H13-150
IDENTIFICATION OF SAHARAN DUST EPISODES OVER ITALY IN 2003-2005

A. Pederzoli[1], M. Mircea [1], S. Finardi[2], G. Zanini [1], A. di Sarra[3], T. Di Iorio[4]

[1] ENEA, Bologna, Italy
[2] ARIANET srl, Milan, Italy
[3] ENEA, Rome, Italy
[4] Sapienza University, Rome, Italy

Abstract: This study presents a monthly distribution of the main Saharan dust outbreaks registered in the period 2003-2005 at seven Italian locations. The identification has been carried out by looking at several sources of information such as monitoring network observations, satellite images, ground measurements of aerosol optical properties, dust model simulations and air mass backward trajectory analysis. Dust intrusions are mainly focused in spring (40%-45%) and summer (35%-55%). In winter and autumn the sites in Northern Italy registered a significant number of episodes in January and February (between 7% and 10%) whereas the stations in Central Italy and in the islands were not affected by any dust intrusion. The highest number of episodes was identified at the Mediterranean island of Lampedusa in summer (57% of the total). A specific dust event in 2005 (17^{th}-20^{th} July) identified by using this methodology is also described.

Key words: *aerosols; Saharan dust; Mediterranean; Italy*

INTRODUCTION

There are multiple ways to identify dust in the atmosphere, such as satellite retrievals, ground measurements of aerosol optical properties, aerosol sampling and chemical analysis, dust model simulations and air mass backward trajectory analysis. These sources provide information about the origin of dust, its vertical and horizontal extent and its presence and amount in the atmosphere. This study aims to identify the most significant daily Saharan dust episodes which affected Italy between 2003 and 2005. A first discrimination of days with dust intrusions has been carried out by looking at daily series of PM10 concentrations as measured at seven remote rural sites distributed across Italy. They are located in isolated areas where the anthropogenic contribution to PM10 is assumed to be negligible. Thus, in "no dust" conditions, the PM10 measured at these sites is assumed to have local or regional origin only and unusual peaks in the PM10 observed concentration time series may be attributed to natural events such as dust episodes. Daily peaks in PM10 concentration daily series have been identified and analysed in detail, in order to verify the presence of absorbing aerosols such as atmospheric dust in the atmosphere in these days.

To this purpose, the daily evolution of aerosol optical properties like the Aerosol Optical Depth (AOD) and related Angström exponent (α) over the Mediterranean area was studied. The combined use of AOD and α values allows the identification of different aerosol types including dust (Pace *et al.*, 2006). This method is based on the sensitivity of these two parameters on number and size of aerosol particles. Whereas AOD is directly proportional to the aerosol column density (number of particles), α mainly depends on the particle size distribution. Usually high AOD values combined with low α values are typical of Saharan dust (Pace *et al.*, 2006). According to Moulin *et al.* (1997a) low α values qualitatively indicate a prevalent presence of large particles (coarse mode) such as mineral dust particle or sea salt particles (or a mixture of them) in the atmosphere. Daily maps of α and AOD at 550 nm from satellite retrievals have been analysed in detail to verify the presence of Saharan dust over Italy. The identification of dust events in the island of Lampedusa was performed by looking at hourly series of AOD and related α as derived from ground observations by a Multi Filter Rotating Shadow band Radiometer (MFRSR) (Meloni *et al.*, 2007). Lidar measurements in Lampedusa (Di Iorio *et al.*, 2009) were also performed in order to estimate the aerosol vertical distribution in dust days. Vertical profiles of extinction (a_{aer}) and backscatter (b_{aer}) coefficients helped to identify the presence of free tropospheric dust layers in the aerosol distribution.
The existence of dust over Italy was also supported by daily maps of dust concentration as modelled by the atmospheric modelling system SKIRON/Eta (Kallos *et al.*, 2005; Nickovic *et al.*, 2001). The African origin of dust was finally verified by applying a model for air mass backward trajectory analysis, the HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model (Draxler and Rolph, 2003). HYSPLIT has been used to compute 4-days backward trajectories from seven remote rural background stations.

