Response to Referee 4

The paper of Song et al exploits the aerosol spin-off products for the European wind lidar mission Aeolus for a specific extreme event, namely a heavy Sharan dust outbreak observed over the Atlantic. To compensate the drawbacks of the wind lidar Aladin in the vicinity of non-spherical particles, the authors use the polarization observations from NASA CALIPSO mission to correct Aeolus' co-polar backscatter coefficient and SEVIRI dust mask as a cloud screening proxy.
The paper is of interest for the scientific community, exploits the synergy between different space-born profiles and describes an intense extreme event in a changing climate based on vertically resolved optical properties. It furthermore shows, how different sensors could be used in a synergistic way to retrieve optimized aerosol profiles. It is this worth publishing, however, only after addressing the issues listed below.

We greatly appreciate the review and detailed comments provided by the referee. Our responses to the specific comments are as follows.

Major/General comments:

- Most of the comparisons, especially of extinction coefficient are plotted on logarithmic scale in separated plots. However, by doing so, it is not possible to see major differences in case of strong backscatter and extinction as it is the case for in this paper. Thus, comparisons should be shown in linear scale an, maybe divided by low and high values, to allow the reader to see, how well the results agree. Best, also in the same Figure. Later you state, that „Assessing the accuracy of ALADIN's aerosol retrievals within the upper atmospheric region exceeding the dust layer is beyond the scope of this work." Thus, there is no need to use a log scale.
  At least, I cannot follow many conclusions you have drawn based on the log-based figures you provided.

Thank you for your comments regarding the linear/logarithmic scale of plots (Fig.4 – Fig.7) in our manuscript. We tested with presenting the backscatter coefficients (Fig.4 in the manuscript) on a linear scale as shown below in Fig. S1. However, a linear representation can significantly compromise the visibility of lower backscatter coefficients as they span several orders of magnitude. For this reason, we have decided to retain the logarithmic scale for the figures in our manuscript, as it more effectively displays the full range of data, particularly the comparisons of smaller coefficients. This is consistent with the expectation that particle concentration decreases exponentially with height above the boundary layer.

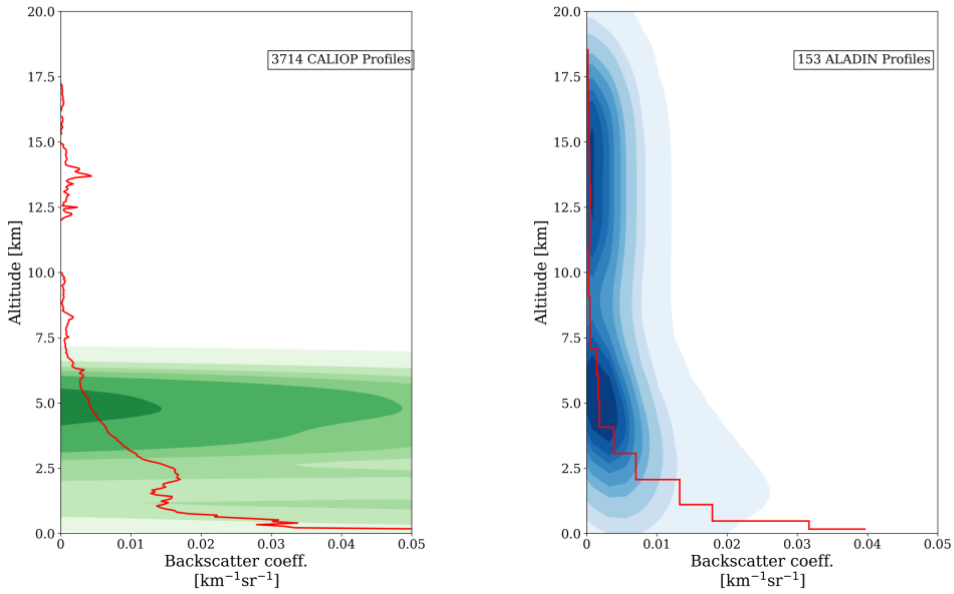

Figure S1. CALIOP (a) and ALADIN (b) backscatter coefficients in linear scale.

