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**Corresponding Address:**

Nobuhiro Takahashi  
Applied Electromagnetic Research Center,  
National Institute of Information and Communications Technology (NICT)  
4-2-1 Nukui-kita, Koganei, Tokyo 184-8795 Japan  
ntaka@nict.go.jp

Toshiyoshi Kimura  
EarthCARE/CPR Project Team,  
Space Applications Mission Directorate  
Japan Aerospace Exploration Agency (JAXA)  
2-1-1 Sengen, Tsukuba, Ibaraki, 305-8505, Japan  
kimura.toshiyoshi@jaxa.jp

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# THE EARLINET CONTRIBUTION TO THE EARTHCARE MISSION

Gelsomina Pappalardo<sup>1</sup>, Ulla Wandinger<sup>2</sup>, Lucia Mona<sup>1</sup>, Ina Mattis<sup>2</sup>, Anja Hiebsch<sup>2</sup>, Aldo Amodeo<sup>1</sup>, Albert Ansmann<sup>2</sup>, Holger Linné<sup>3</sup>, Arnoud Apituley<sup>4</sup>, Lucas Alados Arboledas<sup>5</sup>, Dimitris Balis<sup>6</sup>, Anatoli Chaikovskiy<sup>7</sup>, Giuseppe D'Amico<sup>1</sup>, Ferdinando De Tomasi<sup>8</sup>, Volker Freudenthaler<sup>9</sup>, Elina Giannakaki<sup>6</sup>, Aldo Giunta<sup>1</sup>, Ivan Grigorov<sup>10</sup>, Marco Iarlori<sup>11</sup>, Fabio Madonna<sup>1</sup>, Rodelize-Elizabeth Mamouri<sup>12</sup>, Francisco Molero<sup>13</sup>, Alexandros Papayannis<sup>12</sup>, Aleksander Pietruczuk<sup>14</sup>, Vincenzo Rizi<sup>11</sup>, Francesc Rocadenbosch<sup>15</sup>, Franziska Schnell<sup>9</sup>, Nicola Spinelli<sup>16</sup>, Xuan Wang<sup>16</sup>, Matthias Wiegner<sup>9</sup>

<sup>1</sup>Istituto di Metodologie per l'Analisi Ambientale CNR-IMAA, Potenza, Italy

<sup>2</sup>Leibniz-Institut für Troposphärenforschung, Leipzig, Germany

<sup>3</sup>Max-Planck-Institut für Meteorologie, Hamburg, Germany

<sup>4</sup>Rijksinstituut voor Volksgezondheid en Milieu, Bilthoven, The Netherlands

<sup>5</sup>Universidad de Granada, Granada, Spain

<sup>6</sup>Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

<sup>7</sup>Institute of Physics, National Academy of Sciences, Minsk, Bjelarus

<sup>8</sup>Università del Salento, Department of Physics, Lecce, Italy

<sup>9</sup>Ludwig-Maximilians-Universität, München, Germany

<sup>10</sup>Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria

<sup>11</sup>Università degli Studi dell'Aquila - Dipartimento di Fisica - CETEMPS, L'Aquila, Italy

<sup>12</sup>National Technical University of Athens, Department of Physics, Athens, Greece

<sup>13</sup>Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Madrid, Spain

<sup>14</sup>Institute of Geophysics, Polish Academy of Sciences, Warsaw, Poland

<sup>15</sup>Universitat Politècnica de Catalunya / IEEC CRAE, Barcelona, Spain

<sup>16</sup>Consorzio Nazionale Interuniversitario per le Scienze Fisiche della Materia, Napoli, Italy

## 1. INTRODUCTION

The uncertainty about radiative forcing is mainly related to tropospheric aerosols and their interactions with clouds, because of the high variability both in space and time of tropospheric, and in particular anthropogenic, aerosols (Forster et al., 2007).

A new generation of satellite borne aerosol measurements, such as lidar provided aerosol vertical profiles gives us the opportunity to improve the knowledge about aerosol impact on climate and radiative forcing.