The combined use of these sources of information allowed the identification of the main dust events on a daily resolution. The available data did not allow to discriminate minor events (i.e. hourly episodes). The description of a specific event in 2005 (17^{th}-20^{th} July) identified by using this methodology is reported, as well as a monthly distribution of daily dust events in 2003-2005.

CASE STUDY: 17^{th}-20^{th} July 2005

Monitoring network

There are seven rural background monitoring stations in Italy measuring PM10 concentrations ($\mu g\ m^{-3}$) on a daily basis in the period 2003-2005 (Figure 1). They are located in areas far from anthropogenic sources such as residential areas, streets, industrial activities, so the anthropogenic contribution to PM10 concentration at these stations can be considered negligible. All sites except the one in Lampedusa (35.52°N, 12.63°E) and Ispra (45.82°N, 8.62°E) are part of the Italian air quality monitoring network BRACE (http://www.brace.sinanet.apat.it). Ispra is part of the EMEP (European Monitoring and Evaluation Programme) monitoring network. Measurements at Lampedusa are carried out at the ENEA station for Climate Observations (http://www.palermo.enea.it/Lampedusa). Figure 1b shows a high peak concentration registered at S.Antioco between the 17th and the 20th July 2005. Because the anthropogenic contribution is supposed to be minor at this site, such peak may be attributed to a natural event such as a Saharan dust episode.

a) b)

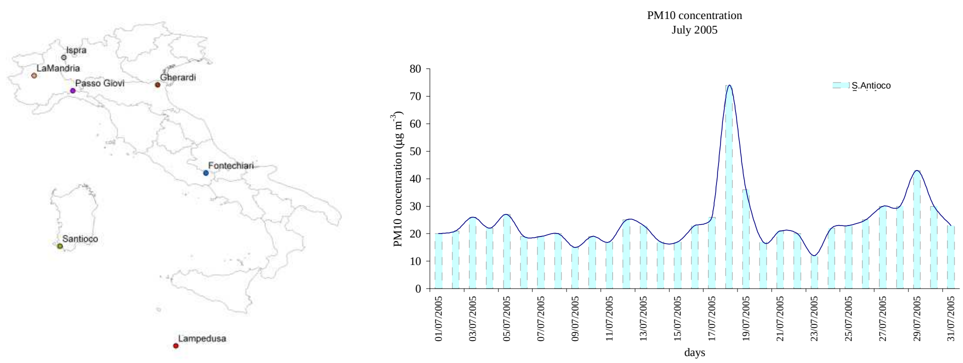

Figure 1. a) Remote rural background monitoring sites measuring daily PM10 concentration (µg m^3) in the period 2003-2005. b) Daily series of PM10 concentration measured at S. Antioco in July 2005. A peak is visible between the 17th and the 20th July 2005.

Atmospheric charts

The synoptic chart (figure 2a) for the 17th July at 1200 UTC as retrieved by the European Centre for Medium-Range Weather Forecasts (ECMWF) forecast re-analysis over Europe suggests that between the low pressure located over North Western Africa and the high pressure area over Southern Italy –Northern Libya a pressure gradient produces air masses moving towards Italy. This is confirmed by the wind speed chart (figure 2b) at 950 hPa for the 17th July at 1800 UTC as provided by ECMWF re-analysis, which shows winds between 15 ms^{-1} and 17 ms^{-1} developing in the low pressure region. The high pressure area over Italy, typical of summer time, is favourable to persistent aerosol presence in the atmosphere. Two days earlier (15th July) the meteorological situation over North Africa is different. Northern Algeria and Morocco are characterised by stability: high pressure, relatively slow surface winds (less than 6 ms^{-1}) (figure 2c) and cloudy sky (figure 2d).

a) b) c) d)

