Deliverable D2.13: implementation of EARLINET Level 3 products

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Objectives

This deliverable aims to provide for the first time a climatological product of ground-based measurements of aerosol optical properties. Following the new reshape of the EARLINET database these are Level 3 products containing climatological datasets obtained as aggregated products from the Level 2 aerosol optical products.

This document describes the data and it consists of a synthetic description of the Level 3 release and 2 Appendixes: one with the data format description and meaning of the parameters, and a further Appendix B with the ATBD (Algorithm Theoretical Basis Document) of such datasets. Both appendixes are available on website (EARLINET and ACTRIS portal), where also datasets themselves are available. All these materials will be available through the new interface of the EARLINET database (then, through the ACTRIS data portal), which will be available in the next few weeks.

The release of Level 3 products is essential for climatological studies for the different kind of potential users (related to air quality, meteorological application, climate study, modelling and so on). In particular, this product, providing high-quality information about the vertical distribution and optical properties of the aerosol over the European continent on long-term scale, could be precious also for the European climate and air quality policy makers. Additionally, these products could be a term of reference also for stations performing measurements in order to identify special situation observed at their stations.

This is a first release of the data, more will follow enlarging the provided information, but also including the new version of the data and of the quality control procedures. The Level 3 products are centrally and automatically produced by the CNR, guarantying harmonized procedures on the datasets. This is compliant with the general new structure of the EARLINET database allowing for versioning, traceability and harmonization of the processes.

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Level 3 climatologicalproducts

Level 3 climatological products have been designed as a result of the cooperation between EARLINET and AEROCOM carried out during the previous ACTRIS project, responding to the global aerosol modeling community needs for aggregated data and their representativeness.

Level 3 data products are centrally calculated by the ACTRIS DC unit of the CNR-IMAA. The methods applied are reported in Appendix B of this document.

The Level 3 standard product contains climatological datasets obtained as aggregated products from the fully QC aerosol optical products (i.e. Level 2 products). For this first release, the dataset for 2000-2015 period is considered as the published ones [The EARLINET publishing group 2018a, b and c]. In particular, this release considers only data of this period and fully compliant to the QC procedure v1.1 [EARLINET Data Quality Check –Action report ; EARLINET Data Off Line Quality Check –v1.1 ; EARLINET Data On Line Quality Check v1.1]. In order to avoid biases due to measurements made on purpose specifically for capturing special events, it is considered only subset of data corresponding to regular schedule and measurements done for satellite validation purposes (i.e. *climatological* and *calipso* category files following the current EARLINET database organization [Pappalardo et al., 2012]). Among these data, the cases reporting cirrus observations have been screened out, since at the current stage the cirrus altitude is not codified inside the aerosol optical property profiles[1].

Currently the ACTRIS aerosol profiling database is being substantially modified for allowing versioning. This means that, in the near future, some QC issues found for data will be corrected and so the climatological datasets will be more populated in the next release.

Data are organized for station in order to allow into the future the update of the climatological product even at station level.
Data are aggregated into seasonal and annual datasets for both profiles and integrated quantities. Additionally, normal averages for months and seasons are also provided. Information about the number of collected samples, mean, median and standard deviation of the properties, as well as mean statistical error for each property are reported. Weighted means are applied for avoiding unbalanced situations in terms of temporal coverage: climatological values calculated using appropriate statistical methods which are described into details in the Appendix B.

The specific data format (reported in Appendix A) has been constructed following as much as possible the new format (currently in implementation) of Level 1 / Level 2 data nomenclature and compliant with international standards for international harmonization and compliance.
Another aspect taken into account is the traceability: in the Level 3 product information about the PI of the station for all the relevant period is provided reporting for the time being the information as available at the EARLINET web site (plus historical records), but constructing this in such a way that when the PI information will be mandatory in the new Level1/Level2 format this will be automatically included into the next releases. Moreover, the list of data used for the calculation of aggregated products is also reported in the Level 3 product for traceability purposes.

[1] This will change in the next release because of the cloud mask which will be available in the new aerosol optical property profiles, providing the inputs for a screening of the cloud for the aerosol climatological products.

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Specifically, the first release of Level 3 products contains information for 39 stations. For each station, 68 files are produced: 1 file for normal seasonal average for integrated quantities and 1 for the profiling ones; 1 file for normal month averages for integrated and 1 for profiles; then there are 16 seasonal average for integrated and 16 for profile quantities and 16 annual averages for integrated and 16 for profile quantities.

Next plans and release

The current release of the EARLINET Level 3 climatological dataset is the first official release of such kind of dataset. Further versions are expected in the future for updating the fully QC dataset of aerosol optical properties used for the Level 3 aggregation but even for adding new parameters to the Level 3 data.
The following are identified as further features to be included into next releases of Level 3 data:

- a specific Level3 products containing lidar ratio values distribution;
- metrics of the comparison with AERONET AOD in the integrated products
- statistics on Level 2 aerosol layer products
- a specific Level3 products containing Angstrom exponent values distribution;

For the distribution of lidar ratio (and Angstrom exponent) the file format is under implementation and, for the sake of harmonization within the other components of the ACTRIS DC, will be based on Cloudnet products for the model evaluation, which also report pdf of values.

The metrics of the comparison with AERONET data has been postponed to a successive step because data outside the RI are included or referred to for this evaluation. Moreover, it will be evaluated the feasibility of including here the AOD obtained by lunar photometer available inside the network from CIMEL photometer, which are more relevant for such comparison because of the real simultaneity with the lidar aerosol extinction measurements.

Statistics on layer products are postponed to the availability of the correspondingly Level 2 products.
Finally, the automatic evaluation of the Angstrom exponent values is not possible now because the aerosol extinction profiles at the different wavelengths are not reported at the same vertical resolution, which moreover it is not reported in a codified way. This investigation will be possible whenever the multi-wavelength aerosol profile product will be available.

As reported above, independently from new features to be included into Level 3 dataset, there will be a new release of Level 3 datasets whenever a new release of Level 2 data will occur. This can be due to: availability of dataset for new periods; availability of new version of data (correction on old data or reprocessing possible when versioning is implemented); implementation of new quality control procedure (holding to a new version of Level 2 data, too). However, following the previous expertise on publishing network-level database, a bi-annual release of the Level 3 standard dataset is envisaged.

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Appendix A

EARLINET Level 3 Data Product Catalogue

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Consiglio Nazionale delle Ricerche

CNR-IMAA

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Summary

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Introduction

This document describes the ACTRIS/EARLINET Level 3 Data products. Level 3 data are the climatological products obtained from the fully quality controlled (Level 2) data for providing useful aggregated information to the users. The methods applied for obtaining Level 3 products from Level 2 ones are described in a companion document, the EARLINET Level 3 - Algorithm Theoretical Basis Document. This document describes instead the content of the products, including data format and data organization.

Following the standards adopted within EARLINET DC and in agreement with the whole ACTRIS database, Level 3 data are netCDF files, and the variables nomenclature and file format is aligned with the new data format of the pre-processed and processed aerosol remote sensing data. Information about the origin of the files are reported for traceability needs.

The Level 3 data are centrally obtained by the ACTRIS aerosol remote sensing Data Center node of the CNR in Potenza. This allows the harmonization and reproducibility of the products.

