EARLINET correlative measurements for CALIPSO

Ina Mattis, Lucia Mona, Detlef Müller, Gelsomina Pappalardo, Lucas Alados-Arboledas, et al.

Ina Mattis, Lucia Mona, Detlef Müller, Gelsomina Pappalardo, Lucas Alados-Arboledas, Giuseppe D'Amico, Aldo Amodeo, Arnoud Apituley, José Maria Baldasano, Christine Böckmann, Jens Bösenberg, Anatoli Chaikovsky, Adolfo Comeron, Elina Giannakaki, Ivan Grigorov, Juan Luis Guerrero Rascado, Ove Gustafsson, Marco Iarlori, Holger Linne, Valentin Mitev, Francisco Molero Menendez, Doina Nicolae, Alexandros Papayannis, Carlos Perez Garcia-Pando, Maria Rita Perrone, Aleksander Pietruczuk, Jean-Philippe Putaud, Francois Ravetta, Alejandro Rodríguez, Patric Seifert, Michaël Sicard, Valentin Simeonov, Piotr Sobolewski, Nicola Spinelli, Kerstin Stebel, Andreas Stohl, Matthias Tesche, Thomas Trickl, Xuan Wang, Matthias Wiegner, "EARLINET correlative measurements for CALIPSO," Proc. SPIE 6750, Lidar Technologies, Techniques, and Measurements for Atmospheric Remote Sensing III, 67500Z (17 October 2007); doi: 10.1117/12.738090

Event: SPIE Remote Sensing, 2007, Florence, Italy

Invited Paper

EARLINET correlative measurements for CALIPSO

Ina Mattis[a], Lucia Mona[b], Detlef Müller[a], Gelsomina Pappalardo[b],

Lucas Alados Arboledas[c]Giuseppe D'Amico[b], Aldo Amodeo[b], Arnoud Apituley[d], José María Baldasano[e], Christine Böckmann[f], Jens Bösenberg[g], Anatoli Chaikovsky[h], Adolfo Comeron[i], Elina Giannakaki[j], Ivan Grigorov[k], Juan Luis Guerrero Rascado[c], Ove Gustafsson[l], Marco Iarlori[n], Holger Linné[g], Valentin Mitev[o], Francisco Molero Menéndez[p], Doina Nicolae[q], Alexandros Papayannis[r], Carlos Pérez García-Pando[e], Maria Rita Perrone[s], Aleksander Pietruczuk[t], Jean-Philippe Putaud[u], Francois Ravetta[v], Alejandro Rodríguez[i], Patric Seifert[a], Michaël Sicard[i], Valentin Simeonov[w], Piotr Sobolewski[t], Nicola Spinelli[x], Kerstin Stebel[m], Andreas Stohl[m], Matthias Tesche[a], Thomas Trickl[y], Xuan Wang[*], and Matthias Wiegner[z]

[a]Leibniz Institute for Tropospheric Research, Leipzig, Germany;
[b]Consiglio Nazionale delle Ricerche - Istituto di Metodologie per l'Analisi Ambientale, Potenza, Italy;

[c]Universidad de Granada, Granada, Spain;
[d]National Institute for Public Health and the Environment, Bilthoven, The Netherlands;
[e]Barcelona Supercomputing Center, Barcelona, Spain;
[f]Institut für Mathematik, Universität Potsdam, Germany;
[g]Max-Planck-Institut für Meteorologie, Hamburg, Germany;
[h]Institute of Physics National Academy of Sciences, Minsk, Belarus;
[i]Universitat Politecnica de Catalunya, Barcelona, Spain ;
[j]Aristotle University of Thessaloniki, Greece;
[k]Institute of Electronics, BAS, Sofia, Bulgaria;
[l]Swedish Defence Research Agency (FOI), Linköping, Sweden;
[m]Norwegian Institute for Air Research, Tromsö, Norway;
[n]Universita degli Studi L'Aquila, Italy;
[o]Observatory of Neuchâtel, Switzerland;
[p]Atmospheric Pollution Unit Environmental Department CIEMAT, Madrid, Spain;
[q]National Institute of R&D for Optoelectronics, Bucharest, Romania;
[r]Ethnikon Metsovion Polytechnion Athinon, Athens, Greece;
[s]University of Lecce, Italy;
[t]Institute of Geophysics, Polish Academy of Sciences, Warsaw, Poland;
[u]JRC Institute for Environment and Sustainability, Ispra, Italy;
[v]Institute Pierre Simon Laplace, Paris, France;
[w]Ecole Polytechnique Federale de Lausanne, Switzerland;
[x]Consorzio Nazionale per le Scienze Fisiche della Materia, Unità di Napoli and Università di Napoli Federico II, Napoli, Italy;
[y]Forschungszentrum Karlsruhe, IMK-IFU, Garmisch-Partenkirchen, Germany;
[z]Meteorological Institute, University of Munich, Germany;
[*] CNISM and CRS- Coherentia, CNR-INFM Napoli, Italy

Further author information: (Send correspondence to Ina Mattis)
Ina Mattis: E-mail: ina@tropos.de, Telephone: +49 341 235 3412, postal: IfT, Permoserstr. 15, 04318 Leipzig, Germany

Lidar Technologies, Techniques, and Measurements for Atmospheric Remote Sensing III,
edited by Upendra N. Singh, Gelsomina Pappalardo, Proc. of SPIE Vol. 6750, 67500Z, (2007)
0277-786X/07/$18 · doi: 10.1117/12.738090

