Final Report

EARLINETASOS

European Aerosol Research Lidar Network: Advanced Sustainable Observation System

Integrating Activity

implemented as

Coordination Action

Contract number: *RICA-CT-2006-025991*

Project coordinator: *Gelsomina Pappalardo – Consiglio Nazionale delle Ricerche*

Project website: *http://www.earlinetasos.org*

Project Duration : *60* months from *01/03/2006* to *28/02/2011*

Project funded by the European Community
under the "Structuring the European Research Area" specific programme
Research Infrastructures Action

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The present knowledge of the aerosol distribution in the atmosphere is far from sufficient to properly estimate the role of aerosols in changes of the global and regional environmental conditions and climate. The information on the vertical distribution is particularly lacking and lidar remote sensing is the most appropriate tool to close this observational gap. In particular, lidar networks are fundamental to study aerosol on large spatial scale and to investigate transport and modification phenomena. These are the motivations for the establishment in 2000 of EARLINET, the European Aerosol Research Lidar Network, as a research program funded by the European Commission in the frame of the 5th framework program. After the end of the project, the network activity continued based on a voluntary association.

On March 2006, the EC Project EARLINET-ASOS (Advanced Sustainable Observation System) started on the basis of the EARLINET infrastructure. The main objective is to improve the EARLINET infrastructure resulting in a better spatial and temporal coverage of the observations, continuous quality control for the complete observation system, and fast availability of standardized data products.

The overall objectives are:

- 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 this instrument 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.
- To play a leading role in the development of a global observation network for the aerosol vertical distribution as a major innovative element of GEOSS, by setting the standards for instruments, methodology, and organization in this specific area.

These objectives have been reached by strengthening the co-operation among the partners with several networking activities: exchange of expertise with the main goal of defining and disseminating best practice and knowledge; quality assurance program for both algorithms and instruments for assessing and assuring common high quality standards; optimization of instruments for achieving a better temporal coverage and standardization of performance; optimization of data processing with the goal of establishing an automatic processing from raw data to final products; establishing a database provided with an user interface for dissemination of data.

List of participants

Participant number	Organisation (name, department, city, country)	Short name
1	Consiglio Nazionale delle Ricerche - Istituto di Metodologie per l'Analisi Ambientale, Potenza, Italy	CNR-IMAA
2	Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V. represented by Max-Planck-Institut für Meteorologie, Hamburg, Germany	MPIMET
3	Aristotle University of Thessaloniki, Thessaloniki, Greece	AUTH
4	Universitat Politecnica de Catalunya, Department of Signal Theory and Communications, Barcelona, Spain	UPC
5	Ludwig-Maximilians-Universität Muenchen, Meteorologisches Institut, Department of Phisics, Munich, Germany	LMU-MUENCHEN
6	Leibniz Institut für Troposphärenforschung e. V., Physics department, Leipzig, Germany	IFT
7	Rijksinstituut voor Volksgezondheid en Milieu, Bilthoven, The Netherlands	RIVM
8	Universität Potsdam, Institute of Mathematics, Potsdam, Germany	UP
9	B.I. Stepanov Institute of Physics - National Academy of Sciences of Belarus, Minsk, Bjelarus	BISIP.SMO
10	Norsk Institutt for Luftforskning, Norwegian Institute for Air Research at the Polar Environmental Centre, Tromsö, Norway	NILU
11	Observatoire Cantonal de Neuchatel, Neuchatel, Switzerland	CSEM
12	National Technical University of Athens, Mathematics and Physical Sciences, Athens, Greece	NTUA
13	Università del Salento, Department of Physics, Lecce, Italy	US
14	Università degli Studi dell'Aquila - Dipartimento di Fisica - CETEMPS, L'Aquila, Italy	UNIAQ
15	Ecole Polytechnique Federale de Lausanne, Lausanne, Switzerland	EPFL
16	Institute of Geophysics, Polish Academy of Sciences, Warsaw, Poland	IG PAS
17	Consorzio Nazionale Interuniversitario per le Scienze Fisiche della Materia, Unita' di Napoli- Dipartimento di Scienze Fisiche, Napoli, Italy	CNISM
18	Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria	IE-BAS
19	Karlsruher Institut für Technologie, Institut für Meteorologie und Klimaforschung, Garmisch-Partenkirchen, Germany	KIT-G
20	Centre National de la Recherche Scientifique - Institut Pierre Simon Laplace, Paris, France	CNRS
21	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Department of Environment Air Pollution Unit, Madrid, Spain	CIEMAT

Associated partners

- Universidad de Granada, Granada, Spain
- INOE National Institute of R&D for Optoelectronics, Bucharest, Romania
- JRC Institute for Environment and Sustainability, Ispra, Italy
- Swedish Defence Research Agency, Linköping, Sweden
- Centro de Geofísica de Évora CGE, Evora, Portugal

EARLINET-ASOS is organized in 6 networking activities listed in the table below:

Activity Number	**Descriptive Title**	**Short description and specific objectives of the activity**
NA1	Management of *CA*	Management comprises the areas of communication with the Commission for all contractual and administrational matters, organization of annual and special reports, organization of consortium meetings, monitoring the progress of work based on milestones and deliverables.
NA2	Exchange of expertise	The objective of this networking activity is to provide effective means to improve the EARLINET infrastructure through a comprehensive and organized flow of information both between the participants and between the participants and the external scientific community.
NA3	Quality assurance	Inter-comparison activities for both instruments and algorithms to assure the quality of the lidar aerosol products for all EARLINET-ASOS stations.
NA4	Optimisation of instruments	To improve the observation system on the basis of well defined subsystems and system integration by selection of the optimal approach from various solutions existing at individual stations.
NA5	Optimisation of data processing	Optimisation of data processing to retrieve aerosol optical properties and microphysical properties. Common single chain data processing procedure for the automatic retrieval of aerosol properties.
NA6	Data base construction and operation	The establishment of the EARLINET-ASOS database and the development of a web-based interface to provide easy access to the data products for internal and external users.

All the activities, started right at the beginning of the project and lasted for the whole project duration.

In the following a summary of all the activities, beside the management is reported, with focus on the employed methodologies and approaches and on the main achievements.

Networking Activity 2: Exchange of Expertise

Introduction

The main objective of the exchange of expertise Networking Activity (NA2) in EARLINET-ASOS was to provide effective means to improve the EARLINET infrastructure through a comprehensive and organized flow of information both between the participants and between the participants and the external scientific and general community. Fig. 2.1 shows in a graphical way the backbone role the exchange of expertise plays in the overall project structure. To effectively achieve the activity goals, the following instruments were used:

- Workshops and short courses.
- Publication in peer-reviewed journals and participation in conferences and scientific events.
- Web site
- Symposium

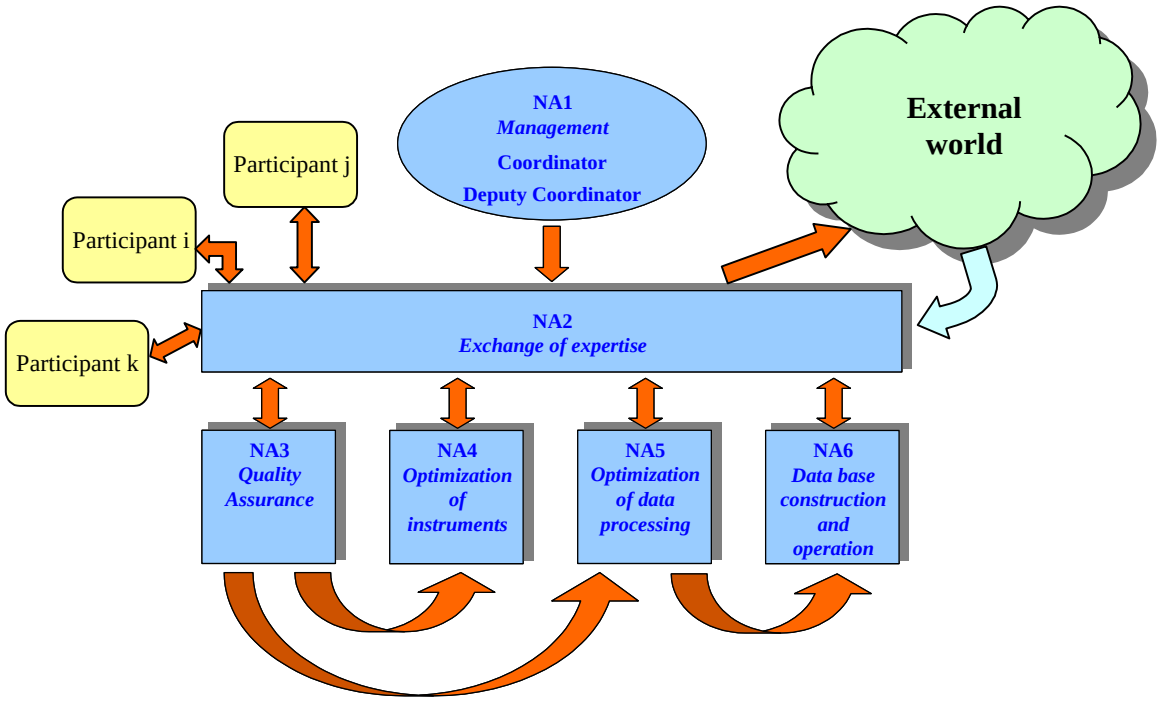

***Figure. 2.1**: Inter-relation between the EARLINET-ASOS networking activities, showing the backbone role of the exchange of expertise*

The networking activity was structured according to the following tasks:

NA2.1: Organization of workshops

NA2.2: Exchange of information with the general aerosol community

NA2.3: Symposium

NA2.4: Web site

In the following, goals achieved in the networking activity are reported according to this task structure. However, the project has also favored a continuous, spontaneous flow of exchanges among the participants and among the participants and external organizations in the form of visits for technical discussions, PhD and senior scientist stays, short courses and seminars at partner premises, etc. that, going beyond these tasks, has multiplied the efficiency of the instruments used to achieve them, and has effectively contributed to the specific goal of scientific training, especially of young researchers.

Organization of workshops

Ten workshops, two workshops per year, were organised throughout the whole project duration (one in coincidence with the Symposium). These workshops had typical durations of two and a half days and were held in late winter or early springtime and in early fall. They assembled representatives of the whole EARLINET-ASOS consortium and associated partners, with an active participation of young researchers from the different groups.

The workshops were typically structured in two parts: the first one consisted in the presentation and discussion of progress in the different networking activities by the respective activity leaders, frequently complemented by contributed technical presentations by other EARLINET participants. The second part was organised around either communications presenting scientific results enabled by the improvements that EARLINET-ASOS was producing in the EARLINET infrastructure or topical sessions.

To cover special needs regarding the training of (young) scientists, some workshops had associated short training courses. At the 2nd EARLINET-ASOS workshop (Granada, Spain, 9-11 October 2006), it was organised a short training course devoted to ray-tracing techniques tools for optimising the lidar receiving optics. This topic was fully developed later in a following training course organised on 26 and 27 February 2007 at the Netherlands National Institute for Public Health and the Environment (RIVM), preceding the 3rd EARLINET-ASOS Workshop (Bilthoven, The Netherlands, 28 February – 2 March 2007). Likewise, the 4th EARLINET-ASOS workshop (Thessaloniki, Greece, 27-29 February 2008), was preceded on 25 and 26 February by training course on the retrieval of optical properties of aerosols and clouds.

All the presentation materials of the workshops and training courses are made available to the EARLINET community through the internal part of the EARLINET web site.

Exchange of information with the general aerosol community.

As a means to reach the external scientific community, a number of scientists external to the EARLINET-ASOS consortium were invited to some workshops. This was the case of the 3rd EARLINET-ASOS workshop (Bilthoven, The Netherlands, 28 February – 3 March, 2007), which was attended by ESA-ESTEC scientists, the 4th EARLINET-ASOS workshop (L'Aquila, Italy, 1-3 October 2007), where experts from the European Space Agency (ESA), the Institut Pierre-Simon Laplace (IPSL, France), the Deutsches Zentrum für Luft und Raumfahrt (DLR, Germany), and the National Oceanic and Atmospheric Administration (NOAA, USA) were invited in connection with the synergies between ground-based lidar networks and present and future spaceborne lidar missions (CALIPSO, ADM-Aeolus, EarthCARE), and of the 8th EARLINET-ASOS workshop (Bucharest, Romania, 28-30 September 2009), which counted with external contributions from the US Forest Service on

new analysis tools, and from the Laboratoire de Modélisation du Climat et de l'Environnement (CEA, France) on new networking opportunities. Some sessions in the workshops were also open to external scientists interested in the EARLINET activities attending on their own budgets.

Publications in journals and participation in conferences were a choice mean to achieve the EARLINET expertise outreach before the scientific community, favored by the progress deriving from the EARLINET-ASOS networking activities and its funding backing.

During the EARLINET-ASOS project 123 papers in peer-reviewed journals have been published, and there are 263 publications in conference proceedings or conference presentations, some of them corresponding to invited presentations, on EARLINET-ASOS related subjects. The complete list of publications is available on the project website and it is also reported in Appendix A of this report.

The participation of EARLINET members in the programme committees of recognized conferences in the fields of aerosol science and remote sensing has helped to disseminate the EARLINET-ASOS progress and to organise special sessions devoted to relevant topics for the aerosol scientific community that aroused a considerable interest, such as those devoted to the Eyjafjallajökull eruption in the 2010 International Laser Radar Conference (ILRC25, Saint Petersburg, Russia), the 2010 International Aerosol Conference (Helsinki, Finland), and the 2010 SPIE Remote Sensing Symposium (Toulouse, France).

Symposium

The aim of the EARLINET-ASOS Symposium was to present to a wider audience and in a formalised way the results achieved in the project by the various working groups in the project networking activities. Due to its summarizing character, the Symposium was held close to the end of the project and, to reach a wide and qualified audience it was co-located with the 2nd Workshop of the World Meteorological Organization's Global Atmosphere Watch Aerosol Lidar Observation Network (GALION), held in the Geneva WMO headquarters from 20 to 23 September 2010. The first day of the workshop consisted entirely of the EARLINET-ASOS Symposium, which was attended by more than 30 experts external to EARLINET. The materials of the Symposium presentations are available from the public part of the EARLINET website. The proceedings of the EARLINET-ASOS Symposium have been distributed among the scientific community.

Web site

In the framework of EARLINET-ASOS, a new EARLINET web site (http://earlinetasos.org) has been built. The EARLINET web site is intended as an interface between EARLINET and the external scientific audience and general public, as well as an internal means of exchange for the EARLINET community. The double function of the EARLINET web site is reflected in its overall organization, with an open access part and an internal part requiring logging in reserved to the EARLINET members.

The open access part contains general information about EARLINET (objectives, approach, members, constitution and bylaws of the association, a list of the EARLINET lidar stations with links to the particular web sites and contact information), a list of publications, information of the projects in which EARLINET as a whole is or has been involved, and links to relevant events and organisations. A very important feature is the access to the EARLINET

database of lidar products, allowed to all the EARLINET participants upon logging in through their internal EARLINET account, and to external individuals after having agreed to the data use policy and registered to obtain an account. The external part also provides access to quick-looks produced by many stations of the network, which proved to be a very useful tool for a rapid interaction with the VAACs and other regulatory bodies during the Eyjafjallajökull eruption and can be used as a browser by data users for bounding searches in the database.

The internal part contains complete information about all the EARLINET-ASOS workshops and training courses, including the material of all the presentations. All the information regarding management and coordination are also available.

Full information on the progress of the networking activities is included. The information that can be found about the networking activities NA3 (Quality Assurance), NA4 (Optimisation of instruments), and NA5 (Optimisation of data processing) has been of particular interest from the point of view of the exchange of expertise aimed at improving the performance of the EARLINET lidar systems and the quality of their products.

The website, which outlives EARLINET-ASOS, is being updated in a continuous basis with regard to both its contents and its design, to keep improving its usability.

Other activities

Besides the instruments employed in the tasks reported above to achieve the exchange of expertise, the existence of EARLINET-ASOS has given rise to a spontaneous flow of information on the topics relevant for the project in the form of exchanges (short visits, young scientist stays, ad-hoc seminars, etc.) within the consortium and also between EARLINET-ASOS participants and external groups, not necessarily funded through the project, but decidedly favoured by the project dynamics. In fact, as the project progressed and general knowledge consolidated, a great deal of training activities has shifted from the format of short courses or seminars contiguous to the workshops to hands-on courses on lidar hardware and on advanced retrieval software carried out at the premises of EARLINET-ASOS partners. In total a number of 87 exchange visits took place during the project.

EARLINET-ASOS has also provided EARLINET with the momentum to export its expertise through the interaction with external groups and lidar networks; the technologies, techniques and procedures it has helped to define and develop are regarded as the standard upon which GALION, the WMO GAW Aerosol Observation Lidar Network, will operate.

A singular instance of expertise flow from EARLINET to the external scientific community and regulatory bodies, promoted by EARLINET-ASOS, are the information EARLINET provided almost on-line to the Volcanic Ash Advisory Centres (VAACs) during the eruption of the Eyjafjallajökull volcano from 14 April to 23 May 2010, and the eruption-wake requests for EARLINET participation in a special session of the European Geosciences Union (EGU) General Assembly, held in Vienna (Austria), 2-7 May 2010, in the EUTMETSAT-ESA workshop held in the ESA-ESRIN center in Frascati (Italy) on 26 -27 May 2010, and in the European Aviation Safety Agency (EASA) workshop held in Cologne (Germany) on the 21st of June 2010 on detection, observation and modeling of volcanic clouds.

An effort has also been made to reach an interested audience beyond the aerosol scientific community, ranging from the scientific community at large to the general public through other stakeholders (regulatory bodies, policy makers, etc.). This has been achieved through the

EARLINET web site, media releases, interviews, etc. In particular, the public impact of the Eyjafjallajökull eruption and the troubles it caused on air traffic provided an occasion to extend the awareness about the activities carried out by EARLINET beyond the scientific community.

Conclusions

Networking Activity 2 (Exchange of Expertise) has been a transversal and instrumental networking activity enabling the other focused activities in EARLINET-ASOS to fulfil the project overall objectives of extending the development of EARLINET as a world-leading instrument for the observation of the space-time distribution of aerosols on a continental scale, enhancing the operation of this instrument, and playing a leading role in the development of a global observation network for the aerosol vertical distribution.

The exchange of expertise both inside EARLINET and with the external scientific community has been successfully achieved through a combination of regular activities (workshops, training courses), contributions to journals and conferences, outreaching planned activities such as the setting and keeping up of a web site and the final Symposium, and spontaneous exchanges involving EARLINET participants and partner institutions, as well as the external community.

This activity has resulted in an effective improvement of the EARLINET infrastructure (see the part of Networking Activity 4 in this report) and has helped in defining technologies, techniques and procedures that will significantly contribute to the GALION worldwide aerosol lidar network and to the new European Aerosol, Clouds and TRace gases Research Infrastructure (ACTRIS) starting in 2011 under a EU 7th FP Infrastructures project.

Networking Activity 3: Quality assurance

Introduction

The contract of EARLINET-ASOS comprised 26 active lidar stations and 31 Lidar systems in 2010. The lidar systems in EARLINET are quite different. Laboratory systems, large container systems, small container systems, out-of-the-box systems, and portable lidar systems are among them. The number of total measurement channels per system ranges between one and 21, using one or two telescopes. Most lidars measure at several elastic wavelengths, and most measure Raman signals, some linear depolarization, and one system a high spectral resolution signal. All these different lidar systems provide their measurement results to the common EARLINET data base of atmospheric scattering coefficient profiles. Considering this variety of lidar systems it becomes clear that it is important to evaluate the quality and the useful range of each system, as well as the temporal stability. The systems are updated, improved, extended, repaired, moved, used in field campaigns - they change with time, and so does the system performance.
Usually one evaluates the quality of a measurement instrument by either comparing the measured quantity with the known quantity, like a standard target, or one compares with the outcome of a standard measurement instrument of the same target. For lidar systems both standards do not exist, neither a standard target nor a standard instrument. Hence each lidar group develops its own knowledge and best practice procedures to assure the quality of the lidar system as good as possible.
In the frame of EARLINET-ASOS the activity NA3 (Quality Assurance) had been established to develop tools for testing the accuracy and the temporal stability of the quality of the lidar systems (NA3.1 Quality assurance of the hardware) and to develop tools for testing of the accuracy of the analysis software (NA3.2 Quality assurance of the algorithms).

Quality assurance of the hardware NA3.1

An absolute calibration technique for lidar systems for the whole measurement range and for their performance in the presence of aerosol layers does not exist. Especially in the very important near range containing the boundary layer, aerosol lidar systems suffer from electronic saturation effects and from the uncertain optical overlap function, which is influenced by many opto-mechanical parameters. Added to this are in general non-linear analog signal distortions depending on changing near range aerosol load and signal strength. The direct intercomparison of the signals of different collocated instruments is the only generally accepted, objective way to assess the overall performance of individual lidars in the presence of aerosols. Hence direct lidar intercomparisons had been scheduled during EARLINET-ASOS for all lidar systems not checked in this way during the antecedent EARLINET-FP5 project. These direct intercomparisons have been performed during five intercomparison campaigns in EARLINET-ASOS. As such intercomparsions are expensive and time consuming, and cannot be performed when needed because of changes or upgrades in a lidar system, other tools are necessary to check the performance of a lidar system regularly. The first step in finding such tools was to get an overview of the parts of a lidar system which influence the lidar performance, and in which way they influence. In a second step the internal checkup tools have been developed, and their applicability to all lidar systems and the comprehensibleness and feasibility have been tested extensively in EARLINET-ASOS leading to improvements and showing limits of the tools.

A summary of the investigated error sources, of their effects, and of the applicable checkup tools can be found in Table 3.1.

