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Atmospheric Chemistry and Physics Discussions

Interactive comment on "African dust outbreaks over the western Mediterranean basin: 11 year characterization of atmospheric circulation patterns and dust source areas" *by* P. Salvador et al.

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Reply to Anonymous Referee #1:

We wished to thank Referee #1 for the very valuable comments and suggestions on the first version of our manuscript. They will help us to write a new version with higher quality. In brief we agree with Referee #1 that the description of the methodology was too long. We will reduce this section as much as possible in the new version of the manuscript. Results section will be rewritten with the aim to include more detailed in-

formation, especially in relation with the source identification section. The Abstract and the Conclusions section will be also rewritten, avoiding the abusive use of acronyms and emphasizing in the key findings.

Reply to general comments:

1. First of all we would like to clarify some statements expressed by Referee #1 in the first paragraph. a) The analysis was not performed using time series of PM10 data. We used time series of estimations of African dust contribution to daily PM10 levels. The difference between both parameters must be highlighted because the use of dust contributions assures that the intensity of the African dust outbreak is being considered. Weak African dust outbreaks can contribute with a low dust load to the daily PM10 bulk levels at a specific site but it does not assure that the daily PM10 levels would be low. b) It must be noted that we considered more accurate to define the western Mediterranean basin as the area of study, than the Iberian Peninsula or simply Spain. In spite of the fact that data from Portuguese air quality monitoring stations were not included for the reason exposed in page 5501, lines 8-10, most of the regions of the Iberian Peninsula have been analyzed. As we also included data from stations within the Balearic Islands we extended the study area further along the Iberian Peninsula. Besides, the Canary Islands were not included in this study for some reasons that will be discussed later. Consequently it would not be strictly correct to talk about the influence of the African dust outbreaks over Spain. c) Finally, although perhaps the reviewer had interpreted, we cannot say that "the impact index was higher in spring". This index was not computed on a seasonal basis.

2. Referee #1 declared that our results were not original and suggested building up a story from our previous work. In spite of the fact that the characterization of synoptic meteorological situations leading to African dust outbreaks were addressed in previous works for some authors of this work, among others, it should be stressed that they were produced over specific areas of the Iberian Peninsula with different methodologies, during different time periods. As it was noted in page 5508 lines 14-16 and page 5509 lines

4-5, two main circulation types were obtained in these works. Namely, the mode 4 (or CT-4) that was identified in our paper, which is the responsible of causing the most frequent and intense African dust outbreaks and other mode which incorporates features of the modes 1 and 2 that we identified in our paper. Our aim was to complement and improve these studies, by analyzing all the events produced over the whole area of study during a longer time period and then classify the main circulation types which are responsible of them by applying a systematic and objective methodology. Then, the impact of each circulation type over each specific area would be estimated. In page 110 of the Alonso-Perez et al. (2011a) paper the same inference was used to justify its characterization of meteorological scenarios, favoring high African dust concentrations in the subtropical eastern north Atlantic region. One of the main results of this work is the demonstration that the circulation types identified produced different degrees of impact, in terms of frequency of occurrence of events and African dust contribution to PM10 levels, over the different regions analyzed. For this reason this study must be considered as necessary and original.

3. In relation with the manuscript of Alonso-Perez et al. (2011a) it was not considered because it was exclusively dedicated to the African dust outbreaks influencing the Canary Islands. The phenomenology of these events is different in this case in comparison with the western Mediterranean basin, with clear differences in their seasonal trends and the associated meteorological patterns (Viana et al., 2002; Alonso-Perez et al., 2011a). You suggested that "It would be valuable to know if the present results differ from Alonso-Perez et al., (2001, Meteorol. Atmos. Phys., 113, 109-124)". As expected, the circulation types obtained in our work strongly differed from those determined by these authors, specially the so-called "return African mass episodes" which are produced in winter-spring months over the subtropical eastern north Atlantic region. However, we agree with the reviewer that similar methodologies and some common objectives exist between both papers, so that we thank the reviewer to notice this and provide the opportunity to improve our work with additional comments based on the comparison of both works that will be included in the revised version of the

paper.

