Anonymous Referee #3

In this manuscript, "3D evolution of Saharan dust transport towards Europe based on a 9-year EARLINET-optimized CALIPSO dataset", the authors use a combination of CALIPSO and EARLINET to present a climatology of recent dust vertical distribution and transport to Europe from Africa. The consideration of both climatological extinction and 'conditional' extinction is useful to elucidate the episodic transport as well as the dust distribution.

The manuscript is generally well written and the climatology will be useful to the community and to evaluate models. However, there is a lack of discussion of uncertainties in the product and some limited interpretation of the particle depolarization ratio and interannual variability that need revision. Please see the major and minor comments below.

[REPLY] We thank the reviewer for the thorough revision and comments. We agree with the importance of the discussion on the uncertainties in the product, thus we added a new section (Section 2.4) discussing all the uncertainties of the product in the manuscript. We decided to delete the particle depolarization ratio discussion from the paper, so as to help the reader concentrate on the other parts of this work. The section of the interannual variability is substantially revised. Replies to general and specific comments can be found below.

Major Comments

There is limited discussion of the uncertainties and detection limits of dust occurrences throughout the manuscript. There are some very high occurrences of dust shown in regions far from dust sources in Figure 1 (e.g. the North Atlantic). How certain are we that this is actually dust and based on what detection limit? Similarly, Figures 3 and 4 show infrequent but high extinction dust at the surface at high latitudes. Can we besure this is not a retrieval artifact? When climatological extinctions as low as 5 Mm-1 are considered (e.g. pg9 line 22) it would be useful to know the uncertainty on the estimates.

[REPLY] We thank the reviewer for these comments. We added a new section (Section 2.4) discussing the uncertainties of the produced product. In the same section, we mention also the detection limit for dust occurrences and the uncertainty introduced from this choice by stating: "Moreover, we have calculated that the uncertainty of the dust occurrences presented in Sec. 3.1 ("% Dust / Used Overpasses"), might be up to 8% in latitudes away from the sources, induced from the error in the selection of the δ_{nd} value (0.03±0.04)." In a more detail explanation on how this percentage is estimated: the selected detection limit is based on depolarization measurements, and any layer with depolarization values greater than 0.03 is considered as mixture of dust with other aerosols. This detection threshold correspond to the lowest the depolarization values found in nature for clean marine, smoke and anthropogenic aerosols, i.e., 0.03 ± 0.01, 0.06 ± 0.01 and 0.06 ± 0.01, respectively. We estimated the uncertainty that this detection limit may induce in the occurrences of dust far from sources. For cases where the depolarization of the non-dust feature is$0.03 < \delta_{\mathrm{nd}} \leq 0.075$, the low selected δ_{nd} value, may introduce error as high as 100%. In CALIPSO dataset of our domain, these cases correspond to less than 4% of the dust and polluted dust layers used (1% of the dust layers used and 8% of the polluted dust layers used). This uncertainty is transferred to the uncertainty of the dust occurrences presented in Sec. 3.1, inducing a positive bias up to 8% in latitudes away from the sources for the parameter "% Dust / Used Overpasses", as this parameter refers to observations with DOD > 0.

In Figures 3 and 4 (new figures 4 and 5), the uncertainty of the dust extinction values close to the surface and at high latitudes are <54%. At high altitudes and for latitudes up to 45°N, the uncertainty of the values in these figures is <20%. Nevertheless, the standard deviation of the Cilm-DE product, originating from the natural variability of the dust events, may excess to a large extent the uncertainty of the retrieval, reaching values from 100% to 200%.

