Atmospheric aerosol characterization in the urban area of Napoli

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1. Abstract

A systematic study of atmospheric aerosols in the Urban area of Napoli is presented; it is based on a set of data collected over nine years (from 2000) of Lidar measurements at the Napoli lidar station (40°50' 18''N, 14°10' 59''E, 118 m asl).
The Lidar technique is able to give information about the vertical distribution and to retrieve aerosol optical properties, like backscattering and extinction coefficients, scattering ratio, angstrom exponent and lidar ratio. Measurements have been performed systematically twice a week providing information about aerosol optical properties with a final spatial resolution of 60m and a temporal resolution of 30 min. Additional measurements have been carried in order to study: -Saharan dust transport events; - complete diurnal cycles of aerosol layers and the correlation with local atmospheric circulation phenomena; - Etna volcanic eruptions; - urban and rural sites intercomparison.
The seasonal dependence of the optical parameters and of the frequency distribution of Saharan dust events has been analyzed on a statistical basis. A detailed characterization of the Planetary Boundary Layer aerosol content of natural and anthropic origin is also reported.

2. Introduction

Recently there is a growing interest in the study of aerosol compounds in the troposphere because of their influence in many atmospheric processes as well as their role in the Earth's radiative budget. The monitoring of aerosol particles in the atmosphere can be realised in real time with lidar systems using optical backscattering for the study of atmospheric properties.
Laser remote-sensing techniques (lidar systems) have gained high acceptance as long-range non-invasive probes of the chemical composition and physical properties of the atmosphere. Through its high spatial and temporal resolution, the lidar technique is a powerful tool in monitoring the evolution of the basic meteorological and atmospheric parameters and in particular to study: a) the atmospheric dynamical transport processes using the aerosols particles as tracers, b) the vertical distribution of aerosol particles, either produced locally over the measuring site (car traffic, domestic heating, industrial activities), or transported by the atmospheric circulation (trans-boundary air pollution) and c) the structure of the lower atmosphere (PBL, aerosol layers), and its correlation with air pollution levels at ground.
In particular in Napoli, in the Western part of the city, on the top of a volcanic hill, few kilometres far from the Tirrenic Sea, is located The Napoli Lidar station (40°50' 18''N, 14°10' 59''E, 118 m asl). Thanks to its favourable location the main part of the air trajectories coming from North Africa passes over Napoli allowing Lidar measurements to be performed every time a Saharan dust transport event over Mediterranean Sea takes place.
Alert cases are provided by the Atmospheric Modelling Weather Forecasting Group of the University of Athens (Greece).

Napoli Lidar station is included in a network of 26 Lidar stations distributed all over Europe in the framework of the EARLINET [1] project.

The main goal of this network, operating since 2000, is to collect data and overtake the derived incertitude in the knowledge about the atmospheric aerosols and their role on atmospheric processes. Especially concerning the Planetary Boundary Layer (the lowest part of the atmosphere) the aerosols contents is strongly dependent from the characteristics of the sources at ground. In this paper we present the statistical analysis of systematic lidar measurements of the aerosol optical properties performed by the lidar operating in Napoli-Italy since 2000 aimed to characterize the local as well as the long range transport phenomena influencing the atmospheric aerosol load.

A field measurements campaign aimed to study comparatively the planetary boundary layer (referred as PBL, hereinafter) structure and evolution in two sites (Naples and Pontecagnano) differing for orography and urbanization level has been worked out. The two sites are located 50 km on the Tyrrhenian coast. Naples is an urban area with a very high level of urbanization and huge aerosol content located mainly below the PBL. Pontecagnano (40°37'N-14°53'E) is a rural and flat area. The correlation between the height of the PBL and the temperature of the ground in Napoli (where data were available) and the heat flux in Pontecagnano is presented.

Additionally, measurements have been performed during the eruption of Mt. Etna volcano during July and August 2001[2]. The backtrajectory analysis has been used to study the aerosol source region and plume transport and to distinguish special aerosol types.

3_Methodology

The Napoli lidar system from 2000 to 2003 was based on a XeF Excimer laser emitting 351 nm light pulses at 50 Hz repetition rate, with a pulse energy up to 60 mJ, pulse width of 20 nsec, and divergence lower than 1 mrad (0.1 mrad with beam expander) . Since 2003 the laser source is a NdYAG solid state laser operating at 30Hz retetition rate with pulses of 100 mJ, 5 ns, on both the second (532nm) and the third (355 nm) harmonics. A 30 cm diameter, 120 cm focal length Newtonian telescope was used to collect the backscattered radiation, with a field of view of 1.7 mrad. The signal detection system included acquisition channels corresponding to the elastic backscattered radiation and the Raman shifted echoes from N_2 and H_2O molecules Elastic and Raman signals were analyzed by a dichroic beam splitters and interferential filters. A double data acquisition system, which includes both analog digitizing and photon counting techniques, was used in order to extend the sounded range from 150 m up to 20 km. Data were collected with a spatial resolution of 15m.

