CALIOP_CLOUDSAT_MODIS_25KM ATBD

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Merged CloudSat-CALIPSO-MODIS data for aerosol-cloud interactions studies

Version 1.0

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Key Points:

- This document provides a description of the dataset used in the article Li et al. (2026) published in Atmospheric Chemistry and Physics.
- Dataset includes cloud and aerosol retrievals from CloudSat, CALIPSO, and MODIS (on Aqua) at 25-km spatial resolution.
- The products are mainly intended for replicating the results in Li et al. (2026).

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1 Introduction

This ATBD provides a description of the dataset generated to conduct the research for the paper titled "Advancing the quantification of aerosol-cloud interactions with the CALIPSO-CloudSat-Aqua/MODIS record" by Li et al. (2026), published by Atmospheric Chemistry and Physics. The merged files combine products from CloudSat, the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO), and The MODerate resolution Imaging Spectroradiometer (MODIS) based on the algorithms developed for the Clouds and the Earth's Radiant Energy System (CERES). The dataset is made available to facilitate interested individuals to replicate the analysis reported in Li et al. (2026). Any use beyond the scope of Li et al. (2026) should be informed to Dr. David Painemal (david.painemal@nasa.gov).

Keywords: aerosol-cloud interactions, MODIS cloud properties, CALIPSO aerosol

2 ATBD Version Description

"This is Version 1.0 of "CALIOP_CLOUDSAT_MODIS_25KM quantification of aerosol-cloud interactions"

3 Overview and Background Information

3.1 Historical Perspective

The methods and algorithms were intended to support the research conducted by Drs. David Painemal and Zhujun Li in the context of the NASA funded project titled: "*New observational constraints for evaluating aerosol-cloud interactions with the use of vertically resolved CALIPSO aerosol properties".*

4 Algorithm Description

4.1 Methods

We combine the different products into a spatial resolution and data screening that enable the analysis in Li et al. (2026). Cloud retrievals are limited to boundary layer clouds, defined as samples with cloud tops below 3 km. In addition, vertically resolved aerosol retrievals from merged CALIPSO and the Synergized Optical Depth of Aerosols (SODA) aerosol extinction coefficient (σ_{ext}) are only reported for 3 vertical levels: near-surface (SFC), cloud-level (CL), and free troposphere (FT). Near-surface σ_{ext} (σ_{ext}^{SFC}) is estimated as the vertical average value between the height 43 m and 343 m above the sea level. Cloud-level average σ_{ext} (σ_{ext}^{CL}) is computed as the

average for the 300-m layer between 360 m and 60 m below the mean CALIOP cloud top height. Free tropospheric σ_{ext} (σ_{ext}^{FT}) is the 300-m layer average between the altitude 60 m and 360 m above the mean CALIPSO cloud top height.

The data matching methodology follows Painemal et al. (2020) and is designed to combine datasets with different spatial resolutions, as well as to reduce potential sources of uncertainties that could otherwise impact joint aerosol-cloud analysis. Briefly, the matching is conducted for individual 25-km segments along the CALIPSO ground track (Fig. 1), with the goal of creating a dataset of MODIS, CALIPSO's Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP), and CloudSat retrieval aggregated to a 25-km resolution.

We start by averaging the CALIPSO cloud height to yield a single value per 25-km segment, with values retained for averages constructed with at least 20 % of cloudy observations for the 25-km scanning line to guarantee a significant number of samples in the computation of cloud top height. Next, cloud-free CALIOP-S aerosol extinction coefficients at 5-km resolution are spatially averaged over the same 25-km segment. Lastly, the closest CloudSat Cloud Profiling Radar (CPR) pixels to the 25-km line are combined to derive a probability of precipitation (POP) defined as the fraction of precipitating pixels of the total cloudy pixels within the segment, with precipitation defined for samples with Z_{max} greater than -15 dBZ.