The following section is added in the manuscript (page 7, line 31):

"2.4 Dust product uncertainties

The sources of uncertainties for the pure-dust product are discussed in this section. CALIOP is able to detect aerosol layers with $AOD > 0.005$ and $\beta > 0.25\ Mm^{-1}\ sr^{-1}$ (Winker et al. 2009). The uncertainty estimation of particulate backscatter, extinction and AOD retrievals reported in the CALIPSO Level 2, Version 3 Data Release, are based on the simplified assumption that all the uncertainties are random, uncorrelated and produced no biases (Young, 2010). More specifically, ignoring multiple scattering, the errors in the layer optical depth calculations typically arise from three main sources: (a) signal-to-noise ratio within a layer, (b) calibration accuracy, and (c) the accuracy of the lidar ratio used for the extinction retrieval. The lidar ratio uncertainty is the dominant contributor to the total uncertainties, and the relative error in the layer optical depth is always at least as large as the relative error in the lidar ratio of the layer, and grows as the solution propagates through the layer (CALIPSO L2-V3, 2010). In our dataset the typical uncertainties in the CALIPSO Level 2 version 3 product are between 30% and 100% for the AOD, between 30% and 160% for the aerosol backscatter and extinction coefficient and >100% for the particle depolarization ratio.

Several studies report that CALIPSO underestimates the columnar AOD due to undetected aerosol in the free atmosphere. For instance, Rogers et al. (2014) report a ~ 0.02 AOD CALIPSO underestimation, when compared to collocated airborne HSRL measurements over the North American and Caribbean regions at night. In their data, the dust layers were primarily non-opaque with extinction less than $1\ km^{-1}$ so there were negligible multiple scattering effects. The aforementioned detection limits and uncertainties of CALIPSO products are propagated to the dust product presented here.

As already described, the EARLINET-optimized CALIPSO dust product is derived using the depolarization-based separation method, coupled with the selection of a uniform climatological LR value. These steps introduce uncertainties in the pure dust product. In particular, the uncertainty in the selection of the representative LR (55 ± 11) is 20% for the study area (e.g. Wandinger et al. 2010; Baars et al. 2016 and references within). This uncertainty in LR is less than half of the uncertainty of the generic LR in CALIPSO version 3 product (40 ± 20 for dust layers and 55 ± 22 for polluted dust layers). As already addressed in several studies (e.g. Wandinger et al. 2010; Schuster et al. 2012; Amiridis et al. 2013), CALIPSO V3 dust extinction coefficient and AOD values are about 30% lower than those obtained from collocated ground-based Raman lidar retrievals due to the low LR used in the CALIPSO aerosol retrievals. Amiridis et al. (2013) applied the EARLINET LR for the pure dust CALIPSO cases above North Africa and Europe, and compared with synchronous and collocated AERONET measurements. The results showed an absolute bias on the AOD of the order of −0.03, improving on the statistically significant biases of the order of −0.10 reported in the literature for the original CALIPSO product. The bias of -0.03 is similar to the low bias of CALIPSO's column AOD due to undetected aerosol layers. In Kim et al. (2017), they found a global mean undetected layer AOD of 0.0031 ± 0.052 by comparing 2 year of CALIPSO (L1-V4) and MODIS AODs.

Regarding the error induced from the application of the dust separation method, this might be due to the selection of the particle depolarization ratio of dust and the other aerosol types (marine, anthropogenic or smoke). Tesche et al. (2009; 2011) and Ansmann et al. (2012) estimated that the uncertainty in dust related backscatter coefficients is 15-20% in well-detected dessert dust layers and 20-30% in less pronounce aerosol layers. Moreover, we have calculated that the uncertainty of the dust occurrences presented in Sec. 3.1 ("% Dust / Used Overpasses"), might be up to 8% in latitudes away from the sources, induced from the error in the selection of the δ_{nd} value (0.03±0.04). Finally, an uncertainty induced in the dust product presented in this work, originates from the CALIPSO subtype selection algorithm. In this version of our product, both dust and polluted dust observations are considered polluted dust, and the pure dust component is separated using the dust separation method. The other aerosol layers, which are characterised as clean marine (CM), smoke (S), polluted continental (PC) or clean continental (CC) are considered to be cases clear of dust and are not tested for a dust component. This introduces negligible error in our analysis and is expected to induce a negative bias in the parameter "% Dust / Used Overpasses" less than 8%, mainly in areas above sea. In general, Clim-DE and Cond-DE products, the uncertainty of the dust extinction values close to the surface and at high latitudes is < 54%. At high altitudes and for latitudes up to 45°N, the uncertainty of the values is < 20%. Nevertheless, the standard deviation of the climatological products, coming from the natural variability of the dust events, may exceed to a large extent the uncertainty of the retrieval, reaching values as high as 100% and 200%.

