CALIPSO Lidar Level 2 Polar Stratospheric Cloud Mask Data Description Document Version 3.00

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Introduction

The CALIPSO Lidar Level 2 Polar Stratospheric Cloud (PSC) data product ensemble describes the spatial distribution, optical properties, and composition of PSC layers observed by the CALIPSO lidar (CALIOP). The product contains profiles of PSC presence, composition, optical properties, and meteorological information along CALIPSO orbit tracks. PSC detection is limited to nighttime CALIOP observations because higher levels of background light during daytime significantly reduce the signal-to-noise and, hence, the PSC detection sensitivity. Each file contains data from all nighttime orbit segments from a single day reported on a 5-km horizontal by 180-m vertical grid. The PSC data ensemble is derived from nighttime only CALIPSO Lidar Level 1B data products.

PSCs form in the cold, polar winter stratosphere when the temperatures fall below ~195 K. Over the Antarctic, the PSC season extends from May through October. Over the Arctic, the PSC season is more variable but may extend from December through March. The PSC Mask data files are therefore only produced for the months May-October (Antarctic) and December-March (Arctic).

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Glossary and Acronym Dictionary

Term	Meaning
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
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
NAT	Nitric Acid Trihydrate
PSC	polar stratospheric cloud
QC	quality control/quality assurance
SAA	South Atlantic Anomaly
SIBYL	Selective Iterated Boundary Locator
STS	supercooled ternary solution

Data Product Descriptions

Number_Of_LIDAR_L1_Files

Units: No Units

Format: Int_16

Valid Range: 1, 15

Description: Number of Lidar Level 1B nighttime orbit files that were used to produce the PSC data product.

Number_Altitudes

Units: No Units

Format: Int_32

Valid Range: 1, 121

Description: Number of standard altitudes in each PSC data product profile.

Number_Profiles

Units: No Units

Format: Int_32

Valid Range: 1, 30000

Description: Number of CALIOP profiles in each daily PSC data product file.

L1_Input_Filenames

Units: No Units

Format: String

Description: List of the names of the Lidar Level 1B nighttime orbit files that were used to produce the PSC data product for this day.

L1_Input_Start_Times

Units: yymmdd.ffffffff

Format: Float_64

Valid Range: 60426.0, 230701.0

Description: Starting times of all the Level 1B nighttime orbit files that were used to produce the PSC data product for this day, reported in Coordinated Universal Time (UTC); format = yymmdd.ffffffff, where yy is a two digit data acquisition year number (06 to 23), mm is a month number (01 to 12), dd is a day number (1 to 31), and ffffffff is the elapsed fraction of the data acquisition day.

L1_Input_End_Times

Units: yymmdd.ffffffff

Format: Float_64

Valid Range: 60426.0, 230701.0

Description: Ending times of all the Level 1B nighttime orbit files that were used to produce the PSC data product for this day, reported in Coordinated Universal Time (UTC); format = yymmdd.ffffffff, where yy is a two digit data acquisition year number (06 to 23), mm is a month number (01 to 12), dd is a day number (1 to 31), and ffffffff is the elapsed fraction of the data acquisition day.

Profile_Time

Units: TAI seconds

Format: Float_64

Valid Range: 4.203E8,9.623E8

Description: Profile time expressed in International Atomic Time (TAI) in elapsed seconds from January 1, 1993.

Profile_UTC_Time

Units: yymmdd.ffffffff

Format: Float_64

Valid Range: 60426.0, 230701.0

Description: Profile time expressed in Coordinated Universal Time (UTC), and formatted as ‘yymmdd.ffffffff”, where ‘yy” represents the last two digits of year, ‘mm” and ‘dd” represent month and day, respectively, and ‘ffffffff’ is the fractional part of the day.

Latitude

Units: degrees north

Format: Float_32

Valid Range: -90.0, 90.0

Description: Geodetic latitude at the center point of the horizontal along-track averaging bin (5, 15, 45, or 135 km).

Longitude

Units: degrees east

Format: Float_32

Valid Range: -180.0, 180.0

Description: Longitude at the center point of the horizontal along-track averaging bin (5, 15, 45, or 135 km).

Altitude

Units: km

Format: Float_32

Valid Range: 8.0, 31.0

Description: Altitudes at which the Level 2 PSC profile products are reported; consisting of 121 levels between approximately 8.3 and 30.1 km, with an interval of approximately 180 m. The altitudes are a subset of the standard lidar Level 1 profile altitudes.

Orbit_Index

Units: No Units

Format: Int_16

Valid Range: 0, 15

Description: Array of orbit indices that can be used to associate each profile from the given day with a discrete orbit number ordered by time. Since there are at most 15 night profiles per day, the orbit index will range between 1 and 15, with the first night orbit assigned as 1 and the last night orbit assigned as 15.

Temperature

Units: K

Format: Float_32

Valid Range: 150.0, 350.0

Description: Temperature reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. Temperature values are interpolated from the ancillary meteorological data provided by the MERRA-2.

Potential_Temperature

Units: K

Format: Float_32

Valid Range: 200.0, 1200.0

Description: Potential temperature reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. Potential temperature values are derived from the ancillary meteorological data provided by the MERRA-2.

Pressure

Units: hPa

Format: Float_32

Valid Range: 1.0, 1000.0

Description: Atmospheric pressure reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. Pressure values are derived from the ancillary meteorological data provided by the MERRA-2.

Vortex_Edge_Outer

Units: degrees north

Format: Float_32

Valid Range: -90.0, 90.0

Description: Distance from the outer edge of vortex, in Equivalent Latitude degrees, reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. Values are derived from the ancillary meteorological data provided in the Aura MLS version 2 (V2) derived meteorological products (Manney et al., 2007; 2011).

