CALIPSO Quality Statements
Lidar Level 3 Aerosol Profile Monthly Products
Version Release: 1.00

Introduction

This document provides a high level quality assessment of the CALIPSO lidar level 3 aerosol data product, a globally gridded monthly product derived from the CALIPSO lidar level 2 aerosol profile product, as described in section 2.10 of the CALIPSO Data Products Catalog (Version 3.4) (PDF). As such, it represents the minimum information needed by scientists and researchers for appropriate and successful use of these data products. We strongly suggest that all authors, researchers, and reviewers of research papers review this document periodically, and familiarize themselves with the latest status before publishing any scientific papers using these data products.

These data quality summaries are published specifically to inform users of the accuracy of CALIOP data products as determined by the CALIPSO Science Team and Lidar Science Working Group (LSWG). This document is intended to provide cautions in those areas where users might easily misinterpret the data; supply links to further information about the data products and the algorithms used to generate them; and offer information about planned algorithm revisions and data improvements.

Since level 3 data is produced by aggregating level 2 data, this document describes and assesses attributes specific to the level 3 product and how nuances in level 2 data manifest themselves in level 3 statistics. Users are advised to consult the Data Quality Summaries for the lidar level 2 aerosol profile and lidar level 2 cloud and aerosol layer products for detailed quality information of the inputs for level 3.

Data Product Maturity

The initial release of the CALIPSO lidar level 3 aerosol data product is considered beta, as defined below. Even though level 3 is an aggregate of level 2 data products which are at higher maturity levels, averaging can reveal artifacts not apparent in level 2 data. Additionally, the algorithms used for quality screening and re-binning are still considered beta. Thus, the maturity levels of all scientific level 3 data sets are uniformly classified as beta for this initial release.

Maturity Level Definitions

Beta:	Early release products for users to gain familiarity with data formats and parameters. Beta products have not been validated and contain both known and unknown artifacts. **Users are strongly cautioned against using these data products as the basis for research findings or journal publications.**
Provisional:	Limited comparisons with independent sources have been made and obvious artifacts fixed.
Validated Stage 1:	Uncertainties are estimated from independent measurements at selected locations and times.
Validated Stage 2:	Uncertainties are estimated from more widely distributed independent measurements.
Validated Stage 3:	Uncertainties are estimated from independent measurements representing global conditions.
External:	Data are not CALIPSO measurements, but instead are either obtained from external sources (e.g., the Global Modeling and Assimilation Office (GMAO)) or fixed constants in the CALIPSO retrieval algorithm (e.g., the 532 nm calibration altitude).

Documentation and Resources

- Omar, Ali H., and Coauthors, 2009: "The CALIPSO Automated Aerosol Classification and Lidar Ratio Selection Algorithm", *J. Atmos. Oceanic Technol.*, **26**, 1994-2014, doi: http://journals.ametsoc.org/doi/abs/10.1175/2009JTECHA1231.1
- Liu, Z. and Coauthors, 2009: "The CALIPSO Lidar Cloud and Aerosol Discrimination: Version 2 Algorithm and Initial Assessment of Performance", *J. Atmos. Oceanic Technol.*, **26**, 1198-1213, doi: http://journals.ametsoc.org/doi/abs/10.1175/2009JTECHA1229.1

- Young, S. A. and M. A. Vaughan, 2009: "The retrieval of profiles of particulate extinction from Cloud Aerosol Lidar Infrared Pathfinder Satellite Observations (CALIPSO) data: Algorithm description", *J. Atmos. Oceanic Technol.*, **26**, 1105-1119, http://journals.ametsoc.org/doi/abs/10.1175/2008JTECHA1221.1
- Vaughan, M., K. Powell, R. Kuehn, S. Young, D. Winker, C. Hostetler, W. Hunt, Z. Liu, M. McGill, and B. Getzewich, 2009: "Fully Automated Detection of Cloud and Aerosol Layers in the CALIPSO Lidar Measurements", *J. Atmos. Oceanic Technol.*, **26**, 2034-2050, doi: http://journals.ametsoc.org/doi/abs/10.1175/2009JTECHA1228.1

CALIPSO Lidar Level 3 Aerosol Data Product

Overview

The CALIPSO lidar level 3 aerosol data product reports monthly mean profiles of aerosol optical properties on a uniform spatial grid. It is intended to be a tropospheric product and so data are only reported below altitudes of 12 km. All level 3 parameters are derived from the version 3 CALIOP level 2 aerosol profile product and have been quality screened prior to averaging. The primary quantities reported are vertical profiles of aerosol extinction coefficient at 532 nm and its vertical integral, the aerosol optical depth (AOD). Aerosol type and spatial distribution information are also included. Averaged profile data is reported for all aerosols, regardless of type, and for mineral dust aerosol only. Classification of dust is based on the aerosol type flags in the level 2 profile product. This document describes the different types of level 3 files available, their grid spatial resolution, the organization of their contents, and the quality screening strategy implemented.

Organization of Level 3 Files

In order to keep level 3 file sizes manageable, there are four different types of level 3 files produced, depending on the sky condition and the temporal coverage of the data prior to averaging:

Aerosol Data Files Produced

Sky Condition	Temporal Coverage
All Sky	Daytime
All Sky	Nighttime
Combined (cloud-free + above cloud)	Daytime
Combined (cloud-free + above cloud)	Nighttime

As is shown, statistics are reported by each file separately corresponding to the relevant sky condition and the lighting condition. Sky conditions indicate where the aerosol being aggregated exists in relation to cloud cover in the vertical. There are four varieties of sky condition, described below.

Note that for a given level 3 file, profile statistics correspond to a single sky condition, while AOD statistics are reported for all four sky conditions within *every* level 3 file. So, if a user is interested in average profiles of aerosol extinction with the "All Sky" sky condition, they need to look in the "All Sky" level 3 file. If they want to examine AOD in "Cloud-Free" column only, they could still look in the same "All Sky" level 3 file because all four sky conditions are reported there for AOD.

Description of the Four Sky Conditions

Sky Condition	Description
All Sky	All quality screeened aerosol is included when deriving statistics, whether from cloudy or cloud-free columns.
Cloud-Free	Only quality screened aerosol optical depths in cloud-free columns are included in the statistics. *Reported for AOD only.*
Above Cloud	Only quality screened aerosol in cloudy columns and located above the highest cloud layer are included in the statistics. *Reported for AOD only.*
Combined	Quality screened aerosol in cloud-free columns and above clouds are included in the statistics. This selectively excludes aerosol retrieved beneath cloud.

* Note that aerosol is never reported within clouds in any CALIPSO data product.

