Study of a desert dust event over the South-Western Iberian Peninsula in summer 2010

Obregón, M.A.[1], Pereira, S.[2], Serrano, A.[1], Cancillo, M. L.[1], Wagner, F.[2], and Silva, A. M.[2]

Abstract —During August 2010, between days 7 and 11, an intense dust outbreak in the atmospheric column was simultaneously detected at three AERONET stations located in the Southwestern Iberian Peninsula: Évora and Cabo da Roca, in Portugal, and Cáceres, in Spain. The transport of dust from the Sahara region towards the Iberian Peninsula is one regular phenomenon that notably influences the radiation balance as well as the atmospheric visibility at those sites overspread by these aerosols. Optical and microphysical aerosol properties, such as aerosol optical depth, Ångström exponent α, single scattering albedo and size distributions were obtained from CIMEL sun-photometer measurements performed at the three mentioned stations which belong to the AERONET network. This Saharan dust event lasted almost a week and it was analyzed in terms of several optical and microphysical aerosols properties combined with air mass back-trajectories computed by means of the Hybrid Single Particle Lagrangian Integrated Trajectory model (HYSPLIT_4), as well as with the synoptic conditions responsible for the long-range transport of the dust particles. The measurements show a significant increase in the atmospheric turbidity caused by the input of coarse particles, with daily averages of aerosol optical depth at 870nm about 0.5, daily averages of Ångström exponent α between 0.1 and 0.2, and spectral single scattering albedo increasing in 0.9 at 440nm and in 1.0 at 870nm the last two days of the dust event. All the measured values of these parameters and their variation range are typical for desert dust intrusions.

Keywords — aerosol, desert dust, intrusion, Iberian Peninsula

1 Introduction

Atmospheric aerosols play a substantial role in the Earth's radiation balance influencing it at regional and global scales and producing cooling or warming of the planet. Nowadays, due to their complex spatial and temporal variability, chemical variety and inherent physical an optical properties, aerosols are still a large source of uncertainty concerning their climate effects. They directly interact with solar and terrestrial radiation through scattering, and absorption as well as through emission processes. They also indirectly affects the radiation balance by influencing the cloud formation and modification. Regarding the human health, they can be very detrimental favoring respiratory diseases [1].

The Saharan desert is the main source of mineral aerosols in the Northern Hemisphere [2], injecting large amounts of desert dust in the atmosphere, and playing an important role in the radiation balance of the Climate System [3].

1. *They are with the Department of Physics, University of Extremadura, Avda.Elvas s/n, 06006, Badajoz, Spain. E-mail: nines@unex.es*
2. *They are with the Évora Geophysics Centre and University of Evora,R. Romao Ramalho, 59, 7000 Evora. Portugal. E-mail: sergiopereira@uevora.pt*

According to the Intergovernmental Panel on Climate Change 2007, the global average aerosol direct radiative forcing is estimated to be about -0.5 [-0.9 to -0.1] W/m^2 and the global indirect forcing about -0.7 [-1.8 to -0.3] W/m^2, therefore contributing to the cooling of the planet. However there are still many uncertainties and accurate and reliable measurements and analyses are demanded to reduce those uncertainties.

This paper focuses on the desert dust outbreaks originated in the Sahara Desert (Northern Africa) that reach the Iberian Peninsula. Although there are several studies in the literature focused on Saharan desert episodes, only a few deal with their effect on the Iberian Peninsula using the AERONET sun-photometer measurements [4], [5], [6]. Due to the proximity of the Sahara Desert to the Iberian Peninsula and the annual latitudinal displacement of the general atmospheric circulation, the desert dust event in the Iberian Peninsula show a typical seasonal pattern [7], [8] associated to certain synoptic situations [9],[10], [11].

Most studies about desert dust in the Iberian Peninsula using sun-photometer data consist of case studies where the microphysical and optical properties of the desert dust aerosols are determined [12], [13]. A recent study by Toledano et al., 2007 [14], to our knowledge, the only one using a multiyear data set from ground-based remote sensing instruments.

