Replies to the Reviewer #2

We would like to thank the Reviewer for this second round of comments. We believe that the revised manuscript addresses adequately the two points raised by the Reviewer. Please see below our replies (regular font) to your comments (bold font).

General reply

I would like to cordially thank the authors for their efforts and their detailed response. They made a great effort to restructure parts of the manuscript and to clarify the open questions. The earlier concerns on the cilmatological AOD analysis can be dropped based on the provided explanations and the additional data in the manuscript and supplement (coefficient of variation, spatial correlation and textual changes). Also, the textual changes regarding the 4 specific cases are appropriate, now being less conclusive and leaving open the possibility to noise-induced mismatches between SCA retrievals. I was particularly glad to see the negative values included in the Figure 3, which complement this discussion. However, two of the raised points have not been addressed to full satisfaction, but both of which will require mainly changes within the text. Hence, I recommend a minor review.

Point 1: Regarding the colocation criterion

Thanks for agreeing that it would be better to use the BRC center instead of the BRC start for colocation. I want to thank the authors for the effort of giving a detailed overview of the number of BRCs that are not affected: It is good to know that 77% of the BRCs (observations) are correctly colocated, which makes me confident that the reached conclusions are not too sensitive to any changes. However, below a discussion of open points:

"*On the contrary, in Athens, due to the "peculiarity" of the site such decision would exclude most of the matchups between Aeolus and ground-based profiles since ALADIN track resides near the edge of the defined circle.*"

I disagree with the statement that a change from the starting coordinate to the center coordinate will effectively reduce the number of BRCs.

To illustrate this point, a small graph below with some randomly simulated overpasses (Fig 1): Panel A shows the colocation method as is, illustrating the skewness around the circle in flight direction because of using the starting coordinate. Panel B resembles the procedure that the authors have shown in their rebuttal: Using the starting coordinate for colocation in the first place, but then checking subsequently whether also the center falls inside the circle. This method of course reduces the number of BRCs, because both the center and the starting coordinate are required to fall within the circle. In line with what the authors state, about 41/53 = 77% of the observations were correctly colocated in this example and remain. Nevertheless, panel C shows what happens using the center

coordinate right away, which results in a non-skewed choice of BRCs around the circles center.

On average, the version A and C will result in the same number of BRCs, because the density of observations is not reduced, just different BRCs are considered. However, in this random realisation, there are of course small fluctuations allowing for small differences (53 vs 52).

"Therefore, we think that it is better to proceed with our initial approach trying not to reduce further the already limited number of cases and BRCs."

Following my point above, this cannot be the motivation for keeping the flawed colocation method, as the number of BRCs is not reduced by changing to the center coordinates (since other BRCs that were previously disregarded are "entering the game" from below). Nevertheless, since the 77 % of the BRCs are correctly colocated, I do not expect a huge impact on the statistical analysis and the reached conclusions. So, although I am not agreeing with the authors, redoing the analysis with the correct colocation is probably a disproportional effort compared to the potential gain. I strongly recommend however, that since the authors conclude only satisfactory performance of Aeolus, they should stress clearly the weakness of their applied colocation criterion in the methods section. A reader might argue that any poor performance might be caused by the ~45 km offset, which allows in fact observations at 165 km distance instead of 120 km.
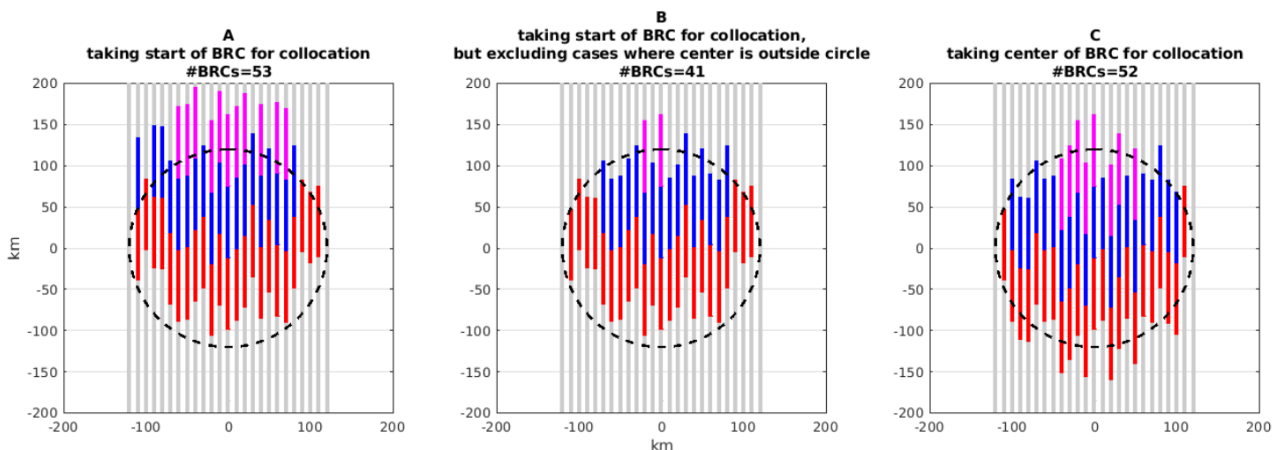

