



Influence of Saharan dust outbreaks and atmospheric stability upon vertical profiles of size-segregated aerosols and water vapor

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ABSTRACT

Vertical profiles of aerosols and meteorological parameters were obtained using a hot air balloon and motorized paraglider. They were studied under anticyclonic conditions in four different contexts. Three flights occurred near sunrise, and one took place in the central hours of the day. The effects of North African dust intrusions were analyzed, whose entrance to the study area took place above the Stable Boundary Layer (SBL) in flight 1 and below it in flight 2. These flights have been compared with a non-intrusion situation (flight 3). A fourth flight characterized the profiles in the central hours of the day with a well-formed Convective Boundary Layer (CBL). With respect to the particle number distribution, the results show that not all sizes increase within the presence of an intrusion; during the first flight the smallest particles were not affected. The particle sizes affected in the second flight fell within the 0.35–2.5 μm interval. Under situations of convective dynamics, the reduction percentage of the particle number concentration reduces with increasing altitude, independently of their size, with respect to stability conditions. The negative vertical gradient for aerosols and water vapor, characteristic of a highly stable SBL (flight 3) becomes a constant profile within a CBL (flight 4). There are two situations that seem to alter the negative vertical gradient of the water vapor mixing ratio within the SBL: the presence of an intrusion and the possible stratification of the SBL based on different degrees of stability.

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1. Introduction

Air pollution modeling and management require an understanding of pollutant distributions in three dimensions, in particular within the Planetary Boundary Layer (PBL). Vertical profiles of aerosol concentration and knowledge about their size distributions help determine the properties of the lower troposphere in clean and polluted conditions (Raga and Jonas, 1995).

The PBL height is often a rather unspecific parameter whose definition and estimation is not straightforward (Seibert et al., 2000). The practical and theoretical problems associated with the determination of the PBL height, and sometimes even its definition, are reflected in the numerous definitions found in the literature (Stull, 1988; Seibert et al., 1998). It also seems that the PBL height definitions of different authors must be seen in the context of the data available to them (Seibert et al., 2000).

The PBL height is an interesting parameter in the study of the vertical structure of aerosols. Some researchers (O'Dowd and Smith, 1996; Flocas et al., 2006; Guerrero-Rascado et al., 2008) have shown

the importance the altitude of this layer has upon the vertical profile of atmospheric particle concentrations. Knowledge about the PBL height is especially important when dealing with specific situations, like Saharan dust intrusions in the Mediterranean basin. Along its trajectory in the Mediterranean basin, Saharan dust can reach altitudes of 5–6 km, and its transport appears to be multilayered due to the complexity of the wind field that activates different dust sources (Hamonou et al., 1999). In this sense it is probable that Saharan dust outbreaks can reach the PBL, and as such, affect particulate matter (PM) levels at ground level (Colette et al., 2008; Guerrero-Rascado et al., 2008). North African dust contributions to PM have been amply studied at ground level in the Mediterranean basin (Kubilay et al., 2000; Rodríguez et al., 2001; Nicolás et al., 2008). This contribution of PM has implications on air pollution regulation strategies, and account for the marked difference in the features of airborne particulates between Southern and Northern Europe (Rodríguez et al., 2001).

Saharan air outbreaks cover very large areas and are usually highly loaded with mineral particles. Dust particles reflect and absorb UV, visible and infrared radiation, and may serve as cloud nuclei (Yin et al., 2002). They can impact atmospheric photochemistry by providing a surface for heterogeneous reactions (Schwartz et al., 1995). Thus, the presence of dust aerosol alters the

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surface radiation budget and affects the concentration and distribution of some atmospheric gases like ozone. The radiative effects of this type of aerosol have received considerable attention in the last ten years (Sokolik et al., 2001; Tanré et al., 2003). During the SHADE campaign a global mean net radiative impact of Sahara dust of around -0.4 W m^{-2} was determined (Myhre et al., 2003).

Attempts to measure the vertical size-segregated PM distribution in the PBL have been constrained by instrumentation size and weight. Successful measurements have been made from aircraft but at a considerable expense. The suitability of a GRIMM 1.108, a lightweight aerosol spectrometer, to obtain size-segregated vertical profiles of PM in the PBL using a balloon-borne platform has been described and evaluated (Maletto et al., 2003).

This research was conducted in southeastern Spain, an area frequently affected by Saharan intrusions, using a lightweight aerosol spectrometer onboard a hot air balloon and motorized paraglider, with the intention of meeting the following objectives:

- Characterize the vertical profile of particle number concentrations directly measured with and without Saharan dust outbreaks and relate it to the SBL (Stable Boundary Layer or Nocturnal Boundary Layer) and CBL (Convective Boundary Layer) heights.
- Analyze the similarities and differences between the vertical profiles of particle number concentrations and water vapor profiles.

