The Deep Blue aerosol project:
Aerosol retrievals from VIIRS

Data product user guide and file specification document

This guide is specific to Version-2.0 of the VIIRS Deep Blue Aerosol data products

30 September 2022, Version-2.0

Contents

1 Introduction

This document is designed to provide relevant information to users of the Visible Infrared Imaging Radiometer Suite (VIIRS) 'Deep Blue' aerosol data set from Suomi National Polar-orbiting Partnership (SNPP) and Joint Polar Satellite System (JPSS) series (NOAA-20 onward when operational) satellites. It contains some background information about the algorithms, and lists and explains the content of the data files and how to use them.

The primary data products are orbit-level (level 2, L2) and daily/monthly gridded aggregates (level 3, L3) of aerosol optical thickness (AOT), also known as aerosol optical depth (AOD), at reference wavelengths of 550 nm retrieved using particular VIIRS bands. Other geophysical quantities and related ancillary information, such as pixel-level quality assurance (QA) flags, are also provided. A near-real-time (NRT) data stream, similar to that provided for MODIS products, is also available.

All data files are in NetCDF4 format and include metadata compliant with the Climate and Forecast (CF) conventions version 1.6. Note that these NetCDF4 files can also be accessed with libraries for HDF5.

This document has been revised as follows :

- 27 August 2018 Initial version for Version-1 (V001) products

- 18 May 2021 Version-1.1 (V011) products

- 30 September 2022 Version-2.0 (V002) products

1.1 Algorithm background

The Deep Blue AOD retrieval algorithm family consists of two main algorithms: Deep Blue (DB) over land, and the Satellite Ocean Aerosol Retrieval (SOAR) algorithm over ocean. Note that the overall data product itself is also often referred to as "Deep Blue", after the land algorithm, even though the files contain over-water (i.e., SOAR) data as well. DB itself is further split, using two different methods by which surface reflectance is estimated, dependent upon surface brightness/type. These algorithms have heritage in similar algorithms applied previously to generate AOD records from sensors such as AVHRR, SeaWiFS, and MODIS Terra/Aqua.

DB uses the blue wavelength channels possessed by these sensors; at these wavelengths, the surface reflectance is dark and fairly stable that helps retrieve AOD over otherwise bright surfaces, such as deserts, barren rocks, and urban areas. Over vegetated land surfaces where surface reflectance changes more rapidly with time, it estimates surface reflectance dynamically using known ratios of spectral surface reflectance. For both land surface types, the AOD at the two wavelengths (spanning bright and vegetated surfaces), is used to extrapolate to provide AOD at 550 nm and the Ångström exponent.

SOAR performs a multispectral iterative least-squares fit to simultaneously and self-consistently retrieve AOD at 550 nm, fine-mode fraction (FMF) of AOD at 550 nm, and an indication of best-fitting aerosol type. From these parameters, other related information is derived, such as spectral AOD and the Ångström exponent.

The resulting data products have been validated against Aerosol Robotic Network (AERONET) and Maritime Aerosol Network (MAN) observations, *cf.* https://aeronet.gsfc.nasa.gov. Details of the validation are provided within papers (see below) and we're happy to talk with you if you have questions about performance and likely issues within your specific region of interest.

Additional information, including links to relevant papers, can be found in the References section at the end of this document and at the Deep Blue aerosol project website (https://deepblue.gsfc.nasa.gov).

1.2 Quality flags and data use recommendations

Quality assurance (QA) flags in the level 2 products, sometimes also called confidence flags (CF), are used to identify if there is a suspected problem with an individual retrieval. Examples of this include scenes suspected of cloud contamination or situations, where the retrieval solution was not able to find a good match to the input measurements.

These QA flags take integer values from 1 (worst) to 3 (best). QA=0 indicates no retrieval was performed for a pixel. For scientific applications, **we recommend using only data with a QA flag value of 2 or 3**. Retrievals with QA=1 is, in general, only useful for imagery where data coverage is more important than accuracy, or identifying regions where retrievals are persistently difficult to perform. If you think your application might need to use QA=1 retrievals, we suggest you get in touch so we can advise you how best to do so.

Level 3 (daily/monthly aggregates; see later) are only generated using retrievals with a QA flag of 2 or 3.

Location and meanings of the QA flags within the files are described in Section 3. In addition, note that the files contain several "best estimate" data sets, which are pre-filtered to remove QA=1 retrievals. We recommend these pre-filtered data for most users.

1.3 Contact information and citation for data use

If you have general questions or comments regarding our data products, please email them to Dr. Jaehwa Lee or Dr. Vincent Kim (jaehwa.lee@nasa.gov and woogyung.v.kim@nasa.gov). More information is also available on the Deep Blue aerosol project website, https://deepblue.gsfc.nasa.gov.

Deep Blue data are available to the public without a monetary charge. If you use our data in a publication or report, we request that you read and cite the relevant paper(s) for the specific data set(s) used. The VIIRS-relevant papers include the following:

- Hsu, N. C., J. Lee, A. M. Sayer, W. Kim, C. Bettenhausen, and S.-C. Tsay (2019), VIIRS Deep Blue aerosol products over land: extending EOS long-term aerosol data records, *J. Geophys. Res. Atmos.* 124, doi.org/10.1029/2018JD029688.

- Sayer, A. M., N, C, Hsu, J. Lee, C, Bettenhausen, W. V. Kim, and A. Smirnov (2018), Satellite Ocean Aerosol Retrieval (SOAR) algorithm extension to S-NPP VIIRS as part of the "Deep Blue" aerosol project. *J. Geophys. Res. Atmos.* 123, doi:10.1002/2017JD027412.

- Hsu, N. C., M.-J. Jeong, C. Bettenhausen, A. M. Sayer, R. Hansell, C. S. Seftor, J. Huang, and S.-C. Tsay (2013), Enhanced Deep Blue aerosol retrieval algorithm: The second generation, *J. Geophys. Res. Atmos.,* 118, doi:10.1002/jgrd.50712.

