We thank the referees for their careful evaluation of our manuscript and for the constructive comments, which have helped us substantially improve the clarity, scope, and methodological robustness of the paper. In response to the reviews, we have revised the manuscript extensively, with particular attention to the retrieval of the imaginary part of the complex refractive index.

The main changes are as follows. First, we have clarified throughout the manuscript that we do not attempt to retrieve particle shape, particle size distribution, and the full complex refractive index simultaneously. Instead, we retrieve the imaginary part of the refractive index, *k*, under prescribed assumptions for particle shape, particle density, and the real part of the refractive index, n. Second, we have clarified the distinction between scattering coefficients corrected for truncation, which are used for the description of the campaign optical properties, and truncated scattering coefficients, which are used directly in the retrieval to avoid introducing additional assumptions on the full phase function. Third, we have added a flowchart of the retrieval procedure. Fourth, we have expanded the sensitivity analysis to include particle density, the real part of the refractive index, particle-shape assumptions, and the uncertainty associated with the aethalometer correction. Fifth, following the reviewers' suggestions, we have added synthetic observation experiments in the Supplement to test the behaviour of the inversion under controlled perturbations of the input variables. Finally, we have revised the title, abstract, methods, and conclusions to better reflect the scope and limitations of the retrieval.

We believe that these changes have substantially strengthened the manuscript and clarified both the value and the limitations of the proposed retrieval framework.

Referee #3 Review on: ***Optical Properties and Shape-Dependent Complex Refractive Index Retrievals of Freshly Emitted Saharan Dust***

By Yus-Díez, J. et al. – egusphere-2025-2571

General comments

The paper is well written and structured. It deals with the never-ending topic of properties of desert dust by analysing them in situ next to the source, and thus contributing to a rather scarce dataset of desert dust observations. It is decently illustrated and referenced, althhough I'd put some suggestions if authors would like to add them later. However, at least how it feels to me, these are two papers, one is generally describing a field campain and data colelcted, which is almmost flawless apart of several minor suggestions, and another part dealing with retrievals of desert dust imaginary part of refractive index. I can accept only the first one, since methodologically section 2.6 is so weak, fixing it would require writing another paper, below I'd try to structure my concerns. Generally, I'd leave suggest a majour review, either by getting rid of the sections 2.6 and 3.3 (and I'm afraid changing the name and scope of the paper), either significantly rewriting them.

We thank the referee for the detailed and critical assessment of the manuscript. We appreciate the referee's recognition that the field-campaign component provides a valuable dataset of freshly emitted Saharan dust. We also understand the concern that the manuscript originally combined two components: the description of the field measurements and the retrieval of the imaginary part of the refractive index. We agree that the latter required a clearer explanation of its scope, assumptions, and limitations.

We have therefore substantially revised Sections 2.6 and 3.3, as well as the title, abstract, conclusions, figures, and Supplement. The revised manuscript now makes explicit that we do not retrieve particle shape, particle size distribution, and the full complex refractive index simultaneously. Instead, we retrieve k under prescribed assumptions for particle shape, particle density, and n. The purpose is not to determine a unique "true" shape or refractive index, but to quantify how the retrieved k depends on plausible and literature-supported assumptions, including shapes constrained by campaign-specific particle analyses.

We have also clarified the treatment of scattering measurements by distinguishing corrected scattering coefficients, used to describe the campaign optical properties, from truncated scattering coefficients, used in the retrieval. This distinction is now reflected in the notation tsca and tssa. In addition, we have added a retrieval flowchart and a new Supplementary section with synthetic observation experiments to test the inversion under controlled perturbations of the input variables. These changes were made specifically to address the referee's concerns regarding the reliability, transparency, and interpretation of the retrieval framework.

Major Comments:

Majority of corrections used in situ measurements and described in methodology section are affected by particle shape assumptions, and accuracy of such corrections and resulting impact on observed values and most importantly retrievals are not discussed in the paper.

We thank the referee for pointing out that the role of particle-shape assumptions in the instrumental corrections needed to be clarified. In the revised manuscript, we now separate two different uses of the scattering measurements.

First, for the description of the campaign optical properties in Sections 3.1 and 3.2, scattering coefficients are corrected for truncation following the approach of Teri et al. (2022), which builds on the framework of Müller et al. (2011). These corrected values are used to report and interpret optical quantities such as scattering coefficients, SSA, asymmetry parameter, and backscatter fraction.

Second, for the retrieval of k in Section 3.3, we do not use a scattering coefficient corrected to the full phase function. Instead, we use the truncated scattering coefficient measured by the nephelometer and simulate the corresponding truncated scattering in the observation operator. We have introduced the notation tsca for truncated scattering and tssa for the corresponding truncated single scattering albedo. This choice avoids introducing an additional correction to full scattering that would itself depend on assumptions about particle shape and the phase function.

We have revised Section 2.6 accordingly to make this distinction explicit.

Issues in sections 2.6 and 3.3, describing the retrivals of imaginary part of refractive index. First of all authors do their best to disentangle shape, size and complex refractive index of desert dust particles — an impossible trick using the observations provided. With all due respect having a wide range of values that depend on selected real part and the non-sphericity modelling doesn't give any insite of what this parameter is actually are, all effects combined the unceranty of such retrieval in real world scenario will be huge, even if we limit the analysis to the specific shape model, and disregard completely the uncertainty of the observations used in the retrieval, as authors did.

We agree with the referee that the available observations do not allow particle shape, particle size distribution, and the full complex refractive index to be retrieved independently and simultaneously. This is why the revised manuscript now states more clearly that only the imaginary part of the refractive index, k, is retrieved, and that this retrieval is conditional on prescribed assumptions for particle shape, particle density, and the real part of the refractive index, n.

The objective is therefore not to identify a unique combination of dust shape, PSD, and CRI. Rather, the objective is to quantify how k changes under a set of plausible assumptions that are either constrained by campaign-specific measurements or taken from established optical-property databases and previous studies. We have revised the relevant text to avoid any implication that the inverse problem is fully determined by the observations alone.

To address the uncertainty concerns raised by the referee, we have expanded the analysis to include sensitivity tests to particle density, n, particle-shape assumptions, and the aethalometer correction. We have also added synthetic observation experiments in the Supplement, in which controlled perturbations are applied to the truncated scattering coefficient, absorption coefficient, and PSD. These experiments help assess the behaviour of the retrieval under known perturbations and clarify which assumptions have the strongest effect on retrieved k.

Ideally it would be nice to see another group of retrievals on the edges of the SSA estimation uncertainty. And methodologically speaking to vary also the corrections used to provide this estimations, including the truncation, density packing etc. to see all possible impacts on the parameters that are lately used in the retrievals. As I mentioned above characterising this wil be a hell of astudy, wich will presumably yield very sad and unsatissfactory results increasing the uncertainty of k “retrievals” skyhigh. Nonetheless, I would be pleased to be proven wrong on this one, if such revision will be provided.

We agree that the sensitivity of the retrieved k to measurement and correction uncertainties is important. In the revised manuscript, we have therefore expanded the uncertainty assessment in several ways.

First, we now account for uncertainty in the aethalometer correction by using low and high estimates of the multiple-scattering correction parameter C, based on the 95 % confidence interval reported by Yus-Díez et al. (2025) for Saharan mineral dust samples collected during the same campaign and resuspended in the laboratory. Second, we replaced the previous simplified sensitivity to inlet cut-off with a sensitivity to particle density. We now use a campaign-specific central density estimate of 2.15 g cm^{-3} and test additional values of 1.8 and 2.5 g cm^{-3}, consistent with the range reported in the literature. Third, we explicitly test multiple shape assumptions, including campaign-constrained spheroids, the Dubovik et al. (2006) spheroid distribution, and irregular shapes from MOPSMAP.

In addition, we have added synthetic observation experiments in the Supplement. These tests quantify how controlled perturbations in absorption, truncated scattering, PSD, particle density, and shape assumptions propagate into the retrieved k. Although a complete propagation of all possible instrumental and modelling uncertainties would require a dedicated study beyond the scope of the present manuscript, the revised analysis now provides a more transparent assessment of the main sources of uncertainty affecting the retrieval.

Another issue is the non-sphericity model selection, which seems to be arbitrary, or at least not well justified, why exactly these shapes with these parameters were chosen? Why the most commonly accepted (AERONET/MODIS operational, plus a ton of advanced satellite mission products) spheroid model is disregarded completely? Authors conclude that shape assumption provides a significant change in k retrievals, but without making retrieval with spheroid model (Dubovik et al., 2006) comparison with AERONET doesn't make much sense methodologically, not even rising questions about correctness as a whole of in-situ vs AERONET comparison. There are also impressive next-gen approaches by Bi et al., 2018 and Saito et al. 2021 a,b to tackle non-sphericity. Their existence at least should be acknowledged, and a resonable explanation why specific models are selected for the study should be provided.

We thank the referee for pointing out that the rationale for the selected shape models needed to be better justified. We have revised the manuscript to clarify the selection. The shapes considered in the retrieval now include: (i) spheres, as a reference case; (ii) spheroidal particles with aspect ratios constrained by single-particle analyses from the campaign; (iii) spheroids based on the Dubovik et al. (2006) aspect-ratio distribution, which is widely used in remote-sensing applications; and (iv) irregular particles from the MOPSMAP database.

This set does not cover all possible dust morphologies, which would be impossible in practice. However, it spans a range of commonly used and physically plausible assumptions and includes both campaign-specific and remote-sensing-relevant shape models. We have also expanded the Supplement to show the results for the individual irregular shapes rather than only grouping them in the main text.

