APEL: Assessment of atmospheric optical Properties during biomass burning Events and Long-range transport of desert dust

Alcantara Study Executive Summary

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ABSTRACT:

The main scope of this activity was to foster the exchange of expertise between the European Lidar Network (EARLINET) and South American Lidar Network (LALINET), and demonstrate the capability of joint research, setting the groundwork for GALION (The Global Atmosphere Watch Aerosol Lidar Observation Network) and future Cal/Val of ESA's atmospheric satellite missions such as Aeolus and EarthCARE. During the activity, transfer of knowhow from European research groups to the Latin America lidar research network took place in the area of harmonized measurement and data handling protocols for addressing global science questions related to atmospheric aerosol. APEL paved the way for a continued future cooperation as follows:

- The LALINET stations in Brazil will continue to implement the Quality Assurance program and use the Single Calculus Chain data processing tool, and in parallel transfer the knowhow to other LALINET members.
- Part of the Quality Assurance and instrument optimization activities will continue even with limited support.

The activities carried out during the APEL campaigns will be the backbone for future global Cal/Val activities that involve the use of ground based aerosol lidar instruments as validation tools for the aerosol products from ESA's Earth Observation lidar missions. Furthermore, the data analysis will be applied further to collected measurement datasets from the ground and space-based lidars to address aerosol science questions.

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1 Motivation

ESA Satellite Cal/Val programs requires advanced ground based data providers that are able to cover extended geographical regions with standardized quality assured data products that are compatible with satellite observations.

By using standardized measurement protocols, research networks like EARLINET and LALINET could be used in joint activities in the ESA Satellite Cal/Val programs. In the recent years EARLINET has become a reference network for Europe [12]. The network is using well-defined data processing protocols and well-documented inter-calibration procedures. LALINET also started to implement systematic and similar rigorous inter-calibration and processing tools within the network [8]. In this sense, EARLINET is a mature network, with well-established quality assurance methodologies, and already operational calibration facilities. LALINET, on the other hand, is a young structure, a community avid of increasing its knowledge, where the exchange of expertise with international experts and other networks is its cornerstone. The APEL project was able to meet these goals by developing a common base for operation, quality control and data processing for lidar remote sensing.

From an operational point of view, LALINET has been focused on instrument and algorithm standardization (and the associated quality assurance protocols), taking the advantage of exchange of expertise mainly from EARLINET. However, the strongest shortcomings are lack of funding and limited political support in South America, therefore limiting an effective collaboration among LALINET stations and, consequently limiting the standardization process.

1.1 Objectives

The main scope of Apel was to foster the exchange of expertise between EARLINET and LALINET and to increase the capability of joint research, and thus setting the groundwork for the future Cal/Val of ESA's atmospheric satellite missions. Integration between LALINET and EARLINET is a key argument from the Cal/Val perspective since global measurement and data analysis protocol should be followed. Quality assurance and quality checks (QA/QC) standards should also be followed in order to harmonize the different instruments available in LALINET and bring them down to a set of tests and procedures that are already acceptable among other networks. To achieve these goals, the Apel activities followed two main objectives. a) The first objective was the transfer of knowledge from EARLINET stations to selected LALINET stations. This activity also covered the optimization of selected LALINET instruments by implementing the QA protocols and tests for checking and debugging. b) The second objective was to apply the newly implemented protocols in performing a measurement campaign exercise. This campaign was designed to test the operational aspect of the joint networks and test the newly quality assured lidar instruments in LALINET. A second aspect of the campaign was focused on the scientific perspective. The scientific objectives of the Apel campaign conducted in autumn 2017 was to assess the aerosol vertical structures, aerosol optical properties and aerosol types at selected LALINET and EARLINET stations during clean and biomass burning / dust events.

The scientific questions investigated during the campaign included: › How frequently do clean aerosol condition (free of anthropogenic influences) prevail? › What are the aerosol characteristics (e.g. aerosol optical depth) of these natural aerosol conditions? › How dominant is BBA from vegetation fires over Latin America? Additional analysis based on historical data from two LALINET stations was also conducted. The analysis was focused on two objectives: › To determine which aerosol species occur throughout the year over Europe and South America › To determine what are the height-resolved optical and microphysical aerosol properties under ambient conditions for the two areas. The campaign was divided into two parts [1] [2]. The first part of the campaign was carried out in September 2017 since the window of opportunity for biomass burning is end of August – September [11]. The window of opportunity for dust is November – January [9][10] and the second part of the campaign took place during October – December 2017 [4] [6][7].

