Saharan Dust Events over the Valencian Community (Eastern Iberian Peninsula): Synoptic Circulation Patterns and Contribution to PM₁₀ Levels

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ABSTRACT

This study assessed Saharan dust events (SDE) passing over the Valencian Community (VC; eastern Spain) during the period of 2014–2017 by investigating the following topics: a) the occurrence of SDE and their impact on PM₁₀ mass concentrations, b) the identification of the favorable synoptic patterns at 850 hPa associated with SDE via cluster analysis and c) the applicability of the gamma probability density function (PDF) in fitting the mass contributions of SDE. We determined that these events affect the VC on ~26% of the days of the year, thereby contributing $3.3 \mu\text{g m}^{-3}$ (~23%) to the average PM₁₀ concentration. Five circulation scenarios were identified. In Scenario 1 (17.4%), the transport of Saharan dust was due to the combination of a trough situated over the southwest of the Iberian Peninsula and a high-pressure system centered on western Algeria, Tunisia and eastern Libya. According to the PDF analysis, SDE characterized by this type of pattern were the most likely to substantially increase PM₁₀ mass concentrations. In Scenarios 3 (39.2%) and 5 (19.4%), which contributed to high concentrations of mineral dust in the VC, a high-pressure system was located over North Africa. Scenarios 1, 3 and 5 occurred more frequently during summer, especially Scenario 3 (69%). On the other hand, Scenarios 2 (16.2%) and 4 (7.2%), both characterized by a deep low over the west or northwest of the Iberian Peninsula, typically arose during spring and, to a lesser extent, winter. These two scenarios displayed a lower probability of elevating mineral dust levels in the study area.

Keywords: PM₁₀; Meteorological scenario; Cluster analysis; Saharan dust; Gamma distribution.

INTRODUCTION

The impact of mineral dust advections from arid regions of North Africa on the air quality in European Mediterranean countries may be very significant. This is due to the long residence time of particulate matter (PM) in the atmosphere induced by the low precipitation in the Mediterranean Basin (Querol *et al.*, 2009). As a result of this long-range transport, PM concentrations increase and its chemical composition changes (Galindo *et al.*, 2020). This leads to variations in the morbidity-mortality pattern associated with airborne PM levels. In fact, Saharan dust events (SDE) may be a risk factor for daily mortality (Díaz *et al.*, 2017). Two main reasons may explain the harmful effects of desert dust on human health: the high concentrations of mineral dust recorded during these episodes, and the anthropogenic, biological and microbiological load of dust outbreaks (Querol *et al.*, 2019b). These effects are mainly related to cardiovascular and

respiratory disorders, but it can also produce skin irritations, conjunctivitis, etc. (Goudie *et al.*, 2014).

Several studies carried out in the Mediterranean Basin have analyzed the impact of SDE on human health. Most of these works are related to the effects of coarse particles, since the associations between exposure to the fine fraction (PM_{2.5}) and human health effects during SDE are not usually statistically significant (Karanasiou *et al.*, 2012). Jiménez *et al.* (2010) identified the PM₁₀ fraction as the best air quality indicator for evaluating short-term human health effects of PM during SDE. Mallone *et al.* (2011) observed that PM₁₀ concentrations during dust days caused an important increase in cardiac mortality compared to dust-free days. A review of European studies on the health effects of Saharan dust can be consulted in Karanasiou *et al.* (2012).

Mineral dust also has a relevant role in the climate system. Mineral particles have a slight net cooling effect, although with a high level of uncertainty. Its direct radiative forcing varies between -0.3 and $+0.1 \text{ W m}^{-2}$ at a global scale (IPCC, 2013). Nevertheless, the effects can be much greater at a local scale, especially close to source regions (García *et al.*, 2011).

