Manuscript prepared for Atmos. Meas. Tech.
with version 5.0 of the LaTeX class copernicus.cls.
Date: 20 March 2015

EARLINET Single Calculus Chain - general presentation methodology and strategy

Giuseppe D'Amico[1], Aldo Amodeo[1], Holger Baars[2], Ioannis Binietoglou[1,3], Volker Freudenthaler[4], Ina Mattis[2,5], Ulla Wandinger[2], and Gelsomina Pappalardo[1]

[1]Consiglio Nazionale delle Ricerche, Istituto di Metodologie per l'Analisi Ambientale (CNR-IMAA), Tito Scalo, Potenza, Italy
[2]Leibniz Institute for Tropospheric Research, Leipzig, Germany
[3]National Institute of R&D for Optoelectronics INOE,Bucharest, Romania
[4]Ludwig-Maximilians-Universität, Munich, Germany
[5]Deutscher Wetterdienst, Meteorologisches Observatorium Hohenpeißenberg, Germany

Correspondence to: Giuseppe D'Amico
(giuseppe.damico@imaa.cnr.it)

Abstract. In this paper we describe the EARLINET Single Calculus Chain (SCC) a tool for the automatic analysis of lidar measurements. The development of this tool started ~~in~~ the framework of EARLINET-ASOS (European Aerosol Research Lidar Network - Advanced Sustainable Observation System) project and ~~it~~ is ~~still~~ continuing within ACTRIS (Aerosol, Clouds and Trace gases Research InfraStructure Network) project. The main idea was to develop a chain which allows all EARLINET stations to retrieve in a full automatic way the aerosol backscatter and extinction profiles starting from the raw lidar data of the lidar systems they operate. The calculus subsystem of the SCC is composed ~~by~~ two modules: a pre-processor module that handles the raw lidar data and corrects them for instrumental effects and an optical processing module for the retrieval of aerosol optical products from the pre-processed data. All the input parameters needed to perform the lidar analysis are stored in a database ~~to get them in an efficient way~~ and also to keep track of all the changes that may occur on any EARLINET lidar system over the time. The two calculus modules and the data are coordinated and synchronized by a further module (deamon) which makes ~~fully automatic~~ the whole analysis process. The end-user can interact with the SCC using a user-friendly web interface. All the SCC modules are developed using open source and free available software packages. The final products retrieved by the SCC fulfill all constraints fixed in the framework of the EARLINET quality assurance programs on both instrumental and algorithm levels. Moreover the man power needed to provide aerosol optical products is greatly reduced improving the near-real time availability of lidar data. The high quality of the SCC products is demonstrated by the good agreement between the SCC analysis and the corresponding independent manual retrievals. Finally, a real example of the applicability of the SCC in providing high quality aerosol optical products ~~in case of intense observation period is provided.~~

1 Introduction

The contribution of ~~the~~ aerosols in ~~the~~ atmospheric processes is not well known. In particular an important gap needs to be filled to clarify ~~better~~ the ~~rule the~~ aerosols play in the Earth radiation budget problem and in climate changes (IPCC, 2007, 2013).

The most critical issue in understanding the processes in which the aerosols are involved is the high variability they have in terms of type, source, time and space (Diner et al., 2004). For this reason for the scientific community is particularly ~~interesting~~ to have access to the optical parameters characterizing the aerosol in terms of high resolution vertical atmospheric profiles. The lidars have the advantage ~~to provide~~ space and time resolved vertical profiles of aerosol optical parameters and to allow us ~~the full characterization~~ of each layer present in the atmosphere.

Another important aspect to consider for the study of aerosols is the ~~good coverage of lidar measurements on large scale.~~ To support this need several coordinated lidar networks have been ~~set-up~~ in the last years. In particular EARLINET (European Aerosol Research LIdar NETwork) ~~is operative~~ ~~in~~ Europe since 2000 and provides the scientific community with the most complete database ~~of aerosol optical parameters vertical profiles on European scale~~ (Pappalardo et al., 2014; Earlinet, 2014). The EARLINET data can be used for several purposes ~~like~~ model~~s~~ evaluation and assimilation, full exploitation of satellite data, study of aerosol long range transport mechanism, monitoring of special events like volcanic eruption, large forest fire or dust outbreaks.

Within the EARLINET-ASOS (European Aerosol Research Lidar Network - Advanced Sustainable Observation System) project great importance was given to the optimization of lidar data processing (http://www.earlinetasos.org). The core of this activity was the development of the EARLINET Single Calculus Chain (SCC) a tool for the automatic evaluation of lidar data from raw signals up to the final products.

The SCC has been developed to accomplish the fundamental need of any coordinated lidar network to have an optimized and automatic tool providing high quality aerosol products. High quality is obtained enstablishing, at network level, a rigorous quality assurance program and taking care to deliver to the end-users only homogeneous products compliant with this program. In many specific situations it is also quite important these products retrieved on large geographical scale (for example on continental scale) are made available in real-time or in near-real-time. This is the case for example of vertically resolved lidar products used to improve the forecast of air quality or climate change models, to validate satellite sensors or models or to monitor special events. Without a common analysis tool it could be difficult to assure at the same time homogenous high quality products and short time availabiliby of the data because usually high quality manual lidar data analysis requires time and man power. Moreoever different groups within the network may use different retrieval approaches to derive the same type of aerosol product with a consequent loss in the homogeneity of the network dataset.

Another important key point to take into account in developing the SCC is heterogeneity of the lidar systems composing a typical lidar network. Excluding few exceptions, usually a lidar network is formed by really different and not standardized lidar systems ranging from single elastic backscatter lidar to advanced multi-wavelength Raman systems. Frequently, a system is improved or upgraded from a basic configuration to a more complex one by adding, for example, new detection channels. As consequence the SCC must adapt itself to handle data acquired by different instruments which usually require different instrumental corrections and also different approaches to get quality assured products. For example as, in general, not all the lidars are characterized by the same signal to noise ratio (SNR), different smoothing algorithms or different integration times need to be selected to constrain the final products to the same accuracy level. EARLINET is a good example on how heterogenous the lidar systems forming a network can be. Typically EARLINET lidar systems can differ in terms of emitted or detected wavelengths, acquisition mode (analog and/or photon-counting), space and time resolution, and detection systems. A network like AERONET (Holben et al., 1998) for example, does not suffer too much about this problem as it is based on the same standardized instrument. In cases like that a common scheme for the analysis of raw data does not need to take into account many different instrumental aspects with a consequent reduction (from this point of view) of the development complexity. On the contrary, the EARLINET lidar systems are really heterogeneous in many aspects and many of them are home-made or highly customized. This makes, from practical point of view, impossible to develop a single algorithm to analyze all the EARLINET data.

For these reasons the main concept to put at the base of the SCC development is the implementation of a tool able to provide quality assured aerosol optical products from raw lidar data in an fully unattended way. At the same time, to make the use of this tool really sustainable over the time an easy expandiblility should be assured to guarantee the analysis of the data from new or upgraded lidar systems.

The main advantage of this approach is to increase the rate of population of the aerosol databases which is the main outrich of any lidar network promoting, in general, the usage of lidar retrieved vertically resolved aerosol parameters within the scientific community.

To the above general considerations some specific EARLINET constraints need to be considered in developing the SCC. The EARLINET quality assurance program involves both the instrumental and algorithm retrieval levels (Mattias et al., 2004; Freudenthaler et al., 2015). As consequence an aerosol optical product can be considered EARLINET quality assured only if it has been measured with a lidar system which passed the instrumental quality assurance tests and if it has been calculated using certified algorithms (Böckmann et al., 2004; Pappalardo et al., 2004). The SCC products automatically fulfill both these requirements as all the algorithms implemented are EARLINET quality assured and specific tests that have been set up to verify the raw lidar data have been measured by a quality assured lidar system.

Using the SCC it is possible to calculate mainly aerosol extinction and backscatter profiles. This set of optical parameters, especially in case of multi-wavelength measurements, can provide a full characterization of atmospheric aerosol from both quantitative and qualitative point of view (Mattis et al., 2003; Wandinger et al., 2002; Müller et al., 2005; Ackermann, 1998). Moreover such kind of products can be used as inputs to infer microphysical properties of atmospheric aerosols (Müller et al., 1999a,b; Böckmann, 2001). In particular, it is important to mention that two independent SCC modules have been developed to retrieve microphysical properties of the atmospheric aerosols from multi-wavelength Raman lidar data (Müller et al., 2015). The main products of both these modules are particle effective radius, volume concentration, and refractive index which are calculated with a semi-automated and unsupervised algorithm. However, even if these modules have been released in their operational versions, they are not yet included in the automatic structure of the SCC.

Even if the SCC has been developed to be the main tool to analyze EARLINET lidar data, its high degree of flexibility and expandibility makes the same tool easily usable in a more general contests and for other lidar networks. As EARLINET represents already a quite complete example of all the available lidar system typologies it is expected to smoothly adapt the SCC to run in more extended frameworks like for example GALION (GAW Aerosol LIdar Observation Network).

To our ~~knowlegde~~ the SCC is the first tool that can be used to analyze raw data measured by many different typologies of lidar systems in a full automatic way. The other existing tools for the automatic analysis of lidar data are usable only for a specific lidar system and cannot be easily extended to retrieve aeorol products of whole lidar networks which are usually composed by different instruments. Another unique characteristic of the SCC is that its ~~aerosol~~ products are delivered according to a rigorouus quality assurance program to provide always the highest possible quality products at network level.

This paper is the first of three publications about the SCC and it presents an overview of the SCC and its validation. Two separated papers are used to describe the technical details of the SCC pre-processing module (D’Amico et al., 2015) and of the optical processing module (Mattis et al., 2015) respectively.

In the first section of ~~the~~ paper the main requirements the SCC should fulfill are described. The second section is devoted to explain the whole structure of the SCC. The last two sections of the paper explain the strategy we adopted to validate the SCC and an example of the application of the SCC to provide a tool to provide network lidar data in near real time.

2 Requirements

In this section the requirements to accomplish all the key points explained in the previous section will be described.

In the framework of the EARLINET quality assurance program several algorithms for the retrieval of aerosol optical parameters have been inter-compared to evaluate their performances in providing high quality aerosol products (Böckmann et al., 2004; Pappalardo et al., 2004). This intercomparison was mainly addressed to asses a common European standard for the quality assurance of lidar retrieval algorithms and to ensure the data provided by each individual station are permanently of highest possible quality according to common standards. All the different quality-assured analysis algorithms developed within EARLINET have been collected, critically evaluated with respect to their general applicability, optimized to make them fully automatic and finally implemented in the SCC. A critical point was the implementation of reliable and robust algorithms to assure accurate calibration of aerosol backscatter profile. In a fully automatic analysis scenario particular attention should be devoted to this issue to avoid large inaccuracy in the final optical products. Noisy raw lidar signals or the presence of aerosol within the calibration region can induce large errors in the lidar calibration constant.

The SCC has been developed having in mind the following concepts: platform independency, open source philosophy, standard data format (NetCDF), flexibility through the implementation of different retrieval procedures, expandability to easily include new systems or new system configurations. All the libraries and the compilers needed to install and run the SCC are open source and free available. The SCC can operate on centralized server or on local PC. The users can connect to the machine on which the SCC is running and use or configure the SCC retrieval procedures on their data using a web interface. The centralized server solution (which is the preferred way of using the tool) has many advantages with respect to local installation especially when the SCC is used within a coordinated lidar network as EARLINET. First of all it is possible to keep track of all the system configurations of all systems and also to certify which configurations are quality assured. Moreover in this way it is always sure to use the same and the latest SCC version to produce optical products.