In the latest release of CALIPSO Level 2 version 4 product (CALIPSO L2-V4, 2016), based on CALIPSO team announcement, the accuracy of the original CALIPSO product is increased and the uncertainty is reduced. This version is based on a revised calibration approach which leads to an increase in the total attenuated backscatter coefficients by ~3% overall as compared to the version 3 values (CALIPSO L1-V4, 2016). Several bugs are fixed and a major overhaul of the aerosol subtyping algorithms along with revisions on the lidar ratio selections is applied."

The retrieval is provided only for clear-sky conditions. Can you comment on how this might bias the dust extinction and how it relates to cloud formation (mentioned on page 10)?

[REPLY] We thank the reviewer for this comment. Indeed the restrictions of the dataset, related to the cloudy meteorological conditions were not addressed in the manuscript, therefore we commented analogously below.

First, let us address the second part of the question, to comment on how it relates to cloud formation (mention on page 10). The impact of dust on cloud formation is part of a second study we are working on. In this work, we use dust profiles from CALIPSO, in combination with EARLINET parameterizations, in order to calculate the dust mass concentration for particles with radius greater than 250 nm and from there, based on known ice nuclei parameterizations to estimate ice nuclei concentration profiles. A detailed analysis of this technique is provided in the work of Mamouri and Ansmann (2016). In order not to confuse the readers, we decided to delete the part where we mention "and the impact on cloud formation" from our manuscript.

Regarding the first part of the reviewer's comment, we added a new Table in the manuscript, in order to provide a more informative representation of the dataset. In this table (Table 3) the percentages of the cloud free observations used, in relation to the total observations are provided, aggregated on 6 areas over the study region. Furthermore we added the following discussion in the manuscript (page 9, line 14):

"Table 2 shows the impact of cloud contamination in our dataset. During AMJ, JAS and OND, more than 80% of the total observations are cloud-free above North Africa. Above Central-East Mediterranean (C-E Med.), more than 80% of the total observations are cloud-free and above Central West Mediterranean (C-W Med.) approximately 60% - 80% of the total observations are cloud-free. With increasing latitude, the cloud-free sampling is reduced to percentages of ~ 40% - 60% in latitudes greater than 45° N. During JFM, cloudy conditions restrict our dataset in the greatest extent. During the same period, the cloud-free cases used represent ~ 80% of the total observations above North Africa, approximately 60 - 70% of the total observations above the Mediterranean and ~ 30% in the domain between 45° N - 60° N. In the areas (and seasons) where clouds do not dominate (e.g. 70% clear-sky conditions), our cloud-free product is considered representative of the dust distribution. In areas where cloudy skies dominate (e.g. 30% clear-sky conditions), the clear-sky CALIPSO profiles cannot be considered as representative of all meteorological conditions, so the results should be used with caution."

In Figure 1 there is a strong boundary along the European coastline for dust occurrences, is this the result of a marked difference in used overpasses between the mainland and the Mediterranean? Please make sure that this feature is explained.

[REPLY] Unfortunately, we cannot see the boundary the reviewer is referring to along the European coastlines. There might be a boundary along the French coastlines, however it looks like that over the Iberian Peninsula, Greece and Italy the number of dust overpasses well penetrate over land.

I don't think simply listing papers that have used specific instruments to explore dust over the Mediterranean is the best way of presenting the introduction (pg3 lines 10-20). Please consider reconstructing this paragraph to briefly discuss what these papers show that is relevant to understanding dust transport to Europe, rather than framing around the instrument used.

