LIDAR RATIO CLIMATOLOGY: 5 YEARS OF SYSTEMATIC RAMAN LIDAR MEASUREMENTS OVER POTENZA, ITALY

Lucia Mona, Aldo Amodeo, Giuseppe D'Amico, Marco Pandolfi, Gelsomina Pappalardo

Istituto di Metodologie per l'Analisi Ambientale CNR-IMAA,
C.da S. Loja,Tito Scalo, Potenza, Italy, I-85050
mona@imaa.cnr.it

1. INTRODUCTION

Aerosols effects on the radiation budget are a critical component on global climate. In particular, the high variability both in space and time of the tropospheric aerosols, in terms of concentration, shape, size distribution, refractive index and vertical distribution, make the tropospheric aerosols one of the most uncertain elements in the estimation of radiation budget [1]. Vertical profiles of aerosol optical properties are needed in order to reduce the uncertainty in the aerosol forcing on climate [2]. Lidar is the most powerful remote sensing technique for aerosol profiling because of its very high vertical and temporal resolution. The most common aerosol lidar is the elastic lidar, based on the detection of the laser light elastically backscattered by the atmosphere. Since April 2006, a global high vertical resolution aerosol profiling will be provided by CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations), the first satellite-borne elastic lidar specifically conceived for aerosol and cloud study. However, the retrieval of the aerosol backscatter coefficient by an elastic lidar needs an assumption about the ratio between aerosol extinction and aerosol backscatter coefficients (i.e. the lidar ratio). Since the lidar ratio depends on aerosol microphysical properties, such as the aerosol size distribution, refractive index, chemical composition and shape [3-5], lidar ratio values applied in the retrieval of aerosol backscatter coefficient by elastic lidar must be carefully selected. Typically lidar ratio values are chosen constant within the observed aerosol layer and peculiar to the aerosol type under investigation. Of course, the accuracy of the retrieved aerosol backscatter coefficient strongly depends on the accuracy of assumed lidar ratio [6]. This assumption is particularly critical in inhomogeneous conditions like in the lowest troposphere and in many situations where the natural tropospheric variability is not negligible. In order to increase the accuracy of aerosol optical properties retrieved from pure backscatter lidar, widely used worldwide, a big effort to develop a climatology of lidar ratio values for specific aerosol types is necessary. Direct measurements of the lidar ratio can be performed by using the Raman/elastic lidar combined approach. This technique is based on the contemporary detection of both elastic and nitrogen Raman shifted signals backscattered from the atmosphere. From the Raman signal, the aerosol extinction coefficient profile is obtained [7] and used for the retrieval of the aerosol backscattered coefficient. From these two independent measurements, the lidar ratio vertical profile is obtained. In this paper, we present the results of a climatological analysis of the lidar ratio measurements performed in 5 years at CNR-IMAA lidar station located in Potenza, Southern Italy.

2. METHODOLOGY

The CNR-IMAA lidar system located in Tito Scalo, Potenza (40°36'N, 15°44' E, 760 m above sea level), is a Raman/elastic lidar system operational since May 2000 in the framework of EARLINET, the first lidar network for tropospheric aerosol study on continental scale [8].
This system is based on a Nd:YAG laser equipped with second and third harmonic generators. Elastic backscattered signals at 355 nm and 532 nm, and nitrogen Raman signal at 386 nm are detected. Aerosol extinction and backscatter coefficients and lidar ratio at 355 nm are retrieved in an independent way. In addition, the aerosol backscatter coefficient profiles at 532 nm is retrieved from the elastic signal at 532 nm, with an iterative approach. In this case, a lidar ratio profile is assumed on the basis of multi-years lidar ratio measurements at 355 nm and with the support of values reported in literature [9].
The utilized algorithms for the aerosol optical parameters retrieval and the CNR-IMAA lidar system itself have been successfully tested with devoted intercomparison exercises performed within EARLINET [10-12].
Starting on May 2000, we perform three systematic lidar measurements per week according with the EARLINET schedule [8]. Further measurements are performed in order to investigate particular events, like dust intrusions, volcanic eruptions and forest fires [13-14].

3. RESULTS

The results of the first 5 years of Raman measurements performed in a systematic way at CNR-IMAA are reported. In particular, we report a climatological analysis of the lidar ratio measurements in the Planetary Boundary Layer (PBL) and for Saharan dust intrusions. Lidar ratio measurements concerning forest fires and volcanic eruptions are also reported.

3.1 Planetary Boundary Layer

A statistical analysis on regular measurements performed in the May 2000-April 2005 period has been carried out within the PBL, defined as that height below which most of the aerosol is confined. The PBL height is determined out of lidar data by looking at the first significant negative gradient in the range corrected lidar signal, starting from the ground [15]. This altitude range is the part of the atmosphere where local aerosol component dominates and complex mechanisms of mixing and interactions of different types of aerosols should be considered.
In 5 years of regular measurements about 110 lidar ratio profiles have been collected. The PBL average lidar ratio has a mean values of 36 sr and it varies from a minimum of 10.2 sr to a maximum of 77 sr with rapid changes from day to day. This can be ascribed to the variability of aerosol microphysical properties related to differences in the composition and modification of aerosol confined in the PBL.