Table 3.1: *Investigated error sources of lidar signals, their possible effects on the lidar signals, and the checkup tools which have been developed to detect them.*

Error source	Effect on	Checkup tool / solution
wrong Rayleigh scattering coefficients	apparent overlap function, lidar calibration	use of most accurate formulas
misalignment between laser and receiver	monotonic distorted overlap function in near and far range, monotonic signal distortions	camera in the telescope's focal plane or equivalent, optical ray tracing tool
misalignment of receiver optics	spatial truncation of the beam in the receiver optics, monotonic signal distortions	telecover test, Rayleigh fit, optical ray tracing tool
optical coatings/filters and inaccurate laser wavelength	angular attenuation of the beam in the receiver optics, diattenuation, monotonic signal distortions	telecover test, Rayleigh fit, optical ray tracing tool
trigger delay uncertainty	monotonic distortion of the near range signal	trigger delay checkups
spatial inhomogeneity of photomultiplier sensitivity	non monotonic signal distortions in the near range	telecover test, exchange or axial rotation of the detector
signal induced electronic distortions	non monotonic signal distortions	pulse generator test, telecover test
synchronous but signal independent electronic distortions	non monotonic signal distortions	dark measurement
wrong gluing parameters	monotonic or non monotonic signal distortions	telecover test of analog and photon counting signals

Parts and parameters that can perturb the lidar signals or their analysis

There are electronic and optical parameters which influence the range dependent quality of a lidar system and cause systematic errors. Considering the optical parameters, the ratio of the measured signal to the ideal signal is called "*overlap function*", which was used originally for the overlap of the laser field of view (determined by the laser divergence and laser alignment) with the telescope field of view (determined mainly by the field stop (or aperture) and the telescope focal length) in the near range. A closer look reveals that several other optical parts can influence the effective overlap function, also in the far range. The effects do not depend on the actual lidar signal and result in general in a monotonic increase of the overlap function in the near range and possibly in a monotonic decrease in the far range. Regarding the electronic influences, the deviations from the ideal lidar signal mainly stem from saturation, linear distortion and nonlinear responses of the signal amplification. The effects are in general signal dependent and not necessarily monotonic with range.

Rayleigh scattering coefficients

Backscatter lidar systems are usually calibrated by means of the so called "*Rayleigh fit*" in ranges where clean air can be assumed. In these ranges scattering stems only from air molecules, whose density and hence scattering coefficients can be calculated from the height

dependent air temperature and pressure, which are regularly measured by radiosondes, or can be taken with sufficient accuracy from model analyses in case a weather service station with radiosonde ascents is not close enough to the lidar site. The calculated signals can be directly compared to the measured and range corrected signals, revealing immediately non aerosol-free ranges and systematic deviations of the measured signal. Rayleigh signals calculated for the Rayleigh fit test with wrong Rayleigh scattering coefficients result in a wrong appearance of the overlap function. Although the theory for these calculations is known, several sorts of approximations have been used and also published in the past, leading to different results from different lidar groups as a survey among EARLINET-ASOS groups showed (see Fig. 3.1).

As a result of this survey, the Rayleigh scattering theory has been revised and updated using the developments in latest publications, and a table with conversion factors between air pressure and temperature from radiosonde data and the total Rayleigh and Cabannes scattering coefficients for all laser wavelengths used in EARLINET has been provided.

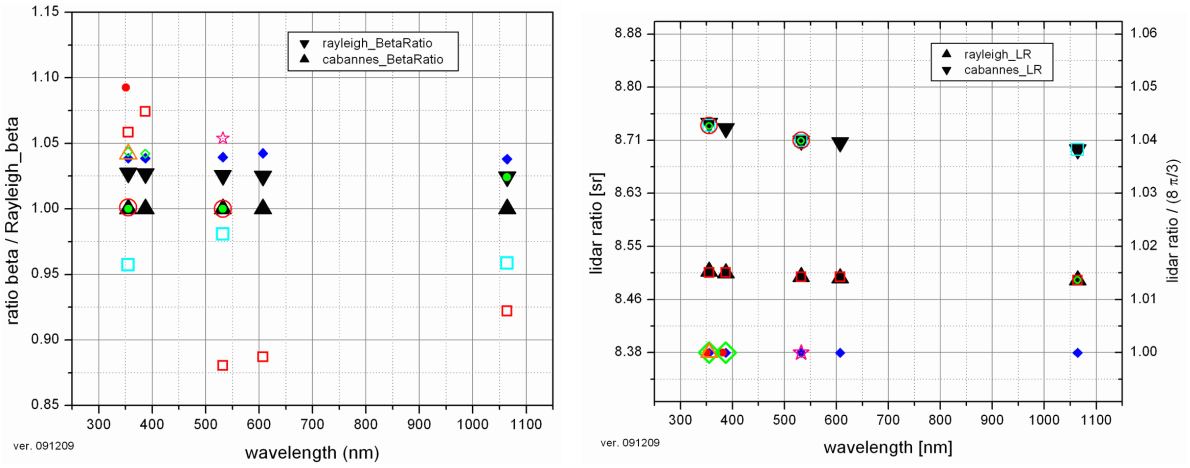

Figure 3.1: *In the left plot the ratio of the molecular backscatter coefficients at STD conditions* used by several EARLINET groups (different symbols) to the ones calculated for the Cabannes line (upward black triangle). The downward black triangles show values for the total Rayleigh scattering relative to the Cabannes values. The right plot shows the reported lidar ratios used (same symbols as left plot); the right scale of the right plot shows the ratio to (8π/3).*
** Standard conditions: 1013.25 hPa and 288.15 K, i.e.* ICAO, ISA, and ISO 13443 STD conditions

Interference filter

Most lidar systems use small bandwidth interference filters to suppress the daylight background and the adjacent laser wavelengths in the individual lidar signals. This is especially important for the Raman signals, which are very weak compared to the adjacent elastic backscatter signals, and which is why the latter have to be strongly suppressed. Interference filters have limited acceptance angles; small bandwidth interference filters in the range of ±2°. This can influence the effective overlap function of a lidar system in the near and in the far range. Furthermore the effective interference filter bandwidth influences the Rayleigh scattering coefficients used for calibration as described above. Neither the acceptance angles nor the design of the interference filters themselves, from which one could calculate the exact accpetance angles, are usually specified by the manufacturers. In order to be able to estimate the possible influence of interference filters, information about commercial

interference filters have been collected, like the effective refractive index, bandwidths, and materials used for the coatings, and with this information interference filter structures have been designed which fit the manufacturers specifications best. For certain bandwidths and wavelengths several possible solutions have been investigated. The interference filters' structures have been made available to the EARLINET-ASOS groups in a ZEMAX coating file for typical lidar wavelengths between 355 nm and 1064 nm and with bandwidths between 0.14 nm and 1 nm, to be used with the ray tracing tools. The results of the interference filter investigations are also available in tabular form.

Laser wavelengths

The Rayleigh scattering coefficients depend weakly on the laser wavelength, but the transmission of the lately introduced small bandwidth interference filters and hence the effective range dependent overlap function depend strongly on the transmitted laser wavelengths. Hence it became more important to know the laser wavelength as accurately as possible. Laser manufacturers don't specify the exact laser wavelength of unseeded lasers, probably because it can vary in a certain range from model to model depending on the individual settings. Our investigation revealed that the fundamental wavelength of Nd:YAG lasers can lie between about 1064.3 nm and 1064.8 nm, and hence the second and third harmonic between about 532.15 nm and 532.4 nm, and between 354.8 nm and 354.9 nm, respectively. When using extremely small bandwidth interference filters, these possible deviations from the nominal Nd:YAG wavelengths must be taken into account in the optical design of the receiver.

Furthermore, this uncertainty must be considered in case a lidar shows deviations using one of the internal checkup tools or in direct lidar intercomparisons. A possible effect on the range dependent overlap function can be investigated with exact ray tracing of the optical system using the ZEMAX overlap and telecover macros developed in EARLINET-ASOS and the information about the interference filters.

Optical fibers in the receiver optics

Optical fibers offer attractive properties for the design of an optical lidar receiver, and hence several EARLINET lidar systems include them. However, they are usually not used for quantitative measurements similar to lidar, and hence the performance of fibers under these special circumstances are hardly known. Fiber manufacturers usually do not provide their specifications accurately enough to estimate the errors resulting from divergent input beams, fiber bending, or depolarization. Our investigations showed that a trustworthy simulation and hence estimation of these errors with exact ray tracing are not possible, because the relevant fiber characteristics are frequently determined by the irregular imperfections of the fibers. The imperfections influence the range dependent overlap function of the lidar signals, which can be checked with the telecover tool. With an experimental setup it was shown that a proper installation of an optical fiber scrambler should include two consecutive fibers connected with a Fourier transform lens (double scrambler) and a mode scrambler for each fiber.

Diattenuation of the receiver optics

All optical surfaces, especially those with coatings and with larger incident angles, show diattenuation, i.e. different transmission for light polarized parallel and perpendicular to the plane of incidence. This effect sums up from consecutive surfaces and causes systematic errors in the lidar signals in lidar ranges with atmospheric depolarization. Provided that the coatings of the most important surfaces, which are the inclined beamsplitters, are known, the

range dependent diattenuation can be simulated with the developed ZEMAX tools and the resulting errors can be estimated and possibly corrected.

Effect of photomultiplier spatial inhomogeneity and the detector eyepiece

Most of the EARLINET lidar systems use the small Hamamatsu R7400 or H5600 series photomultipliers or alike. These detectors exhibit a strong spatial inhomogeneity of the sensitivity of the detector surface, which can lead to strong lidar signal distortions, especially in the near range. The detector eyepiece solution has been refined using the developed ZEMAX tools. The application of such eyepieces in several EARLINET lidar systems led to significant improvements of the lidar signals.

Electronic distortion

A very important part of the lidar signal is the weak tail, the range where one calibrates the lidar signal (about 5 to 15 km, i.e. the free troposphere with assumed clean air) and where the background is subtracted (usually above 20 km range). Lidar signals have an extreme dynamic range (up to 18 bit) with an unfortunate shape, i.e. a strong and short near range pulse and a long about exponentially decaying tail. In this tail the signal is very small, and distortions due to the strong near range pulse (signal induced distortions) can lead to very large errors in the retrieval of the scattering coefficients. This effect must not be confused with "*signal induced noise*" in photon counting signals, which are caused by the photomultipliers. Signals at wavelengths above 607 nm are mainly measured with PIN diodes and avalanche photo diodes using high-gain analog preamplifiers before the analog-to-digital converters. These preamplifiers are very prone to signal induced distortions, which can be investigated with the test pulse generator developed in EARLINET-ASOS.

Electromagnetic pulses from laser power supplies or other switching electronics can distort the lidar signals in a repeatable systematic way, which can be determined by means of the "*dark measurement*" tool described later in this report.

Gluing

The widely used LICEL data acquisition uses combined (glued) analog and photon counting signals to extend the dynamic range of the data acquisition. Wrong gluing (merging) parameters can cause large signal errors in the near range where the analog signal is used. Direct lidar intercomparisons clearly reveal such errors, but also the telecover tool can be used, because in many cases the signal strength of different telecovers differ, resulting in differences in the errors. During EARLINET-ASOS improved criteria for the gluing range and an improved gluing algorithm have been developed, which are more reliable.

Trigger delay

An error in the delay between the moment the laser pulse leaves the laser and the data acquisition system start (trigger delay) can cause large errors in the near range signal up to about 1 km range, because for the analysis of the signals the latter are multiplied by the squared lidar range (range correction). Especially the Raman signals can be distorted dramatically, because the signal slope in the near range changes very much when the trigger delay for the range correction is varied. The error formulation for the extinction coefficient from Raman signals has been developed, which yields that for example at 400 m range a trigger delay error of ±15 m results in an absolute error of the extinction coefficient of ±0.1 / km, increasing very much with deceasing range. Furthermore, when two signals from different signal channels are used to calculate a lidar product, like the depolarization ratio or the

backscatter coefficient with the Raman method, an error in the range of one of the channels leads to errors in the lidar product. The trigger delays of individual signal channels can be measured using the proposed methods.

NA3.1 Tools

Laser alignment

The basic adjustment of a lidar is the alignment of the direction of the laser beam with the optical axis of the receiving optics, which has to be done with very high accuracy in the order of 0.1 mrad. This alignment, which directly determines the overlap function, can change with time depending on the mechanical and thermal stability of the setup under varying environmental conditions (day-night, summer-winter). Additionally the operational conditions of the laser itself can change the beam direction. Hence this alignment should be controlled frequently. The telecover test is a good tool for this purpose, but it is time consuming. Many lidar systems are aligned by inspecting and maximizing the laser signal strength in a certain lidar range; a procedure that depends on subjective criteria and is not reliable. During EARLINET-ASOS the use of a CCD-camera in the focal plane of the telescope (or equivalent) has been promoted for the online control of the laser alignment during the adjustment, which provides in general better than 0.1 mrad accuracy. Several lidar systems have been equipped with such a camera.

Test pulse generator

In order to detect distorsions of the detector electronics and of the data acquisition system, a pulse generator with very low ringing, lower than the effects sought-after, must be used. A survey of commercially available pulse generators revealed that commercial pulse generators are not designed for such a purpose. Their design goals are a fast rise time, and the dynamic range is adapted to the ones of commercial oscilloscopes with maximum resolution of 12 bit, which is orders of magnitudes away from what we need for the testing of our lidar data acquisition. Hence a custom-made pulse generator concept has been developed with emphasis on lowest possible ringing after the test pulse. The quality of the pulse shape itself is unimportant, because long tail signal distortions seem to be mainly caused by the integral current (electric charge) of the near range pulse, and not by the pulse shape or length. A survey of the analog data acquisition systems used in EARLINET-ASOS at the begin of the project revealed that the available test pulse generator developed by the LMU Munich was not versatile enough to cover all the possible input ranges and polarities in order to test all EARLINET-ASOS systems in a standardized and comparable way. Hence MPI-MET Hamburg redesigned the electronic part of the pulse generator including several improvements like fiber optic coupling of the laser master trigger to the battery driven DAQ trigger box providing a connection free of ground loops. MPI-MET produced four identical test pulse generators, which were distributed among the EARLINET partners. Several transient recorders on PC-cards and oscilloscopes used to record the lidar signals have been tested. It was found that the main distortions are a result of complex preamplifier circuits. Once they are removed or simplified the distortions became much smaller, which results in improved lidar signals with larger usable dynamic range.

Trigger delay measurements

In case the data acquisition system permits pretriggering, i.e. starting the signal recording before the laser pulse, the detection of the time when the pulse leaves the laser is an easy task using diffuse reflections of the laser beam in the vicinity of the telescope, which produce a peak in the signal at the so called zero-rangebin. In order to keep this pulse sharp and small, the telescope should be covered to reduce the aperture to an adequate degree. But standard transient recorders and pulse counters do not provide pretriggering. In these cases the use of a cheap plastic optical fiber as a delay line for the outgoing laser pulse has been demonstrated to be a suitable solution. A small amount of the outgoing laser beam pulse is fed into an optical fiber of adequate length by means of a beam diffuser, and the end of the optical fiber is placed and aligned at the telescope aperture so that sufficient light passes the field stop of the telescope. The exact pulse delay can be calculated by multiplying the length of the fiber with the refractive index of the fiber at the laser wavelength and dividing by the speed of light. As a wrong trigger delay causes large errors in the lidar products, this test is one of the mandatory internal checkups in EARLINET-ASOS.

Dark measurement

Electronic distortions of a lidar signal are often caused by electromagnetic influences synchronous with the laser firing and the triggering of the data acquisition system, which therefore do not decrease with increasing number of laser shots in the averaged signal. Such distortions are independent of the received light and can be measured directly by fully excluding light from contributing to the lidar signal, e.g. by fully covering the receiver telescope. This "*dark* signal" can be subtracted from the measured signal. One has to ensure that the measured dark signal really is always the same – at least over the time period considered for the averaging of the lidar signals, because it has been found e.g. that even small changes of the orientation of signal cables in the contact resistance of connectors can change the shape of the dark signal. Furthermore, in analog signals there are always low frequency components in the signal noise which possibly do not decrease fast enough within the averaging time of the dark signal compared to the usually much longer averaging time of the lidar signal. Hence it has been proposed to determine the intensity of the pure statistical noise components from consecutive dark signal measurements and to determine herewith the usefulness of the dark signal subtraction. This test is one of the mandatory internal checkups in EARLINET-ASOS for channels with analog detection.

Rayleigh fit

The Rayleigh fit test shows the level of agreement between a lidar signal and a calculated molecular (Rayleigh) signal in a lidar range presumably without aerosols. Figure 2 shows an example where an aerosol free range is assumed between 5 km and 6 km. Although there are several aerosol signatures in this signal, the deviation plot at right indicates that the lidar signal can be used up to about 11 km, above which the analog signal distortions become too strong. Usually the quality of such a fit is evaluated "by eye" by a lidar expert, and an estimation of the signal uncertainty can be retrieved in the scale of the backscatter ratio. This uncertainty can be directly used in error calculations for the retrieval of aerosol scattering parameters. In the frame of the NA3 activity we developed objective criteria for the quality of a Rayleigh fit. The Rayleigh fit test is one of the mandatory internal checkups in EARLINET-ASOS to determine the degree of accuracy in the calibration range and the useful maximum range of a lidar signal.

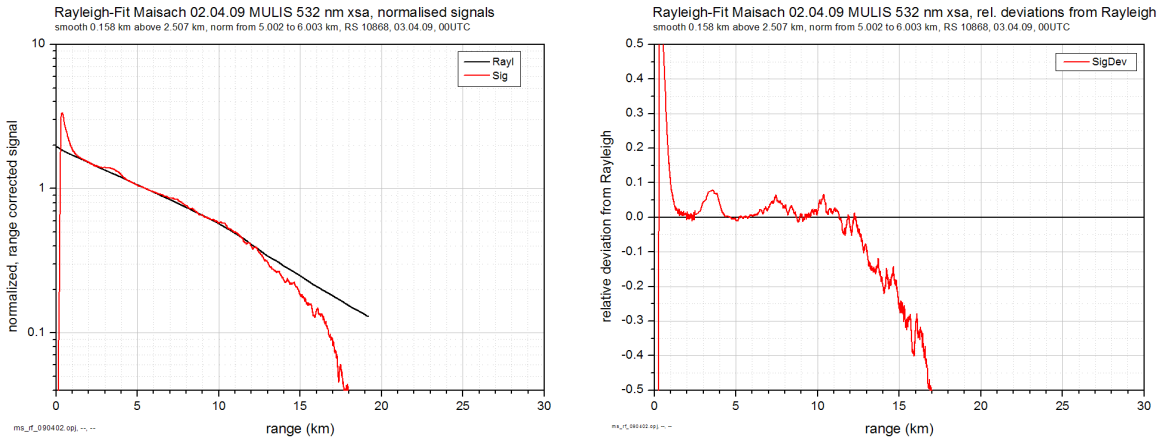

Figure 3.2: *Left: measured lidar signal (red) and calculated Rayleigh signal (black), normalized between 5 and 6 km range. Right: difference between the lidar signal and the Rayleigh signal relative to the Rayleigh signal, which is approximately the backscatter ratio assuming negligible aerosol extinction.*

Telecover

The Rayleigh fit is a very good checkup tool for the far range in the free troposphere or above, where frequently aerosol-free regions can be found. The accuracy of this test is only limited by the increasing signal noise with range. But in the near range in the boundary layer, which is the most interesting region for the EARLINET climatology of aerosol scattering parameters, all lidar systems suffer from electronic signal saturation effects and are additionally limited by the optical overlap function. In this near range region the telecover test can be used to estimate the optical overlap function and other near range distortions. For this test consecutive measurements are performed while covering different sectors of the telescope aperture, and the signals from different sectors are compared to each other. Their agreement to a high degree is a necessary prerequisite in the usable lidar range span. Figure 3.3 explains the nomenclature of the telecover sectors.

Due to the spatial inhomogeneity of the sensitivity of detector surfaces, the lidar signals from different telecover sectors usually differ by constant factors for an otherwise well performing lidar system. Range dependent differences are not acceptable as they indicate that either the optical overlap function differs for different sectors or that the different signal heights induce different electronic distortions. The drawback of the telecover test is, that the signals from different sectors can be measured only one after the other, which allows for atmospheric changes in the meantime. Hence the test should be accomplished in a time period in which the atmosphere changes as little as possible. In order to compare the sector signals they must be normalized, and the normalization range must be selected in a range without major atmospheric changes. A test is needed to estimate the amount of the atmospheric change during the period of the telecover test from the first measurement to the last one. For this purpose the measurement of the first sector (usually the N-sector) can be repeated at the end. This atmospheric test measurement (N2) is then directly compared to the first (N) with the formula $N2Dev = 2(N - N2) / (N+N2)$.

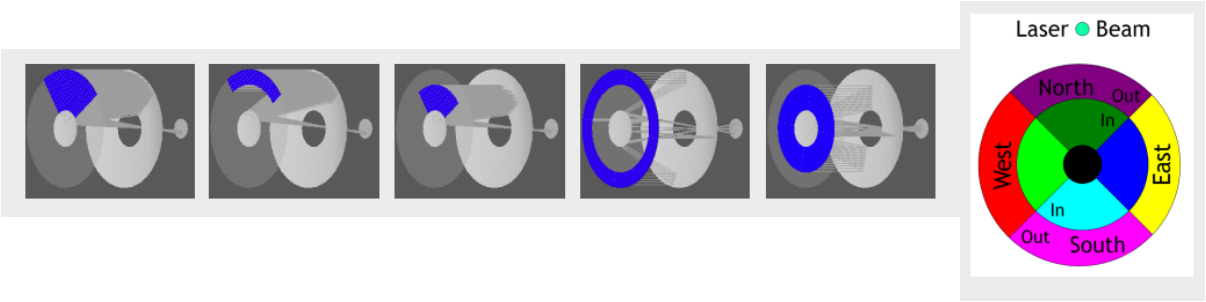

Figure 3.3: *Nomenclature of the telecover parts (plot at right) with respect to the laser position at North (biaxial systems) or any prominent orientation of the receiver optics (monoaxial systems). Using the four quarters, N,E, S and W in the left picture is called the quadrant test. Using the outer and inner parts of the quadrants is called the octant test. The picture shows (from left to right) the sectors North (N), North-Out (NO), North-In (NI), Full-Out (FO), and Full-In (FI) on a Cassegranian telescope, assuming the laser on top.*

Atmospheric changes have more effect at larger wavelengths due to the relatively higher backscatter ratio compared to smaller wavelengths and are hence most visible at 1064 nm. A relatively strong effect can also be seen in cross depolarization channels as the Rayleigh contribution to the signal is very small, especially when atmospheric changes are caused by high depolarizing aerosols like Saharan dust. Additionally, atmospheric changes produce different attenuation between the normalization range and ranges below, resulting in additional deviation of the sector signal. Currently this influence can only be estimated by eye.
In the raw signals without spatial smooth and normalization, the overall absolute differences between the sector signals are caused mainly by the spatial inhomogeneity of the detector sensitivity as can be seen in Figure 3.4, but may also stem from unsymmetrical beam truncation or differences in the transmission of the optical paths. The amount of noise in the far range gives an estimate of the validity range of this test. When signals are too noisy, the comparison between the sectors is distorted by noise fluctuations. The plots in Figure 3.5 show for each channel the normalized signals at left and the relative deviations from the mean signal at right. The mean signal is an arithmetic mean of all signals but the atmospheric test measurement. The relative deviations are calculated like NDev = (N – mean) / mean, and e.g. AllDev = sqrt [($NDev^2$ + $Edev^2$ + $Sdev^2$ + $Wdev^2$) /4]. For the octant test all eight signals are considered.
As we do not know a priory which of the sectors is closest to the truth, these plots give only a rough estimation of the range dependent uncertainty of the full telescope signal. In the worst case the error of the total signal is in the range of the difference between the lowest and highest sector signal. At best all deviations compensate each other well, except in the overlap region, where they always differ, but this happens only by chance and we never know a priori which is the case.