Certain meteorological patterns at a synoptic scale are responsible for dust transport from the Saharan region towards higher latitudes. Thus, mineral dust can reach European

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countries located in the Mediterranean Basin or, although less frequently, more northern regions. These scenarios have been described in some previous studies performed in the Mediterranean area (Escudero *et al.*, 2005; Meloni *et al.*, 2008; Nastos, 2012; Valenzuela *et al.*, 2012; Salvador *et al.*, 2014). The characterization of these advections is relevant for further prediction, as well as for the implementation of preventive measures to minimize the health impacts. The frequency of days with Saharan influence in a certain location depends on the specific meteorological scenarios and the distance to dust sources (Díaz *et al.*, 2017). This frequency (on an annual basis) oscillates between 17% and 37% along the Mediterranean Basin (Pey *et al.*, 2013), and its percentage contribution to PM_{10} levels decreases with latitude. Specifically, for the Iberian Peninsula, the contribution of Saharan dust to PM_{10} concentrations varies between percentages higher than 20% in the southeast to values lower than 10% in the north (Querol *et al.*, 2019a). African desert dust episodes also show some seasonality, so its contribution to PM levels can vary throughout the year. In the western Mediterranean, African dust inputs are considerably higher between May and October (Pey *et al.*, 2013).

The present study aims to characterize the impact of SDE on PM_{10} background levels in eastern Spain. Besides quantifying the contribution of these events to PM_{10} mass concentrations, the scenarios that trigger the transport of mineral dust to the studied region will be discussed. Finally, the distribution of the Saharan inputs obtained for each meteorological scenario will be simulated by using a probability function. By doing so, threshold concentrations can be predicted as a function of the meteorological pattern.

MATERIAL AND METHODS

Monitoring Site

PM_{10} data used in this study were obtained from the air quality monitoring station Caudete de las Fuentes (1°16'43"W,

39°33'30"N, 794 m a.s.l.), belonging to the Environmental Surveillance Network of the regional Government of Valencia. The site is located inland, ~83 km from the Mediterranean coast, in the Valencian Community (VC), in eastern Spain (Fig. 1). This location is highly sensitive to SDE due to its proximity to the African continent, its height above sea level and its distance from anthropogenic sources (the station can be classified as *regional background*).

The study area is characterized by a typical Mediterranean climate, classified as *Csa* in the Köppen climate classification, with mild winters and moderately hot and dry summers. Global mean temperatures range from 13.9°C in winter to 25.5°C in summer, with low annual precipitations around 450 mm, concentrated primarily in spring and autumn.

PM_{10} data from the period 2014–2017 were analyzed in order to study its seasonal variation and the contribution of SDE to PM_{10} mass concentrations. For this, the year was divided into four seasons: winter (January–March), spring (April–June), summer (July–September) and autumn (October–December).

SDE: Identification and Quantification of its Contribution to PM_{10} Levels

The identification of SDE was based on the results of predictive models (SKIRON dust simulations [<http://forecast.uoa.gr/dustindx.php>], NRL NAAPS model [<http://www.nrlmry.navy.mil/aerosol>] and BSC-DREAM8b [<http://www.bsc.es/ess/bsc-dust-daily-forecast>]). The use of back-trajectory analysis by means of the HYSPLIT model (Draxler and Rolph, 2013) along with the analysis of PM_{10} time series helped to confirm the presence of SDE over the study area.

The procedure used to obtain the contribution of these events to PM_{10} mass concentrations in this work is the so-called “40th percentile method” (http://ec.europa.eu/environment/air/quality/legislationpdf/sec_2011_0208.pdf). This is the reference method for the determination of the contribution

Fig. 1. Geographical location of the Valencian Community (VC) in the south eastern coast of the Iberian Peninsula and location of the monitoring site.

of SDE (% dust) to PM levels in Spain and Portugal since 2014, and it is applicable to southern European regions (Querol *et al.*, 2009). The methodology is based on statistical data treatment of time series of PM concentrations recorded at regional background stations (RBS). The basis of this method can be found in Escudero *et al.* (2007) and Pey *et al.* (2008) and will be applied in this work under the name of *P40*. The feasibility of this procedure has been demonstrated in several previous studies (Querol *et al.*, 2009; Aleksandropoulou and Lazaridis, 2013; Ealo *et al.*, 2016; Fernández *et al.*, 2017; Nicolás *et al.*, 2018; Conte *et al.*, 2020). Recently, certain aspects of this methodology have been revised, mainly those associated with the estimation of the Saharan dust contribution to PM concentrations at urban sites (Barnaba *et al.*, 2017). On the other hand, the application of this methodology may lead to an overestimation of the crustal contribution to PM levels when the contribution from other background sources is high, as can be the case of Lampedusa, an island located in the central Mediterranean Sea very close to the Tunisian coast (Marconi *et al.*, 2014).

