ALGORITHM THEORETICAL BASIS DOCUMENT (ATBD)
SPECTRAL PHOTOMETER

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See configuration management system for approval history.

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Change Record

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A	09/03/2015	ECO-03108	Initial Release

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LIST OF TABLES AND FIGURES

1 DESCRIPTION

Contained in this document are details concerning a group of measurements (e.g., Almucantars sky radiance, Principal Planes sky radiance, etc.) made by a spectral photometer, as well as their associated derived data products (e.g., AOD, perceptible water, aerosol size distribution, spectral flux, etc.) at all NEON 20 core sites and 21 selected relocatable sites. Sun photometer measurements of the direct (collimated) solar radiation provide information to calculate the columnar aerosol optical depth (AOD). AOD can then be used to compute columnar water vapor (Precipitable Water) and estimate the aerosol size using the Angstrom parameter relationship, and derive other inversion data products. Before NEON is capable of processing data using international recognized standards (e.g., AERONET methodology), NEON data will be processed by AERONET.

Data processed at AERONET are available for two versions (version 1 and 2) and 3 quality levels (i.e., level 1.0 [unscreened], level 1.5 [cloud screened] and level 2.0 [quality assured]) and 3 time scales (i.e., all points, daily average, and monthly average). Version 1 data was only available before 2006. Version 2 is an improved version of version 1 to include O_3 and NO_2 correction. Version 3 is under development. All processed NEON data will be Version 2 data. The Version 2 data products for direct sun measurement will be available at Level 1.0, Level 1.5 and Level 2.0; while Version 2 inversion data products will be only available at Level 2.0. Although AERONET data are available at all measurement points, daily average and monthly average, NEON will only acquire the “all points” data. To summarize:

- Only Version 2 data will be archived/distributed by NEON
- Only “All Points” data (no daily or monthly averages) will be archived/distributed by NEON
- The following quality levels will by archived/distributed by NEON:
    - Direct Sun Products: Level 1.0, Level 1.5, and Level 2.0
    - Radiance Products: Level 2.0
    - Derived Inversion Products: Level 2.0

Because the raw data (i.e., .K7 files) will be transmitted to AERONET directly for processing, NEON will receive a subset of processed data back from AERONET (see Cooperative Services Agreement Between The National Ecological Observatory Network, INC., and NASA AERONET; data April 18th, 2014 for data transmission details). As such, no conversion and computation description of the data products are included in this document. Instead, the reader is referred to the AERONET website (http://aeronet.gsfc.nasa.gov) for information and descriptions on data processing and data products.

At NEON, we define the .K7 files as equivalent to the NEON L0 data. AERONET Raw Radiances (almucantar and principal plane radiance files) are equivalent to NEON L1 data products. The derived data products (Direct Sun Products, Radiance Products, and Derived Inversion Products) are subproducts within a single NEON Level 2 data product. The mapping between AERONET and NEON products is shown graphically in Figure 1.

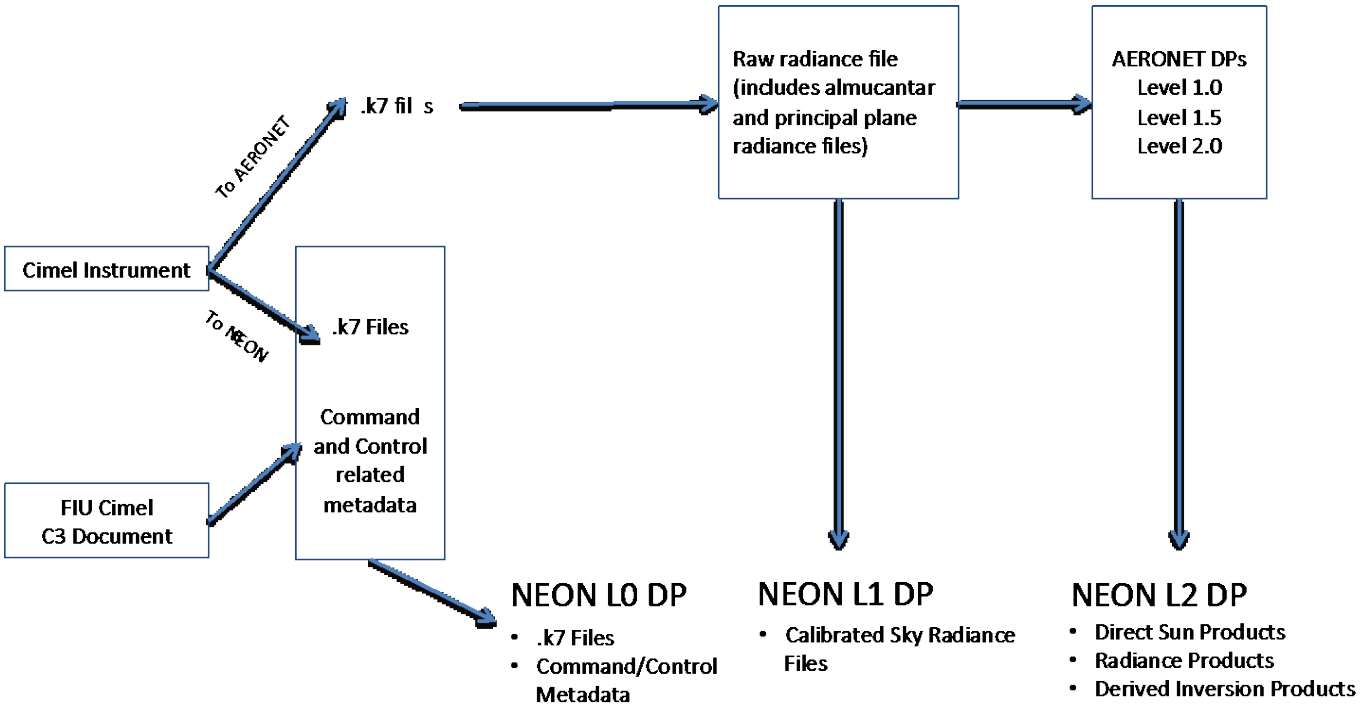

Figure 1 A diagram to show the relationship between AERONET data products and NEON data products

1.1 Purpose

This document establishes the specifications for the interface between AERONET and the NEON Cyber-Infrastructure (CI) group, specifically for the ingest and distribution of Spectral Sun Photometer Data Products derived from the NEON Cimel sun photometers. This document includes a brief discussion of measurement theory. However, because the data will be processed by AERONET and provided to NEON, and no further data processing will be done at NEON, this document will not include algorithm implementation, theoretical background, data product provenance, quality assurance and control methods. Uncertainty values will be calculated by AERONET and provided as available.