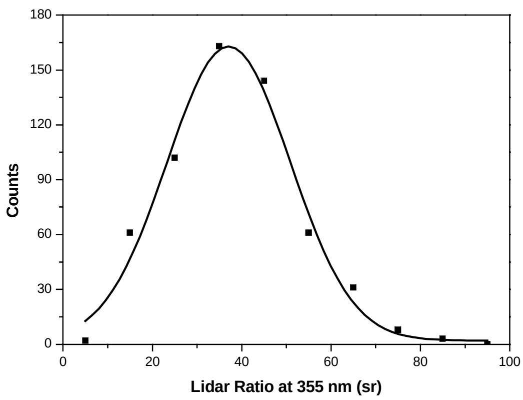

Figure 1. Count distributions of all lidar ratio values (10 sr bins) at 355 nm collected within the PBL (black square). The solid line represents the Gaussian distribution that best fits the experimental points.

It has to be considered also that the lidar ratio varies along the profile too: the standard deviation from the mean provides a quantitative measure of how much the observed values are spread inside the PBL and so of its variability along the profile. Within the PBL a mean variability along the profile of 6 sr is observed, ranging between 0.3 sr and 29 sr. Therefore the variability of the lidar ratio itself is not negligible and has to be taken into account.
For this aim, a statistical analysis on all lidar ratio data collected in the PBL is performed. In Fig. 1 the counts of values observed within the PBL is reported in 10 sr bins together with the Gaussian distribution that best fits the experimental points (correlation coefficient 0.99). The distribution is centered around a mean value of 37.1 ± 0.8 sr with a standard deviation of 13.8 sr. This large standard deviation is due both to the variability along the PBL and to the day by day variability.

3.2 Saharan Dust intrusions

Within EARLINET, particular attention is devoted to Saharan dust intrusions, in fact an alert system is established on the base of Saharan dust forecasts performed by the Atmospheric Modeling Weather Forecasting Group of the Athen's University, Greece, and by the Euro-Mediterranean Centre on Insular Coastal Dynamics (ICoD) of the University of Malta.
We find out cases of Saharan dust intrusions at our site by means of 4-day backtrajectories analysis provided by the German Weather Service (GWS) and in accordance with the TOMS images. Because of the short distance between our site and the Sahara desert, about 1 day of Saharan dust intrusion every 10 days is observed at CNR-IMAA [16].
In the Saharan dust layer, the lidar ratio mean values at 355 nm range between 6 and 78 sr, with a mean value of 38 ± 15 sr, in agreement with theoretical values of Saharan dust lidar ratio at 355 nm [5].
As for the low troposphere, also in the case of desert dust a high variability along the profile, of about 12 sr, is observed and has to be taken into account.
Fig. 2 reports the count distribution of all lidar ratio values collected within the Saharan dust layer in 10 sr bins (black squares). The experimental distribution is well fitted (correlation coefficient 0.997) by a tri-modal Gaussian distribution (solid line) that is the sum of three Gaussian distributions (dotted lines) centered around 21.9 ± 0.3 sr, 37.0 ± 1.6 sr and 57 ± 27 sr and characterized by a standard deviation of 4, 13 and 23 sr, respectively. Each one of these modes represents a different situation.
The mode centered around 21.9 sr is very narrow, indicating a situation with low variability. This mode is related to few cases of Saharan dust intrusion in which lidar ratio profiles are almost constant with the altitude and characterized by low values and a high aerosol load is present at low altitude. In these cases, a large amount of dust is transported at low altitudes over the Mediterranean Sea, with a consequent contamination between desert dust and maritime aerosols.
The second mode centered around 37 sr is well reconstructed by the counts distribution of lidar ratio

values collected between -0.5 and 0.5 km around the desert dust layer's center of mass. Therefore a lidar ratio value of about 37 sr is representative of the core of the desert dust layer, in perfect agreement with theoretical values reported in the literature for desert dust [5].
Finally a wide Gaussian distribution centered around 57 sr collects all the other situations, i.e. the tails of the desert dust layer, where the mixing between Saharan dust and free troposphere and PBL aerosols are relevant. The large standard deviation of this mode is strictly related to the complex variety of mixing processes that occurs in this part of the layer. Furthermore, the higher lidar ratio value can be related to the presence of small and absorptive particles near the surface and of small particle in the upper part of the desert dust layer.

