



CALIOP Clear-Sky Constrained Aerosol Extinction Profiles Version 1

User Guide

April 2nd, 2026

How to Cite These Data

As a condition of using these data, it is recommended that you include a citation using the following format:

CAL_MERRA2_ext_05km_V4-5:

Ferrare, R, A (2025). CALIOP Clear-Sky Constrained Aerosol Extinction Profiles MERRA2 Version 1. Hampton, Virginia USA. NASA Atmospheric Science Data Center Distributed Active Archive Center. https://doi.org/10.5067/CALIOP_MODIS_MERRA2/CAL_MERRA2_ext_05km_V4-5_L2.001

CAL_MODIS_DTDB_ext_05km_V4-5:

Ferrare, R, A (2025 CALIOP Clear-Sky Constrained Aerosol Extinction Profiles DTDB Version 1. Hampton, Virginia USA. NASA Atmospheric Science Data Center Distributed Active Archive Center. https://doi.org/10.5067/CALIOP_MODIS_MERRA2/CAL_MODIS_DTDB_ext_05km_V4-5_L2.001

CAL_ODCOD_ext_05km_V4-5:

Ferrare, R, A (2025 CALIOP Clear-Sky Constrained Aerosol Extinction Profiles ODCOD Version 1. Hampton, Virginia USA. NASA Atmospheric Science Data Center Distributed Active Archive Center. https://doi.org/10.5067/CALIOP_MODIS_MERRA2/CAL_ODCOD_ext_05km_V4-5_L2.001

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ASDC User Guide

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USER GUIDE REVISION RECORD

Table 1. User Guide Revision Record

<i>Document Version Number</i>	<i>Date of Change</i>	<i>Summary of Document Updates</i>
1.0	2026-04-02	<i>Initial release of User Guide</i>

DATA DESCRIPTION

Summary

The Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) Clear-Sky Constrained Aerosol Extinction Profiles (CALIOP AEP) collections are Level 2 satellite data products derived from CALIOP attenuated backscatter measurements onboard the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite. These collections improve upon the operational CALIOP V4.51 aerosol extinction retrievals by replacing the traditional lidar ratio approach which introduces systematic uncertainties of ~30–50% with a constrained retrieval method that uses column aerosol optical depth (AOD) from external sources. Three separate collections are produced, each using a different AOD constraint source: MERRA-2 reanalysis (CAL_MERRA2), MODIS Dark Target/Deep Blue (CAL_MODIS_DTDB), and CALIOP Ocean-Derived Column Optical Depth (CAL_ODCOD). The collections are archived at and distributed by the NASA Atmospheric Science Data Center (ASDC) at NASA Langley Research Center.

1.0 COLLECTION OVERVIEW

These three collections provide global, clear-sky aerosol extinction profiles derived from CALIOP lidar backscatter data, constrained by independent column AOD estimates. Traditional CALIOP retrievals depend on assumed lidar ratios (aerosol extinction-to-backscatter ratios) that carry large systematic uncertainties. By substituting column AOD as a constraint, the derived lidar ratio, and subsequently the aerosol extinction profile is directly linked to an independently measured or modeled aerosol optical depth. Validation against over 150 coincident airborne High Spectral Resolution Lidar (HSRL) datasets shows mean RMS differences of 40-60%, consistent with previous studies of constrained retrievals (Burton et al., 2012; Painemal et al., 2019). These results also show nearly twofold reductions in bias and root-mean-square (RMS) errors compared to operational CALIOP V4.51. It is important to note that while these constrained retrievals of aerosol extinction

profiles showed significantly smaller bias and RMS differences than those from CALIOP operational V4.51 retrievals, evaluation of coincident airborne HSRL extinction profiles constrained by AOD measured by HSRL indicates that vertical variability in the lidar ratio causes aerosol extinction profiles constrained by AOD to have RMS differences of 20-30%, on average, when compared to the aerosol extinction profiles directly measured by the HSRL (Burton et al., 2012; Painemal et al., 2019). The data are globally distributed along the CALIPSO ground track and cover both land and ocean surfaces during daytime and nighttime (coverage varies by collection). Key applications include PM2.5 estimation, aerosol direct radiative forcing assessments, and air quality studies. Data are provided in netCDF-4 classic format.

