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

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

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Preface

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

Any questions should be addressed to:

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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. 47974DGM2S is complete, accurate, and complies with all requirements of the Subcontract.

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

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

CDRL A032

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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
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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
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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. Incorporates ECR A-210A	All

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1.0 INTRODUCTION

1.1 Objective

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

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

The purpose of an OAD is two-fold:

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

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

1.2 Scope

The scope of this document is limited to the description of the core operational algorithm(s) required to create the VIIRS RSR IP and the VIIRS OCC EDR. The theoretical basis for this algorithm is described in Section 3.3 of the Atmospheric Correction Over Ocean For Production Of Remote Sensing Reflectance Intermediate Product VIIRS ATBD, D43314 and VIIRS Ocean Color/Chlorophyll ATBD, D43763.

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
Atmospheric Correction Over Ocean For Production Of Remote Sensing Reflectance Intermediate Product VIIRS ATBD	D43314 Rev. A	6 Feb 2008
MODIS Normalized Water-leaving Radiance ATBD	MOD18 Version 4	Apr 1999
VIIRS Ocean Color/Chlorophyll ATBD	D43763 Rev. ---	26 Jan 2007
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
NPP EDR Production Report	D37005 Rev. C	16 Mar 2007
EDR Interdependency Report	D36385 Rev. C	7 Nov 2007

Document Title	Document Number/Revision	Revision Date
NPP Mission Data Format Control Book (MDFCB)	GSFC 429-05-02-42 R1	14 Apr 2006
CDFCB-X Volume I - Overview	D34862-01 Rev. B	27 Aug 2007
CDFCB-X Volume II – RDR Formats	D34862-02 Rev. B	27 Aug 2007
CDFCB-X Volume III – SDR/TDR Formats	D34862-03 Rev. A	27 Aug 2007
CDFCB-X Volume IV Part 1 – IP/ARP/GEO Formats	D34862-04-01 Rev. A	10 Sep 2007
CDFCB-X Volume IV Part 2 – Atmospheric, Clouds, and Imagery EDRs	D34862-04-02 Rev. A	10 Sep 2007
CDFCB-X Volume IV Part 3 – Land and Ocean/Water EDRs	D34862-04-03 Rev. A	10 Sep 2007
CDFCB-X Volume IV Part 4 – Earth Radiation Budget EDRs	D34862-04-04 Rev. A	10 Sep 2007
CDFCB-X Volume V - Metadata	D34862-05 Rev. B	27 Aug 2007
CDFCB-X Volume VI – Ancillary Data, Auxiliary Data, Reports, and Messages	D34862-06 Rev. C	10 Sep 2007
CDFCB-X Volume VII – Application Packets	D34862-07 Rev. ---	10 Sep 2007
NPP Command and Telemetry (C&T) Handbook	568423 Rev. A	5 Apr 2005
Data Processor Inter-subsystem Interface Control Document (DPIS ICD)	D35850 Rev. U.2	27 Aug 2008
NPP Mission Data Format Control Book (MDFCB)	GSFC 429-05-02-42 R1	14 Apr 2006
NPOESS EDR Performance Report	NPOESS.02.520.010 Ver. 3.3	2 Feb 2002
NPOESS EDR Synergisms and Fusion Summary	D34837 Rev. ---	20 Feb 2002
NPOESS IDP Segment Central Specification	SY10-0003 Rev. N	21 Sep 2007
NPOESS Modeling and Simulation Plan	D34475 Ver. 1.0	15 Mar 2002
NPOESS Scene Generation Development Report	D34861 Ver. 1.0	11 Feb 2002
NPOESS Software Development Plan	D31417-01 Rev. A	31 May 2005
NPOESS Subcontract Management Plan	D34845 Ver. 1.0	18 Feb 2002
NPOESS System Specification	SY15-0007 Ver. M	18 Oct 2007
NPOESS System Test Plan	D31406 Rev. C	6 May 2005
NPOESS Calibration/Validation Plan	D34484 Draft Version 3.0	17 Dec 2002
VIIRS Cloud Mask (VCM) Intermediate Product (IP) OAD	D36816 Rev. A11	17 Oct 2008
Processing SI Common IO Design Document	DD60822-IDP-011 Rev. A	21 June 2007
D35836_G_NPOESS_Glossary	D35836_G Rev. G	10 Sep 2008
D35838_G_NPOESS_Acronyms	D35838_G Rev. G	10 Sep 2008
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
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

