CALIPSO Quality Statements Lidar Level 1B Profile Products Version Releases: 3.01, 3.02, 3.30

Introduction

This document provides a high-level quality assessment of the level 1B lidar data products, as described in Section 2.1 of the CALIPSO Data Products Catalog (Version 3.6) (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 for the latest status before publishing any scientific papers using these data products.

The purpose of these data quality summaries is 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

Documentation and References

- Algorithm Theoretical Basis Documents (ATBDs): Lidar Level 1 ATBD - Calibration and Level 1 Data Products (PDF)
- CALIPSO Data Products Catalog: Version 3.6 (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: Callable routines in Interactive Data Language (IDL)

Standard and Expedited Data Set Definitions

Standard Data Sets:
Standard data processing begins immediately upon delivery of all required ancillary data sets. The ancillary data sets used in standard processing (e.g., GMAO meteorological data and data from the National Snow and Ice Data Center) must be spatially and temporally matched to the CALIPSO data acquisition times, and thus the time lag latency between data onboard acquisition and the start of standard processing can be on the order of several days.
The data in each data set are global, but are produced in files by half orbit, with the day portion of an orbit in one file and the night portion of the orbit in another.

Expedited Data Sets:
Expedited data are processed as soon as possible after following downlink from the satellite and delivery to LaRC. Latency between onboard acquisition and analysis expedited processing is typically on the order of 6 to 28 hours. Expedited processing uses the most recently current available set of ancillary data (e.g., GMAO meteorological profiles) and calibration coefficients available, which may lag the CALIPSO data acquisition time/date by several days.
Expedited data files contain at the most, 90 minutes of data. Therefore, each file may contain both day and night data.
NOTE: Users are strongly cautioned against using Expedited data products as the basis for research findings or journal publications. Standard data sets only should be used for these purposes.

The differences between expedited processing and standard processing are explained in more detail in "Adapting CALIPSO Climate Measurements for Near Real Time Analyses and Forecasting" (PDF).

CALIPSO Lidar Level 1B Data Products

The CALIOP Level 1B data product contains a half orbit (day or night) of calibrated and geolocated single-shot (highest resolution) lidar profiles, including 532 nm and 1064 nm attenuated backscatter and depolarization ratio at 532 nm. The product released contains data from nominal science mode measurement.

The CALIOP Level 1B product also contains additional data not found in the Level 0 lidar input file, including post processed ephemeris data, celestial data, and converted payload status data. The major categories of lidar Level 1B data are:

- Attenuated Backscatter Profiles
- Calibration Coefficients and Uncertainties
- Column Reflectance
- Geolocation and Altitude Registration
- Meteorological Data
- Time Parameters
- Profile Identification
- Ancillary Data
- Lidar Operating Modes
- Laser Energy and Instrument Gain Parameters
- Instrument Characterization
- Quality Check Flags
- Spacecraft Orientation
- Spacecraft Position and Attitude
- Metadata Parameters

To make proper use of the CALIOP Level 1B products, all users must be aware of the uncertainties inherent in the data products. The data quality of each product is summarized briefly below:

Attenuated Backscatter Profiles

Total Attenuated Backscatter 532

The total attenuated backscatter at 532 nm, ®'$_{532}$ in Section 6.2.2 of the Lidar Level I ATBD (PDF), is one of the primary lidar Level 1 data products. ®'$_{532}$ is the product of the 532 nm volume backscatter coefficient and the two-way optical transmission at 532 nm from the lidar to the sample volume. The construction of the 532 nm total attenuated backscatter from the two constituent polarization components is described in detail in Section 6 of the Lidar Level I ATBD (PDF). The attenuated backscatter profiles are derived from the calibrated (divided by calibration constant), range-corrected, laser energy normalized, baseline subtracted lidar return signal.

The 532 nm attenuated backscatter coefficients are reported for each laser pulse as an array of 583 elements that have been registered to a constant altitude grid defined by the Lidar Data Altitude field.

Note that to reduce the downlink data volume, an on-board averaging scheme is applied using different horizontal and vertical resolutions for different altitude regimes, as shown in the following table.

Table 1: Range Resolutions of Different Altitude Ranges for Downlinked Data

Altitude Range (km)	Bin Number	Horizontal Resolution (km)	532 nm Vertical Resolution (m)	1064 nm Vertical Resolution (m)	Altitude Region
30.1 to 40.0	1-33	5	300	N/A	5
20.2 to 30.1	34-88	5/3	180	180	4
8.3 to 20.2	89-288	1	60	60	3
-0.5 to 8.3	289-578	1/3	30	60	2
-2.0 to -0.5	579-583	1/3	300	300	1

Uncertainties for the attenuated backscatter are not explicitly reported in the CALIOP Level 1 data products to save data volume, which would otherwise approximately double the Level 1 data volume. If needed, users can compute random errors for the attenuated backscatter products as described in Uncertainties for Attenuated Backscatter (PDF). IDL code for computing the attenuated backscatter uncertainties is contained in IDL Code for Uncertainty Calculations (PDF).

Perpendicular Attenuated Backscatter 532

This field reports the perpendicular component of the 532 nm total attenuated backscatter, as described in section 6 of the CALIPSO Lidar Level I ATBD (PDF). Profiles of the perpendicular channel 532 nm attenuated backscatter are reported in the same manner as are profiles of the 532 nm total backscatter. Profiles of the parallel component of the backscatter can be obtained by simple subtraction of the perpendicular component from the total.