The aim of this study is to detect and analyze an intense dust outbreak in the atmospheric column simultaneously detected, at three AERONET stations located in Southwestern Iberian Peninsula: Évora and Cabo da Roca, in Portugal, and Cáceres, in Spain. The opportunity to follow Saharan desert episodes that reach the Iberian Peninsula at these three different sites is not common, and it is the first study of this kind using data from these three stations obtained with CIMEL sun-photometers. This episode also was detected at other Spanish and Portuguese stations such as Huelva, Malaga, Granada and Autilla, in Spain, and Sagres, in Portugal. As already mentioned, Southwestern Iberian Peninsula is an appropriate area for the detection of desert dust aerosol events from North Africa due to the proximity of the Sahara desert.

In this study, the aerosol optical depths $\tau(\lambda)$ at 440 and 870 nm, the Angstrom exponent α obtained for the spectral range (440-870nm), the aerosol single scattering albedo $\omega(\lambda)$ at 440 and 870 nm and the aerosol volume size distributions (VSD) at the three sites above mentioned were daily averaged for each day from 5th to 12th of August 2010, that include a dust event occurred from 7th to 11th August.

This paper is organized as follows: a brief description of the region study and instrumentation is presented in Section 2; data set and methodology are provided in section 3; results are discussed in section 4. Finally, conclusions are given in section 5.

2 STUDY REGION AND INSTRUMENTATION

Fig. 1 shows the locations of the three AERONET stations used in this study: Cabo da Roca (38.8° North, 9.5° West, 140 m a.s.l), Évora (38.5° North, 7.9° West, 293 m a.s.l) and Cáceres (39.4° North, 6.3° West, 397 m a.s.l).

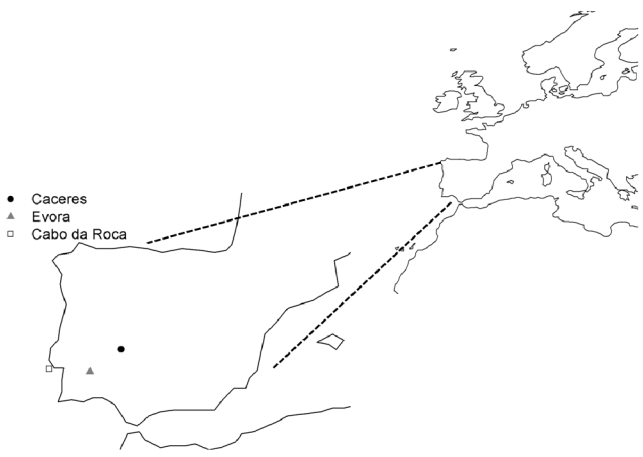

Fig. 1. Map of the Iberian Peninsula showing the location of three AERONET stations analyzed in this study.

None of the sites are directly influenced by industrial emissions and the aerosol background levels are generally moderate to low (median values of the aerosol optical depth at 440 nm lower than 0.11). Therefore, the measurements registered by the stations will be notably sensitive to the arrival of air masses transporting desert aerosols.

Typical weather conditions in Cáceres and Évora are similar: rainy periods occur in autumn, winter and March-April; during the summer air temperatures can reach values higher than 40 °C and relative humidities can go down to 5-10 % . At Cabo da Roca, due to its location in the Westernmost sea coast of Southern Iberian Peninsula, temperatures are milder than at the other two sites and relative humidity is normally higher, all over the year, [15].

The sun-photometers CIMEL used in this study belong to the AERONET global network and are described by Holben et al. [15]. This type of instrument makes direct sun measurements using filters at wavelengths 340, 380, 440, 500, 675, 870, 940, and 1020 nm, and sky measurements at 440, 675, 870, and 1020 nm under two different observational geometries. All irradiance measurements recorded by photometers of this network are processed through AERONET protocol described in Holben et al. [16], obtaining different levels of quality for the retrieved aerosol parameters (levels 1.0, 1.5 and 2.0). In this study the level 1.5 has been used because there is no level 2 during the episode of desert aerosol.

