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An anomalous African dust event and its impact on aerosol radiative forcing on the Southwest Atlantic coast of Europe in February 2016

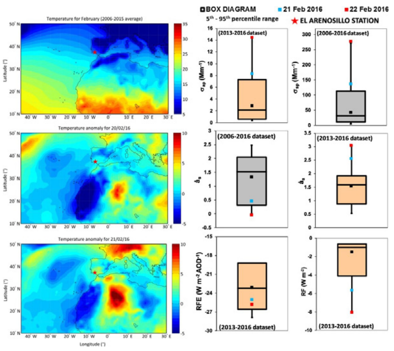
M. Sorribas [a],*, J.A. Adame [a], E. Andrews [b], M. Yela [a]

[a] Atmospheric Sounding Station – El Arenosillo, Atmospheric Research and Instrumentation Branch, INTA, Mazagón, Huelva 21130, Spain
[b] University of Colorado, CIRES, Boulder, CO 80309, USA

HIGHLIGHTS

- A desert dust (DD) event originating in North Africa occurred.
- DD event was exceptional due to its unusual intensity during the coldest season.
- Increase in dust source region temperature by up to 7 °C relative to the last decade
- Aerosol radiative forcing at the top of atmosphere reached a value of −8.1 W m^{-2}

GRAPHICAL ABSTRACT



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ABSTRACT

A desert dust (DD) event that had its origin in North Africa occurred on the 20th–23rd of February 2016. The dust transport phenomenon was exceptional because of its unusual intensity during the coldest season. A historical dataset (2006–2015) of February meteorological scenarios using ECMWF fields, meteorological parameters, aerosol optical properties, surface O_3 and AOD retrieved from MODIS at the El Arenosillo observatory (southwestern Spain) were analysed and compared with the levels during the DD event to highlight its exceptionality. Associated with a low-pressure system in western North Africa, flows transported air from the Sahel to Algeria and consequently increased temperatures from the surface to 700 hPa by up to 7–9 °C relative to the last decade. These conditions favoured the formation of a Saharan air layer. Dust was transported to the north and reached the Western Mediterranean Basin and the Iberian Peninsula. The arrival of the DD event at El Arenosillo did not affect the surface weather conditions or ozone but did impact the aerosol radiative forcing at the top of atmosphere (RF_{TOA}). Aerosol radiative properties did not change relative to historical; however, the particle size and the amount of the aerosol were significantly higher. The DD event caused an increase (in absolute terms) of the mean aerosol RF_{TOA} to a value of −8.1 W m^{-2} (long-term climatological value ~ − 1.5 W m^{-2}). The aerosol RF_{TOA} was not very large relative other DD episodes; however, our analysis of the historical data concluded that the importance of this DD event lay in the month of occurrence. European phenological datasets related to extreme atmospheric events predominantly reflect changes that are probably associated with climate change. This work is an example of this phenomenon, showing an event that occurred in a hotspot, the Saharan desert, and its impact two thousand km away.

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* Corresponding author.
E-mail address: sorribasm@inta.es (M. Sorribas).

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1. Introduction

An extreme weather event includes unexpected, unusual, severe or unseasonal events within its statistical reference distribution at a particular place (IPCC, 2014). During the last decade there has been an increase in the study of many aspects of change in extreme weather events and discussions of their connections with climate change (Sillmann et al., 2013; Liu et al., 2015). Some open questions are: (1) are events occurring earlier or later in the season than they used to? and (2) are events becoming more severe, with the potential for more damaging effects? While extreme weather events are typically rare, global warming is increasing the odds that more such events will take place (World Meteorological Organization, 2011).

Although climate change is a global issue, impacts vary widely. A hotspot is a place where the impact of climate change is pronounced; some examples of climate change impact include: sea-level rise, melting glaciers, earlier spring arrival date, changes in hurricane activities and/or dust storm patterns. Changes in desert dust (DD) storm location, intensity, transport and timing are one of the major climate change impacts in Africa and Southern Europe (Müller et al., 2014; Martínez-Valderrama et al., 2016). The study presented here is an example of this phenomenon, showing an event that occurred in a hotspot – the Saharan desert – and its subsequent impact on southwest Spain.

The influence of DD aerosols on the Earth's energy balance has been extensively studied in recent years because the net dust aerosol radiative effects are still very unclear (e.g., Denjean et al., 2016 and references therein). The Iberian Peninsula is frequently affected by African dust episodes with large mineral dust particle loads that modulate its aerosol climatology, especially in the southern areas (Toledano et al., 2007a; Valenzuela et al., 2012). Over the last decade there have been many analyses exploring various aspects of DD events in the Iberian Peninsula. Some of these studies have focused on columnar optical and microphysical properties during DD events (Cachorro et al., 2006, 2008). Antón et al. (2012) evaluated the effects of a dust event on spectral UV irradiance, as well as the relative differences between ground-based UV data and those derived from the Ozone Monitoring Instrument (OMI). Meteorological information and remote sensing techniques, both ground-based active (lidar) and passive (sun photometer), together with back-trajectory analysis and in-situ measurements, were used synergetically to characterize dust transport from the Canary Islands to sampling sites in southern Spain (Córdoba-Jabonero et al., 2011). The effects of Saharan dust on surface meteorology and atmospheric boundary layer structure and their influence on ozone at the surface have also been analysed during a desert dust event (Adame et al., 2015).

