With black text from the Reviewer1, and with *red coloring authors comments.*

Review of “Microphysical and Compositional Differences Between Saharan and Middle Eastern Dust Revealed by UAS Observations” by Kezoudi et al.

General comments
The manuscript describes ground-based remote sensing and airborne in situ measurements of dust particles above Cyprus. The manuscript reaches sound conclusions. However, the overall presentation of the results needs improvement. In its current form, the paper reads more like a measurement report than a scientific article. To my disappointment, there is limited integration of the remote-sensing and in situ observations; based on the abstract, I expected more blending of these complementary approaches. They both keep their supportive but distinct lines. The manuscript deserves publication, but major revision is necessary. Please find below my comments and suggestions for improving the manuscript.

We sincerely thank the reviewer for the careful evaluation of our manuscript and for the constructive comments. We appreciate your recognition that the study reaches sound conclusions and deserves publication.
We acknowledge your concern regarding the limited integration of the remote-sensing and in-situ observations. Our intention was not to strongly emphasize a tight blending of these approaches, but rather to present them as complementary measurements addressing the same dust events. To avoid creating misleading expectations, we have revised the abstract to better reflect the actual scope and focus of the study. The sentence “The campaign took place between 18/10/2021 and 18/11/2021 with continuous ground-based remote-sensing measurements, complementing 36 UAS flights.” is now rephrased to “The campaign was conducted from 18 October to 18 November 2021 and comprised 36 UAS flights.” (Lines 6-7).
We thank you again for your valuable suggestions, which have helped us improve the clarity and presentation of the manuscript.

There are several issues with indentation/formatting and inconsistent terminology (e.g., aerosol, dust, particles) throughout the manuscript.
We have carefully revised the manuscript to ensure consistent terminology regarding "aerosols," "dust," and "particles," while also correcting all indentation and formatting issues to maintain a uniform presentation.

The ordering of references in the text appears somewhat inconsistent. In some cases, references seem to be sorted by relevance, while in others they appear alphabetical and/or chronological. I suggest that the authors choose one consistent approach and apply it throughout the manuscript.

Thank you for the comment. Now the references are ordered in chronological order. See example at lines 43-44: "(Mona et al., 2012; Sugimoto and Zhongwei, 2014; Mamouri and Ansmann, 2015; Toledano et al., 2019)".

Specific comments

Abstact, there are acronyms that are used for the first time and are not expanded (GPAC, POPS, UCASS).

Thank you for the comment. They are now expanded in the abstract too.

Page 3, starting line 77, What OPCs were used (manufacturer and model)? The same applies to COBALDs. Similarly, for the remote-sensing instrumentation: lidars, ceilometers, and sun photometers come in different models with different features. Were the same instrument sets used at all ground stations (CAO-AMX, CAO-Nicosia, CARO-LIM NF)?

Thank you for this suggestion. The manuscript has been updated to include the specific manufacturers, numbers, and technical specifications for the instruments whose data are directly utilized in this study. This includes the OPCs, impactors, and relevant remote-sensing instrumentation (lidars, ceilometers, and sun photometers), supported by appropriate literature citations. See updated Sections 2.1 and 2.4.

Page 4, line 83, CAMS is an acronym, please expand.

Thank you. It is now expanded as Copernicus Atmosphere Monitoring Service (CAMS) in Line 296.

Page 4, line 85, HYSPLIT is an acronym, please expand and use appropriate reference (e.g. Stein et al., 2015).

Thank you. It is now expanded and citation added in Lines 299-300.

Page 4, line 85, authors use North Sahara (expanded) but later line 87 they use acronym ME, later they use NA (North Africa) not North Sahara on line 94.

We thank the reviewer for the comment. We have updated the revised version to use the acronym NA instead of 'North Sahara' throughout the paper where applicable.

Page 5, Table 1, there is a mixture of terms altitude (i.e. above sea level) and height (i.e. above ground) it is very confusing especially in remote sensing field. In the table, the term "Africa" is used for HYSPLIT source, should it be "North Africa" or the HYSPLIT analysis source is nonspecific?

i) *All altitudes are expressed in kilometers ASL; this effectively clarifies the measurements presented (clarified in the legend). Also, to avoid confusion, we have renamed the "BL height" to "BL top" in Table 1.*

ii) Corrected to NA.

Page 5, line 96, the sentence starting with “Both UAS belong...” sounds akward, did you mean something like: “Both UAS are fixed-wing aircraft, primarily made of foam with plywood reinforcements.”?

Thank you for the feedback. It is now corrected to what suggested by the reviewer (Lines 116-117).

Page 5, line 99, “Relative Humidity” should be lower case, unless you are introducing a variable (Relative Humidity (RH)).

It is corrected to lower case (Line 123).

Page 5, line 96, The paragraph as a whole feels superficial for a scientific paper. Even though a reference is provided (Kezoudi et al., 2021a), it would still be helpful to include key details such as aircraft weight and wingspan, sensor manufacturers, operating ranges, and (ideally) calibration procedures and uncertainties.

Details added in this paragraph where the UAS are described (Lines 117-120) as following: “The I-SOAR has a wingspan of 2.5m, a Maximum Take-Off Weight (MTOW) of 6.5kg, can carry a payload of up to 2kg, and is capable of flying for up to 110 minutes. The Skywalker-2015 features a 1.83m wingspan, a MTOW of 4.2kg and is capable of carrying a payload of up to 1.5kg, with a flight endurance of 90 minutes.”.

In the revised paper, sensor manufacturers, operating ranges, calibration procedures and uncertainties are discussed in Sections (2.4.1 and 2.4.2).