Particular attention has been addressed to the design of a suitable NetCDF structure for the SCC input file as it needs to fulfill the following constrains:

1. it should contain the raw lidar data as they are measured by the lidar detectors (output voltages for analog lidar channels, counts for photoncounting channels) without any correction earlier applied by the user. This is particularly important to ensure the quality assurance of the final products: all the necessary instrumental corrections should be applied by the SCC using quality assured procedures. This is the reason for which a specific pre-processing SCC module has been developed;

2. it should contain also additional input parameters needed for the analysis. As it will be explained in the next section the main part of the required input parameters are efficiently stored in a SCC database. However there are some parameters easily changing from measurement to measurement (for example electronic background or laser shots) that cannot be usefully stored in a database. The only way to pass such kind of parameters to the SCC is via the input file. To improve the self-consistency of the SCC input file it has been allowed the option to include in the file also some important parameters already stored in the SCC database. In case these

paramenters are found in the input file their value will be used in the analysis;

3. it should contain unique method to link the information contained in the input file with the ones included in the SCC database. As it will be explained in the next section this is assured by the definition of unique channel IDs which identify the different lidar channels.

4. it should allow efficient data processing. As the SCC has been designed to be a multi-user tool it is important to improve the computational speed as much as possible to avoid long delay in getting the final products. This has been accomplished putting in a single SCC input file the time-series of all the channels available for a lidar configuration.

Finally concerning the NetCDF output file structure, as the SCC products need to be uploaded on EARLINET database, it is fully compliant with the structure of EARLINET *e* and *b* files. The *e* files contain the aerosol extinction profile and optionally the Raman backscatter profile at the same effective vertical resolution. The *b* files contain the elastic backscatter profile or alternatively the Raman backscatter profile at highest possible vertical resolution. More details about EARLINET *e* and *b* file are provided in (Pappalardo et al., 2014; Earlinet, 2014).

3 SCC structure

Figure 1 shows the general structure of the SCC which consists ~~in~~ several independent but inter-connected modules. Basically there is a module responsible for the pre-processing of raw lidar data, a module for the retrieval of the aerosol extinction and backscatter profiles, a daemon which automatically starts the pre-processing or the processing module when it is necessary, a database to collect all the input parameters need for the analysis and finally a web interface. Once the new raw data file is submitted to the SCC via the web interface, the deamon automatically starts the pre-processing module and in succession the processing module. The status of the analysis in each step can be monitored using the web interface and both the pre-processed or the optical results can be downloaded.

3.1 SCC database

The retrievals of aerosol optical products from lidar signals require a ~~lot of~~ input parameters to be used in both pre-processing and processing phase. Two different types of ~~such kind of~~ parameters are needed: experimental which are mainly used to correct instrumental effects and configurational which define the way to apply a particular analysis procedure. An example of experimental parameter is the dead time of a photoncounting system. Once measured, the value of the dead time for a particular photoncounting lidar channel can be included in the database among the other parameters that characterize the channel and, consequently, will be used to correct the corresponding raw lidar data. The dead time is an example of an experimental parameter that in general changes from channel to channel. There are other experimental parameters which may be shared by multiple channels ~~like~~ for example telescope or laser characteristics (usually several lidar channels share the same laser or the same telescope).

Configuration parameters are then ones used to identify which algorithm, among the implemented ones, has to be used to calculate a particular product. In general, in the SCC there are multiple quality assured algorithms to calculate a particular aerosol product. For example for the aerosol elastic backscatter both the iterative (Di Girolamo et al., 1995) and the Klett method (Klett et al., 1981, 1985; Fernald, 1984) have been implemented. The user can choose which one use for his data setting a correspondent parameters in the database.

In general, both configuration and experimental parameters can change from one lidar system to another and, even for the same lidar system, they can change for the different configurations under which the lidar can run. For example a lidar that in nighttime configuration can deliver aerosol extinction and Raman backscatter in daytime configuration may provide only aerosol elastic backscatter as the Raman channels could not have daytime capabilities.

In this complex context, a relational database represents an optimal solution to handle, in an efficient way, all this information. For this reason, a SCC database has been implemented to store the input parameters for all the EARLINET systems and, at the same time, to ~~get~~ the subset of all the parameters associated to a particular lidar configuration. A multiple table~~s~~ MySQL database has been used to make the SCC database. All the software needed to run and configure a MySQL databases is free available over internet and the whole project is based on an open-source project.

In the SCC database, the experimental parameters are grouped in terms of stations, lidar configurations and lidar channels. All the EARLINET stations are registered in the SCC database and are univocally identified by a 2-character code (for example *at* identifies the EARLINET station of Athens). Each station is then linked to one or more lidar configurations which in turns are linked to one or more lidar channels. Unique numerical IDs are associated to each lidar configuration and to each lidar channel. In this way, with specific database query, it is possible to easily get, for a particular lidar station, any detail of all the available lidar configurations running at that site or any information for all the channel IDs belonging the each lidar configuration (for example the geographical coordinates at which the lidar is running or the wavelengths of all the lidar channels).

Each lidar configuration is associated to a set of products that the SCC should calculate. Basically all the SCC configuration parameters are linked to the product IDs. Each product is linked to a product type (for example aerosol extinction, Raman backscatter,...) to a set of channel IDs needed to calculate the products and to an usecase that, as it will be explained later, represents the way to calculate the product. Moreover, for a particular product, it is possible to fix a set of configuration parameters like for example the pre-processing vertical resolution, the Raman backscatter calibration method, the maximum statistical error we would like to have on the final products and so on.

A measurement to get analyzed by the SCC needs to be first registered in the SCC database. The registration consists in associating an unique measurement ID to the measurement session. The measurement ID is then linked to the lidar configuration at which the measurement refers to and to the SCC input file containing the data to analyze.

A so structured database allows us to keep track of all the information used to generate a particular SCC product. For each product, for example, it is possible to get the measurements date and the list of channel IDs used for its calculation. If all those channel IDs at measurement time have passed all the required instrumental quality checks the corresponding product can be considered quality assured. This is a fundamental point in order to implement a reliable and rigorous quality assurance program at network level.

3.2 Pre-processor module (ELPP: Earlinet Lidar Pre-Processor)

This module implements all the corrections to be applied to the raw lidar signals before they can be used to derive optical properties. As the details of this module are described in (D'Amico et al., 2015) here just the main characteristics will be reported.

The main reason for which we implemented a pre-processor module along with a optical processing module is that the EARLINET quality assurance program does not apply only to the retrieval of aerosol optical properties but also to the procedures needed to correct for instrumental effects. Moreover handling with the ~~really~~ raw data it is possible to identify problems in lidar signals that could be not so evident in already pre-processed signals. The raw lidar signals have to be submitted in a NetCDF format with a well-defined structure (D'Amico et al., 2015). In particular the raw lidar data should consist ~~in~~ the signal as detected by the lidar detectors. In case of analog detection mode the signal should be provided in mV while for photoncounting mode it should be expressed in pure counts. According to the specific lidar system and to the input parameters defined both in the SCC database configuration and in the NetCDF input file, different types of operations can be applied on raw data. To make the SCC a tool useful for all EARLINET systems it is ~~needed the~~ pre-processing module implements all the different instrumental corrections used for the different EARLINET lidars. The complete description of all these corrections are reported in (D'Amico et al., 2015), here we just report a list of the most common: dead-time correction, trigger-delay correction, overlap correction, background subtraction (both atmospheric and electronic). Beside ~~to~~ these corrections the pre-processor module is also responsible ~~to generate~~ the molecular signal needed to calculate the aerosol optical products. This can be done using standard atmosphere model or correlative radiosounding profile. Finally the pre-processor module implements low- and high-range automatic signal gluing, vertical interpolation, time averaging and statistical uncertainty propagation. The outputs of the pre-processor module are intermediate pre-processed NetCDF files which will be the input files for the optical processor module. These files contain the range corrected pre-processed lidar signals and the corresponding molecular atmospheric profiles. As these quantities can be used in many different fields of application (quick-look generation, model assimilation, intercomparison campaigns) the intermediate NetCDF files can be considered ~~an~~ additional ~~not calibrated~~ products provided by the SCC.

3.3 Optical processor module (ELDA: Earlinet Lidar Data Analyzer)

ELDA applies to the pre-processed signals, produced by the pre-processor module, the algorithms for the retrieval of aerosol optical parameters. All the details of ELDA module are provided in (Mattis et al., 2015). Only a very brief overview of its main functionalities is provided here. ELDA module can provide aerosol products in a flexible way choosing from a set of possible pre-defined analysis procedures (usecases). ELDA implements retrieval of elastic aerosol backscatter profile (~~Klett~~ Klett et al. (1981); Fernald (1984), iterative algorithm Di Girolamo et al. (1995)), retrieval of aerosol extinction profile (Ansmann et al., 1990) and finally retrieval of Raman aerosol backscatter profile (Ansmann et al., 1992). An automatic vertical-smoothing and time-averaging technique selects the optimal smoothing level as a function of altitude on the ~~base~~ of different thresholds on product uncertainties fixed in the SCC database for each product. The final optical products are written in NetCDF files with a structure fully compliant with the *e* and *b* EARLINET files.

3.4 Usecase

To improve the flexibility of the SCC the concept of *usecase* has been introduced. The SCC uses the usecases to adapt the analysis of lidar signal to a specific lidar configuration. Each usecase identifies a particular way to handle lidar data. An example on how the usecase are defined is illustrated in figure 2. In the left part of the figure it is schematically shown the usecase 0 for the aerosol Raman backscatter calculation. This usecase refers to a basic Raman lidar configuration where ~~are detected~~ only an elastic signal (elT) and the corresponding vibrational-rotational N_2 Raman one (vrRN2). These two signals are preprocessed by the SCC pre-processor module and then the results are saved in a NetCDF intermediate file. Then ELDA module gets the preprocessed signals and delivers as final result the aerosol Raman backscatter profile. In the right part of figure 2 ~~it is reported~~ a more complex usecase (the usecase 13) for aerorol Raman backscatter calculation which corresponds to a lidar system which uses two different telescopes: one optimized to detect the signal backscattered by the near range atmospheric region and an other one optimized to detect the atmospheric signal by the far range. Moreover for both these telescopes the elastic and the ~~ro-vibrational~~ N_2 Raman channels are detected in analog and photoconting mode. In this case, the SCC should combine 8 raw signals to get an unique aerosol Raman backscatter profile. Looking at the figure 2 we can see the details of this combination for the usecase 13. First the analog and the corresponding photoncounting signals are combined by the pre-processor module. ~~In this way in the intermediate NetCDF file there are 4 signals~~ ~~which represent~~ the combined (analog and photoncounting) elastic and ro-vibrational N_2 Raman channels detected by the near range and far range telescope. The ELDA module combines these 4 pre-processed signals ~~retrieving~~ two different aerosol Raman backscatter profiles (one for the near range and the other for the far range) and finally these products are glued together to get a single aerosol Raman backscatter profile.

