Title: Ground-based MFRSR UV-Vis spectral retrievals of Saharan dust absorption at Izaña Observatory

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Response to Reviewer 1:

Our response to the comments and concerns raised by Reviewer 1 are presented in two parts:

1) Comments related to the dust shape factor distribution
2) Comments associated with the usage of SDLS (now renamed as API) tool for RT calculations

Reviewer's comments are in "***blue italic***" fonts.
Authors' response in regular black fonts.

Part 1

General comments

I appreciate the time and effort the authors invested in revising the manuscript. However, despite these efforts, the central methodological concern raised in my initial review has not been addressed. Moreover, a substantial part of my previous comments on this issue appears to have been ignored, with little to no modification of the relevant text. This represents a major methodological flaw that must be either properly justified or, at minimum, thoroughly discussed.

For clarity: in its current form, the manuscript cannot be recommended for publication. Addressing the concerns outlined below is essential and would, in my view, allow this otherwise strong and potentially impactful work to be considered after major revision.

I elaborate below on the primary unresolved issue, which concerns the justification and use of the aspect ratio distribution in the retrievals. The logic used by the authors to motivate this choice is problematic and, as currently presented, insufficient.

1. Lack of justification and documentation of the empirical distribution

The empirically derived aspect ratio distribution ("red curve" in Fig. 5) is not discussed in any of the studies cited in line 343, notably Torres et al. (2018, 2020) and Ahn et al. (2021). The parameters of this distribution are not specified, and the methodology used to derive it remains unclear. In fact, the derivation of such a distribution is a topic of sufficient importance that it would normally warrant a dedicated publication. Without a clear description and justification, its use in the current study is not adequately supported.

The reviewer has stated correctly here that the empirically derived dust aspect ratio distribution adopted in the present work hasn't been explicitly documented in Torres et al. (2018, 2020) and Ahn et al. (2021). We take this opportunity to describe the process of deriving empirical aspect ratio adopted in the near-UV aerosol algorithm in section 3.2.

Torres et al. (2018) introduced the non-sphericity of dust aerosols in the near-UV aerosol algorithm of OMI by adopting the aspect ratio distribution proposed in Dubovik et al. (2006). Post publication, it was realized that the use of this spheroidal-only shape distribution model led to an inconsistency in satellite near-UV AOD retrievals of transported Saharan dust over the Atlantic Ocean between the west and east sides of the OMI swath. These concerns led us to test the effect of different mixtures of spherical and spheroidal shape distributions on the OMI dust AOD retrievals. We tested three distinct aspect ratio distributions reflecting different adjusting weighting factors, as shown in Figure 1 below, and used them individually in the OMI-based near-UV aerosol retrievals.

The weighting factors adjustment of the three aspect ratio distributions was carried out empirically by gradually increasing the contribution of spherical particles while forcing the sum of the weighting factors to be 1 (a requirement of the DLS software tool). We selected the continuous aspect ratio distribution, shown as red curve (Spheroid V4), which largely eliminated the observed asymmetry in the OMI dust AOD retrievals over the Atlantic Ocean. Although these results have not been previously documented in the published literature, they were adopted for **over-ocean dust aerosol AOD and SSA operational retrievals** using near-UV observations by the OMI and TROPOMI sensors (Torres et al. 2020), EPIC-DSCOVR measurements (Ahn et al. 2021), as well as in the Unified Aerosol Algorithm of PACE-OCI (Lorraine et al., 2026, *in preparation*). **The over-land dust AOD/SSA retrievals by these sensors still use the original aspect ratio distribution proposed in Dubovik et al. (2006)**. This description is now added to the revised paper in section **3.2 Spheroidal Shape Treatment of Dust Aerosols.**

The weighting factors distribution parameter as a function of radius for randomly oriented spheroids proposed in Dubovik et al. (2006) and those used in the over-ocean aerosol retrievals from near-UV sensors are listed in Table 3 in the revised paper.

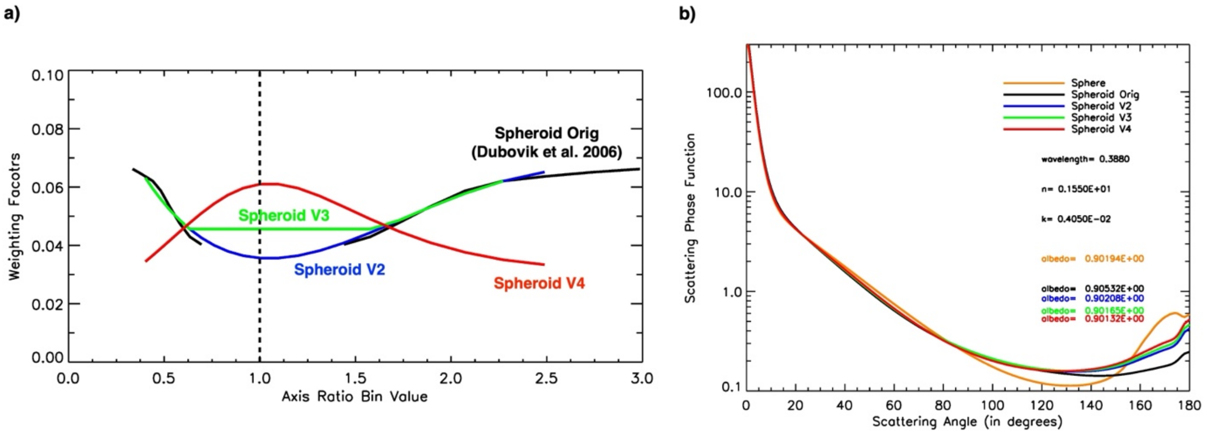

Figure 1 a) Different aspect ratio distributions as a function of axis ratio bins and 2) corresponding scattering phase functions F11 for the 388-nm wavelength. Spheroid V4 aspect ratio distribution (red curve) was adopted in the operational near -UV satellite retrievals of transported dust plumes over oceans.