3 DATASET AND METHODOLOGY

The total number of data (level 1.5) used for the calculation of the different parameters in the three stations studied are shown in Table 1.

Table 1. Total number of data used during the desert dust event

Site	Direct sun Algorithm Products (τ , α)	Inversion Products (ω, VSD)
Cabo da Roca	143	21
Évora	394	73
Cáceres	188	21

The first step of our study was to compare the aerosol optical properties evolution for the three stations during this desert dust episode, detected between August 7 and August 11, 2010. The time evolution of the daily averages of the three aerosol physical parameter values, (τ, α and ω) as well as the daily average values of the size distributions will be analyzed for each station and day of this period.
The uncertainty in aerosol optical depth estimated by Holben et al. [16] is 0.01 for wavelengths greater

than 440 nm and 0.02 for smaller wavelengths. This uncertainty alters the Ångström exponent α by 0.03–0.04 [17]. Regarding to the uncertainty of single scattering albedo reported by AERONET, it varies from 0.03 to 0.07 [18], being higher for lower wavelengths. The errors in VSD depend on the aerosol type [19]. For aerosol dominated by coarse particles, the error is 15-25% for r≥0.5 μm and 25-100% r<0.5μm. And for the intermediate particle size range ($0.1 \leq r \leq 7$ μm), the error is <10%, and 25-100% for r<0.1 μm and r>7μm.

120-hour back trajectories ending at each site were calculated using the HYSPILT (Hybrid Single-Particle Lagrangian Integrated Trajectory) [20], [21]. All trajectories have been calculated at 12:00 UTC, at 4000 m a.s.l. (corresponding to approximately 600 hPa). This height has been chosen because of being representative of the long-range transport of aerosols, namely Saharan dust [9], [10], [22]. The back-trajectories were used to identify this episode, because they have a clear origin over North Africa.
To confirm the development of this synoptic maps at 600 hPa geopotential provided by the National Centers for Environmental Prediction (NCEP) Climate Diagnostics Center (http://www.esrl.noaa.gov/psd/data/composites/hour/).

4 RESULTS

Fig. 2 shows the time evolution of τ870 and α during the Saharan dust episode occurred between 7 and 11 August 2010. From the 8 August there is a distinct increase of τ870 from about 0.1 up to 0.9 (for Évora on the day 9) and a simultaneous significant decrease of α from about 1.5 down to 0.1 (also for Évora). This behavior is common to the three sites with slight differences among them.
Daily average values, computed using all available data for each day, of aerosol optical depth τ at 870 and 440 nm, Ångström exponent (440-870) α and single scattering albedo ω at 870 and 440 nm, during the days of dust influence, have been calculated (Table 2).
On 5, 6 and 7 August the measured values of τ are very low. On August 8, Cabo da Roca and Évora

Table 2. Number of measurements for each day and daily average values of aerosol optical depth at 870 and 440 nm, α Ångström exponent (440-870) and single scattering albedo at 870 and 440 nm, during the time period 5-12/08/2010 which includes the desert dust event (7-11/08) at **Cabo da Roca/ Évora /Cáceres**.

