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Back-trajectory analysis of African dust outbreaks at a coastal city in southern Spain: Selection of starting heights and assessment of African and concurrent Mediterranean contributions

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HIGHLIGHTS

- Study of African dust outbreaks in the southernmost largest European city.
- Proposed a new procedure to find the best starting heights for trajectory analysis.
- Decoupling in height may explain concurrent dust and aged pollutants load.
- At the lowermost levels flows are most frequently of Mediterranean origin.
- Lowest arrival height of African air masses mostly within 1000–2000 m.

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ABSTRACT

The present study uses a back-trajectory analysis at multiple heights for better interpretation of the impact of the African dust outbreaks in the coastal Mediterranean city of Málaga (Spain), the southernmost large city in Europe. Throughout a 3-year period, 363 days were identified as dusty days by atmospheric transport models. During these events, PM_{10}, SO_2, O_3, temperature, AOD and Ångström exponent showed statistically significant differences compared to days with no African dust. It was found that under African dust events, the study site was influenced by Mediterranean air masses at the lowermost heights and by Atlantic advections at high altitudes, while African air masses mostly reached Málaga at intermediate levels. Specifically, the lowest heights at which air masses reached the study site after having resided over Africa are confined into the 1000–2000 m range. The decoupling between the lowest heights and the ones for dust transport may explain the presence of aged air masses at the time of the African outbreak. Additionally, with the aim of studying the influence of the air mass origin and history on air quality, a new procedure based on Principal component analysis (PCA) is proposed to determine which altitudes are best suited as starting points for back-trajectory calculations, as they maximize the differences in residence time over different areas. Its application to Málaga identifies three altitudes (750, 2250 and 4500 m) and a subsequent analysis of back-trajectories for African dust days provided the main source areas over Africa as well as further insight on the Mediterranean contribution.

1. Introduction

North Africa is widely considered as the Earth's largest dust producing source, and the Sahara desert is identified as one of the major source areas of windblown dust in the Northern Hemisphere (e.g., Middleton and Goudie, 2001; Prospero et al., 2002). It is therefore of great interest to analyze and quantify the African dust impact on receptor areas. Indeed, a considerable literature is available on African dust transport being exported across the Mediterranean basin to Europe and the Middle East (e.g., Papayannis et al., 2005; Barkan et al., 2005; Griffin et al., 2007; Santese et al., 2008; Pey et al., 2013; Salvador et al., 2014), or even travelling for long distances such the Caribbean and the

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United States (Prospero et al., 2002; Bristow et al., 2010). African mineral dust has been extensively studied by different techniques such as in situ measurements at the receptor areas, remote sensing observations, model calculations, or aircraft measurements (Koren et al., 2006; Pérez et al., 2006; Querol et al., 2009; Johnson and Osborne, 2011; Cabello et al., 2012).

Due to the proximity to the African continent, the Iberian Peninsula is especially affected by those dust plumes, with a decreasing south to north impact (Cabello et al., 2012; Pey et al., 2013). Thus, there are a number of works devoted to the influence of African dust on health, air quality, ecosystem dynamics or climatic change in this area (Ávila and Peñuelas, 1999; Artíñano et al., 2003; Querol et al., 2008; Pérez et al., 2012), as well as to the study of aerosol properties, or the mechanism of dust transport (Ávila et al., 1997; Escudero et al., 2005; Wagner et al., 2009). Rodríguez et al. (2001) and Escudero et al. (2007) reported the impact of dust-events at seventeen air quality monitoring stations in Southern and Eastern Spain and at the Spanish sites belonging to the European Monitoring and Evaluation Programme (EMEP) respectively. Furthermore, Escudero et al. (2007) suggested a methodology which is the basis for the Guidance proposed by the European Commission for demonstration and subtraction of exceedances attributable to African dust contribution to the PM_{10} burden (Commission staff working paper, 2011).

Back-trajectory analyses have a wide range of applications in the atmospheric and air quality fields, to identify transport pathways affecting a study site and determine potential source areas of air tracers. For instance, Moody and Galloway (1988) performed a trajectory cluster analysis to assess the influence of atmospheric transport on the precipitation chemistry. Other technique to identify source areas of air pollutants with back-trajectory analysis which involves air pollution data is the residence time analysis proposed by Ashbaugh et al. (1985). Since then, numerous researches have used these and other techniques on different atmospheric topics for the Iberian Peninsula (e.g., Jorba et al., 2004; Salvador et al., 2004; Cabello et al., 2008; Alarcón et al., 2010; Hernández-Ceballos et al., 2011; Orza et al., 2012).