2. Inadequate motivation based on median aspect ratio

The argument provided in lines 320–335, based on median aspect ratio values, does not justify the choice of the proposed distribution. Visually ("by eye") and given that the aspect ratio kernels used are symmetric, the median of the proposed distribution appears to be 1. More importantly, selecting a distribution based solely on its median value is non-unique and does not constrain the distribution shape in any meaningful way.

Lines 320-335 of the submitted revision presents the dust aspect ratios documented in different studies for providing a perspective. We included this discussion in the paper to emphasize that the dust aspect ratio varies significantly both regionally and seasonally, and that adopting a specific spheroidal distribution for the remote sensing of dust from ground and space-based observations is a challenging problem.

However, we concur with the reviewer's point here that selecting a distribution based solely on its median value is non-unique and may not represent and constrain the entire range of shape factor distribution in real-world application. In the manuscript text (page 10, lines 342-351), we emphasize that

"Accurately representing the true aspect ratio distribution of dust airmass observed by the MFRSR during absorption inversion at the study site remains a challenging problem. As a first approximation, we adopted an empirically derived model previously used in satellite-based Aura/OMI AOD retrievals in UV. It is important to note that improved aerosol retrievals from satellite observations do not necessarily confirm the presence of a mixture of spherical and spheroidal particles. Rather, this improvement suggests that such a mixture best reproduces the observed solar backscattered UV (BUV) radiances, even though real dust particles are typically angular and irregular, not smooth and spheroidal as represented in the model. Driven by the improved OMI AOD retrievals over land and ocean using two distinct models of spheroidal aspect ratio distribution, the over-ocean dust retrievals in the near-UV aerosol algorithm applied to OMI (Torres et al., 2018), S5p-TROPOMI (Torres et al., 2020), and DSCOVR-EPIC sensors (Ahn et al., 2021) was also updated."

3. **Inconsistent interpretation of prior literature and unsupported claims**

In lines 293–305, Torres et al. (2018) is cited as showing that moving from spherical to non-spherical particles improves the OMI asymmetry issue (referred to as an "anomaly"). In contrast, the present manuscript suggests moving back toward more spherical assumptions, claiming (without supporting evidence) that this further improves the asymmetry. At the same time, counterexamples provided in my initial review, where similar instruments are treated with different retrieval methods using unmodified non-spherical shape distributions and do not exhibit such asymmetry issues, were ignored. This raises the question of whether the observed asymmetry is truly an instrumental issue (e.g., OMI-specific), a limitation of the retrieval methodology, or due to other factors.

Within the scope of this paper, it cannot be uniquely attributed to particle shape. While it is possible that the shape distribution proposed by Dubovik et al. (2006) is not optimal in all situations (e.g., its known limitations for the P22 element in backscattering directions), these issues are unrelated to OMI, TROPOMI, or EPIC viewing geometries. Fine-tuning a well-established shape distribution to compensate for a specific instrumental or retrieval artifact is not an appropriate basis for defining a globally applicable dust shape model across different sensors.

The explanations on the use of the OMI spheroid model shape distribution implemented in Torres et al. (2018) and other previously undocumented modifications of the characterization of dust over ocean is provided on page 1-2 of this response.

The observed asymmetry in the OMI dust AOD retrievals was unlikely related to instrumental issue. OMI is a very well characterized and radiometrically stable UV spectrometer. The sensitivity tests of the AOD/SSA inversion from OMI to different shape factor distributions were carried out on the first three "row anomaly" free years (2005-2007) of OMI dust observations over oceans only.

We adopted the empirically derived spheroids combined with spheres dust aspect ratio distribution in the present work because of the resulting level of agreement between the MFRSR- and AERONET-retrieved SSA at 440 nm at the Izana site. We do not claim anywhere in the paper that this OMI-specific distribution is applicable globally and, therefore, we are not suggesting replacing the distribution proposed in Dubovik et al. (2006). In fact, the near-UV aerosol algorithms applied to OMI, TROPOMI, DSCOVR-EPIC, and more recent PACE-OCI observations, still use Dubovik et al. (2006) suggested spheroidal distribution model for dust look-up tables over land.

We adopted the empirically derived dust aspect ratio distribution, shown as the “red curve” in Figure 1 of this report, in the present work because of two compelling reasons: 1) the location of our ground instrument on Tenerife Island is more representative of the over-ocean dust retrievals, and 2) resulting level of agreement between the MFRSR- and AERONET-retrieved SSA at 440 nm at the Izaña site, as shown in Figure 11 of the paper.

4. Internal inconsistency in assessing the impact of shape assumptions

The manuscript presents conflicting statements regarding the impact of the aspect ratio distribution. On the one hand, lines 314–318 state: “Despite these differences, the corresponding retrieved SSA (black and red) show a close agreement—indicating that the choice of aspect ratio distribution didn't play a significant role in the inversion at least for these three dust events.” On the other hand, improved agreement with AERONET SSA at 440 nm is later used to justify the modified shape distribution (line 347): “Incorporating these empirically derived aspect ratios into the aerosol LUT significantly improved the agreement between the retrieved SSA at 440 nm from the MFRSR and corresponding AERONET inversions.”

We believe these statements are appropriate to the specific sections and figures where they are referred to.

For the three dust cases analyzed in Figure 5, the retrieved SSA (440 nm) from MFRSR and AERONET are found to be consistent with minimal differences. On the other hand, when tested on a much larger dataset encompassing the entire 2020 collocated observations, as demonstrated in Figure 12 (in the revised paper), the AERONET-like spheroid + sphere mixing approach yields an overall negative bias of -0.018 (-0.027) for AOD440>0.4 (AOD440<0.4) against -0.003 (-0.014) obtained using the empirically derived aspect ratio distribution.

Comparison results presented in Figure 12 and improved over-ocean dust AOD retrievals from space-based near-UV sensors form the basis of our selection of empirically derived dust aspect ratio distribution implemented in the entire MFRSR inversion dataset.

