Suomi National Polar-Orbiting Partnership (SNPP) Visible Infrared Imaging Radiometer Suite (VIIRS) Aerosol Products User's Guide

Version 2.0.1, October 2013

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1. Purpose of this Guide

This VIIRS Aerosol Products Environmental Data Record (EDR) Users Guide is intended for users of the Aerosol and Suspended Matter EDRs generated from the Visible Infrared Imaging Radiometer Suite (VIIRS) on board the Suomi National Polar-Orbiting Partnership (SNPP) satellite. It provides a general introduction to the VIIRS instrument, data products, format, content, and their applications. It serves as an introduction and reference to more detailed technical documents about the VIIRS aerosol products and algorithms such as the Algorithm Theoretical Basis Document (ATBD) and Operational Algorithm Document (OAD) for the aerosol algorithms (see Section 9).

2. Points of Contact

For questions or comments regarding this document, please contact Istvan Laszlo (Istvan.Laszlo@noaa.gov) and Shobha Kondragunta (Shobha.Kondragunta@noaa.gov).

3. Acronym List

Table 1. Acronyms

AOD	Aerosol Optical Depth
AOT	Aerosol Optical Thickness
APSP	Aerosol Particle Size Parameter (Ångström Exponent)
AE	Ångström Exponent
ATBD	Algorithm Theoretical Basis Document
AVHRR	Advanced Very High Resolution Radiometer
CDFCB	Common Data Format Control Book
CLASS	Comprehensive Large Array-Data Stewardship System
EDR	Environmental Data Record
HDF5	Hierarchical Data Format 5
IDPS	Interface Data Processing System
IP	Intermediate Product
JPSS	Joint Polar Satellite System
LUT	Look Up Table
MODIS	Moderate Resolution Imaging Spectroradiometer
NCEP	National Center for Environmental Prediction
NPP	National Polar-orbiting Partnership
OAD	Operational Algorithm Description
QF	Quality Flag
RDR	Raw Data Records
SDR	Sensor Data Record
SM	Suspended Matter
TOA	Top of Atmosphere
VCM	VIIRS Cloud Mask

4. Document Definitions

This document will refer to aerosol optical thickness (AOT) instead of aerosol optical depth (AOD) for consistency with other VIIRS Aerosol Product documentation.

Aerosol particle size parameter (APSP) is defined as the Ångström Exponent (α) (see ATBD for more details).

5. VIIRS

5.1 Overview

VIIRS is one of the five instruments on board the Suomi NPP satellite. It is a scanning radiometer with capabilities that are intended to extend and improve upon or continue the heritage of AVHRR and MODIS. VIIRS data is used to measure cloud and aerosol properties, ocean color, sea and land surface temperature, ice motion and temperature, fires, and Earth's albedo. The NPP satellite, and therefore VIIRS, has an 824 km sun-synchronous orbit (inclination=98.7°) with a 1:30 pm ascending node. It achieves global coverage every day and has a repeat cycle of approximately 16 days. VIIRS has a swath width of 3040 km with a spatial resolution of ~375 m at nadir in the Imagery (I) Bands and ~750 m at nadir in the Moderate (M) Bands. Through a system of pixel aggregation techniques, VIIRS controls pixel growth towards the edge of scan such that the pixel sizes are comparable to nadir. For more information about this "bow-tie removal" aggregation scheme, look at the SDR User's Guide (https://cs.star.nesdis.noaa.gov/NCC/UsersGuideVIIRS, beginning on page 29) and the Imagery Products ATBD (http://npp.gsfc.nasa.gov/science/sciencedocuments/ATBD_122011/474-00031_Rev-Baseline.pdf, beginning on page 26). Additional information and specifications for NPP and VIIRS can be found at http://npp.gsfc.nasa.gov/spacecraft_inst.html.

5.2 Data Processing Chain

The NPP satellite transmits raw instrument data to the Command, Control, and Communications Segment (C3S) which is then routed to the Interface Data Processing Segment (IDPS). The IDPS processes the Raw Data Records (RDRs) to create Sensor Data Records (SDRs), which are subsequently processed into Environmental Data Records (EDRs). The IDPS then transmits RDRs, SDRs, and EDRs to NOAA's Comprehensive Large Array-data Stewardship System (CLASS) for distribution and archiving.

5.3 Data Records Overview

VIIRS data products are stored and distributed in HDF5 format. There is no special "HDF-NPP" library for use with these data files, but the NPP data products were designed using the native HDF5 library. VIIRS files from IDPS contain a single granule of a single data type. Granules are associated with an integer number of sensor scans, so the definition varies between sensors and data products. VIIRS aerosol product granules are 48 scan lines, or approximately 86 seconds in length, and the pixel-level M-band resolution data is contained in 768 x 3200 arrays. The CDFCBs provide information on other products and their granule lengths (see Section 9). Due to the relatively short granule length and the data resolution, users should expect approximately 1000 files (sizes are ~1.3 MB each for aggregated aerosol EDR and geolocation, ~15 MB each for pixel level Intermediate Product (IP) AOT, 1.5 MB for pixel level Suspended Matter, and ~78 MB each for M-band pixel-level geolocation) per data product per day. Some data sources downstream of IDPS may post-process data, including aggregating multiple granules or packaging different data types into a single file which will alter these approximations (see Section 5.4).

5.3.1 Raw Data Records (RDRs)

SNPP RDRs are binary data generated by the sensors on board the SNPP spacecraft. They contain engineering and house-keeping data for spacecraft and sensor monitoring as well as science data for the production for SDRs. The required inputs for generating SDR products are verified RDRs, which contain the information that is converted into calibrated TOA radiance, reflectance, and brightness temperature, along with other sensor calibration information. A comprehensive discussion of the contents and structure of RDR products is available in Volume II of the CDFCB (see Section 9).

5.3.2 Sensor Data Records (SDRs)/Level 1B

SNPP SDRs contain calibrated and geolocated TOA radiance and reflectance data produced from processing the RDRs along with quality flags and metadata. An excellent overview of the SDR products is available in the SDR User's Guide at https://cs.star.nesdis.noaa.gov/NCC/UsersGuideVIIRS and a complete description is available in Volume III of the CDFCB (see Section 9).

5.3.3 Environmental Data Records (EDRs)/Level 2

SNPP EDRs contain derived bio-geophysical parameters that are broadly categorized into four sections: land, ocean, imagery and clouds, and aerosols. Only the aerosol product EDRs are discussed in this document (see Section 7), but a full list of all available EDRs is located at http://npp.gsfc.nasa.gov/science/DataProducts.html and described in more detail in Volume IV, Parts II-IV of the CDFCB (see Section 9).

5.3.4 Intermediate Product (IP)

Intermediate products are the retrieval byproducts or data subsets that are created through processing that are required for a later primary data product's generation or used as input for secondary processing. Some IPs such as the cloud mask and aerosol optical thickness are delivered and available to the user. The contents of IP AOT files are discussed in more detail in Section 7.1 of this document.

5.3.5 Geolocation

Unless packaged through post processing, the VIIRS Geolocation data is stored in separate geolocation files that must be used in conjunction with SDRs, EDRs, and IPs. The contents of the geolocation files related to the aerosol products are discussed in more detail in Section 7 of this document and a full description of all geolocation files can be found in Volume IV, Part I of the CDFCB (see Section 9).

5.4 Data Availability

5.4.1 CLASS

The primary data source for SNPP products is through NOAA's CLASS web interface (www.class.noaa.gov; Note that there are actually three CLASS sites that users are directed to from this link depending on usage and maintenance of each site. Be careful bookmarking one of the specific sites as it may be temporarily down when it is accessed explicitly). All aerosol products described in this document are available from this source. Data delivered to CLASS from the IDPS has a latency specification of 6 hours from observation, but can increase due to data issues along the processing chain described in Section 5.2. On CLASS, users will have options with respect to the format in which they prefer data. Data searches on CLASS can be defined by data type, date and time range, geolocation, node, granule ID, and beginning orbit number. When ordering data, it is possible to request a certain level of packaging and aggregation of the NPP data files. By default, CLASS will package and aggregate data orders, meaning they will package corresponding geolocation files together with the requested data files and aggregate four 86-second granules into a single file. This can be changed on a case-by-case basis on the order form or can be re-set in the user preferences to apply to all orders. There are two basic ways to order data from CLASS: ad hoc orders and subscriptions. Within the ad hoc category, there are three options. If the user elects to search using the normal "Search" button, file orders will be restricted to 100 files. This option is useful if you would like to view and inventory listing of the data available within your search parameters and select a small number of specific files. If the user is confident about their search parameters, they may also use the "Quick Search and Order" button that will skip the inventory list and allow users to order up to 1000 files each time. For larger order sizes, users can request Block Orders through the CLASS helpdesk (class.help@noaa.gov). This access will allow orders of up to 3000 files. Finally, subscriptions are also available to users who require regular data access in the form of an automatic push or pull distribution. Requests for subscriptions must be sent to the CLASS helpdesk. Ad hoc data orders are delivered using FTP, where data will remain for 48 hours (requests can be made for longer holding times). An excellent visual walk through of the NPP data order procedure is available at: http://www.class.ngdc.noaa.gov/notification/pdfs/CLASS_Tutorial_NPPDataAccess_20110909.pdf.

