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Cloud – Aerosol LIDAR and Infrared Pathfinder Satellite Observations (CALIPSO)

Data Description and Quality Summary

Lidar Level 3 Stratospheric Aerosol Data

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CALIPSO Lidar Level 3 Stratospheric Aerosol Data Description Document

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Introduction

The lidar Level 3 (L3) stratospheric aerosol profile product reports monthly mean profiles of aerosol extinction, aerosol backscatter, attenuated scattering ratio and stratospheric aerosol optical depths on a uniform spatial grid of 5° in latitude, 20° in longitude, and 360 m in altitude. Profiles are derived from level 1B attenuated backscatter coefficients ($\beta'(z)$). The product has two components. For the “Background” component, all layers detected in the CALIOP level 2 analyses are removed prior to averaging $\beta'(z)$ profiles, including clouds, aerosols, and polar stratospheric clouds (PSC). For the “All aerosol” component, only clouds and PSCs are removed, thereby retaining $\beta'(z)$ for detected aerosol layers in addition to “Background” $\beta'(z)$. Profiles of aerosol extinction and backscatter are retrieved using a constant extinction-to-backscatter ratio (lidar ratio) of 50 sr. Data harvesting for the stratospheric aerosol profile product is limited to nighttime measurements only, as daytime solar background signals degrade the stratospheric signal-to-noise ratios to unacceptably low levels. A complete description of the retrieval process is given in [Kar et al., 2019](#).

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Additional Documentation

- CALIPSO Data Products Catalog Release 5.00
- Kar, J., K.-P. Lee, M. A. Vaughan, J. L. Tackett, C. R. Trepte, D. M. Winker, P. L. Lucker, and B. J. Getzewich, 2019: CALIPSO Level 3 Stratospheric Aerosol Product: Version 1.00 Algorithm Description and Initial Assessment, *Atmos. Meas. Tech.*, **12**, 6173–6191, <https://doi.org/10.5194/amt-12-6173-2019>.

Glossary and Acronym Dictionary

Term	Meaning
AMSL	above mean sea level
CAD	cloud-aerosol discrimination
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
COTS	commercial off-the-shelf
EOS	Earth Observing System

Term	Meaning
frame	a fundamental data averaging interval used extensively in CALIOP's level 1 and level 2 data processing. A frame consists of 15 consecutive single-shot profiles spanning an along-track distance of ~5 km. 15 shots is the least common multiple of the along-track averaging intervals defined by CALIOP's vertically varying onboard data averaging scheme (Hunt et al., 2009).
granule	continuous data segment in which all measurements were acquired while the lidar was configured for daytime data acquisition only or nighttime data acquisition only; each granule spans approximately one half of a full orbit, with daytime granules being slightly larger/longer than nighttime granules
HDF	Hierarchical Data Format
LEM	low energy mitigation
MERRA-2	Modern-Era Retrospective analysis for Research and Applications, Version 2
N/A	not applicable
PSC	polar stratospheric cloud
QC	quality control/quality assurance
SAA	South Atlantic Anomaly
SAP	Stratospheric Aerosol Product
SDS	scientific data set
SNR	signal-to-noise ratio

Scientific Data Sets: Location

Longitude_Midpoint

Units: degrees_east

Format: Float_32

Valid Range: -180.0, 180.0

Description: Longitude at the latitude/longitude/altitude grid cell midpoint.

Latitude_Midpoint

Units: degrees_north

Format: Float_32

Valid Range: -90.0, 90.0

Description: Latitude at the latitude/longitude/altitude grid cell midpoint.

Altitude_Midpoint

Units: km

Format: Float_32

Valid Range: 8.2, 36.2

Description: Altitude (AMSL) at the latitude/longitude/altitude grid cell midpoint.

Scientific Data Sets: Meteorological Parameters

Tropopause_Height_Mean

Units: km

Format: Float_32

Fill value: -9999.0

Valid range: 5.0, 18.0

Description: The mean tropopause height above local mean sea level within a latitude/longitude grid cell, derived from the MERRA-2 reanalyses.

Potential_Temperature_Mean

Units: K

Format: Float_32

Fill value: -9999.0

Valid range: 300.0, 1250.0

Description: Mean potential temperature within a latitude/longitude/altitude grid cell, calculated from the MERRA-2 reanalyses.

Scientific Data Sets: Counting Statistics

Number_of_Granules

Units: No units

Format: Int_16

Fill value:

Valid range: 0, 451

Description: Number of granules passing through the latitude/longitude grid cell which contribute.

Samples_Accepted_Background

Units: No units

Format: Int_32

Fill Value: -9999.0

Valid Range: 0, 8000

Description: Number of samples within a latitude/longitude/altitude grid cell that pass all quality filtering criteria and thus contribute to the gridded value of the total attenuated backscatter coefficient for the background component.

Samples_Rejected_Background

Units: No units

Format: Int_32

Fill Value: -9999.0

Valid Range: 0, 8000

Description: Number of samples within a latitude/longitude/altitude grid cell that have been rejected by the quality filtering scheme for the background component.

Samples_Accepted

Units: No units

Format: Int_32

Fill Value: -9999

Valid Range: 0, 8000

Description: Number of samples within a latitude/longitude/altitude grid cell contributing to the gridded value of the total attenuated backscatter in the grid cell, for the all aerosol component. This is the number of samples that pass the quality filtering criteria. Figure 1 compares samples accepted to samples rejected for July 2015.

