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Aerosol properties of mineral dust and its mixtures in a regional background of north-central Iberian Peninsula

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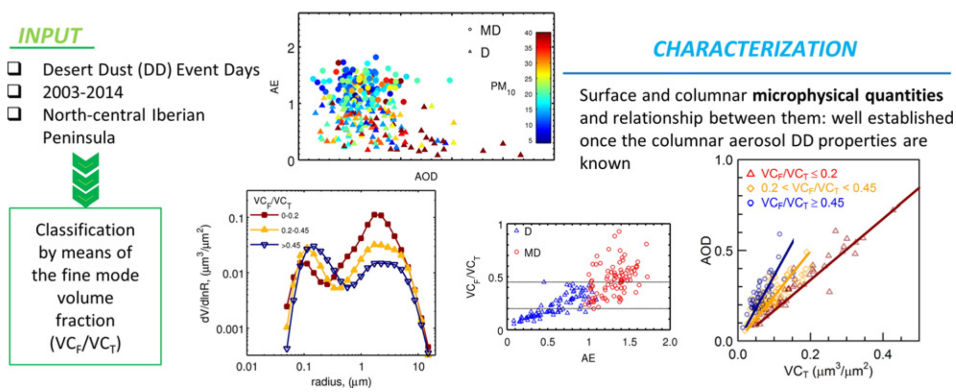
HIGHLIGHTS

- Long-term characterization of mineral dust aerosols and its role in mixtures
- Volume extinction efficiency for mineral dust ranges between 1.7 and 3.7 $\mu m^2/\mu m^3$.
- Aerosol scale height factor is about 9 km in the columnar-surface analysis.

GRAPHICAL ABSTRACT



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ABSTRACT

To broaden the knowledge about desert dust (DD) aerosols in western Mediterranean Basin, their fingerprints on optical and microphysical properties are analyzed during DD episodes in the north-central plateau of the Iberian Peninsula between 2003 and 2014. Aerosol columnar properties obtained from the AErosol RObotic NETwork (AERONET), such as aerosol optical depth (AOD), Ångström exponent (AE), volume particle size distribution, volume concentration (VC), sphericity, single scattering albedo, among others, are analyzed in order to provide a general characterization, being some of them compared to particle mass surface concentrations PM_{10}, $PM_{2.5}$, and their ratio, data obtained from EMEP network. The mean intensity of DD episodes exhibits: $AOD_{440nm} = 0.27 \pm 0.12$, $PM_{10} = 24 \pm 18\ \mu g/m^3$, $AE = 0.94 \pm 0.40$ and $PM_{2.5}/PM_{10} = 0.54 \pm 0.16$. The AOD and PM_{10} annual cycles show maximum intensity in March and summer and minima in winter. A customized threshold of $AE = 1$ distinguishes two types of dusty days, those with a prevailing desert character and those of mixed type, which is corroborated by sphericity values. Three well established intervals are obtained with the fine mode volume fraction (VC_F/VC_T). Coarse-mode-dominated cases ($VC_F/VC_T \leq 0.2$) present a mineral dust character: e.g., particle maximum concentration about 2 μm, non-sphericity, stronger absorption power at shorter wavelengths, among others. The relevance of the fine mode is noticeable in mixtures with a predominance of particles about 0.2–0.3 μm radii. Conditions characterized by $0.2 < VC_F/VC_T < 0.45$ and $VC_F/VC_T \geq 0.45$ present a larger variability in all investigated aerosol properties. Relationships between AOD and columnar particle volume concentration give volume extinction efficiencies between 1.7 and 3.7 $\mu m^2/\mu m^3$ depending on VC_F/VC_T. Aerosol scale height is obtained from relationships between surface and columnar concentrations displaying very large values up to

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10 km. The uncertainty associated with the transformation between AOD and PM_{10} can be partially reduced when the aerosol microphysical properties are known.

1. Introduction

Airborne dust is a key player in the atmospheric science studies since it is considered to impact climate, air quality and human health by causing respiratory diseases and infections or even certain epidemics; Earth's radiative budget by scattering/absorbing solar radiation; life cloud cycle acting as cloud condensation nuclei or ice nuclei; air visibility that can affect traffic or military operations; different continental and maritime ecosystems by changing the provided nutrients; and the soil erosion in agriculture (e.g., Horvath, 1998; Dubovik et al., 2002; Eck et al., 2010; Yannopoulos et al., 2015; Gkikas et al., 2013; Knippertz and Stuut, 2014). Mineral dust accounts for 13% of the total natural emissions in the Earth's system (e.g., Viana et al., 2014), being the Sahara and Sahel deserts the most relevant natural sources of crustal aerosols in the Northern Hemisphere (Prospero et al., 2002) with >200 Tg per year emitted to the atmosphere and transported over the Atlantic Ocean (Kaufman et al., 2005). The injection of desert dust (DD) into the atmosphere from the Sahara's two major dust sources (Bodélé depression and eastern Mauritania) by different re-suspension processes can achieve high atmospheric layers, being responsible for high aerosol loads that are transported very large distances, to the northern Atlantic Ocean, Caribbean Sea, Amazon Basin, Mediterranean Basin, and European continent (e.g., Goudie and Middleton, 2001).