	Number of data	**τ 870**	**τ 440**	**α**	**Number of data**	**ω 870**	**ω 440**
05-08-2010	24/62/33	0.06 / 0.04 / 0.07	0.11 / 0.12 / 0.11	0.83 / 1.76 / 0.81	3/11/3	0.92 / 0.75 / 0.78	0.93 / 0.82 / 0.85
06-08-2010	31/62/35	0.06 / 0.04 / 0.07	0.10 / 0.12 / 0.14	0.84 / 1.63 / 1.06	4/12/3	0.71 / 0.82 / 0.83	0.77 / 0.86 / 0.88
07-08-2010	12/59/29	0.08 / 0.14 / 0.11	0.19 / 0.26 / 0.25	1.32 / 1.16 / 1.29	2/12/3	0.83 / 0.90 / 0.87	0.84 / 0.88 / 0.90
08-08-2010	3/9/-	0.92 / 0.63 / -	0.99 / 0.66 / -	0.11 / 0.09 / -	-/-/-	- / - / -	- / - / -
09-08-2010	3/38/15	0.54 / 0.39 / 0.53	0.60 / 0.45 / 0.58	0.14 / 0.25 / 0.17	1/7/1	0.97 / 0.97 / 0.97	0.90 / 0.88 / 0.89
10-08-2010	24/62/25	0.48 / 0.43 / 0.47	0.52 / 0.49 / 0.53	0.12 / 0.18 / 0.18	4/12/4	0.98 / 0.98 / 0.97	0.90 / 0.88 / 0.89
11-08-2010	46/53/27	0.42 / 0.54 / 0.24	0.45 / 0.59 / 0.34	0.12 / 0.14 / 0.53	8/10/5	0.98 / 0.98 / 0.92	0.89 / 0.89 / 0.84
12-08-2010	-/49/24	- / 0.03 / 0.09	- / 0.08 / 0.29	- / 1.53 / 1.59	-/9/3	- / 0.84 / 0.80	- / 0.86 / 0.87

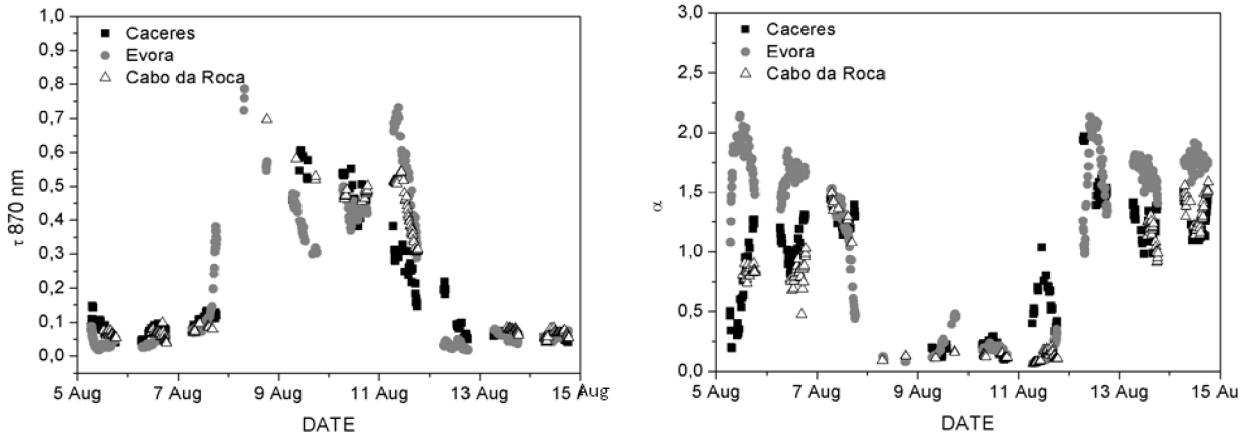

Fig. 2. Evolution of τ870 nm and α at the three sites during the time period 5-12/08/2010 which includes the desert dust event (7-11/08).

