

# Replies to the comments from anonymous referee #1

We would like to start the reply by thanking the anonymous referee#1 for their constructive and insightful review. Their suggestions regarding the restructuring and expansion of the text have significantly enhanced the quality of the manuscript. All the comments and insight are very much appreciated. We have copied the comments into this document; the comments are in Times New Roman blue font while our answers are in Calibri black font. Line numbers refer to the revised version of the manuscript without track changes.

Dust aerosols are key players in the Earth system, exerting a variety of impacts that are many times shaped by their mineralogical composition. This manuscript presents advances in the characterization of the dust mineralogy from North African sources and approaches one fundamental problem that dust models face when trying to incorporate minerals in their formulation: the distribution of minerals across aerosol particle sizes. The core of the study focuses on the methodological improvements included in the COSMO-MUSCAT model to improve the emitted minerals' Particle Size Distribution (PSD) and the evaluation of a set of simulations against observations. The authors also report new observational data of mineral and elemental composition from two different and recent campaigns, which are of value for increasing our understanding of the dust mineralogy and its regional variations. The improvements included in the model as well as the observational data merit publication and are useful for the scientific community to advance in this field.

However, in my view, some aspects of the observational campaigns and the model evaluation methodology have to be clarified. Also, the manuscript's current presentation is quite dense and the structure makes it difficult for the reader to clearly identify the primary findings. I would recommend the authors to split the work in two different articles: one devoted to the observational campaigns and the other related to the modelling work and its evaluation. Alternatively, a synthesis of these two parts is recommended, moving to supplementary materials the non-essential information.

Thank you for this general comment. We have revised the methodology significantly. To improve readability, we have moved several technical details to the Appendix and synthesized the remaining content to ensure the manuscript remains a concise, cohesive work.

Please, see my specific comments below.

## **Specific comments:**

The authors report information on two different experimental campaigns: DUSTRISK2022 and JATAC2022. The protocols, instruments and characteristics of the measurement methods are explained in some detail, however the actual measurements, their representativity and uncertainty ranges are not reported or clearly discussed in the main article. These are relevant details to assess their strengths and weaknesses as a target for model evaluation. Some of the details reported in sections 4.2 and 4.3 (e.g., Table 3) could be moved to supplementary materials, while more information on the results of the measurement campaigns and their uncertainties could be added in the main paper. For instance, the JATAC2022 campaign reports close to 0 % of illite and smectite in fine particle sizes in Cape Verde. Is this expected? How is this reconciled with dusts close to sources with illite contents up to 40%? On the other hand,

the estimate of iron oxides content from JATAC2022 relies on information from other experimental studies (DiBiagio et al., 2019), how does this impact their reliability?

Regarding the JATAC 2022 dataset, we have implemented a revised classification method for the measured elemental masses. Consequently, the previous finding of 0% illite has been updated, yielding results that align more closely with established literature. The mass fraction of iron oxides relative to total dust varies by geography; thus, we adopted the representative iron oxide mass fractions for 19 desert locations from Di Biagio et al. (2019). This fingerprint was applied to our mass ratio measurements to derive the reported percentage values. Details on this new classification and its associated uncertainties have been added to Section 3.1 (lines 398–408).

For the DUSTRISK 2022 dataset, trace elements were quantified via S4-Tstar TXRF instrumentation following established procedures (Fomba et al., 2020; Souza et al., 2025). Elemental concentration uncertainties were maintained below 15%, arising from sample preparation and instrumental limits as detailed in Fomba et al. (2020). Methodological clarifications and uncertainty analyses have been integrated into lines 431–448.

The description of the model evaluation procedure overrelies on a workflow schematic (Figure 3). I would recommend to expand the description and justify the different steps taken in the main text.

A clearer description of this schematic figure has been done. Now, this is Figure 4 and it is explained in Section 4.2 (lines 493-498).

As mentioned in the general comments, some aspects of the paper organization could be improved for clarity. For instance, in the current structure:

- Section 2 is not connected to the narrative of the paper. This should be either contextualized, moved or entirely removed.

We agree, Section 2 has consequently been removed.

- Sections 4.1, 4.2 and 4.3 mix the methodology used to obtain or gather the observations with the actual processing and methods used to compare to the model outputs.