ABSTRACT

The European Aerosol Research Lidar Network (EARLINET) was established in 2000 to derive a comprehensive, quantitative, and statistically significant data base for the aerosol distribution on the European scale. At present, EARLINET consists of 25 stations: 16 Raman lidar stations, including 8 multi-wavelength Raman lidar stations which are used to retrieve aerosol microphysical properties. EARLINET performs a rigorous quality assurance program for instruments and evaluation algorithms. All stations measure simultaneously on a predefined schedule at three dates per week to obtain unbiased data for climatological studies. Since June 2006 the first backscatter lidar is operational aboard the CALIPSO satellite. EARLINET represents an excellent tool to validate CALIPSO lidar data on a continental scale. Aerosol extinction and lidar ratio measurements provided by the network will be particularly important for that validation. The measurement strategy of EARLINET is as follows: Measurements are performed at all stations within 80 km from the overpasses and additionally at the lidar station which is closest to the actually overpassed site. If a multi-wavelength Raman lidar station is overpassed then also the next closest 3+2 station performs a measurement. Altogether we performed more than 1000 correlative observations for CALIPSO between June 2006 and June 2007. Direct intercomparisons between CALIPSO profiles and attenuated backscatter profiles obtained by EARLINET lidars look very promising. Two measurement examples are used to discuss the potential of multi-wavelength Raman lidar observations for the validation and optimization of the CALIOP Scene Classification Algorithm. Correlative observations with multi-wavelength Raman lidars provide also the data base for a harmonization of the CALIPSO aerosol data and the data collected in future ESA lidar-in-space missions.

Keywords: EARLINET, CALIPSO, Raman lidar

1. INTRODUCTION

Aerosol particles are the main source of uncertainty regarding the prediction of climate change. Especially the indirect aerosol effect on climate — via the aerosol influence on cloud properties and precipitation processes — is not yet well understood. A lot of effort has been done in the past to measure the horizontal, vertical and temporal distribution of the aerosol particles on a global scale and to acquire the optical and hygroscopic properties of different aerosol types. Passive remote sensing instruments aboard satellites or ground based sun photometers cannot derive the vertical layering of aerosols which is very important for, e.g., the indirect effect. Vertically resolved lidar measurements therefore are an indispensable tool to study the vertical structure of the aerosol field and its temporal development. Unfortunately, single ground-based lidar observations cannot detect the horizontal variability of the aerosol field and lidars aboard aircraft cannot perform process studies or long-term measurement series.

The European Aerosol Research Lidar Network (EARLINET) is the first tool capable of doing 4-dimensional aerosol measurements. It was established in 2000 to derive a comprehensive, quantitative, and statistically significant data base for the aerosol distribution on the continental and long-term scale.[1] Fig. 1 illustrates the locations of the 25 stations which are participating in EARLINET. EARLINET extends from the Mediterranean in the south to Andøya north of the Arctic circle. There are midlatitude marine stations like Bilthoven, Cabauw, Hamburg and lidar sites with continental climate like Belsk and Minsk. The Mediterranean Sea is covered by 3 Spanish stations in the west, 4 sites in Italy, and 2 Greek stations in the east of the Mediterranean. Because of this large geographical extent EARLINET can study a variety of aerosol types under different meteorological and climatological conditions. There are very clean conditions in Andøya. There are EARLINET sites in relatively clean areas like Cabauw as well as in the highly polluted megacity Athens. Several times per year we observe mineral dust plumes which are transported from the Saharan region across Europe. We also detect smoke plumes from European forest fires mainly inside the planetary boundary layer (PBL), and in the free troposphere (FT) from sources in North America or Siberia. We observe differences between fresh anthropogenic pollution in the highly industrialized regions of western Europe, e.g., in the PBL over Leipzig, anthropogenic pollution in less developed areas, e.g., the Balkan, and aged anthropogenic pollution from the east coast of North America which is advected to Europe in the FT.

The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite was launched in April 2006. It carries the first satellite-borne lidar instrument CALIOP (Cloud-Aerosol Lidar with Orthogonal

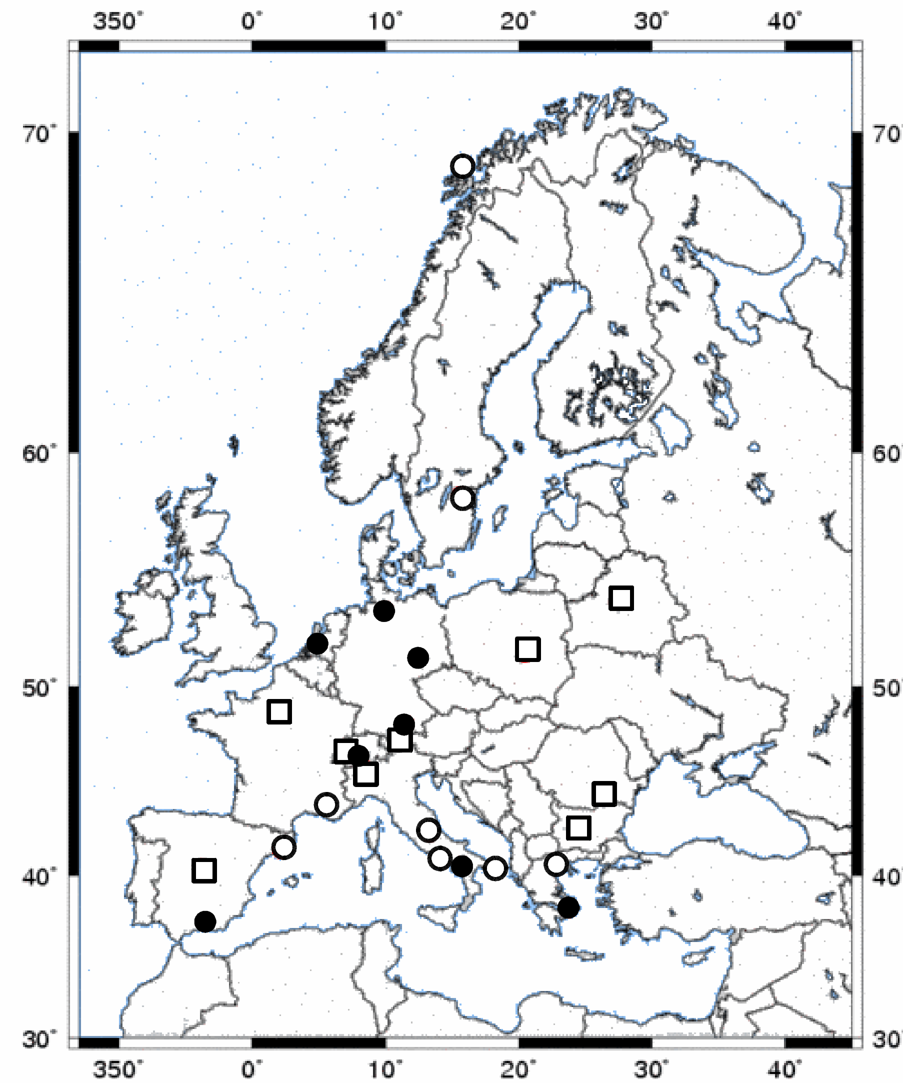

Figure 1. Locations of the 25 lidar stations of the EARLINET consortium in August 2007. Open squares indicate simple backscatter lidars, open circles show Raman lidar stations and solid circles indicate multi-wavelength Raman lidar stations.

