CALIPSO Quality Statements: Lidar Level 2 Cloud and Aerosol Profile Products Version Releases: 2.01, 2.02

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Introduction

This document provides a high-level quality assessment of the cloud and aerosol profile products derived from the CALIPSO lidar measurements, as described in Sections 2.5 and 2.6 of the CALIPSO Data Products Catalog (Version 2.4) (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 briefly summarize key validation results; 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.

The primary new parameters included in the version 2.0 release are aerosol and cloud extinction and backscatter profiles (Aerosol Profile Product and Cloud Profile Product), layer optical depth, aerosol type, and cloud ice/water phase (Aerosol and Cloud Layer Product), and aerosol type and cloud ice/water phase in the Vertical Feature Mask (VFM). Although extinction or optical depth appear in several different products, all extinction retrievals are produced by the same algorithm. Therefore, the Data Quality Summaries include a section which discusses general characteristics of the extinction and optical depth data applicable to all products.

Additional Documentation and References

Algorithm Theoretical Basis Documents (ATBDs)

- PC-SCI-202.01 - Mission, Instrument, and Algorithms Overview (PDF)
- PC-SCI-202.02 - Feature Detection and Layer Properties Algorithms (PDF)
- PC-SCI-202.03 - Scene Classification Algorithms (PDF)
- PC-SCI-202.04 - Extinction Retrieval Algorithms (PDF)

General References

- PC-SCI-503 : CALIPSO Data Products Catalog (Version 2.4) (PDF)
- Data analysis overview: Fully automated analysis of space-based lidar data: an overview of the CALIPSO retrieval algorithms and data products (PDF)
- Additional publications (journal articles and conference proceedings about CALIPSO science, algorithms, and data processing)
- CALIPSO Data Read Software

CALIPSO Cloud and Aerosol Profile Products

Version 2.01 Detailed Profile Products Quality Summary

WARNING!
The backscatter and extinction coefficients reported in the the version 2.01 release of the CALIPSO profile products are unvalidated, beta-quality data products. As such, they still contain a number of errors and/or inconsistencies. Furthermore, the current products contain no data quality information, and hence cannot be used as standalone products. Users are cautioned against the indiscriminate use of these data products; using them as the basis for research findings, journal publications, and/or presentations at scientific conferences is strongly discouraged.

The CALIOP Version 2 data release includes extinction products for the first time. The Cloud Profile Product and Aerosol Profile Product report profiles of particle extinction and backscatter. The Cloud and Aerosol Layer Product includes layer optical depths. The layer optical depths are derived from the same retrievals which are used to compute the extinction and backscatter profiles in the Profile Products, although the horizontal averaging of the final products may be different. All of these extinction products are produced using the same basic algorithm.

There are layers for which the optical depth can be reliably measured directly from the CALIOP backscatter signal. For these layers, the measured optical depths are reported in the layer products, and the layer two-way transmittance is used to constrain the extinction solution, so that an optimal estimate of the layer lidar ratio is retrieved. These constrained solutions are the most reliable retrievals. The implementation in Version 2 is fairly conservative though, and only a small fraction of the retrievals are constrained. Uncertainties of the other, unconstrained, retrievals are larger, and primarily depend on how closely the lidar ratio initially assumed by the algorithm agrees with the true lidar ratio, and on how well the attenuation of overlying layers has been estimated. Errors in the initial lidar ratio and attenuation correction propagate non-linearly into subsequent retrievals, so that extinction errors do not average out but instead produce biases.

In the case of opaque layers - i.e., where the lidar signal does not penetrate to the base of the layer - the reported optical depth refers only to the upper portion of the layer where there is measurable lidar signal. About 20% of cloud layers are identified as being opaque, as are a few very dense aerosol layers. In these cases CALIOP does not give the true layer base height and underestimates the true layer optical depth. The Opacity Flag in the Cloud and Aerosol Layer Products identifies layers which are opaque. There is no corresponding flag in the profile products.

About 90% of cloud retrievals and 99% of aerosol retrievals conclude successfully, in the sense that a physically possible solution is found (retrieved extinction is non-negative and finite). The results of the remaining retrievals can also be found in the data products, but are non-physical. For these cases, the extinction QC flags reported in the layer products will enumerate the condition(s) that caused the failure. There are no corresponding flags in the profile products.

