ESA-CALIPSO

AEROSOLS AND CLOUDS: LONG-TERM DATABASE
FROM SPACEBORNE LIDAR MEASUREMENTS
ESTEC Contract No. 21487/08/NL/HE

Aerosols and Clouds: Long-term Database from Spaceborne Lidar Measurements

Executive Summary

Authors:

Ulla Wandinger, Gelsomina Pappalardo, Lucia Mona,
Anja Hiebsch, Ina Mattis, and Fabio Madonna

Document status sheet

Title	**ESA-CALIPSO** Aerosols and Clouds: Long-term Database from Spaceborne Lidar Measurements Executive Summary
Date	2012-01-02
Status	FINAL
Issue	2.0
Project No.	21487/08/NL/HE General Studies Programme
Prepared for	ESTEC Keplerlaan 1 2201 AG Noordwijk The Netherlands
Authors	Ulla Wandinger (IfT) Gelsomina Pappalardo (CNR-IMAA) Lucia Mona (CNR-IMAA) Anja Hiebsch (IfT) Ina Mattis (IfT) Fabio Madonna (CNR-IMAA)
IfT	Leibniz Institute for Tropospheric Research Permoserstr. 15 04318 Leipzig, Germany
CNR-IMAA	Istituto di Metodologie per l'Analisi Ambientale, Contrada S. Loja, Tito Scalo zona industriale 85050 Potenza, Italy
ESA Study Manager	Paul Ingmann Mission Science Division Earth Observation Programmes

Document Change Sheet

Issue	Revision	Date	Reason for Change	Author
1.0	Baseline	2011-12-29	Baseline Issue	UW / IfT
2.0	Final	2012-01-02	Co-author comments included	UW / IfT

Table of Contents

1. Scope of the study

The ESA–CALIPSO (EARLINET's Spaceborne-related Activity during the CALIPSO mission) study was set up to establish a long-term aerosol and cloud database from ground-based lidar network measurements taken in the frame of EARLINET (European Aerosol Research Lidar Network) and spaceborne lidar observations with CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization) onboard the polar-orbiting satellite CALIPSO (Cloud-Aerosol Lidar Infrared Pathfinder Satellite Observations). The database shall support the continuous, harmonized observation of relevant climatological parameters with active remote-sensing techniques from space over the next decade(s). CALIPSO provides vertically resolved information on aerosol and cloud parameters since June 2006. This date can be regarded as the starting point of a unique long-term, global, 4-dimensional data set that will substantially improve our knowledge on the role of aerosols and clouds in the Earth's climate system. The ADM–Aeolus (Atmospheric Dynamics Mission–Aeolus of the European Space Agency ESA) and EarthCARE (Earth Clouds, Aerosols and Radiation Explorer of ESA and the Japan Aerospace Exploration Agency JAXA) missions will continue such kind of observations in subsequent years and prolong the data set to more than a decade. In this way, we can expect a unique data set on the global aerosol and cloud distribution and respective trends in cloud cover, cloud amount, and aerosol pollution state.

However, the lidar instruments onboard the three missions represent different system types with different sets of measured parameters at different wavelengths (355, 532, and 1064 nm). CALIOP is a two-wavelength backscatter lidar operating at 532 and 1064 nm. In contrast, the Atmospheric Laser Doppler Lidar Instrument (ALADIN) onboard the ADM–Aeolus mission and the Atmospheric Lidar (ATLID) of the EarthCARE satellite make use of the high-spectral-resolution lidar technique in the UV. Consequently, ALADIN and ATLID will deliver independent information on extinction and backscatter coefficients at 355 nm and thus on the extinction-to-backscatter ratio (lidar ratio) at this wavelength. From CALIOP we obtain backscatter coefficients at 532 and 1064 nm and thus the 1064-nm-to-532-nm backscatter ratio, also called color ratio. To derive extinction profiles and optical-depth information from CALIOP measurements, assumptions on the lidar ratio are needed. CALIOP and ATLID also measure the particle linear depolarization ratio at 532 and 355 nm, respectively. In contrast, the radiation emitted by ALADIN is circularly polarized and the co-polarized component of the backscattered light is detected only.