If the MFRSR and AERONET retrievals share more similar assumptions, closer agreement in SSA would be expected. Under this logic, adopting the AERONET shape distribution should have yielded the best SSA(440) agreement, which is not demonstrated. Furthermore, shape is not the only inconsistency between the two methods. Differences in gaseous absorption corrections (notably at 440 nm), surface reflectance assumptions (Ross–Li BRDF in AERONET versus Lambertian surface here), and the substantial redevelopment of the MFRSR retrieval core since Krotkov et al. (2005b), including the introduction of LUTs (line 403) instead of the original iterative approach, all may contribute to the observed discrepancies. These factors must be systematically examined before concluding that the observed SSA (440) bias (with a reported mean difference of ~0.01 over ~180 observations at a single site) is primarily driven by particle shape, let alone before proposing that the Dubovik et al. (2006) shape distribution should be replaced by the empirically derived one.

The reviewer has valid points here. Given the similar assumptions of PSD, real part of refractive index, AERONET-like spheroid + sphere mixing approach, and surface albedo, one would expect a close agreement between AERONET and MFRSR. Despite consistent assumptions, the MFRSR-retrieved SSAs are found to be biased lower by 0.02. Several factors, as suggested by the reviewer, including dust shape factor, could have contributed to these observed discrepancies. The MFRSR calibration procedure uses AERONET direct AOD measurements on cleaner days applied to dusty observations. Surface is assumed to be a Lambertian reflector against Ross–Li BRDF implemented in AERONET, which is not explicitly addressed in the present work.

We compared both iterative versus LUT-based retrieval approaches and did not find significant differences. A comparison between the two approaches yields almost similar values of the retrieved SSA within 0.005. Moreover, the LUT nodes in the imaginary part of the refractive index are closely spaced, reducing the effect of non-linearity in the inversion. Such changes in the inversion code were primarily made for improving computational efficiency. Again, we never claimed anywhere in the paper that the dust shape factor proposed by Dubovik et al. (2006) should be replaced globally with the empirical distribution implemented in the present work.

To further clarify, we have added this discussion in the revised paper in section 5.1 SSA RETRIEVALS AT 440 NM AND ITS COMPARISON AGAINST AERONET (pages 16-17, lines 558-573).

A sensitivity analysis of the retrieved SSA to change in dust aspect ratio distribution is discussed in the following response.

Recommendations
To address the issues above, I strongly recommend the following:

1. Quantitative assessment of aspect ratio impact
Add an explicit estimate of the impact of the aspect ratio distribution to Table 3, analogous to how the effects of other assumptions are evaluated. Given that the primary novelty of this work lies in the treatment of non-spherical particles, a rigorous and isolated assessment of the shape distribution impact is essential. Numerical tests are particularly important, as real datasets may contain confounding factors.

We find this suggestion useful for quantifying the changes in retrieved SSA (440 nm) due to the change in the dust aspect ratio distribution. Table 3 now explicitly includes these results. We report uncertainties in the retrieved SSA (440 nm) caused by changing dust shape factor distribution quantified using synthetic diffuse-to-direct (DD) ratio analysis (discussed in the next comment) as well as those calculated from the actual MFRSR measurements. Note that in both cases, the AEROENT-like spheroid + sphere approach is treated as a reference for estimating uncertainties.

Updated Table 3 is included in the revision.

	ΔSSA due to change in spectral AOD (ΔAOD=±0.01 at 440 nm ΔAOD=±0.02 at UV Wavelengths)					
Wavelength	**AOD Range**					
	0.2-0.4	**0.4-0.6**	**0.6-0.8**	**0.8-1.0**	**1.0-1.2**	**1.2-1.4**
440 nm	0.031	0.019	0.013	0.009	0.008	0.007
380 nm	0.058	0.034	0.024	0.017	0.014	0.012
340 nm	0.053	0.031	0.023	0.016	0.013	0.013
332 nm	0.052	0.030	0.023	0.015	0.012	0.013
325 nm	0.050	0.030	0.022	0.015	0.012	0.013
	ΔSSA due to 1% change in MFRSR-measured diffuse-to-direct ratio					
440 nm	0.009	0.008	0.006	0.006	0.006	0.004
380 nm	0.011	0.008	0.007	0.006	0.006	0.004
340 nm	0.012	0.009	0.007	0.006	0.006	0.004
332 nm	0.012	0.009	0.007	0.006	0.006	0.004
325 nm	0.013	0.009	0.007	0.006	0.006	0.007
	ΔSSA due to change in dust aspect ratio distribution (Synthetic DD ratio analysis 2020)					

440 nm	**0.011**	**0.014**	**0.016**	**0.018**	**0.014**	**0.015**
	ΔSSA due to change in dust aspect ratio distribution (Actual MFRSR DD Ratio measurements 2020)					
440 nm	**0.011**	**0.017**	**0.024**	**0.024**	**0.038**	**0.015**

	ΔSSA due to change in ALH by ±1 km		**ΔSSA due to ±0.05 change in Real Part of Refractive Index (ΔRR)**	
	AOD~1.0	**AOD~0.4**	ΔRR=**-0.05**	ΔRR=**+0.05**
440 nm	0.002	0.0002-0.005	-0.0080	+0.0079
380 nm	0.005	0.001-0.002	-0.0066	+0.0066
340-325 nm	0.007	0.002-0.003	-0.0054	+0.0055

2. Validation using synthetic datasets

Demonstrate the ability of the retrieval to reproduce known inputs using synthetic datasets. This should first be done for spherical particles to avoid ambiguity introduced by aspect ratio assumptions. There is a non-negligible possibility that the retrieval itself introduces bias, which is then partially compensated by tuning the shape distribution. Specifically, please perform forward simulations using AERONET-consistent inputs (including the imaginary refractive index) and retrieve k and SSA under identical and systematically varied assumptions: spheres, AERONET aspect ratio distribution, and the proposed empirical distribution, across different aerosol loadings. The results should be discussed in detail. If all assumptions are identical, the retrieval should reproduce the input SSA exactly.

We followed this valuable suggestion offered by the reviewer and conducted a theoretical sensitivity analysis for quantifying the changes in the retrieved SSA at 440 nm due to different choices of dust aspect ratio distribution. The AERONET Level 1.5 direct AOD and inversion parameters, including PSD, real and imaginary parts of the refractive index, and surface albedo, were used to simulate the surface-level, synthetic diffuse-to-direct (DD) downwelling irradiance ratio (as it would have been measured by the MFRSR sensor).