We agree that more recent shape models, including hexahedral and more advanced irregular-particle models, are relevant and promising. We now acknowledge these approaches in the manuscript. A comprehensive comparison of all available shape models, however, is beyond the scope of the present study.

Generally, it is not fully clear for me why a rather complex (and inevitebly biased) procedure to estimate SSA was used, and then these values were fitted. Why not use the both absorption and scatering instead (as in DB19 e.g.). This also allows to simulate scattering with truncation and fit exactly what was measured.

We thank the referee for raising this important point. We agree that using absorption and scattering coefficients directly, as in Di Biagio et al. (2019), is a valid and powerful approach, particularly in controlled chamber experiments where the sampling conditions and particle losses can be better characterized.

In our field setting, however, the optical instruments and the OPC did not sample the aerosol population under perfectly equivalent conditions. Our tests suggested a possible mismatch between the OPC-derived PSD and the optical measurements, which would directly affect a cost function based on extensive absorption and scattering coefficients.

For this reason, we chose a cost function based on *tssa*, the truncated single scattering albedo, rather than on absorption and scattering coefficients separately. This choice reduces sensitivity to absolute concentration mismatches between instruments and avoids the need to correct the measured scattering to a full-phase-function value. The drawback is that *tssa* is less sensitive to the real part of the refractive index, *n*. We therefore do not retrieve *n* and *k* simultaneously; instead, we retrieve *k* for a range of fixed *n* values representative of mineral dust.

We have clarified this rationale in the revised manuscript and have added synthetic experiments in the Supplement comparing the behaviour of the adopted *tssa*-based cost function with an alternative cost function closer to that of Di Biagio et al. (2019). The revised manuscript now explicitly presents the retrieval as a conditional retrieval of *k*, not as a full retrieval of the complex refractive index.

Also method is not tested on “clean” simulated data and immediately applied to measurements, taking them as ideal, and not accounting for any possible errors and biases. Whole section 3.3 would be a proper set up for the syntetic data input generated for method testing, free of any noise and biases, but not real observations. And performing this test would also allow to perturb data and estimate retrieval accuracy by adding controlled noises and biases to the “ideal” dataset.

We agree with the referee that synthetic tests are useful to assess the behaviour of the retrieval independently of the complexity of the field observations. Following this suggestion, we have added a new section to the Supplement with synthetic observation experiments.

In these experiments, known “true” values are prescribed for the PSD, absorption, truncated scattering, particle density, and refractive index. We then perturb the input variables and test whether the retrieval can recover the prescribed value of k under different assumptions. These experiments show how the retrieved k responds to perturbations in truncated scattering, absorption, PSD, particle density, n, and particle shape. They also illustrate the consequences of using a shape assumption different from the one used to generate the synthetic observations.

We have added these experiments to make the retrieval framework more transparent and to better quantify its sensitivity to the main sources of uncertainty.

Also paper lacks consistency: some shapes were retrieved, some shapes were compared to but not retrieved, PM10 measurements are analysed provided, but not retrieved. It would be nice to see a more consistent approach.

We thank the referee for pointing out that this needed to be clarified. We do not retrieve particle shape in any case. Instead, we prescribe different particle-shape assumptions and perform the retrieval of k independently for each assumption. We have revised the manuscript to make this clearer and have expanded the Supplement to show results for the individual irregular shapes.

Regarding PM10, we agree that applying the retrieval to both PM2.5 and PM10 periods would be valuable. However, we restricted the k retrieval to the PM2.5 period because it provides a longer and more stable dataset, a larger number of dust-emission cases, and a more reliable basis for matching the OPC-derived PSD with the optical measurements. The PM10 period was shorter and more affected by instrumental and sampling challenges during high dust concentrations. In addition, extending the retrieval to PM10 would increase the sensitivity to large-particle losses and to the validity range of the optical-property databases.

The PM10 measurements are retained in the manuscript because they provide useful descriptive information on the optical properties of coarser dust. However, the retrieval of k is limited to the PM2.5 period to avoid adding an additional layer of uncertainty that could not be robustly constrained with the available data.

Minor comments:

Line 124: “at eight angular positions (0 ◦ , 10◦ , 25◦ , 40◦ , 55◦ , 70◦ , 90◦ , and 170◦).” Were this positions used in this study? If not why mention it?

Thank you for pointing this out. The eight angular positions were used to obtain the asymmetry parameter, as described in Sect. 2.5, intensive parameter e). We have added a sentence to reflect how we use them.

“The scattering collected at the different positions was used to obtain the asymmetry parameter (e.g., Liou et al., 2002; Horvath et al., 2018).”

Line 125: “Forward (0 ◦) and backward (170◦) scattering measurements were then corrected for non-ideal illumination of the light source and truncation errors using the correction scheme from Müller et al. (2011) for coarse particles”. Contradits with line 260 (see below). Please, clarify. Also, truncation correction in Muller et al. provided only for spheres. Maybe for PM2.5 impact isn’t small, but for PM10 I belive it’ll be more noticeable. It is not clear how his affects the k retrievals.

We agree that the original wording could create confusion. In the revised manuscript, we now distinguish between two quantities. The corrected scattering coefficient is used in Sections 3.1 and 3.2 to describe the campaign optical properties. In contrast, the retrieval of k uses the truncated scattering coefficient measured by the nephelometer, denoted tsca, and the corresponding truncated single scattering albedo, tssa. Thus, the truncation correction is not applied to the scattering coefficient used as input to the retrieval; instead, the observation operator simulates the corresponding truncated quantity.

We have revised Sections 2.2 and 2.6 to make this distinction explicit.

Line 128: I find using PM2.5 inlet to study dust particles, rather unorthodox. Please provide some explanation why such set up was selected, it is not clear.

We agree with the referee that using a PM2.5 inlet is not the standard choice if the objective is to characterize the full mineral-dust size distribution or the total dust radiative effect, for which PM10, TSP, or inlet-free approaches would be preferable. However, in this field campaign the PM2.5 inlet was selected as a compromise between scientific objectives and instrumental robustness under very high near-source dust concentrations.

The aim of the first part of the campaign was to obtain stable, high-temporal-resolution optical measurements of freshly emitted dust, particularly absorption and scattering in the wavelength range covered by the AE33 and nephelometer. Although PM2.5 does not include the full coarse and super-coarse dust mass, it captures a size range that is highly relevant for shortwave absorption measurements and that can be sampled more reliably by filter-based and nephelometer instruments during strong dust events. In contrast, operating PM10 or TSP in a source region during intense dust storms substantially increases the risk of inlet losses, particle deposition in the sampling line, filter loading, flow instabilities, and more frequent maintenance interruptions. Indeed, the later PM10 period in our campaign was shorter and more challenging from an instrumental point of view.

We therefore use the PM2.5 period for the retrieval of k, because it provides the longest and most stable dataset and reduces uncertainties associated with large-particle sampling, inlet transmission, particle losses, and the validity range of the optical-property databases. Importantly, we do not present the PM2.5 measurements as a complete characterization of the full dust size range. The PM10 period is retained and analysed in the manuscript to describe the optical effect of including a broader coarse-particle fraction, while the k retrieval is restricted to PM2.5 for methodological robustness.

We have clarified this point in the revised manuscript. In Sect. 2.2, we now explicitly state the two inlet periods, PM2.5 followed by PM10. In Sect. 2.6.2, we explain that the retrieval is restricted to PM2.5 because this period provides the longest and most stable dataset, whereas extending the retrieval to PM10 would increase sensitivity to large-particle sampling, inlet transmission, particle losses, and the validity range of the optical-property databases. In Sect. 3.1 and Sect. 3.2, we nevertheless discuss both PM2.5 and PM10 optical properties to show how the inclusion of coarser dust affects SSA, mass efficiencies, the asymmetry parameter, and the backscatter fraction.

Line 140: “This conversion requires assumptions about 140 the particles’ CRI and shape”. How then retrival can be done, if we need CRI to estimate PSD, to retrieve CRI? Can the uncertainty of such PSD estimations be assesses, same as it’s impact on k retrievals? Technically if you don have a unique solution, I is not retrieval, at least I wouldn’t call it this way. Provide a flowchart of the retrieval to make it clearer.

We agree that this point needed clearer explanation. There is no sequential circular dependency in which a retrieved k is first used to estimate the PSD and then retrieved again. Instead, for each prescribed combination of particle shape, particle density, and real refractive index, the OPC optical-to-geometric diameter conversion and the optical-property simulation are treated consistently within the same retrieval framework.

For the Fidas conversion, the relevant light source is represented by the inferred 389 nm spectral response. The value of k at this wavelength is first estimated consistently with the OPC diameter conversion. This conversion is then used for the retrieval at the other wavelengths. We have added a flowchart to the revised manuscript to clarify the sequence of steps.

Line 213: “minimizes the discrepancy between simulated and measured SSA”. I do believe “measured” is a very strong term for an estimation that relies on multiple assumptions and comes from separate instrumentation and in addition has no accuracy characterisation for the “measured” values.

We agree with the referee that the term “measured SSA” may be too strong, because SSA is derived from absorption and scattering measurements rather than measured directly. We have therefore replaced “measured SSA” with “SSA derived from the measurements” or, where appropriate, “truncated SSA derived from the measurements”. In the retrieval section, we now use the notation tssa to avoid confusion with the full-phase-function SSA.

Line 226: having a flow chart of the “retrieval” will be nice, it’ll bring more clarity how everything organised.

We thank the referee for this suggestion. We have added a flowchart to the revised manuscript showing the retrieval procedure, including the OPC optical-to-geometric diameter conversion, the prescribed assumptions for shape, density, and n, the simulation of absorption and truncated scattering, and the minimization of the tssa-based cost function.

Line 246: ”biaxial prolate ellipsoids” is there any reason oblate ellipsoids were disregarded?