Document Title	Document Number/Revision	Revision Date
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

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
VIIRS OCC science-grade software	ISTN_VIIRS_NGST_1.0	31 Mar 2003
VIIRS ACO_OCC operational software	B1.4	20 Apr 2006
VIIRS ACO_OCC Unit Test Data	20050923_ISTN_VIIRS_NGST_4.1	12 Sep 2005
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
VIIRS ACO Code Modifications and No Double Precision Implementation	NP-EMD.2008.510.0008 Rev. A	7 Feb 2008
VIIRS Ocean Color Science Code Updates	NP-EMD.2008.510.0020	15 Apr 2008

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.

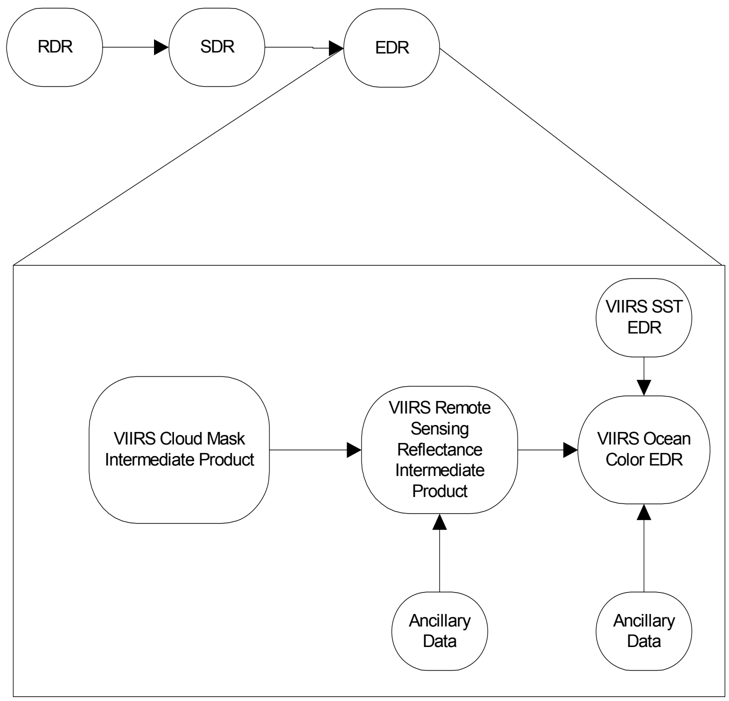

Figure 1. Processing Chain to Create VIIRS RSR IP and OCC EDR.

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, ETOPO30 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 algorithm 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, depicted in Figure 2.