Started on April 2006, the CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) mission provides for the first time the opportunity to address the 4-dimensional distribution of aerosols and clouds on a global scale. Since June 2006, CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization), the first satellite-borne lidar specifically designed for aerosol and cloud study, is providing near-continuous global data set of aerosols and clouds high-resolution vertical profiles (Winker et al., 2007). Stratospheric and free-tropospheric layer dynamics (Liu et al., 2008) and the complex effects of mixing processes that influence the microphysical and optical properties of aerosols

and clouds have been studied thanks to CALIPSO high-resolution vertical profiles.

The near global 4D dataset of aerosol and clouds optical properties provided by CALIPSO will be virtually extended by the next space missions equipped with lidar designed for aerosol and cloud investigation: the ESA's ADM-Aeolus (Atmospheric Dynamics Mission) (Stoffelen et al., 2005; Ansmann et al., 2006) and the EarthCARE (Earth Clouds Aerosols and Radiation Explorer) mission of the ESA and the Japan Aerospace Exploration Agency JAXA (ESA, 2004).

All together the 3 missions observations will provide a unique long data set on the global aerosol and cloud distribution, allowing the investigation of trends in cloud cover, cloud amount, and aerosol pollution state. In addition, such long-term global aerosol record is strongly needed in order to quantify the direct and indirect climate forcing by aerosols, and in particular by anthropogenic aerosols.

## 2. EARLINET

EARLINET, the European Aerosol Research Lidar Network, is the first aerosol lidar network, established in 2000, with the main goal to

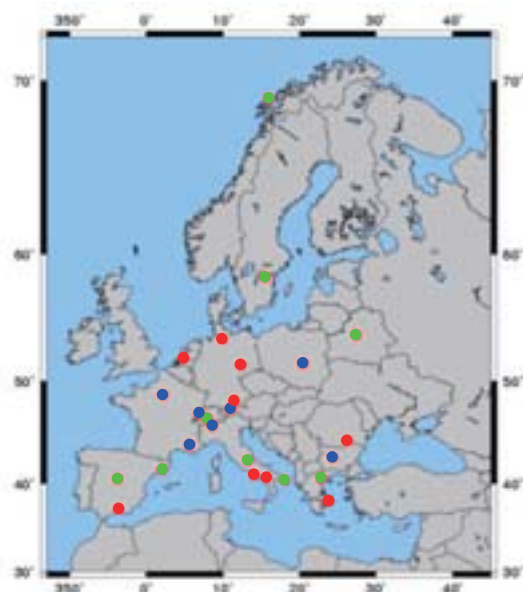
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\*Corresponding author address: Gelsomina Pappalardo, Istituto di Metodologie per l'Analisi Ambientale CNR-IMAA Tito Scalo (Potenza), Italy, e-mail: [pappalardo@imaa.cnr.it](mailto:pappalardo@imaa.cnr.it)

provide a comprehensive, quantitative, and statistically significant data base for the aerosol distribution on a continental scale.

At present, the network includes 25 lidar stations distributed over Europe, as shown in figure 1. The geographical distribution of the current 25 EARLINET stations covers the whole European continent from Madrid to Belsk and from Andøya to Athens. There are midlatitude near-coastal stations like Bilthoven, Cabauw, Hamburg but also lidar sites with continental climate like Belsk and Minsk. The Mediterranean Sea is covered by 3 Spanish stations in the west, 5 sites in Italy, and 2 Greek stations in the east.

Figure 1 shows also the geographical distribution of the different kinds of EARLINET stations: 7 simple backscatter lidars are reported in blue, 9 Raman lidar stations with the UV Raman channel for independent measurements of aerosol extinction and backscatter are reported in green. Finally the red dots represents 9 multi-wavelength Raman lidars (elastic channel at 1064 nm, 532 nm, 355 nm, Raman channels at 532 nm and 355 nm, plus depolarization channel at 532 nm) for the retrieval of aerosol microphysical properties.



**Figure 1:** Location of the 25 EARLINET stations. Blue dots represent simple backscatter lidars, the green dots the UV Raman lidar stations and the red ones the multiwavelength stations.

EARLINET stations perform measurements almost simultaneously 3 times per week following a regular schedule: one daytime measurement per week around noon, when the

boundary layer is typically well developed, and two night-time measurements per week, with low background light, in order to perform Raman extinction measurements. Besides routine measurements that provide a long unbiased dataset for aerosol climatological study, additional observations are performed to address specifically important events like Saharan dust, forest fires, volcanic eruptions, and photochemical smog.