1.1 Collection Identification

	Short Name	Full Title	Version
CAL_MERRA2	CAL_MERRA2_ext_05km_V4-5	CALIOP Clear-Sky Constrained Aerosol Extinction Profiles MERRA2 Version 1	1
CAL_MODIS_DTDB	CAL_MODIS_DTDB_ext_05km_V4-5	CALIOP Clear-Sky Constrained Aerosol Extinction Profiles DTDB Version 1	1
CAL_ODCOD	CAL_ODCOD_ext_05km_V4-5	CALIOP Clear-Sky Constrained Aerosol Extinction Profiles ODCOD Version 1	1

1.2 Collection Introduction

All three collections contain clear-sky aerosol extinction profiles at 5 km horizontal resolution along the CALIPSO satellite ground track. Each profile extends vertically from approximately 22 m to 10,000 m altitude and represents

tropospheric aerosol extinction coefficients (km^{-1}) derived from CALIOP attenuated backscatter measurements. The elemental measurement unit is a CALIOP lidar pulse (along-track profile). The constrained retrieval method derives a single column lidar ratio such that the column-integrated aerosol extinction matches the externally provided column AOD.

- *CAL_MERRA2: Covers daytime and nighttime, land and ocean; 2006–2023.*
- *CAL_MODIS_DTDB: Covers daytime only, land and ocean; 2006–2018.*
- *CAL_ODCOD: Covers daytime and nighttime, ocean only; 2006–2023.*

Processing Level: L2 — Derived geophysical variables at the same resolution and location as L1 source data.

1.3 Objective/Purpose

The overall science objective of the CALIOP AEP project is to produce improved aerosol extinction profiles from CALIOP by leveraging independent, high-quality column AOD estimates to constrain the retrieval, bypassing the largest source of systematic error in CALIOP operational retrievals (i.e., lidar ratio uncertainty of ~30–50%).

Specific objectives include:

- *Providing improved global aerosol extinction profiles for aerosol radiative forcing and direct radiative effect assessments.*
- *Supporting air quality applications such as near-surface PM_{2.5} estimation.*
- *Assessing the feasibility of constrained retrievals as a technique for future spaceborne backscatter lidars (e.g., NASA's Aerosol and Ocean Science, AOS, mission).*
- *Evaluating and comparing multiple AOD constraint methods (MERRA-2, MODIS DT/DB, ODCOD) to quantify their relative advantages in different observing conditions (day/night, land/ocean).*

1.4 File Format and Parameters

- *File Format: netCDF-4 classic*
- *Total Collection File Size: ~480 GB per collection*

Table 2. Science Variable Table

Variable Name	Long Name	Units	Valid Range	Collection
Alt	CALIPSO Lidar_Data_Altitudes from L1-Standard-V4-51	meters	0 to 40,000	CAL_MERRA2 CAL_MODIS_ DTDB CAL_ODCOD
AOD_532_StDev	Standard Deviation of 5km average AOD	unitless	0.0 to 99999.0	CAL_MERRA2 CAL_MODIS_ DTDB CAL_ODCOD
AOD_532_Uncert	ODCOD Effective Optical Depth 532 Uncertainty	unitless	0.0 to 99999.0	CAL_ODCOD
AOD_fract	fraction of valid AOD values in 5km average	unitless	0.066 to 1.0	CAL_MERRA2 CAL_MODIS_ DTDB CAL_ODCOD
Cld_fract	fraction with clouds	unitless	0.0 to 1.0	CAL_MERRA2 CAL_MODIS_ DTDB CAL_ODCOD
Ext	Extinction 532 nm	1/km	-999.0 to 99999.0	CAL_MERRA2 CAL_MODIS_ DTDB CAL_ODCOD
Lat	Latitude	degrees North	-90.0 to 90.0	CAL_MERRA2 CAL_MODIS_ DTDB CAL_ODCOD
lidar_ratio_532	average column aerosol extinction/backscatter (lidar) ratio 532 nm	steradians	-50 to 150	CAL_MERRA2 CAL_MODIS_ DTDB CAL_ODCOD
Lon	Longitude	degrees East	-180.0 to 180.0	CAL_MERRA2 CAL_MODIS_ DTDB CAL_ODCOD
MERRA2_AOD_532	5km average MERRA-2 TOTEXTTAU 550 nm converted to 532 nm using TOTANGSTR	unitless	-999.0 to 99999.0	CAL_MERRA2
MODIS_AOD_Comb_550	5km average MODIS AOD_550_Dark_Target_Deep_Blue_Combined 550 nm	unitless	-999.0 to 99999.0	CAL_MODIS_ DTDB

