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Joint Polar Satellite System (JPSS) Operational Algorithm Description (OAD) Document for Atmospheric Correction Over Ocean / Ocean Color Chlorophyll (ACO/OCC) Environmental Data Record (EDR) Software

For Public Release

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

Goddard Space Flight Center
Greenbelt, Maryland

National Aeronautics and
Space Administration

Joint Polar Satellite System (JPSS) Operational Algorithm Description (OAD) Document for Atmospheric Correction Over Ocean / Ocean Color Chlorophyll (ACO/OCC) Environmental Data Record (EDR) 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:

JPSS Configuration Management Office
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Change History Log

Revision	Effective Date	**Description of Changes** (Reference the CCR & CCB/ERB Approve Date)
Original	05/20/2011	**474-CCR-11-0075:** This version baselines D36813, Operational Algorithm Description (OAD) Document for Atmospheric Correction Over Ocean / Ocean Color Chlorophyll (ACO/OCC), Rev A, dated 02/11/09, as a JPSS document, version Rev –. 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. This CCR was approved by the JPSS Algorithm ERB on May 20, 2011.
Revision A	01/18/2012	**474-CCR-11-0253:** This version baselines 474-00057, Joint Polar Satellite System (JPSS) Operational Algorithm Description (OAD) Document for Atmospheric Correction Over Ocean / Ocean Color Chlorophyll (ACO/OCC) Environmental Data Record (EDR) 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 474-00057, Joint Polar Satellite System (JPSS) Operational Algorithm Description (OAD) Document for Atmospheric Correction Over Ocean / Ocean Color Chlorophyll (ACO/OCC) Environmental Data Record (EDR) Software, for the Mx 6.1 – 6.3 IDPS releases. Includes **ECR-ALG-0035** which contains Raytheon PCR031656, OAD: Implement 474-CCR-11-0219 (OCV3 Revised RSR Look Up Table Update) (ADR 4395), updated in Table 15.

NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM (NPOESS)

OPERATIONAL ALGORITHM DESCRIPTION DOCUMENT FOR ATMOSPHERIC CORRECTION OVER OCEAN / OCEAN COLOR CHLOROPHYLL (ACO/OCC)

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 ATMOSPHERIC CORRECTION OVER OCEAN / OCEAN COLOR CHLOROPHYLL (ACO/OCC)

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Engineering & Manufacturing Development (EMD) Phase
Acquisition & Operations Contract

CAGE NO. 11982

Operational Algorithm Description Document
Atmospheric Correction Over Ocean (ACO) for Production of Remote Sensing Reflectance (RSR) Intermediate Product and the Ocean Color / Chlorophyll (OCC) EDR

Document Date: Nov 05, 2011

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Revision: B10

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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 D36813

Revision	Document Date	Revision/Change Description	Pages Affected
---	3-31-03	Initial Release.	All
A1	7-22-03	Updated to combine ACO, OCC algorithms and IDPS changes.	All
A2	2-5-04	Updated to list units in input and output tables, ERB updates.	All
A3	5-4-05	Reflects NGST comment corrections plus inserted new logo and updated upper right header date, title/signature page dates, Revision/Change Record.	All
A4	7-13-05	Reflects dCUTPR comment corrections. Removed export markings per 26May05 official policy change and under section 1.3.2, Source Code References, inserted a more detailed table listing paths to find applicable source code within the ClearCase configuration management tool to include Dan Antzoulatos' 11Jul05 email with rewording comments.	All
A5	5-19-06	15Dec05 – Reflects corrections based on reviewer comments from the 15Dec05 Follow-on I-P-O dDDPR. 20Dec05 – Inserted new Figure 2 per Tim Gardner's comment. 09Mar06 – Updated per comments from follow-on I-P-O CUTPR. Inserted latest Unit Test (03/07/06); removed section 5.2 Summary of Differences (same data is in Unit Test); renumbered all tables due to removal of Table 1, 3, and 4 plus fixed all table references within the text; updated Table of Contents, List of Tables, and List of Figure page numbers. 17Apr06 – added aerocoef to Table 2, added ylog & y2 to Table 3, added thetav and updated parameter dimension, removed note in 2.3.8.1. 21Apr06 – updated OAD per Tech Memo NP-EMD.2005.510.xxxx. 08May06 – updated Fig2, table data, added main inputs dimensional parameter table. 16May06 – Inserted a 19May06 date in doc's upper right header and next to Raytheon electronic signatures in preparation for official delivery on that date. Inserted Raytheon electronic signatures. Made other edits in preparation for delivery. 19May06 – Fixed Omaha QA's suggested changes.	All
A6	9-25-06	Updated Document ID number from D36813-IDP-002 to D36813 per NGST DM.	All
A7	6-15-07	Logo, cleanup updates. Delivered to NGST.	All

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

Revision/Change Record	**Document Number** **D36813**

Revision	Document Date	Revision/Change Description	Pages Affected
A8	12-13-07	ECR A-103, EDRPR 1.8 CP 3 updates -Format changes for CDFCB-X compliance- removed Table 2.2.3-3. Granule Level Quality Bit Flags for the VIIRS OCC EDR.	All
A9	2-14-08	ECR A-132 updates for Drop 4.1.2 delivery.	All
A10	9-4-08	Updated Graceful Degradation.	27, TOCs
A11	10-15-08	Updated for NP-EMD.2008.510.0020, NP-EMD-2008.510.0008. Prepared for NGST delivery.	All
A12	12-4-08	Addressed NGST SDRL comments.	All
A13	1-21-09	Updated based on comments from TIM (CDA RFA Nos. 278 & 282	6, 14, 19 & 30
A	2-11-09	Rev rolled for ACCB Delivery	All
B1	4-1-09	Updated table 4 (Main Inputs) and section 2.1.2.2 to correct the units of total column ozone from Dobson units to atm-cm	8, 16
B2	11-4-09	Incorporated RFA Nos. 277, 279, 280, 281& 546; implemented the OAD portion of PCR21639 (Table 15); updated for SDRL	All
B3	2-10-2010	Implemented TM NP-EMD.2009.510.0057_NPP_RevA_OC_QualityFlagUpdates	All
B4	5-10-10	Replaced reference from ETOPO30 to SRTM30+, updated the SCN, logo, and copyright no.	4, cover pages
B5	07-08-10	Prepared for OAD Giver UID 35077	All
B6	09-23-10	Incorporated Drop 4.24 and prepared for SDRL	All
B7	10-12-10	Updated due to document convergence, to include tech memos 2010.510.0011, 2010.510.0012, 2010.510.0013, 2010.510.0014, 2010.510.0015, 2010.510.0016,	All
B8	03-01-11	Changes for OCC Drop 4.24.2: TM NP-EMD.2010.510.0101, NP-EMD.2010.510.0102, and NP-EMD.2010.510.0103 (PCR026155)	ALL
B9	09-26-11	Updated for PCR026650.	ALL
B10	11-05-11	Updated for PCR026447	Table 18

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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 RSR IP and the VIIRS OCC EDR. The theoretical basis for this algorithm is described in Section 3.3 of the VIIRS Atmospheric Correction Over Ocean Algorithm Theoretical Basis Document ATBD, 474-00050 and VIIRS Ocean Color/Chlorophyll Algorithm Theoretical Basis Document ATBD, 474-00035.

1.3 References

The primary software detailed design documents listed here include science software documents; NPOESS program documents; plus 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 Atmospheric Correction Over Ocean Algorithm Theoretical Basis Document ATBD	474-00050	12 Apr 2011
MODIS Normalized Water-leaving Radiance ATBD	MOD18 Version 4	Apr 1999
VIIRS Ocean Color/Chlorophyll Algorithm Theoretical Basis Document ATBD	474-00035	12 Apr 2011

Document Title	Document Number/Revision	Revision Date
MODIS Case 2 Chlorophyll *a* ATBD	ATBD 19 Version 7	30 Jan 2003
VIIRS Ocean Module Level Software Architecture	Y2476 Ver. 5 Rev. 8	15 Apr 2003
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
NPP Mission Data Format Control Book and App A (MDFCB)	472-REF-00057	06 Jan 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
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 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
Operational Algorithm Description Document for VIIRS Cloud Mask Intermediate Product (VCM IP)	474-00062, Rev A	27 Jan 2012
Operational Algorithm Description Document for VIIRS Sea Surface Temperature (SST) Environmental Data Records (EDR)	474-0006, Rev A	27 Jan 2012
Operational Algorithm Description Document for the Granulate Ancillary Software	474-00089, Rev A	27 Jan 2012
IDPS Processing SI Common IO Design Document	DD60822-IDP-011 Rev. A	21 Jun 2007
JPSS CGS Acronyms and Glossary	LI60917-GND-005, Rev -	17-Oct-11
VIIRS Ocean Module Data Dictionary	Y2485 Ver. 5 Rev. 4	Mar 2003
VIIRS Atmospheric Correction over Ocean Unit Level Detailed Design	Y2508 Ver. 5 Rev. 4	Mar 2003

Document Title	Document Number/Revision	Revision Date
VIIRS Ocean Color Unit Level Detailed Design	Y3227 Ver. 5 Rev. 4	Apr 2003
VIIRS Ocean Module Level Interface Control Document	Y3280 Ver. 5 Rev. 4	Mar 2003
VIIRS Algorithm Verification Status Report	D36812	31 Mar 2003
Atmospheric Correction Over Ocean Visible Infrared Imager/Radiometer Suite Science Grade Software Unit Test Document	D36817	31Mar 2003
Applied Optics	Vol. 33, Issue 3	Jan1994
MS Engineering Memo_ACO-OCC OAD Update	NP-EMD.2005.510.0108	28 Aug 2005
NPP_VIIRS_ACO-OCC_BugsFix_20061106	NP-EMD.2006.510.0082	6 Nov 2006
NPP_Bright_Pixel_Flag_for_OceanColor	NP-EMD.2007.510.0051	4 Sep 2007
NPP_GracefulDegradation_for_OceanColor_Branching	NP-EMD.2007.510.0052	4 Sep 2007
NPP_ACO_CodeFixes_CT&Xtalk	NP-EMD.2007.510.0053	4 Sep 2007
NPP_OceanColor_OAD_Updates	NP-EMD.2007.510.0054	4 Sep 2007
VIIRS ACO Code Modifications and No Double Precision Implementation	NP-EMD.2008.510.0008 Rev. A	07 Feb 2008
VIIRS Ocean Color Science Code Updates	NP-EMD.2008.510.0020	15 Apr 2008
NPP_OceanColor_QualityFlagUpdate	NP-EMD.2009.510.0025	18 May 2009
NPP_RevA_OC_QualityFlagUpdates	NP-EMD.2009.510.0057	18 Jan 2010
VIIRS Ocean Color Science Code Updates Drop 4.24	NP-EMD.2010.510.0048	8 Jun 2010
NPP_OceanColor_InlandWater_Coastal_NoRetreval	NP-EMD.2010.510.0054	30 Jun 2010
NPP_OceanColor_GlintCorr&NegativeNLWUpdates	NP-EMD.2010.510.0062_RevB	24Aug2010
NGST/SE technical memos: LUT_OAD_Drop History_Corrections LUT_Format_Corrections PC_OAD_Last_Drop_Corrections PC_Format_Corrections SAD_OAD_Last_Drop_Corrections SAD_Formatand Usage_Corrections	 NPOESS GJM-2010.510.0011 NPOESS GJM-2010.510.0012 NPOESS GJM-2010.510.0013 NPOESS GJM-2010.510.0014 NPOESS GJM-2010.510.0015 NPOESS GJM-2010.510.0016	 21 Sep 2010 21 Sep 2010 22 Sep 2010 22 Sep 2010 22 Sep 2010 22 Sep 2010
Joint Polar Satellite System (JPSS) Common Ground System (CGS) IDPS PRO Software User's Manual Part 2	UG60917-IDP-026, Rev-	18 Jul 2011
NGST/SE technical memos: ACO Science Algorithm and LUT Updates Based on the VIIRS Fused RSR	NP-EMD.2010.510.0101	22 Dec 2010
NGST/SE technical memos: OC3V Regression Coefficient Update Based on the A&DP Global Synthetic Data using the VIIRS Fused RSR	NP-EMD.2010.510.0102	22 Dec 2010
NGST/SE technical memos: Ocean Color OAD Update	NP-EMD.2010.510.0103	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
VIIRS ACO science-grade software	ISTN_VIIRS_NGST_1.0	31 Mar 2003

Reference Title	Reference Tag/Revision	Revision Date
VIIRS OCC science-grade software	ISTN_VIIRS_NGST_1.0	31 Mar 2003
VIIRS ACO_OCC operational software	B1.4 (OAD Rev A4)	13 Jul 2005
VIIRS OCC science-grade software	ISTN_VIIRS_NGST_4.1 (ECR A-064A)	22 Sep 2005
Instruction for Updating the ACO-OCC OAD at the IDPS named 050504 SDRL S141 D36813-IDPS-002 VIIRS ACO OCC-OAD	NP-EMD.2005.510.0108	15 Sep 2005
VIIRS ACO_OCC operational software	B1.4 Follow-on (OAD Rev A5)	20 Apr 2006
VIIRS OCC science-grade software includes Tech Memo NP-EMD.2006.510.0082	ISTN_VIIRS_NGST_4.1.1_Data (ECR A-110C)	19 Dec 2006
VIIRS ACO_OCC operational software	B1.5 (OAD Rev A7)	15 Jun 2007
VIIRS OCC science-grade software includes Tech Memos NP-EMD.2007.510.0051 & NP-EMD.2007.510.0052	ISTN_VIIRS_NGST_4.1.2_Data (ECR -A132A)	26 Nov 2007
NPP_OceanColor_OAD_Updates	NP-EMD.2007.510.0054	4 Sep 2007
VIIRS OCC science-grade software	ISTN_VIIRS_NGST_4.1.3 (ECR A-139A)	12 Mar 2008
VIIRS OCC science-grade software includes Tech Memo NP-EMD.2008.510.0020	ISTN_VIIRS_NGST_4.1.4 (Data Only)	15 Apr 2008
VIIRS ACO/OCC Science software	ISTN_VIIRS_NGST_4.12	21 Oct 2008
VIIRS ACO/OCC operational software	B1.5.X.1 (OAD Rev A11)	15 Oct 2008
ACCB Approval	OAD Rev A	11 Feb 2009
SDRL	(OAD Rev B2)	4 Nov 2009
NPP_RevA_OC_QualityFlagUpdates NP-EMD.2009.510.0057 (PCR021792)	Sensor Characterization Build SC-14 (OAD Rev B3)	10 Feb 2010
VIIRS ACO/OCC Science software Includes Tech Memos: NPP_OceanColor_InlandWater_Coastal_NoRetreval NP-EMD.2010.510.0054 (PCR024328) and NPP_OceanColor_GlintCorr&NegativeNLWUpdates NP-EMD.2010.510.0062_RevB (PCR024614)	ISTN_VIIRS_NGST_4.24 and ISTN_VIIRS_NGST_4.24.1_DATA Sensor Charactrization Build SC-14 (ECR A-295) (OAD Rev B6)	23 Sep 2010
Convergence Updates (No code updates)	(OAD Rev B7)	12 Oct 2010
Changes for OCC Drop 4.24.2 (PCR026155) TM NP-EMD.2010.510.0101, NP-EMD.2010.510.0102, and NP-EMD.2010.510.0103	(OAD Rev B8)	11 Mar 2011
PCR026650 (OAD update for ADL)	(OAD Rev B9)	26 Sep 2011
PCR026447 (x-ref PCR026444) and PCR026155	(OAD Rev B10)	05 Nov 2011

2.0 ALGORITHM OVERVIEW

This document details an operational algorithm description of the ACO and OCC units of the VIIRS Ocean Module algorithms. These algorithms produce the RSR IP and OCC EDR respectively. Most of the signal (about 90%) reaching a satellite-based visible-wavelength detector above the ocean is of atmospheric origin or reflected light from the sea surface. In order to obtain information like chlorophyll concentration just beneath the ocean surface, atmospheric and surface reflection components must be removed from the signal. Removing the atmospheric effects from the signals and creating the RSR IP is the purpose of the ACO algorithm. This RSR IP then becomes the input to the OCC algorithm in producing the OCC EDR.