We agree with the referee that oblate spheroids should also be considered. In the revised manuscript, we have added the Dubovik et al. (2006) aspect-ratio distribution, which includes both oblate and prolate spheroids and is widely used in remote-sensing applications. The corresponding computations and figures have been updated. Including this spheroid distribution does not alter the main conclusions but makes the comparison with AERONET more consistent.

Table 1. SSA values are provided with ± (not indicated what), is it variation in the dataset, is heit accuracy? For the latter assuming there are uncertainties on each part of the SSA estimation, b_abs has uncertainty, they are interpolated to another wl (with uncertain AE), b_scat in uncertain too, and these are combined and divided to get SSA, I found the provided uncertainty of 0.001 unrealistically low. DB19 claims uncertainty of SSA340 up to 12%, which is a whopping 0.1 (two magnitudes higher). (Once again, how this error will propagate to k, is **the** question)

We thank the referee for pointing this out. The values reported with the ± symbol combine measurement uncertainty from absorption and scattering with the temporal variability of the measurements. After reviewing the analysis, we identified and corrected a bug that affected the uncertainty values shown in Table 1. The revised uncertainty estimates are larger and more realistic.

We also note that our uncertainty calculation differs from that of Di Biagio et al. (2019), because their approach is designed for chamber experiments with concentration decay, whereas our analysis is based on ambient field measurements. To further address this point, we have added synthetic experiments in the Supplement that quantify the sensitivity of the retrieved k to perturbations in tssa.

Line 260: “These computations provided the truncated scattering coefficient and the absorption coefficient. To avoid introducing additional assumptions, we defined a modified SSA, using the truncated scattering coefficient rather than an assumed full-phase-function scattering coefficient.” This phrase is confusing, if truncation correction were not used, why pu so much descriptions about, and was the effect of having/not having truncation on SSA and importantly retrievals of k studied?

We agree that the previous wording was confusing. The truncation correction is discussed because corrected scattering coefficients are used to describe the campaign optical properties in Sections 3.1 and 3.2. However, for the k retrieval, we use the truncated scattering coefficient measured by the nephelometer and simulate the same truncated quantity in the observation operator. We have introduced the notation tsca and tssa to make this distinction explicit.

Lines 270 and 425: “and the three inlet cut-off diameter efficiencies (1.7 and 1.7 ± 10%)”, please justify that 10% is realistic innacuracy due to all affecting factors combined. Do you account the effective chage of cut-off due to the shape and consecutive PSD changes?

In the revised manuscript, we have replaced the previous ±10 % inlet-cut-off sensitivity with a sensitivity analysis based on particle density. This is more physically grounded. The aerodynamic-to-geometric diameter conversion is now computed using particle density and shape factor following Huang et al. (2021) and Bagheri and Bonadonna (2016). We use a central density value of 2.15 g cm^{-3}, measured from campaign samples, and test additional values of 1.8 and 2.5 g cm^{-3}, consistent with the range reported for mineral dust in the literature.

Line 275: “We repeated the optimisation for multiple fixed values of n within the 1.48–1.55 range, in 0.01 increments.” If understood correctly you get 7 results with different k, due to the intrinsic ill-posity of the problem, which value out of this solution group is then selected?

We do not select a single value of k as the unique solution across all possible n values. Instead, we present the retrieved k as a function of the prescribed n, because n is not retrieved independently in our framework. For summary purposes, we highlight the case n = 1.49, because this is the value reported by Di Biagio et al. (2019) for the Moroccan sample. We have clarified this point in the revised manuscript.

Figure 7. Where are the subplots for A-F shapes similar to subplots of sph, di dist and bi fix?

We have added the corresponding results for the individual irregular shapes A–F to the Supplement. This allows the reader to assess the variability among the irregular-shape assumptions rather than relying only on the grouped representation shown in the main text.

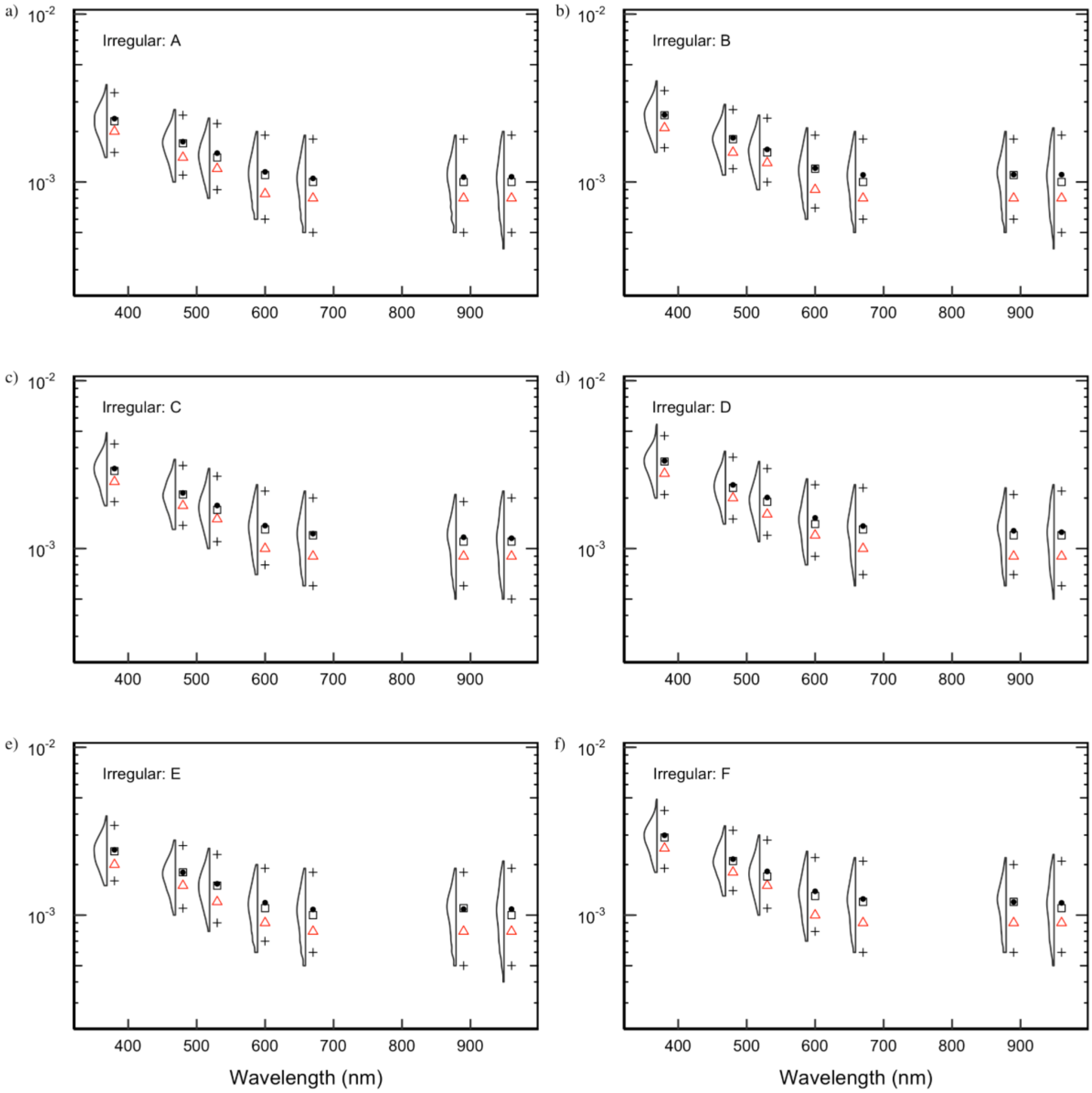

Figure S9: Retrieved *k* as in Fig. 7 for the irregular shapes from the mops database: A, B, C, D, E and F

Figure 8 Is confusing, what are shapes A,B,C,D,E and F? They are mentioned only in the caption of the figure 7 and never discussed in the paper. It is also not clear were retrievals performed for these shapes?

We agree that the description of irregular shapes A–F was insufficient. We have revised the text to clarify that these are the six irregular dust particle shapes defined by Gasteiger et al. (2011) and included in the MOPSMAP database. The retrievals were performed for each of these shapes in the same way as for the other prescribed shape assumptions. The revised Supplement now provides the corresponding individual results.

Table 2 and Table 3. Focusing on PM2.5 retrievals, were any made for PM10? The rest of article analyses properties at these cut-offs. This part lack consistency. Seeing (no) differences in k retrievals for PM2.5 and PM10 would be nice, and demonstration that they are comparable will be a good sanity check for the retrieval.

We agree that a PM10 retrieval would be a useful additional test. However, we limited the retrieval to the PM2.5 period because this period provides a longer and more stable dataset and avoids the additional uncertainties associated with large-particle sampling, particle losses, and the validity range of the optical-property databases. The PM10 period is retained for the descriptive analysis of optical properties but is not used for the retrieval of k to avoid overinterpreting a shorter and more uncertain dataset.

Figure 9. Where are shapes A-F as in Fig 7 and 8? A bit confused what are theese are and what are the logic in putting them on that figures. Why the box plots include only best estimates of n and cutoff, but not showing the realistic box plot as in fg 7 (b-d)?

We have revised the figure to include all particle-shape assumptions, including the individual irregular shapes A–F. We have also clarified in the caption which assumptions are represented and how the displayed values relate to the range of n and particle-density assumptions explored in the retrieval.

Line 218: “minimizing a quadratic cost function based on SSA” please provide the thresholds on SSA differences and typical cost function values achieved during retrievals, how the method knows when to stop? Was the SSSA fitted to satisfactory levels? And what these levels are.