2. Experimental site and instruments

The study area is located in southeastern Spain. Four sampling sites were selected for this study. The launch sites are located within the municipal boundaries of the towns of Pinoso, La Murada, Granja de Rocamora, and Catral, all in the province of Alicante. Pinoso is located 56 km from the Mediterranean coast and surrounded by low hills. La Murada lies 35 km from the seaside, while Granja de Rocamora and Catral are 17 km from the coast in very flat terrain. The proximity to the African continent makes the area highly sensitive to dust intrusions. The Köppen climate classification for the area is Csa (Ahrens, 2000).

The geographic features of the launch sites are shown in Table 1 and the characteristics of the four flights in Table 2.

Measurements were taken during the ascents and descents for both the balloon and paramotor, finding almost perfect agreement of the values between the ascents and descents for all parameters, with the exception of slight warming in the lower layers during the descent due to the advancing day. Because of this we can state that the atmosphere remained homogenous during the experiments.

In this study, the principal instrument used was a GRIMM 1.108 “Dustcheck” aerosol spectrometer (GRIMM Labortechnik Ltd., 1996), having a weight of 2.4 kg (including battery) and dimensions of $24 \times 12 \times 6 \text{ cm}$. This instrument determines the particle number concentration in 15 particle size channels from 0.3–0.4 to $20 \mu\text{m}$. The uncertainty in the particle counting determination is about 5% and its resolution is 1 particle liter^{-1} . The average size of each channel, which will be used to refer to the particle sizes, are 0.35, 0.45, 0.575, 0.725, 0.9, 1.3, 1.8, 2.5, 3.5, 4.5, 6.25, 8.75, 12.5, 17.5 and

Table 1
Location and characteristics of the four measurement sites for the study.

Flight number/data	Site	Latitude	Longitude	Height ASL
1/19-07-06	1-Pinoso	38°24'14" N	01°01'44" W	665 m
2/31-10-06	2-La Murada	38°11'27" N	00°59'55" W	100 m
3/25-02-08	3-Catral	38°08'05" N	00°50'05" W	60 m
4/31-02-08	4-Granja de Rocamora	38°09'27" N	00°46'39" W	59 m

Table 2
Characteristics of the four flights.

Flight number	Displacement ^a (km)	Duration of the flight (min)	Height (m)
1	10	26	2250
2	11	31	2927
3	4	12	1298
4	5	42	2357

^a Horizontal displacement from the launch sites.

$20 \mu\text{m}$. As said before, its suitability and characteristics on a balloon-borne platform have been described and evaluated (Maletto et al., 2003).

A Delta Ohm ultrasonic anemometer model HD 2003 was used to record the temperature, relative humidity and pressure. This device was also implemented on the airborne platforms (hot air balloon and motorized paraglider). The motorized paraglider was used for the sole launch occurring during the central hours of the day, a time when thermals impeded use of the balloon.

Temperature, relative humidity and pressure sensor features are shown in Table 3.

3. Methodology

3.1. Sampling and data treatment

The data were collected between July 2006 and January 2008. Synoptic conditions were anticyclonic. The aerosol spectrometer and the GPS recorded data each six seconds while the ultrasonic anemometer recorded each second.

The dew point, water vapor mixing ratio and virtual potential temperature were derived from the temperature, relative humidity and pressure data. Wind information on the hot air balloon flights was obtained from GPS data. For the motorized paraglider flight no wind data are available. Altitude data was supplied from the GPS and additionally from the temperature, pressure and relative humidity data, with good agreement between them.

To determine the SBL height we focused on the height where:

- The temperature gradient vanishes ($\partial T / \partial z = 0$; inversion top), (Yu, 1978; Stull, 1988).
- $\bar{M}$ (Mean wind) is maximum (nocturnal low level jet (LLJ)) (Stull, 1988).
- The virtual potential temperature gradient $\partial \theta / \partial z$ is less than $3.5 \times 10^{-3} \text{ K m}^{-1}$, the low level value of the standard atmosphere (André and Mahrt, 1982).
- The wind speed and direction smoothly changes to geostrophic (Stull, 1988).

To determine the CBL height the parcel method (Holzworth, 1964, 1967, 1972; Seibert et al., 2000) was used.

The webpage <http://weather.uwyo.edu/upperair/sounding.html>, provided by the University of Wyoming was also utilized, where meteorological soundings are available. In our case we consulted the soundings gathered at the station located near the city of Murcia ($37^{\circ}59' \text{ N}$; $1^{\circ}7' \text{ W}$; 62 m a.s.l.), a location near our launch sites.

Table 3
Temperature, relative humidity and pressure sensors features.

Parameter	Sensor	Range	Resolution	Accuracy
Temperature	Pt100	$-40^{\circ} \text{ C} - +60^{\circ} \text{ C}$	0.1 $^{\circ} \text{ C}$	$\pm 0.2^{\circ} \text{ C}$
Relative humidity	Capacitive	0–100%	0.1%	$\pm 2.5\%$
Pressure	Piezoresistive	800–1100 hPa	0.1 hPa	$\pm 0.4 \text{ hPa}$

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