Following the EARLINET protocol, lidar measurements have been performed systematically twice a week (Monday at noon time and evening, Thursday in the evening). Additional measurements have been carried out during special events such as Saharan dust transport event and Etna eruptions.

The measurements provide information about aerosol optical properties with a final spatial vertical resolution of 60m and a temporal resolution of 30 min.

A movable Lidar realized by CO.RI.S.T.A. [3] was used for the measurements in Potecagnano. It was provided with an optical apparatus of emission/reception in sligthly bistatic configuration, composed by a Cassegrain telescope, a beam-steerer, a Nd:YAG laser, and two acquisition channels. A laser source working at two different wavelenghts 532 nm and 355 nm alternatively has been used with pulse energy of 500 µJ and 300 µJ at 532 nm and 355 nm, respectively, with a rapetition rate of 1 kHz. The telescope diameter was 20 cm with focal length of 1.4 m.

Lidar measurements are expressed in terms of aerosol backscattering and extinction profiles. From night-time measurements the vertical distribution of aerosol extinction coefficient α and of aerosol backscattering coefficient β at laser wavelength has been obtained without any a-priori hypothesis by the method based on the Raman signal [4].

In the retrieval of the backscattering coefficient profiles obtained from the elastic signal only, we have fixed the LR values taking into account the source regions of the air masses determined from the back-trajectories analysis and having as references the values of LR determined in the nearest Raman measurements for the Napoli station.

About portable Lidar the only possibility is to perform elastic measurements so the method used to retrieve atmospheric aerosols properties used the Klett-Fernald algorithm[5].

4_Data analysis and Discussion

Lidar measurements of aerosol optical properties and of their vertical distribution have been systematically performed in Naples (from May 2000). The reported analysis is based on regular measurements performed in clear sky conditions three times a week on two days (Monday at noon and in the evening, Thursday in the evening).

The main aerosol optical properties are studied by means of a statistical analysis of integrated backscatter (IB), optical depth (OD) and extinction-to-backscatter ratio (LR), measured in a definite set of atmospheric layers. In the lower troposphere maximum values of IB and OD are found during summer/spring days, while minimum values are observed in winter/autumn.

Mean values of the optical parameters in a definite set of atmospheric layers are reported in Table 1 and Table 2.

# file	season	IB ($x10^{-3}sr^{-1}$)			
		<1km	1-2km	2-5km	PBL
93	Spring	3.6±0.2	2.0±0.1	2.1±0.2	5.1±0.3
69	Summer	4.0±0.2	2.5±0.2	2.6±0.3	5.9±0.4
71	Autumn	3.3±0.2	1.5±0.2	1.3±0.2	4.1±0.3
61	Winter	3.6±0.3	1.5±0.1	1.1±0.2	4.6±0.4

Tab.1:

Mean values of integrated backscattering (IB)

# file	season	LR (sr)				OD ($x10^{-1}$)			
		<1km	1-2km	2-5km	PBL	<1km	1-2km	2-5km	PBL
37	Spring	84±7	55±4	52±5	69±6	1.6±0.2	1.1±0.1	1.1±0.2	2.8±0.2
39	Summer	84±6	51±3	53±5	78±6	2.3±0.2	1.1±0.1	1.7±0.3	3.6±0.4
45	Autumn	76±6	52±4	37±4	74±6	1.9±0.2	1.0±0.2	0.5±0.1	2.5±0.2
39	Winter	87±7	72±5	57±8	85±6	2.0±0.2	0.9±0.1	0.9±0.3	2.5±0.2

Tab.2: Mean values of Lidar ratio (LR) and optical depth (OD)

LR values are larger in winter than in summer, as expected in case of small dimension of pollution particles produced by local sources as combustion product, vehicular traffic, domestic heating.

We have also studied the annual trend of the PBL height and the evolution of different layers characterizing its structure. In particular, we have characterized the sea-breeze influence both on the PBL evolution and on the development of aerosol layers. The statistical analysis of the aerosol optical properties observed in the selected layers indicate that the layering structure develops above 1000 m and the sea-breeze circulation moves aerosol particles into the atmospheric region above this height, generating a second aerosol layer, where an increase between 60% and 100% in aerosol load has been observed after the sunset.

Due to the geographic location very close to the African continent, the Naples area represents an ideal site to study the transport of dust particles across the Mediterranean Sea towards the European continent. Lidar technique has been successfully applied to study the optical properties and the spatial distribution of the tropospheric aerosols under Saharan dust outbreaks. Dust measurements have been taken on 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.

From May 2000 to August 2003 about 290 days of measurements corresponding to 860 lidar profiles of atmospheric aerosols optical parameters have been performed in Naples, 319 of which are related to Saharan dust transport events.