5.5 Filenames

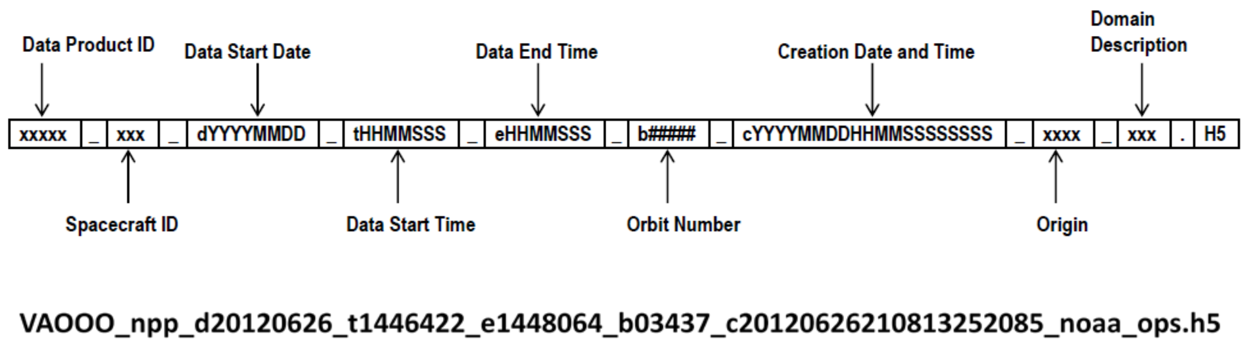

Figure 1. SNPP Filename Fields with AOT EDR Filename Example.

Figure 1 describes the file naming convention of SNPP data products. A full description of each of the file name data field along with applicable values is available in the CDFCB, Volume 1 beginning on page 22. The relevant Data Product IDs for the aerosol products are IVAOT (Aerosol IP), VAOOO (Aerosol EDR), VSUMO (Suspended Matter EDR), GAERO (Aerosol EDR Geolocation), and GMTCO (Pixel-Level Terrain Corrected Geolocation). It is worth noting that the SNPP granule ID does not appear in the file name. The granule ID is available within each data file as the metadata item “N_Granule_ID”. It is written as a 15 character string, where the first three characters are the satellite identifier of SNPP and the next 12 numeric characters specify the number of tenths of a second since the first ascending node after launch.

6. VIIRS Aerosol Algorithm

6.1 VIIRS Bands Relevant to the Aerosol Products

VIIRS has 22 spectral bands, of which 16 are M-bands (~750 m resolution at nadir) and 5 are I-bands (~375 m m resolution at nadir). Table 2 is a chart of the bands used when creating the aerosol products. A comprehensive chart of the VIIRS bands can be found at http://www.star.nesdis.noaa.gov/jpss/documents/meetings/2011/NPP_Users_Workshop/02.0%20NPP%20SDR%20Overview-July%2023%202011%20Weng.pdf on slide 17.

Table 2. VIIRS Aerosol Bands

Band Name	Wavelength(µm)	Bandwidth	Aerosol Algorithm Use
M1	0.412	0.0200	Land Retrieval
M2	0.445	0.0180	Land Retrieval, Land Angstrom Exponent
M3	0.488	0.0200	Land Retrieval, Internal Tests
M4	0.555	0.0200	Internal Tests
M5	0.672	0.0200	Land Retrieval (Reference), Ocean Retrieval, Internal Tests, Land Angstrom Exponent
M6	0.746	0.0150	Ocean Retrieval
M7	0.865	0.0390	Ocean Retrieval (Reference), Internal Tests, Ocean Angstrom Exponent
M8	1.240	0.0200	Ocean Retrieval, Internal Tests
M9	1.378	0.0150	Internal Tests
M10	1.610	0.0600	Ocean Retrieval, Internal Tests, Ocean Angstrom Exponent
M11	2.250	0.0500	Land Retrieval, Ocean Retrieval, Internal Tests
M12	3.700	0.1800	Internal Tests
M15	10.7625	1.0000	Internal Tests
M16	12.0125	0.9500	Internal Tests

6.2 Summary of the Aerosol Algorithm

The VIIRS Aerosol Algorithm retrieves AOT at a pixel level for a range of 11wavelengths (0.412, 0.445, 0.488, 0.550, 0.555, 0.672, 0.746, 0.865, 1.240, 1.610, and 2.250 microns). The current version of the algorithm does not retrieve aerosol properties over bright surfaces, in cloud-affected pixels, over inland water such as the Great Lakes, or at night. The AOT is calculated separately for land and ocean using a LUT of pre-computed values for several atmospheric parameters to simplify radiative transfer calculations. Pixel level AE is then calculated from AOT at two different wavelengths (0.455 and 0.672 microns over land and 0.865 and 1.610 microns over ocean). The pixel level AOT and AE products are aggregated to create the EDR (see Section 6.3). The suspended matter type for each pixel is derived for pixels with an AOT greater than a specified threshold. Possible suspended matter types and the conditions under which they are chosen are shown in Table 3. In depth descriptions of the algorithms are available in the Aerosol Optical Thickness and Particle Size Parameter ATBD and the Suspended Matter ATBD, and algorithm flow and logic charts are provided in Figures 1, 2, 3, 4, and 5 of the Aerosol Products OAD (see Section 9).

Table 3. Suspended Matter types and conditions under which each type is chosen.

SM Type	Conditions over Land	Conditions over Ocean
Ash	VIIRS Cloud Mask identifies the presence of volcanic ash (tuned out in IDPS build as of November 2, 2012 due to false positives)	
Dust	AOT at 550 nm > 0.15 and dust Land Aerosol Model selected (See EDR Quality Flags in Appendix A)	AOT at 550 nm > 0.15 and fine mode fraction < 0.2
Smoke	AOT at 550 nm > 0.15 and non-dust Land Aerosol Model selected (high/low absorbing smoke; clean/polluted urban aerosol) (See EDR Quality Flags in Appendix A)	AOT at 550 nm > 0.15, fine mode fraction ≥ 0.5 (See EDR Quality Flags in Appendix A)
Sea Salt	N/A	0.15 < AOT at 550 nm < 0.3 and 0.2 ≤ fine mode fraction < 0.5
Unknown (Undetermined SM Type)	N/A	AOT at 550nm ≥ 0.3 and 0.2 ≤ fine mode fraction < 0.5 (See EDR Quality Flags in Appendix A)
None (No SM)	AOT at 550 nm ≤ 0.15	

6.3 Aggregation of the Aerosol EDR from the Aerosol IP

The aerosol EDR is created from the IP product through a system of quality checks, filtering, and spatial aggregation of 8x8 pixel IP values. The logic flow for creating each 8x8 pixel horizontal cell within the aerosol EDR is shown in Figure 2 below. The top two pixel-level quality flags referenced in Figure 2 are "good" and "degraded". The conditions for each of these quality flags are described in Table 4, along with the conditions for "excluded" quality pixels (have a retrieval but are excluded from the aggregation process), and "not produced" quality pixels (no retrieval). The EDR quality flags referenced in Figure 2 are discussed in more detail in Appendix A. The corresponding aerosol EDR geolocation is determined by simply taking the central geolocation point for each horizontal cell.