- Sayer, A. M., N. C. Hsu, J. Lee, W. V. Kim, and S. T. Dutcher (2019), Validation, stability, and consistency of MODIS Collection 6.1 and VIIRS Version 1 Deep Blue aerosol data over land, *J. Geophys. Res. Atmos.* 124, doi.org/10.1029/2018JD029598

- Sayer, A. M., N. C. Hsu, J. Lee, W. V. Kim, O. Dubovik, S. T. Dutcher, D. Huang, P. Litvinov, A. Lyapustin, J. L. Tackett, and D. M. Winker (2018), Validation of SOAR VIIRS over-water aerosol retrievals, and context within the global satellite aerosol data record, *J. Geophys. Res. Atmos.* 123, doi.org/10.1029/2018JD029465

If a significant portion of our data is used in your publication, offers of co-authorship are also appreciated. In this case, please contact Dr. N. Christina Hsu (christina.hsu@nasa.gov), the PI of the Deep Blue aerosol project.

In addition to citation, the following text can be used in an Acknowledgements or Data Availability section of a paper:

> *We thank the Deep Blue science team (https://deepblue.gsfc.nasa.gov) for the VIIRS Deep Blue aerosol data record.*

1.4 Algorithm update history

- V1: 27 August 2018, Version-1(V001)

- V1.1: 18 May 2021 Version-1.1(V011)

  - A coding error in the initialization of some variables has been fixed; this is expected to result in slight (almost negligible) differences in the retrieved products

  - The QA flag error, which limited the QA flag to be 3 over the Sahara Desert, has been fixed

  - 3-hourly instead of 6-hourly GEOS5 data are used for ancillary atmospheric information

  - The algorithm flag not defined correctly over some European areas has been fixed

- Slight modification has been made to the minimization process in the SOAR inversion for increased stability

- The smoke flag has been modified over Australia and India

- The Chlorophyll concentration SDS is not produced anymore

- V2.0: 30 September 2022 Version-2.0(V002)

    - NOAA20 VIIRS product is now available.

    - New uncertainty SDS layers are added: Aerosol_Optical_Thickness_550_Expected_Uncertainty_Land, Aerosol_Optical_Thickness_550_Expected_Uncertainty_Ocean (Expected uncertainty of aerosol optical thickness at 550 nm over land and water)

    - New SDS is added: Unsuitable_Pixel_Fraction_Land_Ocean (Fraction of level 1 pixels in cell not used by the retrieval algorithms)

    - Surface pressure is better accounted for both over-land and over-ocean retrievals by adding surface pressure nodes in the aerosol lookup table. This improved retrieval accuracy over elevated land surfaces as well as water surfaces.

    - New surface database describing the surface reflectance relationships between visible and 2.2 μm bands in each geographic grid is introduced for the over-land retrievals. This new data base mitigates overall biases.

    - New fine-mode dominant aerosol optical models are added to existing nonspherical dust models, together replacing the original Deep Blue optical models over land. This improves retrieval accuracy for fine-mode dominant aerosol cases.

    - Optimized global retrieval performance

    - QA filtering and smoke detection scheme has improved.

2 Data organization

Level 2 (L2) files are available as 6-minute granules along the orbit track. Level 3 (L3) files are available as aggregates on a 1x1 degree horizontal grid for daily (D3) and monthly (M3) time steps.

2.1 File naming convention

For L2 files, a sample filename is as follows, broadly following the conventions familiar to users of MODIS data products:

AERDB_L2_VIIRS_SNPP.**A2020001**.**0000**.**002**.**2022244160133**.**nc**

The filename is interpreted as follows:

- **AERDB_L2_VIIRS_SNPP** indicates the Earth Science Data Type (ESDT) of the product. The ESDT is separated into 4 components <product>_<level>_<sensor>_<satellite>. In this case this is the Aerosol Deep Blue Level 2 product from VIIRS instrument on the SNPP satellite. The ESDT for NOAA20 VIIRS is AERDB_L2_VIIRS_NOAA20.
- **A2020001** indicates the data acquisition year and day: YYYY represents the year followed by the day of year (DOY from 001 to 366) per the Julian calendar.
- **0000** indicates the time (HHMM UTC) at which the 6-minute-long granule begins.
- **002** indicates the algorithm processing version, also known as 'Version' (here, Version 2.0).
- **2022244160133** indicates the date and time (UTC) at which the file was created (YYYY DOY per the Julian calendar HHMMSS).
- **nc** indicates a NetCDF4 file.

For level 3 daily files, a sample filename is as follows:

AERDB_D3_VIIRS_SNPP.**A2020001**.**002**.**2022245184505**.**nc**

This is interpreted as follows:

- **AERDB_D3_VIIRS_SNPP** indicates the ESDT of the product. The ESDT is separated into 4 components <product>_<level>_<sensor>_<satellite>. In this case this is the

Aerosol Deep Blue Level 3 daily product from VIIRS instrument on the SNPP satellite. The ESDT for NOAA20 VIIRS is AERDB_D3_VIIRS_NOAA20

- **A2020001** indicates the date at which the aggregation period begins, using the first four numbers for the year (YYYY) and following three for the Julian day of year (from 001 to 366). Daily files comprise data from only a single calendar date.

- **002** indicates the algorithm processing version, also known as 'Version' (here, Version 2.0).

- **2022245184505** indicates the date and time (UTC) at which the file was created (YYYY DOY per the Julian calendar HHMMSS).

- **nc** indicates a NetCDF4 file.

For level 3 monthly files, a sample filename is as follows:

AERDB_M3_VIIRS_SNPP.**A2020001**.**002**.**2022229164944**.**nc**

This is interpreted as follows:

- **AERDB_M3_VIIRS_SNPP** indicates the ESDT of the product. The ESDT is separated into 4 components <product>_<level>_<sensor>_<satellite>. In this case this is the Aerosol Deep Blue Level 3 monthly product from VIIRS instrument on the SNPP satellite. The ESDT for NOAA20 VIIRS is AERDB_M3_VIIRS_NOAA20

- **A2020001** indicates the date at which the aggregation period begins, using the first four numbers for the year (YYYY) and following three for the Julian day of year (from 001 to 366). Monthly files comprise data from a calendar month.