To support the conclusions illustrated in the figures, we added quantitative analyses into our discussion. Following Fig. 4 the following sentences have been added:

"..... In general, CALIOP and ALADIN show good consistency in detecting dust aerosols, with evidence of dust being uplifted to 7 km. Within the main aerosol layer from 1.5 to 7.5 km in altitude, the mean backscatter coefficients retrieved by CALIOP and ALADIN show a strong correlation, with an R-square (R2) of 0.967. At ~3.5 km, the altitude with the most valid retrievals, ALADIN's retrieved backscatter coefficient averages 0.004 km−1sr−1. CALIOP, which offers a higher vertical resolution, has an average backscatter coefficient of 0.01 km−1sr−1 when adjusted to match ALADIN's vertical resolution."

Following Fig. 5 the following sentences have been added:

"The two instruments generally show a good agreement in their extinction coefficients within the dust layer, with an R2 value of 0.992 for mean extinction retrievals between 1.5 and 7.5 km altitude. However, some disparities are also apparent. For instance, at the altitude of ~3.5 km, ALADIN has an extinction coefficient of 0.057 km−1 while CALIOP has an extinction coefficient of 0.046 km−1."

- In my opinion, the first part of the section 4, case study is a methodological part and should be put in a respective section. This section should be expanded with respect to CALIPSO observation which have been used: E.g., the quality controls are not clearly described. I can't figure out which CALIOP cloud screening is applied.

We have made several revisions to 'Section 2 Data and Methods'. The methodological content initially in the first part of Section 4 has been relocated to Section 2. This content is now appropriately positioned at the end of the subsection titled "Aeolus ALADIN Aerosol Products".

Additionally, we have revised 'Section 2 Data and Methods' to enhance clarity regarding the QA criteria. In the subsection about Aeolus ALADIN data, we have included the following paragraph:

"The quality control of ALADIN's Level-2 SCAmb products involves several criteria: the validity of extinction and backscatter coefficient retrievals; the backscatter-to-extinction ratio (BER); Mie and Rayleigh SNRs; estimated errors in extinction and backscatter coefficients; and the accumulated optical depth. These criteria are comprehensively detailed in (Flamant et al., 2020b). ALADIN's L2A processing strategy has a high sensitivity to errors so that small errors in extinction propagate from one bin to the next, often leading to negative extinction coefficients. To mitigate this issue, an additional filtering step is used in this study to eliminate negative extinction coefficients."

Regarding the subsection of CALIOP data, we have revised the following paragraph:

In this study, the CALIOP Level-2 V-4.21 aerosol profiles APro (CAL_LID_L2_05kmAPro-Standard-V4-21) are used for comparison against ALADIN aerosol retrievals. The Level-2 APro data include a cloud-aerosol discrimination (CAD) score, which we use as QC flags, selecting only aerosol retrievals with a CAD score less than -20.

- Furthermore, have you used mean Calipso depol profiles for correction or did you make a case by case correction? It is not clearly stated.

Thank you for highlighting this ambiguity in Section 6 regarding the lidar ratio correction. To clarify, we have applied the CALIOP extinction coefficient correction on a case-by-case basis, using depolarization ratios from each individual profile rather than an averaged mean value. To make this clear in the manuscript, we have revised the sentence to explicitly state: "…… where $LR_{updated}$ is set to 63.5 sr and LR_{CALIOP} is derived from each individual CALIOP profile."

- In Section 6, important information is missing, e.g. on how the columnar AOD is calculated from Calipso profiles which obviously are not available down to the ground. Currently, the section is really misleading.

The CALIPSO column AOD is derived by integrating the 532 nm aerosol extinction profile from the 5 km Aerosol Profile Products. Importantly, we have excluded profiles containing fully attenuated bins. This detail has now been added to the last sentence in the first paragraph of Section 4 (updated Section number).

- As the authors focus on a specific atmospheric scene at a specific time of the Aeolus mission, conclusions drawn should not be too general.

We have revised sentences in the conclusion section to emphasise that our findings and statements are specific to this extreme dust event.

Specific comments:

- Please invert color scale, in all other plots of this color map high values are dark and low ones light.

We have now inverted the colourbar in Fig.1 to avoid any confusion and ensure consistency.

- Fig. 4b: Please use a different color for the mean, hardly seen. And please use contours instead of gradients as wording.

We have revised Fig. 4(b) & Fig.5(b) by changing the colour of the mean profiles to red and increasing the line width to enhance visibility. Additionally, we have replaced the term 'gradient' with 'contour' throughout the figure description.

- Please explain all abbreviations (e.g. HSRL) and reference if appropriate (e.g. for A-Train).

Abbreviations and reference have been checked and added accordingly.