1.2 Scope

NEON L1 and corresponding AERONET data products are listed in this document, but no algorithmic process for data conversion, computation, derivation, QAQC will be described in this document. Theory of measurement is provided, and the numbers of sensor deployed at each site are also specified in this document. The spectral photometer used at the NEON sites is Cimel CE-318N with 1020-870-675-440-936-500-340-380 nm filters.

Data products developed by AERONET will be “pushed” to NEON per the Cooperative Services Agreement Between The National Ecological Observatory Network, INC. and NASA AERONET.

2 RELATED DOCUMENTS AND ACRONYMS

2.1 Applicable Documents

AD[01]	NEON.DOC.000001	NEON Observatory Design
AD[02]	NEON.DOC.005003	NEON Scientific Data Products Catalog
AD[03]	NEON.DOC.002652	NEON Level 1-3 Data Products Catalog
AD[04]	NEON.DOC.005005	NEON Level 0 Data Products Catalog

2.2 Reference Documents

RD[01]	NEON.DOC.000008	NEON Acronym List
RD[02]	NEON.DOC.000243	NEON Glossary of Terms
RD[03]	Nonreimbursible Space Act Agreement between National Aeronautics and Space Administration, NASA AERONET & National Ecological Observatory Network	

2.3 Acronyms

Acronym	Explanation
ATBD	Algorithm Theoretical Basis Document
CVAL	NEON Calibration, Validation, and Audit Laboratory
DAS	Data Acquisition System
DP	Data Product
GRAPE	Grouped Remote Analog Peripheral Equipment
L0	Level 0
L1	Level 1
L2	Level 2
AERONET	**AE**rosol **RO**botic **NET**work
AOD	Aerosol Optical Depth
AOT	Aerosol Optical Thickness

3 DEFINITIONS

3.1 AERONET

The AERONET (AErosol RObotic NETwork) is a network of ground-based sun photometers that measure atmospheric aerosol properties. The measurement system is a solar-powered CIMEL Electronique 318A spectral radiometer that measures sun and sky radiances at a number of fixed wavelengths within the visible and near-infrared spectrum. AERONET provides continuous cloud-screened observations of spectral aerosol optical depth (AOD), precipitable water, and inversion aerosol products in diverse aerosol regimes. Inversion products are retrieved from almucantar scans of radiance as a function of scattering angle and include products such as aerosol volume size distribution, aerosol complex refractive index, optical absorption (single scattering albedo) and the aerosol scattering phase function. All these products represent an average of the total aerosol column within the atmosphere.

The aerosol properties are retrieved via an inversion algorithm developed by Dubovik and King (2000). Further algorithms were developed, for example, by Dubovik et al. (2006) to take into account non-spherical shapes of aerosol particles such as mineral dust.

AERONET is an observing system in the NOAA Observing System Architecture. For further information on AERONET, the reader is referred to Holben et. al., 1998.

3.2 CI

The NEON Cyber-Infrastructure (CI) provides the core hardware and software infrastructure for data management, processing, archiving and distribution of NEON data.

4 INTERFACE DESCRIPTION

The interface between AERONET and CI is comprised of the following:

- Data Product files
- Data transfer
- Message passing
- Timing and event sequencing

5 INTERFACE REQUIREMENTS

The AERONET-to-CI interface is defined by the data products to be transferred, the messages to confirm receipt of the data, and the relative timing or sequence of events necessary for the data transfer, and input to the CI processing workflow. It is assumed that CI will provide the necessary hardware for data ingest, processing, archiving and distribution of the data.

5.1 Data Product Files

The raw data generated by the Cimel spectral photometer are exported in files with the extension of .K7. A copy of these .K7 raw files will be backed up at NEON, and another copy will be transmitted to AERONET. Before NEON is capable of processing data using international recognized standards (e.g., AERONET methodology), all NEON data will be processed by AERONET into NEON Level 1 and Level 4 Data Products. Processing levels from AERONET mapped to NEON are shown in the table below:

Table 5-1 Mapping of AERONET Raw, Calibrated, and Derived data products to the NEON Processing Levels.

AERONET Level	Description	NEON Level	Desription
Raw Data (.K7 files)	Raw files as downloaded from the Cimel instruments	Level 0	Raw, uncalibrated data, generally from a single measurement stream; data are still in machine units (e.g. DN); includes NEON command and control metadata
Calibrated Sky Radiance	Calibration applied to almucantar scenario data in .K7 files to generate Almucantar Sky Radiance; and calibration also applied to principal planes scenario data in .K7 files to generate Principal Plane Sky Radiance	Level 1	Calibrated data products, generally from a single measurement stream (e.g. single sensor, single observation record type, etc.); data are processed to physical units
Level 1.0 (unscreened)	Unscreened data (no cloud screening applied) and may not have final calibration applied	Level 4	Derived data products, generally from a single measurement stream (e.g. single sensor, single observation record type, etc.) over a single instance; data are processed to biogeophysical units
Level 1.5 (cloud screened)	Automatically cloud cleared but may not have final calibration applied. These data are NOT quality assured		
Level 2.0 (Quality assured)	Pre- and post-field calibration applied, automatically cloud cleared and manually inspected		

AERONET raw radiance, level 1.0 and level 1.5 data are typically available a few hours after .k7 files are transmitted to AERONET. The AERONET Level 2.0 data are not available until the Cimel Spectral Sunphotometer is returned to AERONET for calibration and the post-calibration calibration coefficients are applied to data, and data quality assurance is completed. These steps typically occur a year after a Cimel spectral sunphotometer is deployed at site.

5.1.1 NEON L0 Data Products

NEON L0 Data Products will consist of individual .K7 files downloaded from each Cimel instrument, plus the NEON command and control metadata.

5.1.1.1 .K7 files

A .K7 file is originally an image of the inquired Cimel instrument memory. Its size is 32kb, exactly the size of the classical CIMEL Electronique instrument memory. The new extensions permit the file size to exceed 32kb, and the .K7 files produced by ASTPWin may be larger than 32kb.