A total of 34 different usecases have been defined and implemented within the SCC for the calculation of all the optical products. A schematic description of all the implemented usecases is provided in the appendix A. This set of usecases assures all the different EARLINET lidar setups can be processed by the SCC. Moreover we may have further flexibility choosing among the different usecases compatible for a fixed lidar configuration.

Finally the concept of usecase improves also the expandability of the SCC: to implement in the SCC a new lidar configuration it is enough to implement a new usecase if the ones already defined are not compatible with it.

3.5 SCC daemon module

The SCC database, the ELPP and ELDA modules are well separated objects that need to act in a coordinated and synchronized way. When a measurements is submitted to the SCC a new entry is created in the SCC database. As soon as this operation is completed the pre-processing module should be started on the submitted measurements. As soon as there are pre-processed data available, the ELDA modules should be started on them to get the aerosol optical products. All these operations are performed by the module SCC daemon. The SCC daemon is a multithread process running continuously in the background and it is responsible to start thread instances for the pre-processor or the optical processor module when it is necessary. Another important function of the SCC daemon is to monitor the status of started modules and to track the corresponding exit status in the SCC database. In this way the user can be informed about the success or the failure of the SCC on the submitted measurement with detailed and specific error messages. It is also possible to define timeout periods after which started modules should be forced to stop.

As the SCC is mainly designed to be run on a single server where multiple users can perform at the same time different lidar analysis, the SCC daemon has been developed to act in a multithread environment. In this way different processes can be started in parallel by the SCC daemon enhancing the efficiency of the whole SCC. The SCC daemon has an ~~high~~ configurable multithread mode to adapt itself to the hardware resources available on the hosting server.

3.6 Web interface

This module represents the interface between the end-user and the SCC. In particular, to use the SCC, the user needs to interact only with the SCC database as the calculus modules ELPP and and ELDA are automatically started by the SCC daemon that in turns gets and provides info to the SCC database. ~~Therefore,~~ the web interface is an user-friendly way to interact with the SCC database using any of available Internet browsers. Using the web interface it is possible to:

1. change or visualize all the input parameters for a particular lidar system or add a new system;

2. upload data to the SCC server and register the measurements in the SCC database. Along with raw lidar data it is possible also to upload ancillary files like for example correlative sounding profile and overlap correction function which can be used in the analysis. All these files should be in NetCDF format with a well-defined structure. The interface does not allow to upload on the server files in wrong format or not compliant with the defined structure;

3. visualize the status of the SCC analysis. In case of failure a specific error message is shown in a way the user can easily figure out the reason ~~of~~ failure;

4. download the pre-processing or the optical products from the server. In particular, it is possible to visualize the calculated profile of aerosol optical products;

5. ~~restart~~ the SCC on an already analyzed measurement;

The web interface has been developed in a way that the above actions can be performed depending on different type of accounts. For example users belonging to a particular lidar stations cannot modify any input parameters for a lidar system linked to a different lidar station. Moreover it is possible to define users that can only perform analysis and cannot change input parameters.

Moreover the processing status of each measurement can be also monitored using a web API (Applications programming interface). Using this API, the SCC can be tightly integrated to each stations processing system making the process of submission of the raw data and the corresponding analysis fully automatic.

Finally, using the web interface it is possible to have access to an EARLINET Handbook of Instrument (HOI) where all the instrumental characteristics of the lidar systems registered in the SCC database are reported. The main goal of the HOI is to collect all the characteristics of all EARLINET lidar systems and to make this information available for the end-user in an efficient and user-friendly way. For this reason the information in the HOI is grouped in terms of the different subsystems that a complete lidar system has: laser source, telescope, spectral separation, acquisition system. Additional information concerning the station running the lidar system is also ~~provided. Moreover as usually the lidar systems can be updated over the time any change is tracked and visible in the HOI.~~

4 Validation

A validation strategy to prove whether SCC can provide quality assured aerosol optical products has been implemented. The performances of the SCC have been evaulated on both synthetic and real lidar data.

As first step, the SCC has been tested on the synthetic lidar signals used during the algorithm inter-comparison exercise performed in the framework of the EARLINET-ASOS project (Pappalardo et al., 2004). This set of synthetic signals was simulated with really realistic experimental and atmospheric conditions to test the performances of specific algorithms for the retrieval of aerosol extinction, backscatter and lidar ratio. Comparing the calculated profiles with the corresponding inputs profile used to simulate the signals it is possible verify if an implemented algorithm returns reliable results. As the details of this exercise are provided in (Mattis et al., 2015) we just mention here that all the algorithms implemented within the SCC produce profiles that agree with the solutions within the statistical uncertainties.

As second validation level, we have evaluated the SCC performances when it is applied on real lidar data comparing the optical products calculated by the SCC with the corresponding optical products generated by the analysis software developed by different lidar groups. This comparison has been performed using two different approaches. First we compared the analysis obtained by the lidar measurements taken by several lidar systems measuring in the same place at the same time. In this way we can check the ability of the SCC to adapt itself to analyze data coming from different lidar systems in the same atmospheric conditions. Secondly we have compared the mean profiles which were obtained from profiles measured by two EARLINET stations over several months at the same place. This kind of test is devoted to evaluate possible biases in the SCC analysis not visible comparing the ~~analysis in~~ one single case.

4.1 Single profiles validation

The EARLI09 (EArlinet Reference Lidar Intercomparison 2009) measurement campaign held in Leipzig, Germany, in May 2009 (Freudenthaler et al., 2010; Wandinger et al., 2015) gave us the possibility to test the SCC on the measurements taken by different lidar systems ~~in~~ the same atmospheric conditions. Eleven lidar systems from ten different EARLINET stations performed one month of co-located, coordinated measurements under different meteorological conditions. During the campaign the SCC pre-processor module was successfully used to provide, in a very short time, signals corrected for instrumental effects for all the participating lidar systems (Wandinger et al., 2015). In this way, all the signals were pre-processed with the same procedures and consequently discrepancies among pre-processed signals could be due only to unwanted or unknown system effects.

The dataset of EARLI09 campaign gives us a good opportunity to test not only the pre-processor module but also all other SCC modules. After the campaign, few cases were selected characterized by data availability from all the participating systems. All the participants were asked to produce their own analysis for these cases giving us the possibility for a comparison with the corresponding results of the SCC. The cases differ in terms of atmospheric conditions and refer to both nighttime and daytime measurements.

For the SCC validation we focus on the case of 25^{th} May 2009 from 2100 to 2300UT when a Saharan dust event was occurring over Leipzig. Moreover, to allow an evaluation of the SCC retrieval algorithms ~~as complete as possible~~ we first selected only the EARLI09 lidar systems able to measure at same time aerosol backscatter profiles at 3 wavelengths (1064nm, 532nm and 355nm) and 2 aerosol extinction profile at 532nm and 355nm. Among these advanced systems, we made a further selection on the base of their differences in terms of technical characteristics. In particular we considered the Multiwavelength Raman Lidar - RALI from Bucharest station (Nemuc et al., 2013) as an example of commercial system; the MARTHA sytem from Leipzig station as an example of home made lidar (Mattis et al., 2004); the Polly$^{\mathrm{XT}}$ from Leipzig station as representative of the Polly$^{\mathrm{Net}}$ network (Althausen et al., 2013); the CIS-LiNet (Lidar Network for CIS countries) (Chaikovsky et al., 2005) reference system MSTL-2 from Minsk station and finally the MUSA (MUlti-wavelength lidar System for Aerosol) from Potenza station as an example of EARLINET network reference system(Madonna et al., 2011).

Figure 3 shows the aerosol elastic-backscatter profiles at 1064nm obtained from the infrared elastic-backscatter signal of five different lidar systems participating the EARLI09 campaign. ~~In red is plotted~~ the profiles obtained by the SCC while ~~in blue are reported~~ the corresponding profiles provided by each group with its own analysis software. The same color convention will be valid for all the other figures in this paper. The agreement between the two analysis is in general good for all the lidar systems indicating the good performances of the algorithm for the retrieval of the elastic aerosol backscatter coefficient implemented in the SCC. The red profiles shown in figure 3 are obtained using the iterative method. However we found that the SCC profiles obtained using Klett approach are practically indistinguishable from the ones calculated by iterative technique.

Only for the leftmost plot on the top it is possible to see small discrepancies which are probably due to slightly different calibration input parameters as the infrared wavelength is quite sensible to calibration procedure (Engelmann et al., 2015).

The Raman backscatter profiles at 355nm (at 532nm) from the same lidar systems are shown in figure 4 (figure 5); the profiles are calculated combining the elastic signal at 355nm (532nm) with the nitrogen vibration-rotation Raman signal at 387nm (607nm). The manually obtained profiles agree quite with the corresponding SCC ones considering the reported error bars. The residual discrepancies can be explained by small differences in the used reference value and height for the calibration and also by the depolarization correction which is taken into account in some of the manual analyses but not yet implemented in the SCC. This is for example the case of the differences between 2 and 4 km of the two rightmost plots on the top of figure 4. These two plots refer to lidar systems equipped with optics with quite different trasmissitivy at 355nm along the two components of the polarization light. If the depolarization correction is not considered, this condition together with the presence of strong depolarizing aerosol (like in this case where Saharan dust is present between 2 and 4 km) produces an overestimation of the backscatter coefficient which is clearly visible in the two mentioned plots. This correction of the depolarization effect is not implemented in the SCC because its application requires the measurements of the depolarization ratio that is not yet a standard SCC product.

Figures 6 and 7 are examples of comparisons of the Raman extinction retrieval. The curves in Figure 6 are the aerosol extinction profiles at 355nm obtained from the nitrogen vibration-rotation Raman signal at 387nm for six different lidar systems, while Figure 7 shows the aerosol extinction profiles at 532nm calculated from the nitrogen vibration-rotation Raman signal at 607nm for the same systems. The agreement between the two independent analyses is good for both wavelengths. In particular the extinction profiles at 532nm are noisier than the ones at 355nm and so, for same cases, it is not easy to clearly evaluate the agreement between manual and SCC analysis. Nevertheless, for all the systems the atmospheric structures are present with very similar and consistent shape in the manual and the SCC retrived profiles.

4.2 Mean profiles validation

In the previous section we have shown the comparisons of the SCC analysis with the corresponding manual ones for a single measurement case considering several different lidar systems. This comparison allows us to investigate the ability of the SCC to provide aerosol optical products for different systems but it does not assure the algorithms implemented in the SCC are not affected by systematic errors or that they work well under different atmospheric conditions. To prove this, mean SCC profiles have been compared to the corresponding mean profiles obtained by the independent analysis procedure. In particular several measurement cases have been inverted with both the SCC and the manual analysis software. The results have been averaged and finally compared. Two representative EARLINET lidar systems have been taken into account for this comparison: MUSA (MUltiwavelength lidar System for Aerosol) from Potenza station and Polly^{XT} system operating at Leipzig station.