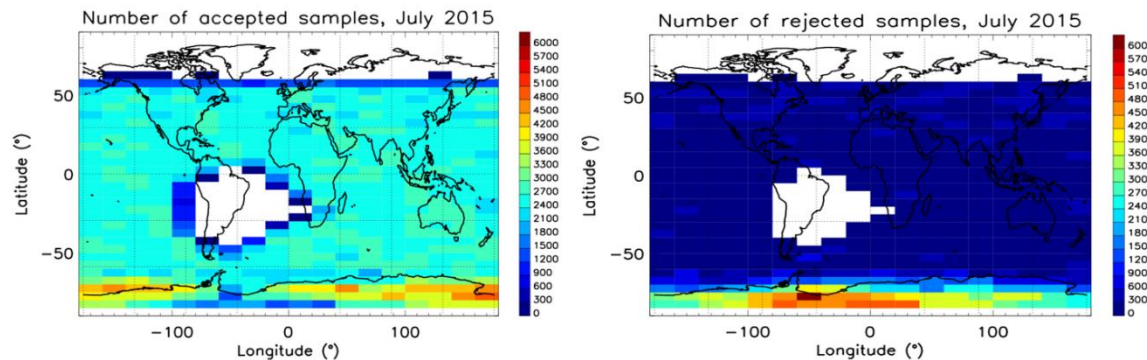


Figure 1: Global distribution of the number of accepted and rejected samples at 18.2 km for July 2015 for the all aerosol component. Data over the SAA region (in white) are not used. Numbers of both accepted and rejected samples are highest over Antarctica because of the orbital geometry.

Samples_Rejected

Units: No units

Format: Int_32

Fill Value: -9999

Valid Range: 0, 8000

Description: Number of samples within a latitude/longitude/altitude grid cell that have been rejected by the quality filtering scheme for the all aerosol component.

Scientific Data Sets: Calibration

Calibration_Coefficient_Mean_532

Units: $\text{km}^3 \times \text{sr} \times \text{J}^{-1} \times \text{Count}$

Format: Float_32

Fill Value: -9999.0

Valid Range: 4.4E10, 6.6E10

Description: Mean 532 nm calibration coefficient within a latitude/longitude grid cell, calculated using all the contributing profiles falling within the grid cell.

Calibration_Coefficient_Standard_Deviation_532

Units: $\text{km}^3 \times \text{sr} \times \text{J}^{-1} \times \text{Count}$

Format: Float_32

Fill Value: -9999.0

Valid Range: 0.0, 5.7E8

Description: Standard deviation of 532 nm nighttime calibration coefficients within a latitude/longitude grid cell, calculated using all the contributing profiles falling within the grid cell.

Samples_Calibration_Coefficient_532

Units: No units

Format: Int_32

Fill Value: -9999.0

Valid Range: 0, 8000

Description: Number of samples used for calculating the calibration coefficient statistics within a latitude/longitude grid cell.

Scientific Data Sets: Background Integrated Optical Properties

Stratospheric_Optical_Depth_Background

Units: No units

Format: Float_32

Fill Value: -9999.0

Valid Range: -0.05, 0.06

Description: Optical depth in the background component, within a latitude/longitude grid cell, calculated by integrating the mean extinction coefficient profile from the uppermost altitude bin (36 km) down to the altitude of the mean tropopause in that grid cell or to the last point above the tropopause if the extinction profile does not extend all the way to the tropopause.

Stratospheric_Optical_Depth_Uncertainty_Background

Units: No units

Format: Float_32

Fill Value: -9999.0

Valid Range: 0.0, 0.02

Description: The uncertainty in the stratospheric optical depth in the background component, within a latitude/longitude grid cell.

Scientific Data Sets: “All Aerosol” Integrated Optical Properties

Stratospheric_Optical_Depth

Units: No units

Format: Float_32

Fill Value: -9999.0

Valid Range: -0.02, 2.00

Description: Optical depth in the all aerosol component, within a latitude/longitude grid cell, calculated by integrating the mean extinction coefficient profile from the uppermost altitude bin (36 km) down to the altitude of the mean tropopause in that grid cell or to the last point above the tropopause if the extinction profile does not extend all the way to the tropopause. The differences between the background only and all aerosol data sets are illustrated in Figure 2, which shows a global comparison for August 2017.

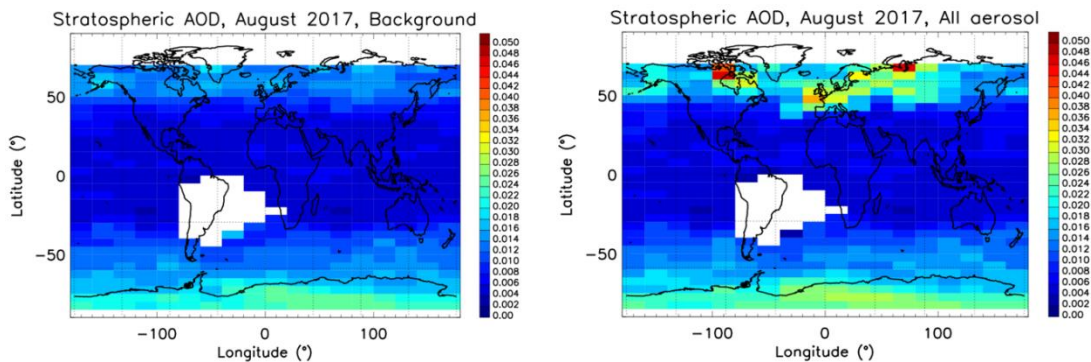


Figure 2: Spatial distribution of stratospheric aerosol optical depth in August 2017 from (left) the background component and (right) the all aerosol component. The signature of the smoke layers from the intense biomass burning in Canada during this month can be seen in the all aerosol component.