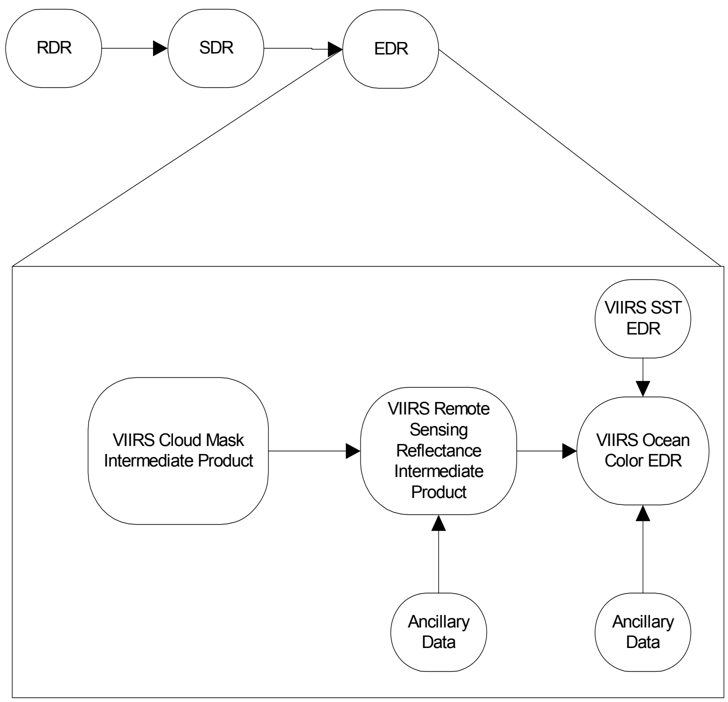

Figure 1. Processing Chain to Create VIIRS RSR IP and OCC EDR.

Inputs to the algorithms are measured Top-Of-Atmosphere (TOA) VIIRS reflectances in the visible and near-infrared bands, VCM IP, VIIRS Sea Surface Temperature (SST) EDR, SRTM30+ global bathymetric data and MODIS Nitrate Temperature Depletion (NDT) data interpolated to VIIRS granule resolutions, sea surface wind speed (SSWS), surface atmospheric pressure, and total column ozone. The ACO algorithm uses a sun glint flag, obtained from the VCM IP to mask the sun glint exclusion. Bathymetric data is used to distinguish shallow water from deep water. Corrections are made for ozone absorption, whitecaps, and the sensitivity of the VIIRS instrument to radiation polarization. The algorithm then subtracts contributions of molecular and aerosol scattering in the atmosphere, as well as reflection from the air-sea interface from the corrected VIIRS reflectances.

For the OCC algorithm, the Case 2 Chlorophyll-*a* algorithm *[ATBD 19]* for use on the initial Moderate Resolution Imaging Spectroradiometer (MODIS) data is employed. This algorithm is based on the Carder semi-analytical, bio-optical model of remote sensing reflectance, $R_{rs}(\lambda)$, where remote sensing reflectance is defined as the normalized water-leaving radiance divided by the downwelling irradiance just above the sea surface. The model has two free parameters—the absorption coefficient due to phytoplankton at 675-nm, $a_{ph}(675)$, and the absorption coefficient due to gelbstoff at 400-nm, $a_g(400)$. This model has many other parameters that are fixed or specified based on region and season of the scene. The initial MODIS strategy (MODIS ATBD 19, January 2003) using SST and NDT is employed to set variable packaging parameters. $R_{rs}(\lambda)$ is modeled in the VIIRS visible bands. $R_{rs}(\lambda)$ values at 412, 445, 488, 555, and 672 nm wavelengths are retrieved from the atmospheric correction algorithm and put into the model. The model is inverted and $a_{ph}(675)$ and $a_g(400)$ are computed. Chlorophyll-*a* concentration is then derived simply from the $a_{ph}(675)$ value. This algorithm also outputs inherent optical properties (IOP) for both back-scattering and total absorption at the VIIRS visible wavelengths and the derived normalized water-leaving radiance at the five VIIRS visible bands. Additional inputs include the VIIRS retrieved SST and seasonal global NDT map. In highly turbid waters, an empirical $R_{rs}(488)/R_{rs}(555)$ ratio algorithm is used instead of the bio-optics model to estimate chlorophyll concentration.

The ACO agorithm is performed only under clear-sky daytime conditions. Major sources of uncertainty in the retrieved normalized water-leaving radiance include: (1) possibility that the candidate aerosol models are not representative of some regions or selected aerosol models are not sufficiently accurate; (2) assumption of zero water-leaving radiance in two near-infrared bands are not valid for regions with high chlorophyll or coccolithophore concentration or turbid water; (3) uncertainty in whitecap reflectance; (4) uncertainty in VIIRS radiometric calibration, polarization sensitivity, and sensor noise. It should be pointed out that the signal to noise ratio is a key factor affecting selection of the aerosol model and calculation of the diffuse transmittance for conversion of the normalized water-leaving reflectance to remote sensing reflectance.

2.1 Atmospheric Correction Over Ocean/Ocean Color Chlorophyll Algorithm Description

2.1.1 Interfaces

To begin data processing, the ACO/OCC algorithm is initiated by the IDPS Infrastructure (INF) subsystem Software Item (SI). The INF SI provides tasking information to the algorithm indicating which granule to process. The Data Management Subsystem (DMS) SI provides data storage and retrieval capability. A library of C++ classes is used to implement the SI interfaces. More information regarding these topics is found in document UG60917-IDP-026 with reference in particular to sections regarding PRO Common (CMN) processing and the IPO Model.

2.1.1.1 Inputs

All the required input data for the ACO-OCC algorithms have been summarized in Table 3 and Table 4. Some of the input data can originate from multiple sources. For these situations, a hierarchy is established for order of preference (see Section 2.1.3, Graceful Degradation, for additional information). Refer to the CDFCB-X, 474-00001, for a detailed description of the inputs.

Table 3. Main Inputs Dimensional Parameters

Input	Data Type/Size	Description/Source	Units/Valid Range
m_viirs_sdr_rows	int32	Number of rows in a VIIRS moderate resolution granule (number of pixels in scan direction)	Unitless/ m_viirs_sdr_rows = 768
m_viirs_sdr_cols	int32	Number of columns in a VIIRS moderate resolution granule (number of along-track lines)	Unitless/ m_viirs_sdr_cols = 3200

Table 4. Main Inputs (ACO/OCC)

Input	Data Type/Size	Description/Source	Units/Valid Range
VIIRS Moderate Band Geolocation File for latitude, longitude, sensor azimuth angle, sensor zenith angle, solar azimuth angle and solar zenith angle.	float32 x m_viirs_sdr_rows x m_viirs_sdr_cols	Earth location for each satellite view point as well as solar, sensor angles and view geometry	Degree
VIIRS Reflectance for moderate bands M1-M7	float32 x m_viirs_sdr_rows x m_viirs_sdr_cols	VIIRS calibrated top of the atmosphere (TOA) reflectance for M1-M7 bands	Unitless Refer to VIIRS Radiometric Calibration Document, Y2490-VIIRS-CAL-SW-DDD-023
VIIRS OBC IP	float32 x m_viirs_sdr_rows x m_viirs_sdr_cols	The HAM_SIDE values for the VIIRS RDR scans are used from OBC IP.	Unitless
BrightPixel	unsigned char x m_viirs_sdr_rows x m_viirs_sdr_cols	M1-M7 Bright Pixel IP	Unitless/ 0 <= BrightPixel <= 15
Bathymetry	int16 x m_viirs_sdr_rows x m_viirs_sdr_cols	Digital Granulated Ancillary Data	m/ -11000 <= Bathymetry <= 200
NDT	float32 x m_viirs_sdr_rows x m_viirs_sdr_cols	Nitrate Depletion Temperature	Kelvin/ $268 \leq NDT \leq 343$
SST	float32 x m_viirs_sdr_rows x m_viirs_sdr_cols	Skin Sea Surface Temperature	Kelvin/ $268 \leq SST \leq 343$ See VIIRS SST OAD, 474-00061
Pres	float32 x m_viirs_sdr_rows x m_viirs_sdr_cols	NCEP Surface Pressure	mb or hPa/ Pres ≥ 0 Refer to Gran ANC OAD, 474-00089

Input	Data Type/Size	Description/Source	Units/Valid Range
Wind Direction	float32 x m_viirs_sdr_rows x m_viirs_sdr_cols	Digital Granulated Ancillary Data	Degrees/ 0 <= Wind Speed <= 360 Refer to Gran ANC OAD, 474-00089
Wind Speed	float32 x m_viirs_sdr_rows x m_viirs_sdr_cols	Digital Granulated Ancillary Data	m/s / 0 <= Wind Speed <= 120 Refer to Gran ANC OAD, 474-00089
OZ	float32 x m_viirs_sdr_rows x m_viirs_sdr_cols	NCEP Total Column Ozone	atm-cm
VCM	uint8 x 6 x m_viirs_sdr_rows x m_viirs_sdr_cols	VIIRS Cloud Mask IP	See VCM OAD, 474-00062
Precipitable Water (PW)	float32 x m_viirs_sdr_rows x m_viirs_sdr_cols	Total column precipitable water	Cm Refer to Gran ANC OAD, 474-00089
aerosol properties lut	See Table 5, and Table 6	Aerosol Properties LUT Parameters (See Table 5, and Table 6)	See Table 5 , and Table 6
aerosol coeff LUT	See Table 5, and Table 7	Aerosol LUT Parameters (See Table 5, and Table 7)	See Table 5, and Table 7
ray_lut	See Table 8 and Table 9	Rayleigh LUT Parameters (See Table 8 and Table 9)	See Table 8 and Table 9
diffuse_lut	See Table 10 and Table 11	Diffuse Transmittance LUT Parameters (See Table 10 and Table 11)	See Table 10 and Table 11
BP Threshold LUT	See Table 12 and Table 13	Bright pixel threshold LUT	See Table 12 and Table 13
polcor_lut	See Table 12, and Table 13	Polarization Sensitivity LUT	See Table 12, and Table 13
Rgainfctr_lut	See Table 14, and Table 15	Detector-Dependent Rayleigh Correction Adjustment Factors LUT	See Table 14, and Table 15
OCC Processing Coefficient	See Table 19	Contains the configurable parameters used for the ACO OCC algorithm	See Table 19

2.1.1.1.1 ACO/OCC LUT Description

2.1.1.1.1.1 Aerosol LUTs

The Aerosol LUT, provided by Dr. Menghua Wang of the NPP Science team (NOAA), consists of aerosol parameters pertaining to 12 different aerosol models. These models are enumerated as follows:

1. Oceanic (Relative Humidity (RH) of 99%) – (1)
2. Maritime (RH = 50%, 70%, 90%, 99%) – (2-5)
3. Coastal (RH = 50%, 70%, 90%, 99%) – (6-9)
4. Troposphere (RH = 50%, 90%, 99%) – (10-12)

Where the indices enclosed by the parentheses, symbolically represent each aerosol model in the ACO algorithm. Each of these contains parameters which are described in Table 7, Aerosol Coefficients. NOTE: The configurable parameter **thetav** (containing preset sensor viewing angle range and increments) was previously hard coded but has now been added to the Aerosol Coefficients LUT. There also exists another LUT which contains additional aerosol parameters that correspond to each of the 12 models just described; these values are detailed in Table 6, Aerosol Properties. The computation of the ACO parameter ε_{model} ("Epsilon") for each of the aerosol models requires the values from the Aerosol Properties LUT. Table 5 describes the parameter dimensions for Tables 6 and 7.

