EARLINET SINGLE CALCULUS CHAIN FOR AUTOMATIC LIDAR DATA PROCESSING: FIRST TESTS ON OPTICAL PRODUCTS

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ABSTRACT

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. The main goal was to develop a common processing chain (the Single Calculus Chain - SCC) to get atmospheric aerosol products from raw lidar data in an automatic way and without the need for operator interaction. The data from all EARLINET lidar systems can be analyzed with the SCC producing homogeneous and quality-assured products. The SCC was already tested successfully with synthetic lidar signals used for the EARLINET algorithm inter-comparison exercise. In this work we present the first tests of the SCC on real lidar data. In particular data from EARLI09 (EARlinet Lidar Inter-comparison) have been used to compare SCC results with the analysis made by the analysis software developed by each EARLINET group individually. SCC retrievals for elastic and Raman aerosol backscatter and for aerosol extinction have been compared obtaining a good agreement.

1. INTRODUCTION

An important and innovative activity of the EARLINET-ASOS project [1] was addressed to the optimization of lidar data processing. The core of this activity was the development of a common calculus system (SCC) for the automatic evaluation of lidar data from raw signals up to the final products [2]. A tool like the SCC is fundamental for a coordinated network like EARLINET because it represents the best way to produce homogeneous and quality-assured database of atmospheric aerosol profiles on European scale. Moreover, the SCC can also improve the near-real-time availability of the range-resolved aerosol optical products which can be very useful in monitoring situations like volcanic eruptions, strong forest fires, or other similar events.

One of the main difficulties in developing such kind of tool was the implementation of optimized and fully automatic algorithms to retrieve aerosol optical parameters such as extinction and backscatter coefficients from lidar signals. The different quality-assured analysis algorithms [3, 4] implemented by each EARLINET group have been collected and critically evaluated during the development of the SCC. Another challenging task consisted in the ability to handle raw data coming from very different and not standardized lidar systems. This is particularly true for EARLINET where 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.

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.

2. SINGLE CALCULUS CHAIN

The SCC has been developed having in mind the following concepts: platform independency, open source philosophy within the network, standard data format (NetCDF), flexibility through the implementation of different retrieval procedures, expandability to easily include new systems or new system configurations. The SCC has been installed on a single server hosted and managed by the Barcelona Supercomputer Center: the users can connect to that server and use and configure the retrieval procedures implemented in the SCC using a web interface. The main advantage of using this approach instead of different local SCC installations (which is also

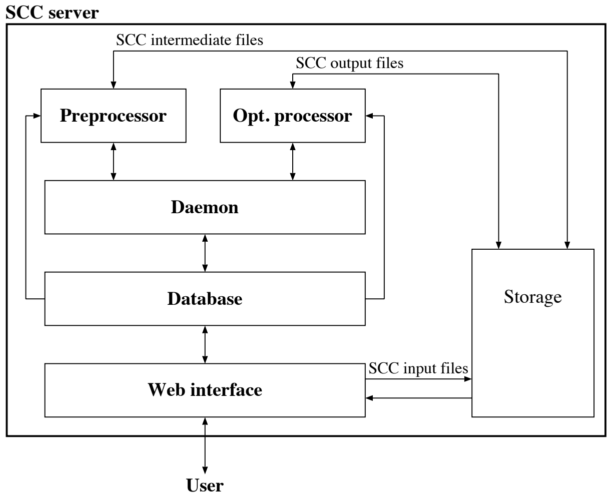

Figure 1: Block structure of the Single Calculus Chain.

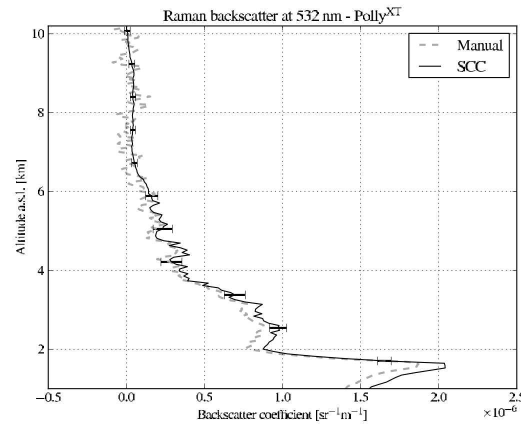

Figure 2: Comparison of the SCC Raman backscatter retrieval with the corresponding analysis performed by the Leipzig group. Date: 25.05.2009 21:00-23:00 UT; System: Polly^{XT}.

possible) consists in to be always sure to use the same and the latest SCC version to produce optical products.

Figure 1 shows the general structure of the SCC which consists in several independent but inter-connected modules:

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 ones which are mainly used to correct instrumental effects (for example the dead time of a photomultiplier) and configuration ones which define the way to apply a particular procedure (for example which algorithm, among the implemented ones, has to be used to calculate a particular product). In general, these 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 nighttime or daytime configurations). In this context, a relational database represents an optimal solution to handle, in an efficient way, all this information. For this reason, a SCC database was implemented to store the input parameters for all the EARLINET systems and, at the same time, to get the set of parameters associated to a particular lidar configuration.