Three aspect ratio distributions were considered: 1) Dubovik et al. (2006) distribution, 2) OMI empirical distribution adopted in this work, and 3) spherical particles (i.e., aspect ratio=1.0). The synthetic DD ratios were used as measurements for the retrieval of SSA at 440 nm assuming three aspect ratio scenarios independently. The retrieval procedure and the software kept identical to the one used for inversion of actual MFRSR observations. For the comparison, SSA retrieved assuming Dubovik et al. (2006) aspect ratio distribution were treated as a reference.

Figure shown below (also included in the revised paper) demonstrates that the SSA retrieved assuming a) OMI empirical aspect ratio distribution and b) spherical particle assumption yield a consistent positive bias of 0.014 and 0.012, respectively, for measurements of AOD440>0.4, relative to those derived assuming spheroidal distribution proposed in Dubovik et al. (2006).

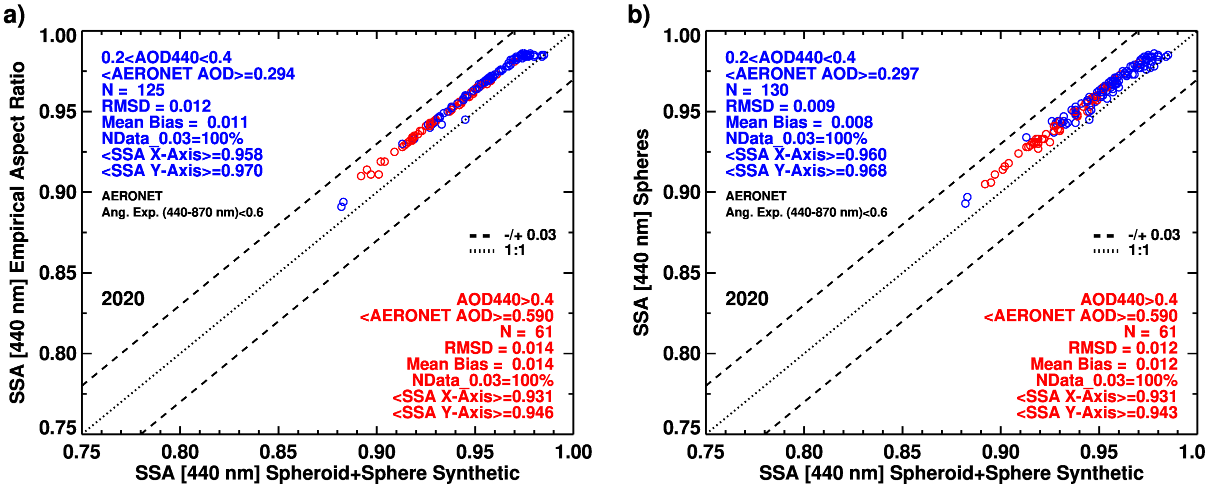

Figure 2 SSA440 comparison charts between a) empirical aspect ratio and b) spherical particles against those retrieved assuming AERONET-like spheroid + sphere approach. Blue (red) data points indicate AOD440 conditions < 0.4 (> 0.4).

Next, when compared against the AERONET Level 1.5 SSA inversions, as shown in Figure 3 below, the use of empirical aspect ratio distribution in the inversion results in a positive bias of 0.008, which if accounted for a negative bias of -0.006 noted in the AERONET-like inversion approach (a), becomes even larger and 0.014.

These results, based upon the synthetic DD ratio simulation using actual AERONET inversion data, suggest noticeable sensitivity of the choice of dust aspect ratio distribution on the SSA retrievals from MFRSR ground sensor, where the empirical distribution adopted in the present work as well as spherical dust model tested in the inversion procedure would result in higher SSA.

This analysis and findings are added into the revision in section 4 Uncertainty Characterization (pages 14-15, lines 482-507).

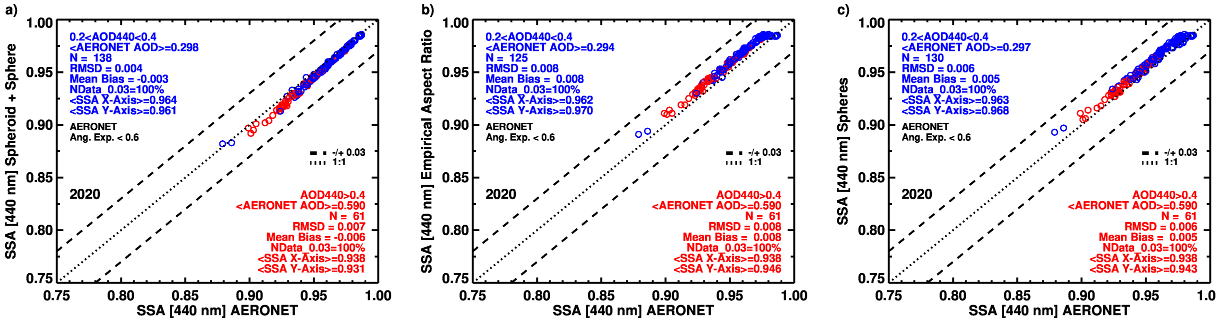

Figure 3 Similar to Figure 2 but retrieved SSA440 are compared against AERONET Level 1.5 inversions.

Minor comments

- *Throughout the manuscript, the term "retrieved" is used for SSA obtained from the MFRSR technique. Strictly speaking, only the imaginary part of the refractive index is retrieved, while SSA is subsequently estimated based on additional microphysical assumptions. Please consider rephrasing accordingly. The same applies, to some extent, to AERONET. Given that much of the analysis focuses on SSA, it would be more consistent to also compare the retrieved imaginary refractive index k (as was done with SSA in Figs. 11 and 12).*

We agree here that the actual retrieved quantity from MFRSR observations is the imaginary part of the refractive index at different wavelengths, which is translated to corresponding SSA using the aerosol PSD derived from AERONET inversion. We've changed the terminology in the revision from "retrieved" to either "derived" or "calculated".