Vortex_Edge_Center

Units: degrees north

Format: Float_32

Valid Range: -90.0, 90.0

Description: Distance from center of the vortex edge (defined as maximum in wind speed), in Equivalent Latitude degrees, reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. Values are derived from the ancillary meteorological data provided in the Aura MLS version 2 (V2) derived meteorological products (Manney et al., 2007; 2011).

Equivalent_Latitude

Units: degrees north

Format: Float_32

Valid Range: -90.0, 90.0

Description: Equivalent latitude is a Lagrangian coordinate. Each isoline in a map of equivalent latitude follows the flow velocity and encloses the same area as the latitude line of equivalent value, hence "equivalent latitude." Values are derived from the ancillary meteorological data provided in the Aura MLS version 2 (V2) derived meteorological products (Manney et al., 2007; 2011).

Tropopause_Altitude_MERRA2 (external data)

Units: km

Format: Float_32

Valid Range: 3.0, 25.0

Description: Mean tropopause height in kilometers above local mean sea level. Tropopause height information is based on the MERRA-2 "blended" tropopause altitudes. The MERRA-2 blended tropopause is the lower (in altitude) of the temperature-based ("thermal") tropopause and potential vorticity (PV)-based ("dynamic") tropopause (Bosilovich et al., 2016; Ott et al., 2016).

Parallel_Attenuated_Backscatter_532_Initial

Units: per km per sr

Format: Float_32

Valid Range: 0.0, 0.10

Perpendicular_Attenuated_Backscatter_532_Initial

Units: per km per sr

Format: Float_32

Valid Range: 0.0, 0.05

Description: Parallel and perpendicular attenuated backscatter at 532 nm reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. The initial values of the CALIOP Level 1 parallel component of the 532-nm total attenuated backscatter averaged to 180-m vertical and 5-km horizontal resolution. Profiles of the parallel component of the backscatter are obtained by simple subtraction of the perpendicular component from the total.

Parallel_Attenuated_Backscatter_532

Units: per km per sr

Format: Float_32

Valid Range: 0.0, 0.1

Description: Parallel attenuated backscatter at 532 nm reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. These are the values at resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution).

Parallel_Attenuated_Backscatter_532_Uncertainty

Units: per km per sr

Format: Float_32

Valid Range: 0.0, 0.1

Description: Uncertainty in parallel attenuated backscatter at 532 nm reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. These are the values at resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution).

Perpendicular_Attenuated_Backscatter_532

Units: per km per sr

Format: Float_32

Valid Range: 0.0, 0.05

Description: Perpendicular attenuated backscatter at 532 nm, in units of km^{-1} sr^{-1}, reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. These are the values at resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution).

Perpendicular_Attenuated_Backscatter_532_Uncertainty

Units: per km per sr

Format: Float_32

Valid Range: 0.0, 0.05

Description: Uncertainty in perpendicular attenuated backscatter at 532 nm reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. These are the values at resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution).

Particulate_Depolarization_Ratio_532

Units: No Units

Format: Float_32

Valid Range: 0.0, 1.0

Description: The particulate depolarization ratio reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. The particulate depolarization is defined as the ratio of the perpendicular and parallel polarization components of particulate attenuated backscatter coefficient at 532 nm. The values are reported at the resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution). Note that the particulate depolarization ratio values are not affected by attenuation since both parallel and perpendicular backscatter components experience the same two-way attenuation in the atmosphere.

Particulate_Depolarization_Ratio_532_Uncertainty

Units: No Units

Format: Float_32

Valid Range: 0.0, 99.0

Description: Uncertainty in the particulate depolarization ratio reported for each Level 2 profile at the 121 standard altitudes in the Altitude field.

Total_Attenuated_Scattering_Ratio_532

Units: No Units

Format: Float_32

Valid Range: 0.0, 1.0

Description: Ratio of the total attenuated backscatter at 532 nm to the molecular backscatter at 532 nm, no units, reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. The values are reported at the resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution).

Total_Attenuated_Scattering_Ratio_532_Uncertainty

Units: No Units

Format: Float_32

Valid Range: 0.0, 99.0

Description: Uncertainty in the total attenuated scattering ratio at 532 nm, no units, reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. The values are reported at the resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution).

Total_Attenuated_Backscatter_1064

Units: per km per sr

Format: Float_32

Valid Range: 0.0, 0.1

Description: Total attenuated backscatter at 1064 nm reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. These are the values at resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution).

Total_Attenuated_Backscatter_1064_Uncertainty

Units: per km per sr

Format: Float_32

Valid Range: 0.0, 0.1

Description: Uncertainty in the total attenuated backscatter at 1064 nm reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. The values are reported at the resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution).

Molecular_Backscatter_532

Units: per km per sr

Format: Float_32

Valid Range: 0.0, 0.1

Description: Molecular backscatter at 532 nm reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. These are the values at resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution).

Particulate_Backscatter_532

Units: per km per sr

Format: Float_32

Valid Range: 0.0, 0.8

Description: Retrieved (attenuation-corrected) particulate backscatter at 532 nm reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. These are the values at resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution).

Particulate_Backscatter_532_Uncertainty

Units: per km per sr

Format: Float_32

Valid Range: 0.0, 0.1

Description: Uncertainty in particulate backscatter at 532 nm reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. These are the values at resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution).

Total_Scattering_Ratio_532

Units: No Units

Format: Float_32

Valid Range: 0.0, 1.0

Description: Attenuation-corrected total scattering ratio at 532 nm reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. These are the values at resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution).