Stratospheric_Optical_Depth_Uncertainty

Units: No units

Format: Float_32

Fill Value: -9999.0

Valid Range: 2.4E-2, 0.40

Description: Uncertainty in the stratospheric optical depth in the all aerosol component, within a latitude/longitude grid cell.

Scientific Data Sets: Background Optical Property Profiles

Total_Attenuated_Backscatter_Background

Units: $\text{km}^{-1} \times \text{sr}^{-1}$

Format: Float_32

Fill Value: -9999.0

Valid Range: 0.0, 5.3E-4

Description: Mean of the calibrated total attenuated backscatter coefficients within a latitude/longitude/altitude grid cell for the background component. This is the primary input into the extinction engine, along with the gridded molecular backscatter coefficients and ozone absorption coefficients. Note that we exclude all measurements over the [South Atlantic Anomaly \(SAA\)](#) region because of noise issues ([Noel et al., 2014](#)). For the background mode, all layers detected by the CALIOP level 2 algorithm are removed, which includes aerosol, cloud and polar stratospheric clouds (PSC).

Total_Attenuated_Backscatter_Standard_Deviation_Background

Units: $\text{km}^{-1} \times \text{sr}^{-1}$

Format: Float_32

Fill Value: -9999.0

Valid Range: 0.0, 2.1E-5

Description: Standard deviation of total attenuated backscatter within a latitude/longitude/altitude grid cell for the background component.

Molecular_Backscatter_Background

Units: $\text{km}^{-1} \times \text{sr}^{-1}$

Format: Float_32

Fill Value: -9999.0

Valid Range: 0.0, 5.3E-4

Description: Mean of the molecular backscatter coefficients within a latitude/longitude/altitude grid cell, for the background component, calculated from the MERRA-2 derived molecular densities reported in the CALIOP level 1B files and the theoretical value of the molecular backscatter cross section. The molecular data are gridded using the same number of profiles corresponding to the profiles accepted for gridding the primary input of total attenuated backscatter within a grid cell for the background component.

Molecular_Backscatter_Standard_Deviation_Background

Units: $\text{km}^{-1} \times \text{sr}^{-1}$

Format: Float_32

Fill Value: -9999.0

Valid Range: 0.0, 2.1E-5

Description: Standard deviation of the MERRA-2 derived molecular backscatter coefficients within a latitude/longitude/altitude grid cell, calculated for the background component.

Ozone_Absorption_Coefficient_Background

Units: km^{-1}

Format: Float_32

Fill Value: -9999.0

Valid Range: 0.0, 1.9E-3

Description: Mean of the ozone absorption coefficients within a latitude/longitude/altitude grid cell for the background component. As for the molecular backscatter, ozone absorption is also computed using the ozone density profiles from the MERRA-2 input data and is gridded using the same number of profiles corresponding to the accepted profiles of total backscatter within a grid cell in the background component.

Ozone_Absorption_Coefficient_Standard_Deviation_Background

Units: km^{-1}

Format: Float_32

Fill Value: -9999.0

Valid Range: 0.0, 8.0E-5

Description: Standard deviation of ozone absorption coefficient within a latitude/longitude/altitude grid cell, calculated from meteorological data, for the background component.

Attenuated_Scattering_Ratio_Background

Units: No units

Format: Float_32

Fill Value: -9999.0

Valid Range: 0.30, 1.70

Description: Attenuated scattering ratio is defined as the ratio of the measured attenuated backscatter coefficients to the attenuated backscatter coefficients calculated from the molecular model. This parameter provides the mean attenuated scattering ratio computed in a latitude/longitude/altitude grid cell for the background component.

Attenuated_Scattering_Ratio_Uncertainty_Background

Units: No units

Format: Float_32

Fill Value: -9999.0

Valid Range: 0.03, 0.35

Description: Uncertainties in attenuated scattering ratio calculated within a latitude/longitude/ altitude grid cell in the background component.

Particulate_Backscatter_Background

Units: $\text{km}^{-1} \times \text{sr}^{-1}$

Format: Float_32 $\times \text{sr}$

Fill Value: -9999.0

Valid Range: -1.1E-4, 1.3E-4

Description: Retrieved value of the particulate backscatter within a latitude/longitude/altitude grid cell for the background component.

Particulate_Backscatter_Uncertainty_Background

Units: $\text{km}^{-1} \times \text{sr}^{-1}$

Format: Float_32

Fill Value: -9999.0

Valid Range: 0.0, 4.5E-5

Description: Uncertainties in particulate backscatter in the background component computed in a latitude/longitude/altitude grid cell.

Extinction_Coefficient_Background

Units: km^{-1}

Format: Float_32

Fill Value: -9999.0

Valid Range: -5.4E-03, 6.5E-3

Description: Extinction coefficients in the background component in a latitude/longitude/altitude grid cell obtained from the retrieved particulate backscatter profiles and using a lidar ratio of 50 sr.