For Potenza station we have compared the mean profiles obtained by averaging the measurements made by MUSA system (Madonna et al., 2011) in correspondence of CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) (Winker et al., 2007), overpasses between March 2010 and November 2011. In Table 1 ~~are summarized~~ the number of single profiles that have been considered in calculating the mean profiles for both SCC and manual analysis. The quantity *b1064* indicates the elastic backscatter profile at 1064nm while *b532* (*b355*) and *e532* (*e355*) represent respectively the mean Raman or elastic backscatter and extinction profile at 532nm (355nm). The number of averaged profiles are not the same for all the averaged quantities as ~~not~~ for all the cases it is possible to get optical products for all the lidar channels. For nighttime conditions backscatter at 532nm and 355nm have been obtained using the elastic signal with the corresponding N_2 Raman one. In daytime conditions both the Raman channels at 607nm and 387nm are not usable and therefore there are no extinction profiles available and the backscatter at all wavelengths are calculated using elastic-only techniques.

~~The~~ figure 8 summarizes the result of the mean analysis comparison made in nighttime conditions. For each analysis 3 mean backscatter profiles are reported (first plot on the left) at 1064nm (red curve) at 532nm (green curve) and at 355nm (blue curve) and the 2 mean extinction profiles (second plot for the left) at 532nm (green curve) and at 355nm (blue curve). In the same figure other important aerosol parameters are plotted which are directly derived from the extinction and backscatter profiles: the extinction to backscatter ratio usually called lidar ratio and the Angstrom coefficients. As it is well known that these parameters depend only on the type of aerosol, it is quite interesting to test the SCC performance ~~also on~~ these parameters.

In general the agreement between the two analysis is good for all the profiles shown in figure 8. ~~The~~ Table 2 provides a more quantitative comparison. In particular two separate altitude ranges were selected in order to allow direct comparison of statistical quantities. The first (*Range 1*) extends up to 2 km and the second one (*Range 2*) from 2 up to 4 km height. ~~In~~ both these ranges mean values and corresponding standard errors of all the vertical profiles plotted in figure 8 have been calculated.

In figure 9 the comparison for MUSA system in daytime condition is shown. As already mentioned in this case the 2 Raman channels are not available and so it is possible to compare only backscatter related quantities. As it can be seen from Table 2, where the mean values in *Range 1* and *Range 2* are shown, also for daytime conditions we have a good agreement between the two analysis.

For the Leipzig station, we have compared all regular EARLINET climatology and CALIPSO measurements made by Polly$^{\mathrm{XT}}$ from September 2012 to September 2014 for which the complete data set of 3 backscatter coefficient and, at nighttime, 2 extinction coefficient profiles were available. The numbers of Polly$^{\mathrm{XT}}$ single profiles that have been included in the calculation of mean profiles are reported in Table 1.

~~The~~ figures 10 and 11 show the result of the mean analysis comparison for Polly$^{\mathrm{XT}}$ system made in nighttime and daytime conditions respectively. All the quantities displayed in these figures are the same already described for the figures 8 and 9. The agreement between the two analysis is good in both nighttime and daytime conditions. All the manual calculated profiles plotted in figures 10 and 11 look quite similar to the corresponding ones calculated by the SCC. Moreover the same quantitative comparison made for the Potenza MUSA system has been carried out also for Polly$^{\mathrm{XT}}$ lidar. The results are summarized in Table 3 that shows a very good agreement of both mean values and standar errors calculated within the *Range 1* and *Range 2*.

5 Example of applicability

In July 2012 eleven EARLINET stations performed an intense period of coordinated measurements with a well defined measurement protocol. The measurements started on 9 July at 06:00 UT and continued uninterrupted for 72 hours whenever the atmospheric conditions allow lidar measures. The details of this quite intensive observation period are provided in (Sicard et al., 2015). In this section the main objectives of this 72h operationality excercise will be briefly recalled and some technical specific details about how the SCC has been used during that period will be provided. The main scope of the 72h operationality exercise was to show the EARLINET capabilities to provide in near-real time a large set or aerosol parameters obtained in a standardized way for a large number of stations around the Mediterranean basin. In particular the SCC was used to retrieve both pre-processed products in real time (mainly range corrected lidar signals) and optical processed products in near real time for all the stations participating to the exercise. The outputs of the SCC produced in that way can be used for a large variety of applications like the assimilation of lidar data in air quality model or in dust transport model, models validation, monitoring of special events like volcano eruptions. In particular the SCC pre-processed data measured during the 72h operationality exercise have been succesfully assimilated in the air quality model Polyphemus developed by Centre d'Enseignement et de Recherche en Environnement Atmosphérique (CEREA) to improve the quality of PM10 and PM2.5 forecast on the ground (Wang et al., 2014).

All the participating stations agreed to provide raw data in SCC format containing 1 hour timeseries of raw lidar signals each synchronized with the start of each hour. Starting from these raw data files the SCC was configured to provide 30 minutes time averaged range corrected signals (pre-processed files) for all the involved lidar systems. During the exercise the SCC was an important step toward the standardization of lidar products as the lidars participating to the operate at different raw time resolutions (from 1 minute to 5 minutes) and they also differ in many other characteristics requiring different instrumental corrections.

To make the SCC outputs available as soon as possible, an infrastructure was set up to automatically submit the data to the SCC. Usually to start the retrieval of the SCC on a particular measurement the user needs to register the measurement into the SCC database using the web interface. This operation needs time and also the presence of an operator. To improve that, a fully automatic uploading system has been implemented and used during the 72h measurement exercise. Once the system has detected the presence of a new measurement, a check on the format of the uploaded datafile is automatically performed and in case of success the measurement is automatically registered to the SCC database and consequently the SCC is started on it. The results of the SCC analysis are sent back to the originator for their evaluation as soon as they are available. With such kind of system it was possible to automatically retrieve the needed aerosol products and make them available within 30 minutes from the end of measurement.

6 Conclusions

The SCC, an automatic tool for the analysis of EARLINET lidar data has been developed and made available to all the EARLINET stations. The SCC has been installed on a centralized server where the user can submit data in a predefined NetCDF structure. The SCC is highly configurable and can be easily adapted to new lidar systems. In particular an user-friendly web interface allows the user to change all the instrumental and configuration parameters to be used in the analysis. The products of the SCC are all quality certified in terms of EARLINET quality assurance program. The SCC can provide different levels of output: pre-processed signals, which are range corrected lidar signals corrected for all the instrumental effects, and aerosol optical products, which are aerosol backscatter or extinction profiles. The pre-processed and the aerosol optical products are calculated by two different SCC modules: ELPP ~~that~~ accepts as input the raw lidar data and ELDA which takes as inputs the outputs of the ELPP module. The actions of the two modules are automatically synchronized and coordinated by an other module called SCC daemon. All the parameters required by ELPP and ELDA modules are stored in an efficient way in a SCC database.

The SCC has been validated comparing its optical products with the corresponding products retrieved with independent manual quality certified procedures. The validation has been carried out into two different steps. First, considering a case study selected from the EARLI09 inter-comparison campaign, it has been proved the SCC is able to provide optical products in good agreement with the corresponding manual analysis for all the EARLI09 lidar system considered. Second, it has been checked the SCC can provide reliable results in different atmospheric conditions. This has been ~~archieved~~ comparing mean profiles obtained averaging several optical profiles for two EARLINET representative systems. Also in this case the comparisons indicate good performances of the SCC.

An example of the applicability of the SCC has been provided describing the use we made of the SCC in the 72h EARLINET measurement exercise. In this case, the SCC has been used to provide high quality aerosol products at different levels (pre-processed signals or aerosol optical products) in near-real time. Such kind of aerosol products can be assimilated in models or can be used for model validation purposes or to monitor special events at network level.

The development of the SCC modules is continuing. New features like aerosol depolarization-ratio calculation, automatic determination of aerosol layer properties from both geometrical and optical point of view, and cloud masking are under investigation and will be included in the SCC in the framework of the ACTRIS (Aerosol, Clouds and Trace gases Research InfraStructure Network) project (http://www.actris.org). Due to its flexibility the SCC could be easily extended to GALION (GAW Aerosol LIdar Observation Network) to evaluate lidar data of networks different from EARLINET.

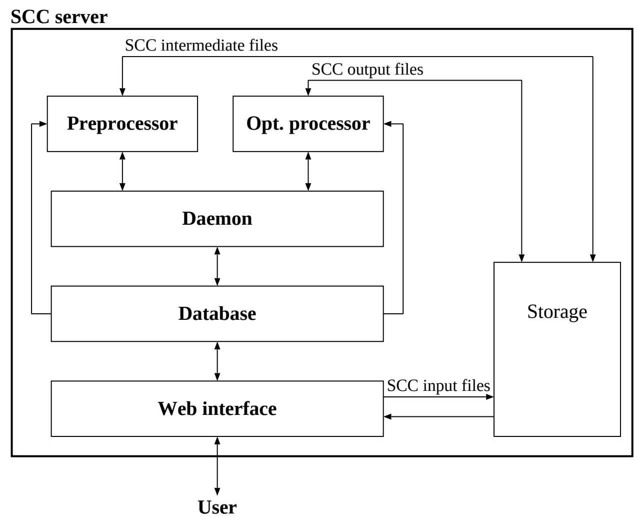

Fig. 1. Block structure of the Single Calculus Chain.

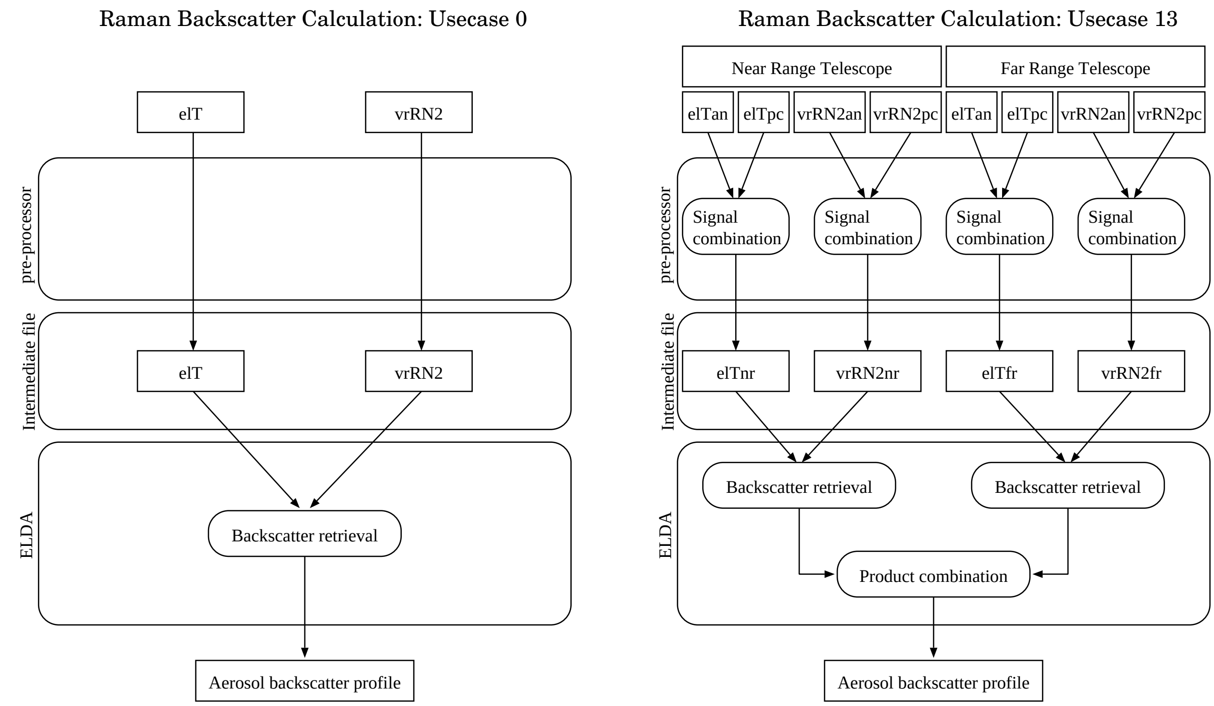

Fig. 2. Two examples of Raman backscatter calculation usecases implemented in the SCC. In particular the usecase 0 (on the left) can be used for a lidar system measuring only the elastic backscattered signal (elT) and the corresponding N_2 Raman backscattered signal (vrRN2). The usecase 13 (on the right) refers to more complex lidar configuration in which there are two different telescopes and each channel is acquired in both analog and photoncounting mode.