Total_Scattering_Ratio_532_Uncertainty

Units: No Units

Format: Float_32

Valid Range: 0.0, 1.0

Description: Uncertainty in total scattering ratio at 532 nm reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. These are the values at resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution).

Perpendicular_Scattering_Ratio_532

Units: No Units

Format: Float_32

Valid Range: 0.0, 1.0

Description: Perpendicular component of the total scattering ratio at 532 nm, no units, reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. These are the values at resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution). It is calculated as the ratio of the attenuation-corrected perpendicular backscatter at 532 nm to the perpendicular molecular backscatter at 532 nm. The perpendicular molecular backscatter is estimated as 0.0366% of the total molecular backscatter.

Perpendicular_Scattering_Ratio_532_Uncertainty

Units: No Units

Format: Float_32

Valid Range: 0.0, 1.0

Description: Uncertainty in the perpendicular component of the total scattering ratio at 532 nm reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. These are the values at resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution).

Perpendicular_Backscatter_532

Units: per km per sr

Format: Float_32

Valid Range: 0.0, 0.5

Description: Perpendicular component of the total backscatter at 532 nm reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. These are the values at resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution).

Perpendicular_Backscatter_532_Uncertainty

Units: per km per sr

Format: Float_32

Valid Range: 0.0, 0.1

Description: Uncertainty in the perpendicular component of the total backscatter at 532 nm reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. These are the values at resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution).

Parallel_Backscatter_532

Units: per km per sr

Format: Float_32

Valid Range: 0.0, 0.5

Description: Parallel component of the total backscatter at 532 nm reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. These are the values at resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution).

Parallel_Backscatter_532_Uncertainty

Units: per km per sr

Format: Float_32

Valid Range: 0.0, 0.2

Description: Uncertainty in the parallel component of the total backscatter at 532 nm reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. These are the values at resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution).

Particulate_Extinction

Units: per km

Format: Float_32

Valid Range: 0.0, 10.0

Description: Retrieved particulate extinction at 532 nm reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. These are the values at resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution). See Pitts et al., 2018 for more detail.

Particulate_Surface_Area_Density_532

Units: square micron per cubic cm

Format: Float_32

Valid Range: 0.0, 350.0

Description: Estimated particulate surface area density reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. These are the values at resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution). See Pitts et al., 2018 for more detail.

Particulate_Volume_Density_532

Units: cubic micron per cubic cm

Format: Float_32

Valid Range: 0.0, 350.0

Description: Estimated particulate volume density reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. These are the values at resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution). See Pitts et al., 2018 for more detail.

Lidar_Ratio_532

Units: sr

Format: Float_32

Valid Range: 0.0, 250.0

Description: Ratio of extinction to backscatter at 532 nm reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. These are the values assumed in the particulate backscatter retrieval and are reported at the resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution).

Multiple_Scattering_Factor_532

Units: No Units

Format: Float_32

Valid Range: 0.5, 1.0

Description: Multiple scattering factor at 532 nm reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. These are the values assumed in the particulate backscatter retrieval and are reported at the resolution of the PSC detection (180-m vertical and 5, 15, 45, or 135-km horizontal resolution). The multiple scattering factor is a function of temperature from a spline fit to results from Garnier et al., 2015.

Retrieval_QC_Flag

Units: km / No Units

Format: Float_32

Valid Range: 8.0, 30.0

Description: Provides information on success of the particulate backscatter retrieval. For a successful retrieval, the reported value is simply the altitude of the measurement. Failed retrievals are reported as a value of -6666 = retrieval did not converge; -7777 = retrieval failed due to calculated molecular backscatter > attenuated backscatter; or -8888 = calculated layer transmission unrealistic. In all cases where the retrieval failed, retrieved quantities have been set to the fill value of -9999.

PSC_Feature_Mask

Units: No Units

Format: Int_16

Valid Range: -350, 350.0

Description: The PSC Feature Mask provides information on the detected PSC layers and also the location of the PSC relative to the tropopause. The reported values are signed integers comprising three significant digits

(PSC_Feature_Mask = $N_1N_2N_3$), defined in table 1 and table 2. Parameter is set to fill (-9999) if missing or bad data.

Table 1: definition of PSC Feature Mask, N_1 component

N_1 = PSC presence flag	
< 0	No cloud detected
> 0	Cloud detected
-1 or 1	$z < z_{tropopause}$
-2 or 2	$z_{tropopause} < z < z_{tropopause} + 4$ km
-3 or 3	$z > z_{tropopause} + 4$ km
0	No tropopause reported

Table 2: definition of PSC Feature Mask, N_2N_3 component

N_2N_3 = Horizontal Averaging Required and Parameter Used for Detection	
01	Detected at 5 km with *R* (Total scattering ratio at 532nm)
02	Detected at 15 km with *R*
09	Detected at 45 km with *R*
27	Detected at 135 km with *R*
02	Detected at 5 km with β'_{perp} (Perpendicular Attenuated Backscatter at 532 nm)
04	Detected at 15 km with β'_{perp}
10	Detected at 45 km with β'_{perp}
28	Detected at 135 km with β'_{perp}

PSC_Composition

Units: No Units

Format: Int_16

Valid Range: -6, 6

Description: PSC composition reports information on the composition of the detected PSC. The composition is determined based on the retrieved lidar optical parameters in terms of unattenuated total scattering ratio and perpendicular backscatter at 532 nm using the algorithm described by Pitts et al., 2018. The valid values for the PSC composition are defined in table 3.