Extinction_Coefficient_Uncertainty_Background

Units: km^{-1}

Format: Float_32

Fill Value: -9999.0

Valid Range: 0.0, 2.6E-3

Description: Uncertainties in the extinction coefficients in the background component, in a latitude/longitude/altitude grid cell, computed in the same way as the particulate backscatter uncertainties. This is the primary quality assurance metric for the extinction profiles.

Scientific Data Sets: “All Aerosol” Optical Property Profiles

Total_Attenuated_Backscatter

Units: $\text{km}^{-1} \times \text{sr}^{-1}$

Format: Float_32

Fill Value: -9999.0

Valid Range: 0.0, 6.3E-4

Description: Mean of the calibrated total attenuated backscatter within a latitude/longitude/altitude grid cell for the all aerosol component. This is the primary input into the extinction engine, along with the gridded molecular backscatter and the ozone absorption coefficient. Note that we exclude all measurements over the South Atlantic Anomaly (SAA) region because of noise issues. For the all aerosol component, the clouds and PSCs are removed while the total backscatter from the aerosol layers are retained.

Total_Attenuated_Backscatter_Standard_Deviation

Units: $\text{km}^{-1} \times \text{sr}^{-1}$

Format: Float_32

Fill Value: -9999.0

Valid Range: 0.0, 2.2E-4

Description: Standard deviation of total attenuated backscatter within a latitude/longitude/altitude grid cell for the all aerosol component.

Molecular_Backscatter

Units: $\text{km}^{-1} \times \text{sr}^{-1}$

Format: Float_32

Fill Value: -9999.0

Valid Range: 0.0, 5.3E-4

Description: Mean of molecular backscatter within a latitude/longitude/altitude grid cell, for the all aerosol component, calculated from the MERRA-2 meteorological input data on molecular density given in CALIOP level 1B files and the theoretical value of the molecular backscatter cross section. The molecular data are gridded using the same number of profiles corresponding to the profiles accepted for gridding the primary input of total attenuated backscatter within a grid cell for the all aerosol component.

Molecular_Backscatter_Standard_Deviation

Units: $\text{km}^{-1} \times \text{sr}^{-1}$

Format: Float_32

Fill Value: -9999.0

Valid Range: 0.0, 2.1E-5

Description: Standard deviation of molecular backscatter within a latitude/longitude/altitude grid cell, calculated from the meteorological data, for the all aerosol component.

Ozone_Absorption_Coefficient

Units: km^{-1}

Format: Float_32

Fill Value: -9999.0

Valid Range: 0.0, 1.9E-3

Description: Mean of the ozone absorption coefficient within a latitude/longitude/altitude grid cell, for the all aerosol component. As for the molecular backscatter, ozone absorption is also computed using the ozone density profiles from the MERRA-2 input data and is gridded using the same number of profiles corresponding to the accepted profiles of total backscatter within a grid cell in the all aerosol component.

Ozone_Absorption_Coefficient_Standard_Deviation

Units: km^{-1}

Format: Float_32

Fill Value: -9999.0

Valid Range: 0.0, 9.5E-5

Description: Standard deviation of ozone absorption coefficient within a latitude/longitude/altitude grid cell, calculated from meteorological data, for the all aerosol component.

Attenuated_Scattering_Ratio

Units: No units

Format: Float_32

Fill Value: -9999.0

Valid Range: 0.60, 25.00

Description: Attenuated scattering ratio is defined as the ratio of the measured attenuated backscatter coefficients and the attenuated backscatter coefficients calculated from the molecular model. This parameter provides the mean attenuated scattering ratio computed in a latitude/longitude/altitude grid cell for the all aerosol component.

Attenuated_Scattering_Ratio_Uncertainty

Units: No units

Format: Float_32

Fill Value: -9999.0

Valid Range: 0.03, 5.6

Description: Uncertainties in attenuated scattering ratio calculated within a latitude/longitude/altitude grid cell in the all aerosol component.

Particulate_Backscatter

Units: $\text{km}^{-1} \times \text{sr}^{-1}$

Format: Float_32

Fill Value: -9999.0

Valid Range: -6.2E-5, 0.15

Description: Retrieved value of the particulate backscatter within a latitude/longitude/altitude grid cell for the all aerosol component.

Particulate_Backscatter_Uncertainty

Units: $\text{km}^{-1} \times \text{sr}^{-1}$

Format: Float_32

Fill Value: -9999.0

Valid Range: 0.0, 2.1E-2

Description: Uncertainties in particulate backscatter in the all aerosol component computed in a latitude/longitude/altitude grid cell.

Extinction_Coefficient

Units: km^{-1}

Format: Float_32

Fill Value: -9999.0

Valid Range: -3.2E-3, 7.5

Description: The extinction coefficients in the all aerosol component in a latitude/longitude/altitude grid cell obtained from the retrieved particulate backscatter profiles and using a lidar ratio of 50 sr.

Extinction_Coefficient_Uncertainty

Units: km⁻¹

Format: Float_32

Fill Value: -9999.0

Valid Range: 0.0, 1.56

Description: Uncertainties in the extinction coefficients in the all aerosol component, in a latitude/longitude/altitude grid cell, computed in the same way as the particulate backscatter uncertainties. This is the primary quality assurance metric for the extinction profiles.