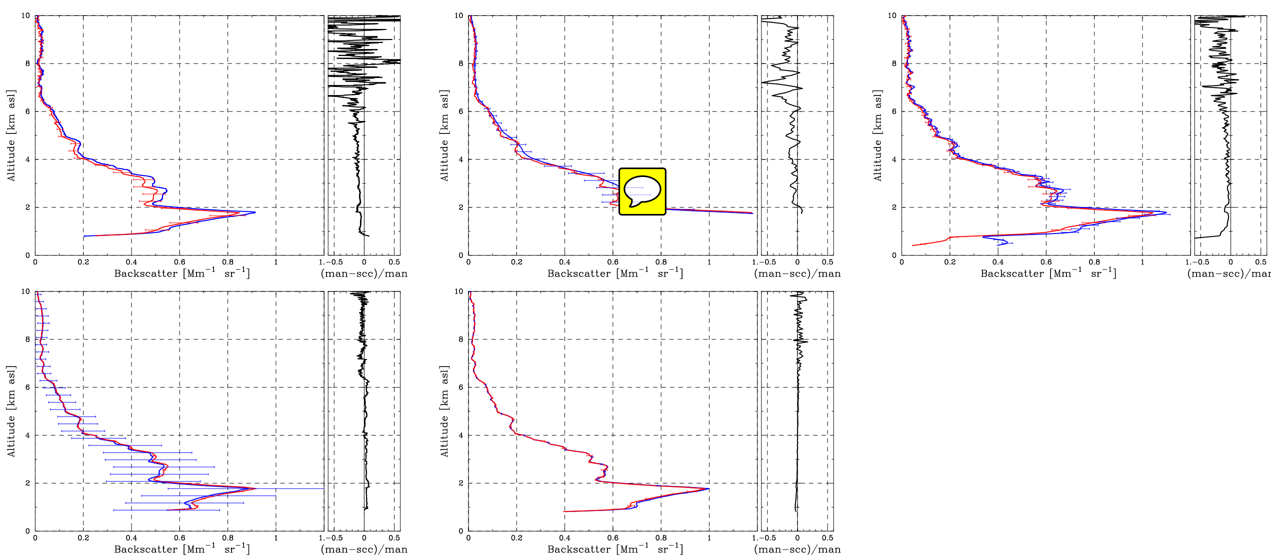

Fig. 3. Comparison of elastic backscatter profiles at 1064nm for five lidar systems participating to the EARLI09 inter-comparison campaign. All the profiles refer to measurement session taken on 25th May 2009 from 21:00 to 23:00 UT. The profiles in blue are the analysis provided by the originator of the data using ~~his~~ own analysis software. The profiles in red are the ones retrieved by the SCC

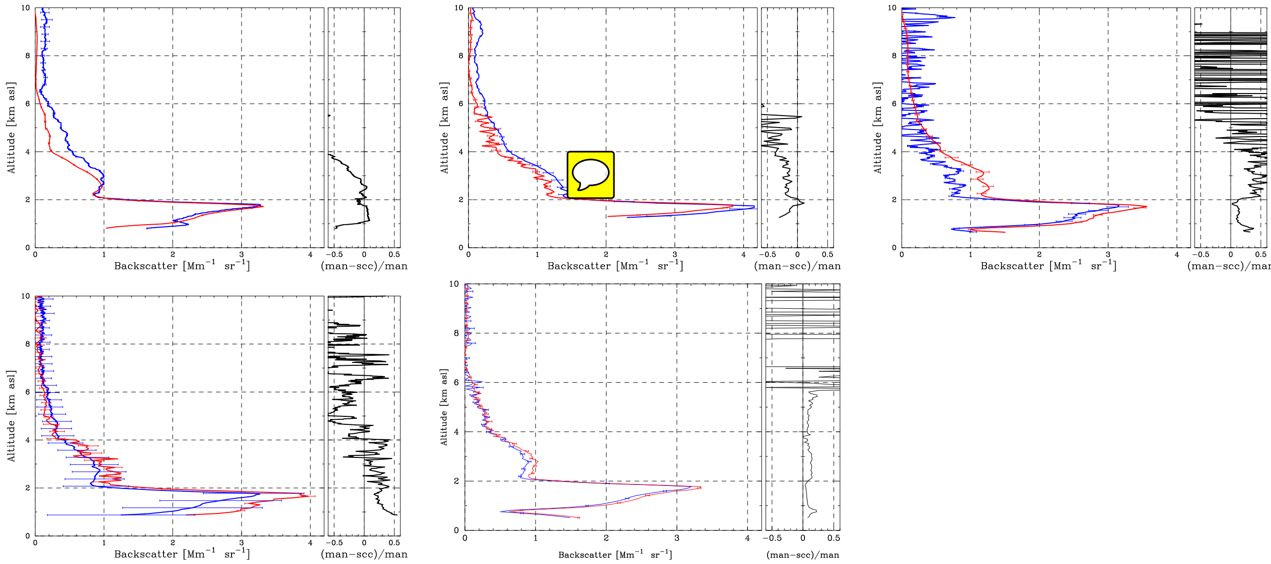

Fig. 4. Comparison of Raman backscatter profiles at 355nm for five lidar systems participating to the EARLI09 inter-comparison campaign. All the profiles refer to measurement session taken on 25th May 2009 from 21:00 to 23:00 UT and they have been retrieved combining elastic backscattered channel at 355nm and the corresponding N_2 Raman backscatter signal at 387nm. The profiles in blue are the analysis provided by the originator of the data using his own analysis software. The profiles in red are the ones retrieved by the SCC

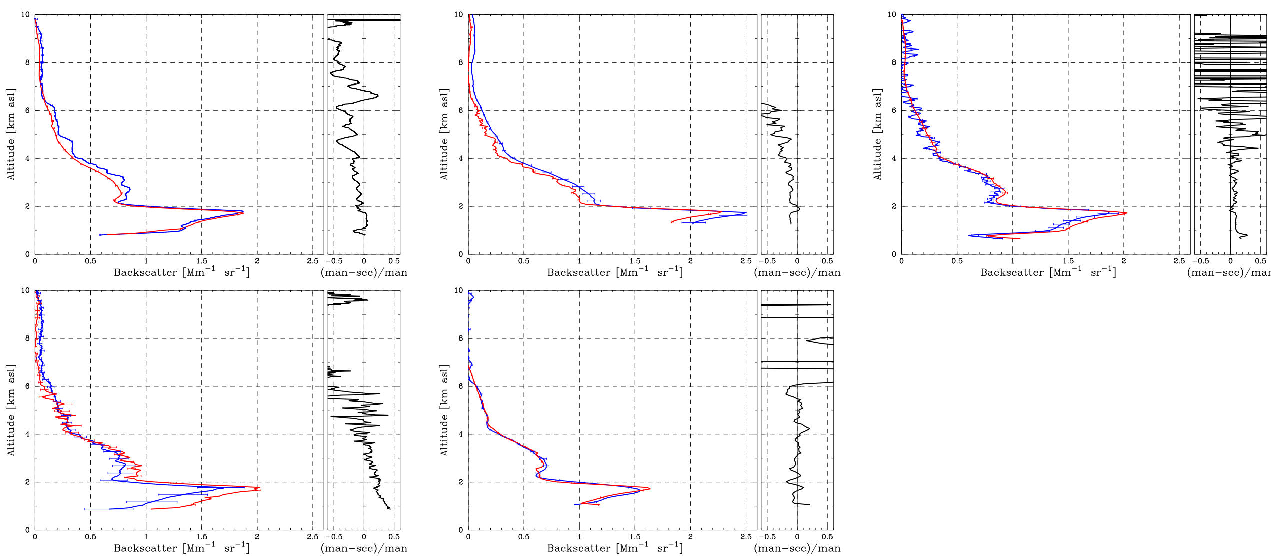

Fig. 5. Comparison of Raman backscatter profiles at 532nm for five lidar systems participating to the EARLI09 inter-comparison campaign. All the profiles refer to measurement session taken on 25th May 2009 from 21:00 to 23:00 UT and they have been retrieved combining elastic backscattered channel at 532nm and the corresponding N_2 Raman backscatter signal at 607nm. The profiles in blue are the analysis provided by the originator of the data using his own analysis software. The profiles in red are the ones retrieved by the SCC.

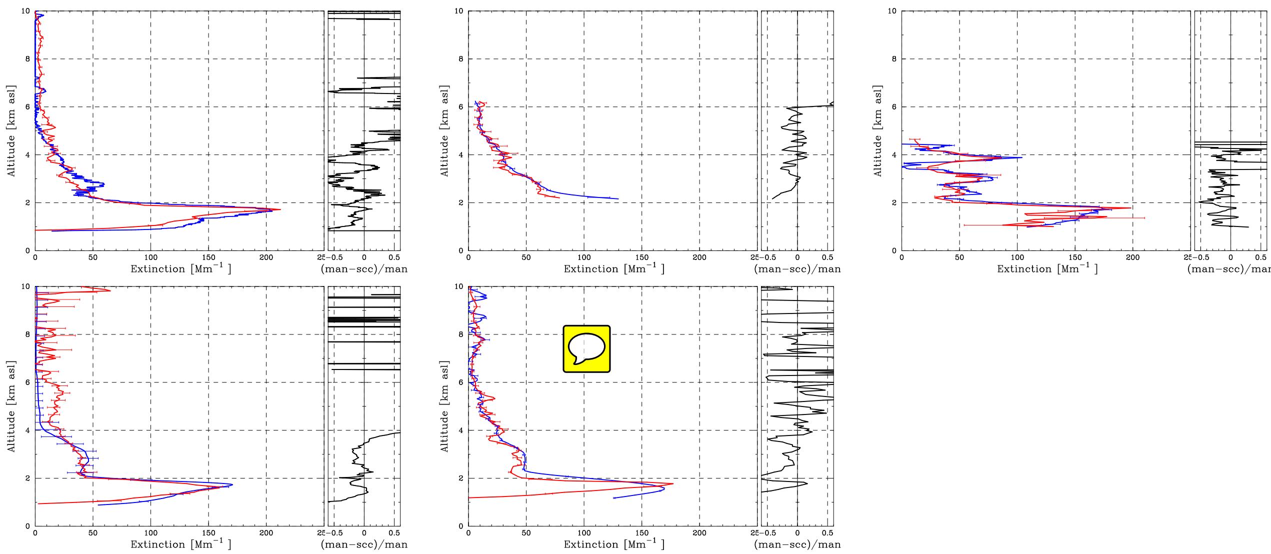

Fig. 6. Comparison of aerosol extinction profiles at 355nm for five lidar systems participating to the EARLI09 inter-comparison campaign. All the profiles refer to measurement session taken on 25th May 2009 from 21:00 to 23:00 UT and they have been retrieved using the N_2 Raman backscatter signal at 387nm. The profiles in blue are the analysis provided by the originator of the data using his own analysis software. The profiles in red are the ones retrieved by the SCC