Thank you for this reconstructing comment, Section 3 now focuses exclusively on the observational campaign, while a new Section 4 has been added to clarify the model comparison framework.

- Section 5.1 (“North Africa”) includes a comparison of the emitted PSD of a specific soil type with results from another model which could be moved to supplementary material.

It has been moved to the Appendix.

My general recommendation would be to:

- Clearly distinguish between observational data gathering (e.g., from previous studies or observational campaigns) and the methods to assess the model itself.

Thank you for the suggestion, we did the rearrangement accordingly.

- Include a section where model configuration and setup is clearly defined. Adding a table with the simulations conducted, their differences and an id to track them throughout the article could help.

We appreciate this suggestion. The “Input files and simulation setup” content has been relocated to Section 2.4, where we have also included a new Table 2 summarizing the specific simulations conducted. Furthermore, the description of the model configuration has been expanded for greater clarity (lines 340-351).

- Define the methodology followed for model evaluation in detail, including how the temporal and spatial dimensions are matched between model and observations.

Section 4 is now dedicated to this topic.

- The results are organized at present by campaign or observational dataset, which makes some of the aspects of the discussion of the improvements repetitive (e.g., improvements in the representation of PM10 PM2.5 Si in DUSTRISK vs JATAC, same for quartz). Maybe organizing them by "area" (sources vs. transport) or target variable (elemental composition vs mineral) could help streamline the discussion of results.

Thank you for the helpful suggestion, the results section has been re-organized to improve clarity and flow. Specifically, the “Model validation” section (Section 5) is now structured by target variables, with subsections dedicated to “Mineralogy” (Section 5.1) and “Elemental composition” (Section 5.2).

#### **Technical comments:**

- Section headers could be more descriptive of its contents (e.g. “North Africa” shows results of mineral evaluation, “Cape Verde - JATAC 2022” refers to the results of the evaluation with this specific campaign data...).

We have changed some of the headers to be more descriptive as proposed.

- L1: The focus put in the abstract on the JATAC campaigns seems disproportionate after reading the article.

We agree, we have changed this line to better reflect the content.

- L47-48: keep consistent size definitions for clay and silt throughout the manuscript.

We have checked these instances and made it consistent throughout.

- L49-51: while the statement is true, the quartz overestimation is only one of the many uncertainties related to size distribution of minerals in soils.

We have changed the wording to better reflect that is indeed only one of the many related uncertainties between lines 50-52.

- L64-79: These lines now first state model evaluation against mineralogy, then discusses the two PSD approaches, then describes the datasets for evaluation again, mentions the seasonal variability analysis and again the results of the evaluation. Please, summarize and reorganize for clarity.

We have reorganized these paragraphs to reflect the content of the manuscript on a progressive manner (lines 64-88).

- L183-184: There is no previous definition of the model configuration or simulation domain. Please, clarify or reorganize the text (the simulation setup is explained next in Sect 3.1.2).

All the information regarding model configuration and simulation domain can be found now in Section 2.4. To maintain a logical narrative flow, this subsection now follows the description of the emission scheme and the subsequent modifications changes to the mineralogical scheme, which we felt ensures a more cohesive transition for the reader.

- L187-189: Rewrite this sentence to make it clearer.

This sentence has now been split into two; they can be found in lines 336 – 338.

- Section 3.1.2 - How long are the simulations? Which is the output frequency? A graphical representation of the domain, even if in a supplementary file, would help the reader. It could be used also to represent the location of the observational datasets used as a reference for evaluation.

These questions have been addressed with the inclusion of Table 2 and Figure 3 and in line 351.

- L223-224: Please, clarify the last sentence. Why is the Journet et al. 2014 article cited here?

This content has been deleted for synthesis's sake.

- L225-233: It is difficult to understand the justification of the use of a specific SMA for this work based on the purpose of a previous study. Given that this work aims at assessing the impact of different methods to define the emitted PSD I would say this justification is unnecessary.

This justification has been removed.

- L241: Figure 2 is mentioned before Figure 1. Revise.

Figures have been renamed accordingly.

- Figure 2. The assumption made for aerosol particles larger than 50  $\mu\text{m}$  has to be explained somewhere

A description has been added to the figure caption.