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File naming conventions

Filenames for the Level 3 aerosol profiles follow this convention:
ACTRIS_AerRemSen_sss_Lev03_ mmmmmm _pppp_ttt_vxx_qcyyy.nc

with

- sss: station ID code (see below)
- mmmmmm: average mode (Season= seasonal averages, Annual = annual averages; NorMon =normal monthly averages; NorSea = normal seasonal averages)
- pppp: period of the calculated averages
  for the seasonal and annual averages pppp=yyyy;
  for normal averages pppp code can be written as iiff ii=yy of the initial year; ff=yy for the final year
- ttt: product type (Int=integrated; Pro=profile)
- vxx: version of the data product. The first version is 01, the second 02 and so on
- qcyyy: version of the qc used for the evaluation of Level 3 data products (see https://www.earlinet.org/index.php?id=125

the station code is as follows:

ARR	Andøya	LEI	Leipzig	ABY	Aberystwyth
ATZ	Athens	LLE	Lille	HBU	Hamburg
BRC	Barcelona	LIM	Limassol	OHP	Haute-Provence
COG	Belsk	MDR	Madrid	JFJ	Jungfraujoch
INO	Bucharest	MAS	Minsk	KUH	Kuehlungsborn
CBW	Cabauw	NAP	Naples	LAQ	L'Aquila
PUY	Clermont-Ferrand	HPB	Hohenpeissenberg	LKP	Linkoping
UCC	Cork	SIR	Palaiseau	LIS	Lisbon
DUS	Dushanbe	POT	Potenza	MUC	Maisach
EVO	Evora	PAY	Payerne	MUN	Munich
GAR	Garmisch-Partenkirchen	SOF	Sofia	NEU	Neuchatel
GRA	Granada	THE	Thessaloniki		
IPR	Ispra	WAW	Warsaw		
KUO	Kuopio				
SAL	Lecce				

Database organization

The Level 3 data products are stored in a zip file containing all the netcdf files, this document describing the file organization and content and the algorithm theoretical basis document.
For each station a new version of the Level 3 dataset contains: 2 annual average files (one for integrated quantities and one for profiles) and 2 seasonal average file (one for integrated quantities and one for profiles) per year plus 2 files (one for integrated and 1 for profiles) for normal seasonal average over the whole considered time period and 2 files (one for integrated and 1 for profiles) for normal month averages over the whole considered time period.

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Definition and meaning of the parameters

Each one of the above shortly described file is structured in such a way that for a single station and the decided temporal interval and aggregation the parameters are reported all together. This will allow the users to easily investigate the evolution of the different parameters all together instead of having fragmentary information reported in several files.

For implementing this, both profiling and integrated products have the ***wavelength*** **dimension** (accommodating products at different wavelength in the same variable) and ***time*** **dimension** (accommodating to have different years or season in the same variable, so that temporal analysis can be performed easier). The **dimension *n_char*** instead allows the recording of the names of source files from which the level 3 products are evaluated. The **dimension *nv*** is used following the cf convention whenever a bound is needed for some evaluation. In our case nv is used for defining variables which have per definiotn some bound as time_bounds reported below.
For the profile products an additional **dimension** is defined which is ***altitude*** for reporting the information as a function of the altitude.

All the quantities (variables and attributes) are mandatory for this product, in the sense that the files are written in such a way that all the fields are set up and filled in case information are available and empty or with Fill_Value if not.

In the following the definition and meaning of the variables are reported.

altitude: is the altitude for which the profiles are reported. The profiles indeed are reported at a fixed grid of 200 m of vertical resolution starting from 0 m above the sea level. This harmonized grid allows easier multi-stations combined study. This variable is reported only in profile products. This is linked to the *altitude* dimension.

time: this is the central time for which the climatological values are reported. In annual files, there is just one, while for seasonal products there are 4 times correspondingly to the central day of the 4 seasons. This is linked to the *time* dimension.

wavelength: this variable reports the wavelengths now available for the aerosol extinction and backscatter products in EARLINET, i.e. 355, 532 and 1064 nm. Data at 351 nm are assimilated at the 355 nm and treated as such. However, the different wavelength information is completely traceable through the source file list available inside the Level 3 file itself (see below *source* variable). This is linked to the *wavelength* dimension.

time_bounds: these are the extremes of the temporal range on which calculations are done.

source: this variable contains as text the list of level 2 (or e- and b- files for previous releases) files from which are retrieved values averaged in this file.

latitude: latitude in degrees of the ACTRIS/EARLINET station.

longitude: longitude in degrees of the ACTRIS/EARLINET station.

station_altitude: station altitude above sea level of the ACTRIS/EARLINET station.

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Optical property profiles

The aerosol extinction and backscatter profiles are the primary products of the ACTRIS/EARLINET component. In the Level 3 data these quantities are aggregated over different time period for providing climatological information.

The statistical methods for obtaining climatological information is reported in the ATBD (Algorithm Theoretical Basis Document) document. Climatological profile products are reported in a fixed altitude range allowing direct comparisons between the different stations. The grid for the Level 3 profiles starts from 0 m asl and reaches 12 km asl with a vertical resolution of 200 m. This resolution is a good compromise between the need of providing tiny resolution and the needs for collecting a statistically significant number of point for each point in the vertical profile of the Level 3 product.

mean_of_extinction (altitude, wavelength, time): mean of the aerosol extinction value observed within the time_bound and correspondingly to the specific altitude range and wavelength. The aerosol extinction values from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or e-files for previous versions).

median_of_extinction (altitude, wavelength, time): median of the aerosol extinction value observed within the time_bound and correspondingly to the specific altitude range and wavelength. The aerosol extinction values from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or e-files for previous versions).

standard_deviation_of_extinction (altitude, wavelength, time): standard deviation of the aerosol extinction value observed within the time_bound and correspondingly to the specific altitude range and wavelength. The aerosol extinction values from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or e-files for previous versions).

statistical_error_mean_of_extinction (altitude, wavelength, time): mean of the statistical error of the aerosol extinction value observed within the time_bound and correspondingly to the specific altitude range and wavelength. The values of statistical error affecting the aerosol extinction from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or e-files for previous versions).

number_of_extinction_profiles_averaged (altitude, wavelength, time): number of the aerosol extinction profiles averaged within the time_bound and correspondingly to the specific altitude range and wavelength. The aerosol extinction values from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or e-files for previous versions).

number_of_extinction_values_averaged (altitude, wavelength, time): number of the values of aerosol extinction averaged within the time_bound and correspondingly to the specific altitude range and wavelength. The aerosol extinction values from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or e-files for previous versions). This quantity provides an information about the vertical coverage of the single original EARLINET aerosol extinction profiles.

mean_of_backscatter (altitude, wavelength, time): mean of the aerosol backscatter value observed within the time_bound and correspondingly to the specific altitude range and wavelength. The aerosol backscatter values from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

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median_of_backscatter (altitude, wavelength, time): median of the aerosol backscatter value observed within the time_bound and correspondingly to the specific altitude range and wavelength. The aerosol backscatter values from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

standard_deviation_of_backscatter (altitude, wavelength, time): standard deviation of the aerosol backscatter value observed within the time_bound and correspondingly to the specific altitude range and wavelength. The aerosol backscatter values from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

statistical_error_mean_of_backscatter (altitude, wavelength, time): mean of the statistical error of the aerosol backscatter value observed within the time_bound and correspondingly to the specific altitude range and wavelength. The values of statistical error affecting the aerosol backscatter from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

number_of_backscatter_profiles_averaged (altitude, wavelength, time): number of the aerosol backscatterprofiles averaged within the time_bound and correspondingly to the specific altitude range and wavelength. The aerosol backscatter values from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

number_of_backscatter_values_averaged (altitude, wavelength, time): number of the values of aerosol backscatteraveraged within the time_bound and correspondingly to the specific altitude range and wavelength. The aerosol backscatter values from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions). This quantity provides an information about the vertical coverage of the single original EARLINET aerosol backscatter profiles.