2 Main study outcome and achievements

As presented in the latter section, the goal of Apel was to foster the exchange of expertise between EARLINET and LALINET by implementing the QA/QC protocols and data processing to harmonize the different instruments available in LALINET and bring them down to a set of tests, measurement procedures and data processing protocols which are already accepted in EARLINET. The outcome of Apel can be summarized in the following achievements:

Implementation of the EARLINET QA/QC program at LALINET stations.

- Training of LALINET users and implementation of the Single Calculus Chain (SCC) data format and processing

- Implementation of standard operation procedures (SoPs) & QA tests at the selected LALINET stations

- Identification of problems and optimization of the LALINET lidar instruments

Apel campaign and data analysis

Description of the project achievements:

During the implementation of Apel, the QA/QC program developed by EARLINET was transferred at selected LALINET stations. The selected LALINET stations included the Manaus station (MAO 02.60°S, 60.21°W), the San Paulo station (SPU 23.13°S, 46.28°W), the Natal station (NAT 05.82°S, 35.20°W) and from the European network the Granada station (MUL 37.16°N, 3.61°W) and the Bucharest station (RALI 44.34°N, 26.02°E). Two additional LALINET stations took part of the research activities in Apel: Punta Arena station (PAR 53.13°S, 70.88°W) and the Buenos Aires station (VMA 34.56°S, 58.42°W). The participation of the two stations was strictly on voluntary basis and the data analysis was not included in the project reports. The data will be used in common research activities for further analysis and publications.

Implementation of the EARLINET QA/QC program at LALINET stations

<u>Training of LALINET users and implementation of the SCC data format and processing</u>: During this task, LALINET members took part of training activities like workshops, remote sessions, on site visits and summer-schools. Advanced LALINET users had the opportunity to configure and use the EARLINET SCC [5] under the assistance of SCC developers from EARLINET. For LALINET users unable to take part of these activities, additional documentation related to the SCC, lidar processing and the quality

assurance protocols was provided via the dedicated Apel hub. Based on these activities, the LALINET users managed to setup and use the SCC for all processing related tasks carried out in the project.

link of the events:

http://ecars.inoe.ro/index.php/2016/03/16/ecars-workshop-on-good-practices-in-lidar-operation/

http://lical.inoe.ro/apply-for-access/

Implementation of standard operation procedures (SoPs) & QA tests at the selected LALINET stations: During the Apel project, the EARLINET QA expert Volker Freudenthaler provided his support for the implementation of the EARLINET QA program to the selected LALINET stations. Full description of each lidar was required to characterize each of the instruments. This information was collected in a standard worksheet named the Handbook of Instruments (HOI). For the preparation of the worksheet, each selected station has been asked to provide the required technical characteristics of their system. Part of this information was further used to setup the system in the SCC interface, and prepare submission of the raw data, and part of the information was used as a basis for the analysis of the QA hardware tests. In the first phase of the process, all required documentation related to the principles and the reasoning for each test in the QA program were provided to the LALINET team. The theoretical and hands-on standard operation procedures, initially designed for the EARLINET community were provided via a common Apel hub.

Identification of problems and optimization of the LALINET lidar instruments: After the first set of tests, Volker provided his expertise to analyze the QA data and assess the performance of each LALINET instrument that was part of Apel (SPU, SPT, MAN, NAT). Based on a series of iterative QA tests and iterations, the LALINET instruments were optimized. Even if the QA activity was finalized, the instruments are on a continuous process of improvement based on the contact and feedback with EARLINET experts. Even if the time dedicated for this task was limited and work is still ongoing, the optimization of the LALINET instruments during the Apel project was significant. At the end of the task all lidar instruments were fully prepared for the campaign.

The instrument optimization was followed up by several research activities designed to test the capabilities of the optimized instruments. The LALINET participants could actively use the common EARLINET processing platforms (SCC) to analyze the results and compare the output to the LALINET operational data analysis. The main scope of these activities was to increase the capability of joint research in setting up the groundwork for future Cal/Val activities.