- **002** indicates the algorithm processing version, also known as 'Version' (here, Version 2.0).

- **2022229164944** indicates the date and time (UTC) at which the file was created (YYYY DOY per the Julian calendar HHMMSS).

- **nc** indicates a NetCDF4 file.

2.2 File format and structure

Each data file is in NetCDF format, compliant with climate and forecast (CF) conventions version 1.6. Each file contains multiple Scientific Data Sets (SDS), listed in Section 3.

2.3 L2 production and filtering

Each L2 file contains data from a 6-minute portion of a single VIIRS swath. We produce L2 data at a resolution of 8x8 native VIIRS moderate-resolution (M) band pixels (nominal ~750 m

horizontal pixel size). These 8x8 aggregates are often referred to as 'cells' to distinguish from native instrument 'pixels', and are sometimes also called 'retrieval pixels'. These L2 products therefore are around 6 km x 6 km at the sub-satellite point, and larger away from that point, due to a combination of the sensor scanning geometry and Earth's curvature.

All scientific data sets are filtered to exclude clouds, sea ice, and surface snow or ice.

SDS layers with "_Best_Estimate" in their name are ones whose suspected poor-quality (QA=1) retrievals have been eliminated. Such screened output is provided to facilitate most users who may analyze these data sets without additional filtering. The content of these is the same as the non-best-estimate equivalents, except that QA=1 cells are populated with fill values.

Data fields that contain both land and ocean data (referred to with '_Land_Ocean' in the SDS names) are provided to simplify the user experience. In these combined SDS, each cell in the L2 data is designated as land if half or more of the pixels (determined from the VIIRS internal land/water mask) in that 8x8 pixel cell are over land, and as water otherwise. The values of land cells are derived using only data from land pixels, and vice versa for water cells.

2.4 Daily L3 production and filtering

Daily level 3 (gridded) files at 1° horizontal resolution are produced from the L2 data. In most cases, each data field represents the arithmetic mean of all cells whose latitude and longitude places it within the bounds of each grid element, although other quantities (e.g., standard deviations) are in some cases also provided.

Only retrievals from _Best_Estimate data sets (i.e., QA-filtered) are used in the aggregation. Furthermore, only cells measured on the day of interest are included in this calculation. At least 3 such retrievals are required for a given grid cell to be valid on a given day.

2.5 Monthly L3 production and filtering

We also produce a monthly L3 gridded product based on the daily L3 gridded data at the same 1° horizontal resolution. Statistics for the monthly product are based on the arithmetic mean values from the daily L3 gridded products (e.g., mean, standard deviation of daily means).

To remove poorly sampled grid elements, at least 3 valid days of data in the month are required for the monthly grid element to be populated. SDS names in the monthly L3 products are the same as in the daily L3 products.

3 Data contents

A summary of some of this information about file contents, with a focus on the SDS of relevance for most user applications, can also be found on the Deep Blue aerosol project website at https://deepblue.gsfc.nasa.gov/data .

3.1 Dimensions

Five dimensions are defined within the L2 files:

- Land_Bands, the spectral bands at which AOD over land is provided. This currently has 3 elements.

- Ocean_Bands, the spectral bands at which AOD over water is provided. This currently has 7 elements.

- Reflectance_Bands, the spectral bands at which cloud-screened cell-averaged TOA reflectances over land/water are provided. Note that these do not directly correspond to retrieval inputs and are intended primarily for reflectance data assimilation applications. This currently has 8 elements.

- Idx_Atrack, the index of the L2 cell in the along-track (roughly North-South) direction. This is typically around 404.

- Idx_Xtrack, the index of the L2 cell in the across-track (roughly East-West) direction. This is typically 400.

Five dimensions are defined within the L3 daily and monthly files:

- Land_Bands, the spectral bands at which AOD over land is provided. This currently has 3 elements.

- Ocean_Bands, the spectral bands at which AOD over water is provided. This currently has 7 elements.

- Latitude_1D, the central latitudes of grid cells. This is 180 for 1 degree resolution. Note: a two-dimensional SDS is also provided in the files (see below), but the 1D one is included as the formal dimension scale to comply with metadata conventions.

- Longitude_1D, the central longitudes of grid cells. This is 360 for 1 degree resolution. Note: a two-dimensional SDS is also provided in the files (see below), but the 1D one is included as the formal dimension scale to comply with metadata conventions.

- Aerosol_Types, numerical indices to denote the different aerosol types which can be reported in the combined land and ocean aerosol type SDS.

3.2 Global attributes

The global attributes in the table below are present in the L2 files. In a few cases, metadata are duplicated in multiple attributes to meet specific system needs or maintain data continuity with heritage sensors.

Attribute Name	Example
processing_level	"L2"
cdm_data_type	"swath"
keywords_vocabulary	"NASA Global Change Master Directory (GCMD) Science Keywords"
Keywords	"EARTH SCIENCE > ATMOSPHERE > AEROSOLS > AEROSOL OPTICAL DEPTH/THICKNESS > ANGSTROM EXPONENT, EARTH SCIENCE > ATMOSPHERE > AEROSOLS > AEROSOL OPTICAL DEPTH/THICKNESS"
license	"http://science.nasa.gov/earth-science/earth-science-data/data-information-policy/"
stdname_vocabulary	"NetCDF Climate and Forecast (CF) Metadata Convention"
naming_authority	"gov.nasa.gsfc.sci.atmos"
NCO	"4.7.9"
title	"SNPP VIIRS Deep Blue Aerosol L2 6-Min Swath 6 km (AERDB_L2_SNPP_VIIRS)" / "NOAA20 VIIRS Deep Blue Aerosol L2 6-Min Swath 6 km (AERDB_L2_NOAA20_VIIRS)"
long_name	"SNPP VIIRS Deep Blue Aerosol L2 6-Min Swath 6 km" / "NOAA20 VIIRS Deep Blue Aerosol L2 6-Min Swath 6 km"
history	""
LocalGranuleID	"AERDB_L2_VIIRS_SNPP.A2020001.0000.002.2022244160133.nc" / "AERDB_L2_VIIRS_NOAA20.A2020001.0018.002.2022244160053.nc"
product_name	"AERDB_L2_VIIRS_SNPP.A2020001.0000.002.2022244160133.nc" / "AERDB_L2_VIIRS_NOAA20.A2020001.0018.002.2022244160053.nc"
source	"deepBlue 20220907-1, viirs_l1 3.1.0"

