Atmospheric
Measurement
Techniques
Discussions

EARLINET: towards an advanced sustainable European aerosol lidar network

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Abstract

The European Aerosol Research Lidar Network, EARLINET was founded in 2000 as a research project for establishing a quantitative, comprehensive and statistically significant database for the horizontal, vertical, and temporal distribution of aerosols on a continental scale. Since then EARLINET is continuing to provide the most extensive collection of ground-based data for the aerosol vertical distribution over Europe.

This paper gives an overview of the network's main developments since 2000 and introduces the dedicated EARLINET special issue which reports on the present innovative and comprehensive technical solutions and scientific results related to the use of advanced lidar remote sensing techniques for the study of aerosol properties as developed within the network in the last thirteen years.

Since 2000, EARLINET has strongly developed in terms of number of stations and spatial distribution, from 17 stations in 10 countries in 2000, to 27 stations in 16 countries in 2013. EARLINET has strongly developed also in terms of technological advances with the spread of advanced multi-wavelength Raman lidar stations in Europe. The developments for the quality assurance strategy, the optimization of instruments and data processing and dissemination of data have contributed to a significant improvement of the network towards a more sustainable observing system, with an increase of the observing capability and a reduction of operational costs.

Consequently, EARLINET data have already been extensively used for many climatological studies, long-range transport events, Saharan dust outbreaks, plumes from volcanic eruptions and for model evaluation and satellite data validation and integration.

Future plans are in the direction of continuous measurements and near real time data delivery in close cooperation with other ground-based networks, as in the ACTRIS research infrastructure, and with the modelling and satellite community, bridging the research community with the operational world towards the establishment of the atmospheric part of the European component of the integrated global observing system.

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1 Introduction

At present, the atmospheric aerosols are considered one of the major uncertainties in climate forcing (Forster et al., 2007; Boucher et al., 2013), and a detailed aerosol characterization is needed in order to understand their role in the atmospheric processes as well as on human health and environment. The major cause of uncertainty is the large variability in space and time. Due to their short lifetime and strong interactions, their global concentrations and properties are poorly known. For these reasons, information on the large scale 3-dimensional aerosol distribution in the atmosphere should be continuously monitored.

It depends strongly on the scientific objective which aerosol parameter must be observed and which resolution and accuracy is required. For example, for radiative studies it is useful to measure aerosol optical properties, whereas for studies on the impact on the environment and health, it is more relevant to investigate aerosol microphysical properties. Specifically for climate studies related to aerosol-clouds-radiation interaction, it is necessary to measure aerosol optical properties, size, morphology and composition as a function of time and space, with high resolution in both domains to account for the large variability. Since it is in particular the information on the vertical distribution that is lacking, advanced laser remote sensing is the most appropriate tool to close the observational gap.

Lidar techniques represent the optimal tool to provide range-resolved aerosol data. Several lidar techniques are suitable for aerosol studies and in the last ten years rapid progress in laser technology, measurement techniques, and data acquisition systems have contributed to a much wider use of these techniques for aerosol monitoring ranging from the simple elastic backscatter lidar to the most advanced multi-wavelength Raman lidar systems.

In case of an elastic backscatter lidar, the detected wavelength is identical to the transmitted wavelength, and the magnitude of the received signal at a given range depends on the backscatter cross section of scatterers and the transmission along

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the path to that range (Weitkamp, 2005). Typical operating wavelengths are 355, 532, 1064 nm. The typical product of a backscatter lidar is the vertical profile of the aerosol backscatter coefficient obtained by assuming a lidar ratio, i.e. the aerosol extinction-to-backscatter ratio. It is necessary to underline that without an a-priori assumption about the lidar ratio, this kind of lidar systems cannot provide quantitative aerosol backscatter data. The Raman lidar (Ansmann et al., 1990, 1992) or High Spectral Resolution lidar (HSRL) (Shipley et al., 1983) techniques overcome this difficulty by providing independent aerosol extinction and backscatter coefficient measurements. Vertical profiles with high resolution provided by these lidars allow the optical characterization of atmospheric aerosol layers in the planetary boundary layer (PBL) as well as in the free troposphere. The aerosol characterization can be further improved by the use of multi-wavelength Raman lidar equipped with depolarization channels and by combination with passive radiometry, e.g. sun photometers. These data can be inverted to provide information about aerosol microphysical properties such as size, shape, refractive index, effective radius (Müller et al., 1999, 2004; Veselovskii et al., 2002, 2012; Böckmann et al., 2005; Gasteiger et al., 2011). Lidar observations can be even more beneficial if used in coordinated networks. They are fundamental to study aerosols on large spatial scale and to investigate transport and modification phenomena, when combined with appropriate atmospheric transport models. These arguments were the motivation for the establishment of EARLINET, the European Aerosol Research Lidar Network (Bösenberg et al., 2001a, 2003) in the year 2000.

This special issue aims at giving an overview of the achievements of EARLINET in the last thirteen years. It includes the presentation of innovative and comprehensive technical solutions, and scientific results related to the use of advanced lidar remote sensing techniques for the study of aerosol properties. Major topics addressed in this special issue include quality assurance methodologies and tools, calibration techniques, technological solutions for the optimization of lidar system design, advanced and sustainable data processing system, new algorithms for the retrieval of aerosol

properties, and the assessment of different lidar techniques and systems for providing quantitative aerosol information.

This introductory paper presents specific networking topics that are not covered in the individual papers of this special issue. In particular, the EARLINET network and its main developments in the last thirteen years are presented in Sect. 2. Section 3 presents the fundamental activities, which are the basis for the establishment and achievements of the EARLINET network towards a sustainable observation system. Section 4 provides a selection of relevant scientific results obtained using the EARLINET data. A summary with an outlook and brief description of future plans concludes this paper.

2   EARLINET overview

EARLINET (www.earlinet.org) was established in 2000 (Bösenberg et al., 2001a, 2003) as a research project funded by the European Commission, within the 5th Framework Program, with the main goal to provide a comprehensive, quantitative, and statistically significant data base for the aerosol distribution on a continental scale. After the end of this three-year project, the network activity continued based on a voluntary association. The objectives of the association, as reported in the EARLINET Constitution and Bylaws (EARLINET General Assembly in Matera, 2004, www.earlinet.org), are to promote cooperation and discussion in Europe among scientists concerned with studies of aerosol remote sensing by means of lidars and to promote and encourage the development of any or all of the relevant sciences. The network activity continued successfully and in 2006 the five-year EC Project EARLINET-ASOS (Advanced Sustainable Observation System) started on the basis of the EARLINET infrastructure.

The main objectives of the EARLINET-ASOS project were:

– To extend the development of the European Aerosol Research Lidar Network as a world-leading instrument for the observation of the 4-dimensional

spatio-temporal distribution of aerosols on a continental scale, resulting in accurate, well-defined, and easily accessible data products for use in science and environmental services.

- To enhance the operation of the network to foster aerosol-related process studies, validation of satellite sensors, model development and validation, assimilation of aerosol data into operational models, and to build a comprehensive climatology of the aerosol distribution.

These objectives were achieved by defining and using common standards for instruments, operating procedures, observational schedules, data processing including advanced retrieval algorithms, and dissemination of data. The EARLINET-ASOS project strongly contributed to optimize the operation of the network. EARLINET is now integrated in the FP7 EU research infrastructure project ACTRIS (Aerosols, Clouds and Trace gases Research InfraStructure Network, www.actris.net) that will, for the first time, provide coordinated observations of the major atmospheric variables.