Temporal and Spatial Resolution

Statistics are aggregated with a temporal resolution of one month and are reported on an equal-angle grid with the following specifications.

Spatial Coverage	Spatial Resolution
360° longitude (180°W to 180°E)	5° longitude
170° latitude (85°N to 85°S)	2° latitude
-0.5 km to 12 km altitude	60 m vertical

Based on the resolution of the grid above, level 3 gridded variables are reported in arrays having two, three, or four dimensions. The following table lists the sizes of all arrays of 2 dimensions or greater, *excluding* aerosol type distribution *and* aerosol spatial distribution *arrays. Those arrays have similar dimensionality as the 3-D and 4-D arrays below, except the final dimension length depends on the purpose of the array. See product descriptions of those arrays for size descriptions.*

Level 3 Array Sizes

Number of Dimensions	Dimension Lengths
2-D	num. latitudes x num. longitudes (85 x 72)
3-D *all except AOD percentiles*	num. latitudes x num. longitudes x num. altitudes (85 x 72 x 208)
3-D AOD percentiles	num. latitudes x num. longitudes x num. percentiles * (85 x 72 x 11)
4-D	num. latitudes x num. longitudes x num. altitudes x num. percentiles * (85 x 72 x 208 x 11)
* Number of percentiles is 11 because it contains the minimum, maximum, and the 10th, 20th, 30th, …, 90th percentiles.	

Quality Screening Strategy

Prior to generating level 3 statistics, all level 2 aerosol profile extinction samples are quality screened using filters designed to eliminate samples and layers that were detected or classified with very low confidence or that have untrustworthy extinction retrievals. Quality filters are described below along with a preliminary assessment of their impact on the reported level 3 statistics. A paper describing the justification of these filters in-depth along with detailed sensitivity analyses is in preparation.

1. **CAD score filter.** Only aerosol layers having cloud-aerosol discrimination (CAD) scores between -100 and -20 are used. Layers with CAD scores between 20 and -20 are often the result of erroneous layer detection triggered by noise. (The sign of the CAD score indicates layer type - clouds have positive CAD scores and aerosols have negative CAD scores - and the magnitude of the score indicates the degree of confidence in the classification. A CAD score of -100 thus indicates a layer that has been classified as an aerosol with the highest degree of confidence. Similarly, a CAD score of -1 indicates a layer that has been classified as an aerosol with essentially no confidence at all. Layers which cannot be classified as either cloud or aerosol are assigned a CAD score of 0.)

   The lower confidence boundary of -20 was selected empirically by generating level 3 type averages for one month of level 2 data and performing a sensitivity study to assess the dependence of the number of layers rejected, the average extinction, and the propagated extinction uncertainties on the CAD score limit. This study revealed that varying the CAD threshold between -60 and -20 does little to remove large or negative extinction outliers or to reduce the propagated uncertainty. However, allowing aerosol layers with CAD scores near 0 does allow large and negative outliers into the extinction averages and increases the uncertainty.

   Examination of the relationship between CAD score and layer IAB QA factor and also the frequency distribution of CAD scores and (Figures 7 and 8 of the level 2 aerosol layer data quality summaries) show that this behavior is expected because low confidence CAD scores typically occur beneath optically thick layers and because there are relatively fewer layers with medium confidence CAD scores (-80 to -20) compared to low and high confidence CAD scores.

   Consequence for level 3: Since dust layers tend to have better CAD scores than other aerosol types, this filter removes fewer aerosol layers over the regions where dust is prevalent compared to regions of the world containing other aerosol types.

2. **Extinction QC flag filter.** Only aerosol layers having extinction QC flag values of 0, 1, 16, or 18 are allowed. Extinction QC flag values of 16 and 18 correspond to layers classified as opaque where, in the former case, the retrieval completes successfully without adjusting the initial lidar ratio, and in the latter case, the lidar ratio is reduced to prevent the retrieval from diverging to infinity. Aerosol layers having extinction QC flag set to any other value are ignored since these retrievals show a greater propensity to exhibit erroneously large or negative values compared to aerosol layers with extinction QC = 0, 1, 16, or 18.

3. **Aerosol extinction uncertainty filter.** Only samples where aerosol extinction uncertainty is less than 99.9 km-1 are allowed. Uncertainty of 99.9 is a flag value assigned by the retrieval algorithm when the extinction uncertainty estimate has begun to diverge to infinity while iterating down the profile. In this case the retrieval results become unreliable and we exclude aerosol samples having extinction uncertainty equal to 99.9 and all aerosol samples at lower altitudes in the same profile since the untrustworthy extinction

solution is propagated to lower altitudes as the retrieval proceeds downward.

Sensitivity studies were conducted to assess if a more restrictive extinction uncertainty threshold is appropriate to reduce the occurrence of extinction outliers. For extinction uncertainty thresholds less than about 5 km-1 (uncertainty is expressed as an absolute uncertainty, not a relative uncertainty), we found that the propagated uncertainty had indeed been reduced, but the shape of level 3 mean extinction profiles had also changed in the lowest altitudes. This is because uncertainty increases at lower altitudes because errors are propagated from above. As a result, samples with relatively large aerosol extinction are selectively removed and the mean extinction is reduced in the lowest altitudes. To avoid changing the shape of the average extinction profile, all aerosol extinction uncertainty values are allowed except the flag value above (uncertainty = 99 km-1). Fortunately, just removing these samples reduces the number of extinction and extinction uncertainty outliers existing in level 3 statistics significantly.

4. **Isolated 80 km layer filter.** Detection of layers averaged to 80 km is occasionally triggered by anomalous noise spikes, likely due to high energy particles impacting the lidar detectors. Aerosol layers detected at 80 km horizontal resolution that are not adjacent (either vertically or horizontally) to another aerosol layer or containing an embedded aerosol layer are excluded from quality screened level 3 statistics. Requiring that another aerosol layer is adjacent improves the confidence that a real aerosol layer exists in the region. These isolated 80 km layers tend to occur at higher altitudes and to have very low extinction values. Therefore excluding them removes sporadic extinction values which can be significant in the upper troposphere, but have little impact on the column AOD.

5. **Filter for misclassified cirrus.** Occasionally, the tenuous edges of cirrus clouds are misclassified as aerosol by the CALIPSO Cloud Aerosol Discrimination algorithm as shown in Figure 1 below. When this happens, it is often on layers averaged to 80 km horizontal resolution and noise can cause a weak cloud layer to appear to have an aerosol signature. Therefore if an aerosol layer appears adjacent to an ice cloud, the aerosol layer is assumed to be misclassified cloud and is rejected.