Table 3: interpretation of the PSC_Composition flag

Value	Interpretation
0	No Cloud Detected
1	Liquid Supercooled Ternary (sulfuric acid, water, nitric acid) Solution (STS) droplets
2	Liquid NAT Mixtures: STS + low number densities/volumes of nitric acid trihydrate (NAT) particles
4	Water ice clouds
5	Enhanced NAT Mixtures: STS + high number densities/volumes of NAT particles
6	Wave ice: Mountain wave induced water ice clouds (R > 50)
-1	Composition not determinable; total backscatter < calculated molecular backscatter
-4	Likely tropospheric ice clouds, but pressure level is below (in altitude) lowest valid MLS HNO_3 level of 215 hPa

PSC_Composition_Confidence_Index_Non_Spherical

Units: No Units

Format: Float_32

Valid Range: -20.0, 130.0

Description: Distance (in number of standard deviations) in perpendicular backscatter vs. total scattering ratio optical space between the measured point and the non-spherical composition boundary defined by the Perpendicular Backscatter 532 Threshold value for this measurement point.

PSC_Composition_Confidence_Index_NAT_Ice

Units: No Units

Format: Float_32

Valid Range: -150.0, 40.0

Description: Distance (in number of standard deviations) in perpendicular backscatter vs total scattering ratio optical space between the measured point and NAT/ice composition boundary defined by the PSC_Ice_Mixture_Boundary value for this measurement point.

PSC_Composition_Confidence_Index_STS

Units: No Units

Format: Float_32

Valid Range: 0.0, 30.0

Description: Distance (in number of standard deviations) in perpendicular backscatter vs. total scattering ratio optical space between the measured point and the STS composition boundary defined by the Total_Scattering_Ratio_532_Threshold for that point.

PSC_Ice_Mixture_Boundary

Units: No Units

Format: Float_32

Valid Range: -1.0, 10.0

Description: Value of Total Scattering Ratio at 532 nm (no units) defining the boundary between NAT mixture and ice PSCs, reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. This value is dependent on the amount of available condensable nitric acid and water in the stratosphere (see Pitts et al., 2018 for more detail).

Total_Scattering_Ratio_532_Threshold

Units: No Units

Format: Float_32

Valid Range: 0.0, 5.0

Description: PSC detection threshold in terms of total scattering ratio at 532 nm (no units) reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. The thresholds are calculated daily in five overlapping 100 K-thick potential temperature layers from 400 to 700 K at each of the four successive horizontal averaging scales (5, 15, 45, and 135 km). See Pitts et al., 2018 for more detail.

Perpendicular_Attenuated_Backscatter_532_Threshold

Units: No Units

Format: Float_32

Valid Range: 0.0, 1.0E-4

Description: PSC detection threshold in terms of perpendicular backscatter at 532 nm (no units) reported for each Level 2 profile at the 121 standard altitudes in the Altitude field. The thresholds are calculated daily in five overlapping 100 K-thick potential temperature layers from 400 to 700 K at each of the four successive horizontal averaging scales (5, 15, 45, and 135 km). See Pitts et al., 2018 for more detail.

Number_HNO3_Pressure_Levels

Units: No Units

Format: Int_32

Valid Range: 0, 25

Description: Number of pressure levels reported for each Aura MLS HNO_3 profile.

Number_H2O_Pressure_Levels

Units: No Units

Format: Int_32

Valid Range: 0, 25

Description: Number of pressure levels reported for each Aura MLS H_2O profile.

Pressure_HNO3

Units: hPa

Format: Float_32

Valid Range: 1.0, 500.0

Description: Pressure levels reported for each Aura MLS HNO_3 profile.

Pressure_H2O

Units: hPa

Format: Float_32

Valid Range: 1.0, 500.0

Description: Pressure levels reported for each Aura MLS H_2O profile.

HNO3_Mixing_Ratio

Units: No Units

Format: Float_32

Valid Range: 0.0, 2.0e-8

Description: Profiles of Aura MLS HNO_3 (Manney et al., 2015) mixing ratios derived from the publicly available MLS/Aura Level 2 V4 HNO_3(https://disc.gsfc.nasa.gov/datasets/ML2HNO3_004/summary) data product. These are reported on their standard vertical pressure grid but have been interpolated horizontally to the CALIOP profile locations along each CALIPSO orbit track.

H2O_Mixing_Ratio

Units: hPa

Format: Float_32

Valid Range: 0.0, 8.0e-4

Description: Profiles of Aura MLS H_2O (Lambert et al., 2015) mixing ratios derived from the publicly available MLS/Aura Level 2 V4 H_2O (https://disc.gsfc.nasa.gov/datasets/ML2H2O_004/summary) data product. These are reported on their standard vertical pressure grid but have been interpolated horizontally to the CALIOP profile locations along each CALIPSO orbit track.

Data Release Information

Table 4: dates, versions, and production strategy for all CALIPSO Lidar level 2 PSC Mask data releases

Lidar Level 2 Polar Stratospheric Cloud Mask Information			
Release Date	**Version**	**Data Date Range**	**Production Strategy**
October 2025	3.00	June 13, 2006 to June 30, 2023	Standard
May 2010	2.00	June 13, 2006 to March 21, 2021	Standard
October 2020	1.11	October 1, 2020 to February 20, 2022	Provisional
December 2016	1.01	December 1, 2016 to September 30, 2020	Provisional
October 2013	1.00	June 13, 2006 to November 30, 2016	Provisional

Data Quality Information

Data Quality Statement for the release of the CALIPSO Lidar Level 2 Polar Stratospheric Cloud Product Version 3.00