Polarization) which provides highly vertically resolved aerosol profiles on the global scale. ESA's Atmospheric Dynamics Mission (ADM-Aeolus) and the Earth Clouds Aerosols and Radiation Explorer (EarthCARE) mission will provide a continuation of the CALIPSO cloud and aerosol observations (see Table 1). These three missions offer the great opportunity to establish a 10-year data set of aerosol and cloud properties to the benefit of numerical weather prediction, climate research, and future climate prediction. Such an accurate, consistent, and cohesive long-term global aerosol record is needed in order to quantify the direct climate forcing by anthropogenic aerosols as well as the indirect aerosol effects on climate.

Table 1 shows that NASA's and ESA's space lidars operate at different wavelengths. Thus 355-nm-to-532-nm conversion factors are required which allow for a harmonization of the three data sets. The unbiased, high-quality measurements with the EARLINET multi-wavelength Raman lidars provide a unique data set of the wavelength dependence of aerosol backscatter and extinction coefficients as well as simultaneously measured aerosol lidar ratios at 2 wavelengths for a large variety of aerosol types and meteorological situations.

Table 1. Present and future space-borne lidar missions. The measured aerosol properties are: particle extinction coefficient (α), particle backscatter coefficient (β), particle lidar ratio (S), and depolarization ratio (δ).

Mission	Lidar	Lidar type	Products at wavelength:			Expected
			355 nm	532 nm	1064 nm	operational period
CALIPSO	CALIOP	backscatter lidar	—	β^a, δ	β^a	2006-2009
ADM-Aeolus	ALADIN	HSRL	α,β, S	—	—	2009-2011
EarthCARE	ATLID	HSRL	α,β, S, δ	—	—	2013-2016

[a] α can be estimated from β with assumptions on the lidar ratio

CALIOP aboard CALIPSO is a simple backscatter lidar. Profiles of the extinction-to-backscatter (lidar) ratio S are needed to derive profiles of extinction coefficients which are one key parameter for the assessment of the aerosol effect on climate. An improper assumption of the lidar ratio results in large uncertainties of the extinction profiles. The CALIOP Scene Classification Algorithm estimates layer-mean lidar ratios with the transmittance method in case of lofted layers or selects S among the values for six predefined aerosol types for surface-attached layers.[2] In contrast to simple backscatter lidars like CALIOP, High Spectral Resolution Lidars (HSRL) and Raman lidars do not need the critical assumption on the lidar ratio. With both techniques α and β can be derived directly and independently of each other. Thus, the EARLINET Raman lidars are an indispensable tool to perform ground truth observations during CALIPSO overpasses. Direct intercomparisons between backscatter and extinction profiles measured by EARLINET Raman lidars and by CALIPSO can be used to validate and to improve the CALIOP Scene Classification Algorithm and the aerosol model that is implemented it that algorithm.

In this paper we present in the first section the goal and methodologies of EARLINET. Next our measurement strategy of correlative observations for CALIPSO is explained. We present first results of direct intercomparisons between attenuated backscatter profiles simultaneously measured by CALIOP and by EARLINET Raman lidars. We show two measurement examples of multi-wavelength Raman lidar observations to illustrate the potential of such data sets for further CALIPSO validation studies. In the outlook section we list future EARLINET validation activities which are planned in the framework of correlative observations during CALIPSO overpasses.

2. THE EUROPEAN AEROSOL RESEARCH LIDAR NETWORK (EARLINET)

A detailed list of all partners can be found in Table 2. The instrumentation of the currently 25 EARLINET stations is as follows. Three of the stations operate fully automated lidars on the basis of round-the-clock observations. There are 9 simple backscatter lidars. Sixteen of the EARLINET stations operate Raman lidars which allow for the independent retrieval of profiles of the particle extinction and backscatter coefficients.[3] The particle extinction-to-backscatter (lidar) ratio contains information on particle size and particle light-absorption and thus allows for a rough separation among different aerosol types. Eight multi-wavelength Raman lidar stations belong to EARLINET. These lidars allow for the retrieval of three backscatter coefficients at 355, 532, and 1064-nm wavelength plus two extinction coefficients and lidar ratios at 355 and 532 nm. The wavelength

Table 2. Locations of the 25 lidar stations of the EARLINET consortium in August 2007. The institution IDs are identical with the affiliation IDs of the authors. Some EARLINET partners do not operate a lidar system. For those groups their main contribution to the EARLINET community is listed.