[REPLY] We reconstructed this paragraph according to the reviewer's suggestions. The new paragraph is (page 3, line 8):

“Many studies have used satellite observations to derive dust properties over the Mediterranean during the last 15 years. Most of them focus on the horizontal distribution of dust using passive remote sensing techniques. Antoine and Nobileau, (2006) used SeaWIFS (Sea-Viewing Wide Field-of-View Sensor) observations to study the seasonal evolution and variability of dust aerosols over the broader Mediterranean Sea during the period 1998-2004. Alpert and Ganor (2001) and Israelevich et al. (2002) used the Total Ozone Mapping Spectrometer (TOMS) Aerosol Index (AI) product in order to study the concentration of dust over Middle East and the dust sources of Northern Africa, respectively. The MODIS instrument, onboard both Terra and Aqua satellites has been extensively used in studies of airborne mineral dust over the Mediterranean basin. Barnaba and Gobbi (2004) analysed one-year (2001) MODIS/Terra AOD at 550 nm observations and reported on the spatial distribution and seasonal variability of aerosols, including dust, over the Southern Europe, with a focus over the Mediterranean region. Papayannis et al. (2005) used MODIS/Terra data synergistically with lidar measurements and dust model simulations and investigated the vertical distribution of aerosols during dust outbreaks over Greece. Kosmopoulos et al. (2008) and Papadimas et al. (2008) used MODIS/Terra and MODIS/Aqua to investigate the seasonal and interannual variability of AOD at 550 nm over Athens (Greece) and over the broader Mediterranean Sea, respectively. Marey et al. (2011) analysed ten-years of MODIS data synergistically with MISR and OMI and they produced a monthly climatology of aerosols over a domain covering the Nile Delta and northeast Africa.”

The seasonal climatological and conditional meridional dust extinction product will be useful for evaluating model representation of dust transport to Europe. I recommend that the authors make this available to the research community and include a link to the dataset in the manuscript, if possible.

[REPLY] We added a new section for data availability where we provide the availability of this dataset. In the new Section 5 we provide this information (page 17, line 22) :

“The LIVAS database is publicly available at http://lidar.space.noa.gr:8080/livas/. LIVAS EARLINET-optimized pure dust products are available upon request from Eleni Marinou (elmarinou@noa.gr) and Vasilis Amiridis (vamoir@noa.gr).”

The section on interannual variability is quite weak. The comparisons with other studies should be relevant to the time period considered in this work.

[REPLY] We agree with the reviewer that a more extended discussion on the interannual variability section would improve the structure of the manuscript. The referenced literature was mainly focused on studies related to the decrease of both dust concentration and frequency close to the surface, for two basic reasons. Firstly, most of the available studies focus on the interannual variability and trends of AOD, not of DOD. This is due to the difficulty of disentangling the dust component of the total aerosol load. Secondly, interannual variability studies have been carried out mainly over the second half of the past decade and mostly by using columnar SeaWiFS, MODIS (Aqua/Terra), MISR, AVHRR and AERONET data. In this study, CALIIOP/CALIPSO vertically-resolved observations in nine years are used, which provide an accurate and robust way of identifying mineral dust from space. Furthermore, the methodology has been established and validated based on EARLINET for CALIPSO mineral dust research. In this way, CALIPSO is considered as an ideal tool from space to decouple the dust component from the total aerosol burden and for studies of the variability of DOD. Nevertheless, since the authors agree with the reviewer and in order to ratify the results, modifications on the manuscript were made. The authors extended the list of referenced studies related to the interannual variability not only for DOD but additionally for AOD, with an effort to be more focused over the study region. The "Interannual variability of dust" section is modified by adding the following text (page 15, line 29):

