Deliverable D2.1: Structure of the level-based EARLINET data processing chain

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Objectives

At the beginning of the ACTRIS-2 project,the EARLINET database was organized as follows:

- EARLINET variables are contained in 2 types of files: the e-file and b-file.
- The e-files contain the particle extinction coefficient profiles as primary variable accompanied by the corresponding particle backscatter coefficient if it is available. Lidar ratio, i.e. the extinction-to-backscatter ratio is reported too.
- The main information included in the b-files is the aerosol backscatter coefficient profile. Optionally, these files could report the particle linear depolarization ratio as well. The e and b-files could report also the planetary boundary layer height determined by using the aerosol as tracer as reported in Matthias et al., 2004.

The main concept behind the ***EARLINET database in the pre-ACTRIS-2 phase*** is that ***EARLINET should provide its basic products at the best capability*** to allow the users to work with the best products.

A strong link with EARLINET data users has been establishedsince the beginning of EARLINET in which EARLINET people acted as mentor and guide for users to assure a correct use and interpretation of the data. This was from one side a big effort for the EARLINET community as a whole,on the other side it was the opportunity to improve the knowledge about the user needs.

This was the seed for the development of new products which are more effective for specific uses of different communities. In particular, a new era is starting with the Copernicus program during which the aerosol vertical profiling capability will be fundamental for assimilation and validation purposes. Nowadays it is well known that the vertical dimension is fundamental for addressing aerosol impact on air quality, ecosystems, hazards, precipitations and climate. Even if the EARLINET database contains much information needed for these applications, the actual relevance of the e- and b-files is not easily understandable to many external users. The result is that the EARLINET databaseis under exploited. New data products are needed for making EARLINET data more visible to potential users.

On the other side, EARLINET maturity improved during these 16 years, going from a research lidar network to a research infrastructure. The high level of maturity in terms of quality checks and data processing reached during the ACTRIS FP7 project was the trigger of the EARLINET database restructuring. The current availability of the Single Calculus Chain (SCC) for the automatic lidar aerosol profile analysis allows for a larger amount of data to be submitted to the EARLINET database with respect to the past. This aspect could be really relevant for different applications, because it has the potentiality to significantly improve the spatial (more stations could provide data with this less time consuming tool) and temporal (more data can be analyzed even at short time scales) coverage.

All this considered, it is timely and feasible to ***reshape the EARLINET database in a more user oriented approach***. For the sake of continuity with the past, the new EARLINET database will be based on the standard e- and b-file, providing the users more directly accessible information with no needs forexperts mediation.

Definition of level structure

The user community interested in atmospheric data is a more and more extended audience spanning from advanced users (like modelers) to end user (like citizens). These users have to face the problem to access and exploit a large variety of databases currently available, with related problems of data formats, metadata and describing documentation. From the data producers side, the harmonization is

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essential for fostering the use of their own data. Data not compliant with established standards and/or very different from well-known datasets will probably not be used by a wide audience, reducing the impact of the research infrastructure. As described in the first version of the Data Management Plan(see deliverableD10.1), all EARLINET data and metadata follow specific standards and are accomplished by devoted documentations. However, the first contact of a potential data user with a research infrastructure database is its overarching structure, which is therefore the business card of the RI.

The new EARLINET database structure follows the concept of the most used databases in this field: a level structure going from low level and fast delivered data towards more advanced and correspondingly later released data. Taking as a reference CALIPSO, the first satellite mission with lidar onboard for aerosol and cloud investigation on global scale, data are organized in levels corresponding to different steps in the data analysis procedure. As for the AERONET database, probably the most used remote sensing database for aerosol studies and applications,the number of quality check procedures increases with the level of the data.

