Three years of systematic lidar observations of Saharan dust outbreaks at Naples EARLINET station

A. Boselli[a], M. Armenante[b], G. Pisani[c], N. Spinelli[c], X. Wang[d]
(a) IMAA-CNR Istituto di Metodologie per l'Analisi Ambientale, C.da S. Loja 85050 Tito-Scalo (PZ)- Italy
(b) INFN Istituto Nazionale di Fisica Nucleare Sezione di Napoli- , Compl. Universitario di Monte S. Angelo - Via Cintia, 80126, Napoli-Italy
(c) CNISM Consorzio Nazionale Interuniversitario per le Scienze Fisiche della Materia UdR Napoli, and Dipartimento di Scienze Fisiche - Università di Napoli Federico II- Compl. Universitario di Monte S. Angelo - Via Cintia, 80126, Napoli - Italy
(d) CNR-INFM Coherentia-Unità di Napoli, Dipartimento di Scienze Fisiche - Università di Napoli Federico II- Compl. Universitario di Monte S. Angelo - Via Cintia, 80126, Napoli - Italy

The optical properties and the spatial distribution of tropospheric aerosols layers over Naples have been studied by means of Raman lidar observations performed during Saharan dust outbreaks from May 2000 to August 2003 in the frame of the EARLINET project (Bösenberg et al., 2003). Starting from lidar profiles, the characterization of the desert dust layer in term of base, top and thickness has been performed. In order to study the mean optical properties of the aerosol and to evaluate the contribution of the dust and its variability with height a statistical approach have been followed. The optical properties of the Saharan dust layer have been studied in terms of mean values of integrated backscatter (IB), optical depth (OD) and extinction-to-backscatter ratio (LR).

1. Introduction

During the last years a growing interest has been developed in the study of atmospheric aerosols. Moreover, the absence of a systematic statistical survey during a long time period and in a large spatial scale and the variability of aerosols sources, properties and spatial distribution gives rise to noticeable uncertainties in the aerosol role on climate and environmental conditions. In particular, this is true for tropospheric mineral aerosol. Wide amount of such aerosol is formed by dust particles produced by wind erosion in desert areas; these particles are introduced in the atmosphere and successively carried far from their sources. In particular, as evidenced by many authors, large amounts of dust are transported over the Europe (Papayannis et al., 2008).

Actually, the scientific community is devoted to study regional and global transport of dust, with the aim to investigate their effects on the radiative budget in the atmosphere over different spatial and temporal scales. In this context, range resolved lidar measurements represent the key to obtain profile of atmospheric parameters with high spatial and temporal resolution and to distinguish boundary layer aerosol from long range advected one. Due to its closeness to the African continent, the Naples area (Southern Italy, 40.838°N, 14.183°E, 118 m above sea level) represents an ideal site to

study the transport of dust particles across the Mediterranean Sea towards the European continent.
In this area lidar technique has been successfully applied to study the lower atmospheric structure and to analyze the vertical distribution of aerosol particles during three years of Saharan dust outbreaks.

Tab.1 Technical specifications of the Naples lidar system.

LASER SOURCE		
XeF excimer laser (Lambda Physik)		
Wavelength and pulse energy	λ = 351 nm, E_{MAX} = 60 mJ	
Maximum pulse repetition rate	200 Hz	
Beam divergence	< 1 mrad	
Pulse duration	23 ns	
RECEIVER		
Newtonian Telescope		
Primary mirror diameter	0.3 m	
Combined focal length	1.2 m	
Field of view	0.2 - 2 mrad	
SPECTRAL SELECTION		
Interference Filters		
Wavelengths	351 nm	382 nm
Bandwidth	< 1.5 nm	< 1 nm
Out of band rejection	$\leq 10^{-6}$	$\leq 10^{-8}$
Transmission efficiency	~ 20 %	~ 20 %
ELECTRONIC CHAIN		
Photon counting acquisition		
EG&G Ortec Turbo MCS		
Minimum time resolution	5 ns	
300 MHz PHILLIPS SCIENTIFIC fast discriminator		
Analog acquisition		
500 Mz TECKTRONIX digital oscilloscope		
DETECTORS		
Photomultipliers enclosed in cooled housing (-30°C)		
ADDITIONAL EQUIPMENT		
Ground based sondes (T, P, RH)		