2. *Pre-processor module*
   This module implements all the corrections to be applied to the raw lidar signals before they can be used to derive optical properties. The raw lidar signals have to be submitted in a NetCDF format with a well-defined structure [1]. According to the specific lidar system, different operations can be applied: dead-time correction, trigger-delay correction, overlap correction, background subtraction (both atmospheric and electronic), low- and high-range automatic signal gluing, vertical interpolation, molecular profile calculation, time averaging, 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.

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. The analysis can be done in a flexible way choosing from a set of possible pre-defined analysis procedures. ELDA implements retrieval of elastic aerosol backscatter profile (Klett [6, 7], iterative algorithm [8]), retrieval of aerosol extinction profile [5] and finally retrieval of Raman aerosol backscatter profile [9]. 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 a NetCDF file with a structure according to the EARLINET rules [1].

4. *Daemon module*
   The SCC daemon is a process running continuously in the background. It is responsible to start the pre-processor or the optical processor module as soon as there are input data available for these modules. It also monitors the status of the modules started to check if they succeeded or failed.

5. *Web interface*
   The web interface represents the interface between

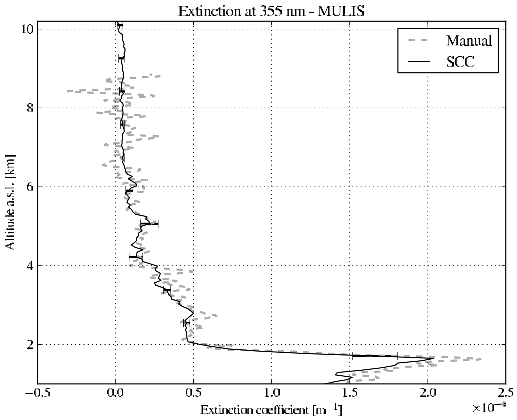

Figure 3: Comparison of the SCC Raman extinction retrieval at 355 nm with the corresponding analysis performed by the Munich group. Date: 25.05.2009 21:00-23:00 UT; System: MULIS.

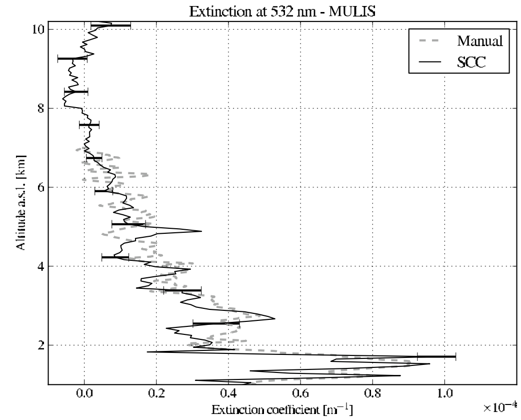

Figure 4: Comparison of the SCC Raman extinction retrieval at 532 nm with the corresponding analysis performed by the Munich group. Date: 25.05.2009 21:00-23:00 UT; System: MULIS.

the end-user and the SCC. It gives the user the possibility to submit data to the SCC and to modify any SCC input parameter associated with a particular lidar system configuration. The interface also informs the user about the status of the analysis made by the SCC on his data. Finally, it allows the user to download the pre-processed and the processed files produced by the SCC analysis.

The algorithms implemented in the SCC passed the test on the synthetic lidar signals used during the algorithm inter-comparison exercise performed in the framework of the EARLINET project [2].

A further SCC module for microphysical properties retrieval from multi-wavelength Raman lidar data has been developed. The main products are particle effective radius, volume concentration, and refractive index which are calculated with a semi-automated and unsupervised algorithm. Even if this module has been released in its operative version, it is not yet included in the automatic structure of the SCC. The results presented in this work regards only the SCC aerosol optical products and not the microphysical ones.

3. RESULTS

In this work, we present the first tests of the SCC analysis made on real lidar data. We have compared the optical products calculated by the SCC with the corresponding optical products generated by the analysis software developed by different lidar groups. All the data we have considered were collected during the EARLI09 measurement campaign hold in Leipzig, Germany, in May 2009 [10]. 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. 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 EARLI09 campaign gives us a good opportunity to test not only the pre-processor module but also all other SCC modules using data from different systems. 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. We focus on the case of 25$^{\text{th}}$ May 2009 from 2100 to 2300UT when a Saharan dust event was occurring over Leipzig.

The Raman backscatter profiles at 532 nm from the Leipzig system Polly$^{\text{XT}}$ are shown in Figure 2. The backscatter profile obtained by the SCC Raman backscatter retrieval is plotted using solid back line while the corresponding profile produced by the analysis software developed by the Leipzig group is shown using grey broken line. Some error bars from the SCC analysis are also shown in the plot. The profiles are calculated with both algorithms by combining the elastic signal at 532 nm with the nitrogen vibration-rotation Raman signal at 607 nm. The agreement between the two curves is in general good. However there are some differences in the lower part of the two profiles. Improvements of the SCC Raman backscatter retrieval are currently under development especially regarding the automatic determination of the atmospheric aerosol-free region in which the backscatter profile is calibrated.