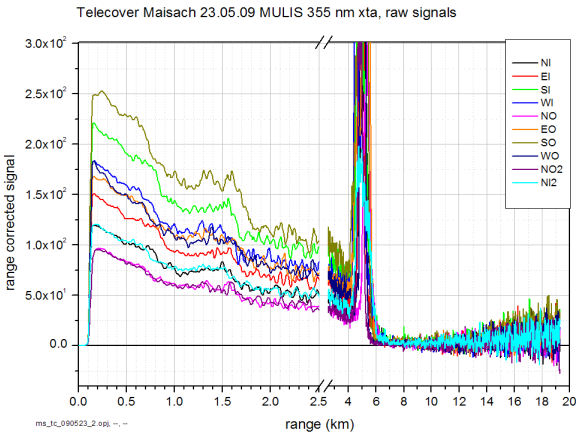

Figure 3.4: *Raw signals of a telecover measurement example showing an octant telecover test with NI2 and NO2*

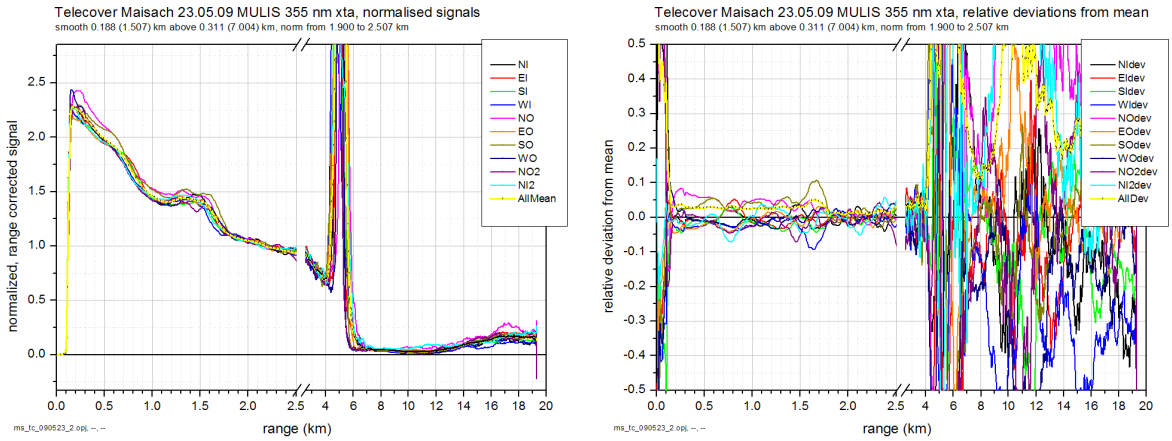

Figure 3.5: *Normalized octant telecover measurements (left) and the relative deviations from the mean signal (right).*

Only one deviation curve, which is the cyan curve NI2dev in the right plot of Figure 3.5, shows the relative difference of the two atmospheric change measurements, the NI sector (not the NO) in this case, which gives an estimate of the atmospheric changes in certain ranges. In this case the atmospheric changes seem to be in the range of 5% up to about 4 km. As the sector deviations from the mean signal are also in this range, the relative uncertainty of the total signal can be roughly estimated to about 5% between about 0.2 km and 4 km range. Well designed and aligned lidar systems exhibit a *relative deviation from the mean* below 5% (0.05). Depending on the wavelength, on the type of the retrieval (e.g. scattering coefficients or depolarization), and on the amount of aerosol load, a *relative deviation from the mean* of 10% could be acceptable. But deviations above 10% should be carefully investigated. Due to the complex nature and different effects of this uncertainty, it is not possible to define a maximal allowable limit. The telecover test is one of the mandatory internal checkups in EARLINET-ASOS which has to be repeated regularly at least once a year, but also after each change in the optical or electronic parts of a lidar system. In case the telecover differences are

above accepted thresholds in certain lidar ranges, additional specific measurements are needed to find possible causes.

Optical ray tracing

Another possibility to discover possible error sources is to compare the results of the telecover test, like e.g. the estimated distance of full overlap, with results from exact ray tracing of the simulated optical setup of the lidar system including the laser beam geometry. For this purpose a basic lidar optical design tool has been developed as a first step for the investigation in Microsoft EXCEL using paraxial formulas. This tool can be used by everybody without the purchase of expensive software. But the information gained with this tool is limited and only gross design errors can be discovered. Hence more refined tools have been developed during EARLINET-ASOS using the exact ray tracing software ZEMAX and the included macro language. In the final version of the tool, which can be applied to any lidar system, the laser beam can be arbitrarily tilted and simulated with Gaussian or constant beam intensity distributions with adjustable divergence, which is realized with a Monte-Carlo Simulation for the ray distribution. All results are calculated for a series of different lidar ranges, which allows to simulate range dependent signals. This is also possible for the telecover test signals, which can be compared to the measurements and used for their interpretation. With the tool also the effect of optical coatings on the overlap function can be investigated including the simulated coatings of interference filters. Using the possibilities of ZEMAX, all optical parts can be misaligned in five axes to study the relative effects on the lidar signals. The accuracy of the results is only limited by the limited knowledge about the exact location and parameters of the optical parts and of their coatings. A drawback of exact ray tracing software is that optical fibers cannot be simulated realistically, because most of their undesired or sometimes desired effects result from inhomogeneities of the internal optical surfaces, which cannot be modeled accurately enough.

As the ray tracing software is expensive and its use needs expert knowledge, which applies to every sophisticated ray tracing software, not all EARLINET partners were able to use this tool by themselves. More than fifteen EARLINET partners have been supported during EARLINET-ASOS with detailed simulations and recommendations for improvements of their lidar systems.

Direct lidar intercomparisons

Five direct lidar intercomparisons had been carried out during EARLINET-ASOS for all lidar systems not checked in this way during the antecedent EARLINET-FP5 and those which were new in EARLINET (see Table 3.2). For direct lidar intercomparisons two or more lidar systems are moved and located close to each other. They should measure the same atmosphere during the same time periods. The movement, re-installation and calibration of a lidar system is expensive and time consuming, and hence direct intercomparisons cannot be repeated frequently. For the intercomparisons covered by the EARLINET-ASOS contract several reference lidar systems had been designated (see Table 3.2), which had to be mobile and include the standard wavelength channels of EARLINET, i.e. 355 nm, 532 nm, and 1064 nm for the elastic backscattering, and for extinction measurements at 355 and 532 nm vibrational Raman channels at 387 nm and 607 nm, respectively, or rotational Raman channels. Although the linear depolarization ratio is not a standard product of the EARLINET measurements, these measurements showed to be very useful for aerosol characterization, and many lidar systems already include such channels. Hence the POLIS system is used as an additional reference especially for linear depolarization at 355 nm. The reference systems had

to proof their performance during EARLI09 (EARLINET Reference Lidar Intercomparison 2009) at the Institut für Troposphärenforschung (IfT) in Leipzig, Germany, May 07 - May 28, 2009. Dedicated software had been developed for this intercomparison using parts of the Single Chain Calculus software developed during EARLINET-ASOS in order to process and compare the 114 signals of all lidar systems in a homogeneous way without additional problems due to differences in the software from individual groups. With this software it was possible to compare the signals within one day after the measurements and to react to detected deviations of individual lidar systems. This was a big step forward compared to former lidar intercomparisons, and thereby many system improvements had been made possible during this campaign. For the same reasons this software was also used during ROLI10 (ROmanian Lidar intercomparison 2010) at the Babes Bolyai University, Cluj-Napoca, Romania, between Oct. 17 and Oct. 23 2010, and during SPALI10 (SPAnish Lidar intercomparison 2010) at the Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), in Madrid, Spain, between Oct. 18 and Nov. 05 2010. During ALI09 (Alomar Lidar Intercomparison 2009) at Alomar/Andenes, Norway, between October 22 and November 05, 2009, and during SOLI10 (SOfia Lidar Intercomparison 2010) at the Institute of Electronics, BAS, Sofia, Bulgaria, between Oct. 09 and Oct. 14 2010 only two lidar systems were intercompared at a time. ROLI10 was an additional intercomparison, firstly because the RALI system had been upgraded considerably since EARLI09, and secondly as a support to the Romanian Lidar Network ROLINET. A list of the participants of each campaign can be found in Table 3.2.

Several lidar systems which had not to be compared and some even not being part of EARLINET joined one or the other intercomparison campaign in order to profit from the collected expert knowledge. The fruitful discussions together with the hands-on experience during the campaigns showed to be a very valuable, irreplaceable achievement of the intercomparisons.

In general the reference lidar systems showed a very good agreement with relative deviations of the range corrected lidar signals less than 5%. The reasons for the few exceptions from this agreement could be determined during EARLI09 and subsequently corrected. The comparison with the other lidar systems also revealed good agreement for many channels, but also weak points and deficiencies. The reasons for most of the problems were identified and solutions found, which have been implemented in the meantime or are planned for the near future. The therewith achieved improvements will be checked with the internal checkup tools described in the chapters above, and if necessary the upgraded systems will participate in another direct lidar intercomparison.

Table 3.2: *Lidar systems and wavelength channels which were intercompared during the direct lidar intercomparisons within EARLINET-ASOS. Reference lidar systems are in bold, and lidar systems, which had to be validated during EARLINET-ASOS, are with gray background. (* not EARLINET partners;* ***R*** *= reference lidar system for the campaign,* ***D*** *= linear depolarization channels,* ***H*** *= High spectral resolution channel).*

EARLINET partner / Institution	**Lidar system**	**Wavelengths**					**Campaigns**				
		355 nm	**387 nm or RR**	**532 nm**	**607 nm or RR**	**1064 nm**	**EARLI09**	**ALI 09**	**SOLI10**	**ROLI10**	**SPALI10**
MPI-MET,Hamburg, D	**ARL2mobile**	X	X	X	X	X	**X**	**R**			
LMU-MUENCHEN, Munich, D	**POLIS$^{2/3}$ - 2/3 channels**	D^{2}	X^{2}	X^{3}			**R^{2}**		**R^{3}**	**R^{3}**	
LMU-MUENCHEN, Munich, D	**MULIS**	X	X	D	X	X	**R**				
LMR-mobile, Minsk, UA	**LMR-mobile**	X	X	D	X	X	**X**				
CNR-IMAA, Potenza, I	**MUSA**	X	X	D	X	X	**X**				**R**
IfT, Leipzig, D	MARTHA	X	X	D	X	X	X				
IfT, Leipzig, D	PollyXT	D	X	X	X	X	X				
JRC, Ispra, I	CAML			X			X				
INOE, Bucharest, RO	Raymetrics RALI	X	X	D	X	X	X			X	
IMK-IFU, Garmisch-Part., D	HSRL	X		H		X	X				
RIVM, Bilthoven, NL	CAELI	X	X	D	X	X	X				
NILU/ARR/UiO, Andenes, N	tropospheric lidar	X	X	D		X		X			
IE-BAS, Sofia, BG	CoBr lidar			X					X		
IE-BAS, Sofia, BG	NdYAG lidar			X					X		
Politehnica University of Timisoara, RO*	TOLI			X						X	
INOE, Bucharest, RO	MILI	D								X	
Babes Bolyai University of Cluj-Napoca, RO*	COLI			X						X	
NTUA, Athens, GR	Raymetrics RM108	D	X							X	
CIEMAT, Madrid, E	LIDAR-CIEMAT	X		X	X	X					X
CEAMA, Granada, E	Raymetrics LR313-D400	X	X	D	X	X					X
Universidade de Évora, Évora, P	PAOLI (PollyXT)	X	X	X	X						X
UPC, Barcelona, E	UPC_MRL	X	X	X	X	X					X

Quality assurance of algorithms NA3.2

Since the main goal of EARLINET-ASOS was to establish a comprehensive statistically representative data set of the aerosol vertical distribution it was very important to have a quality assurance for the software algorithms used for the evaluation from lidar signals to the optical backscatter and extinction-coefficient profiles. Furthermore, 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 data set and its use in comparative studies are major objectives of EARLINET-ASOS, specific attention is given to data quality assurance. Most of the lidar systems transmit at least two wavelengths between the ultraviolet (UV) and the near infrared (NIR) spectral region. A large number of systems are also equipped with Raman channels to detect the inelastic Raman backscattering from nitrogen molecules to derive quantitative aerosol extinction profiles. The EARLINET community had already extensive and well established experiences in algorithm inter-comparisons from the previous project EARLINET (2000-2003) concerning the backscatter algorithm software as well as the Raman algorithm software.

Concerning NA3.2 “Quality assurance of the inversion algorithms” an inter-comparison of aerosol backscatter lidar and Raman lidar algorithms was performed during the first year of the EARLINET-ASOS project. The objective of this activity was to test the correctness of the algorithms and the influence of the lidar ratio profile, the reference values and the temperature and pressure profiles for calculation of backscatter coefficient and extinction coefficient profiles from the lidar signals. This inter-comparison exercise was conducted for all the new or recently added stations and for all the stations that have upgraded the system with Raman channel or changed their evaluation procedure in any significant way.

During the second year, synthetic lidar signals, both elastic and Raman, were distributed to ALL stations together with the solution, see the EARLINET-ASOS web page, http://www.earlinetasos.org/index.php?id=92, as a tool for an internal check for all participants. The results are shown as an example for the wavelength 532 nm in Figure 3.6 (a), (b), (c).

Moreover, all groups were asked to deliver error bars for the Raman-extinction profiles as well as for the Klett-backscatter profile for each wavelength as an accuracy control as well as for additional information to the database. This is necessary, firstly, since without error bars measurements are more or less worthless. Secondly, those error bars are very important for the EARLINET database since later users of the data base needs to know about the accuracy level of the profiles, e.g. the retrieval of microphysical properties from the optical profiles via regularization techniques needs for the necessary parameter-choice rule the error level of the given data.

During the third and fourth year some groups improved their algorithms and error bar calculation techniques. Also three additional groups participated to the algorithm inter-comparison, see Table 3.3 for an overview of participating groups.

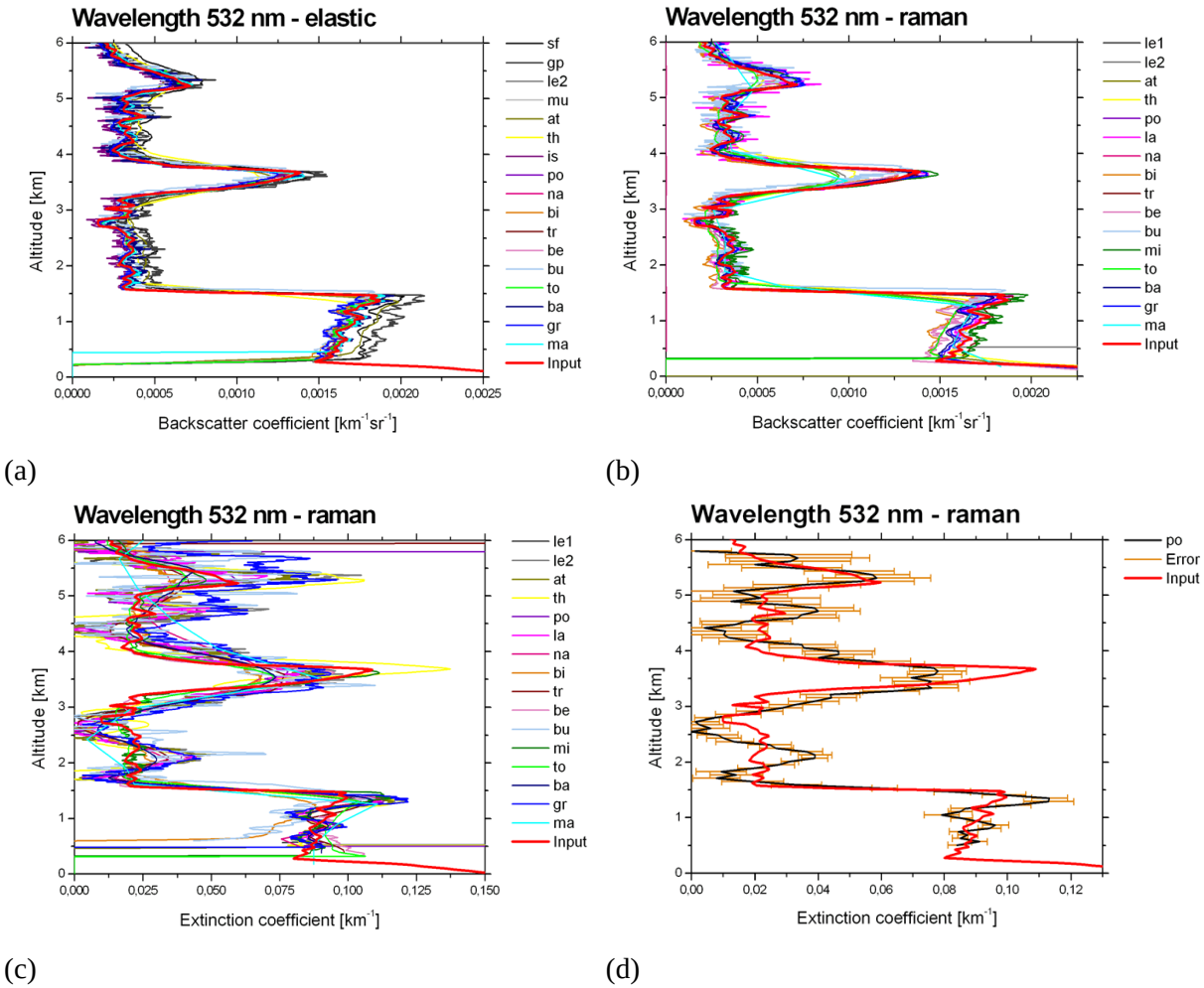

***Figure 3.6**: Results of the inter-comparisons for elastic signals (a) and (b) for the Raman signals at 532 nm as well as an example for the error bar analysis via Monte-Carlo technique (d).*

Table 3.3: *Participating groups in software inter-comparison*

	Lidar group	status		error bars
sf	Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria (IE-BAS)	elastic	inelastic	yes
gr	Grupo de Fisica de la Atmósfera Universidad de Granade, Granade, Spain	elastic	inelastic	yes
at	Department of Physics, National Technical University of Athens, Greece	elastic	inelastic	yes
le1	Institute for Tropospheric Research Leipzig, Germany (Polly lidar system)		inelastic	yes
le2	Institute for Tropospheric Research Leipzig, Germany (Martha lidar system)	elastic	inelastic	yes
ma	CIEMAT Madrid, Spain	elastic	inelastic	yes
bu	INOE National Institute of R+D for Optoelectronics, Bucharest, Romania	elastic	inelastic	yes
po	CNR-IMAA Potenza, Italy	elastic	inelastic	yes
th	Aristotleleo Panepistimio Thessalonikis Thessaloniki, Greece	elastic	inelastic	yes
na	Instituto Nazionale per la Fisica della Materia Napoli, Italy	elastic	inelastic	yes
ba	Universitat Politecnica de Catalunya Barcelona, Spain	elastic	inelastic	yes
mu	Ludwigs-Maximilians-Universität Munich, Germany	elastic	inelastic	yes
la	Universita degli Studi L'Aquila L'Aquila, Italy		inelastic	yes
mi	B.I. Stepanov Inst. of Physics (BISIP.SMO) Minsk, Belaruss		inelastic	yes
to	Institute of Atmospheric Optics (guest) Tomsk, Russia	elastic	inelastic	yes
bi	National Institute for Public Health and Environment Bilthoven, The Netherlands	elastic	inelastic	
be	Institute of Geophysics Belsk, Poland, (IG-PAS)	elastic	inelastic	
tr	Norwegian Institute for Air Research Tromsö, Norway, (NILU)	elastic	inelastic	
gp	Inst. für Meteorologie und Klimaforschung Garmisch-Patenkirchen, Germany (FZK)	elastic		
is	JRC Institute for Environment and Sustainability, Ispra, Italy	elastic		
lk	Swedish Defence Research Agency (FOI) Linköping, Sweden	elastic		
hh	Meteorological Institute (MPI) Hamburg, Germany		inelastic	yes
pl	IPSL University of Paris Paris, France	elastic		yes
co	University College Cork, Physics Dept., Cork, Ireland		inelastic	yes

The last years of the project were devoted to evaluate the quality of common algorithms used in the retrieval of derived optical aerosol properties, like backscatter and extinction. In particular, the comparison has been applied to the automatic algorithms developed in the frame of NA5 and implemented in the Single Calculus Chain (SCC). This is a very crucial point, because the Single Calculus Chain is the tool provided to all the partners to retrieve the derived aerosol optical properties to be released to the EARLINET database. The quality of the derived products is fundamental for the quality of the database. The criticism is related also to the fact that data come from different and not standardized instruments used by individual groups. Differences exist for the wavelengths used, acquisition mode (analog and/or photoncounting), space resolution, detection systems. The quality assurance test has been performed in two steps. The first step has been the assessment of SCC retrieval applying the algorithms to the same synthetic lidar signals used in the previous algorithm inter-comparison exercises. The second step has been the assessment of the SCC retrieval using experimental data. In this case, the comparison has been carried out among the derived products retrieved by the algorithms of the single stations (already quality assured) and the same derived products retrieved by the SCC. This comparison has been performed on data acquired during the EARLI09 inter-comparison measurement campaign. This dataset represents an optimal benchmark for the test, because during the campaign eleven lidar systems, with quality assured retrieval algorithms, performed measurements co-located and simultaneously.
The results of the inter-comparison of the derived products between the Single Calculus Chain retrieval and the synthetic input data was excellent both in terms of shape and of statistical error. Concerning the comparison using experimental data, the retrievals of backscatter and extinction obtained with the Single Calculus Chain and the same products obtained with the data analysis performed with the algorithms of the single groups, already quality assured previously, also in this case it gives good results both in terms of shape and of statistical error. The result is very important, because it demonstrates that the common algorithms developed in the frame of the activity NA5 and implemented in the Single Calculus Chain have been assessed to produce quality controlled data. The Single calculus Chain will be the calculus tool that will provide derived products to the EARLINET database starting from raw lidar signals. This will assure that the data in the EARLINET database will be quality controlled.