The minimization is performed on a predefined grid of possible k values, following the general approach of Di Biagio et al. (2019). The algorithm evaluates the cost function across this grid and selects the value of k that minimizes the difference between simulated and observation-derived tssa. Therefore, no iterative stopping threshold is required. We have added a representative example of the cost function to the response and clarified the minimization procedure in the manuscript. An example of a typical cost function was included in Fig. 1 of this document, where the minimum of the cost function is around 4x10-8 , so the difference in SSA is approximately 0.002.

Line 227: “incorporating extensive information from the polar nephelometer”, it would be nice to read what options were considered, and generally speaking see a reference to a paper on retrieval design choice/optimisation, or at least some of the results shared in this one. In DB19 they used both absorption and scattering and managed to get both n and k. Please, discuss.

We have expanded the manuscript to explain the rationale behind the selected cost function. We tested alternatives that incorporated additional information from the nephelometer, including cost functions involving tssa and backscatter fraction. However, the available field data did not support a robust simultaneous retrieval of n and k. This limitation likely reflects the sensitivity of the retrieval to particle shape, particle density, inlet modelling, and possible mismatches between the OPC-derived PSD and the optical measurements.

Because the possible OPC-optical mismatch could bias retrievals based on extensive absorption and scattering coefficients, we selected a tssa-based cost function. This choice reduces sensitivity to absolute concentration differences between instruments, but it also reduces sensitivity to n. We therefore retrieve k for fixed values of n rather than retrieving both parameters simultaneously.

We have added this rationale to the revised manuscript and included synthetic tests in the Supplement comparing the adopted approach with an alternative cost function closer to that of Di Biagio et al. (2019).

Technical comments:

Figure 1. Middle panel text is too small to read. Caption (a,b and c,) should be **(a, b and c)**, also a/b/c/ notion is too hard to distinguish, concider making them bigger or higher contrast.

We thank the referee for this suggestion. We have modified Figure 1 to improve readability, including larger panel labels and clearer formatting of the caption.

Line 40-41: For instance, the presence of iron oxides ***in such minerals*** as goethite and hematite, plays a dominant role in dust absorption (e.g., Di Biagio et al., 2019).

We have revised the sentence as suggested to clarify that iron oxides, including goethite and hematite, play a dominant role in dust absorption.

It is not clearly mentioned anywhere but I presume aethaelometer and nephelometer share the inlet, cyclone and pump?

Yes. The aethalometer and nephelometer shared the same sampling line, inlet, and pump. We have added this information explicitly to Section 2.2 of the revised manuscript.

The name of the article states that complex refractive index is retrieved, even though, technically speaking, it is not, since n is fixed.

We agree. We have changed the title to specify that the retrieval concerns the imaginary part of the complex refractive index, k, rather than the full complex refractive index.

I'm not sure that figure colour schemes are following the guidelines for colour vision deficiencies. There's a nice set that can be used: https://www.fabiocrameri.ch/colourmaps/

We tried to follow divergence and colour friendly color schemes through-out. If there was any figure where this was not achieved it was because it was not feasible.

Citation: https://doi.org/10.5194/egusphere-2025-2571-RC1

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Referee #4 Review on: ***Optical Properties and Shape-Dependent Complex Refractive Index Retrievals of Freshly Emitted Saharan Dust***

This study presents high-resolution field measurements conducted in the Moroccan Sahara Desert to investigate the optical properties of dust and to retrieve the imaginary part of the refractive index. It explores the influence of particle size and shape on these properties. The study addresses an existing gap in measurements of fresh dust optical characteristics and helps improve understanding of how size and shape affect dust refractive index retrieval.

However, there are still areas where the clarity and methodological rigor of the manuscript could be improved.

We thank the referee for the constructive assessment of the manuscript and for recognizing the value of the high-resolution field measurements of freshly emitted Saharan dust. We agree that the original manuscript needed a clearer presentation of the scope, assumptions, and limitations of the refractive-index retrieval. We have therefore substantially revised the manuscript, particularly Sect. 2.6 and Sect. 3.3, and expanded the Supplement.

The main changes are: (i) we now clarify that we retrieve only the imaginary part of the refractive index, k, under prescribed assumptions for particle shape, particle density, and the real part of the refractive index, n; (ii) we distinguish corrected scattering coefficients, used for the descriptive optical-property analysis, from truncated scattering coefficients, used in the retrieval; (iii) we introduce the notation tsca and tssa for truncated scattering and truncated single scattering albedo; (iv) we add a flowchart describing the retrieval procedure; and (v) we add synthetic observation experiments to evaluate the behaviour of the retrieval under controlled perturbations of the input variables.

We believe these revisions substantially improve the transparency and robustness of the manuscript.

Major Comments

While the retrieval of the imaginary part of the refractive index (k) is performed, the aim of disentangling uncertainties due to particle size and shape is ambitious, especially in the context of real measurements. Reducing uncertainties in climate models presents a further challenge. Directly investigating these uncertainties often favors theoretical studies, as real-world measurements and retrievals can introduce numerous errors and biases. A primary concern here is the reliability of the retrieval method.

The authors use a modified SSA for retrieval, which differs from other studies (e.g., Di Biagio et al., 2019) that directly use scattering and absorption coefficients. Can the authors explain their choice of using SSA? What are the advantages and disadvantages compared to using scattering and absorption coefficients directly?

We thank the referee for raising this important point. We agree that fitting absorption and scattering coefficients directly, as in Di Biagio et al. (2019), is a robust approach in controlled chamber experiments, where the particle population sampled by the instruments is better constrained. In our field campaign, however, the OPC-derived PSD and the optical measurements from the nephelometer and aethalometer were not obtained under perfectly equivalent sampling conditions. Closure tests indicated a possible mismatch between the PSD measured by the OPC and the aerosol population sampled by the optical instruments.

For this reason, we chose a cost function based on the truncated single scattering albedo, tssa, rather than on absorption and scattering coefficients separately. This approach has two advantages. First, it reduces sensitivity to absolute concentration mismatches between the OPC and the optical measurements. Second, it avoids applying a correction from truncated scattering to full-phase-function scattering in the retrieval itself; instead, the observation operator simulates the same truncated quantity measured by the nephelometer.

The main disadvantage is that tssa is less sensitive to the real part of the refractive index, n. Therefore, unlike Di Biagio et al. (2019), we do not retrieve n and k simultaneously. Instead, we retrieve k for a range of prescribed n values representative of mineral dust. We have revised Sect. 2.6 to make this rationale explicit and added synthetic experiments in the Supplement comparing the adopted tssa-based approach with an alternative cost function closer to that of Di Biagio et al. (2019).

In Section 2.6, the authors state that a robust simultaneous retrieval of both the real part (n) and imaginary part (k) is not feasible. Could the authors provide more detailed explanations on this point? For example, Kong et al. (2024) demonstrated that discrepancies in particle size distributions (PSDs) between inversion models and inhomogeneous irregular dust particles can lead to biases in scattering coefficients, complicating the retrieval of n. Could a similar mechanism explain the limitations encountered in this study?

We thank the referee for this important comment. Yes, we believe that a similar mechanism is likely relevant in our case. The simultaneous retrieval of n and k is particularly sensitive to the consistency between the PSD used in the optical simulations and the particle population actually sampled by the optical instruments. Because the real part of the refractive index mainly affects scattering, any mismatch in the PSD, inlet transmission, counting efficiency, or particle losses can be partly compensated by the retrieval through changes in n. In that situation, the retrieved n would not necessarily represent the dust refractive index, but could instead absorb systematic differences between the OPC-derived PSD and the nephelometer/aethalometer measurements.

To investigate this possibility, we performed an additional diagnostic experiment, shown in Fig. R4.1 below. In this experiment, the OPC particle number concentrations were artificially multiplied by a factor *fnum* before performing the inversions. The retrievals were then repeated using two cost functions: (i) the tssa-based cost function used in the revised manuscript, and (ii) an alternative cost function closer to Di Biagio et al. (2019), based on extensive optical properties, namely truncated scattering and absorption coefficients. The purpose of this experiment was not to derive a definitive correction factor for the OPC data, but to test whether the retrievals based on extensive optical properties are sensitive to possible differences in the total particle number sampled by the OPC and by the optical instruments.

The results show that the extensive-property-based cost function is strongly sensitive to the assumed particle number scaling, whereas the tssa-based cost function is much less affected because tssa is a ratio. Depending on wavelength and particle-shape assumption, the best closure between the two approaches would require increasing the OPC particle number concentrations by factors of approximately 1.2 to 1.8. This wavelength dependence suggests that the mismatch may not be a simple constant bias in total particle number, but may also involve size-dependent effects, such as inlet transmission, particle losses, or OPC sizing/counting uncertainties.

We therefore agree with the referee that discrepancies between the PSD used in the inversion and the optically active particle population can complicate the retrieval of n, as also discussed by Kong et al. (2024). This is the main reason why we do not attempt a simultaneous retrieval of n and k from the field data. Instead, we retrieve k for a range of prescribed n values representative of mineral dust. This approach prevents the retrieval from using n to compensate for possible PSD or sampling biases and provides a more robust conditional estimate of k under prescribed assumptions.

We have added this explanation to Sect. 2.6 of the revised manuscript and have further supported it with synthetic experiments in the Supplement. These experiments show that biases in the PSD or total particle number can propagate into biases in the retrieved k, especially when cost functions based on extensive optical properties are used.