Figures 3 and 4 are examples of comparisons of the Raman extinction retrieval implemented in the SCC and the corresponding one implemented in the analysis software of the Munich group. The curves in Figure 3 are the aerosol extinction profiles at 355 nm obtained from the nitrogen vibration-rotation Raman signal at 387 nm of the MULIS (MUlti-wavelength LIdar System) system, while Figure 4 shows the aerosol extinction profiles at 532 nm calculated from the nitrogen vibration-rotation Raman signal at 607 nm for the same system. For both the wavelengths the Raman extinction retrieval was applied to the signal obtained by gluing the analog and photon-counting signals. The agreement between the two independent algorithms is good for both wavelengths. The extinction profiles at 355 nm show small discrepancies only below 1.6 km which are under investigation. The extinction profiles at 532 nm are noisier than the ones at 355 nm and so it is not easy to clearly evaluate the agreement between them. Nevertheless, it seems that the atmospheric structures are present in both profiles in similar way.

Figure 5 shows the aerosol elastic-backscatter profiles at 1064 nm obtained from the infrared elastic-backscatter signal of the Potenza system MUSA (MUlti-wavelength lidar System for Aerosol). The agreement is really good over the entire range as the two curves are practically indistinguishable.

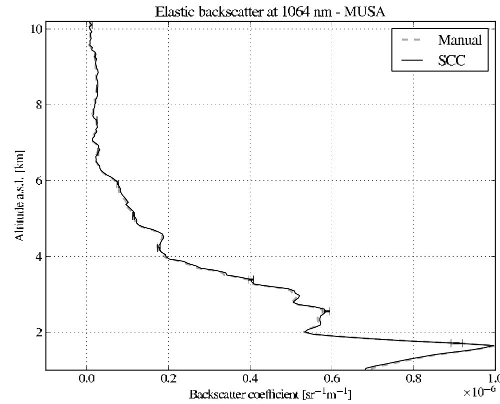

Figure 5: Comparison of the SCC elastic-backscatter retrieval with the corresponding analysis performed by the Potenza group. Date: 25.05.2009 21:00-23:00 UT; System: MUSA.

4. FUTURE DEVELOPMENT

A more complete test of the SCC is under development, and the other selected cases of the EARLI09 campaign will be considered to investigate the SCC behavior under different atmospheric conditions and also for daytime measurements. Moreover, other intercomparison campaigns were performed in the framework of the EARLINET-ASOS quality assurance program: SPALI10 (SPAin Lidar Inter-comparison, 18th October - 5th November 2010, Madrid, Spain) and ROLI10 (ROmania Lidar Inter-comparison 17th - 23th October 2010, Cluj Napoca, Romania). In both campaigns the pre-processor module of the SCC was used to compare lidar signals in a fast and efficient way as for the EARLI09 campaign. The data of these campaigns will be used to extend the test of SCC on lidar systems different from the ones participating in EARLI09. In addition, 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 [11]. 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.

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REFERENCES

1. http://www.earlinetasos.org
2. Amodeo, A. et al., 2010: The common calculus chain developed in the frame of the EARLINET-ASOS project, *Proceedings of 25th ILRC*, St. Petersburg, Russia, 5-9 July 2010.
3. Böckmann, C. et al., 2004: Aerosol lidar intercomparison in the framework of EARLINET. 2. Aerosol backscatter algorithms, *Applied Optics*, **43**, pp. 977-989.
4. Pappalardo, G. et al., 2004: Aerosol lidar intercomparison in the framework of EARLINET. 3. Raman lidar algorithm for aerosol extinction, backscatter and lidar ratio, *Applied Optics*, **43**, pp. 5370-5385.
5. Ansmann, A. et al., 1990: Measurement of atmospheric aerosol extinction profiles with a Raman lidar, *Optics Letters*, **15**, pp. 746-748.
6. Klett, J. D. et al., 1981: Stable analytic inversion solution for processing lidar returns, *Applied Optics*, **20** , pp. 211-220.
7. Fernald, F. G. 1984: Analysis of atmospheric lidar observations: some comments, *Applied Optics*, **23** , pp. 652-653.
8. Di Girolamo, P. et al., 1995: Two wavelength lidar analysis of stratospheric aerosol size distribution, *Journal of Aerosol Science*, **26**, pp. 989-1001.
9. Ansmann, A. et al., 1992: Combined Raman elastic-backscatter lidar for vertical profiling of moisture, aerosol extinction, backscatter and lidar ratio, *Applied Physics B*, **55**, pp. 18-28.
10. Freudenthaler, V. et al., 2010: EARLI09 - Direct intercomparison of 11 EARLINET lidar systems, *Proceedings of 25th ILRC*, St. Petersburg, Russia, 5-9 July 2010.
11. http://www.actris.org