2. Methodology

A lidar system in elastic-Raman configuration was operative at Department of Physical Science of the Naples University from May 2000 to August 2003. The system was based on a XeF Excimer laser (λ=351nm) working at 50Hz repetition rate, with a pulse energy up to 60 mJ, pulse width of 20 nsec, and divergence <1 mrad. The backscattered radiation was collected by means of a vertically pointing Newtonian telescope with primary mirror diameter of 30 cm and with focal length and field of view of 120cm and 1.7 mrad, respectively. The acquisition chain included two different channels for the elastic backscattered radiation and the N_2 Raman shifted echoes. The lidar signals were detected by photomultipliers and than acquired with a vertical resolution of 15 meters and a temporal resolution of 1 minute trough analog and photon counting techniques. More details about the technical specifications of the system are reported in table 1.

Following the EARLINET protocol lidar measurements have been systematically performed on Monday at noon time and in the evening and on Thursday in the evening.

Lidar measurements are expressed in terms of aerosol backscattering and extinction profiles. These data are retrieved with a final spatial vertical resolution of 60m and a temporal resolution of 30min. In particular, for daytime measurements the retrieval of the backscatter coefficient profile $\beta(\lambda,z)$ has been obtained trough the Klett-Fernald algorithm (Klett, 1981; Fernald, 1984). In night time conditions we obtained an independent measurement of aerosol backscatter $\beta a(\lambda, z)$ and extinction $\alpha a(\lambda,z)$ coefficients profiles from the simultaneous acquisition of both the elastic and the N_2 Raman lidar signals, using the methods proposed by Ansmann (Ansmann 1990, Ansmann, 1992). In this way, we obtain also a direct measurements of the lidar ratio (LR), i.e. the extinction to backscatter ratio, related to aerosol microphysical properties as chemical composition, refractive index, shape and particles size distribution (Ackermann, 1998).

Typical errors on backscattering and extinction coefficients final data are evaluated by using a Monte Carlo method and resulted of the order of 5% at 2 km of altitude in nighttime conditions.

As part of the EARLINET network, the lidar system and the used algorithms have been quality assured trough several intercomparison experiments (Matthias et al., 2004) and by means of a comparative evaluation of the used inversion procedures (Böckmann et al., 2004; Pappalardo et al., 2004).

3. Data Analysis

Systematic lidar measurements have been performed from May 2000 to August 2003 over Naples. During the whole period regular observations of Saharan dust transport events in the troposphere have been carried out on basis of Atmospheric Modelling Weather Forecasting Group of the University of Athens (Greece) alert, and online forecast of Euro-Mediterranean Centre on Insular Coastal Dynamics (ICoD-Malta). Forecasts are based on DREAM (Dust Regional Atmospheric Module) model predicting desert aerosol load over the measurement area (Nickovic et al., 2001).

From May 2000 to August 2003 we observed 36 strong Saharan dust episodes which mean length was 4.5±0.5 days. Dust outbreak have been identified by crossing the forecasts with 96 hours back-trajectories provided by the German Weather Service.

In particular, the back-trajectories analysis revealed that desert dust follows two main directions from the source to Southern Italy, as outlined in figure 1. This result is in agreement with the hypothesis of a relationship of outbreaks with low pressure system coming from Nord West direction, as a previous study of synoptic situation associated with Saharan dust events over western and central Mediterranean pointed out (Frontoso et al., 2007).

Fig. 1: Picture shows the two main trajectories for air masses coming from Sahara.