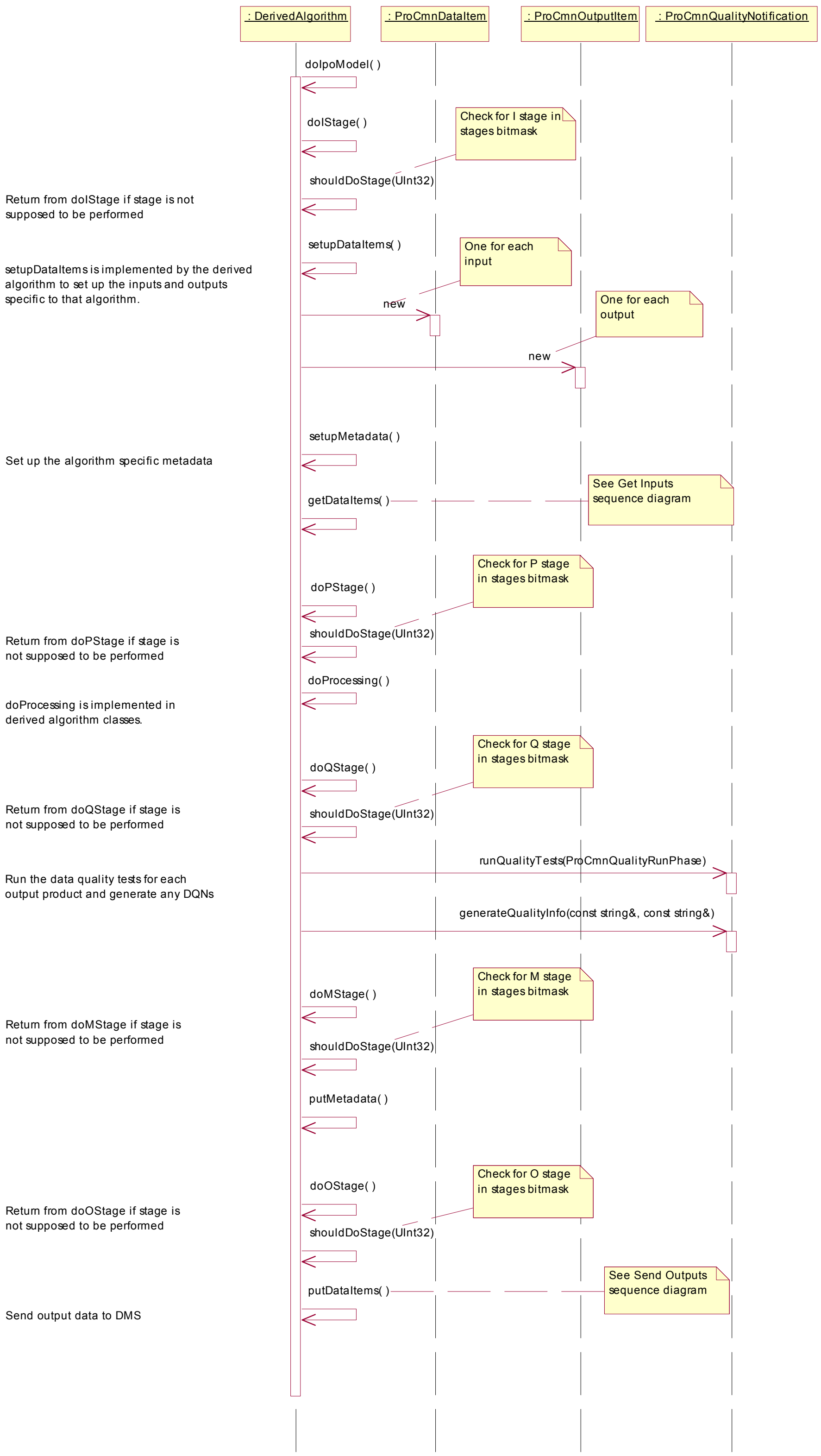

Figure 2. IPO Model Interface to INF and DMS

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 Data Processor Inter-subsystem Interface Control Document (DPIS ICD), D35850, 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
Latitude	float32 x m_viirs_sdr_rows x m_viirs_sdr_cols	Geodetic latitude of the VIIRS pixels	Degrees/ -90° ≤ Latitude ≤ 90° (positive to the North) *FILL_VALUE = -999.9*
Longitude	float32 x m_viirs_sdr_rows x m_viirs_sdr_cols	Geodetic longitude of the VIIRS pixels	Degrees/ -180° ≤ Longitude ≤ 180° (positive to the East of Greenwich) *FILL_VALUE = -999.9*
SolZenAng	float32 x m_viirs_sdr_rows x m_viirs_sdr_cols	solar zenith angle relative to the VIIRS pixels measured from the local vertical	Degrees/ 0 ≤ SolarZenith ≤ 180 *FILL_VALUE = -999.9*
SenZenAng	float32 x m_viirs_sdr_rows x m_viirs_sdr_cols	S/C zenith angle relative to the VIIRS pixels measured from the local vertical	Degrees/ 0 ≤ satZen ≤ 180 *FILL_VALUE = -999.9*
SolAziAng	float32 x m_viirs_sdr_rows x m_viirs_sdr_cols	S/C azimuth angle relative to the VIIRS pixels and measured from the local North towards East	Degrees/ 0 ≤ SolarAzimuth ≤360 *FILL_VALUE = -999.9*
SenAziAng	float32 x m_viirs_sdr_rows x m_viirs_sdr_cols	S/C azimuth angle relative to the VIIRS pixels and measured from the local North towards East	Degrees/ 0 <= satAzm <= 360 *FILL_VALUE = -999.9*
Reflectance_Mod	float32 x m_viirs_sdr_rows x m_viirs_sdr_cols	M1-M7 Reflectances	Unitless/ Reflectance_Mod > 0 *FILL_VALUE = 65535* (Integer Scaled)
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 ≤ NDT ≤ 343
SST	float32 x m_viirs_sdr_rows x m_viirs_sdr_cols	Skin Sea Surface Temperature	Kelvin/ 268 ≤ SST ≤ 343

Input	Data Type/Size	Description/Source	Units/Valid Range
Pres	float32 x m_viirs_sdr_rows x m_viirs_sdr_cols	NCEP Surface Pressure	mb or hPa/ Pres ≥ 0
Wind Direction	float32 x m_viirs_sdr_rows x m_viirs_sdr_cols	Digital Granulated Ancillary Data	Degrees/ 0 <= Wind Speed <= 360
Wind Speed	float32 x m_viirs_sdr_rows x m_viirs_sdr_cols	Digital Granulated Ancillary Data	m/s / 0 <= Wind Speed <= 120