Metadata Parameters

Product_ID

Units: No units

Format: Char

Valid range: CAL_LID_L3_Stratospheric_APro

Description: An 80-byte maximum character string specifying the data product name. For the L3 stratospheric aerosol profile this will be "CAL_LID_L3_Stratospheric_APro".

Date_Time_of_Production

Units: No units

Format: Char

Valid range: 4/2006 - 12/2026

Description: A 27-byte character string that specifies the granule UTC start date and time. The format is yyyy-mm-ddThh:nn:ss.ffffffZ, where yyyy is the year, mm is the month, dd is the day, hh is the hour, nn is the minute, ss is the second, and fffffff is the fractional second. Date and time are separated by the character 'T'. The 'Z' indicates that time is given in UTC.

Nominal_Year_Month

Units: No units

Format: Char

Valid range: 200606 – present

Description: A six-digit integer indicating the year and month when data within the level 3 file was measured by CALIPSO in the format yyyyymm, where yyyy indicates the year and mm indicates the month.

Number_of_Level_1_Files_Analyzed

Units: No units

Format: UInt_16

Valid range: 1, 451

Description: This integer field specifies the number of Level 1B files that are included for analysis from this month.

List_of_Level_1_Input_Files

Units: No units

Format: UInt_16

Valid range: 1, 451

Description: This field lists all the nighttime Level 1 files that are used in the analysis for the current month.

List_of_Level_2_5kmMerged_Input_Files

Units: No units

Format: UInt_16

Valid range: 1, 451

Description: This field lists all the corresponding Level 2 5 km merged layer files used in the analysis for the current month.

List_of_Level_2_PSC_Input_Files

Units: No units

Format: UInt_16

Valid range: 1, 31

Description: This field lists all the Level 2 PSC files that are used in the analysis for the current month.

Initial_Aerosol_Lidar_Ratio_532

Units: sr

Format: Float_32

Description: The value of the initial lidar ratio used for extinction retrievals. A constant value of 50 sr is used for all calculations.

Initial_Aerosol_Lidar_Ratio_Uncertainty_532

Units: sr

Format: Float_32

Description: The value of the uncertainty on the initial lidar ratio used for extinction retrievals. A constant value of 10 sr is used for all calculations.

Molecular_Backscatter_Cross_Section

Units: $\text{m}^2 \times \text{sr}^{-1}$

Format: Float_32

Description: The value of the molecular backscatter cross section used in computing the molecular backscatter values.

Molecular_Extinction_Cross_Section

Units: m^2

Format: Float_32

Description: The value of the molecular extinction cross section used to compute the molecular extinction coefficients which in turn are used for the two-way transmission calculations.

Ozone_Absorption_Cross_Section

Units: m^2

Format: Float_32

Description: The value of the ozone absorption cross section used to compute the ozone absorption coefficient which is used in the two-way transmission calculations.

Data Release Information

Release Date	Version	Data Date Range	Production Strategy	Input Products and Versions
October 2025	2.00	June 13, 2006 to June 30, 2023	Standard	V5.00 Level 1B, V5.00 Level 2 5km MLay, V3.00 Level 2 PSC Mask
October 2020	1.01	July 1, 2020 to December 31, 2021	Standard	V4.10 Level 1B, V4.10 Level 2 5km MLay, V1.00 & V1.10 Level 2 PSC Mask
May 2018	1.01	June 13, 2006 to July 31, 2020	Standard	V4.10 Level 1B, V4.10 Level 2 5km MLay, V1.00 Level 2 PSC Mask

Data Quality Information

Data Quality Statement for CALIPSO's Version 2.00 Lidar Level 3 Stratospheric Aerosol Product Release

Version 2.00 (V2) is the first major update of the CALIPSO level 3 stratospheric aerosol product (SAP) since the initial version 1.00 release. An interim version 1.01 was released solely to reflect upgrades made to the operating system used in the CALIPSO computing environment; no changes were made to the underlying science algorithms or data inputs. The V2 SAP introduces a number of significant changes made in response to both data user feedback and the substantial modifications made to the CALIOP level 1 and level 2 version 5.0 (V5) data products. In particular, the V2.0 SAP now accommodates all of the low laser energy mitigation (LEM) strategies introduced in the V5.0 level 1 and level 2 products, which in turn enables reliable V2 SAP production over the course of the entire CALIPSO mission.

Modifications due to low energy mitigation

A new filter has been implemented in the V2 stratospheric aerosol product to remove data affected by low energy laser pulses. The quality of CALIPSO data started degrading starting around 2017 because of low energy laser pulses associated with coronal arcing inside the laser canister ([Tackett et al., 2025](#)). Initially this behavior was limited to the South Atlantic Anomaly region (SAA), but the phenomenon spread globally in later years. This necessitated formulation of a strategy to recover good quality data after removing bad data with the goal of maintaining similar levels of signal-to-noise (SNR) in both the LEM-filtered data and the data unaffected by the low energy pulses. This comprehensive strategy is called the Low Energy Mitigation algorithm (LEM, [Tackett et al., 2025](#)). Several LEM quality control flags are included in the Version 5.0 level 2 files to indicate which level 1B profiles are rejected from level 2 processing due to excessive low energy. The V2 SAP product uses these LEM flags to identify level 1B data that should be excluded from level 3 processing. Because the aerosol signal in the stratosphere is typically weak, additional LEM-related quality control checks are included in level 3 processing to thoroughly avoid data affected by low energy:

The following conditions are required to be met for each 5 km attenuated backscatter profile which is input to the level 3 stratospheric aerosol product.