Apel campaign and data analysis: A four-month scientific campaign was organized in the frame of APEL, involving LALINET and EARLINET lidars. The scope of the campaign was to measure particle backscatter and extinction products at the three LALINET locations in a harmonized way, i.e. using a common QA and data processing framework. For this purpose, the EARLINET Single Calculus Chain (SCC) was used by all participants as a common data processing tool. The campaign data was also used to assess the vertical distribution of aerosols - and quantify their optical properties, focusing on long-range transport of desert dust and biomass burning events in Latin America [3]. Young scientists from LALINET took an active role in this analysis. A comparison between the SCC output and the internal processing algorithms used in LALINET was performed. The results are available in D3 of the project.

Data analysis:

A statistical approach on how often do background atmospheric conditions prevail was performed based on sun-photometer measurements (2.0 AOD and Angstrom https://aeronet.gsfc.nasa.gov/). The SPU AOD data shows increased values for September and October compared to an annual average of 0.2 for the 500nm AOD in 2017. Similar AOD behavior can also be seen for the MAO station. The annual values for the MAO 500nm AOD shows a mean value of 0.13 which is lower than for the SPU station indicating higher aerosol loads for the latter. In the case of BUC (Fig. 3) the 2017 AOD values show irregular patterns indicating multiple aerosol sources. The Angstrom exponent time series shows a mean value of 1.5 – indicating small particles throughout the year. For the MUL station, the AOD time series indicates lower than average values for Oct-Dec 2017. The low AOD and high Angstrom exponent values indicate low concentrations of small particles. The lidar time series (Apel D2) also confirms a clean atmosphere with minor episodes of regional aerosol transport (smoke).

An overview analysis on aerosol characteristics of background aerosol conditions was also performed by using an aerosol typing retrieval code based on Artificial Neural Networks (NATALI - http://natali.inoe.ro/, also see D3). This analysis was possible only for stations with a sufficient amount of spectral channels (see D3). As an example, figure 1 shows the output provided by the code for the SPU station.

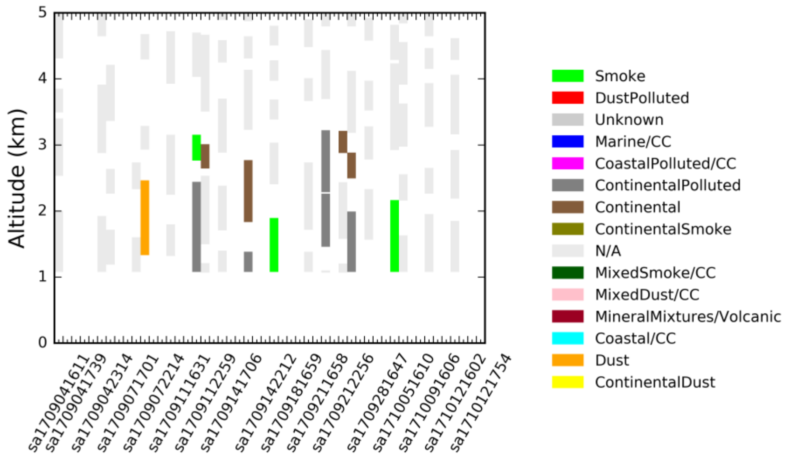

Figure 1: NATALI aerosol typing output for SPU station.

Several case studies were analyzed to cover the two areas of interest for the two scientific studies (biomass burning and dust events) based on the overview analysis from sun-photometer and NATALI. A typical example of continental aerosol is presented in figures 2-5 for the SPU station. Based on these cases, a comparison between the EARLINET SCC and LALINET processing algorithms was also provided (See Figure 6).