In order to establish a useful common aerosol and cloud data set from the spaceborne observations, long-term, ground-based support with advanced lidar instruments is required. The ground-based instruments must deliver necessary conversion information for different aerosol and cloud types to relate the spaceborne measurements at 355, 532, and 1064 nm to each other. A second major aspect is the investigation of the representativeness of spaceborne observations on the regional and continental scale. Here, the comparison of measurements from the orbiting satellite and from a network of ground-based stations provides the required information based on a statistically significant data set, i.e. a sufficient large number of correlative observations.

Our study represents the first dedicated activity in this context. The main objectives driving this activity were:

- Take advantage of the unique opportunity to conduct comprehensive ground-truth lidar observations at 16 EARLINET stations during overpasses of the CALIPSO satellite. The goal is to achieve an optimum adjustment of long-term aerosol and cloud data sets in preparation for later missions in view of the development of a climatological database.
- Explore aerosol optical characteristics with the goal to investigate the potential to retrieve the aerosol type, to separate man-made from natural aerosol effects, and to relate spaceborne observations carried out with different lidar instruments to each other.
- Explore cloud characteristics with the goal to distinguish water and ice clouds by means of measured sets of extinction and backscatter coefficients, lidar and depolarization ratios.
- Compare the representativeness of cross sections along an orbit against network observations over Europe for an extended period of time and investigate to what extent satellite and network observations can be combined to provide information about the characteristics of aerosols and clouds.
- Investigate the potential applications of the long-term database established as a result of the study.

2. Implementation

In the course of the study, the initial set of observational data for the long-term aerosol and cloud database has been sampled and evaluated in detail. EARLINET had started correlative measurements with CALIPSO already at the beginning of the CALIPSO mission in June 2006. Based on the experience gained within the first two years, an optimized observational strategy has been set up in the beginning of the study. During an 18-month intensive observational period from May 2008 to October 2009 correlative EARLINET–CALIPSO measurements were taken at 16 EARLINET stations distributed over Europe (see Fig. 1). Seven of the 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 them provide also backscatter coefficients at 1064 nm and the particle linear depolarization ratio. This detailed information from the EARLINET core stations allows us to investigate the potential of spaceborne lidar instruments to identify certain aerosol types and to distinguish man-made from natural aerosol.

The data are used for the development of sophisticated aerosol-type classification schemes considering the CALIOP as well as the ALADIN/ATLID data information content. The EARLINET core stations are located such that four European core regions are covered: 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.

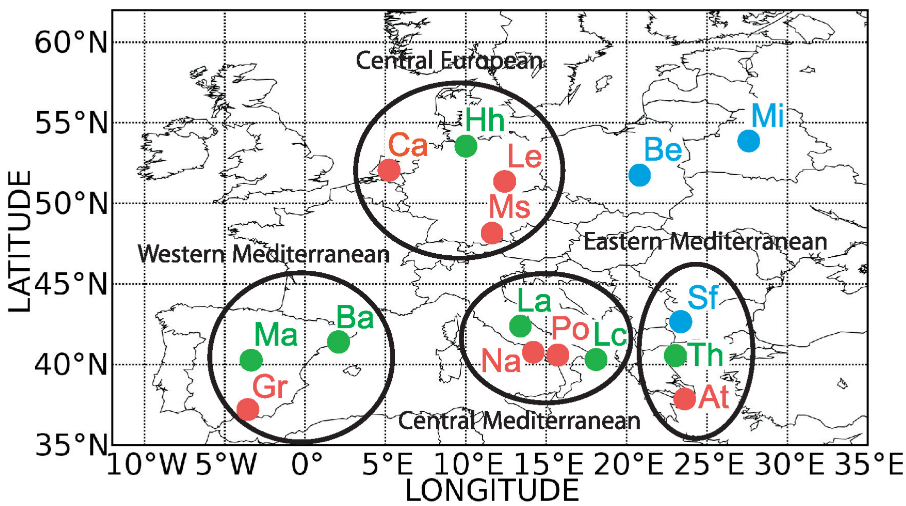

Figure 1: Map of EARLINET stations contributing to the long-term aerosol and cloud data set. Red dots show the high-performance core stations (At-Athens, Ca-Cabauw, Gr-Granada, Le-Leipzig, Ms-Maisach, Na-Napoli, Po-Potenza). Green and blue dots represent contributing stations (Ba-Barcelona, Be-Belsk,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

The remaining stations participating in this study create clusters around the core stations. Most of them 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 spaceborne lidar measurements from the polar-orbiting satellites.