Location	Institution	Station ID	Latitude	Longitude
Andøya, Norway	*m*	An	69.28° N	16.01° E
Athens, Greece	*r*	At	37.9° N	23.6° E
Barcelona, Spain	*e*	Ba	41.39° N	2.12° E
Belsk, Poland	*t*	Be	51.8° N	20.8° E
Bilthoven, The Netherlands	*d*	Bh	52.12° N	5.20° E
Bucharest -Magurele, Romania	*q*	Bu	44.35° N	26.03° E
Garmisch-Partenkirchen, Germany	*y*	GP	47.6° N	11.1° E
Granada, Spain	*c*	Gr	37.2° N	3.6° W
Hamburg, Germany	*g*	HH	53.6° N	10.0° E
Jungfraujoch, Switzerland	*w*	Ju	46.5° N	8.0° E
Ispra JRC, Italy	*u*	Is	45.80° N	8.6° E
L'Aquila, Italy	*n*	La	42.35° N	13.38° E
Lecce, Italy	*s*	Lc	40.3° N	18.1° E
Leipzig, Germany	*a*	Le	51.35° N	12.43° E
Linköping, Sweden	*l*	Lk	58.4° N	15.6° E
Madrid, Spain	*p*	Ma	40.45° N	3.73° W
Minsk, Belarus	*h*	Mi	53.9° N	27.6° E
Munich, Germany	*z*	Mu	48.2° N	11.6° E
Napoli, Italy	*x*	Na	40.8° N	14.3° E
Neuchâtel, Switzerland	*o*	Ne	47.0° N	7.0° E
Observatoire de Haute-Provence, France	*v*	HP	43.93° N	5.70° E
Palaiseau, France	*v*	Pl	48.6° N	2.2° E
Potenza-Tito Scalo, Italy	*b*	Po	40.60° N	15.72° E
Sofia, Bulgaria	*k*	Sf	42.65° N	23.38° E
Thessaloniki, Greece	*j*	Th	40.6° N	22.97° E
Potsdam, Germany	*f*	retrieval of microphysical aerosol properties		
Leipzig, Germany	*a*			
Barcelona, Spain	*e*	operation of DREAM		
Kjeller, Norway	*m*	operation of FLEXPART		

dependence of the backscatter and extinction coefficients and of the lidar ratios allow for a more detailed differentiation of aerosol types.[4] In the framework of EARLINET inversion algorithms were developed to obtain microphysical aerosol properties such as effective radius, volume- and surface-area concentration, and real and imaginary part of the complex refractive index from multi-wavelength Raman lidar informations.[5–7] Backscatter coefficients at three wavelengths plus extinction coefficients at two wavelengths are the minimum required input data for such inversion schemes.[8]

We perform a rigorous quality assurance program for instruments[9] and evaluation algorithms.[10, 11] In 2006 we launched the EC funded infrastructure project European Aerosol Research Lidar Network: Advanced Sustainable Observation System (EARLINET-ASOS). The main concerns of EARLINET-ASOS are the development of tools for the automatization and homogenization of the lidar systems and the development of a centralized and homogenized data analysis.[12]

All EARLINET stations measure simultaneously on a predefined schedule of at least three dates per week, i.e., Monday afternoon, and Monday and Thursday after sunset. This data set is used to obtain unbiased data for climatological studies. The increasing number of automated EARLINET lidars drastically improves the overall measurement time. Additionally to these regular measurements, coordinated network observations are performed to address specifically important events like Saharan dust, forest fires, volcanic eruptions, and photochemical smog. All measured profiles are stored in a centralized data base with a standardized data format which allow for an easy access to the complete data set for further scientific studies.

The German meteorological service (DWD) provides 4-day backward trajectories on a daily schedule for all EARLINET stations for 6 arrival heights between 925 and 200 hPa and for 2 arrival times (13 UT and 19 UT). Those trajectories provide information about the origin of the observed air masses. The Dust REgional Atmospheric Model (DREAM)[13] is used in EARLINET for the coordination of special intensive measurement periods during dust outbreaks over Europe. The Barcelona Supercomputing Center (BSC) provides daily updated analysis data and forecasts up to 72 h at the web site.[14] There one can find, e.g., maps of Europe showing the predicted optical depth of dust, cloudiness, surface concentration. DREAM is also used to predict vertical profiles of the dust concentration at 20 EARLINET sites. Beside the coordination of our network observations during the Saharan dust events, DREAM is also a very useful tool for the scientific interpretation of the EARLINET measurements.[15]

The Lagrangian particle dispersion model FLEXPART[16,17] which is operated by the Norwegian Institute for Air Research (NILU) is also used for the interpretation of network observations during special events. This model is used only in case of special events and not routinely for all the EARLINET observations because it requires large run time.

3. EARLINET CORRELATIVE OBSERVATIONS FOR CALIPSO

3.1 Measurement strategy

Besides the above mentioned measurement schedule, the EARLINET groups perform correlative observations during CALIPSO overflights since the CALIOP measurements started in June 2006. EARLINET acts as a single partner in the CALIPSO validation activities. A suitable, three-stage strategy for correlative measurements has been implemented within EARLINET. Following this strategy about 7 stations would perform measurements contemporaneously while CALIPSO passes over Europe. The measurement strategy is as follows:

case 1 (Mandatory) Each EARLINET station is one validation point for CALIPSO and performs measurements as close as possible in time and space to the CALIPSO overflights (see Figure 2, left). According to the CALIPSO validation plan, measurements made within 2 h and 40 km of the satellite overpass are preferred, but within 4 h and 80 km are acceptable.

case 2 (Suggested) Beyond these simple comparisons at individual points, our network provides the unique opportunity to perform studies on the spatial and temporal variability of the aerosol field over Europe. We perform additional correlative observations at the lidar station which is closest to the actually overpassed lidar site (see Figure 2, center). These correlative network observations produce also the data base for studies on the representativeness of the CALIPSO observations. Furthermore they provide, together with the CALIPSO data, comprehensive data sets for detailed process studies.

case 3 (Suggested) The third stage of correlative observations is designed to study the variability of microphysical aerosol properties over Europe and to support the CALIPSO aerosol type identification procedures.[2] If a multi-wavelength Raman lidar station is overpassed then also the next closest 3+2 station performs a measurement (see Figure 2, right).

The coordinated measurement schedule for all EARLINET stations is calculated by CNR-IMAA on the basis of CALIPSO overpass data provided by NASA. The actual measurement schedule with lists of case-1, case-2, and case-3 observations and plots reporting CALIPSO groundtrack and EARLINET correlative measurements (similar to Figure 2) are weekly distributed to all partners by email. Altogether we performed more than 1000 correlative observations between June 2006 and June 2007. Table 3 lists the subdivision of all these observations into the different measurement cases.