OZ	float32 x m_viirs_sdr_rows x m_viirs_sdr_cols	NCEP Total Column Ozone	Dobson unit
VCM	uint8 x 6 x m_viirs_sdr_rows x m_viirs_sdr_cols	VIIRS Cloud Mask IP	See VCM OAD, D36816
aer_lut	See Table 5, Table 6 and Table 7	Aerosol LUT Parameters (See Table 5, Table 6 , and Table 7)	See Table 5, Table 6 , 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

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 2.2.2.1-2 and 2.2.2.1-3.

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

Input	Data Type/Size	Description/Source	Units/Valid Range
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 ≤ angle ≤ 180 (increments vary)
wavelength	Int32 x acobands	VIIRS band center wavelengths	nm/ wavelength = [412,443,448, 555,670,748, 865]
omega0	float32 x model x acobands	Aerosol Single Scattering Albedo	Unitless/ 0.9295 ≤ omega0 ≤ 1.0
extinc	float32 x model x acobands	Aerosol extinction coefficient	Unitless/ $1.8376x10^{-5}$ ≤ extinct ≤ 0.0885
s11	float32 x **model** x acobands x num_scat_angles	Aerosol Scattering Phase Function	Unitless/ 0.0350 ≤ s11 ≤ 9.4143 x 10^{3}
ylog	float32 x **model** x acobands x num_scat_angles	Logs of s11 (scattering phase function)	Unitless/ max and min are dependant 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 dependant 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
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 Placeholder for Polarization LUT

Instrumental polarization correction has been implemented in the ACO science code but has not been tested and the LUT has not been populated since sensor characterization has not been completed.

2.1.1.1.1.5 Bright Pixel Flag Threshold LUT

Table 12 shows the BP Threshold LUT parameters and Table 13 shows the BP Threshold LUT information.

Table 12. 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 13. 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

2.1.1.2 Outputs

The ACO/OCC unit produces an output OCC EDR with five fields, described in Table 14. 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 15.