Fig 1: Illustration of the differences between colocation methods on a random realisation of overpasses (the same realisation is used for panels A, B, C). The panels show the results of different colocation strategies. The satellite is passing from south to north in this example. The color-code follows the Figure 2 of the manuscript.

We have added the following paragraph in the revised manuscript.

"Following this approach there is a possibility of including BRCs where more than half of their length to fall outside of the defined circle. This might affect the evaluation outcomes because we are not considering the BRC center in the collocation. Nevertheless, we are expecting a negligible impact on the statistical analysis since the 77% of the BRCs would have been selected using alternatively the coordinates at their center."

Point 2: Differentiating between "Aeolus", the "L2a product" and the "SCA product (or retrieval)"

I earlier made the remarks:

"Throughout most of the text, the authors do not differentiate between the performance of the Aeolus satellite itself and the performance of the retrieved SCA co-polar backscatter coefficient within the L2A product. This needs to be clarified, particularly since two significantly improved optical properties products are available as of March this year (see specific comments)."

and

">the most important finding is that Aeolus is not capable to reproduce satisfactorily the backscatter profiles< I find this a bolt statement to make here. It is not Aeolus but specifically the current Aeulos SCA product in absence of cloud flagging. "

To which the authors answered:

"As it is explained below, we have modified the relevant parts as suggested by the reviewer."

Overall, this has not been adjusted throughout the manuscript so I explain below in a more detailed manner: What I meant to stress is that sentences like "The most important finding is that Aeolus is not capable to reproduce satisfactorily the backscatter profiles." (L.945 , manuscript with tracked changes) are not correct. Such statement suggests and concludes incapability of the Aeolus mission itself, while it is particularly the shortcomings of the SCA product that the authors want to underline. Hence, the above statement should be changed to either:

"The most important finding is that Aeolus' SCA product is not capable to reproduce satisfactorily the backscatter profiles."

 Or

"The most important finding is that the SCA retrieval is not capable to reproduce satisfactorily the backscatter profiles."

I stress this point particularly, since the science teams are and have been working on more refined L2a backscatter coefficient profiles that are already released and included into the L2a product. Hence, there is a need for specification. This is where my impression originated from, that the authors generalize a lot in sections 6.1.x, though I am now sure that this is certainly not intended and hence a misunderstanding due to choice of words. I strongly encourage the authors to differentiate, so all statements that state "L2a product" and "Aeolus" in place of "SCA product" need to be changed accordingly.

To provide an extensive list:

L. 39 "L2A backscatter coefficient" → change to "SCA backscatter coefficient"

Done

L. 165, 950 "L2A optical properties" "L2a backacatter" → please specify which of the product(s) they used in the references (SCA, MIE, ICA, AEL-PRO or SCA-MLE)

Done

L. 174 "L2A particle backscatter" → "SCA particle backscatter"

Done

L. 273 "Aeolus L2A product " → change to "SCA product"

Done

L. 322 "The L2A optical properties product which will be described in the next section, derived by the so-called Standard Correct Algorithm (SCA) (Flament et al., 2021), are provided at the observation scale (on a horizontal resolution of ~90 km) and are available through the Aeolus Online Dissemination System (https://aeolus-ds.eo.esa.int)." → The SCA is part of the L2a, but not the whole L2a is derived by the SCA algorithm. Please change to e.g. "The SCA optical properties are part of the L2A product which will be described in the next section, and are derived by the so-called Standard Correct Algorithm (SCA) (Flament et al., 2021). They are provided at the observation scale (on a horizontal resolution of ~90 km) and are available through the Aeolus Online Dissemination System (https://aeolus-ds.eo.esa.int)."