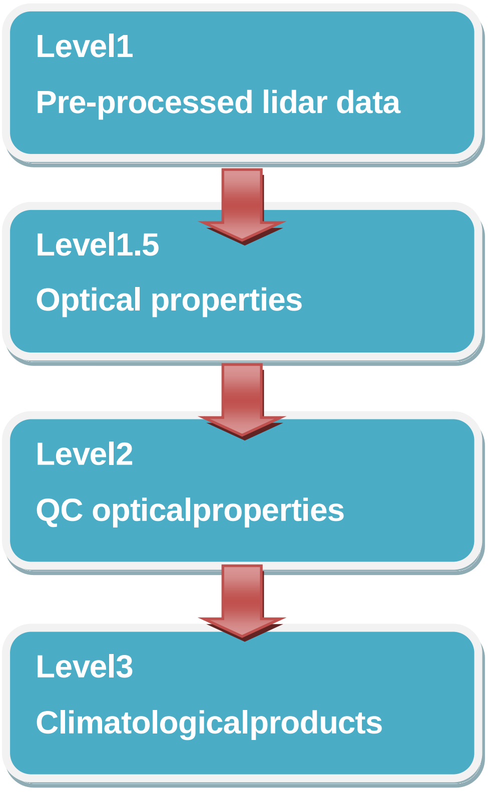

Fig. 1: Layout of the new structure of the EARLINET database.

The new structure of the EARLINET database is schematically reported in Figure 1. The ***Level 1*** contains ***pre-processed lidar data***, i.e. a step in between the raw signal (Level 0 data stored at each station) and the optical properties, where all instrumental corrections are already implemented. The Level 1 data are the base for the retrieval of the ***optical properties*** contained in the ***Level 1.5*** products. The Level 1.5 datasets are not quality checked, exceptfor format aspects, and therefore released as soon as data originators submit them to the database. Afterwards, all the Level 1.5 data pass through quality check procedures. Data originators are informed about data not passing these procedures. Only the data that passed the quality checksgointo the ***Level 2*** which is therefore the ***quality checkedoptical properties*** level. Of course, the QC data from the previous phase of the EARLINET database (pre-ACTRIS-2) (aerosol extinction and backscatter profiles) are part of the Level2. Finally, the ***Level 3*** data contain

climatological datasets retrieved from the Level2optical products. A draft of the netCDF header for each of the products described below in more details is reported in the Appendix.

The increase of the quality checks from the Level 1 to 3 implies a corresponding increase in delivery time of the data from potential NRT for the Level 1 and 1.5 to annual and bi-annual release of the Level2 and Level 3 data.

The new structure of the EARLINET database is organized in such a way that both SCC users and data originators using their own QA algorithm for data analysis can submit data in there. The data of each level are SCC compliant facilitating the wide use of the SCC within the network and the collection of a database as wide as possible.

Level 1 products

The Level 1 data contain the pre-processed lidar data, i.e. range-corrected signals derived from the raw lidar data acquired at each station for each detection channel of the lidar system corrected for dead-time, partial overlap between laser beam and receiving system etc. The Level 1 data products include standardized data at high temporal and vertical resolution, which are also compliant to the SCC. The Level 1 products could be the result of the pre-processing module of the SCC or not, but in any case the application of all the quality check procedures will be assured. Moreover, a direct link is established between the Level 1 products and both the Handbook ofInstruments and the approval of instrumental quality checks scheduled within the network.

The high resolution characterizing these products makesthem very suitable for variability studies and investigations.The standardized pre-processed data could serve as input for any further processing of lidar data, within the SCC as well as in other processing algorithms (e.g., combined retrievals with sun photometer, combined retrievals with Cloudnet). In particular, ICARE will process automatically the raw lidar data from the EARLINET DB, combine them with coincident AERONET data, and finally retrieve the vertical profiles of aerosol propertiesusing the GARRLiC (Generalized Aerosol Retrieval from Radiometer and Lidar Combined data) algorithm.

The standardized and quality-assured pre-processed lidar data will also be used to develop a homogeneous network-wide, open and freely accessible quick-look database (high-resolution images of time-height cross sections). Furthermore, the results of cloud/aerosol masking will be graphically reported in these quick-looks.Homogeneous quick-looks for different EARLINET stations were reported, for the first time,in the frame of the ACTRIS summer 2012 campaign as result of an operational exercise of the SCC (Sicard et al., 2015). An example is reported in Figure 2.