Table 14. ACO/OCC EDR Output Description

Input	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 < Chl ≤ 75 *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 < IOP-a ≤ 15 *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) 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 15. 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
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

Byte	Bit	Flag Description Key	Bit Value
	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
	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)
3	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 <= 50.3 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
	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	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 □$_0$(M4) < 0.7) Exclusion	0 = No exclusion, or no □$_0$(M4) available 1 = Strongly absorbing aerosol present (□$_0$(M4) < 0.7)
	7	Aerosol Optical Thickness (AOT @ 550 nm) Exclusion (AOT>0.3)	0 = No AOT exclusion, or no AOT available 1 = AOT exclusion (AOT>0.3)
	0	Turbid Water (R_{rs}(M5) > 0.012) Exclusion	0 = No (R_{rs}(M5) $\leq$ 0.012), or no R_{rs}(M5) available 1 = Yes (R_{rs}(M5) > 0.012)
	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)
5	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

Byte	Bit	Flag Description Key	Bit Value
	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	Spare	Set to 0

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 inherited 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, 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 degradation. The algorithm first applies corrections for ozone absorption, whitecaps, and detector polarization to the VIIRS reflectances. The algorithm then subtracts the contributions of molecular and 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 3. Data flow for producing the OCC EDR is shown in Figure 4.