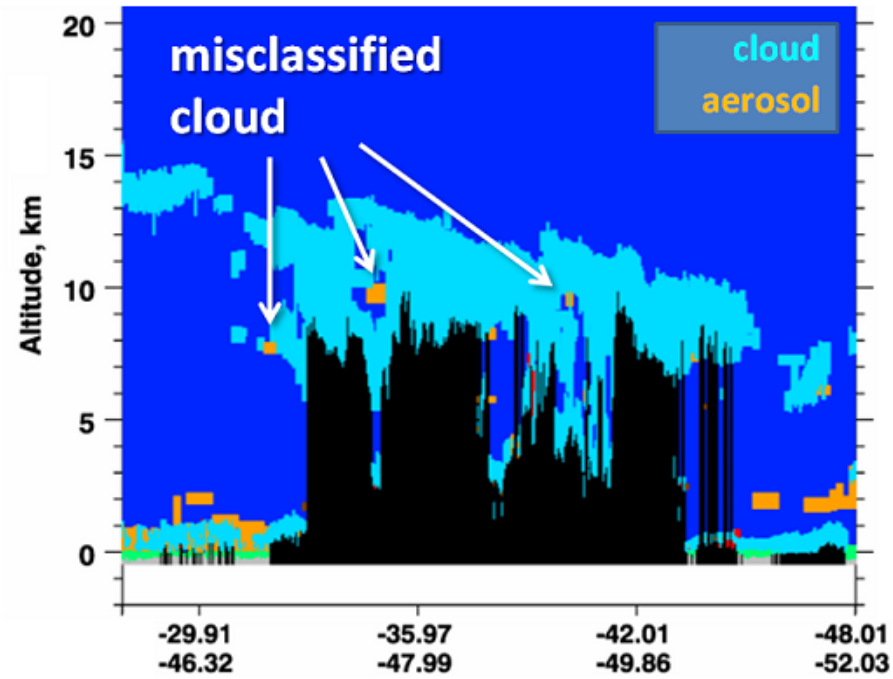

Figure 1. CALIPSO level 2 vertical feature mask example showing where the fringe of cirrus clouds have been misclassified as aerosol. Orange, light blue, and green features have been classified as aerosol, cloud, and surface, respectively.

In order to remove these from level 3 statistics, aerosol layers above 4 km in altitude that are adjacent to an ice cloud (ice/water phase is randomly oriented or horizontally oriented) having cloud top temperature less than 0°C are excluded prior to computing level 3 statistics. Since this problem seems to occur much more frequently with ice clouds than with water clouds, this test is not applied to aerosol layers adjacent to water clouds.

6. **Undetected surface attached aerosol low bias filter.** At times the CALIPSO feature detection algorithm may not detect the entire vertical extent of surface attached aerosol layers. Often aerosol bases are assigned at 30 - 90 meters above the local surface due to overlying attenuation. If the aerosol base extension algorithm is invoked, the base is assigned to 90 meters above the local surface by default. This results in a low bias in the mean extinction profiles near the surface since "clear air" extinction is assumed to be 0.0 km^{-1} and undetected aerosol with non-zero extinction likely exists beneath these assigned bases.

In order to avoid a low bias in level 3 mean aerosol extinction, for each level 2 profile, samples classified as "clear air" lying beneath the lowest quality screened aerosol layer whose base is below 2.5 km are excluded from level 3 statistics; i.e., these values are not

assumed to have clear air extinction of 0.0 km^{-1}; they are ignored. The requirement that the lowest aerosol base is below 2.5 km is to avoid ignoring clear air extinction beneath elevated aerosol layers such as elevated smoke plumes off the west African coast.

7. **Large negative near-surface extinction filter.** Surface contamination in level 2 aerosol extinction can manifest itself as very large negative extinction values for samples adjacent to the local surface. To reduce the effects of surface contamination in level 3 data, all level 2 aerosol extinction samples adjacent to the surface having a value less than -0.2 km^{-1} are ignored and not used in the computation of level 3 statistics.

8. **Surface contamination beneath surface-attached opaque layer filter.** Surface contamination can also occur in level 2 aerosol extinction when an opaque layer is adjacent to the surface. For a transparent surface-attached aerosol layer, the feature finder typically assigns the layer base altitude one range bin above the surface as determined by the lidar surface elevation (please consult Section 3.2 of the CALIPSO Feature Detection ATBD (PDF) for a detailed description of how layer base is determined as it is much more sophisticated than is described here). However if the surface attached layer is opaque, then the feature finder assigns the layer base altitude as the nearest range bin in the standard CALIPSO lidar altitude array above the DEM surface elevation. If the nearest CALIPSO range bin is below the true surface altitude, surface contamination occurs. It has been noticed that one occurrence of this error can bias the AOD of an entire level 3 grid cell. Preliminary analysis reveals that this issue occurs primarily over the southern oceans at night, though occurrence over land has not been quantified.

   The following filter was implemented in order to remove these surface contaminated samples: all level 2 aerosol samples belonging to opaque aerosol layers at altitudes beneath the maximum DEM surface elevation having extinction > 2 km-1 that have increased in magnitude by more than 10 times when compared to the extinction at one range bin higher in altitude are excluded when computing level 3 statistics.

   The effect of this filter is illustrated in Figure 2 below. The circled area in the top panel shows grid cells with high aerosol optical depth peppered about the southern oceans due to surface contamination beneath surface-attached opaque layers. The bottom panel shows that these high AOD spikes have been removed after this filter was implemented.

