Lidar and punctual observations for the characterization of the Saharan dust impact on PM_{10} levels

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We present a case study of a Saharan dust outbreak observed in Tito Scalo (Southern Italy, 40° 36' N; 15° 44' E, 760m a.s.l.) from 15 to 18 of May 2001. The study has been performed integrating tropospheric aerosol optical properties measured by an Elastic/Raman lidar system and daily concentrations of particulate matter (PM_{10}) measured at ground level by means of a low-volume gravimetric sampler. Lidar vertical resolved measurements allowed to characterize the dust cloud. Moreover, measurements performed during complete diurnal cycles, allowed to follow the temporal evolution of the aerosol vertical distribution. The observations point out the influence of vertical exchanges from higher to lower atmospheric levels on daily PM_{10} concentrations. In particular, during the Saharan episode PM_{10} and Fe concentrations increase from 17 to 55 µg m^{-3} and from 330 to 2227 ng m^{-3}, respectively. Because the Fe is a characteristic crustal element it could reveals the influence of the long-range transport of African desert dust on the PM_{10} composition. This case study allows also to provide a devoted methodology for an optimal integration of PM_{10} and multi-wavelength lidar measurements.

1. Introduction

In recent years, Saharan dust storms were investigated for atmospheric transport and deposition processes and for their strong impact on the concentration levels and composition of atmospheric aerosol.

In particular, a large amount of Saharan dust is transported over the Mediterranean Sea as satellite observation, modelling and ground–base measurements have shown (Moulin et al., 1998; Pérez et al., 2006; Mona et al., 2006). In many part of the Mediterranean, about 10 African dust episodes occur per year (Rodriguez at al. 2007). Each event lasts for about 4 days contributing to increase the PM_{10} level at ground until to exceed the threshold limit established by European Directive (50 µg m^{-3}). In particular, in Italy Saharan dust have been found to contribute on average to about 20 µg m^{-3}in a year. (Gobbi et al., 2007).

In this context, lidar observations combined with punctual measurements have been used to evaluate the impact of long range transport phenomena related to Saharan dust outbreaks on the particulate matter (PM_{10}) measured at ground level.
Here, we present the study of an episode of Saharan dust outbreak observed over Tito Scalo, Southern Italy, from 15 to18 of May, 2001. The study area, due to its closeness to the African continent, represents an good site to study the dust transport across the Mediterranean Sea towards the Italian peninsula.
During the performed study we integrated PM_{10} daily concentrations measured at ground level with atmospheric aerosol optical properties in the Planetary Boundary Layer (PBL). Moreover, lidar ratio (LR) and backscatter-related Ångström exponent (δ) have been also obtained from the lidar data to analyse the effect of the aerosol typology and dimension on measured PM_{10} values. Fe concentration in the PM_{10} samples collected has been also analysed to further support the origin of the monitored particulate.

2. Methodology and data analysis

Daily samples of aerosol particles (PM_{10}) were collected by means of a low-volume gravimetric sampler TCR Tecora. The air flow rate was 16.7 lmin-1 and the sampling time for each cellulose filter was 24 h. In order to determine the mass collected, we applied the gravimetric method weighing the filters before and after sampling by means of a microbalance METTLER TOLEDO MX5 Each sample was analysed for its content of Fe by means Varian AA200 atomic absorption spectrophotometer
Lidar measurements of atmospheric aerosol optical properties have been performed in the frame of EARLINET project (Bösenberg et al., 2003) by means of an Elastic/Raman lidar system based on a Nd:YAG laser source. In the configuration used during the analysed period the system provided independent measurements of aerosol extinction and backscatter at 355 nm and aerosol backscatter profiles at 532 nm. Independent measurements in the UV of aerosol backscatter and extinction coefficients allows also to obtain a direct measure of the LR, i.e. the extinction to backscatter ratio. Moreover, the possibility to perform simultaneous measurements of backscattered signals at two transmitted wavelengths allows to estimate the $\delta(z)$ profile, related to the aerosol particles dimensions.
In night-time conditions, to obtain the aerosol extinction coefficient profile $\alpha_a(\lambda,z)$ we applied the method proposed by Ansmann (Ansmann et al.,1990) using the Nitrogen Raman signal. Simultaneous and independent determination of backscatter coefficient βa (λ,z) profile has been obtained using the Raman method (Ansmann et al., 1992) that requires the simultaneous acquisition of both the elastic and the N_2 Raman lidar signals. In daytime conditions, vertical profiles of βa (λ, z) are obtained with an iterative approach (Di Girolamo et al., 1995) assuming LR values on the base of the LR values typically measured in the PBL and in the free troposphere at mid latitude (Pappalardo et al., 2004).