date_created	"2020-09-01T16:00:53Z"
Conventions	"CF-1.6, ACDD-1.3"
ShortName	"AERDB_L2_VIIRS_SNPP"/ "AERDB_L2_VIIRS_NOAA20"
product_version	"2.0"
AlgorithmType	"OPS"
identifier_product_doi	"10.5067/VIIRS/AERDB_L2_VIIRS_SNPP.002"
identifier_product_doi_authority	"http://dx.doi.org"
input_files	"VNP02MOD.A2020001.0000.002.2021277210900.uwssec.nc,VNP03MOD.A2020001.0000.002.2021277210716.uwssec.nc"
ancillary_files	"GEOS.fpit.asm.inst3_2d_asm_Nx.GEOS5124.20200101_0000.V01.nc4,GEOS.fpit.asm.inst3_2d_asm_Nx.GEOS5124.20200101_0300.V01.nc4"
l1_version	"3.1.0"
l1_lut_version	"3.1.0.2"
l1_lut_created	"2021-04-09"
DataCenterId	"UWI-MAD/SSEC/ASIPS"
project	"NASA VIIRS Atmosphere SIPS"
creator_name	"NASA VIIRS Atmosphere SIPS"
creator_url	"https://sips.ssec.wisc.edu"
creator_email	"sips.support@ssec.wisc.edu"
creator_institution	"Space Science & Engineering Center, University of Wisconsin - Madison"
publisher_name	"LAADS"
publisher_url	"https://ladsweb.modaps.eosdis.nasa.gov/"
publisher_email	"modis-ops@lists.nasa.gov"
publisher_institution	"NASA Level-1 and Atmosphere Archive & Distribution System"
platform	"Suomi-NPP" / "NOAA20"
instrument	"VIIRS"
GRingPointSequenceNo	[1 2 3 4]
GRingPointLatitude	[5.333398 9.474411 -11.107638 -15.350701]
GRingPointLongitude	[-175.08533 -147.68365 -142.75565 -170.8307]
geospatial_lat_units	"degrees_north"

geospatial_lon_units	"degrees_east"
geospatial_lat_min	-15.350701
geospatial_lat_max	9.474411
geospatial_lon_min	-175.08533
geospatial_lon_max	-142.75565
NorthBoundingCoordinate	9.474411
SouthBoundingCoordinate	-15.350701
EastBoundingCoordinate	-142.75565
WestBoundingCoordinate	-175.08533
time_coverage_start	"2020-01-01T00:00:00.000Z"
time_coverage_end	"2020-01-01T00:06:00.000Z"
startDirection	"Ascending"
endDirection	"Ascending"
OrbitNumber	42372
DayNightFlag	"Day"
xmlmetadata	""

The global attributes in the table below are present in the L3 files. In a few cases, metadata are duplicated in multiple attributes to meet specific system needs or maintain data continuity with heritage sensors.

Attribute Name	Example
description	"VIIRS Deep Blue Level 3 daily aerosol data, 1x1 degree grid"
comment	Data are the arithmetic mean of all VIIRS Deep Blue/SOAR L2 data located in each grid element after filtering by confidence flag. Sources are the best_estimate SDS in L2 files.
references	"https://deepblue.gsfc.nasa.gov"
institution	"NASA Goddard Space Flight Center"

long_name	"SNPP VIIRS Deep Blue Level 3 daily aerosol data, 1x1 degree grid" / "NOAA20 VIIRS Deep Blue Level 3 daily aerosol data, 1x1 degree grid"
title	"SNPP VIIRS Deep Blue Level 3 daily aerosol data, 1x1 degree grid" / "NOAA20 VIIRS Deep Blue Level 3 daily aerosol data, 1x1 degree grid"
Short_name	"AERDB_D3_VIIRS_SNPP" / "AERDB_D3_VIIRS_NOAA20"
version_id	1
pge_version	1
LocalGranuleID	"AERDB_D3_VIIRS_SNPP.A2018278.011.2020315145938.nc"
production_datetime	"2020-11-10T14:59:38Z"
instrument	"VIIRS"
platform	"Suomi-NPP"
geospatial_lat_max	90
geospatial_lat_min	-90
geospatial_lon_min	180
geospatial_lon_max	-180
NorthBoundingCoordinate	90
SouthBoundingCoordinate	-90
EastBoundingCoordinate	180
WestBoundingCoordinate	-180
latitude_resolution	1
longitude_resolution	1
creator_name	"NASA VIIRS Atmosphere SIPS"
creator_url	"https://sips.ssec.wisc.edu"
creator_email	"sips.support@ssec.wisc.edu"
creator_institution	"Space Science & Engineering Center, University of Wisconsin - Madison"
publisher_name	"LAADS"
publisher_url	"https://ladsweb.modaps.eosdis.nasa.gov/"
publisher_email	"modis-ops@lists.nasa.gov"
publisher_institution	"NASA Level-1 and Atmosphere Archive & Distribution System"