Data quality is assured by a specific program for the quality assurance. The quality of the different instruments participating to the network is checked through direct intercomparison with reference transportable systems and through tools, developed and optimised within the network, for the continuous quality check of the instruments. The quality of the retrieval algorithms for both backscatter and Raman lidar data used by the EARLINET stations is continuously checked and improved thanks to blinded intercomparison exercises and developed tools.

This data quality control establishes a common European standard for routine quality assurance of lidar instruments and algorithms and ensures that the data products provided by the individual stations are homogenous and permanently of the highest possible quality according to common standards.

### 3. THE EARLINET-CALIPSO EXPERIENCE

Because of its geographical coverage and its high quality data, EARLINET represents an optimal tool to validate satellite lidar data and to support the fully exploitation of the information from present and future satellite missions.

EARLINET ground based lidars as reference points are strongly necessary to increase and validate the accuracy of aerosol optical properties retrieved from CALIPSO. In particular EARLINET Raman station's data are important to validate and improve, if it is the case, the aerosol retrievals from the pure backscatter lidar on board CALIPSO.

Furthermore, an integrated study of CALIPSO and EARLINET correlative measurements opens new possibilities for spatial (both horizontal and vertical) and temporal representativeness investigation of polar-orbit satellite measurements also in terms of revisit time.

Since June 2006, EARLINET has extended its program of measurements in order to perform measurements also in correspondence of CALIPSO overpasses. Within the EARLINET correlative program for CALIPSO, still in



progress, a great experience has been gained in developing suitable strategies, on the base of the analysis of the high resolution ground track data provided by NASA, for correlative observations, validation and full exploitation of satellite lidar data.

In particular, each EARLINET station performs measurements as close as possible in time and space to CALIPSO ones, within 4 h and 100km. Additional measurements are performed in order to take advantage from the geographical coverage of the network, especially in cases of interesting transport of aerosol, like Saharan dust outbreaks. Each EARLINET correlative measurement lasts for 150 minutes (centered around the overpass), whenever atmospheric conditions allow it, for investigating the temporal variability of aerosol/cloud fields.

After about 3 years of correlative observations, more than 6500 hours of correlative measurements have been performed and about 3200 correlative files are available for comparisons. Preliminary results in terms of direct comparison between CALIPSO data and ground based data are quite promising (Mattis et al., 2007; Mona et al., 2009; Mamouri et al., 2009; Pappalardo et al., 2009).

### 3.1 Level 1 comparisons

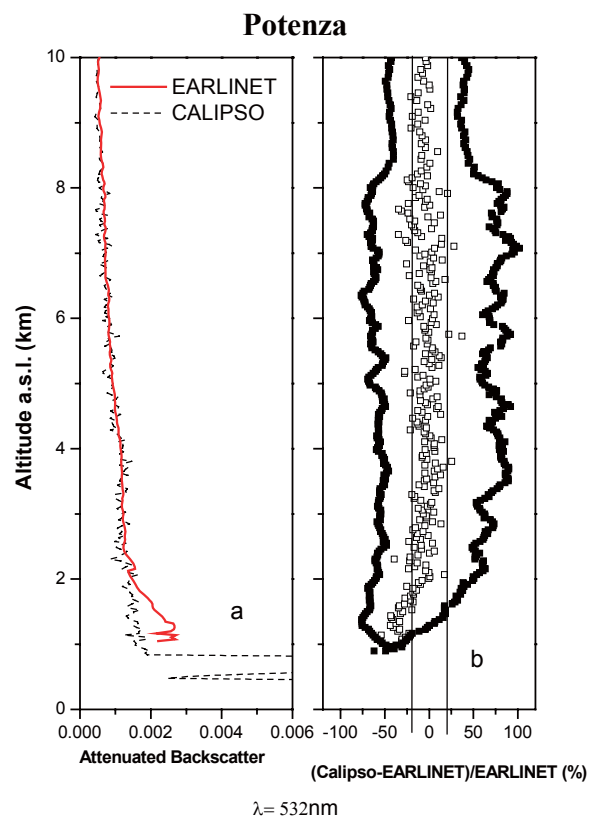
The comparison between EARLINET and CALIPSO vertical profiles of the aerosol optical properties cannot be correctly carried out without a previous assessment of the accuracy of CALIPSO raw signals (namely Level 1 data) (Winker et al., 2009). Comparing EARLINET ground-based measurements with the CALIPSO Level 1 data products, any potential problems and biases already contained in the calibrated CALIPSO lidar signals can be distinguished from any errors and uncertainties due to assumptions needed for the inversion.