In the first thirteen years of its existence, EARLINET has strongly increased its observing capacity. Currently, EARLINET is composed of 27 active stations; a station is considered active when submitting aerosol extinction and/or backscatter coefficient profiles to the EARLINET database. Furthermore, six stations are members of EARLINET but not currently contributing either because they are newly admitted stations, with instruments not yet ready or undergoing quality assurance tests, or because they are facing operational problems. Figure 1 shows the geographical distribution of today's active EARLINET stations.

The stations can be classified in the following categories according to their capabilities:

1. Multiwavelength Raman lidar stations (red dots on Fig. 1) that combine elastic and N_2 Raman channels, complying with the so-called "EARLINET core stations" (Pappalardo et al., 2011) of a minimum of three elastic channels (corresponding usually to the 1064 nm fundamental wavelength of the Nd:YAG laser, and to

the wavelengths of the second and third harmonics, at 532 nm and 355 nm respectively) and two Raman channels, shifted 2330 cm^{-1} down the excitation frequencies (usually at 607 nm and 387 nm wavelengths), corresponding to the Q, O, S branches of the N_2 vibro-rotational Raman spectrum. For these systems, the combination of three backscatter-coefficient profiles and two extinction-coefficient profiles obtained without resorting to an assumed lidar ratio (3+2 configuration) allows advanced aerosol typing, able to provide, in addition to lidar ratio and Ångström exponents, range-resolved microphysical properties of the aerosols, such as particle effective radius, radius distribution, volume concentration and refractive index (Böckmann, 2005; Müller et al., 1999, 2004; Veselovskii et al., 2002).

2. Raman lidar stations (green dots on Fig. 1), which operate at least one Raman channel permitting to retrieve extinction-coefficient profiles without assumptions. They allow the determination of the lidar ratio, gaining useful information on the aerosol type.

3. Backscatter lidar stations (violet dots on Fig. 1), without Raman channels, which must rely on an estimate of the lidar ratio to retrieve the backscatter and extinction coefficient profiles.

Furthermore, 17 EARLINET stations operate depolarization channels (∥⊥ symbol on Fig. 1) that measure the depolarization of the emitted linearly polarized radiation, yielding as a product the aerosol particle linear depolarization ratio which enhances the aerosol typing capabilities by providing information on the particle shape.

In addition, 20 EARLINET stations are collocated with AERONET sun-photometers (sun symbol on Fig. 1), which allows the synergetic exploitation of lidar and sun-photometer data at daytime, thus providing range-resolved information to the otherwise column-integrated sun-photometer products. Table 1 summarizes the locations and capabilities of the EARLINET stations.

The exchange of expertise fostered by EARLINET since its inception in 2000, together with specific efforts to optimize the instruments, in particular in the framework of the EARLINET-ASOS project, has been paramount in achieving the present status of the network. The development of the characteristics of the instruments is described in Fig. 2a and b. At the start of EARLINET, backscatter lidars, some of them multi-wavelength, were predominant in the network. Within the EARLINET-ASOS project most of the backscatter lidars were first upgraded to single wavelength Raman lidars, and finally towards multi-wavelength Raman lidars that currently form the most frequent class. As to the depolarization-measurement capabilities, the number of systems featuring depolarization channels has grown from 2 in the year 2000 to 17.

3   EARLINET pillars

The overarching EARLINET pillar is the systematic performance of lidar observations. EARLINET observations are performed on a regular schedule of one daytime measurement per week (Monday) around noon, when the PBL is usually well developed, and two night-time measurements per week (Monday and Thursday), with low background light, in order to perform Raman extinction measurements. In addition to these systematic measurements for the consolidation of a European aerosol climatology, further observations are devoted to monitor special events over the continent, such as Saharan dust outbreaks, forest fires, photochemical smog and volcanic eruptions. Moreover, EARLINET started correlative measurements during CALIPSO, the NASA-CNES satellite mission "Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation", overpasses on 14 June 2006, during the commissioning phase of CALIOP, the CALIPSO lidar (Winker et al., 2009). A strategy for correlative measurements has been defined on the base of the analysis of the ground track data provided by NASA (Pappalardo et al., 2010).

EARLINET measurements must meet stringent stability and absolute accuracy standards to achieve the desired confidence in aerosol radiative forcing needs, thus the

network has developed a rigorous quality assurance program addressing both instrument performance (Matthias et al., 2004a; Freudenthaler et al., 2010) and evaluation of the algorithms (Böckmann et al., 2004; Pappalardo et al., 2004a). These operation pillars have been developed to ensure instrument standardization and consistent lidar retrievals within the network in a standardized data exchange format and are described in the following sections.

3.1   Quality assurance

Homogeneous and well established data quality is one of the key conditions for the combined use of data originating from different systems. Because the establishment of a joint dataset and its use in comparative studies are major objectives of EARLINET, specific attention is given to data quality assurance. The EARLINET Quality Assurance (QA) program has been developed for both hardware and retrieval algorithms and it is based on intercomparisons and quality check tools developed ad hoc.

EARLINET consists of quite different lidar systems regarding the number of measured wavelengths and signal channels, the detection range, which is mainly determined by laser power and telescope size and number, the optical design and the electronic signal detection techniques. Reasons for this variety are that lidar systems are quite expensive, mostly developed by research groups with different backgrounds, aims, and financial capabilities, and that expensive technical improvements often can be implemented only part by part and gradually over years. Such different systems contain many different systematic error sources. Furthermore, a lidar system consists of several parts or sub-systems which contains mainly an optical part comprising the laser beam, telescope, and beam-splitting and -shaping optics, and an electronic part comprising the detectors and data acquisition including the trigger electronics of the laser, and the signal analysis part, which consist of the software. Each part contains its individual errors, that may often not be discerned from each other, making a systematic error analysis and consequential system improvement very difficult.

The goal of the EARLINET QA program was to improve this situation wherever possible and to homogenize the different approaches of the individual research groups towards common quality criteria for the lidar products in the EARLINET data base. Several papers of this special issue describe the different aspects of this effort.

As an overall calibration is not possible, methods and tools have been collected and developed to determine deviations on subsystem levels, and to identify and assess the impact of critical subsystems by means of analytical methods. Freudenthaler et al. (2014) describes mandatory quality checkups for each lidar system, some of which have to be performed regularly every year, some only once, in order to assess the performance and the temporal stability of a lidar system.

One-time checkups are the test of the accuracy limits of the analog detection systems due to signal-induced distortions by means of a specialized electronic lidar test-pulse generator developed in the framework of EARLINET, and the trigger-delay test, with which the accuracy of the zero-range for the range correction can be determined. The latter is important because extreme errors of the retrieved optical properties in the near range are introduced, if the zero-range is wrong by a few meters. Checkups, that have to be performed every year in order to verify the long-term stability of a lidar sytems, are the dark measurement, the telecover test, and the Rayleigh fit. The dark measurement records all signal components other than atmospheric returns and reveal systematic and random electronic signal interspersion, e.g. from the trigger system or other electronic equipment. The telecover test checks the consistency of the range dependent transmission of the optical receiver by comparing the signals acquired by different parts of the receiving telescope. Differences are a relative measure for the range dependency of the overlap function and can be used to estimate the optical part of the lidar signal uncertainty especially in the near range. The far range lidar signal can be calibrated with a fit to the so-called Rayleigh signal; a signal calculated from the height dependent molecular density of the atmosphere, which is best determined by coincident and co-located radiosonde data. For this test it has to be assumed that

the height range where the calculated and the measured signals are compared is free of aerosols and clouds.

