (derived or default LN_M15_M16_Mid) to define the confident clear threshold for the M15 – M16 emission thin cirrus test	Kelvin	-0.25
LN_M15_LO_CORR	float	correction added to the derived M15 clear/cloudy threshold used in the land/night M15 emission test to produce the confident cloudy threshold	Kelvin	2.0
LN_M15_HI_CORR	float	correction added to the derived M15 clear/cloudy threshold used in the land/night M15 emission test to produce the confident clear threshold	Kelvin	-2.0
SD_M12_M13_Hi	float	confident clear threshold used in the snow/day M12 – M13 emission difference test	Kelvin	10.5
SD_M12_M13_Mid	float	clear/cloudy threshold used in the snow/day M12 – M13 emission difference test	Kelvin	12.5
SD_M12_M13_Lo	float	confident cloudy threshold used in the snow/day M12 – M13 emission difference test	Kelvin	14.5
SD_M12_M15_Hi	float	confident clear threshold used in the snow/day M15 – M12 emission difference test when terrain height is less or equal to high elevation threshold, HiElevThresh	Kelvin	25.00
SD_M12_M15_Mid	float	clear/cloudy threshold used in the snow/day M15 – M12 emission difference test when terrain height is less or equal to high elevation threshold, HiElevThresh	Kelvin	27.5
SD_M12_M15_Lo	float	confident cloudy threshold used in the snow/day M15 – M12 emission difference test when terrain height is less or equal to high elevation threshold, HiElevThresh	Kelvin	30.0

Name	Type	Description	Units	Sug Value
SD_M12_M15_HiHiElev	float	confident clear threshold used in the snow/day M15 – M12 emission difference test when terrain height is greater than high elevation threshold, HiElevThresh	Kelvin	25.0
SD_M12_M15_MidHiElev	float	clear/cloudy threshold used in the snow/day M15 – M12 emission difference test when terrain height is greater than high elevation threshold, HiElevThresh	Kelvin	27.5
SD_M12_M15_LoHiElev	float	confident cloudy threshold used in the snow/day M15 – M12 emission difference test when terrain height is greater than high elevation threshold, HiElevThresh	Kelvin	30.0
SD_M9_Hi	float	confident clear threshold used in the snow/day M9 thin cirrus reflectance test	unitless	0.030
SD_M9_Mid	float	clear/cloudy threshold used in the snow/day M9 thin cirrus reflectance test	unitless	0.035
SD_M9_Lo	float	confident cloudy threshold used in the snow/day M9 thin cirrus reflectance test	unitless	0.040
SN_M12_M16_Hi	float	confident clear threshold used in the snow/night M12 – M16 emission difference test	Kelvin	3.500
SN_M12_M16_Mid	float	clear/cloudy threshold used in the snow/night M12 – M16 emission difference test	Kelvin	4.000
SN_M12_M16_Lo	float	confident cloudy threshold used in the snow/night M12 – M16 emission difference test	Kelvin	4.500
SN_M15_M12_Hi	float	confident clear threshold used in the snow/night M15 – M12 emission difference test	Kelvin	-5.00
SN_M15_M12_Mid	float	clear/cloudy threshold used in the snow/night M15 – M12 emission difference test	Kelvin	-6.00
SN_M15_M12_Lo	float	confident cloudy threshold used in the snow/night M15 – M12 emission difference test	Kelvin	-7.00
SN_M15_LO_CORR	float	correction added to the derived M15 clear/cloudy threshold used in the snow/night M15 emission test to produce the confident cloudy threshold	Kelvin	2.0
SN_M15_HI_CORR	float	correction added to the derived M15 clear/cloudy threshold used in the snow/night M15 emission test to produce the confident clear threshold	Kelvin	-2.0
WD_M12_M13_Hi	float	confident clear threshold used in the water/day M12 – M13 emission difference test	Kelvin	10.0
WD_M12_M13_Mid	float	clear/cloudy threshold used in the water/day M12 – M13 emission difference test	Kelvin	10.5
WD_M12_M13_Lo	float	confident cloudy threshold used in the water/day M12 – M13 emission difference test	Kelvin	11.0
WD_M15_M12_Hi	float	confident clear threshold used in the water/day M15 – M12 emission difference test	Kelvin	-8.000
WD_M15_M12_Mid	float	clear/cloudy threshold used in the water/day M15 – M12 emission difference test	Kelvin	-10.000
WD_M15_M12_Lo	float	confident cloudy threshold used in the water/day M15 – M12 emission difference test	Kelvin	-12.000

Name	Type	Description	Units	Sug Value
WD_M15_M16_Mid	float	clear/cloudy default threshold used in the water/day M15 – M16 emission thin cirrus test	Kelvin	3.0
WD_M15_M16_LO_CORR	float	correction added to the water/day M15 – M16 clear/cloudy threshold (derived or default WD_M15_M16_Mid) to define the confident cloudy threshold for the M15 – M16 emission thin cirrus test	Kelvin	0.50
WD_M15_M16_HI_CORR	float	correction added to the water/day M15-M16 clear/cloudy threshold (derived or default WD_M15_M16_Mid) to define the confident clear threshold for the M15 – M16 emission thin cirrus test	Kelvin	-0.25
WD_M14_M15_M16_LO_CORR	float	correction added to a derived clear/cloudy threshold to define the confident cloudy threshold for the trispectral emission test	Kelvin	0.5
WD_M14_M15_M16_HI_CORR	float	correction added to a derived clear/cloudy threshold to define the confident clear threshold for the trispectral emission test	Kelvin	-0.5
WD_M5_M7_Hi1	float	confident clear threshold used in the water/day M7/M5 reflectance threshold test when no land (e.g., island) and no sun glint is present	unitless	~~0.85~~ 0.94
WD_M5_M7_Mid1	float	clear/cloudy threshold used in the water/day M7/M5 reflectance threshold test when no land (e.g., island) and no sun glint is present	unitless	~~0.90~~ 0.99
WD_M5_M7_Lo1	float	confident cloudy threshold used in the water/day M7/M5 reflectance threshold test when no land (e.g., island) and no sun glint is present	unitless	~~0.95~~ 1.05
WD_M5_M7_Hi2	float	confident clear threshold used in the water/day M7/M5 reflectance threshold test when no sun glint is present but some land (e.g., land) is present	unitless	~~1.15~~ 1.10
WD_M5_M7_Mid2	float	clear/cloudy threshold used in the water/day M7/M5 reflectance threshold test when no sun glint is present but some land (e.g., land) is present	unitless	~~1.10~~ 1.05
WD_M5_M7_Lo2	float	confident cloudy threshold used in the water/day M7/M5 reflectance threshold test when no sun glint is present but some land (e.g., land) is present	unitless	~~0.95~~ 1.00
WD_M7_HI_POLY_COEFS	double	0th-3rd order polynomial coefficients on scattering angle when used in the Confident Clear threshold calculation for the water/day /noGlint M7 reflectance test 1 Dimensional Array: NUM_WD_M7_POLY_COEFS Size of Dimension(s): 4	unitless	see CDFCB-X, vol VIII