The CALIPSO Lidar Level 2 Polar Stratospheric Cloud (PSC) Product Version 3.00 is based on analyses of the Version 4.51 lidar level 1B (L1B) data product. The primary change to the Version 3.00 PSC detection and composition algorithm is the mitigation for low laser energies in the input Version 4.51 L1B data. Starting in late 2016 it was observed and publicly reported that there were noticeable increases in the frequency and global distribution of these low energy shots. Although the overall effect on the Polar Stratospheric Cloud Product is thought to be minimal, the low energy shots may induce spurious backscatter values that result in false cloud detections. Therefore, in Version 3.00, L1B data having unusually low laser pulse energies, particularly those observed in the South Atlantic Anomaly (SAA) region, have been effectively filtered out using a low energy mitigation (LEM) algorithm following the approach of Tackett et al., 2025. The LEM algorithm detects and removes low energy laser pulses while accounting for differing on-board averaging regimes (Hunt et al., 2009). This is crucial to accurately account for signals that are averaged differently as a function of altitude, rather than just filtering on a per-profile basis.

Other than the low laser pulse energy mitigation, no significant changes were made to the detection and composition classification Version 2.00 algorithms as described in Pitts et al., 2018. Selected comparisons of the Version 3.00 and Version 2.00 products indicate that the quality of the Version 3.00 products is similar to that of the Version 2.00 products as described below.

Data Quality Statement for the Version 2.00 Release of the CALIPSO Lidar Level 2 Polar Stratospheric Cloud Product

Polar Stratospheric Cloud (PSC) Detection

As described in Pitts et al., 2018, PSCs are detected using a successive horizontal averaging (5, 15, 45, 135 km) procedure similar to the approach used in the standard CALIOP feature detection algorithm (SIBYL; Vaughan et al., 2009). This approach ensures that optically thicker clouds (e.g., ice and fully developed supercooled ternary solution, STS) are found at the finest possible spatial resolution while also enhancing the detection of tenuous PSCs (e.g., low number density NAT mixtures) that are found only through additional averaging. Prior to PSC detection, CALIOP data between 8.3 and 30.1 km are averaged to a common 5-km horizontal by 180-m vertical grid to account for the change in spatial resolution of the Level 1B data products at the 20.2 km altitude. PSCs are then identified as statistical outliers in either the 532 nm attenuated scattering ratio, R'_{532}, or the 532 nm perpendicular attenuated backscatter coefficient, $B'_{\perp}$, relative to the background stratospheric aerosol population. The inclusion of $B'_{\perp}$ is a significant enhancement over the detection approach used in SIBYL that increases the sensitivity to depolarizing, low scattering ratio PSCs and results in an increase in total PSC area of 15% (Pitts et al., 2009). Individual profiles of R'_{532} and $B'_{\perp}$ are scanned from the top altitude (~30.1 km) downward, and a CALIOP observation is assumed to be a PSC if either R'_{532} or $B'_{\perp}$ exceeds a statistical threshold. The thresholds for the background aerosol - assumed to be those data at MERRA-2 temperatures above 200 K - are defined as the daily median plus one median absolute deviation of $B'_{\perp}$ and R'_{532}. These are computed in overlapping 100 K-thick potential temperature (ϑ) layers over the range from ϑ = 250-750 K. Then for a candidate CALIOP data point to be identified as a PSC, its value of $B'_{\perp}$ (or R'_{532}) must exceed the background aerosol threshold by at least its uncertainty, u($B'_{\perp}$) (or u(R'_{532})). We also impose a spatial coherence test that requires that more than 11 of the points in a 5-point horizontal by 3-point vertical box centered on the candidate feature exceed the current PSC detection threshold or to have been identified as a PSC at a previous (finer) averaging scale. This revised approach does a better job overall of capturing PSC clusters identified by the naked eye in CALIOP orbital images while continuing to eliminate false PSC identifications stemming from positive noise spikes in the data. Spot checks of the V2 Antarctic PSC database from early May - when no PSCs observations are expected - indicate that the V2 false positive rate is much less than 0.01%.

Note, the tropopause is often difficult to locate in the polar regions and we make no explicit attempt to distinguish tropospheric cloud from stratospheric cloud in the 8.5-30 km altitude range over which we produce the CALIOP PSC cloud mask. However, we do tag each observation in the database with a feature flag that identifies its altitude location relative to the reported MERRA-2 tropopause as one of three possibilities: (1) below the tropopause, (2) between the tropopause and tropopause + 4 km, or (3) above the tropopause + 4 km. This allows data users to perform some crude separation between tropospheric and stratospheric cloud as desired.

PSCs form in the cold, polar winter stratosphere when the temperatures fall below ~195 K. Over the Antarctic, the PSC season extends from May through October. Over the Arctic, the PSC season is more variable but may extend from December through March. The PSC Mask V2 data files are therefore only produced for the months May-October (Antarctic) and December-March (Arctic).