Done

L. 359 "L2a extinction retrievals" → change to "SCA extinction retrievals"

Done

L. 428 "Aeolus L2A products" → may be changed to "Aeolus SCA optical properties product"

Done

L. 602 "L2a backscatter profiles" → "SCA backscatter profiles"

Done

L. 616 "Aeolus L2A profiles" → "Aeolus SCA profiles"

Done

L. 624, 641, 651, 652, 659, 880, 882, 923, 985, 1081, 1138 "L2A" → "SCA"

Done

L. 39 "Aeolus profiles" → "SCA profiles" or "L2a profiles"

Done

L. 45 "Aeolus performance" → "SCA performance"

Done

L. 48 "Aeolus profiles" → "SCA profiles"

Done

L. 53 "Aeolus performance" → "SCA performance" (though this is likely an issue with all the retrieval algorithms)

Done

L. 170 "Aeolus backscatter profiles" → lease specify which of the product(s) they used in the references (SCA, MIE, ICA, AEL-PRO or SCA-MLE) instead of "Aeolus backscatter profiles"

Done

L. 365, 626, 627, 658, 664, 816, 822, 877, 938, 943 "Aeolus" → "SCA"

Done

L. 716, 730 "Aeolus" → "Aeolus SCA product"

Done

L. 814, 1146 "Aeolus' performance" → "SCA performance"

Done

L. 816, 826, 867,1053 "Aeolus" → "the SCA retrievals"

Done

L. 842, 845 "Aeolus" → "the SCA "

Done

L. 883 "Aeolus satellite (SAT) backscatter coefficient" → "Aeolus satellite (SAT) SCA backscatter coefficient"

Done

L. 1002, 1024, 1025, 1027, 1039, 1042, 1050, 1163, 1164 "Aeolus" → "SCA"

Done

<u>**Replies to the Reviewer #4**</u>

We would like to thank the Reviewer for his/her comments helping us to clarify better critical points of our analysis. Please see below our point-by-point replies (regular font) to the comments (bold font) raised by the Reviewer.

The authors responded to most of the reviewers' comments. There was an effort to make the paper lighter but long, heavy sentences, of the kind you need to read twice to be sure you understand, are still present. I propose some simplifications in the specific comments.

We have made an effort to simplify further "heavy" sentences in the manuscript.

Following reviewer #2, I think it is important to mention that the SCA mid-bin backscatter is not expected to perform better than the normal SCA, the mid-bin algorithm is designed to reduce the extinction errors. The authors are aware of this, because it is mentioned on l. 397-405. But the comparison of performance between the two results is still at the heart of the paper. I am not sure the paper is clear enough on this point. From his/her comments, it seems that even reviewer #1 misunderstood this.

In the revised manuscript we are clarifying better this point.

Also, it is important to note that the SCA performance is not the performance of Aeolus itself. It's one of the optical properties products and, hopefully, there is still room for improvement.

We have corrected all the relevant instances in the revised manuscript.

Getting back to the main subject of the paper, the validation of satellite observations from ground-based measurements, I think the work is useful and presents an important contribution to a difficult problem. A meta-analysis, exploiting more numerous profiles from more locations would be very useful (e.g. co-ordinated at EARLINET level? Ok, it is mentioned in the conclusion!).

We are already mentioning the ongoing work of the Aeolus EARLINET Cal/Val study.

On the scientific side, I think most limitations of the study are properly acknowledged.

Thanks!

Specific comments:

l. 27: "along with wind HLOS profiles" could be removed to make the sentence lighter. Or simply replaced by "also".

Done.

l. 31 "(capital of Greece)" the administrative status is not a geographical indication. Centre of Greece?

We have replaced "capital of Greece" with "central Greece".

Several occurrences in the text of "the performance downgrades" (l.45, l.53, l.1157). I would replace "downgrade" with "degrade". I am being picky but this bothered me. You wouldn't use "upgrade" if the performance improved, would you?