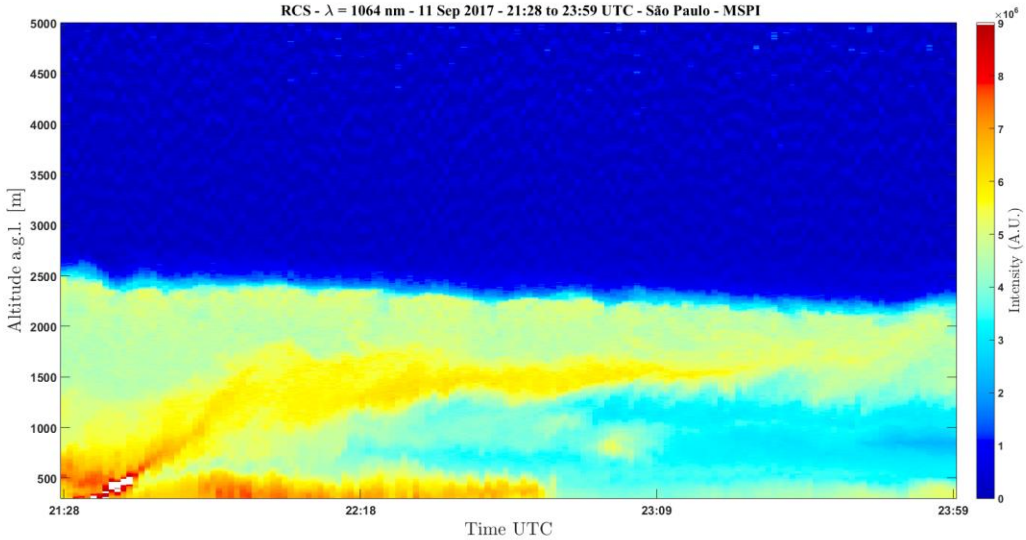

Figure 2: Time-height cross section of the range corrected lidar signal at 1064nm from SPU station, 11th of September 2017.

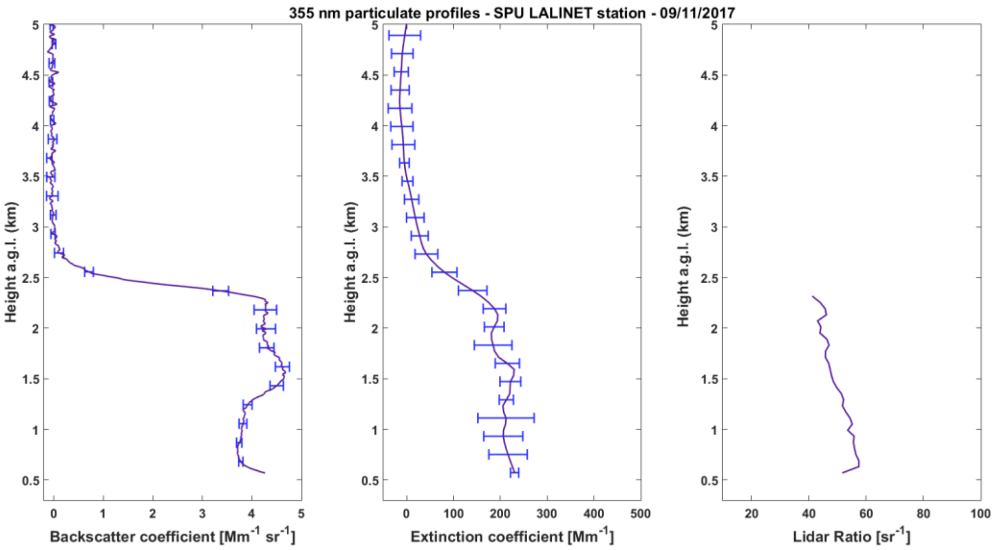

Figure 3: Particle backscatter, extinction and lidar ratio profiles on 11th of September 2017 – SPU station, 355nm, 22:00 – 23:00 UTC

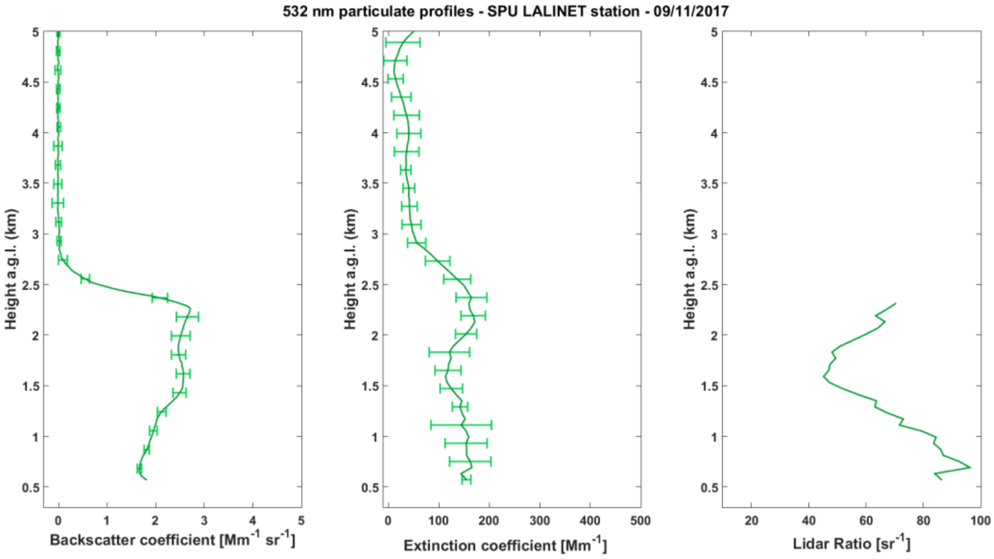

Figure 4: Particle backscatter, extinction and lidar ration profiles for 11th of September 2017 – SPU station, 532nm, 22:00 – 23:00 UTC