Name	Type	Description	Units	Sug Value
WD_M7_MID_POLY_COEFS	double	0th-3rd order polynomial coefficients on scattering angle when used in the Clear / Cloudy threshold calculation for the water/day /noGlint M7 reflectance test 1 Dimensional Array: NUM_WD_M7_POLY_COEFS Size of Dimension(s): 4	unitless	see CDFCB-X, vol VIII
WD_M7_LO_POLY_COEFS	double	0th-3rd order polynomial coefficients on scattering angle when used in the Confident Cloudy threshold calculation for the water/day /noGlint M7 reflectance test 1 Dimensional Array: NUM_WD_M7_POLY_COEFS Size of Dimension(s): 4	unitless	see CDFCB-X, vol VIII
WD_M7_HI_CORR	float	Confident Clear threshold correction for the water/day /noGlint M7 reflectance test,	unitless	see CDFCB-X, vol VIII
WD_M7_MID_CORR	float	Clear / Cloudy threshold correction for the water/day /noGlint M7 reflectance test,	unitless	see CDFCB-X, vol VIII
WD_M7_LO_CORR	float	Confident Cloudy threshold correction for the water/day /noGlint M7 reflectance test,	unitless	see CDFCB-X, vol VIII
Implicit_pad0	Char	Padding	Unitless	-
WD_M7_SNGLNT_HI_POLY_COEFS	float	0th-3rd order polynomial coefficients on scattering angle when used in the Confident Clear threshold calculation for the M7 reflectance test over inland water or in glint 1 Dimensional Array: NUM_WD_M7_POLY_COEFS Size of Dimension(s): 4	unitless	see CDFCB-X, vol VIII
WD_M7_SNGLNT_MID_POLY_COEFS	float	0th-3rd order polynomial coefficients on scattering angle when used in the Clear / Cloudy threshold calculation for the M7 reflectance test over inland water or in glint 1 Dimensional Array: NUM_WD_M7_POLY_COEFS Size of Dimension(s): 4	unitless	see CDFCB-X, vol VIII

Name	Type	Description	Units	Sug Value
WD_M7_SNGLNT_LO_POLY_COEFS	float	0th-3rd order polynomial coefficients on scattering angle when used in the Confident Cloudy threshold calculation for the M7 reflectance test over inland water or in glint 1 Dimensional Array: NUM_WD_M7_POLY_COEFS Size of Dimension(s): 4	unitless	see CDFCB-X, vol VIII
WD_M7_SNGLNT_HI_CORR	float	Confident Clear threshold correction for the M7 reflectance test over inland water or in glint	unitless	see CDFCB-X, vol VIII
WD_M7_SNGLNT_MID_CORR	float	Clear / Cloudy threshold correction for the M7 reflectance test over inland water or in glint,	unitless	see CDFCB-X, vol VIII
WD_M7_SNGLNT_LO_CORR	float	Confident Cloudy threshold correction for the M7 reflectance test over inland water or in glint	unitless	see CDFCB-X, vol VIII
WD_M9_Hi	float	confident clear threshold used in the water/day M9 thin cirrus reflectance test	unitless	0.030
WD_M9_Mid	float	clear/cloudy threshold used in the water/day M9 thin cirrus reflectance test	unitless	0.035
WD_M9_Lo	float	confident cloudy threshold used in the water/day M9 thin cirrus reflectance test	unitless	0.040
WN_M15_M12_Hi	float	confident clear base threshold used in the water/night M15 – M12 emission difference test; threshold adjusted for precipitable water	Kelvin	2.0
WN_M15_M12_Mid	float	clear/cloudy base threshold used in the water/night M15 – M12 emission difference test; threshold adjusted for precipitable water	Kelvin	2.5
WN_M15_M12_Lo	float	confident cloudy base threshold used in the water/night M15 – M12 emission difference test; threshold adjusted for precipitable water	Kelvin	3.0
WN_M15_M12_MAX_PTPW	float	maximum slant-path-corrected total precipitable water limit for the water/night M15 – M12 BTD emission test	cm	5.0
WN_HI_PTPW_FACTOR	float	slant path total precipitable water factor used for adjusting the M15 – M12 confident clear sky threshold WN_M15_M12_Hi, see above	Kelvin/cm	0.6
WN_MID_PTPW_FACTOR	float	slant path total precipitable water factor used for adjusting the M15 – M12 clear/cloudy threshold WN_M15_M12_Mid, see above	Kelvin/cm	0.5
WN_LO_PTPW_FACTOR	float	slant path total precipitable water factor used for adjusting the M15 – M12 confident cloudy threshold WN_M15_M12_Lo, see above	Kelvin/cm	0.4
WN_M15_M16_Mid	float	clear/cloudy default threshold used in the water/night M15 – M16 emission thin cirrus test	Kelvin	3.0
WN_M15_M16_LO_CORR	float	correction added to the water/night M15-M16 clear/cloudy threshold (derived or default WN_M15_M16_Mid) to define the confident cloudy threshold for the M15 – M16 emission thin cirrus test	Kelvin	0.50