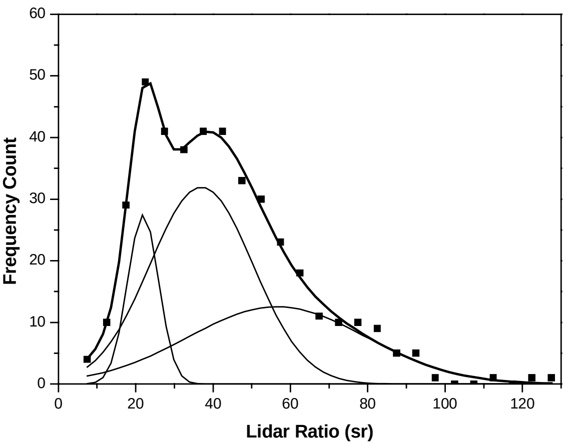

Figure 2. Counts distribution of lidar ratio values (10 sr bins) collected within the Saharan dust layers (black square) and best fitting curve (solid line). This curve is the three mode Gaussian distribution, sum of the 3 single mode Gaussian distributions reported as thin lines.

3.3 Forest fires

During the summer 2004, aerosol load in the free troposphere related to large forest fires burning occurred in Alaska and Canada have been observed at CNR-IMAA in the frame of the International Consortium for Atmospheric Research on Transport and Transformation (ICARTT). Fig. 3 reports the lidar ratio mean value calculated within the shown aerosol layers related to the North America forest fires and observed in the 22 July-03 August, 2004. The lidar ratio mean values observed in these aerosol layers range between 50 and 66 sr, while the standard deviation along the layer itself (reported as error bars in Fig.3) varies between 4.5 and 12.5 sr. In particular, the lidar ratio variability inside the layer seems to be higher when the aerosol layer is lower in altitude. A peculiar case is the 3 August 2004: on this day also Saharan dust particles are transported over Europe and the contamination between forest fires and desert dust particles can explain the lower lidar ratio mean value (50 sr) as well as the larger variability inside the layer (12.5 sr) observed in this period.

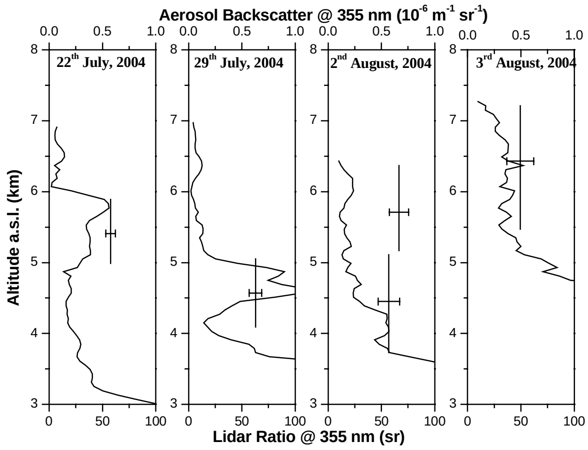

Figure 3. Lidar ratio mean values calculated within the aerosol layers, evidenced by the aerosol backscatter coefficient profiles reported. The lidar ratio standard deviation calculated within the reported aerosol layer altitude range (vertical bar) is reported as error bar.

3.4 Volcanic eruptions

The first lidar ratio measurement of aerosol particles emitted in the free troposphere during a volcanic eruption have been collected at CNR-IMAA during the Etna eruption in 2002. On 1-2 November the direct transport of the volcanic plume from Mt. Etna to Potenza has been observed between 4 and 5.5 km a.s.l. [14]. Inside the volcanic aerosol layer, a mean lidar ratio value of 55 ± 4 sr is measured. A detailed study based on lidar ratio at 355 nm and Angstrom backscatter exponent allowed to conclude that the observed volcanic aerosol layer contains young sub-micron sulphate particles, a low soot content, with no presence of large ash particles [14].
The lidar ratio vertical profile (see Fig.4) measured on 1 November at the moment of direct and fast transport toward our site, is almost constant within the volcanic aerosol layer (4-4.5 km a.s.l.), indicating a very homogeneous aerosol layer in terms of chemical-physical properties. On the contrary, on the previous day, a large variability around the mean lidar ratio value of 53 sr is observed in the volcanic aerosol layer extending between 3.2 –5.5 km a.s.l.. In this case the larger variability can be related to a longer travelled path during which the chemical-physical properties of these particles were modified. This hypothesis is confirmed by model simulations that show for this day particles released at Etna volcano and reaching Potenza after a long path [17].

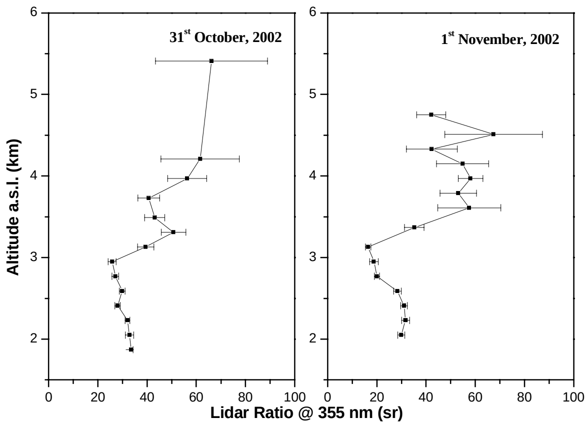

Figure 4. Vertical profiles of lidar ratio at 355 nm measured during the Etna 2002 volcanic eruptions.

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