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LONG-TERM AEROSOL AND CLOUD DATABASE FROM CORRELATIVE EARLINET–CALIPSO OBSERVATIONS

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ABSTRACT

The European Aerosol Research Lidar Network, EARLINET, performs correlative observations during CALIPSO overpasses based on a sophisticated measurement strategy since June 2006. Within a dedicated activity supported by the European Space Agency (ESA), sixteen EARLINET stations contributed about 1500 measurements during an intensive observational period from May 2008 to October 2009. From these measurements, we establish a long-term aerosol and cloud database of correlative EARLINET-CALIPSO observations. This database shall provide a basis for homogenizing long-term space-borne observations conducted with different lidar instruments operating at different wavelengths on various platforms over the next decade(s). The database is also used to study the quality and representativeness of satellite lidar cross sections along an orbit against long-term lidar network observations on a continental scale.

1. INTRODUCTION

In June 2006, the satellite-borne lidar CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization) began its observations onboard CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations; [1]). This date is regarded the starting point of a unique long-term, global, 4-dimensional aerosol and cloud data set. The forthcoming missions ADM-Aeolus (Atmospheric Dynamics Mission; [2; 3]) of the European Space Agency ESA and EarthCARE (Earth Clouds, Aerosols, and Radiation Explorer) of ESA and the Japan Aerospace Exploration Agency JAXA [4], with their lidar instruments ALADIN (Atmospheric Laser Doppler Lidar Instrument) and ATLID (Atmospheric Lidar), respectively, will continue such kind of observations. It is expected that the long-term data set gained in this way will substantially improve our knowledge on the role of aerosols and clouds in the Earth's climate system. CALIOP is a two-wavelength backscatter lidar which provides aerosol and cloud optical properties at 532 and 1064 nm. In contrast, next-generation space-borne lidar missions will operate high-spectral-resolution lidars at 355 nm. In order to homogenize the long-term data set, it is necessary to establish a substantiated state of knowledge on the spectral optical properties of different aerosol and cloud types. Respective information is obtained with advanced ground-based multiwavelength lidars. Only they can deliver the required wavelength conversion information to relate space-borne measurements at 355 nm to those at 532 and 1064 nm. In the following, we present a long-term ground-based measurement program initiated by ESA and EARLINET (European Aerosol Research Lidar Network) to support the ongoing and upcoming space-borne aerosol and cloud lidar missions. The database established within this project aims at two major tasks. Firstly, it provides a tool for homogenizing long-term space-borne observations conducted with different lidar instruments on various platforms. Secondly, it is used to study the quality and representativeness of a limited number of satellite lidar cross sections along an orbit against long-term lidar network observations on a continental scale.

2. EARLINET MEASUREMENT STRATEGY

EARLINET has started correlative measurements with CALIPSO at the majority of the network stations in June 2006 on a voluntary basis [5]. In 2008, EARLINET and ESA initiated a dedicated observational program to establish a long-term aerosol and cloud database of correlative ground-based and space-borne observations. The ESA-CALIPSO (EARLINET's Space-borne-lidar-related Activity during the CALIPSO mission) study is based on observations at 16 EARLINET stations over a time period of 18 months from May 2008 to October 2009. Fig. 1 shows the EARLINET stations which contribute to the long-term database. For the study, we have defined two types of stations: *high-performance* and *contributing* stations. *High-performance stations* are equipped with instruments to measure at least extinction and backscatter coefficients at both 355 and 532 nm (two-wavelength Raman lidar). Most of these stations provide backscatter coefficients at 1064 nm and the particle depolarization ratio at 532 nm as well. This detailed information from the EARLINET core stations offers the unique chance to investigate the potential of space-borne lidar instruments to identify certain aerosol types and to distinguish man-made from natural aerosol. The data can be used to develop a high-sophisticated aerosol-type classification scheme considering the CALIOP as well as the ALADIN/ATLID data information content. The stations are located such that four European core regions are covered (see Fig. 1): central Europe (Germany and The Netherlands), the western Mediterranean (Spain), the central Mediterranean (Italy), and the eastern Mediterranean (Greece). In this way, a broad variety of aerosol types and scenarios can be investigated, which include maritime aerosol as well as urban and rural continental aerosol, Saharan dust, and forest-fire smoke, including long-range-transport aerosols in the free troposphere from America and Asia.