We have replaced all the relative instances in the manuscript as suggested by the reviewer.

l. 287 named by -> named after?

Done

l.295 The orbital velocity is actually closer to 7.7 km/s

Thanks for the correction!

l.298: The precision that solar panels are facing the sun is not useful. If you want to keep this sentence, you should focus on the telescope rather than on the panels. Something like "The telescope is pointed to the right of the flight direction, aiming into the night hemisphere". As you are not discussing the influence of solar background signal, you could omit this sentence.

We have modified this sentence as follows: "*Aeolus is flying over the terminator between day and night (dawn/dusk orbits), with its telescope pointing to the right of the flight direction (aiming into the night hemisphere) for minimizing the solar background illumination (Kanitz et al., 2019).*"

l. 300 "HSRL lidar" contains lidar twice. "HSRL" alone or "HSR lidar"?

Done

l. 309 As you want to focus on the description of the geometry here, you may simply say that "Aeolus provides observations at the slant nadir angle of 35 degrees".

We prefer to keep our description.

l.315 You could use a simpler structure: "Therefore, the discrimination between aerosol and clouds, as well as the typing of aerosols, is challenging".

We have modified this part of the text as follows: "*However, ALADIN only measures the co-polar part of the atmospheric backscatter and at a single wavelength. Therefore, the discrimination between aerosols and clouds and their respective subtypes is challenging.*"

l. 336: I would call the product "(particulate) optical properties product", to stress that it focusses purely on optical properties, without any classification or any chemistry consideration.

We believe that it is pretty clear and there is not any misunderstanding here.

l. 344: Is it correct to replace "backscatter (either molecular or particulate) where the squared one-way transmission through the atmosphere is taken into account" by "attenuated backscatter"?

Not yet because it has not been introduced in the text the cross-talk correction, the normalization by the range bin thickness and the correction by the squared range.

l. 346-354: I am not sure that this description of the cross-talk correction with the coefficients name is needed. This paragraph could probably be summarized in one sentence.

We believe that it is better to keep this short paragraph.

l. 354-405: This is a long introduction to explain the interest of the "SCA mid-bin" product. As a reader, I would prefer to be pointed to the ATBD or to Flament et al. 2021. It would save one page of reading and allow the reader to focus on the actual comparison.

We believe that it is better to provide this information (shortly mentioned) in the text.

l. 411:

- Do you have a reference on comparisons of the MLE to ground based lidars? Ehlers et al. only provide comparisons with simulated and CALIPSO data.

There are some first comparisons versus eVe at Cabo Verde shown in Aeolus meetings.

- Also, the sentence spanning l. 410 to l. 413 is a long one again. "Comparison against ground based observation showed that the precision of the extinction and LR retrieved by the MLE is much better than the one from the SCA".

We think that it is better to keep this sentence as is.

- What are "SCA end-to-end simulated optical products"? It is not clearly described.

We are copying from Ehlers et al. (2022) and we are providing for further details the work of Reitebuch et al. (2018)

"The simulated data are produced with the Aeolus end-to-end simulator described in Reitebuch et al. (2018b), which allows realistic simulations of ALADIN measurements from defined atmospheric scenes as input to the L1B algorithm. Its output data are provided in the same format and temporal and spatial resolution as nominally downlinked from the satellite in order to test the whole processing chain up to the optical properties delivered in the L2A product. The simulation covers the charge transfer and detection on the accumulation charge-coupled device (ACCD) including offsets, non-linearity and noise sources, such as dark current noise, read-out noise, Poisson detection noise (shot noise) and the analogue-to-digital conversion with 16 bit."

Reitebuch, O., Marksteiner, U., Rompel, M., Meringer, M., Schmidt, K., Huber, D., Nikolaus, I., Dabas, A., Marshall, J., de Bruin, F., Kanitz, T., and Straume, A.-G.: Aeolus End-To-End Simulator and Wind Retrieval Algorithms up to Level 1B, EPJ Web Conf., 176, 02010, https://doi.org/10.1051/epjconf/201817602010, 2018.

l. 566: It is not clear to me whether this is the standard deviations with respect to time or space. I would think time.

In the previous sentence we are discussing about the temporal variability. Nevertheless, a better explanation is given in the revised text.

l. 588 "cycles" should be "circles"?