Table 4. Pixel-level quality flag conditions for AOT and APSP

	Not Produced	Excluded	Degraded	High
AOT	Solar zenith angle > 80º; Missing or saturated channel reflectance (L: M1, M2, M3, M5, M8, M11; O: M5, M6, M7, M8, M10, M11); Missing ancillary data (wind speed, wind direction, precipitable water, surface air temperature, column ozone, surface pressure); Probably or confidently cloudy; Snow/ice present; Fire present; Inland or coastal water; Sun glint present; Turbid water present; Bright surface present.	Retrieved AOT at 550nm is out of spec range (0.0-2.0); Missing channel reflectance/brightness temperature (L: M7, M9, M10, M12, M15, M16; O: M3, M4, M15, M16)	65º ≤ Solar Zenith Angle < 80º Cloud shadow present; Cirrus present; Adjacent pixel probably or confidently cloudy; Volcanic ash present; Soil dominant pixel; Retrieval residual beyond threshold.	Otherwise
APSP	Non-positive AOT at the channels used for AE Calculation (L: M2/M5; O: M7/M10)	Out of spec range (-1.0-3.0)	AOT at 550 nm < 0.15	Otherwise

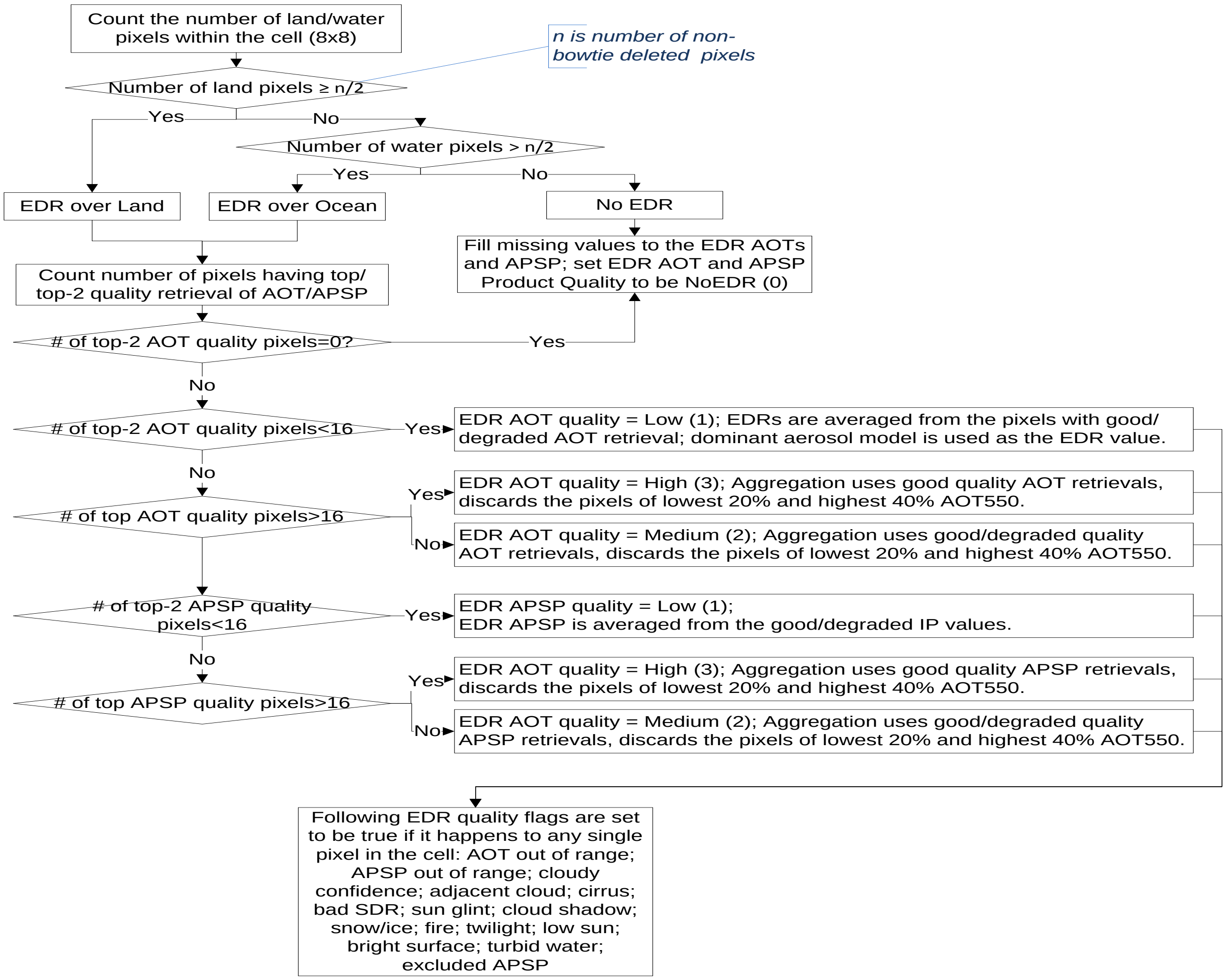

Figure 2. IP to EDR Aggregation

7. VIIRS Aerosol Products

The VIIRS aerosol algorithm produces several data products that are available to users via CLASS. The following sections describe the data that appears in unaggregated, unpackaged granules of the aerosol data products. Helpful tools for working with these data products are described in Appendix B.

7.1 IP AOT

The VIIRS aerosol IP contains AOT at 550 nm (see Section 6.2), slant column AOT at 550 nm, and Angstrom Exponent. This is a pixel level (~750 m) retrieval that is stored in 768 X 3200 floating point array. There are numerous quality flags (described in detail in Appendix A) which are in 8-bit integer format. Finally, the HDF5 file contains all the metadata for the granule. To match an Aerosol IP to its corresponding Aerosol Geolocation file, ensure that the date, start time, end time, and orbit number in each filename are identical. For example,

GMTCO_npp_d20120104_t0001202_e0002443_b00959_c20120402274595541 6_noaa_ops.h5

is the corresponding geolocation file for the Aerosol IP

IVAOT_npp_d20120104_t0001202_e0002443_b00959_c20120402274595541 6_noaa_ops.h5

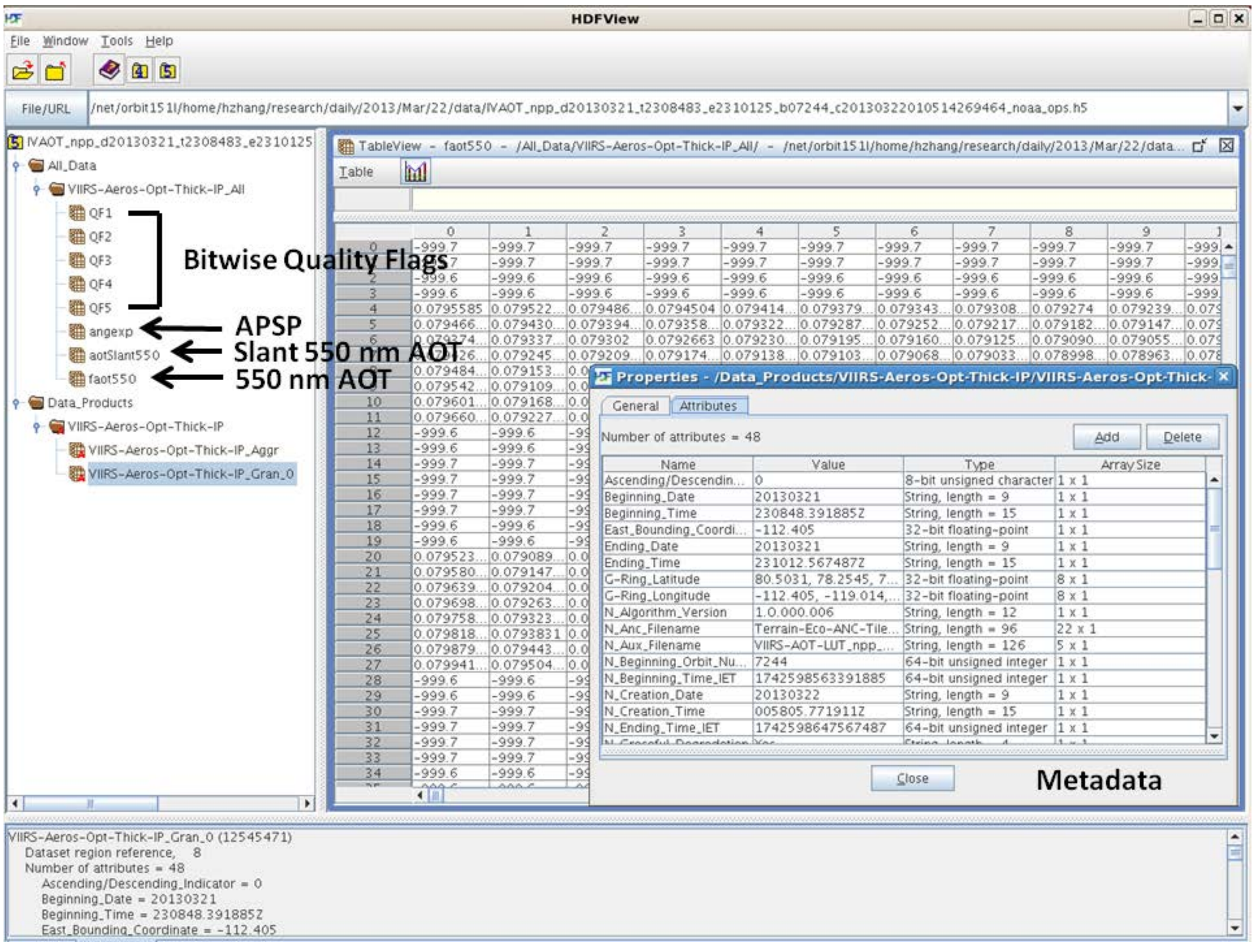

Figure 3. IP AOT file opened in HDFView to examine details of data structures and metadata.