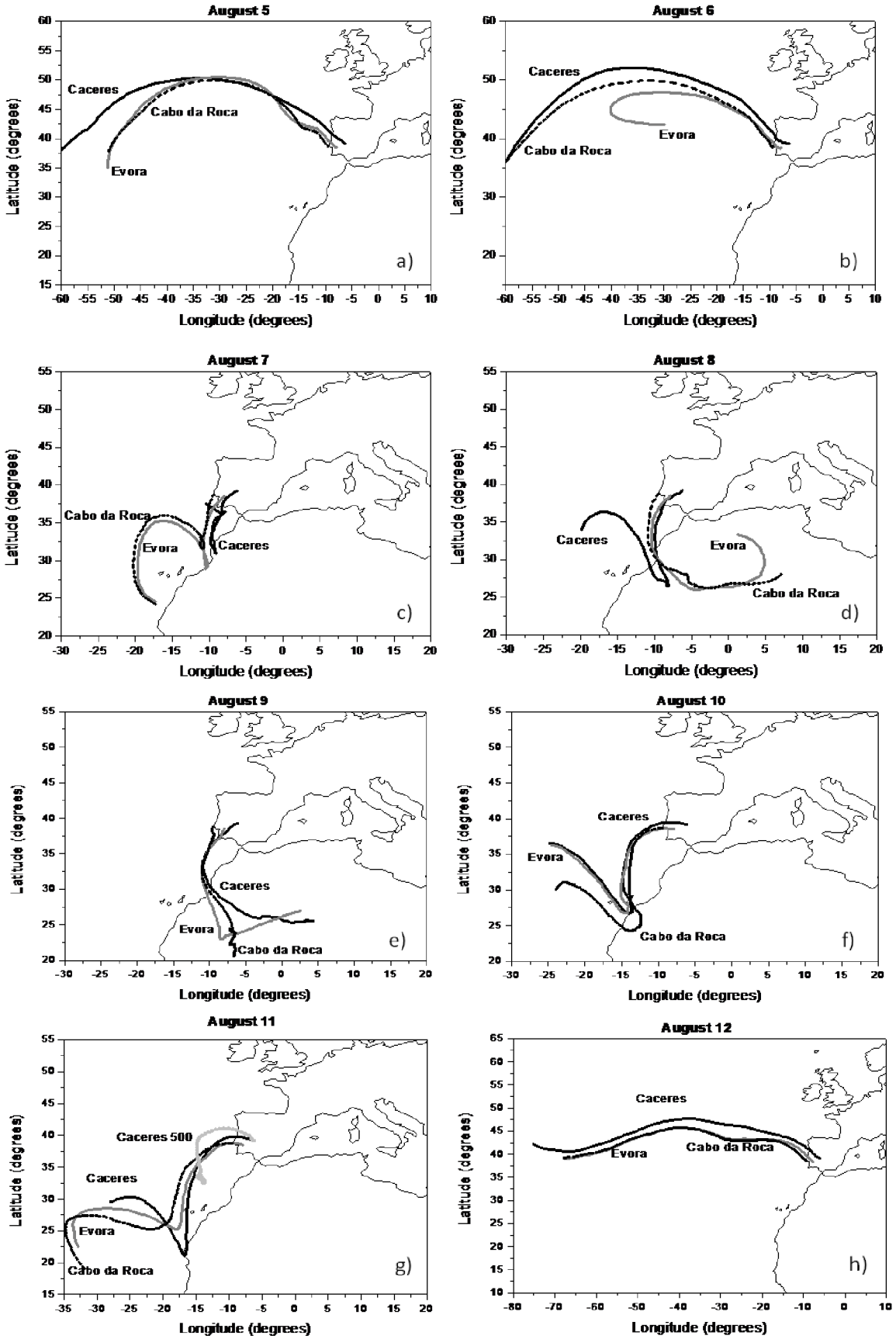

Fig. 3. 120 h back trajectories at 4000 m a.s.l. arriving at each station between August 5 and August 12, 2010. Fig. 3g) also appears the trajectory at 500 m a.s.l., used to explain the influence of biomass burning aerosol.

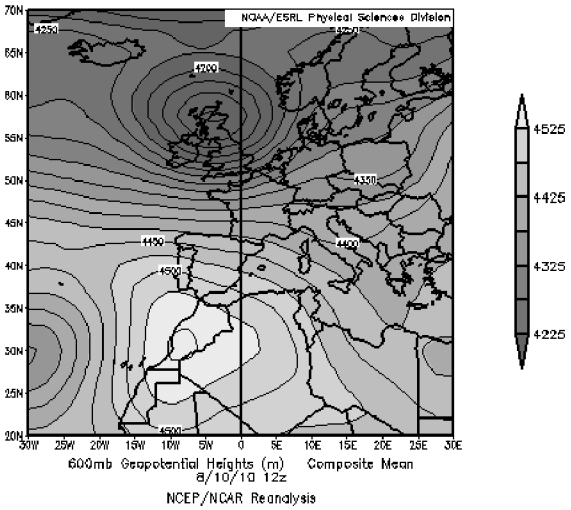

Fig. 4. Synoptic situation at 600 hPa geopotential on August 10, 2010.