Among 36 measured outbreaks with a mean temporal length of about 4 days have been observed, with the maximum occurrence found in spring. Moreover, about one half of events are characterised by dust plume intrusion into the Planetary Boundary Layer (PBL).

In order to derive the main characteristics of the Saharan dust layer, the plume base, top, and thickness have been determined. The mean values and the corresponding standard deviations of the parameters of desert dust vertical distribution are reported in Table 3.

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

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

The analysis of observed events revealed a large variability of the Saharan dust clouds vertical extension. In particular, dust has been revealed up to 8700 m, nevertheless in 70% of the observed events dust layer was confined below 5000 m of height. On the other hand, 90% of the dust plumes had a base height lower than 2000 m.

In order to study the mean optical properties of the aerosol observed over the city and to evaluate the contribution of the dust also studying its variability with height a statistical approach have been followed. The seasonal dependence of the Saharan dust layer have been retrieved and dust optical properties have been studied in terms of mean values of the aerosol optical parameters.

We measured mean values of IB and OD of (4.4 ±0.2) $10^{-3}sr^{-1}$ and 0.21±0.02, respectively. 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 [6,7]. Differences between these values can be related to differences in the dust particles shape and dimensions and to probable mixing with marine and anthropogenic aerosols along the atmospheric path from the source region to the observation site.

Finally, the Seasonal behaviour of aerosol optical parameters in different atmospheric layers has also been studied comparing the aerosol optical parameters with values retrieved in normal condition from regular measurements. The comparison between the data showed a sensitive change OD and BI during Saharan dust events in the 2-5 Km layer. A reduction of LR below 2 km has been observed also related to gravitational settling of larger particles.

During July 2001 an eruption of Mt.Etna occurred. Continuous measurements during July and August were performed by Lidar stations.

An intercomparison campaign was done on 9th-10th May 2005 between Napoli and Pontecagnano sites.

Using aerosols as tracers, the lidar technique has been applied in order to follow the evolution of the PBL in Naples and in Pontecagnano during a complete diurnal cycle.

From results some interesting considerations can be done:

- PBL height is systematically lower in urban than in rural site of about one hundred meters ;
- The decrease of PBL height in the nocturnal hours seems to be more regular for rural than for urban sites. In fact, the PBL structure is more complex over urban areas than rural ones, as it consists of canopy and roughness sub-layers not found within typical rural atmospheric surface layers.

Moreover, in both sites, also the ground temperature (referred as T_g, hereinafter) has been measured as a function of the time. The temporal evolution of PBL height and ground temperature permits to calculate their correlation factor (referred as ρ, hereinafter) as a function of the relative temporal delay (referred as Δt). Figure 3 shows the correlation factor ρ between H and T_g as a function of their temporal delay Δt for the two sites.

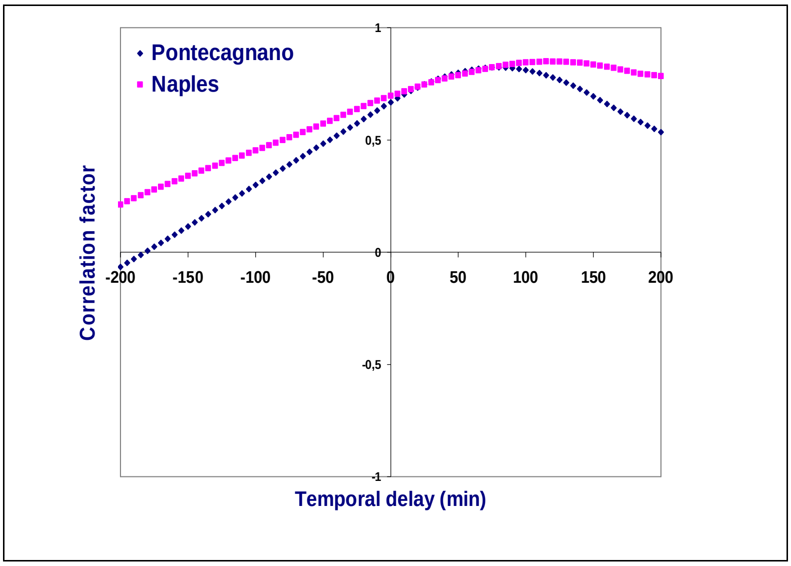

Fig. 3: Correlation factor between the PBL height and the ground temperature as a function of the temporal delay in Naples (pink squares) and in Pontecagnano (blue squares).

5. Conclusions

Lidar systems have been used in monitoring atmospheric aerosol particles and to retrieve their optical properties vertical profiles. A statistical study was done in Napoli based on a set of measurements accumulated over several years of systematic observations in the frame of EARLINET network. During the eruption of Mt.Etna in 2001 and during the Saharan dust transport from North Africa some additional measurements were performed and the experimental results were presented in terms of the aerosol optical properties. A comparative analysis between two sites, Napoli and Pontecagnano, was performed in order to study the influence of the ground use on the PBL development.

6. References

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