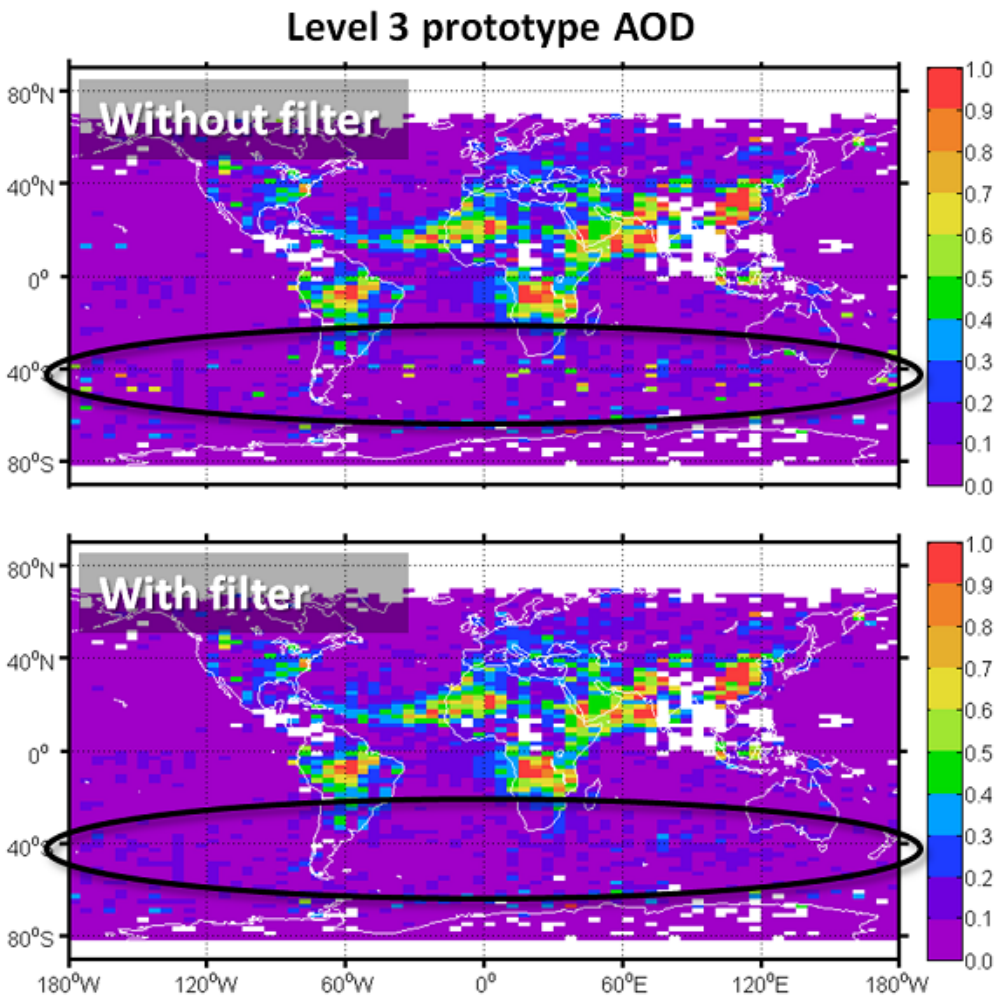

Figure 2. Aerosol optical depth for August 2007 at night from a prototype version of level 3 without the surface-attached opaque layer surface contamination filter (top) and with the filter (bottom).

Product Descriptions

Descriptions of all parameters included in the level 3 file are described below. They are organized into the following categories.

Spatial Coordinates

Longitude Midpoint (1-D array)
Longitude, in degrees, at the latitude/longitude/altitude grid cell midpoint.

Latitude Midpoint (1-D array)
Latitude, in degrees, at the latitude/longitude/altitude grid cell midpoint.

Altitude Midpoint (1-D array)
Altitude, in kilometers, at the latitude/longitude/altitude grid cell midpoint.

Meteorological Context

Pressure Mean (external) (3-D array)
Pressure Standard Deviation (external) (3-D array)
Mean and standard deviation of all pressures reported within the latitude/longitude/altitude grid cell in hectopascals; derived from the GEOS-5 data product provided to the CALIPSO project by the GMAO Data Assimilation System.

Temperature Mean (external) (3-D array)
Temperature Standard Deviation (external) (3-D array)
Mean and standard deviation of all temperatures reported within the latitude/longitude/altitude grid cell in degrees C; derived from the GEOS-5 data product provided to the CALIPSO project by the GMAO Data Assimilation System.

Relative Humidity Mean (external) (3-D array)
Relative Humidity Standard Deviation (external) (3-D array)
Mean and standard deviation of all relative humidity reported within the latitude/longitude/altitude grid cell, in percent; derived from the GEOS-5 data product provided to the CALIPSO project by the GMAO Data Assimilation System.

Tropopause Height Minimum (external) (2-D array)
Tropopause Height Maximum (external) (2-D array)
Tropopause Height Median (external) (2-D array)
Tropopause Height Mean (external) (2-D array)
Tropopause Height Standard Deviation (external) (2-D array)
Statistics of all tropopause heights reported within the latitude/longitude grid cell in kilometers above local mean sea level; derived from the GEOS-5 data product provided to the CALIPSO project by the GMAO Data Assimilation System.

Meteorological Profiles Averaged (2-D array)
Number of 5 km horizontal resolution meteorological profiles averaged within the latitude/longitude grid cell.

Surface Elevation and Overflight Parameters

Surface Elevation Minimum (external) (2-D array)
Surface Elevation Maximum (external) (2-D array)
Surface Elevation Median (external) (2-D array)
Surface elevation statistics for all columns reported in the latitude/longitude grid cell in kilometers above local mean sea level, obtained from the GTOPO30 digital elevation map (DEM).

Land Samples (external) (2-D array)
Number of columns within the latitude/longitude grid cell having surface type at the lidar footprint classified as land (i.e., not water) by the International Geosphere/Biosphere Programme (IGBP). The IGBP surface types reported by CALIPSO are the same as those used in the CERES/SARB surface map.

Water Samples (external) (2-D array)

Number of columns within the latitude/longitude grid cell having surface type at the lidar footprint classified as water by the International Geosphere/Biosphere Programme (IGBP). The IGBP surface types reported by CALIPSO are the same as those used in the CERES/SARB surface map.

Days of Month Observed (2-D array)

The days of month observed flags are bit-mapped 32-bit floats indicating which calendar days of the month CALIPSO made observations within a latitude/longitude grid cell. Bits are set to true when CALIPSO makes an observation on that calendar day with the least significant bit corresponding to the first day of the month. Bit 1 is the least significant bit.

For example, if CALIPSO made an observation within a grid cell on the 1st day of the month, then bit 1 would be set to true and if CALIPSO made an observation on the 2nd day of the month, then bit 2 would be set to true and so on. Based on CALIPSO"s orbit, a grid cell at the equator would have much fewer days set to true than a grid cell near the poles.

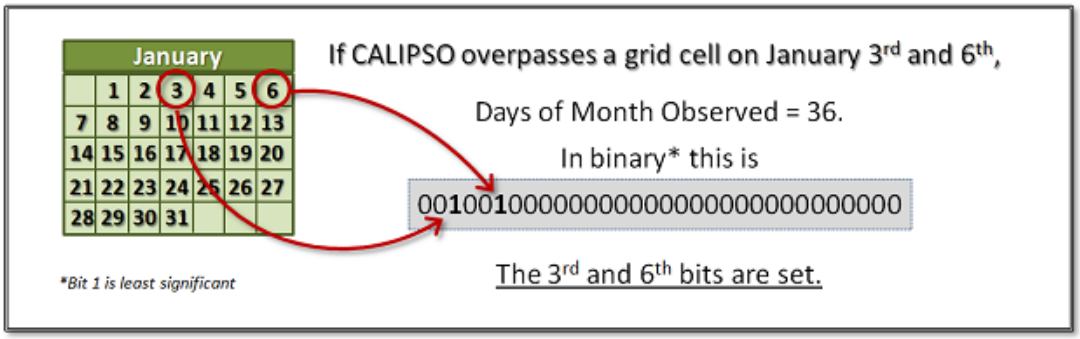

Figure 3. Example of how to interpret Days of Month flag.