4. For our study, the selection of the classification method (K-means) was based in four main criteria: 1) cluster separability ability, 2) ability to reproduce known circulation patterns, 3) computational needs, and 4) physical explainability of the results. When we talk about "physical explainability" we are referring to circulation patterns that were detected during all the years of the period of study, with a common seasonal trend and with influence over the same geographical areas. Gong and Richman (1995) and Huth (1996) demonstrated that there is not a classification method which could be considered as the best in all aspects among other tested. Methodological deficiencies can be found in any classification method and some subjective decisions must be taken when any of them are applied (Huth et al., 2008). Principal Components Analysis (PCs) has been widely used for circulation patterns classification although, as all computer-assisted classification method, they have some weaknesses. First of all, as explained in Huth et al. (2008), PCs in S-mode (grid points being in columns and cases in rows) are widely used for atmospheric pattern classification. However, S-mode actually detects modes of variability, which are the elements that through a linear combination, form circulation patterns. So, it is a common error to identify circulation patterns as the first solutions of the S-mode PCs. The correct procedure is to use PCs in T-mode (grid point values in rows and cases in columns), but this method also has a major drawback: the physical explainability of the resulting solutions can be troublesome, and usually a rotation of the principal components is necessary to deal with this issue. Rotations add extra computational time and power needs. In addition, rotated PC solutions have overlapping solutions, i.e., the variables do not necessarily belong to any component, or some variables could belong to more than one component (Gong and Richman, 1995). Moreover, PCs may have two phases, positive and negative (this is more common in the case of using anomalies data; Huth, 1996), and only one of them should be taken to interpret results. As it can be seen in Table 2 of Huth et al. (2008) and in Huth (1996), K-means provides very good separability (poor in the case of PCs), good temporal and spatial stability (not worse than for PCs), and

a moderate ability to reproduce known underlying structure of data, so we chose to use this nonhierarchical algorithm with our data. After comparing several classification methods (including K-means and Principal Components), Huth (1996) stated that "if the preferred property is the separation (among clusters as well as between clusters and the whole data set), the K-means method is best." For these reasons we preferred to use the K-means methodology which is less complex in the mathematical discrimination of different patterns than other methods, but allowed us obtaining a reasonably number of patterns which could be physically interpreted. Alonso-Perez et al. (2011a) used the same reasoning when they decided not to apply rotations to the PCA solutions because unrotated solutions resulted in patterns with an easy physical explainability. Finally we would like to emphasize that from the Alonso-Perez et al. (2011a) work it could not be interpreted that the K-means method provides erroneous results in comparison with Principal Components Analysis, as Reviewer#1 alleged. In page 112 of this paper it is clearly declared that "Among all possible methods, K-means is the most suitable partitional clustering technique for dealing with a great number of patterns in a high dimensional space, which is a habitual case in climatology". Alonso-Perez et al. (2011a) also stated that K-means and PCs resulted to be complementary methods, so the use of both methods was useful Moreover, these authors confirmed in page 113 that "In most cases, the two leading PCs patterns are very similar to the two leading patterns obtained with K-means method". Giving the successful use of both methods, there was no clear reason presented in this study to choose one over the other. With the aim to validate our results we have carried out a Principal Component Analysis in T-mode with the same 850 hPa geopotential height data base used in our paper. 4 PCs were retained to be compared to the 4 clusters obtained with the K-means procedure. Different rotations (Oblimin as in Huth, (1996) but also Varimax) were checked and the 4 final composite maps were calculated by averaging 850 hPa geopotential height using the fields corresponding to the days assigned to each PC. Figure 1 in this document shows the 4 circulation patterns obtained from PCA (Oblimin rotation) and K-means. Varimax and Oblimin rotations resulted in the same structures. It is evident

that the main features characterizing the 4 circulation types that were obtained in our work can be found in the 4 circulation types obtained from PCA. PC1, PC2, PC3 and PC4 circulation patterns resembled quite well cluster 2, 4, 3 and 1 circulation patterns, respectively. Moreover, the 4 circulation patterns obtained with PCs have almost the same physical explainability than those obtained with k-means in our study, in terms of the frequency of episodic days attributed to each pattern and the season with a higher frequency of occurrence (Table I in Supplement). It can be concluded that both methodologies produced the same qualitative results.