Comparison plots of the retrieved imaginary part of the refractive index (*k*) for the year 2020 data are added to Figure 11. An additional figure comparing *k* for years 2020-2023 is also included and discussed in the revised paper in section 5.2.

- *Line 355: "derived aspect ratio distribution was simulated using a modified, substantially faster version of the Light Scattering…" Faster compared to what? The original DLS implementation? As already noted in my previous review, the description in the Appendix indicates that the DLS package was not used in an optimal configuration. Under these circumstances, performance comparisons are not meaningful, especially since computational efficiency is not the focus of this study. An analogy would be outperforming a high-performance system that is improperly configured, this does not constitute a meaningful benchmark. Please revise this wording.*

The statement on Line 355 refers to SDSL's (now re-named as API) faster performance (i.e., substantially less computational time) relative to the original DLS software package.

I recommend providing a comparison of SDLS outputs against independent Mie calculations for spherical particles to rule out interpolation-induced biases as a possible contributor to the observed SSA discrepancies.

We used both original DLS software package and modified API in the derivation of SSA440 from the synthetic downwelling DD ratio data simulated using the actual AERONET Lev 1.5 direct and inversion datasets for 2020 at the Izana site. These dust aerosols were treated as spherical particles in both inversion runs, as suggested by the Reviewer. The SSA440 comparison chart shown below in Figure 4 shows negligible differences between the two software tools with RMSD and Mean Bias in SSA440 remain very low (0.002-0.003). The level of agreement found in these comparison results demonstrated consistency between the two tools, ruling out any major errors or biases in simulating phase matrices with modified API tool. These results are now included as Supplementary Figure 3.

A detailed response to additional concerns on DLS vs. SDLS is presented in Part 2 of this report.

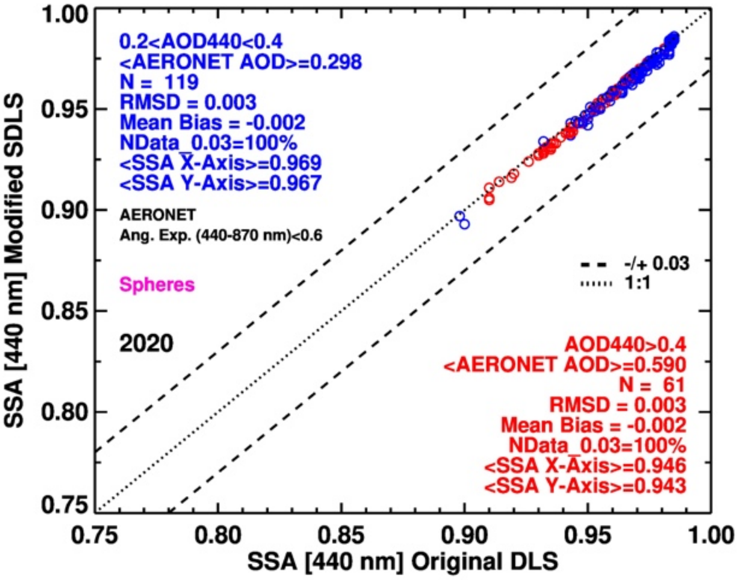

Figure 4 Comparison of SSA440 derived using refactored DLS (SDLS or the API) (y-axis) and Original DLS (x-axis) software tools. Synthetic downwelling surface diffuse-to-direct ratio simulated using 2020 actual AERONET Lev 1.5 measurements were used. The dust aerosols were treated as spherical particles in both simulations.

Part 2

2nd Response on SDLS (now renamed and referred to as API) Comments (led by ***S. Korkin***)

We thank Reviewer 1 for their second careful review and for taking the time to provide detailed comments again, particularly regarding the Appendix, despite it constitutes only ~5% of the manuscript. We now better understand the Reviewer's concerns and acknowledge that the first two versions of the Appendix were not clearly formulated in several places. We have revised the former SDLS (now the API) Appendix accordingly - hopefully to the Reviewer's satisfaction - and we sincerely appreciate Reviewer's time and effort devoted to improving our work.

As for DLS, the past two decades have shown the original DLS package to be exceptional: since 2006, to the best of our knowledge, no comparable alternative has emerged. Focusing on our specific needs, we use only a subset of its capabilities, omitting those not currently required in our algorithm, thereby reducing computational costs and streamlining our particular applications.

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Definitions, notation, color coding: Given that Reviewer 2 did not comment on the SDLS (now the API) Appendix, neither in the first nor in the second round of reviews, in this 2nd response we address Reviewer 1 as the Reviewer for simplicity.

As in our 1st response to the Reviewer, we use the following colors and fonts. The Reviewer's comments are quoted in "*Blue Italic*". Our response is in regular black font, quotations from the Appendix are in "*Black Italic*"; **Bold** demarcates parts and sections in the response, e.g., **Summary of Changes**.

This is the third version (second revision) of the Appendix. Where necessary, we refer to the first two by explicitly indicating the date of submission (MM/DD/YY), e.g., *"... original Appendix (10/2/2025) ..."*, *"...previous Appendix (12/31/25) ...."*; we call the third version as "*current*". All indicated line numbers correspond to the current version of the Appendix.

Most of the Reviewer's concerns incorporate several issues. Below, we address each concern (usually framed by the Reviewer as a paragraph or a numbered item) by splitting it into smaller pieces (issues) and addressing each issue individually.

Part One - Response to Report #1 form

We first address the last paragraph in the Report as it summarizes the Reviewer's concerns. This gives us an opportunity to also summarize the changes we made in the Appendix at the very beginning, before we proceed to detail.

"Finally, I emphasize that it is entirely acceptable to fork and adapt scientific software to suit specific retrieval needs, provided appropriate references and acknowledgments are given, and the authors have clearly invested significant effort in this regard."

We thank the Reviewer for this comment.

"*However, the justification for such developments should not rely on mischaracterizing or implicitly discrediting the original implementation, particularly when it may not have been used under optimal or representative settings. I strongly encourage the authors to revise the SDLS discussion, especially lines 740–750, to ensure factual accuracy and a balanced presentation.*"

Summary of Changes: We agree with the Reviewer and have substantially revised the Appendix accordingly. The previous version (10/02/25) contained ~930 words, while the current one contains ~1480. This increase accounts for the removal of ~170 words that discussed spline interpolation.