A methodology for the comparison is presented and discussed into details by Mona et al., 2009, where it is shown that a comparison in terms of the main CALIPSO Level 1 product, the attenuated backscatter, starting from ground-based measurements is possible without assumptions only if independent extinction and backscatter profiles are available, i.e. with the elastic/Raman technique and High Spectral Resolution Lidar (HSRL).

A first systematic comparison between EARLINET and CALIPSO data in terms of Level 1 data has been carried out on the base of almost 18 months of EARLINET and CALIPSO correlative measurements performed in the June 2006 - November 2007 period before the change

of CALIPSO pointing angle from 0.3° to 3° off nadir (Pappalardo et al., 2009).

CALIPSO Level 1 data (Version V2.01) averaged on a horizontal scale of 5 km are used. In order to avoid any significant assumptions in the attenuated backscatter calculation, only EARLINET cases for which independent measurements of extinction and backscatter at 532 nm are available are considered. For a first comparison only cases without observation of cirrus clouds both in EARLINET and CALIPSO data are considered.



**Figure 2:** CALIPSO and EARLINET mean profiles of attenuated backscatter profile at 532 nm (a) and corresponding mean percentage difference (b) for Potenza EARLINET station. The maximum and minimum values of percentage differences are reported too as black squares.

As example, figure 2a reports the mean attenuated backscatter profiles at 532 nm as measured by CALIPSO and EARLINET Potenza station. Figure 2b shows vertical profile of the corresponding mean percentage differences, together with the minimum and maximum values of these observed differences.

There is on average a good agreement between CALIPSO and EARLINET measurements, demonstrating the good

performances of CALIPSO and the absence of evident biases in the CALIPSO raw signals. In particular, there is a very good agreement apart from the low altitudes, where horizontal distances between the two sensors in conjunction with the high variability in the aerosol content at these altitudes leads to larger differences.

This kind of comparison has been performed for each EARLINET station providing aerosol extinction and backscatter at 532 nm. On the base of this multi-station dataset, we found a good agreement with relative mean difference of 4.6%, typically within 20%, and with a relative standard deviation of 50% (Pappalardo et al., 2009).

### 3.2 Representativeness study

CALIPSO level 2 data, i.e. profiles of backscatter and extinction coefficients and aerosol layer products, can be directly compared with EARLINET data for nearby overpasses.

Furthermore EARLINET Raman lidars allow to investigate intensive optical parameters (like lidar ratios and Ångström exponents) and their dependences on the specific aerosol and cloud types, information strongly needed for the development and optimisation of space-borne lidar algorithms.

Finally, an integrated study of CALIPSO and EARLINET correlative measurements opens new possibilities for spatial (both horizontal and vertical) and temporal representativeness investigation of polar-orbit satellite measurements also in terms of revisit time.

Since April 2008, the European Space Agency supports the EARLINET-CALIPSO correlative measurements program, with two main goals: providing conversion factors in dependence of aerosol and cloud type, and investigating representativeness of CALIPSO data in describing aerosol and cloud fields through correlation analysis with EARLINET measurements.

First results concerning conversion factors and first comparisons of CALIPSO Level 2 and EARLINET data, performed on the basis of an extended experimental data set related to a major Saharan dust outbreak, are presented in a companion paper (Wandinger et al., 2009).

In the following, an example illustrates the approach for the representativeness study.

Figure 3 reports vertical profiles of the aerosol backscatter and extinction coefficient at 532 nm as measured almost simultaneously at Potenza EARLINET station (PO) and CALIPSO at different horizontal distances. Additional profiles

measured at Potenza at a different time are reported to provide information about the temporal variability. Profiles measured at Naples EARLINET station (NA) are reported too in order to provide information related to a larger horizontal distance between independent observations (Naples is about 130 km far away from Potenza).