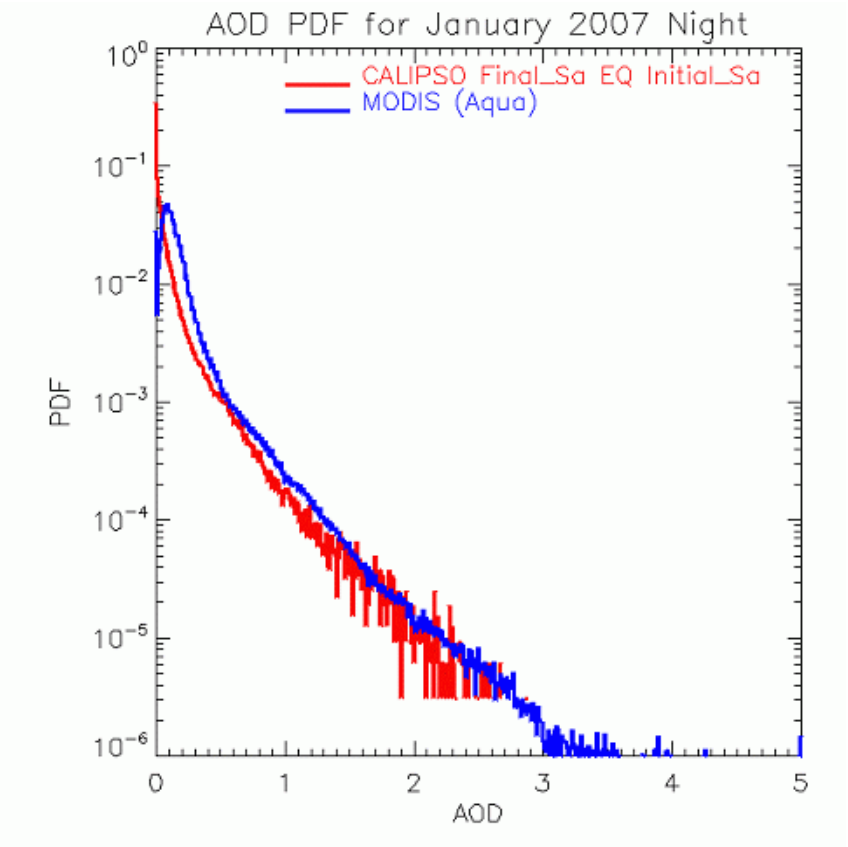
The extinction retrieval will, if necessary to avoid a non-physical solution, adjust the initial lidar ratio as required to produce a physical solution. The most common problem is that the extinction solution diverges and the retrieved values tend toward infinity if the assumed lidar ratio is too large. For weakly scattering layers the lidar ratio is most often left unchanged, as a physical solution is usually obtained on the first iteration. However, if the initial lidar ratio is much larger than the true value, divergence can occur even for optically thin (optical depth

Retrievals in Aerosol Layers:

In the current implementation of the extinction retrieval algorithm, the lidar ratio adjustment scheme does not result in realistic retrievals in aerosol layers in cases where the initial divergence is due to a misclassification of aerosol type. When divergence occurs, it can be because the true lidar ratio is much less than the lidar ratio selected by the algorithm, or that the attenuation of overlying layers was overcorrected, or both. Aerosol retrievals where the final lidar ratio is not equal to the initial lidar ratio should be regarded as invalid and ignored. The lidar ratio is adjusted in only about 5% of the aerosol retrievals.

Figure 1 (below) shows a comparison of column aerosol optical depth (AOD) from CALIOP with MODIS AOD. The comparison is for all CALIOP nighttime aerosol measurements in cloud-free columns during the month of January 2007 vs. all daytime MODIS AOD during the same month. In computing the distribution of CALIOP column AOD in Figure 1, retrievals where the initial lidar ratio was adjusted during the retrieval were screened out, as were any aerosol layers with integrated attenuated backscatter values greater than 0.01 /km/sr. While the two distributions agree fairly well, with MODIS appearing to slightly over-estimate values at the lower end of the optical depth range, global maps of monthly-average AOD show significant regional differences. A similar comparison of the distribution of MODIS AOD with daytime CALIOP shows CALIOP has a significant low bias with respect to MODIS. The difference is probably due to a combination of differences in day and night calibration and somewhat lower detection sensitivity during daytime.