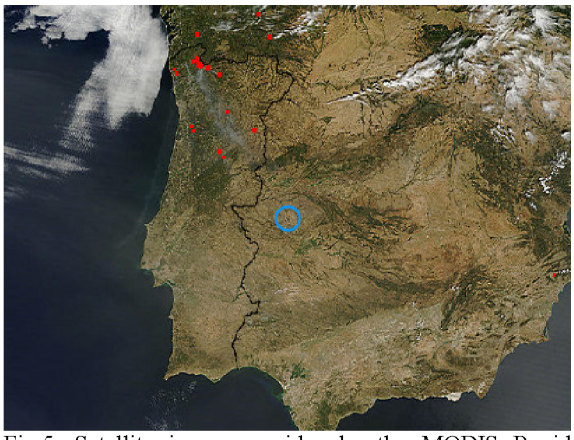

Fig.5. Satellite image provides by the MODIS Rapid Response System on August 10, 2010. Fires are shown as red points.

sites experienced a first significant increase in τ870 and a significant decrease in α. At Cabo da Roca τ870 increases up to 0.92 whereas in Évora reaches as high as 0.63. The α values decrease to 0.11 in Cabo da Roca and to 0.09 at Évora.

As can be seen in Table 2, on the 8, 9 and 10 of August, the highest daily average values of τ 870 (0.92, 0.54 and 0.48) and the lowest daily average values of α (0.11, 0.14 and 0.12) were detected in Cabo da Roca**.** These values indicate that on average the influence of dust aerosols was larger at Cabo da Roca followed by Évora where the influence was stronger only on the beginning of 8 and on the 11 of August. In Cáceres there are no data during this day although it is visible from Fig. 2 in the subsequent days that an increase of the τ870 and a decrease of α took place as well.

On the 9 and 10 August high turbidity was still observed in the three sites, with the τ870 values above 0.4. During the day 11, the influence of desert dust can still be detected in Cabo da Roca and Évora, but not in Cáceres. As it can be seen in Table 2, aerosol optical depth values τ870 in Cáceres are lower than in the other sites and the α values are higher, which suggests that during that day Cáceres may have been under the influence of a different aerosol population with smaller sizes, as could be the case of biomass burning aerosols.

All the data presented in Fig.2 and Table 2 are in agreement with the 5 days back trajectories calculated for these days at 4000m a.s.l and shown in Fig. 3. On 5, 6 and 7 August (Fig.3a, 3b and 3c) the trajectories for the three sites illustrate an atmospheric circulation from the Atlantic area. On 8, 9 and 10 August (fig.3d, 3e and 3f), all trajectories are originated at North Africa transporting desert