For the closest and simultaneous measurements, reported in Figure 3 as solid lines, large differences are observed also in terms of the vertical layering. These observed differences are an effect of the horizontal inhomogeneity of the aerosol field. For the backscatter profiles, a better agreement is observed between the CALIPSO observation related to an horizontal distance of about 107 km far from Potenza and Potenza measurement on 29 May evening (temporal shift from CALIPSO of 320 min). This corresponds to a wind speed of about 5.6 m/s in agreement with the typical wind speed of 5-10 m/s observed over Potenza at 2-5 km a.s.l.. A similar agreement is not observed for the corresponding aerosol extinction coefficient, however it has to be kept in mind that CALIPSO extinction measurements are strongly affected by the lidar ratio assumption needed for the retrieval, that can lead to the observed differences.

This example shows that it is necessary to take into account the aerosol spatial and temporal variability in comparison between non-perfectly coincident measurements.

Horizontal and temporal variability of aerosol /clouds fields are investigated on different scales following two different approaches: a point-to-point comparison, in which each EARLINET observation is compared with the corresponding CALIPSO overpass measurement and a multiple-point approach, in which observations of more EARLINET stations are compared with satellite data opportunely averaged, for different scenarios, such as long-range aerosol transport.

In order to illustrate the approach for the representativeness study, an example based on a peculiar case is shown in the following.

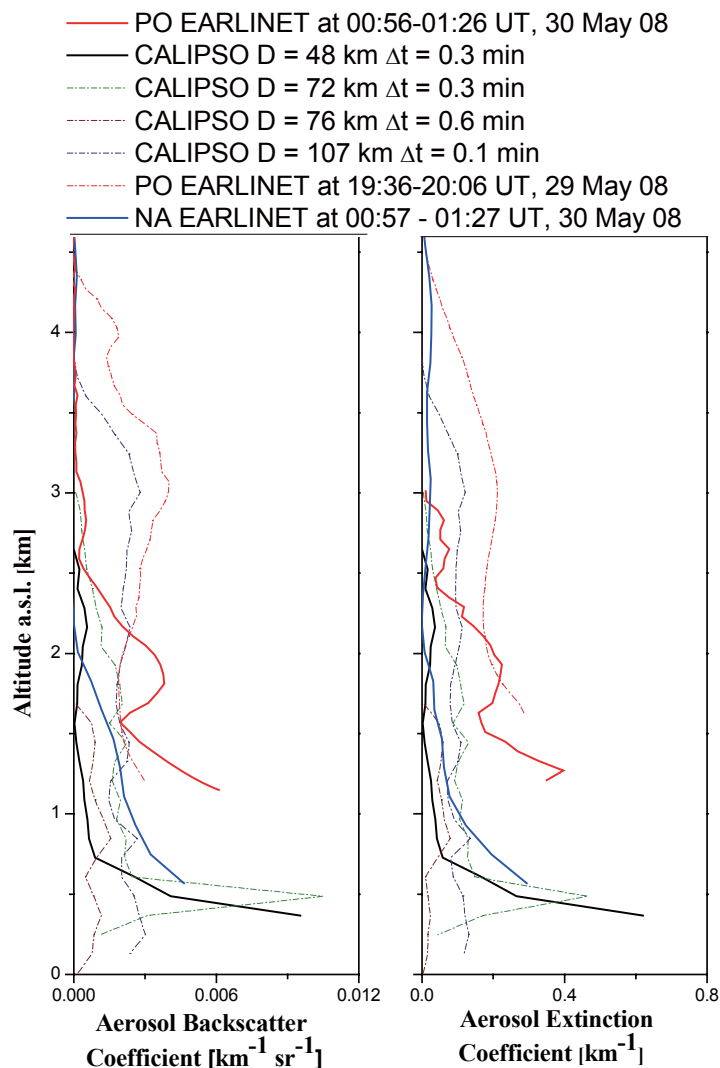
The observational period of 26-31 May 2008 has been chosen for a first correlation analysis because EARLINET stations performed a large number of measurements for investigating dust coming from Saharan over Mediterranean and Central Europe.

Comparisons within 100 km and different time shifts are used to study the temporal variability of the aerosol field, while almost simultaneous measurements (within 10 minutes by CALIPSO) at different horizontal distances are selected in order to study the spatial variability. In particular, the backscatter coefficient at 532 nm are

considered in the following, because it is a primary product of CALIPSO and it is available from most of the EARLINET participating stations, so that a large number of data is available.