Starting from the extinction and backscatter profiles provided by the individual EARLINET stations, the measurements have been 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, 1064/355 nm, 532/355 nm, and of extinction coefficients at 532/355 nm). Observed aerosol and cloud layers are classified. For aerosols an extended analysis of source regions, age, and state of humidification is performed with the help of models and auxiliary data.

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 Level 2 products are calculated in dependence on the spatial and temporal distance of the observations.

Based on a comprehensive sample of more than 1300 observations performed by EARLINET stations during overpasses of CALIPSO from May 2008 to October 2009, a relational database has been set up which contains information on EARLINET and CALIPSO Level 2 profile data, EARLINET-CALIPSO difference profiles, geometrical and optical data of a large number of selected aerosol and cloud layers from EARLINET measurements and respective comparisons of EARLINET and CALIPSO layer products. The structure of the database is shown in Fig. 2. An aerosol and cloud classification scheme has been developed and applied to the database. The aerosol classification has been evaluated in detail, based on a critical assessment of the CALIPSO typing schemes and built on the expert knowledge within EARLINET and the experience of the partners gained in field experiments around the world. The database has been used for the exploitation of the results and the statistical evaluation of the complete data set.

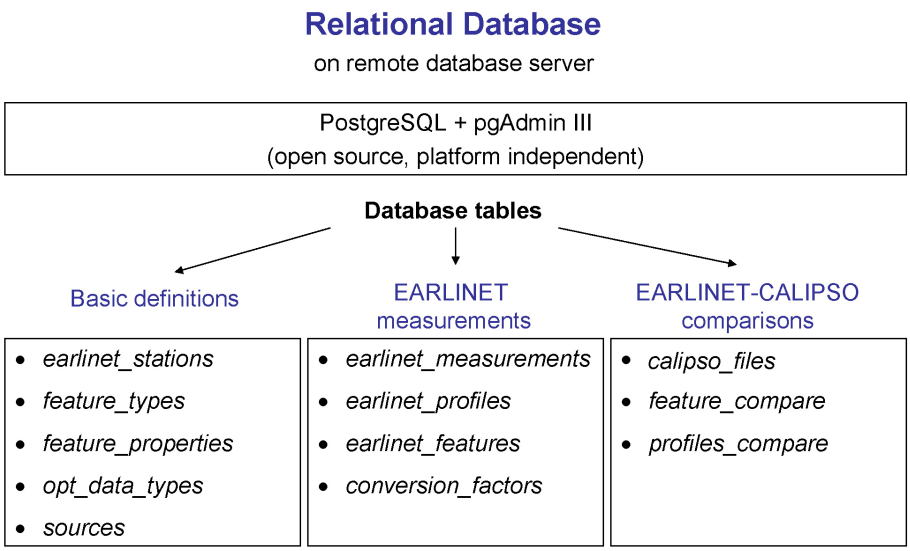

Figure 2: Structure of the relational database for aerosol and cloud products.

The relational database is maintained by the Leibniz Institute for Tropospheric Research, Leipzig, Germany. It is based on open-source software (PostgreSQL) and allows platform-independent access. A graphical user interface (pgAdmin III) is provided. External files are stored in NetCDF and HDF formats. The database is open for scientific use.

3. Major findings

The exploitation of the database was focused on two major aspects. First, the large number of EARLINET observations was used to develop a classification scheme of aerosols over Europe and to determine the respective type-dependent conversion factors. Second, based on the comparison of correlative EARLINET and CALIPSO observations, the representativeness of satellite cross sections against network observations was investigated.

3.1. Aerosol classification

The occurrence of different aerosol types over Europe has been explored based on an in-depth investigation of more than 400 individual aerosol layers selected from measured profiles provided by 16 EARLINET stations. Each measurement has been inspected regarding quality (e.g., noise level) and the occurrence of distinct aerosol layers. For each selected layer, a transport simulation was performed to determine its origin, transport path, and age. Additional modeling tools and satellite products, e.g., fire maps, were used to cross-check the sources and to assign a pure aerosol type or an aerosol mixture for each layer.