One notable difference between Aerosol IP and Aerosol EDR (Section 7.2) is that the IP AOT file contains information from Navy Aerosol Analysis and Prediction System (NAAPS). When there are pixels with no retrievals due to clouds or bright surface or night time, NAAPS predicted AOT interpolated to VIIRS observation time are used to fill in. If NAAPS predictions are not available, a climatology based on Global Aerosol Climatology Project (GACP) is used. This information is for downstream use by the land surface albedo retrievals and not used by the

Aerosol EDR. The NAAPS values in the Aerosol IP file are explicitly flagged and should not be used when VIIRS Aerosol IP data are analyzed. The quality flags for Aerosol IP are 0 for good, 1 for degraded, 2 for excluded, and 3 for not produced. It is recommended that only data with quality flag 0 be used.

7.2 Aerosol EDR

The VIIRS aerosol EDR contains the AOT for 11 wavelengths ranging from 0.412-2.25 microns (see Section 6.2) and the Angstrom Exponent. These values are stored as a 96 x 400 array of 16-bit integers with the corresponding scale and offset stored separately in the granule. To convert the 16-bit integers to floating point numbers, users need to multiply by the scale first, and then add the offset. There are numerous quality flags (described in detail in Appendix B) which are in 8-bit integer format. The small mode fraction is provided in 8 bit integer format. Finally, the HDF5 file will contain all the metadata for the granule. All the data in this file is at the horizontal cell resolution (8x8 pixels, approximately 6km at nadir). The Aerosol EDR requires a corresponding Aerosol EDR geolocation for analysis. To match an Aerosol EDR to its corresponding Aerosol Geolocation file, ensure that the date, start time, end time, and orbit number in each filename are identical. For example,

GAERO_npp_d20120626_t1958134_e1959376_b03440_c20120627021509002956_noaa_ops.h5

is the corresponding geolocation file for the Aerosol EDR

VAOOO_npp_d20120626_t1958134_e1959376_b03440_c20120627024612139725_noaa_ops.h5

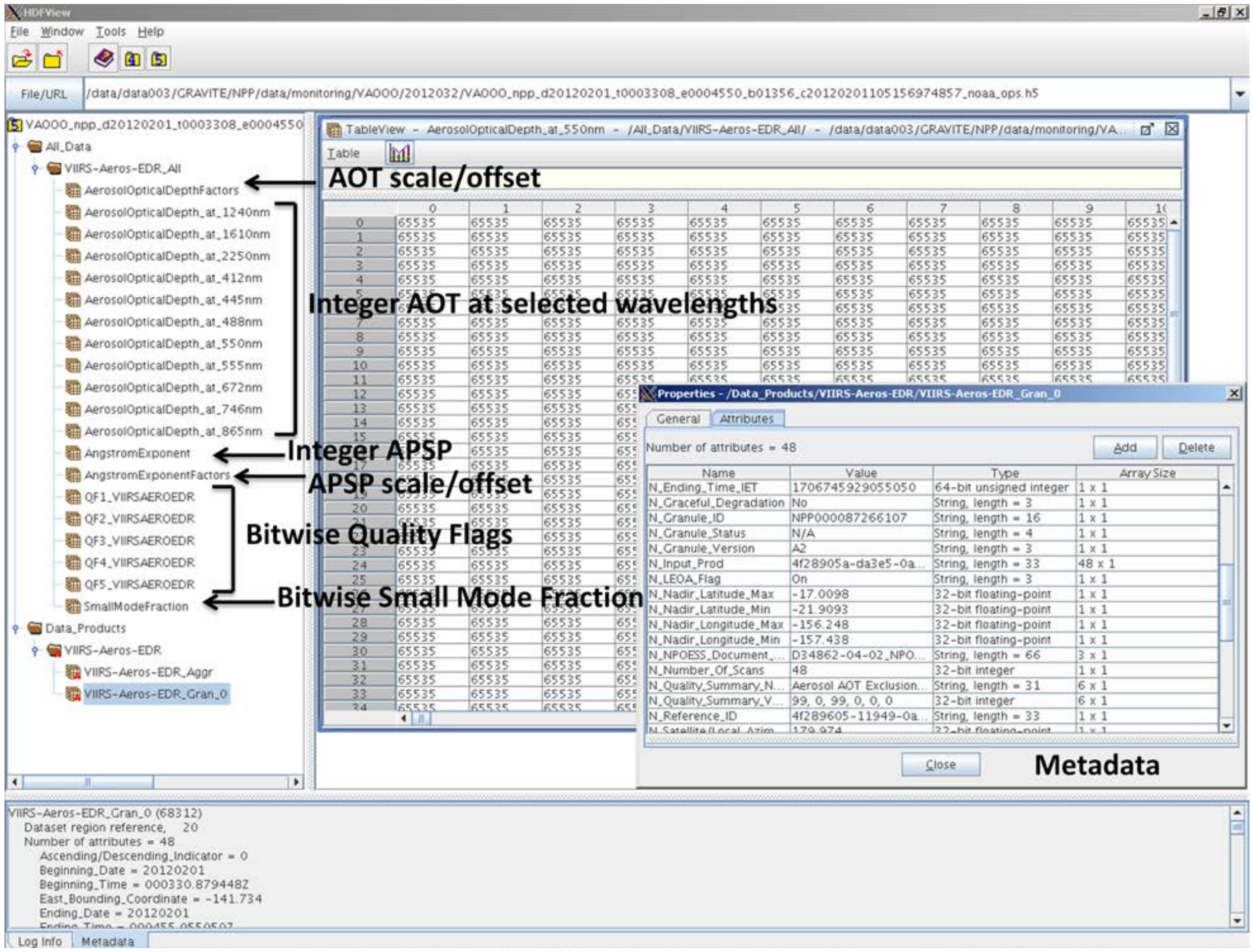

Figure 4. Aerosol EDR File opened in HDFView to examine details of data structures and metadata.

7.3 Aerosol EDR Geolocation

The aerosol EDR geolocation file contains the geolocation information, overpass time and satellite geometry at the horizontal cell resolution to be used in conjunction with the AOT and APSP data in the Aerosol EDR files. Note that the start and mid times are expressed in milliseconds after the launch basetime (1698019234000000).