Profiles of differences (absolute and relative) related to space-borne vs ground-based lidar are investigated and classified in classes on the

base of the time shift and horizontal distance between the 2 observations. For different distances (in time and space), count distributions of CALIPSO and EARLINET backscatter coefficient measurements these classes are compared (Pappalardo et al., 2009).



**Figure 3:** Aerosol backscatter (left panel) and extinction (right panel) coefficient at 532 nm measured at Potenza (PO) and Naples (NA) EARLINET stations, and CALIPSO at different horizontal distance from Potenza lidar station for the 29-30 May 2008 night-time case.

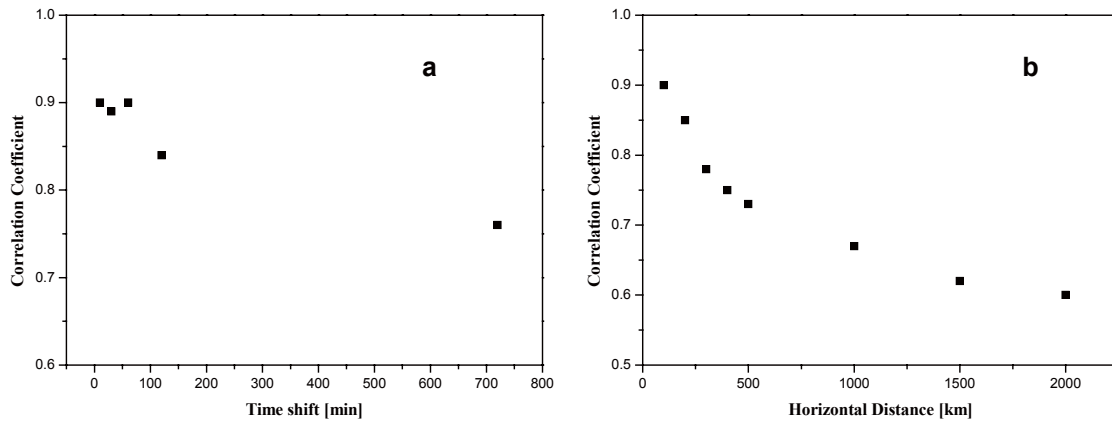
Figure 4a reports the behaviour of the correlation coefficient between CALIPSO and EARLINET backscatter counts distributions for horizontal distances lower than 100 km as a function of the maximum considered time shift between the two observations. Figure 4b reports the correlation coefficient between CALIPSO and EARLINET backscatter counts distributions

as a function of the maximum considered horizontal distance between the two observations for a maximum time shift of 10 minutes.

These plots show that within 100 km, the time shift does not have a strong influence on the observed differences, even if obviously large temporal distances correspond to a decrease in

the agreement between the two observations. On the contrary, there is a strong dependence of the agreement, and therefore of the representativeness of the measurements, on the horizontal distance over 10 minutes as timescales. In particular, the correlation coefficient goes from 0.9 for 50 and 100 km as

maximum horizontal distance down to 0.6 for 2000 km as maximum distance following an exponential decay law ( $r = 0.993$ ) characterized by a length scale of about 500 km.



**Figure 4:** Correlation coefficient between CALIPSO and EARLINET backscatter counts distributions for horizontal distances lower than 100 km as a function of the maximum considered time shift between the two observations (a) and for time shifts lower than 10 minutes reported as a function of the maximum considered horizontal distances between the two observations (b).

#### 4. SUMMARY

Since June 2006, the number of EARLINET measurements is increased for CALIPSO correlative study. Development of a suitable strategy for correlative measurements started well before the first CALIPSO measurement. In May 2008, this strategy was optimised taking advantage from the EARLINET expertise gained in almost two years of CALIPSO correlative measurements.

First results concerning comparisons between EARLINET and CALIPSO data are promising. In particular, the investigation of the spatial and temporal representativeness is approached through an integrated study of CALIPSO and EARLINET correlative measurements.

In addition, the EARLINET experience can be transferred to next satellite missions with lidar on board. In particular for the EarthCARE mission that will involve a High Spectral Resolution Lidar at 355 nm able to give independent measurements of aerosol extinction and backscatter coefficient in the UV.

The GAW Aerosol Lidar Observations Network (GALION) will be essential for extending the investigation on global scale (Bösenberg, J. and R. Hoff, 2008).

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