Networking Activity 4: Optimisation of instruments

The objective of this activity is to improve the instruments of the observation system by selecting the optimal approach from the various solutions existing at individual stations, for the components and subsystems as well as for system integration. In system integration emphasis is on automation of operation in order to reduce the necessary manpower, to improve temporal coverage, and to make the performance independent from operator characteristics.

This objective should be looked upon from the EARLINET-ASOS perspective, which is:
"… 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. …"

Other keywords for this activity are: homogenisation and standardisation of instruments with the object of achieving similar performance across the networks stations. The number of instrumental details to be addressed to accomplish these tasks can become very large, considering the wide variety of issues and lidar systems involved. Therefore, activity NA4 started looking for optimisations fitting the following overall goals:

- Optimal performance for the main data products of our lidars for aerosol pro-filing: i.e. aerosol backscatter profiles, aerosol extinction profiles and lidar ratio. The minimum recommendation for an optimised product is to add a nitrogen Raman channel to a backscatter lidar.
- Daytime performance
  Aerosol radiative properties play their most important role during daytime. Aerosol characteristic can change in relatively short periods of time. The lidar ratio obtained during nighttime measurements can differ significantly from that actually occurring in aerosols whose elastic backscatter is measured during daytime hours before or after. Therefore daytime measurements of the aerosol properties are needed and technical solution to accomplish this are collected.
- Increased operationality
  Increase automation in instrument control so that more data will become available, at a reduced manpower/data ratio.

Contrary to some other observational networks, such as the MPL-net and AERONET that are largely based on standardised and even commercialised instruments, most EARLINET stations are equipped with lidars that were not series-produced and consequently these instruments are different in set-up and construction among each other. As an illustration, pictures of several lidar instruments installed in the network are shown in Fig. 4.1. As a consequence to the instrumental differences, the performance of the individual instruments can be quite different, for instance with respect to the altitude range covered or the number of operating wavelengths.

This task in EARLINET-ASOS is to optimize individual instruments with the aim of homogenization of aerosol data products over the network and increased data coverage by automation. The approach to accomplish this is by selection of the optimal approach from the various solutions existing at individual stations for components and subsystems.

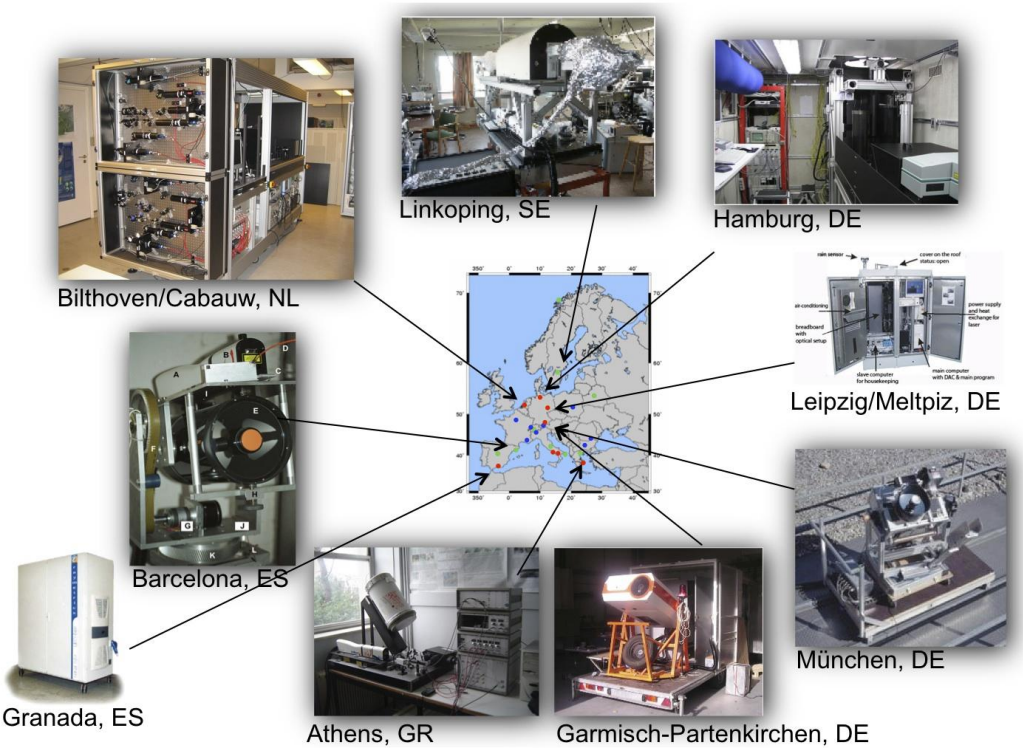

***Figure 4.1**: A collection of pictures from a few instruments in EARLINET. Most systems were custom built by researchers. A few commercial instruments are also part of the network – depicted at Granada and Leipizg.*

System integration is a separate subject, since it is not directly related to the scientific data products that are produced, but proper integration as well as automation, have significant impact on reliability and operability of a lidar instrument. So proper integration is a prerequisite to steady and reliable dataflow and to make performance independent from individual instrument operators.

Inversion algorithms to obtain microphysical aerosol properties such as effective radius, volume and surface-area concentration, real and imaginary part of the complex refractive index, and single-scattering albedo from multi-wavelength Raman lidar observations have become available and are further developed in EARLINET-ASOS. Backscatter coefficients at three wavelengths (usually 355, 532, 1064 nm) plus extinction coefficients at two wavelengths (usually 355, 532 nm) are the minimum required input data for such inversion schemes. EARLINET strives to increase the number of stations equipped with such high-performance instruments and the approach for optimization and tools play an important part in this. With our approach, future expansion of EARLINET data products is also facilitated through instrumental development.

Approach

Since no funds were allocated from the project to the activity for upgrades of individual instruments, all improvements would have to be based on contributions from individual

partners. As a network activity, sharing of instrumental and technological knowledge generated by individual groups was the basis.

Handbook of Instruments

In the approach chosen, a format was developed to comprehensively describe the installed base of instruments in the network. This description, called the Handbook of Instruments, consists of a table of system parameters that was completed by all network partners and associated partners. Not only provides the handbook an overview of the general capabilities of individual instruments. With the parameters in the handbook, it is also possible to globally simulate the most important performance parameters of each individual instrument, e.g. closest measurement range, daylight background suppression, sensitivity and noise. Results from such simulations can be compared to actual system performance.

Two updates of the handbook were provided as deliverables to the project; one at the start of the project and one at the end. In this way the development of the network could be monitored.

Instrument optimisation

The approach was based on the extensive list of system parameters in the Handbook of Instruments and a set of tools that were used to evaluate actual system performance against requirements for the EARLINET database on the one hand and the expected system performance based on the data provided in the Handbook of Instruments on the other.

The general approach can be broken down in the following iterative sequence:

1. Collect essential system information and compile it in the handbook of instruments (HoI)
2. Define criteria for system performance, according to requirements of the EARLINET database (i.e. maximum error of aerosol properties vs. height. These requirements will be classified in a number of categories. Suggested are PBL, PBL+ residual layers, Upper free troposphere)
3. Develop and apply tools to assess individual system performance, based on data in the HoI, and perhaps system inter-comparisons
4. Check the system performance against the requirements in 2.
5. If errors are found to be outside the requirements, optimisations are needed
6. HoI can be used to find improvements and implement them. Perhaps new technologies need to be developed.
7. Update HoI
8. Re-iterate from 4

In order to execute the optimisation sequence several tools were developed, also in collaboration with NA3 “Quality Assurance”.

Expertise about specific solutions were discussed during the workshops and documented on the EARLINET internal webpages. From this expertise, other partners could benefit and select solutions that were best suited for their instruments.

System Integration

Optimal system integration solutions depend very much on the location and housing of the individual instruments. A nested approach was chosen to break down solutions in a modular way. This structure is schematically represented in Fig.4.2. Again, expertise about specific solutions were discussed during the workshops and documented on the EARLINET internal webpages. From this expertise, other partners were able to benefit and select solutions that were best suited for their instruments.

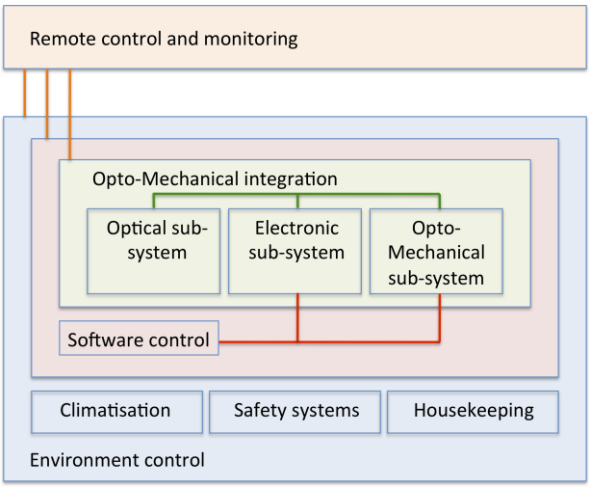

***Figure 4.2**: Nested structure for aerosol lidar system integration. Each coloured box represents a new level around the main instrument that is in the centre. For a stand-alone instrument, remote control could be implemented, if underlying sub-systems are sufficiently automated.*

Commercial components and systems

During the five years project commercial subsystems for lidar systems have been investigated starting from the experience of the different lidar groups within the consortium.

From the requirements of quantitative aerosol profiling, the Raman lidar technique has become the default for the EARLINET installed base of instruments.
It has been demonstrated that a quantitative aerosol Raman lidar can be robustly built with standard, commercially available Nd:YAG lasers. The use of this type of laser already implies which wavelength, or wavelengths are emitted and which options exist for detection. Therefore, the range of properties of the optical components is restricted. However, given the fact that many participating groups may have different sets of research questions, i.e. the desired set of measured parameters may vary, different implementations result. This is reflected in the EARLINET handbook of instruments (HoI). Therefore, no 'golden standard' is recommended from NA4 but rather, a range of possible solutions is given.

For building new systems from the ground up, a range of parts and sub-systems are available. Many of those parts can be found through communication with network members and can be purchased off-the-shelf or from catalogs. These parts include lasers, telescopes, lenses,

mirrors, optical fibers, trigger and delay generators, transient digitizers, photomupltipliers, etc.. Some parts, however, need to be custom made, and have to be specified for each batch produced. To this purpose common specifications have been defined depending on the particular design of the system under development.

End Results

The EARLINET-ASOS implementation of the handbook is currently the most comprehensive handbook for lidar instruments in the world. Representatives from other lidar networks (GALION, NDACC) have expressed interest in adopting the approach of the EARLINET handbook of instruments.

As an example of an end result an overview of the system configurations distilled from the handbook is presented in Tab.4.1. In this table, the configurations over several stages of the development of the network are shown; at the start of EARLINET (2000), at the start of EARLINET-ASOS (2006) and at the end of EARLINET-ASOS (2011). EARLINET is a network that is strongly in development – 22 lidars in 2000, 33 lidars in 2010 with the number or Raman capable systems increasing from 8 to 27 over this period.

Overall, more parameters can now be measured thanks to the increased complexity of the systems. This increase of parameters/complexity fully supports the main goals of quantitative aerosol profiling with muti-wavelength Raman lidar techniques. Therefore the performance of the network has increased in this dimension as well.

In the development of the network we also observe the adoption of new techniques for aerosol profiling. In particular, new technologies have enabled the use of pure-rotational Raman channels. Using this technique, usually better daytime performance is gained, which is important for combined use of aerosol lidar data with passive (sun-light dependent) measurements, e.g. sunphotometers. At the same time, two pure rotational Raman channel bands give access to temperature measurements.

Alternative techniques were also adopted. For one station, the high-spectral resolution lidar (HSRL) technique for aerosol profiling has been implemented.

The information in Tab. 4.1 is graphically represented in Fig. 4.3. For this graph, the number of configurations of lidar systems has be counted in terms of the aerosol profiling capabilities. That is, additional capabilities for depolarization and water vapour measurements etc.. were not regarded. Here it becomes visible that while the most frequent system configuration in the year 2000 was a single wavelength backscatter lidar, in 2011 the most frequent system configuration is now a 3+2 system.

At a more detailed level, the Handbook of Instruments provides information on further standardization in sub-systems which has taken place. In particular we see that, the types of digitizers, detectors, optical components, imaging systems and overlap techniques developed in one or a few stations, have been adopted by other stations, where possible.

In-house developments, as well as close collaboration with SME’s have enabled the development of the network.

Some in-house developments can now be obtained, but not always through SME's. Volumes are probably too small for highly specialised equipment to be series produced.

Complete Raman capable lidar systems have resulted from collaborations of EARLINET members with industry. These systems are now incorporated in the network in several (new) stations.

***Table 4.1**: Overview of development of EARLINET instruments since the start of the network in 2000. For each station, the instrument name is listed with the location (latitude, longitude) and the respective configurations over the years. Note that some existing stations were removed from the network, while other stations were added. Also, more than one instrument may be present for one station. The configurations are coded with 'b' for backscatter, 'v' for vibrational Raman, 'd' for depolarization and 'r' for rotational Raman. The number in front of each letter indicates the number of wavelengths for which the 'v', 'b', 'd' is measured. Further capabilities indicated are 'wv' for water vapour and 'lw' for liquid water.*

Code	Station	System name	Country	Lat	Lon	2000	2006	2011
AB	Aberystwyth		GB	52.4 N	4.06 W	1b+1v+wv	-	-
AN	Andenes	ALOMAR Troposphere Lidar	NO	69.278 N	16.008 E	-	3b+2v+1d+wv	3b+2v+1d
AT	Athens	EOLE	GR	37.9716 N	23.7875 E	1b	3b+2v+wv	3b+2v+wv
BA	Barcelona	UPCLidar	ES	41.393 N	2.120 E	1b	2b	3b+2v+wv
BE	Belsk		PO	51.5 N	20.47 E	3b	2b	3b
BU	Bucharest	LISA	RO	44.348 N	26.029 E	-	2b	2b
		RALI				-	-	3b+2v+1d+wv
CA	Cabauw	RBL	NL	51.97 N	4.93 E	-	1b	-
		Caeli				-	3b+2v+1d+wv	3b+2v+1d+wv
EV	Evora	PAOLI (Polly-XT)	PT	38.568 N	7.912 W	-	-	3b+2v
GP	Garmisch-Partenkirchen		DE	47.476 N	11.063 E	3b	-	-
		NDSC lidar				-	2b+1d	2b+1d
		HSRL				-	3b+1v	3b+1v
GR	Granada	Raymetrics LR321 - D400	ES	37.164 N	3.605 W	-	3b+1v+1d+wv	3b+2v+1d+wv
HH	Hamburg	ARL2	DE	53.568 N	9.973 E	1b+1v+1d	3b+2r	3b+1v+1d+2r+wv
HP	Saint-Michel (HP)	LTA-LOR	FR	43.935 N	5.712 E	-	1b+1v+wv	1b+1v+wv
IS	Ispra	CIMEL	IT	45.811 N	8.621 E	-	1b	1b
	Kühlungsborn		DE	54.1167 N	11.7667E	3b+2v+2r+1d+wv	-	-
LA	L'Acquila		IT	42.344 N	13.327 E	1b+1v+wv	1b+1v+wv+lw	1b+1v+wv+lw
LS	Lausanne	EPFL-MeteoSwiss	CH	46.5481 N	7.9839 E	3b+1v+1d	2b+2v	-
	Payerne	RALMO		46.812 N	6.943 E	-	1b+1v+2r+wv	1b+1v+2r+wv
LC	Lecce	UniLe	IT	40.33 N	18.10 E	1b+1v+wv	1b+1v+wv	1b+1v+wv
LE	Leipzig	Martha	DE	51.35 N	12.43 E	3b+2v+1d+2r+wv	3b+2v+1d+2r+wv	3b+2v+1d+wv
		Polly				-	1b+1v	-
		Polly-XT				-	-	3b+2v+1d
LK	Linköping	FOI UV Lidar	SE	58.392 N	15.575 E	1b	2b+2v	2b+2v
LI	Lisbon		PT	37 N	8.5 W	1b	-	-
MA	Madrid	LIDAR-CIEMAT	ES	40.456 N	3.726 W	-	1b+1v	3b+2v
MI	Minsk	MSTL-2	BY	53.917 N	27.383 E	2b	4b+1v+1d	4b+2v+1d
		LMR-Mobile				-	-	3b+2v+1d
MS	Maisach	POLIS	DE	48.209 N	11.258 E	-	1b+1v+1d	1b+1v+1d/2b+1d
MU	München	MULIS	DE	48.15 N	11.57 E	3b	3b+2v+1d	3b+2v+1d
NA	Napoli		IT	40.833 N	14.183 E	1b	3b+2v+wv	2b+2v+1d+wv
NE	Neuchatel		CH	47.001 N	6.955 E	3b+1d	-	-
		MAL-ground				-	1b+1d	1b+1d
NZ	Ness-Ziona	IIBR	IL	31.55 N	34.47 E	-	-	2b
OX	Oxylithos	EOLE-OXY	GR	38.55 N	24.13 E	-	-	1b
PL	Palaiseau	LNA	FR	48.42 N	2.16 E	2b+2d	2b+2d	2b+2d
		ALS450				-	-	1b
PO	Potenza	PEARL	IT	40.6 N	15.733 E	2b+1v	3b+2v+1d+wv	3b+2v+1d+wv
		MUSA				-	-	3b+2v
SF	Sofia	Sofia-EARLINET station IE	BU	42.65 N	24.38 E	2b	3b+1v	4b+1v
TH	Thessaloniki	AUTH	GR	40.5N	22.9 E	1b	2b+1v	2b+2v

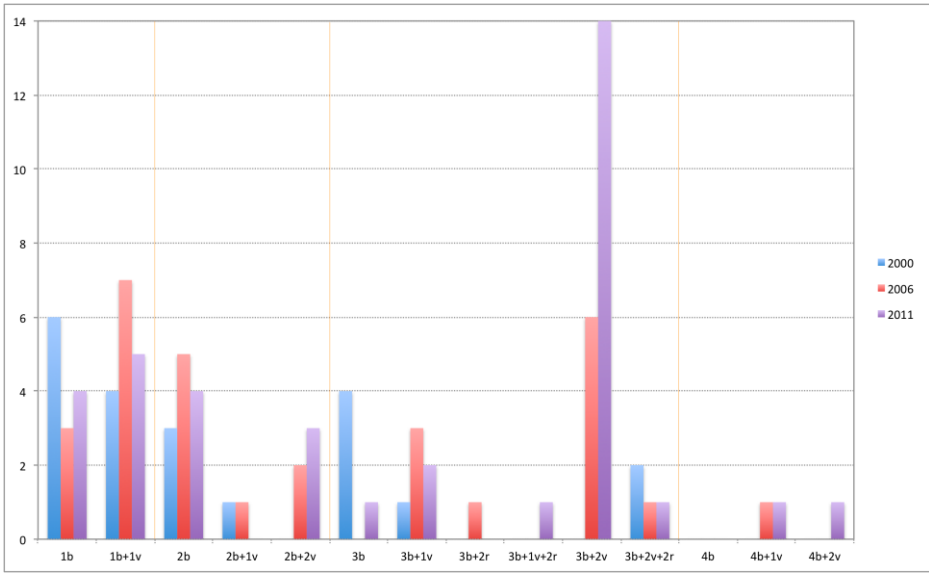

***Figure 4.3**: Frequency distribution of lidar system configurations of EARLINET.*

Involved contractors

All contractors in the EARLINET-ASOS project participated to this activity, as well as EARLINET-ASOS associated partners, EARLINET institutional members and new EARLINET members.

Networking Activity 5: Optimisation of data processing

Introduction

The optimization of lidar data processing, Activity 5, represents an important and innovative part of the project. The main objective of this activity has been to provide all partners with the possibility to use a common calculus system (the Single Calculus Chain – SCC) for the evaluation of their data, from raw signals to final products, so providing the EARLINET database with homogeneous results of well characterized quality results in nearly real time.
The main difficulty consisted in handling raw data coming from different and not standardized instruments used by individual groups. Differences exist for the wavelengths used, acquisition mode (analog and/or photoncounting), space resolution, detection systems. Moreover, the implementation of the SCC analysis algorithms had to match all the analysis algorithms developed by each group.
The above argumentations evidence that the aim of the activity was a real challenge. The reached goal of this activity will produce a great benefit for scientific community because of the quality and the fast availability of the aerosol data in the EARLINET database.
The activity was articulated in three tasks: 1) the optimisation of data processing to retrieve aerosol optical properties; 2) the optimisation of data processing to retrieve aerosol microphysical properties; 3) the implementation of a common calculus chain processing procedure for the automatic retrieval of aerosol properties.
The specific goals of the activity have been:

- implementation of an optimised algorithm to retrieve, in an automatic way and without the need for operator interaction, aerosol optical properties, such as extinction and backscatter coefficients, lidar ratio, optical depth, Ångström coefficient using Raman lidar signals, or backscatter coefficients and Ångström coefficients using elastic lidar signals only (when no Raman signal is available);
- implementation of the capability of constraining elastic lidar solutions using colocated sun-photometer data;
- implementation of an optimised software package to retrieve aerosol microphysical properties: particle size, surface and volume concentrations, and refractive index from multi-spectral Raman lidar measurements;
- implementation of a software package to derive the microphysical properties of particles in the vertical column starting from combined lidar/photometer data;
- the implementation of a single data processing chain starting from raw lidar data, to include system-dependent pre-processing, and providing aerosol properties as final products.