Systematic errors in lidar signals often stem from an inaccurate optical design of the receiver optics or from imperfect optical parts like dichroic beam-splitters. The impact of such flaws and possible improvements have been investigated with optical raytracing (Freudenthaler et al., 2014) and by means of the Müller–Stokes formalism (Freudenthaler, 2014). Optical raytracing helps to determine the theoretical limits of the optical design of lidar receivers, especially regarding the range dependent transmission (overlap function). It showed that the design of many optical receivers are close to the theroetical limits, which don't leave margins to tolerate inevitable thermal and mechanical instabilities and optical alignment inaccuracies.

The polarization-sensitive transmission (diattenuation) of inclined optical parts in the receiver optics, like beam-splitters, mirrors, and filters, which has been generally neglected in the past, causes systematic errors in all lidar signals (Mattis et al., 2009; Freudenthaler et al., 2009). Especially polarization sensitive lidar systems suffer from this effect. A rigorous treatment of this effect with the Müller–Stokes formalism is presented in Freudenthaler (2014), Bravo-Aranda et al. (2014), and Belgante et al. (2014) present experimental examples and results of the application of this theory.

The final quality check of an EARLINET lidar is the direct comparison with a reference lidar system. Since the beginning of EARLINET, several direct lidar comparisons have been performed, and from the outcome the best lidar systems have been selected as reference systems. A requirement for that wasg that such a reference system must be mobile to be transported to other stationary lidar systems for comparison, and that it comprises a minimum number of wavelengths. These reference systems were checked against each other during EARLI09 (EArlinet Reference Lidar Intercomparison 2009) in Leipzig/Germany in 2009 (Wandinger et al., 2014). The results from a similar comparison campaign in the first stage of EARLINET are presented in Matthias et al. (2004a).

The EARLINET QA program for retrieval algorithms is mainly based on inter-comparison exercises of aerosol backscatter lidar and Raman lidar algorithms used by the different groups. These intercomparisons are based on synthetic lidar signals simulated ad hoc in order to test the correctness of the algorithms and the influence of the lidar ratio profile, the reference value and the temperature and pressure profiles on the retrieved backscatter and extinction coefficient profiles (Böckmann et al., 2004; Pappalardo et al., 2004a). Moreover synthetic lidar signals, both elastic and Raman, are also used by each group for testing new algorithm development as an internal quality assurance tool.

However, the different methods used to analyze and invert lidar signals into aerosol optical properties such as extinction and backscatter coefficients, lidar ratios and de-polarization ratios, use mathematical techniques with different spatial filter techniques and approximations, and hence introduce additional random or systematic differences from each other and errors. To avoid inconsistencies in the signal inversion and the error calculation, and to automate the evaluation process a common data scheme, the so called Single Calculus Chain (SCC), was developed in the frame work of EARLINET (D'Amico et al., 2014a, b; Mattis et al., 2014). The paper by Amodeo et al. (2014) presents the consolidated error calculation used in the SCC.

3.2 Optimization of instruments

A further pillar of the EARLINET network is the homogenisation and optimization of the performance of the contributing lidar systems. Increasing performance will enable the network to provide data of better quality and a larger number of delivered parameters. In addition, standardization of systems leads to improved interoperability in future networks and in a more general integrated observing system.

The key elements for the instrument development are:

- Optimal performance for the main data products of the lidars for aerosol profiling: i.e. profiles of aerosol backscatter coefficient, aerosol extinction coefficient and

lidar ratio. The minimum recommendation is to add a nitrogen Raman channel to a backscatter lidar. For a candidate EARLINET core station the implementation of a multi-wavelength Raman lidar is recommended.

- Daytime performance: aerosol optical properties play their most important role during daytime. Aerosol characteristics can change in relatively short periods of time, e.g., the lidar ratio obtained during night-time measurements can significantly differ from daytime conditions. Therefore, daytime measurements of the aerosol optical properties are needed, that means that Raman lidars, which typically are operated during night time only, must be upgraded for daytime operation. Technical solutions to accomplish this were investigated in the framework of EARLINET.

- Increased operationality: as lidar measurements normally are quite expensive in terms of maintenance and man power, an increased automation in instrument control is urgently required so that more data for aerosol characterization will become available.

Contrary to some other atmospheric observation networks, such as MPLNET (mplnet.gsfc.nasa.gov) and AERONET (aeronet.gsfc.nasa.gov) that are largely based on standardised and even commercialised instruments, most EARLINET stations use lidar systems that were not series-produced. As an illustration, a few pictures of EAR-LINET lidars are shown in Fig. 3. Although the measurement principle is the same, these instruments vary in set-up and construction. As a consequence, the performance of the individual instruments can be significantly different, for instance with respect to the altitude range covered, the number of operating wavelengths or the integration time needed for the measurements to reach a sufficient signal to noise ratio.

The homogenisation of the network instruments was approached through a survey of the various solutions existing at individual stations, for the components and sub-systems. The specifications of the systems are compiled in detail in the "Handbook of Instruments" (HoI). It consists of more than a hundred parameters for each detection

channel including laser emitter parameters, such as the number of wavelengths and emitted power, as well as detailed information about the optical and geometrical configuration, such as the number of receiving telescopes, as well as parameters related to the optical and electronic detection for each channel of the lidar instrument. As a result, a detailed insight of the properties in each EARLINET lidar system can be obtained.

The individual systems are described in tables, giving the main system characteristics. Since it is not possible to list all parameters in this paper, a schematic of the setup of the HoI is presented in Fig. 4. As shown in Fig. 4, the tables are divided in several sections. First the identification of the lidar station and instrument is recorded. Next, the emitter is described. By putting columns side by side, it is possible to include more than one laser into the table and it is possible to see which type of laser(s) are used in the emitter and which wavelengths they produce, with which characteristics, related to the emitted beam, or sometimes multiple beams. The same approach is used for the receiver. It is not uncommon that two or more receiving telescopes are used by a single lidar system. The main characteristics of each telescope are tabulated followed by a section listing the detection channels. In some configurations the same wavelength is received by more than one telescope, so also multiple detection channels can be found for one wavelength. Next, the characteristics of the amplification and digitisation of the electrical signals from each detector are listed. Also, any change of the lidar system is uniquely documented. If necessary, the number of parameters can be expanded.

The final two sections in the table describe the mode of operation and which ancillary data is available at the measurement site. Although this is not directly related to the performance of the lidar instrument, it is quite important for the application of data and for the potential of synergistic approaches.

The HoI also contains essential information needed for data processing (e.g. photon counting deadtime, overlap function, etc.). It was therefore decided that the HoI is implemented as a relational database. Each configuration change is entered into the database including the date of implementation. In this way, each measurement is linked to the specific instrument configuration parameters which are needed for the

data processing. This system allows the tracking of the possible changes for a specific system, which is essential for consistent long-term data from a distributed network. An overview of technical solutions underlining the development of the network instruments as summarised in this section is given in an accompanying paper (Apituley et al., 2014).

3.3 Optimization of data processing

The optimization of data processing is based on the idea of developing a common and automatic processing calculus system for the evaluation of lidar data measured with the instruments operating within EARLINET, from raw signals to final products, i.e. profiles of optical properties, in particular aerosol backscatter and extinction coefficients.

A common calculus system for the network should allow uniformity in the data analysis, standardization of the data products format, control of the data's quality, assessment of the errors, near real time analysis and product provision. Moreover, it is a prerequisite for the sustainability of the network because it allows to increase the amount of available products and also to reduce the time needed for data analysis, both of routine measurements and during special but intensive observational measurement campaigns.

The concept for a common data processing system was initiated a few years after the constitution of EARLINET. During the EARLINET-ASOS project it became one of the main goals to reach, laying the foundations for its implementation and developing the first prototype (Amodeo et al., 2007). In the frame of the ACTRIS project finally an operational version is made available.