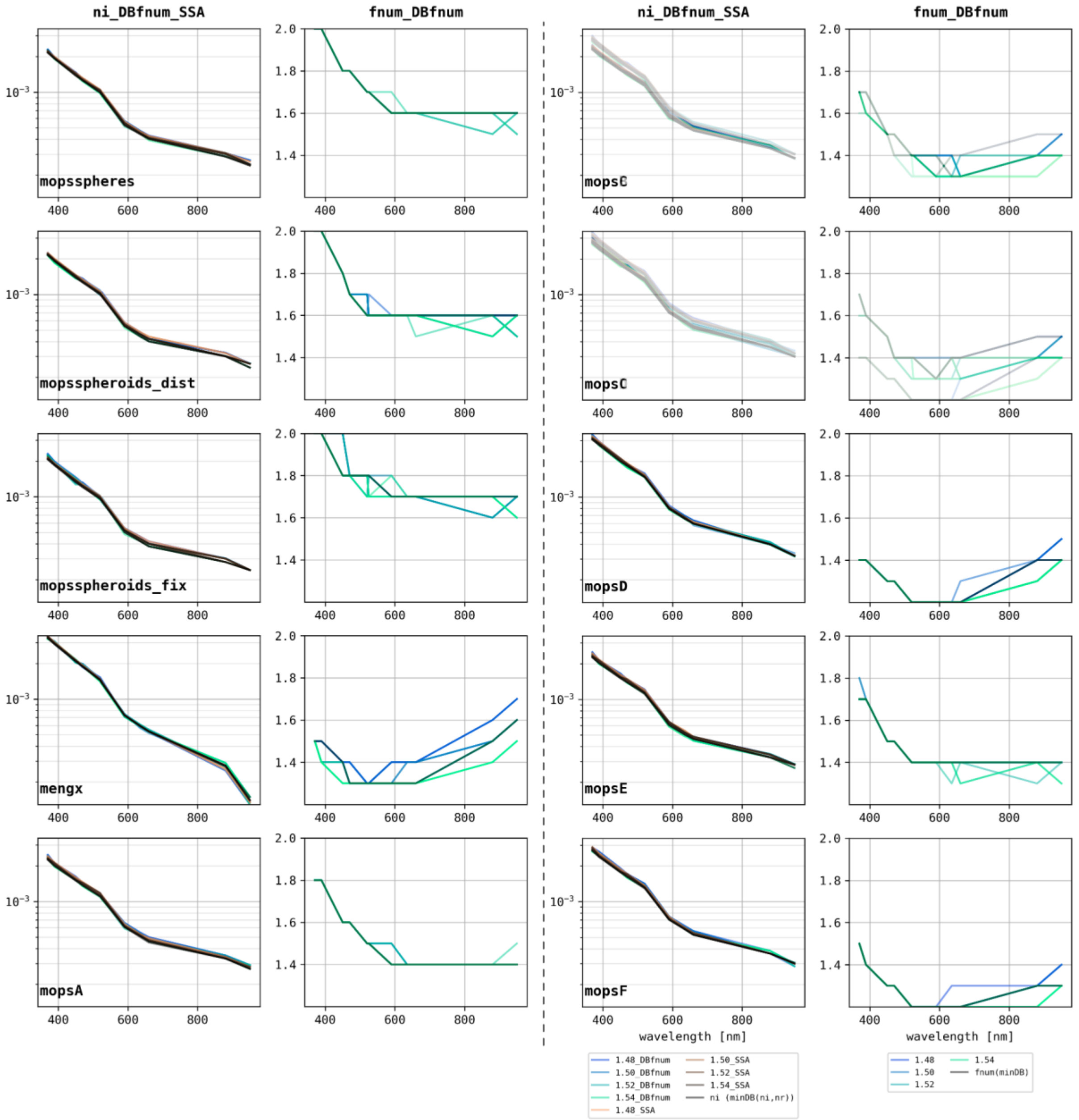

Figure R4.1. Diagnostic sensitivity of the retrieval to possible OPC particle-number bias. The OPC particle number concentrations were multiplied by a factor *fnum* before performing the inversions. Retrievals were repeated using the tssa-based cost function adopted in this study and an alternative cost function based on extensive optical properties, closer to Di Biagio et al. (2019). The comparison shows that extensive-property-based retrievals are sensitive to the assumed OPC particle number scaling, whereas the tssa-based retrieval is less affected because it is based on a ratio. The experiment suggests a possible mismatch between the OPC-derived PSD and the aerosol population sampled by the nephelometer/aethalometer, with the optimal *fnum* varying with wavelength and particle-shape assumption. This diagnostic supports our decision to avoid a simultaneous retrieval of n and k and instead retrieve k conditionally for prescribed values of n.

Additionally, it’s recommended that the authors illustrate the optical properties (e.g., scattering and absorption coefficients) computed from the retrieved refractive indices. It would be insightful to discuss the differences between these model-derived optical properties and the measurements, especially given that the retrieval of the refractive indices relies on the ratio of scattering to extinction coefficients (i.e., SSA).

We agree that this is a useful diagnostic. In the revised Supplement, we added synthetic observation experiments in which the retrieved k is used to compute the corresponding truncated scattering coefficient, absorption coefficient, and tssa. These experiments show that, when the cost function is based on tssa, the retrieved k reproduces the target tssa well, while the simulated absorption and truncated scattering can still differ if the PSD or particle number concentration is perturbed.

This behaviour is expected because the tssa-based retrieval is designed to match the ratio between truncated scattering and extinction, not necessarily the absolute absorption and scattering coefficients separately. Conversely, a cost function based on extensive absorption and scattering coefficients is more sensitive to biases in the OPC-derived PSD and total particle number. We now discuss this trade-off in the revised Supplement, where Figs. S12–S15 show the retrieved k, simulated truncated scattering, simulated absorption, and tssa under controlled perturbations.

We have not added the equivalent simulated absorption and scattering coefficients for all campaign data to the main text because, given the likely OPC–optical sampling mismatch, such a comparison would mainly reflect the uncertain absolute particle-number closure rather than provide an independent validation of *k*. We instead use the synthetic experiments to illustrate this behaviour under controlled conditions.

A robust validation of the algorithm is needed. Testing the method by adding controlled noise and biases to synthetic data, and then evaluating the retrieval accuracy, would be highly beneficial. Beyond these points, what are the authors’ suggestions for improving refractive index retrieval in real measurement scenarios?

We agree with the referee that a robust validation of the retrieval framework is needed. Following this suggestion, we added a new Supplementary section with synthetic observation experiments. In these experiments, known “true” values are prescribed for the PSD, absorption, truncated scattering, particle density, particle shape, and refractive index. We then perturb the input variables in a controlled way and apply the retrieval to evaluate how accurately k can be recovered.

The synthetic experiments evaluate the sensitivity of retrieved k to perturbations in truncated scattering, absorption, tssa, PSD, particle density, and particle-shape assumptions. These tests show that the retrieval behaves consistently when the main assumptions are correct, but that biases in PSD, particle number, density, or shape can propagate into systematic biases in the retrieved k. This confirms that, in field applications, the consistency between PSD and optical measurements is a central limitation.

We also used the OSSE framework to test the role of the OPC optical-to-geometric diameter conversion. In the main retrieval, this conversion is performed consistently with the retrieved k: the value of k relevant for the OPC wavelength is first estimated and then used to convert the PSL-calibrated optical diameters into dust geometric diameters. We compared this approach with a procedure closer to Di Biagio et al. (2019), in which the OPC diameter conversion is computed from a prescribed set of plausible refractive indices. The results are very similar when the assumed particle shape is consistent. This suggests that the simpler Di Biagio et al.-type OPC conversion can be adequate when the prescribed refractive-index range and shape assumption are representative of the sampled dust.

Therefore, our main recommendation for future field retrievals is to prioritize consistency in the sampling of PSD and optical properties. Ideally, the PSD and optical measurements should represent the same particle population, with well-characterized inlet transmission, particle losses, and size-dependent sampling efficiency. Independent information on particle density and shape is also important, because both affect the aerodynamic-to-geometric diameter conversion and the optical simulations. When such consistency is achieved, a Di Biagio et al.-type OPC conversion based on a prescribed range of refractive indices may be sufficient and computationally efficient. In contrast, when PSD–optical closure is uncertain, as in our field dataset, the retrieval should be interpreted more cautiously and presented as conditional on the assumed shape, density, and refractive-index range.

We have added the synthetic experiments and the corresponding discussion to the revised Supplement and have clarified these points in the revised manuscript.

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Kong, S., Wang, Z., & Bi, L. (2024). Uncertainties in laboratory-measured shortwave refractive indices of mineral dust aerosols and derived optical properties: A theoretical assessment. Atmospheric Chemistry and Physics, 24(11), 6911–6935. https://doi.org/10.5194/acp-24-6911-2024

Meyer, H., Kandler, K., Dupont, S., Escribano, J., Girdwood, J., Nikolich, G., Alastuey, A., Etyemezian, V., González-Flórez, C., González-Romero, A., Hussein, T., Irvine, M., Knippertz, P., Möhler, O., Querol, X., Stopford, C., Vogel, F., Weis, F., Wieser, A., Pérez García-Pando, C., and Klose, M.: From fine to giant: multi-instrument assessment of the dust particle size distribution at an emission source during the J-WADI field campaign, Atmos. Meas. Tech., 19, 21–61, https://doi.org/10.5194/amt-19-21-2026, 2026.

Minor Comments

Line 49: The citation sequence is incorrect. It would be clearer as: (e.g., Gasteiger and Wiegner, 2018).

Corrected. We have revised the citation sequence as suggested.

Line 263: Please clarify whether the modified SSA is used in subsequent analyses.