Table 5. Aerosol LUT Dimensional Parameters (Set in aco_dimensions.f)

Input	Data Type/Size	Description/Source	Units/Valid Range
acobands	int32	Number of VIIRS Moderate Resolution Bands used in ACO Algorithm (M1-M7)	Unitless/ acobands = 7
model	int32	Number of Aerosol Models needed by the ACO Algorithm	Unitless/ model = 12
num_scat_angles	int32	Number of scattering angles	Unitless/ num_scat_angles = 75
nrad	int32	Number of Sensor Viewing (Zenith) Angles	Unitless/ nrad = 35
mphi	int32	Number of Relative Azimuth Angles	Unitless/ mphi = 19
msun	int32	Number of Solar Zenith Angles	Unitless/ msun = 33
aero_coef	int32	Number of Aerosol coefficients	Unitless/ aerocoef = 5

Table 6. Aerosol Properties LUT

Input	Data Type/Size	Description/Source	Units/Valid Range
angle	float32 x num_scat_angles	Scattering angles	Degree/ $0 \leq$ angle ≤ 180 (increments vary)
wavelength	Int32 x acobands	VIIRS band center wavelengths	nm/ wavelength = [412,445,488, 555,672,746, 865]
omega0	float32 x model x acobands	Aerosol Single Scattering Albedo	Unitless/ $0.9295 \leq$ omega0 ≤ 1.0
extinc	float32 x model x acobands	Aerosol extinction coefficient	Unitless/ $1.8376\text{x}10^{-5} \leq$ extinct ≤ 0.0885
s11	float32 x **model** x acobands x num_scat_angles	Aerosol Scattering Phase Function	Unitless/ $0.0350 \leq$ s11 $\leq 9.4143 \times 10^{3}$
ylog	float32 x **model** x acobands x num_scat_angles	Logs of s11 (scattering phase function)	Unitless/ max and min are dependent on the original y values
y2	float32 x **model** x acobands x num_scat_angles	Spline (second derivative) of s11 (scattering phase function)	Unitless/ max and min are dependent on the original y values

Table 7. Aerosol Coefficients LUT

Input	Data Type/Size	Description/Source	Units/Valid Range
cost	float32 x aero_coef x model x acobands x msun x mphi x nrad	Coefficients for fit as rho_a + rho_ra vs. rho_as for the VIIRS bands, or Coefficients for fit rho_as vs. (rho_a + rho_ra) for the VIIRS NIR bands. Coefficients are used to compute the multi-scattering aerosol reflectance for bands M1-M5. Note: aerocoef corresponds to a,b,c,d,e (i.e. acost)	Unitless/ ~-0.05 ≤ acost ≤ ~27.0 ~-0.7 ≤ bcost ≤ ~4.0 ~-219≤ ccost ≤ ~136.0 ~-5254 ≤ dcost ≤ ~10,247 ~-144187 ≤ ecost ≤ ~64163
cost_rev	float32 x aero_coef x model x acobands x msun x mphi x nrad	Coefficients for fit as rho_a + rho_ra vs. rho_as for the VIIRS bands, or coefficients for fit rho_as vs. (rho_a + rho_ra) for the VIIRS NIR bands. Single-scattering aerosol (M6 – M7) reflectance coefficients are stored in these arrays (acost_rev, …). Note: aerocoef corresponds to a,b,c,d,e (i.e. acost_rev)	Unitless/ ~-5996 ≤ acost_rev ≤ ~6167 ~-7972 ≤ bcost_rev ≤ ~3423 ~-1937 ≤ ccost-rev ≤ ~3664 ~-3160 ≤ dcost_rev ≤ ~2539 ~-34950 ≤ ecost_rev ≤~33761
thetav	float32 x nrad	Sensor zenith angles	Degree/ 1 ≤ thetav ≤ 75

2.1.1.1.1.2 Rayleigh LUTs

The ACO code requires Rayleigh LUT values to compute the Rayleigh Component of the TOA reflectance. The LUT parameters are summarized in Table 8 and Table 9.

Table 8. Rayleigh LUT Dimensional Parameters

Input	Data Type/Size	Description/Source	Units/Valid Range
nsigma	int32	Number of Surface Roughness Parameters; also represents the number of wind speeds intervals used in the Rayleigh LUTs.	Unitless/ nsigma = 8
acobands	int32	Number of VIIRS Moderate Resolution Bands used in the ACO Algorithm (M1-M7)	Unitless/ acobands = 7
nsun	int32	Number of Solar Zenith Angles	Unitless/ nsun = 45
nrad_ray	int32	Number of Sensor Zenith Angles	Unitless/ nrad_ray = 41
norder_ray	int32	Number of Fourier Coefficients for each of the stokes components I,Q, and U.	Unitless/ norder = 3

Table 9. Rayleigh LUT

Input	Data Type/Size	Description/Source	Units/Valid Range
ray_tau	float32 x acobands	Rayleigh Optical Thickness values for bands M1-M7	Unitless/ 0.0156 (M7) ≤ ray_tau ≤ 0.3187(M1)
sigma_g	float32 x nsigma	Surface Roughness Parameter (Not used in the code)	Unitless/ 0.0296 ≤ sigma_g ≤ 0.4
ray_dep	float32 x acobands	Depolarization Factor for bands M1-M7	Unitless/ 0.0273 ≤ ray_dep ≤ 0.0296

Input	Data Type/Size	Description/Source	Units/Valid Range
ray_sun	float32 x nsun	Solar Zenith Angles	Degree/ 0.0 ≤ ray_sun ≤ 88.0 (2 degree intervals)
ray_ang	float32 x nrad_ray	Senor Zenith Angles	Degree/ 0.0 ≤ ray_ang ≤ 84.215 (~ 2 degree intervals)
ray_for_i	float32 x nrad_ray x norder x nsun x nsigma x acobands	I Stokes Parameter	Unitless/ ~-0.013 ≤ ray_for_i ≤ ~ 0.107
ray_for_q	float32 x nrad_ray x norder x nsun x nsigma x acobands	Q Stokes Parameter	Unitless/ ~-0.066 ≤ ray_for_q ≤ ~ 0.027
ray_for_u	float32 x nrad_ray x norder x nsun x nsigma x acobands	U Stokes Parameter	Unitless/ 0.0 ≤ ray_for_u ≤ ~0.064

2.1.1.1.1.3 Diffuse Transmittance LUTs

The subroutine **diffuse_t_viirs( )** computes the diffuse transmittance values for the ocean-atmosphere system at VIIRS bands M1 to M7, using LUT coefficients **tt_coeff_a** and **tt_coeff_b**, along with the aerosol optical thickness computed in the aerosol correction subroutine **aerosol_rads()**. The LUT coefficients are summarized in Table 10 and Table 11.

Table 10. Diffuse Transmittance LUT Dimensional Parameters

Input	Data Type/Size	Description/Source	Units/Valid Range
acobands	int32	Number of VIIRS Moderate Resolution Bands used in the ACO Algorithm (M1-M7)	Unitless/ acobands = 7
model	int32	Number of Aerosol Models needed by the ACO Algorithm	Unitless/ model = 12
msun	int32	Number of Sensor Zenith Angles	Unitless/ msun = 33

Table 11. Diffuse Transmittance LUT

Input	Data Type/Size	Description/Source	Units/Valid Range
tt_coeff_a	float32 x msun x acobands x model	Diffuse Transmittance Coefficient	Unitless/ 0 ≤ tt_coeff_a ≤ ~1.0
tt_coeff_b	float32 x msun x acobands x model	Diffuse Transmittance Coefficient	Unitless/ 0 ≤ tt_coeff_b ≤ ~0.33

2.1.1.1.1.4 Polarization LUT

The subroutine aco_pol_corr() computes the instrumental polarization sensitivity correction using the instrumental polarization sensitivity LUT with the VIIRS TVAC sensor characterization data. The LUT has HAM mirror side, detector, wavelength, and scan angle dependency, and has been summarized in Tables 12 and 13.

Table 12. Instrumental Polarization Sensitivity LUT Dimensional Parameters

Input	Data Type/Size	Description/Source	Units/Valid Range
nHAM	Int32	VIIRS HAM Mirror Side	Unitless/ nHAM = 2
nDetector	Int32	Detector in Porduct Order	Unitless/ nDetector = 16
acobands	int32	Number of VIIRS Moderate Resolution Bands used in the ACO Algorithm (M1-M7)	Unitless/ acobands = 7
nCoef	Int32	Number of Coefficients	Unitless/ nCoef = 3

Table 13. Instrumental Polarization Sensitivity LUT

Input	Data Type/Size	Description/Source	Units/Valid Range
polcor_coef_a	float32 x acobands x nHAM x nDetector x nCoef	Polarization Correction Coefficient	Unitless/ -0.1 ≤ polcor_coef_a ≤ 0.1
polcor_coef_b	float32 x acobands x nHAM x nDetector x nCoef	Polarization Correction Coefficient	Unitless/ -0.1 ≤ polcor_coef_b ≤ 0.1

2.1.1.1.1.5 Detector-Dependent Rayleigh Correction Adjustment Factors LUT

Tables 14 and 15 describe the contents of the LUT.

Table 14. Detector-Dependent Rayleigh Correction Adjustment LUT Parameter

Input	Data Type/Size	Description/Source	Units/Valid Range
nDetector	Int32	Detector in Product Order	Unitless/ nDetector = 16

Table 15. Detector-Dependent Rayleigh Correction Adjustment LUT

Input	Data Type/Size	Description/Source	Units/Valid Range
ray_detcor	float32 x ndet x acobands	Detector-Dependent Rayleigh Correction Adjustment Factors for detectors 1-16 of bands M1-M7	Unitless/ 0.989 ≤ ray_detcor ≤ 1.008

Detector-Dependent Rayleigh Correction Adjustment Factors are to Address Detector-to-Detector Variations in Implementing the TOA Rayleigh Radiance Correction. The Detectors are in engineering order which is the reverse of the Product Order.

2.1.1.1.1.6 Bright Pixel Flag Threshold LUT

Table 16 shows the BP Threshold LUT parameters and Table 17 shows the BP Threshold LUT information.

Table 16. BP Threshold LUT Parameters

Input	Data Type/Size	Description/Source	Units/Valid Range
NUM_ BP_THRESHOLDS	Int32	Total number of thresholds.	10
NUM_BANDS	Int32	Total number of bands	21

Table 17. BP Threshold LUT

Input	Data Type/Size	Description/Source	Units/Valid Range
Pattern Array	unsigned char x NUM_BP_THRESHOLDS	Pattern for Bright Pixel input	Unitless/ 0 ≤ pattern ≤ 15
Thresholds Array	float32 x NUM_BANDS x NUM_BP_THRESHOLDS	Threshold for bright pixel processing.	Unitless/ 0.002 ≤ threshold ≤ 0.1

2.1.1.1.1.7 Program Parameters for continuous monitoring

Configurable parameters used in the operational code for the VIIRS ACO OCC algorithm are listed in the table below.

Table 18. Configurable Parameters

Field Name	Description	Type	Size (bytes)
esol	Coefficient to convert the RSR(remote sensing reflectance) to water leaving radiance	double[OCCBANDS]	40
band1	Index of band M1	int	4
band2	Index of band M2	int	4
band3	Index of band M3	int	4
band4	Index of band M4	int	4
lam	Array of VIIRS ocean band centers	int[OCCBANDS]	20
bb_denom	Model selection parameter for a(675) calculation	int	4
chl_key	Chlorophyll algorithm selection enumeration (Carder, Carder with OC3V, or OC3V)	int	4
d1	Values used to determine chlorophyll packaging	float	4
d2	Values used to determine chlorophyll packaging	float	4
d3	Values used to determine chlorophyll packaging	float	4
delta	Values used to determine chlorophyll packaging	float	4
s	Spectral slope in absorption model	float	4
bbw	Spectral value of backscattering by pure water	float[OCCBANDS]	20
aw	Spectral value of absorption by pure water	float[OCCBANDS]	20
ga0	Coefficients for phytoplankton absorption function for the global branch at VIIRS bands	float[OCCBANDS]	20

Field Name	Description	Type	Size (bytes)
ga1	Coefficients for phytoplankton absorption function for the global branch at VIIRS bands	float[OCCBANDS]	20
ga2	Coefficients for phytoplankton absorption function for the global branch at VIIRS bands	float[OCCBANDS]	20
ga3	Coefficients for phytoplankton absorption function for the global branch at VIIRS bands	float[OCCBANDS]	20
x0	Regression coefficient for x (used to calc bbp)	float	4
x1	Regression coefficient for x (used to calc bbp)	float	4
y_0	Regression coefficient for y (used to calc bbp)	float	4
y_1	Regression coefficient for y (used to calc bbp)	float	4
aph_lo	Minimum phytoplankton absorption coefficient value for semi-analytic formula to apply	float	4
aph_hi	Maximum phytoplankton absorption coefficient value for semi-analytic formula to apply	float	4
gc0	Global Coefficients for Default and Model Chlorophyll Concentrations at VIIRS bands	float	4
gc1	Global Coefficients for Default and Model Chlorophyll Concentrations at VIIRS bands	float	4
gc2	Global Coefficients for Default and Model Chlorophyll Concentrations at VIIRS bands	float	4
gc3	Global Coefficients for Default and Model Chlorophyll Concentrations at VIIRS bands	float	4
gp0	Global Coefficients for Default and Model Chlorophyll Concentrations at VIIRS bands	float	4
gp1	Global Coefficients for Default and Model Chlorophyll Concentrations at VIIRS bands	float	4
gp2	Global Coefficients for Default and Model Chlorophyll Concentrations at VIIRS bands	float	4
low_412_thresh	flag cutoffs	float	4
low_555_thresh	flag cutoffs	float	4
chl_inconsistent_thresh	flag cutoffs	float	4
upa0	Unpackaged Coefficients for Phytoplankton Absorption Function	float[OCCBANDS]	20
upa3	Unpackaged Coefficients for Phytoplankton Absorption Function	float[OCCBANDS]	20
pa0	Packaged Coefficients for Phytoplankton Absorption Function	float[OCCBANDS]	20
pa3	Packaged Coefficients for Phytoplankton Absorption Function	float[OCCBANDS]	20
upc0	Unpackaged Coefficients for Default and Model Chlorophyll Concentrations	float	4

Field Name	Description	Type	Size (bytes)
upc1	Unpackaged Coefficients for Default and Model Chlorophyll Concentrations	float	4
upc2	Unpackaged Coefficients for Default and Model Chlorophyll Concentrations	float	4
upc3	Unpackaged Coefficients for Default and Model Chlorophyll Concentrations	float	4
pc0	Packaged Coefficients for Default and Model Chlorophyll Concentrations	float	4
pc1	Packaged Coefficients for Default and Model Chlorophyll Concentrations	float	4
pc2	Packaged Coefficients for Default and Model Chlorophyll Concentrations	float	4
pc3	Packaged Coefficients for Default and Model Chlorophyll Concentrations	float	4
upp0	Unpackaged Coefficients for Default and Model Chlorophyll Concentrations	float	4
upp1	Unpackaged Coefficients for Default and Model Chlorophyll Concentrations	float	4
upp2	Unpackaged Coefficients for Default and Model Chlorophyll Concentrations	float	4
pp0	Packaged Coefficients for Default and Model Chlorophyll Concentrations	float	4
pp1	Packaged Coefficients for Default and Model Chlorophyll Concentrations	float	4
pp2	Packaged Coefficients for Default and Model Chlorophyll Concentrations	float	4
hpa0	Fully Packaged Coefficients for Phytoplankton Absorption Function	float[OCCBANDS]	20
hpa1	Fully Packaged Coefficients for Phytoplankton Absorption Function	float[OCCBANDS]	20
hpa2	Fully Packaged Coefficients for Phytoplankton Absorption Function	float[OCCBANDS]	20
hpa3	Fully Packaged Coefficients for Phytoplankton Absorption Function	float[OCCBANDS]	20
hpc0	Fully Packaged Coefficients for Default and Model Chlorophyll Concentrations	float	4
hpc1	Fully Packaged Coefficients for Default and Model Chlorophyll Concentrations	float	4
hpc2	Fully Packaged Coefficients for Default and Model Chlorophyll Concentrations	float	4
hpc3	Fully Packaged Coefficients for Default and Model Chlorophyll Concentrations	float	4
hpp0	Fully Packaged Coefficients for Default and Model Chlorophyll Concentrations	float	4
hpp1	Fully Packaged Coefficients for Default and Model Chlorophyll Concentrations	float	4