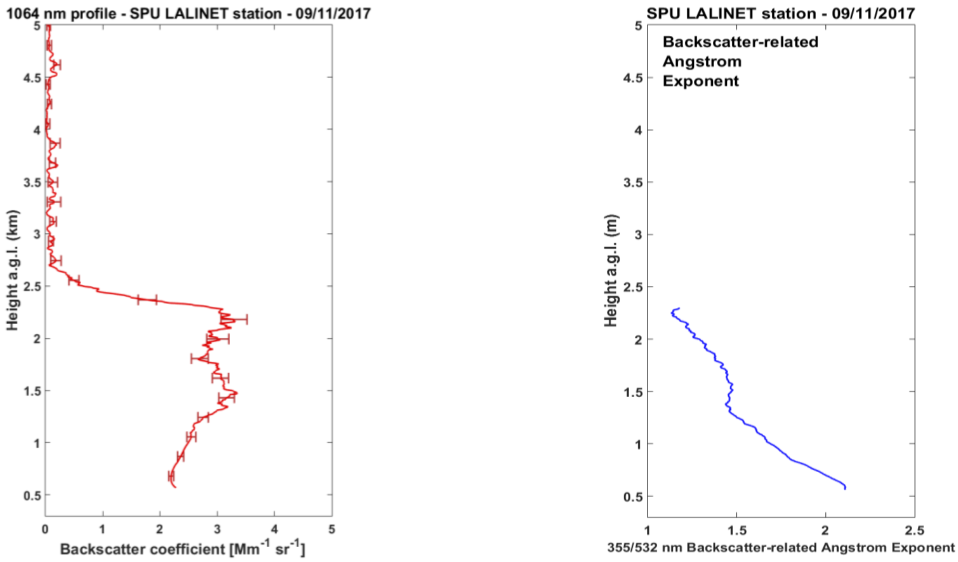

Figure 5: Particle backscatter 1064 nm and Angstrom exponent 355/532 nm for 11th of September 2017 – SPU station, 22:00 – 23:00 UTC

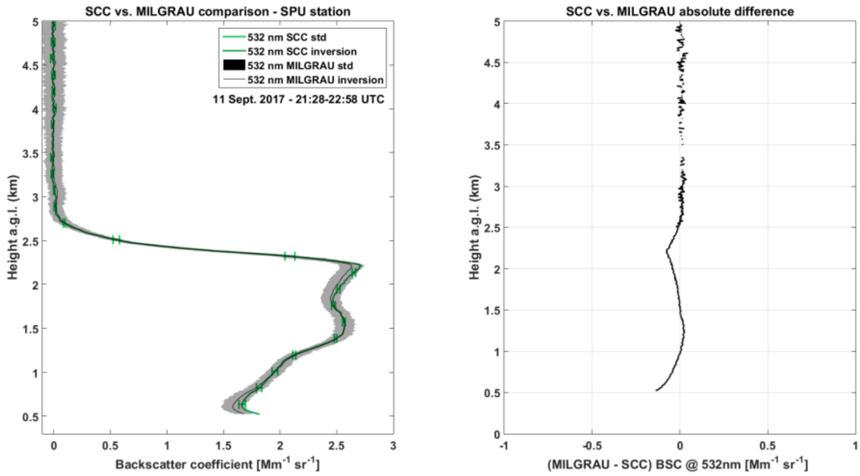

Figure 6: SCC vs MILGRAU output: a) backscatter coefficient; b) absolute difference for 11th of September 2017 21:28 – 22:58 UTC

The LALINET processing and SCC presents a good agreement, especially for regions above 1.5 km. Results show some specific differences inside of aerosol planetary layer that can be investigated and solved by using the same parameters for both algorithms.