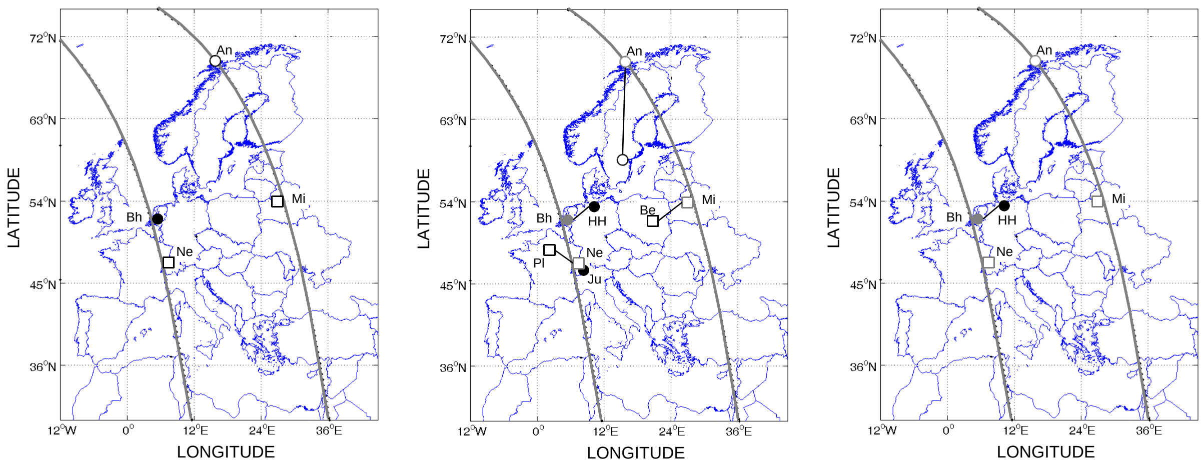

Figure 2. Illustration of EARLINET measurement strategy for correlative observations during CALIPSO overpasses. The symbols indicate the different types of lidar sites, see Figure 1. The station ID's refer to Table 2. The bold lines show the ground track of the satellite. Left: all stations which have to perform a case-1 observation. Center: case-1 stations (gray symbols) and the respective case-2 stations (black symbols) are connected by thin lines. Right: same as center, but for case-3 observations.

Table 3. Number of correlative observations which were performed by the whole EARLINET community between June 2006 and June 2007.

Case 1	Case 2	Case 3	Total
569	448	93	1110

3.2 Case 1 validation measurements for CALIPSO

In this section we present some examples of CALIPSO validation measurements. At the moment CALIPSO provides only level-1 data products. Level-1 products are time series of profiles of total attenuated backscatter and perpendicular-polarized attenuated backscatter at 532-nm wavelength, and attenuated backscatter at 1064 nm. Those attenuated backscatter profiles are not directly comparably to the profiles of the particle backscatter coefficient measured by the EARLINET lidars. Mona et al.[18] suggest the following procedure to convert EARLINET backscatter coefficients into CALIPSO-like attenuated backscatter profiles:

1. The profile of the total backscatter coefficient $\beta^{\mathrm{tot}}(z)$ is calculated from the molecular backscatter coefficient $\beta^{\mathrm{mol}}(z)$ and the particle backscatter coefficient $\beta^{\mathrm{par}}(z)$

$$\beta^{\mathrm{tot}}(z) = \beta^{\mathrm{par}}(z) + \beta^{\mathrm{mol}}(z). \tag{1}$$

2. The particle transmission term ${T^{\mathrm{par}}}^2(z)$ of the well known lidar equation for a downward looking lidar can be obtained from the profile of the particle extinction coefficient $\alpha^{\mathrm{par}}(\zeta)$ measured with the Raman method[19]

$${T^{\mathrm{par}}}^2(z) = \exp\left(-2\int_z^{z_S} \alpha^{\mathrm{par}}(\zeta)\mathrm{d}\zeta\right). \tag{2}$$

   z_S is the height of the satellite. Accordingly we can calculate the molecular transmission term from $\alpha^{\mathrm{mol}}(\zeta)$ together with $\beta^{\mathrm{mol}}(z)$ from actual radio soundings or from a standard atmosphere.

3. The attenuated backscatter $\beta'(z)$ is defined in Ref. 20 (Eqs. 3.12 and 4.10) as

$$\beta'(z) = \beta^{\mathrm{tot}}(z)\ {T^{\mathrm{par}}}^2(z)\ {T^{\mathrm{mol}}}^2(z)\ {T^{\mathrm{O_3}}}^2(z). \tag{3}$$

   ${T^{\mathrm{mol}}}^2(z)$ and ${T^{\mathrm{O_3}}}^2(z)$ are the transmission terms which describe the influence of molecular scattering and ozone absorption, respectively. If we assume that the ozone absorption is negligible we can estimate $\beta'(z)$ with these equations from the $\beta^{\mathrm{par}}(z)$ and $\alpha^{\mathrm{par}}(z)$ profiles measured with our EARLINET Raman lidars.

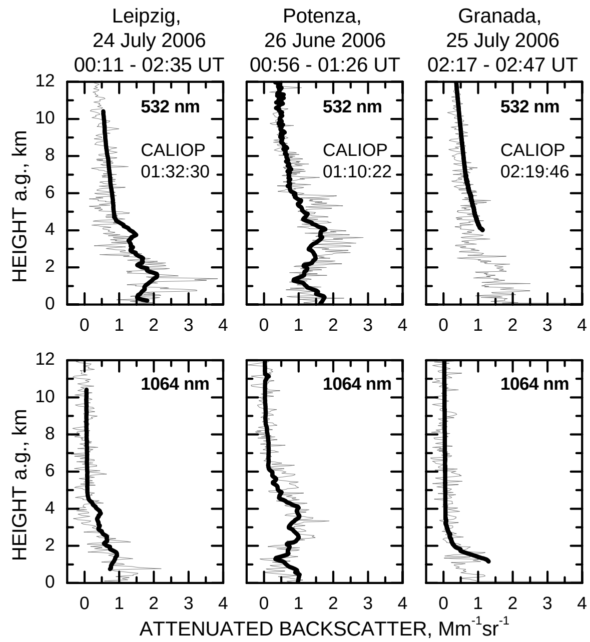

Figure 3. Attenuated backscatter profiles at 532-nm wavelength (top) and 1064 nm (bottom). CALIPSO profiles (thin gray lines) have a horizontal resolution of 5 km and a vertical resolution of 15 m. CALIPSO data were obtained from the NASA Langley Research Center Atmospheric Science Data Center. The integration times of the EARLINET profiles (bold lines) are larger than 30 minutes, the vertical resolution is 60 m. The vertical axes refer to height above ground.