Page 6, Section 2.3 The authors omitted a description of the sampling strategy. Did they use data from both ascent and descent? Were the flights helical or linear? Was remote sensing used to plan the flight strategy, and if so, how?

Thank you for the comment. The flight strategy is now described in the text in Lines 125-131: “The flight pattern consisted of linear vertical profiles, with the aircraft climbing and descending along segments of 1.5–2 km at rates of 2–3 m/s. Flight duration typically ranged from 50 to 80 minutes, primarily constrained by battery capacity and weather conditions. The UAS missions aimed to obtain high-resolution vertical profiles through coordinated ascents and descents between waypoints, with representative profiles derived by averaging data from both phases. The flight strategy was guided by high-resolution, near-real-time lidar observations (Section 2.1.1), which were used to identify the presence and vertical extent of dust layers before and during operations, enabling optimized flight timing and coordination, and defining the altitudes at which the impactors were deployed to ensure effective in situ sampling of the dust layers.”

Page 6, line 106, uncomplete reference (POPS; et al., 2016)

Thank you, reference is now updated in line 136.

Page 6, line 110, the flow rate unit is wrong, probably should be cubic centimeters per second, about 0.18 l/min.

Thank you. Corrected to cm^3/s (Line 141).

The sentence: "POPS is able to accurately measure …" sounds very optimistic, the size range 0.1 to 3.4 um too, please check Pilz et al., 2022 and Pohorsky et al., 2024 for details on actual calibration of POPS.

Sentence changed to: "POPS measures the particle number size distributions in an optical size range of 0.13–3 µm at 1Hz resolution." (Line 143)

Page 6, line 116, double parentheses after reference. *Corrected*

Page 6, line 117, the sentence beginning "Computational Fluid Dynamics (CFD)…" in the context of Girdwood et al. (2022) is misleading. No CFD simulation was conducted for the underwing setup, but only for the Talon top-nose setup. It would be better to base the argument on the angle of attack (AoA): if the AoA in the underwing UCASS setup remains within the recommended range, then it should be acceptable.

Corrected to: "Computational Fluid Dynamics (CFD) simulations confirm that integrating the UCASS beneath the wings enables its airflow measurements to align with those obtained from the UAS nose-mounted pitot tube for an angle-of-attack range of ±10° (Girdwood et al., 2022)". (Lines 150-152)

Page 6, line 130, (i) when combining the size distributions from both instruments (POPS and UCASS), it is unclear what equivalent diameters were used. POPS was calibrated with PSL spheres, whereas UCASS was calibrated with dust particles of different refractive index. Was the POPS size range recalculated to dust-equivalent diameters using the same refractive index as UCASS? If yes, how? Please clarify. (ii) Also, in Figure 1b the size distributions were merged; please describe the merging procedure. Were the overlapping bins and counts simply averaged, or did the authors use a more sophisticated method?

(i) We thank the reviewer for raising this point. The POPS size range was not recalculated to dust-equivalent diameters when combining it with UCASS measurements. As clarified in the revised manuscript (Section 2.4.2: OPC calibration and associated uncertainties) and Lines 206-215, we explicitly assessed the impact of refractive index differences between the PSL-based POPS calibration and dust conditions using Mie scattering calculations at the POPS operating wavelength. Assuming a dust-representative refractive index (m = 1.52 + 0.002i), the resulting diameter adjustment is approximately 4%. In absolute terms, this corresponds to shifts of <0.05 µm for particle diameters below 1.22 µm and up to ~0.1 µm for larger particles. These differences are small relative to the POPS size bin widths (>10%) and therefore do not significantly affect the combined size distributions. For this reason, no correction was applied. Given the minor magnitude of this adjustment and its negligible impact on the derived size distributions and integrated quantities, a full recalculation of the POPS size bins to dust-equivalent diameters was not applied."

We have now clarified this point explicitly in the revised manuscript to ensure transparency and consistency in the combined use of POPS and UCASS data.

(ii) This is mentioned in Lines 164-167 with the below text: "To achieve a complete particle size distribution for both POPS and UCASS, the size bins of the two instruments were combined. For the size range between 0.1 and 2.3 μm, POPS data were solely utilized in the analysis. For particle sizes exceeding 2.3 μm, UCASS data were employed. This cutoff diameter was chosen based on prior research that indicated possible artifacts of size around 2.2μm of ambient measurements within this size range when using UCASS (Kezoudi, 2020).".

Page 7, line 161, the sentence "In principle, there is no upper cut-off…", followed by "However, the upper limit is mainly limited…", is confusing. Is there an upper limit or not? Please clarify.

Clarified and corrected to: "In principle, there is no strict upper cut-off diameter for dust collection on the adhesive substrate. In practice, however, the effective limit is set by the sticking efficiency, which decreases for larger particles due to their higher inertia and tendency to rebound." (Lines 246-248)

Page 9, line 171, The authors describe using multiple-substrate GPaC systems for sampling multiple atmospheric layers. From the current text, it is unclear how the second layer is identified during flight in order to deploy the second substrate. Additionally, there is a general discussion of sampling duration; could the authors provide basic statistics on successful samples (16 out of 22)?

Thank you, relevant text was added (Lines 246-249) to clarify this topic: "During flight, the identification of distinct atmospheric layers and the timing of the opening and closing of the two impactors were guided by real-time lidar observations, which allowed for the detection of dust layers, and were further supported by the vertical structure obtained from UAS profiling flights conducted earlier on the same day, when available.".

Regarding the sampling duration of each sample is given in Table 2; additional text is added in Lines 459-460 using basic statistics as requested: "The average sampling duration of the successful samples was 238±147 seconds.".

Page 11, Section 2.4, I suggest moving/merging this section into Section 2.1. This would address my comments regarding Section 2.1 and improve clarity. The same applies to Section 2.5.