Aerosol Boundary Layer

The lowest portion of the atmosphere where the most of the aerosol are confined is particularly important because of the impacts aerosol can have on different sectors of life, like air quality, health, solar energy production, aviation management, agriculture and fishery. For this reason, since the beginning particular attention was paid by EARLINET to the identification of the top of planetary boundary layer through aerosol lidar measurements. It was agreed within EARLINET community to use aerosol as tracer for identifying a proxy of the planetary boundary layer. In order to clearly state that this proxy has been obtained using aerosol as tracer this quantity is called: aerosol boundary layer. **Aerosol boundary layer** (previously called dust layer height, but renamed in 2019 for avoiding misunderstanding) is defined as the lowest layer that generally contains most of the aerosol except special elevated layers like Saharan dust etc (Matthias et al., 2004) . Within EARLINET, aerosol boundary layer is considered as the mixing layer plus the residual layer, if that exists. The top of this layer can again be identified by a minimum of d/dR (PR^2) (where PR2is the range corrected lidar signal P), but the existence of mixing processes is not required. If several layers exist that are clearly separated, only the lowest layer is labeled "aerosol boundary layer". In the morning, when both mixing layer and the residual layer on top of it may exist, these layers are typically well connected, but 2 local minima of d/dR (PR2) are observed.
The aerosol boundary layer is not evaluated centrally but at the stations. In the Level 3 products, only statistical value of this quantity are reported and evaluated with statistical methods as reported in the level 3 ATBD document.

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mean_of_aerosol_boundary_layer (time): mean of the aerosol boundary layer values as reported calculated from the aerosol backscatter coefficient profiles correspondingly to the specific time range (time). The aerosol backscatter profiles from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

median_of_aerosol_boundary_layer (time): median of the aerosol boundary layer values as reported calculatedfrom the aerosol backscatter coefficient profiles correspondingly to the specific time range (time). The aerosol backscatter profiles from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

standard_deviation_of_aerosol_boundary_layer (nv, time, wavelength): standard deviation of the aerosol boundary layer values as reported calculated from the aerosol backscatter coefficient profiles correspondingly to the specific time range (time). The aerosol backscatter profiles from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

statistical_error_mean_of_aerosol_boundary_layer (nv, time, wavelength): mean statistical error of the aerosol boundary layer values as reported calculated from the aerosol backscatter coefficient profiles correspondingly to the specific time range (time). The aerosol backscatter profiles from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

number_of_aerosol_boundary_layer_averaged (nv, time, wavelength): number of the aerosol boundary layer values as reported calculated from the aerosol backscatter coefficient profiles correspondingly to the specific time range (time). The aerosol backscatter profiles from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

Optical properties integrated values

The **aerosol optical depth (AOD)**and the **integrated backscatter (IB)** are the integrals over the altitude of the aerosol extinction and backscatter profiles, respectively. These integrated properties directly provide an information about the quantity of aerosol present in the considered portion of the atmospheric column. However, aerosol optical depth and integrated backscatter also depend on the type of the particles, because the extinction and backscatter efficiencies depend on the size, shape and refractive index of the particles. So that it is also important to store the information as a function of the wavelength and also differentiating between extinction and backscatter integrated quantities. In particular, aerosol optical depth is a relevant quantity because it is directly comparable with the same quantity (sometimes called as aerosol optical thickness) retrieved by photometer instruments like the AERONET ones available worldwide and from satellite passive sensors like MODIS and MISR. Then the lidar profiling capability also allows to provide the integrated quantities not only for the whole column but also inside the aerosol boundary layer whenever this is available into the original aerosol optical property profile files.

It has to be noted that for calculating these properties we assume that below the first data provided in altitude by the stations the aerosol is well mixed and the corresponding optical property is constant with the altitude down to the ground. This is a typical hypothesis made in such kind of study and of course is more accurate for stations equipped with lidar with a low overlap range.

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Details on how the AOD and IB are calculated from the Level 2 (or e- and b- files for previous versions) are reported in the Level 3 ATBD document.

The following variables are reported about the integrated optical properties:

integral_bounds: this variable indicates whether the integration has been done on the total column (integral_bounds=0), or into the aerosol planetary boundary layer (integral_bounds= 1).

mean_of_aerosol_optical_depth (nv, time, wavelength): mean of the aerosol optical depth values observed correspondingly to the specific integration altitude range (nv), at the specific time range (time) and wavelength. The aerosol extinction values from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or e-files for previous versions).

median_of_aerosol_optical_depth (nv, time, wavelength): median of the aerosol optical depth values observed correspondingly to the specific integration altitude range (nv), at the specific time range (time) and wavelength. The aerosol extinction values from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or e-files for previous versions).

standard_deviation_of_aerosol_optical_depth (nv, time, wavelength): standard deviation of the aerosol optical depth values observed correspondingly to the specific integration altitude range (nv), at the specific time range (time) and wavelength. The aerosol extinction values from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or e-files for previous versions).
statistical_error_mean_of_aerosol_optical_depth (nv, time, wavelength): mean statistical error of the aerosol optical depth values observed correspondingly to the specific integration altitude range (nv), at the specific time range (time) and wavelength. The aerosol extinction values from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or e-files for previous versions).

number_of_aerosol_optical_depth _averaged (nv, time, wavelength): number of the aerosol optical depth values observed correspondingly to the specific integration altitude range (nv), at the specific time range (time) and wavelength. The aerosol extinction values from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or e-files for previous versions).

mean_of_aerosol_integrated_backscatter (nv, time, wavelength): mean of the aerosol integrated backscatter values observed correspondingly to the specific integration altitude range (nv), at the specific time range (time) and wavelength. The aerosol extinction values from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or e-files for previous versions).

median_of_aerosol_integrated_backscatter (nv, time, wavelength): median of the aerosol integrated backscatter values observed correspondingly to the specific integration altitude range (nv), at the specific time range (time) and wavelength. The aerosol extinction values from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or e-files for previous versions).

standard_deviation_of_aerosol_integrated_backscatter (nv, time, wavelength): standard deviation of the aerosol integrated backscatter values observed correspondingly to the specific integration altitude range (nv), at the specific time range (time) and wavelength. The aerosol extinction values from which

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these values are calculated are the ones reported in the EARLINET file (Level2 optical products or e-files for previous versions).

statistical_error_mean_of_aerosol_integrated_backscatter (nv, time, wavelength): mean statistical error of the aerosol integrated backscatter values observed correspondingly to the specific integration altitude range (nv), at the specific time range (time) and wavelength. The aerosol extinction values from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or e-files for previous versions).

number_of_aerosol_integrated_backscatter_averaged (nv, time, wavelength): number of the aerosol integrated backscatter values observed correspondingly to the specific integration altitude range (nv), at the specific time range (time) and wavelength. The aerosol extinction values from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or e-files for previous versions).

Indicators of the aerosol vertical distribution

Center of mass

In physics, one refers to the **center of mass** of a body as the hypothetical point where entire mass of an object may be assumed to be concentrated to visualize its motion. In other words, the center of mass is the punctual particle equivalent of a given object for application of Newton's laws of motion. So that, this quantity is important for understanding the dynamics of an aerosol layer and to visualize where is the core of the aerosol content. For estimating the center of mass of the aerosol layer, the **center of mass of the aerosol content** in the portion of atmospheric column is estimated as the backscatter weighted altitude in the considered altitude range (Mona et al., 2006). This quantity is an approximation of the center of mass of the aerosol layer, that exactly coincides with the true center of mass if both composition and size distribution of the particles are constant with the altitude. This estimate of the center of mass gives us information about the altitude where the most relevant part of the aerosol load is located.

The calculation of the center of mass for the total column and inside the aerosol boundary layer is calculated centrally for the Level 3 products delivery. The center of mass is calculated from backscatter profiles (reported in Level 2 products or b-files (or e- when not available in the b-files) for previous releases). Aerosol backscatter profiles are preferred because of the better vertical resolution when compared to extinction profiles. All the wavelengths are considered for the calculation for eventually taking into account the wavelength dependence of the aerosol backscatter.

Details on how the center of mass is calculated from the Level 2 (or e- and b- files for previous versions) are reported in the Level 3 ATBD document.