We thank the referee for pointing out that the terminology was unclear. In the revised manuscript, we no longer use the term “modified SSA”. Instead, we define the truncated single scattering albedo, tssa, as:

tssa = tsca / (tsca + babs),

where tsca is the truncated scattering coefficient measured by the nephelometer and simulated in the retrieval observation operator. The variable tssa is used only for the retrieval of the imaginary part of the refractive index, k. In contrast, the standard SSA reported in the descriptive optical-property analysis is calculated using the corrected scattering coefficient and the absorption coefficient. We have revised the terminology throughout Sect. 2.6 to make this distinction explicit.

This is important because the revised manuscript now defines tssa directly in the retrieval section and distinguishes it from corrected-scattering SSA used elsewhere.

Figure 2: Could the authors comment on the origin of some of the peaks observed in k525nm in panel (b)?

We thank the referee for this comment. The peaks in retrieved k are associated with short periods of lower measurement-derived tssa. Since k controls absorption in the retrieval, a decrease in tssa requires a higher retrieved k to reproduce the observed optical ratio. These peaks occur mainly during calmer periods and during Period C, when the influence of locally advected anthropogenic absorbing particles is larger relative to mineral dust. This interpretation is consistent with the higher absorption Ångström exponent observed during these periods.

We have clarified this point in the revised text. We now state that, during dust events, k remains relatively stable, whereas Period C and the calm phases of Periods A and B show increases of up to about one order of magnitude, indicating a stronger influence of absorbing anthropogenic particles during these intervals.

Figure 3: The font size is too small, particularly for the labels indicating different AAE values. Increasing the font size would improve readability.

We agree with the referee that the AAE labels in Figure 3 were difficult to read. We explored increasing the font size, but because several labels are close to one another, a larger font led to overlap and reduced readability. As a compromise, we adjusted the figure formatting where possible and added a clearer explanation of the AAE values in the figure caption. This makes the information accessible without relying exclusively on the small labels within the panel.

Line 414: The text refers to “Figs. 6c, d,” but it seems this should be “Figs. 6c, f.”

Corrected. We have revised the figure reference.

Line 506: Typo: “Moreovover” should be corrected to “Moreover.”

Corrected.

Line 546-547: The dependence of optical properties on composition is minimally addressed. Please either modify the expression to reflect this or add more details to elaborate on this aspect.

We agree with the referee. Because the manuscript does not provide a detailed compositional analysis of the optical-property variability, we have revised the sentence to avoid overemphasizing composition. The revised wording now focuses on the dependencies that are directly analysed in the manuscript, namely particle size, shape assumptions, and absorption/scattering behaviour. This avoids implying that composition was explicitly quantified in the present study.

Citation: https://doi.org/10.5194/egusphere-2025-2571-RC2

Referee #5 Review on: ***Optical Properties and Shape-Dependent Complex Refractive Index Retrievals of Freshly Emitted Saharan Dust***

The study “Optical Properties and Shape-Dependent Complex Refractive Index Retrievals of Freshly Emitted Saharan Dust” presents and discusses key optical properties of freshly emitted Saharan dust, utilizing synergies of in-situ measurements conducted close to dust sources in southeastern Morocco.

More specifically, the authors focus on the wavelength- and size-dependent scattering and absorption behavior of dust while they also present a methodology for the retrieval of the imaginary part (k) of the complex refractive index (CRI) while accounting for different particle shape models. It is found that the derived values of k are higher when triaxial ellipsoids are employed in the retrieval process instead of spheres, underscoring the significant impact of particles’ asphericity.

I believe the study falls well within the scope of ACP, a novel dataset from a key dust source region is presented which can provide valuable field-based constraints on the radiative effects of dust. The manuscript is well-written / structured, the presentation clear, and the authors give credit to related work. However, I believe there are some key points which require greater clarity and methodological refinement.

We thank the referee for the positive assessment of the manuscript and for recognizing the value of the dataset and its relevance to ACP. We also appreciate the detailed comments, which helped us clarify the treatment of nephelometer corrections, particle-shape assumptions, the scope of the k retrieval, and the uncertainty associated with the aethalometer correction and particle size distribution.

Line 125: I was a little bit confused with the correction scheme you applied for the truncation error of the nephelometer data. In Section 2.2, you cite Müller et al. (2011), but in Section 2.6.2, you refer to Teri et al. (2022). Could you clarify which method was ultimately used?
Additionally, is the PSD derived from the Fidas -based on spherical particles and mean CRI from Di Biagio et al. (2019)- also used here, as described in Section 2.6?

If so, and the Müller et al. (2011) correction (which assumes spheres) is applied alongside a spherical particles assumption for the PSD calculations, how might this influence the accuracy of retrieved scattering coefficients, the asymmetry parameter (g), and the backscatter fraction (BF)? For instance, Gasteiger and Wiegner (2018) suggest that using spherical rather than spheroidal particles can introduce up to 7% uncertainty in hemispheric backscattering.

Lastly, were different correction factors applied during the PM2.5 and PM10 periods? If so, it would be helpful to briefly mention this.

We thank the referee for pointing out that the original wording was confusing. In the revised manuscript, we clarified that the truncation correction applied to the descriptive optical-property analysis follows Teri et al. (2022) using the SAE. We have updated the citations accordingly. Using this approach, there is a distinction in the parameters between coarse and fine, which we have used both for PM2.5 and PM10.

We also clarify that the corrected scattering coefficient is used for the description of the campaign optical properties, whereas the retrieval of k uses the truncated scattering coefficient measured by the nephelometer, denoted tsca, and the corresponding truncated single scattering albedo, tssa. In other words, the scattering coefficient used in the k retrieval is not first corrected to a full-phase-function scattering coefficient. Instead, the observation operator simulates the truncated quantity measured by the nephelometer. This avoids introducing an additional full-phase-function correction that would itself depend on assumptions about particle shape and refractive index.

The Fidas-derived PSD is not used to apply the empirical truncation correction in the descriptive part of the analysis. For the k retrieval, however, the PSD is converted from optical to dust geometric diameter using the procedure described in Sect. 2.6.1 and is then used in the optical simulations. The revised manuscript now distinguishes these two uses more clearly.

Lines 249 – 256: For the calculation of the PSD and k retrievals, i) biaxial prolate ellipsoids with a single aspect ratio, ii) triaxial ellipsoids with the same aspect ratio, iii) a distribution on biaxial prolate ellipsoids with aspect ratios derived from single particle measurements and iv) single irregular dust shapes from Gasteiger et al. (2011) were used.

i. How did you derive this specific single aspect ratio value?

We thank the referee for asking for clarification. The fixed aspect ratio used in the original analysis was based on the median of the aspect-ratio distribution measured from single-particle analyses of samples collected during the same field campaign, reported by Panta et al. (2023).

ii. Should this value be the same in case of triaxial ellipsoids? For example, in Figures 3-5 of Huang et al., (2023) it is shown that the angular distribution of spheroids and triaxial ellipsoids is different for dust particles at side scattering angles.

The major semiaxis to middle semiaxis value (aspect ratio) is the same, but the calculation of the scattering at 90+-5 degrees (used by the OPC conversion) is dependent on the shape: biaxial and triaxial spheroids will differ on the phase function and the scattering coefficient.

iii. Can you include a plot with the distribution of aspect ratios derived from the single particle analysis during the campaign? How does this compare to the fixed value you have selected in (i)?

The distribution is published in Figure 11 of Panta et al. (2023): https://acp.copernicus.org/articles/23/3861/2023/acp-23-3861-2023-f11-high-res.pdf . The aspect ratio used in the original manuscript is the median of the distribution.

iv. Why are single particle shapes used here instead of a distribution of shapes? Is it realistic to assume the same irregular shape for all the particles? This question also holds for (i) and (ii).

We thank the referee for raising this important point. We agree that it is not realistic to assume that all atmospheric dust particles have the same irregular shape. This is not the intended interpretation of the single-shape calculations. The individual irregular shapes A–F from Gasteiger et al. (2011) and MOPSMAP are used as sensitivity cases to quantify how different plausible non-spherical morphologies affect the OPC optical-to-geometric diameter conversion, the simulated optical properties, and ultimately the retrieved k. They should therefore be interpreted as shape-specific experiments rather than as literal representations of the full atmospheric dust population.

Where shape distributions are available and appropriate, we now use them. In the revised manuscript, we include a distribution of biaxial oblate and prolate spheroids based on the aspect-ratio measurements from the campaign by Panta et al. (2023), and we also include the Dubovik et al. (2006) spheroid distribution, which is relevant for comparison with remote-sensing retrievals. These distributions are now treated as the more representative spheroidal cases.

For the irregular particles, however, constructing a physically justified distribution of shapes A–F would require additional assumptions about the relative abundance of each irregular morphology, their possible dependence on particle size, and their relationship to the campaign-specific dust population. We do not have sufficient observational constraints to define such a distribution robustly. Introducing an arbitrary distribution of irregular shapes could therefore give a misleading impression of realism while adding another unconstrained degree of freedom to the retrieval.

The same reasoning applies to the fixed biaxial and triaxial cases. The fixed aspect-ratio cases are retained only as controlled sensitivity tests, not as realistic population-wide assumptions. For the biaxial spheroids, the revised manuscript now prioritizes the campaign-derived aspect-ratio distribution. For the triaxial ellipsoids, the available optical-property database limits the range of axis-ratio and size combinations that can be explored; therefore, we use the closest available triaxial shape to the campaign measurements as a sensitivity case.

We have revised the manuscript to make this explicit: particle shape is not retrieved, and the single-shape calculations are not intended to represent the full atmospheric dust population. They are used to bracket the sensitivity of the retrieved k to plausible particle-shape assumptions.

Line 419- 420: ‘*The analysis for the k retrieval focuses exclusively on periods classified as dust events (see Sect. 3.1) during the PM2.5 measurement period.*’
Why is the PM10 period not included here?