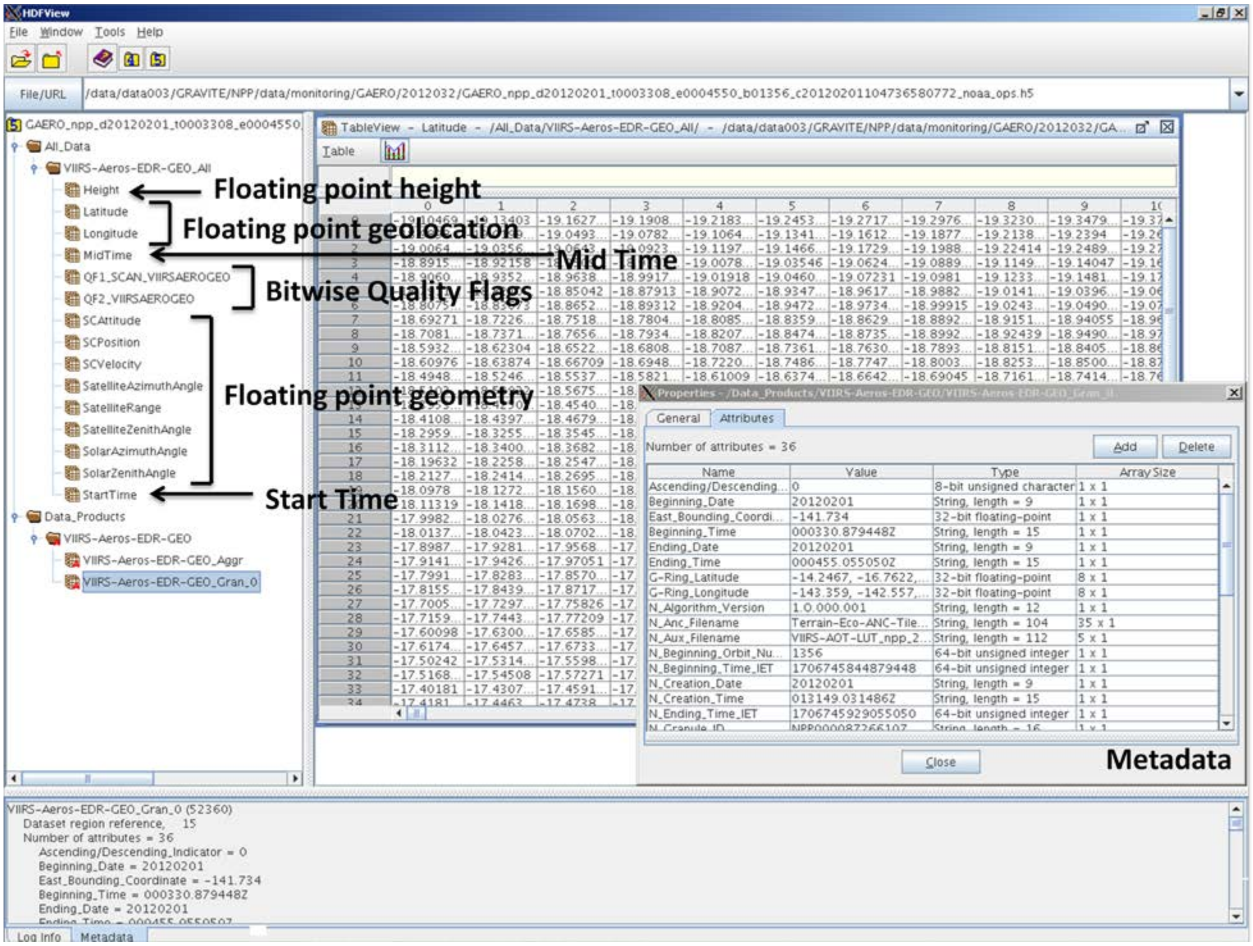

Figure 5. Aerosol Geolocation File opened in HDFView to examine details of data structures and metadata.

7.4 Suspended Matter EDR

The Suspended Matter EDR contains the suspended matter type (see Table 3) in 8-bit integer format and the smoke concentration in 16-bit integer format with the corresponding scale and offset for floating point conversion. All data in this file is at the pixel resolution (~750 m at nadir). There are also numerous 8-bit integer quality flags (described in more detail in Appendix A and also in the Aerosol Product OAD). The Suspended Matter EDR requires a corresponding terrain-corrected M-Band pixel-level geolocation for analysis. To match a Suspended Matter EDR to its corresponding geolocation file, ensure that the date, start time, end time, and orbit number in each filename are identical. For example,

GMTCO_npp_d20120626_t0804087_e0805328_b03433_c20120626103033053917_noaa_ops.h5

is the corresponding geolocation file to the Suspended Matter EDR file

VSUMO_npp_d20120626_t0804087_e0805328_b03433_c20120626143251807592_noaa_ops.h5

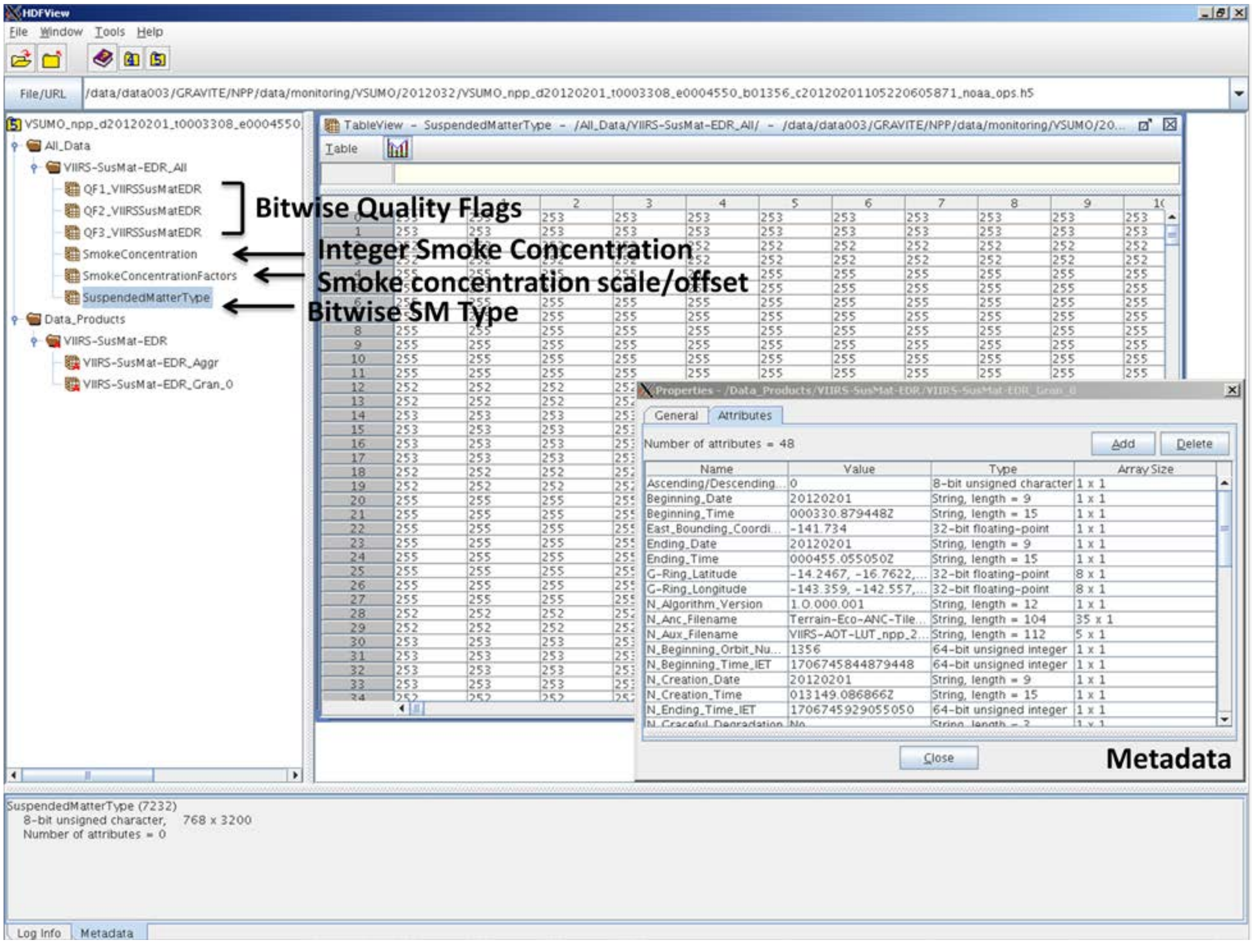

Figure 6. Suspended Matter EDR File opened in HDFView to examine details of data structures and metadata.

7.5 M-Band Terrain-Corrected Geolocation

Although it is not an output product of the aerosol algorithm, the M-Band pixel-level terrain-corrected geolocation product is required for use with the Suspended Matter EDR products. The file contains geolocation information, overpass time and satellite geometry at the M-Band pixel resolution (~750 m at nadir). Note that the start and mid times are expressed in milliseconds after the launch basetime (1698019234000000).