Static Lidar Ratio Parameters

Initial Aerosol Lidar Ratio 532 (1-D array)
Initial Aerosol Lidar Ratio Uncertainty 532 (1-D array)

Indicates estimated initial lidar ratios used in the level 2 retrievals, and their uncertainties, for each aerosol subtype in units of steradians. Retrieving aerosol extinction, backscatter and optical depth from CALIPSO measurements requires an estimate of the particulate extinction-to-backscatter ratio, known as the "lidar ratio". These initial estimates are based on the aerosol subtype of the layer being analyzed. The six values reported correspond to the six aerosol type that the automated classification system identifies: clean marine, dust, polluted continental, clean continental, polluted dust, and smoke, respectively. More information on the rationale for these estimates and their errors is discussed in the Lidar Level 2 Cloud and Aerosol Layer Products Quality Statements.

Aerosol Optical Parameters

Extinction 532 Mean [Dust] (3-D array)
Extinction 532 Standard Deviation [Dust] (3-D array)
Extinction 532 Median [Dust] (3-D array)
Extinction 532 Skew [Dust] (3-D array)
Extinction 532 RMS [Dust] (3-D array)
Extinction 532 Percentiles [Dust] (4-D array)

Vertical profiles of mean, standard deviation, median, skew, and RMS error for all quality screened lidar level 2 aerosol profile extinction coefficients reported with the latitude/longitude/altitude grid cell in units of km-1, except skew which is unitless. Percentiles are 11-element arrays with the first value containing the minimum quality screened aerosol extinction coefficient within the grid cell and the last containing the maximum. Intermediate elements specify aerosol extinction coefficients corresponding to percentiles between 10% (element 2) and 90% (element 10). If the parameter name ends with "Dust", then only aerosol layers classified as dust are used to compute statistics. Otherwise, all aerosol species are included in the statistics. Example profiles of level 3 aerosol extinction statistics and percentiles are shown in Figure 4.

In computing extinction statistics, regions identified as "clear air" by the feature finder are assumed to have an aerosol extinction coefficient of 0.0 km^{-1}. This results in an underestimate of mean extinction, but we believe the low bias is small in most cases. This is being addressed in initial validation studies. Also, aerosol extinction in the lowest few range bins above the surface often exhibit a low bias and may also exhibit surface contamination. **Aerosol extinction coefficients within 180 meters of the** surface elevation maximum **in this beta release are untrustworthy and should be ignored.** Please see the discussion on near-surface aerosol

extinction issues below for more details.

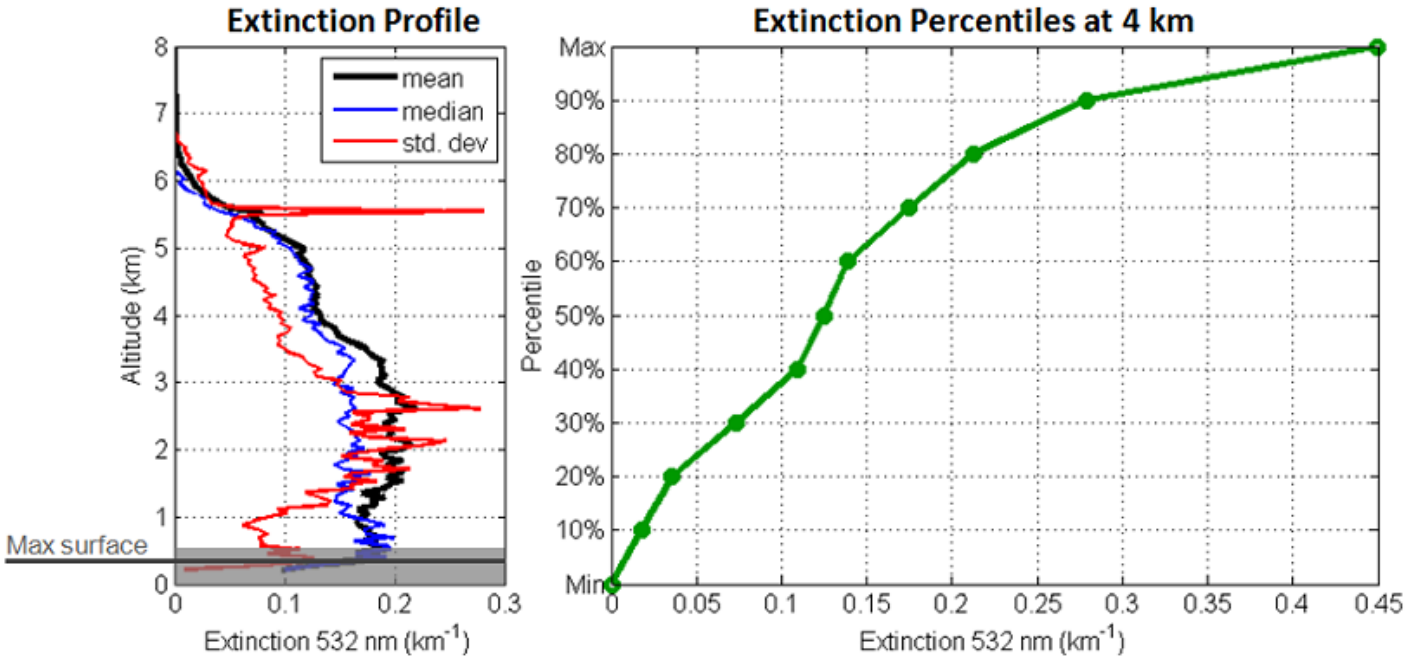

Figure 4. Example profiles of extinction statistics for a single latitude/longitude grid cell (left) and the percentiles of extinction for the altitude bin at 4 km in the same latitude/longitude grid cell (right). The maximum surface altitude of the grid cell is also labeled in the left panel; grey shading is a reminder that samples within 180 meters of the maximum surface altitude and below should be ignored.