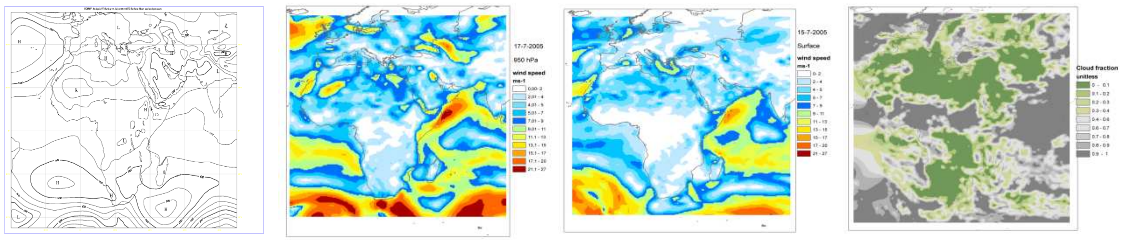

Figure 2 a) Mean sea level pressure at 0000 UTC on 17th July 2005 b) Wind speed chart (ms^{-1}) at 950 hPa on 17th July 2005 at 1800 UTC c) Wind speed chart at surface (ms^{-1}) on 15th July 2005 at 0000 UTC and d) Cloud fraction (unitless) as retrieved by MODIS on 15th July 2005 at night time

Satellite retrievals

Figure 3 shows the evolution of the Aerosol Optical Depth (AOD) at 550 nm over the Mediterranean area as retrieved by MODIS-Terra from the 17th to the 20th July. The grid resolution is 1 degree x 1 degree. Large amounts of dust (AOD > 0.6) move from Northern Africa across the Mediterranean sea towards Sardinia on 17th July. The dust reaches Northern Italy on 18th July. The day after (19th July) dust is advected, with lower AOD values, towards Central and Southern Italy before leaving the peninsula and moving to Greece (20th July).

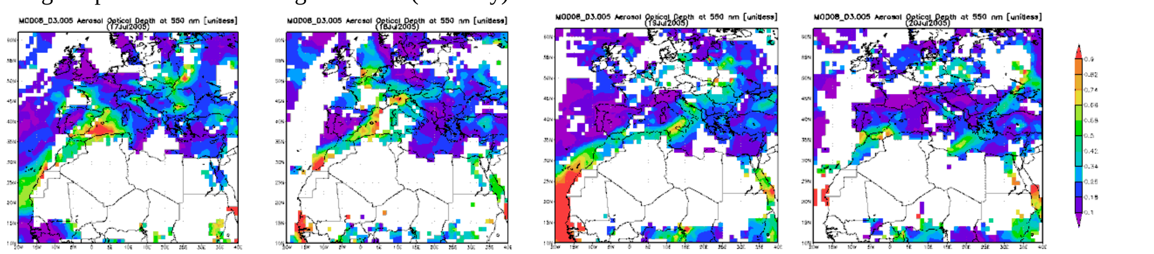

Figure 3. Maps of Aerosol Optical Depth (AOD) at 550 nm as retrieved by MODIS from 17th to 20th July 2005.

Ground measurements of optical properties

Hourly series of AOD and related α as derived from observations by a Multi Filter Rotating Shadow band Radiometer (MFRSR) helped to identify the presence of dust over Lampedusa (Meloni *et al.*, 2007). The MFRSR measures global and diffuse irradiances at seven channels with a 15 sec time-step. The direct radiance is calculated as the difference between global and diffuse irradiances, and it is used to compute the AOD using the Lambert-Beer law (Pace *et al.*, 2006). α is calculated as a function of AOD with λ_1 and λ_2 equal to 500 nm and 869 nm respectively. Further details about the instrument can be found in Pace *et al.* (2006). AOD slowly increases on the 19th July reaching a peak value of approximately 0.5 around 15 UT (figure 4a). Average vertical profiles of b_{aer} retrieved by a Lidar system in Lampedusa (Di Iorio *et al.*, 2009) were also analysed. The profile at 13.20 UT on the 19th July (figure 4b) shows an enhanced aerosol layer between 1.4 km and 2.6 km, with a b_{aer} peak of 0.001 km^{-1} sr^{-1}. Larger values of b_{aer} at altitudes lower than 1 km (with a peak of approximately 0.0045 km^{-1}sr^{-1} around 400 m) are visible.

a) b)