The following variables are reported for the center of mass:

mean_of_center_of_mass (nv, time, wavelength): mean of the center of mass values calculated from the aerosol backscatter coefficient profiles correspondingly to the specific time range (time) and wavelength. The center of mass is calculated both for the whole profile and the aerosol boundary layer (accordingly to nv). The aerosol backscatter profiles from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

median_of_center_of_mass (nv, time, wavelength): median of the center of mass values calculated from the aerosol backscatter coefficient profiles correspondingly to the specific time range (time) and

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wavelength. The center of mass is calculated both for the whole profile and the aerosol boundary layer (accordingly to nv). The aerosol backscatter profiles from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

standard_deviation_of_center_of_mass (nv, time, wavelength): standard deviation of the center of mass values calculated from the aerosol backscatter coefficient profiles correspondingly to the specific time range (time) and wavelength. The center of mass is calculated both for the whole profile and the aerosol boundary layer (accordingly to nv). The aerosol backscatter profiles from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

statistical_error_mean_of_center_of_mass (nv, time, wavelength): mean statistical error of the center of mass values calculated from the aerosol backscatter coefficient profiles correspondingly to the specific time range (time) and wavelength. The center of mass is calculated both for the whole profile and the aerosol boundary layer (accordingly to nv). The aerosol backscatter profiles from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

number_of_center_of_mass_averaged (nv, time, wavelength): number of the center of mass values calculated from the aerosol backscatter coefficient profiles correspondingly to the specific time range (time) and wavelength. The center of mass is calculated both for the whole profile and the aerosol boundary layer (accordingly to nv). The aerosol backscatter profiles from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

H63

The aerosol profiling capability offered by ACTRIS aerosol remote sensing provides the possibility to also investigate the so called **h63**, i.e. altitude below which 63% of the total column aerosol content is confined. This is particularly important because it is the main product used in the study about the vertical distribution of the aerosol at global scale using CALIPSO observations (Winker at al., 2013) and can be also used in studies for comparison with aerosol models.

Both aerosol optical depth and aerosol integrated backscatter are considered because the H63 from AOD is used in CALIPOS and potentially available from AEROCOM, while the aerosol backscatter profiles could be preferred because of the better vertical resolution when compared to extinction profiles. All the wavelengths are considered for the calculation for eventually taking into account the wavelength dependence of the aerosol backscatter.

Details on how the h63 is calculated from the Level 2 (or e- and b- files for previous versions) are reported in the Level 3 ATBD document.

The following variables are reported for h63:

mean_of_h63_of_aerosol_optical_depth(nv, time, wavelength): mean of the h63 values calculated from the aerosol backscatter coefficient profiles correspondingly to the specific time range (time) and wavelength. The h63 is calculated both for the whole profile and the aerosol boundary layer (accordingly to nv). The aerosol backscatter profiles from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

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median_of_h63_of_aerosol_optical_depth(nv, time, wavelength): median of the h63 values calculated from the aerosol backscatter coefficient profiles correspondingly to the specific time range (time) and wavelength. The h63 is calculated both for the whole profile and the aerosol boundary layer (accordingly to nv). The aerosol backscatter profiles from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

standard_deviation_of_h63_of_aerosol_optical_depth(nv, time, wavelength): standard deviation of the h63 values calculated from the aerosol backscatter coefficient profiles correspondingly to the specific time range (time) and wavelength. The h63 is calculated both for the whole profile and the aerosol boundary layer (accordingly to nv). The aerosol backscatter profiles from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

statistical_error_mean_of_h63_of_aerosol_optical_depth(nv, time, wavelength): mean statistical error of the h63 values calculated from the aerosol backscatter coefficient profiles correspondingly to the specific time range (time) and wavelength. The h63 is calculated both for the whole profile and the aerosol boundary layer (accordingly to nv). The aerosol backscatter profiles from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

number_of_h63_of_aerosol_optical_depth_averaged (nv, time, wavelength): number of the h63 values calculated from the aerosol backscatter coefficient profiles correspondingly to the specific time range (time) and wavelength. The h63 is calculated both for the whole profile and the aerosol boundary layer (accordingly to nv). The aerosol backscatter profiles from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

mean_of_h63_of_integrated_backscatter (nv, time, wavelength): mean of the h63 values calculated from the aerosol backscatter coefficient profiles correspondingly to the specific time range (time) and wavelength. The h63 is calculated both for the whole profile and the aerosol boundary layer (accordingly to nv). The aerosol backscatter profiles from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

median_of_h63_of_integrated_backscatter (nv, time, wavelength): median of the h63 values calculated from the aerosol backscatter coefficient profiles correspondingly to the specific time range (time) and wavelength. The h63 is calculated both for the whole profile and the aerosol boundary layer (accordingly to nv). The aerosol backscatter profiles from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

standard_deviation_of_h63_of_integrated_backscatte(nv, time, wavelength): standard deviation of the h63 values calculated from the aerosol backscatter coefficient profiles correspondingly to the specific time range (time) and wavelength. The h63 is calculated both for the whole profile and the aerosol boundary layer (accordingly to nv). The aerosol backscatter profiles from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

statistical_error_mean_of_h63_of_integrated_backscatter (nv, time, wavelength): mean statistical error of the h63 values calculated from the aerosol backscatter coefficient profiles correspondingly to the specific time range (time) and wavelength. The h63 is calculated both for the whole profile and the aerosol boundary layer (accordingly to nv). The aerosol backscatter profiles from which these values are

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calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

number_of_h63_of_integrated_backscatter_averaged (nv, time, wavelength): number of the h63 values calculated from the aerosol backscatter coefficient profiles correspondingly to the specific time range (time) and wavelength. The h63 is calculated both for the whole profile and the aerosol boundary layer (accordingly to nv). The aerosol backscatter profiles from which these values are calculated are the ones reported in the EARLINET file (Level2 optical products or b-files for previous versions).

Attribute description

The attributes of the variables are structure in such a way to provide all needed information about units, corresponding name (if existing) in the CF convention, FillValue, and indications about statistical methods applied for the calculation underlying such variable definition.

Global Attributes are mainly information related to traceability of the data where are reported information about: software used for generating Level 3 products, station to which Level 3 data refer to, data originator and data provider and info about potential modification and versions of the Level 3 data. In particular, in agreement with the GEOMS definition (https://evdc.esa.int/documents/1/geoms-1.0.pdf), the **Data Originator** is the person that generated and quality controlled the data. Where no single Data Originator (DO) exists, the DO_NAME and DO_AFFILIATION will hold the name of the entity responsible for the instrument, while the DO_ADDRESS and DO_EMAIL will contain the appropriate contact information. The DO may or may not be the same person as the PI. Specifically, for the ACTRIS/EARLINET Level 3 data, original profiles datafile did not contain the DO information (and often neither the PI information) till beginning of 2019, while this information becomes mandatory with the release of the new version of the database.