Thank you for this suggestion. The specified sections have been moved accordingly, resulting in a more cohesive and streamlined presentation of the text.

Page 12, Figure 4, it is unclear how the authors arrived at these specific end points. On which estimates are the end points based?

Figure 1 caption is now clarified as follows: "HYSPLIT backward trajectories used for the sensitivity analysis for two dust events on 31/10/2021 (13:00 UTC, arriving at 2.5 km ASL) and 15/11/2021 (13:00 UTC, arriving at 2.0 and 2.5 km ASL) over Orounda. Multiple *trajectories were initiated from the same endpoint using small spatial offsets in the meteorological grid to assess variability. These cases are representative examples of the dust events analyzed in this study."*

Page 13, line 254, please be specific which Lidar you are talking about on the first occasion you mention it. This comment holds for any other instrument thought the whole text, please be specific.

It is mentioned in the following sentence (Line 321): "This is derived from the height-resolved observations of the Range Corrected Signal (RCS) in the green channel and volume depolarization ratio recorded by the CE376 Cimel aerosol lidar".

This is addressed for all the instruments mentioned in the text.

Page 16, starting line 287, the following paragraphs mix the terms "height" and "altitude." Furthermore, Figure 9 uses the unusual combination "height ASL." Typically, "altitude" is referenced to sea level, and "height" is referenced to ground level. This is not necessarily incorrect, but it is confusing—especially when the terms are used inconsistently throughout the text.

Thank you for noting this. Now the term "altitude" is used throughout the paper.

Page 16, line 298, above this line authors use kilometers, here they changed to meters, please be consistent.

Corrected to km (Line 403).

Page 17, line 300, there is no Table 2.1, probably typo.

Thank you. Corrected to Table 1 (Line 405).

Page 17, lines 309-311, the authors use the terms "coarse aerosol" and "coarse dust particles." Does this reflect different coarse-mode composition for NA and ME? "Coarse dust particles" is a specific aerosol type, whereas "coarse aerosol" may include dust, sea salt, pollen, etc.

To ensure scientific accuracy and consistency, we have revised the manuscript to distinguish between size-based and composition-based descriptions.

Specifically, we now use the term "coarse-mode particles" when referring to the general size distribution or the physical distinction between fine and coarse modes (e.g. Lines 408-409: "A clear separation between fine and coarse particles is evident around 0.7μm"). The term "dust particles" is reserved strictly for instances where the chemical or optical properties specifically identify the mineral dust component of the aerosol (e.g. Lines 503-504: "This study demonstrates the effectiveness of a novel, cost-efficient methodology for quantitative characterization of airborne dust particles using a sensor package that integrates OPCs and impactors deployed on UAS.")

Page 19, Figure 11, the lognormal fits appear to be far off (up to 5 orders of magnitude for the ME data) on the right-hand side of the size distribution. Is there an explanation for this?

Were the fits applied to all data points, or only to averaged distributions? Could the authors include uncertainty estimates (e.g., error bars) for the averaged data points?
We thank the reviewer for the comment. The lognormal fits were consistently applied to the averaged size distribution data; however, in response to the reviewer's suggestion, we have now refined the fitting procedure. By identifying and removing specific outliers that previously skewed the right-hand tail of the distribution, the revised fits provide a significantly more accurate representation of the measured data. Error bars are added in the revised figure. The updated fits and error bars are now shown in Figure 13.

If I understand correctly, the authors used averaged number/volume distributions (Figures 10, 11, and 13) for the OPC/GPaC flights, whereas Figure 9 shows clearly stratified layers (in mass concentration). On what basis do the authors assume that layers (e.g., at 0.5 km and 2 km ASL) are of the same type? This also seems at odds with Section 4, where the authors claim that the method "enables high-resolution vertical profiling." Why is such resolution needed if the analysis averages over the whole dust layer?
The averaged number and volume size distributions correspond to layers that were first identified from the vertical OPC profiles. The altitude ranges used for averaging were therefore based on the stratified structures visible in these profiles. We assume the layers are of the same type based on a synergistic identification and validation approach. While the layers appeared at different altitudes (e.g., 0.5 km and 2 km ASL), they both exhibited volume depolarization ratios > 0.1, which consistently indicates the presence of non-spherical mineral dust. This lidar-based classification was further corroborated by in-situ chemical and morphological analysis of the impactor samples collected at both altitudes, confirming their shared mineralogical characteristics (Lines 129–132).
Regarding the altitude range selected for opening and closing the impactor, this was determined using real-time lidar quicklook data and, when available, profiles from flights conducted within the previous hour (please see Lines 129-131). This allowed us to identify the vertical boundaries of the dust layer and target the appropriate sampling altitudes. The high vertical resolution of the measurements is therefore essential for detecting these layers and defining the altitude intervals used for the subsequent averaging and analysis.
Page 22, Figure 13, could the authors add standard deviations (as error bars) to the figure?
Thank you for the suggestion. Standard deviations are now added. Figure 13 is now Figure 15 in the updated manuscript.
Page 22, line 377, the authors introduced the terms "Cyprus cases" and "Cyprus samples", first I had impression they were trying to build an argument that collected NA and ME samples are very distinct from "Cyprus samples" and the NA and ME samples are not contaminated from local sources (Cyprus samples). I was wrong. Please, try to be

consistent if you introduce certain terms through the manuscript and keep using the same terms.