- 1) All 15 single shot profiles within the 5 km horizontal resolution frame are rejected if there are any low energy shots present within the frame.
- 2) All 15 single shot profiles within the 5 km frame are rejected if the frame is part of a 20 km or 80 km segment where the level 2 LEM algorithm has prohibited feature detection at either of those resolutions due to SNR considerations.

The second condition prevents contamination by possible cloud layers that might be present in these frames, but undetected. Both conditions are implemented simultaneously for the V2 level 3 SAP by using the Low Energy Column QC Flag (a new SDS in the level 2 layer files). This flag is greater than 0 for either of the above conditions and is therefore used to identify and remove bad/low quality data. However, even after implementing LEM for the V2 SAP, there were noisy data remaining over the SAA region with concomitant noisy extinction retrievals over this region. Therefore, data over the SAA region will be excluded from the version 2.0 level 3 stratospheric aerosol product, as was done in V1.00 and V1.01.

Modifications to the Level 2 Polar Stratospheric Cloud mask

The level 2 Polar Stratospheric Cloud (PSC) mask product has undergone several version changes since the last release of the V2 SAP. Versions 1.0 and 1.01 of CALIPSO stratospheric aerosol product used version 1.0 of the PSC mask product to identify and remove all polar stratospheric features. Version 2 of the PSC mask product was a major update that made significant improvements in PSC detection and composition discrimination. The current version 3 of the PSC mask product now adds LEM-like corrections for low energy shots. These version changes in the PSC mask product impact both the background and “all aerosol” modes of the level 3 stratospheric aerosol product. For example, the total number of PSC samples (all compositions) during the May-October, 2009 PSC season over Antarctica increases by ~30%, from 3.26×10^7 in the V1.0 PSC mask to 4.25×10^7 in the V3.00 PSC mask.

Change in vertical resolution

The vertical resolution has been increased to 360 m in version 2.0 in response to user feedback. By contrast, the vertical resolution was 900 m in previous versions. The choice of 900 m was made because the level 1B attenuated backscatter profiles have different vertical resolutions at different altitude ranges: 60 m between 8-20 km, 180 m between 20-30 km, and 300 m between 30-36 km. To achieve a uniform gridding for the level 3 product, the least common multiple of 900 m was used. In version 2.0, the vertical gridding is changed to 360 m. This was achieved by first creating a uniform 60 m vertical grid for the entire altitude range (8-36 km, depending on the tropopause altitude). Level 1B attenuated backscatter was averaged in altitude regions having finer resolution to achieve 360 m resolution and attenuated backscatters were replicated in the altitude range of 30-36 km (five 60 m bins for each 300 m range bins).

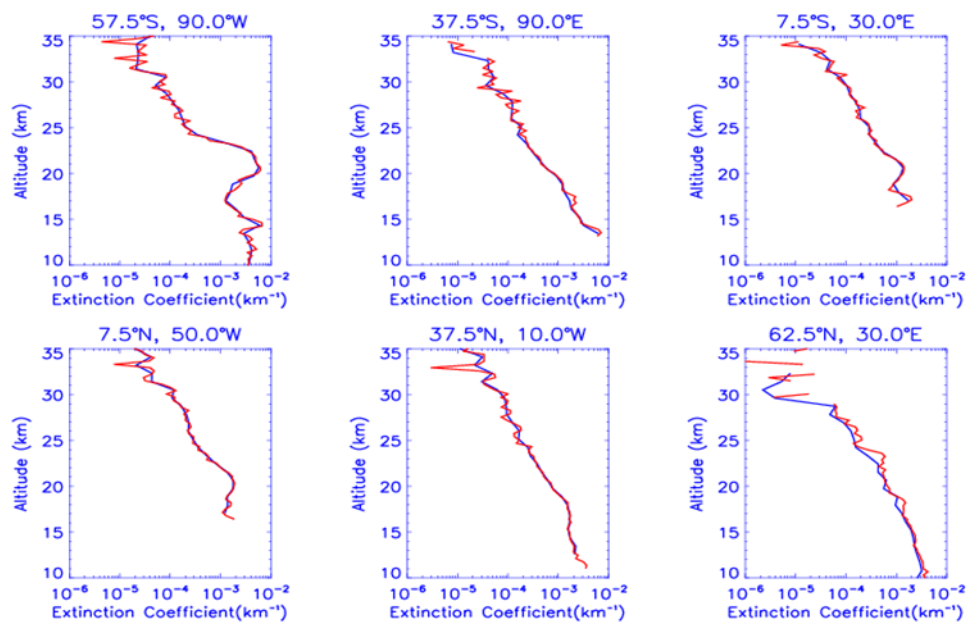


Figure 3: Profiles of aerosol extinction coefficient in the stratosphere in January 2020 at several latitudes (V1.01 in blue and V2.0 in red).