PSC Composition Classification

CALIOP PSC composition is inferred from the knowledge that enhancements in $B_{\perp}$ are produced by non-spherical PSC particles (NAT or ice), whereas spherical STS PSC droplets produce enhancements in R_{532} but not in $B_{\perp}$. Based on a comparison of $B_{\perp}$ and R_{532} data with temperature-dependent theoretical optical calculations for non-equilibrium mixtures of liquid droplets and prolate NAT or ice spheroids with an aspect (diameter-to-length) ratio of 0.9, CALIOP PSC observations are separated into three major composition classes: STS, liquid-NAT mixtures ("NAT mixtures"), and liquid-ice mixtures ("ice"). There are two additional subclasses: "enhanced NAT mixtures," which capture higher NAT number density; and "wave ice", which are high number density ice PSCs likely triggered by mountain waves. As an example, Fig. 1a shows the distribution of CALIOP Antarctic PSC measurements of 10-18 July 2008 in the $B_{\perp}$ vs. R_{532} coordinate system, with PSC composition class/sub-class boundaries. Figure 1b shows optical calculations presented in the same reference frame assuming 50 hPa atmospheric pressure, 5 ppmv H_2O, and 3 ppbv HNO_3, with instrument noise, which is predominantly shot noise. The V2 algorithm includes improvements to correct a number of known deficiencies in the previous V1 composition classification scheme. The V2 algorithm also incorporates a retrieval of 532-nm particulate backscatter, $B_{\text{particulate}}$, through which $B'_{\perp}$ and R'_{532} are later corrected for attenuation due to overlying particulate layers (i.e. the "primes" are removed), allowing for a more robust comparison with the theoretical results. These improvements are discussed below in context of Fig. 1b, where the theoretical optical results are plotted in the coordinate system $B_{\perp}$ vs. R_{532}, surrogates for the measured attenuated CALIOP quantities $B'_{\perp}$ and R'_{532} used for PSC detection. The following points are to be noted in our revised V2 algorithm:

- The former V1 Mix1 and Mix2 classes of liquid-NAT mixtures have been combined into a single class named "NAT mixtures" for brevity.
- The former V1 Mix2-enhanced class has been renamed "enhanced NAT mixtures" and it is now defined as the sub-class of NAT mixtures with R_{532} > 2 and $B_{\perp}$ > 2×10^{-5} $km^{-1}sr^{-1}$. This conservative boundary was determined

empirically by comparing CALIOP Antarctic PSC data to contemporaneous MIPAS observations with and without a belt of NAT clouds formed by heterogeneous nucleation on wave ice PSCs over the Antarctic Peninsula (Höpfner et al., 2006). MIPAS data from 2008 May 27/28/30 (M. Höpfner, Karlsruhe Institute of Technology, private communication) showed no evidence of these NAT clouds, and only about 2% of CALIOP NAT mixture data from those days had R_{532} > 2 and $B_{\perp}$ > 2×10^{-5} km^{-1}sr^{-1}. In contrast, NAT belt clouds were clearly evident in MIPAS data on 2008 May 29 and 2008 June 01/02, and their locations were matched extremely well by CALIOP NAT mixtures with R_{532} > 2 and $B_{\perp}$ > 2×10^{-5}km^{-1}sr^{-1}. In theoretical terms, CALIOP enhanced NAT mixture points correspond roughly to those NAT mixtures with particle radius r_{NAT} < 3 µm and NAT volume density (VD) > 1.0 µm^{3}cm^{-3}, which match the MIPAS NAT detection limits (r_{NAT} < 3 µm and NAT VD > 0.3 µm^{3}cm^{-3}) reasonably well. Since our criteria defining enhanced NAT mixtures are conservative, the enhanced NAT mixtures sub-class is not all-inclusive, i.e., it does not capture all NAT mixture PSCs heterogeneously nucleated in wave ice PSCs.

- The wave ice class remains the same as in V1, i.e. ice PSCs with R_{532} > 50. We reemphasize that this definition of wave ice is not all-inclusive, i.e. some additional ice PSCs are likely associated with mountain waves, but do not meet our stringent wave-ice classification criterion.
- The dashed horizontal line labeled $B_{\perp,thresh}$ represents qualitatively the CALIOP statistical threshold for detection of PSCs containing non-spherical particles. In practice, this threshold changes with horizontal averaging scale and differs from point to point due to its dependency on $u(B_{\perp})$. Each data point is assigned a non-spherical particle confidence index $CI_{NS} = [B_{\perp}-u(B_{\perp})]/u(B_{\perp})$. Points with CI_{NS} > 1 are presumed to be PSCs containing non-spherical particles.
- The dashed magenta vertical line labeled R_{thresh} represents qualitatively the CALIOP statistical threshold for detection of liquid PSCs. In practice, R_{thresh} also changes with horizontal averaging scale and differs from point to point due to its dependency on $u(R_{532})$. Data points classified as STS are those with $CI_{NS} \leq 1$, but with $R_{532} > R_{thresh}$. Each is assigned an STS confidence index $CI_{STS} = [R_{532} - u(R_{532})]])/u(R_{532})$; $CI_{STS} > 1$.
- Note that in practice, there is not a distinct separation between histograms of $B_{\perp}$ for V2 STS and NAT mixtures. We estimate that 10-15% of data points in either class may fall in the overlap region and thus could be misclassified.
- Points in the grey box at the lower left fall below both CALIOP PSC detection thresholds and are classified as non-features. It should be noted that all measured and derived quantities for non-features are also retained in the V2 data product. A comprehensive discussion of so-called "sub-visible" PSCs can be found in the paper by Lambert et al., 2016, who show that they often can be detected through gas-phase uptake of HNO_3 as observed by MLS even though they are not detectable as PSCs by CALIOP.
- The position of the boundary separating NAT mixtures and enhanced NAT mixtures from ice (labeled $R_{NAT|ice}$) now is calculated dynamically according to the total abundances of HNO_3 and H_2O vapors. $R_{NAT|ice}$ is based on a parameterization of theoretical calculations of R_{532} for fully developed STS (assumed to be points between T_{ice} and T_{ice}-1 K) over a wide range of atmospheric pressures and HNO_3 and H_2O mixing ratios. Total HNO_3 and H_2O abundances are determined on a daily basis as a function of altitude and DMP equivalent latitude based on nearly coincident "cloud-free" Aura MLS data, where the CALIOP PSC data themselves are used to filter out MLS data affected by uptake in the cloud particles. Then each point with CI_{NS} > 1 is assigned a NAT|ice confidence index $CI_{NAT|ice} = (R_{532}-R_{NAT|ice})/u(R_{532})$. For points classified as ice or wave ice, $CI_{NAT|ice} > 0$. For NAT mixtures or enhanced NAT mixtures, $CI_{NAT|ice} < 0$.
- The V2 composition classification extends downward in altitude to the 215 hPa pressure level (~10 km), the lowest reliable level for Aura MLS HNO_3 data that is required to define the location of the NAT mixture/ice boundary ($R_{NAT|ice}$) in our classification scheme. All clouds at altitudes below this pressure level are assumed to be ice.