keywords	"EARTH SCIENCE > ATMOSPHERE > AEROSOLS > AEROSOL OPTICAL DEPTH/THICKNESS > ANGSTROM EXPONENT, EARTH SCIENCE > ATMOSPHERE > AEROSOLS > AEROSOL OPTICAL DEPTH/THICKNESS"
data_set_language	"en"
format	"NetCDF4"
processing_level	"L3"
keywords_vocabulary	"NASA Global Change Master Directory (GCMD) Science Keywords"
license	"http://science.nasa.gov/earth-science/earth-science-data/data-information-policy/"
stdname_vocabulary	"NetCDF Climate and Forecast (CF) Metadata Convention"
naming_authority	"gov.nasa.gsfc.sci.atmos"
NCO	"4.7.9"
Conventions	"CF-1.6, ACDD-1.3"
history	""
time_coverage_start	"2018-10-05T00:00:00.000000"
time_coverage_end	"2018-10-05T23:59:59.000000"
source	"AERDB_L2 1.1, deepBlue_L3 20220921-1"
date_created	"2020-11-10T14:57:03Z"
product_name	"AERDB_D3_VIIRS_SNPP.A2018278.011.2020315145938.nc"
LocalGranuleID	"AERDB_D3_VIIRS_SNPP.A2018278.011.2020315145938.nc"
ShortName	"AERDB_D3_VIIRS_SNPP"
product_version	1.1
AlgorithmType	"OPS"
identifier_product_doi	"10.5067/VIIRS/AERDB_D3_VIIRS_SNPP.001"
identifier_product_doi_authority	"http://dx.doi.org"
input_files	"AERDB_L2_VIIRS_SNPP.A2018278.0000.011.2020312154347.nc,AERDB_L2_VIIRS_SNPP.A2018278.0006.011.2020312154345.nc,…"
ancillary_files	""

DataCenterId	"UWI-MAD/SSEC/ASIPS"
project	"NASA VIIRS Atmosphere SIPS"
creator_name	"NASA VIIRS Atmosphere SIPS"
creator_url	"https://sips.ssec.wisc.edu"
creator_email	"sips.support@ssec.wisc.edu"
creator_institution	"Space Science & Engineering Center, University of Wisconsin - Madison"
publisher_name	"LAADS"
publisher_url	"https://ladsweb.modaps.eosdis.nasa.gov/"
publisher_email	"modis-ops@lists.nasa.gov"
publisher_institution	"NASA Level-1 and Atmosphere Archive & Distribution System"
DayNightFlag	"Day"

3.3 Data field attributes

The attributes in the table below are present for each SDS in both L2 and L3 (daily and monthly) files, where applicable (not all are applicable for each SDS).

Attribute name	Description	Data type
long_name	Long, descriptive name of data field	string
units	Units of the data field	string
_FillValue	Value assigned to missing/invalid data	same type as data field
valid_range	Minimum and maximum values to consider valid in the data	same type as data field
standard_name	Standard name of variable in CF conventions	string

Note that scale_factor and add_offset attributes are not defined for the geophysical data in these data products, as they take values of 1 and 0 respectively. No scaling or unit conversion is necessary.

3.4 SDS names and descriptions

3.4.1 Level 2 data fields

A large number of SDS are contained within these files. The below table groups related SDS together.

SDS name	Type	Description	Units
Latitude	Float	Latitude of center of grid element (2D)	degrees_north
Longitude	Float	Longitude of center of grid element (2D)	degrees_east
Idx_Atrack	Float	Index of cells along track	-
Idx_Xtrack	Float	Index of cells across track	-
Land_Bands	Float	Wavelength bands used over land	nm

Ocean_Bands	Float	Wavelength bands used over ocean	nm
Reflectance_Bands	Float	Wavelength bands at which cloud-screened averaged TOA reflectance is provided	nm
Solar_Zenith_Angle	Float	Solar zenith angle	degrees
Viewing_Zenith_Angle	Float	Viewing zenith angle	degrees
Relative_Azimuth _Angle	Float	Relative azimuth angle (following Gordon convention)	degrees
Scattering_Angle	Float	Scattering angle	degrees
Scan_Start_Time	Double	Scan start time (TAI93)	seconds
Aerosol_Optical_Thickness_550_Expected_Uncertainty_Land	Float	Deep Blue expected uncertainty of aerosol optical thickness at 550 nm over land	none
Aerosol_Optical_Thickness_550_Expected_Uncertainty_Ocean	Float	Deep Blue expected uncertainty of aerosol optical thickness at 550 nm over water	none
Aerosol_Optical_Thickness_550_Land	Float	Deep Blue aerosol optical thickness at 550 nm over land	none
Aerosol_Optical_Thickness_550_Land_Best_Estimate	Float	Deep Blue aerosol optical thickness at 550 nm over land, QA-filtered	none
Aerosol_Optical_Thickness_550_Land_Ocean	Float	Deep Blue/SOAR aerosol optical thickness at 550 nm over land and ocean	none
Aerosol_Optical_Thickness_550_Land_Ocean_Best_Estimate	Float	Deep Blue/SOAR aerosol optical thickness at 550 nm over land and ocean, QA-filtered	none
Aerosol_Optical_Thickness_550_Ocean	Float	SOAR aerosol optical thickness at 550 nm over water	none
Aerosol_Optical_Thickness_550_Ocean_Best_Estimate	Float	SOAR aerosol optical thickness at 550 nm over water, QA-filtered	none
Spectral_Aerosol_Optical_Thickness_Land	Float	Deep Blue spectral aerosol optical thickness at 412, 488, and 670 nm over land	none
Spectral_Aerosol_Optical_Thickness_Ocean	Float	SOAR spectral aerosol optical thickness at 488, 550, 670, 865, 1240, 1610, 2250 nm over water	none