In the current revision, we have made the following key changes:

1. The term SDLS was dropped as it potentially creates confusion and conflict with original DLS, both in the Appendix and in the main text. We now use the Reviewer's suggested term API, keeping "*reader/interpolator*" as a synonym.

2. Our previous criticism of interpolation over radius was indeed not sufficiently justified. We removed that paragraph entirely and replaced it with a concise explanation of why such interpolation is unnecessary for our specific application, and what approach we use instead [lines 786-800].

3. In the numbered list of the API modifications, as compared to DLS, we have added a new item #1 [lines 803-805] clarifying that:
    a. The original ~5 GB kernels from (Dubovik et al., 2006) were not modified in any way.
    b. The fixed kernels, in ASCII format, were generated in a standard way using the original DLS package.

4. Only after this step 3(b) did we convert the fixed kernels from ASCII to binary format as it is now clarified in item #2 of the same list [lines 806-811]. The item #2 also clarifies that we have checked the kernels in the binary format against those generated by DLS in ASCII. Link to the open-source kernel converter, that also compares binary vs. ASCII, have been retained in the last paragraph of the Appendix.

5. We have expanded the description of the API validation to include four independent methodologies, each described in a separate paragraph, with quantitative estimates of deviations from DLS and their impact on SSA 440 nm retrieval [lines 829-853].

6. We have added traceable (weblinks) references (Korkin et al., 2024a, b), also co-authored by a few members of the original DLS team, documenting prior public presentation of the API [lines 854-858].

7. Throughout the revised Appendix, we now explicitly emphasize that the modifications are made "for our specific needs," in the context of the MFRSR retrieval algorithm. Generalized statements and broader interpretations have been minimized.

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"Line 355: "derived aspect ratio distribution was simulated using a modified, substantially faster version of the Light Scattering…" Faster compared to what? The original DLS implementation? As already noted in my previous review, the description in the Appendix indicates that the DLS package was not used in an optimal configuration."

This performance-measurement concern is closely relevant to the next one – so we give one answer to both, after the next concern.

"Under these circumstances, performance comparisons are not meaningful, especially since computational efficiency is not the focus of this study. An analogy would be outperforming a high-performance system that is improperly configured, this does not constitute a meaningful benchmark. Please revise this wording."

“*Faster*” compared to the original DLS that was used by the MFRSR team before the API was tried in February, 2025. Initially, the MFRSR team ran the original DLS with linear interpolation (keyLS = 1 in input.dat file) – not spline:

```
4 6 0 1 0 0 1       ! key,keyEL,keySUB,keyLS,key_org,key_fx,key_RD1
```

Except for bilinear interpolation over real and imaginary parts of refractive index, the API does no other interpolation. Also, the API reads the fixed kernel files in binary format. Without loss of accuracy (we checked that), these two modifications accelerate retrievals. The speed up is so obvious that its precise quantification was not deemed necessary (approximately, it is on the order of tens of times).

Our **Summary of Changes** above indicates that the revised Appendix no longer discusses interpolation but attributes the speed up to avoiding the one and to reading the fixed kernels from binaries.

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“*Lines 742–743: “Next, DLS relies on a computationally expensive cubic spline for interpolating the fixed kernels k…” This statement is incorrect. Spline interpolation is an optional setting in the DLS software. Linear interpolation is also available and is the most straightforward option.*”

Yes, we agree with the Reviewer and deleted the entire paragraph discussing interpolation. Co-author Korkin was not aware of the linear interpolation option because the DLS version he has used since 2012 (obtained from the original developers around that time) does not include keyLS = 1 or 2:

```
2 0 0 0 0       ! key,key_f11,key_f344,key_org,key_fx
```

However, co-author Korkin argues that a “no interpolation” option would be the most straightforward, with linear and spline interpolation as more accurate in certain cases, yet always more complex, alternatives.

“ *… It is unlikely that AERONET would rely on an unnecessarily inefficient DLS configuration….*”

The internal AERONET implementation details are not publicly documented, so we cannot directly assess the specific configuration used in their operational setup.

“I recommend providing a comparison of SDLS outputs against independent Mie calculations for spherical particles to rule out interpolation-induced biases as a possible contributor to the observed SSA discrepancies.”

The Reviewer is correct that earlier versions of the Appendix did not explicitly describe how the API was tested against the original DLS. We have addressed this by adding several paragraphs describing different tests, as noted above in the **Summary of Changes**. However, the suggested comparison would primarily test the DLS kernels themselves. This has already been extensively validated since the original 2006 release of DLS and over the past two decades by multiple groups. Our objective here was more specific: to ensure that the API reproduces the original DLS results for identical input conditions.

Part Two: Response to “Reviewer 1 Comment on Highlight Status on SDLS”

“I would proceed with extreme caution in publishing this article due to the possible affiliation issues, most of which are related to the appendix, describing DLS code “refactoring” or SDLS. My concerns are the follows:”

We now better understand the Reviewer’s concerns because the previous versions of the Appendix did not clearly explain what data from the original DLS was used in the API (which we believe the Reviewer means by *“affiliation”* - relationship between the two codes), nor how the API was tested and discussed. These issues are now addressed in the revisions specified in the **Summary of Changes** above; details are below.

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“1) Linked repository is not a branch of the DLS package it is a “from scratch” commit made by a single author …”

Yes, this is correct. The original DLS reader/interpolator was adapted in 2022/23 for the needs of a different project, not directly related to the present manuscript. We have kept the following sentence in the Appendix: “*This work was initiated as part of the translation of MAIAC’s (Lyapustin et al., 2021) polarized radiative transfer solver IPOL (Korkin and Lyapustin, 2023) from FORTRAN into C*.” After completion, co-author Korkin uploaded the source code to his GitHub to enable public discussion of the modifications, as well as for the case of other groups might be interested in the changes. This subsequently led to collaboration with the present co-authors.

