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An outstanding Saharan dust event at Mt. Cimone (2165 m a.s.l., Italy) in March 2004

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HIGHLIGHTS

- Saharan dust event raises PM_{10} concentration to 80 μg m^{-3} above 2000 m asl.
- Mt. Cimone, WMO-GAW station representative of the Southern Europe free troposphere.
- Bulk aerosol experimental data in connection with highly time resolved particle countings.
- Synoptic analysis accompanied by time/space characterizations of the event.
- Integrated assessment of OPC and AERONET data for the event.

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ABSTRACT

A severe PM_{10} episode was observed at the high elevation observatory of Mt. Cimone (2165 m a.s.l.) in the period of 13th-15th March 2004; during the event PM_{10} reached the maximum concentration (80 μg m^{-3} against an average of 8.8 ± 8.0 μg m^{-3}) between 1998 and 2011. Meteo-synoptical analysis allowed to ascribe this event to a long lasting and highly coherent Saharan dust outbreak, starting at the beginning of March. The peculiar synoptic configuration causing this massive transport of dust was characterized by a steep gradient between an upper level trough extending to low latitudes with a minimum centred over the North-Western Algerian coast and a Saharan high extending all over the Mediterranean Sea with an elongated north-eastward tongue, whose synergic effect led to a peculiar funnel-shaped dust plume. During the period Mt. Cimone was located exactly along its main axis. The event was first analysed in association with simultaneous more or less conventional compositional parameters such as ^{7}Be, ^{210}Pb, and ozone. Subsequently, it was characterized in details both in terms of time and space evolution. The former aspect was investigated using number densities of fine and coarse particles obtained through an Optical Particle Counter which allowed to follow the event evolution at the sub-daily time scale while PM_{10} membrane gravimetric analysis was limited by the 48-h sampling schedule suggesting the value of 80 μg m^{-3} recorded is even potentially smoothed down by sampling duration. Besides precise timing, optical counting enabled to detect the inception and development of the event through a steep and simultaneous increase of both coarse and fine particle number densities. Although the former increase was much more relevant, the latter occurrence is much less frequently documented for Saharan Dust events: a clear increase of particles in all the diameter ranges from 0.3 μm (lower limit of an OPC) up to 5.0 μm was observed during the event. The spatial extension of the event was also examined by means of the analysis of the AERONET ground-based sun photometer data from the Venice station for the event. Results confirmed a relevant increase of coarse particles over a distance of more than 150 km. Interestingly AERONET data indicates a more significant variation in the scattering properties of the aerosol rather than in the absorbing ones in connection with the arrival of the Saharan dust, an observation that within the intrinsic limitations of inverse methods to derive aerosol's optical properties is in agreement

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with some previous observations showing that dust in the Saharan desert region is much less absorbing than previously measured.

1. Introduction

Mineral dust from desert regions is one of the major constituents of airborne particles on the global scale. Dust plumes frequently enter the atmosphere and can travel up to tens of thousands of kilometres downwind before settling back to the surface (Engelbrecht and Derbyshire, 2010), being one of the most prominent and commonly visible features in satellite imagery.

Dust is presently recognized as one of the main uncertainties in climate change assessment (IPCC, 2013), owing to the wide range in the estimates of global dust emissions spanning a factor of about five (Huneeus et al., 2012). Even if the effects of dust on visibility and human health (e.g., are fairly well known (e.g., Middleton et al., 2008; Zauli Sajani et al., 2011), the impact on ecosystems and on cloud processing has been focused only recently (see for example Okin et al., 2004; Bangert et al., 2012; Smoydzin et al., 2012). Mineral dust particles deeply affect climate, acting both directly (by scattering and absorbing radiation) and indirectly (through the modification of the optical properties of clouds and cryosphere such as albedo) on the Earth's radiation balance (IPCC, 2013). Complex feedbacks between dust, ecosystems and climate exist: for instance, dust can modify regional patterns of rainfall, disrupting ecosystems. The associated changes in vegetation might close the loop in this feedback mechanism being possibly able to create new dust sources (Gassó et al., 2010). Moreover climate change itself might induce variations on dust loadings, with a wide range of results reflecting different responses of the atmosphere and vegetation cover to climate change forcings (Tegen et al., 2004; Woodward et al., 2005; Mahowald et al., 2006; Jacobson and Streets, 2009; Liao et al., 2009). Iron- and phosphorus-rich particles are able to affect the primary phytoplankton production and the carbon cycle through biogeochemical interactions acting as fertilising agents (Ridgwell, 2002; Maher et al., 2010), while dust deposited in marine areas could trigger algal blooms (Guerzoni et al., 1999).