The development of the common processing calculus system, the SCC, can be considered as a real challenge because of the heterogeneous structure of a network as EARLINET. The main difficulty consisted in the fact that the instruments used by the individual groups are different. Differences exist for the wavelengths used, acquisition mode (analog and/or photon-counting), spatial resolution, and detection systems. Then, all the possible processing algorithms should be implemented and optimized in the EARLINET SCC.

The EARLINET SCC has been designed to be very flexible and is characterized by the following features:

- platform independence;

- open source philosophy;

- netCDF as standard data format;

- flexibility allowing the user to choose the retrieval procedure suitable for his/her own instrument;

- easy expandability allowing to handle data from new and upgraded lidar systems;

- operability both on a central single server accessible from web and on local server/PC.

The SCC allows us to retrieve, automatically and without any operator interaction, aerosol optical properties, such as extinction and backscatter coefficients, lidar ratio, optical depth, Ångström exponent if Raman lidar signals are available. In cases when elastic lidar signals only are used, backscatter and a backscatter-related Ångström exponent are derived.

The SCC as a whole is presented in more details in D'Amico et al. (2014a). Here only a brief outline is given. In general, the structure of the SCC consists of different modules:

- *The pre-processing module*: gets system specific parameters from the SCC database; checks if the raw data are from a lidar system that passed all the required instrumental quality checks; reads netCDF input raw lidar signals; performs several corrections and handlings on lidar signals; calculates molecular profile; provides time averaging depending on the product); and calculates the statistical error of pre-processed lidar signals. More details are given in D'Amico et al. (2014b).

- *The optical processing module* reads the intermediate netCDF file produced by the pre-processing module; gets information from the SCC database; performs analysis in a flexible way using the algorithm and analysis procedure selected by the user; retrieves aerosol extinction and backscatter profiles (and lidar ratio profiles); retrieves backscatter either from elastic lidar signal alone or from Raman and elastic signals, respectively; calculates the statistical error of extinction and backscatter coefficients; transfers output files to the EARLINET database in netCDF format according to the EARLINET rules. This is presented in details in Mattis et al. (2014).

- *The daemon software* organizes the batch mode of the different calculus modules (sending start/stop commands, handling of errors etc.).

- *The SCC data base*, is the tool where system specific parameters are stored.

- *The web interface* provides a front-end for the daemon software and for the relational SCC data base. This user interface allows the station manager to set system-specific parameters (e.g., used wavelengths), to upload the raw signals and to start the analysis.

In the future, the inclusion of a module for the retrieval of microphysical properties is also planned.

The EARLINET SCC structure has been designed in such a way that the optimization of data processing is strictly linked to the quality assurance. Raw lidar signals are accepted for analysis only if the corresponding lidar system has passed all the required quality checks, both at algorithm and instrument levels. This information is periodically updated in the SCC database. The SCC also includes tools to check the quality of the submitted raw signals. Thus, low-quality raw lidar signals (in terms, e.g., of signal-to-noise ratio, distortions, far-range dynamics) are not accepted for analysis.

Through the SCC database, the optimization of data processing is also linked to the optimization of instruments. The SCC database is directly linked to the HoI containing the information of the set-up parameters of the instruments. The optimization

of data processing takes into account also changes in parameters and configurations that come out from the observational and instrumental improvements produced by the research related to the optimization of instrument.

Of course, the optimization of data processing is also linked to the EARLINET database. The SCC products are automatically uploaded into EARLINET database and therefore the products must fulfill all the requirements for the database in terms of file name conventions, content, format, data quality flags, software version, etc.

3.4 Database

It is one of the central objectives of EARLINET to provide all internal and external users with a single location where they can access all data from all EARLINET stations in a homogeneous way. This has been accomplished by establishing the EARLINET data center at the Max-Planck-Institute in Hamburg since 2000; this datacenter is responsible for the collection of data from all the EARLINET stations and provision of access to the data through a web interface.

The EARLINET dataset covers the time period from April 2000 until today. To keep a maximum of data available, measurements from the preceding project "Deutsches Lidarnetz", a nationwide German lidar network (1997–2000) (Bösenberg et al., 2001b), have been added to the EARLINET data set.

All lidar data in the database are stored in netCDF format. Additional meta data is also provided in the netCDF files.

The user access to the database is realized using two different web pages. Logging in to the web page at http://data.earlinet.org provides the data maintenance. This page is only accessible for EARLINET data providers. It allows the users to upload new data, edit its meta-data and to remove datasets. Read-only access to the database is realized through the web portal at http://access.earlinet.org/EARLINET. Here EARLINET members as well as external users can search, download and plot information from the database.

3.4.1 Database content

The main information stored in the files of the EARLINET database is the vertical distribution of aerosol backscatter and aerosol extinction coefficients. The EARLINET database stores only quantitative information. Qualitative parameters like range corrected signals or graphical quick looks are not available. This kind of qualitative information is made available through the EARLINET website in case of specific events on request of end users as in the case of the Eyjafjallajökull volcanic eruption in 2010 (Pappalardo et al., 2013).

There are two types of files defined in the EARLINET database:

- The backscatter files (b-files). These files contain at least a profile of the aerosol backscatter coefficient $[m^{-1} sr^{-1}]$ derived from the elastic backscatter signal. This backscatter profile may be accompanied by an extinction coefficient profile. This extinction coefficient profile is not necessarily derived from Raman measurements. Any other method to derive the extinction profile may be used here.

- The extinction files (e-files). These files contain vertical profiles of aerosol extinction coefficient $[m^{-1}]$ and of aerosol backscatter coefficient retrieved independently from Raman lidars without a-priori assumptions on the existing relation between them. Also extinction coefficient profiles derived from high spectral resolution lidars are included here.

Additional to backscatter- and extinction coefficient profiles (and their statistical errors) there are more optional variables defined in the EARLINET format specification. These variables may be included into the b- (or e-) files. Among these parameters are the lidar ratio, the particle linear depolarization ratio and the water vapor mixing ratio profiles. Whenever available, these variables are accompanied by the corresponding error estimate. An example of primary EARLINET data from a core station (multiwavelength Raman lidar) is given in Fig. 5.

Each file in the EARLINET database can be assigned to one or more special groups of files (categories). This categorization can be used in the data selection to limit the access to a subset of files covering a specific event. The categories currently used in the database are: cirrus, climatology, diurnal cycles, volcanic eruptions, forest fires, photo smog, rural/urban, Saharan dust, stratosphere and CALIPSO.

3.4.2 Data publication scheme

EARLINET follows a very simple scheme for publication of data. This scheme only consists of three levels of data visibility.

1. The first level of data access is reached by just uploading new data to the central database. These data shall be uploaded to the database within three months after measurement. All EARLINET members can access these data immediately. These data are not visible to the public.

2. In the next step, the data are made public. All new data shall be made accessible to the public as soon as possible and at latest one year after the measurement. These "public" data get visible to registered external users who signed the "EARLINET data usage policy" agreement available at www.earlinet.org.

3. In the last step, the data are published in bi-annual volumes at the world data center for climate (WDCC). For this an approval process is applied to the data within two years after measurement. Data not passing this approval process are corrected in cooperation with the provider. Publication of the data and assignment of a digital object identifier (DOI) to the volumes makes them citable. This process also guaranties the permanent accessibility of the published data from the WDCC as a second source. At moment the publication of the first volume of the EARLINET database at the WDCC is in preparation.

3.4.3 User access

EARLINET members as well as external users get access to the database through a web interface. This web portal is accessible through a corresponding link on the EARLINET web page (www.earlinet.org) or directly through the link to http://access.earlinet.org/EARLINET. The access to this page is restricted and a username/password is required for login.