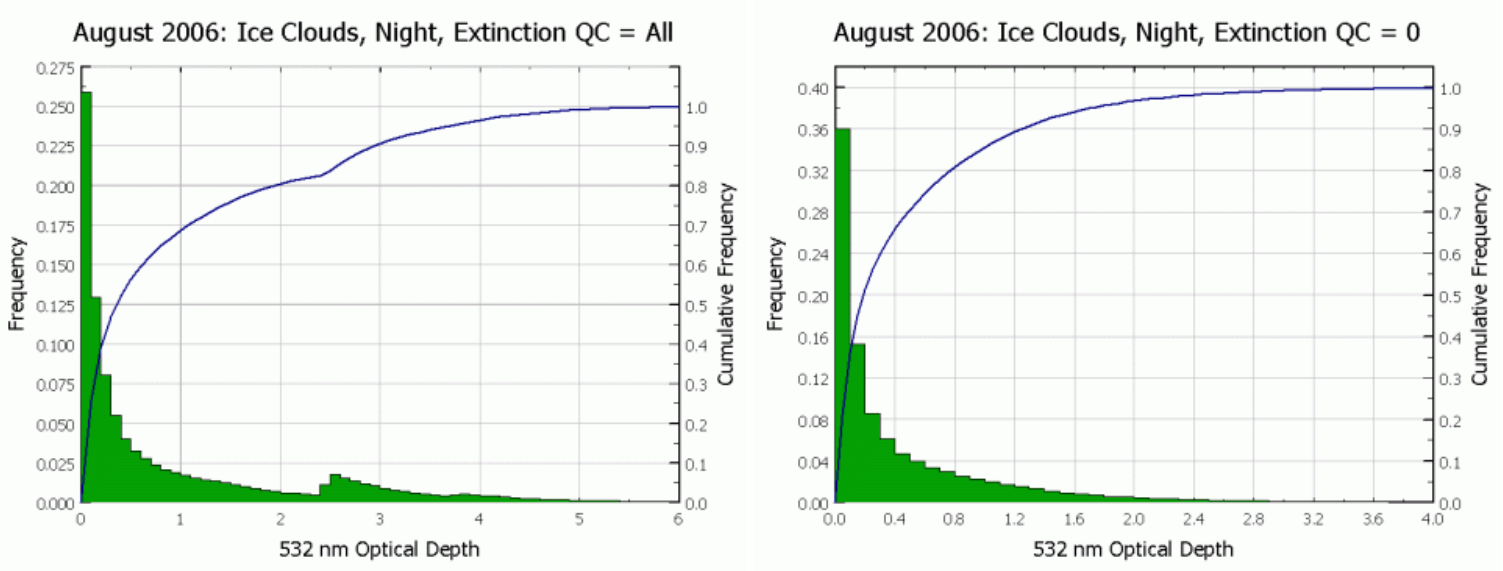
Figure 1: Comparison of CALIPSO aerosol optical depths to those derived from MODIS (Preliminary - January 2007, nighttime data, final lidar ratio = initial lidar ratio only)



Retrievals in Cirrus Clouds:

A histogram of cirrus optical depths from the Cloud Layer Product shows a bimodal distribution (see Figure 2, left panel). The peak on the right, at an optical depth of ~2.5, appears to be an artifact due to the behavior of the retrieval algorithm when the initial retrieval diverges and the lidar ratio is reduced to produce a convergent solution. This happens most often in totally attenuating (i.e., opaque) clouds, and when the true cirrus lidar ratio is significantly smaller than the initial value assumed by the algorithm. The second peak disappears when we consider only those solutions for which the lidar ratio was unchanged (i.e., the extinction QC flag = 0; see Figure 2, right panel). In any case, errors grow rapidly when the true cirrus lidar ratio is different from the assumed value. Errors in optical depth for thin cirrus (optical depth < 0.5) are on the order of 50% for unconstrained retrievals.