Attenuated Backscatter 1064

The attenuated backscatter at 1064 nm, β'_{1064}, is computed according to equation 7.23 in section 7.2 of the Lidar Level I ATBD (PDF). Like β'_{532}, β'_{1064} is one of the primary lidar Level 1 data products. β'_{1064} is the product of the 1064 nm volume backscatter coefficient and the two-way optical transmission at 1064 nm from the lidar to the sample volume. Profiles of the 1064 nm attenuated backscatter are reported in the same manner as are profiles of the 532 nm total backscatter. However, the first 34 bins of each profile contain fill values (-9999), because no 1064 nm data is downlinked from the 30.1 - 40 km altitude range.

Calibration Coefficients and Uncertainties

Calibration Constant 532

This is the lidar calibration constant at 532 nm, as defined in section 3.1.2 of the Lidar Level I ATBD (PDF).

For the nighttime portion of an orbit, the 532 nm calibration constant is determined for each 55 km averaged profile (11 frames) by comparing the 532-parallel signals in 30 km to 34 km altitude range to a scattering model derived from molecular and ozone number densities provided by NASA's Global Modeling and Assimilation Office (GMAO). This calculation uses equation 4.7 in Section 4.1.2.1 of the CALIPSO Lidar Level I ATBD (PDF). The computed 532 nm calibration constants are then smoothed over an interval of 1485 km using equation 4.8. A constant value of the calibration constant is applied to all single-shot profiles in each 55 km averaging region.

The calibration technique used during the nighttime cannot be used in the daytime portions of the orbits, because the noise associated with solar background signals (i.e., sunlight) degrades the backscatter signal-to-noise ratio (SNR) in the calibration region below usable levels. Therefore, for the daytime portion of the orbit, the calibration constants are derived by interpolating between values derived in the adjacent nighttime portions of the orbits.

Calibration Constant 1064

The lidar calibration constant at 1064 nm, C_{1064}, is determined by comparing 1064 nm signals to 532 nm signals in properly selected high cirrus clouds, using the procedure described in Section 7.1.2.2 of the CALIPSO Lidar Level I ATBD (PDF). For the current data release, the ratio of cirrus backscatter coefficients at 1064 nm and 532 nm is assumed to be uniformly 1. This assumption is being extensively assessed in on-going validation activities.

For each granule (day or night) a single, constant value (granule mean) for C_{1064} is derived by averaging all individual calibration constant estimates that were obtained. This granule mean serves as the calibration constant that is subsequently applied to all 1064 nm profiles in the granule.

We note that the procedure used in the 532 nm calibration cannot be applied for the 1064 nm measurements, because the molecular scattering at 1064 nm is ~16 times weaker than at 532 nm, and because the avalanche photodiode (APD) detector used in the 1064 nm channel has significantly higher dark noise than photomultiplier tube (PMTs) used in the 532 nm channels.

Calibration Constant Uncertainty 532

The uncertainty due to random noise for 532 nm calibration constant is computed based on the 532 nm noise scale factors using equation 4.24 in Section 4.3.2 of the CALIPSO Lidar Level 1 ATBD (PDF). Estimates of systematic errors, if any, are not included in this release. An extensive assessment of possible systematic errors is currently underway.

For nighttime calibrations, the uncertainty due to noise is estimated to be typically smaller than 1%. Additional systematic errors may arise from aerosol contamination of the calibration region (less than a few percent), and from large signal spikes seen frequently in the South Atlantic Anomaly (SAA) and occasionally outside the SAA region.

A stratospheric aerosol model is currently being developed to correct for the aerosol present in the calibration region. Upon completion, this model will be applied to calibration processing for subsequent data releases.

Large noise spikes can be present both in the lidar return signals and in the baseline signals. Baseline signals are determined on-board by calculating the mean signal value over 15000 data points (1000 15 meter samples in the 65 to 80 km altitude region from each of the 15 shots within a frame). This calculation is performed for each frame, and the resulting value is subtracted from each sample of all profiles in that frame. The presence of large outliers -- i.e., "spikes" -- in the backscatter signals in the calibration region tends to bias the calibration constant toward a larger value. On the other hand, the spikes present in the baseline region can cause and erroneous overestimate of the measured baseline signal, and the subsequent subtraction of this baseline value will thus introduce a bias in all data within the frame, causing it to be lower than it otherwise should be. This in turn tends to bias the calibration constant toward a smaller value. Threshold-based data filtering schemes are applied to 532 nm data to remove large spikes in the lidar signal prior to performing the nighttime calibration. Two threshold boundaries - a maximum and a minimum - are set. By excluding values outside this range, large signal excursions are effectively removed. Spikes with smaller magnitudes may remain, depending on the selection of the maximum threshold value. Perturbations to the calibration due to spikes in the baseline region can be only partly eliminated by this kind of threshold-based filtering scheme. However, by properly selecting the threshold limits, the impacts of spikes in the calibration region and the baseline region will cancel each other out to some degree. Preliminary comparisons of CALIOP's 532 nm attenuated backscatter coefficients, which are critically dependent on the accuracy of the calibration, with validation measurements acquired by the LaRC airborne high-spectral-resolution lidar (HSRL) and Goddard's airborne Cloud Physics Lidar (CPL) show consistency to within a few percent.

Because the daytime calibration constants are interpolated from nighttime values, the uncertainties contained in the nighttime calibration are transferred to daytime. Additional error may arise from the selection of interpolation scheme. In general, the uncertainty for daytime calibration constants is somewhat higher than the uncertainty for the nighttime values.

Calibration Constant Uncertainty 1064

This field reports the uncertainty in the 1064 nm calibration constant due solely to random noise contained in 1064 nm data. Systematic errors are not estimated in this release.