In Fig. 3 the frequency of occurrence of different pure and mixed aerosol types is shown. In 28% of the cases, a pure aerosol type was assigned. For the remaining 72%, a mixing of different aerosol types could not be excluded. For the pure aerosol types, the majority is defined as polluted or clean continental aerosol. 21% of the layers were identified as Saharan dust and 11% as smoke. Clean marine conditions were found for 5% of the pure-type fraction (i.e. 1.4% of all layers). 6% of the layers of the pure-type fraction occurred in the stratosphere. In principle, all kind of mixtures of pure tropospheric aerosol types can occur over Europe as the analysis shows. Predominantly the mixed aerosols contain pollution and/or dust. The mixture of dust, pollution, and marine aerosol is most frequently obtained. This can be explained with the large number of measurements contributed by stations in the Mediterranean (see Fig. 1).

Even if clean marine aerosol is found seldom, a marine influence cannot be excluded for many cases. It is caused by typical transport pattern from the North Atlantic or from the Sahara over the Mediterranean Sea toward Europe. For 76% of the layers a marine influence has at least to be taken into account. Pollution and dust occur in 59% and 53% of the layers, respectively, in either pure or mixed state. It should be noted that, with the tools applied here, it is estimated whether the presence of a certain aerosol type is likely or not. It is not possible to determine the absolute contribution of different aerosol types to a mixture.

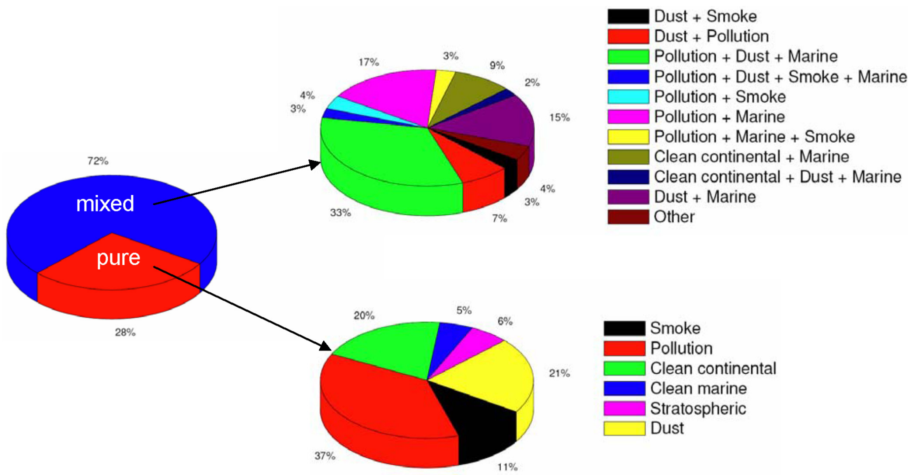

Figure 3: Frequency of occurrence of pure and mixed aerosol types as obtained from the aerosol-layer analysis. Left: fraction of layers containing either pure or mixed aerosols. Lower right: distribution of smoke, pollution, clean continental, clean marine, and dust aerosol within the fraction of pure aerosol types. Upper right: distribution of different mixtures within the fraction of mixed aerosols.

The statistical exploitation of 400 aerosol layers from the long-term database already provides a valuable insight into the benefits and limits of aerosol typing schemes for space-borne lidar missions. One of the core results is presented in Fig. 4. This plot shows a two-dimensional distribution of aerosol types in terms of the 1064-to-532 nm color ratio as measured with CALIOP versus the 355-nm-lidar ratio as measured with ATLID. Big color dots stand for the pure aerosol types, whereas smaller dots represent the mixtures discussed in the previous section. Colored lines indicate which pure types contribute to the mixtures.