Focusing on the studies devoted to the analysis of DD over the Iberian Peninsula (IP), it has been observed that different areas exhibit different behavior and annual cycle of DD events because of the orography and the uneven synoptic conditions along the IP (Silva et al., 2002; Estellés et al., 2007; Toledano et al., 2007; Obregón et al., 2015; Mateos et al., 2014). The closeness of the IP to the African continent enhances the impact of these high turbidity events on different aspects. For example, DD outbreaks impact on air quality by increasing aerosol load, being the main responsible of the daily exceedances over 50 μg m^{-3} (limit established by the 2008/50/EC European Directive) in the particulate matter with aerodynamic diameter less than 10 micrometers (PM_{10}) levels (e.g., Escudero et al., 2007; Querol et al., 2014; Salvador et al., 2013, 2014). This is reinforced by long residence times of dust particles in the atmosphere favored by the low precipitation levels (e.g., Escudero et al., 2005; Cabello et al., 2012). Moreover, aerosol seasonal patterns are modulated by mineral dust producing two maxima along the year of PM or aerosol optical depth (AOD) in certain areas of the IP (e.g., Mateos et al., 2015). The DD aerosols also present influence on the radiative budget with an aerosol forcing efficiency about -70 Wm^{-2} at the surface in south-eastern IP (Valenzuela et al., 2014). Acute effects on human health also occur during DD events in Spain, accelerating cardiovascular and respiratory mortality (Pérez et al., 2012; Reyes et al., 2014).

Different methodologies have been recently developed in order to detect and identify DD intrusions by means of PM_x (x refers here to the upper particle cut-off) or AOD data. Likewise, other tools are used to identify DD outbreaks, such as aerosol model forecasts, air mass back trajectories, satellite images, among others (e.g., Pace et al., 2006; Tafuro et al., 2006; Escudero et al., 2007; Toledano et al., 2007; Querol et al., 2009; Cabello et al., 2012; Pey et al., 2013; Salvador et al., 2014; and Cachorro et al., 2016). All these tools can be used in very different and combined ways in order to carry out the DD detection and the evaluation of its occurrence, intensity and impact, as for example over the entire Mediterranean Basin.

An extensive work about desert dust studies has been carried out during the last years in the Mediterranean area. Pace et al. (2006) and Meloni et al. (2007) obtained occurrence maxima in May and July in the Lampedusa island (Central Mediterranean) using MFRSR measurements and air mass backward trajectories in the DD detection. A summer maximum (June and August) is reported by Toledano et al. (2007) in south-western Spain by a combination of Sun photometer data and back-trajectory analysis of air mass origin. Valenzuela et al. (2012) reported the maximum of annual occurrence in July over south-eastern Spain by analyzing air mass back trajectories. Pey et al. (2013) obtained a shifted annual maximum from April to July between eastern and western Mediterranean Basin in the 2000s using PM_x surface data and a combination of meteorological products, aerosol maps, satellite images and air mass back-trajectories. Cachorro et al. (2016) obtained an annual cycle of dusty day occurrence over north-central IP of similar characteristics to that reported by Salvador et al. (2013) for Madrid area, but with lower occurrence.

The application of the mentioned methodologies for DD detection allows further characterization studies, which are related to the evaluation of the different properties that define DD aerosols. However, only some of these properties are used in the methodology of DD identification. In our case, columnar AOD and Ångström exponent (AE), and surface PM_{10} concentration are used for detection. These quantities will be characterized in the present study, together with other properties, such as volume particle size distribution (VPSD), asymmetry parameter (g) or single scattering albedo (SSA).

Previous studies in the African surroundings have shown that mineral dust aerosols are dominated by large particles beyond 0.6 μm, and they exhibit non-sphericity and a pronounced absorption in the blue spectral range, among others (e.g., Dubovik et al., 2002; Eck et al., 2010; Giles et al., 2012). These are however the expected properties for pure dust near the sources. The dust over our study region has experienced long-range transport, with possible apportioning of other aerosol particles as well as mixture with local aerosol. So it is to expect that some variability and differences with respect to pure dust properties are found in the intensive properties.

The aerosol characterization developed in this article is based on a DD inventory previously reported by Cachorro et al. (2016). This inventory is composed by DD event days occurring in the north-central area of the Iberian Peninsula between January 2003 and December 2014. The methodology behind the inventory simultaneously uses columnar and surface aerosol data to identify DD events. Once the DD fingerprint is recognized in one or both of these core variables, a thorough manual inspection of the data is carried out together with the analysis of air mass backward trajectories, meteorological maps, satellite images, and model forecasts, in order to corroborate the right classification of each DD outbreak.

As a natural continuation of the inventory analysis, the aim of this study is to carry out the characterization of the main optical and microphysical properties during mineral dust events, for a better understanding of mineral aerosol over the IP. One of the most interesting results reported by Cachorro et al. (2016) is the analysis of the two sub-groups of DD aerosols, one labeled as desert (D) and the other one labeled as mixed-desert (MD). These groups were discriminated by means of the Ångström exponent. Such kind of study is required in those areas where aerosol mixtures play a non-negligible role caused by different reasons (large distance to the sources, orography, presence of big industrial cities or other aerosol types, among others) and where the DD identification is complicated since the boundaries among well-known (pure) aerosol types are ambiguous.

A detailed analysis of the aerosol surface concentration and columnar optical and microphysical properties is carried out here using