As already reported by several authors (Gobbi et al., 2003; Balis et al., 2004; Papayannis et al., 2008) also in Naples the seasonal distribution of the Saharan dust outbreaks pointed out a predominance (about 40%) of sand transport events during spring time, while fewer dust episodes were observed during the winter (Tab.2). This is probably due to low pressure system coming from Nord West direction which is more frequent in spring than in other seasons.
In order to derive the main characteristics of the Saharan dust layer, the plume base, top, and thickness have been determined (Mona et al., 2006). The main values and the corresponding standard deviations of the desert dust parameters are reported in table 3.
The data analysis revealed a large variability of the vertical extension of the Saharan dust clouds that in 70% of the observed events resulted confined below 5000 m of height.
Finally, the lidar data analysis revealed that more then 40% of measured events seeped into the boundary layer.

Tab.2: Number of Saharan dust events measured at Naples for each season in the time period between May 2000 and August 2003.

Season	# events
Spring	14
Summer	9
Autumn	8
Winter	5
Total	36

Tab.3: Main values and standard deviation (SD) of base, top and thickness of the Saharan dust layers. The reported values refers to measurements performed over Naples in the period 2000-2003.

	Mean value	**SD**
Base (m)	1500	800
Top (m)	4700	1100
Thickness (m)	3500	1400

The mean optical properties of the dust plume have been studied by means of a statistical analysis. The analysis was performed in terms of integrated backscattering (IB), optical depth (OD), and mean extinction to backscattering ratio (LR) mesured inside the clearly identified dust layer region. The frequency distributions are shown in figure 2.

We measured mean values of IB and OD of $(4.4 \cdot \pm 0.2) \cdot 10^{-3} sr^{-1}$ and 0.21±0.02, respectively. Moreover, the mean value of LR resulted 44±3 sr, in agreement with theoretical and experimental values reported in the literature for Saharan Dust (Ackermann, 1998; Mona et al., 2006;Papayannis et al., 2008). In particular, the reported values result in agreement with the values obtained over Europe from other EARLINET lidar stations which LR typical values range from about 38 to 60 sr inside the Saharan dust layer.

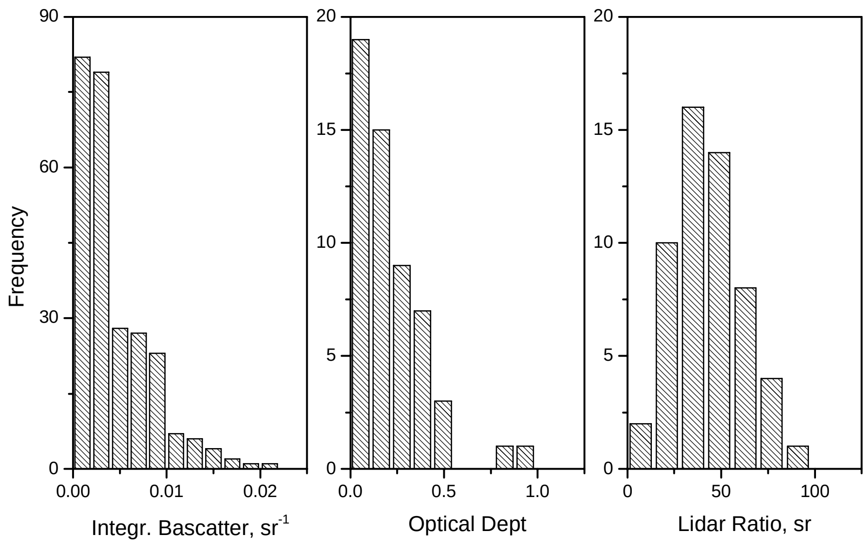

Fig.2: Frequency Distribution of optical properties for Saharan dust evaluated between the top of PBL up to the top of Saharan dust layer. Data refers to lidar measurements performed in the period 2000-2003.

Tab.4: Measured mean values of lidar ratio as function of height in Saharan dust outbreak cases.