In addition to the studies of individual DD cases, a long-term programme to measure the column atmospheric aerosol properties with a sun photometer has resulted in the development of an inventory of desert dust events at the El Arenosillo observatory in southwest Spain over a 6 year period (2000–2005) (Toledano et al., 2007a). Toledano et al. (2007a) found that DD episodes had a duration of about 4 days and were more frequent in March (6.7 d yr^{-1}) and in summer months (>30 d yr^{-1} during June–August period). April experienced the least DD events (0.5 d yr^{-1}). A decrease in the number of occurrences was observed after the peak in summer, with a minimum in December (0.7 d yr^{-1}). The contribution of desert dust aerosol to the AOD (440 nm) is was high as 0.09 in August and 0.07 in March, corresponding to 50% and 39% respectively, of the total AOD. From October to January the influence was much smaller. Because of the low occurrence of dust events in April, AOD increased only 0.003 (or 2%). Additionally, the programme established an automatic method for the detection of DD episodes over the Iberian Peninsula using sun photometer data. The impact of DD events at ground level has also been studied in terms of submicron particle size distribution (Sorribas et al., 2011), the use of in situ aerosol scattering and microphysical properties (Sorribas et al., 2015a), and analysis of the role of spheroidal dust particles on closure studies (Sorribas et al., 2015b).

The studies of African dust outbreaks described above were primarily carried out under the framework of long-term monitoring at the El Arenosillo observatory which has been making DD relevant measurements since 2000. The long-term aerosol data record from El Arenosillo allows for the study of potential changes in the strength of the episodes and, in conjunction with meteorology and satellite data, the location of the desert dust sources. The main objective of the present paper is to report in detail the meteorological data and characteristics of an exceptional desert dust outbreak that originated in North Africa. This event took place from the 20th to 23rd of February 2016. It was an unusual event within the historical context of meteorological scenarios and aerosol optical properties typically observed during the month of February and it has thus been considered an extreme weather event. Here, the features of the meteorology resulting in the dust event have been analysed, and the subsequent impact of the transported desert dust plumes on atmospheric conditions and constituents in southwest Spain has been explored. To highlight the exceptionality of the February 2016 event, we analysed the historical dataset for February from 2006 to 2015 of aerosol optical properties and O_3 concentration at El Arenosillo, as well as the daily AOD retrieved from the MODIS instrument. The historical data were compared with the levels observed during the DD event.

2. Material and methods

2.1. Meteorological, trajectory models and satellite observations

The European Centre for Medium-Range Weather Forecasting (ECMWF) meteorological fields were used to study the synoptic conditions as well as to perform several meteorological analyses. Specifically, the ERA Interim dataset, with a spatial resolution of 0.5° × 0.5°, 22 vertical levels from the surface to 250 mb and a time resolution of 6 h was used. Variables used in the analysis included mean sea level pressure, wind speed at the surface and temperature at the surface and at several pressure levels.

To understand the air mass origin during the DD event, back-trajectories were computed using the HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) model developed by the NOAA's Air Resources Laboratory (ARL) (Draxler et al., 2009). For computations of the back trajectories, the ECMWF meteorological fields were converted to ARL format and used as model input. Three-dimensional kinematic back-trajectories were calculated. Hourly back-trajectories with a 120 h pathway (5 days) were computed at the surface (500 m), 1500 m (850 hPa level) and 3000 m (700 hPa level).

Daily aerosol optical depth (AOD) and extinction Ångström exponent from the MODIS (Moderate Resolution Imaging Spectroradiometer) instrument at a 1° spatial resolution have been used. Specifically, collection 6 of the Deep Blue 550 nm AOD and the (412–470 nm) Ångström exponent from the MODIS Aqua satellite (Hubanks et al., 2015) were used. Only the MODIS observations of the study region have been analysed, i.e., North Africa, Southwest Europe and the Western Mediterranean.

2.2. Surface instruments at El Arenosillo observatory

The impact of this particular DD event on aerosol optical properties at ground level was studied in southwestern Spain at El Arenosillo observatory (37.18 N, 6.78 W, 40 m a.s.l.). The site is located in a protected rural environment in Doñana National Park on the coast of the Atlantic Ocean (<1 km), in the mouth of the Guadalquivir valley, and close to the Mediterranean Sea and North African coast. Previous research at El Arenosillo has shown that the site can be impacted by dust, biomass burning, marine aerosol and anthropogenic emissions (from industry/population centers in the Guadalquivir valley) depending on time of year and air flow patterns. More information regarding the desert dust

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