If a sufficient number of cirrus clouds are present in any granule, the uncertainty due to noise in the granule mean of the 1064 nm calibration constant can be very small. Larger systematic errors may arise from the assumption that the cirrus color ratio (the ratio of backscatter coefficients at 1064 nm and 532 nm) has a constant value of 1.0. A very preliminary study on the ratio of gain and energy-normalized, range-corrected signals (i.e., the quantity X defined in equations 3.7 and 3.8 in the CALIPSO Lidar Level I ATBD (PDF)) at 1064 nm and 532 nm in selected dense cirrus clouds shows a distribution having a width of exceeding 10% of the mean value.

Column Reflectance

Parallel Column Reflectance 532
Parallel column reflectance for 532 nm is reported for each lidar Level 1 profile.

Perpendicular Column Reflectance 532
Perpendicular column reflectance for 532 nm is reported for each lidar Level 1 profile.

Parallel Column Reflectance Uncertainty 532
Not calculated for the current release; data products contain fill values in this field.

Perpendicular Column Reflectance Uncertainty 532
Not calculated for the current release; data products contain fill values in this field.

Geolocation and Altitude Registration

Latitude
Geodetic latitude, in degrees, of the laser footprint on the Earth's surface.

Longitude
Longitude, in degrees, of the laser footprint on the Earth's surface.

Lidar Data Altitude
This is an HDF metadata field that defines the altitudes of the 583 range bins (refer to Table 1: Range Resolutions of Different Altitude Ranges for Downlinked Data) to which lidar Level 1 profile products are registered.

Number Bins Shift
Number bins shift contains the number of 30 meter bins the profile specific 30 meter array elements are shifted to match the lowest altitude bin of the fixed 30 meter altitude array. Profile specific altitude arrays are computed as a function of the actual spacecraft off-nadir angle, which varies slightly from the commanded spacecraft off-nadir angle. The fixed altitude array is computed using the commanded spacecraft off-nadir angle (0.3 or 3.0 degrees). The profile specific array elements may be shifted up or down.

Surface Altitude Shift
Surface altitude shift contains the altitude difference between the profile specific 30 meter altitude array and the fixed 30 meter altitude array at the array element that includes mean sea level. Profile specific altitude arrays are computed as a function of the actual spacecraft off-nadir angle, which varies slightly from the commanded spacecraft off-nadir angle. The fixed altitude array is computed using the commanded spacecraft off-nadir angle (0.3 or 3.0 degrees). The units are in kilometers and the values may be positive or negative. The difference is calculated as: Surface_Altitude_Shift = altitude (profile specific 30 meter mean sea level bin) - altitude (fixed 30 meter mean sea level bin).

Orbit Number
Orbit Number consists of three HDF metadata fields that define the number of revolutions by the CALIPSO spacecraft around the Earth and is incremented as the spacecraft passes the equator at the ascending node. To maintain consistency between the CALIPSO and CloudSat orbit parameters, the Orbit Number is keyed to the Cloudsat orbit 2121 at 23:00:47 on 2006/09/20. Because the CALIPSO data granules are organized according to day and night conditions, day/night boundaries do not coincide with transition points for defining orbit number. As such, three parameters are needed to describe the orbit number for each granule as:

- **Orbit Number at Granule Start:** orbit number at the granule start time
- **Orbit Number at Granule End:** orbit number at the granule stop time
- **Orbit Number Change Time:** time at which the orbit number changes in the granule

Path Number
Orbit Number Path Number consists of three HDF metadata fields that define an index ranging from 1-233 that references orbits to the Worldwide Reference System (WRS). This global grid system was developed to support scene identification for LandSat imagery. Since the A-Train is maintained to the WRS grid within +/- 10 km, the Path Number provides a convenient index to support data searches, instead of having to define complex latitude and longitude regions along the orbit track. The Path Number is incremented after the maximum latitude in the orbit is realized and changes by a value of 16 between successive orbits. Because the CALIPSO data granules are organized according to day and night conditions, day/night boundaries do not coincide with transition points for

defining path number. As such, three parameters are needed to describe the path number for each granule as:

- **Path Number at Granule Start:** path number at the granule start time
- **Path Number at Granule End:** path number at the granule stop time
- **Path Number Change Time:** time at which the path number changes in the granule

Meteorological Data

Met Data Altitude

This is an HDF metadata field that defines the altitudes of the 33 range bins at which the ancillary meteorological data (i.e., molecular number density, ozone number density, temperature, and pressure, and relative humidity) are generated.

Molecular Number Density

Molecular number density, in units of molecules per cubic meter, reported for each lidar Level 1 profile at the 33 standard altitudes recorded in the Met Data Altitudes field. Molecular number density values are obtained from the ancillary meteorological data provided by the GMAO.

Ozone Number Density

Ozone number density, in units of molecules per cubic meter, reported for each lidar Level 1 profile at the 33 standard altitudes recorded in the Met Data Altitudes field. Ozone number density values are obtained from the ancillary meteorological data provided by the GMAO.

Pressure

Pressure, in millibars, reported for each lidar Level 1 profile at the 33 standard altitudes recorded in the Met Data Altitudes field. Pressure values are obtained from the ancillary meteorological data provided by the GMAO.

Relative Humidity

Relative humidity reported for each lidar Level 1 profile at the 33 standard altitudes recorded in the Met Data Altitudes field. Relative humidity values are obtained from the ancillary meteorological data provided by the GMAO.

Surface Wind Speeds

Surface wind speeds, in meters per second, are reported for each lidar Level 1 profile as eastward (zonal) and northward (meridional) surface wind stress. Surface wind speed values are obtained from the ancillary meteorological data provided by the GMAO.