Name	Type	Description	Units	Sug Value
WN_M15_M16_HI_CORR	float	correction added to the water/night M15-M16 clear/cloudy threshold (derived or default WN_M15_M16_Mid) to define the confident clear threshold for the M15 – M16 emission thin cirrus test	Kelvin	-0.25
WN_M15_LO_CORR	float	correction added to the derived M15 clear/cloudy threshold used in the water/night M15 emission test to produce the confident cloudy threshold	Kelvin	2.0
WN_M15_HI_CORR	float	correction added to the derived M15 clear/cloudy threshold used in the water/night M15 emission test to produce the confident clear threshold	Kelvin	-2.0
WN_M14_M15_M16_LO_CORR	float	correction added to a derived clear/cloudy threshold to define the confident cloudy threshold for the trispectral emission test	Kelvin	0.5
WN_M14_M15_M16_HI_CORR	float	correction added to a derived clear/cloudy threshold to define the confident clear threshold for the trispectral emission test	Kelvin	-0.5
HiElevThresh	int16	minimum high terrain value required for 1) performing snow/day and snow/night M12 – M15 emission difference test, and 2) setting a M12-M15 BT difference threshold in snow/ice determination	meters	2000
sst_thres	float	clear/cloudy base threshold used for ocean pixels in the water/night M15 – M16 emission threshold test; value adjusted with brightness temperature difference and corrected for sensor zenith angle	Kelvin	6.0
sst_in_water_thres	float	clear/cloudy base threshold used for inland water pixels in the water/night M15 – M16 emission threshold test; value adjusted with brightness temperature difference and corrected for sensor zenith angle	Kelvin	10.0
lst_thres	float	clear/cloudy base threshold used for non-desert pixels in the land/night M15 – M16 emission threshold test; value adjusted with brightness temperature difference and corrected for sensor zenith angle	Kelvin	12.0
lst_desert_thres	float	clear/cloudy base threshold used for desert pixels in the land/night M15 – M16 emission threshold test; value adjusted with brightness temperature difference and corrected for sensor zenith angle	Kelvin	20.0
lst_snow_thres	float	clear/cloudy base threshold used in the snow/night M15 – M16 emission threshold test; value adjusted with brightness temperature difference and corrected for sensor zenith angle	Kelvin	12.0
VCM_MIN_SFC_TEMP	float	minimum surface temperature required to perform the nighttime M15 – M16 emission threshold test	Kelvin	170.0
VCM_MAX_SFC_TEMP	float	maximum surface temperature required to perform the nighttime M15 – M16 emission threshold test	Kelvin	350.0

Name	Type	Description	Units	Sug Value
snglntRatio_Hi1	float	confident clear threshold used in the water/day M7/M5 reflectance threshold test when sun glint is present but no land (e.g., island) is present	unitless	0.95
snglntRatio_Mid1	float	clear/cloudy threshold used in the water/day M7/M5 reflectance threshold test when sun glint is present but no land (e.g., island) is present	unitless	1.00
snglntRatio_Lo1	float	confident cloudy threshold used in the water/day M7/M5 reflectance threshold test when sun glint is present but no land (e.g., island) is present	unitless	1.05
snglntRatio_Hi2	float	confident clear threshold used in the water/day M7/M5 reflectance threshold test when sun glint and some land (e.g., island) is present	unitless	~~1.20~~ 1.10
snglntRatio_Mid2	float	clear/cloudy threshold used in the water/day M7/M5 reflectance threshold test when sun glint and some land (e.g., island) is present	unitless	~~1.10~~ 1.06
snglntRatio_Lo2	float	confident cloudy thresholds used in the water/day M7/M5 reflectance threshold test when sun glint and some land (e.g., island) is present	unitless	~~1.05~~ 1.02
BTM12_limit	float	minimum brightness temperature M12 required for performing M15 – M12 emission difference test under nighttime conditions	Kelvin	230.0
highLat	float	maximum northern latitude in which M12-M13 BT Difference Test is used	degrees	60.0
lowLat	float	Maximum southern latitude in which M12-M13 BT Difference Test is used	degrees	–60.0
VCM_M15M12DIFF_MIN_TOCNDVI	float	minimum TOC NDVI required to perform the land/day and coast/day M15 – M12 emission difference test.	unitless	0.20
VCM_M12M13DIFF_MIN_TOCNDVI	float	minimum TOC NDVI required to perform the land/day M12 – M13 emission difference test	unitless	0.20
VCM_NIGHT_MIN_TOCNDVI	float	minimum TOC NDVI required to perform the land/night M15 – M12 emission difference test	unitless	0.25
VCM_TRISPEC_C0	float	coefficients for the trispectral clear/cloudy threshold calculation, where midpt = VCM_TRISPEC_C0 + VCM_TRISPEC_C1 * T + VCM_TRISPEC_C2 * T^2 + VCM_TRISPEC_C3 * T^3	Kelvin	2.7681
VCM_TRISPEC_C1	float		unitless	- 3.729
VCM_TRISPEC_C2	float		1/Kelvin	1.054
VCM_TRISPEC_C3	float		1/$Kelvin^2$	-0.102
M15_M16_WV_CORR_THRESH	float	minimum threshold at which the M15 – M16 BTD clear/cloudy threshold is corrected for water vapor effects; used for nighttime tests for land, water and snow	Kelvin	1.00
M15_MIDPT_WV_CORR_FACTOR	float	water vapor correction factor applied to the M15 – M16 brightness temperature difference; the resulting product is used to adjust the nighttime M15 clear/cloudy threshold for land, water and snow	unitless	2.0
M15_ATM_SLANT_WV_CORR_FACTOR	float	slant path water vapor correction factor used in the M15 emission nighttime tests for land, water and snow	Kelvin	3.0
GEMI_RATIO1_CONST_1	float	Coefficients used in the M7/M5 GEMI ratio	unitless	2.0