A very interesting result which becomes clear from Fig. 4 is that the pure types of smoke, dust, pollution, and marine aerosol define the corner points of this two-dimensional distribution and that all mixtures lie on nearly straight connecting lines between their constituents. Such a clear behavior is not necessarily expected, because particles can be mixed in different ways, externally or internally. In the case of internal mixtures, the individual properties of the constituents are not conserved and optical parameters may completely change. For instance, when discussing the aging (and thus mixing) of dust during transport, it is often assumed that soluble substances (e.g., sea salt or organic matter) condensate on the dust particles and produce a coating. In such a case the particles would grow, change their absorption properties, and probably lose their non-spherical shape, so that it is not very likely that the optical parameters of the mixture remain on a straight line in between those of the constituents. If we can neglect the internal mixing and presume the dominance of external mixing when airmasses cross different source regions, we can work with probability density functions to describe the state of mixing of the aerosol, i.e. we can define “trajectories” between pure aerosol types in a multi-dimensional parameter space on which the mixtures occur. Further discussion on aerosol classification and findings for conversion factors is provided in the Final Report of the study (Wandinger et al., 2011).

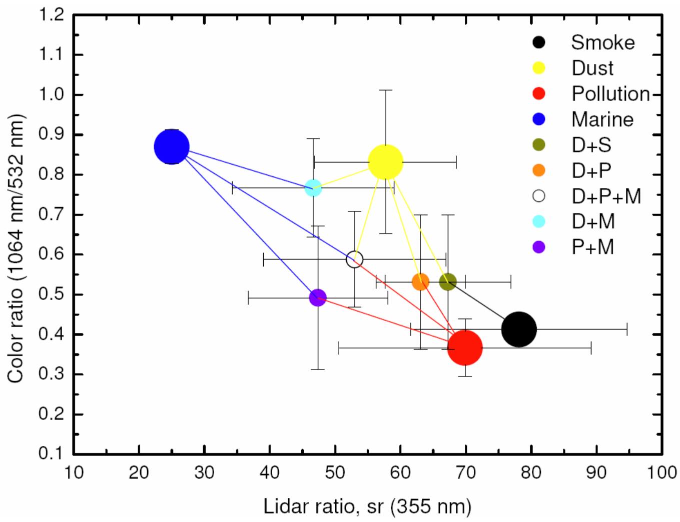

Figure 4: Relation between color ratio (1064/532 nm) as measured with CALIOP and lidar ratio at 355 nm as measured with ATLID for pure and mixed aerosol tpyes derived from the long-term database.

3.2. Representativeness study

In order to study the representativeness of CALIPSO observations in space and time, comparisons of CALIPSO and EARLINET backscatter measurements at 532 nm have been performed for a fixed maximum distance and different time shifts as well as for a fixed time shift and different horizontal distances. In this way, we can provide an estimate of the typical scale-length for aerosol spatial and temporal variability. Fig. 5 shows results obtained in a large Saharan dust plume observed in May 2008. Good correlation between EARLINET and CALIPSO observations with a correlation coefficient of 0.9 was found for horizontal distances below 100 km and time shifts of less than 10 min. The correlation coefficient drops to 0.76 for distances between 100 and 200 km and continues to decrease with the increase of the horizontal distance between the CALIPSO and EARLINET observations. More details can be found in the paper by Pappalardo et al. (2010) and in the Final Report of the study (Wandinger et al., 2011).

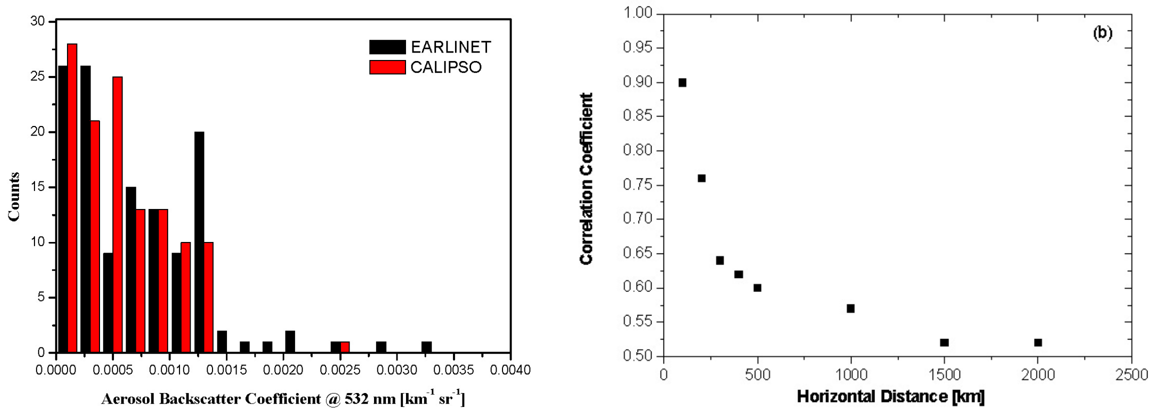

Figure 5: Left: Count distribution of EARLINET and CALIPSO measured values of aerosol backscatter coefficient at 532 nm for distances <100 km and time shifts <10 minutes. Right: Correlation coefficient between CALIPSO and EARLINET backscatter count distributions for time shifts <10 minutes and different horizontal distances of the observations.