Thank you for highlighting this potential point of confusion. We appreciate the opportunity to clarify that these labels denote collection sites rather than geochemical origins. In accordance with your suggestion, we have revised the text to ensure consistent terminology and improved clarity for the reader. Text (Lines 483-492) corrected to: "The NA and ME samples collected over Cyprus can be differentiated from the other source regions in the Ca-Al-Mg and K-Ca-Fe ternary plots. In the Ca–Al–Mg ternary diagram, dust of ME origin observed over Cyprus exhibits a distinct shift toward the Ca-rich vertex, whereas NA samples align more closely with previously reported Saharan measurements (Kandler et al. 2020), where the same analytical procedure was applied. This pattern likely reflects intrinsic differences in the mineralogical composition and soil structure of the respective source regions. A similar trend is observed in the K–Fe–Ca ternary diagram, where Ca enrichment again serves as a distinguishing feature between the sources; however, the Saharan samples collected during the campaign exhibit relatively higher Fe and lower K contents compared to previously reported Saharan dust. Overall, both NA and ME samples collected over Cyprus show slightly lower inter-particle variability than those from other regions, as indicated by the reduced extent of the statistical confidence envelope."

References

- Pilz, C., Düsing, S., Wehner, B., Müller, T., Siebert, H., Voigtländer, J., and Lonardi, M.: CAMP: an instrumented platform for balloon-borne aerosol particle studies in the lower atmosphere, Atmos. Meas. Tech., 15, 6889–6905, https://doi.org/10.5194/amt-15-6889-2022, 2022.
- Pohorsky, R., Baccarini, A., Tolu, J., Winkel, L. H. E., and Schmale, J.: Modular Multiplatform Compatible Air Measurement System (MoMuCAMS): a new modular platform for boundary layer aerosol and trace gas vertical measurements in extreme environments, Atmos. Meas. Tech., 17, 731–754, https://doi.org/10.5194/amt-17-731-2024, 2024.
- Stein, A.F., Draxler, R.R., Rolph, G.D., Stunder, B.J.B., Cohen, M.D., & Ngan, F. (2015). NOAA's HYSPLIT atmospheric transport and dispersion modeling system. Bulletin of the American Meteorological Society, 96(12), 2059-2077

We thank the reviewer for the suggested citations; these have been studied and integrated into the updated text (Lines 143-144, 288) and reference list.

Black text: Reviewer2 comments. *Red text: Authors comments*

Review of a manuscript titled

"Microphysical and Compositional Differences Between Saharan and Middle Eastern Dust Revealed by UAS Observations"

General comments:

The manuscript presents an interesting and timely study on airborne dust characterization using a low-cost sensor package integrating optical particle counters (OPCs) and impactors on UAS platforms. The combination of in situ size distributions with offline SEM analysis of sampled particles is valuable, and the focus on Saharan and Middle East dust outbreaks is relevant for both regional air quality and long-range transport studies.

Thank you very much for your thoughtful and constructive comments. We sincerely appreciate your positive evaluation of our work and your recognition of its relevance to both regional air quality and long-range transport studies.
Your supportive feedback reinforces the significance of integrating these approaches to better understand dust transport processes and their impacts on regional and larger scales.

However, the manuscript has two major weaknesses that, in my view, must be addressed before the results can be considered robust:

1. The calibration and sizing of the OPCs are not treated with sufficient rigor, especially given that the instruments were originally calibrated for different particle types than mineral dust.
2. The claim of providing vertical information on dust is not fully supported by the way the vertical structure is presented and analyzed.

Below, I detail these points and offer suggestions for improvement.

Thank you again for your careful review and encouraging remarks. We address these two points below.

1. Calibration and sizing of the OPCs in Section 2.3

The study relies heavily on OPC-derived particle number and volume size distributions to infer dust loadings and to derive mass concentrations. However, the description and justification of the calibration procedure for the OPCs, as well as their suitability for mineral dust, are not adequately presented.

- The OPCs are inherently sensitive to particle refractive index, shape, and the instrument's optical configuration (wavelength, angular range). In the present work, it appears that the instruments were used with standard calibrations (e.g. PSL or other reference aerosols) and then directly applied to Saharan and Middle East dust without a systematic correction for the optical properties of dust.

  We agree with the reviewer that OPC measurements are sensitive to particle refractive index, shape, and instrument optical configuration. In this study, UCASS instruments were not operated with a generic PSL-only calibration. Instead, UCASS was calibrated at the University of Hertfordshire using Mie scattering theory in combination with laboratory calibration measurements, to yield specifically a calibration representative of the refractive index of mineral dust. The calibration assumes a dust refractive index of 1.52 + 0.002, consistent with values reported for Saharan and Middle Eastern dust in the literature. The particle size bins used in this work are those defined by this dust-specific calibration and were therefore directly applicable to the environments sampled. While uncertainties associated with refractive index variability remain inherent to all OPC-based measurements, the applied calibration minimizes systematic bias for mineral dust and is appropriate for the conditions encountered in this study and is consistent with previous UCASS deployments in dust-dominated environments (Kezoudi et al., 2021). Please see Lines 195-208.

  POPS is calibrated with polystyrene latex (PSL) spheres and dioctyl sebacate (DOS), which have refractive indices of m = 1.615 + 0.001i for PSL and m = 1.45 + 0i for DOS (Gao et al., 2016). To account for refractive index differences in POPS measurements, Mie scattering calculations are applied, yielding a 4% diameter correction for dust, using same refractive index as UCASS equal to m = 1.52 + 0.002i. For POPS size bins smaller than 1.22 μm, this corresponds to a diameter adjustment of less than 0.05 μm, while for bins larger than 1.22 μm, the correction can reach up to 0.1 μm. Given that these shifts are small relative to the corresponding POPS bin widths and have a negligible impact on the derived volume concentrations and overall size distribution shape, the correction was not applied to the POPS data. We have now clarified this explicitly in the manuscript. Please see Lines 209-219.