- L355: which is the assumption for gypsum and feldspar?

The assumptions for gypsum and feldspar are that their extension into finer fractions can be done via the quartz clay-to-silt and calcite clay-to-silt ratio, respectively. This is done following the methodology of Gonçalves Ageitos et al. (2023) as detailed in lines 302 – 310.

- L363: if aggregates disintegrate, why do they contribute to larger size classes?

Thank you for pointing out this inconsistency. The term 'disintegrate' was used incorrectly in this context. We intended to convey that while some aggregates break down, many clay-sized primary minerals remain bound within silt-sized aggregates during the emission process. We have revised the sentence (line 315) to clarify that these clay-rich species contribute to the silt-sized aerosol fraction because they are emitted as part of larger aggregates, rather than being fully dispersed into the clay-sized fraction.

- L392: Perlwitz is a global dataset ... explain which sites are selected.

The site selection within the global dataset is now clarified (lines 492-498).

- Figure 4: Figure 4 and comparison with MONARCH can be moved to supplementary materials. There should be some clarification regarding the last bin of COSMO, which has unknown composition from 50 to 80  $\mu\text{m}$ .

The lower panel of Figure 4 has been moved to the Appendix.

- Figure 5 caption - remove the modified from note. Include the size range. What are the uncertainty bars? Are all measurements bulk?

A size range comparison clarification has been added to the Model comparison framework section (lines 534 – 545). A line in Figure's 5 caption has been added clarifying where the uncertainty bars come from. Indeed, not all measurements are bulk, and model results were carefully selected to match the measurement size ranges at the highest available resolution.

- Figures 5 to 12: Use a consistent set of evaluation metrics across the paper and explain how these are calculated in the methods section. Is the correlation spatial, temporal? Please, use the same range in the figures when possible to allow "by-eye" comparison. For instance in Figure 8.

A consistent set of evaluation metrics is now used throughout the results Figures (Figs. 5-11). To this end, tables with mean biases have been added for each of the validating datasets (Tables 4-7). The correlation is spatial and the set of evaluating metrics are

now detailed in Section 4.1. The same ranges were used, when possible, in the figures to allow the “by-eye” comparison as the reviewer suggested. Whenever uniform scales obscured key data trends, we have retained independent scales and noted this clearly in the respective figure captions, specifically for Figs. 7 & 11.

- [L560: what do the uncertainties represent?](#)

The error bars in Figure 5 represent the observational uncertainties (e.g., analytical precision or standard deviation of samples) as specifically reported by the authors of the individual measurement campaigns included in the North African compilation. Because these data come from various sources (e.g., Kandler et al. (2007), Panta et al. (2023)), the specific methodology for calculating uncertainty varies by study; however, we have included them to provide the best available estimate of observational confidence. We have updated the text in Section 5.1.1 (line 604) and the Figure’s 5 caption to explicitly state this.

- [L573: what do these size limitations refer to?](#)

This is now clearly stated on line 595. These size limitations refer to the fact that on the original scheme, phyllosilicates were not considered at coarser sizes.

- [L623: the Fe content of phyllosilicates different from illite, and other minerals \(e.g., feldspar\) is not considered in this study, why? Please, discuss the impact of these assumptions on the Fe evaluation results. \(Related also to line 804 in the conclusions\).](#)

While Fe content is accounted for illite, it is not included for smectite or feldspar. This decision is based on the predominant mineralogical signatures typically observed in long-range transported Saharan dust (Moreno et al., 2006; Scheuven et al., 2013; Formenti et al., 2011, 2014). Some discussion on the impact of these assumptions on the Fe evaluation results has been added on lines 765-769.

- [Figure 8: Which minerals are included in the clay measurements? Are they exclusively illite, kaolinite, smectite? How is the mineral composition matched between model and observations?](#)

Yes, the clay minerals are exclusively Illite, kaolinite and smectite. These are the minerals used in the model and are selected based on common mineralogical assemblages observed in Saharan dust aerosols reported.