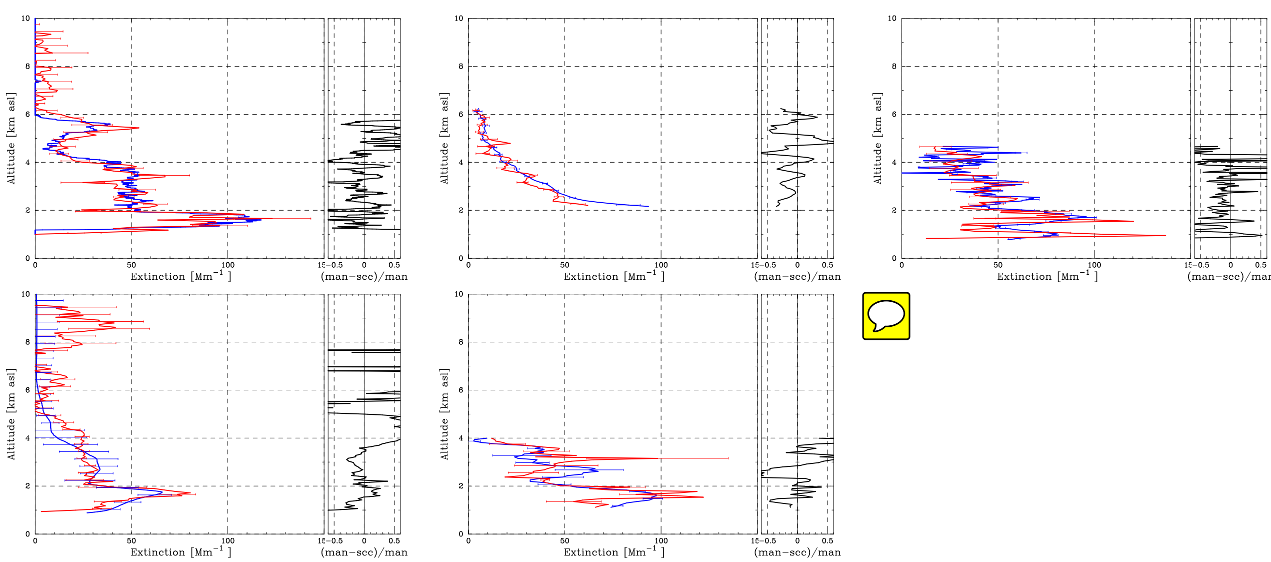

Fig. 7. Comparison of aerosol extinction profiles at 532nm for five lidar systems participating to the EARLI09 inter-comparison campaign. All the profiles refer to measurement session taken on 25th May 2009 21:00 to 23:00 UT and they have been retrieved using the N_2 Raman backscatter signal at 607nm. The profiles in blue are the analysis provided by the originator of the data using his own analysis software. The profiles in red are the ones retrieved by the SCC

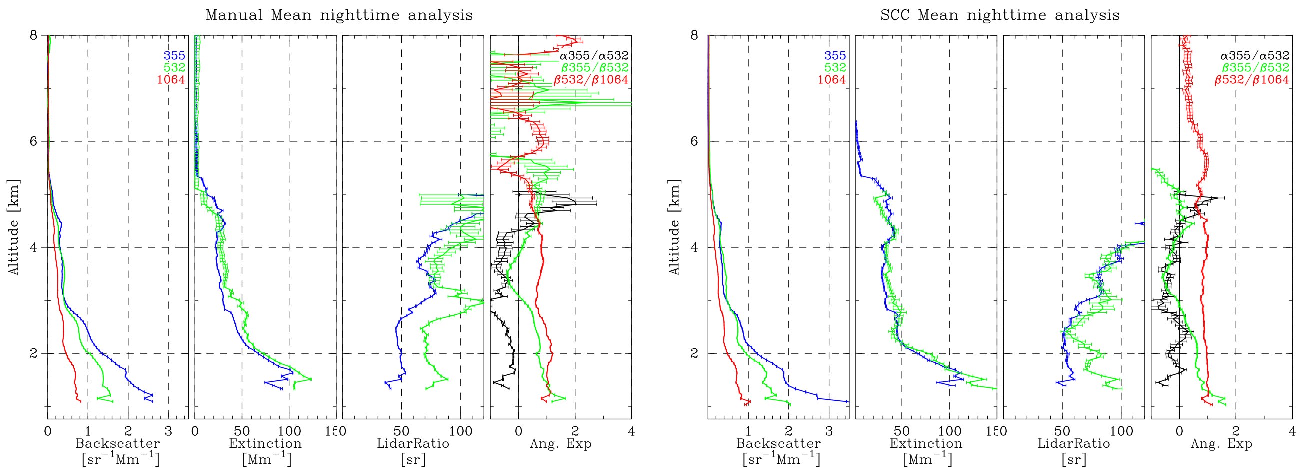

Fig. 8. Mean nighttime analysis comparison for Potenza station (MUSA system). On the left it is reported the mean analysis obtained using the manual analysis while on the right the results obtained by the SCC are shown. Several measurement cases (see table 1) have been analyzed and the corresponding backscatter and extinction profiles have been avaraged and shown respectively in the first and in the second subplots of both manual and SCC analysis plots. The other two subplots staring from the left show respecvitely the lidar ratios and the Angstrom exponents as calculated from the mean aerosol extinction and backscatter profiles.

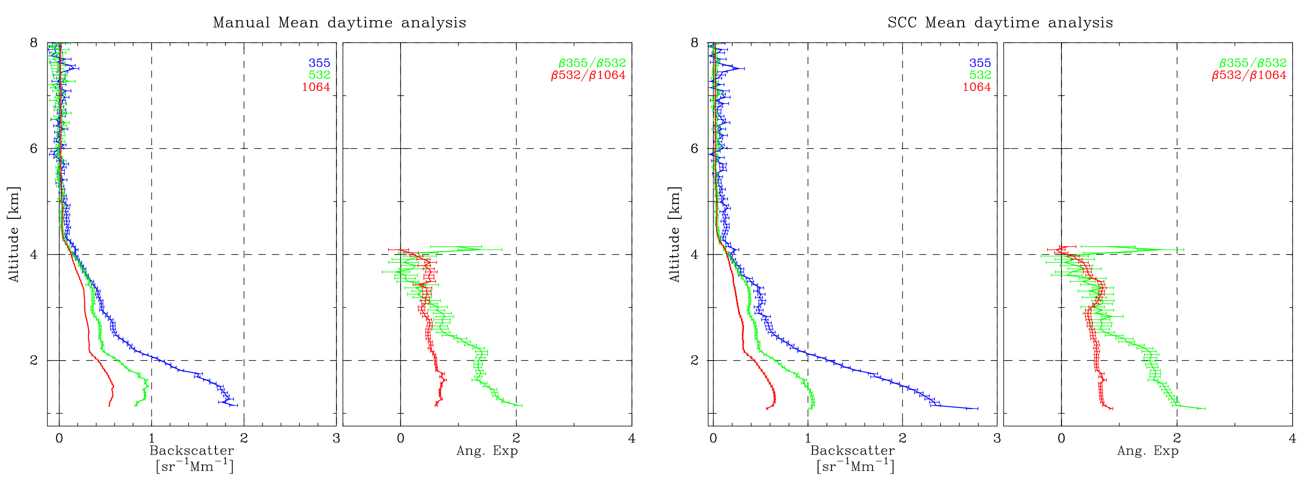

Fig. 9. Mean daytime analysis comparison for Potenza station (MUSA system). On the left it is reported the mean analysis obtained using the manual analysis while on the right the results obtained by the SCC are shown. Several measurement cases (see table 1) have been analyzed and the corresponding backscatter profiles have been avaraged and shown in the first subplot of both the manual and SCC analysis plots. The other subplot shows the backscatter related Angstrom exponents as calculated from the mean backscatter profiles.

Appendix A

SCC Usecases description

In this appendix all the usecases currently implemented in the SCC are ~~reported schematically.~~ A specific nomenclature has been used to ~~identify univocally~~ the different types of lidar signals detected by all EARLINET lidars. In particular the name assigned to each lidar signal is composed by four different substrings separated by the character underscore. The first substring describes the scattering mode characterizing the detected signal, the second identifies the polarization state, the third describes the detection mode used to measure the signal and finally the fourth identifies the range for which the signal is optimized. For example a channel called "elT_cross_pc_fr" represents the photoncounting perpendicular polarization component (with respect to the direction of linear polarized incident laser light) of the elastic backscattered lidar signal optimized (in terms of the signal to noise ratio) to detect the atmospheric signal from the far range. The table A1 summarizes all the possible substrings used to identify the signals.

All the implemented usecases, separated by product type, are reported in the tables A2 A3 and A4 using the same structure. The first column gives the number identifying the usecase. This number ~~identify univocally~~ the usecase once a product type has be selected. The second column reports all the lidar channels involved in the product calculation. This information allows us the identification of the relevant usecases fitting with one specific experimental setup. The other columns specify the steps to be performed in the calculation of the product. The third column shows which channels are combined at pre-processing level typically to enhance the detected dynamic range glueing signals optimized for the far range detection with the corresponding ones optimized for the low range. The fourth column specifies which pre-processed signals are used to calculate the corresponding optical product. If in this column ~~it is present~~ only one subcolumn (~~like~~ for example the usecase 7 in table A2) it means the final product is directly calculated using the selected preprocessed signal. If there are two subcolumns (~~like~~ for example the usecase 4 in table A2) two products are calculated in the processing phase (typically one for the far range and one for the low range) and then these products are combined together to get the final product. The presence of product combination in the usecase is specified by the last column of the tables. It is worth mentioning that to each usecase correponds always a single optical product.

Table 1. Number of MUSA (Potenza) and Polly^{XT} (Leipzig) measurement cases included in the calculation of the mean profiles shown in figures 8, 9, 10 and 11. The quantity *b1064* indicates the elastic backscatter profile at 1064nm while *b532* (*b355*) and *e532* (*e355*) represent respectively the mean Raman or elastic backscatter and extinction profile at 532nm (355nm).

	Nighttime		Daytime	
	MUSA	Polly^{XT}	MUSA	Polly^{XT}
b1064	23	15	12	9
b532	20	15	12	9
b355	24	15	10	9
e532	16	15	-	-
e355	14	15	-	-

Acknowledgements. The financial support by the European Commission grants RICA-025991 EARLINET-ASOS and 262254 ACTRIS is gratefully acknowledged.
Ioannis Binietoglou would like to acknowledge funding received from the European Union's Seventh Framework Programme for research, technological development and demonstration under grand agreement no 289923 - ITaRS.

References

Ackermann, J.: The extinction-to-backscattering ratio of tropospheric aerosol: a numerical study, J. Atmos. Ocean. Technol., 15, 1043–1050, 1998.