ODCOD_AOD_532	5km ODCOD_Effective_Optical_Depth_532	unitless	-999.0 to 99999.0	CAL_ODCOD
Strat_AOT	CALIPSO Stratospheric_Optical_Depth 532 nm from LID_L3_Stratospheric_APro	unitless	-999.0 to 99999.0	CAL_MERRA2 CAL_MODIS_DTDB
Time	Time	Hours UTC	0.0 to 24.0	CAL_MERRA2 CAL_MODIS_DTDB CAL_ODCOD

*All variables have a _fillvalue of -999.0 and a 32-bit float data type

1.5 Directory Structure

Files are stored in netCDF-4 classic format and are organized in a flat file structure by granule. Data are accessible via:

S3 (Direct Cloud Access):

- CAL_MERRA2: `s3://asdc-prod-protected/CALIOP/CAL_MERRA2_ext_05km_V4-5_1/yyyy.mm.dd/CAL_MERRA2_ext_05km_V4-5.yyyy-mm-ddThh-nn-ssZx.nc`
- CAL_MODIS_DTDB: `s3://asdc-prod-protected/CALIOP/CAL_MODIS_DTDB_ext_05km_V4-5_1/yyyy.mm.dd/CAL_MODIS_DTDB_ext_05km_V4-5.yyyy-mm-ddThh-nn-ssZx.nc`
- CAL_ODCOD: `s3://asdc-prod-protected/CALIOP/CAL_ODCOD_ext_05km_V4-5_1/yyyy.mm.dd/CAL_ODCOD_ext_05km_V4-5.yyyy-mm-ddThh-nn-ssZx.nc`

1.6 Naming Convention

Table 3. Description of the components of the CALIOP AEP filenames

Product	Filename
CAL_MERRA2	CAL_MERRA2_ext_05km_V4-5.yyyy-mm-ddThh-nn-ssZx.nc
CAL_MODIS_DTDB	CAL_MODIS_DTDB_ext_05km_V4-5.yyyy-mm-ddThh-nn-ssZx.nc
CAL_ODCOD	CAL_ODCOD_ext_05km_V4-5.yyyy-mm-ddThh-nn-ssZx.nc

Variable	Description
CAL	CALIOP instrument
MERRA2 / MODIS_DTDB / ODCOD	AOD constraint source
ext	Extinction product
05km	Horizontal resolution of 5 km
V4-5	Based on CALIOP V4-51
yyyy-mm-ddThh-nn-ssZ	The start date and time of the granule's observation are defined by the following fields: <ul style="list-style-type: none"> • Date: yyyy (year), mm (month), and dd (day). • Separator: The T character is a constant separates the date from the time. • Time: hh (hour), nn (minute), and ss (second). • Time Zone: The Z character is a constant indicating the time is in UTC.
x	Describes lighting conditions for the granule: <ul style="list-style-type: none"> • D: Daytime • N: Nighttime
nc	netCDF format

1.7 Related Collections

These collections are directly related to the CALIOP V4.51 operational aerosol extinction profile product. The key algorithmic difference is that, instead of assigning a lidar ratio based on inferred aerosol type (as in V4.51), these collections derive the lidar ratio by constraining the extinction integral to match an independently measured or modeled column AOD. This results in significantly improved agreement with airborne HSRL measurements relative to V4.51, with ~2× reductions in bias and RMS differences. Users requiring longer temporal coverage over land should consider the CAL_MERRA2 or CAL_MODIS_DTDB collections; users focused on ocean regions should also consider the CAL_ODCOD collection.