External users are required to (self-) register to the database system. The user has to sign the "EARLINET data usage policy" before access is granted. External users have access to all public data according to the data publication scheme. Access to the database has been opened in April 2010. Since then a slowly but steadily increasing number of users has registered for data access as it can be seen in Fig. 6a.

The system provides also a "search" form which allows entering search criteria to select a subset of data from the database e.g. Saharan dust outbreaks and plotting capabilities.

In addition to the data access at the EARLINET database, the public EARLINET data are also available through the ACTRIS data center at www.actris.net. Access to EARLINET data is also possible at the CERA database of the world data center for climate (WDCC) at http://cera-www.dkrz.de/WDCC/ui/Index.jsp.

3.4.4 Database status

The EARLINET database represents the largest collection of ground-based data of the vertical aerosol distribution on a continental scale. The database holds measurements performed by 30 groups since January 1998. Some of these groups are not active members of EARLINET anymore. Nevertheless, all data uploaded once are kept in the database.

From the beginning of the systematic collection of data from coordinated lidar measurements a total of 43 150 files (Fig. 6b) has been uploaded to the database. The very high number of files covering the period April/May 2010 is due to the almost continuous

observation of the volcanic outbreak of the Eyjafjallajökull on Iceland by nearly all stations of the network. Since April 2010 when the user web portal was made accessible to the public, more than 1.2 million files were downloaded from the database (Fig. 6c).

Most of the files available from the database have been assigned to at least one category. These categories label the measurements to be part of a bigger data set. Figure 7 reports the distribution of the EARLINET data files for the different categories. The climatological category is the most populated category with 19 855 data files corresponding to the systematic observations. The CALIPSO and Saharan dust categories are also well populated (8418 and 5808 data files, respectively). EARLINET correlative data for CALIPSO, together with the differences with corresponding CALIPSO level 2 layer and profile products, have also been collected in a specific relational database available at www.earlinet.org (Pappalardo et al., 2010; Wandinger et al., 2011). 3387 data files belong to the volcanic category; most of them are related to the Eyjafjallajökull volcano eruption in April/May 2010. EARLINET specific geometrical and optical properties related to the Eyjafjallajökull eruption are collected in a specific relational database, available at www.earlinet.org, which provides the volcanic mask over Europe for the whole event (Pappalardo et al., 2013). Data files are also in other categories: forest fires (1076 files), photosmog (112 files), urban/rural (2078 files) and stratosphere (820 files), which are also reported all together in "other" category in the Fig. 7.

3.5 Contribution to other networks and programs

A further important pillar of EARLINET is its cooperation with other observing networks and European and international programs. This cooperation will certainly increase with the time, some examples of the present state shall be briefly outlined in the following paragraphs.

Synergies with AERONET, using the co-location of most of the EARLINET stations with AERONET have been exploited for the retrieval of aerosol microphysical properties as discussed in details in Wagner et al. (2013), Granados-Muñoz et al. (2014), Chaikovsky et al. (2014) and Binietoglou et al. (2014).

EARLINET is a contributing network to GAW, the Global Atmosphere Watch program of the World Meteorological Organization (WMO) (www.wmo.int/pages/prog/arep/gaw/aerosol.html) and within this program is strongly contributing to the implementation of GALION, the GAW Aerosol Lidar Observation Network (WMO, 2007b, 2012). The specific objective of GALION is to provide the vertical component of the aerosol distribution through the coordination of existing lidar networks: the American Lidar Network (ALINE), Latin America; the Asian Dust and Aerosol Lidar Observation Network (AD-Net), East Asia; CIS-LINET, Commonwealth of Independent States Lidar Network (Belarus, Russia and Kyrgyz Republic) LIdar NETwork; the Canadian Operational Research Aerosol Lidar Network (CORALNet), Canada; the European Aerosol Research LIdar NETwork (EARLINET), Europe; Network for the Detection of Atmospheric Composition Change (NDACC), Global; CREST, Eastern North America; the MicroPulse Lidar NETwork (MPLNET), Global.

Another example of a WMO-cooperation is the contribution to the WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) (www.wmo.int/pages/prog/arep/wwrp/new/Sand_and_Dust_Storm.html). Here EARLINET is providing profiling of aerosol optical properties during Saharan dust outbreaks for dust model verification. In particular, a quantitative systematic comparison between measured and modelled profiles at network level is currently in progress.

Furthermore, EARLINET is involved in the exploitation of the recently established networks of ceilometers, mainly operated by national weather services. Ceilometers are simple one-wavelength eye-safe backscatter lidars operating continuously and unattended. They were primarily designed for the height assignment of clouds only, but currently their capability to provide aerosol information is under discussion (Wiegner and Geiß, 2012), in particular after the Eyjafjallajökull eruption in 2010. EARLINET can serve as a benchmark to quantitatively assess the potential of such secondary networks, can demonstrate their benefits and the limitations, and work out strategies of synergism (Wiegner et al., 2014). In particular, advanced EARLINET lidars can be used to calibrate ceilometers. Of special interest is to which extent the aerosol

characterization at the few EARLINET core stations can be "interpolated" by means of ceilometers, taking into account the limited information content of their products. This will, e.g., be of significant relevance for air traffic in case of future volcanic eruptions. In this context, EARLINET is working closely with EUMETNET (www.eumetnet.eu) to support and contribute to the preparation of future community research in the field of robustness of the air transport system when faced with major weather hazards, in particular volcanic ash and icing.

EARLINET provides an important support for ongoing and future satellite missions. Systematic observations within EARLINET, in particular when combined with aerosol transport models, can help to reduce or avoid the errors due to aerosol interference on the atmospheric optical parameters. Passive optical remote sensing from space is also used to derive aerosol parameters on a global scale. However, these retrievals are severely underdetermined so that a priori knowledge or assumptions about aerosol properties must be used. In this context EARLINET observations can be used to assess the performance of these retrievals, to identify the problems, and thus to improve the methodology and for this reason EARLINET cooperates with the most important space agencies (i.e. ESA, NASA, JAXA).

Since 2011 EARLINET has been integrated in ACTRIS which is a European Project aiming at integrating European ground-based stations equipped with advanced atmospheric probing instrumentation for aerosols, clouds, and short-lived gas-phase species. ACTRIS is building the next generation of the ground-based component of the EU observing system by integrating three existing research infrastructures EUSAAR (www.eusaar.net, for in-situ aerosol observations), EARLINET, CLOUDNET (www.cloud-net.org, for cloud profiling), and a new trace gas network component into a single coordinated framework.

4   Main EARLINET outcomes

Thirteen years of EARLINET operation have provided a data set that has been widely used for aerosol climatological studies, for studies of specific events as Saharan dust intrusions and spread of volcanic ash plumes, and for the validation of aerosol data retrieved from spaceborne missions.

The spatiotemporal distribution of aerosols on a continental scale provided by EARLINET contribute to the quantification of anthropogenic and biogenic emissions and concentrations of aerosols, quantification of their budgets, radiative properties, and prediction of future trends. EARLINET contributes therefore to the improvement of the understanding of physical and chemical processes related to aerosols, their long-range transport and deposition, and their interaction with clouds (e.g. Guibert et al., 2005; Meier et al., 2012).

In the following a brief overview over selected, more specific studies with a significant contribution of EARLINET is presented. A complete list of publications related to all the specific EARLINET activities is available at www.earlinet.org.