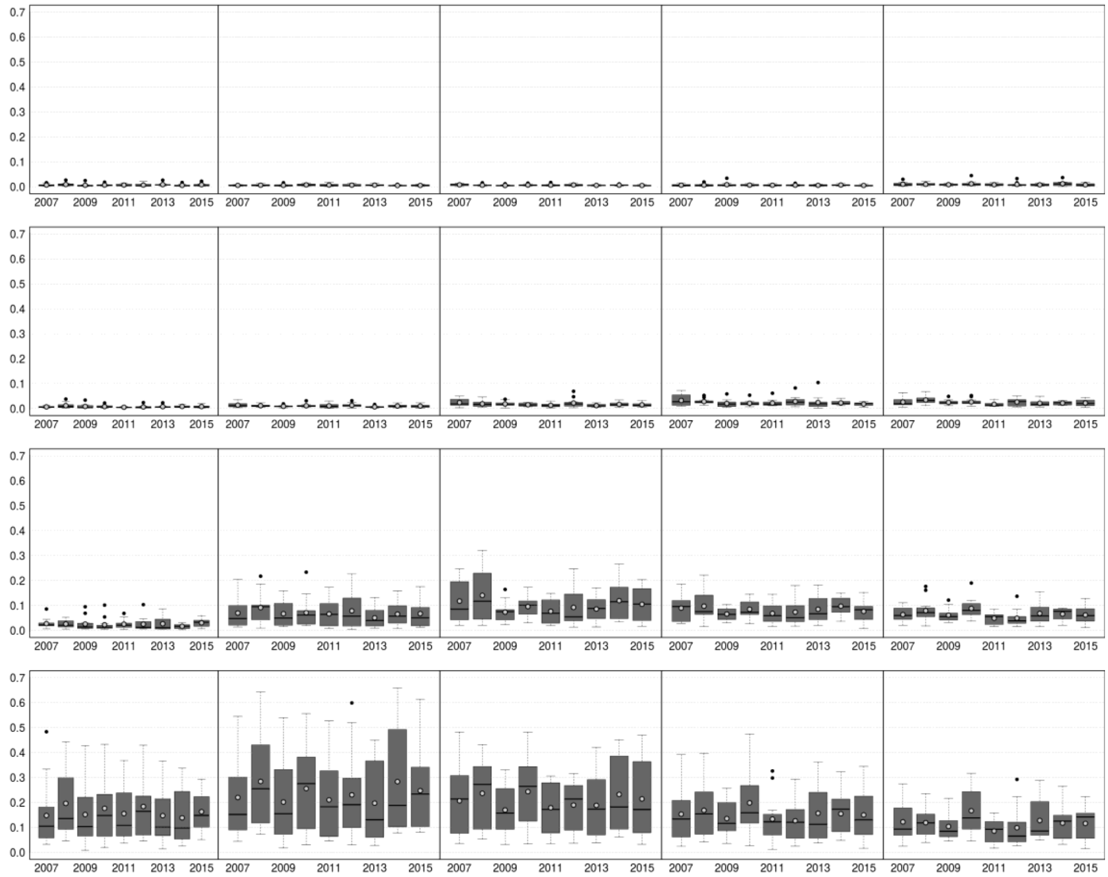
"In comparison with studies relevant to the time period considered in this work, the DOD decrease of 0.001 yr^{-1} over the northern coast of Africa is in agreement with Floutsi et al. (2016), who based on 12 years of MODIS-Aqua observations (2002-2014) reported an average decrease of 0.003 yr^{-1} for the coarse mode fraction of AOD over the broader Mediterranean Sea. Furthermore, over the same domain the decreasing trend of DOD coincides with the decrease of Saharan desert dust episodes as reported by Gkikas et al. (2013). Regarding the AERONET stations over the domain of northern Africa and Europe, Yoon et al. (2012) reported on the trends of AOD at 440 nm along with the corresponding Ångström Exponents (440 and 870nm). The documented negative trends over the AERONET stations of Avignon (France), Dakar (Senegal) and Ispra (Italy) are in agreement with the negative DOD reported here, although with discrepancies in the magnitude, while trend disagreements are observed over the AERONET station of Banizoumbou (Niger). The decreasing trends of DOD observed over the domain northern of Africa and Europe coincide with the generally documented downward AOD trends reported based on several satellite observations of MODIS/Aqua, MODIS/Terra, MISR and SeaWiFS (Pozzer et al., 2015; de Meij et al., 2012; Hsu et al., 2012; Georgoulias et al. 2016b). More particular, in the most recent study of Georgoulias et al. (2016b), using MODIS/Terra and MODIS/Agua observations, they reported negative statistically significant trends over Algeria, Egypt and the Mediterranean and positive trends over Middle East. Overall, for the Mediterranean they reported an AOD trend of -0.0008 yr^{-1} for the MODIS/Terra observations (2000 – 2015) and -0.0020 $yr^{-1}$for the MODIS/Aqua observations (2002 – 2015), with the trends being statistical significant at the 95% confidence level in both cases."