We agree that applying the retrieval to both PM2.5 and PM10 periods would be valuable. However, we restricted the k retrieval to the PM2.5 period for methodological reasons. The PM2.5 period provides a longer and more stable dataset, a larger number of dust-emission cases, and a more reliable basis for matching the OPC-derived PSD with the optical measurements.

The PM10 period was shorter and more affected by instrumental and sampling challenges under high dust concentrations. In addition, extending the retrieval to PM10 would increase the sensitivity to large-particle losses, inlet transmission, and the validity range of the available optical-property databases, especially for irregular particles. We therefore retain the PM10 measurements for the descriptive analysis of optical properties, but restrict the k retrieval to the PM2.5 period to avoid adding an additional layer of uncertainty that cannot be robustly constrained with the available data.

Section 2.6: It is confusing to me how shape and k retrievals are disentangled when you need to assume multiple combinations of CRI and shapes to perform the conversion to dust geometric diameters and calculate the PSDs. I assume the combinations of CRI/shapes will be limitless and for a given CRI, a given shape assumption would provide the same results as for another CRI and another shape assumption

We agree that this point required clearer explanation. In the revised manuscript, we added a flowchart of the retrieval procedure and clarified that we do not retrieve particle shape. Instead, particle shape is prescribed, and k is retrieved independently for each prescribed combination of particle shape, particle density, and real refractive index n. Therefore, the result is not a single unique value of k across all possible assumptions, but a set of conditional k values corresponding to the tested assumptions.

For each fixed set of assumptions, the retrieval is performed on a predefined grid of k values. The OPC optical-to-geometric diameter conversion and the optical-property simulation are treated consistently. First, k is estimated at the wavelength relevant for the OPC conversion. This value is then used to convert the PSL-calibrated optical diameters to dust geometric diameters. The resulting PSD is subsequently used to retrieve k at the AE33 wavelengths.

Thus, the solution is not unique across all shapes, densities, and values of n. However, for any fixed combination of these assumptions, the cost function has a well-defined minimum within the prescribed grid. We have revised the manuscript to avoid implying that the inverse problem is fully determined by the observations alone.

Figure 7: The maximum differences in the retrieved imaginary refractive index (k) across particle shapes appear to be around 0.001 at shorter wavelengths. How these differences translate into variations in the derived SSA?

Because the retrieval minimizes the difference between simulated and measurement-derived tssa, the simulated tssa values at the retrieved k are very similar across shape assumptions by construction, within the resolution of the k grid. Therefore, the shape dependence does not primarily appear as a large difference in retrieved tssa. Rather, it appears in the value of k required to reproduce the observed tssa under each particle-shape assumption.

The corresponding absorption and scattering coefficients can differ even when tssa is similar. This is now illustrated in the synthetic experiments added to the Supplement, where Figs. S12 and S13 show retrieved k, simulated truncated scattering, simulated absorption, and tssa when the assumed particle shape is either consistent or inconsistent with the synthetic truth.

Additionally, are the shape-related differences in SSA significant in the context of climate studies? (see for example the study of Mishchenko et al. (2004) on the accuracy requirements for satellite-based SSA retrievals (Table 5)).

As explained before, the (truncated) SSA for the retrieved set of k are well fitting the observed truncated SSA, thus they are very similar. The actual change is done by finding different k for different shapes. Changes in k and particle shape (maintaining a fixed SSA) should impact the computation of the extinction coefficient (and AOD) and asymmetry parameter, which could also have impacts in climate modelling. However, it is out of the scope of this work to quantify these effects.

Section 3.3.1: Regarding the comparison with AERONET, wouldn't it be more appropriate to use the same spheroid shape distribution employed in the AERONET retrieval algorithm to ensure consistency?

We agree with the referee. In the revised manuscript, we added retrievals using the Dubovik et al. (2006) spheroid aspect-ratio distribution, which is widely used in AERONET-type remote-sensing retrievals. We now include this shape assumption in the comparison with AERONET-derived k values.

Additionally, can you provide the particle size distributions (PSDs) retrieved from the Fidas instrument for the PM2.5 period and compare them with AERONET-derived PSDs? How do the two compare? Could some of the observed discrepancies in the results stem from differences in particle size rather than shape alone?

We thank the referee for this important comment. We agree that differences in particle size distribution can contribute to the discrepancies between our in-situ retrievals and AERONET-derived retrievals, and that the comparison should not be interpreted as reflecting particle-shape effects alone.

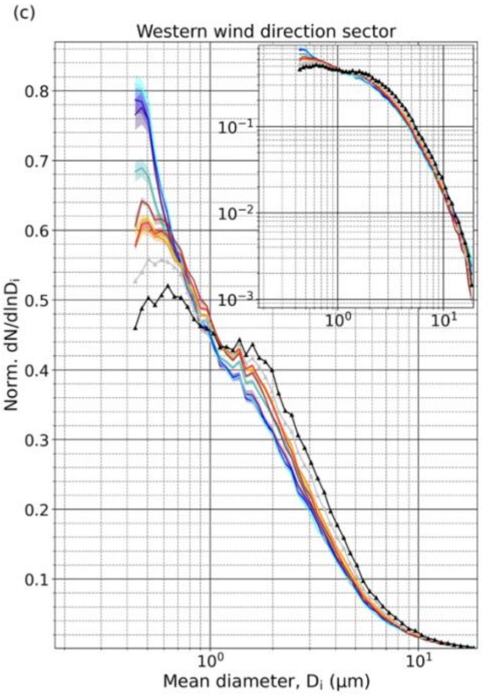
Following the referee's suggestion, we added a comparison between the Fidas-derived PSDs from the FRAGMENT-Morocco campaign and the AERONET-derived volume size distribution at the Ouarzazate station, which is the closest AERONET site to our measurement location. The Fidas distributions are taken from the campaign analysis of González-Flórez et al. (2023), while the AERONET distribution corresponds to dust-filtered retrievals at Ouarzazate over the 2000–2020 period.

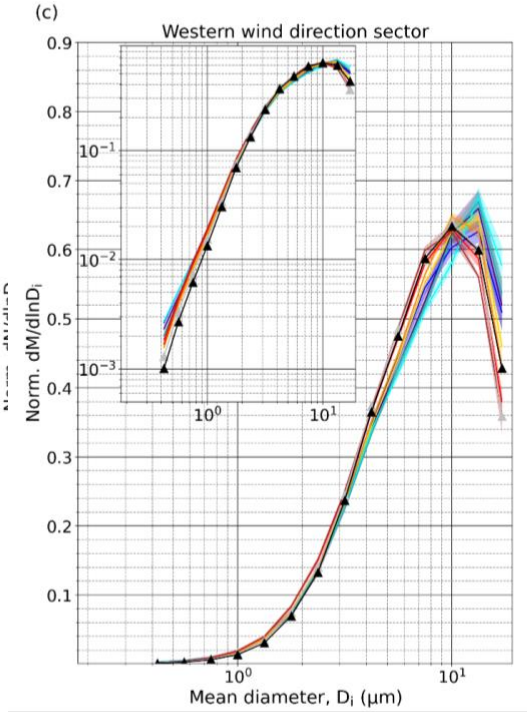
The comparison shows important differences. The AERONET-derived volume distribution has a relatively larger contribution from smaller particles and a coarse-mode maximum around approximately 3 µm, whereas the Fidas-derived mass distribution during the campaign shows a maximum closer to approximately 10 µm. These differences are not unexpected, because the two datasets differ in several respects: Fidas provides near-surface in-situ measurements during the campaign, whereas AERONET provides column-integrated retrievals over a much longer period; the Fidas PSD is measured locally at the emission site, whereas the AERONET PSD is retrieved from radiance inversions and depends on retrieval assumptions, including particle shape and size parametrization.

This comparison supports the referee's point that part of the discrepancy between our in-situ k retrievals and AERONET-derived k may arise from PSD differences rather than from particle shape alone. In our retrieval, the PM2.5 size range observed with the OPC includes most of the particles in number and is directly relevant for the AE33 absorption wavelengths used to retrieve k. In contrast, AERONET retrievals are column-integrated and include a different fine-to-coarse partitioning. A higher relative contribution of smaller particles in the AERONET size distribution could affect the retrieved absorption properties and may contribute to the larger AERONET-derived k values.

This interpretation is consistent with Adebiyi et al. (2023), who showed that dust absorption estimates are highly sensitive to dust size distribution, shape, and refractive index, and further noted that AERONET dust retrievals over North Africa may overestimate fine particles and underestimate coarse particles relative to observational constraints. They also found that dust-dominated AERONET retrievals yield larger imaginary refractive indices than their observationally constrained estimates.

We have therefore revised the discussion to make clear that the AERONET comparison is provided for context, not as a direct validation of the in-situ retrieval. Differences in spatial and temporal representativeness, vertical sampling, PSD, retrieval assumptions, and possible residual aerosol contamination can all contribute to the observed differences. Accordingly, we now interpret the comparison more cautiously and explicitly state that PSD differences, in addition to shape and mineralogical variability, may explain part of the discrepancy between our in-situ retrievals and the AERONET-derived values.