Height (m)	**Average LR (sr)**
2000-2500	51±3
2500-3500	46±2
3500-5000	58±5
5000-8000	77±8

The statistical analysis on LR performed on four different layers (Tab. 4) revealed that above 2.5 km the LR increases with height, probably because of gravitational settling of desert dust. In fact, the lidar ratio depends on the effective size of particles and increases as the fine particles concentration become larger. Due to the geographic location of Naples, very close to dust sources, the suspended coarse particles can play an important role in the lower troposphere by decreasing the lidar ratio value. Values found for higher layers are comparable with ones carried out from EARLINET stations far from desert sources (North of the Europe) where the gravitational settling acted for a longer time because of long range transport. In a different way, below 2 ÷ 2.5 km, the influence of local aerosols in the PBL, where mixing processes occur, can involve higher values for LR.

4. Conclusions

Systematic lidar measurements have been performed from May 2000 to August 2003 over Naples (40°50'N-14°10'E, 118m a.s.l). During the whole period regular observations of Saharan dust transport events in the troposphere have been carried out.
We have measured among 36 Saharan dust outbreaks with a mean temporal length of about 4 days and a prevalence in spring months. Statistical analysis of measured events revealed that in 70% of the observed cases the vertical extension of the Saharan dust clouds was confined below 5000 m of altitude. Moreover, 16 events are characterized by intrusion of the sand plume in the PBL.
The analysis of the back-trajectories revealed that during Saharan dust events air masses reaching Southern Italy regions followed two main directions. These directions are compatible with the hypothesis of a correlation of outbreaks with low pressure system coming from Nord West direction, as the synoptic situation study pointed out.
The mean optical properties of the dust plume have been studied by means of a statistical analysis of the observed aerosol parameters. The analysis revealed mean value of backscattering integrated over the plume (IB) is $(4.4\cdot\pm0.2)\cdot10^{-3}$ sr^{-1} and optical dept (OD) is 0.21±0.02. Moreover, the mean value of extinction-to-backscatter ratio (LR) results to be 44±3 sr, in agreement with theoretical and experimental values reported in the literature for Saharan Dust. Finally, the LR statistical analysis performed on four

different layers revealed that above 2.5 km LR increases with the height, probably because of gravitational settling of desert dust.

Acknowledgments

The financial support of this work by the European Commission under grant RICA-025991 is gratefully acknowledged. The authors also thank the German Weather Service (DWD) for the air mass back-trajectory analysis.
This work has been carried out in the framework of the research agreement between CNISM Consortium and Consiglio Nazionale delle Ricerche.

References

Ackermann J., 1998, The Extinction-to-Backscatter Ratio of Tropospheric Aerosol: A Numerical Study. American Meteorological Society, 1043-1050.

Ansmann A., M. Riebesell, and C. Weitkamp, 1990, Measurement of atmospheric aerosol extinction profiles with a Raman lidar, Opt. Lett., 15, 746–748.

Ansmann A., U. Wandinger, M. Riebesell, C. Weitkamp, and W. Michaelis, 1992, Independent measurement of extinction and backscatter profiles in cirrus clouds using a combined Raman elastic-backscatter Lidar, Appl. Opt. 31, 7113.

Balis D., V. Amiridis, S. Nickovic, A. Papayannis, and C. Zerefos, 2004, Optical properties of Saharan dust layers as detected by Raman lidar at Thessaloniki, Grece, Geophys. Res. Lett, 31, L3104, doi: 10.1029/2004GL019881.

Böckmann C., U. Wandinger, A. Ansmann, J. Bösenberg, V. Amiridis, A. Boselli, A. Delaval, F. De Tomasi, M. Frioud, A. Hågård, M. Horvat, M. Iarlori, L. Komguem, S. Kreipl, G. Larchevêque, V. Matthias, A. Papayannis, G. Pappalardo, F. Rocadembosch, J.A. Rodriguez, J. Schneider, V. Shcherbakov, M. Wiegner, 2004, Aerosol lidar intercomparison in the framework of the EARLINET project. 2. Aerosol backscatter algorithms, Appl. Opt. 43, N. 4, 977-989.