“*… it does not contain clear affiliation to the DLS package itself, only a screenshot of original article…*”

Here we respectfully disagree with the Reviewer. In response to their similar comment during the first revision, the previous Appendix (12/31/2025) was entirely copy-pasted to co-author Korkin’s GitHub / Readme section (first page that opens) https://github.com/korkins/spheroids/, including references to:

- Dubovik et al., 2006: https://doi.org/10.1029/2005JD006619
- The GRASP website: https://www.grasp-open.com/
- The modern DLS package on the GRASP website: https://code.grasp-open.com/open/spheroid-package/

In particular, the last paragraph in the previous Appendix (12/31/2025) states: “*Our improvements are relevant to the software. We added nothing to the scientific aspects described in Dubovik et al. (2006) …*”. The current Appendix has also been uploaded to co-author Korkin’s GitHub, and the above references are retained.

“*- it requires manual analysis and can not be done automatically*”

Yes, as the Reviewer has noted above, the new reader/interpolator was developed *“from scratch”* (strictly speaking by looking in the original DLS-2012) and in a different programming language – C, as opposed to FORTRAN in the original DLS. This implies that all executable lines (operators) of the code are new. As a result, there is no direct line-by-line correspondence that could be tracked automatically using tools such as GitHub’s version control (to the best of our understanding, this is the essence of the Reviewer’s comment).

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“*2) Reasons for the code re-writing are not clear …* ”

The code re-writing was completed for another NASA GSFC LUT-based algorithm, MAIAC (Lyapustin et al., 2021), in order to: (a) convert it to C, MAIAC’s main language; (b) optimize the original DLS reader/interpolator first for MAIAC and later for MSRSR needs by avoiding interpolation and converting the fixed-kernels from ASCII to binary format. In addition to that, (c) refactoring brings in-house experience and eliminates black boxes. As it is known, the original DLS is currently supported from France, while both algorithms, MAIAC and MFRSR currently using the new API, are based in the US.

“… *the performance issues described could be attributed with package misuse or use of outdated version*”

The Reviewer is correct that co-author Korkin refactored an *“outdated”* version of the DLS (circa 2012) and, for that reason, criticized interpolation unfairly. However, the modern DLS version does not offer the “no interpolation” option and still reads the fixed kernels from ASCII – just like the outdated DLS. As the Reviewer wrote during the first round of reviews: *“I do understand that binary format is more practical* *and faster, ... "* - in their "Minor Comments" sections, about lines 639-644 in that Appendix (10/03/2025). So, using binary instead of ASCII format seems an obvious optimization; avoiding unnecessary (for us) interpolation speeds up the code further.

As to the *"misuse"*, the Reviewer seems to refer to an input parameter keyLS in the DLS input file, controlling two options for interpolation over the radius: keyLS = 1 for linear, 2 for spline. Unlike co-author Korkin, the MFRSR algorithm has always used a newer DLS version (circa 2015) with keyLS set to 1 (linear). Still the API outperformed it in our algorithm without loss of accuracy. Otherwise, we would not have replaced one code with the other.

***

"3) The essence of the publication is the use of non-spherical kernels (retrievals with spheres were already done before)."

We do not see a concern expressed here; however, based on the context, it appears that (3) was meant to be part of (4). We proceed there.

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"4) The non-spherical kernels, result of original work by Dubovik et al., 2006 contain significant computational and methodological effort that being stored in the text form take approximately 5GB represent main volume of the original DLS package."

Yes, we agree with this and have never claimed the opposite.

" *These didn't undergo any change…"*

This is correct.

"... but were converted to a proprietary binary format ..."

Here the Reviewer is mistaken. We have not modified the 5GB kernels in any way. To avoid this misreading, in the numbered list of changes (see **Summary of Changes** above) we have added item #1 clarifying that the fixed kernels were generated in ASCII format using the original DLS package (i.e., no changes yet). Item #2 then states that these fixed kernels are converted to a binary format (i.e., no change in data – only in its format). And in the last paragraph of the Appendix we have also preserved the statement: *"... we added nothing to the scientific kernels* **K** ..." (note the capital **K** notation for 5 GB kernels has been introduced in the Appendix since its original submission, now in the 3rd paragraph from its top).

"*… and were published on github with the affiliations that nobody would call spotless.*"

In response to the Reviewer's concern #1 above we say that, to the best of our knowledge and belief, our GitHub properly indicates affiliation: we give reference to Dubovik et al, 2006, the GRASP website and, additionally, the stand-alone modern DLS package with the 5GB kernels. The Reviewer does not specify what other references or weblinks we must include in addition to those already mentioned in the Appendix and on our GitHub (the latter is a copy-paste of the former).

"Without these kernels, which still comprise of the 90% of SDLS package in volume, it is useless, since the rest provides rather straightforward API to work with them."

Yes, we again absolutely agree with the Reviewer's statement. The 5GB DLS LUTs contain key scientific achievement, while our reader/interpolator is indeed just the API.

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“5) The code of conversion from original text kernels to binary is not published. The link to the original kernel repository is not published.”

The Reviewer is mistaken here. In response to their comments four months ago, we have uploaded the conversion code, with instructions and reproducible example: https://github.com/korkins/spheroids/tree/main/convert_kernels_src_linux (note, it was specifically tested on Linux as it is widely used by the scientific community). Both the previously discussed and the current versions of the Appendix contain the link to the original DLS – the 5GB “main” kernels are there, on the GRASP website.

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“*6) It is unclear was the SDLS mentioned in the paper used in other works …*”

Yes. Since 2023, co-author Korkin has routinely generated TOA reflectance LUTs accounting for polarization over land and ocean in algorithm MAIAC using the API. All versions of the Appendix contain this sentence:

“*This work* [API optimization] *was initiated as part of translation of MAIAC’s (Lyapustin et al., 2021) polarized radiative transfer solver IPOL (Korkin and Lyapustin, 2023) from FORTRAN into C.*”

Since that year 2023, the MAIAC team has published several papers which Dr. Korkin also co-authored, including: https://doi.org/10.3389/frsen.2025.1677438; https://doi.org/10.3389/frsen.2025.1654779; https://doi.org/10.3389/frsen.2025.1533803; and https://doi.org/10.5194/acp-24-10543-2024.