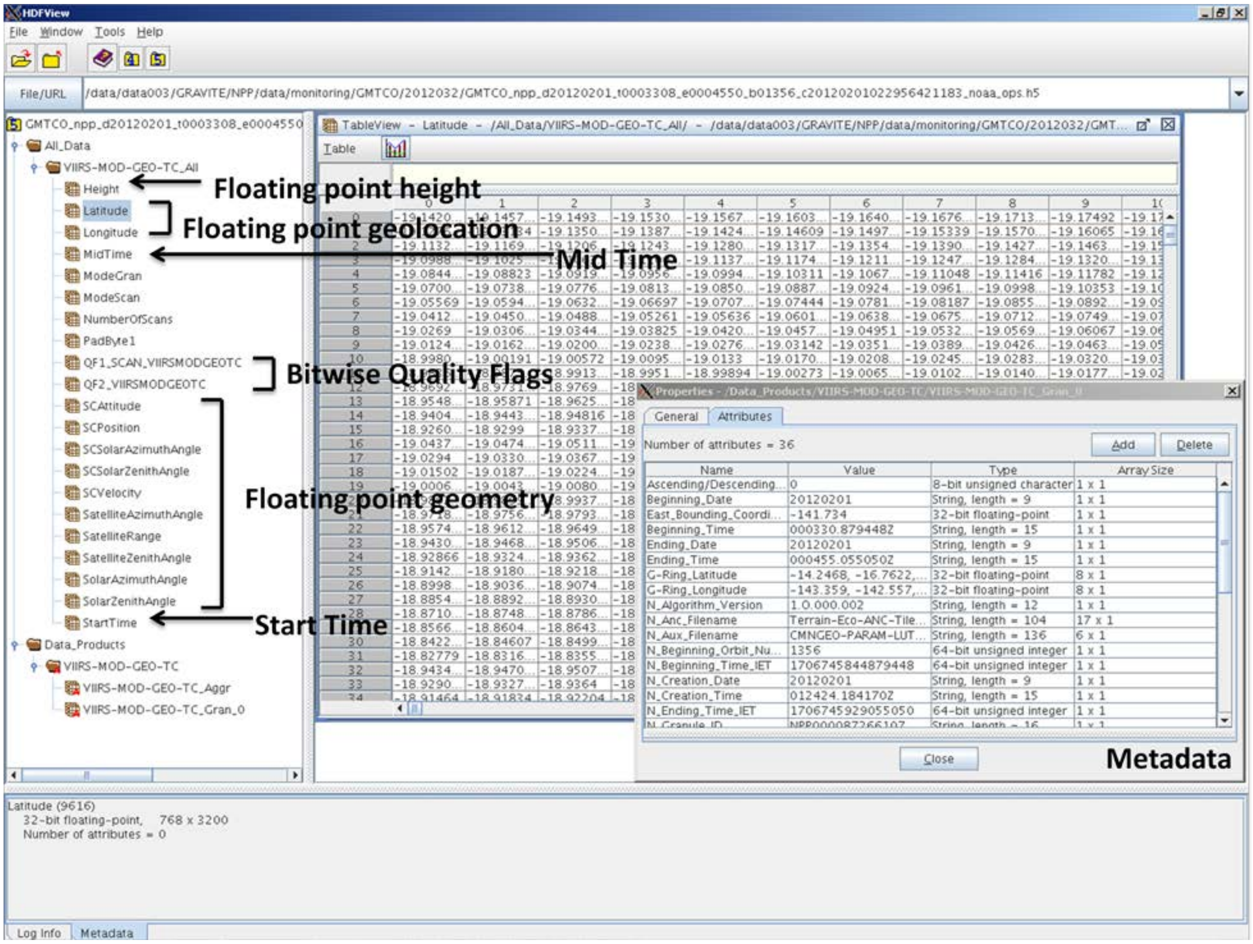

Figure 7. M-Band Terrain-Corrected Geolocation File opened in HDFView to examine details of data structures and metadata.

8. Known Issues to Date

The VIIRS Aerosol team has identified the following data quality problems that the user should be aware of:

- Artificially high AOT and APSP in the snow melt region of the Northern Hemisphere during the Spring thaw.
- Low AOT bias over ocean in dust outflow regions.
- Proportion of AOT attributed to small particles is too high over ocean.
- There is no skill in retrieving APSP information over land.
- Overabundance of smoke, and not enough dust in Suspended Matter product.
- Overabundance of ephemeral water over bright surfaces (though no retrieval in either case).

- Some internal tests (for detection of snow/ice, bright pixel, fire detection, etc.) are under evaluation for updates.
- There are no retrievals over inland water bodies.
- In heavy aerosol regions (dust and smoke plumes), the pixel-level AOT is often out of range (0.0 – 2.0) and is therefore excluded from aggregation and the EDR product.
- An inadvertent error introduced in the operational aerosol code resulted in significantly degraded aerosol EDRs for the following timeframe, invalidating the aerosol beta maturity results for the period: 10/15/2012 to 11/27/2012. Users should be aware that within this timeframe, AOT values were retrieved for confidently cloudy areas (as determined by the VIIRS cloud mask) where there should not have been retrievals, leading to increased AOT values and significantly degraded products.

The VIIRS Aerosol team strongly recommends that the following quality flags be applied:

- Use only products that are flagged as High (QF = 3) or Medium (QF = 2) quality for Aerosol EDR, and Good (QF=0) for Aerosol IP.

9. Additional Documentation

9.1 Common Data Format Control Book (CDFCB)

The CDFCB documents provide in depth technical information about the NPP data products. They are available publically at http://npp.gsfc.nasa.gov/science/documents.html. A summary of the contents are below.

Table 5. Summary of CDFCB contents.

Volume I	Overview
Volume II	RDR Formats
Volume III	SDR/TDR Formats
Volume IV	EDR/IP/ARP and Geolocation Formats
Volume V	Metadata
Volume VI	Ancillary Data, Auxiliary Data, Messages and Reports
Volume VII	Downlink Formats (Application Packets)
Volume VIII	LUT Formats

The CDFCB sections relevant to the Aerosol Products are Volume I and Volume IV, Parts I and II.

9.2 Algorithm Theoretical Basis Document (ATBD)

The AOT/APSP and Suspended Matter ATBDs provide a description of the physical theory and mathematical background of the aerosol algorithm as well as implementation details and describes the assumptions and limitations of the scientific approach. It also identifies the VIIRS and non-VIIRS sources for required input data. The ATBD is available publically at http://npp.gsfc.nasa.gov/science/documents.html.

9.3 Operational Algorithm Description (OAD)

The Aerosol Products OAD provides a description of the aerosol algorithm and end-user data products in computer science terms. It is available publically at http://npp.gsfc.nasa.gov/science/documents.html

Appendix A: VIIRS Aerosol IP Quality Flags

A.1. IP Quality Flags

A.1.1. QF1

Flag	Values	Bits	Conditions

AOT Quality	00 = 0 = Good
	01 = 1 = Degraded
	10 = 2 = Excluded
	11 = 3 = Not Produced
		0,1	NOT PRODUCED(3):
			• Solar zenith angle > 80°
			• Missing channel reflectance
			  • Over land: M1, M2, M3, M5, M8, M11
			  • Over ocean: M5, M6, M7, M8, M10, M11
			• Missing ancillary model data
			  • Over land: precipitable water, surface air temperature, column ozone, surface pressure
			  • Over ocean: wind speed, wind direction, precipitable water, surface air temperature, column ozone, surface pressure
			• Probably or confident cloudy
			• Snow/ice present
			• Fire present
			• Unfavorable surface: inland water or coastal
			• Internal test
			  • Over land: sun glint; fire; snow/ice
			  • Over ocean: sun glint; turbid water; sea ice
			• Bright surface over land (bright pixel index $\frac{M8-M11}{M8+M11}$<0.05 and TOA reflectance at M11 > 0.3)
			
			EXCLUDED(2):
			• Retrieved AOT550 out of spec range [0,2]
			• Internal test
			  • Missing channel reflectance or brightness temperature (M3,M5,M7,M8,M9,M10, M11,M12, M15, M16 over land; M3,M4,M15,M16 over ocean)
			
			DEGRADED(1):
			• 65° ≤ Solar zenith angle < 80°
			• Presence of cloud shadow ; cirrus ; adjacent pixel cloud confidence level being probably or confidently cloudy ; volcanic ash
			• Soil dominant over land (bright pixel index ≤ 0.2)
			• Retrieval residual beyond the threshold
			  • Minimum residual > 0.05 when AOT550 >

			0.5 over land • Minimum residual > 0.5 when AOT550 > 0.5 over ocean GOOD(0): otherwise
Ångström exponent Quality	00 = 0 = Good 01 = 1 = Degraded 10 = 2 = Excluded 11 = 3 = Not Produced	2,3	Copy from the AOT quality flag, with additional criteria: NOT PRODUCED(3): • Non-positive AOT at channels used for AE calculation (M2 / M5 over land; M7 / M10 over ocean) EXCLUDED(2): • Out of spec range [-1.0, 3.0] DEGRADED(1): • Low AOT 550 (< 0.15) GOOD(0): otherwise
Suspended Matter Type Quality	00 = 0 = Good 01 = 1 = Degraded 10 = 2 = Excluded 11 = 3 = Not Produced	4,5	Copy from the AOT quality flag, with additional criteria: NOT PRODUCED(3) EXCLUDED(2): • 0.15 < AOT550 < 0.5 DEGRADED(1) GOOD(0): • Volcanic ash is detected.
Cloud Mask Quality	00 = 0 = Poor 01 = 1 = Low 10 = 2 = Medium 11 = 3 = High	6,7	Copy from VIIRS cloud mask (VCM**)**

A1.2. QF2

Flag	Values	Bits	Conditions
Cloud Detection Result & Confidence Indicator	00 = 0 = Confident Clear 01 = 1 = Probably Clear 10 = 2 = Probably Cloudy 11 = 3 = Confident Cloudy	0,1	Copy from VCM, with one modification on confident clear case CONF CLOUDY (3) PROB CLOUDY(2) PROB CLEAR(1) CONF CLEAR(0): • if the heavy aerosol flag is turned on in VCM
Adjacent Pixel Cloud Confidence Value	00 = 0 = Confident Clear 01 = 1 = Probably Clear 10 = 2 = Probably Cloudy 11 = 3 = Confident Cloudy	2,3	Set to be the most cloudy category available from the adjacent 3x3 pixel cloud confidence flags CONF CLOUDY (3) PROB CLOUDY(2) PROB CLEAR(1) CONF CLEAR(0)
Land/Water Background	000 = 0 = Desert 001 = 1 = Land (No Desert) 010 = 2 = Inland Water 011 = 3 = Sea Water 101 = 5 = Coastal 110 = 6 = Ephemeral Water	4-6	Copy from VCM, add a new surface type if ephemeral water is detected in the internal test over land. DESERT (0) LAND (1) INLAND WATER(2) SEA WATER (3) COASTAL (5) EPH WATER (6): • New type added through internal test over land