Figure 2: CALIPSO cirrus cloud optical depths (Preliminary - August 2006, nighttime only)



Retrievals in Water Clouds:

Although the production code applies the extinction retrieval algorithm to all layers detected, the CALIOP extinction retrieval algorithm was developed for retrievals of aerosol and ice clouds, not water clouds. Results from water clouds are unreliable and should be ignored, except for constrained retrievals. One of the new parameters in the Version 2 Cloud and Aerosol Layer Products and the VFM is cloud ice/water phase. There is no corresponding flag in the profile products.

Profile Products Data Description

The CALIPSO data processing system generates separate sets of profile products for clouds and aerosols. The cloud profile products are reported at a uniform spatial resolution of 60-m vertically and 5-km horizontally, over a nominal altitude range from 20-km to -0.5-km. The aerosol profile products are reported over a broader altitude range of 30-km to -0.5-km. Profile data for all features detected in the stratosphere are reported in the aerosol profile product, thus users seeking to obtain CALIPSO retrievals of backscatter and extinction profiles of polar stratospheric clouds are directed to the aerosol profile products. Due to constraints imposed by CALIPSO's on-board data averaging scheme, the vertical resolution of the aerosol profile data varies as a function of altitude. In the tropospheric region between 20-km to -0.5-km, the aerosol profile products are reported at a spatial resolution of 120-m vertically and 40-km horizontally. In the stratospheric region (above 20-km), the aerosol profile products are reported at a spatial resolution of 360-m vertically and 40-km horizontally. In the text below we provide brief descriptions of individual data fields reported in the CALIPSO cloud and aerosol profile products. Where appropriate, we also provide an assessment of the quality and accuracy of the data in the current release.

Latitude Start
Latitude Stop
: Geodetic latitude, in degrees, of the laser footprint for the first (Latitude Start) and the last (Latitude Stop) of the sequence of laser pulses averaged to produce the reported profile products. For the 5-km cloud profile products, 15 pulses are averaged; the 40-km aerosol profile products, 120 pulses are averaged.

Longitude Start
Longitude Stop
: Longitude, in degrees, of the laser footprint for the first (Longitude Start) and the last (Longitude Stop) of the sequence of laser pulses averaged to produce the reported profile products. For the 5-km cloud profile products, 15 pulses are averaged; for the 40-km aerosol profile products, 120 pulses are averaged.

Profile Time TAI Start
Profile Time TAI Stop
: Time, expressed in International Atomic Time (TAI), for the first (Profile Time TAI Start) and the last (Profile Time TAI Stop) of the sequence of laser pulses averaged to produce the reported profile products. Units are in seconds, starting from January 1, 1993.

Profile Time UTC Start
Profile Time UTC Stop
: Similar to Profile Time TAI, but for time expressed in Coordinated Universal Time (UTC), and formatted as 'yymmdd.ffffffff', where 'yy' represents the last two digits of year, 'mm' and 'dd' represent month and day, respectively, and 'ffffffff' is the fractional part of the day.

Tropopause Height
: Mean tropopause height, 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

Tropopause Temperature
: Mean tropopause temperature, in degrees C; derived from the GEOS-5 data product provided to the CALIPSO project by the GMAO Data Assimilation System

Temperature
: Mean temperature, in degrees C, reported for the midpoint of each range bin in the profile; derived from the GEOS-5 data product provided to the CALIPSO project by the GMAO Data Assimilation System

Pressure
: Mean pressure, in hectopascals, reported for the midpoint of each range bin in the profile; derived from the GEOS-5 data product provided to the CALIPSO project by the GMAO Data Assimilation System

Molecular Number Density
: Mean molecular number denisty, in molecules per cubic meter, reported for the midpoint of each range bin in the profile; derived from the GEOS-5 data product provided to the CALIPSO project by the GMAO Data Assimilation System

Relative Humidity
: Mean relative humidity, reported for the midpoint of each range bin in the profile; derived from the GEOS-5 data product provided to the CALIPSO project by the GMAO Data Assimilation System

Profile QA Flag
: Not calculated for the current release; data products contain fill values in this field.

Surface Elevation Statistics

Provides the maximum, minimum, mean, and standard deviation of the surface elevation obtained from the GTOPO30 digital elevation map (DEM) for the horizontal distance spanned by the averaged profile; units are kilometers.

Surface Winds (aerosol products only)

Provides the mean zonal and meridional component of the surface wind speed computed over the horizontal distance spanned by the averaged profile; units are meters per second.