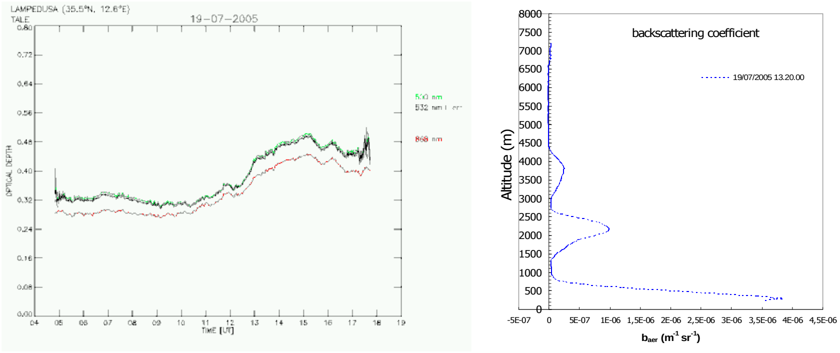

Figure 4. a) Hourly series of AOD at 500 nm (green), 532 nm (black) and 868 nm (red) as derived from MSFR measurements in Lampedusa on the 19th July 2005. b) Vertical profile of backscattering coefficient (b_{aer}) in m^{-1} sr^{-1} from Lidar measurements on the 19th July at 13.20 UT (blue dotted line).

Modelled data

The Saharan dust event is also predicted by the SKIRON/Eta model (Kallos *et al.*, 2005). The modelling system consists of two main parts: the modified Eta/NCEP atmospheric model (Papadopoulos *et al.*, 2002) and the dust cycle modules (Nickovic *et al.*, 2001) which incorporate state-of-the-art parameterizations of all the main atmospheric processes involving dust such as production, horizontal diffusion (Janjic, 1990), horizontal advection (Janjic, 1997) and vertical advection (Van Leer, 1979), wet deposition (Seinfeld and Pandis, 1998) and dry deposition (Slinn and Slinn, 1981). SKIRON output data for this work have been provided by the University of Athens, Atmospheric Modelling and Weather Forecasting Group (UOA/AM&WFG). Maps of PM10 ground concentration (first SKIRON vertical level) in μgm^{-3} from the 17th to the 20th July 2005 have been analysed (not shown). The daily evolution of surface PM10 concentration over the Mediterranean area predicted by SKIRON is qualitatively similar to the AOD evolution by MODIS shown in Figure 3a-d.

Air mass backward trajectory analysis

The transport of dust from Sahara is confirmed by a 4-day air mass back-trajectory analysis computed using the atmospheric Lagrangian model HYSPLIT. Four rural remote stations (S.Antioco, Lampedusa, Gherardi, Fontechiari) have been selected as target for the back trajectories. Figure 5 shows three particle pathways originating at the same site from different heights above ground (500m, 1000m, 1500m). Starting time is 00 UTC on 19th July 2005, ending at 00 UTC on 15th July 2005. 500 m trajectories do not provide clear information about the starting point because they are within the boundary layer so particles are subjected to short range transport. On the contrary, the computation of the trajectories at 1000 m and 1500 m supports the North African origin of the dust, mainly from Morocco and North Algeria.

a) b) c) d)

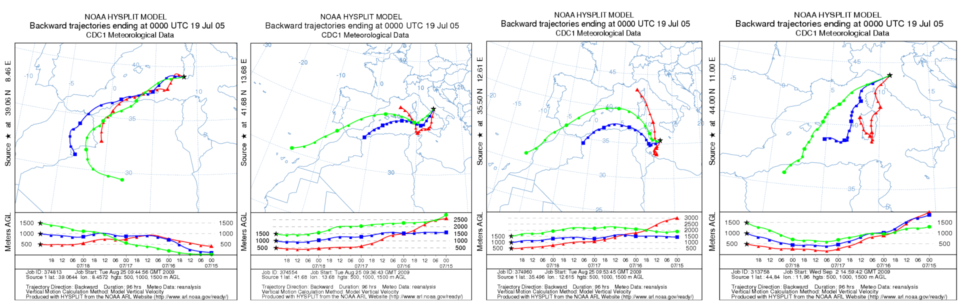

Figure 5. 96-hours back trajectories ending over a) S.Antioco b) Fontechiari c) Lampedusa d) Gherardi at 0000 UTC on 15th July 2005 at 500 m (red line), 1000 m (blue line) and 1500 m (green line).