Bad SDR	1 = Yes 0 = No	7	YES(1) if channel reflectance or brightness temperature are missing : • Over land: M1-M12, M15, M16 • Over ocean: M3-M8, M10, M11, M15, M16

A.1.3. QF3

Flag	Values	Bits	Conditions
Day/Night Flag	00 = 0 = Day 01 = 1 = Low Sun 10 = 2 = Twilight 11 = 3 = Night	0,1	NIGHT (3): • Solar zenith angle > 85° LOW SUN (2): • 80° < Solar zenith angle ≤ 85° TWILIGHT (1): • 65° < Solar zenith angle ≤ 80° DAY (0): • Solar zenith angle ≤ 65°
Interpolation / NAAPS / Climatology Processing Used	000 = 0 = None 001 = 1 = Interpolation only 010 = 2 = Interpolation & Climatology/NAAPS 011 = 3 = Climatology /NAAPS	2-4	CLIMO (3): • If there is no good or degraded quality retrieval available within the searching window (41x41 pixels) • Use NAAPS (if available) or climatology AOT550 only; aerosol model information is from climatology INTCLIMO (2): • Ratio of the total weight of pixels with available retrievals to the total weight of all pixels within the searching window < 0.25 • Combine interpolated (weighted average of good/degraded retrievals) and NAAPS/climatology AOT550; aerosol model information is from the retrieval with highest weight (if available) or climatology. INT (1): • Available retrieval weight ratio ≥ 0.25 • Use interpolated (weighted average of good/degraded retrievals) AOT550 only; aerosol model information is from the retrieval with highest weight (if available) or

			climatology. NOINTCLIMO (0): • Good/degraded aerosol retrieval is available
Sun Glint	000 = 0 = None 001 = 1 = Geometry Based 010 = 2 = Wind Speed Based 011 = 3 = Geometry & Wind 100 = 4 = Internal 101 = 5 = Internal & Geometry 110 = 6 = Internal & Wind 111 = 7 = Internal& Geometry& Wind	5-7	Last two bits are copied from VCM sunglint flag (not set over land) with extra internal test NONE (0): • No glint detected by VCM and internal test GEO (1): • Detected by VCM based on geometry over ocean (glint angle < 36°) or detected by internal test over land WIND (2): • Detected by VCM based on wind speed GEO & WIND (3): • Detected by VCM based on geometry and wind speed INT (4): • Detected by internal test over ocean INT&GEO (5): • Detected by internal test over ocean • Detected by VCM based on geometry INT&WIND (6): • Detected by internal test over ocean • Detected by VCM based on wind speed INT&GEO&WIND (7): • Detected by internal test over ocean • Detected by CVM based on geometry • Detected by VCM based on wind speed

A.1.4. QF4

Flag	Values	Bits	Conditions
Snow/Ice	1 = Yes 0 = No	0	Set by VCM and internal test
Cirrus	1 = Yes 0 = No	1	Set by VCM and internal test over land
Cloud Shadow	1 = Yes 0 = No	2	Copied from VCM
Fire	1 = Yes 0 = No	3	Set by VCM and internal test over land
Bright Land Pixel	00 = 0 = Dark 01 = 1 = Soil Dominated 10 = 2 = Bright	4,5	BRIGHT (2): • Bright pixel index ($\frac{M8-M11}{M8+M11}$)<0.05 and TOA Reflectance at M11 > 0.3 SOIL (1): • Bright pixel index ≤ 0.2 DARK (0): otherwise
Turbid/Shallow Water	1 = Yes 0 = No	6	Set by internal test over ocean
Ash	1 = Yes 0 = No	7	Copied from VCM

A.1.5. QF5

Flag	Values	Bits	Conditions
Low AOT – SM Typing Excluded	1 = Yes 0 = No	0	YES (1) if 0.15 < AOT550 < 1.0
Low AOT – SM Detection Excluded	1 = Yes 0 = No	1	YES (1) if 0.15 < AOT550 < 0.5
AOT Out of Spec Range	1 = Yes 0 = No	2	YES (1) if retrieved AOT550 < 0.0 or AOT550 > 2.0, filled with interpolation, NAAPS, or climatology value
APSP Out of Spec Range	1 = Yes 0 = No	3	YES (1) if AE < -1.0 or AE > 3.0
Low AOT, APSP Excluded	1 = Yes 0 = No	4	YES (1) if AOT550 < 0.15
Residual Threshold Exceeded	1 = Yes 0 = No	5	YES (1) if • Minimum residual > 0.05 when AOT550 > 0.5 over land • Minimum residual > 0.5 when AOT550 > 0.5 over ocean

A.2. EDR Quality Flags

A.2.1. QF1

Flag	Values	Bits	Conditions
AOT Quality	00 = 0 = Not Produced 01 = 1 = Low 10 = 2 = Medium 11 = 3 = High	0,1	HIGH (3): • Number of good quality pixel AOT retrievals > 16 (1/4 the total number of pixels in aggregated horizontal cell) MEDIUM (2): • Number of good quality retrievals ≤ 16 and the number of good/degraded quality retrievals ≥ 16 LOW (1): • Number of good/degraded quality retrievals < 16 NOT PRODUCED (0): • No good/degraded quality pixel retrievals • Neither land or sea water dominant • Ellipsoid fill in the geolocation • Night scan • Solar zenith angle > 80º
APSP Quality	00 = 0 = Not Produced 01 = 1 = Low 10 = 2 = Medium 11 = 3 = High	2,3	HIGH(3): • Number of good quality pixel APSP retrievals > 16 (1/4 the total number of pixels in aggregated horizontal cell) MEDIUM (2): • Number of good quality retrievals ≤ 16 and the number of good/degraded quality retrievals ≥ 16 LOW (1): • Number of good/degraded quality retrievals < 16 NOT PRODUCED (0): • No good/degraded quality pixel retrievals • Neither land or sea water dominant • Ellipsoid fill in the geolocation • Night scan • Solar zenith angle > 80º

Land, Ocean, or Not Produced	00 = 0 = Land 01 = 1 = Ocean 11 = 3 = Not Produced	4,5	LAND (0): • Number of land/desert pixels ≥ half of the number of total non-trimmed pixels within the 8x8 horizontal cell OCEAN (1): • Number of sea water pixels > half of the number of total non-trimmed pixels within the 8x8 horizontal cell NOT PRODUCED (3): otherwise
AOT out of Spec Range	1 = Yes 0 = No	6	YES (1) if any pixel AOT550 in the 8x8 horizontal cell is out of spec range (0.0-2.0)
APSP out of Spec Range	1 = Yes 0 = No	7	YES (1) if any pixel AE in the 8x8 horizontal cell is out of spec range (-1.0-3.0)

A.2.2. QF2

Flag	Values	Bits	Conditions
Cloud Contamination	1 = Yes 0 = No	0	YES (1) if any non-trimmed pixel in the 8x8 horizontal cell is not confidently clear (A.1.2)
Cloud adjacent to cell	1 = Yes 0 = No	1	YES (1) if any non-trimmed pixel in the cell is flagged for probably or confidently adjacently cloudy (A.1.2)
Cirrus Contamination	1 = Yes 0 = No	2	YES (1) if any non-trimmed pixel in the cell is flagged for cirrus (A.1.4)
Bad SDR	1 = Yes 0 = No	3	YES (1) if any non-trimmed pixel in the cell is flagged for bad SDR (A.1.2)
Sunglint	1 = Yes 0 = No	4	YES (1) if any non-trimmed pixel in the cell is flagged for sunglint (A.1.3)
Cloud Shadow	1 = Yes 0 = No	5	YES (1) if any non-trimmed pixel in the cell is flagged for cloud shadow (A.1.4)
Snow/Ice	1 = Yes 0 = No	6	YES (1) if any non-trimmed pixel in the cell is flagged for snow/ice (A.1.4)
Fire	1 = Yes 0 = No	7	YES (1) if any non-trimmed pixel in the cell is flagged for fire (A.1.4)

A.2.3. QF3

Flag	Values	Bits	Conditions
Low sun, degraded	1 = Yes 0 = No	0	YES (1) if any non-trimmed pixel in the cell is flagged for "Low sun, Degraded" (IP Day/Night Flag in A.1.3)
Low sun, excluded	1 = Yes 0 = No	1	YES (1) if any non-trimmed pixel in the cell is flagged for "Twilight, Excluded" or "Night" (IP Day/Night Flag in A.1.3)
Bright surface (land)/Shallow or Turbid Water (ocean)	1 = Yes 0 = No	2	YES (1) if any non-trimmed pixel in the cell is flagged for bright pixel (land) or turbid/shallow water (ocean) (A.1.4)
Low AOT, APSP Excluded	1 = Yes 0 = No	3	YES (1) if any non-trimmed pixel in the cell is flagged for "low AOT - APSP Excluded" (A.1.5)