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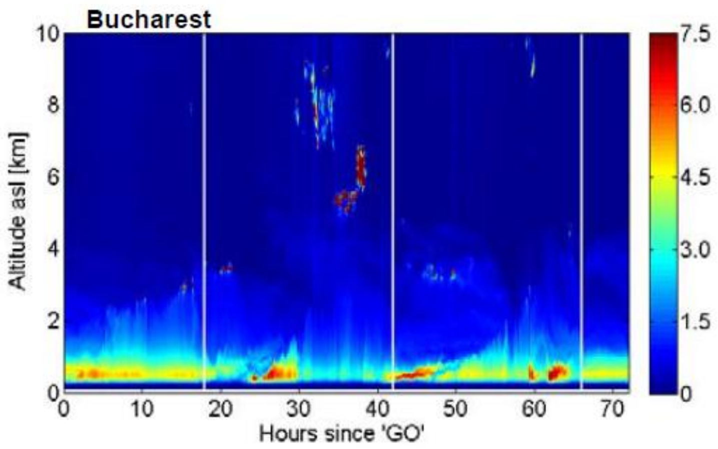

Fig. 2: Example of a homogeneous network-wide quick-look image (Sicard et al., 2015).

Level 1.5 products

At the present time, EARLINET data originators submit analyzed data to the database. After some basic quality controls on format issues, data are available only for internal use. Data become publicly available after one year. Finally, the selection of data for publication on recognized repositories as CERA databaseis made on the base of a manual quality check (Pappalardo et al., 2014). However, this procedure prevents the fast use of the data which is essential for assimilation purposes and hazards. On the other hand, the difference between quality-checked and not quality-checked data is not clear to the external users.

Because of all these reasons, an intermediate step between the pre-processed and quality-checked data has been added: the Level 1.5. The data products contained in there are the same planned for the Level2 and they will be discussed in the next section. The only difference is that they did not pass through quality check procedures. The only QC procedures for Level 1.5 data will be some basic format checks.

The Level 1.5 will permit the use of lidar data in NRT. EARLINET already proved its capability of providing data in NRT using the SCC during a 72-h experiment carried out in the ACTRIS campaign in 2012 (Sicard et al., 2015). This capability is particularly interesting for assimilation purposes (as planned in JRA3 of ACTRIS-2), but also in more general context like for instance the activities of the Copernicus programme.

Level 2 products

Level 1.5 data are the object of the quality check procedures (activity planned in WP2). A subset that does not passthe QC will be re-sent to the data originator together with the description of the failure(s), for fostering the upload of a new compliant analysis and, if necessary, for fixing system and software problems at station level. The Level 1.5 data that are compliant with the QC will flow into the Level 2 dataset. Data will be maintained inthe Level 1.5 dataset in any case.

In the following, the description of all the Level 2 products is provided. It is worth mentioning here that all these products are reported also in the Level 1.5.

Three different data products are present in Level 2 (and Level 1.5): single-wavelength optical property profiles, multi-wavelength optical property profilesand layer products. The temporal resolution of these products is around 30minto 1.5 h in continuity with the pre-ACTRIS-2 situation, but it could be longer in case of the multi-wavelength products according to the specific signal-to-noise ratio needs.

Single-wavelength optical property profiles

In continuity with the past, the new EARLINET database structure will report the e- and b-files, where the extinction (and backscatter) profiles are reported at their best vertical resolution. This allows the extension of the long-term database already achieved before the beginning of ACTRIS-2 and published with doi on the CERA database (The EARLINET publishing group, 2014a and 2014b).

Multi-wavelength optical property profiles

In addition to the standard (single-wavelength) optical property profiles reported until now in the EARLINET database, a new product is envisaged in order to take the most from the multi-wavelength capabilities widely available within the network. The multi-wavelength profile product contains the vertical profiles of all the optical properties measured in the same temporal window and with the same vertical resolution. This allows investigation of the aerosol type and, if applicable, mixing (e.g., Mona et al., 2012) as well as the determination of aerosol microphysical properties (e.g., Müller et al., 1999; Müller et al., 2005; Veselovski et al., 2005).

Layer products

In the last years, EARLINET gained experience in providing tailored datasets to different communities. In particular a database for the conversion factors between different aerosol optical properties was developed under the ESA-CALIPSO project funded by ESA (Wandinger et al., 2011; Amiridis et al., 2015) and a database about aerosol masking and aerosol layer properties was established for the study of volcanic particle distribution over Europe during the 2010 volcanic crisis (Pappalardo et al., 2013). Both these datasets found abroad consensus among different communities such as satellite data originators, space agencies and transport modelers. The main strength of those databases was the easy access to specific quantities which could be calculated from the lidar-derived aerosol optical properties, but which would not be calculated otherwise by the users.