AOD Cloud Free Mean [Dust] (2-D array)
AOD Cloud Free Standard Deviation [Dust] (2-D array)
AOD Cloud Free Median [Dust] (2-D array)
AOD Cloud Free Skew [Dust] (2-D array)
AOD Cloud Free RMS [Dust] (2-D array)
AOD Cloud Free Percentiles [Dust] (3-D array)

Mean, standard deviation, median, skew, and RMS error of all aerosol optical depth (AOD) values reported in cloud-free columns within each latitude/longitude grid cell. AOD is calculated as the vertical integral of quality screened lidar level 2 aerosol profile extinction coefficients. Percentiles are 11-element arrays with the first value containing the minimum AOD within the grid cell and the last containing the maximum. Intermediate elements specify AODs corresponding to percentiles between 10% (element 2) and 90% (element 10).

For the purposes of the level 3 aerosol product, clouds detected at 5 km horizontal resolution or greater are used for screening; i.e., cloud-free columns do not contain clouds found at 5 km or coarser resolution, but they may contain clouds found at 1/3 km and 1 km horizontal resolution. These higher resolution clouds have been removed by the boundary layer cloud clearing algorithm prior to computing aerosol layer properties.

AOD Above Cloud Mean [Dust] (2-D array)
AOD Above Cloud Standard Deviation [Dust] (2-D array)
AOD Above Cloud Median [Dust] (2-D array)
AOD Above Cloud Skew [Dust] (2-D array)
AOD Above Cloud RMS [Dust] (2-D array)
AOD Above Cloud Percentiles [Dust] (3-D array)

Mean, standard deviation, median, skew, and RMS error of all aerosol optical depth (AOD) values reported above clouds within each latitude/longitude grid cell. AOD is calculated as the vertical integral of quality screened lidar level 2 aerosol profile extinction coefficients. Percentiles are 11-element arrays with the first value containing the minimum AOD within the grid cell and the last containing the maximum. Intermediate elements specify AODs corresponding to percentiles between 10% (element 2) and 90% (element 10).

AOD Combined Mean [Dust] (2-D array)
AOD Combined Standard Deviation [Dust] (2-D array)
AOD Combined Median [Dust] (2-D array)
AOD Combined Skew [Dust] (2-D array)
AOD Combined RMS [Dust] (2-D array)
AOD Combined Percentiles [Dust] (3-D array)

Mean, standard deviation, median, skew, and RMS error of all aerosol optical depth (AOD) values reported in cloud-free columns and above clouds within each latitude/longitude grid cell. This "combined" case selectively excludes aerosol samples beneath clouds. AOD

is calculated as the vertical integral of quality screened lidar level 2 aerosol profile extinction coefficients. Percentiles are 11-element arrays with the first value containing the minimum AOD within the grid cell and the last containing the maximum. Intermediate elements specify AODs corresponding to percentiles between 10% (element 2) and 90% (element 10).

AOD All Sky Mean [Dust] (2-D array)
AOD All Sky Standard Deviation [Dust] (2-D array)
AOD All Sky Median [Dust] (2-D array)
AOD All Sky Skew [Dust] (2-D array)
AOD All Sky RMS [Dust] (2-D array)
AOD All Sky Percentiles [Dust] (3-D array)

Mean, standard deviation, median, skew, and RMS error of all aerosol optical depth (AOD) values reported within each latitude/longitude grid cell. AOD is calculated as the vertical integral of quality screened lidar level 2 aerosol profile extinction coefficients. Percentiles are 11-element arrays with the first value containing the minimum AOD within the grid cell and the last containing the maximum. Intermediate elements specify AODs corresponding to percentiles between 10% (element 2) and 90% (element 10).

Sample Counting Statistics

Users may want to spatially or temporally aggregate these level 3 data. Therefore, the sample numbers required to correctly aggregate the statistics are included.

Samples Searched (3-D array)

Reports the total number of atmospheric measurements made in each latitude/longitude/altitude grid cell, regardless of whether they were accepted, rejected, or ignored. It can be thought of as the number of chances that CALIOP had to measure an atmospheric feature. As such, range bins beneath the surface and range bins beneath opaque layers do not contribute to this number since CALIOP did not have a chance to measure beneath these features. Level 3 sample numbers are reported based on a 5 km horizontal x 30 meter vertical resolution grid to match resolution at which layers are reported in the level 2 aerosol and 5 km cloud layer products.

Samples Averaged [*Dust*] (3-D array)

Reports the number of samples contributing to the mean, standard deviation, and skew of aerosol extinction coefficients in each latitude/longitude/altitude grid cell. In computing these statistics, regions identified as "clear air" are assumed to have an aerosol extinction coefficient of 0.0 km^{-1}. Therefore, the number of samples averaged includes both the aerosol extinction coefficients passing all quality assurance filtering criteria and the number of "clear air" extinction values in the grid cell. Level 3 sample numbers are reported based on a 5 km horizontal x 30 meter vertical resolution grid to match resolution at which layers are reported in the level 2 aerosol and 5 km cloud layer products.

Samples Aerosol Detected Accepted [*Dust*] (3-D array)

Reports the number of aerosol samples in each latitude/longitude/altitude grid cell that were detected and passed all quality assurance filtering criteria. However, this is not the number of samples that contributes to extinction and AOD statistics (excluding RMS uncertainty) because clear air extinction samples are included in those calculations (see Samples Averaged, above). For the case of RMS uncertainty, this is the number of samples used because only uncertainties from detected aerosol layers passing all quality assurance filtering criteria are propagated into level 3 RMS uncertainties. Level 3 sample numbers are reported based on a 5 km horizontal x 30 meter vertical resolution grid to match resolution at which layers are reported in the level 2 aerosol and 5 km cloud layer products.

Samples Aerosol Detected Rejected [*Dust*] (3-D array)

Reports the number of aerosol samples in each latitude/longitude/altitude grid cell that were detected but failed to pass our filtering criteria. These samples are ignored in all statistical calculations. Level 3 sample numbers are reported based on a 5 km horizontal x 30 meter vertical resolution grid to match resolution at which layers are reported in the level 2 aerosol and 5 km cloud layer products.

Samples Cloud Detected [*Dust*] (3-D array)

Reports the number of 5 km x 30 m resolution range bins that are entirely cloudy (cloud layer fraction is 100%) occurring in each latitude/longitude/altitude grid cell. Level 3 sample numbers are reported based on a 5 km horizontal x 30 meter vertical resolution grid to match resolution at which layers are reported in the level 2 aerosol and 5 km cloud layer products.

Aerosol Type Distribution

Aerosol Type (4-D array)

Histogram of aerosol type for each latitude/longitude/altitude grid cell. This array of six integers counts the number of aerosol samples having the CALIPSO aerosol type clean marine, dust, polluted continental, clean continental, polluted dust, and smoke, respectively for each latitude/longitude/altitude grid cell. Therefore this array has size num. latitudes x num. longitudes x num. altitudes x num. aerosol types (85 x 72 x 208 x 6).