The .K7 files from a specific site will be recorded by CI for backup as a single image file.

There is currently no plan on publishing these .K7 files on data web portal, but will be available to science community upon request.

NEON has agreed to not collect any command and control data as L0 DPs. Therefore, there are no L0 DPs from instrument command and control.

5.1.2 NEON L1 Data Products

5.1.2.1 Calibrated Sky radiance data from AERONET

Calibrated sky radiance data products from AERONET include Almucantar Sky Radiance and Principal Plane Sky Radiance; these data products are equivalent to the NEON L1 Calibrated Sky Radiance Products, which are displayed in the accompanying datapub_NEONDOC001455_1minute.csv

The corresponding data files will be received from AERONET as separate files (*.alm and *.ppl) via a *push* process, and be ingested by CI as two distinct files, maintaining the formats described below.

Table 5-2 AERONET Raw Almucantars file format; Example file is included with ICD (130601_130630_NEON-CPER.alm)

Header	Description	Units	Format	Notes/examples
Comment	Description of level of processing at AERONET	Text	String	
Location	Descriptor used on AERONET site to link data	Text	string	
long	Longitude of mounted instrument	decimal	numeric	
lat	Latitude of mounted instrument	decimal	numeric	
elev	Elevation of mounted instrument	Meters	numeric	
Nmeas	Number of measurements collected	integer	numeric	
PI	Principal Investigator	Text	String	Default is “Brent Holben”
Email	Contact email of PI	Text	String	Default is “brent@aeronet.gsfc.nasa.gov”
Data Type	Description of type of data included	Text	String	Radiance - Almucantars
Data Points	All points, or description of binning (if used)	Text	String	All Points
Units	Description of units, in	radiance	numeric	µW/cm^2/sr/nm

	radiance			
Data	**Description**	**Units**	**Format**	**Example**
Date (dd:mm:yyyy)	Day, month, and year data were collected	Date	Numeric	25:06:2013
Time (hh:mm:ss)	Time data were collected	Time	Numeric	16:03:19
Wavelength (um)	Wavelength at which the data were collected	microns	Numeric	0.8711
SolarZenithAngle(degrees)	Solar Zenith Angle at which the data were collected	degrees	Numeric	41.05056
Radiance at N Degree	Measured radiance at a specific angular view	radiance	Numeric	µW/cm^2/sr/nm
….76 more columns of Radiance data/Degree	Measured radiance at a specific angular view	radiance	Numeric	µW/cm^2/sr/nm

Table 5-3 AERONET Principal Plane file format; Example file is included with ICD (130601_130630_NEON-CPER.alm)

Header	Description	Units	Format	Notes/examples
Comment	Description of level of processing at AERONET	Text	String	
Location	Descriptor used on AERONET site to link data	Text	string	
long	Longitude of mounted instrument	decimal	numeric	
lat	Latitude of mounted instrument	decimal	numeric	
elev	Elevation of mounted instrument	Meters	numeric	
Nmeas	Number of measurements collected	integer	numeric	
PI	Principal Investigator	Text	String	Default is “Brent Holben”
Email	Contact email of PI	Text	String	Default is “brent@aeronet.gsfc.nasa.gov”
Data Type	Description of type of data included	Text	String	Radiance - Almucantars
Data Points	All points, or description of binning (if used)	Text	String	All Points
Units	Description of units, in	radiance	numeric	µW/cm^2/sr/nm

	radiance			
Data	**Description**	**Units**	**Format**	**Example**
Date (dd:mm:yyyy)	Day, month, and year data were collected	Date	Numeric	25:06:2013
Time (hh:mm:ss)	Time data were collected	Time	Numeric	16:03:19
Wavelength (um)	Wavelength at which the data were collected	microns	Numeric	0.8711
SolarZenithAngle(degrees)	Solar Zenith Angle at which the data were collected	degrees	Numeric	41.05056
Radiance at N Degree	Measured radiance at a specific principal plane, defined by degrees	radiance	Numeric	µW/cm^2/sr/nm
….39 more columns of Radiance data/Degree	Measured radiance at a specific angular view, defined by degrees	radiance	Numeric	µW/cm^2/sr/nm

NEON L1 DP is equivalent to AERONET level 1.5 data products, which include AERONET version 2 level 1.5 direct sun measurement data products and version 2 level 1.5 inversion data products. AERONET version 2 level 1.5 direct sun measurement data products (Table 5-2) are approximately in 15 min intervals. Version 2 level 1.5 inversion data products (Table 5-3) are hourly data.

5.2 Product Instances

Cimel Spectral Photometer will be deployed at 20 core and 21 Relocatable tower sites. Cimel Spectral Photometer will be located on the top of tower above top rail at the southeast most corner.

Table 5-4 Number of spectral photometer that will be deployed at NEON sites

Domain	SiteName	Site Type	Cimel quantity
1	Harvard Forest	Core	1
1	Bartlett Experimental Forest	Relocatable	1
1	Plum Island Suburban- Burlington, MA	Relocatable	0
2	SCBI	Core	1
2	Blandy Experimental Farm	Relocatable	0
2	Smithsonian Environmental Research Center	Relocatable	1
3	Ordway-Swisher Biological Station	Core	1
3	Disney Wilderness Preserve	Relocatable	1
3	Jones Ecological Research Center	Relocatable	0

4	Guanica Forest	Core	1
4	Lajas Experimental Station	Relocatable	0
4	Ponce Metro	Relocatable	1
5	UNDERC	Core	1
5	Steigerwald Land Services	Relocatable	0
5	Tree Haven	Relocatable	0
6	Konza Prairie Biological Station	Core	1
6	Konza Prairie Biological Station (Agricultural Lowland)	Relocatable	0
6	The University of Kansas Field Station	Relocatable	1
7	Oak Ridge	Core	1
7	Great Smoky Mountains National Park, Twin Creeks	Relocatable	1
7	Mountain Lake Biological Station (SW Virginia)	Relocatable	1
8	Talladega National Forest	Core	1
8	Deadlake	Relocatable	0
8	Lenoir Landing	Relocatable	1
9	Woodworth	Core	1
9	Dakota Coteau Field School	Relocatable	0
9	Northern Great Plains Research Laboratory	Relocatable	1
10	Central Plains Experimental Range	Core	1
10	North Sterling, CO	Relocatable	1
10	RMNP, CASTNET	Relocatable	1
11	Caddo/LBJ	Core	1
11	Klemme Range Research Station	Relocatable	1
11	University of Oklahoma Biological Station	Relocatable	0
12	Yellowstone Northern Range (Frog Rock)	Core	1
12	Bozeman, MT (MOR)	Relocatable	1
12	Paradise valley, MT	Relocatable	0
13	Niwot Ridge/Mountain Research Station	Core	1
13	Moab, Canyonlands Ecological Research Site	Relocatable	1
13	Winter park	Relocatable	1
14	Santa Rita Experimental Range	Core	1
14	CAP LTER Urban	Relocatable	1
14	Jornada LTER	Relocatable	0
15	Onaqui-Ault	Core	1
15	Murray Tower (Urban)	Relocatable	1
15	Red Butte Canyon (Low Elevation-Urban Influence)	Relocatable	0
16	Wind River Experimental Forest	Core	1
16	Abby road	Relocatable	0