3. May 15-18, 2001

A Saharan dust outbreak occurred over the measurements area from 15 to 18 of May 2001.
Lidar measurements allowed us to follow the main features of the Saharan dust layer revealing its variability in depth and altitude during four consecutive days. Models results and satellite-derived data reveal that the event lasted until 22 of May. Because of cloud covering over the study area, we did not perform measurements in the days following May 18.
The synoptic situation is characterized by a high-pressure system extending from Northern Africa to the Western Mediterranean that contributes to the advection of warm and dry air from Northern Africa to the Italian peninsula, progressively increasing from 15 to 17 of May. On May 18 the high-pressure system shows a reduced intensity owing to the presence of a depression area over the east of the Mediterranean sea that moves to the Italian peninsula.
The MODIS (Moderate Resolution Imaging Spectroradiometer) on NASA’s Terra satellite shows the blowing dust on May 15, 2001. In the image (Fig.1), the dust plume appears over the Mediterranean area, in the south part of the Italian peninsula.

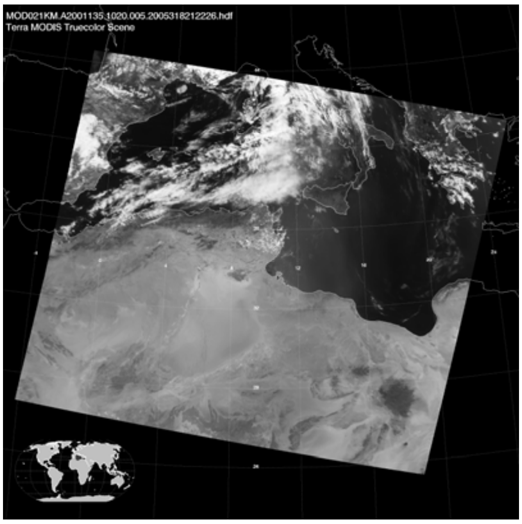

Fig.1 MODIS image derived on NASA’s Terra satellite showing the dust long range transported over the measurement area on 15 of May 2001.

The temporal evolution of the lidar vertical profiles during the whole studied period reveals the presence of an aerosol layer extending up to 6000 meters of altitude and with thickness variable from 1000 to 3000 meters. The analysis of 96-hours back-trajectories provided by the German Weather Service allows us to identify the Saharan origin of the monitored layering.
Long runs of lidar measurements have been performed from 19:22 UT of May 15 to about 14:00 UT of May 18, to follow the aerosol layering evolution. The dust cloud appears weakly visible in the later afternoon on May 15. On May 16, the layered structure is clearly visible: the dust cloud is at first located above the PBL and moves

downward successively, until to interact with it in the evening. On May 17 the PBL height rises with the incoming solar radiation and reaching its maximum extent around noon. The proximity of the dust plume to the PBL, makes possible dust injection from high to lower levels during the diurnal evolution of the PBL, also supported by subsidence favoured by the synoptic situation (Colette et al. 2008). In fact, as we can see in the figure 2, the dust plume is close to the PBL in its maximum extent (at 3000m around 14:00 UT) and its interaction with the PBL could increases in the afternoon the aerosol load at lower altitude. Successively, after the sunset when the top of the PBL height lowers, the Saharan dust in the troposphere results well separated in an aloft plume. A layered vertical structure of the PBL and a lower growing rate is observed on May18 due to the presence of the depression area over the measurement area.

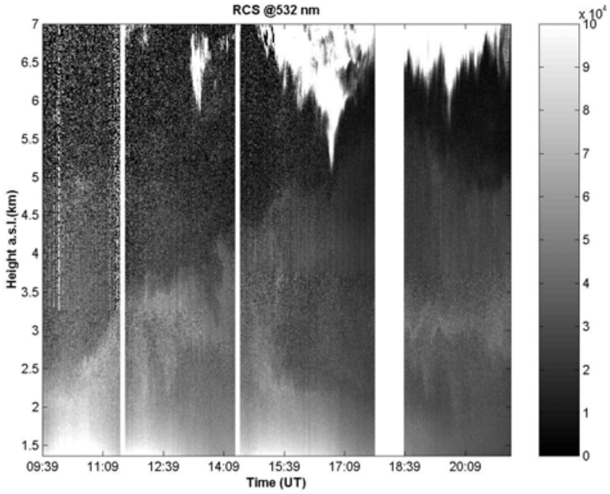

Fig.2: Temporal evolution of the Range Corrected Signal at 532nm measured on May 17, 2001. Time resolution is 1 min and vertical resolution is 15m. The measurements have been performed from 09:39 UT to about 20:30 UT.

Starting from lidar profiles measured at λ=532nm the characterization of the desert dust layer in term of the base, top and center of mass and the mean aerosol backscatter coefficient have been performed following the procedure suggested by Mona (Mona et al., 2006) (Tab. 1).