EARLINET data have been used for a first statistical range resolved analysis of aerosol optical properties over Europe (Matthias et al., 2004b), climatological studies (Amiridis et al., 2005; De Tomasi et al., 2006; Giannakaki et al., 2010; Mattis et al., 2004, 2008; Wandinger et al., 2004; Navas-Guzmán et al., 2013a; Preißler et al., 2013), long range transport analysis (Ansmann et al., 2003; Damoah et al., 2004; Papayannis et al., 2008; Wang et al., 2008; Mattis et al., 2010; Sawamura et al., 2012; Pappalardo et al., 2013) aerosol characterization and implication of dust in the weather forecast modelling (Pérez et al., 2006a). Moreover, retrieval algorithms for aerosol microphysical properties were developed and tested extensively with synthetic data and with real multiwavelength lidar data (e.g. Veselovskii et al., 2002; Müller et al., 2004, 2005; Böckmann et al., 2005; Tesche et al., 2008; Balis et al., 2010; Alados-Arboledas et al., 2011; Gasteiger et al., 2011; Mamouri et al., 2012; Wagner et al., 2013; Navas-Guzmán et al., 2013b). In many of these studies, lidar data were used for long-term monitoring

of aerosol optical properties relevant for the Earth's radiation budget. In particular, the variability and the distribution of the most important aerosol parameters such as extinction and backscatter coefficient, lidar ratio, optical depth, linear depolarization ratio and Angström coefficient, were studied. Their annual and seasonal cycles were investigated allowing the comprehension of the role played by the different orography of the EARLINET stations (e.g. Matthias and Bösenberg, 2002; Matthias et al., 2004b; De Tomasi et al., 2006). Moreover, studies of the correlation between measured lidar ratio values and the origin and path of the air masses on the base of the backward trajectory analysis have been performed (e.g. Müller et al., 2007a, b; Giannakaki et al., 2010).

Based on the capability of (multi-wavelengths) Raman lidars to retrieve intensive aerosol properties, i.e. the lidar ratio, the linear depolarization ratio and Angström exponents, EARLINET constitutes an excellent basis to distinguish different aerosol types. Examples of the corresponding approaches of "aerosol typing" can be found in e.g. Müller et al. (2007a, b), Groß et al. (2011b). In particular the discrimination between dust aerosols and volcanic ash is urgently needed for aviation.

Beside climatological measurements, EARLINET performs also specific observations during special events such as Saharan dust outbreaks (e.g. Ansmann et al., 2003; Balis et al., 2004; Mona et al., 2006; Papayannis et al., 2008; Guerrero-Rascado et al., 2009; Wiegner et al., 2011), volcanic eruptions (e.g. Pappalardo et al., 2004b, 2013; Wang et al., 2008; Ansmann et al., 2010; Groß et al., 2011a; Wiegner et al., 2012; Navas-Guzmán et al., 2013b), and bio-mass burning (e.g. Alados-Arboledas et al., 2011; Amiridis et al., 2009; Müller et al., 2007b; Balis et al., 2003; Mattis et al., 2003). In particular, within the network an alert service for Saharan dust outbreaks has been established based on the use of operational dust forecast of different regional models as Skiron (Nickovic et al., 2001) and BSC-DREAM8b models (Pérez et al., 2006b, c; Basart et al., 2012). Back-ward trajectories derived from operational weather prediction models and provided by the German Weather Service are used to characterise the history of the observed air parcels, accounting explicitly for the vertical distribution. EARLINET long-term observations of Saharan dust events over Europe performed from

May 2000 permit to investigate dust modification processes during transport over the continent through suitable case studies involving several stations around Europe (e.g. Ansmann et al., 2003) and it is a unique tool for Saharan dust climatological studies on a continental scale. A first study on the impact of Saharan dust on European aerosol content has been performed on the base of all EARLINET data acquired during the first period of operation of the network (2000–2002) (Papayannis et al., 2008), documenting the horizontal and vertical extent of dust outbreaks over Europe. This long-term database is a unique tool for a systematic comparison with dust model outputs. A methodology for lidar measurements vs. model outputs comparison and first results related to EARLINET observations in Potenza and BSC-DREAM8b modelled profiles are reported in Mona et al. (2013).

Further EARLINET observations are devoted to monitor volcanic eruptions. During eruptions occurred in 2001 and 2002, volcanic aerosol emitted from Etna was observed by EARLINET lidar stations (Pappalardo et al., 2004b; Wang et al., 2008; Villani et al., 2006).

A study of long range transport of aerosol of volcanic origin over central Europe has been done for the period 2008–2010 related to eruptions of different volcanoes on the Aleutian Islands, Kamchatka, Alaska, and on the Kuril Islands (Mattis et al., 2010). Another long range transport event of volcanic aerosols was studied for the Nabro eruption in 2011 (Sawamura et al., 2012).

The most intensive period of EARLINET measurements related to a volcanic eruption is without any doubt the Eyjafjallajökull eruption in 2010. The EARLINET coordinated observations and a methodology (Mona et al., 2012), specifically designed ad hoc for this event, provided a detailed description of the 4-D distribution of the volcanic cloud over Europe for the whole event from April – till May 2010 (Pappalardo et al., 2013). The derivation of mass concentration as the most relevant property for air safety issues using data of advanced EARLINET-type lidars and sun photometers was covered in detail by Ansmann et al. (2011), Gasteiger et al. (2011), and Sicard et al. (2012). Furthermore, EARLINET lidar observations were successfully used to validate chemistry

transport model results (Wiegner et al., 2012). The results about the 4-D distribution of the volcanic cloud are reported in a specific relational database available on request through the EARLINET web site. Quantitative optical data collected by EARLINET for this event, including the specific relational database related to the geometrical properties of the volcanic cloud, represent a unique database for model evaluation, data validation, and integration.

EARLINET long-term observations of aerosol optical properties profiles are important for comparison and integration studies with satellite-borne passive measurements (van Gijsel et al., 2011). In particular comparisons in terms of AOD of EARLINET (state-of-the-art data) vs. MODIS (data currently used as reference for assessing aerosol effects) permit also to investigate EARLINET measurement scheduling representativeness.

EARLINET is playing an important role in the validation and in the full exploitation of the lidar data that the space mission NASA/CNES CALIPSO is providing continuously since April 2006. EARLINET started correlative measurements for CALIPSO in June 2006. Correlative data have been used for investigating performances of CALIPSO (Mona et al., 2009; Wandinger et al., 2010). First EARLINET-CALIPSO combined studies on the representativeness of aerosol optical properties profiles have been carried out (Pappalardo et al., 2010; Wandinger et al., 2011). Moreover, EARLINET climatological values of the lidar ratio and methods for the discrimination of dust in lidar measurements using depolarization information (Tesche et al., 2009) have been used to provide optimized dust products from CALIPSO observations (Amiridis et al., 2013).

5 Summary and outlook

Aerosols play a key role in many atmospheric processes governing, e.g., the atmospheric radiation budget, water cycle, and chemistry, which in turn affect human health, traffic systems, and development of ecosystems. Thus, it is necessary to improve observational capabilities for aerosol distribution and their properties. It is undoubted

that information on the vertical distribution is particularly important and that lidar remote sensing is the most appropriate tool to provide this information. Multi-wavelength backscatter and extinction coefficient profiles are available from EARLINET by means of an easily accessible data base, covering the European continent and 13 years of measurements.

In the last ten years, significant technological improvements of lasers, and as well as optical and electronic components have contributed to a much wider use of lidar technologies for aerosol monitoring and detailed studies on the role of atmospheric aerosols. There is an increasing demand for profiling data from modelers and from operational communities, for climatological studies, for air quality, but also for observation of specific events related to atmospheric hazards such as volcanic eruption and dust outbreaks. EARLINET has contributed significantly to these developments, setting the standards for instruments, methodology, and organization in this specific area.