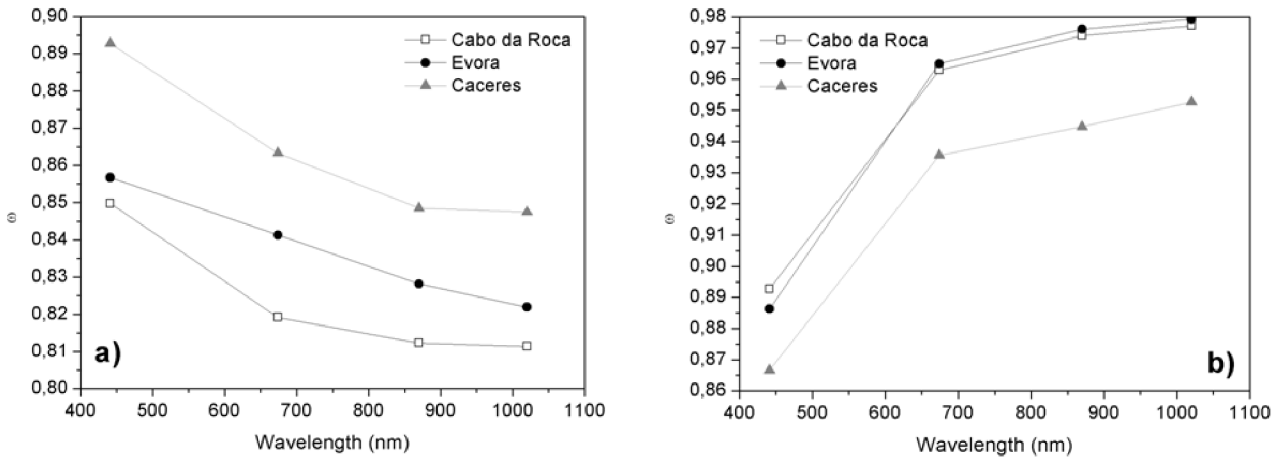

Fig.6. Relation between the average single scattering albedo values and the wavelengths during: a) the days before the desert dust event (from August 5 to August 7); and b) the days after the desert dust event (from August 8 to August 11)**.**