- Lines 104-105: "corresponding to an along-track horizontal resolution of approximately 87 km". Here it should be mentioned that this nominal along-track horizontal resolution of ~87km corresponds to one Basic Repeat Cycle (BRC) also referred as Observation, and pointing to the L2A Algorithm Technical Basis Document (ATBD).

Thank you for the suggestion. We have added this detail and reference into the manuscript following this sentence.

“Each observation by ALADIN integrates laser shots over a 12-second interval, corresponding to an along-track horizontal resolution of approximately 87 km, which is defined as one basic repeat cycle or ‘observation’, as detailed in the Level 2A Algorithm Theoretical Baseline Document (Flamant et al., 2020a).”

- Line 105: "Each observation is comprised of 24 vertical bins". This is only valid for SCA, the SCAmb used within the study being aligned with only 23 vertical range-bin.

Yes, we agreed on this point. We explained this in the following sentence: “…… the SCAmb method averages extinction values over two consecutive bins.”

- Line 121 "Level-2 SCAmb products are used" and line 183 "the ALADIN L2A data from the study period". Here the L2A baseline reference (i.e. 2AXX) should be clearly mentioned as the exact date of downloading from the ESA ADDF.

Baseline reference (baseline 2A11) has been added to both places. Data access information has been added to the ***Data Availability*** Section.

- Line 174: "official L2A Aeolus processor". The term official could be replaced by operational.

Corrected.

- Line 235, „For the sake of comparison, the ALADIN aerosol retrievals 235 in Fig. 4 (a) have been converted from co-polar to total backscatter coefficients, aligning them with the CALIOP aerosol retrievals in Fig. 4 (b).“I think you mixed up here something. Please check!

Thank you. Checked and corrected.

- Lines 237- 239: Did you use the mean depol value of Calipso or each single profile? At least stating that the depol ratio remains constant with a mean value of 0.32 is quite confusing.

The sentence used to describe the depolarization values in Fig.4(c) is referring to the mean value. We have rephrased the sentence to avoid confusion. “After omitting values below 0 and above 1, the depolarization ratio has an average of 0.32 between altitudes of 2.5 and 7 km.”

- Fig. 5. Caption wrong, its extinction not backscatter

Corrected.

- Line 264 "CALIOP’s extinction retrieval relies on a predefined lidar ratio tailored for specific aerosol types". Here it might be interesting to point the lidar ratio value assigned to the tropospheric aerosol class highlighted in Figure 8.

The following sentence has been added: “... e.g. 23 ± 5 sr for clean marine, and 44 ± 9 sr for desert dust aerosols at 532 nm”.

- 280: „For Fig. 6(b), both measurements show an extinction of ∼15 km−1, except where ALADIN observations fail quality-control.“ How can I see that they fail quality control? Are these the non-existent data points? This is not clear. Please describe better and also which quality control was applied.

We have added a paragraph in Section 2.1 to introduce the QC method used for ALADIN.

“The quality control of ALADIN’s Level-2 SCAmb products involves several criteria: the validity of extinction and backscatter coefficient retrievals; the backscatter-to-extinction ratio (BER); Mie and Rayleigh SNRs; estimated errors in extinction and backscatter coefficients; and the accumulated optical depth. These criteria are comprehensively detailed in (Flamant et al., 2020b). ALADIN’s L2A processing strategy has a high sensitivity to errors so that small errors in extinction propagate from one bin to the next, often leading to negative extinction coefficients. To mitigate this issue, an additional filtering step is used in this study to eliminate negative extinction coefficients.”

- Fig. 6 and 7: Could you also plot the evolution of the Aeolus lidar ratio (after correction).

We are unable to meaningfully plot the evolution of the Aeolus lidar ratio. Aeolus aerosol retrievals are not constrained by lidar ratio, resulting in derived lidar ratios that are often very noisy and require extensive filtering. Additionally, the Aeolus lidar ratio is not directly available from the product. It requires calculation from backscatter and extinction coefficients, each

subject to separate quality control flags. This limitation leads to fewer valid lidar ratios. To address this, we grouped Aeolus measurements over two days and applied filtering to remove abnormal lidar ratios, as depicted by the blue lines in Fig.10.

- Line 293: "This example illuminates a common problem with ALADIN extinction retrieval: retrievals at the base of a thick aerosol layer are very likely to be significantly underestimated or excluded" by quality control due to low SNRs. What does this statement refer to ? Which test cases or analysis have been used to qualify it as a common issue ?