5. Regarding your comment about the discussion of the effects of NAO on dust inter-annual variability in Alonso-Perez et al. (2011a), it was concluded that the findings of other authors regarding this relationship were in agreement with the finding of a high-pressure system over Southern Europe and North Africa in their three first clusters in January and July. A study on the correlation of NAO and dust inter-annual variability in the Subtropical Eastern North Atlantic Region was done subsequently by Alonso-Perez et al. (2011b) but, unlike our current study, no links with synoptic patterns were done. It must be said that we included a discussion in pages 5510-5511 on the relationship between the occurrence of African dust episodic days for the difference circulation types and the values of the NAO index. This relationship was especially outstanding for circulation types 2 and 3.

6. In relation with this discussion we completely disaccord with your statement that, "circulation patterns of mode 2 and 3 in Figure 2 appeared very similar". A visual inspection of Figure 2 may lead to wrong conclusions. For instance, mode 2 and mode 3 were characterized by the North-African high located over western Lybia. However the trough placed over the western Iberian Peninsula in mode 2 was not detected in mode 3. In spite of the fact that both modes were more frequently produced in spring, there are many outstanding differences between them that have been showed in the manuscript (Figures 4 and 5) Figure 4 revealed an opposite behavior of the annual occurrence of both modes in relation with the annual NAO index. Figure 5 illustrated

these differences. In spring 2011, a period characterized by the advection of Atlantic air masses at latitudes higher than 45°N (higher than normal NAO index values) the occurrence of African dust episodic days was dominated by mode 2. In these days African air masses moved northward towards the Iberian Peninsula helped by the Atlantic low pressure system and the North-African high. In spring 2005, a period during which the advection of Atlantic air masses was produced at lower latitudes than usual (lower than normal NAO index values), African air masses moved northeastward towards the eastern side of the Iberian Peninsula and the Balearic Islands mostly during episodic days dominated by mode 3. As a consequence, different regions of the western Mediterranean basin were influenced by the African dust under both modes (Figure 8).

7. It is also suggested by the reviewer to remark similarities and/or differences between the results of this study and those obtained by Pey et al. (2013). In page 5499, lines 22-25 we clearly expressed that they used part of our data set, among others, to characterize the African dust outbreaks over the western, central and eastern Mediterranean basin, with different purposes than ours. Consequently it was not easy to find similarities and/or differences between both studies. An additional effort will be done to find links between our results and the comments on the atmospheric patterns which governed the 2001-2011 summer periods showed in the Pey et al. (2013) work.

Reply to more detailed comments:

Abstract:

We agree with Referee #1 that the description of the methodology in the abstract could be shortened. The Abstract will be rewritten emphasizing in the key findings, in the new version of the manuscript.

1. In relation with the statement that we were "unable to identify sources of dust beyond the entire northern Africa", it should be noted that Prospero et al. (2002) demonstrated that most regions of the African continent at latitudes higher than 10°N were active

sources of dust. Ginoux et al. (2001; 2012) also identified dust source regions all over Northern Africa. This fact is well illustrated in the Figure 7 in page 14 of the Ginoux et al. (2012) paper. Figure 7 in our paper showed that most of the potential sources areas of dust identified in the RCF agreed with maxima in the dust source function S (Ginoux et al., 2001). However, some other outstanding maxima in the geographic distribution of the function S in northern Africa, such as those representing the Bodelé depression, the eastern Lybian Desert or the Qattarah depressions in northern Egypt (Ginoux et al., 2012) were not identified as potential sources of dust. It must be taken into account that the RCF showed in Figure 6, were calculated including all the episodic days identified for each circulation type and all the African dust values estimated at the nine monitoring sites over 11 years. As we showed that the contribution of the sources dust varied with the circulation type (Figure 6) and also with the season (Figure S03) new RCF computed for specific time periods and with values of dust from specific regions of the study area, will help to provide a more detailed identification of source areas of dust and to differentiate between source areas. This information will be included in the Revised version of the manuscript to strengthen the Identification of potential source areas of dust section. Thus, the new findings will be highlighted in the abstract and the conclusions section. Figure 2 in this document serves as an example. It depicts the fact that during the summer period the circulation type 1 transported dust from different source areas. On the one hand the low pressure system located southwest of the Iberian Peninsula coast leads the transport of dust from Western Sahara and southern Morocco towards the western and the central sides of the Iberian Peninsula. On the other hand, the upper-level high over Northern Algeria promotes the transport of dust from Tunisia towards the eastern side of the Iberian Peninsula and the Balearic Islands.