MONTHLY DISTRIBUTION OF SAHARAN DUST EVENTS OVER ITALY IN 2003-2005

A detailed analysis of years 2003-2005 by using the sources of information previously described lead to the classification, on a daily basis, of the most significant Saharan dust events in this period (table 1). Several of these events have also been mentioned in previous studies (Kaskaoutis *et al.*, 2008; Toledano *et al.*, 2007; Meloni *et al.*, 2007; Kishcha *et al.*, 2007; Mona *et al.*, 2006).

Spring and summer

Dust intrusions are mainly concentrated in spring (March and April) and summer (June, July and September). About 45% of the total number of daily intrusions in Gherardi and La Mandria happen in spring, between March (23%-25%), April (12%-14%) and May (7%-8%). In summer the highest percentage of episodes at Gherardi station is in June (14%) whereas in La Mandria it is equally split between June (13%) and July (14%). At Passo Giovi and Ispra about 40% of the events are in March (36% and 30% respectively). In summer there is a peak in July at both sites (15% at Ispra and 18% at Passo Giovi). In S.Antioco the highest number of dust outbreaks is also in July (23%). The summer distribution in S.Antioco is very similar to the one in Fontechiari (highest percentages in July, August and September). Some remarkable differences are visible in June and May, when Fontechiari recorded approximately half of the episodes seen at S.Antioco (7% in Fontechiari and 15% in S.Antioco). Lampedusa is the site which registered the highest number of episodes. This is expected because of its proximity to the Northern coast of Africa, which makes the reaching of the island easier by the dust. 57% of all episodes happened in summer (7% in June, 28% in July, 12% in August and 10% in September).

Winter and autumn

La Mandria, Gherardi and Ispra, all in Northern Italy, recorded a significant number of episodes in January and February (9%, 7% and 10% respectively) whereas the stations in Central Italy and in the islands were not affected by any dust intrusion. The sites in Northern Italy also registered 3% of the total number of episodes in October. Lampedusa shows a higher number of dust events (more than 12% of the total) in October compared to the other monitoring sites. Some episodes also happened on the island in December (~3%).

Table 1. Monthly distribution of Saharan dust events (%) registered by the rural remote monitoring sites in Italy in 2003-2005

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fontechiari	0.0	1.5	10.3	7.4	7.4	7.4	30.9	13.2	17.6	4.4	0.0	0,0
Gherardi	1.8	5.3	22.8	14.0	7.0	14.0	8.8	7.0	15.8	3.5	0.0	0.0
Ispra	3.2	7.5	30.1	11.8	4.3	6.5	15.1	6.5	11.8	3.2	0.0	0.0
Lampedusa	0.0	1.8	10.7	5.4	9.8	7.1	27.7	12.5	9.8	12.5	0.0	2.7
La Mandria	3.0	6.0	24.0	12.0	8.0	13.0	14.0	6.0	12.0	2.0	0.0	0.0
Passo Giovi	0.0	0.0	35.9	12.8	2.6	17.9	17.9	5.1	7.7	0.0	0.0	0.0
S.Antioco	0.0	0.0	15.4	3.8	15.4	15.4	23.1	15.4	11.5	0.0	0.0	0.0

CONCLUSIONS

This study shows for the first time the monthly distribution of Saharan dust outbreaks over a multi-year period (2003 – 2005) across Italy. The identification of dust events has been carried out by looking at several sources of information, such as monitoring network observations, satellite images, measurements of aerosol optical properties, model simulations and backward trajectory analysis. Dust intrusions are mainly concentrated in spring (40%-45%) and summer (35%-55%). In winter and autumn the Northern sites registered a significant number of episodes in January and February (between 7% and 10%) whereas the stations in Central Italy and in the islands were not affected by any dust intrusion. The highest number of episodes was registered at the Mediterranean island of Lampedusa in summer (57% of the total). This is expected because of its proximity to the Northern coast of Africa, which makes the reaching of the island easier by the dust. Lampedusa was also affected by a higher number of dust events (12%) in October compared to the other monitoring sites. Some episodes also happened in the island in December (~3%).

AKNOWLEDGMENTS

This work is part of the MINNI ((Integrated National Model in support to the International Negotiation on Air Pollution) project, funded by the Italian Ministry for Environment, Territory and Sea and carried out by ENEA.

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