Figure 3 shows the profiles of aerosol extinction coefficients retrieved in the “all aerosol” mode in version 1.01 (blue) and version 2.0 (red) at several locations. The improved vertical resolution in the new version (360 m) sometimes leads to increased noise seen at high altitudes, but otherwise tracks the smooth profile from the older version (900 m). The strong layer near 20-23 km at 57.5°S represents the enhanced aerosol in the stratosphere from the Australian New Year biomass burning event.

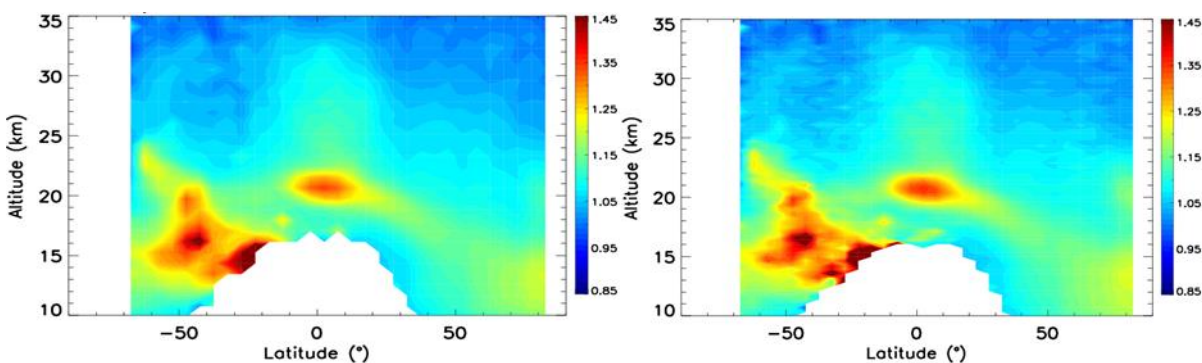


Figure 4: Height-latitude distribution of the attenuated scattering ratio in V1.01 (left panel) and V2.0 (right panel) in January 2020.

Figure 4 shows the height-latitude cross-section of the attenuated scattering ratios from the two versions. Once again, the improved vertical resolution shows up more structures in the new version within the strong pyrocumulonimbus (pyroCb) plume in the southern hemisphere. Further, the plume of aerosol near 20 km centered on the equator is better delineated in version 2.0. This plume is likely signature of the Raikoke volcano which erupted in June 2019 and the aerosols spread to both hemispheres with time.

HDF File Changes

The CALIPSO data products are distributed as Hierarchical Data Format Version 4 (HDF4) files, consistent with the EOS requirement in effect when CALIPSO launched in 2006. Since launch, there have been substantial technological advances in data discoverability and access to resources. To make the V2 SAP data readily accessible to the scientific community beyond the life of the mission, several modifications were made to the format and content of the HDF files. These include:

- All units are updated to conform to [NetCDF Climate and Forecast \(CF\)](#) metadata conventions.
- All array dimensions are named, to allow HDF to netCDF conversions using commercial off the shelf (COTS) tools that currently exist.
- SDS attributes and comments were created/expanded to make the V2 SAP HDF files more self-documenting.

These changes take advantage of newer data access capabilities and are expected to make the V2 SAP data more readily accessible to the scientific community beyond the life of the mission.

Data Quality Statement for CALIPSO’s Version 1.01 Lidar Level 3 Stratospheric Aerosol Product Release

Version 1.01 reflects a change in the data products due to a required upgrade to the operating system on the CALIPSO production computing cluster. The source code for all executables was re-compiled to process in this new environment with no change to the underlying science algorithms or inputs.

Data Quality Statement for CALIPSO’s Version 1.01 Lidar Level 3 Stratospheric Aerosol Product Release

There are five fundamental steps in generating output for the level 3 stratospheric aerosol product.

1. Features detected in the level 2 analyses are removed from the level 1B attenuated backscatter ($\beta'(r)$) depending on the component. The “All aerosol” component removes $\beta'(r)$ for the following layers reported by the CALIOP level 2 products: clouds, stratospheric aerosol with the “Polar Stratospheric aerosol” subtype, and PSCs identified by the PSC mask product, while retaining stratospheric aerosol layers with all other subtypes. The “Background” component removes $\beta'(r)$ for all features reported by the CALIOP level 2, including clouds, aerosols, and PSCs.
2. The $\beta'(r)$ profiles are then averaged to 5 km horizontal resolution.
3. Quality filters are applied next to remove untrustworthy $\beta'(r)$ measurements. Specifically, all data over the South Atlantic Anomaly region is discarded due to high noise. Outliers are eliminated using a spike filter that uses a thresholding scheme similar to the one used in the automatic layer detection scheme in the CALIOP level 2 algorithm (Vaughan et al., 2009). The quality-filtered $\beta'(r)$ profiles from 1 km below the MERRA-2 tropopause height to 36 km are then averaged onto the 5° latitude x 20° longitude x 900 m altitude grid; each gridded-average value is hereafter termed as a “sample”.
4. The gridded data from the single granule are further filtered to remove undetected thin clouds in different ways, depending on the component. For the “Background” component, samples having volume depolarization ratios > 0.05 are rejected. For the “All aerosol” component, samples having attenuated color ratio > 0.5 are rejected to eliminate thin clouds while simultaneously preserving possible ash layers (Vernier et al., 2013). In addition, the “All aerosol” component rejects samples containing detected aerosol layers having | CAD score | < 20 because there is no confidence in cloud-aerosol discrimination. Monthly averaged gridded datasets for attenuated backscatter coefficients, meteorological data, and ancillary data are then created which serve as the inputs to the extinction module in the next step.
5. Aerosol extinction (σ_p), particulate backscatter (β_p), attenuated scattering ratio (R'), and stratospheric aerosol optical depth are then retrieved/calculated from the monthly mean gridded attenuated backscatter profiles. Particulate backscatter is solved from equations (1) and (2):