Field Name	Description	Type	Size (bytes)
hpp2	Fully Packaged Coefficients for Default and Model Chlorophyll Concentrations	float	4
lambda0bb	Reference VIIRS wavelength for computing Rrs/bb ratios	float	4
lambda0dom	Reference VIIRS wavelength for computing gelbstoff absorption coefficients g12, g34	float	4
bathy_thresh	Threshold for shallow water flag	float	4
rsr_thresh	Maximum remote sensing reflectance value	float	4
rsr_min	Minimum remote sensing reflectance value	float	4
turbid_water_thresh	Threshold for Turbid Water flag	float	4
Max_nLw	Range of Ocean Color (nLw)	float	4
Min_nLw	Range of Ocean Color (nLw)	float	4
Max_chlo	Range of Chlorophyll Concentration (Thresholds)	float	4
Min_chlo	Range of Chlorophyll Concentration (Thresholds)	float	4
Chlo_1	Range of Chlorophyll Concentration (various regimes)	float	4
Chlo_10	Range of Chlorophyll Concentration (various regimes)	float	4
Max_iopa	Range of IOP-a	float	4
Max_iops	Range of IOP-a	float	4
Min_iopa	Range of IOP-s	float	4
Min_iops	Range of IOP-s	float	4
NLW_M2_THRESH	Coccolithophores Exclusion thresholds	float	4
NLW_M4_THRESH	Coccolithophores Exclusion thresholds	float	4
M2_M4_RATIO_MIN	Coccolithophores Exclusion thresholds	float	4
M2_M4_RATIO_MAX	Coccolithophores Exclusion thresholds	float	4
aa	Regression coefficients from MOIDS/AQUA for OC3M	float[OCCBANDS]	20
sphae	phaeophytin term for total absorption coeff calculation	float	4
lam412	phaeophytin term for ag412 used in the total absorption coeff calculation	float	4
ag_def_coeff	ag coeff values for OCC band	float[OCCBANDS]	20
aph_def_coeff	Aph coeff values for OCC bands	float[OCCBANDS]	20
w0_thresh	Strongly Absorbing Aerosol Exclusion	float	4
tau_thresh	tau_thresh for AOT	float	4
ViCal_Coef	Pre-multipliers to the M1 to M7 reflectances for performing Vicarious Calibration post-launch	float[ACOBANDS]	28
Pad	Pad bytes added by the compiler to memory align the structure	float	4

2.1.1.2 Outputs

The ACO/OCC unit produces an output OCC EDR with five fields, described in Table 19. The Quality Flag (QF) Data Fields in the OCC EDR contain the ocean color QFs for each moderate resolution pixel and for the granule stored as bit fields within 8-bit unsigned integers. Bit structure of the OCC pixel level QFs is described in Table 20.

Table 19. ACO/OCC EDR Output Description

Output	Data Type/Size	Description/Source	Units/Valid Range
Chlorophyll	float32 x m_viirs_sdr_rows x m_viirs_sdr_cols	Chlorophyll Concentration	mg/m^3 0.05 < Chl ≤ 50 *FILL_VALUE = -999.9*
IOP-a	float32 x 5 x m_viirs_sdr_rows x m_viirs_sdr_cols	Inherent Optical Properties – Absorption Coefficients	m^{-1} 0.01 < IOP-a ≤ 10 *FILL_VALUE = -999.9*
IOP-s	float32 x 5 x m_viirs_sdr_rows x m_viirs_sdr_cols	Inherent Optical Properties – Back-Scattering Coefficients	m^{-1} 0.01 < IOP-s ≤ 50 *FILL_VALUE = -999.9*
nLw	float32 x 5 x m_viirs_sdr_rows x m_viirs_sdr_cols	Normalized Water Leave Radiance	W/m^2 /µm/sr) 0.1 < nLW ≤ 40 *FILL_VALUE = -999.9*
Pixel QFlags	uint8 x 7 x m_viirs_sdr_rows x m_viirs_sdr_cols	OCC/Chlorophyll Pixel Level Quality Bit Flags (See Table 15)	See Table 15

Table 20. Bit Structure of the Pixel Level Quality Bit Flags for the VIIRS OCC EDR

Byte	Bit	Flag Description Key	Bit Value
0	0	Ocean Color quality at M1	0 = Good, 1 = Poor
	1	Ocean Color quality at M2	0 = Good, 1 = Poor
	2	Ocean Color quality at M3	0 = Good, 1 = Poor
	3	Ocean Color quality at M4	0 = Good, 1 = Poor
	4	Ocean Color quality at M5	0 = Good, 1 = Poor
	5	Chlorophyll Concentration quality	0 = Good, 1 = Poor
	6	IOP-a quality at M1	0 = Good, 1 = Poor
	7	IOP-s quality at M1	0 = Good, 1 = Poor
1	0	IOP-a quality at M2	0 = Good, 1 = Poor
	1	IOP-s quality at M2	0 = Good, 1 = Poor
	2	IOP-a quality at M3	0 = Good, 1 = Poor
	3	IOP-s quality at M3	0 = Good, 1 = Poor
	4	IOP-a quality at M4	0 = Good, 1 = Poor
	5	IOP-s quality at M4	0 = Good, 1 = Poor
	6	IOP-a quality at M5	0 = Good, 1 = Poor
	7	IOP-s quality at M5	0 = Good, 1 = Poor

Byte	Bit	Flag Description Key	Bit Value
2	0	SDR Quality for Ocean Bands M1 to M7	0 = Good for all seven bands 1 = Poor (any band greater than thresholds)
	1	Input Total Ozone Column Quality	0 = Good, 1 = Poor
	2	Wind Speed Indicator	0 = Low wind (0 ≤ speed ≤ 8.0 m/s) 1 = High wind (speed > 8.0 m/s)
	3	Epsilon Out of Aerosol Models Range	0 = Within model range (0.85 ≤ □ ≤ 1.35) 1 = Out of model range, or no □□available
	4-6	Atmospheric Correction Failure	000 = Atmospheric correction successful 001 = Ozone correction failure 010 = Whitecap correction failure 011 = Polarization correction failure 100 = Rayleigh correction failure 101 = Aerosol correction failure 110 = Zero diffuse transmittance 111 = No correction possible
	7	Spare	Set to 0
3	0-1	Land/Water	00 = Sea water, 01 = Coastal water, 10 = Inland water, 11 = Land
	2	Snow/Ice	0 = Not snow/ice 1 = Snow/ice
	3	Day/Night Exclusion	0 = Day (SZA<70 degrees) 1 = Night (SZA >=70 degrees)
	4	Sun Glint Exclusion	0 = No sun glint, 1 = Sun glint
	5	Horizontal Reporting Interval (HRI) > 1.3 km Exclusion	0 = No, nadir to 1.3km (0 degrees <= SZA <= 53 degrees) 1 = Yes, HRI > 1.3 km exclusion
	6	Shallow Water	0 = Deep water (Depth >= 50 m) 1 = Shallow water (Depth < 50 m)
	7	Spare	Set to 0
4	0-1	Cloud Confident Indicator	00 = Confident clear, 01 = Probably clear 10 = Probably cloudy, 11 = Confident cloudy
	2	Adjacent Pixel Cloud Confident Indicator	0 = Confident clear, 1 = Cloudy
	3	Cirrus Cloud Detection	0 = No Cirrus detected 1 = Cirrus detected
	4	Cloud Shadow Exclusion	0 = No cloud shadow, 1 = Shadow present
	5	Non Cloud Obstruction (Heavy Aerosol)	0 = No, 1 = Yes
	6	Strongly Absorbing Aerosol (Single Scattering Albedo ω_0(M4) < 0.7) Exclusion	0 = No exclusion, or no ω_0(M4) available 1 = Strongly absorbing aerosol present (ω_0(M4) < 0.7)
	7	Aerosol Optical Thickness (AOT @ 865 nm(M7)) Exclusion (AOT>0.3)	0 = No AOT exclusion, or no AOT available 1 = AOT exclusion (AOT>0.3)
5	0	Turbid Water (R_{rs}(M5) > 0.0012) Exclusion	0 = No (R_{rs}(M5) ≤ 0.0012), or no R_{rs}(M5) available 1 = Yes (R_{rs}(M5) > 0.0012)
	1	Coccolithophores Present (nLw(M2) ≥ 1.1 & nLw(M4) ≥ 0.81 & L_{aer}(M6) ≤ 1.1 & 0.6 ≤ nLw(M2)/ nLw(M4) ≤ 1.1)	0 = No coccolithophores, or no information 1 = Yes (nLw(M2) ≥ 1.1 & nLw(M4) ≥ 0.81 & L_{aer}(M6) ≤ 1.1 & 0.6 ≤ nLw(M2)/ nLw(M4) ≤ 1.1)

Byte	Bit	Flag Description Key	Bit Value
	2	Dissolved Organic Matter Absorption Dominant Waters Exclusion (DOM absorption a(410) > 2/m)	0 = No DOM absorption exclusion, or no a(410) available 1 = DOM absorption exclusion (a(410) > 2/m)
	3-4	Range of Chlorophyll Concentration	00 = No chlorophyll retrieval 01 = Chlorophyll < 1 mg/m^3 10 = 1.0 ≤ Chlorophyll < 10 mg/m^3 11 = Chlorophyll ≥ 10 mg/m^3
	5-7	Carder Bio-Optics Algorithm Branching	000 = Initialized Value 001 = Carder empirical algorithm 010 = Unpackaged phytoplankton model 011 = Weighted global-unpackaged algorithm 100 = Weighted packaged-global algorithm 101 = Weighted fully packaged-packaged 110 = Fully packaged phytoplankton model 111 = No OCC retrieval
6	0	Ocean Color (any band) Out of Reporting Range	0 = In range (1.0 ≤ nLw ≤ 40 W/m2/□m/sr) 1 = Out of range
	1	Chlorophyll Concentration Out of Reporting Range	0 = In range (0.05 ≤ Chl ≤ 50 mg/m3) 1 = Out of range
	2	IOP-a (any band) Out of Reporting Range	0 = In range (0.01 ≤ IOP_a ≤ 10 /m) 1 = Out of range
	3	IOP-s (any band) Out of Reporting Range	0 = In range (0.01 ≤ IOP_s ≤ 50 /m) 1 = Out of range
	4	Input skin SST EDR Quality	0 = Good, 1 = Poor
	5	Bright Target Exclusion	0=No Exclusion (bpflag≤0.002), 1=Bright Target Exclusion
	6-7	Chlorophyll Algorithm Branching	00 = Carder algorithm with Carder empirical 01 = Carder algorithm with OC3V default 10 = OC3V algorithm

2.1.2 Algorithm Processing

The VIIRS Remote Sensing Reflectance Intermediate Product (RSR IP) is produced by the Atmospheric Correction Over Ocean (ACO) algorithm through removal of atmospheric and surface reflection components from signals received by the satellite-based visible-wavelength detectors. The VIIRS OCC EDR contains ocean color (normalized water-leaving radiance) and inherent optical properties for scattering and absorption at the five visible wavelength bands, chlorophyll concentration, and a 7-byte quality flag is produced by the Ocean Color/Chlorophyll (OCC) algorithm. Inputs to the ACO and OCC algorithms include measured TOA VIIRS reflectances in the visible and near-infrared bands M1 to M7, Bright Pixel IP bands M1 to M7, VCM IP, VIIRS SST EDR, granulated bathymetric data and NDT data, SSWS, surface atmospheric pressure, total precipitable water, and total column ozone. The ACO algorithm utilizes the sun glint flag and the snow/ice flag obtained from the VCM IP for setting the sun glint and ice ocean exclusion, bathymetric data for setting the shallow water flag. The algorithm first applies corrections for atmospheric gaseous absorption for ozone, water vapor, and other constant species as total transmittance and whitecaps. Then the algorithm computes the Rayleigh reflectance due to molecular scattering and adjusts for detector-to-detector variation of the RSR and corrects for scan angle, HAM side, and detector dependent residual instrumental polarization. The algorithm then correct for sun glint and subtracts the contributions of aerosol scattering in the atmosphere, and reflection from the air-sea interface, from the corrected VIIRS reflectances. The OCC algorithm starts with the RSR IP retrieved by the ACO algorithm and utilizes SST and NDT to select the branching algorithm and the corresponding model parameters to produce the ocean color EDR. A derived class of the ProCmnAlgorithm class, two algorithm drivers, and fourteen FORTRAN 90 functions are discussed below, including descriptions of the algorithms used. Data flow for producing the RSR IP is shown in Figure 2. Data flow for producing the OCC EDR is shown in Figure 3.