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Level 3 average profile file NetCDF structure

Example for Annual file structure

Dimension:

- Name=altitude
- Name=time
- Name=wavelength
- Name=nv
- Name=n_char

Variables:

- Name=**altitude**
  Type=double
  N. Dimension=1
  Dimension=altitude
  Number of attribute=5
  Attribute name=units
  Attribute value=m
  Type=text

  Attribute name=long_name
  Attribute value=Altitude of middle point of layer
  Type=text

  Attribute name=axis
  Attribute value=Z
  Type=text

  Attribute name=positive
  Attribute value=up
  Type=text

  Attribute name=standard_name
  Attribute value=altitude
  Type=text

- Name=**time**
  Type=double
  N. Dimension=1
  Dimension=time
  Number of attribute=6
  Attribute name=units
  Attribute value=seconds since 1970-01-01T00:00:00Z
  Type=text

  Attribute name=long_name
  Attribute value=Time
  Type=text

  Attribute name=calendar
  Attribute value=gregorian
  Type=text

  Attribute name=axis

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Attribute value=T
Type=text

Attribute name=standard_name
Attribute value=time
Type=text

Attribute name=bounds
Attribute value=time_bounds
Type=text

- Name=**wavelength**
  Type=double
  N. Dimension=1
  Dimension=wavelength
  Number of attribute=2
  Attribute name=units
  Attribute value=nm
  Type=text

  Attribute name=long_name
  Attribute value=Wavelength of the transmitted laser pulse
  Type=text

- Name=**mean_of_extinction**
  Type=double
  N. Dimension=3
  Dimension=altitude, time, wavelength
  Number of attribute=5
  Attribute name=units
  Attribute value=1/m
  Type=text

  Attribute name=__FillValue
  Attribute value=9.96920996838687e+36
  Type=double

  Attribute name=long_name
  Attribute value=mean of aerosol particle extinction coefficient
  Type=text

  Attribute name=statistical_method
  Attribute value=mean within months; mean over months
  Type=text

  Attribute name=standard_name
  Attribute name=mean_of_volume_extinction_coefficient_in_air_due_to_ambient_aerosol_particles
  Type=text

- Name=**median_of_extinction**
  Type=double
  N. Dimension=3
  Dimension=altitude, time, wavelength
  Number of attribute=5
  Attribute name=units
  Attribute value=1/m
  Type=text

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Attribute name=__FillValue
Attribute value=9.96920996838687e+36
Type=double

Attribute name=long_name
Attribute value=median of aerosol particle extinction coefficient
Type=text

Attribute name=statistical_method
Attribute value=weigthed median; weights are computed
inverting the amount of measured profiles by month
Type=text

Attribute name=standard_name
Attribute value=median_of_volume_extinction_coefficient_in_
air_due_to_ambient_aerosol_particles
Type=text

- Name=**standard_deviation_of_extinction**
  Type=double
  N. Dimension=3
  Dimension=altitude, time, wavelength
  Number of attribute=5

  Attribute name=units
  Attribute value=1/m
  Type=text

  Attribute name=__FillValue
  Attribute value=9.96920996838687e+36
  Type=double

  Attribute name=long_name
  Attribute value=standard deviation of aerosol particle extinction coefficient
  Type=text

  Attribute name=statistical_method
  Attribute value=weigthed standard deviation; weigths are computed
  inverting the amount of measured profiles by month
  Type=text

  Attribute name=standard_name
  Attribute value=standard_deviation_of_volume_extinction_coefficient_
  in_air_due_to_ambient_aerosol_particles

- Name=**statistical_error_mean_of_extinction**
  Type=double
  N. Dimension=3
  Dimension=altitude, time, wavelength
  Number of attribute=5

  Attribute name=units
  Attribute value=1/m
  Type=text

  Attribute name=__FillValue
  Attribute value=9.96920996838687e+36
  Type=double

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Attribute name=long_name
Attribute value=statistical error mean of aerosol particle extinction coefficient
Type=text

Attribute name=statistical_method
Attribute value=mean within months; mean over months
Type=text

Attribute name=standard_name
Attribute value= statistical_error_mean_of_volume_extinction_coefficient _in_air_due_to_ambient_aerosol_particles
Type=text

- Name=**number_of_extinction_profiles_averaged**
  Type=integer
  N. Dimension=3
  Dimension=altitude, time, wavelength
  Number of attribute=1
  Attribute name=long_name
  Attribute value=number of aerosol particle extinction coefficient profiles averaged
  Type=text

- Name=**number_of_extinction_values_averaged**
  Type=integer
  N. Dimension=3
  Dimension=altitude, time, wavelength
  Number of attribute=1
  Attribute name=long_name
  Attribute value=number of aerosol particle extinction coefficient values averaged
  Type=text

- Name=**mean_of_backscatter**
  Type=double
  N. Dimension=3
  Dimension=altitude, time, wavelength
  Number of attribute=4
  Attribute name=units
  Attribute value=1/m*sr
  Type=text

  Attribute name=__FillValue
  Attribute value=9.96920996838687e+36
  Type=double

  Attribute name=long_name
  Attribute value=mean of aerosol particle backscatter coefficient
  Type=text

  Attribute name=statistical_method
  Attribute value=mean within months; mean over months
  Type=text
- Name=**median_of_backscatter**
  Type=double
  N. Dimension=3
  Dimension=altitude, time, wavelength
  Number of attribute=4
  Attribute name=units

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Attribute value=1/m*sr
Type=text

Attribute name=__FillValue
Attribute value=9.96920996838687e+36
Type=double

Attribute name=long_name
Attribute value=median of aerosol particle backscatter coefficient
Type=text

Attribute name=statistical_method
Attribute value=weighted median; weights are computed inverting the amount of measured profiles by month
Type=text

- Name=**standard_deviation_of_backscatter**
  Type=double
  N. Dimension=3
  Dimension=altitude, time, wavelength
  Number of attribute=4

  Attribute name=units
  Attribute value=1/m*sr
  Type=text

  Attribute name=__FillValue
  Attribute value=9.96920996838687e+36
  Type=double

  Attribute name=long_name
  Attribute value=standard deviation of aerosol particle backscatter coefficient
  Type=text

  Attribute name=statistical_method
  Attribute value=weighted standard deviation; weights are computed inverting the amount of measured profiles by month
  Type=text

- Name=**statistical_error_mean_of_backscatter**
  Type=double
  N. Dimension=3
  Dimension=altitude, time, wavelength
  Number of attribute=4

  Attribute name=units
  Attribute value=1/m*sr
  Type=text

  Attribute name=__FillValue
  Attribute value=9.96920996838687e+36
  Type=double

  Attribute name=long_name
  Attribute value=statistical error mean of aerosol particle backscatter coefficient
  Type=text

  Attribute name=statistical_method
  Attribute value=mean within months; mean over months
  Type=text

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- Name=**number_of_backscatter_profiles_averaged**
  Type=integer
  N. Dimension=3
  Dimension=altitude, time, wavelength
  Number of attribute=1
  Attribute name=long_name
  Attribute value=number of aerosol particle backscatter coefficient profiles averaged
  Type=text

- Name=**number_of_backscatter_values_averaged**
  Type=integer
  N. Dimension=3
  Dimension=altitude, time, wavelength
  Number of attribute=1
  Attribute name=long_name
  Attribute value=number of aerosol particle backscatter coefficient values averaged
  Type=text
- Name=**time_bounds**
  Type=double
  N. Dimension=2
  Dimension=nv, time
  Number of attribute=1
  Attribute name=units
  Attribute value=seconds since 1970-01-01T00:00:00Z
  Type=text
- Name=**source**
  Type=char
  N. Dimension=1
  Dimension=n_char
  Number of attribute=2
  Attribute name=long_name
  Attribute value=source files
  Type=text

  Attribute name=description
  Attribute value=List of level 2 files from which are retrieved values averaged in this file
  Type=text

- Name=**latitude**
  Type=float
  N. Dimension=0
  Number of attribute=3
  Attribute name=units
  Attribute value=degrees_north
  Type=text

  Attribute name=long_name
  Attribute value=latitude of station
  Type=text

  Attribute name=standard_name
  Attribute value=latitude
  Type=text

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- Name=**longitude**
  Type=float
  N. Dimension=0
  Number of attribute=3
  Attribute name=units
  Attribute value=degrees_east
  Type=text

  Attribute name=long_name
  Attribute value=longitude of station
  Type=text

  Attribute name=standard_name
  Attribute value=longitude
  Type=text

- Name=**station_altitude**
  Type=float
  N. Dimension=0
  Number of attribute=2
  Attribute name=units
  Attribute value=m
  Type=text