To further support our statement regarding the common issue of ALADIN's low SNRs, we have now referenced two studies (Ehlers et al., 2022; Baars et al., 2020).

- 297: „A noteworthy observation is that ALADIN persistently records an extinction coefficient higher by ∼2 compared to CALIOP“ I do not see that in you plots.

Thank you for your comment. This is illustrated in Fig.7(e), specifically within the latitude ranges of 8° N to 14° N, and 20° N to 22° N.

- Figure 9. Why do you not provide the Aeolus AOD as well?

In this case of an extreme dust event, a significant number of Aeolus profiles contain bins with missing extinction retrievals. Given Aeolus's 1 km vertical resolution within the dust plume, attempting to integrate the extinction to compute columnar AOD would introduce a substantial bias. Consequently, our focus in this analysis was on utilising Aeolus's lidar ratio to correct CALIOP's extinction and AOD retrievals, rather than on the direct use of Aeolus AOD.

- Fig. 10. Please clearly indicate the wavelength in the plot (355 for Aeolus, 532 nm for CALIOP)

Thank you. Wavelengths have been added to the legend in Fig.10.

- 335: “This scaling method is an approximation, as a different lidar ratio can alter the lidar profile and subsequently affect the retrieval process.” Please describe a bit more. I guess you mean the lidar ratio choice already influences the backscatter retrieval during the Klett inversion?

Thank you for the suggestion, and we have revised this sentence: “This scaling method is an approximation, as varying the lidar ratio can influence the lidar profile by impacting the backscatter retrieval during the Klett inversion process. This alteration in backscatter retrieval, in turn, affects the subsequent extinction retrieval.”

- Table 1.: I recommend to check the values and complete it with the recent publication of Floutsi et al. (DeLiAn).

Thanks for suggesting this recent reference. Based on the measurements from multiple experiments provided in this reference, we added an extra row of 355 and 532 nm lidar ratio into Table 1.

- Line: 343ff: According to Figure 11, there are no extinction profiles below ca. 1.8 km. Thus I was wondering how did you calculate the total AOD from Calipso? Did you interpolate? Did you just skip the lowermost altitudes? Please clearly describe.

The extinction is not zero below 1.8 km; merely < 1e-2 as shown in Fig.11. The integration of extinction coefficients to obtain AOD has considered all altitudes down to the surface.

- Line 355: “The grouped extinction profile indicate a mean layer AOD 355 of 0.413 between the 0 and 2.4 km layer, accompanied by a considerable standard deviation due to the random distribution of strongly attenuated bins along the satellite track. Conversely, the alternative set of measurements devoid of strongly attenuated bins demonstrates a layer AOD of 1.015 between 0 and 2.4 km.” I do not understand this statement at all, please rephrase and describe more!

We have amended the paragraph to enhance the explanation: “……CALIOP measurements with a column AOD below 1.8 often include profiles that feature strong attenuation at the lower boundary of the dust layer, even after applying the described filtering strategy. Specifically, extinction profiles grouped under this threshold demonstrate an average layer AOD of 0.413 for the 0 - 2.4 km layer, with a considerable standard deviation reflecting the presence of strongly attenuated bins. In contrast, profiles with a column AOD of 1.8 or greater, which are free from such attenuation, exhibit a mean layer AOD of 1.015 in the same vertical range. It is this latter set of profiles that tends to yield AOD values consistent with those derived from MODIS observations.”

- Conclusion: Please highlight a bit more the synergistic use of Calipso and Aeolus and Seviri for optimum aerosol profiles in this specific dust case.

This sentence has been added to the second paragraph of the conclusion: “This study demonstrates the importance of integrating observations from multiple platforms for optimal aerosol profiling in the context of dust events.”.

Language:

- Line 34: „Spaceborne lidars have the advantage of minimal aerosol loading between the instrument and the calibration region.“ .. I know what you mean with that, but a non-expert user will not understand what is mean there. Please rephrase.

This sentence has been rephrased as: “Spaceborne lidars often self-calibrate by assuming some section of the atmosphere lacks aerosol contamination, typically the stratosphere.”

- - Lines 109-110: "Standard Correction Algorithm (SCA)" and "Standard Correction Algorithm middle bin (SCAmb)" should be replaced by "Standard Correct Algorithm (SCA)" and "Standard Correct Algorithm middle bin (SCAmb)"

Thank you. Corrected.