4. Spin-off results and additional investigations

The eruptions of several volcanos in the North Pacific between July 2008 and September 2009 initiated an unexpected focus of the study on the properties of volcanic aerosol layers in the upper troposphere and lower stratosphere. These results have been published by Mattis et al. (2010).

An additional activity was triggered by discrepancies found between EARLINET and CALIPSO measurements of optical properties of Saharan dust. It could be shown that multiple scattering plays a role in spaceborne observations of large dust particles which leads to a significant bias in the derived optical depth for desert aerosol (Wandinger et al., 2010).

An extension of the study became necessary because of a major change in the CALIPSO data evaluation strategy in 2009. On 16 February 2009 the CALIPSO payload shut itself down due to low laser energy, a few weeks before the planned switch to the backup laser. EARLINET stopped correlative observations at that time. On 9 March 2009 the CALIPSO backup laser was turned on and successfully tested and aligned. CALIPSO has been operating in data acquisition mode with the backup laser nearly continously since 18 March 2009. EARLINET restarted correlative measurements immediately on 18 March 2009. However, at that time the CALIPSO Science Team decided that both Level 1 and Level 2 data from the backup laser will be processed with the new Version 3 code only. The delivery of Version 2 data used in the study so far was completely stopped. Unfortunately, because the new code was still in the test stage, it took a rather long time until CALIPSO data became available again. Level 1 Version 3 data have been published in November 2009, Level 2 Version 3 data which are most essential for the study became available at the end of May 2010 only. An even longer break occurred in the delivery of the EARLINET subset of data which had been directly transferred according to a bilateral agreement between NASA and EARLINET until February 2009.

The change in the CALIPSO data evaluation procedures caused not only a delay, but had several other consequences for the study. First of all, new hardware and software had to be implemented in order to handle the comprehensive Version 3 data sets. Because of the storage limitations of the EARLINET data archive hosted at the Max Planck Institute in Hamburg, a completely new and specifically designed archive was implemented at CNR–IMAA. The automatic upload of CALIPSO data from NASA could finally be completed in 2011. Although limited by these technical constraints, we had the opportunity to perform first comparisons and investigate changes and improvements of the new CALIPSO data release. In particular, working on the dust case observed in May 2008 for which also a representativeness study was performed on Version 2 data (see Fig. 5), we could investigate the utility of aerosol profiles with 5 km horizontal resolution provided in the Version 3 release. Details can be found in the Final Report of the study (Wandinger et al., 2011).

5. Recommendations and further developments

5.1. Recommendations for EarthCARE and ADM algorithm development

One aim of the study was to provide recommendations with specific view on ongoing and future algorithm developments related to ESA's EarthCARE and ADM missions. In the course of the study, we gained experience with CALIPSO data which have been very useful in this context.

From the EARLINET–CALIPSO comparison studies we found that cloud-aerosol discrimination is a very critical issue. Problems occur in particular for thick dust layers and thin ice clouds (with optical thicknesses of the order of 1–2), because these targets exhibit very similar optical properties. Thus reliable aerosol-cloud discrimination should consider not only optical data but a multitude of parameters, i.e. lidar-derived products, auxiliary data, and geographical constraints.

Conversion factors can only be applied based on a common and reliable aerosol classification for different spaceborne missions, i.e., a common typing scheme for CALIPSO and EarthCARE is required. We have shown that, in principle, it is possible to distinguish major aerosol types with ATLID in the same way as with CALIOP, even if a different set of parameters is used in the classification (see Fig. 4). Thus we recommend the development of an ATLID aerosol classification scheme which uses the same pure aerosol types as the CALIPSO algorithm. However, we have also demonstrated that aerosol mixtures play an important role. Therefore, we recommend to consider aerosol mixtures in a more sophisticated way than in the CALIPSO algorithm, e.g., by using probability density functions in a multi-parameter space.