In the frame of the activity, 5 milestones were reached, as planned, and 10 deliverables were released, as planned, consisting in reports or software.
The SCC was developed to implement the capability to retrieve aerosol optical properties (aerosol extinction, backscatter and lidar ratio). Therefore, it was designed to include the procedures to handle the raw lidar signals before the retrieval of the atmospheric optical parameters through analysis procedures. These topics were developed in the frame of tasks 1 and 3. Concerning the optimization of microphysical aerosol properties retrieval (e.g. effective radius, total volume concentration, single scattering albedo), two different software modules were developed, on the base of the research expertise within the network. This is an added value because the two modules, perfectly running, evidence the strength and the weakness of

two different procedures and offer the opportunity to merge the best of the two approaches in the frame of the critical problem of the microphysical aerosol properties retrieval.
Also the module based on the combination of sun-photometer and lidar data for the retrieval of both optical and microphysical aerosol properties was developed. This is an important feature planned in the frame of the project that enhances the lidar system performances extending the network observation capabilities.
All the partners were involved in this activity. In fact, the calculus procedures developed and implemented in the SCC took into account the different experimental setups, the different handling procedures of raw lidar signals and the different analysis algorithms used within EARLINET. Moreover, also new joined EARLINET members were involved providing their contribution.
The report is structured in the following way: a description of the philosophy, structure and functionality of the SCC developed in the frame of task 3; the description of both pre-processing and processing modules developed in the frame of task 3 and task 1 respectively; the description of the aerosol microphysical properties retrieval modules developed in the frame of task 2; the description of the modules to combine lidar and sun-photometer data for the retrieval of aerosol microphysical properties.

The Single Calculus Chain (SCC)

The basic ideas about the design and the development of the SCC were defined during the first year of the project. These were included in a concept document distributed and discussed within the network. The SCC is characterized by the following features that, on the other hand, have been implemented:

- **platform independency**: all the modules of the SCC must be compilable and installable on any platform;
- **open source philosophy**: the source code of the SCC will be made available within the EARLINET network; in this way all the partners can contribute to the development and to the improvement of the SCC;
- **standard data format**: NetCDF;
- **flexibility:** the user can choose the retrieval procedure suitable for his own instrument just selecting a suitable usecase. In particular several usecases have been implemented within the SCC. To each usecase corresponds a specific way to analyze the lidar data. For example selecting different usecases the user can decide if the low range and high range gluing procedure should be applied to the raw lidar profiles or to the optical products;
- **easy expandibility:** the possibility to handle data from new and upgraded lidar systems without changing the modules of the SCC but only modifying information contained in a database. Moreover, thanks to the modular structure of the SCC, new analysis algorithms can be implemented without major changes.;
- **operability both on a central single server accessible from web and on local server/PC.** The central single server has been hosted and managed by the BSC (Barcelona Supercomputing Center).

In order to take into account all the different calculus subsystems existing within EARLINET (experimental specifications, data pre-processing and processing methods), a collection of all the relevant information was carried out. After a critical analysis of these information, the SCC was designed by defining its architecture, the input and intermediate data files format and

content, and the structure and content of a relational database containing information regarding all EARLINET lidar systems.
The software consists of different modules, schematically represented in Figure 5.1:

- **pre-processing module** for the pre-processing of raw lidar data;
- **processing module** for the automatic retrieval of optical data from pre-processed lidar data;
- calculus module for **microphysical properties retrieval.**

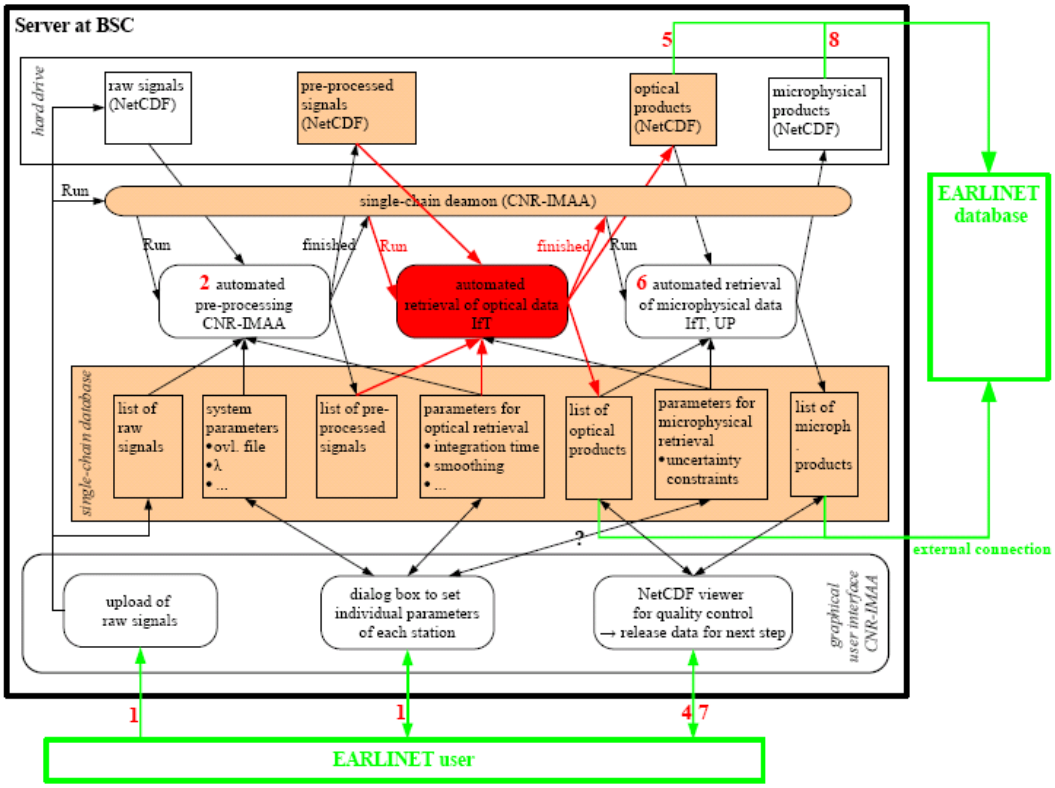

***Figure 5.1**: Block structure of the single calculus chain.*

The modules for the pre-processing and for the retrieval of optical aerosol properties are connected to the other components of the single chain through the following interfaces:

- **the relational SCC database**: used to store system specific parameters which do not change from measurement to measurement and to organize the data transfer between the SCC modules; it is structured very similar to the Handbook of Instrument.
- **input NetCDF files** which contain the raw lidar data coming from lidar systems and parameters which change from measurement to measurement (input for pre-preprocessing module); some parameters can be found only in the input files (those ones changing from measurement to measurement), others can be found only into SCC database, other ones that can be found in both these locations. The SCC can handle four different types of input files: raw ridar data, radiosounding data, overlap function, Lidar Ratio.
- **intermediate NetCDF files** which contain the pre-processed lidar signals (Output of pre-processing module and Input for processing module). They also provide

measurement specific meta data which change from measurement to measurement like measurement, time, comments, Rayleigh scattering profiles etc.

- **output NetCDF files** which contain the profiles of optical aerosol properties (Output of processing module). The format of the output NetCDF files strictly follows the EARLINET rules (for details see [http://www.earlinet.org]).
- **daemon software** to organize the batch mode of the different calculus modules (sending start/stop commands, handling of errors, control of all the operations of the SCC: starts the preprocessing module after that NetCDF input file has been uploaded, starts the processing module after the pre-processing has terminated successfully, etc.). The pre-processing and optical processing modules can be started manually by the user or automatically by the SCC daemon software.
- **web interface,** developed as a prototype and operating through the most common web browsers (Firefox, Opera, Internet Explorer, Chrome) providing a front-end for the daemon software and for the relational database; this interface allows the user to set and get system specific parameters (e.g., used wavelengths), to upload the raw signals, to start the analysis, to re-start the SCC analysis on a measurement without submit again the corresponding raw NetCDF input file, to view the status of the SCC analysis on a measurement.

The SCC, starting from the raw lidar data, calculates aerosol backscatter and extinction profiles, using the combined Raman-elastic method, and aerosol backscatter profiles, using the iterative method when only elastic signals are available. The SCC can handle lidar data acquired by multiscan lidar systems and also timeseries in which the time scales used to acquire the different lidar channels are not necessarily the same.

The pre-processing module implemented in the SCC

Measured lidar signals have to be pre-processed before they can be used to derive optical aerosol properties. The pre-processing module gets system specific parameters from the relational 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.
On the base of the collected calculus systems present within EARLINET, procedures of raw lidar signals handling have been developed and implemented in the SCC. According to the specific lidar system, the following operations can be applied:

- Correction of photoncounting lidar signals for dead time
- Correction of lidar signals for trigger delay
- Subtraction of dark measurement profiles from lidar signals
- Subtraction of atmospheric background from lidar signals
- Time integration of lidar signals over a fixed time window
- Calculation of molecular atmosphere from both model (“US Standard Atmosphere 1976”) and correlative radiosounding, for correction of lidar signals for molecular extinction;
- Interpolation of lidar signals to a fixed vertical resolution
- Gluing of low range and far range lidar profiles

- Overlap correction

The SCC has been tested comparing the performances and the results using both synthetic and experimental lidar signals. The synthetic lidar signals are the same as the signals thate were used for the inter-comparison of algorithms for new stations performed during the project. On the other hand, the experimental lidar signals have been acquired during three EARLINET-ASOS inter-comparison campaigns:

- EARLI09 - Leipzig 05.05.2009-05.06.2009 (involving 11 lidar systems)
- ROLI10 - Bucharest 16.10.2010-24.10.2010 (involving 6 lidar systems)
- SPALI10 - Madrid 18.10.2010-05.11.2010 (involving 5 lidar systems)

The SCC pre-processing and processing modules took part in the EARLINET-ASOS quality assurance program for algorithms. Realistic backscatter and extinction profiles have been used to model synthetic lidar signals. These signals have been analyzed by all participating groups and with the SCC pre-processing and processing modules.
Concerning the comparison with experimental data, Figure 5.2 shows some examples of the pre-processed signals of the stations involved in the three inter-comparison campaigns. The results are excellent with the only exceptions of low range, where the overlap functions of the systems are different.

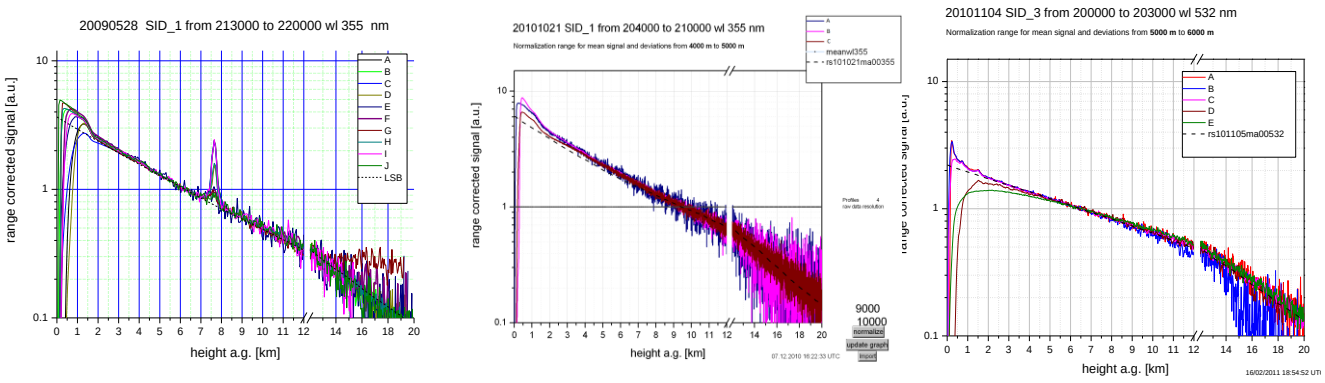

***Figure 5.2**: Comparison between the range corrected pre-processed lidar signals measured during three inter-comparison campaigns: EARLI09 at 355nm (left panel), ROLI10 at 355 nm (middle panel), SPALI10 at 532 nm (right panel). The stations have been conventionally indicated by letters.*

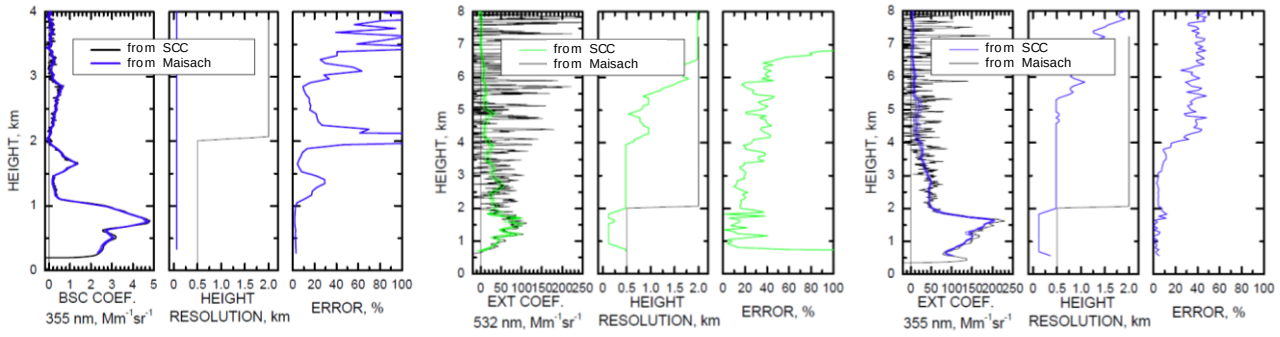

***Figure 5.3**: Comparison of the retrieval obtained using pre-processing and processing modules of SCC with the home retrieval by Maisach group. Raw lidar data are from EARLI09 measurement campaign. Backscatter coefficient at 355nm by Klett retrieval (left panel); extinction coefficient at 532nm (middle panel); extinction coefficient at 355nm (right panel).*

Even if the details of the processing module will be presented in detail in the next section, Figure 5.3 shows an example of comparison between the retrieval of the SCC and the results obtained by Maisach group. The results for the backscatter coefficient at 355nm using Klett method, and for the extinction coefficient at 355nm and 532nm are very satisfactory considering the shape, the resolution and the statistical uncertainty.

The processing module for aerosol optical properties implemented in the SCC

The module of the single-calculus chain for the retrieval of optical particle properties is named *ELDA* (EARLINET Lidar Data Analyzer).

ELDA delivers profiles of the following products:

1) extinction coefficients at different wavelengths, calculated with the Raman method
2) backscatter coefficients at different wavelengths, calculated from a combination of a Raman signal and an elastically backscattered signal
3) backscatter coefficients at different wavelengths from elastically backscattered signals only
4) extinction-to-backscatter (lidar) ratio.

All products are derived completely automatically. It is possible to calculate profiles from signals of two different telescopes (near-range and far-range). If a lidar system splits the polarization components of an elastically backscattered signal before detection, total signals can be recombined and processed by *ELDA*.

Input data for ELDA are intermediate netCDF files that are provided by the pre-processing module of the single calculus chain (see previous section). Those files usually have a vertical and temporal resolution of 60 m and 15 minutes, respectively. The retrieved profiles of optical particle properties are stored in NetCDF files that strictly fulfill the requirements of the EARLINET database format. System specific parameters for the retrieval algorithms (e.g., detection limits or statistical errors that shall be achieved) are stored in a relational database where *ELDA* can read them. ELDA is a command line application that can directly be executed by a user or can be called by the single-calculus-chain daemon. ELDA writes a log file with variable user defined log levels that range from llQuiet (no log output) to llDebug (all messages are logged).

ELDA has been developed with the platform independent programming language Free Pascal. It can be used on Linux, Windows, Mac, and other operating systems. Since the Free Pascal compiler is always the same, it produces identical executables on the different operating systems and platforms. Free Pascal is freely available and comes under the GNU General Public License.

For some retrievals, ELDA provides different alternative algorithms. The user can select the algorithm that fits best to the actual lidar instrument. The selection of algorithms that are implemented in ELDA is based on the assessment, carried out during the project, of all the existing calculus subsystems used within the EARLINET community. All the algorithms were evaluated with respect to their general applicability for the automated algorithms of the single-calculus chain software.

The user can also select between 6 (18) different usecases for the retrieval of extinction (Raman backscatter) profiles. The usecases describe, how the input signals are processed. For instance, the extinction usecase 0 has to be selected if only a single signal is used for the calculation. Usecase 1 describes the case that a photon-counting signal and an analog signal has to be combined in the pre-processing module. Usecase 2 shall be selected if the Raman signals are measured with two different telescopes (for near-range and far-range). In this case, first two extinction profiles are calculated by *ELDA* and then they are combined. The large number of usecases cover all situations that can occur from the large variety of EARLINET lidar systems.
ELDA provides new methods for the automated vertical smoothing and temporal averaging. These algorithms are constraint by some pre-defined thresholds:

- The effective vertical resolution shall not be worse than 500 m below 2-km height and not worse than 2 km above this height. The vertical resolution shall not differ by more than 200 m between neighboring height bins.
- The user can select error thresholds for these two height ranges. The automated averaging and smoothing algorithms try to keep the statistical error of the retrieved products below these thresholds.
- The temporal averaging time must be at least 30 minutes (according to the EARLINET rules) and not larger than 2 hours.

ELDA was validated and tested in two steps. First, as said in the previous section, ELDA took part in the EARLINET ASOS quality assurance program for algorithms. Realistic backscatter and extinction profiles have been used to model synthetic lidar signals. These synthetic signals have been analyzed by all participating groups and also by *ELDA*.

Second, the applicability of *ELDA* was tested with experimental data that were obtained during the EARLI09 campaign in May 2009 in Leipzig, Germany. This campaign was part of the EARLINET ASOS quality assurance program for hardware. Eleven lidar systems from the EARLINET stations in Bilthoven, Bucharest, Garmisch-Partenkirchen, Hamburg, Ispra, Leipzig, Minsk, Maisach, Munich, and Potenza performed one month of co-located, coordinated measurements under different meteorological conditions.

The night-time measurement of May 25, 2009 are presented as an example. The top height of the planetary boundary layer (PBL) was at about 2 km. Above the PBL was a Sahara dust layer up to 8 km height. The time period between 21:00 and 23:00 UTC has been selected for the comparison of backscatter and extinction profiles. The aerosol atmospheric conditions were stationary during this period.
Figure 5.4 shows the extinction coefficients at 355 nm that were obtained with the Raman method from the data of seven EARLINET lidars. Two of the systems are not equipped with the 387-nm Raman channel that is needed for the extinction retrieval. One system requires a special correction for the non-complete overlap between the receiver field-of-view and the laser, but the correction function was not yet provided. Another lidar missed the measurement.

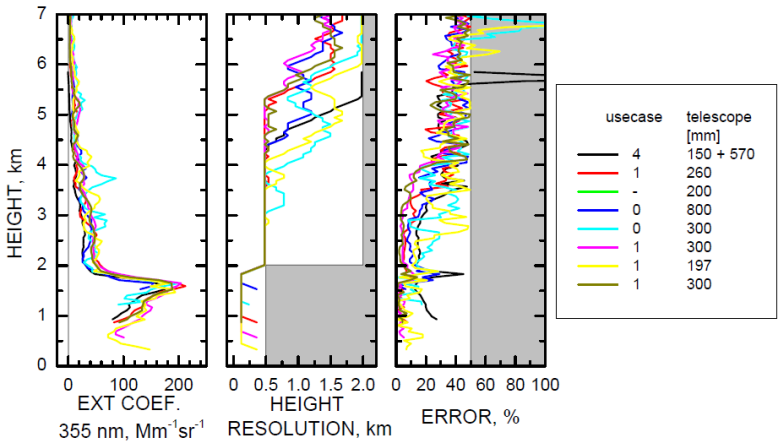

***Figure 5.4**: Extinction coefficients at 355 nm, measured with 7 different EARLINET lidar systems during the EARLI09 campaign in Leipzig on May 25, 2009 between 21:00 and 23:00 UTC. All profiles have been calculated with the scc. The legend lists the different usecases and telescope sizes of the systems. Those measures indicate the variability of the complexity and size of the different lidars. The gray shaded areas show the pre-defined thresholds of the maximum allowable vertical smoothing (height resolution) and statistical errors.*

The agreement of the retrieved extinction profiles is very good. In general, the statistical errors of the extinction profiles are below the pre-defined threshold of 50%. This is achieved by a stronger vertical smoothing in case of lidars with smaller telescopes. The hardware configurations of the participating lidar systems are very inhomogeneous. This variety is reflected by the fact that three different usecases had to be used for the extinction retrieval.

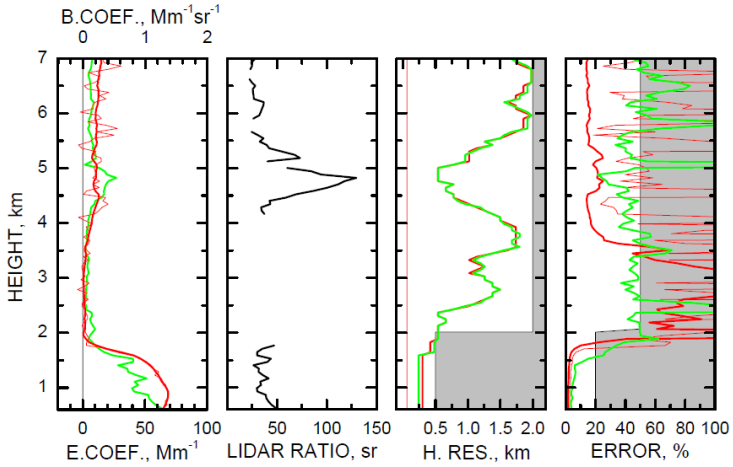

***Figure 5.5**: Retrieval of extinction and backscatter profiles with the same effective vertical resolution (lidar ratio profiles). Red lines correspond to backscatter profiles with raw resolution (thin) and smoothed (bold). Green lines correspond to extinction coefficients. The lidar-ratio profile (black) is calculated only for heights, where both, the extinction and the backscatter coefficients are larger than the detection limits of the specific lidar system (5E-6 Mm^{-1} and 1E-7$Mm^{-1}sr^{-1}$, respectively).*

Figure 5.5 illustrates the retrieval of lidar-ratio profiles. The lidar ratio is defined as the ratio between the particle extinction and backscatter coefficient. This calculation requires, that both

profiles are calculated with the same effective vertical resolution. Usually, the statistical error of the extinction profile is much larger than the error of the backscatter profile. Thus, the extinction needs stronger vertical smoothing than the backscatter profile. *ELDA* first calculates the extinction profile with an automated smoothing and a backscatter profile with a higher vertical resolution. In a next step, the resolution of the backscatter profile needs to be adopted to the extinction resolution by means of Savitzky-Golay filtering.