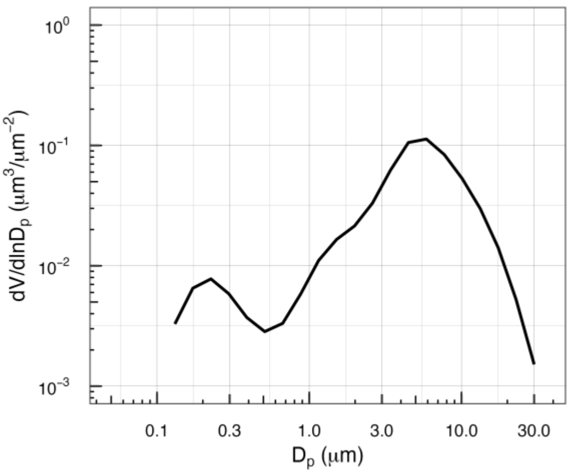


Figure R5.X. Comparison between in-situ and AERONET particle size distributions. Upper panels: Fidas-derived particle size distributions measured during the FRAGMENT-Morocco campaign, adapted from González-Flórez et al. (2023). Lower panel: AERONET-derived volume size distribution, dV/dlnD, for dust-filtered retrievals at the Ouarzazate station over 2000–2020. The comparison highlights the different size ranges and representativeness of the two datasets: the Fidas distributions represent near-surface, source-region in-situ measurements during the campaign, whereas the AERONET distribution is column-integrated and retrieval-dependent. The AERONET distribution shows a relatively larger contribution from smaller particles and a coarse-mode maximum around ~3 µm, while the Fidas-derived mass distribution peaks closer to ~10 µm. These differences may contribute to discrepancies between in-situ and AERONET-derived k values, in addition to differences related to particle shape and mineralogy.

Line 119: *'using the C and multiple scattering fitted values provided therein in a mountain- top station during Saharan dust outbreaks'*
To what extent is it valid to apply a C value derived from a different site with distinct meteorological conditions, instrument state, and aerosol properties (even though in both cases you discuss about dust dominated scenes)? Can you include an uncertainty estimate for the chosen C value (4.82) and discuss how this uncertainty may influence the derived SSA and the retrieval of k?

We thank the referee for raising this important point. In the original manuscript, the AE33 absorption correction relied on a value of the multiple-scattering parameter C derived from a mountain-top station during Saharan dust outbreaks. We agree that this introduced an additional uncertainty because that value was not directly obtained from the dust samples collected during the present campaign.

In the revised manuscript, we have therefore changed the correction approach. We now use the scattering artefact parameter, ms, and the multiple-scattering parameter, C, reported by Yus-Díez et al. (2025) for Saharan mineral dust samples collected during the same FRAGMENT-Morocco campaign and later analysed under controlled laboratory conditions. This provides a correction that is more directly representative of the dust investigated in the present study.

To quantify the sensitivity of the AE33-derived absorption to this correction, we repeated the absorption calculation using the lower, central, and upper values of C derived from the 95 % confidence interval reported by Yus-Díez et al. (2025). The figures added to the response show the resulting absorption coefficients for the three cases, labelled C-down, C, and C-up. We also show the same sensitivity stratified by the PM2.5 effective radius, following the dust-emission regimes used in the main manuscript.

The sensitivity analysis shows that the uncertainty introduced by the range of C values is wavelength dependent. The relative uncertainty is about 5 % at 370 nm and increases towards the near-infrared, reaching up to about 20 % at 950 nm. This larger relative uncertainty at longer wavelengths is expected because mineral dust absorption is weaker in the near-infrared, while the contribution of the scattering artefact becomes relatively more important for highly scattering dust samples. This behaviour is consistent with the analysis of the scattering artefact in Yus-Díez et al. (2025).

The figures also show that the qualitative spectral behaviour of absorption and the separation among the different dust-emission regimes are preserved when using the lower and upper values of C. The sensitivity to C therefore affects the absolute value of the corrected absorption coefficients, and consequently propagates into AAE, SSA, and the retrieved k, but it does not change the main interpretation of the optical properties. We have included this uncertainty source in the revised manuscript and in the sensitivity analysis of the k retrieval.

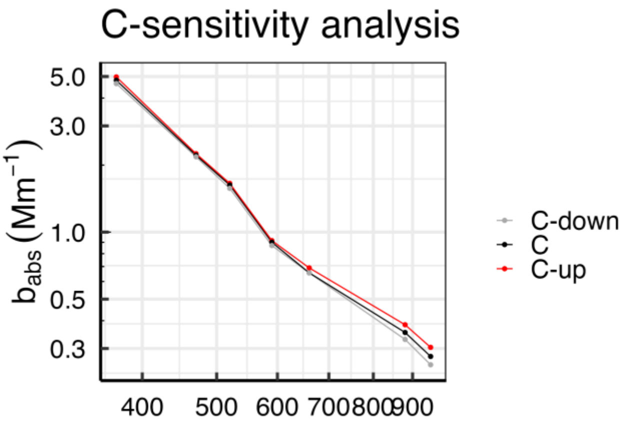


Figure R5.X. Sensitivity of AE33-derived absorption to the multiple-scattering correction parameter. Absorption coefficients calculated using the central value of *C* from Yus-Díez et al. (2025), together with lower and upper values derived from the corresponding 95 % confidence interval. The sensitivity is shown for the full PM2.5 period and stratified by particle effective radius, following the dust-emission regimes used in the main manuscript. The resulting uncertainty in absorption is approximately 5 % at 370 nm and increases towards the near-infrared, reaching up to approximately 20 % at 950 nm.

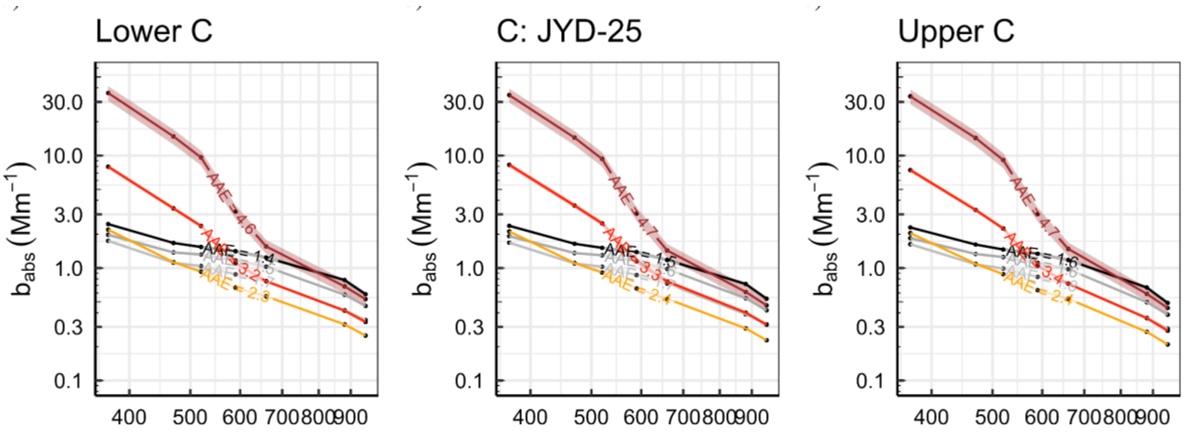


Figure R5.Y. Sensitivity of absorption spectral behaviour to the multiple-scattering correction parameter. Same as Fig. R5.X, but grouped by PM2.5 effective-radius classes. The comparison shows that varying C affects the absolute magnitude of the corrected absorption coefficients and propagates into AAE, but does not change the qualitative dependence of absorption on particle-size regime.

We added the following text to Sect. 2.2:

"To account for possible uncertainties introduced by the AE33 multiple-scattering correction, we performed a sensitivity analysis using the lower and upper values of *C* derived from the 95 % confidence interval reported in Table S2 of Yus-Díez et al. (2025). This sensitivity results in an uncertainty of approximately 5 % in the corrected absorption coefficient at 370 nm, increasing up to approximately 20 % at 950 nm, where the relative contribution of the scattering artefact is larger for mineral dust."

Line 153: *'the aerodynamic diameter of the inlet cut-off, which will vary depending on the inlet cut-off period–PM2.5 or PM10'*
What is the sampling efficiency of the Fidas 200S instrument in relation to particle sizes and wind speed? How these conversions affect the end results for the derived particle size distribution (PSD)?

We thank the referee for raising this point. The Fidas 200S OPC did not use the PM2.5 or PM10 inlet. The reference to PM2.5 and PM10 in the original sentence concerns the upper integration limit used to calculate moments of the PSD corresponding to the size range theoretically sampled by the optical instruments. We have revised the text to avoid this ambiguity.

For the retrieval, the Fidas optical diameters are converted to dust geometric diameters using the procedure described in Sect. 2.6.1. This conversion depends on particle shape and refractive index. We also now account for particle density in the aerodynamic-to-geometric diameter conversion and use a campaign-specific density value of 2.15 g cm^{-3}, with sensitivity tests at 1.8 and 2.5 g cm^{-3}.

Regarding sampling efficiency, previous work with the Sigma-2 inlet used by the Fidas 200S showed good agreement for PM10 particles under different dust-load and wind-speed conditions when compared with individual particle analysis. Nevertheless, we acknowledge that uncertainties in sampling efficiency and size-dependent particle losses remain relevant, particularly for coarse particles. This is one reason why the k retrieval is restricted to the PM2.5 period.

Equation 4 and 5: what is β here?

Here, β, refers to the intercept of the linear fit. This has been added to the manuscript.

Line 439: '*likely more strongly affecting the longer wavelengths'* why is this?

In the original version, this sentence referred to the sensitivity of the retrieval to uncertainties in the inlet cut-off. Longer wavelengths are more sensitive to particles with diameters closer to the inlet cut-off, so uncertainties in the cut-off diameter would be expected to have a larger effect at longer wavelengths.

However, in the revised manuscript this sensitivity analysis has been reformulated. Instead of prescribing an arbitrary ±10 % uncertainty in the inlet cut-off, we now vary particle density and compute the aerodynamic-to-geometric diameter conversion accordingly. As a result, the original sentence has been removed.

Line 476: as a result

Typo fixed.

Line 40: on a microscopic scale

Typo fixed.

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