Samples Averaged

Specifies the number of full resolution samples averaged for each profile range bin; for the purposes of this computation, 'full resolution' is taken to mean 30 meters vertically, and a single shot (~1/3-km) horizontally. Thus a single range bin in the cloud profile products (resolution = 60-m vertical, 5-km horizontal) will have at most 480 samples averaged (i.e., for those clouds that required 80-km averaging for detection, 240 shots horizontally by two 30-m range bins vertically). Similarly, a single range bin in the tropospheric region of aerosol profile products (resolution = 120-m vertical, 40-km horizontal) will have at most 960 samples averaged (i.e., four 30-m range bins vertically by 240 shots horizontally). In the stratospheric region, where the aerosol profile products are reported at at a 360-m vertical resolution, the maximum number of samples averaged will be 2880.

Cloud Layer Fraction (cloud products only)

Not calculated for the current release; data products contain fill values in this field.

Aerosol Layer Fraction (aerosol products only)

Not calculated for the current release; data products contain fill values in this field.

Atmospheric Volume Description (aerosol products only)

Not calculated for the current release; data products contain fill values in this field.

Total Backscatter Coefficient 532
Total Backscatter Coefficient 1064 (aerosol products only)

Reported for each profile range bin for which the appropriate particulates (i.e., clouds or aerosols) were detected; those range bins in which no particulates were detected contain fill values (-9999). Units are kilometers^{-1} steradians^{-1}.

WARNING! The backscatter coefficients reported in the the version 2.01 release of the CALIPSO profile products are unvalidated, beta-quality data products. As such, they still contain a number of errors and/or inconsistencies. Furthermore, the current products contain no data quality information, and hence cannot be used as standalone products. Users are cautioned against the indiscriminate use of these data products; using them as the basis for research findings, journal publications, and/or presentations at scientific conferences is strongly discouraged.

Total Backscatter Coefficient Uncertainty 532
Total Backscatter Coefficient Uncertainty 1064 (aerosol products only)

Not calculated for the current release; data products contain fill values in this field.

Perpendicular Backscatter Coefficient 532

Not calculated for the current release; data products contain fill values in this field.

Perpendicular Backscatter Coefficient Uncertainty 532

Not calculated for the current release; data products contain fill values in this field.

Particulate Depolarization Ratio Profile 532

Not calculated for the current release; data products contain fill values in this field.

Particulate Depolarization Ratio Uncertainty 532

Not calculated for the current release; data products contain fill values in this field.

Extinction Coefficient 532
Extinction Coefficient 1064 (aerosol products only)

Reported for each profile range bin for which the appropriate particulates (i.e., clouds or aerosols) were detected; those range bins in which no particulates were detected contain fill values (-9999). Units are kilometers^{-1}.

WARNING! The extinction coefficients reported in the the version 2.01 release of the CALIPSO profile products are unvalidated, beta-quality data products. As such, they still contain a number of errors and/or inconsistencies. Furthermore, the current products contain no data quality information, and hence cannot be used as standalone products. Users are cautioned against the indiscriminate use of these data products; using them as the basis for research findings, journal publications, and/or presentations at scientific conferences is strongly discouraged.

Extinction Coefficient Uncertainty 532
Extinction Coefficient Uncertainty 1064 (aerosol products only)

Not calculated for the current release; data products contain fill values in this field.

Multiple Scattering Profile 532
Multiple Scattering Profile 1064 (aerosol products only)

Multiple Scattering Uncertainty 532
Multiple Scattering Uncertainty 1064 (aerosol products only)
Not calculated for the current release; data products contain fill values in this field.

Ice Water Content Profile (cloud products only)
Not calculated for the current release; data products contain fill values in this field.

Ice Water Content Profile Uncertainty (cloud products only)
Not calculated for the current release; data products contain fill values in this field.

Data Release Versions

Lidar Level 2 Cloud and Aerosol Profile Information *Half orbit (Night and Day) averaged cloud and aerosol profile data and ancillary data*			
Release Date	**Version**	**Data Date Range**	**Maturity Level**
October 2008	2.02	September 14, 2008 to present	Beta
January 25, 2008	2.01	June 13, 2006 to September 13, 2008	Beta

Data Quality Statement for the release of the CALIPSO Lidar Level 2 Cloud and Aerosol Profile Products Version 2.02, October 2008

Version 2.02 of the Level 2 data products is a maintenance release that implements the following changes.