Name	Type	Description	Units	Sug Value
GEMI_RATIO1_CONST_2	float	equation for land/day. Refer to Eqn 3.	unitless	1.5
GEMI_RATIO1_CONST_3	float		unitless	0.5
GEMI_RATIO2_CONST_1	float		unitless	0.005
GEMI_EQU_CONST_1	float		unitless	1.0
GEMI_EQU_CONST_2	float		unitless	0.25
GEMI_EQU_CONST_3	float		unitless	0.00125
GEMI_EQU_CONST_4	float		unitless	0.01
Thin Cirrus Detection Parameters				
LD_M9_thin_cirrus	float	default M9 thin cirrus clear/cloudy threshold for land/day	unitless	0.0125
CD_M9_thin_cirrus	float	default M9 thin cirrus clear/cloudy threshold for coast/day	unitless	0.0125
DD_M9_thin_cirrus	float	default M9 thin cirrus clear/cloudy threshold for desert/day	unitless	0.0300
SD_M9_thin_cirrus	float	default M9 thin cirrus clear/cloudy threshold for snow/day	unitless	0.0300
WD_M9_thin_cirrus	float	default M9 thin cirrus threshold for water/day	unitless	0.0125
M15_M16_THIN_CIRRUS_MID_CORR	float	correction added to the M15 – M16 clear/cloudy thin cirrus threshold	Kelvin	0.250
high_tpw_value	float	maximum limit on slant-path-corrected total precipitable water; for this limit and below, the M9 thin cirrus clear/cloudy threshold is corrected for water vapor effects; above this limit the default M9 thin cirrus clear/cloudy threshold is used	cm	3.0
DD_M9_TPIWV_cutoff	float	see Cloud Confidence Parameters section (minimum total path integrated water vapor value required for conducting desert/day M9 reflectance threshold test and thin cirrus test; also used in thin cirrus to set threshold over coast/day pixels)	cm	See Cloud Confidence Parameters section
Ephemeral Water Detection				
VCM_TOA_NDVI_THRESH	float	maximum TOA NDVI for detection of ephemeral water	unitless	0.01
Cloud Phase				
CP_LAMBDA_M12	float	M12 band center used in Cloud_Phase()	meters	3.7e-06
CP_M12_MEAN_TOA_SOL_IRRAD	float	mean M12 top of atmosphere solar irradiance	W/m^2	10.725412
CP_M12_BW_MICRONS	float	M12 bandwidth	microns	0.18
CP_M12_BW_METERS	float	M12 bandwidth	meters	0.18e-06
CP_EARTHSUNRATIO	float	ratio of the earth to sun distance/sun diameter	unitless	1.0
CP_M14M15_BTM15_LIMIT	float	Maximum valid BTM15 used in the M14M15 BTD test	Kelvin	320.0
CP_WIN_OVER_CORRECTION	float	SWBTD correction to vary MIN_win_over threshold table	Kelvin	0.1
CP_NIR_OVERLAP_WATER_CORRECTION	float	NIR correction to M9 over water which alters the M10 threshold	unitless	0.03
CP_NIR_OVERLAP_LAND_CORRECTION	float	NIR correction to M9 over land which alters the M10 threshold	unitless	0.05
CP_NIR_OVERLAP_LAND_MAX_POLY	float	lower limit on M10 reflection used with NIR test over land	unitless	0.25

Name	Type	Description	Units	Sug Value
CP_M9_WATER_HI_LAT_N	float	latitude for NIR cloud overlap test	degrees	50.0
CP_M9_WATER_HI_LAT_S	float	latitude for NIR cloud overlap test	degrees	-50.0
CP_IR_WATER_TROPIC_LAT_N	float	north latitude defining humid tropics for nighttime overlap test	degrees	30.0
CP_IR_WATER_TROPIC_LAT_S	float	south latitude defining humid tropics for nighttime overlap test	degrees	-30.0
CP_M9_DESERT_HI_LAT_N	float	latitude for NIR cloud overlap test	degrees	50.0
CP_M9_DESERT_HI_LAT_S	float	latitude for NIR cloud overlap test	degrees	-50.0
CP_M12_WATER_HI_LAT_N	float	hi polar latitude for NIR M12 test; assumes surf type is water	degrees	60.0
CP_M12_WATER_HI_LAT_S	float	lo polar latitude for NIR M12 test; assumes surf type is water	degrees	-60.0
CP_M12_DESERT_EXCLREG1_LAT_HI	float	hi latitude desert exclusion for NIR daytime cirrus M12 test	degrees	32.0
CP_M12_DESERT_EXCLREG1_LAT_LO	float	lo latitude desert exclusion for NIR daytime cirrus M12 test	degrees	12.0
CP_M12_DESERT_EXCLREG1_LON_LF	float	left longitude desert exclusion for NIR daytime cirrus M12 test	degrees	-20.0
CP_M12_DESERT_EXCLREG1_LON_RT	float	right longitude desert exclusion for NIR daytime cirrus M12 test	degrees	45.0
CP_M9_LAND_HI_LAT_N	float	north latitude for NIR cloud overlap test	degrees	40.0
CP_M9_LAND_HI_LAT_S	float	south latitude for NIR cloud overlap test	degrees	-40.0
CP_M10_SNOW_HI_LAT_N	float	north latitude for SWBTD cloud overlap test	degrees	50.0
CP_M10_SNOW_HI_LAT_S	float	south latitude for SWBTD cloud overlap test	degrees	-50.0
CP_MAX_BTM15_CERTAIN_ICE	float	maximum BTM15 for certain ice; all water is frozen at -40°C	Kelvin	233.16
CP_MIN_BTM15_MIXED	float	minimum BTM15 where water/ice coexist	Kelvin	253.16
CP_MAX_BTM15_MIXED	float	maximum BTM15 where water/ice coexist	Kelvin	273.16
CP_MAX_M10M5_RATIO_OVER_LAND	float	maximum M10/M5 ratio for M10 refl over land	unitless	1.0
CP_OP_ICE_MAX_M10M5_RATIO	float	maximum M10/M5 ratio for opaque cirrus	unitless	1.0
CP_CIRRUS_MIN_M9_THRESH	float	minimum M9 reflectance to detect presence of cirrus cloud; also used to reclassify mixed phase to cirrus. Note intentional double use.	unitless	0.025
CP_CIRRUS_MAX_M5_THRESH	float	maximum M5 reflectance to detect presence of cirrus cloud	unitless	0.40
CP_CIRRUS_MIN_M9M5_RATIO_THRESH	float	minimum M9/M5 ratio to detect presence of cirrus cloud	unitless	0.17
CP_OP_ICE_MAX_BTM15_THRESH	float	maximum BTM15 allowed to reclassify mixed phase to opaque ice	Kelvin	263.16
CP_M14_M15_THRESH_CORR	float	M14M15 BTD threshold correction to reclassify opaque ice to mixed phase	unitless	0.2
CP_THIN_CIRRUS_MIN_M9_THRESH	float	minimum M9 reflectance threshold to reclassify water phase to cirrus	unitless	0.01
CP_MIN_M14M15BTD_THRESH	float	minimum M14M15 BTD to reclassify water phase to cirrus	Kelvin	0.5
CP_M12_MIN_EMIS_THRESH_NIGHT	float	minimum EMSM12 to identify cirrus clouds at night using M15M16BTD test	unitless	1.2
CP_M12_MAX_EMIS_THRESH_NIGHT	float	maximum EMSM12 to identify cirrus clouds at night using M12 emission test	unitless	1.4