Cluster Analysis of Meteorological Patterns

Cluster analysis (CA) is a multivariate statistical technique that aims to classify elements (or variables) into different groups or clusters. This analysis seeks to maximize the homogeneity of elements within the clusters and also to maximize the heterogeneity among the clusters. The solution of the CA is not necessarily unique as it depends on the procedure used to group the elements. The reason is that different algorithms for grouping objects are available. In this study, the non-hierarchical k-means algorithm was chosen to classify atmospheric circulation patterns. It divides the data into k clusters at random and calculates the centroid of each cluster, assigning each element to the closest cluster. Then, new centroids are computed and elements are reassigned to the closest new cluster. This process is repeated until no more reassignment can be made. The number of clusters is to be specified by the user prior to clustering.

This method has been used in similar previous studies with good results (Alonso-Pérez *et al.*, 2011; Salvador *et al.*, 2013, 2014). CA was applied on geopotential height daily fields at the 850 hPa level for days under Saharan influence (362 days) during the 2014–2017 period. These data were obtained from the website <https://www.esrl.noaa.gov/psd/data/composites/hour/> (Kalnay *et al.*, 1996) of the National Centers for Environmental Prediction (NCEP). The domain of study extended from 15°N to 55°N latitude and from 25°E to 15°W longitude. The grid included a total of 289 points since each geopotential height covered an area of $2.5^\circ \times 2.5^\circ$ (spatial resolution). As a result, an initial matrix with 362 rows $\times$ 289 columns was formed.

The software used for the analysis was SPSS v.24. Each “dust day” was assigned to a cluster. Then, we calculated composite maps by averaging geopotential heights at 850 hPa from the data of all days assigned to a particular cluster. The maps for each cluster were obtained using the Surfer software package (v.8.01). In this study, a total of 362 geopotential pressure maps have been grouped into 5 meteorological patterns that will be described in the “Results” section.

Gamma Distribution

The gamma probability distribution was selected to examine the frequency of the Saharan dust contribution to PM₁₀ mass concentrations. This analysis was conducted for each cluster. The Kolmogorov-Smirnov test was used to evaluate the goodness of fit of the probability density function (PDF) to the data.

The gamma distribution is described as follows:

$$f(x) = \frac{1}{\beta^\alpha \cdot \Gamma(\alpha)} x^{\alpha-1} \cdot e^{-x/\beta}; x > 0 \quad (1)$$

where $\Gamma(\alpha)$ is the gamma function, calculated as:

$$\Gamma(\alpha) = \int_0^\infty x^{\alpha-1} \cdot e^{-x} dx \quad (2)$$

The coefficients α and β in the previous equation are the shape and scale parameters, respectively. Values of the α parameter are always greater than zero. Shape and scale parameters determine the maximum intensity and the right skewness of the distribution, respectively. To obtain both parameters, the method of moments was used.

In general, the gamma distribution can be useful to analyze pollution data. Besides, the distribution can provide the probability of exceedances of a certain limit value. With these objectives, several studies have successfully used this distribution (Hrdličková *et al.*, 2008; Ozel and Cakmakyapan, 2015).

RESULTS

PM₁₀: Concentrations and Seasonality

Fig. 2 shows seasonal PM₁₀ concentrations at the monitoring site during the study period. As can be observed, the highest

Fig. 2. Average seasonal concentration of PM₁₀ for the 2014–2017 period. Yellow diamonds represent mean values and red rectangles represent median values. The whiskers correspond to the P25 and P75 quartiles. Maximum and minimum concentrations are represented by dashes (-). Circles denote outliers.

mean PM_{10} value was reached in summer ($19.1 \mu\text{g m}^{-3}$) and the lowest ($11.0 \mu\text{g m}^{-3}$) in winter. The average PM_{10} concentration for the whole study period was $14.2 \mu\text{g m}^{-3}$. The seasonal variation and the average value of PM_{10} are typical of RBS in Spain (Querol *et al.*, 2008, 2009), and in general in the western Mediterranean (Pey *et al.*, 2013). On the other hand, all the outliers shown in Fig. 2 occurred on dust days. The average PM_{10} concentration recorded on days not affected by SDE throughout the study period was $11.5 \mu\text{g m}^{-3}$. This value increased to $22.2 \mu\text{g m}^{-3}$ when only dust days were considered. SDE are responsible for most of the exceedances of the European daily limit value for PM_{10} ($50 \mu\text{g m}^{-3}$) at RBS in Spain (Escudero *et al.*, 2007; Querol *et al.*, 2008, 2009). In this study, the limit value was exceeded on 12 days.