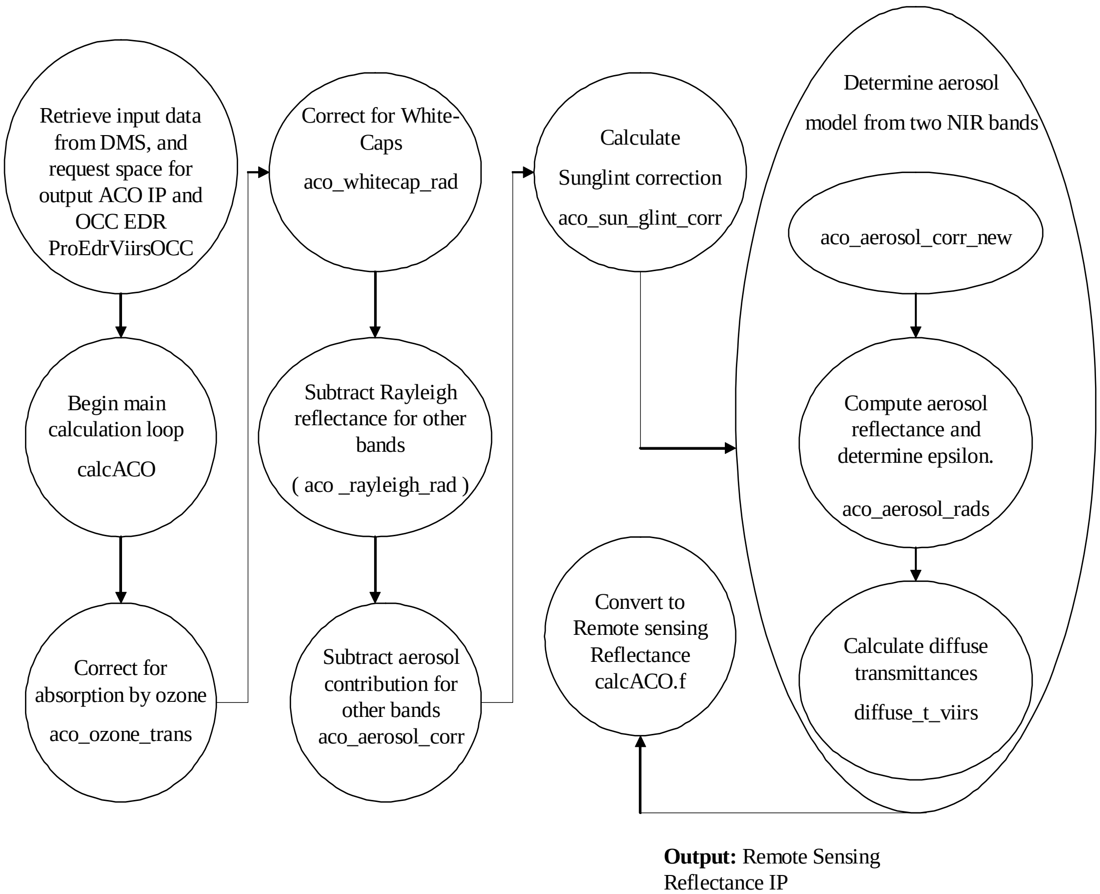

Figure 2. Processing Steps for calcACO.f to Produce the RSR IP

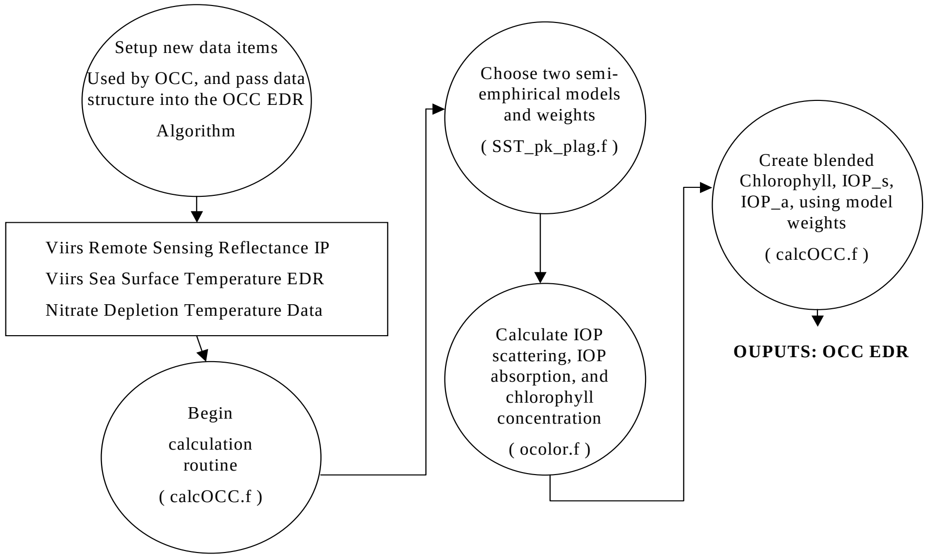

Figure 3. Processing Steps for calcOCC.f to Produce the OCC EDR

2.1.2.1 Main Module - OO Controller/Interface for ACO/OCC (ProEdrViirsOCC.cpp)

This object is the ACO/OCC derived class of ProCmnAlgorithm.cpp responsible for controlling the calculation of both the RSR IP and OCC EDR. The routine obtains from DMS both VIIRS and non-VIIRS input data then assigns output data locations within DMS. This object has methods that are responsible for obtaining input data items required to perform the algorithm, calling the FORTRAN90 science code responsible for operation of the algorithms, and outputting the generated IP and EDR as well as any associated metadata.

2.1.2.2 Atmospheric Correction Over Ocean subroutine driver (calcACO.f)

This routine loops through VIIRS moderate-resolution pixels calling the subroutines for each component of the atmospheric correction for every pixel. Each of the correction functions are called sequentially in the following order:

1. Gaseous absorption
2. Whitecap
3. Rayleigh
4. Polarization
5. Sun glint
6. Aerosol.

As these corrections are computed they are applied to the incoming TOA reflectance. The corrections are designated as the following parameters:

1. *t_ozone*

2. *Lwc* (Section 2.1.2.3)
3. *Lray* (Section 2.1.2.4)
4. *Lpol_corr* (Section 2.1.2.6.1)
5. *Lsg_corr*, and
6. *Laer* (Section 2.1.2.6.3).

The code also computes the diffuse transmittance (*t_diffuse*) summarized in Section 2.1.2.6.4.

The code does not retrieve the remote sensing reflectance (RSR) for pixels flagged as land, confidently cloudy, snow/ice, or night. If any of the SDRs visible/IR bands (M1 to M7) is not available (i.e. a fill value), the code will not retrieve the RSR.

The interpolated total column ozone from OMPS or NCEP, *OZ_interp*, and the total column ozone (*oz*) used in the code is in atm-cm. The interpolated total precipitable water from NCEP TPW interp is in cm.

The subsequent atmospheric corrections are computed as follows:

- $Lcorr\_gas(\lambda) = Lin(\lambda)/t\_gas(\lambda)$ -> *Gaseous Absorption Correction*
- $Lcorr\_wc(\lambda) = Lcorr\_oz(\lambda) – Lwc(\lambda)$ -> *Whitecap Correction*
- $Lcorr\_ray(\lambda) = Lcorr\_wc(\lambda) – Lray(\lambda)\cdot pol\_corr(\lambda)$ -> *Rayleigh and Polarization Correction*
- $Lcorr\_sg(\lambda) = Lcorr\_ray(\lambda) – Lsg(\lambda)$ -> *Sun-glint Correction*
- $Lcorr\_aer(\lambda) = Lcorr\_sgl(\lambda) – Laer(\lambda)$ -> *Aerosol Correction*
- $RSR(\lambda_{visible}) = (1/\pi)Lcorr\_aer(\lambda)/t\_diffuse(\lambda_{visible})$, -> *RSR Computation*

where *Lcorr_gas*, *Lcorr_wc*, *Lcorr_ray*, *Lcorr_sg, and Lcorr_aer* are the corrected TOA reflectances after the ozone, whitecap, Rayleigh, polarization, sun glint correction, and aerosol corrections respectively; *t_diffuse* is the diffuse transmittance. All of these parameters are a function of wavelength (λ) which represent VIIRS VISIR bands M1 to M7. RSR is the normalized remote sensing reflectance in sr^{-1} where the normalization factor is the $1/\pi$ multiplier; the RSR is a function of bands M1 to M5 ($\lambda_{visible}$).

2.1.2.3 Atmospheric Gaseous Absorption (aco_ozone_trans.f)

The 2-way total gaseous transmittance for VIIRS bands M1 to M7 is given as $t_{gas} = t_{oz}\, t_{h2o}\, t_{og}$. The subroutine aco_ozone_trans() is used to compute the ozone transmittance for bands M1 to M7 given the viewing geometry, total ozone column, and the ozone absorption coefficients for each band. The ozone transmittance for bands M1 to M7 is given by

$$t_{oz}(\lambda) = e^{-Z\cdot k_{oz}(\lambda)\cdot\left(\frac{1}{\mu}+\frac{1}{\mu_0}\right)}$$

where, Z is the total column ozone concentration in atmospheres-cm (converted from Dobsons by dividing by 1000), $k_{oz}(\lambda)$ is the ozone absorption coefficient, μ is the cosine of the viewing zenith angle, μ_0 is cosine of the solar zenith angle.

The subroutine aco_water_trans() is used to compute the water vapor transmittance. The 2-way water vapor transmittance for each ocean band is given by

$$t_{H2O}(\lambda) = e^{a(\lambda)\cdot x + b(\lambda)\cdot\log(x) + c(\lambda)\cdot x\cdot\log(x)}$$

$$x = U\left[\frac{1}{\mu} + \frac{1}{\mu_0}\right]$$

where, U is the total precipitable water, a, b, and c are the band dependent water vapor absorption coefficients.

Similarly, the subroutine aco_other_trans() is used to compute the transmittance for other constant species gas. The total transmittance for other constant species is given as:

$$t_{OG}(\lambda) = \exp[m\cdot(a_0P + a_1\log P)]\cdot\exp[(b_0P + b_1\log P)\cdot\log(m)]\cdot\exp[(c_0P + c_1\log P)\cdot m\log(m)]$$

$$m = \frac{1}{\mu} + \frac{1}{\mu_0}$$

where P is the surface pressure, a_0, a_1, b_0, b_1, c_0, and c_1 are the band dependent absorption coefficients. The gaseous absorption corrected reflectance $\rho_{gas\ corr}(\lambda)$ is then computed as $\rho_{gas\ corr}(\lambda) = \rho_N(\lambda) / t_{gas}(\lambda)$.

2.1.2.4 Calculate Reflectance Due To Whitecaps (aco_whitecap_rad.f)

This subroutine calculates whitecap reflectance corrections for each band. If the surface wind speed is zero then the reflectance due to whitecaps is zero, otherwise the whitecap reflectance is a function of the wind speed. The white foam reflectance is given by

$$white = 0.25 * 6.49x10^{-7} * (winds^{3.52})$$

where “winds” is the wind speed in m/s. The whitecap reflectance, Lwc, for each band is

$$Lwc(nl) = white*t\_rho$$

where *nl* are the M1 to M7 band indices (1-7) and *t_rho* is a set of band dependent whitecap coefficients inherited from the MODIS ACO algorithm/data package (*t_rho* is declared in **aco_geom_phys.f**). Both *Lwc* and *t_rho* are unitless.

2.1.2.5 Calculate Reflectance Due to Atmospheric Rayleigh Scattering (aco_rayleigh_rad.f)

The Rayleigh scattering radiance components “I”, “Q”, and “U” are extracted from the Rayleigh LUTs detailed in Section 2.1.1.1.1.2. These LUT values are then interpolated with respect to the viewing geometry (solar zenith (θ_0) and sensor zenith angles (θ)). In addition to interpolating with respect to the viewing geometry, the code also interpolates the radiance with respect to wind speed; these are denoted *ray_i_lut*, *ray_q_lut*, and *ray_u_lut* for the I, Q, and U Stokes components. After computing the interpolated radiance values a correction factor *fac* is computed as follows:

$$fac = \frac{1-e^{-cc\tau_r'(\lambda)\left(\frac{1}{\cos(\theta)}+\frac{1}{\cos(\theta_0)}\right)}}{1-e^{-cc\tau_r(\lambda)\left(\frac{1}{\cos(\theta)}+\frac{1}{\cos(\theta_0)}\right)}}$$

Where: $\frac{1}{\cos(\theta)}+\frac{1}{\cos(\theta_0)}$ (cosines of the sensor zenith and solar zenith angles respectively) is the air mass, $\tau_r'(\lambda)=\tau_r(\lambda)P_0$, and $\tau_r(\lambda)$ is defined as the Rayleigh optical depth for bands M1 to M7, and ***cc*** is the coefficient that accounts for atmospheric variations and is computed as follows:

$$cc = (0.6543 - 1.608\tau_r) + (0.8192 - 1.2541\tau_r)\log\left(\frac{1}{\cos(\theta)}+\frac{1}{\cos(\theta_0)}\right).$$

P_0 accounts for the surface pressure variations by taking the ratio of the measured surface pressure *pres* (NCEP data) and the standard pressure *pres0* at 1013.25mb.

The final Rayleigh reflectance is computed as such:

$$ray\_i(\lambda) = ray\_i\_lut(\lambda)\cdot fac\cdot\pi/\cos(\theta_0)$$
$$ray\_q(\lambda) = ray\_q\_lut(\lambda)\cdot fac\cdot\pi/\cos(\theta_0)$$
$$ray\_u(\lambda) = ray\_u\_lut(\lambda)\cdot fac\cdot\pi/\cos(\theta_0)$$

where the $\pi/\cos(\theta_0)$ factor converts the Rayleigh radiance, normalized with solar-irradiance F_0=1, into reflectance. The parameter $ray\_i(\lambda)$ is the $Lray(\lambda)$ parameter.

Upon examination of the individual detector RSRs for each band, it was determined that there is sufficient detector-to-detector variation (especially for band M1) to warrant implementing a simple detector-dependent adjustment to the TOA Rayleigh radiance correction, which is currently determined from the Rayleigh LUT based solely on detector-averaged RSRs. The detector-dependent adjustment multiplies the normalized radiance obtained from the Rayleigh Radiance LUT by the ratio of the band-averaged Rayleigh Optical Thickness computed from each detector RSR to that produced from the detector-averaged RSR. This approach is based on the approximation for the band-averaged Rayleigh radiance from Gordon [2], where:

$$\langle L_r(\lambda)\rangle_{S_i} \cong G(\theta_0,\theta_V,\phi)\int_\lambda \tau_r(\lambda)F_0(\lambda)S_i(\lambda)d\lambda$$

$$so\,that\ \langle\hat{L}_r(\lambda)\rangle_{S_i} \equiv \frac{\langle L_r(\lambda)\rangle_{S_i}}{\langle F_0(\lambda)\rangle_{S_i}} \cong G(\theta_0,\theta_V,\phi)\frac{\int_\lambda \tau_r(\lambda)F_0(\lambda)S_i(\lambda)d\lambda}{\int_\lambda F_0(\lambda)S_i(\lambda)d\lambda} = G(\theta_0,\theta_V,\phi)\langle\tau_r(\lambda)\rangle_{S_i}.$$

Based on the above relation, the normalized band-averaged Rayleigh radiance for each detector, $\langle L_r(\lambda)\rangle_{S-Det}$, can be easily determined using the normalized band-averaged radiance from the Rayleigh LUT, $\langle L_r(\lambda)\rangle_{S-Avg}$ and the ratio of the Rayleigh Optical Thicknesses,

$$\langle \hat{L}_r(\lambda)\rangle_{S-Det} = \langle \hat{L}_r(\lambda)\rangle_{S-Avg} \frac{\langle \tau_r(\lambda)\rangle_{S-Det}}{\langle \tau_r(\lambda)\rangle_{S-Avg}}.$$

The above ratio of Rayleigh Optical Thicknesses has been pre-computed for each detector and is provided as a detector-dependent Rayleigh correction factor LUT, shown in Tables 14 and 15.