Assessment

Generally favorable comparisons between CALIOP PSC results and measurements from the MIPAS (Michelson Interferometer for Passive Atmospheric Sounding) instrument on the Envisat spacecraft MIPAS and earlier (V1) CALIOP PSC composition results were found by Höpfner et al., 2009 and more recently by Spang et al., 2016 using a new Bayesian classifier approach. Most recently, Höpfner et al., 2018 found that for coincident PSC scenes classified as predominantly (> 50%) STS by CALIOP, there was good agreement between the magnitudes and vertical profile shapes of CALIOP and MIPAS particle VD. Recent comparisons of CALIOP V2 and MIPAS Bayesian PSC composition classifications for the 2006-2011 overlap period found a high degree of consistency between the datasets.

The near-simultaneous and collocated measurements of gas phase HNO_3 and H_2O by Aura MLS have provided additional validation of the PSC composition inferred from CALIOP data. The basic approach was introduced by Lambert et al., 2012 and involves comparing the observed temperature-dependent uptake of HNO_3 by CALIOP-detected PSCs of different compositions with modeled uptake of HNO_3 for equilibrium STS and NAT. The technique was refined by Pitts et al., 2013, who restricted the CALIOP-MLS comparisons to homogeneous scenes: those with > 75% PSC coverage over the effective MLS measurement volume, with 2/3 of those PSCs identified as a single CALIOP PSC composition. More recent analysis of CALIOP V2 PSC observations and MLS HNO_3 and H_2O data from 2006-2018 (see Fig. 2) show that both STS and ice PSCs are near thermodynamic equilibrium with the gas phase, as expected from theoretical considerations. The ice and STS histogram mode peaks occurring below T_{eq} are consistent with a small cold bias in the MERRA-2 temperature analyses as noted by Lambert et al., 2012 and Lambert and Santee, 2018. The NAT mixture distributions are broader and roughly bimodal with one mode slightly below the NAT equilibrium temperature and a second more populous mode at 3-4 K below NAT equilibrium, which corresponds approximately to the STS equilibrium temperature. As discussed in Pitts et al., 2013, this bimodality is likely a consequence of different exposure times of air parcels to temperatures below T_{NAT}. The mode near the STS equilibrium temperature represents air parcels with relatively brief exposure to temperatures below T_{NAT}. These parcels contain non-equilibrium liquid-NAT mixtures with a detectable enhancement in $B_{\perp}$, but the uptake of HNO_3 is dominated by the much more numerous liquid droplets at the lower temperatures. The NAT mixture mode near the NAT equilibrium temperature corresponds to parcels that have been exposed to temperatures below T_{NAT} for extended periods of time, allowing a larger fraction of the gas-phase HNO_3 to condense onto the thermodynamically-favored NAT particles and bringing the mixture closer to NAT equilibrium. These composite histograms, which incorporate over 12 years of CALIOP PSC measurements, demonstrate behavior consistent with theoretical expectations for each composition class, providing confidence that the V2 composition classification scheme is robust.

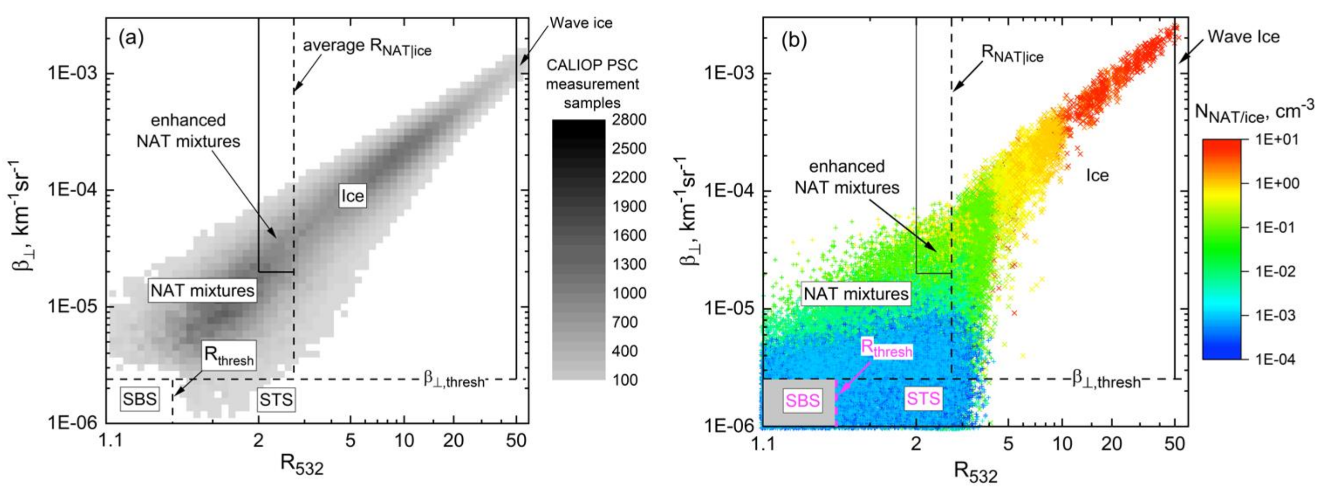

Figure 1: (a) 2-D histogram of CALIOP Antarctic PSC data for 10-18 July 2008 at latitudes 65-75° S and potential temperatures (θ) 475-525 K. (b) Theoretical optical calculations for non-equilibrium liquid–NAT and liquid–ice

mixtures. The dashed and grey boxes at the lower left represent points that fall below both CALIOP V2 PSC detection thresholds and are classified as non-PSCs, i.e. supercooled binary solution (SBS) background aerosol.