Name	Type	Description	Units	Sug Value
CP_MAX_BTM15_WIN_OVER	float	maximum BTM15 for SWBTD test to detect cloud overlap	Kelvin	270.0
CP_MAX_BTM15_NIR_OVER	float	maximum BTM15 for NIR test to detect cloud overlap	Kelvin	280.0
CP_MAX_BTM15_NIGHT_OVER	float	maximum BTM15 for nighttime detection of cloud overlap	Kelvin	290.0
CP_NIR_CIRRUS_THRES_WATER_M12	float	maximum NIR M12 threshold for detection of cirrus over water	Kelvin	0.15
CP_NIR_CIRRUS_THRES_LAND_M12	float	maximum NIR M12 threshold for detection of cirrus over land	Kelvin	0.15
CP_NIR_CIRRUS_THRES_DESERT_M12	float	maximum NIR M12 threshold for detection of cirrus over desert	Kelvin	0.40
CP_MIN_CIRRUS	float	minimum allowable cirrus threshold for M15-M16 BTD cirrus test	Kelvin	0.7
CP_MAX_CIRRUS	float	maximum allowable cirrus threshold for M15-M16 BTD cirrus test	Kelvin	4.0
CP_MIN_M5_OVER	float	SWBTD cloud overlap test param; minimum M5 reflectance to ensure presence of lower level water cloud	unitless	0.35
CP_MID_M5_OVER	float	SWBTD cloud overlap test param; M5 breakpoint. 4th degree polynomial applied min to mid region; linear mid to max	unitless	0.6
CP_MAX_M5_OVER	float	SWBTD cloud overlap test param; max M5 where curve fit is linear	unitless	1.00
CP_MIN_M1_OVER	float	min M1 refl over desert for valid SWBTD threshold	unitless	0.50
CP_MIN_M9_OVER_WATER_LOW	float	lower M9 limits of the NIR detection window for daytime overlap for water, tropic/mid latitudes	unitless	0.025
CP_MIN_M9_OVER_LAND_LOW	float	lower M9 limits of the NIR detection window for daytime overlap for land, tropic/mid latitudes	unitless	0.027
CP_MIN_M9_OVER_WATER_HIGH	float	lower M9 limits of the NIR detection window for daytime overlap for water, high latitudes	unitless	0.10
CP_MIN_M9_OVER_LAND_HIGH	float	lower M9 limits of the NIR detection window for daytime overlap for land, high latitudes	unitless	0.10
CP_M9_WIN_CHECK_THRES_LAND	float	upper M9 limits of the NIR window for daytime overlap for land	unitless	0.12
CP_M9_WIN_CHECK_THRES_WATER	float	upper M9 limits of the NIR window for daytime overlap for water	unitless	0.08
CP_MAX_M9_OVER	float	maximum M9 reflectance for valid NIR overlap threshold	unitless	0.40
CP_SNOW_M10_THRES_LOW	float	minimum M10 threshold in for detection of cloud overlap in non-polar latitudes with SWBTD test	unitless	0.10
CP_SNOW_M10_THRES_HIGH	float	minimum M10 threshold in for detection of cloud overlap in polar latitudes with SWBTD test	unitless	0.30
CP_M15_M16_N_OVER_L_TROPWATER	float	M15-M16 BTD low threshold for overlap over tropic oceans at night	Kelvin	0.58
CP_M15_M16_N_OVER_H_TROPWATER	float	M15-M16 BTD hi threshold for overlap over tropic oceans at night	Kelvin	2.50

Name	Type	Description	Units	Sug Value
CP_M12_N_OVER_L_TROPWATER	float	BTM12 low threshold for overlap over tropic oceans at night	Kelvin	1.00
CP_M12_N_OVER_H_TROPWATER	float	BTM12 hi threshold for overlap over tropic oceans at night	Kelvin	2.60
CP_M15_M16_N_OVER_L_MIDWATER	float	M15-M16 BTD low threshold for overlap over mid latitude oceans at night	Kelvin	0.58
CP_M15_M16_N_OVER_H_MIDWATER	float	M15-M16 BTD hi threshold for overlap over mid latitude oceans at night	Kelvin	2.00
CP_M12_N_OVER_L_MIDWATER	float	BTM12 low threshold for overlap over mid latitude oceans at night	Kelvin	1.00
CP_M12_N_OVER_H_MIDWATER	float	BTM12 hi threshold for overlap over mid latitude oceans at night	Kelvin	2.00
CP_M15_M16_N_OVER_L_LAND	float	M15-M16 BTD low threshold for overlap over land at night	Kelvin	0.58
CP_M15_M16_N_OVER_H_LAND	float	M15-M16 BTD hi threshold for overlap over land at night	Kelvin	2.00
CP_M12_N_OVER_L_LAND	float	BTM12 low threshold for overlap over land at night	Kelvin	1.00
CP_M12_N_OVER_H_LAND	float	BTM12 hi threshold for overlap over land at night	Kelvin	2.00
CP_M12_M15_N_OVER_L	float	M12-M15 BTD low threshold at night	Kelvin	3.0
CP_M12_M15_N_OVER_H	float	M12-M15 BTD hi threshold at night	Kelvin	15.0
A_nir_over_water[NSCT]	double * NSCT	NIR cloud overlap test coefficients used to define the M10 threshold over a water surface. Thresholds are a function of scattering angle (i.e., 18 bins used at 10 deg intervals represent 0 to 180 degrees scattering geometry). Coefficients are for a 4-degree polynomial in M9 reflectance, x: $Ax^4 + Bx^3 + Cx^2 + Dx + E$ Refer to Eqn 4.		
B_nir_over_water[NSCT]	double * NSCT			
C_nir_over_water[NSCT]	double * NSCT			
D_nir_over_water[NSCT]	double * NSCT			
E_nir_over_water[NSCT]	double * NSCT			
A_nir_over_land[NSCT]	double * NSCT	NIR cloud overlap test coefficients used to define the M10 threshold over a grass surface. Thresholds are a function of scattering angle (i.e., 18 bins used at 10 deg intervals represent 0 to 180 degrees scattering geometry). Coefficients are for a 4-degree polynomial in M9 reflectance, x: $Ax^4 + Bx^3 + Cx^2 + Dx + E$ Refer to Eqn 5.		
B_nir_over_land[NSCT]	double * NSCT			
C_nir_over_land[NSCT]	double * NSCT			
D_nir_over_land[NSCT]	double * NSCT			
E_nir_over_land[NSCT]	double * NSCT			