The higher summer PM_{10} levels are associated with: (a) higher resuspension rates, (b) increased production of secondary aerosols by photochemical reactions, (c) higher frequency of SDE, and (d) lower rainfall rates.

Characterization of SDE

Table 1 depicts a summary of the number of days under the influence of SDE (N_{SDE}) according to the season for the four years of the study. Seasonal and annual percentage contributions are presented in brackets.

On average, there were 94 dust days per year. This implies that ~26% of the days of the year were under the influence of SDE. This percentage is consistent with those obtained by Galindo *et al.* (2017) and Castañer *et al.* (2017) at a high mountain station (> 1500 m a.s.l.) located approximately 200 km southeast. This result indicates that the altitude of the sampling point is enough to be considered sensitive to most of the SDE passing over the VC. For the study area, it has been reported that mountain stations are more affected by SDE than sites located at lower altitudes, due to the altitude of the Saharan dust transport (Nicolás *et al.*, 2014). Nevertheless, this result should be taken with caution. In the analysis of the spatiotemporal evolution of a severe winter dust event in Spain, Titos *et al.* (2017) showed that the maximum daily PM_{10} concentration does not always increase with altitude.

The high percentage of dust days at the monitoring site is also an indicator of the importance of Saharan mineral dust in the VC. As shown in Table 1, the number of dust days can vary considerably over the years. For instance, during 2017 N_{SDE} was 32.5% higher than in 2014. On average, summer was the season with the highest percentage of dust days, while in winter the percentage fell to below 15%. This result is in agreement with monthly frequencies obtained at other sites located in southern Spain (Valenzuela *et al.*, 2012).

During the study period a total of 93 SDE were identified, with a mean value of ~23 episodes per year. Fig. 3 shows the number of Saharan events recorded throughout the study period according to their duration. The length of the episodes was divided into seven intervals. The figure also shows the relative frequency for each interval according to season.

As can be seen in Fig. 3, the frequency of episodes decreased as its length increased. The reduction in the number of events as a function of the length in days fitted well to a quadratic function ($R^2 = 0.92$). Long-lasting episodes (length > 13 days) occurred more frequently during summer. During winter shorter episodes were recorded, while in autumn and spring the duration of these events ranged from 1 to 15 days. Therefore, there was a seasonal effect on the length of Saharan dust events. The average duration of these episodes was lowest during winter (2.1 days episode⁻¹), followed by autumn (3.6 days episode⁻¹), spring (4.1 days episode⁻¹) and summer (6.7 days episode⁻¹). The longest episode lasted 20 days and was recorded in July 2015. The average duration of SDE throughout the study period was about 4 days. The mean episode duration and the average number of episodes per year were slightly greater than those obtained in Central Spain during the 2001–2008 period (Salvador *et al.*, 2013) or south-eastern Italy over a six year period (2013–2018) (Conte *et al.*, 2020). They were also higher than those previously reported for the same study area over the period 1996–2002 (Escudero *et al.*, 2005).

Fig. 3. Number of Saharan events identified throughout the study period according to their length (black line). The figure also shows the relative frequency of Saharan episodes for each season.

Table 1. Number of dust days (N_{SDE}) by season and year throughout the study period. Seasonal and annual percentage contributions are presented in brackets.