Bösenberg J., V. Matthias, A. Amodeo, V. Amoiridis, A. Ansmann, J. M. Baldasano, I. Balin, D. Balis, C. Böckmann, A. Boselli, G. Carlsson, A. Chaikovsky, G. Chourdakis, A. Comerón, F. De Tomasi, R. Eixmann, V. Freudenthaler, H. Giehl, I. Grigorov, A. Hågård, M. Iarlori, A. Kirsche, G. Kolarov, L. Komguem, S. Kreipl, W. Kumpf, G. Larcheveque, H. Linné, R. Matthey, I. Mattis, A. Mekler, I. Mironova, V. Mitev, L. Mona, D. Müller, S. Music, S. Nickovic, M. Pandolfi, A. Papayannis, G. Pappalardo, J. Pelon, C. Pérez, R. M. Perrone, R. Persson, D. P. Resendes, V. Rizi, F. Rocadenbosch,. A. Rodrigues, L. Sauvage, L. Schneidenbach, R. Schumacher, V. Shcherbakov, V. Simeonov, P. Sobolewski, N. Spinelli, I. Stachlewska, D. Stoyanov, T. Trickl, G. Tsaknakis, G. Vaughan, U. Wandinger, X. Wang, M.Wiegner, M. Zavrtanik, and C. Zerefos, 2003, EARLINET: A European Aerosol Research Lidar Network to Establish an Aerosol Climatology. Max-Planck-Institut Report No. 348.

Fernald F.G., 1984, Analysis of atmospheric lidar observation: some comments. Applied Optics 23, 652-653.

Frontoso M.G., N. Spinelli, C. Pérez, M. Sicard, A. Comeron, and J.M.Baldasano, 2007, The vertical distribution of Saharan dust over the western and central Mediterranean through dust modelling and lidar observations, Geoscience and Remote Sensing Symposium, (IGARSS-07). IEEE, 2007, p. 1059-1062.

Gobbi G.P., and F. Barnaba, 2003, The vertical distribution of aerosol, Saharan dust and cirrus clouds at Rome (Italy) in the year 2001, Atmos. Chem. Phys. Discuss., 3, 5755-5775.

Klett J., Stable analytic inversion solution for processing lidar returns. Applied Optics, No.2, vol.20 (1981).

Matthias V., 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.A. Rodriguez, V. Simeonov, X. Wang, 2004, Aerosol lidar intercomparison in the framework of the EARLINET project. 1. Instruments, Appl. Opt. 43, N. 4, 961-976.

Mona L., A. Amodeo, M. Pandolfi, and G. Pappalardo, 2006, Saharan dust intrusions in the Mediterranean area: three years of lidar measurements in Potenza - J. Geophys. Res., vol. 111, D16203, doi:10.1029/2005JD006569.

Nickovic S., G. Kallos, A. Papadopoulos, and O. Kakaliagou, 2001, A model for prediction of desert dust cycle in the atmosphere, J. Geophis. Res., 106, 18,113-18,129.

Papayannis A., V. Amiridis, L. Mona, G. Tsaknakis, D. Balis, J. Bösenberg, A. Chaikovski, F. De Tomasi, I. Grigorov, I. Mattis,V. Mitev, D. Müller,S. Nickovic, C. Pérez, A. Pietruczuk, G. Pisani, F. Ravetta, V. Rizi, M. Sicard, T. Trickl ,M. Wiegner, M. Gerding, R.E. Mamouri, G. D'Amico, and G. Pappalardo, 2008, Systematic lidar observations of Saharan dust over Europe in the frame of EARLINET (2000-2002), accepted for publication on J. Geophys. Res.

Pappalardo G., A. Amodeo, M. Pandolfi, U. Wandinger, A. Ansmann, J. Bosenberg, V. Matthias, V. Amiridis, F. De Tomasi, M. Frioud, M. Iarlori, L. Komguem, A. Papayannis, F. Rocadenbosch, X. Wang, 2004, Aerosol lidar intercomparison in the framework of the EARLINET project. 3. Raman lidar algorithm for aerosol extinction, backscatter and lidar ratio, Appl. Opt., 43. N. 28, 53705385.