Figure 3 illustrates three examples of direct intercomparisons between attenuated backscatter profiles measured with EARLINET lidars and with CALIOP. Even if the horizontal resolution of the CALIPSO profiles is much higher than the resolution of the EARLINET profiles, they agree very well. CALIPSO attenuated backscatter profiles are more noisy than the corresponding EARLINET profiles. Small-scale aerosol structures can be reproduced even better if the measurement times are selected not with respect to the closest horizontal distance, but with respect to catch the same atmospheric sampling volume. Mona et al.[18] show how to take into account horizontal advection of air parcels. If the atmosphere can be considered horizontally homogeneous the signals of CALIOP and of a simple ground-based backscatter lidar can be also combined with the two-stream method, e.g., the CESC algorithm proposed by Wang et al.[21]

3.3 Multi-wavelength Raman lidar observations

Figure 4 shows two examples of multi-wavelength Raman lidar observations which were performed on July 24, 2006. Potenza was covered with mid-level clouds, thus the profiles of optical aerosol properties could be obtained only below the cloud-base height and for a short period during a gap in the lowest cloud layer (between 20:08 UT and 20:10 UT). From both measurements we derived backscatter profiles at 355, 532, and 1064 nm with a relative uncertainty of about 5% and extinction profiles at 355 and 532 nm with an uncertainty of approximately 10%. From those β and α profiles we obtained the following aerosol-type dependent, intensive optical aerosol properties:

- the lidar ratio at 355 nm (uncertainty ≈20%),
- the lidar ratio at 532 nm (uncertainty ≈ 20%),
- the Ångström exponent, calculated from α_{355} and α_{532} (uncertainty ≈ 20%),
- the Ångström exponent, calculated from β_{355} and β_{532} (uncertainty ≈ 20%), and
- the Ångström exponent, calculated from β_{532} and β_{1064} (uncertainty ≈ 20%).

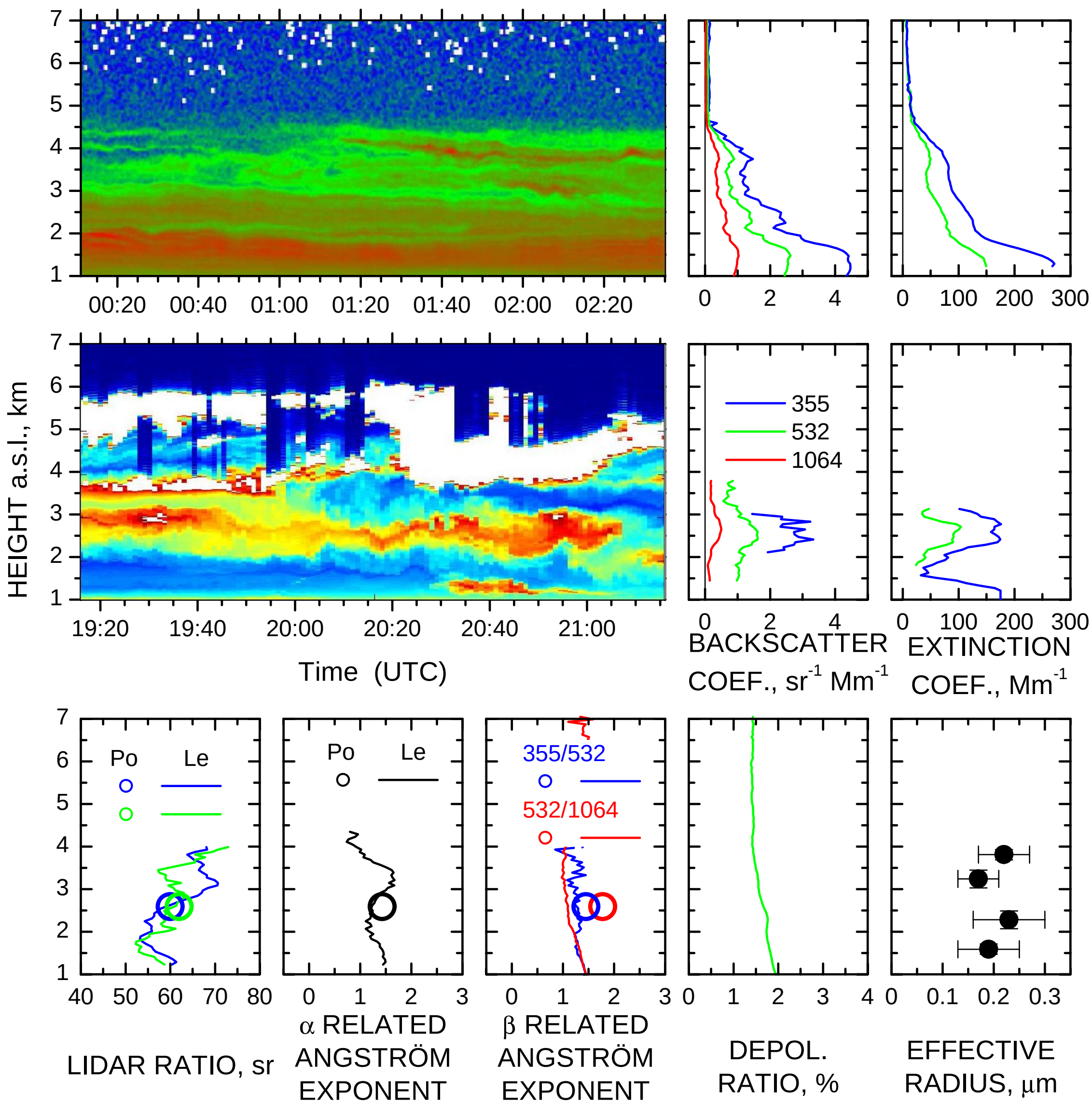

Figure 4. Multi-wavelength Raman lidar observations at Leipzig on 24 July 2006, 00:11-02:35 UT (top) and at Potenza on 24 July 2006, 19:16-21:16 UT (middle). Top and middle, left: Time series of range-corrected signals at 1064 nm. Top and middle, right: Profiles of β and α derived with the Raman method at 3 and 2 wavelength, respectively. Bottom: Profiles of lidar ratios, Ångström exponents and volume depolarization ratio, and effective radius derived for Leipzig (lines and solid circles) and layer mean values (2.4-2.8 km) for Potenza (open circles).