16	Thayer	Relocatable	0
17	San Joaquin	Core	1
17	Soaproot Saddle	Relocatable	0
17	Lower Teakettle	Relocatable	1
18	Toolik Lake	Core	1
18	Barrow	Relocatable	1
19	Caribou Creek (CPCRW)	Core	1
19	Poker flats	Relocatable	0
19	Eight Mile Lake (Healy Alaska)	Relocatable	1
19	Delta Junction, Non-permafrost	Relocatable	1
20	Olaa	Core	1
20	PuuWaaWaa-forest	Relocatable	0
20	PuuWaaWaa-grassland	Relocatable	0

5.3 Temporal Resolution and Extent

For the NEON L0 DPs, direct sun measurements are made typically at 15 minute intervals. NEON L1 DPs will be reported on a one-hour basis.

5.4 Spatial Resolution and Extent

Only 1 Cimel Spectral Sun Photometer will be deployed at a selected site on the top of tower. A total of 41 TIS sites were selected and will be outfitted with sun photometers. In addition, a Cimel Spectral Sun Photometer may be deployed to support AOP engineering flights. Those data will be processed and made available to the community on an ad hoc basis.

6 SCIENTIFIC CONTEXT

Radiation measurements provide a key variable into prognostic models that enable understanding and forecasting of the impacts of climate change, land use change and invasive species on continental-scale ecology. The CE-318N photometer measures the optical properties of the atmosphere and provides quantification and physical-optical characterization of the aerosols. The key applications include:

- Characterization and quantification of aerosols
- Satellite calibration of aerosol measurements
- Detection of volcanic ashes plumes in real time
- Determination of particle grain size
- Determination of the optical properties of the atmosphere for satellite imaging
- Determination of the ocean's color
- Determination of the amount of precipitable water

- Air quality monitoring

At NEON, measurements of the radiative transfer through the boundary layer using a Cimel spectral photometer enable us to understand how climate (change), dust generation and transport, land use, and pollution interact with ecosystem productivity, local-to-regional energy balance, and organismal health. Measurements of radiative transfer also provide connectivity to the AOP measurements by anchoring the boundary-layer attenuation of radiation, and are used to parameterize AOP measurements and needed constraints for the spatial extrapolation of satellite based data (outside sources of NEON).

6.1 Theory of Measurement

The NEON Cimel spectral photometer is model CE-318N. It carries out sun and sky radiance measurements on several bands (with filters for the 1020, 870, 675, 440, 936, 500, 340, and 380 nm wavelengths with the 1.6 µm spectral channel, but without polarized channels). A sensor head fitted with 25 cm collimators is attached to a 40 cm robot base which systematically points the sensor head at the sun according to a preprogrammed routine. The robot mounted sensor head is parked and pointed near-nadir when idle to prevent deterioration of the optical windows from rain and foreign particles.

The information below is extracted from the AERONET website and Holben *et al.* 1998.

Cimel makes two basic measurements, either direct sun or sky, both within several programmed sequences. The direct sun measurements are made in eight spectral bands requiring approximately 10 seconds for each measurement. Eight interference filters at wavelengths of 340, 380, 440, 500, 670, 870, 940 and 1020 nm are located in a filter wheel which is rotated by a direct drive stepping motor. The 940 nm channel is used for column water abundance determination. A preprogrammed sequence of measurements is taken by these instruments starting at an air mass of 7 in the morning and ending at an air mass of 7 in the evening. Optical depth is calculated from the spectral extinction of direct beam radiation at each wavelength based on the Beer-Bouguer Law. Attenuation due to Rayleigh scattering, and absorption by ozone and gaseous pollutants is estimated and removed to isolate the aerosol optical depth (AOD). A sequence of three such measurements is taken 30 seconds apart creating a triplet observation per wavelength. During the large air mass periods direct sun measurements are made at 0.25 air mass intervals, while at smaller air masses the interval between measurements is typically 15 minutes. The time variation of clouds is usually greater than that of aerosols causing an observable variation in the triplets that can be used to screen clouds in many cases. Additionally the 15-minute interval allows a longer temporal frequency check for cloud contamination.

In addition to the direct solar irradiance measurements that are made with a field of view of 1.2 degrees, these instruments measure the sky radiance in four spectral bands (440, 670, 870 and 1020 nm) along the solar principal plane (i.e., at constant azimuth angle, with varied scattering angles) up to nine times a day and along the solar almucantar (i.e., at constant elevation angle, with varied azimuth angles) up to six times a day. The approach is to acquire aureole and sky radiances observations through a large range

of scattering angles from the sun through a constant aerosol profile to retrieve size distribution, phase function and aerosol optical depth. More than eight almucantar sequences are made daily at an optical air mass of 4, 3, 2 and 1.7 both morning and afternoon. Sky radiance measurements are inverted with the Dubovik (Dubovik et al., 2000) and Nakajima inversions (Nakajima et al. 1996) to provide aerosol properties of size distribution and phase function over the particle size range of 0.1 to 5 um.