A.2.4. QF4

Flag	Values	Bits	Notes
Land Model Aerosol Index (land)	000 = 0 = Dust 001 = 1 = Smoke, High Absorption 010 = 2 = Smoke, Low Absorption 011 = 3 = Urban, Clean 100 = 4 = Urban, Polluted 111=7=NA (not land)	0-2	Selects the dominant aerosol model (largest number of pixels involved in the EDR aggregation) over land; See AOT ATBD for all model details

A.2.5. QF5

Flag	Values	Bits	Notes
Small Mode Aerosol Model (ocean)	000 = 0 = Fine mode 1 001 = 1 = Fine mode 2 010 = 2 = Fine mode 3 011 = 3 = Fine mode 4 111 = 7 = NA (not ocean)	0-2	Selects the dominant small mode aerosol model (largest number of pixels involved in the EDR aggregation) over ocean; See AOT ATBD for all model details
Large Mode Aerosol Model (ocean)	000 = 0 = Coarse mode 1 001 = 1 = Coarse mode 2 010 = 2 = Coarse mode 3 011 = 3 = Coarse mode 4 100 = 4 = Coarse mode 5 111 = 7 = NA (not ocean)	3-5	Selects the dominant large mode aerosol model (largest number of pixels involved in the EDR aggregation) over ocean; See AOT ATBD for all model details

A.3. Suspended Matter Quality Flags

A.3.1. QF1

Flag	Values	Bits	Conditions
Suspended Matter Detection Product Quality	00 = 0 = Not Produced 01 = 1 = Low 10 = 2 = Medium 11 = 3 = High	0,1	HIGH (3): • IP SM type quality is good MEDIUM (2): • IP SM type quality is degraded LOW (1): • IP SM type quality is excluded NOT PRODUCED (0): • IP SM type quality is not produced

Suspended Matter Type Product Quality	00 = 0 = Not Produced 01 = 1 = Low 10 = 2 = Medium 11 = 3 = High	2,3	HIGH (3): • IP SM type quality is good and "Low AOT-SM Typing Excluded" flag is not set MEDIUM (2): • IP SM type quality is degraded and "Low AOT- SM Typing Excluded" is not set LOW (1): • IP SM type quality is good or degraded and "Low AOT - SM Typing Excluded" is set NOT PRODUCED (0): • IP SM type quality is not produced
Smoke Concentration Product Quality	00 = 0 = Not Produced 01 = 1 = Low 10 = 2 = Medium 11 = 3 = High	4,5	HIGH (3): • IP SM type quality is good and smoke concentration is not larger than the maximum threshold (1000 µg/m^3) MEDIUM (2): • IP SM type quality is degraded and smoke concentration is not larger than the maximum threshold (1000 µg/m^3) LOW (1): • IP SM type quality is good or degraded and smoke concentration is larger than the maximum threshold (1000 µg/m^3) NOT PRODUCED (0): • IP SM type quality is not produced
Land, Ocean, or Not Produced	00 = 0 = Land 01 = 1 = Ocean 11 = 3 = Not Produced	6,7	LAND (0): • Pixel surface type is land or desert (Land/Water Background flag in A.1.2) OCEAN (1): • Pixel surface type is sea water NOT PRODUCED (3): • Other surface types

A.3.2. QF2

Flag	Values	Bits	Conditions
Cloud Contamination	1 = Yes 0 = No	0	YES (1) if IP "Cloud Detection Result & Confidence Indicator" flag is not confident clear (A.1.2)
Cloud adjacent to cell	1 = Yes 0 = No	1	YES (1) if IP "Adjacent pixel Cloud Confidence Value" flag is confident or probably cloudy (A.1.2)
Cirrus Contamination	1 = Yes 0 = No	2	Copied from IP "Cirrus" flag (A.1.4)
Bad SDR	1 = Yes 0 = No	3	Copied from IP" Bad SDR" flag (A.1.2)
Sunglint	1 = Yes 0 = No	4	YES (1) if IP "Sun Glint" flag is not zero (A.1.3)
Cloud Shadow	1 = Yes 0 = No	5	Copied from IP "Cloud Shadow" flag (A.1.4)
Snow/Ice	1 = Yes 0 = No	6	Copied from IP "Snow/Ice" flag (A.1.4)
Fire	1 = Yes 0 = No	7	Copied from IP "Fire" flag (A.1.4)

A.3.3. QF3

Flag	Values	Bits	Conditions
Smoke Concentration out of Expected Range	1 = Yes 0 = No	0	YES (1) if pixel smoke concentration is beyond the expected range (0-1000 µg/m^3)
Excluded SM typing	1 = Yes 0 = No	1	Copied from the IP "Low AOT - SM Typing Excluded" Quality Flag (A.1.5)
Excluded SM Detection	1 = Yes 0 = No	2	Copied from the IP "Low AOT - SM Detection Excluded" Quality Flag (A.1.5)
Low Sun	1 = Yes 0 = No	3	YES (1) if IP "Day/Night Flag" is set to "Low Sun, Degraded" (65º < Solar zenith angle ≤ 80º)
Bright Surface/ Shallow or Turbid Water	1 = Yes 0 = No	4	YES (1) if IP "Bright Pixel" flag is not zero or "Turbid/Shallow Water" flag is set (A.1.4)

Appendix B: Helpful Tools for Working with VIIRS Files

B.1 HDF5 Tools

For users unaccustomed to working with HDF5 formatted files, the HDF Group has a tutorial with example programs and available tools (including HDFView) on their website at http://www.hdfgroup.org/HDF5/.

B.2 IDL Tools

IDL has a built-in library of commands for HDF5 files. Documentation can be found online at http://idlastro.gsfc.nasa.gov/idl_html_help/Hierarchical_Data_Format_-_HDF5.html or using IDL Help.

Also, Michael Galloy has written a particularly helpful IDL program to read HDF5 arrays into IDL. It is available at http://michaelgalloy.com/lib/hdf5/mg_h5_getdata.html. Example usages for reading in fields from the VIIRS Aerosol EDR and Aerosol Geolocation is below.

Extracts Latitude and Longitude from Aerosol Geolocation:

```
IDL>  Latitude = mg_h5_getdata(GAERO_File, $
                                    '/All_Data/VIIRS-Aeros-EDR-GEO_All/Latitude')
IDL> Longitude = mg_h5_getdata(GAERO_File, $
                                    '/All_Data/VIIRS-Aeros-EDR-GEO_All/Longitude')
```

Extracts Day/Night Metadata from Aerosol Geolocation:

```
IDL> DayNight = mg_h5_getdata(GAERO_File, $
'/Data_Products/VIIRS-Aeros-EDR-GEO/VIIRS-Aeros-EDR-
GEO_Gran_0.N_Day_Night_Flag')
```

Extracts AOT and AOT Scale and Offset from Aerosol EDR and converts to floating point numbers:

```
IDL> AOT = mg_h5_getdata(VAOOO_File, $
                              '/All_Data/VIIRS-Aeros-EDR_All/AerosolOpticalDepth_at_550nm')
IDL> AOT_Factors = mg_h5_getdata(VAOOO_File, $
                              '/All_Data/VIIRS-Aeros-EDR_All/AerosolOpticalDepthFactors')
IDL> AOT_float = (AOT * AOT_Factors[0]) + AOT_Factors[1]
```

B.3 Extract Individual Quality Flag Value

Each individual quality flag is described in a single row in the tables in Appendix A. Flag values need to be extracted from the output 8-bit QFs (QF1, QF2, etc.) based on the corresponding bit positions, which are listed in the table column “Bits” and numbered from right (least significant bit) to the left (most significant bit), i.e., the rightmost bit position is numbered 0.

Example 1:

The EDR AOT quality is saved in the bit 0 and 1 of the output QF1 (A.2.1). To get the AOT quality (0: Not Produced; 1: Low; 2: Medium; 3: High) of the EDR cell [x,y], following IDL command can be used:

IDL> flag = QF1[x,y] AND 3

Example 2:

The IP “Interpolation/NAAPS/Climatology Processing Used” flag is saved in the bit 2, 3 and 4 of the output QF3 (A.1.3). To check whether the IP AOT is from retrieval (flag value of 0 indicating no filling with interpolation/NAPPS/climatology) of the pixel [x,y], following IDL command can be used:

IDL> flag = ISHFT(QF3[x,y], -2) AND 7

IDL> IF (flag EQ 0) THEN PRINT, ‘Not filled value’

The corresponding C code used to extract this flag value is:

```
flag = (QF[x][y] >> 2) & 0x07;
```