2.0 DATA ACQUISITION AND PROCESSING

2.1 Background

The primary data source is CALIOP onboard the CALIPSO satellite. CALIOP is a two-wavelength (532 nm and 1064 nm) polarization-sensitive elastic backscatter lidar. It provides vertical profiles of attenuated backscatter from the surface up to 40 km altitude. CALIOP measurements are well-calibrated to 1–2%, which is critical for constrained retrievals.

Auxiliary AOD data sources differ by collection:

- *CAL_MERRA2: AOD from MERRA-2 (Modern-Era Retrospective analysis for Research and Applications, Version 2), which assimilates AOD from MODIS, MISR, and AERONET.*
- *CAL_MODIS_DTDB: AOD from MODIS Dark Target/Deep Blue (Collection 6) on NASA's Aqua satellite, combining separate algorithms for different surface types.*
- *CAL_ODCOD: AOD from CALIOP Ocean-Derived Column Optical Depth (ODCOD, V4.51), derived from cloud-screened CALIOP surface returns combined with modeled surface wind speed.*

2.2 Acquisition

CALIPSO flies in a sun-synchronous polar orbit as part of the A-Train constellation. CALIOP acquires near-continuous, nadir-pointing lidar profiles along the satellite ground track at ~5 km horizontal sampling and sub-kilometer vertical resolution. Observations are acquired during both daytime and nighttime (with some collection-specific limitations described in Section 1.2). Cloud-free (clear-sky) scenes are identified using CALIOP VFM cloud identification and, where applicable, MODIS and PARASOL cloud screening.

2.3 Instrumentation

2.3.1 Description

CALIOP uses the elastic backscatter lidar technique at 532 nm and 1064 nm. At 532 nm, it measures both parallel and perpendicular polarization components, providing attenuated backscatter and depolarization profiles. The aerosol extinction profiles in these collections are derived at 532 nm.

The constrained retrieval algorithm works as follows:

- 1. Cloud-clear the CALIOP attenuated backscatter profile.*
- 2. Obtain column AOD from the external constraint source (MERRA-2, MODIS DT/DB, or ODCOD).*
- 3. Derive a single column lidar ratio (S_a) such that the column-integrated aerosol extinction from the CALIOP profile equals the constraint AOD.*
- 4. Apply the derived lidar ratio to compute the aerosol extinction profile at each altitude level.*

CALIOP points at nadir (straight down) with a small off-nadir angle ($\sim 3^\circ$) to avoid specular reflection from horizontal ice crystals. No solar/view zenith angle data are required for the aerosol extinction retrieval.

2.4 Processing

- 1. Inputs: CALIOP V4.51 attenuated backscatter profiles (L1B), CALIOP VFM (L2), and the respective AOD constraint source (MERRA-2 / MODIS DT/DB / ODCOD).*
- 2. Cloud Clearing: Cloud-free profiles are identified using CALIOP VFM and additional cloud screening from MODIS (for DT/DB) or HSRL (for validation).*
- 3. AOD Constraint: Column AOD is co-located from the appropriate source to each CALIOP profile.*
- 4. Constrained Retrieval: The aerosol extinction profile is computed iteratively, deriving the lidar ratio so the column extinction matches the AOD.*
- 5. Output: Aerosol extinction profiles in netCDF-4 classic format, archived at ASDC.*

3.0 DATA DESCRIPTION

3.1 Spatial Characteristics

3.1.1 Spatial Coverage

All three collections provide global coverage along the CALIPSO satellite ground track:

- *Latitude: -90° S to 90° N*
- *Longitude: -180° W to $+180^{\circ}$ E*
- *Vertical: 22 m to 10 km altitude*
- *Horizontal resolution: ~ 5 km*
- *Projected Coordinate System: CARTESIAN*

Coverage is limited to clear-sky (cloud-free) scenes along the CALIPSO track.

Ocean-only coverage applies to CAL_ODCOD; CAL_MERRA2 and

CAL_MODIS_DTDB cover both land and ocean.

3.2 Temporal Characteristics

3.2.1 Temporal Coverage

Collection	Start Date	End Date
CAL_MERRA2	2006-06-12	2023-06-30
CAL_MODIS_DTDB	2006-06-12	2018-08-31
CAL_ODCOD	2006-06-12	2023-06-30

CAL_MODIS_DTDB ends in 2018 due to the loss of Aqua MODIS data availability.