6.2 Theory of Algorithm

Some theory of algorithms for the AERONET raw radiance data, level 1.0 and level 1.5 data products can be found at AERONET website, e.g.,
http://aeronet.gsfc.nasa.gov/new_web/Documents/version2_table.pdf
http://aeronet.gsfc.nasa.gov/new_web/Documents/Cloud_scr.pdf
http://aeronet.gsfc.nasa.gov/new_web/PDF/tauf_tauc_technical_memo.pdf
http://aeronet.gsfc.nasa.gov/new_web/Documents/Inversion_products_V2.pdf
http://aeronet.gsfc.nasa.gov/new_web/Documents/AERONETcriteria_final1_excerpt.pdf
http://aeronet.gsfc.nasa.gov/new_web/PDF/AERONETcriteria_final1.pdf

7 Algorithm implementation

NEON L0 and L1 data products will be provided to NEON (the exact format is pending a mutual agreement between NEON CI and AERONET). Data computation, conversion, testing and QA/QC have been implemented by AERONET. No additional data processing and analysis will be done at NEON; therefore, no detailed procedures of algorithm implementation will be included in this document.

8 Uncertainty

As with the above processing algorithms, all uncertainty values will be calculated by AERONET and provided as available.

9 Future plans and modifications

Before NEON is capable of processing data using international recognized standards, NEON data will be processed by AERONET. NEON is planning to train its staff to learn the data processing algorithms, procedures, calibration, software, etc. with guidance from AERONET. The goal is to eventually process spectral photometer data in house at NEON. The MOU to facilitate this collaboration is under development (RD[03]).

10 Bibliography

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Nakajima, T., Tonna, G., Rao, R., Boi, P., Kaufman, Y. 1996: *Use of sky brightness measurements from ground for remote sensing of particulate polydispersions.* **Appl. Opt. 35, 15,2672–2686**

O'Neill, N.T., T.F.Eck, , A.Smirnov, B.N.Holben, and S.Thulasiraman, *Spectral discrimination of coarse and fine mode optical depth*, **J. Geophys. Res., 108(D17), 4559**, doi:10.1029/2002JD002975, 2003.

Recent changes to the coarse/fine mode optical depth deconvolution algorithm, June 2005. (PDF) | (TXT)

11 Changelog

None.

12 APPENDIX A

The data description and units of AERONET data products are described below.

12.1 Direct sun measurement data products

12.1.1 Data description

Information source is from http://aeronet.gsfc.nasa.gov/new_web/data_description_AOD_V2.html .

TIME FORMAT

- All times are provided as Greenwich Mean Time (GMT) for the solar day.
- All averages are calculated using the GMT solar day.
- The GMT solar day may overlap two calendar days for some AERONET sites.
- "Day" is defined as the GMT solar day.

DATA FORMAT

Data Format	Description
All Points	These data are available for each measurement or retrieval moment.

Note: NEON only archive “all points”, which can be used to derive daily and monthly average in the future as needed.

DATA TYPES

Data Type	Description
Aerosol Optical Depth (AOD)	- includes the aerosol optical depth as well as derived products such as precipitable water and Angstrom parameter
Level 1.0 AOD (Unscreened)	Unscreened and may not have final calibration applied
Level 1.5 AOD (Cloud Screened)	Automatically cloud cleared but may not have final calibration applied. These data are NOT quality assured.
Level 2.0 AOD (Quality Assured)	Pre- and post-field calibration applied, automatically cloud cleared and manually inspected
Precipitable Water	The total water vapor in the column derived from the 935nm channel.
Percent Triplet Variability	Each AOD measurement is comprised of a triplet measurement: These measurements are taken every 30 seconds for one minute. The variability of this measurement can provide insight on the quality of the data.
Angstrom Parameter	The angstrom parameter is calculated for all available wavelengths within the Angstrom parameter range. For example, the Angstrom 870-440nm includes the 870, 670, 500 and 440 nm AOD data. A special case for a polarized instrument is Angstrom 870-440nm which only includes 870, 670 and 440 nm AOD data (polarized instruments do not have 500nm channel).
Instrument Information	

Exact Wavelength	The exact filter wavelength is used to determine AOD and other parameters.
Raw Data	- includes radiance data measured using the almucantar and principal plane scenarios
Almucantar Sky Radiance	Calibration applied to almucantar scenario data (See Page 30 of the Cimel Sun Photometer User Manual for more information on almucantars)
Principal Plane Sky Radiance	Calibration applied to principal planes scenario data (See Page (See Page 31 of the Cimel Sun Photometer User Manual for more information on almucantars)
Polar Principal Plane Sky Radiance	Calibration applied to polarized principal planes scenario data (See Page 31 of the Cimel Sun Photometer User Manual for more information on almucantars)
Sky and Surface Radiance for Bidirectional Reflectance Distribution Function (BRDF)	Calibration applied to BRDF scenario data
Total Optical Depth	- includes the total optical depth and other components such as ozone, NO2 and Rayleigh optical depths.
Level 1.0 (Unscreened)	Unscreened and may not have final calibration applied
Level 1.5 (Cloud Screened)	Automatically cloud cleared but may not have final calibration applied. These data are NOT quality assured.
Level 2.0 (Quality Assured)	Pre- and post-field calibration applied, automatically cloud cleared and manually inspected
AERONET-SDA Retrievals	- includes the fine and coarse mode aerosol optical depth as well as the fine mode fraction.
Level 1.0 SDA (Unscreened)	Utilizes AERONET AOD, which is unscreened and may not have final calibration applied
Level 1.5 SDA (Cloud Screened)	Utilizes AERONET AOD, which is automatically cloud cleared but may not have final calibration applied. These data are NOT quality assured. In addition, the following criteria must be met for SDA retrievals: 1. At least three wavelength combinations must include 440 and 870nm with

	either 490, 500 or 675nm. 2. The AOD for each channel must be greater than or equal to 0.02/m, where m is the optical air mass. 3. Outliers are removed according to the following criterion: $Abs(AOD_{500nm}-AOD_{SDA500nm})>(0.02+AOD_{500nm}*0.005)$ AERONET-MAN (microtops instrument) implements the following additional criterion: 4. If within the series any tau_fine or tau_coarse is beyond tau_mean plus/minus 2*stdev for the series we eliminate this measurement.
Level 2.0 SDA (Quality Assured)	Utilizes AERONET AOD, which is pre- and post-field calibration applied, automatically cloud cleared and manually inspected. In addition, the following criteria must be met for SDA retrievals: 1. At least four wavelengths must be included for input. The spectral range must be bounded by 380 and 870nm with at least two additional wavlengths between the bounds (e.g., 440, 500, 675nm). The three channel combination of 380, 500, and 870nm will also be accepted. 2. The AOD for each channel must be greater than or equal to 0.02/m, where m is the optical air mass. 3. Outliers are removed according to the following criterion: $Abs(AOD_{500nm}-AOD_{SDA500nm})>(0.01+AOD_{500nm}*0.005)$ AERONET-MAN (microtops instrument) implements the following additional criterion: 4. If within the series any tau_fine or tau_coarse is beyond tau_mean plus/minus 2*stdev for the series we eliminate this measurement.
Total Mode AOD 500nm [tau_a]	AOD at 500nm computed using a best-fit second order polynomial (SDA output)
Fine Mode AOD 500nm	Fine mode AOD at 500nm (SDA output)