	2014	2015	2016	2017	Mean
Winter	12 (15.2%)	8 (8.7%)	9 (10.2%)	23 (19.7%)	~13 (14.3%)
Spring	27 (34.2%)	22 (23.9%)	13 (14.8%)	41 (35.0%)	~26 (28.6%)
Summer	14 (17.7%)	43 (46.7%)	50 (56.8%)	47 (40.2%)	~39 (42.8%)
Autumn	26 (32.9%)	19 (20.6%)	16 (18.2%)	6 (5.1%)	~17 (18.6%)
Annual	79 (21.6%)	92 (25.2%)	88 (24.1%)	117 (32.1%)	94 (25.8%)

SDE: Mass Contribution to PM₁₀ Concentrations

Table 2 shows the seasonal contribution of Saharan outbreaks to PM₁₀ levels calculated using the P40 method. The percentage contribution of Saharan dust to the seasonal average PM₁₀ values is shown in brackets.

The annual contribution of SDE to PM₁₀ concentrations ranged from 2.8 µg m⁻³ in 2017 to 4.0 µg m⁻³ in 2016. The average percentage contribution of Saharan dust to annual PM₁₀ values ranged from 19.4% to 27.4%. Seasonal contributions varied between 6.2% (summer 2014) and 40.2% (winter 2016). For the whole study period, the average percentage contribution was lower than 30% for all seasons. The highest mass contributions were usually registered during summer months, which is in agreement with the geographic location of the sampling station (Pey *et al.*, 2013).

The annual average contribution of Saharan dust to PM₁₀ levels was 3.3 µg m⁻³ (23.2%), a value slightly higher than that obtained for the same geographical area in a study conducted between 2001 and 2016 (Querol *et al.*, 2019a). Nevertheless, based on the latitude of the sampling point, the average mass contribution was similar to that calculated with the equation described in Pey *et al.* (2013) ($y = 1.8^{13} \cdot x^{-8}$, where x is the latitude and y is the average African dust in PM₁₀).

Similar mass contributions do not necessarily lead to similar percentage contributions, as shown in Table 2. For instance, average percentage contributions during spring and summer were quite similar (~22%), but the mass concentration of mineral dust in summer was substantially higher than that registered in spring.

On 16 out of the 376 identified dust days, the mineral dust contribution to the PM₁₀ concentration was above 35 µg m⁻³, with a daily maximum value of 81 µg m⁻³. These values were higher than those obtained in central Mediterranean areas, like central Italy, where during the most intense episodes the calculated dust concentration reached values as high as 25–30 µg m⁻³ (Nava *et al.*, 2012). However, the values obtained in this study were lower than those registered in the eastern Mediterranean Basin (Querol *et al.*, 2009).

Atmospheric Circulation Types that Trigger SDE in the Valencian Community

The characterization of the different atmospheric patterns that trigger SDE in the VC has been carried out by means of cluster analysis. After carrying out a preliminary study about the optimum number of clusters (C_i), five groups were chosen. Fig. 4 shows the different meteorological scenarios (850 hPa geopotential height) related to each cluster. This figure also graphically depicts the circulation that triggers the arrival of Saharan dust to the VC. Overall, three baric

systems, whose occurrence and mobility determined the patterns shown in Fig. 4, were identified. These systems were: a longitudinal baric gradient produced by a strong Icelandic low, low-pressure systems located west or northeast of Portugal, and a high-pressure system located over North Africa that can be longitudinally displaced from Morocco to Libya.

The percentage of days belonging to each cluster divided by season can be observed in Table 3. The amount of days belonging to Clusters C₁, C₂ and C₅ was similar (16–19%). C₃ was the cluster with the highest number of days (39%), whereas only 7.2% of the days were in C₄. As can be seen, the percentage of days belonging to each cluster depended on the season. Clusters C₂ and C₄ were more frequent in spring, while C₃ prevailed in summer. Clusters C₁ and C₅ were more evenly distributed throughout the year.