The Sahara desert is the world's largest source of aeolian desert dust (Swap et al., 1996; Middleton and Goudie, 2001). Huge amounts of dust are transported every year from the Sahara toward the American and European continents (Chiapello et al., 1997; Collaud Coen et al., 2004; Kaufman et al., 2005). It was estimated that Saharan dust events may induce up to 20 exceedances of the PM_{10} standard per year in southern Europe (Rodríguez et al., 2001). Mineral dust originates from well-defined source regions mainly active during the summer months, with the exception of the Bodele depression which is active all year-round (Prospero, 1996; Ginoux et al., 2001; Prospero et al., 2002; Washington et al., 2003; Barkan et al., 2004). Significant interannual and seasonal variations in the atmospheric dust input exist (Dulac et al., 1996; Moulin et al., 1997; Barkan et al., 2004). The seasonal trend of Saharan dust transport shows a peak during spring and summer, while the winter and autumn seasons are usually characterized by a minimum activity. The more intense dust activity during the warm period is due to several factors, among which high wind speeds, cloud free conditions, high air temperatures (thus thermal convective activity) which promote the dust lifting and transport (Dulac et al., 1996; Varga et al., 2014). All of these factors ultimately depend on the synoptic situation and possibly on teleconnections leading to relevant interannual variations including precipitation, another factor largely affecting the intensity of Saharan dust transport on the synoptical scale (Middleton, 1985; Dulac et al., 1996; Prospero, 1996; Bonasoni et al., 2004; Collaud Coen et al., 2004). Despite the changing nature of large scale atmospheric oscillations, circulation patterns and drought periods in general cannot unequivocally explain the frequency of dust outbreaks (Varga et al., 2014). In particular, the dust level may be influenced by variations in the activity of low pressure disturbances from year to year (Pederzoli et al., 2010). Dust transported across the Mediterranean and into Europe mainly originates from the northernmost African dust sources mainly located in Tunisia, Algeria, and Libya (Prodi and Fea, 1979; Avila et al., 1996; Bonelli and Marcazzan, 1996).

The transportation of Saharan dust towards Europe through the Mediterranean Sea is associated with different synoptic meteorological situations (Barkan et al., 2005; Engelstaedter et al., 2006; Stuut et al., 2009; Barkan and Alpert, 2010; Israelevich et al., 2012; Varga et al., 2013, 2014), usually caused by intense cyclones passing the Northern African coast from west to east (Barkan et al., 2005; Meloni et al., 2008) or convective injection of dust in north Africa coupled with anticyclonic conditions at upper atmospheric levels (e.g., Pey et al., 2013). The intensity and frequency of these disturbances are strongly affected by the penetration depth of cold air from higher latitudes southward (Dayan et al., 1991; Conte et al., 1996; Moulin et al., 1997; Barkan et al., 2005). At times the presence of very severe disturbances can add huge amounts of dust affecting daily and annual mean levels of airborne particulate matter often resulting in exceedances of the thresholds indicated by environmental regulations on air quality aerosol standards (Alpert and Ganor, 1993; Tsidulko et al., 2002; Rodríguez et al., 2001; Kutiel and Furman, 2003; Gerasopoulos et al., 2006).

All over the observational activity at the WMO-GAW station of Mt. Cimone (44.18N, 10.7E, 2165 m asl; Italy) Saharan dust events have been and still are a relevant field of investigation owing to its favourable geographical position in the core of the Mediterranean region frequently exposed to African air masses (site description and information available at http://www.isac.cnr.it/cimone/site_location). Results have been widely reported in many scientific papers (e.g., Balkanski et al., 2003; Bonasoni et al., 2004; Beine et al., 2005; Marenco et al., 2006; Marinoni et al., 2008; Cristofanelli et al., 2009; Zauli Sajani et al., 2011). More recently PM_{10} variability at Mt. Cimone station has been analysed as a function of various factors, revealing a clear and frequent influence of Saharan Dust outbreaks at this location in the centre of the Mediterranean basin typically leading to aerosol maxima (Marinoni et al., 2008; Riccio et al., 2009; Tositti et al., 2013). Other authors have so far published papers based on the mid-March 2004 Saharan Dust event though in a marginal way. In particular, Beine et al. (2005) associated the relationship between the mineral dust deposited on the snow surface and the release of HONO from it, while Mangold et al. (2011) used the event as a case study to evaluate the performance of an aerosol modelling system coupled to a numerical weather prediction model with data assimilation. In this paper instead the focus is the thorough characterization of the event in itself. The reason for such a specific interest emerged from a deep and still on-going analysis of our own dataset. In the specific