- Corrections were made to the code used to interpolate the GMAO meteorological data products to the CALIPSO orbit tracks.
- The Cabannes backscattering cross-sections used to derive the molecular scattering models used for the Level 1 and Level 2 analyses were revised downward by ~0.8%.
- A typographical error was identified in the runtime script that controls the behavior of the aerosol subtyping algorithm in the Level 2 analyses.

The impacts of these changes on the Level 2 data products are as follows:

- Layer detection: As a result of the first two changes, the 532 nm and 1064 nm calibration constants are larger, on average, by ~1%, resulting in corresponding decreases in the magnitudes of the attenuated backscatter coefficients at both wavelengths. These changes in the level 1 data result only small changes to the layer detection statistics. For example, the difference in the total number of layers detected by the two different versions on August 12, 2006 was 4: 9680 layers were detected by the version 2.01 code, versus 9676 layers by the version 2.02 code.

- Cloud-aerosol discrimination: with one exception, there were only minimal changes in cloud-aerosol discrimination results. The exception occurs in the polar regions when PSCs are present. For the August 12, 1006 test case, corrections to the interpolation algorithms applied to the GMAO data result in a slight upward shift in the tropopause heights, and as a consequence, more clouds and fewer stratospheric layers are identified in the version 2.02 results.

- Ice-water phase determination: because this classification is based on depolarization ratio and temperature no substantial changes, there were no substantial changes in the assessments of cloud thermodynamic state.

- Aerosol subtype identification: Correcting the level 2 runtime script error will reduce the number of layers identified as smoke, and increase the number of layers identified as sea salt.

Cloud and aerosol extinction profiles and optical properties: changes in backscatter and extinction coefficients at the tops of layers are small, and proportional to the changes in the calibration coefficients ... however, due to the cumulative nature of error propagation in the extinction retrieval, differences increase with increasing penetration depths, and can grow large when the optical depths of the clouds are large (i.e., > 3).

Data Quality Statements for the release of the CALIPSO Lidar Level 2 Cloud and Aerosol Profile Products Version 2.01, January 25, 2008

Extinction and Backscatter Profiles

The CALIOP cloud and aerosol profiles of extinction and backscatter are released as beta products. Cloud profiles are reported at a horizontal resolution of 5 km; aerosol profiles are reported at a horizontal resolution of 40 km. These products contains a number of known errors and, in their current form, cannot be used as standalone products. The current products contain no data quality information, and hence must be used in conjunction with the Cloud and/or Aerosol Layer Products and/or the Vertical Feature Mask Product, which contain data quality parameters and confidence flags. Data assessment and screening procedures have not yet been developed. Because of this, the profile data product is considered to be not appropriate for scientific publication, but is released to users for evaluation and to provide feedback to the CALIOP algorithm development team.

PLEASE NOTE: users of the CALIOP extinction and backscatter profile data should read and thoroughly understand the information provide in the Profile Products Data Quality Summary. This summary contains an expanded description of the extinction retrieval process from which the layer optical depths are derived, and provides essential guidance in the apppropriate use of all CALIOP extinction-related data products. Validation and improvements to the profile products QA are ongoing efforts, and additional data quality information will be included with future releases.

Layer Detection

Given the accuracy of the CALIPSO altitude registration, the layer heights reported in the Lidar Level 2 Cloud and Aerosol Layer Products appear to be quite accurate. In optically dense layers, the lowest altitude where signal is reliably observed is reported as the base. In actuality, this reported base may lie well above the true base. In this release, the layers which are reported represent a choice in favor of high reliability over maximum sensitivity. Weakly scattering layers sometimes will go unreported, in the interest of minimizing the number of false positives.