Following the previous experiences, the Level 2 Layer Product will report for each Level 2 profile relevant information for each identified layer such as the base, top and thickness of each identified layer as well as mean, median, standard deviation and mean statistical error for each measured optical property. Integrated quantities inside each layer and columnar ones will be reported for extensive optical properties. Finally, information about the aerosol typing will be reported whenever available.

As a whole,the Level 2 products are designed to answer to post-processing validation and evaluation needs of both satellite and model data. The Layer Product could be particularly relevant for providing conversion factors for the next satellite missions with lidar on board operating at different wavelengths from CALIPSO ones (Illingworth et al., 2015;Stoffelen et al., 2005). Information about aerosol typing and microphysical properties could be also fundamental in supporting the aerosol typing harmonization actions planned in AERO-SAT initiatives (http://www.aero-sat.org/), providing a harmonized, controlled and extended ground-based dataset of typing.

Level 3 products

The Level 3 standard product contains climatological datasets obtained as aggregated products from the Level 2 aerosol optical products. Data will be aggregated into monthly, seasonal and annual datasets for both profiles and integrated quantities. Information about the number of collected samples, mean, median and standard deviation of the properties, as well as mean statistical error for each property will be reported. Metrics of the comparison with reference datasets (as AERONET for AOD) will be reported

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whenever available, in order to provide information about data representativeness. This dataset could be released only after the release of a new Level2 dataset, therefore not more than once per year, but following the previous expertise on publishing network-level database (The EARLINET publishing group, 2014a and 2014b), a bi-annual release of the Level 3 standard dataset is envisaged.

The Level 3 standard product is designed as 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. 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.

Additional advanced products will be designed step by step following the specific needs of specific studies. Also these additional advanced products will be based on the QC data. Further advanced products can be the results of the JRAs, as microphysical aerosol products based on the inversion of multi-channel lidar data oron combined lidar and sun-photometer observations.

Conclusions

The EARLINET aerosol vertical profiling database will be completely reshaped during ACTRIS-2 to meet the wide request from the users of more intuitive products from research communities and to face the even wider request related to the new initiatives of EU such as the Copernicus programme. The re-design of the EARLINET database has been carried out in continuity with the EARLINET past, to take advantage from its 15-year long history. In particular, the new structure will provideinformation particularly suitable for synergy with otherinstruments (Level 1), NRT applications (Level 1 and Level 1.5), validation and process studies (Level2) and climate application (Level3). In addition to these products, further tailored products are foreseen in ACTRIS-2 as advanced products, to satisfy specific users needs.

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Appendix

Level1 products

```
netcdf D:\ACTRIS2\JRA3\Meeting\20120710po23_293 {
dimensions:
        time = UNLIMITED ; // (1 currently)
        points = 1023 ;
        channels = 3 ;
        scan_angles = 1 ;
variables:
        doublealtitude_resolution(scan_angles) ;
        doublerange_resolution(scan_angles) ;
        doublelaser_pointing_angle(scan_angles) ;
        doubleemission_wavelength(channels) ;
        doubledetection_wavelength(channels) ;
        intlaser_pointing_angle_of_profiles(time) ;
        int shots(time) ;
        intstart_time(time) ;
        intstop_time(time) ;
        doubleElastic_Mol_Extinction(scan_angles, points) ;
        doubleLR_Mol ;
        doubleEmission_Wave_Mol_Trasmissivity(scan_angles, points) ;
        doubleDetection_Wave_Mol_Trasmissivity(scan_angles, points) ;
        doubleDepolarization_Factor ;
        doubleelPP(time, points) ;
        doubleelPP_err(time, points) ;
        doubleelCP(time, points) ;
        doubleelCP_err(time, points) ;
        double vrRN2(time, points) ;
        double vrRN2_err(time, points) ;
        intoverlap_correction ;
        intcloud_flag(time, points) ;

// global attributes:
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                :System = "MUSA" ;
                :Latitude_degrees_north = 40.601039 ;
                :Longitude_degrees_east = 15.723771 ;
                :Altitude_meter_asl = 760. ;
                :Measurement_ID = "20120710po23" ;
                :Measurement_Start_Date = "20120710" ;
                :Measurement_Date_Format = "YYYYMMDD" ;
                :Measurement_Start_Time_UT = "215903" ;
                :Measurement_Time_Format = "HHMMSS" ;
                :Comments = "" ;
                :SCCPreprocessingVersion = "5.14" ;
```