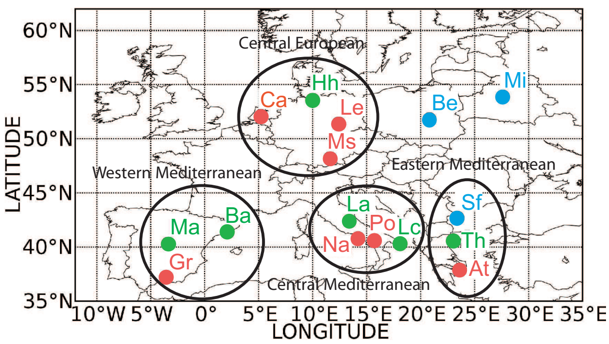

Figure 1: Map of EARLINET stations contributing to the long-term aerosol and cloud data set. Red dots show the high-performance core stations (At-Athens, Ca-Cabauw, Gr-Granada, Le-Leipzig, Ms-Maisach, Na-Napoli, Po-Potenza). Green and blue dots represent contributing stations (Ba-Barcelona, Be-Belsk, Hh-Hamburg, La-L'Aquila, Lc-Lecce, Ma-Madrid, Mi-Minsk, Th-Thessaloniki, Sf-Sofia).

The selected *contributing stations* create clusters around the high-performance stations (see Fig. 1). In addition, the stations in Belsk and Minsk were selected to extend the network towards the east and to provide valuable information on aerosol source regions in this area. Most of the contributing stations operate Raman lidar instruments as well, but not at several wavelengths. Highly reliable extinction and backscatter coefficients are retrieved at either 355 or 532 nm at these sites. Typical distances of neighboring stations within a cluster are 120 to about 800 km. The distribution of the stations allows us to study the temporal, regional and continental-scale representativeness of the observations and to compare these findings with the results of space-borne lidar measurements from the polar-orbiting satellites. This aspect of the study is discussed in more detail in a companion paper [6].

Measurements for the study are primarily performed during overpasses of CALIPSO. In addition, observations were carried out when special aerosol situations occured. Three types of measurement cases are defined.
Case A: Each station performs correlative measurements when the CALIPSO overpass is within 100 km.
Case B: Several stations of the same cluster perform contemporary measurements when the CALIPSO overpass is within 100 km of one of the stations.
Case C: Additional measurements are carried out by all stations during special situations like Saharan dust intrusions, forest fires, volcanic eruptions etc.
From the high-resolution ground-track data of CALIPSO provided by NASA, the time schedule of Case A and Case B measurements is calculated for all stations and distributed to the network weekly. In addition, an alert system is established for special situations. In order to investigate the temporal variability of aerosol and cloud fields, Case A and B measurements typically last 150 minutes, centered around the CALIPSO overpass. For the representativeness study, aerosol profiles are calculated with a resolution of 30 min and cloud profiles with a resolution of 10 min from these measurement sequences.

3. DATABASE APPROACH

Starting from the extinction and backscatter profiles provided by the individual EARLINET stations, the measurements are investigated in detail with respect to layer-mean values of spectral backscatter and extinction coefficients, lidar ratios, depolarization ratio, extinction- and backscatter-related Ångström exponents and color ratios (or wavelength conversion factors, i.e. ratios of backscatter coefficients at 1064/532 nm, 532/355 nm, and of extinction coefficients at 532/355 nm). Each observed cloud and aerosol layer is classified. Aerosol typing follows the

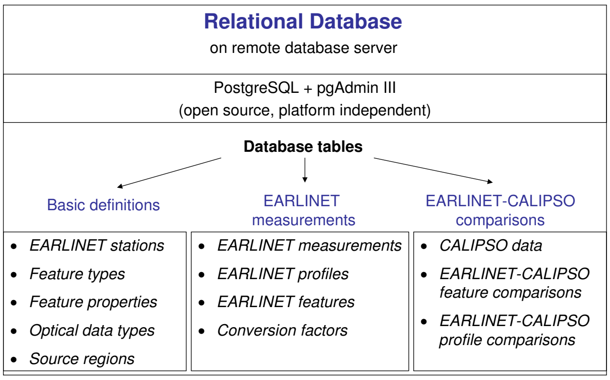

Figure 2: Structure of the relational database of long-term correlative EARLINET-CALIPSO observations.