2. In relation with the reviewer's comment "Is there not a physical way to characterize the circulation patterns?" it has been noted before that we included a discussion in pages 5510-5511 on the relationship between the occurrence of African dust episodic days for the difference circulation types and the values of the NAO index.

3. “Last line is confusing???”. It will be corrected to be sure that the abstract will finish with a key finding.

Introduction:

1. Lines 14-19 (we supposed that Referee #1 referred to page 5498, Line 2-7 in the web version of the manuscript published for discussion) will be removed in the Revised version of the manuscript.

2. In this section the interest of dust over the western Mediterranean basin and in particular over Spain will be underlined. Under the light of recent researches acute effects on human health in this study area could be attributed to the African dust (Pérez et al., 2008; Tobías et al., 2011a-b). More recently, Reyes et al. (2014) found a significant increase in respiratory-cause hospital admissions associated with PM10 and PM10-2.5 fractions during African dust outbreaks in Madrid (Spain).

3. “Page 5, Line 11 to 14: reformulate more clearly”. The methodology used to estimate the impact of the African dust contributions on the PM10 daily records (Page 5, Line 11-14 in the preliminary version of the manuscript; Page 5501, Line 13-16 in the web version of the manuscript published for discussion) will be more clearly reformulated in the revised paper. It was basically the same description showed in the Pey et al. (2013) paper (page 1398). More detailed comments of this methodology have been included in the “Response to Anonymous Referee 2”.

Circulation classification methodology:

1. The description of the K-means circulation classifications methodology was basically the same showed by Alonso-Perez et al. (2011a) in page 112. They explained that: “K-means is based on the minimization of the sum of quadratic distances between the data points and the corresponding centroid of each group. In our case, this algorithm is therefore used to globally diminish the intra-group distance, classifying our geopotential height patterns into K groups”. Formula 1 in our paper represents “the sum of quadratic

distances between the data points and the corresponding centroid of each group” and Formula 2 represents the “intra-group distance”. These Formula were obtained from Philipp A. et al. (2007). This section will be also rewritten in the revised version with the aim to clarify all the steps of the selection procedure and to avoid possible mistakes.

2. We use raw data instead of anomalies for one main reason. In Huth (1996) no significant differences between using K-means with raw or anomalies data were found. However, clear differences are found for rotated T-mode PCs using raw data (excellent reproduction of predefined patterns) or anomalies data (creation of artificial types of patterns). As it seems to be irrelevant to use raw data or anomalies data, and our final goal was to establish a classification of circulation types (not circulation anomalies), raw data were used. Across the text we always referred to daily fields because the results of the circulation classifications were showed as composite maps by averaging geopotential height at 850 hPa using the data (fields) corresponding to all days assigned to a particular cluster.

3. Page 7 line8 (page 5503, line 20 in the web version of the manuscript published for discussion): “Cycle 31r2”. It is the version of the ECMWF’s Integrated Forecast System used by the ERA-Interim atmospheric model and reanalysis system to generate fields of atmospheric variables. More information can be consulted in: http://www.ecmwf.int/publications/library/ecpublications/_pdf/era/era_report_series/RS_1_v2 With the aim to clarify the paragraph, it will be rewritten as: “The ERA-Interim atmospheric model and reanalysis system uses the cycle 31r2 version of the ECMWF’s Integrated Forecast System, which was configured for the following spatial resolution:. . .”.

Identification of potential source areas of dust:

1. We are very sorry that the Referee #1 considered this section so excruciating to read and without sense. More work will be done with the aim to clarify the methodology and the results obtained. We agree that the methodology for the computation of

Redistributed Concentration Fields has been published previously and consequently this section could be shortened. However Stohl (1998) showed that there are many trajectory statistical methods such as residence time analysis (Ashbaugh et al. 1985), Concentration Fields method (Seibert et al., 1994) or Redistributed Concentration Field Method (Stohl, 1996) among others, which have been used and compared by many authors. Moreover some of them have modified the original methods by applying different smoothing procedures or filters (Lupu and Maenhaut, 2002; Kaiser et al., 2007; Han et al., 2004) or using them with data sets from more than one receptor site (Zeng and Hopke, 1989; Lupu and Maenhaut, 2002). Our aim was to describe explicitly the methodology used in this specific case. Do not hesitate that we will rewrite this section for the sake of clarity.