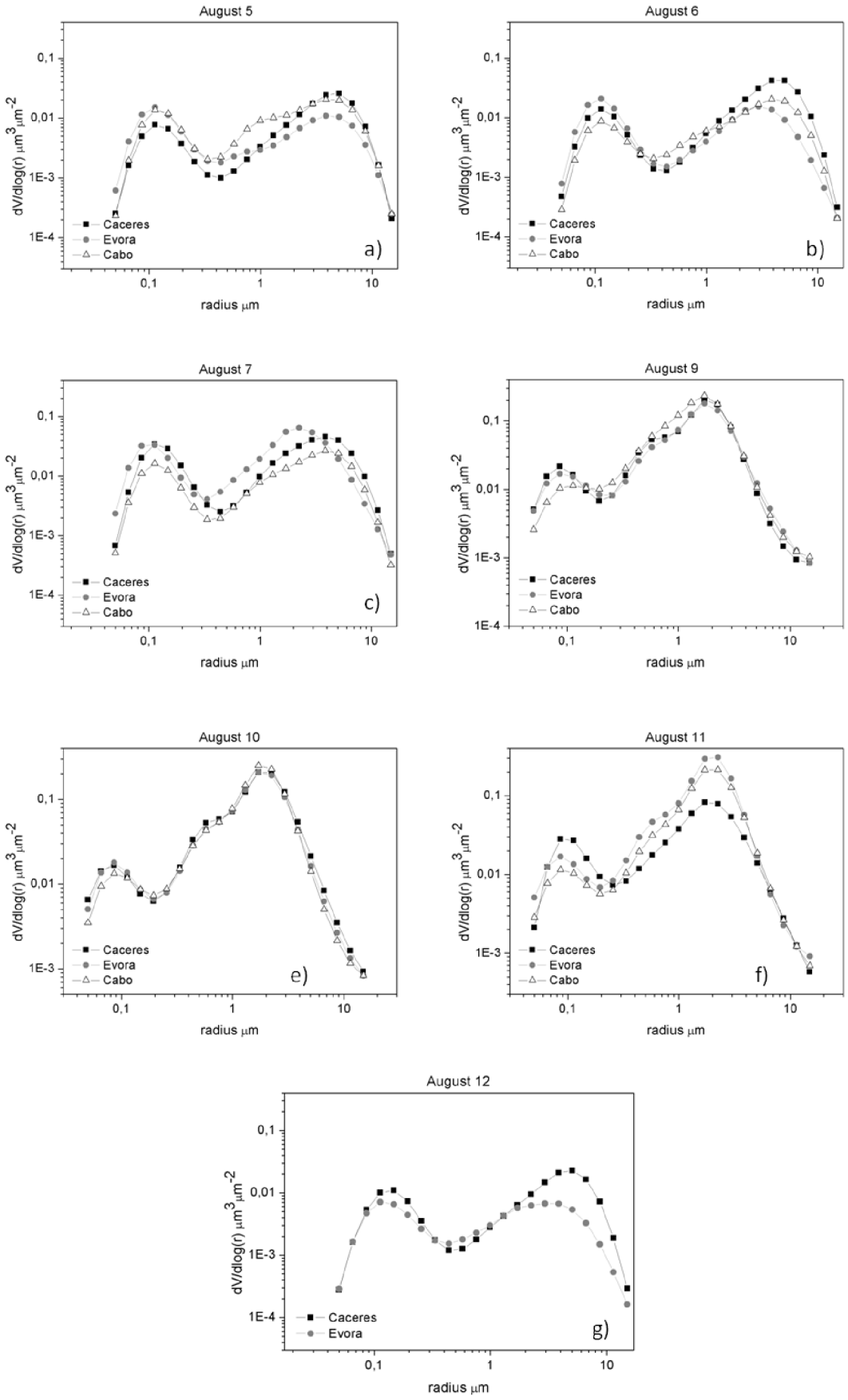

Fig.7. Daily average values of aerosol volume size distribution at each station between August 5 and August 12, 2010

aerosol from this area. On August 11 (Fig. 3g), the trajectory at 500 m a.s.l. arriving at Cáceres station remains during the last hours over central Portugal, where there are fires, as can be seen in Fig.5. On the 12 August (Fig.3h) the back trajectories for the three sites arrive again from the Atlantic area, as in the days before of the dust event.

The synoptic weather conditions over the study region are show in Fig. 4 only for the 10 of August. During the duration of the desert dust event the synoptic situation was similar to the one shown in Fig. 4 and fits in the scenario described by Escudero et al. [11], characterized by high pressure system over North Africa.

Concerning ω values (Table2 and Fig.6), it is noted that the values of ω870 are greater than ω440 during the days of the desert dust episode (Fig.6b). As expected, there is an increase of ω with the wavelength, which seems to be the typical behavior of the spectral single scattering albedo of desert dust aerosols [18].
The behaviour of α values during the desert dust episode is consistent with the values of the aerosol volume size distributions (VSD) presented in Fig.7 for the entire period and the three stations, where an increase of coarse particles is evident (except for August 8, where there are no data from any of the three stations). On 9, 10 and 11 August, the proportion of coarse aerosols in the three sites is clearly higher than on the days before the beginning of the episode (5, 6, 7) and on the days after (from 12 August on). However at Cáceres due to the arrival of smaller aerosol from biomass burning on the 11 August, the proportion of coarse aerosols is lower than other two sites.

5 Conclusions

A Saharan dust event occurring between August 7 and August 11, 2010 was detected simultaneously at the three sites of southern Iberia Peninsula (Cabo da Roca, Évora and Cáceres). Several optical and microphysical properties, such as aerosol optical depth, Ångström exponent α, single scattering albedo and aerosol volume size distributions were analysed. The 5-days back-trajectories were computed using the hybrid single particle Lagrangian integrated trajectory model (HYSPLIT_4) and the maps of synoptic situation at 600 hPa geopotential were analyzed confirming the occurrence of this episode.
Hence, a significant increase in the atmospheric turbidity caused by the input of coarse particles was noticed: daily averages of aerosol optical depth at 870 were as high as about 0.5 and daily averages of Ångström exponent α were found to be between 0.1 or 0.2 on several days. It should be noted that the influence of this episode was larger at Cabo da Roca followed by Évora where the influence was stronger only on the beginning of the 8 and on the 11 of August. These data are in agreement with the values of aerosol volume size distribution and the 5 days back trajectories calculated for these days.
Concerning the behavior of the spectral single scattering albedo values ω (λ), there is an increase of ω with the wavelength, typical of desert dust aerosols.

An intrusion of biomass burning aerosols was detected only at Cáceres during August 11. The air mass arriving at Cáceres station on that day remained during the last hours over central Portugal, where forest fires occurred as shown by MODIS satellite.

Acknowledgments

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