[tau_f]	
Coarse Mode AOD 500nm [tau_c]	Coarse mode AOD at 500nm (SDA output)
Fine Mode Fraction 500nm [eta]	Fine mode fraction at 500nm (SDA output)
2nd Order Reg Fit Error - Total AOD 500nm [regression_tau_a]	Regression error in Total AOD 500nm (SDA output)
RMSE Fine Mode AOD 500nm [Dtau_f]	Estimated error in Fine Mode AOD 500nm (SDA output derived from the estimated AOD accuracy)
RMSE Coarse Mode AOD 500nm [Dtau_c]	Estimated error in Coarse Mode AOD 500nm (SDA output derived from the estimated AOD accuracy)
RMSE Fine Mode Fraction 500nm [Deta]	Estimated error in Fine Mode Fraction 500nm (SDA output derived from the estimated AOD accuracy)
Angstrom Exponent - Total 500nm [alpha]	Angstrom exponent at 500nm (SDA output of {-d ln (AOD) / d ln(wavelength)} at 500nm)
dAE/dln(wavelength)-Total 500nm[alphap]	Spectral derivative of the Angstrom exponent at 500nm (SDA output)
AE-Fine Mode 500nm [alpha_f]	Angstrom exponent of the fine mode AOD at 500nm (SDA output)
dAE/dln(wavlength)-Fine Mode 500nm[alphap_f]	Spectral derivative of the fine mode Angstrom exponent at 500nm (SDA output)
870nm Input AOD, etc.	Input AOD (to the SDA retrieval) at 870nm, etc.

12.1.2 Data unit

Information source is from http://aeronet.gsfc.nasa.gov/new_web/units.html

Data Type	Column Header	Column Header Units	Data Units
Data Products			
Direct Sun Measurements			
Aerosol Optical Depth (AOD) Levels 1.0, 1.5, and 2.0	AOT_(wavelength)	wavelength in nm	None
%TripletVar is the AOD "triplet variability" multiplied by 100.	%TripletVar_(wavelength)	wavelength in nm	None
Angstrom Parameter	(AOD1)-(AOD2)Angstrom	wavelength range in nm	None
Water Vapor	Water(cm)	wavelength at 940 nm	cm^3/cm^2 or g/cm^2
Spectral Deconvolution Algorithm Output (SDA) from Direct Sun Measurements			
Total AOD 500nm	Total_AOD_500nm[tau_a]	wavelength in nm	None
Fine Mode AOD 500nm	Fine_Mode_AOD_500nm[tau_f]	wavelength in nm	None
Coarse Mode AOD 500nm	Coarse_Mode_AOD_500nm[tau_c]	wavelength in nm	None
2nd Order Reg Fit Error - Total AOD 500nm (SDA	2nd_Order_Reg_Fit_Error-Total_AOD_500nm[regression_dtau_a]	wavelength in nm	None
RMSE Fine Mode AOD 500nm	RMSE_Fine_Mode_AOD_500nm[Dtau_f]	wavelength in nm	None
RMSE Coarse Mode AOD 500nm	RMSE_Coarse_Mode_AOD_500nm[Dtau_c]	wavelength in nm	None
RMSE Fine Mode Fraction 500nm	RMSE_FineModeFraction_500nm[Deta]	wavelength in nm	None
Angstrom Exponent - Total 500nm	Angstrom_Exponent(AE)-Total_500nm[alpha]	wavelength in nm	None
dAE/dln(wavelength)-Total 500nm	dAE/dln(wavelength)-Total_500nm[alphap]	wavelength in nm	None
Angstrom Exponent-Fine Mode 500nm	AE-Fine_Mode_500nm[alpha_f]	wavelength in nm	None
dAE/dln(wavelength)-Fine Mode 500nm	dAE/dln(wavelength)-Fine_Mode_500nm[alphap_f]	wavelength in nm	None
Input AOD to SDA	(wavelength)_Input_AOD	wavelength in nm	None
Sky Radiance Measurements			
Almucantars (Sky Radiance)	(azimuth angle)	degrees	µW/cm^2/sr/nm
Principal Planes (Sky Radiance)	(scattering angle)	degrees	µW/cm^2/sr/nm

	from -6 to 6 uses sun collimator from 6 to 150 uses sky collimator		
Polar Principal Planes(Sky Radiance)	(zenith angle)P(polarized channel number)	degrees	µW/cm^2/sr/nm
Degree of Polarization	(zenith angle)[degofpol]	degrees	None
Sky and Surface Radiance for BRDF	(scattering angle)(SAZ=(solar azimuth angle)	degrees, degrees	µW/cm^2/sr/nm
Cloud Mode Radiance	zenith	0 degrees	µW/cm^2/sr/nm
Aerosol Inversion Retrievals from Sky Radiance Measurements			
SKYRAD.PAK	(center of size bin) logarithmic scale	µm^3/µm^2	10^5 * µm^3/µm^2
Size Distribution dV(r)/dln r	(center of size bin) logarithmic scale	µm^3/µm^2	µm^3/µm^2
Single Scattering Albedo	SSA(wavelength)	wavelength in nm	None
Refractive Index (real part)	REFR(wavelength)	wavelength in nm	None
Refractive Index (imaginary part)	REFI(wavelength)	wavelength in nm	None
Volume Concentration	VolCon	None	µm^3/µm^2
Effective Radius	EffRad	None	µm
Volume Median Radius	VolMedianRad	None	None
Standard Deviation	StdDev	None	None
AOD Coincident	AOT_(wavelength)	wavelength in nm	None
AOD Extinction	AOTExt(wavelength)	wavelength in nm	None
AOD Absorption	AOTAbsp(wavelength)	wavelength in nm	None
Phase Functions	(scattering angle)[wavelength]	degrees, nm	None
Asymmetry Factor	ASYM(wavelength)	wavelength in nm	None
Broadband Flux	Downward/Upward at BOA and TOA	wavelength in nm	W/m^2
Spectral Flux	Downward/Upward/Diffuse	wavelength in nm	W/m^2
Radiative Forcing	At BOA and TOA	wavelength in nm	W/m^2
Radiative Forcing Efficiency	At BOA and TOA	wavelength in nm	W/m^2
Other Data and Parameters			