Name	Type	Description	Units	Sug Value
A_cirrus[NVZA]	double * NVZA	10.7µm-12µm as a function of 10.7µm BT coefficients for cirrus detection. Coefficients are for a 4-degree polynomial in M15 BT, x: $Ax^4 + Bx^3 + Cx^2 + Dx + E$ Refer to Eqn 7.		
B_cirrus[NVZA]	double * NVZA			
C_cirrus[NVZA]	double * NVZA			
D_cirrus[NVZA]	double * NVZA			
E_cirrus[NVZA]	double * NVZA			
A_M14_M15[NVZA]	double * NVZA	8.6µm-10.7µm as a function of 10.7µm BT coefficients for cloud typing. Coefficients are for a 4-degree polynomial in M15 BT, x: $Ax^4 + Bx^3 + Cx^2 + Dx + E$ Refer to Eqn 9.		
B_M14_M15[NVZA]	double * NVZA			
C_M14_M15[NVZA]	double * NVZA			
D_M14_M15[NVZA]	double * NVZA			
E_M14_M15[NVZA]	double * NVZA			
A_win_over[NSZA][NVZA]	double * NVZA * NSZA	AVHRR algorithm cloud overlap function coefficients for a 4-degree polynomial in M5 reflectance, x: $Ax^4 + Bx^3 + Cx^2 + Dx + E$. Refer to Eqn 11.		
B_win_over[NSZA][NVZA]	double * NVZA * NSZA			
C_win_over[NSZA][NVZA]	double * NVZA * NSZA			
D_win_over[NSZA][NVZA]	double * NVZA * NSZA			
E_win_over[NSZA][NVZA]	double * NVZA * NSZA			

Name	Type	Description	Units	Sug Value
MIN_win_over[NSZA][NVZA]	double * NVZA * NSZA	The minimum BTM15-BTM16 (10.7um - 12um) required for cloud overlap with SWBTD test; function of sol zen (1st dim) and sat zen (2nd dimension); applied when M5 values are between CP_MID_M5_OVER and CP_MAX_M5_OVER, but may be applied at lower M5. Refer to Eqn 12.		
TOC NDVI Test Thresholds for M1 and M5				
MAX_LOW_TOC_NDVI	float	maximum TOC NDVI limit defining low TOC NDVI conditions. Value is adjusted by the software to coincide with a TOC NDVI bin maximum. For low TOC NDVI conditions (values < limit), the M1 band is used; otherwise the M5 band is used.	unitless	0.15
M5_ndvi_coef[NTHRESH][NUM_NDVI_BINS][NCOEFS]	float * NTHRESH * NUM_NDVI_BINS * NCOEFS	M5 coefficient table, a function of scattering angle and TOC NDVI bins, used in land/day and coast/day M5(M1) reflectance test for determining confident clear, clear/cloudy and confident cloudy thresholds. TOC NDVI bins consist of 10 bins from 0 to 1. Note that final thresholds are scaled by a factor of 0.01 and adjusted by a threshold adjustment, M5_*_THRES_ADJUST, in the software.	unitless	See Table 51
M1_ndvi_coef [NTHRESH][MAX_NUM_M1_NDVI_BINS][NCOEFS]	float * NTHRESH * MAX_NUM_M1_NDVI_BINS * NCOEFS	M1 coefficient table, a function of scattering angle and TOC NDVI bins, used in land/day and coast/day M5(M1) reflectance test for determining confident clear, clear/cloudy and confident cloudy thresholds. TOC NDVI bins consist of MAX_NUM_M1_NDVI_BINS bins from 0 to MAX_NUM_M1_NDVI_BINS * 0.1. Note that final thresholds are scaled by a factor of 0.01 and adjusted by a threshold adjustment, M1_*_THRES_ADJUST, in the software.	unitless	See Table 51
M5_LO_THRES_ADJUST	float	Low clear-sky confidence threshold correction value for the M5 reflectance band used in the M5 reflectance test	unitless	0.03
M5_MID_THRES_ADJUST	float	Mid clear-sky confidence threshold correction value for the M5 reflectance band used in the M5 reflectance test	unitless	0.02
M5_HI_THRES_ADJUST	float	High clear-sky confidence threshold correction value for the M5 reflectance band used in the M5 reflectance test	unitless	0.00
M1_LO_THRES_ADJUST	float	Low clear-sky confidence threshold correction value for the M1 reflectance band used in the M5 reflectance test	unitless	0.03
M1_MID_THRES_ADJUST	float	Mid clear-sky confidence threshold correction value for the M5 reflectance band used in the M5 reflectance test	unitless	0.02
M1_HI_THRES_ADJUST	float	High clear-sky confidence threshold correction value for the M5 reflectance band used in the M5 reflectance test	unitless	0.00
M5_TEST_HI_NDVI_THRESH	float	High TOC NDVI threshold used in land/day and coast/day M5 tests to limit the minimum scattering angle used in calculating the TOA NDVI-based thresholds.	unitless	0.70

Name	Type	Description	Units	Sug Value
M5_TEST_HI_NDVI_MIN_SCAT_ANGLE	float	Minimum scattering angle for high NDVI	degrees	90.0
Cloud Shadows				
VCM_SHADOW_MIN_NUM_DAY_PIXS	Int32	The minimum number of moderate resolution "day" pixels in a granule required to cast a shadow, where "day" for the shadow algorithm is defined as pixels having a solar zenith angle < VCM_SHADOW_MAX_SZA	unitless	2
VCM_SHADOW_GRIDCELL_SIZE	Int32	hopping window size	unitless	20
VCM_SHADOW_LAPSE_RATE	float	atmospheric lapse rate	deg K/km	6.0
VCM_SHADOW_MAX_SZA	float	maximum allowed solar zenith angle	deg.	75.0
VCM_SHADOW_DEFAULT_NCEP_2M_T	float	default NCEP 2 meter surface air temperature	deg Kelvin	300.0
VCM_SHADOW_CLOUDHEIGHT_OFFSET	float	cloud base and top offsets heights	km	1.5
VCM_SHADOW_CLOUDTHICKNESS_FACTOR	float	cloud thickness adjustment factor	unitless	0.30
VCM_SHADOW_MIN_CLOUDBASE	float	minimum cloud base height	km	1.0
VCM_SHADOW_MAX_CLOUDHEIGHT	float	maximum cloud top height	km	16.0
VCM_SHADOW_CLOUDHEIGHT_STEPSIZE	float	default cloud height step size	km	1.0
VCM_SHADOW_CLOUDHEIGHT_MAX_NSTEPS	float	maximum number of cloud height iteration steps (used to compute height step size)	unitless	4.0
VCM_SHADOW_POLAR_TROPO_HEIGHT	float	polar tropopause height	km	8.0
VCM_SHADOW_EQUATORIAL_TROPO_HEIGHT	float	equatorial tropopause height	km	16.0
VCM_SHADOW_ICECLOUD_BOT	float	ice cloud minimum cloud base height	km	1.0
VCM_SHADOW_ICECLOUD_TOP	float	ice cloud maximum cloud top height	km	12.0
VCM_SHADOW_THINCIRRUS_BOT	float	thin cirrus cloud base height	km	7.0
VCM_SHADOW_THINCIRRUS_TOP	float	thin cirrus cloud top height	km	10.0
VCM_SHADOW_CLDCONF_CHECK_WINDOW	Int32	window half width for shadow application	unitless	1
ShadowCastSwitch	Int32	ShadowCastSwitch = 0 ;Shadow Cast Switch for casting shadow from confidently cloudy pixel only ShadowCastSwitch = 1 Shadow Cast Switch for casting shadows from confidently cloudy and probably cloudy pixels	unitless	0 or 1