Temperature

Temperature, in degrees C, reported for each lidar Level 1 profile at the 33 standard altitudes recorded in the Met Data Altitudes field. Temperature values are obtained from the ancillary meteorological data provided by the GMAO.

Tropopause Height

Tropopause height, in kilometers, reported for each lidar Level 1 profile. Tropopause height values are obtained from the ancillary meteorological data provided by the GMAO.

Tropopause Temperature

Tropopause temperature, in degrees C, reported for each lidar Level 1 profile. Tropopause temperature values are obtained from the ancillary meteorological data provided by the GMAO.

Time Parameters

Profile Time

This field reports the International Atomic Time (TAI), in seconds, starting from January 1, 1993.

Profile Time UTC

This field reports the Coordinated Universal Time (UTC), 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.

Profile Identification

Frame Number

This field reports the number of a frame within the sequence of 11 frames making up a Payload Data Acquisition Cycle (PDAC). Each frame consists of 15 laser pulses. All 15 records in a frame have the same value of Frame Number.

Profile ID

This is a 32-bit integer generated sequentially for each single-shot profile record. Each profile ID is unique within each granule.

Ancillary Data

Day Night Flag

This field indicates the lighting conditions at an altitude of ~24 km above mean sea level; 0 = day, 1 = night.

IGBP Surface Type

International Geosphere/Biosphere Programme (IGBP) classification of the surface type at the laser footprint. The IGBP surface types reported by CALIPSO are the same as those used in the CERES/SARB surface map.

Land Water Mask

This is an 8-bit integer indicating the surface type at the laser footprint, with

0 = shallow ocean;
1 = land;
2 = coastlines;
3 = shallow inland water;
4 = intermittent water;
5 = deep inland water;
6 = continental ocean;
7 = deep ocean.

NSIDC Surface Type

Snow and ice coverage for the surface at the laser footprint; data obtained from the National Snow and Ice Data Center (NSIDC).

Surface Elevation

This is the surface elevation at the laser footprint, in kilometers above local mean sea level, obtained from the GTOPO30 digital elevation map (DEM).

Lidar Operating Modes

Lidar Mode

This is a 16-bit integer representing the operating mode of the lidar. For all Level 1B data, the lidar mode will have a value of 3, indicating that the lidar is in autonomous data acquisition mode.

Lidar Submode

This is a 16-bit integer representing the operating submode of the lidar. For all Level 1B data, the lidar submode will have a value of 4, indicating that the lidar operating in its normal configuration.

Laser Energy and Instrument Gain Parameters

Parallel Amplifier Gain 532

This is the gain of the variable gain amplifier for the 532 nm parallel channel, in volts per volt.

Perpendicular Amplifier Gain 532

This is the gain of the variable gain amplifier for the 532 nm perpendicular channel, in volts per volt.

Amplifier Gain 1064

This is the gain of the variable gain amplifier for the 1064 nm channel, in volts per volt.

Laser Energy 532

This field reports the laser energy, in Joules, at 532 nm measured by the laser energy monitor for each shot.

Laser Energy 1064

This field reports the laser energy, in Joules, at 1064 nm measured by the laser energy monitor for each shot.

Depolarization Gain Ratio 532

The depolarization gain ratio is the ratio of the opto-electric gains between the 532 perpendicular and the 532 parallel channels. This product is determined from the Polarization Gain Ratio (PGR) mode measurement, in which a pseudo-depolarizer is inserted into the optical path to generate equal backscatter intensities in both the 532 parallel and 532 perpendicular channels (see equation 5.8 in Section 5.1 of the CALIPSO Lidar Level I ATBD (PDF)).

During the first several months of the mission, the depolarization gain ratio has proved to be very stable, with values falling consistently between 1.02 and 1.05. The uncertainty in these measurements due to random noise is estimated to be smaller than 1% (see the Depolarization Gain Ratio Uncertainty 532, immediately below). Possible systematic errors have not yet been quantified; however, these are estimated to be small, and thus the measured depolarization gain ratio is considered highly reliable.

Depolarization Gain Ratio Uncertainty 532

This field reports the uncertainty in Depolarization Gain Ratio Uncertainty 532 due to random noise. Values are computed based on the 532 nm noise scale factors (NSF) using equation 5.15 in Section 5.2 of the Lidar Level I ATBD (PDF). The uncertainty due to systematic errors is not included for this release, but is estimated to be small.

Instrument Characterization

Noise Scale Factor 532 Parallel

This field reports the NSF for each shot for the 532 nm parallel channel. This product is computed from daytime measurements of the Parallel RMS Baseline 532 and the Parallel Background Monitor 532.

Noise Scale Factor 532 Perpendicular

This field reports the noise scale factor (NSF) for each shot for the 532 nm perpendicular channel. This product is computed from daytime measurements of the Perpendicular RMS Baseline 532 and the Perpendicular Background Monitor 532. The theoretical basis for the calculation relies on the fact that the photons from solar background radiation follow a Poisson stochastic process (Liu et al., 2006 (PDF)). The procedure to compute the NSF is described in Section 8 of the Lidar Level I ATBD (PDF).

Noise Scale Factor 1064

This field reports the NSF for the 1064 nm channel. CALIOP does not measure the background signal level at 1064 nm, because the APD detector dark noise is dominant during both nighttime and daytime measurement. For this reason, the procedure to estimate the NSF for the 532 nm channels cannot be used for the 1064 nm channel. The 1064 nm NSF is therefore set to 0 for Version 1.10 of the CALIPSO lidar Level 1 product, which causes negligible error because, as above, the APD detector dark noise is the dominant error source.