Althausen, D., Engelmann, R., Baars, H., Heese, B., Kanitz, T., Komppula, M., Giannakaki, E., Pfüller, A., Silva, A. M., I., P., Wagner, F., Rascado, J. L., Pereira, S., Lim, J., Ahn, J. Y., Tesche, M., and Stachlewska, I. S.: PollyNET: a network of multiwavelength polarization Raman lidars, in: Proceedings of SPIE 8894, Lidar Technologies, Techniques, and Measurements for Atmospheric Remote Sensing IX, 2013.

Ansmann, A. et al.: Measurement of atmospheric aerosol extinction profiles with a Raman lidar, Optics Letters, 15, 746–748, 1990.

Ansmann, A. et al.: Combined Raman elastic-backscatter lidar for vertical profiling of moisture, aerosol extinction, backscatter and lidar ratio, Applied Physics B, 55, 18–28, 1992.

Böckmann, C.: Hybrid regularization method for the ill-posed inversion of multiwavelength lidar data in the retrieval of aeorosol size distributions, Applied Optics, 40, 1329–1342, 2001.

Böckmann, C. et al.: Aerosol lidar intercomparison in the framework of EARLINET. 2. Aerosol backscatter algorithms, Applied Optics, 43, 977–989, 2004.

Chaikovsky, A., Balin, Y., Elnikov, A., Tulinov, G., Plusnin, I., Bukin, O., and Chen, B.: CIS-LiNet - lidar network in CIS countries, in: Geophysical Research Abstracts, vol. 7, 2005.

D'Amico, G. et al.: EARLINET Single Calculus Chain - technical Part 1: Preprocessing of raw lidar data, in preparation, 2015.

Di Girolamo, P. et al.: Two wavelength lidar analysis of stratospheric aerosol size distribution, Journal of Aerosol Science, 26, 989–1001, 1995.

Diner, D. J., Ackerman, T., Anderson, T. L., et al.: PARAGON: An Integrated Approach for Characterizing Aerosol Climate Impacts and Environmental Interactions, B. Am. Meteor. Soc., 85, 1491–1501, 2004.

Earlinet: EARLINET all observations (2000-2010), http://dx.doi.org/10.1594/WDCC/EN_all_measurements_2000-2010, 2014.

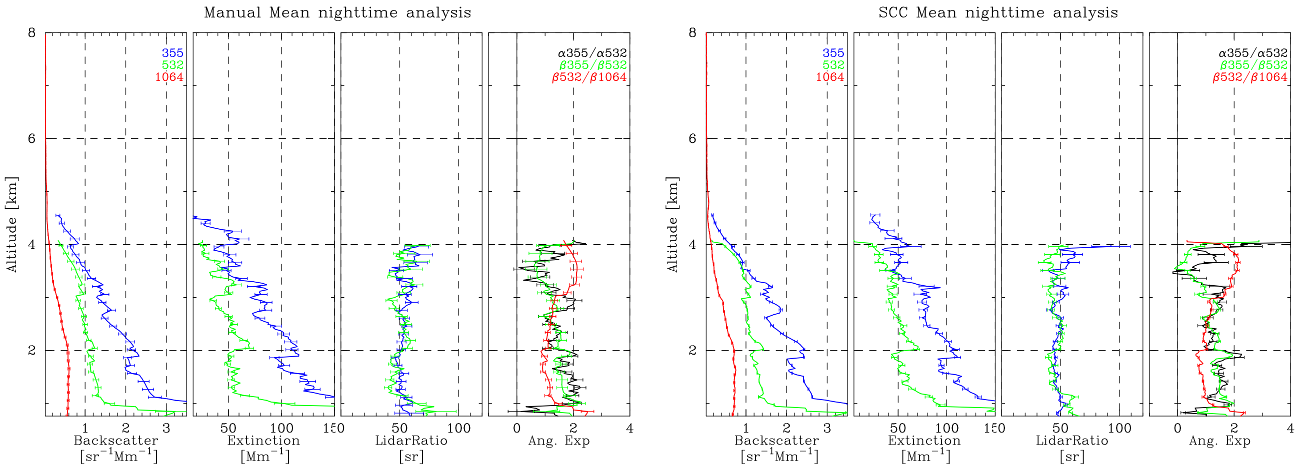

Fig. 10. Mean nighttime analysis comparison for Leipzig station (Polly^{XT} system). On the left it is reported the mean analysis obtained using the manual analysis while on the right the results obtained by the SCC are shown. Serveral measurement cases (see table 1) have been analyzed and the corresponding backscatter and extinction profiles have been avaraged and shown respectively in the first and in the second subplots of both manual and SCC analysis plots. The other two subplots staring from the left show respecvitely the lidar ratios and the Angstrom exponents as calculated from the mean aerosol extinction and backscatter profiles.

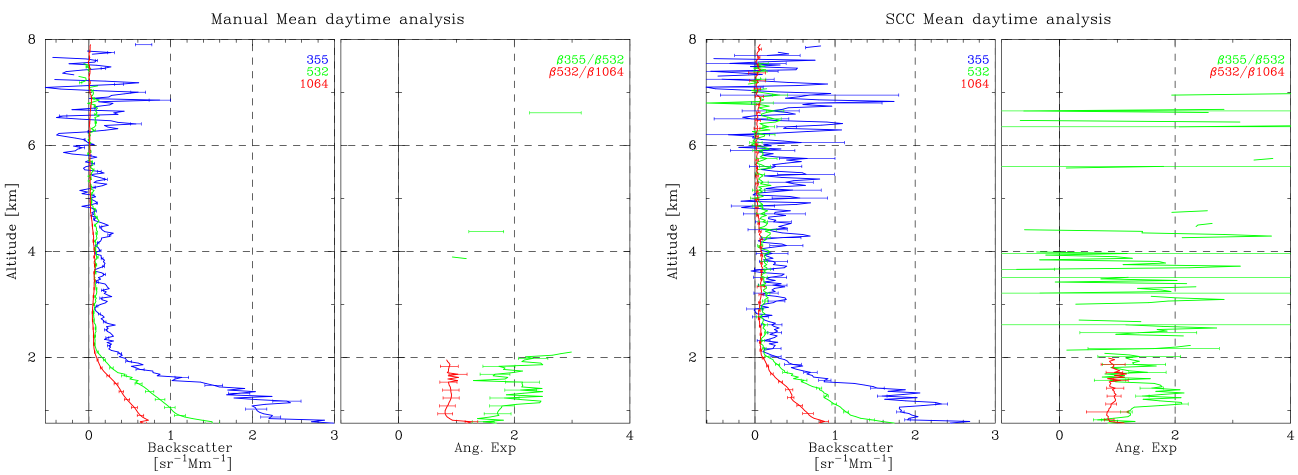

Fig. 11. Mean daytime analysis comparison for Leipzig station (Polly^{XT} system). On the left it is reported the mean analysis obtained using the manual analysis while on the right the results obtained by the SCC are shown. Serveral measurement cases (see table 1) have been analyzed and the corresponding backscatter profiles have been avaraged and shown in the first subplot of both the manual and SCC analysis plots. The other subplot shows the backscatter related Angstrom exponents as calculated from the mean backscatter profiles.

Engelmann, R. et al.: Technical solution for backscatter measurements at 1064nm, in preparation, 2015.

Fernald, F. G.: Analysis of atmospheric lidar observations: some comments, Applied Optics, 23, 652–653, 1984.

Freudenthaler, V. et al.: EARLI09 - Direct intercomparison of 11 EARLINET lidar systems, in: Proceedings of 25thInternational Laser Radar Conference (ILRC), St. Petersburg, Russia, 5-9 July 2010, 2010.

Freudenthaler, V. et al.: Internal Quality Assurance Tools, in preparation, 2015.

Holben, B., Eck, T., Slutsker, I., Tanré, D., Buis, J., Setzer, A., Vermote, E., Reagan, J., Kaufman, Y., Nakajima, T., Lavenu, F., Jankowiak, I., and A., S.: AERONET-A Federated Instrument Network and Data Archive for Aerosol Characterization, Remote Sensing of Environment, 66, 1–16, 1998.

IPCC: Intergovernment Panel on Climate Change: Fourth Assessment Report: Climate Change 2007, Tech. rep., 2007.

IPCC: Intergovernment Panel on Climate Change: Fifth Assessment Report: Climate Change 2013, Tech. rep., 2013.

Table 2. Comparison of the mean values and correspondent standard deviation of the profiles shown in figures 8 and 9. Mean values and standard errors (reported in round braket) have been calculated averaging the mean profiles within *Range 1* (0-2km) and *Range 2* (2-4km)

	Nighttime						Daytime	
	β [$sr^{-1}Mm^{-1}$]		α [Mm^{-1}]		LR [sr]		β[$sr^{-1}Mm^{-1}$]	
λ [nm]	Manual	SCC	Manual	SCC	Manual	SCC	Manual	SCC
	Range 1							
355	2.01(0.10)	2.13(0.18)	86.42(3.52)	93.26(5.07)	47.23(1.65)	54.72(1.25)	1.58(0.07)	2.01(0.13)
532	1.35(0.04)	1.44(0.07)	100.00(4.57)	108.35(6.99)	76.64(1.78)	81.72(2.87)	0.85(0.03)	0.89(0.03)
1064	0.65(0.02)	0.73(0.03)	-	-	-	-	0.52(0.02)	0.57(0.02)
	Range 2							
355	0.62(0.06)	0.58(0.05)	34.74(2.04)	37.86(1.54)	61.71(2.13)	71.89(2.96)	0.52(0.04)	0.54(0.04)
532	0.54(0.03)	0.56(0.03)	43.81(2.17)	41.73(1.39)	84.39(2.52)	77.73(2.22)	0.37(0.02)	0.39(0.02)
1064	0.29(0.01)	0.31(0.01)	-	-	-	-	0.25(0.01)	0.26(0.01)

Table 3. Comparison of the mean values and correspondent standard deviation of the profiles shown in figures 10 and 11. Mean values and standard errors (reported in round braket) have been calculated averaging the mean profiles within *Range 1* (0-2km) and *Range 2* (2-4km)

	Nighttime						Daytime	
	β [$sr^{-1}Mm^{-1}$]		α [Mm^{-1}]		LR [sr]		β[$sr^{-1}Mm^{-1}$]	
λ [nm]	Manual	SCC	Manual	SCC	Manual	SCC	Manual	SCC
	Range 1							
355	3.16(0.22)	3.03(0.19)	168.93(13.40)	147.77(10.64)	52.21(0.59)	47.93(0.53)	2.30(0.23)	2.17(0.23)
532	1.56(0.10)	1.64(0.10)	88.81(9.13)	88.84(8.55)	52.85(1.85)	50.88(1.80)	1.00(0.08)	1.05(0.08)
1064	0.58(0.01)	0.69(0.01)	-	-	-	-	0.48(0.03)	0.53(0.04)
	Range 2							
355	1.39(0.05)	1.47(0.06)	75.81(2.70)	72.05(2.37)	55.37(0.67)	50.80(1.14)	0.20(0.01)	0.20(0.01)
532	0.86(0.02)	0.99(0.02)	45.84(1.50)	45.33(1.39)	53.09(0.75)	45.76(0.55)	0.08(0.01)	0.11(0.01)
1064	0.32(0.02)	0.38(0.02)	-	-	-	-	0.06(0.01)	0.07(0.01)

Klett, J. D. et al.: Stable analytic inversion solution for processing lidar returns, Applied Optics, 20, 211–220, 1981.