Name	Type	Description	Units	Sug Value
Degraded Flags				
VCM_POLAR_LAT	float	Latitude demarking the beginning of the polar region	degrees	60.0
VCM_MIN_DEGRAD_TOC_NDVI	float	Minimum TOC NDVI of the defined degradation/exclusion range	unitless	0.2
VCM_MAX_DEGRAD_TOC_NDVI	float	Maximum TOC NDVI of the defined degradation/exclusion range	unitless	0.4

Table _51. M5,M1 Tunable Coefficients for TOC NDVI Bins

Name	Description	Suggested Value
M5_ndvi_coef[0] [NUM_NDVI_BINS][NCOEFS]	Coefficients used for setting the M5 high clear-sky confidence reflectance thresholds for NUM_NDVI_BINS TOC NDVI bins having bin centers 0.05 to 0.95. Coefficients are scaled by 100 (percent reflectances) and are applied to polynomial $A + Bx + Cx^2 + Dx^3$ where x is the scattering angle in degrees. Note that final threshold value is interpolated between the current bin and closest bin neighbor, scaled by 0.01 and adjusted with tunable parameter M5_HI_THRES_ADJUST.	{ 32.00000000, 0.00000000, 0.00000000, 0.00000000} { 24.00000000, 0.00000000, 0.00000000, 0.00000000} { 99.13076923, -2.00907925, 0.01492075, -0.00003531} { 85.07902098, -1.59413364, 0.01123310, -0.00002556} { 85.03846154, -1.50831391, 0.01006760, -0.00002199} { 81.00979021, -1.37731935, 0.00881294, -0.00001859} { 76.94055944, -1.35441725, 0.00896096, -0.00001952} { 85.83006993, -1.55480575, 0.01025932, -0.00002216} {105.02447552, -1.98017094, 0.01319522, -0.00002877} {105.02447552, -1.98017094, 0.01319522, -0.00002877}
M5_ndvi_coef[1] [NUM_NDVI_BINS][NCOEFS]	Coefficients used for setting the M5 midpoint cloud/no cloud reflectance thresholds for NUM_NDVI_BINS TOC NDVI bins having bin centers 0.05 to 0.95. Coefficients are scaled by 100 (percent reflectances) and are applied to polynomial $A + Bx + Cx^2 + Dx^3$ where x is the scattering angle in degrees. Note that final threshold value is interpolated between the current bin and closest bin neighbor, scaled by 0.01 and adjusted with tunable parameter M5_MID_THRES_ADJUST.	{ 42.00000000, 0.00000000, 0.00000000, 0.00000000} { 28.00000000, 0.00000000, 0.00000000, 0.00000000} {122.19090909, -2.32652292, 0.01659848, -0.00003681} {144.56573427, -2.81054779, 0.01967366, -0.00004324} {165.15314685, -3.24716783, 0.02255594, -0.00004965} {220.36783217, -4.44111888, 0.03087762, -0.00006888} {172.36783217, -3.33144911, 0.02242308, -0.00004810} {160.73706294, -3.07291375, 0.02041900, -0.00004330} {135.50699301, -2.59097902, 0.01749301, -0.00003811} {135.50699301, -2.59097902, 0.01749301, -0.00003811}

Name	Description	Suggested Value
M5_ndvi_coef[2] [NUM_NDVI_BINS][NCOEFS]	Coefficients used for setting the M5 low clear-sky confidence reflectance thresholds for NUM_NDVI_BINS TOC NDVI bins having bin centers 0.05 to 0.95. Coefficients are scaled by 100 (percent reflectances) and are applied to polynomial $$A + Bx + Cx^2 + Dx^3$$ where x is the scattering angle in degrees. Note that final threshold value is interpolated between the current bin and closest bin neighbor, scaled by 0.01 and adjusted with tunable parameter M5_LO_THRES_ADJUST.	{ 52.00000000, 0.00000000, 0.00000000, 0.00000000} { 32.00000000, 0.00000000, 0.00000000, 0.00000000} {142.66293706, -2.57860528, 0.01773252, -0.00003685} {204.35454545, -4.03411810, 0.02816667, -0.00006103} {242.06363636, -4.90912587, 0.03445455, -0.00007587} {359.72587413, -7.50491841, 0.05294231, -0.00011917} {267.90909091, -5.31620047, 0.03597727, -0.00007698} {237.37622378, -4.63444833, 0.03091317, -0.00006525} {165.33006993, -3.18872183, 0.02171387, -0.00004734} {165.33006993, -3.18872183, 0.02171387, -0.00004734}