Aerosol_Optical_Thickness_550_STDV_Land	Float	Deep Blue standard deviation of aerosol optical thickness at 550 nm within cell over land	none
Aerosol_Optical_Thickness_550_STDV_Ocean	Float	SOAR standard deviation of aerosol optical thickness at 550 nm within cell over water	none
Aerosol_Optical_Thickness_QA_Flag_Land	Int	Deep Blue quality assurance flag over land. 0=no retrieval, 1=poor, 2=moderate, 3=good	none
Aerosol_Optical_Thickness_QA_Flag_Ocean	Int	SOAR quality assurance flag over water. 0=no retrieval, 1=poor, 3=good	none
Aerosol_Type_Land	Int	Aerosol optical model over land. -999=no retrieval, 0=dust, 1=smoke, 2=high altitude smoke, 3=pyrocumulonimbus clouds, 4=non-smoke fine mode, 5=mixed, 6=background	none
Aerosol_Type_Land_Ocean	Int	Aerosol optical model over land and water. -999=no retrieval, 0=dust(land+ocean), 1=smoke, 2=high altitude smoke, 3=pyrocumulonimbus clouds, 4=non-smoke fine mode, 5=mixed(land+ocean), 6=background(land+ocean maritime), 7=fine dominated	none
Aerosol_Type_Ocean	Int	SOAR retrieved aerosol optical model over water. -999=no retrieval, 1=dust, 2=fine dominated, 3=maritime, 4=mixed	none
Algorithm_Flag_Land	Int	Deep Blue algorithm flag over land. 0=arid DB, 1=vegetated, 2=mixed	none
Algorithm_Flag_Ocean	Int	SOAR algorithm flag over water. -999=no retrieval, 0=full retrieval, 1=turbid/shallow, 2=mixed	none
Angstrom_Exponent_Land	Float	Deep Blue Angstrom exponent over land; 412/488 nm when Algorithm_Flag_Land=0, 488/670 nm when Algorithm_Flag_Land>0	none

Angstrom_Exponent_Land_Best_Estimate	Float	Deep Blue Angstrom exponent over land; 412/488 nm when Algorithm_Flag_Land=0, 488/670 nm when Algorithm_Flag_Land>0, QA-filtered	none
Angstrom_Exponent_Land_Ocean	Float	Deep Blue/SOAR Angstrom exponent over land and ocean	none
Angstrom_Exponent_Land_Ocean_Best_Estimate	Float	Deep Blue/SOAR Angstrom exponent over land and ocean, QA-filtered	none
Angstrom_Exponent_Ocean	Float	SOAR Angstrom exponent (550/865 nm) over water	none
Angstrom_Exponent_Ocean_Best_Estimate	Float	SOAR Angstrom exponent (550/865 nm) over water, QA-filtered	none
Fine_Mode_Fraction_550_Ocean	Float	SOAR fine mode fraction of aerosol optical thickness at 550 nm over water	none
Fine_Mode_Fraction_550_Ocean_Best_Estimate	Float	SOAR fine mode fraction of aerosol optical thickness at 550 nm over water, QA-filtered	none
Spectral_Single_Scattering_Albedo_Land	Float	Deep Blue single scattering albedo over land; 412/488/670 nm	none
Spectral_Surface_Reflectance	Float	Deep Blue spectral (412, 488, 670 nm) surface reflectance over land	none
Spectral_TOA_Reflectance_Land	Float	Spectral cloud-screened cell-averaged TOA reflectance over land	I/F
Spectral_TOA_Reflectance_Ocean	Float	Spectral cloud-screened cell-averaged TOA reflectance over water	I/F
Cell_Average_Elevation_Land	Float	Cell-averaged elevation above sea level, land pixels	m
Cell_Average_Elevation_Ocean	Float	Cell-averaged elevation above sea level, ocean pixels	m
Number_Of_Pixels_Used_Land	Int	Deep Blue number of pixels used within cell for retrieval over land	none

Number_Of_Pixels_Used_Water	Int	SOAR number of pixels used within cell for retrieval over water	none
Number_Valid_Pixels	Int	Number of non-fill L1b pixels in cell	none
Unsuitable_Pixel_Fraction_Land_Ocean	Float	Fraction of level 1 pixels in cell not used by the retrieval algorithms, calculated as 1 - ((Number_Of_Pixels_Used_Land+Number_Of_Pixels_Used_Ocean) / Number_Valid_Pixels)	none
Ocean_Sum_Squares	Float	Average sum of square residuals for SOAR ocean retrieval	none
Precipitable_Water	Float	Ancillary total column water vapour amount	cm
TOA_NDVI	Float	Average normalized difference vegetation index	none
Total_Column_Ozone	Float	Ancillary total column ozone amount	DU
Wind_Speed	Float	Ancillary wind speed	meters per second
Wind_Direction	Float	Ancillary wind direction	degrees

3.4.2 Level 3 data fields

The following SDS exist in both the level 3 daily (D3) and monthly (M3) products. Note again that the D3 products are derived as an aggregation of the L2 files, while the M3 products are an aggregation of the D3 files.

SDS name	Type	Description	Units
Latitude	Float	Latitude of center of grid element (2D)	degrees_north
Longitude	Float	Longitude of center of grid element (2D)	degrees_east
Latitude_1D	Float	Latitude of center of grid element (1D)	degrees_north