Fig. 4(a) shows the meteorological scenario corresponding to C₁. This circulation was characterized by a high-pressure system (H) located over northeastern Algeria, Tunisia and western Libya coupled with a trough that emanates from the Icelandic low. This meteorological scenario occurred mainly during summer, but it was also quite frequent during winter and spring (Table 3). The main loading area was located in the north of Morocco (according to the isobar pathway that passes over the monitoring point). Fig. 4(b) shows that a deep low-pressure (L) system over the west of Portugal was mainly responsible for the transport of mineral dust. This pattern predominated in spring (more than 57% of the time) and hardly ever occurred in summer. Northwestern Morocco was the main loading area in this scenario. The pattern corresponding to C₃ was similar to the circulation type in Scenario 1, but a displacement of the high-pressure system to the northwest over Algeria and, to a lesser extent, Tunisia was observed (Fig. 4(c)). This scenario was the most frequent (39.2%) and occurred mainly during summer months (69%). In this cluster, the main source region was Algeria and the northeastern part of Morocco. The circulation type in Scenario 4 (Fig. 4(d)) was similar to C₂, although a displacement of the low-pressure system to the North Atlantic was evident. This circulation type occurred mainly in spring, and also during autumn and winter, but never occurred in summer. Cluster 4 was the least frequent circulation type and the main source region was located over the north of Morocco. The pattern belonging to C₅ (Fig. 4(e)) was characterized by a high-pressure system centered over Algeria and the southern Mediterranean. The potential source area was mainly located over Algeria, eastern Morocco and northwestern Libya.

It should be noted that the scenarios C₃ and C₅ were very similar to the meteorological patterns obtained at 850 hPa in other studies (for instance, Scenario 4 obtained in Escudero

Table 2. Contribution (µg m⁻³) of SDE to mean seasonal PM₁₀ concentrations.

	2014	2015	2016	2017	Mean
Winter	2.1 (24.7%)	1.3 (10.8%)	4.5 (40.2%)	3.6 (29.8%)	2.9 (26.4%)
Spring	2.6 (21.7%)	4.0 (23.4%)	1.7 (17.5%)	3.0 (23.4%)	2.8 (21.7%)
Summer	1.2 (6.2%)	5.6 (27.1%)	6.6 (28.6%)	3.4 (26.2%)	4.2 (22.0%)
Autumn	6.5 (37.1%)	1.9 (11.9%)	3.2 (21.2%)	1.3 (15.7%)	3.2 (22.5%)
Annual	3.1 (21.7%)	3.2 (19.4%)	4.0 (27.4%)	2.8 (24.6%)	3.3 (23.2%)

Fig. 4. Meteorological scenarios (850 hPa geopotential height) related to the clusters defined.

Table 3. Percentage of days with Saharan influence belonging to each cluster divided by season for the study period.

	% Winter	% Spring	% Summer	% Autumn	% Global
C ₁	23.8	28.6	38.1	9.5	17.4
C ₂	21.3	57.4	1.6	19.7	16.8
C ₃	2.8	19.7	69.0	8.5	39.2
C ₄	28.0	48.0	0.0	24.0	7.2
C ₅	10.0	22.9	35.7	31.4	19.4

et al., 2005, and Salvador *et al.*, 2014). In these works, Scenario 4 was also more frequent in summer and was responsible for the greatest mass contributions to PM₁₀ levels in eastern Spain. On the other hand, the source regions identified in this work are in agreement with those obtained by means of the potential source contribution function (PSCF) in Elche (southern VC; Nicolás *et al.*, 2011). The same geographic area (Morocco and western Algeria) was identified by Mandija *et al.* (2017) as the main source area in Barcelona (northeastern Spain) and Granada (southern Spain).

Frequency Distribution of Saharan Dust Concentrations

Fig. 5(a) shows the gamma probability density functions of the different Saharan mass contributions obtained for each cluster. A generic characterization of these contributions can be done according to the values of the shape and scale parameters (shown in the figure). Specifically, for each cluster the Kolmogorov-Smirnov test was performed to determine the goodness of fit of the gamma distribution to the Saharan inputs. The null hypothesis (H_0 = the data fits a gamma distribution) was not rejected at the 95% confidence level.

Some features can be observed from Fig. 5(a). Firstly, Clusters C₁, C₃ and C₅ showed the lowest values of the α parameter and the highest for β . It can be deduced from these values that the mass contribution of mineral dust for these clusters was most likely to be higher than for the other clusters. Besides, the shape of the probability distributions for C₁, C₃ and C₅ differed from a Gaussian distribution more

than the shapes for Clusters C₂ and C₄. Taking into account the meteorological patterns described in the previous section, it can be stated that those patterns dominated by low-pressure systems located west (C₂) and northwest (C₄) of the Iberian Peninsula were associated with the lowest mass contributions of African dust to PM₁₀ concentrations.