2.1.2.6 Instrumental Polarization Correction (aco_pol_corr.f)

Instrumental Polarization Correction

The detailed description of the polarization is given in Section 3.3.2 of the VIIRS ACO ATBD (474-00050). In summary, Rayleigh polarization correction, PolCor, is

$$[1+P_{in}P_{pol}\cos 2(\alpha-\varphi-\chi_{in})]$$

where ,

$$P_{in} = Instrument\ polarization\ sensitivity$$

$$\chi_{in} = Instrument\ polarization\ phase\ angle$$

$$P_{pol} = Degree\ of\ polarization\ at\ TOA \equiv \frac{\sqrt{Q_{TOA}^2 + U_{TOA}^2}}{L_{TOA}}$$

$$\varphi = Polarization\ phase\ angle\ at\ TOA \equiv \frac{1}{2}\tan^{-1}\left(\frac{U_{TOA}}{Q_{TOA}}\right)$$

The residual reflectance at each ocean band after correction to Rayleigh (including detector-dependent adjustment) and polarization are:

$$\rho_{ay\_corr}(\lambda) = \rho_m - \rho_r(\lambda)\cdot[1+P_{pol}\cdot P_{in}\cos 2(\alpha-\phi-\chi_{in})]$$

where, ρ_{pol_corr} is the reflectance corrected for instrument polarization and Rayleigh scattering with detector dependent adjustment, ρ_m is the measured reflectance after applying subsequent atmospheric corrections (e.g., gaseous absorption and whitecap).

Approach for Computing the Scan Angle used in the Polarization Correction

The VIIRS scan angle is needed for implementing the polarization correction in the ACO code. Since the scan angle is not a saved variable in the VIIRS SDR, EDRs or any of the IPs, it needs to be computed from information that is contained in these outputted products. Using information that is readily available in the SDR and GEO IP products, a formally exact method for computing the sensor scan angle has been developed. The approach, illustrated in the figure below, uses the Cartesian coordinates of the satellite position in the ECEF frame (which is available from the GEO IP) together with the geodetic latitude and longitude of the center in-track pixel (either pixel 8 or 9) from the SDR to accurately determine the magnitude of the scan angle. In general, we first use the satellite ECEF position, $\vec{r}$, and the pixel ECEF position, $\vec{R}$, to form the line-of-sight (LOS) unit vector from the satellite to the pixel location, $\hat{V} = (\vec{R}-\vec{r})/|\vec{R}-\vec{r}|$. We then compute the normal, $\hat{n}$, to the WGS84 Earth Reference Ellipsoid at the sub-satellite point. This normal is along the direction of the z-axis of the satellite for a geodetic pointing satellite like NPOESS. The scan angle, δ, is then obviously given by $\delta = \cos^{-1}\left\{-\hat{V} \bullet \hat{n}\right\}$.

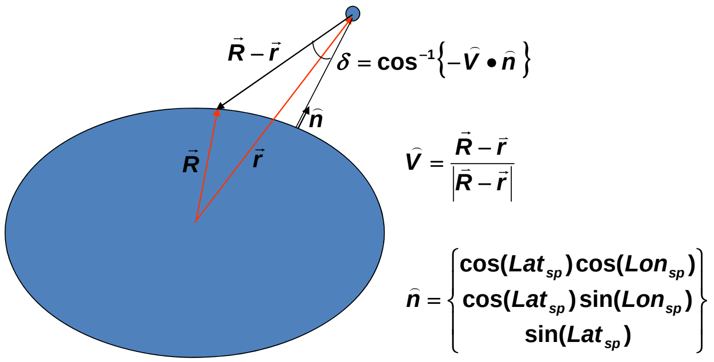

Figure 4. Illustration of the approach for computing the sensor scan angle

The detailed steps of the algorithm described above are as follows:

- Obtain satellite ECEF position, $\vec{r} = \left\{x_{sat}, y_{sat}, z_{sat}\right\}$, from the VIIRS GEO IP
- Obtain the latitude and longitude of in-track pixel 8 for each along-scan frame from the SDR and convert them into Cartesian coordinates in the ECEF frame. The relations for this are:

$$\vec{R} = \begin{Bmatrix} N\cos(lat_p)\cos(lon_p) \\ N\cos(lat_p)\sin(lon_p) \\ (1-e^2)N\sin(lat_p) \end{Bmatrix},$$

$$where,$$
$$N = R_E / \left[1 - e^2 \sin^2(lat_p)\right]$$
$$e^2 = 2f - f^2$$
$$f = 1/298.257223563$$
$$R_E = 6{,}378{,}137\ meters$$

- Compute geodetic latitude and longitude of the sub-satellite point, at which the normal to the WGS84 Earth Reference Ellipsoid will be determined. The latitude and longitude are given by:

$$lon_{sp} = \tan^{-1}(y_{sat}, x_{sat}), where\ lon_{sp} = \mathrm{mod}(lon_{sp}, 2\pi)$$
$$lat_{sp} = \tan^{-1}(z_{sat} + ep^2 b\sin^3\theta,\ p - e^2 R_E \cos^3\theta)$$

where,

$$b = \sqrt{R_E^2(1-e^2)}$$

$$ep = \sqrt{(R_E^2 - b^2)/b^2}$$

$$p = \sqrt{x_{sat}^2 + y_{sat}^2}$$

$$\theta = \tan^{-1}(R_E z_{sat}, bp)$$

- Compute the normal to the Earth Reference Ellipsoid at the sub-satellite point. Since we're using the geodetic latitude and longitude, the normal at the sub-satellite point is simply

$$\hat{n} = \begin{Bmatrix} \cos(lat_{sp})\cos(lon_{sp}) \\ \cos(lat_{sp})\sin(lon_{sp}) \\ \sin(lat_{sp}) \end{Bmatrix}.$$

- Compute the LOS vector from the satellite to the pixel location

$$\vec{V} = \vec{R} - \vec{r}.$$

- Finally, compute the magnitude of the scan angle, δ, from

$$\delta = \cos^{-1}\left\{\frac{-\vec{V}}{|\vec{V}|} \bullet \hat{n}\right\}.$$

Only the magnitude of the scan angle is computed from the above algorithm, not its sign. The only way to obtain the sign of the scan angle is to have prior knowledge of the scan direction (i.e., minus-to-plus or plus-to-minus) and to use the frame number (i.e., frame numbers greater or less than 1600 of 3200 moderate-resolution frames). It should also be noted that any attitude variation of the satellite from geodetic nadir will give rise to an error in the scan angle. Since the nominal attitude variations of the satellite will be less than ~45 arc-seconds, the error in scan angle should be negligible.

To assess the performance of the scan angle computation, several 48 scan VIIRS proxy granules taken at the equator, mid-latitude, and pole were used.

2.1.2.7 Sun Glint Correction (aco_glint_corr.f)

The sun glint correction is performed using the same formulation described in Wang and Bailey (Correction of sun glint contamination on the SeaWiFS ocean and atmosphere products, *Applied Optics*, 40, 4790-4798, 2001). The correction is implemented according to the procedure outlined in the Wang and Bailey article and the SeaDAS software Version 2.8. The majority of the source code for sun glint correction was either provided by Dr. Minghua Wang or extracted from the SeaDAS processing software provided by NASA. The source code has been modified by NGST in order to be integrated into the VIIRS ACO science code. ACO_GLINT_CORR.f contains the following subroutines:

`glint_refl (num_iter,nband,glint_coef,mu0,mu,taur,taua,La,TLg)` is used to compute the sun glint reflectance given the solar and viewing geometry, the glitter radiance from the Cox and Munk model, aerosol optical thickness, and aerosol reflectance.

glitter_refl (glintOn,X1,X2,X3,X4,X5,X6) is used to calculate the glitter reflectance according to the Cox and Munk model.

The sun glint correction is performed just before the aerosol correction. It is done using a two-step iterative scheme, in which the first call to subroutine **glint_refl()** is to use the climatological averaged aerosol optical thickness of 0.1 to obtain an estimate of sun glint reflectance, then an estimated aerosol reflectance is computed using the estimated sun glint reflectance. The subroutine **glint_refl()** is called a second time to obtain a better estimate of the sun glint reflectance.

2.1.2.8 Obtain Aerosol Transmittance and Reflectance Correction (aco_aerosol_corr.f)

The aerosol correction mainly takes place in the **aerosol_rads( )** function. The purpose of the function is to compute the aerosol contribution to the TOA reflectance. The aerosol correction algorithm employs the single-scattering epsilon method laid out by Menghua Wang and Howard Gordan's Retrieval of water-leaving radiance and aerosol optical thickness over the oceans with SeaWiFS: A Preliminary algorithm, *Applied Optics*, 33, 443-452 (1994) and Gordon's Atmospheric correction of ocean color imagery in the Earth Observing System era, *JGR*, 102, 17081-17106 (1997). Section 2.1.2.6.1 summarizes the aerosol correction process.

2.1.2.8.1 Aerosol Correction (aerosol_rads.f)

In order to utilize the single-scattering epsilon method to compute the aerosol correction, the "epsilon" value must be computed for the incoming sensor/viewing geometry. The retrieved epsilon value is defined as:

$$\varepsilon_{retrieved} = \frac{\sum_{i=1}^{M} \frac{\rho_{as}^{(i)}(\lambda_s)}{\rho_{as}^{(i)}(\lambda_l)}}{M}$$

where Σ over i = 1,…,M is the sum over all possible aerosol models; in this algorithm M = 12 (see Section 2.1.1.1.1.1 for details). The ratio of $\rho_{as}^{(i)}(\lambda_s)/\rho_{as}^{(i)}(\lambda_l)$ is the ratio of the single scattering aerosol values at the VIIRS shortwave and long-wave IR bands λ_s=M6 and λ_l=M7 over all 12 aerosol models. λ_s and λ_l are wavelengths at 746 and 865 nm respectively. Thus, the retrieved epsilon function is the average of the ratio of the single scattering aerosol parameter over all aerosol models. In order to compute ρ_{as} for any band, the algorithm must solve the following quadratic equation:

$$\rho_{pol\_corr}^{(i)}(\lambda) = a^{(i)}(\lambda) + b^{(i)}(\lambda)\rho_{as} + c^{(i)}(\lambda)\rho^2{}_{as} + d^{(i)}(\lambda)\rho^3{}_{as} + e^{(i)}(\lambda)\rho^4{}_{as}$$

where i, again, represents the "ith" aerosol model; $a,b,c,d\ e$ are the fitting coefficients extracted from the binary aerosol LUTs with nir_s = 6 (standard ACO mode; see Section 2.1.1.1.1.1 and Table 5); $\rho_{pol\_corr}^{(i)}$ is the TOA reflectance, corrected for ozone, whitecaps, Rayleigh, and polarization; and λ, again, is the VIIRS shortwave/long-wave IR bands at 746nm and 865nm respectively. This only works for these bands because the water-leaving radiance can be ignored in the IR regime. Solving the quartic equation computationally is not trivial. Fortunately the LUTs coefficients can reverse fit the above equation making it trivial to compute $\rho_{as}^{(i)}$:

$$\rho_{as}^{(i)}(\lambda) = a^{(i)}(\lambda) + b^{(i)}(\lambda)\rho_{pol\_corr} + c^{(i)}(\lambda)\rho^2{}_{pol\_corr} + d^{(i)}(\lambda)\rho^3{}_{pol\_corr} + e^{(i)}(\lambda)\rho^4{}_{pol\_corr}$$

where the coefficients *a, b, c, d, e* are the fitting coefficients extracted from the binary aerosol LUTs. One thing to note is that $\rho^{(i)}_{pol\_corr}$ contains the aerosol reflectance due to multiple scattering and single scattering. After computing $\varepsilon_{retrieved}$ the epsilon of the models ε_{model} must be computed. The model "epsilons" can be constructed from the Aerosol Properties LUT values detailed in Section 2.1.1.1.1.1. This value is computed using the following equations:

$$\varepsilon_{model}(\lambda) = \frac{\omega_a(\lambda)c(\lambda)p_a(\theta,\phi;\theta_0,\phi_0;\lambda)}{\omega_a(865)c(865)p_a(\theta,\phi;\theta_0,\phi_0;865)}$$
$$p_a(\theta,\phi;\theta_0,\phi_0;\lambda) = P_a(\theta_-,\lambda) + (r(\theta) + r(\theta_0))P_a(\theta_+,\lambda)$$
$$\cos\theta_\pm = \pm\cos\theta_0\cos\theta - \sin\theta_0\sin\theta\cos(\Delta\phi)$$

where $\omega_a(\lambda)$, $P_a(\theta,\lambda)$, and $c(\lambda)$ are the single-scattering Albedo (omega0 in Table 6), aerosol scattering phase function (s11 in Table 6) for a scattering phase angle θ, and aerosol extinction coefficient (extinct in Table 6) for all 12 aerosol models; and λ are wavelengths of M1 to M7. Parameter $r(\theta)$ is the Fresnel reflectance of the interface of the incident angle θ. The angles θ_0 and ϕ_0 are the zenith and azimuth angles respectively of a vector from the point on the sea surface under consideration to the Sun, and likewise θ and ϕ are the zenith and azimuth angles respectively of a vector from the pixel to the sensor, and $\Delta\phi = \phi_0 - \phi$ is the relative azimuth angle.