At the Leipzig site we measured also the volume depolarization ratio at 532 nm with a relative uncertainty of $\approx 10\%$. Effective radii of the aerosol size distribution could be obtained for the Leipzig data set for 4 different heights by means of the inversion scheme which was developed at IfT Leipzig.[5]

Even if the temporal development and vertical structure were different for the two lidar sites, the intensive aerosol properties are quite similar. The wavelength dependence of the lidar ratio is very small. The values increase with height from about 55 sr below 2-km height to about 65 sr above that height. The mean values in the layer between 2.4 and 2.8-km height above Potenza are very similar to the Leipzig data. Also the Ångström exponents which were derived from the extinction profiles are the same for both stations within the level of uncertainty. The values range from 1 to 1.7. Both data sets of the backscatter-related Ångström exponents for the short-wavelength range are about 1.4 whereas the values for the long-wavelength pair differ. The Leipzig values decrease with height from 1.3 to 1, but the Potenza value of 1.8 is larger. This discrepancy can be caused by the dense cloud cover over Potenza which allowed only the very short integration time of 3 minutes. Such clouds also complicates the estimation of an accurate reference value, especially for the calibration of the backscatter profile at 1064 nm where Rayleigh scattering of molecules is almost negligible. The volume depolarization ratio over Leipzig shows very low values of about 1.5%-2%. The effective radii of the aerosol size distribution over Leipzig are about 0.2 μm.

Similar data sets as presented by the two examples of July 24, 2006, can be obtained from all multi-wavelength Raman lidars of EARLINET. Measurements with such lidars result in a substantial set of aerosol-type dependent, intensive aerosol profiles. EARLINET lidars deliver such data sets for a large number of regular measurements and observations in conjunction with CALIPSO overpasses. Thus, the EARLINET multi-wavelength data set covers a large variety of meteorological conditions, locations and aerosol types.

4. OUTLOOK

EARLINET performed 1110 correlative observations during the first year of operation of the space lidar CALIOP. Our three-stage measurement schedule will be continued. First direct intercomparisons between attenuated backscatter profiles obtained from CALIOP and from the EARLINET lidars look very promising. Next all case-1 observations will be analyzed to derive the data base for further statistical studies. CALIPSO's automated cloud and aerosol layer detection algorithms will be validated with our measurements.

As soon as CALIPSO level 2 data, e.g., profiles of backscatter and extinction coefficients, and aerosol layer products will be available we shall validate the CALIOP lidar ratio selection algorithm by means of direct intercomparison to the corresponding product of the 16 Raman lidars in our network. Further the EARLINET Raman lidars, especially the multi-wavelength Raman lidars allow for the retrieval of an aerosol model which describes aerosol-type-dependent lidar ratios that are derived from vertically resolved lidar observations under ambient conditions.[4] This is in contrast to the presently used aerosol model of the CALIOP retrievals where the different aerosol types and their corresponding lidar ratios are mainly defined from column-integrated sun photometer observations or from in-situ measurements.[2]

Correlative observations with our multi-wavelength Raman lidars will result in a data set of conversion factors for a future homogenization between the backscatter coefficients measured at 532 nm by CALIPSO and the extinction coefficients which probably will be obtained from ADM-Aeolus and EarthCARE at 355 nm.

Ansmann et al.[15] analyzed for the first time the development of an aerosol (Saharan dust) plume using the combined tools of a continental scale lidar network (EARLINET) and chemical transport modelling. Nowadays CALIPSO data are available, which provide a global, but snapshot-like view on the vertical aerosol distribution. Space-borne lidars are an excellent tool, e.g., to study transport processes from regional to inter-continental scale. In contrast, stationary lidars deliver time-series for process studies, e.g., aerosol formation, vertical transport with the diurnal cycle of the PBL etc. Highly sophisticated stationary multi-wavelength Raman lidars even can be used to study the temporal evolution of the aerosol microphysical properties.[22] Aerosol transport models can be used to link the global snapshot observations from space-borne lidars with the temporally resolved point measurements from stationary ground-based lidars. The combination of both observational systems, space-borne and ground-based lidar networks, together with different transport modelling techniques allows for a more detailed description of the temporal and spatial aerosol distribution and evolution than what was possible so far.

ACKNOWLEDGMENTS

The EARLINET project was funded between 2000 and 2003 by the European Commission under grant EVR1-CT-1999-40003. The EARLINET-ASOS project is funded since 2006 by the European Commission under grant RICA-025991.

CALIPSO data were obtained from the NASA Langley Research Center Atmospheric Science Data Center.