  Regarding the instrument configuration, this was taken into account in the Mie scattering computations, and the manuscript has been revised accordingly. The relevant details can be found in lines 195–196 for UCASS and lines 211–212 for POPS.

  With respect to particle shape effects, these are addressed in detail in our response to the following comment.

- Mineral dust is non-spherical and has a refractive index and absorption that differ significantly from calibration aerosols such as PSL. This implies that the "optical equivalent diameter" reported by the OPCs can differ substantially from the true geometric or aerodynamic diameter. This is especially critical for coarse-mode particles, which are central to the paper's conclusions.

  We thank the reviewer for the comment. Related text is now added in the revised manuscript in Lines 220-227 as follows:

  "To quantify the uncertainty associated with particle non-sphericity, we performed a sensitivity analysis using MOPSMAP simulations (Gasteiger and Wiegner, 2018; Papetta et al., 2026) in which the particle aspect ratio was varied. The shape configuration included spheres, as well as spheroids with aspect ratios of 1.45 and 2. Increasing the aspect ratio from 1 to 2, corresponding to more elongated particles, resulted in an approximately 2% change in the simulated extinction coefficient. Because extinction scales approximately with the square of particle diameter, this variation translates to an estimated 1% shift in the inferred optical-equivalent diameter. Given that typical UCASS size-bin widths are substantially larger, such a small diameter perturbation remains well below the instrumental resolution. Consequently, realistic dust particle shape variations introduce only a minor systematic bias in the retrieved size distribution and do not affect the study's main conclusions.".

- The manuscript uses OPC data to compute volume size distributions and dust mass concentrations based on assumed densities (e.g. ~2.6 g cm^{-3} for coarse mineral dust), but the uncertainties introduced by the optical sizing are not quantified. In practice, the combination of refractive index mismatch and non-sphericity can lead to systematic size biases that propagate non-linearly into volume and mass.

  The below text is added in the revised manuscript in Lines 209-227:

  "The POPS OPC was calibrated by the manufacturer using PSL spheres and dioctyl sebacate (DOS), with refractive indices of m=1.615+0.001 for PSL and m=1.45+0i for DOS (Gao et al., 2016). The impact of refractive index differences between the PSL-based POPS calibration and dust conditions using Mie scattering calculations at the POPS operating wavelength was assessed. Assuming a dust-representative refractive index (m=1.52+0.002i), the resulting diameter adjustment is approximately 4% (Papetta et al., 2026). In absolute terms, this corresponds to shifts of <0.05 μm for particle diameters below 1.22 μm and up to ~0.1 μm for larger particles. These differences are small relative to the POPS size bin widths (>10%) and therefore do not significantly affect the combined size distributions. For this reason, no correction was applied. Given the small magnitude of

this correction and its minor impact on derived volume concentrations, the refractive index adjustment was not applied to the POPS data. The associated uncertainty is therefore considered negligible within the context of this study. Nonetheless, uncertainties related to refractive index assumptions were explicitly evaluated and are now acknowledged in the revised manuscript.

To quantify the uncertainty associated with particle non-sphericity, we performed a sensitivity analysis using MOPSMAP simulations (Gasteiger and Wiegner, 2018; Papetta et al., 2026) in which the particle aspect ratio was varied. The shape configuration included spheres, as well as spheroids with aspect ratios of 1.45 and 2. Increasing the aspect ratio from 1 to 2, corresponding to more elongated particles, resulted in an approximately 2% change in the simulated extinction coefficient. Because extinction scales approximately with the square of particle diameter, this variation translates to an estimated 1% shift in the inferred optical-equivalent diameter. Given that typical OPC size-bin widths are substantially larger, such a small diameter perturbation remains well below the instrumental resolution. Consequently, realistic dust particle shape variations introduce only a minor systematic bias in the retrieved size distribution and do not affect the study's main conclusions."

Suggestions:

- Provide a detailed description of the calibration of each OPC used, including:
    - Calibration aerosol (material, refractive index).
    - Calibration method (Mie model, reference instruments, etc.).
    - Operational size range where the calibration is considered reliable.
    - Discuss explicitly how the refractive index and non-sphericity of mineral dust affect the OPC response. At minimum, this should be treated in an uncertainty analysis, and key conclusions should be qualified accordingly.

Thank you very much for your detailed suggestions, which we have followed to formulate additional information on OPC calibration, associated uncertainties, and limitations: now added to the manuscript in a new subsection, starting from line 193, as shown below:

"2.4.2 OPC calibration and associated uncertainties

The UCASS OPCs deployed in this study were calibrated by the University of Hertfordshire using polystyrene latex (PSL) spheres in combination with Mie scattering calculations to establish the *instrument response function. The calibration framework incorporates laboratory measurements and is tailored for a refractive index of 1.52+0.002i, representative of Saharan and Middle Eastern mineral dust. This refractive index is consistent with values reported in the literature for regional mineral dust and ensures that the resulting size bin definition is appropriate for dust-dominated environments (e.g., Nisantzi et al. 2015; Kezoudi et al. 2021b). Scattering intensities computed using Mie theory are linked to particle optical diameters through comparison with laboratory reference measurements, thereby establishing instrument-specific response functions that define the UCASS size bins. For the units deployed in this study, the operational size range where the calibration is considered reliable spans 0.5–21.0 µm. The defined size bins corresponding to this dust-specific calibration were applied directly in the present analysis. While uncertainties associated with refractive index variability remain inherent to all OPC-based measurements, the applied calibration minimizes systematic bias for mineral dust and is appropriate for the conditions encountered in this study and is consistent with previous UCASS deployments in dust-dominated environments (Kezoudi et al. 2021b).*