A historical analysis was also included in D3. Data from MAO and SPU stations was used to investigate which aerosol species occur throughout the year over Europe and South America and what are the height-resolved optical and microphysical aerosol properties under ambient conditions for the two areas. Figure 6 a,b shows the scatter plot Angstrom (440-870nm) versus AOD (500nm) for AERONET level 2.0 data during 2012-2015 at MAO and SPU. The study was able to show relevant aerosol types during the investigated period. To this aim relevant events have been identified as follows: biomass burning particles (1.50 < $AE_{440-870}$ < 1.75 and AOD_{500}>0.50), anthropogenic particles (1.00 < $AE_{440-870}$ < 1.50 and AOD_{500}>0.50) and mineral dust particles ($AE_{440-870}$ < 0.75).

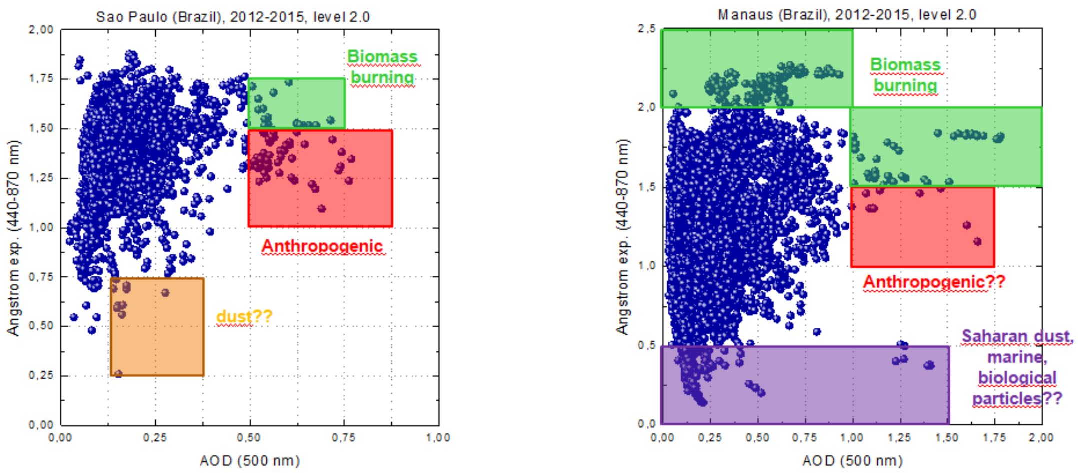

Figure 7: Scatter plot Angström exponent (440-870 nm) versus AOD (500 nm) for AERONET level 2.0 data during the historical period 2012-2015 a) São Paulo SPU b) Manaus MAO

The results of the scientific analysis – both campaign and historical – show similar optical values on both regions (Europe and Latin America) with an increased potential of long range transport mineral dust and biomass burning events for the second region.

3 Concluding statement and Outlook

ESA's Alcantara program aims to support cooperation between research groups in Europe and those based elsewhere, in study areas of mutual benefit like the Cal/Val activities for the future space missions. Under this initiative, the Apel project was the backbone in transfer of knowhow from European research groups to the Latin America lidar research network. The activities carried out in this project showed the potential of harmonized measurement and data handling protocols for joined research. Apel fostered the transfer of expertise from EARLINET to LALINET and acted as groundwork for future cooperation. With these considerations:

- The LALINET stations will continue to implement the QA program and use the SCC processing and in parallel will transfer the knowhow to other Latin America stations.
- The consortium will try to apply for founding in future calls to continue the work started in Apel.
- Part of the QA and instrument optimization activities will continue even with limited support.

Beyond its short-term achievements (presented below), the APEL project fostered research excellence in the field to support international partnerships in applied space research.

The Apel activities showed the potential of the networks to use common protocols for measurements and data analysis for the harmonization of the different instruments available over the two continents. One important factor for the harmonized data analysis was the use of the SCC for the common scientific studies. The activities carried out during the Apel campaign will be the backbone for future global Cal/Val activities that involve the use of ground based lidar instruments as validation tools for satellite-based products. In this perspective we consider the implementation of the QA/QC protocols, the optimization of the LALINET instruments and the Apel campaign a real success for the harmonization process of the data products provided by the two networks.

In the perspective of a continuous joint activity between EARLINET and LALINET, a future framework of Joint publications, harmonized data processing, and future research proposals was targeted during the implementation of Apel. Even if the two research communities had prior contact engaging in various research activities, the Apel project was a great opportunity to strengthen the bonds between the two, providing the means to use common measurement protocols and processing platforms in perspective of satellite validation tools that are able to offer standardized data products.

The implementation of APEL enabled LALINET to become a high level lidar network with standardized data processing protocols and well-documented inter-calibration procedures.

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