In particular, thanks to recent optimization of instruments, data processing schemes, and the strict quality assurance, EARLINET is evolving towards a more advanced and sustainable observing system, resulting in an increase of the observing capability (more stations and more advanced lidar instruments) and reduction of costs of operations (best technical solutions, sustainable quality assurance strategies and data processing). As a consequence, the EARLINET data base will include a series of further aerosol parameters and the extent can grow faster than before.

The network provides an important support for ongoing and future satellite missions. At present, EARLINET is continuing correlative measurements for CALIPSO and it will contribute also to future satellite missions with lidar instrumentations onboard such as the ESA Explorer missions ADM-Aeolus (Stoffelen et al., 2005) and EarthCARE (Illingworth et al., 2014). Both missions will involve a High Spectral Resolution Lidar at 355 nm able to give independent measurements of aerosol extinction and backscatter coefficient in the UV. The multi-wavelength EARLINET data will be very useful for the validation of these missions and providing the conversion factors that allow linking the aerosol data at 532 nm and 1064 nm from CALIPSO with the data at 355 nm from

ADM-Aeolus and EarthCARE for a consistent long-term global data set. In addition, EARLINET will play a crucial role for the validation of further upcoming missions for operational satellites, in particular Sentinel-4 (Ingmann et al., 2012) (in geostationary orbit) and Sentinel-5 (Ingmann et al., 2012) (low earth orbit) that will be deployed in the framework of Copernicus (www.copernicus.eu).

The future availability of EARLINET near-real-time vertical profiles will be an important step for the assimilation of lidar data in models and will result in a strong contribution to the COPERNICUS program and to the WMO SDS-WAS.

EARLINET is now a reference network and represents the forum of lidar experts in Europe for the development of new lidar technologies, retrieval software and methodologies for aerosol study. It will continue to contribute to the improvement of continuous observations and methodological developments that are urgently needed to provide the multi-year continental scale data set necessary to assess the impact of aerosols on the European and global environment, to detect trends and to support future satellite missions. This will be done, even more in the future, in cooperation with the modelling community and the operational community; in this direction are the future planned developments of the network devoted to extend the lidar measurements towards more continuous observations and near real time data delivery.

EARLINET is a key component of the ACTRIS infrastructure which represents a big step towards a better coordination of the atmospheric observations in Europe, towards the establishment of the European component of an Integrated Atmospheric Global System as part of GEOSS, the Global Earth Observation System of Systems (GEOSS, 2005).

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Table 1. Active EARLINET stations. Depol: aerosol depolarization-measurement capability; SP: collocated AERONET sun-photometer; MWRL: multiwavelength Raman lidar; RL: Raman lidar, BL: backscatter lidar.

Station	Coordinates	Type	Depol.	S-P
Andenes, Norway	69°17′ N, 16°0′ E	MWRL	X	X
Athens, Greece	37°58′ N, 23°47′ E	MWRL	X	X
Barcelona, Spain	41°23′ N, 2°7′ E	MWRL		X
Belsk, Poland	51°50′ N, 20°47′ E	BL		
Bucharest, Romania	44°27′ N, 26°2′ E	MWRL	X	X
Cabauw, The Netherlands	51°58′ N, 4°56′ E	MWRL	X	X
Clermont-Ferrand, France	45°46′ N, 3°7′ E	RL	X	X
Cork, Ireland	51°54′ N, 8°30′ W	RL		
Évora, Portugal	38°34′ N, 7°55′ W	MWRL	X	X
Garmisch-Partenkirchen, Germany	47°29′ N, 11°4′ E	BL		
Granada, Spain	37°10′ N, 3°36′ W	MWRL	X	X
Hamburg, Germany	53°34′ N, 9°58′ E	MWRL	X	X
Ispra, Italy	45°48′ N, 8°36′ E	MWRL		X
Kuopio, Finland	62°44′ N, 27°33′ E	MWRL	X	X
L'Aquila, Italy	42°23′ N, 13°19′ E	RL		
Lecce, Italy	40°18′ N, 18°6′ E	MWRL	X	X
Leipzig, Germany	51°21′ N, 12°26′ E	MWRL	X	X
Limassol, Cyprus	34°40′ N, 33°23′ E	RL	X	X
Madrid, Spain	40°27′ N, 3°44′ W	MWRL		
Maisach, Germany	48°13′ N, 11°15′ E	MWRL	X	X
Minsk, Belarus	53°55′ N, 27°36′ E	MWRL	X	X
Naples, Italy	40°50′ N, 14°11′ E	MWRL	X	
Palaiseau, France	48°42′ N, 2°12′ E	BL		X
Payerne, Switzerland	46°49′ N, 6°56′ E	RL	X	
Potenza, Italy	40°36′ N, 15°43′ E	MWRL	X	X
Sofia, Bulgaria	42°40′ N, 23°20′ E	BL		
Thessaloniki, Greece	40°38′ N, 22°57′ E	MWRL		X

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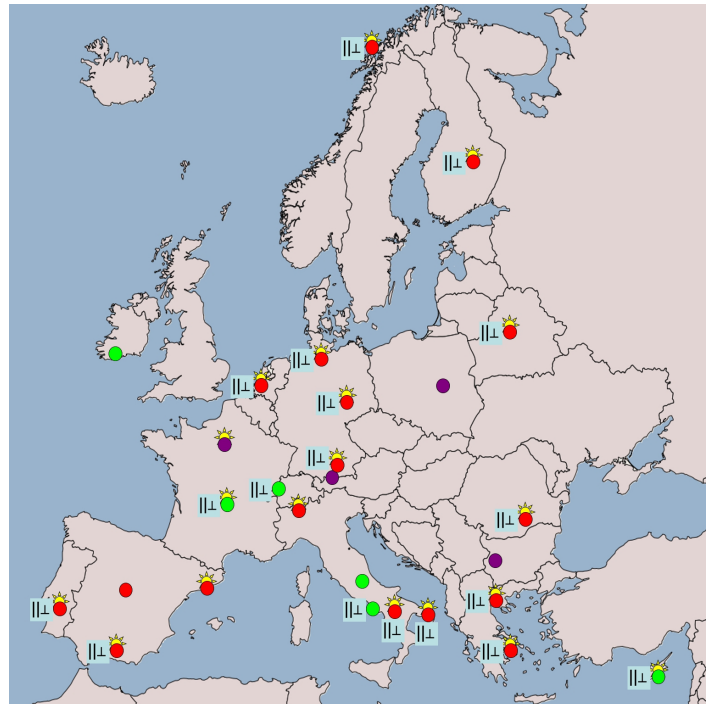
Fig. 1. Map of the EARLINET stations currently active. Red dots indicate multiwavelength Raman lidar stations (EARLINET core stations). Green dots correspond to stations with at least one Raman channel. Violet dots denote lidars with only elastic backscatter channels. The ∥⊥ symbol indicates that the station has depolarization-measurement capabilities. The "sun" symbol means collocation with an AERONET sun-photometer.