Name	Description	Suggested Value
M1_ndvi_coef[0] [NUM_NDVI_BINS][NCOEFS]	Coefficients used for setting the M1 high clear-sky confidence reflectance thresholds for the MAX_NUM_M1_BINS low TOC NDVI bins. Coefficients are scaled by 100 (percent reflectances) and are applied to polynomial $A + Bx + Cx^2 + Dx^3$ where x is the scattering angle in degrees. Note that final threshold value is interpolated between the current bin and closest bin neighbor, scaled by 0.01 and adjusted with tunable parameter M1_HI_THRES_ADJUST.	{ 50.0, 0.0, 0.0, 0.0} { 50.0, 0.0, 0.0, 0.0} { 62.82886887, -1.27375996, 0.01004464, -0.00002431}
M1_ndvi_coef[1] [NUM_NDVI_BINS][NCOEFS]	Coefficients used for setting the M1 midpoint cloud/no cloud reflectance thresholds for the MAX_NUM_M1_BINS low TOC NDVI bins. Coefficients are scaled by 100 (percent reflectances) and are applied to polynomial $A + Bx + Cx^2 + Dx^3$ where x is the scattering angle in degrees. Note that final threshold value is interpolated between the current bin and closest bin neighbor, scaled by 0.01 and adjusted with tunable parameter M1_MID_THRES_ADJUST.	{ 55.0, 0.0, 0.0, 0.0} { 55.0, 0.0, 0.0, 0.0} { 79.90699768, -1.60181057, 0.01247768, -0.00002951}
M1_ndvi_coef[2] [NUM_NDVI_BINS][NCOEFS]	Coefficients used for setting the M1 low clear-sky confidence reflectance thresholds for the MAX_NUM_M1_BINS low TOC NDVI bins. Coefficients are scaled by 100 (percent reflectances) and are applied to polynomial $A + Bx + Cx^2 + Dx^3$ where x is the scattering angle in degrees. Note that final threshold value is interpolated between the current bin and closest bin neighbor, scaled by 0.01 and adjusted with tunable parameter M1_LO_THRES_ADJUST.	{ 60.0, 0.0, 0.0, 0.0} { 60.0, 0.0, 0.0, 0.0} { 96.98512268, -1.92986107, 0.01491071, -0.00003472}

2.1.8 Assumptions and Limitations

2.1.8.1 Assumptions

2.1.8.2 Requirements for NCEP model data

Cloud Mask uses NCEP model data to obtain sea surface wind and total precipitable water data that is not provided by the VIIRS system in time for use in the CM IP module. NCEP models are run four times daily. The CM needs the NCEP data within 6 hours.

2.1.8.3 Requirements for USGS EDC data

Cloud Mask uses USGS EDC data to obtain surface type that is not provided by the VIIRS system in time for use in the CM land/water background determination. The USGS EDC Global Ecosystem map can be obtained prior to launch and updated off-line when a new map becomes available.

2.1.8.4 Requirements for Gridded VIIRS data

Cloud Mask uses VIIRS Gridded Snow/Ice Cover. The CM processing is determined as a result of this data; therefore, the data must be temporarily and spatially relevant to the current granule being processed.

2.1.8.5 Limitations

None.

3.0 GLOSSARY/ACRONYM LIST

3.1 Glossary

Table 52 contains terms most applicable for this OAD.

Table 52 . 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: 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 Configuration Control Board (ACCB)	Interdisciplinary team of scientific and engineering personnel responsible for the approval and disposition of algorithm acceptance, verification, development and testing transitions. Chaired by the Algorithm Implementation Process Lead, members include representatives from IWPTB, Systems Engineering & Integration IPT, System Test IPT, and IDPS IPT.
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 IWPTB facility. Delivered code is executed on compatible IWPTB 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.
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)	*[IORD Definition]* 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.). *[Supplementary Definition]* 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 NPOESS SDRs or EDRs, plus ancillary environmental data provided by others. EDR metadata contains references to its processing history, spatial and temporal coverage, and quality.
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. [Ref.: DoDD 5000.59-DoD Modeling and Simulation Management]
Model Verification	The process of determining that a model implementation accurately represents the developer's conceptual description and specifications. [Ref.: DoDD 5000.59-DoD Modeling and Simulation Management]
Operational Code	Verified science-grade software, delivered by an algorithm provider and verified by IWPTB, 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)	*[IORD Definition]* Full resolution digital sensor data, time referenced, 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. *[Supplementary Definition]* 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 NPOESS (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.
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/NPOESS 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)	*[IORD Definition]* Data record produced when an algorithm is used to convert Raw Data Records (RDRs) to geolocated, calibrated brightness temperatures with associated ephemeris data. 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. The existence of the SDRs provides reversible data tracking back from the EDRs to the Raw data. *[Supplementary Definition]* 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.

Term	Description
Temperature Data Record (TDR)	*[IORD Definition]* 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. *[Supplementary Definition]* 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.

3.2 Acronyms

Table 51 contains the acronyms most applicable for this OAD.

Table 51. Acronyms

Term	Description
ADCS	Advanced Data Collection System
AFM	Airborne Fluxes and Meteorology Group
AOS	Acquisition of Signal
BT	Brightness Temperature
BTD	Brightness Temperature Difference
CDA	Command and Data Acquisition
CDR	Climate Data Records
CI	Configured Item
CLAVR	Cloud Advanced Very High Resolution Radiometer
COMSAT	Communications Satellite
DES	Digital Encryption System
DHN	Data Handling Node
DMS	Data Management Subsystem
EDC	Environmental Data Center
EOS	Earth Observing System
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
GPSOS	GPS Occultation Suite
GSE	Ground Support Equipment
HRD	High Rate Data
I	Imagery
IGS	International GPS Service
IJPS	Initial Joint Polar System
INF	Infrastructure
IOC	Initial Operational Capability
IP	Intermediate Product
LEO&A	Launch, Early Orbit, & Anomaly Resolution
LOS	Loss of Signal
LRD	Low Rate Data
LST	Local Solar Time
LUT	Look-Up Table
M	Moderate
METOP	Meteorological Operational Program
MSS	Mission System Simulator
NA	Non-Applicable
NCA	National Command Authority
NPP	NPOESS Preparatory Program
PIP	Program Implementation Plan
PMT	Portable Mission Terminal
POD	Precise Orbit Determination
R	Reflectance
S&R	Search and Rescue
SCA	Satellite Control Authority

Term	Description
SDE	Selective Data Encryption
SDR	Sensor Data Records
SDS	Science Data Segment
SI	International System of Units
SN	NASA Space Network
SOC	Satellite Operations Center
SRD	Sensor Requirements Documents
SS	Space Segment
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
TOC NDVI	Top of the Canopy Normalized Difference Vegetation Index
TPIWV	Total Path Integrated Water Vapor
TPW	Total Precipitable Water
USB	Unified S-band
UTC	Universal Time Coordinated
VCM	VIIRS Cloud Mask

4.0 OPEN ISSUES

Table 54. TBXs

TBX ID	Title/Description	Resolution Date
None		