Parallel Background Monitor 532

This field reports the background signal, in digitizer counts, for the 532 nm parallel channel.

Perpendicular Background Monitor 532

This field reports the background signal, in digitizer counts, for the 532 nm perpendicular channel. Background signals are measured at very high latitudes, where no backscattering signal will be returned from the atmosphere. Background signals include such things as detector dark current and background radiation signals (e.g., from daytime sunlight). In general, any lidar sample will include both an atmospheric scattering signal and the background signal. The latter is subtracted from lidar samples during data processing. For CALIOP, the background signal is computed on board and subtracted from the lidar data prior to downlink.

Parallel RMS Baseline 532

This field reports the RMS noise, in digitizer counts, of background signal in the 532 nm parallel channel.

Perpendicular RMS Baseline 532

This field reports the root mean square (RMS) noise, in digitizer counts, of the background signals from the 532 nm perpendicular channel The RMS noise is determined on-board for each laser pulse by computing the standard deviation of 1000 15 m samples acquired in the 65-80 km altitude range.

The random error contained in lidar measurements consists of two parts. One is due to the variation in the received laser scattering signal from the atmosphere. The other is due to the variation in the background signal. Both parts have to be taken into account when estimating the random error. The random error arose from the scattering signal can be estimated using the NSF. The random error due to the background signal is the measured RMS noise.

RMS Baseline 1064

This field reports the RMS noise, in digitizer counts, of the background signal in the 1064 nm parallel channel. We note that the *magnitude* of the background signal at 1064 nm is not measured by CALIOP, because this quantity is dominated by the detector dark noise.

Quality Check Flags

QC Flag #1

This is an unsigned 32-bit integer with each bit indicating a specific error condition, as defined by Table 2.

The CALIPSO lidar data are averaged on-board the satellite, prior to being downlinked, using the variable averaging scheme shown in Table 1. Regions 1 and 2 contain single shot data (albeit at different vertical resolutions). In regions 3, 4, and 5, the downlinked data have been averaged to horizontal resolutions of, respectively, 3 shots, 5 shots, and 15 shots. The level 1 processing constructs Pseudo Single Shot Profiles (PSSP) by replicating the data from regions 3, 4, and 5, and then stacking data arrays from the different averaging regions. Two sets of QC flags, as shown in Tables 2 and 3, are computed for each one of these pseudo single shot profiles.

The laser energy assessments reported in QC Flag #1 are computed as follows:

- the laser energies associated with bits 5, 6, 13, and 14 correspond to the laser energies for the genuine single shot portion (i.e., from regions 1 and 2) of each PSSP;
- bits 15-19 are toggled on if any single shot within the horizontally averaged regions of a PSSP falls below the 'near zero energy' threshold; and
- bits 20-24 are toggled on if any single shot within the horizontally averaged regions of a PSSP falls below the 'data quality' threshold.

For example, suppose that (a) the energies for shot #5 in a 15 shot frame fail the data quality threshold tests but are above the 'near zero' threshold; and (b) the energies for all other shots in the frame are normal. In this case, bits 5, 6, 13, and 14 in profiles 1-4 and 6-15 are all set to zero, to indicate acceptable laser energy. In profile #5, bits 5 and 6 are zero (because the energies were above the 'near zero' threshold) and bits 13 and 14 are one (because the energies were below the data quality threshold). Because the averaged data in region 3 of PSSP #4, #5, and #6 was constructed using the low energy data recorded for shot #5, bits 15 and 16 in these three profiles are set to one, whereas in the remaining profiles bits 15 and 16 are set to zero. Similarly, bits 17 and 18 are set to one for PSSP #1 - #5, and bit 19 is set to one for all profiles in the 15 shot frame.

Table 2: Bit assignments for the first QC Flag

Bits	Interpretation
1	532 nm parallel channel missing
2	532 nm perpendicular channel missing
3	1064 nm channel missing
4	Not geolocated
5	Single shot 532 laser energy below calibration threshold (near zero energy)
6	Single shot 1064 laser energy below calibration threshold (near zero energy)
7	Historical value used for the depolarization gain ratio
8	Historical calibration constant used, 532 nm parallel channel
9	Historical calibration constant used, 532 nm perpendicular channel
10	Historical calibration constant used, 1064 nm channel
11	Averaged calibration constant used, 532 nm parallel channel
12	Averaged calibration constant used, 532 nm perpendicular channel
13	Single shot 532 laser energy below data quality threshold (low energy)
14	Single shot 1064 laser energy below data quality threshold (low energy)
15	Near zero 532 nm laser energy profile included in region 3 average
16	Near zero 1064 nm laser energy profile included in region 3 average
17	Near zero 532 nm laser energy profile included in region 4 average
18	Near zero 1064 nm laser energy profile included in region 4 average
19	Near zero 532 nm laser energy profile included in region 5 average
20	Low 532 nm laser energy profile included in region 3

	average
21	Low 1064 nm laser energy profile included in region 3 average
22	Low 532 nm laser energy profile included in region 4 average
23	Low 1064 nm laser energy profile included in region 4 average
24	Low 532 nm laser energy profile included in region 5 average
25-32	Spare

QC Flag #2

This is an unsigned 32-bit integer with each bit indicating a specific error condition, as defined by Table 3. QC Flag #1 contains an explanation of how bits are set for each Pseudo Single Shot Profile (PSSP).