CALIPSO typing scheme and considers marine aerosol, dust, polluted dust, smoke, continental pollution, clean continental background aerosol, and volcanic aerosol. An extended analysis of source regions, age, and state of humidification is performed with the help of models and auxiliary data. The major tool is the Lagrangian particle dispersion model FLEXPART [7; 8] which has been implemented for EARLINET at the Leipzig station to study aerosol origin, transport, and mixing. Cloud classification focuses on the discrimination of water, ice, and mixed-phase clouds. For both profile and layer products the differences to the respective CALIPSO products are calculated in dependence on the spatial and temporal distance of the observations (see [6]). The complete data set is stored in a relational database that will be made available for further scientific use. The structure of the database is shown in Fig. 2.

4. MEASUREMENT EXAMPLE

An example of a multi-wavelength ground-based observation is presented in Fig. 3. The measurement was performed with the Potenza EARLINET lidar on 8 July 2008, 00.19–02.26 UT. From the backscatter (355, 532, 1064 nm) and extinction profiles (355, 532 nm) lidar ratios (355, 532 nm) and Ångström exponents (355–532 nm extinction related, 355–532 nm and 532–1064 nm backscatter related) were derived. Above the PBL (1.75 km a.s.l.), two distinct aerosol layers are obtained. The first one is centered at 2.5 km a.s.l., the second one extends from 3.2 to 4.8 km a.s.l. In the lower layer between 1.9 and 2.8 km a.s.l. mean lidar ratios of 43±7 sr and 44±2 sr are found at 355 and 532 nm, respectively. The extinction-related Ångström exponent in the 355–532-nm range is 0.74±0.22, and the backscatter-related Ångström exponents are 0.61±0.24 and 0.53±0.03 in the 355–532-nm and the 532–1064 nm range, respectively.

Fig. 4 shows a result of FLEXPART transport simulation for the layer obtained between 1.9 and 2.8 km. The footprint represents airmasses which arrived at Potenza on 8 July 2008 and which traveled below 2000 m height during the previous 10 days. The model output is given in terms

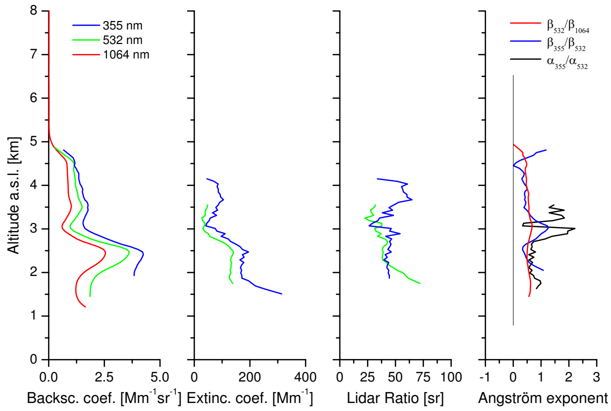

Figure 3: Multi-wavelength profiles measured at Potenza EARLINET station on 8 July 2008, 00.19–02.26 UT; aerosol backscatter coefficient at 355, 532, and 1064 nm, aerosol extinction coefficient and lidar ratio at 355 and 532 nm, Ångström exponent (355–532 nm range) and backscatter-related Ångström exponent (355–532 nm and 532–1064 nm range).

of the integrated residence time in a grid box. The layer is traced back to northwestern Africa. From the time-resolved simulation (not shown), it can be seen that the airmass was above the western Sahara more than three days before the observation. During the last three days it traveled along the coastlines of Morocco and Algeria before it crossed the Mediterranean. In addition, part of the airmass arrived directly from the North Atlantic. Thus the observed aerosol layer represents a typical mediterranean mixture with contributions of aged Saharan dust, marine aerosol, and anthropogenic pollution. Lidar ratios are smaller and Ångström exponents are larger than typically measured in pure dust [5].