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Single-wavelength optical property profiles

```
netcdfheaderoptional {
dimensions:
      Length = UNLIMITED ; // (5 currently)
variables:
float Altitude(Length) ;
Altitude:units = "m" ;
Altitude:long_name = "Height above sea level" ;
floatDustLayerHeight ;
DustLayerHeight:units = "m" ;
DustLayerHeight:long_name = "Top of dust layer above sea level" ;
floatMixingLayerHeight ;
MixingLayerHeight:units = "m" ;
MixingLayerHeight:long_name = "Top of mixing layer above sea level" ;
float Backscatter(Length) ;
Backscatter:units = "1/(m*sr)" ;
float Extinction(Length) ;
Extinction:units = "1/m" ;
floatParticleDepolarization(Length) ;
floatErrorBackscatter(Length) ;
ErrorBackscatter:units = "1/(m*sr)" ;
floatErrorExtinction(Length) ;
ErrorExtinction:units = "1/m" ;
float Error ParticleDepolarization (Length) ;
floatVolumeDepolarization(Length) ;
float Error VolumeDepolarization (Length) ;
floatRayleighExtinction(Length) ;
floatWaterVaporMixingRatio(Length) ;
WaterVaporMixingRatio:units = "g/kg";
floatErrorWaterVapor(Length) ;
ErrorWaterVapor:units = "g/kg" ;
// global attributes:
:System = "MPI UV-system" ;
:Location = "Lindenberg, Germany" ;
:Longitude_degrees_east = 12.345 ;
:Latitude_degrees_north = 54.321 ;
:Altitude_meter_asl = 123 ;
:EmissionWavelength_nm = 351 ;
:DetectionWavelength_nm = 351 ;
:DetectionMode = "analog" ;
:ZenithAngle_degrees = 0 ;
:ShotsAveraged = 10000 ;
:ResolutionRaw_meter = 15 ;
            :ResolutionEvaluated = "60 m up to 1000m, 500 m up to 5000 m" ;
:StartDate = 19970701 ;
:StartTime_UT = 130000 ;
:StopTime_UT = 133000 ;
:EvaluationMethod = " Fernald" ;
:InputParameters = "reference value 1.e-7 1/(m*sr) at 6800 m" ;
```

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Multi-wavelength optical property profiles

```
netcdfheaderoptional {
dimensions:
      Length = UNLIMITED ; // (5 currently)
WavelengthID = 3; //
variables:
float Altitude(Length) ;
Altitude:units = "m" ;
Altitude:long_name = "Height above sea level" ;
floatDustLayerHeight ;
DustLayerHeight:units = "m" ;
DustLayerHeight:long_name = "Top of dust layer above sea level" ;
floatMixingLayerHeight ;
MixingLayerHeight:units = "m" ;
MixingLayerHeight:long_name = "Top of mixing layer above sea level" ;
float Backscatter(Length, WavelengthID) ;
Backscatter:units = "1/(m*sr)" ;
float Extinction(Length, WavelengthID) ;
Extinction:units = "1/m" ;
floatParticleDepolarization(Length, WavelengthID) ;
floatVolumeDepolarization(Length, WavelengthID) ;
floatErrorBackscatter(Length, WavelengthID) ;
ErrorBackscatter:units = "1/(m*sr)" ;
floatErrorExtinction(Length, WavelengthID) ;
ErrorExtinction:units = "1/m" ;
float Error ParticleDepolarization (Length, WavelengthID) ;
float Error VolumeDepolarization (Length, WavelengthID) ;
floatWaterVaporMixingRatio(Length) ;
WaterVaporMixingRatio:units = "g/kg";
floatErrorWaterVapor(Length) ;
ErrorWaterVapor:units = "g/kg" ;

// global attributes:
:System = "MPI UV-system" ;
:Location = "Lindenberg, Germany" ;
:Longitude_degrees_east = 12.345 ;
:Latitude_degrees_north = 54.321 ;
:Altitude_meter_asl = 123 ;
:EmissionWavelength_nm = 351 ;
:DetectionWavelength_nm = 351 ;
:DetectionMode = "analog" ;
:ZenithAngle_degrees = 0 ;
:ShotsAveraged = 10000 ;
:ResolutionRaw_meter = 15 ;
        :ResolutionEvaluated = "60 m up to 1000m, 500 m up to 5000 m" ;
:StartDate = 19970701 ;
:StartTime_UT = 130000 ;
:StopTime_UT = 133000 ;
:EvaluationMethod = " Fernald" ;
:InputParameters = "reference value 1.e-7 1/(m*sr) at 6800 m" ;
```