Considering that cloud retrievals come from MODIS, we take a number of steps to reduce retrieval biases. We first match MODIS pixels with the 5-km CALIPSO pixel (Fig. 1 yellow block) by using 5-pixel x 5-pixel MODIS boxes, with 2 boxes east and 2 boxes west of the CALIPSO ground-track (Figure 1, gray squares). Second, for each of these MODIS data boxes, the 5-km^2 low-cloud fraction is calculated as the number of liquid phase cloudy points with cloud top heights of less than 3 km divided by the total number of points. Third, the 20 5x5 MODIS boxes are individually averaged and averaged boxes with cloud fraction greater or equal than 80% are retained for future averaging. Then, the averaged MODIS boxes centered along the 25-km CALIPSO track segment are finally averaged to produce a single cloud value collocated at the 25-km CALIPSO along-track resolution. At this resolution, averaged MODIS data are used in the analysis when the solar zenith angle is less than 65° and the mean cloud optical depth is greater than 2.0, which helps reduce uncertainties in optically thin clouds. Lastly, we only analyzed samples with CALIOP-S AOD greater than 0.05 to reduce uncertainties in the derivation of very low AOD (Painemal et al., 2019). A final threshold applied to the 25-km aggregated data corresponds to limiting the analysis to MODIS grids with low-cloud fraction equal to or less than 90%. This upper limit enables the removal of 25-km grids with aerosols fully embedded in cloudy regions, which are more severely affected by aerosol swelling in areas with peaks in humidity (Painemal et al., 2020).

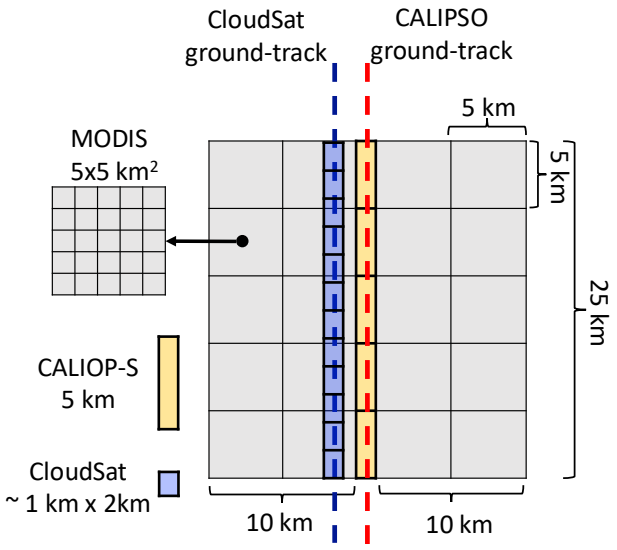

Figure 1: Spatial collocation of the 3 datasets along a 25-km CALIPSO along-track segment. CloudSat footprints are being represented without oversampling. CALIPSO CALIOP-S cross-track footprint is less than 100 m.

4.2 Algorithm Input Variables

Four main products are combined to generated the output variables.

- CloudSat: 2B-GEOPROF Release 05 product (https://www.cloudsat.cira.colostate.edu/data-products/2b-geoprof)
- CALIPSO: LID_L2_01kmCLay-Standard product, CAL_LID_L1-Standard-V4-51. https://subset.larc.nasa.gov/calipso/ , Synergized Optical Depth of Aerosols https://www.icare.univ-lille.fr/soda/. The derivation of aerosol extinction coefficient and lidar ratio follow the methodology in Painemal et al. (2019).
- CERES MODIS Edition 4 cloud products https://ceres.larc.nasa.gov/

4.3 Algorithm Output Variables

Table 3. *Variables provided by this dataset*

Name	Long name	Unit
LAT	MODIS Latitude of instrument field of view at surface	degree
LON	MODIS Longitude of instrument field of view at surface	degree
TIME	MODIS Time of observation (UTC) in fractional hour of the day	hours
CALIOP_LAT	CALIOP latitude	degree
CALIOP_LON	CALIOP longitude	degree
CALIOP_TIME	CALIOP hour in fractional hour of the day	hour
CALIOP_SZA	CALIOP solar zenith angle	degree
CALIOP_TOTAL_CTH	Total mean cloud top height	km
CALIOP_TOTAL_CF	Cloud fraction derived from 1-km data	Unitless, values between 0 and 1.0
CALIOP_SFC_WATER_FRAC	fraction of surface identified as water	Unitless, values between 0 and 1.0
CALIOP_LOW_CTH	Mean cloud top height for samples lower than 3km	km
CALIOP_LOW_CF	Cloud fraction derived from 1-km data below 3km height	Unitless, values between 0 and 1.0
SODA_AOD532nm	SODA AOD at 532nm	unitless
SODA_LR1_532nm	532-nm SODA lidar ratio estimated using 1-layer method	Sr