There does seem to be a general downward trend, but based on the lack of significance in many regions it is understandably difficult to determine long term trends over a relatively short 8 year period. Maybe the authors could include a timeseries panel in Figure 6 to indicate the interannual variability, rather than focus on the weak trends?

[REPLY] In our study, we calculate the DOD trend along with the statistical significance of each trend for the period 2007-2015 (108 monthly values). We also believe that trends might change if a longer time scale is used. According to the reviewer's suggestion, we added a timeseries panel as Figure 7, including the interannual variability of the 9 year observations based on monthly mean DODs. The interannual section was modified, and the following text is added (page 16, line 13):

"In our study, we calculate the DOD trend along with the statistically significance of each trend for the period 2007-2015 (108 monthly values). Nine years are considered a small period for a robust trend calculation and it would be interesting to repeat the same analysis in the future to extended aerosol record. The de-seasonalization process as well as the trend are describing the examined period only. Figure 7 shows the DOD internal variability of the 20 individual areas, as it is calculated from monthly mean DODs. Is evident from this figure that the DOD values in 2008 are relatively higher than the other years and in almost all the domains bellow 40°N. Similarly, relatively high values are observed in some of these areas for the year 2010. Since these years are at the beginning of our study period, they have a significant contribution on the negative trends observed during the examined period."

Figure 7: Interannual variability of the DODs for the 10° x 10° grid cells depicted in Fig. 6, for the period 2007-2015.



Minor Comments

Please replace all instances of 'utilize' with 'use'

[REPLY] It is replaced throughout the manuscript

pg1 ln21 - "During spring..." sentence is not clear, please revise.

[REPLY] We revised the sentence as (page 1, line 21): "During spring, the spatial distribution of dust shows a uniform pattern over the Sahara desert."

pg1 ln22 - "on" should be "in"

[REPLY] It is replaced.

pg1 ln23 - "0.1", should this be "up to 0.1"?

[REPLY] It is rephrased: **“**The dust transport over the Mediterranean Sea results in mean Dust Optical Depth (DOD) values up to 0.1.”

pg1 ln28 - units are sometimes italicized, other times not

[REPLY] We harmonized the units format in the manuscript, and, now, they are italicized everywhere.

pg1 ln31 - change to "the Alps and Carpathian Mountains"

[REPLY] It is changed.

pg2 ln25 - remove "now"

[REPLY] It is removed.

pg3 ln30 - what is meant by "large scale statistics"

[REPLY] This phrase is removed and replaced by the phrase (page 4, line 4):

“To our knowledge, this is the first time that a 3D pure-dust dataset is statistically analyzed over the area of North Africa and Europe in order to provide not only the horizontal but also the vertical patterns of Saharan dust intrusion in the Mediterranean.”

pg4 ln22 - extra space after "biases"

[REPLY] It is removed.

pg5 ln13 - perhaps provide the link as a reference?

[REPLY] We provide the link as a reference now. In the discussion (page 5, line 20):

“In brief, CALIPSO L3 version 3 screening procedure is followed (Winker et al., 2013; CALIPSO L3-V3, 2015)”

Reference:

CALIPSO L3-V3: CALIPSO: Data User's Guide - Data Quality Statement - Lidar Level 3 Aerosol Profile Monthly Product Version 3.00, link: http://www-calipso.larc.nasa.gov/resources/calipso_users_guide/data_summaries/l3/CALIOP_L3Products_3-00_v01.php, 2015.

pg5 ln21 - "categorized"

[REPLY] It is removed.

pg6 ln17 - "However..." it is not clear why this is an issue. Please elaborate or remove.

[REPLY] We removed the sentences from the text.

pg7 ln8 - "suppressed", this should be caveated as there are still significant emissions from African regions, like the Bodele, that are just not transported northwards.