Corrected. Thanks!

l.597-598: "strong horizontal variability" fig 1-iii, 1-iv and S1 say the opposite: strong spatial homogeneity around Antikythera (From S1-ii, I understand that the time series of average AOD within each circle are very strongly correlated in ANT. So, the average within any given circle is close to the average within another one, most of the time.)

We have modified this sentence in the revised manuscript.

l.611 and Figure 2: the green arrow is not much better than the orange one: we cannot see in which direction it is pointing (Maybe because of image compression in the manuscript I received?). It doesn't really matter, all the tracks pictured are descending anyway, this can be said in the text.

Done.

l. 663 "entire" should be replaced by "entirely"

Done.

l.721 "it is revealed" doesn't sound idiomatic

We have replaced "revealed" with "evident".

l. 722-747 I wouldn't use "underestimated" (l.723) or "negative biases" (l.730) which suggests a deficiency of the Aeolus instrument or processing. It is only a deficiency in the nomenclature, I agree that the variables in the L2A should probably be named "circular co-polar backscatter" but we should focus on comparing apples with apples.

Here, it is just a matter of presentation: I would explain the importance of the correction first, and then present the results.

We have slightly modified this paragraph.

l.816-819: "due to overlying noise (i.e. negative backscatter)": I don't agree with this explanation. If you mean that errors from the overlying layers are propagated downwards, this is wrong. Within any profile, backscatter retrievals of the SCA are independent from each other.

We have replaced this sentence and the next one with:

"SCA fails to reproduce the aerosol layer (in terms of structure and backscatter magnitude) seen from the ground-based lidar between 2 and 4 km."

l.841-842: I do not see the "layer" between 5.5 and 8 km on Figure 3-iv. I think it is important to stress that we should not over-interpret single profiles. The noise is very large, and errors are underestimated.

We have modified the sentence as follows:

"As a result, Aeolus possibly (acknowledging the weak signals and the underestimated errors) detects incorrectly an aerosol layer between 5.5 and 8 km under the assumption that clear-sky conditions are appropriately represented in the MSG-SEVIRI imagery and remain constant within the time interval (~6 minutes) of MSG and Aeolus observations."

l. 947: This mostly shows that thin range bins close to the ground are detrimental to optical properties retrieval because of the low SNR they induce (cause (ii) below). The signal from the surface should only leak into the first bin above the ground.

We are providing sufficient interpretation throughout the text.

l. 964-981: How many profiles are used for comparison after filtering?

Initially we are analyzing 82 profiles and after cloud filtering 36.

Figure 5 and this paragraph really underline the importance of proper cloud filtering. The results of figure 4 are only useful to show the contrast.

This is exactly our intention and for this reason we are contrasting the vertically resolved evaluation metrics with and without the consideration of cloud-contaminated profiles.

l. 1078-1080: Out of curiosity: how invalid can the underlying assumptions be? Is there a quantitative assessment somewhere? That would also be an important step for later studies, because few ground lidars actually have the circular polarization capability (could this assessment be a task for eVe?).

This task can be addressed by eVe which is capable of measuring both linear and circular backscatter. The first eVe measurements acquired in Cabo Verde in the framework of the ASKOS campaign show that the linear-circular deviations are small or negligible. Some preliminary results are shown here (it is required a registration to the Aeolus confluence page).

l. 1100-1102: this consideration was not discussed before and only appears here.

This is not a major issue in our study but it is an aspect which should be considered in Cal/Val studies at stations located at areas with highly variable topography.

L. 1141: again this "underestimation" is more a problem of misinterpretation.

We have modified the sentence as follows: *"The misdetection of the cross polarized lidar return signals can interpret the lower Aeolus SCA backscatter values (ranging from 13% to 33%) with respect to ground-based retrievals when depolarizing mineral particles are probed (case of 10th July 2019)."*

l. 1159: why not say: "Our analysis reveals that …"?

Please see below the modified sentence.

"Our statistical assessment analysis reveals that the removal of cloud contaminated spaceborne profiles, achieved via the synergy with MSG-SEVIRI cloud observations, results in a significant improvement of the product performance."

Figure 1: the legend doesn't contain a description for sub-figure 1-v

We have added a description for Figure 1-v. Thank you for the correction!