We have found that multiple scattering is an issue, not only for clouds but also for aerosol, in particular mineral dust. The consequences for extinction and optical depth retrievals have to be studied carefully with view on the ATLID algorithm developments. Aerosol typing becomes a new relevance in context. The identification of dust and the quantification of the dust content in mixed aerosol is an important task. Dust identification mainly relies on the measurement of the particle depolarization ratio, which thus has to be derived with care. The knowledge on microphysical particle properties—multiple-scattering effects are controlled by the particle size—has to be improved. Studies with multiwavelength lidars and the inversion of particle microphysical parameters are very valuable in this context.

The CALIPSO layer approach obviously leads to uncertainties and an underestimation of aerosol load. Aerosol layers which are clearly seen in Level 1 data often do not appear in Level 2 products. The aerosol layer detection often suffers from apparent layer lower boundaries caused by strong attenuation. Even if the situation has remarkably improved with the release of the CALIPSO Level 2 Version 3 data—the algorithm is forced now to derive parameters from the lowest identified layer down to the ground—, we believe that this issue would need further investigation. In contrast to CALIPSO, for ATLID a profile approach is foreseen, i.e. Level 2 products will be delivered as closed profiles from the top of the atmosphere to the ground. Layer products will be retrieved in addition. It has to be studied, which consequences the different approaches have with view on the conversion and comparability of products from the different missions.

Appropriate horizontal averaging is a critical aspect regarding aerosol detection. CALIPSO aerosol profile data in Level 2 Version 2 products are provided with 40 km resolution. Level 2 Version 3 products have 5 km resolution, but up to 80 km horizontal averaging is used for the layer detection. ATLID data are planned to be provided with 10 km horizontal resolution, probably with a downscaling to 1 km, but horizontal averaging of the order of 100 km will be required to detect thin aerosol layers as well. Also here, the consequences for reliable conversion schemes and the comparability of the products have to be studied.

With respect to ALADIN, it has to be stated that the concept developed in this study cannot be directly applied. Because ALADIN is primarily designed for wind measurements, the instrument has several drawbacks for aerosol and cloud detection. ALADIN transmits circular-polarized light. Only the co-polar component of the backscattered light is detected. This will cause a systematic underestimation of the backscatter coefficient for depolarizing targets, i.e. ice clouds and dust/soil/ash-containing aerosols. There is not much experience in the measurement of circular depolarization ratios with ground-based instruments. From scattering theory, a relationship between linear and circular depolarization is known, which holds for symmetric particle shapes and random orientation and allows the conversion of the linear depolarization ratio to the circular depolarization ratio. If we consider typical linear depolarization ratios of 0.4–0.6 for cirrus clouds and 0.35 for large dust and ash particles, we find circular depolarization ratios of 1.3–3 for ice clouds and 0–1 for aerosols, i.e. the cross-polar component can be up to three times higher than the co-polar component in ice clouds. Therefore, ALADIN will underestimate the backscatter coefficient by 50% to 75% in ice clouds and by up to 50% in dust/ash-containing aerosols. Extinction measurements are not influenced by depolarization effects. Thus the extinction-to-backscatter ratio (lidar ratio) will be overestimated by the same factor by which the backscatter coefficient is underestimated, i.e. neither the depolarization ratio nor a trustworthy value of the lidar ratio is measured. Therefore, aerosol typing and ice/water discrimination after the methods discussed and applied in this study will practically not be possible with ALADIN. Vice versa, because such information is missing, empirical corrections of the polarization losses will be very difficult. This problem could only be overcome when supplementary information, e.g., aerosol typing from independent observations with other sensors, would be used.

5.2. Recommendations for future improvements and use of the database

The long-term aerosol and cloud database developed in this study is fed with data from a continental European network so far. Therefore, it lacks information content on aerosol properties in other regions of the globe. In particular, data of clean marine aerosol, continental pollution in Eastern and Southeastern Asia, Asian dust, and tropical and sub-tropical biomass-burning aerosol are required to cover major aerosol sources not considered in the database so far. Observations with multiwavelength lidars to derive conversion factors are available from a number of field experiments and targeted observations performed by partners of this study over the past 15 years. The majority of data from these campaigns has been carefully evaluated and the results are published in the literature. The quality of the data is proven and their implementation in the long-term database would be possible without any risk. Correlative CALIPSO observations are available for all campaigns performed after June 2006.