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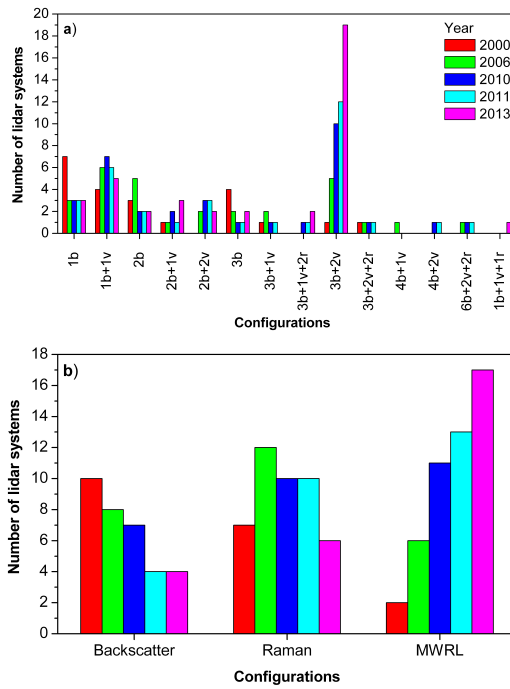
Fig. 2. Development of the number of lidar systems by their configurations in EARLINET between 2000 (the start of EARLINET) and 2013. Configurations are classified **(a)** detailing the receiving system ("b" for backscatter, "v" for vibrational Raman and "r" for rotational Raman, whereas the number before each letter indicates the number of wavelengths for which the "b", "v" and "r" is measured), and **(b)** grouping the receiving systems in larger configuration classes: backcatter lidars, Raman lidars, multiwavelength Raman lidars (MWRL).
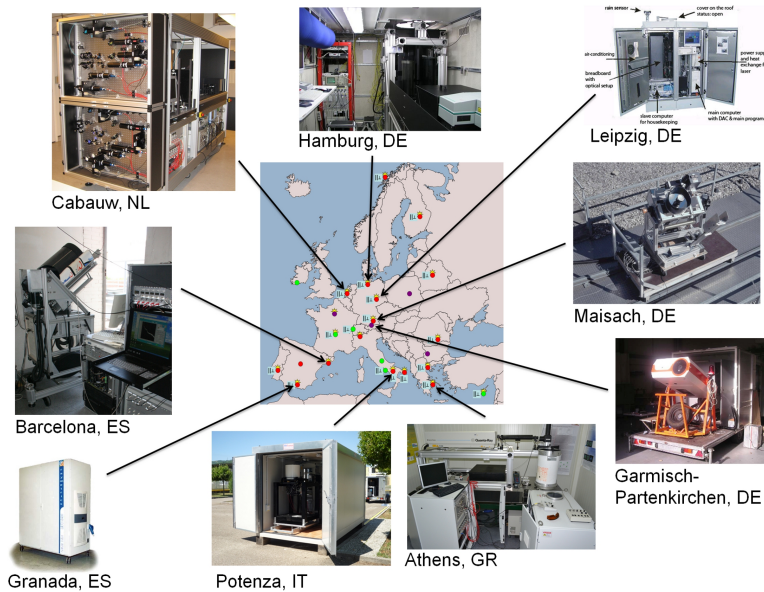
Fig. 3. Pictures of a selection of individual lidar systems that are part of EARLINET.

Fig. 4. Schematic representation of an instrument table from the EARLINET Handbook of Instruments. The structure allows for multiple emitting lasers (with multiple beams) and a multitelescope receiving system. As a result, each detection channel is fully characterized. Also, any change or expansion of the lidar system can be uniquely documented.
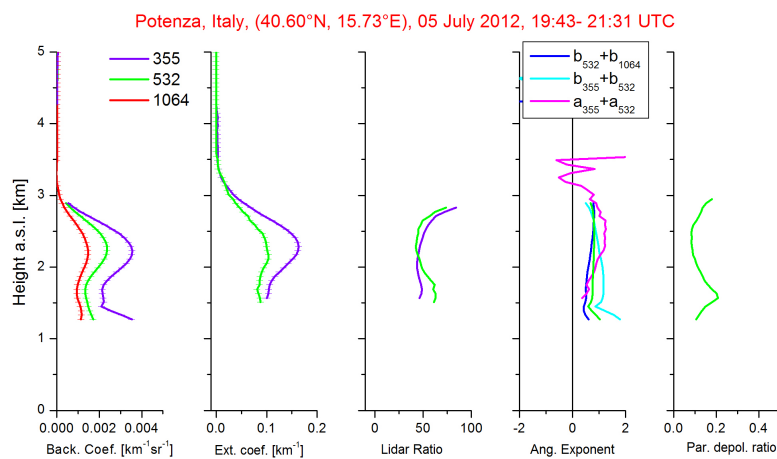
Fig. 5. Example of aerosol optical properties vertical profiles retrieved by a an EARLINET core station. The error bars report the statistical error on the retrieved properties.

Number of external users

(a)

Number of file stored for each month

(b)

Number of file downloaded for each month

(c)
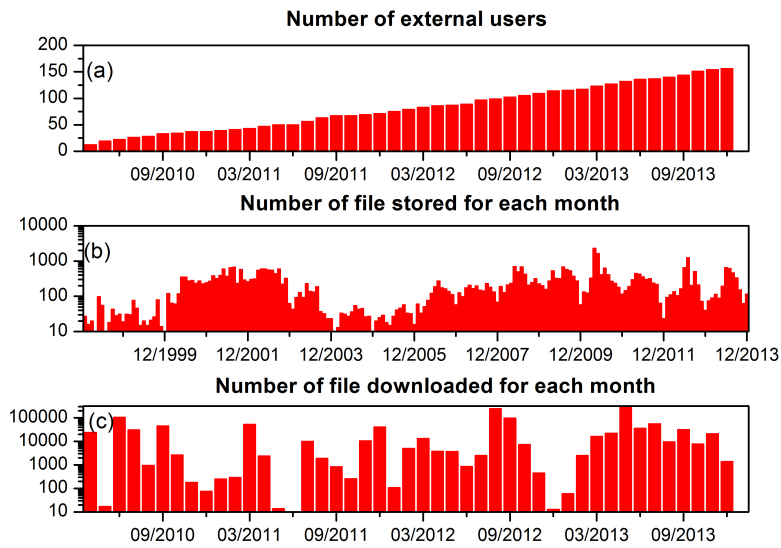
Fig. 6. EARLINET database: number of registered external users **(a)**; number of files uploaded to the database as of 31 December 2013 **(b)**; number of files downloaded from the EARLINET database **(c)**. Public access to the database started in April 2010.
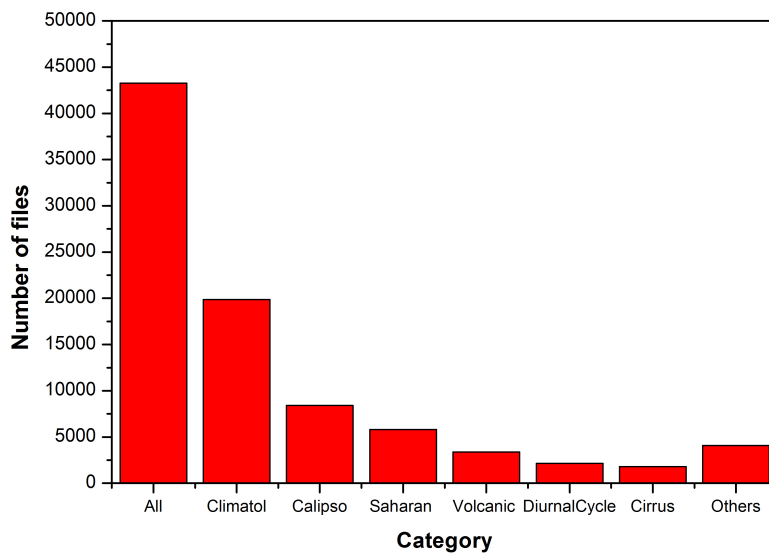
Fig. 7. EARLINET database: distribution of data files in the different categories: climatology, CALIPSO, Saharan dust, volcanic eruptions, diurnal cycles, cirrus, and others (forest fires, photo smog, rural/urban, and stratosphere).