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Layer products

```
netcdf D:\ACTRIS2\WP2\le0905252059_layers {
dimensions:
	number_of_aerosol_layers = 2 ;
variables:
	doublelayer_bottom(number_of_aerosol_layers) ;
	doublelayer_top(number_of_aerosol_layers) ;
	doublelayer_width(number_of_aerosol_layers) ;
	double beta355_mean(number_of_aerosol_layers) ;
	double beta532_mean(number_of_aerosol_layers) ;
	double beta1064_mean(number_of_aerosol_layers) ;
	double e355_mean(number_of_aerosol_layers) ;
	double e532_mean(number_of_aerosol_layers) ;
	double ang_355_532_mean(number_of_aerosol_layers) ;
	double ang_532_1064_mean(number_of_aerosol_layers) ;
	double ang_355_1064_mean(number_of_aerosol_layers) ;
	doubleang_e_mean(number_of_aerosol_layers) ;
	double LR_355_mean(number_of_aerosol_layers) ;
	double LR_532_mean(number_of_aerosol_layers) ;
	double beta355_std(number_of_aerosol_layers) ;
	double beta532_std(number_of_aerosol_layers) ;
	double beta1064_std(number_of_aerosol_layers) ;
	double e355_std(number_of_aerosol_layers) ;
	double e532_std(number_of_aerosol_layers) ;
	double ang_355_532_std(number_of_aerosol_layers) ;
	double ang_532_1064_std(number_of_aerosol_layers) ;
	double ang_355_1064_std(number_of_aerosol_layers) ;
	doubleang_e_std(number_of_aerosol_layers) ;
	double LR_355_std(number_of_aerosol_layers) ;
	double LR_532_std(number_of_aerosol_layers)
// global attributes:
	:System = "MPI UV-system" ;
:Location = "Lindenberg, Germany" ;
:Longitude_degrees_east = 12.345 ;
:Latitude_degrees_north = 54.321 ;
:Altitude_meter_asl = 123 ;
:StartDate = 19970701 ;
:StartTime_UT = 130000 ;
:StopTime_UT = 133000 ;
	:Measurement_ID = "20090525le02" ;
```

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Level3 products

```
netcdfheadermandatory {
dimensions:
      Length = UNLIMITED ; //
variables:
int Day(Length) ;
Day:units = "yyyymmdd" ;
Day:long_name = "Day of measurements" ;
float AOD(Length) ;
AOD:long_name = "Columnar AOD measured by EARLINET system" ;
float FT(Length) ;
FT:long_name = "Free troposphere contribution to the total AOD" ;
floatAeronetDiff(Length);
AeronetDiff: long_name="Difference between EARLINET and AERONET AOD at emitted wavelength";
floatModisDiff(Length);
ModisDiff: long_name="Difference between EARLINET and MODIS AOD at emitted wavelength";

// global attributes:
:Location = "Tito Scalo, Italy" ;
:Longitude_degrees_east = 15.72 ;
:Latitude_degrees_north = 40.6 ;
:Altitude_meter_asl = 760 ;
            :PI_name= "Gelsomina Pappalardo";
            :PI_affiliation="CNR-IMAA";
            :PI_email="gelsomina.pappalardo@imaa.cnr.it";
:Wavelength_nm = 355;
:InputParameters = "Climatological category" ;
            :DataReferences=" doi:10.1594/WDCC/EN_Climatology_2000-2010";
            :Reference=" Mona et al., in preparation, ACP";
            :AERONETsite="IMAA_Potenza";
            :MODISgrid_resolution= "1°x1°";
            :Angstrom_Exponent_355_500= 1.037;
:Comments = "Angstrom exponent is the overall mean on the  AERONET measurements" ;
```

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