Table 3: Bit assignments for the second QC Flag

Bits	Interpretation
1	Reserve
2	Excessive underflows, 532 nm parallel channel in region 6*
3	Excessive underflows, 532 nm perpendicular parallel channel, region 6*
4	Excessive underflows, 1064 nm channel, region 6*
5	Excessive overflows, 532 nm parallel channel, region 6*
6	Excessive overflows, 532 nm perpendicular parallel channel, region 6*
7	Excessive overflows, 1064 nm channel, region 6*
8	Excessive overflows, 532 nm parallel channel, region 2
9	Excessive overflows, 532 nm perpendicular parallel channel, region 2
10	Excessive overflows, 1064 nm channel, region 2
11	LRE Flags in SAD packet indicate bad data, 532 nm parallel channel
12	LRE Flags in SAD packet indicate bad data, 532 nm perpendicular channel
13	LRE Flags in SAD packet indicate bad data, 1064 nm channel
14	Quality Flags in SAD packet indicate bad data, 532 nm parallel channel
15	Quality Flags in SAD packet indicate bad data, 532 nm perpendicular channel
16	Quality Flags in SAD packet indicate bad data, 1064 nm channel
17	Suspicious offset calculation, 532 nm parallel channel
18	Suspicious offset calculation, 532 nm perpendicular channel
19	Suspicious offset calculation, 1064 nm channel
20	Suspicious mean signal value, 532 nm parallel channel (any/all regions)

21	Suspicious mean signal value, 532 nm perpendicular channel (any/all regions)
22	Suspicious mean signal value, 1064 nm channel (any/all regions)
23	RMS noise out of range, 532 nm parallel channel
24	RMS noise out of range, 532 nm perpendicular parallel channel
25	RMS noise out of range, 1064 nm channel
26-32	Spare

*Region 6 is the baseline subtraction region (see baseline signals in Calibration Constant Uncertainty 532).

Spacecraft Orientation

Off Nadir Angle
This is the angle of the viewing vector of the lidar off the nadir, in degrees. Since the beginning of operations in June 2006, CALIPSO has been operating with the lidar pointed at 0.3 degrees off-nadir (along track in the forward direction) with the exception of November 7-17, 2006 and August 21 to September 7, 2007. During these periods, CALIPSO operated with the lidar pointed at 3.0 degrees off nadir. Beginning November 28, 2007, the off-nadir angle was permanently changed to 3.0 degrees.

Scattering Angle
This is the angle, in degrees, between the lidar viewing vector and the line of sight to the sun.

Solar Azimuth Angle
This field reports the azimuth angle from north of the line of sight to the sun, in degrees.

Solar Zenith Angle
This is the angle, in degrees, between the zenith at the lidar footprint on the surface and the line of sight to the sun.

Viewing Azimuth Angle
This field reports the azimuth angle from north of the lidar viewing vector, in degrees.

Viewing Zenith Angle
This is the angle, in degrees, between the lidar viewing vector and the zenith at the lidar footprint on the surface. This angle is close to Off Nadir Angle in value.

Spacecraft Position and Attitude

Earth-Sun Distance
This field reports the distance from the Earth's surface to the Sun, in AU.

Spacecraft Altitude
This field reports the altitude, in kilometers above mean sea level, of the CALIPSO satellite.

Spacecraft Attitude
This field reports the attitude data, expressed as a set of Euler angles in degrees, of the CALIPSO satellite. The Euler angles represent the rotation between orbital and spacecraft coordinates and expresses as roll, pitch, and yaw angles.

Spacecraft Attitude Rate
This field reports the changes of attitude data, in degrees per second, of the CALIPSO satellite.

Spacecraft Position
This field reports the position, in kilometers, of the CALIPSO satellite. The position is expressed in Earth Centred Rotating (ECR) coordinate system as X-axis in the equatorial plane through the Greenwich meridian, the Y-axis lies in the equatorial plane 90 degrees to the east of the X-axis, and the Z-axis is toward the North Pole.

Spacecraft Velocity
This field reports the velocity, in kilometers per second, of the CALIPSO satellite. The velocity is expressed in Earth Centred Rotating (ECR) coordinate system.

Subsatellite Latitude

This field reports the latitude of the geodetic subsatellite point which is a point on the surface where the geodetic zenith vector (perpendicular to the surface tangent) points toward the satellite.

Subsatellite Longitude

This field reports the longitude of the geodetic subsatellite point which is a point on the surface where the geodetic zenith vector (perpendicular to the surface tangent) points toward the satellite.

Subsolar Latitude

This field reports the latitude of the geodetic subsolar point which is a point on the surface where the geodetic zenith vector (perpendicular to the surface tangent) points toward the sun.

Subsolar Longitude

This field reports the longitude of the geodetic subsolar point which is a point on the surface where the geodetic zenith vector (perpendicular to the surface tangent) points toward the sun.

Metadata Parameters

Product ID

This is an 80-byte character that describes the product name. This parameter has the entry "L1_Lidar_Science".

Date Time at Granule Start

This is a 27-byte character that defines the date and granule start time. The format is yyyy-mm-ddThh:mm:ss.ffffffZ.

Date Time at Granule End

This is a 27-byte character that defines the date and granule end time. The format is yyyy-mm-ddThh:mm:ss.ffffffZ.

Date Time at Granule Production

This is a 27-byte character that defines the date at granule production. The format is yyyy-mm-ddThh:mm:ss.ffffffZ.

Number of Good Profiles

This is a 32-bit integer specifiying the number of good attenuated backscatter profiles contained in the granule.

Number of Bad Profiles

This is a 32-bit integer specifiying the number of bad attenuated backscatter profiles contained in the granule.