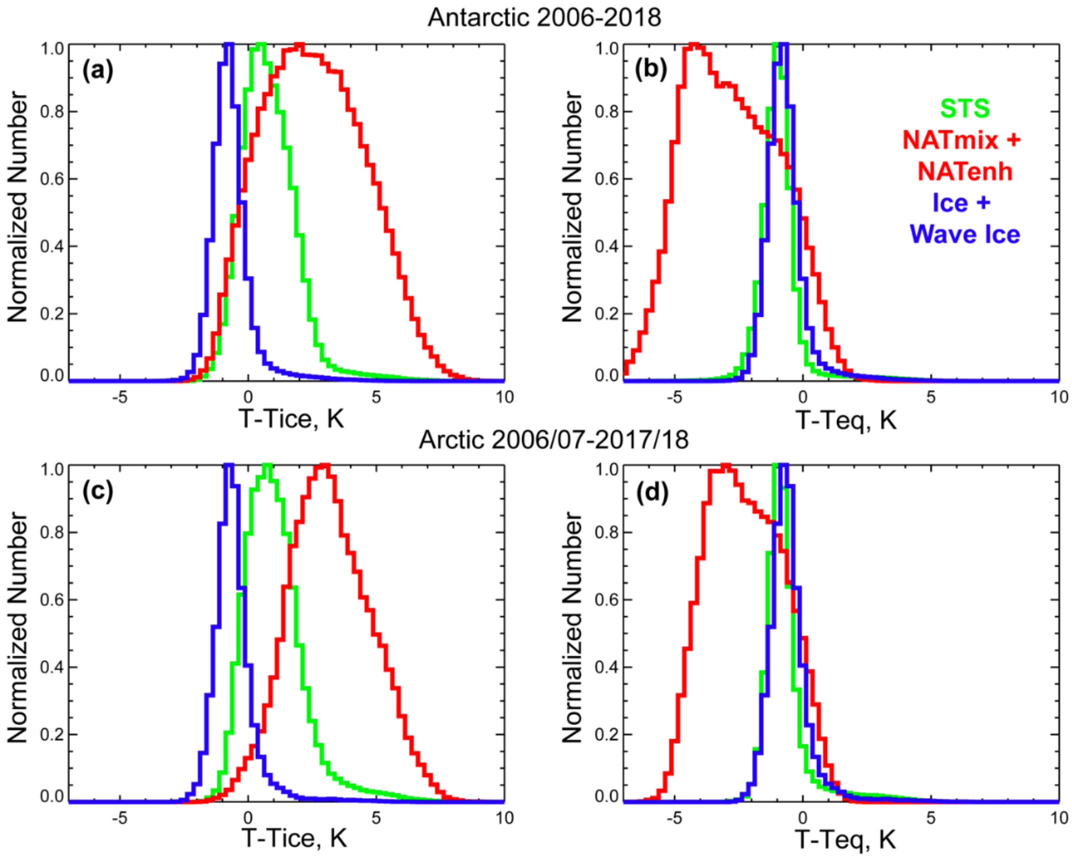

Figure 2: Histograms of CALIOP V2 PSC observations by composition at 21 km altitude from 13 Antarctic and 12 Arctic winters as a function of (a, c) T - Tice and (b, d) T - Teq, where T is the ambient temperature at CALIOP/MLS observation points interpolated from MERRA-2 gridded analyses and T_{eq} is equal to T_{ice}, T_{NAT} or T_{STS} (depending on the respective composition class) calculated using MLS gas-phase H_2O and HNO_3 data. Green = STS; red = NAT mixtures + enhanced NAT mixtures; and dark blue = ice + wave ice. Updated from Pitts et al., 2018.

Data Quality Statement for the Version 1.11 Release of the CALIPSO Lidar Level 2 Polar Stratospheric Cloud Product

Version 1.11 reflects a change in the data products due to a required upgrade to the operating system on the CALIPSO production cluster. All algorithms were re-compiled to process in this new environment with no change to the underlying science algorithms or inputs.

Data Quality Statement for the Version 1.10 Release of the CALIPSO Lidar Level 2 Polar Stratospheric Cloud Product

Version 1.10 reflects a transition of the Global Modeling and Assimilation Office (GMAO) Forward Processing – Instrument Teams (FP-IT) meteorological data version from 5.9.1 to 5.12.4.

Data Quality Statement for the Version 1.00 Release of the CALIPSO Lidar Level 2 Polar Stratospheric Cloud Product

The CALIOP Level 2 PSC data product ensemble consists of the PSC feature mask, composition flag, and optical properties reported on a uniform 5-km horizontal and 180-m vertical grid. Validation of the Level 2 PSC products is an on-going process. In the absence of simultaneous in situ particle observations, the CALIOP PSC detection and composition classification scheme can only be evaluated through comparison with other remote measurements that provide information on particle composition. All studies to date indicate that, with a few notable exceptions, the PSC detection and composition algorithms are performing well. We have a good understanding of the cause of the minor misclassifications that do occur and are planning to correct these minor deficiencies in our next data release.

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