The POPS OPC was calibrated by the manufacturer using PSL spheres and dioctyl sebacate (DOS), with refractive indices of m=1.615+0.001 for PSL and m=1.45+0i for DOS (Gao et al., 2016). Because mineral dust has a lower refractive index (assumed here as m=1.52+0.002i), the potential impact of refractive index differences on particle sizing was evaluated. Mie scattering calculations were performed to estimate the corresponding diameter correction when applying a dust refractive index to a PSL-based calibration. The resulting correction is approximately 4% in particle diameter for dust conditions (Papetta et al., 2026). For POPS size bins below 1.22 µm, this corresponds to a diameter adjustment of less than 0.05 µm, and up to 0.1 µm for bins above 1.22 µm. Given the small magnitude of this correction and its minor impact on derived volume concentrations, the refractive index adjustment was not applied to the POPS data. The associated uncertainty is therefore considered negligible within the context of this study. Nonetheless, uncertainties related to refractive index assumptions were explicitly evaluated and are now acknowledged.

To quantify the uncertainty associated with particle non-sphericity, we performed a sensitivity analysis using MOPSMAP simulations (Gasteiger and Wiegner, 2018; Papetta et al., 2026) in which the particle aspect ratio was varied. The shape configuration included spheres and spheroids with aspect ratios of 1.45 and 2. Increasing the aspect ratio to 2, corresponding to more elongated particles, resulted in an approximately 2% change in the simulated extinction coefficient. Because extinction scales approximately with the square of particle diameter, this variation translates to an estimated 1% shift in the inferred optical-equivalent diameter. Given that typical OPC size-bin widths are substantially larger, such a small diameter perturbation remains well below the instrumental resolution. Consequently, realistic dust particle shape *variations introduce only a minor systematic bias in the retrieved size distribution and do not affect the study's main conclusions."*

With regards to the operational size range where the calibration is considered reliable, it is mentioned: (i) in line 143 for POPS ("POPS measures the particle number size distributions in an optical size range of 0.13–3 μm at 1Hz resolution (Pilz et al., 2022; Pohorsky et al., 2024).") and (ii) line 203 for UCASS ("For the units deployed in this study, the operational size range where the calibration is considered reliable spans 0.5–21.0 μm.").

- If possible, reprocess the OPC data using an assumed refractive index representative of Saharan/Middle East dust, and appropriate Mie calculations for each instrument's wavelength and collection angles. This would help bring the sizing onto a more physically consistent basis.

We thank the reviewer for this constructive suggestion.
As clarified in the newly added subsection "OPC calibration and associated uncertainties" starting *from line 194, the UCASS size bins used in this study are already based on manufacturer calibration employing Mie scattering calculations with a refractive index of 1.52+0.002i, representative of Saharan and Middle Eastern mineral dust.*
For POPS, starting from line 209, the potential impact of refractive index differences relative to dust conditions was explicitly evaluated using Mie calculations at the instrument wavelength, demonstrating that the corresponding diameter correction (~4%, i.e., ≤0.1 μm depending on bin) is small and negligible relative to the instrument bin widths. In addition, a dedicated sensitivity analysis was performed to quantify the effect of dust non-sphericity (via variation of particle aspect ratio), confirming that realistic deviations from sphericity introduce only minor (<~1% in optical diameter) systematic bias.
Based on these considerations, a full reprocessing of the OPC data using alternative refractive indices and instrument-specific Mie recalculations was not undertaken, as the applied calibrations already account for dust-representative optical properties. Further reprocessing would therefore not materially affect the retrieved size distributions or the main conclusions of the study. We believe that the adopted approach is physically consistent with the sampled environments and aligned with established UCASS and POPS dust measurement methodologies, while explicitly acknowledging the inherent uncertainties associated with optical sizing of non-spherical mineral dust.

- Clearly distinguish throughout the text between "optical equivalent diameter" and other size metrics (geometric, aerodynamic) and avoid implying that the OPC diameters are exact physical sizes.

Thank you, the manuscript was updated with the term 'optical equivalent diameter' wherever applicable (please see Lines 441, 471).

- Where mass concentrations are derived from OPC volume and assumed densities, include an estimate of the uncertainty due to optical sizing (not only due to density assumptions). A simple sensitivity analysis using a range of plausible dust refractive indices would already improve confidence in the results.

  Given that the study's conclusions rely on differences in coarse-mode size distributions between NA and ME dust, the robustness of these conclusions depends strongly on the soundness of the OPC calibration and size retrieval.

We thank the reviewer for this constructive suggestion. As discussed above, this is clarified in the newly added subsection "OPC calibration and associated uncertainties", starting from Line 193.

2. Lack of truly vertical-resolved dust information

The manuscript emphasizes the capability of UAS-based OPCs and impactors to provide high-resolution vertical profiling of dust layers. However, the presentation of vertical structure is relatively limited, and the reader is left without a clear, quantitative view of the vertical distribution of dust properties.

We thank the reviewer for the thoughtful and constructive comments. We sincerely appreciate the positive evaluation of our work and the valuable suggestion to further emphasize the height-resolved observations presented in this study. In response, we have included additional figures (Figures 9 and 10) illustrating the vertical profiles, along with corresponding descriptive text, to more clearly highlight and interpret the height-resolved measurements, as discussed in the suggestions below.

- While flights are described as targeting specific altitude ranges and back-trajectory analysis is used to differentiate NA and ME sources, the figures and discussion focus largely on layer-averaged or campaign-averaged size distributions (e.g. Fig. 11 showing number and volume size distributions within "elevated dust layers").
- The vertical variability within these layers is only briefly mentioned (e.g. via standard deviations over entire flights), but the manuscript does not provide systematic vertical profiles of particle number, volume, or derived mass concentration as a function of altitude.