[REPLY] We thank the reviewer for this comment. Indeed the sentence was generic, and hence not correct. We specify it accordingly (page 9, line 25):

"During autumn and winter the emission and transport of dust towards Europe is suppressed due to the more effective removal processes and due to the atmospheric dynamics favouring the transport of dust towards the Atlantic (e.g. Israelevich et al., 2002; Schepanski et al., 2009)."

pg7 ln23 - "Strong topographical heights", unclear meaning - please rephrase

[REPLY] We deleted this part, as it was unclear. Now the sentence is (page 10, line 8):

"The activated dust sources are located in the broad "dust belt" and are usually associated with topographical lows in the arid regions and with the intermountain basins (Prospero et al., 2002)."

pg8 ln3-5 - It is not clear what this tells us (high DOD, high sdev). Please explain what this indicates.

[REPLY] Standard deviation is an indication of the variability of the dataset. We deleted this part, as it was unclear.

pg8 ln3 - "In general,"

[REPLY] Done.

pg8 ln31 - "situation", please be more specific.

[REPLY] We changed the sentence 9Page 11, line 27):

"During OND the horizontal pattern is similar to JJA however with much lower heights (Figs. 3g, h)."

pg9 ln11 - "England" should be "Ireland"

[REPLY] It is corrected.

pg9 ln15 - "England" should be "British Isles"

[REPLY] It is corrected.

pg10 ln2 - "higher" than what?

[REPLY] We rephrased that paragraph. Now the new sentence is (page 13, line 12):

"The values of Clim-DE are higher (>45 Mm^{-1}) over Africa during winter and spring, in relation with the ones observed during the other two seasons (<45 Mm^{-1}) and reach high altitudes (5-6 km a.s.l.) during spring and summer."

pg10 ln18 - no new paragraph and replace "Nevertheless" with "However"

[REPLY] Done.

pg10 ln23 - delete the first sentence

[REPLY] We deleted it.

pg10 ln24 - "Number of Exceedances", exceedances of what? Perhaps "Number of occurences" or "Number of observations" makes more sense?

[REPLY] We changed the "Number of Exceedances (NoE)" into "Number of dust observations (dO)" according to the suggestion of the reviewer.

pg11 ln3 - "move" should be "moves"

[REPLY] It is changed.

pg11 ln11 - "mean" should be "means"

[REPLY] It is changed.

pg11 ln11-20 - this section is out of place as the following paragraph returns to Fig.4. Also, sentences in the paragraph somewhat contradict each other. If the PDR is a means of estimating age, but "cannot be considered as a possible age index". If the latter is true, why is this useful? The paragraph needs moving and restructuring, or removing (which would also mean removing the figure) unless the PDR provides some insight.

[REPLY] In the figure, were we presented the particle depolarization ratio for the cases used for the production of Cond-DE, it was evident that the depolarization is higher for air masses closer to the desert while it decreases as the air-masses travel towards Europe. This is due to the mixing of dust with other aerosol particles, which takes place after some days of transport. However, the depolarization ratio cannot be considered as a possible age index of the pure-dust particles, since it only provides the mixing of dust with other particles (Tesche et al., 2009). It was used here as an age estimator only because the Sahara desert is away from Europe and the mixing of transported dust with anthropogenic particles occurs as soon as the plumes mix with anthropogenic particles over the European Continent.

Because the revised manuscript, after the suggestion of the reviewers, has two new figures and two new tables, which highlight in our opinion very interesting and informative aspects of the product, we decided to delete the depolarization part (and plot) from the paper, so as to help the reader concentrate on the other parts of this work.

pg11 ln22 - I think panel "I" should be panel "i"

[REPLY] It is corrected.

pg11 ln25 - "plums" should be "plumes"

[REPLY] It is corrected throuout the manuscript.

pg11 ln26 - give the latitude range of the mountainous regions

[REPLY] We elaborated the sentence by including the range of the mountainous regions (page 14, line 26):

"The trapping of Saharan dust from the mountainous ridges of Europe (located between 40°N – 50 °N, e.g. the Alps 45°N-48°N) is also evident by the Con-DE cross-sections(e.g. Fig. 5i, m).

pg11 ln29 - "dust in" should be "dust at"

[REPLY] It is changed

pg11 ln30 - can you be more specific why the deposition is stronger during that season - is it primarily wet or dry deposition?