$$\beta_p(r) = \frac{\beta'(r)}{T_m^2(r) \cdot T_{O_3}^2(r) \cdot T_p^2(r)} - \beta_m(r). \quad (1)$$

$$T_p^2(r) = \exp\left(-2 \cdot S_p \cdot \int_{r_0}^r \beta_p(r') dr'\right). \quad (2)$$

T_m^2 , $T_{O_3}^2$ and T_p^2 refer to the two-way transmittance from the molecules, ozone and particulates respectively and β_m is the modeled molecular backscatter coefficient. T_m^2 and $T_{O_3}^2$ are computed from the meteorological model (MERRA-2) used for CALIOP V4.10 data products.

In order to compute the aerosol extinction coefficient, a lidar ratio is required for stratospheric aerosol. The stratospheric aerosol lidar ratio (S) is given a uniform value of 50 sr, globally for this version. The extinction coefficient is computed subsequently using the equation:

$$\sigma_p(r) = S_p \cdot \beta_p(r). \quad (3)$$

The extinction retrievals are carried out from 36 km in altitude down to 1 km below the tropopause. The stratospheric aerosol optical depth is obtained by integrating the monthly mean aerosol extinction coefficients. Attenuated scattering ratios are computed using equation (4):

$$R'(r) = \frac{\beta'(r)}{\beta_m(r) \cdot T_m^2(r) \cdot T_{O_3}^2(r)}. \quad (4)$$

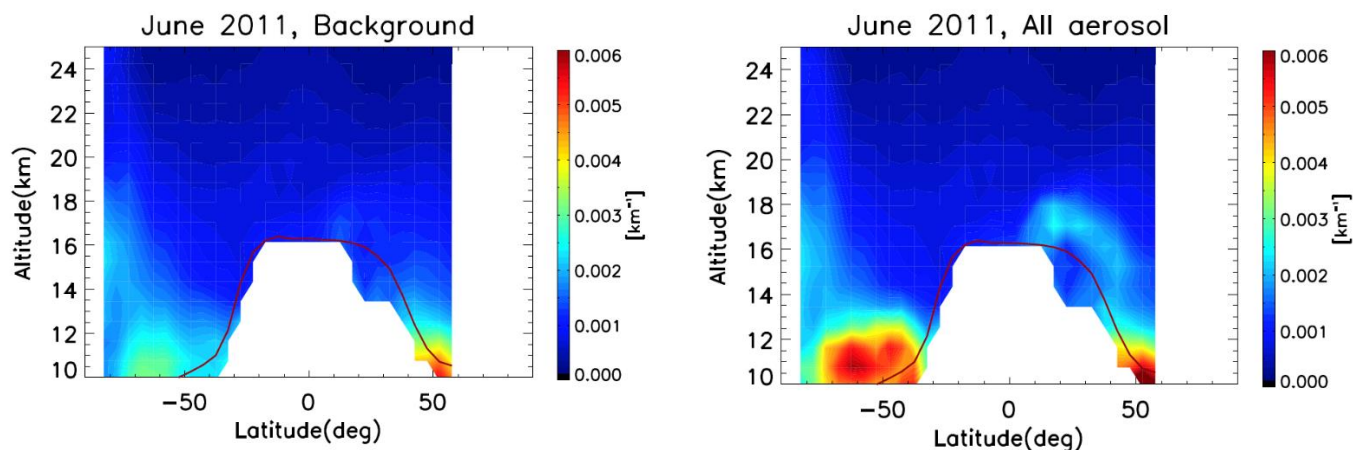


Figure 5: Spatial distribution of the extinction coefficients retrieved in June 2011 in a) background component, and b) all aerosol components.

Figure 5 shows height-latitude cross sections of the aerosol extinction coefficient from the two components for the month of June 2011. During this month two strong volcanic eruptions took place, Nabro in the northern hemisphere (June 13th, 13°N, 41°E) and Puyehue-Cordon Caulle (June 4th, 40°S, 72°W). The composition of Nabro plume was mostly sulfate while the composition of Puyehue-Cordon Caulle was mostly ash (Penning de Vries et al., 2014, Vernier et al., 2013). The background component (Fig. 1a) shows no signature of Nabro and some signature of Cordon Caulle (possibly from aerosol below the layer detection threshold). However, in the all aerosol component (Fig. 1b), signatures of both the volcanoes are captured, with the ash-laden Cordon plumes appearing particularly strong.

Uncertainty estimates are provided for all the retrieved quantities, e.g., particulate backscatter and extinction coefficients. These are the primary quality assurance metrics for this product. Data users are advised to use them for their applications appropriately. The current version uses a constant value of the lidar ratio at all locations and altitudes. This is likely to introduce errors in places where the lidar ratio may vary with altitude. Similarly, the use of constant depolarization ratio and color ratio thresholds for filtering out the thin clouds may not always ensure complete cloud removal.

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