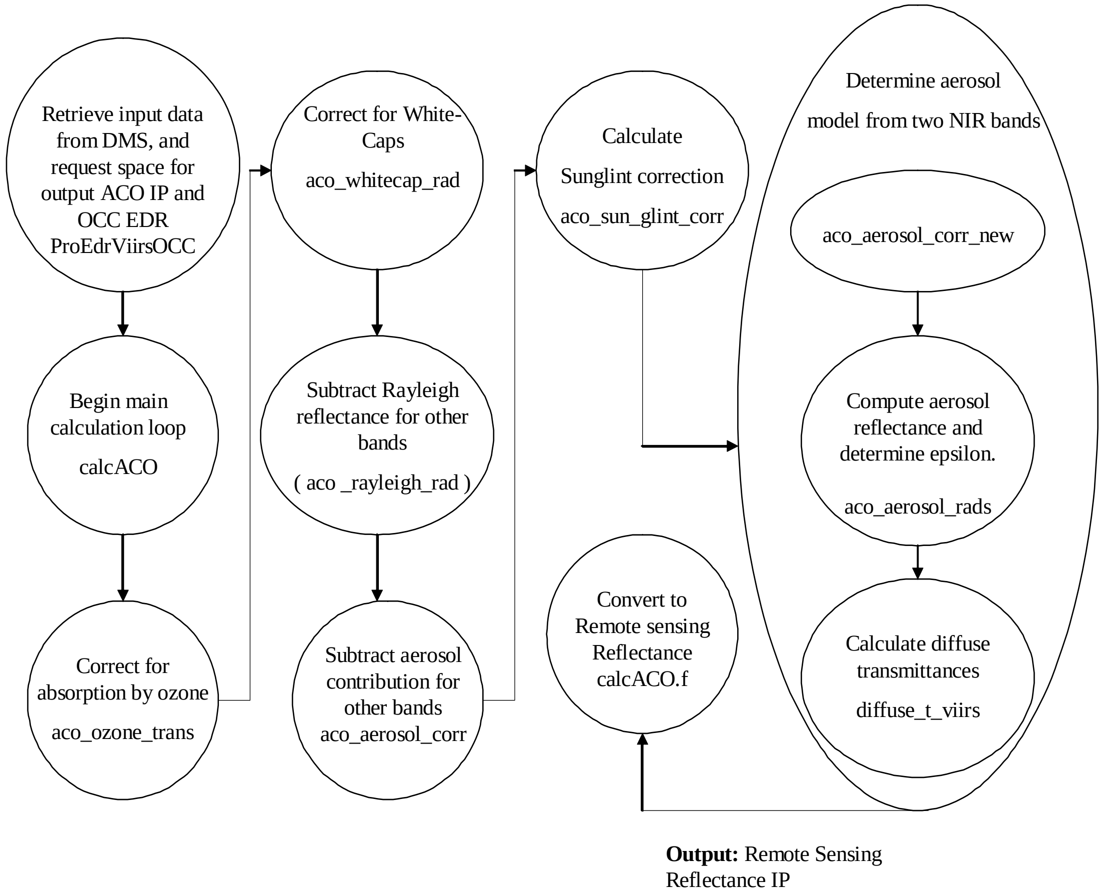

Figure 3. Processing Steps for calcACO.f to Produce the RSR IP

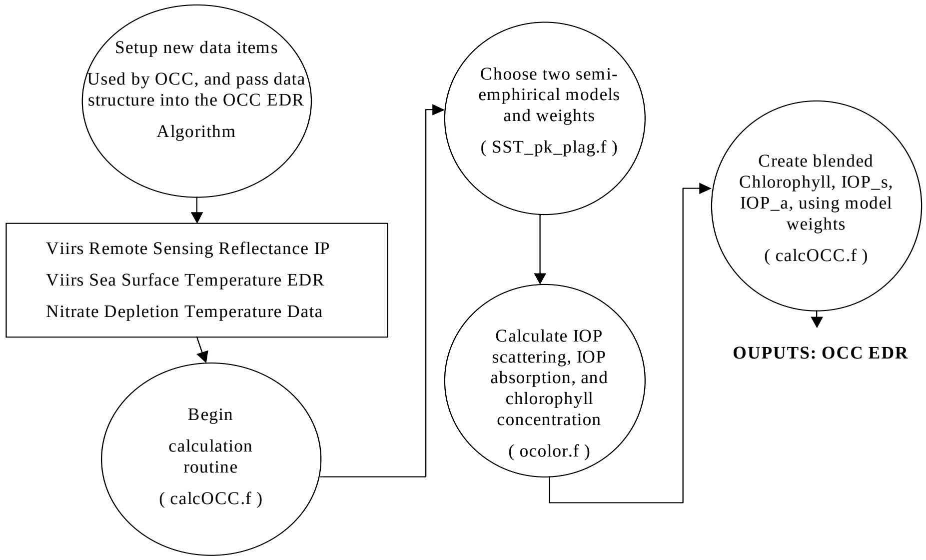

Figure 4. Processing Steps for calcOCC.f to Produce the OCC EDR

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. Ozone
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*, is in Dobson units. The total column ozone (*oz*) used in the code is in atm-cm. The conversion from *OZ_interp* to *oz* is given by *oz = OZ_interp /1000*.

The subsequent atmospheric corrections are computed as follows:

- $Lcorr\_oz(\lambda) = Lin(\lambda)/t\_ozone(\lambda)$ -> *Ozone Correction*
- $Lcorr\_wc(\lambda) = Lcorr\_oz(\lambda) - Lwc(\lambda)$ -> *Whitecap Correction*
- $Lcorr\_ray(\lambda) = Lcorr\_wc(\lambda) - Lray(\lambda)$ -> *Rayleigh Correction*
- $Lcorr\_pol(\lambda) = Lcorr\_ray(\lambda) \cdot pol\_corr(\lambda)$ -> *Polarization Correction*
- $Lcorr\_sg(\lambda) = Lcorr\_pol(\lambda) - Lsg(\lambda)$ -> *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_oz*, *Lcorr_wc*, *Lcorr_ray*, *Lcorr_pol*, *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/π multiplier; the RSR is a function of bands M1 to M5 ($\lambda_{visible}$).

2.1.2.3 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.

2.1.2.4 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 $\tau_r(\lambda)$ is defined as the Rayleigh optical depth for bands M1 to M7, $\frac{1}{\cos(\theta)}+\frac{1}{\cos(\theta_0)}$ (cosines of the sensor zenith and solar zenith angles respectively) is the air mass, $\tau_r^{'}(\lambda) = \tau_r(\lambda)P_0$, and ***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(λ)* is the *Lray(λ)* parameter.