Initial Subsatellite Latitude

This field reports the first subsatellite latitude of the granule.

Initial Subsatellite Longitude

This field reports the first subsatellite longitude of the granule.

Final Subsatellite Latitude

This field reports the last subsatellite latitude of the granule.

Final Subsatellite Longitude

This field reports the last subsatellite longitude of the granule.

Orbit Number at Granule Start

This field reports the orbit number at the granule start time.

Orbit Number at Granule End

This field reports the orbit number at the granule stop time.

Orbit Number Change Time

This field reports the time at which the orbit number changes in the granule.

Path Number at Granule Start

This field reports the path number at the granule start time.

Path Number at Granule End

This field reports the path number at the granule stop time.

Path Number Change Time

This field reports the time at which the path number changes in the granule.

Ephemeris Files Used

This is an 160-byte character that reports a maximum of two ephemeris files used in processing the spacecraft position and velocity.

Attitude Files Used

This is an 160-byte character that reports a maximum of two attitude files used in processing the spacecraft attitude and attitude rate.

GEOS Version

This is an 64-byte character that reports the version of the GEOS data product provided by the GMAO.

Percent 532-parallel Bad

This field reports the percentage of bad 532-nm parallel attenuated backscatter profiles contained in the granule.

Percent 532-perpendicular Bad

This field reports the percentage of bad 532-nm perpendicular attenuated backscatter profiles contained in the granule.

Percent 1064 Bad

This field reports the percentage of bad 1064 nm attenuated backscatter profiles contained in the granule.

Percent 532-parallel Missing

This field reports the percentage of missing 532-nm parallel attenuated backscatter profiles in the granule.

Percent 532-perpendicular Missing

This field reports the percentage of missing 532-nm perpendicular attenuated backscatter profiles in the granule.

Percent 1064 Missing

This field reports the percentage of missing 1064 nm attenuated backscatter profiles in the granule.

Cal Region Top Altitude 532

This field reports the top altitude of the 532 nm calibration region.

Cal Region Base Altitude 532

This field reports the base altitude of the 532 nm calibration region.

Lidar Data Altitude

This field defines the lidar data altitudes (583 range bins) to which lidar Level 1 profile products are registered.

Met Data Altitude

This field defines the met data altitudes (33 range bins) at which the ancillary meteorological data are generated.

Rayleigh Extinction Cross-section 532

This field reports the 532 nm Rayleigh extinction cross-section. The value is 5.167e-31 m^2.

Rayleigh Extinction Cross-section 1064

This field reports the 1064 nm Rayleigh extinction cross-section. The value is 3.127e-32 m^2.

Rayleigh Backscatter Cross-section 532

This field reports the 1064 nm Rayleigh extinction cross-section. The value is 5.930e-32 m^2sr^{-1}.

Rayleigh Backscatter Cross-section 1064

This field reports the 1064 nm Rayleigh extinction cross-section. The value is 3.592e-33 m^2sr^{-1}.

Ozone Absorption Cross-section 532

This field reports the 532 nm Ozone absorption cross-section. The value is 2.728461e-25 m^2.

Ozone Absorption Cross-section 1064

This field reports the 1064 nm Ozone absorption cross-section. The value is 0.0.

Data Release Versions

Lidar Level 1B Profiles Information Half orbit (Night and Day) geolocated, calibrated Lidar Profiles and Viewing Geometry Products			
Standard Version			
Release Date	**Version**	**Data Date Range**	**Maturity Level**
April 2013	3.30	March 1, 2013 to present	Validated Stage 1
December 2011	3.02	November 1, 2011 - February 28, 2013	Validated Stage 1
November 2009	3.01	June 13, 2006 - October 31, 2011	Validated Stage 1
June 2009	3.00	Initial release: June 13 - December 31, 2006 and March 12 - June 10, 2009 **No longer orderable**	Validated Stage 1
Expedited Version			
Release Date	**Version**	**Data Date Range**	**Maturity Level**
June 2013	3.30	June 1, 2013 to present	Provisional
January 2013	3.02	January 1, 2013 – May 31, 2013	Provisional

Summary Statement for the release of the CALIPSO Lidar Level 1B, Level 2, and Level 3 Products Version 3.30, April 2013

The Version 3.30 CALIOP Lidar Level 1, Level 2, and Level 3 data products incorporate the updated GMAO Forward Processing – Instrument Teams (FP-IT) meteorological data, and the enhanced Air Force Weather Authority (AFWA) Snow and Ice Data Set as ancillary inputs to the production of these data sets, beginning with data date March 1, 2013.

Impacts on CALIOP data products caused by the transition to GEOS-5 FP-IT are predicted to be minimal, based on a comparison of CALIOP Version 3.02 against CALIOP Version 3.30, summarized below. Additional details are given in the following document: Impacts of Change in GEOS-5 Version on CALIOP Products (PDF).

GEOS-5 Changes and CALIOP Impact Summary:

- **Level 1B nighttime calibration:**
  GEOS-5 molecular number densities in the CALIOP nighttime calibration region increased by roughly 0.6% on average which caused the nighttime calibration coefficients to decrease on average by −0.6%. Since attenuated backscatter is inversely proportional to the calibration coefficient, nighttime attenuated backscatter will increase by 0.6% on average.

- **Level 1B daytime calibration:**
  GEOS-5 molecular number densities in the CALIOP daytime calibration region increased by 0.1% near the equator and increased by up to 0.4 - 0.7% near the poles which caused daytime calibration coefficients to decrease by <-0.2% near the equator and decrease by roughly -0.8% near the poles. Daytime attenuated backscatters will thereby increase by these same magnitudes.