Multiple Aerosol Type Count (3-D array)

Histogram documenting occurrence of multiple aerosol types in each latitude/longitude grid cell. Each element of this 7-element array records the number of instances for which N different aerosol types were detected in the individual level 2 aerosol profiles within each latitude/longitude grid cell. N ranges from 0 (no aerosol detected in a column) to 6 (all six of the CALIPSO aerosol types were detected in a single column). Therefore this array has size num. latitudes x num. longitudes x num. aerosol types detected (85 x 72 x 7).

Aerosol Spatial Distribution

Number Layers Per Column [*Dust*] (3-D array)

Histogram of the number of aerosol layers detected in the level 2 data products for each latitude/longitude grid cell. The first element of this 9-element array records the number of columns having zero aerosol layers. Similarly, the second element records the number of columns having one aerosol layer, and so on. The ninth array element records the number of columns having eight or more aerosol layers detected. Therefore this array has size num. latitudes x num. longitudes x num. aerosol detected (85 x 72 x 9).

Highest Aerosol Layer Detected [*Dust*] (3-D array)

Distribution of highest aerosol layer top altitudes detected within each latitude/longitude grid cell in units of kilometers, reported as percentile arrays. Percentiles are 11-element arrays with the first value containing the minimum layer top altitude within the grid cell and the last containing the maximum. Intermediate elements specify layer top altitudes corresponding to percentiles between 10% (element 2) and 90% (element 10). Therefore this array has size num. latitudes x num. longitudes x num. percentiles (85 x 72 x 11).

Lowest Aerosol Layer Detected [*Dust*] (3-D array)

Distribution of lowest aerosol layer base altitudes detected within each latitude/longitude grid cell in units of kilometers, reported as percentile arrays. Percentiles are 11-element arrays with the first value containing the minimum layer base altitude within the grid cell and the last containing the maximum. Intermediate elements specify layer base altitudes corresponding to percentiles between 10% (element 2) and 90% (element 10). Therefore this array has size num. latitudes x num. longitudes x num. percentiles (85 x 72 x 11).

Layer Separation Minimum [*Dust*] (3-D array)
Layer Separation Maximum [*Dust*] (3-D array)
Layer Separation Median [*Dust*] (3-D array)
Layer Separation Mean [*Dust*] (3-D array)
Layer Separation Standard Deviation [*Dust*] (3-D array)

Minimum, maximum, median, mean, and standard deviation of vertical separation distances between all detected aerosol layers in all columns within each latitude/longitude grid cell in units of kilometers. Layer separation is defined as the vertical distance between two aerosol layers that are separated by either clear air or cloud. Since there are can be more than two aerosol layers in a column, layer separation statistics are reported using 7-element arrays where the first element reports the separation statistics for columns where two aerosol layers are detected, the second element reports separation statistics for columns where three aerosol layers are detected, and so on. The seventh and last element reports separation statistics for columns where eight or more layers aerosol layers are detected. Therefore this array has size num. latitudes x num. longitudes x num. layers (85 x 72 x 7).

File Metadata Parameters

Product ID

An 80-byte (max) character string specifying the data product name. For all CALIPSO lidar level 3 aerosol data products, the first portion of this string will be "CAL_LID_L3_APro_" and the final portion of the string will indicate the sky condition, "AllSky" or "Combined".

Nominal Year Month

A six digit integer indicating the year and month when data within the level 3 file was measured by CALIPSO in the format yyyymm.

Number of Level 2 Files Analyzed

Integer indicating the number of level 2 granules analyzed to generate the level 3 file.

Earliest Input Filename

A 160-byte (max) character string specifying the filename of the first (by calendar day and time) level 2 aerosol profile granule analyzed within the month of the level 3 file.

Latest Input Filename

A 160-byte (max) character string specifying the filename of the last (by calendar day and time) level 2 aerosol profile granule analyzed within the month of the level 3 file.

Data Screening Script Filename

A 160-byte (max) character string specifying the filename of the script containing configuration information and command sequences that were executed during the processing of the CALIPSO lidar level 3 data product.

Data Screening Script File Contents

A 5000-byte (max) character string containing configuration information and command sequences that were executed during the processing of the CALIPSO lidar level 3 data product. These commands define spatial boundaries and implement quality filters and are described by in-line documentation.

Data Release Versions

Lidar Level 3 Aerosol Profile			
Release Date	**Version**	**Data Date Range**	**Maturity Level**
December 2011	1.00	June 2006 to present	Beta

Data Quality Statement for the release of the CALIPSO Lidar Level 3 Aerosol Product Version 1.00, December 2011

The lidar level 3 aerosol product is a quality screened aggregation of level 2 aerosol profile data. As such, its data quality is inherited in part from the level 2 aerosol profile data inputs and in part from the quality screening and re-gridding algorithms used to produce level 3 outputs. Users are advised to consult the lidar level 2 aerosol profile product data quality statement in conjunction with this statement to acquire a comprehensive understanding of level 3 data quality.

Data in this beta release has not been validated. Several known data quality issues are addressed below. These issues are currently under investigation by the CALIPSO Lidar Science Working Group.

Near-surface aerosol extinction

Extinction values reported in the lowest few range bins near the surface can be impacted by several types of retrieval errors. These surface related issues manifest themselves in level 3 aerosol extinction profiles as rapid decreases in extinction in near-surface range bins and occasionally spikes where surface contamination occurs. Two quality assurance filters have been implemented to remove some of the surface contamination errors which cause extinction spikes. Causes of the anomalous decrease in extinction in the lowest range bins are still under investigation.

Aerosol extinction coefficients within 180 meters of the surface in this beta release are untrustworthy and should be ignored. Users should consult the level 3 parameter Surface Elevation Maximum **in each grid cell to determine which samples exist within 180 m of the maximum surface elevation and then ignore those samples and all that exist at lower altitudes in that grid cell.**

Undetected aerosol influence on level 3 aerosol extinction statistics

Regions classified as "clear air" by the CALIPSO feature detection algorithms are assumed to have aerosol extinction = 0.0 km^{-1} when calculating level 3 averages of aerosol extinction. CALIOP has a limited detection sensitivity however, and weakly scattering layers go undetected, resulting in a low bias. This occurs most often in the upper troposphere where aerosol layers tend to be optically weak, in the daytime since the SNR is smaller than at nighttime resulting in more layer misdetection, and beneath optically thick clouds due to significant signal attenuation. More details of why some aerosol features may go undetected can be found in the level 2 aerosol layer data quality summary. Biases due to missed detections are believed to be small in most regions, though potential biases have not yet been quantified by validation intercomparisons.