SODA_AE	Angstrom exponent calculated from SODA AOD -log(aod532/aod1064) / log(532./1064.)	unitless
SODA_EXT_SURF	Mean 532-nm SODA aerosol extinction coefficient for 300m thick surface layer beginning ~60 m above surface	Km^{-1}
SODA_EXT_CLD	Mean 532-nm SODA aerosol extinction coefficient for 300m thick layer below ~60m below low cloud top	Km^{-1}
SODA_EXT_BL	Mean 532-nm SODA aerosol extinction coefficient from ~60 m above surface to ~60 below low cloud top	Km^{-1}
SODA_EXT_ABOVE	Mean 532-nm SODA aerosol extinction coefficient for 300 m thick layer from ~60 m above the low cloud top	Km^{-1}
SODA_EXT_FREE	Mean 532-nm SODA aerosol extinction coefficient for 1020 m thick layer from 60 m above the low cloud top	Km^{-1}
modis_lowcf_filter	The minimum number of low cloud points in 5x5 MODIS pixel box for calculating MODIS cloud properties	
view_zenith_angle	MODIS instrument viewing zenith angle at surface	degree
relative_azimuth_angle	MODIS instrument relative azimuth angle at surface	degree
cloud_mask_category	MODIS cloud-mask category; most common value in the 25km segment	
cloud_water_path_37um	MODIS cloud water path (from the 3.7 micron particle	$g\ m^{-2}$

	size retrieval)	
cloud_top_pressure	MODIS cloud top pressure	hPa
cloud_top_temperature	MODIS cloud top temperature	K
cloud_top_height	MODIS cloud top height	km
cloud_particle_radius_21um	MODIS cloud particle radius (from the 2.1 micron particle size retrieval). Experimental product, do not use it.	microns
cloud_particle_radius_37um	MODIS cloud particle radius (from 3.7 micron particle size retrieval)	microns
cloud_particle_phase_37um	MODIS cloud particle phase (from 3.7 micron particle size retrieval); most common value in the 25km segment	Unitless, ice or liquid phase
cloud_optical_depth	MODIS cloud visible optical depth	unitless
cloud_droplet_number	MODIS droplet number concentration	cm^{-3}
modis_cf_low	MODIS liquid low cloud fraction from number of low cloud (MODIS cloud top height<3km) points in the 5*4*25 points within the 25 km segment	Unitless, values between 0 and 1.0
modis_cf_tot	MODIS total cloud fraction from number of total cloud points in the 5*4*25 points within the 25 km segment	Unitless, values between 0 and 1.0
cloudsat_total_cf	CloudSat cloud fraction as the cloudy points in 25.3km segment	Unitless, values between 0 and 1.0
cloudsat_low_cf	CloudSat cloud fraction as the cloudy points with CTH<3000m in 25.3km	Unitless, values between 0 and 1.0

	segment	
cloudsat_drizzle_frac	CloudSat drizzle fraction as the number of points with -7>=maxdbz>-15 and cth<3000m / total number of CTH<3000m in the 25.3km segment	Unitless, values between 0 and 1.0
cloudsat_light_rain_frac	CloudSat light rain fraction as the number of points with 0>=maxdbz>-7 and cth<3000m / total number of CTH<3000m in the 25.3km segment	Unitless, values between 0 and 1.0
cloudsat_rain_frac	CloudSat rain fraction as the number of points with maxdbz>0 and cth<3000m / total number of CTH<3000m in the 25.3km segment	Unitless, values between 0 and 1.0

5 Constraints on Data Usage

This data collection was specifically constructed to support the analysis in Li et al. (2026). The dataset is made available with the goal of allowing users to replicate the analysis in Li et al (2026). Caution needs to be taken when applying the merged dataset to a research with a different methodological design from Li et al. (2026). Before using this product, please contact Dr. David Painemal.

6 Algorithm and Data Assessment

6.1 Data Validation Uncertainties

Uncertainties and error quantifications are provided in separate articles . Please, refer to the following articles for a detailed description

- CERES-MODIS cloud retrievals: Minnis et al. (2020).
- MODIS Cloud droplet number concentration: Gryspeerdt et al. (2019)
- CALIOP-S aerosol extinction coefficient and lidar ratio: Painemal et al., (2019)

7 Open-source Science Software and Data Access

7.1 Output Data Access

Output data will be available via NASA's Earthdata Search application at https://search.earthdata.nasa.gov and https://earthdata.nasa.gov.

8 Acknowledgements

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9 Contributors

Dr. David Painemal and Dr. Zhujun Li (algorithm development and code implementation)

10 Primary Point of Contact

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