  Attribute name=long_name
  Attribute value=station altitude above sea level
  Type=text

Global attributes (all mandatory):

- Name=processor_name Type=text
- Name=processor_version Type=text
- Name=processor institution Type=text
- Name=system Type=text
- Name=location Type=text
- Name=institution Type=text
- Name=PI Type=text
- Name=PI_affiliation Type=text
- Name=PI_affiliation_acronym Type=text
- Name=PI_address Type=text
- Name=PI_phone Type=text
- Name=PI_email Type=text
- Name=data_originator Type=text
- Name=data_originator_affiliation Type=text
- Name=data_originator_affiliation_acronym Type=text
- Name=data_originator_address Type=text
- Name=data_originator_phone Type=text
- Name=data_originator_email Type=text
- Name=data_provider Type=text
- Name=data_provider_affiliation Type=text
- Name=data_provider_affiliation_acronym Type=text
- Name=data_provider_address Type=text
- Name=data_provider_phone Type=text
- Name=data_provider_email Type=text
- Name=conventions Type=text

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- Name=references Type=text
- Name=station_ID Type=text
- Name=__file_format_version Type=text
- Name=history Type=text
- Name=title Type=text

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Level3 average integrated values file NetCDF structure

Example for Annual file structure

Dimension:

- Name=nv
- Name=time
- Name=wavelength
- Name=n_char

Variables:

- Name=time
  Type=double
  N. Dimension=1
  Dimensions=time
  Number of attribute=6
    Attribute name=units
    Attribute value=seconds since 1970-01-01T00:00:00Z
    Type=text

    Attribute name=long_name
    Attribute value=Time
    Type=text

    Attribute name=calendar
    Attribute value=gregorian
    Type=text

    Attribute name=axis
    Attribute value=T
    Type=text

    Attribute name=standard_name
    Attribute value=time
    Type=text

    Attribute name=bounds
    Attribute value=time_bounds
    Type=text
- Name=**wavelength**
  Type=double
  N. Dimension=1
  Dimensions=wavelength
  Number of attribute=2
    Attribute name=units
    Attribute value=nm
    Type=text

    Attribute name=long_name
    Attribute value=Wavelength of the transmitted laser pulse
    Type=text

- Name=**integral_bounds**
  Type=byte
  N. Dimension=1
  Dimensions=nv
  Number of attribute=3
    Attribute name=long_name

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Attribute value=integral bounds of integrated values
Type=text

Attribute name=flag_value
Attribute value=0,1
Type=text

Attribute name=flag_meaning
Attribute value=0:total, 1:aerosol planet boundary layer
Type=text

- Name=**mean_of_aerosol_optical_depth**
  Type=double
  N. Dimension=3
  Dimensions=nv, time, wavelength
  Number of attribute=5
  Attribute name=units
  Attribute value=1
  Type=text

  Attribute name=__FillValue
  Attribute value=9.96920996838687e+36
  Type=double

  Attribute name=long_name
  Attribute value=mean of aerosol optical depth
  Type=text

  Attribute name=statistical_method
  Attribute value=mean within months; mean over months
  Type=text

  Attribute name=standard_name
  Attribute value=mean_of_atmosphere_optical_thickness_due_to_ambient_ aerosol_particles
  Type=text

- Name=**median_of_aerosol_optical_depth**
  Type=double
  N. Dimension=3
  Dimensions=nv, time, wavelength
  Number of attribute=5
  Attribute name=units
  Attribute value=1
  Type=text

  Attribute name=__FillValue
  Attribute value=9.96920996838687e+36
  Type=double

  Attribute name=long_name
  Attribute value=median of aerosol optical depth
  Type=text

  Attribute name=statistical_method
  Attribute value=weighted median; weights are computed inverting the amount of measured profiles by month
  Type=text

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Attribute name=standard_name
Attribute value=median_of_atmosphere_optical_thickness_due_to_ambient _aerosol_particles
Type=text

- Name=**standard_deviation_of_aerosol_optical_depth**
  Type=double
  N. Dimension=3
  Dimensions=nv, time, wavelength
  Number of attribute=5
  Attribute name=units
  Attribute value=1
  Type=text

  Attribute name=__FillValue
  Attribute value=9.96920996838687e+36
  Type=double

  Attribute name=long_name
  Attribute value=standard deviation of aerosol optical depth
  Type=text

  Attribute name=statistical_method
  Attribute value=weighted standard deviation; weights are computed inverting the amount of measured profiles by month
  Type=text

  Attribute name=standard_name
  Attribute value=standard_deviation_of_atmosphere_optical_thickness_due_ to_ambient _aerosol_particles
  Type=text

- Name=**statistical_error_mean_of_aerosol_optical_depth**
  Type=double
  N. Dimension=3
  Dimensions=nv, time, wavelength
  Number of attribute=5
  Attribute name=units
  Attribute value=1
  Type=text

  Attribute name=__FillValue
  Attribute value=9.96920996838687e+36
  Type=double

  Attribute name=long_name
  Attribute value=statistical error mean of aerosol optical depth
  Type=text

  Attribute name=statistical_method
  Attribute value=mean within months; mean over months
  Type=text

  Attribute name=standard_name
  Attribute value=statistical_error_mean_of_atmosphere_optical_thickness_ due_to_ambient_aerosol_particles
  Type=text

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- Name=**number_of_aerosol_optical_depth _averaged**
  Type=integer
  N. Dimension=3
  Dimensions=nv, time, wavelength
  Number of attribute=1
    Attribute name=long_name
    Attribute value=number of aerosol optical depth averaged
    Type=text

- Name=**mean_of_integrated_backscatter**
  Type=double
  N. Dimension=3
  Dimensions=nv, time, wavelength
  Number of attribute=4
    Attribute name=units
    Attribute value=1/sr
    Type=text

    Attribute name=__FillValue
    Attribute value=9.96920996838687e+36
    Type=double

    Attribute name=long_name
    Attribute value=mean of aerosol integrated backscatter
    Type=text

    Attribute name=statistical_method
    Attribute value=mean within months; mean over months
    Type=text

- Name=**median_of_integrated_backscatter**
  Type=double
  N. Dimension=3
  Dimensions=nv, time, wavelength
  Number of attribute=4
    Attribute name=units
    Attribute value=1/sr
    Type=text

    Attribute name=__FillValue
    Attribute value=9.96920996838687e+36
    Type=double

    Attribute name=long_name
    Attribute value=median of aerosol integrated backscatter
    Type=text

    Attribute name=statistical_method
    Attribute value=weighted median; weights are computed inverting the amount of measured profiles by month
    Type=text

- Name=**standard_deviation_of_integrated_backscatter**
  Type=double
  N. Dimension=3
  Dimensions=nv, time, wavelength
  Number of attribute=4

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Attribute name=units
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Type=text

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Attribute value=standard deviation of aerosol integrated backscatter
Type=text

Attribute name=statistical_method
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  Number of attribute=4
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  Attribute value=1/sr
  Type=text

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  Type=double

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  Attribute value=statistical error mean of aerosol integrated backscatter
  Type=text

  Attribute name=statistical_method
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  Number of attribute=4
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Type=double

Attribute name=long_name
Attribute value=mean of aerosol center of mass
Type=text

Attribute name=statistical_method
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Type=text

- Name=**median_of_center_of_mass**
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- Name=**standard_deviation_of_center_of_mass**
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  Type=text

  Attribute name=statistical_method
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  Type=text

- Name=**statistical_error_mean_of_center_of_mass**
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  N. Dimension=3
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Number of attribute=4
Attribute name=units
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  Type=text

  Attribute name=statistical_method
  Attribute value=mean within months; mean over months
  Type=text

- Name=**median_of_aerosol_boundary_layer**
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  Attribute value=median of aerosol planet boundary layer altitudes
  Type=text