Though regions of "clear air" are assumed to have aerosol extinction = 0.0 km^{-1}, the same assumption cannot be made about the aerosol extinction uncertainty - there is no such thing as no uncertainty. Thus, level 3 aerosol extinction RMS uncertainties are calculated by only propagating the level 2 aerosol extinction uncertainties of detected aerosol layers that have passed quality screening criteria. Uncertainties due to undetected layers are not included in the propagated level 3 uncertainty.

Overlying cloud influence on level 3 aerosol extinction averages

Level 3 aerosol extinction statistics are reported for two sky conditions, "All Sky" and "Combined". While the former includes all quality screened aerosol extinction in deriving statistics, the latter excludes aerosol detected beneath clouds. Statistics are broken up in this manner because overlying clouds attenuate the lidar signal and decrease SNR, making faint layers more difficult to detect and increasing uncertainty in a variety of ways. The distribution of level 2 aerosol extinction tends to broaden with overlying cloud cover with more increasing occurrence of extreme outliers, shown in Figure 5. Quality filters implemented for level 3 are successful at removing many of these extreme outliers; namely, the extinction QC flag and extinction uncertainty filters.

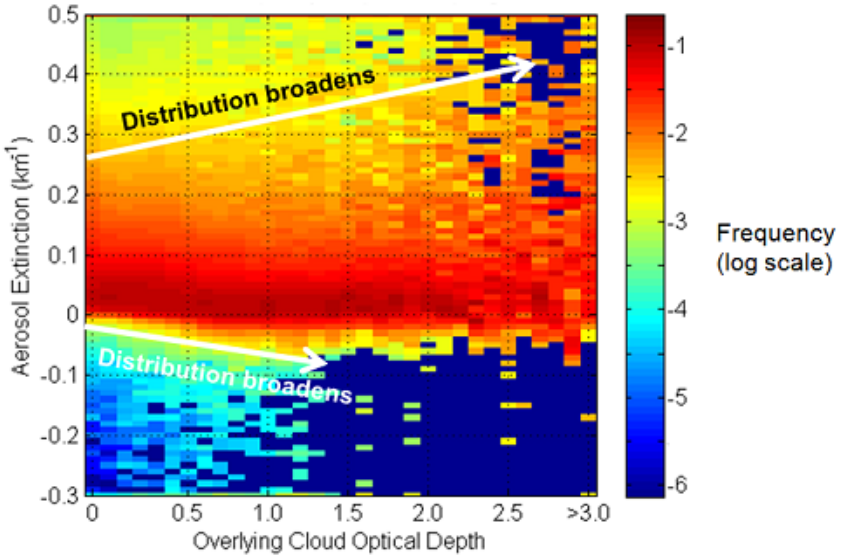

Figure 5. Frequency distribution of quality screened level 2 aerosol extinction samples as a function of overlying *ice* cloud optical depth in August 2007 in a region of frequent cirrus cloud cover (0°E, 120°E; 25°S, 25°N).

In spite of the increased uncertainties of aerosol retrieved below cloud, regional monthly mean all-sky and clear-sky profiles appear to be consistent. Comparison of level 3 aerosol extinction between the "All Sky" and "Combined" sky conditions reveals that the mean level 3 aerosol extinction is slightly lower in magnitude for the "All Sky" case even though more aerosol samples are included. This is shown by the cumulative distribution of level 3 aerosol extinction for one month in Figure 6 (left panel). This may be due to more clear air samples being averaged in with the aerosol beneath cloud, causing the mean extinction to be smaller for "All Sky" compared to "Combined". Also, the RMS uncertainty tends to be slightly larger for the "All Sky" case even though the RMS uncertainty decreases with the inverse of number of aerosol samples accepted (Figure 6, right panel).

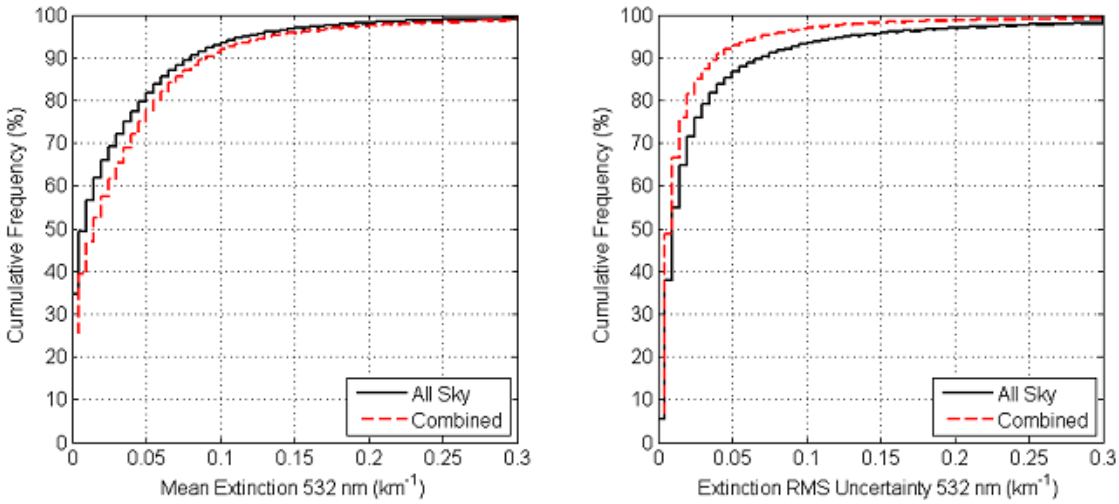

Figure 6. Cumulative frequency distributions of level 3 mean aerosol extinction (left) and level 3 aerosol extinction RMS uncertainty (right) for "All Sky" (black) and "Combined" (red dashed) sky conditions. Data is from a pre-beta level 3 aerosol file, June 2006 at night. Mean level 3 aerosol extinction values where aerosol is not detected are ignored.

Until validation studies are completed, users should treat "All Sky" level 3 optical properties carefully in regions with significant overlying cloud cover (in southeast Asia during the Indian monsoon, for instance). It is also advisable to check the statistic Samples Aerosol Detected Accepted to ensure a sufficient number of aerosol samples are available.

Known issue with meteorological context statistics

Currently, each meteorological context parameter is generated for every grid cell by averaging together all profiles of the parameter that exist within the grid cell together, regardless of cloud cover or aerosol quality screening. As a consequence, there is not a one-to-one

correspondence between the region of sky used to generate aerosol extinction statistics and the region of sky used to generate the meteorological context statistics. For example, the aerosol extinction reported for the "Combined" sky condition will not include samples beneath clouds, but the Temperature statistics (for example), and all other meteorological parameters would still contain those samples beneath clouds. This issue will be addressed in a forthcoming release.

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