Fig. 5(b) shows the probability that the mass contribution of SDE was higher than a certain value X . Calculations were performed using the PDF. Mass contributions were divided into four intervals from $> 5 \mu\text{g m}^{-3}$ to $> 35 \mu\text{g m}^{-3}$. As can be observed, C₂ had the highest probability of exceeding small dust contributions ($5\text{--}10 \mu\text{g m}^{-3}$), whereas C₄ had the lowest probability for any given concentration. For C₃, C₅ and mainly C₁, the probability of exceeding a mass contribution of $35 \mu\text{g m}^{-3}$ was twice and three times higher, respectively, than those for C₂ and C₄. From these results and those shown in Table 3, it can be stated that the greatest contribution of Saharan dust to PM₁₀ levels in the study area was reached in summer. During spring (the season with the highest frequency of C₂ and C₄) the contribution of Saharan dust episodes was lower. This result is consistent with those presented in Table 2.

CONCLUSIONS

The percentage of days on which the Valencian Community (VC) is influenced by Saharan dust varies significantly by year but averaged $\sim 26\%$ annually over the study period. The highest frequency (43%) and the longest duration of dust episodes (~ 6.7 days episode⁻¹), as well as

Fig. 5. (a) Gamma probability density function of dust concentrations (in $\mu\text{g m}^{-3}$) for each synoptic pattern. The scale parameter is expressed in $\mu\text{g m}^{-3}$ and the shape parameter is dimensionless. (b) Probability of exceeding a certain threshold value X (in $\mu\text{g m}^{-3}$) using the Gamma PDF.

the largest contributions from SDE to PM₁₀ concentrations, occurred during summer. The average contribution of African dust for the whole period was 3.3 µg m⁻³ (23.2% of the average PM₁₀ concentration), which is consistent with our sampling point's geographic location in the Mediterranean Basin.

Specific pressure patterns on the synoptic scale induced the transport of air masses loaded with mineral dust to the study area. We identified five different meteorological scenarios based on the following baric systems: a trough emanating from an Icelandic low, the longitudinal displacement of a high-pressure system over North Africa and an Atlantic low over the western Iberian Peninsula. These scenarios exhibited certain seasonal variations. Scenarios 2 and 4, both characterized by an Atlantic low, typically arose during spring and, to a lesser extent, during the winter season. Scenario 1, produced by a North African high-pressure system combined with a longitudinal baric gradient, occurred mainly during summer, but it was also quite frequent during winter and spring. Scenarios 3 and 5, were characterized by a high-pressure system over the north of Africa and appeared more often during the hot season, although the seasonality of Scenario 5 was less pronounced. The contribution of SDE to PM₁₀ concentrations differed depending on the pressure system.

We conclude that the gamma distribution function is suitable for fitting the concentrations of Saharan dust to the PM₁₀ levels. Our PDF analysis of each meteorological scenario revealed a lower probability of high Saharan dust concentrations for Scenarios 2 and 4. The contribution of Saharan dust to PM₁₀ levels was largest when a North African high-pressure system was present.

ACKNOWLEDGEMENTS

This work was supported by the Spanish Ministry of Science, Innovation and Universities (COSMOS Project, ref. RTI2018-098639-B-I00). The authors would like to thank the Environmental Surveillance Network of the regional Government of Valencia for supplying the time series of PM₁₀ used in this study, and the ACTRIS-Spain network (CGL2017-90884-REDT). The authors gratefully acknowledge the NOAA Air Resources Laboratory (ARL) for the provision of the HYSPLIT transport and dispersion model and the READY website (<http://www.ready.noaa.gov>) used in this publication. The authors also thank the NOAA/OAR/ESRL PSL, Boulder, Colorado, USA, for providing the meteorological dataset files used for the composition of the synoptic patterns. We acknowledge the Atmospheric Modelling & Weather Forecasting Group at the University of Athens, the Earth Science Department from the Barcelona Supercomputing Centre, the Naval Research Laboratory and the SeaWiFS project (NASA) for the provision of SKIRON, BSC/DREAM8b, NAAPs aerosol maps and the satellite imagery, respectively.

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Received for review, February 14, 2020

Revised, April 26, 2020

Accepted, June 22, 2020