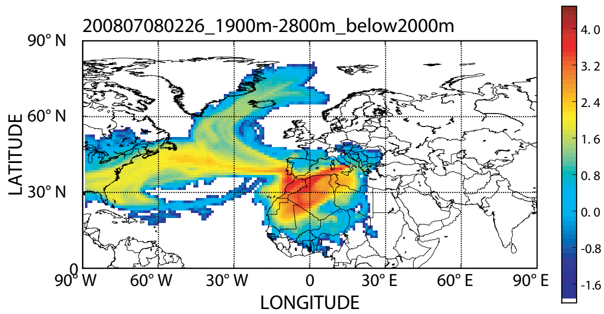

Figure 4: FLEXPART footprint for airmasses traveling below 2000 m height and arriving at Potenza between 1.9 and 2.8 km height at 02.26 UT on 8 July 2008. The colors represent the logarithm of the integrated residence time in a grid box in seconds for 10-day integration time.

Fig. 5 shows the aerosol backscatter profiles measured at 532 and 1064 nm with the EARLINET lidar at Potenza in comparison to the CALIPSO observation for the closest available overpass (about 172 km distance) and temporal coincidence and the corresponding differences profiles. The CALIPSO profiles have a horizontal resolution of 40 km, whereas the ground-based measurement is obtained with an integration time of 2 hours centered around the CALIPSO overpass time at 01.18 UT. A good

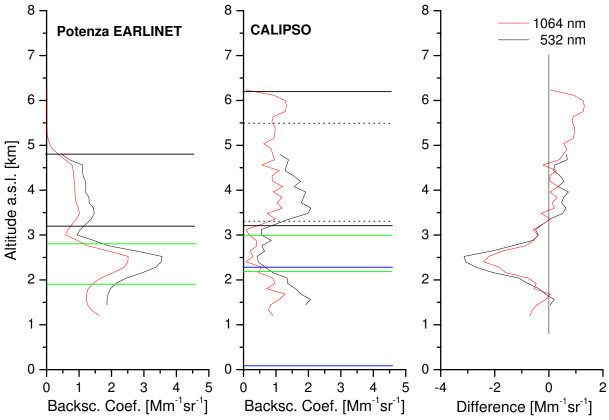

Figure 5: Aerosol backscatter coefficients at 532 and 1064 nm measured at Potenza EARLINET station (left) and by CALIPSO (middle) on 8 July 2008, 01.18 UT. Profiles of the differences are reported in the right panel. Top and base of aerosol layers are also indicated for both EARLINET and CALIPSO profiles as horizontal lines (black, green, and blue).

agreement in the shape of the profiles is observed above 3 km of altitude, while there are considerable differences at lower altitudes to be ascribed to the horizontal distance between the two observations. In Fig. 5, aerosol layer base and top altitudes are reported for both ground-based and space-borne measurements as horizontal lines. For CALIPSO measurements, layers are highlighted by solid lines, when they are detected along the whole 40-km cross section, and by dotted lines, if they are detected only over a fraction of this distance. Along the whole 40-km pass, CALIPSO detects two aerosol layers extending from 2.2 to 3.0 km and from 3.2 to 6.2 km. Therefore, the feature comparison for this case results in a pretty good agreement of the lofted layer bottom altitudes. In the layer above 3.2 km detected by both systems, a relatively small difference of backscatter coefficients is observed resulting in a mean of 0.41 $Mm^{-1}sr^{-1}$ and 0.26 $Mm^{-1}sr^{-1}$ at 532 and 1064 nm, respectively. These small but not negligible differences are caused by the spatial and temporal variability of aerosol content, together with the horizontal distance between the air volumes sampled.

5. CONCLUSION

The establishment of a common database of EARLINET and CALIPSO correlative measurements is a first step towards the long-term harmonization of satellite-based measurements. The database can be used in many ways, e.g., to validate space-borne lidar data, to test and develop aerosol typing schemes, or to study the representativeness of satellite measurements along cross sections against network observations. In view of future space-borne lidar missions and the global aerosol lidar network GALION, a long-term perspective of the database on the global scale is desirable.

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