- The impactor/SEM analysis adds valuable information on morphology and composition, but it is presented mainly by layer or by origin type, rather than as vertical cross-sections or profiles that demonstrate how size, composition, or mineralogy change with height.

Thank you for the comments. They have been addressed below.

Suggestions:

Include explicit vertical profiles of key quantities measured by the OPCs:

- Particle number concentration in relevant size bins.

  Size-resolved profiles were added in new figure (Figure 10(a)) as contour plot (as suggested below). This figure highlights the following as discussed at Lines 369-377: “Across most days, enhanced number concentrations (102–103 cm−3) are consistently observed at small particle diameters (Dp ≤ 0.5 μm), particularly below 1.5–2 km ASL. Elevated concentrations frequently extend up to 2.5–3 km during strong dust episodes (e.g., 25/10, 27/10, 14/11, 15/11, and 18/11), indicating well-developed dust layers. In contrast, larger diameters (Dp ≥ 2–3 μm) exhibit substantially lower number concentrations (≤ 1–10 cm^{-3}), with sporadic enhancements mainly confined below ~2 km. Day-to-day variability is evident in both vertical extent and intensity. For instance, on 13th of November a pronounced elevated layer is visible between 1 and 2.5 km, characterized by high number concentrations in the submicron range, while 4th of November shows a comparatively shallower and weaker structure. In several cases (e.g., 28/10 and 17/11), enhanced concentrations extend nearly uniformly from the surface to 3 km, suggesting vertically homogeneous dust conditions.”

- Volume (or mass) concentration profiles for fine and coarse modes.

  Thank you for the suggestion. A new figure is added (Figure 9) showing the vertical profiles of volume concentration of fine and coarse modes. This figure highlights the following, as discussed in Lines 522-525:

  “Fine-mode aerosol volume concentrations were generally enhanced within the lower 1–2 km and decreased with altitude, with occasional elevated layers above 2 km indicating the transport of dust-laden air masses. In contrast, the coarse mode dominated the aerosol volume throughout the campaign, exhibiting pronounced enhancements below ~2 km and distinct elevated layers up to ~3 km, reflecting the strong presence and vertical structure of mineral dust.”

- Where appropriate, size-resolved profiles (e.g. contour plots of number or volume vs altitude and diameter).

Size-resolved profiles were added in new figure (Figure 10) as contour plot and described in the text. Please see the two previous answers.

- Clarify how “elevated dust layers” are defined (from lidar, back-trajectories, or OPC signal) and how the altitude bounds listed in Table 2 relate to the vertical profiles.

We thank the reviewer for the opportunity to clarify our methodology. Elevated dust layers were defined using a synergistic approach:

1. *Initial Identification: Potential layers were first identified using near-real-time lidar backscatter "quicklook" products. These data allowed us to determine the presence and approximate vertical extent of dust layers to guide the UAS in-situ sampling.*
2. *The classification of these features as 'dust layers' was confirmed by lidar volume depolarization ratios exceeding 0.1 (as shown in Figures 6b and 7b), which denotes the presence of non-spherical mineral particles. This classification was further validated by the morphological and chemical analysis of the collected impactor samples.*

We have updated the manuscript (Lines 128–132) to reflect these definitions more clearly.

Regarding the altitude bounds selected for opening the impactor (listed in Table 2), this was determined based on the near-real-time lidar quicklook data and if available profiles from a flight within the previous hour, which enabled us to identify the vertical boundaries of the dust layer and target the appropriate sampling altitudes (Lines 245-248).

- For the impactor data, consider summarizing composition/morphology as a function of altitude (e.g. showing how the relative contributions of different mineralogical classes or elemental ratios vary with height within a given event).

  One, and in some cases two, integrated samples were collected per flight. Given that typically only two discrete layers were sampled per day, a generalized summary of composition as a function of altitude would not be statistically robust. Moreover, the vertical distribution of aerosol composition varied substantially from day to day due to changing meteorological conditions and air mass transport. As a result, aggregating all observations into a single altitude-dependent summary for the entire campaign could obscure meaningful case-specific features rather than provide additional clarity.

- The manuscript currently states that the approach enables “high-resolution vertical profiling” and “robust detection of coarse particles within elevated dust layers”; these statements would be more convincing if supported by concrete vertical cross-sections or profiles from representative flights.

  Thank you for the constructive comment. New profiles were added (Figures 9 and 10).

- If vertical resolution is constrained by flight logistics (e.g. step-wise levels rather than continuous profiling), this limitation should be clearly stated, and the implications for resolving fine vertical structures (such as multiple dust layers or sharp layer boundaries) should be discussed.

  Thank you for this important comment. The OPC measurements (POPS and UCASS) were acquired at a sampling frequency of 1 Hz (Lines 138, 150). Given this temporal resolution, the effective vertical resolution is determined by the UAS ascent/descent speed, corresponding to approximately ~2 m under typical flight conditions. We note that this represents a practical limitation imposed by flight logistics. For the analysis, the OPC data were subsequently aggregated onto a vertical grid with a resolution of 20 m, which defines the effective vertical resolution of the presented profiles (Line 153).

  For the impactor samples, the approach differs, as particles were collected over discrete altitude intervals with a vertical extent of approximately 0.5-1.5 km. As a result, fine vertical structures (e.g., thin layers or sharp gradients) may not be fully resolved, and this limitation is now clarified in the revised manuscript (Lines 249-250).

Overall, the paper would benefit from a much clearer and more quantitative depiction of the vertical structure, beyond layer-averaged statistics.

Please see our previous replies.