Date/Time	Date, Time	None	GMT Solar Day/GMT Time
N (Number of Measurements for Average)	N[]	None	None
Altitude	Altitude	None	km
Solar Zenith Angle for 1020nm Channel (average between left and right almucantars)	solar_zenith_angle_for_1020nm _scan	None	Degrees
Average Solar Zenith Angle for Broadband Flux Calculation	average_solar_zenith_angle_for_ flux_calculation	None	Degrees
Julian Day	Julian_Day	None	Days
Size Index, Num of Angles	siz_index,num_of_angles	None	None
Alm_type (Data level identifier)	alm_type	None	None
Sky Error, Sun Error	sky_error	None	%
AOD at 440 nm	tau440(measured)	None	None
Spectral Albedo	Albedo_ Wavelength	wavelength in nm	None
Sphericity Parameter	Sphericity Parameter	None	%
Optical Air Mass	Air_Mass	None	None
Exact Wavelength of Instrument Filter	AOT_(wavelength) Exact Wavelength	wavelength in nm	µm

Key:

cm = centimeter (10E-2 m) ; µm = micrometer (10E-6 m); nm = nanometer (10E-9 m);
µW = microwatt (10E-6 W); mV = millivolts (10E-3 V)

T - Total data mode
C - Coarse data mode
F - Fine data mode

sr = steradian
% = percent

BOA - bottom of the atmosphere
TOA - top of the atmosphere

12.2 Inversion data products

12.2.1 Data description

Information source http://aeronet.gsfc.nasa.gov/new_web/data_description_INV_V2.html

TIME FORMAT

- All times are provided as Greenwich Mean Time (GMT) for the solar day.
- All averages are calculated using the GMT solar day.
- The GMT solar day may overlap two calendar days for some AERONET sites.
- "Day" is defined as the GMT solar day.

DATA FORMAT

Data Format	Description
All Points	These data are available for each measurement or retrieval moment.

Note: NEON only archive “all points”, which can be used to derived daily and monthly average in the future as need.

DATA TYPES

Data Type	Description
Raw Data	- includes radiance data measured using the almucantar and principle plane scenarios
Almucantar Sky Radiance	Calibration applied to almucantar scenario data (See Page 30 of the Cimel Sun Photometer User Manual for more information on almucantars)
Principal Plane Sky Radiance	Calibration applied to principal planes scenario data (See Page (See Page 31 of the Cimel Sun Photometer User Manual for more information on almucantars)
Polar Principal Plane Sky Radiance	Calibration applied to polarized principal planes scenario data (See Page 31 of the Cimel Sun Photometer User Manual for more information on almucantars)
Sky and Surface Radiance for Bidirectional Reflectance Distribution Function (BRDF)	Calibration applied to BRDF scenario data
Version 2 Inversion	**Almucantars and Principal Planes**

Products	
Size Distribution	Volume particle size distribution is retrieved logarithmically equidistant bins from 0.05um to 15um.
Refractive Index	The real refractive index (n from 1.33 to 1.6) and the imaginary part (k from 0.0005 to 0.5) is retrieved for wavelengths corresponding to sky radiance measurements.
Single Scattering Albedo	Single scattering albedo (SSA) is retrieved for wavelengths corresponding to sky radiance measurements. Fine and coarse modes are not provided due to the assumption of the retrieval to use the same complex index of refraction for all particle sizes.
AOD Coincident	The coincident aerosol optical depth (AOD) is calculated by averaging the level 1.5 or 2.0 AOD data values (Level 2.0 has priority) +/- 16 minutes of the almucantar retrieval time (typically uses three to five AOD points for the coincident average).
Volume/Particle Parameters	The aerosol volume/particle parameters include the volume concentration, volume median radius, effective radius, and standard deviation (total, fine and coarse modes).
AOD Extinction	The derived extinction aerosol optical depth (AOD) values from the inversion include total, fine and coarse modes.
Phase Function	Phase function is retrieved at 83 scattering angles at wavelengths corresponding to sky radiance measurements (total, fine and coarse modes).
Asymmetry Factor	The asymmetry factor is an integrated value of the phase functions (total, fine and coarse modes) where positive values indicate scattering in the forward direction.
AOD Absorption	Equation: (1-SSA)*AOD (where AOD is AOD Extinction) -- The single scattering albedo is used for each incidence of an almucantar retrieval. The AOD is calculated by adding the derived almucantar AOD fine and coarse modes. AOD absorption is calculated for the following channels: 1020,870,670 and 440 nm.(total, fine and coarse modes)
Combined Retrievals	Combination of all Dubovik Almucantar Retrievals except phase functions.
Sphericity Parameter	The percent of spherical aerosol particles in the retrieval. This parameter should not be used for fine mode particles where Angstrom Parameter 870-440 > 1.2 and the aerosol optical depth is less than 0.1.
Total Errors	The total errors include the random, systematic, and bias. These errors are available for each data point. Total errors are available for size distribution, complex index of refraction,

	extinction aerosol optical depth, single scattering albedo, and phase functions.
Version 2 Retrieval Settings	
Level 1.5	Determined using Level 1.5 (2.0 if available) AOD data No additional screening
Level 2.0 - (Recommended default options)	Determined using Level 2.0 AOD; solar zenith angle greater than 50 degrees; number of angles is greater than 20; Sky error < 5% Spectral sky error <5% Max A&K ratio (|sun-sky|/sun) radiance < 0.05 Show Sphericity Parameter if 870-440nm Angstrom Parameter <1.2 AND AOD at 440nm > 0.1
Version 2 Retrieval Filters	
Angles (No.)	Number of symmetric angles available from the almucantar
Missing Consecutive Angles	The number of missing consecutive angles may not be greater than 2.
Solar Zenith Angles (Degrees)	Minimum and maximum solar zenith angle range in degrees
Sky Error (%) and Spectral Sky Error (%)	The sky radiance error computed from fitting radiance to expected profile.
A_K Ratio	The absolute difference between the sun radiance measured (A) and sky radiance measured (K) divided by the sun radiance (measured with sky detector). A_K_Ratio = |A-K|/A