After computing both $\varepsilon_{retrieved}$ and ε_{model} the code determines the two closest models by comparing the retrieved to the set of model epsilons; only $\varepsilon_{model}(746,865)$ is used for the comparison. From this point on ε_{model} will be denoted as ε. This process involves iteratively refining $\varepsilon_{retrieved}$ until the code reaches the two closest aerosol models and a newly refined value for $\varepsilon_{meas}=\varepsilon_{retrieved}$; in other words, this condition must be reached

$$\varepsilon^{(m1)}(746,865) < \varepsilon_{meas}(746,865) < \varepsilon^{(m2)}(746,865).$$

Once the two models, m1 and m2, are determined, the code computes a weighting factor using $\varepsilon^{(m1)}$ and $\varepsilon^{(m2)}$ in the following manner:

$$w = \frac{\varepsilon_{meas}(765,865) - \varepsilon^{(m1)}(765,865)}{\varepsilon^{(m2)}(765,865) - \varepsilon^{(m1)}(765,865)}.$$

This weighting factor is used to linearly interpolate subsequent calculations of aerosol optical thickness, aerosol reflectance (single scattering and multiple-scattering), and diffuse transmittance.

2.1.2.8.2 Aerosol Optical Thickness (AOT Calculation)

The aerosol optical thickness (AOT) is computed in three steps. The first step is to compute the AOT at 865nm using the following expression:

$$\tau_a^{(i)}(865) = \frac{\rho^{(i)}{}_{as}(865)}{p_a^{(i)}(\theta,\phi;\theta_0,\phi_0;\lambda)}$$

where i are the indices for aerosol models m1 and m2. The second step is to linearly extrapolate the AOT of bands M1 to M6 using $\tau_a^{(i)}(865)$ as an anchor by doing the following:

$$\tau_a^{(i)}(\lambda) = \tau_a^{(i)}(865)\sum_{\lambda=1}^{7}\frac{c(\lambda)}{c(865)}.$$

The final step is to linearly interpolate between the AOTs for m1 and m2 to get the final set of AOTs for bands M1 to M7:

$$\tau_a(\lambda) = (1-w)\tau_a^{(m1)}(\lambda) + w\,\tau_a^{(m2)}(\lambda).$$

2.1.2.8.3 Aerosol Reflectance

In order to compute the aerosol reflectance (Laer) for aerosol models m1 and m2, the code extracts the fitting coefficients *a, b, c, d, e* with nir_s = 8 (see Section 2.1.1.1.1.1 and Table 7), computes ρ_{as}, (the single scattering aerosol reflectance), for bands M1 to M5, then uses the original quartic equation to get the following:

$$\rho_{Laer}^{(m1,m2)}(\lambda) = a^{(m1,m2)}(\lambda) + b^{(m1,m2)}(\lambda)\rho_{as} + c^{(m1,m2)}(\lambda)\rho^2{}_{as} + d^{(m1,m2)}(\lambda)\rho^3{}_{as} + e^{(m1,m2)}(\lambda)\rho^4{}_{as}$$

where λ=M1, M2, M3, …, M7. Note: The code only computed ρ_{as} for bands M1 to M5 because ρ_{as} for M6 and M7 has already been calculated. To compute the final aerosol reflectance array, the code linearly interpolates between Laer for both models:

$$\rho_{Laer}(\lambda) = (1-w)\rho_{Laer}^{(m1)}(\lambda) + w\rho_{Laer}^{(m2)}(\lambda).$$

This is the aerosol component to the TOA reflectance.

2.1.2.8.4 Diffuse Transmittance (diffuse_t_viirs.f)

The diffuse transmittance (t_diffuse) is computed in a few steps.

1. Fitting LUT values, *a* and *b*, described in Section 2.1.1.1.1.3 and the AOT (for aerosol models m1 and m2) output from **aerosol_rads( )** to the equation:
2. $$yfit(i,\lambda) = a(i)\cdot e^{-b(i)\cdot\tau_a(\lambda)}$$

   where $i = 1,2$, $yfit(i)$ are the diffuse transmittance values at sensor angles, defined by the LUT, that straddle the incoming sensor geometry.
3. Linearly interpolate *yfit* with the slant path $xfit(i) = 1/\cos(\theta_i)$ where θ_i are the LUT derived viewing angles. The diffuse transmittance, thus, is
4. $$t\_diffuse(\lambda) = yfit(1) + \frac{yfit(2) - yfit(1)}{xfit(2) - xfit(1)}\cdot(xbar - xfit(1))$$

where $xbar = 1/cos(\theta)$ (θ is the sensor zenith angle). This computation is done for both aerosol models. Then the two transmittance values are linearly interpolated in the same fashion as the AOT and Laer from **aerosol_rads( ).**

2.1.2.9 Ocean Color/Chlorophyll subroutine driver (calcOCC.f)

This process is the driver program that calculates the OCC EDR from RSR for bands M1, M2, M3, M4, and M5, VIIRS SST EDR, and ancillary data. This routine loops over VIIRS moderate-resolution pixels to calculate the water-leaving reflectance and inherent optical properties for each band plus chlorophyll concentration for each pixel. It then fills the output data arrays. If the pixel is not indicated as daytime, clear sky, deep-ocean, and free of sun glint, shadow, and heavy aerosol in the VCM, no calculations are performed for that pixel. The water-leaving radiance (L_w) in units of W m^{-2} μm^{-1} sr^{-1} is calculated from the RSR (in units of sr^{-1}) by

$$L\_w(k) = RSR(k) * \pi / esol(k)$$

where k = 1..5 is the band index for bands M1 to M5 and esol(k) is the solar constant by band in units of W m^{-2} μm^{-1}. The subroutine SST_PK_FLAG is called to determine the two models to be used to calculate the chlorophyll concentration and the inherent optical properties and their relative weight (weit). The subroutine ocolor is then called twice, once for each model to be used in the calculation, and a blended value is determined for the chlorophyll concentration (Chlorophyll) by

$$Chlorophyll = tchlo\_a(pktran(1)) * (1 – weit) + tchlo\_a(pktran(2)) * weit$$

where pktran is a two element array holding the flag that indicates which model is used in the calculation and tchlor_a is the chlorophyll concentration returned for each subroutine call. Chlorophyll, tchlor_a, and weit are unitless. The absorption (IOP_a) and back-scattering (IOP_s) inherent optical properties are given similarly by

$$IOP\_a = tIOPa(pktran(1)) * (1 – weit) + tIOPa(pktran(2)) * weit$$
$$IOP\_s = tIOPs(pktran(1)) * (1 – weit) + tIOPs(pktran(2)) * weit$$

where tIOPa and tIOPs are the absorption and back-scattering IOP values returned for each subroutine call. IOP_a, IOP_s, tIOPa, and tIOPs are in units of m^{-1}.

The Bright Pixel IP will be read in for band M1 to M7. If pixel data is greater than or equal to a pre-defined 4-bit configurable threshold, the bright pixel quality flag will be set. Processing will continue as normal.

2.1.2.10 Determine semi-empirical model using SST (SST_PK_FLAG.f)

This subroutine determines which two models are used in calculating chlorophyll concentration based on SST (sst) relative to NDT (ndt) for the pixel of interest. The sst and ndt are both given in K. Models include the global empirical model, unpackaged phytoplankton model, packaged phytoplankton semi-analytic model, or the fully packaged (or hipackaged) phytoplankton semi-analytic model. Model indicator values are returned in the 2-element integer array pktran. The weighting value (weit) is unitless and is a function of SST. Table 21 shows the various models used and weighting factors as a function of the relation between SST and NDT.

Table 21. Chlorophyll Concentration Models and Weighting for SST vs. NDT

SST Test	Model	Pktran	weit
ndt + 3.0 < sst	unpackaged	1	1.0
	unpackaged	1	
ndt + 1.4 ≤ sst < ndt + 3.0	global	0	(sst – (ndt + 1.4) / 1.6
	unpackaged	1	
ndt – 0.1 ≤ sst < ndt + 1.4	packaged	2	(sst – (ndt – 0.1) / 1.5
	global	0	
ndt – 2.0 ≤ sst < ndt – 0.1	fully packaged	3	(sst – (ndt – 2.0) / 1.9
	packaged	2	
sst < ndt – 2.0	fully packaged	3	1.0
	fully packaged	3	

2.1.2.11 Calculate Chlorophyll a Concentration (ocolor.f)

This subprogram calculates ratio of the RSR (rrs(band), band=1..5) and absorption coefficient due to phytoplankton at 672-nm (aph675) plus absorption coefficient due to gelbstoff at 400-nm (ag400) algebraically from R_{rs} model equations *[ATBD 19]*. Chlorophyll concentration is then calculated from aph675 and either a semi-analytical or empirical model. The subroutine has parameters for three different semi-analytical models: unpackaged, packaged, or fully packaged pigments. A flag (pk) is passed to the subroutine to determine which model is used in the calculation. A default value for the chlorophyll concentration (chl_def) is calculated using the current model parameters and is given by

$$\text{chl\_def} = 10^{c0+c1*abr35+c2*abr35^2+c3*abr35^3}$$

where abr35 = log(rrs(3)/rrs(4)), c0, c1, c2, and c3 are model dependent coefficients. The parameters c0, c1, c2, and c3 and the variables abr35 and chl_def are unitless.

Alternatively, the empirical algorithm, OC3V equivalent to the MODIS OC3M has been implemented as the primary default option. Currently, the OC3V is to replace the Carder default (Equation 14a) as the default algorithm for chlorophyll retrieval. The form of the OC3V algorithm is:

$$\log(C) = \alpha_0 + \alpha_1 x + \alpha_2 x^2 + \alpha_3 x^3 + \alpha_4 x^4$$

$$x = \log\left[\frac{\max(R_{rs}(445), R_{rs}(488))}{R_{rs}(555)}\right]$$

and the initial coefficients are the MODIS OC3M coefficients, α_0 = 0.283, α_1 = -2.753, α_2 = 1.457, α_3 = 0.659, and α_4 = -1.403. These are the coefficients used for MODIS processing in SeaDAS and may be updated using either global synthetic data or MODIS matchup data like the NOMAD dataset before launch.

A control switch has been installed in the software for allowing the different algorithm branching for chlorophyll retrievals. The control switch can be 0, or 1, or 2. It is set to (1) 0 for using the Carder chlorophyll algorithm with the Carder default; (2) 1 for using the Carder chlorophyll algorithm with the OC3V default; (3) 2 for using the OC3V algorithm.

The default values of ag400 (ag_def) and aph675 (aph_def) are also calculated using the current model parameters. They are given by

$$ag\_def = 1.5 \times 10^{-1.147-1.963*abr15-1.01*abr15^2+0.856*abr25+1.702*abr25^2}$$

$$aph\_def = (10^{-0.919+1.037*abr25-0.407*abr25^2-3.531*abr35+1.579*abr35^2} - 0.008)/3.05$$

where abr15 = log(rrs(1)/rrs(4)) and abr25 = log(rrs(2)/rrs(4)). These variables, ag_def, aph_def, abr15, and abr25 are unitless.

The inherent optical properties for back-scattering (IOP_S(band), band = 1..5, IOP_s is in m^{-1}) is given by

$$IOP\_s(band) = bbw(band) + X*[555/lam(band)]^Y$$

where bbw(band) is the measured backscatter due to water for each band in m^{-1}, lam(band) is the wavelength of each band in nm, and X and Y are empirically determined functions for the back-scattering due to particles at 555-nm. The equation for X is given by

$$X = x0 + x1*rrs(4)$$

where x0 = -0.00182 m^{-1} and x1 = 2.058 sr m^{-1} are empirically determined regression coefficients. The equation for Y is given by

$$Y = y\_0 + y\_1*rrs(2)/rrs(3)$$

where y_0 = -1.13 and y_1 = 2.57 are empirically determined regression coefficients. X is in m^{-1} while Y is unitless.

For the semi-analytic models, aph675 is found by finding the root of the following function:

function(aph675) = f0 + f1*aph(1,aph675) + f2*aph(2,aph675) + f3*aph(2,aph675) + f4*aph(4,aph675)

where

f0 = g12*(aw(4) + IOP_s(4) – r34*(aw(2)+IOP_s(2)))
– g34*(aw(2) + IOP_s(2) – r12*(aw(1)+IOP_s(1))) if bb_denom = 1 or
= g12*(aw(4) + IOP_s(4) – r34*(aw(2)+IOP_s(2)))
– g34*(aw(2) + IOP_s(2) – r12*aw(1)) otherwise

f1 = g34*r12
f2 = – g34
f3 = – g12*r34
f4 = g12.

The absorption due to water is given by aw (band) in m^{-1} for each band. The coefficients r12, r34, g12, and g34 are given by

r12 = (rrs(1) / IOP_s(1)) / (rrs(2) / IOP_s(2))
r34 = (rrs(2) / IOP_s(2)) / (rrs(4) / IOP_s(4))
g12 = r12 * exp(-s*(lam(1) – 400) – exp(-s*(lam(2) – 400)
g34 = r34 * exp(-s*(lam(2) – 400) – exp(-s*(lam(4) – 400)

where s = 0.0225 nm^{-1} is the spectral slope for absorption coefficient due to gelbstoff as a function of wavelength (ag(lam)). The coefficients r12, r34, g12, and g34 are unitless. The normalized pigment absorption (aph(band, aph675)) is provided by the function call aph(band,aph675,a0,a1,a2,a3). The coefficients a0, a1, a2, and a3 depend on the model being evaluated. The coefficients a0, a1, and a2 are unitless, while a3 is in m^{-1}. In order to facilitate the determination of the root of function(aph675) by filling an array (tx) of NX + 1 (NX = 32) test values for aph675 where the values are logarithmically spaced between a minimum value (aph_lo = 0.0001 m^{-1}) and a maximum value (aph_hi = 0.030 m^{-1}) of aph675, *i.e.*

$$tx(i) = 10^{log(aph\_lo) – (log(–ph\_hi) - log(apl\_lo))*(I-1)/NX}, i = 1..NX+1.$$

The root (aph_mod in m^{-1}) of function (aph675) is found via bisection, with the search being iterated N_ITER = 5 times. After the last iteration the bi-linear interpolation between the bracketing values tx(xlo+1) and tx(xhi+1), is

aph_mod = tx(xlo+1)+(tx(xhi+1)-tx(xlo+1))*flo/(flo-fhi)

where flo = f0 + f1 * aph(1,tx(xlo+1)) + f2 * aph(2,tx(xlo+1)) + f3 * aph(2,tx(xlo+1)) + f4 * aph(4,tx(xlo+1)) and
fhi = f0 + f1 * aph(1,tx(xhi+1)) + f2 * aph(2,tx(xhi+1)) + f3 * aph(2,tx(xhi+1)) + f4 * aph(4,tx(xhi+1)).