2.1.2.5 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.

2.1.2.6 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.

2.1.2.6.1 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 748 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 748nm 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 $\rho_{pol\_corr}^{(i)}$ 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:

$$\varepsilon_{\mathrm{mod}\,el}(\lambda) = \frac{\omega_a(\lambda)c(\lambda)p_a(\theta,\phi;\theta_0,\phi_0;\lambda)}{\omega_a(865)c(865)p_a(\theta,\phi;\theta_0,\phi_0;865)}$$

$$p_a(\theta,\phi;\theta_0,\phi_0;\lambda) = P_a(\theta_-,\lambda) + (r(\theta) + r(\theta_0))P_a(\theta_+,\lambda)$$

$$\cos\theta_\pm = \pm\cos\theta_0\cos\theta - \sin\theta_0\sin\theta\cos(\Delta\phi)$$

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 $\varepsilon_{model}(748,865)$ 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

$$\varepsilon^{(m1)}(748,865) < \varepsilon_{meas}(748,865) < \varepsilon^{(m2)}(748,865).$$

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.

2.1.2.6.2 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:

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

2.1.2.6.3 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.

2.1.2.6.4 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 m1) 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( ).**

2.1.2.7 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) * π / 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.

2.1.2.8 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 16 shows the various models used and weighting factors as a function of the relation between SST and NDT.

Table 16. 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	

2.1.2.9 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

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

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. 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

$$\begin{aligned} f0 &= g12*(aw(4) + IOP\_s(4) - r34*(aw(2)+IOP\_s(2))) \\ &\quad - g34*(aw(2) + IOP\_s(2) - r12*(aw(1)+IOP\_s(1))) \quad \text{if } bb\_denom = 1 \text{ or} \\ &= g12*(aw(4) + IOP\_s(4) - r34*(aw(2)+IOP\_s(2))) \\ &\quad - g34*(aw(2) + IOP\_s(2) - r12*aw(1)) \quad \text{otherwise} \end{aligned}$$

$$f1 = g34*r12$$
$$f2 = - g34$$
$$f3 = - g12*r34$$
$$f4 = g12.$$

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 17. The same a1 and a2 model coefficients are used for the global, unpackaged, and packaged semi-analytical models. Table 18 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 19. Table 20 shows model dependent coefficients for the global, unpackaged, packaged, and fully packaged semi-analytical models used in calculating chlorophyll concentrations.

Table 17. Model Independent Coefficients

Band	lam	bbw	aw	a1	a2
M1	412	0.003341	0.00480	0.59	-0.48
M2	443	0.002406	0.00742	0.69	-0.48
M3	490	0.001563	0.01632	0.54	-0.48
M4	555	0.000929	0.05910	-0.18	-0.48
M5	670	0.000388	0.43538	0.00	-0.48

Table 18. 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 19. 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 20. 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

2.1.2.9.1 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 21 details the instance of this one case. Note that the shaded cells indicate that the graceful degradation was done upstream at product production.

Table 21. 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 Database*	VIIRS_GD_12.4.1 SRTM30_PLUS	N/A	N/A	N/A	N/A
Surface Pressure	VIIRS_GD_09.4.9 NCEP	VIIRS_GD_09.4.9 NCEP	N/A	N/A	Yes

Input Data Description	Baseline Data Source	Primary Backup Data Source	Secondary Backup Data Source	Tertiary Backup Data Source	Graceful Degradation Done Upstream
		(Extended Forecast)			
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, D34862.

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

The current glossary for the NPOESS program, D35836_G_NPOESS_Glossary, can be found on eRooms. Table 22 contains those terms most applicable for this OAD.

Table 22. 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

The current acronym list for the NPOESS program, D35838_E_NPOESS_Acronyms, can be found on eRooms. Table 23 contains those terms most applicable for this OAD.

Table 23. 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

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4.0 OPEN ISSUES

Table 24. TBXs

TBX ID	Title/Description	Resolution Date
None		