- **Level 2 layer detection:**
  GEOS-5 molecular number densities increased in the CALIOP night and day calibration regions subsequently increasing night and day attenuated backscatters, causing the number of layers detected to increase slightly. For the two months examined, the number of aerosol and cloud layers increased by < 0.8% and < 0.2%, respectively.

- **Level 2 layer classification:**
  GEOS-5 tropopause height decreased by ~1 km at 30°S and 40°N and decreased by 1.5 km over the Antarctic in September 2011. Since CALIOP classifies layers detected above the tropopause as stratospheric features, about 3 - 5% of stratospheric features were instead classified as either cloud or aerosol. These changes are considered minor except in Sep. 2011 over the Antarctic where a 1 - 1.5 km reduction in tropopause height caused 100% of cloud and aerosol layers to be re-classified as stratospheric features. This latter effect may occur seasonally over the Antarctic.

- **Level 3 aerosol extinction and aerosol optical depth:**
  GEOS-5 molecular number densities increased by small amounts in the CALIPSO calibration regions and by smaller amounts at other altitudes, slightly increasing the number of aerosol layers detected and increasing their attenuated backscatter. Consequent small increases in aerosol extinction and aerosol optical depth are much smaller than uncertainties in these parameters.

Data Quality Statement for the release of the CALIPSO Lidar Level 1B Profile Product Version 3.02, December 2011

The CALIPSO Team is releasing Version 3.02 which represents a transition of the Lidar, IIR, and WFC processing and browse code to a new cluster computing system. No algorithm changes were introduced and very minor changes were observed between V 3.01 and V 3.02 as a result of the compiler and computer architecture differences. Version 3.02 is being released in a forward processing mode beginning

November 1, 2011.

Data Quality Statement for the release of the CALIPSO Lidar Level 1B Profile Product Version 3.01, November 2009

Lidar Level 1B Version 3.01 includes corrections to the 532 nm and 1064 nm extinction, backscatter, and ozone cross-sections that were applied in the release of Lidar Level 1B Version 3.00. The data were reprocessed using the corrected values and are being released as Version 3.01.

The following six parameters were added in the file metadata:

- Rayleigh Extinction Cross-section 532
- Rayleigh Extinction Cross-section 1064
- Rayleigh Backscatter Cross-section 532
- Rayleigh Backscatter Cross-section
- 1064 Ozone Absorption Cross-section
- 532 Ozone Absorption Cross-section
  1064

Data Quality Statement for the release of the CALIPSO Lidar Level 1B Profile Product Version 3.00, June 2009

Version 3.00 includes algorithm improvements, modifications to existing data parameters, and new data parameters. The maturity level of Version 3.00 Lidar Level 1B data product is assigned Validated Stage 1. In this stage, all obvious errors have been identified and corrected, and intercomparisons of attenuated backscatter products have been performed at selected locations and times.

Algorithm improvements were implemented for:

- **532-nm daytime calibration**
  The revised 532-nm daytime calibration algorithm produces improved corrections to the thermally-induced drift in signal level that occurs over the course of the daytime orbit segment. In Version 3.00, the empirically determined correction factors are applied using a 34-point linear approximation as compared to the 5-point linear approximation implemented in Versions 2.01 and 2.02. This allows for better characterization of the small scale changes in signal level that take place over the daytime orbit segment. Comparisons of nighttime and newly calibrated daytime clear-air, attenuated scattering ratios over 8-12 km in altitude were made for multiple seasons of LOM 2 (first laser) operation and for the first three months of LOM 1 (backup laser) operation. In all cases the agreement between night and day was within 5% for the entire orbit segment.

- **laser energy calculations and signal normalization by laser energy**
  Two updates to the 532-nm and 1064-nm laser energy calculation algorithm were implemented in Version 3.00 in order to reduce errors in both calibration and the processing of signal profiles for low energy laser shots. The first update uses new laser energy conversion coefficients to improve the accuracy of the laser energy calculation. In the second update, the signal normalization by laser energy is changed to normalize by averaging region instead of by shot. That is, for each averaging region, normalize all averaged shots by the corresponding average energy for that region. Data are averaged on-board over 15, 5, 3, or 1 shot(s) before downlink, with the amount of averaging depending upon the altitude. Application of the new normalization scheme improves the signal normalization for frames with low energy laser shots and has little effect on frames with nominal laser energies.

- **interpolation of GMAO gridded data products to the CALIPSO orbit tracks**
  Corrections were made to the code used to interpolate the GMAO gridded data products to the CALIPSO orbit tracks. In Versions 2.01 and 2.02, two bracketing GMAO files were used to derive meteorological parameters. In some cases, the CALIPSO measurement
  times fell outside of the bracketing file times causing parameters to be extrapolated. In Version 3.00, this problem was rectified by selecting three GMAO files for each orbit track segment. This assures the orbit track times are completely contained within the GMAO data file times.

The modified parameters are:

- **Met_Data_Altitude**
  The altitudes reported in the parameter Met_Data_Altitude were modified so they are now coincident with an altitude reported in the Lidar_Data_Altitude array.

- **QC_Flag and QC_Flag_2**
  The quality flags QC_Flag and QC_Flag_2 were updated to identify the profiles that were normalized using low energy.

New data parameters describe the orbit and path number and are included in the file metadata. The following six parameters were added:

- Orbit_Number_at_Granule_Start
- Orbit_Number_at_Granule_End
- Orbit_Number_Change_Time
- Path_Number_at_Granule_Start
- Path_Number_at_Granule_End
- Path_Number_Change_Time