Cloud-Aerosol Discrimination

Based on the initial CALIOP measurements, an improved version of the cloud-aerosol discrimination (CAD) algorithm has been implemented for this release. Overall, the updated algorithm works well in most cases; manual verification of the classifications for a full day of data suggests that the success rate is in the neighborhood of 90% or better. Nevertheless, several types of misclassifications are still occur with some frequency. Among these, the most prevalent are:

1. Dense aerosol layers (primarily very dense dust and smoke over and close to the source regions) are sometimes labeled as cloud. Because the CAD algorithm operates on individual layers, without a contextual awareness of any surrounding features, it can happen that small but strongly scattering regions within an extended aerosol layer can occasionally be labeled as cloud. This occurs because the optical properties (backscatter and color ratio) within the region are similar to what would be expected for the relatively faint clouds that fall within the PDF overlap region. These misclassifications are often apparent from studying the Level 1 browse images. Based on the initial analysis of the CALIOP measurements, the cloud and aerosol distributions show variabilities that depend on season and on geophysical location. The globally averaged PDFs used in the current release will have a larger overlap between the cloud and aerosol than would occur for more regionally specific statistics. For future versions of the CAD algorithm, we expect to develop and deploy PDFs that will correctly reflect both seasonal and latitudinal variations.

2. Many optically thin clouds, both ice and water, are encountered in the polar regions. The current CAD PDFs do not work as well in the polar regions as at lower latitudes and misclassifications of clouds as aerosol are more common. In particular, thin ice clouds which can extend from the surface to several kilometers in altitude, are sometimes misclassified as aerosol.

3. Correct classification of heterogeneous layers is always difficult, and the process can easily go awry. An example of a heterogeneous layer would be an aerosol layer that is vertically adjacent to a cloud or contains an embedded cloud, but which is nonetheless detected by the feature finder as a single entity. By convention, heterogeneous layers should be classified as clouds. However, depending on the relative strengths of the components, these layers are sometimes erroneously identified as aerosol.

4. Some so-called features identified by the layer detection scheme are not legitimate layers, but instead are artifacts due to the noise in the signal, multiple scattering effects, or to artificial signal enhancements caused by non-ideal detector transient response or an over estimate of the attenuation due to overlying layers. These erroneous "pseudo-features" are neither cloud nor aerosol; however, because they are not properly interdicted in the processing stream, the CAD algorithm nonetheless attempts to assign them to one class or the other. Very frequently these layers can be identified by their very low CAD scores (typically less than 20).

Aerosol Type Identification

The main objective of the aerosol subtyping scheme is to estimate the appropriate value of the aerosol extinction-to-backscatter ratio (S_a) to within 30% of the true value. S_a is an important parameter used in the determination of the aerosol extinction and subsequently the optical depth from CALIOP backscatter measurements. S_a is an intensive aerosol property, i.e., a property that does not depend on the number density of the aerosol but rather on such physical and chemical properties as size distribution, shape and composition. These properties depend primarily on the source of the aerosol and such factors as mixing, transport, and in the case of hygroscopic aerosols, hydration.

The extinction products are produced by first identifying an aerosol type and then using the appropriate values of S_a and the multiple scattering factor, $\eta(z)$. Note that multiple scattering corrections have not yet been implemented for the current data release, so that $\eta(z) = 1$ for all aerosol types. The accuracy of the S_a value used in the lidar inversions depends on the correct identification of the type of aerosol. In turn, the accuracy of the subsequent optical depth estimate depends on the accuracy of S_a.

The underlying paradigm of the type classification is that a variety of emission sources and atmospheric processes will act to produce air masses with a typical, identifiable aerosol 'type'. This is an idealization, but one that allows us to classify aerosols based on observations and location in a way to gain insight into the geographic distribution of aerosol types and constrain the possible values of S_a for use in aerosol extinction retrievals.

The aerosol subtype product is generated downstream of the cloud-aerosol discrimination (CAD) scheme and, therefore, depends on the cloud-aerosol classification scheme in a very fundamental way. If a cloud feature is misclassified as aerosol, the aerosol subtype algorithm will identify this 'aerosol' as one of the aerosol subtypes. The user must exercise caution where the aerosol subtype looks suspicious or unreasonable. Such situations can occur with some frequency in the southern oceans and the polar regions.

Cloud Ice/Water Phase Discrimination

Cloud phase is determined using a depolarization/backscatter relation, together with temperature and backscatter thresholds. Complete descriptions of the algorithm mechanics and underlying theory are given in Section 6 of the CALIPSO Scene Classification ATBD (PDF). The algorithm implemented for the version 2.01 release identifies obvious water and ice clouds and clear cases of oriented ice crystals. Improvements for recognizing mixed phase clouds are planned for future release.