## References:

Di Biagio, C., Formenti, P., Balkanski, Y., Caponi, L., Cazaunau, M., Pangui, E., Journet, E., Nowak, S., Andreae, M. O., Kandler, K., Saeed, T., Piketh, S., Seibert, D., Williams, E., and Doussin, J.-F.: Complex refractive indices and single-scattering albedo of global dust aerosols in the shortwave spectrum and relationship to size and iron content, *Atmospheric Chemistry and Physics*, 19, 15 503–15 531, <https://doi.org/10.5194/acp-19-15503-2019>, 2019.

Fomba, K. W., Deabji, N., Barcha, S. E. I., Ouchen, I., Elbaramoussi, E. M., El Moursli, R. C., Harnafi, M., El Hajjaji, S., Mellouki, A., and Herrmann, H.: Application of TXRF in monitoring trace metals in particulate matter and cloud water, *Atmospheric Measurement Techniques*, 13, 4773–4790, <https://doi.org/10.5194/amt-13-4773-2020>, 2020.

Formenti, P., Schütz, L., Balkanski, Y., Desboeufs, K., Ebert, M., Kandler, K., Petzold, A., Scheuvs, D., Weinbruch, S., and Zhang, D.: Recent progress in understanding physical and chemical properties of African and Asian mineral dust, *Atmospheric Chemistry and Physics*, 11, 8231–8256, <https://doi.org/10.5194/acp-11-8231-2011>, 2011.

Formenti, P., Caquineau, S., Desboeufs, K., Klaver, A., Chevaillier, S., Journet, E., and Rajot, J. L.: Mapping the physico-chemical properties of mineral dust in western Africa: mineralogical composition, *Atmospheric Chemistry and Physics*, 14, 10 663–10 686, <https://doi.org/10.5194/acp-14-10663-2014>, 2014.

Goncalves Ageitos, M., Obiso, V., Miller, R. L., Jorba, O., Klose, M., Dawson, M., Balkanski, Y., Perlwitz, J., Basart, S., Di Tomaso, E., Escribano, J., Macchia, F., Montan., G., Mahowald, N. M., Green, R. O., Thompson, D. R., and Pérez García-Pando, C.: Modeling dust mineralogical composition: sensitivity to soil mineralogy atlases and their expected climate impacts, *Atmospheric Chemistry and Physics*, 23, 8623–8657, <https://doi.org/10.5194/acp-23-8623-2023>, 2023.

Kandler, K., Benker, N., Bundke, U., Cuevas, E., Ebert, M., Knippertz, P., Rodriguez, S., Schütz, L., and Weinbruch, S.: Chemical composition and complex refractive index of Saharan Mineral Dust at Iza.a, Tenerife (Spain) derived by electron microscopy, *Atmospheric Environment*, 41, 8058–8074, <https://doi.org/10.1016/j.atmosenv.2007.06.047>, 2007.

Moreno, T., Querol, X., Castillo, S., Alastuey, A., Cuevas, E., Herrmann, L., Mounkaila, M., Elvira, J., and Gibbons, W.: Geochemical variations in aeolian mineral particles from the Sahara–Sahel Dust Corridor, *Chemosphere*, 65, 261–270, <https://doi.org/10.1016/j.chemosphere.2006.02.052>, 2006.

Panta, A., Kandler, K., Alastuey, A., González-Flórez, C., González-Romero, A., Klose, M., Querol, X., Reche, C., Yus-Díez, J., and Pérez García-Pando, C.: Insights into the single-particle composition, size, mixing state, and aspect ratio of freshly emitted mineral dust from field measurements in the Moroccan Sahara using electron microscopy, *Atmospheric Chemistry and Physics*, 23, 3861–3885, <https://doi.org/10.5194/acp-23-3861-2023>, 2023.

Scheuvs, D., Schütz, L., Kandler, K., Ebert, M., and Weinbruch, S.: Bulk composition of northern African dust and its source sediments — A compilation, *Earth-Science Reviews*, 116, 170–194, <https://doi.org/10.1016/j.earscirev.2012.08.005>, 2013.

Souza, E. J. D. S., Fomba, K. W., Anaya, S. G. M., Schepanski, K., Freire, S. M., MateriÁlc, D., Reemtsma, T., and Herrmann, H.: Particle-bound mercury in Saharan dust-loaded particulate matter in Cabo Verde, *Journal of Hazardous Materials*, 487, 137 053, <https://doi.org/10.1016/j.jhazmat.2024.137053>, 2025.