Gaps in coverage may occur due to cloud cover (constrained retrievals require clear-sky conditions), satellite maneuvers, or instrument downtime.

Data granules correspond to individual CALIPSO orbits or orbit segments. CALIPSO completes approximately 14–15 orbits per day, revisiting the same location approximately every 16 days.

4.0 QUALITY, ERRORS, AND LIMITATIONS

4.1 Data Quality Summary

These collections have been extensively validated against airborne HSRL-1 and HSRL-2 measurements (NASA Langley Research Center) from approximately 150 coincident under flights of CALIPSO between 2006 and 2022. The HSRL technique at 532 nm provides direct, independent measurements of AOD, lidar ratio, and aerosol extinction profiles.

Key validation results:

- *AOD: Mean bias within 0.02 (10%); RMS differences within 0.08 (40%) for all five constraint methods, all outperforming CALIOP V4.51.*
- *Column Lidar Ratio: Bias within 5 sr; RMS differences within 25–35%.*
- *Aerosol Extinction: Mean bias within 0.01 km^{-1} (10%); RMS differences 40–60%.*
- *Improvement over V4.51: Both bias and RMS errors are reduced by nearly a factor of two relative to operational CALIOP V4.51 retrievals.*

Known Limitations:

1. *Constant lidar ratio assumption: The constrained retrieval assumes a single, vertically constant lidar ratio per profile. When aerosol types with significantly different lidar ratios are layered vertically (e.g., Saharan dust above marine aerosol), the retrieval can be biased high near the surface and low aloft, or vice versa. HSRL-constrained HSRL profiles suggest this leads to RMS differences of 20–30% even with perfect AOD.*
2. *Cloud-free scenes only: These profiles are only produced for cloud-free (clear-sky) columns. Cloudy scenes are excluded.*
3. *Temporal coverage limitations: CAL_MODIS_DTDB is limited to 2006–2018 due to Aqua MODIS availability. CAL_ODCOD and CAL_MERRA2 cover 2006–2023.*

4. *Daytime-only for CAL_MODIS_DTDB: MODIS DT/DB AOD is only available during daytime.*
5. *Ocean-only for CAL_ODCOD: ODCOD is derived from CALIOP ocean surface returns and is not applicable over land.*
6. *AOD accuracy dependence: Retrieval accuracy depends on the accuracy of the constraining AOD. Errors in MERRA-2, MODIS DT/DB, or ODCOD AOD will propagate into the extinction profiles.*

5.0 INVESTIGATORS

5.1 Contact Information

Technical Contact

- Name: Richard A Ferrare
- Affiliation: NASA Langley Research Center
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6.0 SOFTWARE AND TOOLS

Data are distributed in netCDF-4 classic format, readable by standard tools including:

- *Panoply (NASA GISS): Free netCDF viewer for quick visualization.*
- *NASA Earthdata Search: <https://search.earthdata.nasa.gov> — for discovery and download*

7.0 RELATED DATA SETS AND WEBSITES

- *CALIOP V4.51 Aerosol Extinction Profiles (operational): The baseline product that these collections improve upon. Available at ASDC.*
- *MERRA-2 Reanalysis: <https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/>*
- *MODIS Aerosol Products (Aqua, Collection 6): <https://modis-atmosphere.gsfc.nasa.gov/>*
- *CALIPSO Data and Information: <https://www-calipso.larc.nasa.gov/>*
- *ASDC Data Center: <https://www.earthdata.nasa.gov/centers/asdc-daac>*
- *NASA Earthdata Search (CAL_MERRA2): https://search.earthdata.nasa.gov/search/granules?p=C3596722667-LARC_CLOUD*

- *NASA Earthdata Search (CAL_MODIS_DTDB):*
https://search.earthdata.nasa.gov/search/granules?p=C3596722736-LARC_CLOUD
- *NASA Earthdata Search (CAL_ODCOD):*
https://search.earthdata.nasa.gov/search/granules?p=C3596722811-LARC_CLOUD

8.0 CONTACTS AND ACKNOWLEDGMENTS

For data access or technical support, contact:

- *ASDC User Services: support-asdc@earthdata.nasa.gov | <https://www.earthdata.nasa.gov/centers/asdc-daac>*
- *Technical Contact: richard.a.ferrare@nasa.gov*

9.0 GLOSSARY OF TERMS

<i>Term</i>	<i>Definition</i>
<i>AOD</i>	<i>Aerosol Optical Depth: A dimensionless measure of column-integrated aerosol extinction</i>
<i>CALIOP</i>	<i>Cloud-Aerosol Lidar with Orthogonal Polarization: The primary instrument on CALIPSO</i>
<i>CALIPSO</i>	<i>Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations: The NASA/CNES satellite</i>
<i>Constrained Retrieval</i>	<i>A lidar retrieval method that uses an independent column AOD to derive the lidar ratio</i>
<i>DT/DB</i>	<i>Dark Target / Deep Blue: MODIS aerosol retrieval algorithms</i>

<i>HSRL</i>	<i>High Spectral Resolution Lidar: Airborne lidar that directly measures aerosol extinction without assuming a lidar ratio</i>
<i>Lidar Ratio</i>	<i>The ratio of aerosol extinction to aerosol backscatter; varies by aerosol type</i>
<i>MAIAC</i>	<i>Multi-Angle Implementation of Atmospheric Correction: A MODIS aerosol retrieval algorithm</i>
<i>MERRA-2</i>	<i>Modern-Era Retrospective analysis for Research and Applications, Version 2: NASA reanalysis product</i>
<i>ODCOD</i>	<i>Ocean-Derived Column Optical Depth: AOD derived from CALIOP ocean surface returns</i>
<i>RMS</i>	<i>Root Mean Square: A statistical measure of error magnitude</i>
<i>VFM</i>	<i>Vertical Feature Mask: CALIPSO L2 product identifying cloud/aerosol feature types</i>

10.0 ACRONYMS

Term	Collection
<i>AERONET</i>	<i>Aerosol Robotic Network</i>
<i>AOS</i>	<i>Aerosol and Ocean Science</i>
<i>ASDC</i>	<i>Atmospheric Science Data Center</i>
<i>AOD</i>	<i>Aerosol Optical Depth</i>
<i>CALIOP</i>	<i>Cloud-Aerosol Lidar with Orthogonal Polarization</i>
<i>CALIPSO</i>	<i>Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations</i>
<i>DT/DB</i>	<i>Dark Target / Deep Blue</i>
<i>HSRL</i>	<i>High Spectral Resolution Lidar</i>
<i>MAIAC</i>	<i>Multi-Angle Implementation of Atmospheric Correction</i>
<i>MERRA-2</i>	<i>Modern-Era Retrospective Analysis for Research and Applications, Version 2</i>
<i>MISR</i>	<i>Multi-angle Imaging SpectroRadiometer</i>

<i>MODIS</i>	<i>Moderate-Resolution Imaging Spectroradiometer</i>
<i>ODCOD</i>	<i>Ocean-Derived Column Optical Depth</i>
<i>PM2.5</i>	<i>Particulate Matter 2.5 micrometers or smaller</i>
<i>RMS</i>	<i>Root Mean Square</i>
<i>SODA</i>	<i>Synergized Optical Depth or Aerosols</i>
<i>VFM</i>	<i>Vertical Feature Mask</i>

11.0 REFERENCES

Burton, S. P., Ferrare, R., Hostetler, C. A., Hair, J. W., Kittaka, C., Vaughan, M. A., Obland, M. D., R. Curtis Rogers, Cook, A., Harper, D., & Remer, L. A. (2010).

Using airborne high spectral resolution lidar data to evaluate combined active plus passive retrievals of aerosol extinction profiles.

<https://doi.org/10.1029/2009jd012130>

Painemal, D., Clayton, M., Ferrare, R. A., Burton, S. P., Josset, D., & Vaughan, M. (2019). Novel aerosol extinction coefficients and lidar ratios over the ocean from CALIPSO–CloudSat: evaluation and global statistics. *Atmospheric Measurement Techniques*, 12(4), 2201–2217. <https://doi.org/10.5194/amt-12-2201-2019>