  Attribute name=statistical_method
  Attribute value=weighted median; weigths are computed inverting the amount of measured profiles by month

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Type=text

- Name=**standard_deviation_of_aerosol_boundary_layer**
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  Type=text

  Attribute name=statistical_method
  Attribute value=weighted standard deviation; weights are computed inverting the amount of measured profiles by month
  Type=text

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Dimensions=time, wavelength
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Attribute name=long_name
Attribute value=median of the altitudes below which stays 63% of total aerosol optical depth
Type=text

Attribute name=statistical_method
Attribute value=weighted median; weights are computed inverting the amount of measured profiles by month
Type=text

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Dimensions=time, wavelength
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Attribute name=long_name
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Attribute name=statistical method
Attribute value=weigthed standard deviation; weights are computed inverting the amount of measured profiles by month
Type=text

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Attribute value=m
Type=text

Attribute name=__FillValue
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Type=double

Attribute name=long_name
Attribute value=mean of the altitudes below which stays 63% of total

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integrated backscatter
Type=text

Attribute name=statistical method
Attribute value=mean within months; mean over months
Type=text

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  Dimensions=time, wavelength
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  Attribute value=m
  Type=text

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  Attribute name=long_name
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  Attribute value=weighted median; weights are computed inverting the amount of meaured profiles by month
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Attribute name=units
Attribute value=seconds since 1970-01-01T00:00:00Z
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  Attribute name=long_name
  Attribute value=longitude of station
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  Attribute name=standard_name
  Attribute_value=longitude
  Type=text

- Name=**station_altitude**
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  Attribute name=long_name
  Attribute value= station altitude above sea level
  Type=text

- Name=**source_file**
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  Dimensions=n_char
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  Attribute name=long_name
  Attribute value=source files
  Type=text

  Attribute name=description

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Attribute value=List of level 2 files from which are retrieved values averaged in this file

Type=text

Global attributes (all mandatory):

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- Name=processor_version Type=text
- Name=processor institution Type=text
- Name=system Type=text
- Name=location Type=text
- Name=institution Type=text
- Name=PI Type=text
- Name=PI_affiliation Type=text
- Name=PI_affiliation_acronym Type=text
- Name=PI_address Type=text
- Name=PI_phone Type=text
- Name=PI_email Type=text
- Name=data_originator Type=text
- Name=data_originator_affiliation Type=text
- Name=data_originator_affiliation_acronym Type=text
- Name=data_originator_address Type=text
- Name=data_originator_phone Type=text
- Name=data_originator_email Type=text
- Name=data_provider Type=text
- Name=data_provider_affiliation Type=text
- Name=data_provider_affiliation_acronym Type=text
- Name=data_provider_address Type=text
- Name=data_provider_phone Type=text
- Name=data_provider_email Type=text
- Name=conventions Type=text
- Name=references Type=text
- Name=station_ID Type=text
- Name=__file_format_version Type=text
- Name=history Type=text
- Name=title Type=text

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Mona, L., A. Amodeo, M. Pandolfi, and G. Pappalardo (2006), Saharan dust intrusions in the Mediterranean area: Three years of Raman lidar measurements, J. Geophys. Res., 111, D16203, doi:10.1029/2005JD006569.

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Appendix B

EARLINET Level 3 Algorithm Theoretical Basis Document

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Consiglio Nazionale delle Ricerche

CNR-IMAA

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Summary

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Introduction

This document reports the details on the methods applied for calculating centrally at data center level the ACTRIS/EARLINET Level 3 products. In particular, the methods related to the first release of such Level 3 products is reported. First of all, methods on how integrated properties are evaluated starting from the aerosol optical property single profiles (Level 2 products) is reported. Then it is detailed how the information (center of mass and h63) related to the distribution in the vertical dimension of the aerosol is calculated. Explanation about the gridding of the profiles in a standardized grid are then reported. Finally, the statistical methods applied for calculating the climatological values is reported. Particular attention has been paid to this aspect to take into account the not continuous dataset of ACTRIS/EARLINET and then the need of avoiding biased climatological values.

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Calculation of integrated quantities

For each extinction/backscatter vertical profile, an integrated quantity is calculated: aerosol optical depth for extinction profiles, and aerosol integrated backscatter for backscatter profiles.

The aerosol optical depth (AOD) and the integrated backscatter (IB) are the integrals over the altitude of the aerosol extinction and backscatter profiles, respectively. These integrated properties directly provide an information about the quantity of aerosol present in the considered portion of the atmospheric column. However, aerosol optical depth and integrated backscatter also depend on the type of the particles, because the extinction and backscatter efficiencies depend on the size, shape and refractive index of the particles.

Let $\alpha(p)$ be extinction values depending on altitude p, and $\beta(p)$ the same for backscatter values. We have:

- **Optical depth:**

$$\int_{h_0}^{h_1} \alpha(p)dp$$

- **Integrated backscatter:**

$$\int_{h_0}^{h_1} \beta(p)dp$$

Before calculating integrated quantities, extinction, backscatter and altitude are submitted to the following quality controls in order to avoid anomalies and missing values (we indicate with l the station altitude asl and with $\varepsilon(p)$ the errors associated to extinction values):

1. $p > l$
2. $-10 < \alpha(p) < 10$
3. $\varepsilon(p) \geq 0$
4. $\varepsilon(p) < 0.5 \cdot |\alpha(p)|$

Identical conditions are applied to backscatter values.
Integrations are calculated with trapezoidal rule [1], which is a common technique in numerical analysis for approximating definite integrals. We explain it in more details. Let$\alpha_1, \dots, \alpha_n$ be extinction (same for backscatter) values, and $p_1, \dots, p_n$ be the corresponding altitudes at which extinction values are retrieved. Then:

$$\int_{h_0}^{h_1} \alpha(p)dp \approx \sum_{j=1}^{n} \frac{\alpha_{j-1} + \alpha_j}{2} \cdot \frac{p_j - p_{j-1}}{2}$$

where $\alpha_0 = \alpha_1$ and $p_0 = l$.
this means that we are assuming that below the first data provided in altitude by the stations the aerosol is well mixed and the corresponding optical property is constant with the altitude down to the ground. This is a typical hypothesis made in such kind of study and of course is more accurate for stations equipped with lidar with a low overlap range.

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The values of the integral bounds h_0 and h_1 are:

1. $h_0 = l$ and $h_1 = p_n$, if we calculate the integrated quantity on the entire vertical profile.
2. $h_0 = l$ and $h_1 = p_i$, if we calculate the integrated quantity on the aerosol boundary layer (where p_i is the highest altitude among $p_1, \dots, p_n$ lower than aerosol boundary layer upper bound).

The aerosol boundary layer is not evaluated centrally but at the stations and provided if any into the Level 2 products. Aerosol boundary layer (previously called dust layer height, but renamed in 2019 for avoiding misunderstanding) is defined as the lowest layer that generally contains most of the aerosol except special elevated layers like Saharan dust etc (Matthias et al., 2004) .
As for what concerns the integrated backscatter values, these are retrieved from both extinction and backscatter type files. Backscatter profiles contained in e-files is not considered in the calculation only when b-file correspondingly to the same date exists.
If aerosol boundary layer is not reported in the specific file, algorithm tries to retrieve it from another file referred to the same date.

Center of Mass and H63

Center of mass is a value associated to every backscatter vertical profile. The center of mass of the aerosol content in the portion of atmospheric column is estimated as the backscatter weighted altitude in the considered altitude range (Mona et al., 2006). This quantity is an approximation of the center of mass of the aerosol layer, that exactly coincides with the true center of mass if both composition and size distribution of the particles are constant with the altitude. This estimate of the center of mass gives us information about the altitude where the most relevant part of the aerosol load is located.