Figure 5.5 shows the extinction profile (green bold line) together with the backscatter profile in raw resolution (red thin line) and with the vertical resolution of the extinction profile (red bold line). The two bold profiles would be stored in the NetCDF file that is delivered to the EARLINET database. The user or customer of the database then can calculate the resulting lidar-ratio profile (black bold line).

Optimisation of the aerosol microphysical properties retrieval

The retrieval of the aerosol microphysical properties (e.g. aerosol index and size distribution) is a highly complex problem; indeed, mathematically speaking, the problem is ill-posed, meaning that a straight-forward approach to solve this problem does not lead to sensible results, as slightest perturbations in the data can lead to huge discrepancies in the solution. So, special care must be taken in identifying the solution of this problem. Moreover, the theoretical problem chosen for this inversion needs to be custom-tailored to the real problem.
Two different programs were developed for the microphysical inversion following two different approaches: one from the mathematician's point of view and the other from the physicist's. Both programs have been designed independently and in order to achieve a minimal degree of user interaction. The independence of the two codes also offered the opportunity to compare and validate the highly complex algorithms needed for this retrieval.
The first kind of software was developed following an approach based mainly on an optimization from a mathematical point of view. The EARLINET software, developed during the previous project from 2000 to 2003, was able to calculate everything that was needed for retrieval of microphysical parameters. But it was neccessary to improve it in terms of stabilization, semi-automatic retrieval and usability. For one, it was not scalable in any way; the software just ran on one machine and one machine only. Furthermore, that machine needed to run a Microsoft Windows operating system; quite a prerequisite, especially in the scientific community. These issues are addressed with the new version of the EARLINET-ASOS software.
For the EARLINET-ASOS project, the implementation of the software for the retrieval of aerosol microphysical properties via LIDAR has been restarted from scratch. The step of a complete redesign of the software has been taken to mainly achieve four goals (from the technical side), which are

- platform independence
- parallel processing
- stability and accuracy
- user-friendly in- and output

These four technical novelties in the software lead to huge improvements. The advantage of **platform indepedence** is clear - especially in the scientific community, computers running on UNIX operating systems are anything but rareties, and the old software only ran on Microsoft Windows. The new software runs on all important operating systems, like Windows, Linux,

Sun Solaris, etc. The GUI has been programmed with the QT library. The **input and output** of the tool can be either in XML format (for better readability) or NetCDF, for integration into the single chain. Also, we have included a tool which allows to interactively pick aerosol layers from the profiles. For this, we have incorporated the possibility to read and open NetCDF files with the microphysical inversion software, so the optical profiles can be directly fed from the EARLINET database into the software.
In order to retrieve the refractive index, we solve the inversion problem for each point in a rectangular grid between suitable limits m_{Rmin}, m_{Rmax}, m_{Imin} and m_{Imax} and a sufficiently small step size. The points in the grid can be processed in **parallel**, completely independent of each other, which makes our application very well-suited for a cluster-computing enabled parallel implementation that can scale up to hundreds of processors. Figure 5.6 shows the algorithm with two workers. This dynamic approach ensures a well-balanced distribution of load.

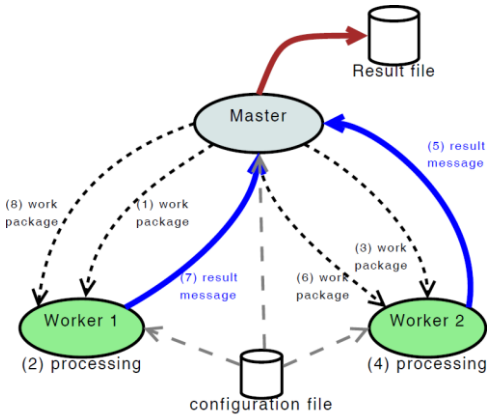

***Figure 5.6**: Master-worker algorithm*

Since the software will be in production use on a small machine consisting of eight processing cores in the EARLINET-ASOS project, the MareNostrum supercomputer located at the BSC (Barcelona Supercomputing Centre) has been used to assess the importance of the different dimensions of the search space. This has indeed produced some interesting results that will make the calculations much faster in the future since many constraints on the search space can be introduced, greatly decreasing the number of regularizations needed to invert lidar profiles.
Also, the **scalability** and **stability** of the parallel algorithm has been assessed, which proved to be excellent (even running with 4000 processing nodes at once, no problems were encountered).
To retrieve aerosol microphysical properties, or the particle distributions, from multiwavelength lidar data, we have to invert a Fredholm integral equation. As this is an ill-posed problem, regularization is needed here, too.
We fully implemented the algorithm from the software of the EARLINET project. This algorithm consisted of a hybrid regularization technique, using both spline collocation as a projection and truncated singular value decomposition as an additional regularization. This algorithm has been made more configurable by adding the choice of exchanging the TSVD here with Tikhonov-Phillips regularization. In addition to that, a new algorithm has also been proposed. This new algorithm is also a hybrid regularization; we still use the same spline collocation as before, but the new algorithm features a part that adapts the set of spline base points to the solution. A projected Padé style iteration is used for that. The projection is used here as a nonnegativity constraint, as we know our solutions will be nonnegative. After the

final set of base points has been found, we restart the Padé iteration without the projection, rendering this algorithm a full regularization technique in the mathemetical sense. Also, the algorithm seems to work well on a varying set of classes of distributions, while the old algorithm worked extremely well only for distribution that are centered around low radii (through the static choice of basepoints). For more details.
To really test the viability of the algorithm, we applied it to real measurement data. We have obtained lidar data for the microphysical inversion from the groups in Bucharest, Hamburg, Munich and Athens. We will now show an inversion example from data taken from Athens. The measurements were taken during a biomass burning event that occurred on June 28- 30, 2007, over Athens. We used our algorithm to retrieve both the size distribution and the refractive index (see Figure 5.7 for details). We can see in Figure 2 that the distribution that has been retrieved is bimodal, which is plausible. As expected, the diagonal in the refractive index grid is clearly visible in Figure 5.7, with a minimum residual error at m = 1:37 and an average index for the ten best points of m = 1:386 + 0:006i. Now, using all the data available, a chemical composition of 2% black carbon and 98% organic carbon for the coarse mode and of 1% black carbon, 49% ammonium sulfate and 51% water for the fine mode is inferred. Entering this data into the ISORROPIA II model results in a refractive index of m = 1:4059 + 0:006i for the coarse mode and of m = 1:4062 + 0:006i for the fine mode. This is in good agreement with the retrieved refractive index of m = 1:386+0:006i:

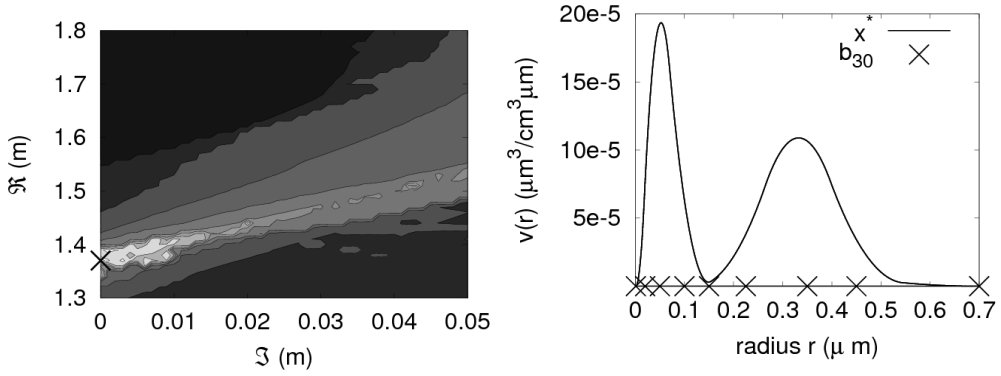

***Figure 5.7**: Refractive index grid (left) and reconstructed distribution (right) for the measurement data from June 29, 2007 from Athens.*

The second kind of software was developed following an approach based mainly on physical point of view. An inversion algorithm has been developed that allows the user to derive microphysical particle properties from optical data acquired with multiwavelength aerosol lidar data. The optical data are backscatter coefficients measured at 355, 532 and 1064 nm, and extinction coefficients measured at 355 and 532 nm. This set of data (data type and measurement wavelengths) is the minimum requirement for a successful retrieval of microphysical data products. The microphysical data products are effective radius, volume and surface, concentration, and complex refractive index. This information allows us to compute the single-scattering albedo (scattering-to-extinction ratio) which is one of the most important input parameters in investigations of the impact of aerosol pollution on climate (climate forcing by aerosols). In this project, the inversion algorithm has been developed to the point that it can be applied by other lidar research groups that operate lidar with the necessary minimum instrument configuration. In the course of EARLINET-ASOS several lidar group upgraded their instruments to this minimum configuration. So now it is possible to provide

microphysical particle parameters on a vertically resolved scale for different locations in Europe. The development required extensive programming work and simulation studies. In the following, the main work and results are highlighted:

1) The software package has been equipped with a multitude of tools, like graphical interfaces which allow for an on-line and near–real time illustrations of the inversion result. Such graphic interface tools are very important as they allows for a highly efficient solution-space post-processing. Data inversion in a first step delivers solutions that may be mathematically sound, but do not make any sense from a physical point of view, i.e., the respective microphysical properties of atmospheric aerosols do not exist. Thus, it is necessary to constrain the mathematical solution space to a physical reasonable output. A multitude of trainings course has been given on site at different EARLINET stations (Athens, Bucharest, Granada, Munich, Potenza, Thessaloniki), but also at IfT (visiting scientists from Athens, Bucharest, Evora, Granada, Naples, Thessaloniki) with the goal of teaching the lidar groups in a proper handling of the graphical interfaces. In the course of this knowledge exchange data acquired with the lidar instruments of these groups were also analyzed. The work with the groups from Thessaloniki and Granada resulted in several publications in peer-reviewed journals.
2) The second main work has been as follows. The inversion algorithm has been developed to the point that a semi-automated data analysis has become possible. This means that an inexperienced user, which usually is the case for the EARLINET consortium, should be able to analyze optical data with reasonable accuracy. This development is very important as staff at a lidar site will usually change after several years. Thus is it clear that any acquired knowledge on operating the inversion software will be sooner or later lost. The development of the inversion software to unsupervised data analysis aims to compensate for this loss of data-operator expertise.
3) Another main work package linked to the programming work involved simulation studies in order to test the performance of the software.

The simulation studies have allowed us to test the software with synthetic optical data (backscatter coefficients at 355, 532, 1064 nm and extinction coefficients at 355 and 532 nm) computed with a Mie-scattering code. The optical data then served as input to the automated inversion methodology. The optical data in this test were assumed error free.
Table 5.1 summarizes the results for the parameters that were tested: effective radius, number concentration, surface-area concentration, volume concentration, complex refractive index, and single-scattering albedo (SSA). Single-scattering albedo is shown for 355, 532, and 1064 nm. Nearly 3000 different optical data sets have been tested.
The retrieval can be considered as successful, if the deviation from the true results is less than 50%. In 87% of all simulation cases , it is possible to derive **effective radius** to better than 50% accuracy. It should pointed out that in all previous versions of the software, which only worked in the hand-operated mode, this accuracy in general could not be achieved.
The 10% accuracy for the **real part** can be achieved in 85% of all cases, which is an excellent value. Regarding **single-scattering albedo**, an accuracy of 10% has been found in 85% (SSA at 355 nm), in 71% (SSA at 532 nm), and in 72% (SSA at 1064) of all investigated cases. The SSA at 355 nm has the highest accuracy. Looking at the accuracy of the individual results, almost always the same pattern can be seen, i.e., the accuracy at 355 nm is the highest.

The overall accuracy of the retrieved **imaginary part**, the requirement is a 50% retrieval accuracy, which in fact is achieved in 48% of all cases. In 33% of all cases a 30% accuracy is achieved which is the final goal of the software development.
The retrieval accuracy regarding **effective radius**, **volume**, and **surface-area concentration** has been accomplished. Regarding number concentration and the real part of the complex refractive index, these are comparably close to our accuracy requirements.
In conclusion, it is possible to state that the automated inversion algorithm is able to identify the correct values of the investigated parameters (size, complex refractive index, extensive size parameters, single-scattering albedo) to an accuracy which is comparable to what has been achieved by hand-operated data analysis in previous studies. In that respect, this version of automated retrieval can be considered as successful software development. In particular, the improved retrieval accuracy of number concentration means a significant step forward in the inversion methodology.

Table 5.1*: Summary of retrieval accuracy of the semi-automated inversion methodology. Shown are the results for 2880 cases that were tested with the software. The parameters of the particle size distributions were as follows: mode radius = 20 nm, 60 nm, 100 nm, 140 nm, 180 nm, 220 nm, 260 nm, and 300 nm. The mode width was set to 1.5, 1.7, 1.9, 2.1, 2.3, and 2.5. The real part of the complex refractive index was 1.4, 1.5, 1.6, and 1.7. The values of the imaginary part were 0i, 0.0001i, 0.001i, 0.0025i, 0.005i, 0.0075i, 0.01i, 0.015i, 0.02i, 0.025i, 0.03i, 0.035i, 0.04i, 0.045i, 0.05i. The meaning of the error levels is as in the previous table.*

Parameter	<5%	5% - 10%	10% - 15%	15% - 20%	10% - 20%	20% - 30%	>20%	30% - 50%	50% - 70%	>50%	>70%
Effective Radius		32			26	15		14		14	
Number Conc.		7.7			10	9.1		18	9.3		45
Surface-Area Con.		67			11	4.8		5.3		12	
Volume Conc.		32			25	13		13		17	
Real Part	58	28	9.5	4.6			0.6				
Imaginary Part		11			11	11		15		5.2	
SSA, 355nm	58	28	9.5	4.6			0.6				
SSA, 532nm	45	26	18	6.6			4				
SSA, 1064nm	46	27	12	6.4			8.5				

The two modules have also been compared. The second algorithm shows a processing speed higher than the first one, but the first algorithm uses high-speed data processing schemes, not yet implemented into the second algorithm, e.g., parallel processing. The second algorithm delivers better results of some of the investigated microphysical parameters (e.g. complex refractive index), while the first algorithm performs better for a different set of the investigated parameters (e.g. size parameters). A synthesis of both algorithms will further improve performance of data inversion.

Aerosol microphysical properties retrieval in the vertical column using combined lidar/photometer data

The AERONET (Aerosol Robotic Network) stations directly measure aerosol optical thickness and from direct and diffuse radiation measurements provide the retrieving detailed microphysical properties of aerosol in the entire atmospheric column. The output includes both retrieved aerosol parameters (size distribution, complex refractive index and partition of spherical/non-spherical particles) and calculated on the basis of the retrieved aerosol properties (e.g. phase function, single scattering albedo, spectral and broad-band fluxes, etc.).

The aerosol columnar properties from AERONET and lidar data on aerosol vertical profiles from lidar networks can be considered as complementary pieces of information describing aerosol properties. Nowadays lidars and sun/sky-scanning radiometers are among the base equipment in complex experiments aimed at studying aerosol transformation and transport.

Nevertheless, lidar and radiometer data are separately processed in accordance with their own algorithms. At the same time, the synergetic processing of co-located radiometric and lidar observations could result in further enhancements of aerosol characterization. Indeed, the lidar algorithms often require some a priori assumptions about aerosol for interpreting lidar observations. The aerosol characteristics derived from radiometer measurements could be utilized for improving those assumptions. As a result, such joint interpretation of lidar and radiometer data can provide superior characterization of aerosol compare to the outcome of detached processing lidar and radiometer observations.

Since many EARLINET stations are equipped with AERONET systems, a methodology to combine lidar and sun-photometer data has been developed.

The method of combining lidar and photometer measuring envisages that two instruments simultaneously operate at the same site. A lidar is to sound the atmosphere over an altitude range contributing to integral aerosol parameters. The structure of algorithm for lidar&photometer data processing is shown in Figure 5.8.

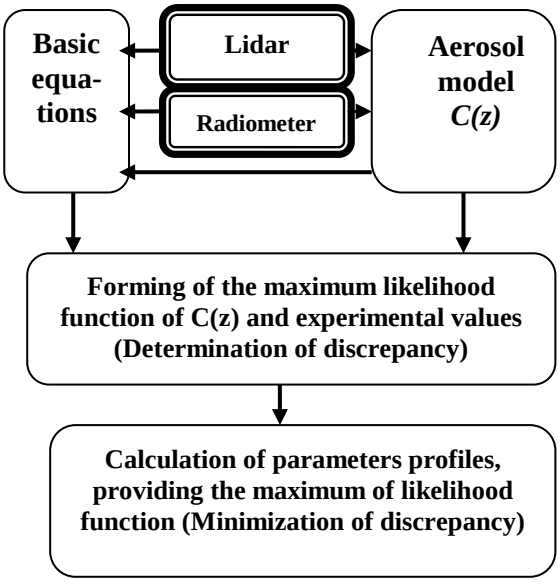

Figure 5.8*:The structure of program package for lidar&photometer data processing*

The algorithm starts from basic equations (multiwavelength lidar equations, integral parameters and characteristics of aerosol layer retrieved from radiometric measurements,

smoothness constraints on concentration distributions) and from the aerosol model containing the concentration distributions *C(z)* as a function of the height *z*. Initial information are lidar signals and integral parameters of aerosol layer from photometer measurements. Through the maximum likelihood function of *C(z)* the algorithm allows to retrieve the concentration distributions, that is the main purpose of the complex lidar and radiometric data processing algorithm.

Conclusions

All the goals planned in the activity were reached and results of high interest were achieved. The activity provided the unique opportunity to share the expertise in data analysis within EARLINET and to build a common analysis calculus chain able to process data in a standard and automatic way, suitable for all the systems. This will produce a great benefit for the end users of the EARLINET database because it guarantees quality and homogeneity of data and the possibility to have data availability in near real time. Moreover, the implementation of the SCC had a positive impact on scientific community also because it demonstrates how it is possible to establish a methodology to develop a common data analysis system within networks equipped with different experimental setups.

On the other hand, the development of modules for microphysical analysis derived from the sharing of the expertise in this field allowed to focus and solve several technical problems related to the retrieval of aerosol microphysical properties starting from lidar data and to implement almost unsupervised retrieval procedures. This aspect was also completed with the implementation of a code to combine lidar and sun-photometer data for the retrieval of aerosol microphysical properties. Also the achieved results in this subject will have a great impact on the scientific community, because they provide a big contribution in the critic problem of the retrieval of aerosol microphysical properties, but also because this is the first attempt to implement automatic procedures for the inversion using lidar measurements.

The carried out research and the achieved results enhanced the EARLINET infrastructure providing it with data analysis calculus systems able to characterize aerosol in terms of both optical and microphysical properties and to provide quality checked, standardized and homogeneous results to the database in an automatic way.

NA6: Database construction and operation

The EARLINET database

Since the year 2000, there have been performed coordinated LIDAR measurements on a continental scale in Europe. The data resulting from these measurements were initially only available as a loose collection of files and the technical correctness of the data was not guaranteed. In this way, it was not possible to work with data from several European stations without investing considerable time in interpreting these files.
It was one of the central objectives of the EARLINET-ASOS project to provide all internal and external users with a single location where they could access all data from all stations of EARLINET-ASOS (and EARLINET as a broader community) in a homogeneous way. This was accomplished by establishing the EARLINET data centre at the Max-Planck-Institute in Hamburg; this data centre is responsible for collection of data from all EARLINET stations. These data are checked for technical correctness before they are made accessible to the public.
To keep a maximum of data available, all data from measurements performed before the EARLINET-ASOS period (2006 – 2011) have been reformatted, checked and added to the database. Additionally measurements from the preceding "Deutsches Lidarnetz", a nationwide German LIDAR network (1998 - 2000), found their way into the EARLINET data set.

Database organisation

The EARLINET database is hosted on a computer located at the Max-Planck-Institute in Hamburg. The storage device used for the database is a redundant RAID5 – array. In addition, this computer is backed up every night to minimize losses in case of a hardware failure.
All LIDAR data in the database are stored in netCDF files. NetCDF (network Common Data Format) is a set of software libraries and machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data. NetCDF allows storing information in a very flexible way. Variables stored in these files are addressed by using their names instead of their position. This makes it possible to extend the predefined set of variables without the need to change existing software to account for these new variables. A number of attributes can be used to further describe the dataset by adding metadata. Today netCDF is a widely used standard for exchange of scientific datasets. It is freely available from Unidata at http://www.unidata.ucar.edu/software/netcdf/.
The compilation and formatting of the files is the responsibility of the individual institutions. During upload, these files are automatically checked for (technical) correctness. Files not matching the EARLINET format specifications are rejected with a printed error protocol. This allows the originator to correct the data immediately. The files are delivered to the end-user as they are. No reformatting is done by the database system.
During upload, the netCDF file is proof - read by a program and checked. If all tests are passed, the data are stored in a relational (SQL-) database. This allows using all data and metadata from the files for further processing like searching specific events or plotting profiles from the data set. After successful upload of the files, the creator is able to add some more information. Therefore, it is possible for example to qualify the measurement as part of the climatological data set or to be part of the observations of a volcanic event.
The user access to the database is realized using two different web pages on two different computers. The data maintenance is provided by logging in to the web page at

http://data.earlinet.org. This page is only accessible for internal users (members of the EARLINET network) and provides write access to the data. Through this interface, the users can only access and manipulate measurements from their own station(s).
Read-only access to the database is realized through the web portal at http://access.earlinet.org/EARLINET. Here internal users as well as external users can search, download and plot information from the database. While internal users have access to all data, external users only can operate on data made public for this purpose.
Additional to the LIDAR profiles, the database holds supplementary data that are accessible to EARLINET members only. Among these data, there are back trajectories stored for every EARLINET station calculated by the German Weather Service (DWD). These data are uploaded by the DWD on a daily base. NASA furthermore uploads a specific subset of CALIPSO satellite data related to Europe and surrounding areas (namely 20°N–80°N, 20°W–50°E).