In the “Author contributions” section of the three Frontiers of Remote Sensing (fresn) papers, “software” is mentioned for co-author Korkin (initials - SK); in the Atmosphere Chemistry and Physics (acp), the same section says: “AL and SK conducted RT calculations (LUTs for MAIAC).” The mentioned “software” and “RT calculations” include results generated with the API.

We acknowledge that no details about the API are provided in these MAIAC papers. For that reason, we do not include them in the current paper’s References. However, in our reply to the Reviewer’s comment #7 below, we include two new references relevant to this concern #6.

“… repository itself is dated 2 years ago”

The Reviewer is not accurate here. The API repository, mentioned in the Appendix https://github.com/korkins/spheroids, is dated 3 (three) years ago as of today (March 25, 2026), except for README.md (API description) and the /convert_kernels_src_linux/ folder, which was uploaded four months ago in response to the Reviewer’s previous request.

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“7) Authors claim that they are aware of improvements of DLS over the years, it is not very clear though if authors of original DLS are aware …”

Yes, they are. Co-author Korkin presented the following two posters at the AERONET-focused meetings:

A) Korkin, S., Lyapustin, A., and Holben, B.: AERONET Project: The Next 30 Years of Software Development, AERONET Science and Application Exchange, University of Maryland College Park MD, September 17-19, 2024(a).

Link to poster (accessed 2026/03/26): https://aeronet.gsfc.nasa.gov/new_web/AERONET_Exchange/2024/Posters/ASAE__SKorkin_ALyapustin_BHolben_Poster.pdf
Note the section “Light Scattering by Spheroids” in its bottom-right part, occupying about 15% of

the poster area, is clearly visible.

B) Korkin, S., Lyapustin, A., Siniuk, A., Slutsker, I., Lind, E., and Holben, B.: AERONET Scientific Software After 30 Years: Time to Re-Optimize? American Geophysical Union Fall Meeting, Washington DC, USA, December 9-13, Abstract #A11Q-1890, 2024(b).

Link to abstract: https://agu.confex.com/agu/agu24/meetingapp.cgi/Paper/1577853 (accessed 2023/03/26).

Note the mentioned poster (B) and the paper by Dubovik et al., 2006 share 3 co-authors: A. Sinyuk, B. N. Holben, and I. Slutsker. AGU does not save posters, but the AGU abstract says: "*Our presentation will review updates to scientific software, relevant to AERONET, over the past few years, including radiative transfer solver, atmospheric absorption spectroscopy, and light scattering by spheroids.*"

Clearly, both AERONET Science and Application Exchange meeting and the AGU session A121 "Remote sensing measurements of aerosols: AERONET 30 years and beyond" were well attended by the international AERONET community, including the original DLS developer, Dr. O. Dubovik and co-developer, Dr. A. Sinyuk.

We have added these traceable references (A) and (B) to the Appendix and the list of References of the manuscript.

"… or gave permission to such drastic code re-use …"

Based on their comment #4, the Reviewer appears to assume we changed the 5GB kernels and based on that they call the change *"drastic"*. But we did not change the 5GB kernels in any way and now clarified that in lines 803-805. We use the original 5GB kernels as is, in ASCII format, and generate the smaller fixed kernels also in ASCII format using the original DLS package – reference to Dubovik et al., 2006 has been provided.

Only after that, we converted the fixed kernels from ASCII into binary, developed an API to read the binary format, and tested the API vs the original DLS. We respectfully disagree with characterizing these changes as *"drastic"*.

Specifically, about *"permission"* we note the following. The original DLS package and the 5GB DLS kernels (*"90%"* of the package significance, according to the Reviewer) were created and published in 2006 by US Civil Servants at NASA (O. Dubovik, B. Holben, and M. Mishchenko), NASA contractors (A. Sinyuk, T. Lapyonok, T. F. Eck, M. Sorokin, and I. Slutsker) in collaboration with non-NASA authors. The work was "*continuously*" (as Dubovik et al., 2006 stated in the Acknowledgements) supported by NASA EOS Project Science Office and partially by NASA Radiation Science Program and NASA Glory Mission. Therefore, the results of this work should be publicly available based on NASA's open science policy: https://www.earthdata.nasa.gov/engage/open-data-services-software-policies.

Hence, we believe that nothing prevents another NASA contractor, like co-author Korkin, from refactoring the original package provided the original work is cited and the result is made publicly available – we have done both. Our Appendix presents support of two NASA-based algorithms, MFRSR and MAIAC, and potentially some others, like NASA GSFC's AERONET which team is aware about the API. Note, that co-author Korkin refactored the original DLS reader dated (circa 2012) as close to the original publication (2006) as possible.

"… none of them is included as a co-author"

Reviewer is correct here that no member of DLS developers were invited as co-author. Following are the reasons for such action:

- The Reviewer is correct in stating that the API " *is a "from scratch" commit made by a single author"*; co-author Korkin did not ask the original developers for help.

- The Reviewer is also correct regarding the 5GB kernels: "*Without these kernels, which still comprise of the 90% of SDLS package in volume, it is useless, since the rest provides rather straightforward API to work with them."* We did not modify the 5GB kernels in any way but only developed the API.

- The Reviewer is aware that the original DLS package has always been open source, either by request from the developers (Dubovik et al., 2006) or, more recently, from the GRASP GitHub. The open-source concept, we believe, allows us to distribute our API as an open source too, and the science ethics obligates us to provide references – we have done both. However, open source does not necessarily and strictly imply that the original developers must be onboard as co-authors.

- The paper under review has 17 co-authors, and a lot of different work has been done by the team. The API Appendix, taking ~5% of the manuscript by word count, does not constitute the main focus of the paper but only briefly describes a supporting tool. For that reason, we placed the API in the Appendix rather than creating a dedicated section in the main text. Although, considering this multi-round discussion, we are now thinking of writing a dedicated paper about the API, to which the original developers will be invited.

Based on these reasons, we believe that inviting the original DLS developers as co-authors was not mandatory.

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