Works on the characterization of African intrusions by in-situ and remote measurements often used back-trajectory analysis as a complementary tool to understand or assess the origin of the air masses (e.g., Escudero et al., 2005; Alonso-Pérez et al., 2012; Salvador et al., 2014). However, the present work reports a detailed study of back-trajectories at multiple heights to characterize African dust outbreaks in the city of Málaga, close to the northern part of the African continent. The use of many different arrival heights of the trajectories grants identifying the main pathways in a vertical profile of the air masses, and together with ground-level measurements, allows gaining better understanding of the atmospheric transport during African intrusions and its impact on the receptor area.

2. Methodology

2.1. Study area

Málaga is located in southern Spain (Fig. 1), close to the African continent (about 120 km far from the closest north African point). With an area of 400 km^2 and almost 570,000 inhabitants, it is the major coastal city of the Andalusia region and the sixth most populated city in Spain. The city lies on the Mediterranean coast, is situated in a two river valley (the Guadalhorce and the Guadalmedina rivers) and bordered to the north by a high mountain range. Due to the influence of the local orography, southeast and northwest winds are the prevailing winds related with the well-developed land-sea breeze regime (Millán et al., 1996). The study area has a temperate climate with dry and hot summer (Peel et al., 2007). According to the Spanish National Institute of Meteorology (AEMET), the mean annual temperature is 18°C being July and December the hottest and the coldest month respectively. The rainfall is scarce with mean annual precipitation of around 525 mm $year^{-1}$ which falls mainly during autumn and winter.

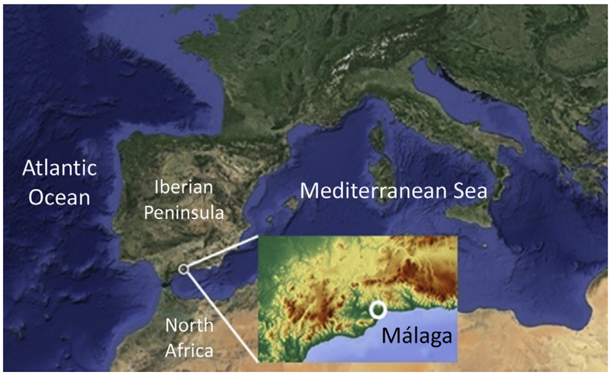

Fig. 1. Location of the study area.

2.2. Data sources

Daily concentrations of air pollutants (SO_2, PM_{10}, NO_2, CO and O_3) and meteorological data (temperature, relative humidity, wind speed and precipitation) for the study period 2009–2011 were collected from the Carranque air quality monitoring station belonging to the Regional Government of Andalusia (www.juntadeandalucia.es/medioambiente), and from the Málaga meteorological station of the Spanish regional agro-climatic network (www.mapa.es/siar/Informacion.asp) respectively. Aerosol Optical Depth (AOD) measured at 440 nm and Ångström exponent (Å) for the wavelength pair (440 nm, 870 nm), both level 2 data (i.e., cloud-screened and quality-assured) from the AErosol RObotic NETwork (AERONET) station of Málaga (http://aeronet.gsfc.nasa.gov), were used as straightforward measures of column integrated extinction and aerosol particle size, respectively.

2.3. Identification of African dust outbreaks

Although both the most common methodology to identify African dust events in the literature and the Guidance proposed by The European Commission (Commission staff working paper, 2011) include the use of satellite images together with atmospheric transport models and synoptic meteorological charts, we have identified African dust outbreaks by using only dust prediction models and back-trajectories. Satellite images present some limitations of availability, mainly related with the presence of cloud cover and the overpass frequency, which could skew the results e.g., the events accompanied by clouds are never taken into account. For example, MODIS data were not available (i.e., no data or cloud fraction > 0.9) for the study period in almost 20% of dusty days identified by the Dust REgional Atmospheric Model (DREAM8b) maps. This percentage greatly increases in the case of the OMI data (up to 70%). Moreover, PM_{10} and AOD data were not used for the identification of the African dust events because these parameters were afterwards examined for significant differences between days affected and unaffected by African events.

Consequently, days affected by African dust outbreaks were identified from data and maps from the BSC-DREAM8b (v2.0) as well as from the Navy Aerosol Analysis and Prediction System (NAAPS) model. We are aware that the identification of events is