It is calculated in the following way:

$$\frac{\int_{h_0}^{h_1} p \cdot \beta(p) dp}{\int_{h_0}^{h_1} \beta(p) dp}$$

Altitudes, backscatter values and error backscatter values are submitted to the same quality controls of the previous section. Integrations are calculated using trapezoidal rule. The values of integral bounds can vary as shown in the previous section.

Backscatter values are retrieved from both extinction and backscatter type files. An extinction type file is discarded only when a backscatter type file with its same date already exists.

The calculation of the center of mass for the total column and inside the aerosol boundary layer is calculated. If aerosol boundary layer is not reported in the specific file, algorithm tries to retrieve it from another file referred to the same date.

H63 is the altitude below which stays 63% of total aerosol optical depth (or aerosol integrated backscatter). More precisely, let $p_1, \dots, p_n$ be altitude values at which are retrieved $\alpha(p_i)$ extinction values. Let l be the station altitude, considering $\alpha(l) = \alpha(p_1)$. H63 is the lowest altitude p among $p_1, \dots, p_n$ such that:

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$$\int_{l}^{p} a(p)dp > 0.63 \cdot \int_{l}^{p_n} a(p)dp$$

Analogously, it can be calculated for integrated backscatter. H63 depends on wavelength at which integrated quantities are retrieved.
Both for the center of mass and H63, it is assumed a constant profile of the optical properties below the lowest in range available observation in the original profile, assuming well mixed condition at that altitude range.

Profile climatological products

Profile products give information about where and how much aerosol particles are placed in vertical profile. We consider all values (extinction or backscatter) retrieved from 0 up to 12000 meters, divided in 60 layers, each one 200 meters wide. Climatological profile products are reported in a fixed altitude range allowing direct comparisons between the different stations. The bounds of layers are at fixed altitudes: 0 – 200m, 200 – 400m, and so on. Intervals are intended in this way: [0,200), [200,400), …, meaning that a measurement retrieved at a bound altitude (200, 400, 600, …) is always putted in the upper layer. When we calculate profile statistical values about backscatter, we retrieve values from both extinction and backscatter type files. An extinction type file is discarded in the backscatter calculations only when a backscatter type file with its same date already exists.

Statistical values

ACTRIS/EARLINET is providing aerosol observations in a no-continuous way: since 2000 to now it is performing measurements 3 times per week plus during CALIPSO overpasses (additionally also during special events which are disregarded in order to avoid biases in this analysis). Additionally, the presence of low clouds, fog and precipitations inhibits the lidar measurements furthermore limiting the measurement. Because of this reason, particular attention has to be paid for avoiding biased climatological values. For taking into account the not uniformity of the temporal coverage in the observations suitable statistical methods are applied (Atkinson , Kendall 1989; Lange, Ed Springer).

- **Annual averages**: mean, median and standard deviation calculations are weighted. This is due to the unbalancing of the number of values in the different months. In the next lines procedures are described in full details.
  Let *n* be the number of values which are going to be averaged, retrieved during the year *y* (at a fixed wavelength laser pulse). Let *m* be the number of months with at least one value. Of course, *m* is between 0 and 12. Let $k_1, \dots, k_m$ the number of values referred to the *m* months with at least a one value. The weight associated to the values x_{ij} (i^{th} value in j^{th} month) is $w_j = \frac{1}{m \cdot k_j}$
  As a consequence, values retrieved in the same month have the same weight. Moreover, the sum of all weights is 1.
  Here we reported formulas to calculate weighted mean, weighted median and weighted standard deviation. About weighted mean, we can also say that this procedure is equivalent to calculate (non-weighted) mean within months, and then calculate (non-weighted) mean over months.

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i. Weighted mean: $\mu = \sum_{j=1}^{m} \sum_{i=1}^{k_j} w_j x_{ij}$

ii. Weighted median is the mean of all x_k values such that $\sum_{i=1}^{k-1} w_i \leq \frac{1}{2}$ and $\sum_{i=k+1}^{n} w_i \leq \frac{1}{2}$

iii. Weighted standard deviation: $\sqrt{\frac{1}{1-\sum_{j=1}^{m} \sum_{i=1}^{k_j} w_j^2} \cdot \sum_{j=1}^{m} \sum_{i=1}^{k_j} w_j \left(x_{ij} - \mu\right)^2}$

- **Seasonal averages:** mean, median and standard deviation are not weighted for season averages, because it has assumed that no significant differences are expected between data collected in the 3 months belonging to each season, so we do not need to fix the unbalancing of number of values in different sub periods.

Besides annual ad seasonal averages, the climatological normal mean are also calculated. Following the WMO definition these are averages computed for a uniform and relatively long period [WMO 2017]. They are of big interest firstly, because they form a benchmark or reference against which conditions (especially current or recent conditions) can be assessed, and secondly, because they are widely used (implicitly or explicitly) as an indicator of the conditions likely to be experienced in a given location.

- **Normal month averages:** mean, median and standard deviation calculations are weighted. This is due to the unbalancing of the number of values in the different years. In the next lines procedures are described in full details.
  Let *n* be the number of values which are going to be averaged, retrieved during every month *m* in the selected range of years, in this case 2000 – 2015. Let *y* be the number of years with at least one value retrieved. Let $k_1, \ldots, k_y$ the number of values per years (retrieved during the month *m*). The weight associated to the value x_{ij} (i^{th} value in j^{th} year) is $w_j = \frac{1}{y \cdot k_j}$
  As a consequence, values retrieved in the same year have the same weight. Moreover, the sum of all weights is 1.
  Here we reported formulas to calculate weighted mean, weighted median and weighted standard deviation. About weighted mean, we can also say that this procedure is equivalent to calculate (non-weighted) mean within years, and then calculate (non-weighted) mean over years.

  iv. Weighted mean: $\mu = \sum_{j=1}^{y} \sum_{i=1}^{k_j} w_j x_{ij}$

  v. Weighted median is the mean of all x_k values such that $\sum_{i=1}^{k-1} w_i \leq \frac{1}{2}$and $\sum_{i=k+1}^{n} w_i \leq \frac{1}{2}$

  vi. Weighted standard deviation: $\sqrt{\frac{1}{1-\sum_{j=1}^{y} \sum_{i=1}^{k_j} w_j^2} \cdot \sum_{j=1}^{y} \sum_{i=1}^{k_j} w_j \left(x_{ij} - \mu\right)^2}$

- **Normal season averages:** mean, median and standard deviation calculations are weighted. This is due to the unbalancing of the number of values in the different years. In the next lines procedures are described in full details.
  Let *n* be the number of values which are going to be averaged, retrieved during every season *s* in the selected range of years, in this case 2000 – 2015. Let *y* be the number of years with at least one value retrieved. Let $k_1, \ldots, k_y$ the number of values per years (retrieved during the season *s*). The weight associated to the value x_{ij} (i^{th} value in j^{th} year) is $w_j = \frac{1}{y \cdot k_j}$
  As a consequence, values retrieved in the same year have the same weight. Moreover, the sum of all weights is 1.

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Here we reported formulas to calculate weighted mean, weighted median and weighted standard deviation. About weighted mean, we can also say that this procedure is equivalent to calculate (non-weighted) mean within months, and then calculate (non-weighted) mean over months.

i. Weighted mean: $\mu = \sum_{j=1}^{y} \sum_{i=1}^{k_j} w_j x_{ij}$

ii. Weighted median is the mean of all x_k values such that $\sum_{i=1}^{k-1} w_i \leq \frac{1}{2}$ and $\sum_{i=k+1}^{n} w_i \leq \frac{1}{2}$

iii. Weighted standard deviation: $\sqrt{\frac{1}{1-\sum_{j=1}^{y} \sum_{i=1}^{k_j} w_j^2} \cdot \sum_{j=1}^{y} \sum_{i=1}^{k_j} w_j \left(x_{ij} - \mu\right)^2}$

References

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