Longitude_1D	Float	Longitude of center of grid element (1D)	degrees_east
Land_Bands	Float	Wavelength bands used over land	nm
Ocean_Bands	Float	Wavelength bands used over ocean	nm
Aerosol_Types	Int	Aerosol types for land and ocean combined data set. 0=dust(land+ocean), 1=smoke, 2=high altitude smoke, 3=pyrocumulonimbus clouds, 4=non-smoke fine mode, 5=mixed(land+ocean), 6=background(land+ocean maritime), 7=fine dominated	none
Aerosol_Optical_Thickness_550_Land_Ocean_Count	Int	Number of retrievals used for aerosol optical thickness at 550 nm over land and ocean	none
Aerosol_Optical_Thickness_550_Land_Ocean_Maximum	Float	Maximum aerosol optical thickness estimated at 550 nm over land and ocean	none
Aerosol_Optical_Thickness_550_Land_Ocean_Mean	Float	Aerosol optical thickness estimated at 550 nm over land and ocean	none
Aerosol_Optical_Thickness_550_Land_Ocean_Minimum	Float	Maximum aerosol optical thickness estimated at 550 nm over land and ocean	none
Aerosol_Optical_Thickness_550_Land_Ocean_Standard_Deviation	Float	Standard deviation of aerosol optical thickness estimated at 550 nm over land and ocean	none
Aerosol_Optical_Thickness_550_Land_Count	Int	Number of retrievals used for aerosol optical thickness at 550 nm over land	none
Aerosol_Optical_Thickness_550_Land_Maximum	Float	Maximum aerosol optical thickness estimated at 550 nm over land	none
Aerosol_Optical_Thickness_550_Land_Mean	Float	Aerosol optical thickness estimated at 550 nm over land	none
Aerosol_Optical_Thickness_550_Land_Minimum	Float	Maximum aerosol optical thickness estimated at 550 nm over land	none

Aerosol_Optical_Thickness_550_Land_Standard_Deviation	Float	Standard deviation of aerosol optical thickness estimated at 550 nm over land	none
Aerosol_Optical_Thickness_550_Ocean_Count	Int	Number of retrievals used for aerosol optical thickness at 550 nm over ocean	none
Aerosol_Optical_Thickness_550_Ocean_Maximum	Float	Maximum aerosol optical thickness estimated at 550 nm over ocean	none
Aerosol_Optical_Thickness_550_Ocean_Mean	Float	Aerosol optical thickness estimated at 550 nm over ocean	none
Aerosol_Optical_Thickness_550_Ocean_Minimum	Float	Maximum aerosol optical thickness estimated at 550 nm over ocean	none
Aerosol_Optical_Thickness_550_Ocean_Standard_Deviation	Float	Standard deviation of aerosol optical thickness estimated at 550 nm over ocean	none
Angstrom_Exponent_Land_Ocean_Maximum	Float	Maximum Ångström exponent estimated over land and ocean	none
Angstrom_Exponent_Land_Ocean_Mean	Float	Ångström exponent estimated over land and ocean	none
Angstrom_Exponent_Land_Ocean_Minimum	Float	Maximum Ångström exponent estimated over land and ocean	none
Angstrom_Exponent_Land_Ocean_Standard_Deviation	Float	Standard deviation of Ångström exponent estimated over land and ocean	none
Angstrom_Exponent_Land_Maximum	Float	Maximum Ångström exponent estimated over land	none
Angstrom_Exponent_Land_Mean	Float	Ångström exponent estimated over land	none
Angstrom_Exponent_Land_Minimum	Float	Maximum Ångström exponent estimated over land	none
Angstrom_Exponent_Land_Standard_Deviation	Float	Standard deviation of Ångström exponent estimated over land	none
Angstrom_Exponent_Ocean_Maximum	Float	Maximum Ångström exponent estimated over ocean	none
Angstrom_Exponent Ocean_Mean	Float	Ångström exponent estimated over ocean	none
Angstrom_Exponent_Ocean_Minimum	Float	Maximum Ångström exponent estimated over ocean	none

Angstrom_Exponent_Ocean_Standard_Deviation	Float	Standard deviation of Ångström exponent estimated over ocean	none
Fine_Mode_Fraction_550_Ocean _Mean	Float	Fine mode AOD fraction estimated at 550 nm over ocean	none
Fine_Mode_Fraction_550_Ocean_Standard_Deviation	Float	Standard deviation of fine mode AOD fraction estimated at 550 nm over ocean	none
Aerosol_Type_Land_Ocean_Histogram	Int	Histograms of retrieved aerosol type over land and ocean. See Aerosol_Types SDS for key. Count of all retrievals in daily files; count of daily mode in monthly files.	none
Aerosol_Type_Land_Ocean_Mode	Int	Modal value of retrieved aerosol type over land and ocean. See Aerosol_Types SDS for key. From all retrievals in daily files; mode of daily mode in monthly files.	none
Spectral_Aerosol_Optical_Thickness_Land_Count	Int	Number of retrievals used for spectral aerosol optical thickness over land	none
Spectral_Aerosol_Optical_Thickness_Land_Mean	Float	Spectral aerosol optical thickness estimated over land	none
Spectral_Aerosol_Optical_Thickness_Land_Standard_Deviation	Float	Standard deviation of spectral aerosol optical thickness over land	none
Spectral_Aerosol_Optical_Thickness_Ocean_Count	Int	Number of retrievals used for spectral aerosol optical thickness over ocean	none
Spectral_Aerosol_Optical_Thickness_Ocean_Mean	Float	Spectral aerosol optical thickness estimated over ocean	none
Spectral_Aerosol_Optical_Thickness_Ocean_Standard_Deviation	Float	Standard deviation of spectral aerosol optical thickness over ocean	none
Unsuitable_Pixel_Fraction_Land_Ocean	Float	Fraction of level 1 pixels in cell not used by the retrieval algorithms, calculated as 1 - ((Number_Of_Pixels_Used_Land+Number_Of_Pixels_Used_Ocean) / Number_Valid_Pixels)	none

4 Reading the data

We use CF-compliant NetCDF4 to maximize the usability and accessibility of our data now and into the future. If you have trouble reading our data, or have suggestions on how to make it more useful, please contact us.

More information on NetCDF, including tools to access files in this format, can be found at https://www.unidata.ucar.edu/software/netcdf/ . For quick browsing of the contents of individual files, the Panoply tool (http://www.giss.nasa.gov/tools/panoply/) provides a quick and easy interface. NetCDF libraries are also available in a variety of higher-level programming languages, such as IDL, Python, C/C++, and FORTRAN.