12.2.2 Data units

Data Type	Column Header	Column Header Units	Data Units
Data Products			
Direct Sun Measurements			
Aerosol Optical Depth (AOD) Levels 1.0, 1.5, and 2.0	AOT_(wavelength)	wavelength in nm	None
%TripletVar is the AOD "triplet variability" multiplied by 100.	%TripletVar_(wavelength)	wavelength in nm	None
Angstrom Parameter	(AOD1)-(AOD2)Angstrom	wavelength range in nm	None
Water Vapor	Water(cm)	wavelength at 940 nm	cm^3/cm^2 or g/cm^2
Spectral Deconvolution Algorithm Output (SDA) from Direct Sun Measurements			
Total AOD 500nm	Total_AOD_500nm[tau_a]	wavelength in nm	None
Fine Mode AOD 500nm	Fine_Mode_AOD_500nm[tau_f]	wavelength in nm	None
Coarse Mode AOD 500nm	Coarse_Mode_AOD_500nm[tau_c]	wavelength in nm	None
2nd Order Reg Fit Error - Total AOD 500nm (SDA	2nd_Order_Reg_Fit_Error-Total_AOD_500nm[regression_dtau_a]	wavelength in nm	None
RMSE Fine Mode AOD 500nm	RMSE_Fine_Mode_AOD_500nm[Dtau_f]	wavelength in nm	None
RMSE Coarse Mode AOD 500nm	RMSE_Coarse_Mode_AOD_500nm[Dtau_c]	wavelength in nm	None
RMSE Fine Mode Fraction 500nm	RMSE_FineModeFraction_500nm[Deta]	wavelength in nm	None
Angstrom Exponent - Total 500nm	Angstrom_Exponent(AE)-Total_500nm[alpha]	wavelength in nm	None
dAE/dln(wavelength)-Total 500nm	dAE/dln(wavelength)-Total_500nm[alphap]	wavelength in nm	None
Angstrom Exponent-Fine Mode 500nm	AE-Fine_Mode_500nm[alpha_f]	wavelength in nm	None
dAE/dln(wavelength)-Fine Mode 500nm	dAE/dln(wavelength)-Fine_Mode_500nm[alphap_f]	wavelength in nm	None
Input AOD to SDA	(wavelength)_Input_AOD	wavelength in nm	None
Sky Radiance Measurements			
Almucantars (Sky Radiance)	(azimuth angle)	degrees	µW/cm^2/sr/nm

Principal Planes (Sky Radiance)	(scattering angle) from -6 to 6 uses sun collimator from 6 to 150 uses sky collimator	degrees	µW/cm^2/sr/nm
Polar Principal Planes(Sky Radiance)	(zenith angle)P(polarized channel number)	degrees	µW/cm^2/sr/nm
Degree of Polarization	(zenith angle)[degofpol]	degrees	None
Sky and Surface Radiance for BRDF	(scattering angle)(SAZ=(solar azimuth angle)	degrees, degrees	µW/cm^2/sr/nm
Cloud Mode Radiance	zenith	0 degrees	µW/cm^2/sr/nm
Aerosol Inversion Retrievals from Sky Radiance Measurements			
SKYRAD.PAK	(center of size bin) logarithmic scale	µm^3/µm^2	10^5 * µm^3/µm^2
Size Distribution dV(r)/dln r	(center of size bin) logarithmic scale	µm^3/µm^2	µm^3/µm^2
Single Scattering Albedo	SSA(wavelength)	wavelength in nm	None
Refractive Index (real part)	REFR(wavelength)	wavelength in nm	None
Refractive Index (imaginary part)	REFI(wavelength)	wavelength in nm	None
Volume Concentration	VolCon	None	µm^3/µm^2
Effective Radius	EffRad	None	µm
Volume Median Radius	VolMedianRad	None	None
Standard Deviation	StdDev	None	None
AOD Coincident	AOT_(wavelength)	wavelength in nm	None
AOD Extinction	AOTExt(wavelength)	wavelength in nm	None
AOD Absorption	AOTAbsp(wavelength)	wavelength in nm	None
Phase Functions	(scattering angle)[wavelength]	degrees, nm	None
Asymmetry Factor	ASYM(wavelength)	wavelength in nm	None
Broadband Flux	Downward/Upward at BOA and TOA	wavelength in nm	W/m^2
Spectral Flux	Downward/Upward/Diffuse	wavelength in nm	W/m^2
Radiative Forcing	At BOA and TOA	wavelength in nm	W/m^2
Radiative Forcing Efficiency	At BOA and TOA	wavelength in	W/m^2

		nm	
Other Data and Parameters			
Date/Time	Date, Time	None	GMT Solar Day/GMT Time
N (Number of Measurements for Average)	N[]	None	None
Altitude	Altitude	None	km
Solar Zenith Angle for 1020nm Channel (average between left and right almucantars)	solar_zenith_angle_for_1020nm _scan	None	Degrees
Average Solar Zenith Angle for Broadband Flux Calculation	average_solar_zenith_angle_for_ flux_calculation	None	Degrees
Julian Day	Julian_Day	None	Days
Size Index, Num of Angles	siz_index,num_of_angles	None	None
Alm_type (Data level identifier)	alm_type	None	None
Sky Error, Sun Error	sky_error	None	%
AOD at 440 nm	tau440(measured)	None	None
Spectral Albedo	Albedo_ Wavelength	wavelength in nm	None
Sphericity Parameter	Sphericity Parameter	None	%
Optical Air Mass	Air_Mass	None	None
Exact Wavelength of Instrument Filter	AOT_(wavelength) Exact Wavelength	wavelength in nm	µm

Key:

cm = centimeter (10E-2 m); µm = micrometer (10E-6 m); nm = nanometer (10E-9 m);
µW = microwatt (10E-6 W); mV = millivolts (10E-3 V)

T - Total data mode
C - Coarse data mode
F - Fine data mode

sr = steradian
% = percent

BOA - bottom of the atmosphere
TOA - top of the atmosphere