Estimation of the Impact Index:

1. "Formula 4 is unclear". ADL was defined in page 5498, as the net African Dust Load transported during African Dust Outbreaks. This parameter is an estimation of the African dust contribution to the daily PM10 concentration levels registered at regional background air quality monitoring sites, during these events. For each sampling site, ADLi is the mean African dust contribution estimated during the Ni episodic days produced by the circulation type i. ADL is the mean African dust contribution estimated during all the episodic days (Nt). Thus, the Impact Index i (IIi) at one sampling site is an estimation of the impact of the circulation type i which give rise to African Dust events, on the mean African dust contribution estimated at this site.

Results and discussion:

1. Page 10, line1 (page 5507, lines 1-2 in the web version of the manuscript published for discussion): "…increased gradient from the N (21% at O Saviñao and Niembro) to the S (65% at Viznar)"???. With the aim of clarifying the paragraph, it will be rewritten as: "The episodic days occurred less frequently at northern locations (21% at O Saviñao and Niembro) than at central (30-50% at Els Torms, Monagrega, Risco llano,

Bellver and Zarra) and southern locations (>50% at Barcarrota and Viznar) of the western Mediterranean basin. At most southern locations it is evident a higher frequency of episodic days due to the higher proximity to the African mainland".

Conclusions:

This section will also be rewritten, avoiding the abusive use of acronyms and emphasizing in the key findings.

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Figure Captions.

Figure 1. Composite 850 hPa geopotential height (m) representing the 4 circulation types, obtained from Cluster Analysis (left) and Principal Components Analysis (right).

Figure 2. Redistributed concentration fields of African dust, during circulation type 1 in summer.

Please also note the supplement to this comment:
http://www.atmos-chem-phys-discuss.net/14/C1874/2014/acpd-14-C1874-2014-supplement.pdf

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Interactive comment on Atmos. Chem. Phys. Discuss., 14, 5495, 2014.

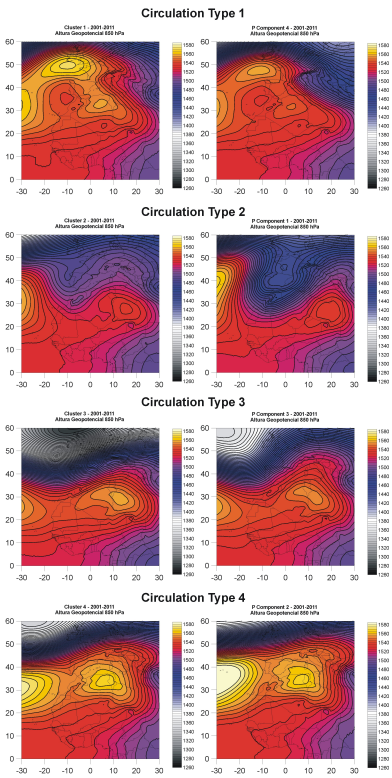

Fig. 1.

Circulation Type 1 - Summer period

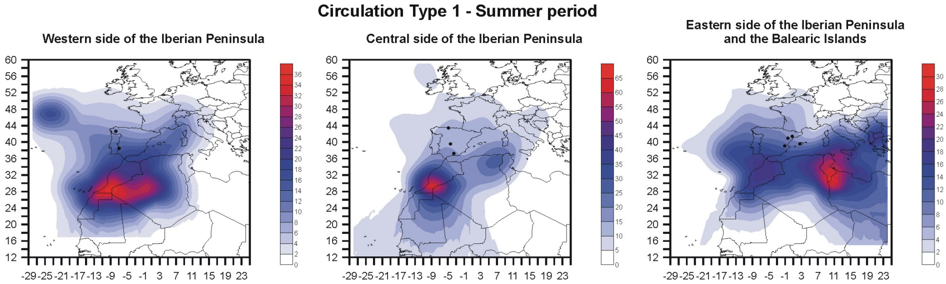

Fig. 2.