REFERENCES

1. J. Bösenberg et. al, "EARLINET: A European Aerosol Research Lidar Network to Establish an Aerosol climatology," Tech. Rep. 348, Max-Planck-Institut für Meteorologie, Hamburg, September 2003.
2. Z. Liu, A. Omar, Y. Hu, M. Vaughan, and D. Winker, "Part 3: Scene classification algorithms," in *CALIOP algorithm theoretical basis document*, NASA Langley Research Center, Hampton, Virginia, USA, Oktober 2005.
3. A. Ansmann, U. Wandinger, M. Riebesell, C. Weitcamp, and W. Michaelis, "Independent measurement of extinction and backscatter profiles in cirrus clouds by using a combined Raman elastic-backscatter lidar," *Appl. Opt.* **31**, pp. 7113–7131, 1992.
4. D. Müller, A. Ansmann, I. Mattis, M. Tesche, U. Wandinger, D. Althausen, and G. Pisani, "Aerosol-type-dependent lidar ratios observed with Raman lidar," *J. Geophys. Res.* **112**(D16202), 2007. doi:10.1029/2006JD008292.
5. D. Müller, U. Wandinger, and A. Ansmann, "Microphysical particle parameters from extinction and backscatter lidar data by inversion with regularization: theory," *Appl. Opt.* **38**(12), pp. 2346–2357, 1999.
6. C. Böckmann, "Hybrid regularization method for the ill-posed inversion of multiwavelength lidar data to determine aerosol size distribution," *Appl. Opt.* **40**, pp. 1329–1342, 2001.
7. C. Böckmann, I. Mironova, D. Müller, L. Schneidenbach, and R. Nessler, "Microphysical aerosol parameters from multiwavelength lidar," *J. Opt. Soc. Am. A* **22**, pp. 518–528, 2005.
8. I. Veselovskii, A. Kolgotin, V. Griaznov, D. Müller, U. Wandinger, and D. N. Whiteman, "Inversion with regularization for the retrieval of tropospheric aerosol parameters from multiwavelength lidar sounding," *Appl. Opt.* **41**, pp. 3685–3699, 2002.
9. V. Matthias, J. Bösenberg, V. Freudenthaler, A. Amodeo, D. Balis, A. Chaikovsky, G. Chourdakis, A. Comeron, A. Delaval, F. de Tomasi, R. Eixmann, A. Hågård, L. Komguem, S. Kreipl, R. Matthey, I. Mattis, V. Rizi, J. Rodriguez, V. Simeonov, and X. Wang, "Aerosol lidar intercomparison in the framework of the EARLINET project. 1. Instruments," *Appl. Opt.* **43**, pp. 961–976, 2004.
10. C. Böckmann, J. Bösenberg, U. Wandinger, A. Ansmann, V. Amiridis, A. Boselli, A. Delaval, F. De Tomasi, M. Frioud, I. Grigorov, A. H. gå rd, M. Horvat, M. Iarlori, L. Komguem, S. Kreipl, G. Larchevêque, V. Matthias, A. Papayannis, G. Pappalardo, F. Rocadenbosch, A. Rodrigues, J. Schnaider, V. Shcherbakov, and M. Wiegner, "Aerosol lidar intercomparison in the framework of EARLINET: Part II - Aerosol backscatter algorithms," *Appl. Opt.* **43**, pp. 977–989, February 2004.
11. G. Pappalardo, A. Amodeo, M. Pandolfi, U. Wandinger, A. Ansmann, J. Bösenberg, V. Matthias, V. Amiridis, F. deTomasi, M. Frioux, M. Iarlori, L. Komguem, A. Papayannis, F. Rocadenbosch, and W. X, "Aerosol lidar intercomparison in the framework of the EARLINET project. 3. Raman lidar algorithm for aerosol extinction, backscatter, and lidar ratio," *Appl. Opt.* **43**, pp. 5370–5385, 2004.
12. A. Amodeo et al., "Optimization of lidar data processing: a goal of the EARLINET-ASOS project," *SPIE* **6750**(6750-14), 2007. this proceedings.
13. S. Nickovic, A. Papadopoulos, O. Kakaliagou, and G. Kallos, "Model for prediction of desert dust cycle in the atmosphere," *J. Geophys. Res.* **106**, pp. 18113–18129, 2001.
14. C. Pérez García-Pando, "`http://www.bsc.es/projects/earthscience/DREAM/`." Web page, 2007.
15. A. Ansmann, J. Bösenberg, A. Chaikowsky, A. Comeron, S. Eckhardt, R. Eixmann, V. Freudenthaler, P. Ginoux, L. Komguem, H. Linné, M. A. L. Marquez, V. Matthias, I. Mattis, V. Mitev, D. Müller, S. Music, S. Nickovic, J. Pelon, L. Sauvage, P. Sobolewsky, M. K. Srivastava, A. Stohl, O. Torres, G. Vaughan, U. Wandinger, and M. Wiegner, "Long-range transport of Saharan dust to northern Europe: The 11-16 October 2001 outbreak observed with EARLINET," *J. Geophys. Res.* **108**, pp. 4783, doi:10.1029/2003JD003757, December 2003.

16. A. Stohl, M. Hittenberger, and G. Wotawa, "Validation of the Lagrangean particle dispersion model FLEXPART against large scale tracer experiment data," *Atmos. Env.* **24**, pp. 4245–4264, 1998.
17. A. Stohl and T. Trickl, "A textbook example of long-range transport: Simultaneous observation of ozone maxima of stratospheric and north american origin in the free troposphere over Europe," *J. Geophys. Res.* **104**(D23), pp. 30445–30462, 1999.
18. L. Mona, A. Amodeo, G. D'Amico, and G. Pappalardo, "First comparisons between CNR-IMAA multi-wavelength Raman lidar measurements and CALIPSO measurements," *SPIE* **6750**(6750-35), 2007. this proceedings.
19. A. Ansmann, M. Riebesell, and C. Weitcamp, "Measurement of atmospheric aerosol extinction profiles with a Raman lidar," *Opt. Lett.* **15**, pp. 746–748, 1990.
20. C. A. Hostetler, Z. Liu, J. Reagan, M. Vaughan, D. Winker, M. Osborn, W. H. Hunt, K. A. Powell, and C. Trepte, "Calibration and level 1 data products," in *CALIOP algorithm theoretical basis document*, NASA Langley Research Center, Hampton, Virginia, USA, April 2006.
21. X. Wang, M. G. Frontoso, G. Pisani, and N. Spinelli, "Retrieval of atmospheric particles optical properties by combining ground-based and spaceborne lidar elastic scattering profiles," *OPTICS EXPRESS* **15**(11), p. 6736, 2007.
22. D. Müller, I. Mattis, A. Ansmann, U. Wandinger, C. Ritter, and D. Kaiser, "Multiwavelength Raman lidar observations of particle growth during long-range transport of forest-fire smoke in the free troposphere," *Geophys. Res. Lett.* **34**(L05803), 2007. doi:10.1029/2006GL027936.