The corresponding model value for ag400 (ag_mod in m^{-1}) is then given by

ag_mod = wph / g34

where wph = aw(4) + aph(4,aph_mod) + IOP_s(4) - r34 * (aw(2) + aph(2,aph_mod) + IOP_s(2)) if bb_denom = 1 or
wph = aw(4) + aph(4–aph_mod) - r34 * (aw(2) + aph(2,aph_mod)) otherwise.

The chlorophyll concentration is then given by

$$chl\_mod = 10^{p0 + p1 * log (aph\_mod) + p2 * log^2 (aph\_mod)}$$

where p0, p1, and p2 are model dependent and are unitless.

If aph_hi/2 < aph_mod < aph_hi, then the semi-analytical model is blended with the default0 empirical model. The weight (wt) for the blending is given by

wt =–(aph_hi - aph_mod) /–(aph_hi - aph_hi/2.)

where wt is unitless. The blended values for chlorophyll, aph675, and ag400 are

chl_mod = wt * chl–mod + (1 - wt) * chl_def,
ag_mod = wt * ag–mod + (1 - wt) * ag_def, and
aph_mod = wt * aph–mod + (1 - wt) * aph_def.

If there was no root between aph_lo and aph_hi, *i.e.* aph_mod > aph_hi, then the default model is used giving

chl_mod = chl_def,

aph_mod = aph_def, and
ag_mod = ag_def.

The inherent optical properties absorption coefficient (IOP_a(band) in m^{-1} for band = 2–4) including absorption from pure water, phytoplankton pigments, and dissolved organic matter is given by

IOP_a(band) = aw(band) + aph(band,aph_mod)
+ ag_mod * exp(-s*(–am(band) - 400)).

For band M1 a phaeophytin term is added, then the IOP_a(1) is given by

IOP_a(1) = aw(1) + aph(1,aph_mod) + ag_mod * exp(-s*(lam(1)-400.0))
+ ag_mod * exp(-s*(lam(2)-400.0))
* (exp(sphae*(lam(2)–-412.0)) - exp(s*(lam(2)-412.0)))

where sphae = 0.0225 nm^{-1}.

The IOP_a for band M5 is given by

IOP_a(5) = aw(5) + aph_mod + ag_mod * exp(-s*(lam(5)-400.0)).

Band wavelengths and model independent coefficients are shown in Table 22. The same a1 and a2 model coefficients are used for the global, unpackaged, and packaged semi-analytical models. Table 23 shows model dependent coefficients of the phytoplankton absorption function aph for the global, unpackaged, and packaged semi-analytical model. Fully packaged semi-analytical model coefficients for the phytoplankton absorption function aph are shown in Table 24. Table 25 shows model dependent coefficients for the global, unpackaged, packaged, and fully packaged semi-analytical models used in calculating chlorophyll concentrations.

Table 22. Model Independent Coefficients

Band	lam	bbw	aw	a1	a2
M1	412	0.003341	0.00480	0.59	-0.48
M2	445	0.002406	0.00742	0.69	-0.48
M3	488	0.001563	0.01632	0.54	-0.48
M4	555	0.000929	0.05910	-0.18	-0.48
M5	672	0.000388	0.43538	0.00	-0.48

Table 23. Model Dependent Coefficients for Phytoplankton Absorption Function aph

Model	Global		Unpackaged		Packaged	
Band	a0	a3	a0	a3	a0	a3
M1	1.82	0.014	2.20	0.0112	1.46778	0.017276
M2	3.05	0.014	3.59	0.0112	2.53786	0.017276
M3	1.94	0.014	2.27	0.0112	1.62954	0.017276
M4	0.39	0.014	0.42	0.0112	0.355520	0.017276
M5	1.00	0.014	1.00	0.0112	1.00	0.017276

Table 24. Fully Packaged Model Coefficients for Phytoplankton Absorption Function aph

Band	a0	a1	a2	a3
M1	1.019	0.26	-0.45	0.021
M2	1.893	0.45	-0.45	0.021
M3	1.237	0.42	-0.45	0.021
M4	0.316	-0.08	-0.45	0.021
M5	1.000	0.00	-0.45	0.021

Table 25. Model Dependent Coefficients for Default and Model Chlorophyll Concentrations

Coefficient	Global	Unpackaged	Packaged	Fully Packaged
c0	0.354824	0.281800	0.423284	0.5100
c1	-2.64124	-2.78300	-2.50834	-2.340
c2	1.13884	1.86300	0.45994	0.400
c3	-1.62316	-2.38700	-0.90706	0.0
p0	1.7454	1.7150	1.7739	1.9000
p1	1.000	1.000	1.000	1.000
p2	0.0	0.0	0.0	0.0

2.1.2.11.1 Calculate Normalized Pigment Absorption (aph)

This function returns the absorption coefficient due to phytoplankton (aph) at a given waveband as a function of the absorption coefficient due to phytoplankton at 672-nm (aph675). The absorption coefficient is given by

aph=a0(band)*exp(a1(band)*tanh(a2(band)*log(aph675/a3(band))))*aph675

where a0, a1, a2, and a3 are the fitting coefficients for each band = M1, M2, M3, and M4. The coefficients a0, a1, and a2 are unitless, while a3 is in m^{-1}. The function is contained in ocolor.f.

2.1.3 Graceful Degradation

2.1.3.1 Graceful Degradation Inputs

There is one case where input graceful degradation is indicated in the OCC.

1. An input retrieved for the algorithm had its N_Graceful_Degradation metadata field set to YES (propagation).

Table 26 details the instance of this one case. Note that the shaded cells indicate that the graceful degradation was done upstream at product production.

Table 26. Graceful Degradation

Input Data Description	Baseline Data Source	Primary Backup Data Source	Secondary Backup Data Source	Tertiary Backup Data Source	Graceful Degradation Done Upstream
Digital Bathymetry	VIIRS_GD_12.4.1 SRTM30_PLUS	N/A	N/A	N/A	N/A

Input Data Description	Baseline Data Source	Primary Backup Data Source	Secondary Backup Data Source	Tertiary Backup Data Source	Graceful Degradation Done Upstream
Database*					
Surface Pressure	VIIRS_GD_09.4.9 NCEP	VIIRS_GD_09.4.9 NCEP (Extended Forecast)	N/A	N/A	Yes
Total Column Ozone	VIIRS_GD_09.4.1 NCEP	VIIRS_GD_09.4.1 NCEP (Extended Forecast)	N/A	N/A	Yes
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
Nitrate Depletion Temperatures*	VIIRS_GD_13.4.1 Univ. of Florida (Kendal Carder) database	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 ACO algorithm produces remote sensing reflectances (RSR) under all circumstances. If the pixel is not over ocean, is indicated as “confidently cloudy” by the cloud mask, includes sun glint, heavy aerosol or shadow, or is observed at night, a null value for the RSR IP is produced. The OCC is retrieved under all conditions except confidently cloudy and is flagged as “degraded” during probably clear and probably cloudy conditions.

Chlorophyll retrievals are performed only if the atmospheric correction algorithm provides positive values of water-leaving radiances in the VIIRS visible bands at 412, 445, 488, and 555-nm. If the algorithm results in chlorophyll concentrations above a predetermined maximum value, algorithm outputs will be set to –999.9.

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 ACO/OCC algorithm requires input items to be 32-bit floating-point precision. All computations within the algorithm are done in 32-bit floating-point precision. Output values of the algorithm (see Section 2.1.1.2) are also all 32-bit floating-point precision, except QFs which are 8-bit integers.

2.1.7 Algorithm Support Considerations

2.1.7.1 Numerical Computation Considerations

The magnitude of the output of the ACO algorithm is much less than the input values and the correction values calculated at each step in the routine. Small differences in inputs or subsequent correction values lead to significant changes in output values.

Both ACO and OCC use modeled data. They analyze current conditions and select an atmospheric model based on those conditions. In a situation where an analysis falls near a decision point between two possible models, machine error can lead to different models being picked on the same input data. The differing model could result in very different output data.

In the OCC routine, the output field Inherent Optical Properties Absorption is much greater than any other output value or any intermediary calculated value, with a large dynamic range. Small differences in input values and in processing calculations could lead to significant changes in output.

Both of these algorithms are very sensitive to calculation precision and rounding error.

2.1.7.2 Software Environment Considerations

Both a Fortran-90 and a C++ compiler are necessary to compile the ACO / OCC source code.

INF and DMS must be running before the ACO / OCC algorithm is executed.

2.1.7.3 Science Enhancement Opportunities

An instrument polarization correction has been implemented for the ACO algorithms. It uses the Rayleigh scattering look-up table (LUT) generated by Liu's polarized RTM. This correction has yet to be tested, and therefore is not part of the current processing scheme.

The ACO algorithm does not perform well, particularly at greater than 50° zenith angles. Examination of intermediate results indicated the algorithm is operating well, with exception of the Rayleigh scattering LUT. Both the software and Algorithm Theoretical Basis Document (ATBD) "state of the science" match. Therefore, the only work remaining is to refine the Rayleigh scattering correction. Exact details of how to improve performance in this regard are not fully known, but it is believed a properly generated LUT with high enough resolution is a likely solution.

To account for residual instrumental polarization sensitivity, a polarized radiative transfer model was developed to extend the algorithm. This module will be delivered to IDPS with the algorithm, but it is not currently active. It was not tested because the test data did not have polarization information and currently no model exists for the expected residual polarization in the VIIRS instrument. During sensor calibration, residual polarization will be measured and a set of calibration coefficients will be developed. Then, the polarization correction will have to be tested and verified.

Further examination of the Rayleigh LUT is required to see if modifying it improves performance. In particular, a polarized radiative transfer model (RTM) that has good performance to 70° solar and sensor zenith angles is required for production of the LUTs. Currently none of the LUTs can be regenerated because no code is available for LUT generation.

Residual errors in VCM are additional sources of errors for the ACO algorithm. In particular, the sun glint mask excludes too large of an area in the granule from attempting retrievals. MODIS products were retrieved in the full granule with flags indicating retrieval quality. The ACO algorithm did not attempt retrieval in approximately a quarter of the granule due to sun glint mask. We should consider correcting for sun glint so ACO can be retrieved as often as it is done for MODIS.

2.1.8 Assumptions and Limitations

2.1.8.1 Assumptions

- ACO receives an image of VIIRS geolocated pixels and calibrated TOA reflectances in the bands used by the ACO in internal IDPS SDR format.
- A cloud mask file, including cloud confidence, ocean/land flags, sun glint flags, a heavy aerosol flag, and a shadow flag for each VIIRS pixel, is provided to match the VIIRS data granule. The cloud mask is in the expected VIIRS cloud mask format.
- An SST EDR is provided to match the RSR granule.
- Ancillary and auxiliary data are provided and interpolated to provide values at each VIIRS pixel.
- Ancillary and auxiliary data will be provided by processing systems of other NPOESS instruments, by a VIIRS module that will run before the ACO/OCC Unit, or from an analysis such as NCEP.
- The aerosol models used are representative of aerosols present over the ocean.
- Water-leaving reflectance is zero in the two near-infrared wavelength bands (M6 and M7).
- The formulation of whitecap reflectance as a function of wind speed and electromagnetic wavelength is valid.
- The two-layer plane-parallel model atmosphere adopted for radiative transfer calculations is valid.
- Water-leaving reflectance is described as a function of the ratio of the total back-scattering coefficient to the total absorption coefficient.
- The spectral slope of the DOM absorption coefficient is empirically determined.
- Parameters of the SPM back-scattering coefficient are empirically correlated to the remote-sensing reflectance.

2.1.8.2 Limitations

- The ACO is only performed under daytime conditions. This correction is not performed for a pixel if the cloud mask indicates confidently cloudy, sun glint, heavy aerosols, or shadow. The OCC is retrieved under all conditions except confidently cloudy and is flagged as “degraded” during probably clear and probably cloudy conditions. If the presence of cloud at an adjacent pixel is possible, or if a pertinent cloud mask test was not performed, the ACO is performed, but the product quality flag is set.

- The presence of an absorbing aerosol will cause the aerosol correction to fail, so the atmospheric correction will not be completed if absorbing aerosol is present.
- In the ACO algorithm, the water-leaving reflectance is assumed negligible in the two near-infrared wavelength bands (M6 and M7). This is not true in turbid coastal waters or in coccolithophore blooms. Techniques for adjusting the atmospheric correction under these conditions are under investigation. Currently, the atmospheric correction over turbid and shallow water is not performed.
- Further studies of the spectral dependence of whitecap reflectance and the variation in its contribution to the TOA reflectance with wind speed should be made.

3.0 GLOSSARY/ACRONYM LIST

3.1 Glossary

Table 27 contains terms most applicable for this OAD.

Table 27. 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 and earth located, with absolute radiometric and geometric calibration coefficients appended, but not applied, to the data. Aggregates (sums or weighted averages) of detector samples are considered to be full resolution data if the aggregation is normally performed to meet resolution and other requirements. Sensor data shall be unprocessed with the following exceptions: time delay and integration (TDI), detector array non-uniformity correction (i.e., offset and responsivity equalization), and data compression are allowed. Lossy data compression is allowed only if the total measurement error is dominated by error sources other than the data compression algorithm. All calibration data will be retained and communicated to the ground without lossy compression. *[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 calibrated brightness temperatures with associated ephemeris data. 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 28 contains acronyms most applicable for this OAD.

Table 28. Acronyms

Term	Expansion
ACO	Atmospheric Correction over Ocean
AFM	Airborne Fluxes and Meteorology Group
AM&S	Algorithms, Models & Simulations
AOS	Acquisition of Signal
API	Application Programming Interfaces
ARP	Application Related Product
BT	Brightness Temperature
BTD	Brightness Temperature Difference
CDA	Command and Data Acquisition
CDFCB-X	Common Data Format Control Book - External
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
DPIS ICD	Data Processor Inter-subsystem Interface Control Document
DQTT	Data Quality Test Table
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
ING	Ingest
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
MDFCB	Mission Data Format Control Book
METOP	Meteorological Operational Program
MSS	Mission System Simulator
NA	Non-Applicable

Term	Expansion
NCA	National Command Authority
NPP	NPOESS Preparatory Program
PIP	Program Implementation Plan
PMT	Portable Mission Terminal
POD	Precise Orbit Determination
QF	Quality Flag
R	Reflectance
S&R	Search and Rescue
SCA	Satellite Control Authority
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

4.0 OPEN ISSUES

Table 29. TBXs

TBX ID	Title/Description	Resolution Date
None		