Database content

The main information stored in the files of the EARLINET database is profiles of aerosol backscatter and aerosol extinction. The EARLINET database only stores quantitative information. There are no qualitative parameters available like range corrected signals or graphical quick looks.
There are two basic types of files defined in the EARLINET database:

1) e-files: these files contain vertical profiles of aerosol backscattering coefficient and of aerosol extinction coefficient retrieved independently without a-priori hypothesis on existing relation between them. Aerosol extinction coefficient is retrieved directly from Raman lidar measurements or from lidar multi angle measurements. Aerosol backscattering coefficient is retrieved from the combination of Raman and elastic lidar measurements. Both parameters are reported with the same vertical resolution and with their statistical errors.

2) b-files: these files contain vertical profiles of aerosol backscattering coefficient. This coefficient has been retrieved from:

    a) only elastic lidar signal, with hypothesis on vertical profile of Lidar Ratio on the base of literature or of local climatological studies. In this case, the vertical profile of the Lidar Ratio (or the constant value used) is also included.

    b) the combination of Raman and elastic measurements, but with a resolution higher than the corresponding reported in e-files. In fact, the improvement of the quality of aerosol extinction coefficient to be reported in e-files requires a degradation of the resolution.

Additional to backscatter and extinction profiles there are a number of optional variables defined in the EARLINET format specification. These variables may be included into the b- (or e-) files. Among these parameters are dust layer height, mixing layer height, depolarization and water vapour mixing ratio.
All files may contain only profiles at one time. However, the EARLINET format is also defined to hold time series of profiles. In this case, it is possible to append to all variables a (unlimited) time dimension.

The originator of the files may introduce new variables to the netCDF – files if required. For this he/she has to define a variable name starting with two underlines. A long name for this variable to explain its meaning as well as units should also be included.

Data Publication Scheme

It has been agreed on a very simple publication scheme for EARLINET 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. All EARLINET members can access these data immediately. They are not visible to the public.
2) In the next step, the data are made public. This is done either by the owner of the data or by the database system according to the publication schedule. The owner shall not change data made public anymore. These data get visible to registered external users who signed the "EARLINET data usage policy" agreement (see Appendix B).
3) In the last step, the data are published in special volumes at the world data centre for climate (WDCC). Assigning a digital object identifier (DOI) to the data makes them citable and hence opens the data access to the world. This process also guaranties the permanent accessibility of the published data from the WDCC as a second source.

To speed up the publication process the EARLINET community arranged the following schedule:

- New data shall be uploaded to the database within 3 months after measurement.
- New data shall be made accessible to the public as soon as possible. Data not made public by the originator will be made public automatically 1 year after the measurement.
- An approval process will be applied to the data within 2 years after measurement.
- Data are published after approval in annual or biannual volumes at WDCC.

Maintenance access

The maintenance of the database is done through a web portal. This portal is accessible for internal users only. The permission to access individual operations on this portal has to be requested for each individual user by the responsible PI. On this web page, the (validated) user can upload new files from his/her own LIDAR station(s) to the database. During upload, the file is checked for correctness. Accepted files are stored in the database immediately and hence get visible to the EARLINET community. After successful upload, the user has the option to assign the measurement to one or more predefined categories. These categories have been created to qualify a measurement to be part of a bigger dataset such as Saharan dust outbreaks or volcano eruption events. It is also possible to manually make files accessible to the public using this web portal. The user may also be validated to remove measurements from the database, as long as the files have not been made public. From that moment on there is no modifying access to the data possible using this web portal. This has been set up that way to allow the consumers to work with stable data sets.

Database status

The database holds files uploaded from 29 groups from the period of January 1998 to December 2010. Some of these groups are not active members of EARLINET anymore.

Nevertheless, all data uploaded once are kept in the database. These 29 groups operated a total of 37 LIDAR stations.

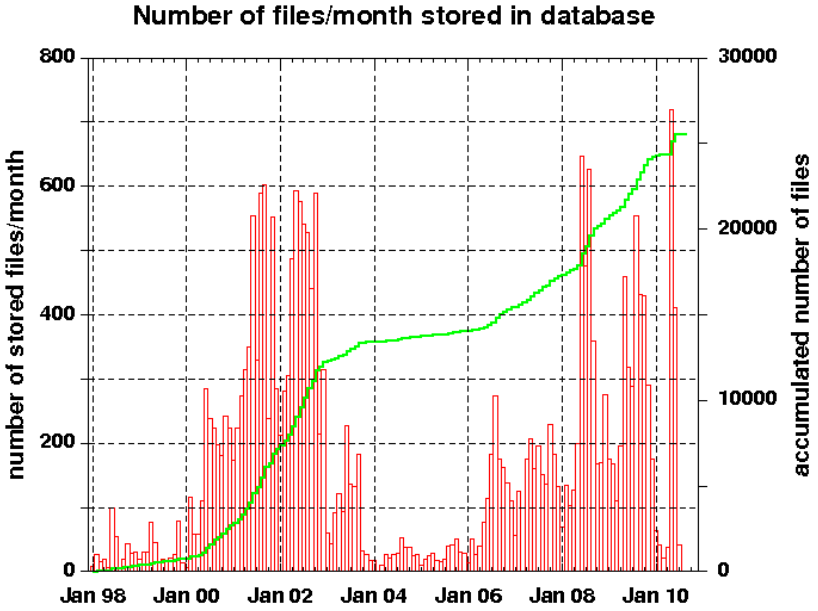

Figure 6.1*: Number of files in the database holding measurements for a certain month. It can be clearly seen that after the very slow start in the "Deutsches Lidarnetz" (1998-2000) the number of measurements increased significantly with start of the funded EARLINET period in the fifth Framework.*

During EARLINET-ASOS from March 2006 to February 2011, 28 stations contributed to the database. During this period, about 16,000 files have been uploaded to the database.
From the beginning of systematically collecting data from coordinated LIDAR measurements 1998 until end of 2010 there has been uploaded to the database a total of 26,779 files. From this more than 24,000 files are accessible by the public.
Many of the files available from the database have been assigned to at least one category. The most prominent categories are:

- 10,812 files have been assigned to the climatological data set. These measurements are performed according to a fixed schedule to provide an unbiased statistically significant data set.
- 6,140 files contain measurements performed in parallel to Calipso – overflights.
- 3,702 files are assigned to Saharan dust outbreaks.
- 1,044 files belong to coordinated measurements during volcanic eruptions. Most of them are related to the Eyjafjallajökull volcano eruption in April/May 2010.

Further predefined categories are: Cirrus (1,238 files), Diurnal Cycles (1,996 files), Forest Fires (313 files), Photo smog (96 files), Urban/Rural (622 files) and Stratosphere (377 files).

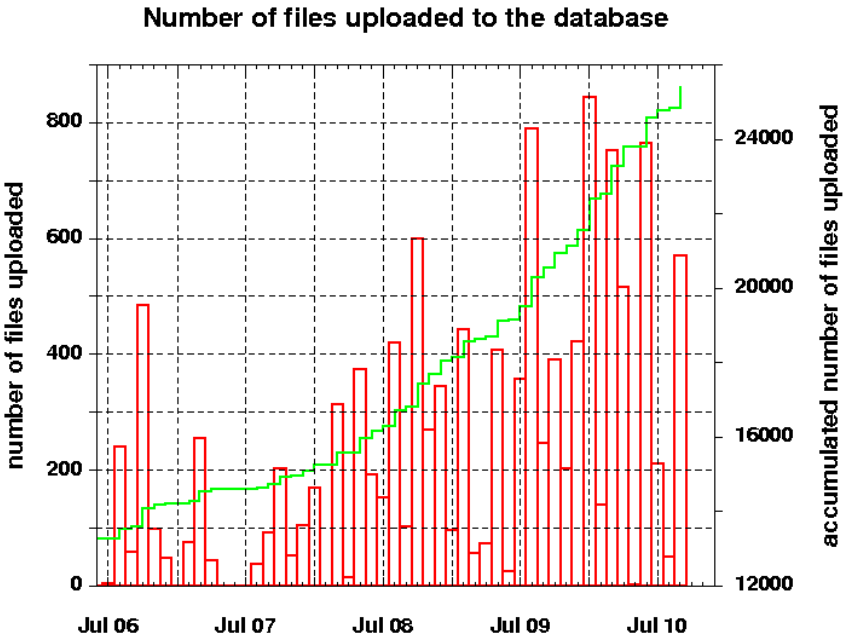

***Figure 6.2**: Number of files uploaded to the database during the EARLINET-ASOS period. As of end of 2010, the number of uploads reached an average of approx. 500 files/month.*

Public Web interface

Like the maintenance access to the database, the public access has been realised with a web portal. The main purpose of this public web portal is to allow users (both project internal and external) to search for data, download files and plot data through a web interface. It is available at http://access.earlinet.org/EARLINET/ and is also available via a link from the main EARLINET site http://www.earlinet.org. The different parts of this web-portal system are presented below.

Access to the EARLINET data and the web portal is restricted, and a username/password is needed to access the system. A user is asked to log in before he/she can access the database.

EARLINET members (internal users) can use their existing accounts (the same accounts they use for uploading data and accessing project internal documentation) to access also the public web interface. External users with no account at the EARLINET database can apply for a username/password by self – registering on this login – page. This registration requires the user to accept the EARLINET data usage policy (see Appendix B).

***Figure 6.3**: Web page to register for access to the EARLIENT database web portal*

After completion of the registration (figure 6.3), the new (external) user gains access to all public data in the EARLINET database by using username and password that are delivered to him by e-mail.
Once logged in, the user may enter the data search page to look for data (figure 6.4). The search page allows the users to search for data by selecting timeframes, specific stations, categories, wavelength and file types. While filling in the search criteria, the number of currently matching datasets is recorded on the bottom line.
When clicking on the "Search" button (from the example in figure 6.4), the result page opens up with an overview of the data-files matching the query. For each file, the result table contains columns with information on the file name, start/end time of measurement, station code, the emission wavelength, publishing date and upload date. The user may click any of the columns and the systems sorts the results according to the chosen column (data files in the result are per default sorted by file-name).

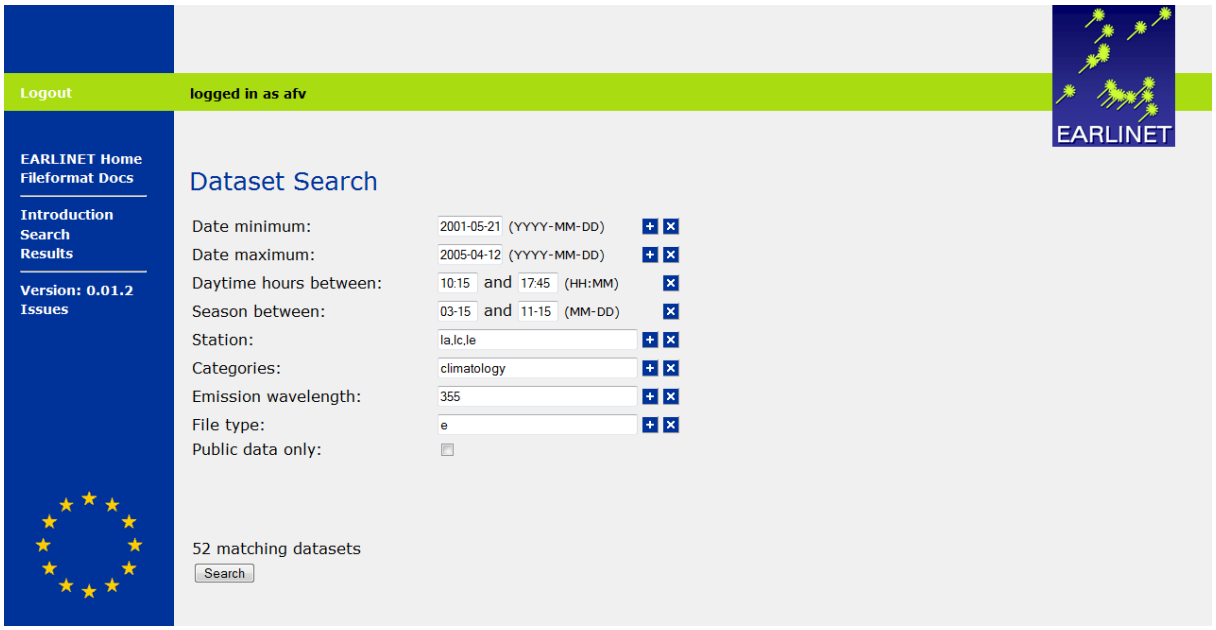

***Figure 6.4**: Web page to search interactively for data in the EARLINET database*

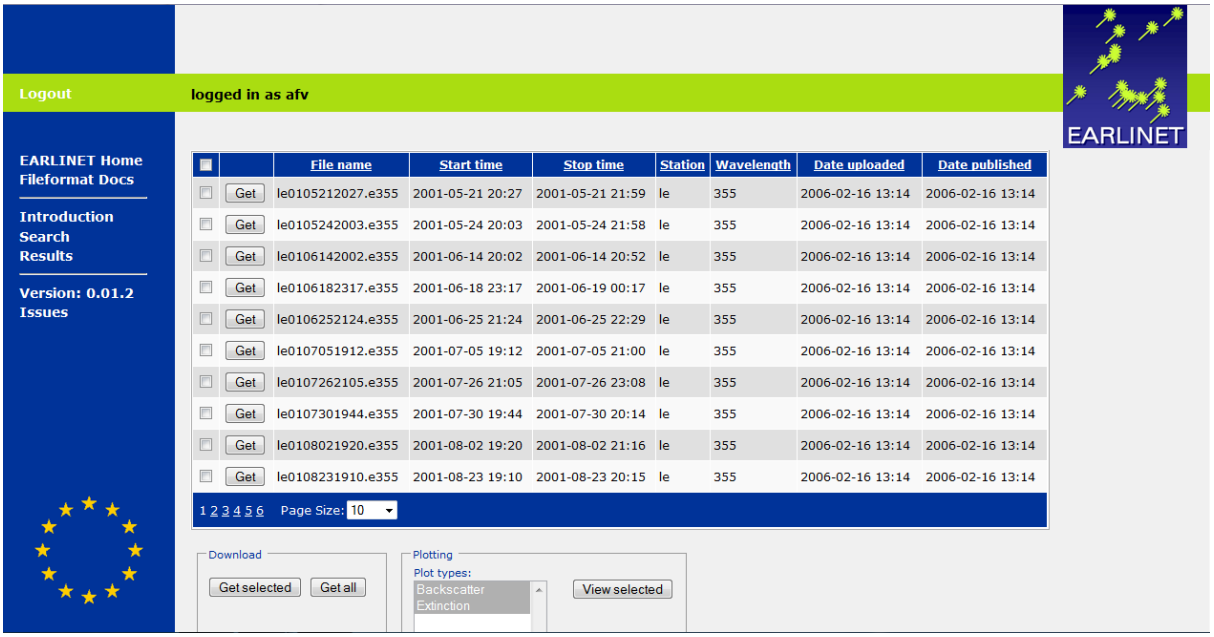

***Figure 6.5**: Web page after a successful search (each data page shows 10 files)*

If the user wants to modify the search criteria, he/she may click the "search" link on the left hand side and the system brings up the search-page with the last used search criteria already filled in. This makes it possible to navigate between the search and result page without having to retype all search parameters every time.
At the bottom of the result page, there are buttons for data download and data plotting. These buttons are to be used after selecting one or more files by clicking in the selection box next to the file name. It is also possible to select all files on the page by clicking the selection box in the top left corner of the result table.
A user can download a single file by clicking on the "Get" button next to the file name. To download more than one file, the user can select any number of files (with the selection boxes) and then click the "Get selected" button in the download area. To get all files matching the search criteria (in the above example, all 52 files), the user may click the "Get all" button instead. When downloading two or more files, the data are delivered in a single zip file
Selecting files from the result table and pressing the "View selected" button plot the profiles from the selected files plotted on the screen. When both backscatter and extinction is chosen, up to two plots are generated for each file.

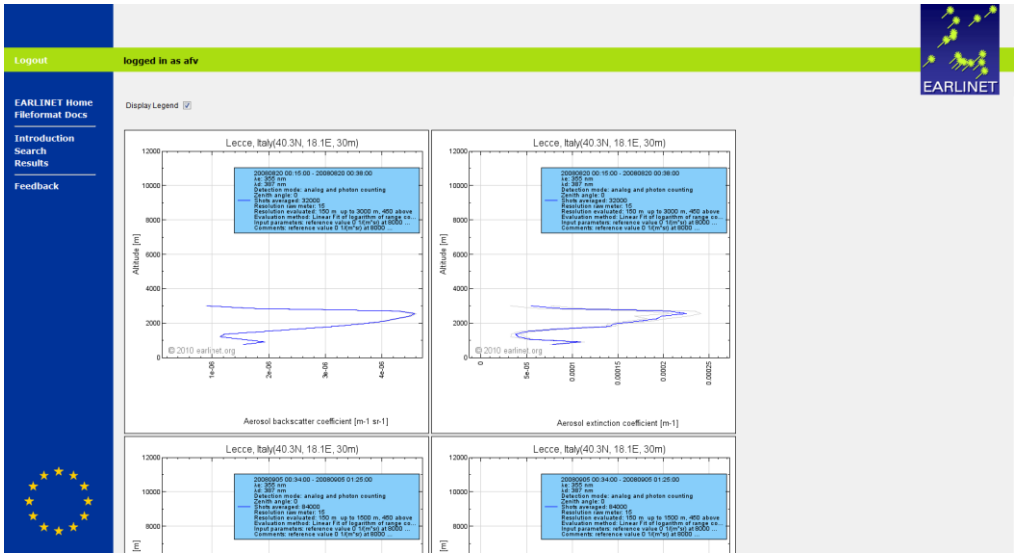

***Figure 6.6**: Web-page after successful plotting request for backscatter and extinction data (This example shows plots from the Lecce station, Italy).*

Independent on what parameter or how many that are plotted, the graphs are automatically scaled to an altitude/y-axis from 0 to 12000m. The backscatter and extinction axes (x-axes) are automatically scaled so that plots on the page have the same backscatter and extinction axes and the system makes sure the complete profiles (including uncertainty) are included on the plots. It is possible to change the default altitude, backscatter and extinction axes to any custom user setting to allow focusing of special areas of the plots.
The plots themselves consist of one profile each (line-plot) including uncertainty and a legend providing key information on the measurement. It is possible to magnify the plot by clicking on it, and it is possible to remove the legend. All plots have the text "© *year* earlinet.org" included. An example of a single plot is shown in figure 6.7.

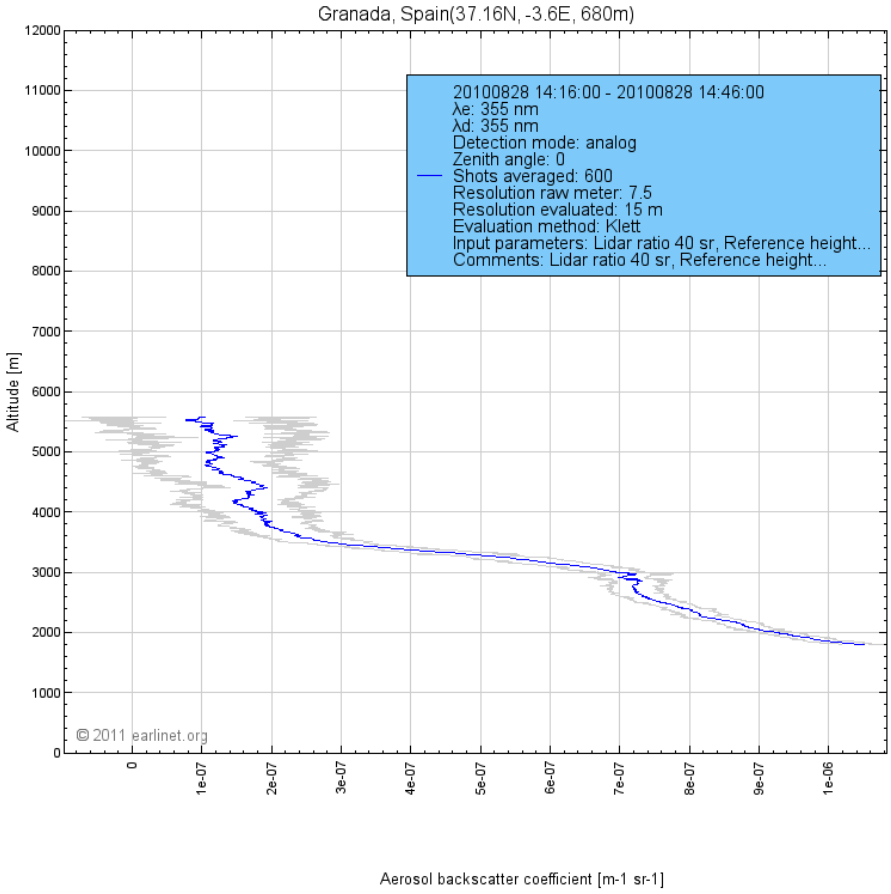

Figure 6.7: *Example of backscatter plot of data from the Granada station (Spain) generated online by the web user interface*

Conclusions

The EARLINET database has been operated for several years very successful. The EARLINET members have accepted it as a central repository for their aerosol LIDAR measurements. The public user interface is operational since April 2010. It is intensely used by the public community. In this year more than 200000 files have been downloaded through this web portal.

The EARLINET database with its well established formats and methods will be a very important component of the integrated database of the European aerosol, clouds and trace gases research infrastructure (ACTRIS), an infrastructure project in frame of the 7th FP of the European Union.

It also has been selected as a starting point for the new database of the WMO-GAW initiative of a global aerosol LIDAR network of networks (GALION, GAW Aerosol LIdar Observation Network).

APPENDIX A: PUBLICATIONS

Publications on reviewed journals

Alados-Arboledas L., D. Müller, J. L. Guerrero-Rascado, F. Navas-Guzmán, D. Pérez-Ramírez, F. J. Olmo, Optical and microphysical properties of fresh biomass burning aerosol retrieved by Raman lidar, and star- and Sun-photometry, Geophys. Res. Lett., vol. 38, L01807, doi:10.1029/2010GL045999, 2011.