Specific comments:

Abstract: The back trajectory information in lines 8-9 doesn’t represent the sampling altitudes of the UAS, but misleads the readers when presented along with the UAS dust information.

Thank you for the comment. To avoid any confusion, the text changed to “Remote-sensing and back-trajectory analyses revealed NA dust layers up to 7 km Above Sea Level (ASL) over Cyprus, compared to 3.8 km for ME dust.” (Lines 9-10)

Introduction: This study didn’t achieve the two objectives outlined in lines 61 -63.

Thank you for the constructive comment. It helped us place greater emphasis on this aspect in the revised manuscript.
Regarding the first (i) objective, which is to investigate the microphysical properties of airborne dust particles from different source regions over Cyprus during the autumn period, the manuscript presents information on key microphysical parameters including particle size, concentration, and chemical composition.
More specifically:

- *Particle concentration is analyzed in terms of number, volume, and mass concentrations, which are presented and discussed in Figures 9, 10, and 11.*
- *Particle size distributions are presented in Figures 12 and 13.*
- *Particle composition is examined through the analysis of the observed dust layers, with results presented in Figures 14, 15, and 16. These figures provide compositional information for dust layers originating from different source regions, namely NA and the ME, as observed during the measurement campaign.*
  Together, these analyses characterize the microphysical properties of the transported dust particles, allowing us to assess differences associated with their source regions and vertical distribution in the atmosphere over Cyprus during the study period.

With regards to the second (ii) objective related to "to establish a robust methodology combining the relevant airborne and remote-sensing instruments to optimize dust sampling and characterization", it has now rephrased to "to establish a UAS-based framework for the optimized in-situ characterization of atmospheric dust" (Line 63) to serve better the statement along the paper. This study prioritizes in-situ UAS measurements, utilizing remote-sensing observations to provide a broader atmospheric context.

Line 85: Is this AOD based on the height of the lidar column or the UAS column or natural atmospheric column? How does it relate to the UAS measurement and lidar retrieval? What is the uncertainty range?

We thank the reviewer for this question. The AOD values reported in the manuscript correspond to column-integrated measurements obtained from sun-photometer, representing the natural atmospheric column above the observation site. This has now been clarified in the revised manuscript (Lines 95-100), as follows:
"The output of the AERONET network includes columnar-integrated aerosol property parameters such as AOD and Angstrom exponent, alongside other properties derived from inversions of sky radiance observations. In this study, the AOD information is used as complementary context to characterize the overall intensity of the dust events throughout the campaign. It provides a physically independent measure on the total aerosol loading within the atmospheric column. The

typical AOD uncertainty remains within the range of ±0.01–0.02, contingent upon the specific wavelength and prevailing atmospheric conditions.”

Line 87, What “height-resolved information” does this study provide? Please clarify.

Clarification in Lines 301-302 as followed: “Height-resolved particle size distributions and concentrations, as well as backscatter signals for each dust event were captured using daily UAS-based OPCs and continuous ground-based lidar observations.”
The mass concentration profiles in Figure 11 as well as the newly added figures 9 and 10 showing the vertical profiles of particle number and volume size distribution from the OPCs.

Section 2.2: The sampling periods are limited. How does this limitation provide representative information for the sampling day? What are the ascending and descending rates of the flights? Does the inlet operate under isokinetic conditions during the flight?

Thank you for this thoughtful comment. We acknowledge that the sampling periods are limited and may not capture full diurnal variability. However, they were conducted under relatively stable conditions and consistent aerosol loading on each sampling day, as supported by the lidar time series (Figures 6 and 7). Therefore, the samples are considered representative of the prevailing conditions during the respective sampling periods.

More details on the flight pattern were added in Lines 125-130 as follows: “The flight pattern consisted of linear vertical profiles, where the aircraft climbed in sections of 1.5-2 km length and ascent/descent rates of 2-3 m/s. The duration and the maximum altitude reachable in each flight in this study typically ranged from 50 to 80 minutes, constrained primarily by battery capacity and weather conditions. The main objective of the flights was to obtain vertical profiles, and this was achieved through linear profile ascents and descents between two waypoints and procedural turns. Vertical profiles were calculated by averaging data collected during both the ascent and descent phases.”

Regarding the inlet conditions of POPS, additional information added in Lines 141-143 as follows: “The sampling inlet of the POPS maintains isokinetic conditions during flight, a performance verified by wind tunnel experiments confirming that inlet flow velocity matches the platform's free-stream velocity.”
With regards to the UCASS, it is an open-path instrument (Line 147), hence there is no isokinetic inlet.

Line 163: What is this size? Aerodynamic size? If so, how does it relate to the optical size measured by POPS and UCASS?

The particle size derived from the collected samples corresponds to a geometric diameter obtained from Scanning Electron Microscopy (SEM) images, defined as the equivalent circular diameter (i.e., the diameter of a circle with the same projected area as the particle), following the methodology of Kandler et al. (2009, 2011). This represents a physical particle dimension and does not correspond to an aerodynamic or optical-equivalent diameter. In contrast, POPS and UCASS report optical-equivalent diameters based on light scattering, which depend on particle refractive index, shape, and orientation. Differences between SEM-derived and optically derived sizes are therefore expected, particularly for irregular mineral dust particles, although they remain broadly comparable within the uncertainties of the respective techniques.
We clarified this point in the revised manuscript in Lines 254-260.

Line 177-178: One sample per flight? If so, no vertical resolution of your samples.

One to two integrated samples were collected per layer per flight as shown in Table 2. No vertical resolution indeed. It is now clarified in Lines 249-250 as: "However, each sample represents an integration over the sampling period and thus does not resolve vertical variability within the atmospheric column."