[REPLY] We changed the sentence as (page 14, line 29):

"Dry deposition of dust at these areas result also in the formation of "brown snow" and albedo reduction, with profound climatological implications (e.g., Fujita, 2007; Shahgedanova et al., 2013). This phenomenon is more intense during JFM period due to the advection of dust at lower heights."

pg11 ln31-34 - why is there a sudden drop off in extinction at 40N during the AMJ season? Please explain this.

[REPLY] We addressed this issue by adding the sentence (figure 14, line 32):

"The transport of dust during AMJ is mostly due to the eastward propagation of N.Africa – Mediterranean low pressure systems (Sharav cyclones). Dust is embedded in the cyclonic circulation and the penetration to latitudes higher than 40°N is limited."

pg12 ln1 - I think panel "i" should be panel "l"

[REPLY] It is corrected.

pg12 ln19-24 - the studies referenced consider longer time periods and/or different geographical regions, please alter to so that the discussion relates better to the region and period you are considering.

[REPLY] As mentioned already in the similar major comment, the "Interannual variability of dust" section is modified by adding the following text (page 15, line 29):

"In comparison with studies relevant to the time period considered in this work, the DOD decrease of 0.001 yr^{-1} over the northern coast of Africa is in agreement with Floutsi et al. (2016), who based on 12 years of MODIS-Aqua observations (2002-2014) reported an average decrease of 0.003 yr^{-1} for the coarse mode fraction of AOD over the broader Mediterranean Sea. Furthermore, over the same domain the decreasing trend of DOD coincides with the decrease of Saharan desert dust episodes as reported by Gkikas et al. (2013). Regarding the AERONET stations over the domain of northern Africa and Europe, Yoon et al. (2012) reported on the trends of AOD at 440 nm along with the corresponding Ångström Exponents (440 and

870nm). The documented negative trends over the AERONET stations of Avignon (France), Dakar (Senegal) and Ispra (Italy) are in agreement with the negative DOD reported here, although with discrepancies in the magnitude, while trend disagreements are observed over the AERONET station of Banizoumbou (Niger). The decreasing trends of DOD observed over the domain northern of Africa and Europe coincide with the generally documented downward AOD trends reported based on several satellite observations of MODIS/Aqua, MODIS/Terra, MISR and SeaWiFS (Pozzer et al., 2015; de Meij et al., 2012; Hsu et al., 2012; Georgoulias et al. 2016b). More particular, in the most recent study of Georgoulias et al. (2016b), using MODIS/Terra and MODIS/Agua observations, they reported negative statistically significant trends over Algeria, Egypt and the Mediterranean and positive trends over Middle East. Overall, for the Mediterranean they reported an AOD trend of -0.0008 yr^{-1} for the MODIS/Terra observations (2000 – 2015) and -0.0020 $yr^{-1}$for the MODIS/Aqua observations (2002 – 2015), with the trends being statistical significant at the 95% confidence level in both cases."

pg12 ln26 - replace LR with lidar ratio

[REPLY] It is replaced.

pg24 - The EARLINET reference is repeated multiple times.

[REPLY] The different EARLINET references refer in different EARLINET publications / products. In particular: (1) EARLINET all observations (2000–2010), 2014a, (2) EARLINET climatology (2000–2010), 2014b, (3) EARLINET correlative observations for CALIPSO (2006–2010), 2014c, (4) EARLINET observations related to volcanic eruptions (2000–2010), 2014d, (5) EARLINET observations related to Saharan Dust events (2000–2010), 2014d.

Figure 2(b,d,f,h) - Why is the color bar different for the CoM panels relative to the Top Height panels when they are both showing altitude? Consider using the same color to avoid confusion

[REPLY] We used different range for the altitude in the two plots, because the CoM variation of the area is not nicely depicted when using the same color bar with Top Height. We understand that this might bring confusion to the readers, so we changed the figures using the same color bar and ranges.

Figure 2 - In titles, "TOP" should be "Top"

[REPLY] It is changed.

Figures 3,4,5 - longitude and latitude labels are too small on the domain panels

[REPLY] The labels size is increased and it is more visible in the new version of the manuscript.