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Guerrero-Rascado J. L., J. Andrey, M. Sicard, F. Molero, A. Comerón, M. Pujadas, F. Rocadenbosch, R. Pedrós, O. Serrano-Vargas, M. Gil, F. Navas-Guzmán, and L. Alados-Arboledas, Aerosol closure study by lidar, sun photometry and airborne optical counters during Damocles field campaign at El Arenosillo sounding station, Spain, J. Geophys. Res., Vol. 116, D02209, 14 pp., 2011, doi:10.1029/2010JD014510.

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APPENDIX B: EARLINET DATA USAGE POLICY

EARLINET data are freely available to individual users upon acceptance of the network data usage policy. Preliminary data are only available to EARLINET consortium members. Usage of data from the EARLINET database should follow these principles:

Use of data from the EARLINET database

- EARLINET data are freely available at http://www.earlinet.org/
- User name and password are required to access the EARLINET Database.
- Registration is necessary in order to get user name and password.
- All the requested fields must be filled (name, Institution, area of expertise, reason of access, email address)

The EARLINET consortium contributes the public domain data you are about to download. Each EARLINET site has a Principal Investigator(s) (PI), responsible for deployment, maintenance and data collection. The PI has priority use of the data collected at the site. The PI is entitled to be informed of any other use of that site data. PI contact information can be found on the EARLINET site.

Recommended guidelines for data use and publication

Using EARLINET data: Please consult with the PI(s) of the data to be used.
Publishing EARLINET data: Please consider authorship for the PI(s).
When data from the EARLINET database are used in a publication, we request the following acknowledgment to be included:
"The authors acknowledge EARLINET for providing aerosol LIDAR profiles available at http://www.earlinet.org/"
and the following reference to cite:
J. Bösenberg, et al., EARLINET: A European Aerosol Research Lidar Network to Establish an Aerosol Climatology. Max-Planck-Institut Report No. 348 (2003)
EARLINET requests a reprint of any published papers or reports or a brief description of other uses (e.g., posters, oral presentations, etc.) of data downloaded from the EARLINET database. This will help us determine the use of EARLINET data, which is helpful in optimizing product development. It also helps us to keep our product-related references current.

B. FINAL MANAGEMENT REPORT

Summary Financial Report

Type of Instrument	CA infrastructures	Project Title (or Acronym)	EARLINETASOS	Contract N°	25991
Reporting period number	P1 - P5	From (dd/mm/yyyy)	01/03/2006	To (dd/mm/yyyy)	28/02/2011	Page	1/1

Contract or n°	Organisation Short Name	Cost model used	Eligible costs (in €)	Type of activities: Research and Technological Development / Innovation (A)			Demonstration (B)			Training (C)			Management of the consortium (D)			Other Specific Activities : Coordination (E)			Total eligible costs (F)=(A)+(B)+(C)+(D)+(E)			Receipts		
				Contractor	AC Third party(ies)	FC/FCF Third party(ies)	Contractor	AC Third party(ies)	FC/FCF Third party(ies)	Contractor	AC Third party(ies)	FC/FCF Third party(ies)	Contractor	AC Third party(ies)	FC/FCF Third party(ies)	Contractor	AC Third party(ies)	FC/FCF Third party(ies)	Contractor	AC Third party(ies)	FC/FCF Third party(ies)	Contractor	AC Third party(ies)	FC/FCF Third party(ies)
1	CNR-IMAA	FC	Direct eligible costs										118 229.97			296 473.83			414 703.80	0.00	0.00			
			of which direct eligible costs of subcontracting										*3 908.62*			*0.00*			*3 908.62*	*0.00*	*0.00*			
			Indirect eligible costs										22 864.27			59 294.77			82 159.04	0.00	0.00			
			Adjustment on previous period(s)										2 092.97			7 185.46			9 278.43	0.00	0.00			
			Total eligible costs										***143 187.21***	***0.00***	***0.00***	***362 954.06***	***0.00***	***0.00***	506 141.27	0.00	0.00			
2	MPIMET	AC	Direct eligible costs										1 237.50			200 596.09			201 833.59	0.00	0.00			
			of which direct eligible costs of subcontracting										*1 237.50*			*0.00*			*1 237.50*	*0.00*	*0.00*			
			Indirect eligible costs										0.00			40 119.22			40 119.22	0.00	0.00			
			Adjustment on previous period(s)										0.00			570.94			570.94	0.00	0.00			
			Total eligible costs										***1 237.50***	***0.00***	***0.00***	***241 286.25***	***0.00***	***0.00***	242 523.75	0.00	0.00			
3	AUTH	AC	Direct eligible costs										1 500.00			62 829.04			64 329.04	0.00	0.00			
			of which direct eligible costs of subcontracting										*1 500.00*			*0.00*			*1 500.00*	*0.00*	*0.00*			
			Indirect eligible costs										0.00			12 565.81			12 565.81	0.00	0.00			
			Adjustment on previous period(s)										0.00			-1 141.68			-1 141.68	0.00	0.00			
			Total eligible costs										***1 500.00***	***0.00***	***0.00***	***74 253.17***	***0.00***	***0.00***	75 753.17	0.00	0.00			
4	UPC	FC	Direct eligible costs										4 150.00			133 342.05			137 492.05	0.00	0.00			
			of which direct eligible costs of subcontracting										*4 150.00*			*0.00*			*4 150.00*	*0.00*	*0.00*			
			Indirect eligible costs										0.00			26 668.41			26 668.41	0.00	0.00			
			Adjustment on previous period(s)										0.00			1 475.44			1 475.44	0.00	0.00			
			Total eligible costs										***4 150.00***	***0.00***	***0.00***	***161 485.90***	***0.00***	***0.00***	165 635.90	0.00	0.00			
5	LMU-MUENCHEN	AC	Direct eligible costs										1 600.00			269 001.83			270 601.83	0.00	0.00			
			of which direct eligible costs of subcontracting										*0.00*			*0.00*			*0.00*	*0.00*	*0.00*			
			Indirect eligible costs										0.00			53 800.37			53 800.37	0.00	0.00			
			Adjustment on previous period(s)										0.00			0.00			0.00	0.00	0.00			
			Total eligible costs										***1 600.00***	***0.00***	***0.00***	***322 802.20***	***0.00***	***0.00***	324 402.20	0.00	0.00			
6	IFT	AC	Direct eligible costs										932.38			272 780.65			273 713.03	0.00	0.00			
			of which direct eligible costs of subcontracting										*900.00*			*0.00*			*900.00*	*0.00*	*0.00*			
			Indirect eligible costs										6.48			54 556.13			54 562.61	0.00	0.00			
			Adjustment on previous period(s)										0.00			0.00			0.00	0.00	0.00			
			Total eligible costs										***938.86***	***0.00***	***0.00***	***327 336.78***	***0.00***	***0.00***	328 275.64	0.00	0.00			
7	RIVM	FC	Direct eligible costs										1 885.00			122 873.87			124 758.87	0.00	0.00			
			of which direct eligible costs of subcontracting										*1 885.00*			*0.00*			*1 885.00*	*0.00*	*0.00*			
			Indirect eligible costs										0.00			24 574.77			24 574.77	0.00	0.00			
			Adjustment on previous period(s)										0.00			5 736.14			5 736.14	0.00	0.00			
			Total eligible costs										***1 885.00***	***0.00***	***0.00***	***153 184.78***	***0.00***	***0.00***	155 069.78	0.00	0.00			

8	UP	AC	Direct eligible costs										781.53			129 169.32			129 950.85	0.00	0.00			
			of which direct eligible costs of subcontracting										*781.53*			*0.00*			*781.53*	*0.00*	*0.00*			
			Indirect eligible costs										0.00			25 833.88			25 833.88	0.00	0.00			
			Adjustment on previous period(s)										0.00			0.00			0.00	0.00	0.00			
			Total eligible costs										***781.53***	***0.00***	***0.00***	***155 003.20***	***0.00***	***0.00***	155 784.73	0.00	0.00			
9	BISIP.SMO	AC	Direct eligible costs										1 563.76			83 496.12			85 059.88	0.00	0.00			
			of which direct eligible costs of subcontracting										*1 563.76*			*0.00*			*1 563.76*	*0.00*	*0.00*			
			Indirect eligible costs										0.00			16 699.23			16 699.23	0.00	0.00			
			Adjustment on previous period(s)										0.00			0.00			0.00	0.00	0.00			
			Total eligible costs										***1 563.76***	***0.00***	***0.00***	***100 195.35***	***0.00***	***0.00***	101 759.11	0.00	0.00			
10	NILU	FC	Direct eligible costs										259.34			199 548.96			199 808.30	0.00	0.00			
			of which direct eligible costs of subcontracting										*259.34*			*0.00*			*259.34*	*0.00*	*0.00*			
			Indirect eligible costs										0.00			39 909.79			39 909.79	0.00	0.00			
			Adjustment on previous period(s)										0.00			0.00			0.00	0.00	0.00			
			Total eligible costs										***259.34***	***0.00***	***0.00***	***239 458.75***	***0.00***	***0.00***	239 718.09	0.00	0.00			
11	ON/CSEM	FC	Direct eligible costs										583.70			52 819.42			53 403.12	0.00	0.00			
			of which direct eligible costs of subcontracting										*583.70*			*0.00*			*583.70*	*0.00*	*0.00*			
			Indirect eligible costs										0.00			10 563.89			10 563.89	0.00	0.00			
			Adjustment on previous period(s)										0.00			407.18			407.18	0.00	0.00			
			Total eligible costs										***583.70***	***0.00***	***0.00***	***63 790.49***	***0.00***	***0.00***	64 374.19	0.00	0.00			
12	NTUA	AC	Direct eligible costs										1 500.00			47 820.22			49 320.22	0.00	0.00			
			of which direct eligible costs of subcontracting										*1 500.00*						*1 500.00*	*0.00*	*0.00*			
			Indirect eligible costs										0.00			9 564.05			9 564.05	0.00	0.00			
			Adjustment on previous period(s)										0.00			0.00			0.00	0.00	0.00			
			Total eligible costs										***1 500.00***	***0.00***	***0.00***	***57 384.27***	***0.00***	***0.00***	58 884.27	0.00	0.00			
13	US	AC	Direct eligible costs										0.00			40 217.78			40 217.78	0.00	0.00			
			of which direct eligible costs of subcontracting										*0.00*			*0.00*			*0.00*	*0.00*	*0.00*			
			Indirect eligible costs										0.00			8 043.55			8 043.55	0.00	0.00			
			Adjustment on previous period(s)										0.00			-717.93			-717.93	0.00	0.00			
			Total eligible costs										***0.00***	***0.00***	***0.00***	***47 543.40***	***0.00***	***0.00***	47 543.40	0.00	0.00			
14	UNIAQ	FCF	Direct eligible costs										500.00			40 169.22			40 669.22	0.00	0.00			
			of which direct eligible costs of subcontracting										*500.00*			*0.00*			*500.00*	*0.00*	*0.00*			
			Indirect eligible costs										0.00			8 033.85			8 033.85	0.00	0.00			
			Adjustment on previous period(s)										0.00			0.00			0.00	0.00	0.00			
			Total eligible costs										***500.00***	***0.00***	***0.00***	***48 203.07***	***0.00***	***0.00***	48 703.07	0.00	0.00			

15	EPFL	AC	Direct eligible costs										1 942.56			45 498.06			47 440.62	0.00	0.00			
			of which direct eligible costs of subcontracting										*1 942.56*			*3 424.39*			*5 366.95*	*0.00*	*0.00*			
			Indirect eligible costs										0.00			8 414.74			8 414.74	0.00	0.00			
			Adjustment on previous period(s)										0.00			0.00			0.00	0.00	0.00			
			Total eligible costs										***1 942.56***	***0.00***	***0.00***	***53 912.80***	***0.00***	***0.00***	55 855.36	0.00	0.00			
16	IGPAS	FCF	Direct eligible costs										1 887.98			30 899.90			32 787.88	0.00	0.00			
			of which direct eligible costs of subcontracting										*1 887.98*			*0.00*			*1 887.98*	*0.00*	*0.00*			
			Indirect eligible costs										0.00			6 179.98			6 179.98	0.00	0.00			
			Adjustment on previous period(s)										0.00			-140.53			-140.53	0.00	0.00			
			Total eligible costs										***1 887.98***	***0.00***	***0.00***	***36 939.35***	***0.00***	***0.00***	38 827.33	0.00	0.00			
17	CNIMS	AC	Direct eligible costs										1 040.00			36 776.71			37 816.71	0.00	0.00			
			of which direct eligible costs of subcontracting										*1 040.00*			*0.00*			*1 040.00*	*0.00*	*0.00*			
			Indirect eligible costs										0.00			7 355.34			7 355.34	0.00	0.00			
			Adjustment on previous period(s)										0.00			-502.78			-502.78	0.00	0.00			
			Total eligible costs										***1 040.00***	***0.00***	***0.00***	***43 629.27***	***0.00***	***0.00***	44 669.27	0.00	0.00			
18	IE-BAS	FCF	Direct eligible costs										1 100.00			52 113.78			53 213.78	0.00	0.00			
			of which direct eligible costs of subcontracting										*1 100.00*			*0.00*			*1 100.00*	*0.00*	*0.00*			
			Indirect eligible costs										0.00			10 422.76			10 422.76	0.00	0.00			
			Adjustment on previous period(s)										0.00			0.00			0.00	0.00	0.00			
			Total eligible costs										***1 100.00***	***0.00***	***0.00***	***62 536.54***	***0.00***	***0.00***	63 636.54	0.00	0.00			
19	FZK/KIT-G	FC	Direct eligible costs										1 764.00			84 815.00			86 579.00	0.00	0.00			
			of which direct eligible costs of subcontracting										*1 764.00*			*0.00*			*1 764.00*	*0.00*	*0.00*			
			Indirect eligible costs										0.00			16 957.40			16 957.40	0.00	0.00			
			Adjustment on previous period(s)										0.00			-28.02			-28.02	0.00	0.00			
			Total eligible costs										***1 764.00***	***0.00***	***0.00***	***101 744.38***	***0.00***	***0.00***	103 508.38	0.00	0.00			
20	CNRS	FCF	Direct eligible costs										0.00			43 038.85			43 038.85	0.00	0.00			
			of which direct eligible costs of subcontracting										*0.00*			*0.00*			*0.00*	*0.00*	*0.00*			
			Indirect eligible costs										0.00			8 607.77			8 607.77	0.00	0.00			
			Adjustment on previous period(s)										0.00			0.00			0.00	0.00	0.00			
			Total eligible costs										***0.00***	***0.00***	***0.00***	***51 646.62***	***0.00***	***0.00***	51 646.62	0.00	0.00			
21	CIEMAT	FC	Direct eligible costs										1 120.69			39 085.34			40 206.03	0.00	0.00			
			of which direct eligible costs of subcontracting										*1 120.69*			*0.00*			*1 120.69*	*0.00*	*0.00*			
			Indirect eligible costs										0.00			7 817.07			7 817.07	0.00	0.00			
			Adjustment on previous period(s)										0.00			5 549.22			5 549.22	0.00	0.00			
			Total eligible costs										***1 120.69***	***0.00***	***0.00***	***52 451.63***	***0.00***	***0.00***	53 572.32	0.00	0.00			
Total eligible costs													168 542.13	0.00	0.00	2 757 742.26	0.00	0.00	2 926 284.39	0.00	0.00	0.00	0.00	0.00
															168 542.13			2 757 742.26			2 926 284.39		0.00
Requested EC contribution for the reporting period (in €) without taking into account receipts													168 542.13	0.00	0.00	2 710 520.22	0.00	0.00	2 879 062.35					
															168 542.13			2 710 520.22					
Requested EC contribution for the reporting period (in €) taking into account receipts [=Periodic Invoice]																			2 879 062.35					
Amount of the financial interests generated by the prefinancing																			0.00					

Personnel effort for the whole duration of the project

Activities		P1 - CNR-IMAA FC		P2 - MPIMET AC		P3 - AUTH AC		P4 - UPC FC		P5 - LMU-MUENCHEN AC		P6 - IFT AC	
		total	*charged*	*total*	*charged*	*total*	*charged*	*total*	*charged*	*total*	*charged*	*total*	*charged*
NA1: Consortium management activity	*actual*	31	31	2	0	0	0	0	0	0	0	0	0
	planned	40	40	6	4	0	0	0	0	0	0	0	0
NA 2	*actual*	4	4	6.5	1	4.6	2.7	4.8	4.8	4.1	2.1	0	0
	planned	4	4	2	1	3	2	4	4	3	2	0	0
NA 3	*actual*	10	10	9	7	0	0	0	0	26.9	18.4	2	1
	planned	9	9	7	5	0	0	0	0	24	17	2	1
NA 4	*actual*	1	1	2	1	3.5	2	4.08	4.08	30	21	3	2
	planned	1	1	2	1	2	1	11	11	30	21	3	2
NA5	*actual*	47	47	10	7	6.6	4.6	5.65	5.65	3.5	2	65	47.05
	planned	46	46	10	7	6	4	2	2	3	2	65	46
NA6	*actual*	3	3	26.5	17.5	10	7	0	0	2	1	6	4
	planned	4	4	23	16	8	6	0	0	2	1	6	4
Total	*actual*	96	96	56	33.5	24.7	16.3	14.53	14.53	66.5	44.5	76	54.05
	planned	104	104	50	34	19	13	17	17	62	43	76	53

Activities		P7 - RIVM FC		P8 - UP AC		P9 - BISIP.SMO AC		P10 - NILU FC		P11 - ON/CSEM FC		P12 - NTUA AC	
		total	*charged*	*total*	*charged*	*total*	*charged*	*total*	*charged*	*total*	*charged*	*total*	*charged*
NA1: Consortium management activity	*actual*	0	0	0	0	0	0	0	0	0	0	0	0
	planned	0	0	0	0	0	0	0	0	0	0	0	0
NA 2	*actual*	0	0	0	0	0	0	0	0	0	0	0	0
	planned	0	0	0	0	0	0	0	0	0	0	0	0
NA 3	*actual*	0	0	6	4	26.25	12.25	0	0	0	0	0	0
	planned	0	0	6	4	14	10	0	0	0	0	0	0
NA 4	*actual*	17.64	17.64	0	0	5	1	1.04	1.04	2.47	2.47	3	2
	planned	11	11	0	0	2	1	1	1	1	1	3	2
NA5	*actual*	1.31	1.31	36	25	72	47	2.18	2.18	4.3	4.3	4.5	3
	planned	2	2	36	25	58	41	2	2	2	2	3	2
NA6	*actual*	0	0	2	1	0	0	20.99	20.99	0	0	4.5	3
	planned	0	0	2	1	0	0	23	23	0	0	5	4
Total	*actual*	18.95	18.95	44	30	103.25	60.25	24.21	24.21	6.77	6.77	12	8
	planned	13	13	44	30	74	52	26	26	3	3	11	8

Activities		P13 - UNILE/US AC		P14 - UNIAQ FCF		P15 - EPFL AC		P16 - IGPAS FCF		P17 - CNISM AC		P18 - IE-BAS FCF	
		total	*charged*	*total*	*charged*	*total*	*charged*	*total*	*charged*	*total*	*charged*	*total*	*charged*
NA1: Consortium management activity	*actual*	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	planned	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
NA 2	*actual*	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	planned	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
NA 3	*actual*	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	planned	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
NA 4	*actual*	**5.5**	**3.4**	**8.5**	**8.5**	**5**	**2**	**4**	**4**	**3.6**	**1.1**	**24.32**	**24.32**
	planned	**2**	**1**	**1**	**1**	**2**	**1**	**2**	**2**	**2**	**1**	**7**	**7**
NA5	*actual*	**10.5**	**8**	**7**	**7**	**6**	**3**	**2**	**2**	**4.9**	**2.4**	**19.25**	**19.25**
	planned	**3**	**2**	**2**	**2**	**3**	**2**	**2**	**2**	**3**	**2**	**2**	**2**
NA6	*actual*	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	planned	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Total	*actual*	**16**	**11.4**	**15.5**	**15.5**	**11**	**5**	**6**	**6**	**8.5**	**3.5**	**43.57**	**43.57**
	planned	**5**	**3**	**3**	**3**	**5**	**3**	**4**	**4**	**5**	**3**	**9**	**9**

Activities		P19 - FZK/KIT-G FC		P20 - CNRS FCF		P21 - CIEMAT FC		Total	
		total	*charged*	*total*	*charged*	*total*	*charged*	*total*	*charged*
NA1: Consortium management activity	*actual*	**0**	**0**	**0**	**0**	**0**	**0**	**33**	**31**
	planned	**0**	**0**	**0**	**0**	**0**	**0**	**46**	**44**
NA 2	*actual*	**0**	**0**	**0**	**0**	**0**	**0**	**24**	**14.6**
	planned	**0**	**0**	**0**	**0**	**0**	**0**	**16**	**13**
NA 3	*actual*	**0**	**0**	**0**	**0**	**0**	**0**	**80.15**	**52.65**
	planned	**0**	**0**	**0**	**0**	**0**	**0**	**62**	**46**
NA 4	*actual*	**7.28**	**7.28**	**1.83**	**1.83**	**4.2**	**4.2**	**136.96**	**111.86**
	planned	**7**	**7**	**1**	**1**	**1**	**1**	**92**	**75**
NA5	*actual*	**5.07**	**5.07**	**6.17**	**6.17**	**3.65**	**3.65**	**322.58**	**252.63**
	planned	**2**	**2**	**2**	**2**	**2**	**2**	**256**	**199**
NA6	*actual*	**0**	**0**	**0**	**0**	**0**	**0**	**74.99**	**57.49**
	planned	**0**	**0**	**0**	**0**	**0**	**0**	**73**	**59**
Total	*actual*	**12.35**	**12.35**	**8**	**8**	**7.85**	**7.85**	**671.68**	**520.23**
	planned	**9**	**9**	**3**	**3**	**3**	**3**	**545**	**436**

The *actual* effort in the first row of each activity should summarize the human effort devoted by the partner to the activity along the entire duration of the project

The *planned* effort in the second row of each activity should correspond to what indicated in Annex I (DoW) to the Contract

AC contractors must include in the column "*total*" the total human effort (including permanent staff) and, in the column "*charged*", usually the additional staff only.

For FC- FCF contractors the two columns ("*total*" and "*charged*") should usually indicate the same effort

D. QUESTIONNAIRES