The Deep Blue website includes a page with more information about the content and format of various Deep Blue data products, including a brief tutorial on the use of Panoply to map aerosol optical depth, at https://deepblue.gsfc.nasa.gov/data

5 Where to download the data

The data set is currently available through the NASA Level-1 and Atmosphere Archive & Distribution System (LAADS) at https://ladsweb.modaps.eosdis.nasa.gov/, which is the same place which hosts (among others) MODIS Deep Blue data products.

All data products are accessible from LAADS without a monetary charge, but users do need to register with NASA Earthdata and obtain a login account. First-time users who need to register may access the NASA User Registration System page via the following URL: https://urs.earthdata.nasa.gov

Users may directly access the VIIRS Deep Blue products via the following URLs:

https://ladsweb.modaps.eosdis.nasa.gov/archive/allData/5110/AERDB_L2_VIIRS_SNPP
https://ladsweb.modaps.eosdis.nasa.gov/archive/allData/5110/AERDB_D3_VIIRS_SNPP
https://ladsweb.modaps.eosdis.nasa.gov/archive/allData/5110/AERDB_M3_VIIRS_SNPP

Users who may want to conduct a specific geographical/temporal search can do so via the LAADS Web search & order interface: https://ladsweb.modaps.eosdis.nasa.gov/search/

Remember to select the sensor (VIIRS/SNPP) and select the version (5110) before you define your spatial and temporal search parameters. If you have difficulties using the LAADS portal, please use the contact information on that webpage for support.

A near-real-time (NRT) data stream, similar to that provided for MODIS products, is also available to the public through the NASA Earthdata website via the following URL:

https://earthdata.nasa.gov

Acknowledgements

References

Scientific references about Deep Blue/SOAR algorithm development and validation can be found on the Deep Blue website at https://deepblue.gsfc.nasa.gov/publications. Some key references dealing with calibration, algorithm, and validation are additionally listed below:

- Hsu, N. C., S. -C. Tsay, M. D. King, and J. R. Herman (2004), Aerosol properties over bright-reflecting source regions, *IEEE Trans. Geosci. Remote Sens.*, 42(3), 557–569, doi:10.1109/TGRS.2004.824067

- Hsu, N. C., S.-C. Tsay, M. D. King, and J. R. Herman (2006), Deep Blue retrievals of Asian aerosol properties during ACE-Asia, *IEEE Trans. Geosci. Remote Sens.*, 44, 3180–3195, doi:10.1109/TGRS.2006.879540

- Hsu, N. C., M.-J. Jeong, C. Bettenhausen, A. M. Sayer, R. Hansell, C. S. Seftor, J. Huang, and S.-C. Tsay (2013), Enhanced Deep Blue aerosol retrieval algorithm: The second generation, *J. Geophys. Res. Atmos.*, 118, 9296–9315, doi:10.1002/jgrd.50712

- Lee, J., N. C. Hsu, A. M. Sayer, C. Bettenhausen, and P. Yang (2017), AERONET-based nonspherical dust optical models and effects on the VIIRS Deep Blue/SOAR over water aerosol product, *J. Geophys. Res. Atmos.*, 122. doi:10.1002/2017JD027258

- Sayer, A. M., N. C. Hsu, C. Bettenhausen, Z. Ahmad, B. N. Holben, A. Smirnov, G. E. Thomas, and J. Zhang (2012), SeaWiFS Ocean Aerosol Retrieval (SOAR): Algorithm, validation, and comparison with other data sets, *J. Geophys. Res.*, 117, D03206, doi:10.1029/2011JD016599

- Sayer, A. M., N. C. Hsu, C. Bettenhausen, and M.-J. Jeong (2013), Validation and uncertainty estimates for MODIS Collection 6 "Deep Blue" aerosol data, *J. Geophys. Res. Atmos.*, 118, 7864–7872, doi:10.1002/jgrd.50600

- Sayer, A. M., L. A. Munchak, N. C. Hsu, R. C. Levy, C. Bettenhausen, and M.-J. Jeong (2014), MODIS Collection 6 aerosol products: Comparison between Aqua's e-Deep Blue, Dark Target, and "merged" data sets, and usage recommendations, *J. Geophys. Res. Atmos.*, 119, 13,965–13,989, doi:10.1002/2014JD022453

- Sayer, A. M., N. C. Hsu, C. Bettenhausen, R. E. Holz, J. Lee, G. Quinn, and P. Veglio (2017), Cross-calibration of S-NPP VIIRS moderate-resolution reflective solar bands against MODIS Aqua over dark water scenes, *Atmos. Meas. Tech.,* 10, 1425-1444, doi:10.5194/amt-10-1425-2017.

- Sayer, A. M., N, C, Hsu, J. Lee, C, Bettenhausen, W. V. Kim, and A. Smirnov (2018), Satellite Ocean Aerosol Retrieval (SOAR) algorithm extension to S-NPP VIIRS as part of the "Deep Blue" aerosol project. *J. Geophys. Res. Atmos.* 123, doi:10.1002/2017JD027412.

- Sayer, A. M., N. C. Hsu, J. Lee, W. V. Kim, O. Dubovik, S. T. Dutcher, D. Huang, P. Litvinov, A. Lyapustin, J. L. Tackett, and D. M. Winker (2018), Validation of SOAR VIIRS over-water aerosol retrievals, and context within the global satellite aerosol data record, *J. Geophys. Res. Atmos*. 123, doi.org/10.1029/2018JD029465

- Hsu, N. C., J. Lee, A. M. Sayer, W. Kim, C. Bettenhausen, and S.-C. Tsay (2019), VIIRS Deep Blue aerosol products over land: extending EOS long-term aerosol data records, *J. Geophys. Res. Atmos*. 124, doi.org/10.1029/2018JD029688

- Sayer, A. M., N. C. Hsu, J. Lee, W. V. Kim, and S. T. Dutcher (2019), Validation, stability, and consistency of MODIS Collection 6.1 and VIIRS Version 1 Deep Blue aerosol data over land, *J. Geophys. Res. Atmos.* 124, doi.org/10.1029/2018JD029598