Klett, J. D. et al.: Lidar inversion with variable backscatter/extinction ratios, Appl. Optics, 11, 1638–1643, 1985.

Madonna, F., Amodeo, A., Boselli, A., Cornacchia, C., D'Amico, G., Giunta, A., Mona, L., Pappalardo, G., and V., C.: CIAO: the CNR-IMAA advanced observatory for atmospheric research, Atmospheric Measurement Techniques (AMT), 4, 1191–1208, 2011.

Mattias, V. et al.: Aerosol lidar inter-comparison in the framework of EARLINET. 1. Instruments, Applied Optics, 4, 961–989, 2004.

Mattis, I., Ansmann, A., Wandinger, U., and D., M.: Unexpectedly high aerosol load in the free troposphere over central Europe in spring/summer 2003, Geophys. Res. Lett., 30, 2178, 2003.

Mattis, I., Ansmann, A., Müller, D., Wandinger, U., and Althausen, D.: Multiyear aerosol observations with dual-wavelength Raman lidar in the framework of EARLINET, J. Geophys. Res., 109, 2004.

Mattis, I. et al.: EARLINET Single Calculus Chain - technical Part 2: Calculation of optical products, in preparation, 2015.

Müller, D., Wandinger, U., and A., A.: Microphysical particle parameters from extinction and backscatter lidar data by inversion with regularization: theory, Appl. Opt., 38, 2346–2357, 1999a.

Müller, D., Wandinger, U., and A., A.: Microphysical particle parameters from extinction and backscatter lidar data by inversion with regularization: simulation, Appl. Opt., 38, 2358–2368, 1999b.

Müller, D., Mattis, I., Wandinger, U., Ansmann, A., Althausen, D., and A., S.: Raman lidar observations of aged Siberian and Canadian forest fire smoke in the free troposphere over Germany in 2003: microphysical particle characterization, J. Geophys. Res., 110, D17 201, 2005.

Müller, D., Böckmann, C., et al.: Single Calculus Chain. Technical Part 3: Microphysical inversion schemes, in preparation, 2015.

Nemuc, A., Vasilescu, J., Talianu, C., Belegante, L., and D., N.: Assessment of aerosol's mass concentrations from measured linear particle depolarization ratio (vertically resolved) and simulations, Atmos. Meas. Tech., 6, 3243–3255, 2013.

Pappalardo, G., Amodeo, A., Apituley, A., Comeron, A., Freudenthaler, V., Linné, H., Ansmann, A., Bösenberg, J., D'Amico, G., Mattis, I., Mona, L., Wandinger, U., Amiridis, V., Arboledas, L., Nicolae, D., and Wiegner, M.: EARLINET: Towards an advanced

Table A1. Nomenclature used to identify univocally the different types of lidar signals detected by all EARLINET lidars.

Name	Description
Scattering mode	
el	elastic backscattered signal
vrN2	ro-vibrational Raman backscattered signal by nitrogen molecules
pRRlow	pure rotational Raman backscattered signal at low quantum number
pRRhigh	pure rotational Raman backscattered signal at high quantum number
Polarization state	
tot	total signal
cross	perpendicular polarization component
paral	parallel polarization component
Detection mode	
an	analog
pc	photoncounting
any	can be analog or photoncounting
Range mode$^{(*)}$	
fr	signal optimized to detect the far range
nr	signal optimized to detect the near range
unr	signal optimized to detect the ultra near range

$^{(*)}$ for signals not optimized for a specific altitude range this substring is omitted.

sustainable European aerosol lidar network, Atmospheric Measurement Techniques (AMT), 7, 2389–2409, 2014.

Pappalardo, G. et al.: Aerosol lidar intercomparison in the framework of EARLINET. 3. Raman lidar algorithm for aerosol extinction, backscatter and lidar ratio, Applied Optics, 43, 5370–5385, 2004.

Sicard, M., G., D., et al.: EARLINET: potential operationality of a research network, in preparation, 2015.

Wandinger, U., Müller, D., Bockmann, C., Althausen, D., Matthias, V., Bosenberg, J., Weiß, V., Fiebig, M., Wendisch, M., Stohl, A., and A., A.: Optical and microphysical characterization of biomass-burning and industrial-pollution aerosols from multiwavelength lidar and aircraft measurements, J. Geophys. Res., 107, 8125, 2002.

Wandinger, U. et al.: Instrument Intercomparison Campaigns, in preparation, 2015.

Wang, Y., Bocquet, M., Sartelet, K., Chazette, P., Dulac, F., Sicard, M., D'Amico, G., Léon, J., et al.: Assimilation of lidar signals: Application to aerosol forecasting in the Mediterranean basin, Atmos. Chem. Phys., 14, 12 031–12 053, 2014.

Winker, D. M., Hunt, W. H., and J., M. M.: Initial performance assessment of CALIOP, Geophysical Research Letters, 34, 2007.

Table A2. SCC usecases implemented for the calculation of the atmospheric aerosol backscatter coefficient profile using Raman technique. The first column provides the number identifying the usecase, the second column reports all the lidar channels involved in the product calculation, the third column shows which channels are combined at pre-processing level, the fourth column specifies which pre-processed signals are used to calculate the final optical product. Finally the last column shows if intermediate products have been combined to get the final optical product.

Usecase	Channels	Signal combination	Product calculation		Product combination
0	el_tot_any		×		
	vrRN2_tot_any		×		
1	el_tot_any_nr	×	×		
	el_tot_any_fr	×			
	vrRN2_tot_any		×		
2	el_tot_any_nr		×		×
	el_tot_any_fr			×	
	vrRN2_tot_any		×	×	
3	el_tot_any		×		
	vrRN2_tot_any_nr	×	×		
	vrRN2_tot_any_fr	×			
4	el_tot_any		×	×	×
	vrRN2_tot_any_nr		×		
	vrRN2_tot_any_fr			×	
5	el_tot_any_nr	×	×		
	el_tot_any_fr	×			
	vrRN2_tot_any_nr	×	×		
	vrRN2_tot_any_fr	×			
6	el_tot_any_nr		×		×
	el_tot_any_fr			×	
	vrRN2_tot_any_nr		×		
	vrRN2_tot_any_fr			×	
7	el_cross_any		×		
	el_paral_any		×		
	vrRN2_tot_any		×		
8	el_tot_any		×		
	pRRlow_tot_any	×	×		
	pRRhigh_tot_any	×			
9	el_cross_any_nr	×	×		
	el_cross_any_fr	×			
	el_paral_any_nr	×	×		
	el_paral_any_fr	×			
	vrRN2_tot_any		×		
10	el_cross_any		×		
	el_paral_any		×		
	vrRN2_tot_any_nr	×	×		
	vrRN2_tot_any_fr	×			

Table A2. SCC usecases implemented for the calculation of the atmospheric aerosol backscatter coefficient profile using Raman technique.[Continued]

Usecase	Channels	Signal combination	Product calculation	Product combination
11	el_cross_any_nr	×	×	
	el_cross_any_fr	×		
	el_paral_any_nr	×	×	
	el_paral_any_fr	×		
	vrRN2_tot_any_nr	×	×	
	vrRN2_tot_any_fr	×		
12	el_cross_any_nr		×	×
	el_cross_any_fr		×	
	el_paral_any_nr		×	
	el_paral_any_fr		×	
	vrRN2_tot_any_nr		×	
	vrRN2_tot_any_fr		×	
13	el_tot_an_nr	×	×	×
	el_tot_pc_nr	×		
	vrRN2_tot_an_nr	×	×	
	vrRN2_tot_an_nr	×		
	el_tot_an_fr	×	×	
	el_tot_pc_fr	×		
	vrRN2_tot_an_fr	×	×	
	vrRN2_tot_pc_fr	×		
14	el_tot_any_unr	×	×	×
	el_tot_any_nr	×		
	pRRlow_tot_any_nr	×	×	
	pRRhigh_tot_any_nr	×		
	el_tot_any_fr		×	
	pRRlow_tot_any_fr	×	×	
	pRRhigh_tot_any_fr	×		
15	el_tot_any_unr	×	×	×
	el_tot_any_nr	×		
	vrRN2_tot_any_nr		×	
	el_tot_any_fr		×	
	vrRN2_tot_any_fr		×	
16	el_tot_any_nr		×	×
	pRRlow_tot_any_nr	×	×	
	pRRhigh_tot_any_nr	×		
	el_tot_any_fr		×	
	pRRlow_tot_any_fr	×	×	
	pRRhigh_tot_any_fr	×		

Table A2. SCC usecases implemented for the calculation of the atmospheric aerosol backscatter coefficient profile using Raman technique.[Continued]

Usecase	Channels	Signal combination	Product calculation	Product combination
17	el_paral_any_nr	×	×	
	el_paral_any_fr	×		
	el_cross_any		×	
	vrRN2_tot_any		×	
18	el_cross_any_nr	×	×	
	el_cross_any_fr	×		
	el_paral_any		×	
	vrRN2_tot_any		×	

Table A3. SCC usecases implemented for the calculation of the atmospheric aerosol extinction coefficient profile using Raman techique. The structure of the table is the same one corresponding to the table A2.

Usecase	Channels	Signal combination	Product calculation	Product combination
0	vrRN2_tot_any		×	
1	vrRN2_tot_any_nr	×	×	
	vrRN2_tot_any_fr	×		
2	vrRN2_tot_any_nr		×	×
	vrRN2_tot_any_fr		×	
3	pRRlow_tot_any	×	×	
	pRRhigh_tot_any	×		
4	vrRN2_tot_an_nr	×	×	×
	vrRN2_tot_pc_nr	×		
	vrRN2_tot_an_fr	×	×	
	vrRN2_tot_pc_fr	×		
5	pRRlow_tot_any_nr	×	×	×
	pRRhigh_tot_any_nr	×		
	pRRlow_tot_any_fr	×	×	
	pRRhigh_tot_any_fr	×		

Table A4. SCC usecases implemented for the calculation of the atmospheric aerosol backscatter coefficient profile using elastic-only techique. The structure of the table is the same one corresponding the the table A2.

Usecase	Channels	Signal combination	Product calculation	Product combination
0	el_tot_any		×	
1	el_tot_any_nr	×	×	
	el_tot_any_fr	×		
2	el_tot_any_nr		×	×
	el_tot_any_fr		×	
3	el_paral_any	×	×	
	el_cross_any	×		
4	el_paral_any_nr	×	×	
	el_paral_any_fr	×		
	el_cross_any_nr	×	×	
	el_cross_any_fr	×		
5	el_paral_any_nr		×	×
	el_paral_any_fr		×	
	el_cross_any_nr		×	
	el_cross_any_fr		×	
6	el_tot_an_nr	×	×	×
	el_tot_pc_nr	×		
	el_tot_an_fr	×	×	
	el_tot_pc_fr	×		
7	el_cross_any		×	
	el_paral_any_nr	×	×	
	el_paral_any_fr	×		
8	el_paral_any		×	
	el_cross_any_nr	×	×	
	el_cross_any_fr	×		