In April–May 2010, EARLINET has monitored the dispersion of the Eyjafjallajökull ash plume over Europe. The respective data set has been evaluated with high priority and would be available for implementation in the long-term database as well. Volcanic ash is listed as one of the pure aerosol types, but no data are stored in the database yet.

Deficiencies also exist regarding quantitative observations of the particle linear depolarization ratio and its wavelength dependence. Simultaneous and well-calibrated measurements at the ATLID and CALIPSO wavelengths of 355 and 532 nm, respectively, are available from the Saharan Mineral Dust Experiments SAMUM 1 and 2. Dedicated activities to improve depolarization-ratio observations and to establish a more comprehensive data set for different aerosol types are highly recommended. With respect to ALADIN, an in-depth investigation of the relationship of circular and linear depolarization ratios is of interest as well.

Only a limited number of cloud observations are included in the database so far. Clouds are highly variable in space and time. For most EARLINET stations the distance to the closest CALIPSO ground track is of the order of 20–40 km. Thus correlative cloud observations are hard to realize and often not representative. Furthermore, the different observation geometries from space and ground prevent quantitative comparisons of cloud properties in many cases. Optically thick clouds are not penetrated by the laser beam. Thus the cloud properties can be investigated either near the cloud base with the ground-based lidar or near the cloud top with the spaceborne system. Multiple scattering effects influence ground-based and spaceborne cloud measurements in different ways. Also depolarization observations are ambiguous, because most EARLINET lidars are vertically pointing whereas CALIOP is pointing off-nadir. Targeted measurements in the vicinity of the satellite track together with a dedicated observation and data evaluation strategy, probably in combination with other instruments such as cloud radars, are required for an in-depth cloud comparison study in the future.

With the release of CALIPSO Level 2 Version 3 data, aerosol and cloud products became available with higher resolution, better data quality, and higher information content. The potential of the new data release could not be fully exploited yet, and the database has to be improved in this context. Furthermore, the new CALIPSO Lidar Level 3 Aerosol Profile Product has been released in December 2011. This product reports monthly mean profiles of aerosol optical properties on a uniform spatial grid at altitudes below 12 km. It provides the opportunity to perform representativeness studies for spaceborne and ground-based observations on the basis of climatological mean values in the future.

Even if the long-term aerosol and cloud database requires further efforts and input in the future, it represents a valuable tool for a variety of investigations already now. The database has been used in the ESA study VRAME (Vertically Resolved Aerosol Model for Europe from a Synergy of EARLINET and AERONET data) to derive characteristic aerosol optical properties that shall be implemented in an aerosol model used for atmospheric corrections in ocean-color retrievals. Furthermore, the database has been made available for the ESA project LIVAS (Lidar Climatology of Vertical Aerosol Structure for Space-Based Lidar Simulation Studies). This project will also help improving the database by contributing new data sets.

6. References

Mattis, I., et al. (2010), Volcanic aerosol layers observed with multiwavelength Raman lidar over central Europe in 2008–2009, J. Geophys. Res., 115, D00L04, doi:10.1029/2009JD013472.

Pappalardo, G., et al. (2010), EARLINET correlative measurements for CALIPSO: first intercomparison results, J. Geophys. Res., 115, D00H19, doi:10.1029/2009JD012147.

Wandinger, U., M. Tesche, P. Seifert, A. Ansmann, D. Müller, and D. Althausen (2010), Size matters: Influence of multiple scattering on CALIPSO light-extinction profiling in desert dust, Geophys. Res. Letts., 37, L10801, doi:10.1029/2010GL042815.

Wandinger, U., A. Hiebsch, I. Mattis, G. Pappalardo, L. Mona, and F. Madonna (2011), Aerosols and Clouds: Long-term Database from Spaceborne Lidar Measurements, Final Report, ESTEC Contract 21487/08/NL/HE, 235 pp.