Tab.1 Characterization of the desert dust layer in term of the base, top and center of mass and the mean aerosol backscatter coefficient in the Saharan dust layer. In the table is also showed the PBL height

YY/MM/DD	PBL (m)	Base (m)	Top (m)	Centre of mass (m)	β_{532} ($m^{-1}sr^{-1}$)
01/05/15	2470	2950	3910	3037	3.0E-8
01/05/16	2590	2950	5770	4018	5.6E-7
01/05/17	2530	3730	5950	4604	4.2E-7
01/05/18	2110	2650	5290	3508	3.5E-7

Vertical profiles of measured aerosol parameters allows to study the variability of the mean aerosol properties observed in the PBL as reported in Tab.2.

During this Saharan dust event we observe an increase in the measured aerosol optical parameters in the PBL. In particular, the integrated backscatter at 355nm (IB_{355}) increased from 6 10^{-3} to 8 10^{-3} sr^{-1}, the optical depth (OD) changed from 0.13 to 0.26. The proximity of the PBL to the Saharan dust layer in the reported measurements makes possible injection from high to lower levels during the PBL evolution, also supported by subsidence. The dust injection from high to lower levels could in part explain the variability of the aerosol properties measured in the PBL.

The analysis of the lidar-derived parameters also reveals a decrease of the δ parameter from the value 3.8, measured on May 14, to values lower than 2.0. The observed change could indicate a change in the mean aerosol size due to a probable mixing of local aerosol particles with larger particles in the coarse mode, like sea salt or dust (Papayannis et al., 2008). The larger LR value measured on May 17 proves the mixing with Saharan dust which non-spherical shape can lead to a strong reduction of the backscattering efficiency (Mattis et al. 2002, Müller et al. 2003). Instead, the averaged value of the LR measured in the PBL on May15 highlights mixing with marine aerosol. This observation was supported by the air mass analytical back-trajectories at 975 and 850 hPa pressure levels, which overpasses the sea for a long time.

During the Saharan episode we also observe an increase of the PM_{10} concentrations at ground level. In particular, from 15 to 17 May the PM_{10} concentrations ranged from 17 to 55 µg m^{-3} exceeding the threshold limit established by European Directive (50µg/Nm^3) and the PM_{10} background levels measured in this area (24 µg m^{-3} PM_{10}) (Ragosta et al., 2006). Simultaneously, higher PM_{10} levels are recorded at further four stations operating in the framework of the Basilicata air quality regional network. Moreover, we observe an increase of Fe concentrations from a minimum value of 330 to a maximum value of 2227ng m^{-3}during these days. The increase of the Fe values, a crustal element useful to characterize the desert dust (Dordevic et al.2004), could reveal the influence of desert aerosols on PM_{10} composition.

Tab.2 PM_{10} and Fe concentrations measured at ground level, lidar-derived aerosol parameters (OD, IB,LR,δ), The reported data refer to the case study of 14-18 of May 2001.

YY/MM/DD	In the PBL				PM_{10} (µg m^{-3})	Fe (ng m^{-3})
	OD	IB_{355} 10^{-3}(sr^{-1})	LR	δ		
01/05/14		5.0±0.2		3.8±0.1	17	330
01/05/15	0.13±0.01	6.1±0.2	22±2	1.4±0.3	17	456
01/05/16		6.3±0.1		1.7±0.1	34	1239
01/05/17	0.26±0.01	6.7±0.1	48±1		55	2227
01/05/18		7.9±0.2		1.9±0.2	48	1853

4. Conclusions

An integrated study between the aerosol optical properties measured in the PBL and the PM_{10} daily concentrations measured at ground level has been carried out using lidar techniques and punctual measurements. The observations have been performed during a Saharan dust outbreak occurred in our study area from 15 to 18 of May 2001.

In particular, the performed study allows us to state that in cases of transport of Saharan dust in the free troposphere one can observe an increase in the PBL aerosol load due to the presence of dust in this close-to-surface atmospheric layer. Therefore, when in the PBL the particle size distribution is dominated by particles with larger dimension (lower δ), the sedimentation is fostered and involves higher return to the ground level. In fact, we observe an increase of PM_{10} concentrations from 17 to 55 μg m^{-3} and a substantial increase of Fe concentrations from a minimum value of 330 to a maximum value of 2227 ng m^{-3}.
Furthermore, long records of lidar measurements allow to study the optical and microphysical properties of the aerosol in the Saharan dust layer and its variability in depth and altitude pointing out that possible intrusion of dust particles in the PBL can influence the daily PM_{10} concentration. The obtained results are very encouraging for developing a strategy devoted to an optimal integration of lidar-PM_{10} measurements.

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