Reviewer #2

We acknowledge anonymous reviewer#2 for his/her comments that helped us to improve the manuscript. Replies to the reviewer's specific comments are provided in the following (text in blue) after the reviewer's comments (text in black). Line numbers correspond to the manuscript version with tracked changes.

Before replying to the reviewer's comments, we must make a clarification for the used RIs.

The refractive indices that have been used for the analysis in the SW are those by Balkanski et al. (2007), Colarco et al. (2014), and OPAC, and not Balkanski et al. (2007), WMO (1983), and OPAC, as stated in the original version of the manuscript. For the LW, we used the refractive index by WMO (1983) (instead of Colarco et al. (2014)) because Colarco et al. (2014) do not provide the refractive index in the LW. We corrected this mistake and clarified what has been done in Section 2.1 (line 164).

This paper documents a sensitivity study to investigate and compare the sources of uncertainty in the estimate of dust direct radiative effects (DRE). Three major sources of uncertainty are considered, dust spectral refractive index (RI), dust particle size and dust particle shape. The magnitude of each uncertainty source is estimated from the differences of DRE estimated based on different assumptions of RT, size and shape. For example, the uncertainty due to dust RI is estimated by computing and contrasting the DRE of dust based on three sets of RI data with different absorptions. The sensitivity studies are performed for different surface conditions (desert vs. ocean) and solar zenith angles. The results from the sensitivity study suggests that the leading uncertainty in dust DRE computation is the dust RI, followed by dust size. The shape of dust has only negligible effects on dust DRE.

I have several main concerns and reservations about this study, which are summarized below. As a result, I have a hard time seeing how this paper advances our understanding of dust DRE and therefore do not think the paper should be accepted for publication in ACP.

My first main concern is that the sensitivity studies seem too simple to capture the variability of dust aerosols in reality, and the complex environments in which the dust aerosols are found. The objective of this study is to understand the uncertainty in dust DRE (i.e., the term). In my view, this objective can only be achieved after a reasonable estimation of the mean DRE (i.e., the term). In this study, the DRE computations are performed in a quite simple and idealized set up. For example, only two types of surfaces (desert vs. ocean) and three values of solar zenith angles are considered. The surface temperature and atmospheric profiles are assumed to be constant without considering the diurnal cycles which can be quite strong in the desert regions. As a result of this rudimentary case set up, the meaningfulness of the mean DRE and therefore DRE uncertainty is quite questionable.

The paper presents the results of a sensitivity study of dust aerosol effects on solar radiation. The main idea comes exactly from reading the suggested papers. Can someone isolate size, shape, and RI effects as a function of various AODs, solar elevations and albedo? To do so we should not deal with "mean dust DRE" which in such a sensitivity study has minimal meaning exactly because diurnal, seasonal and spatiotemporal changes in AODs, shape, size, temperature/albedo, even solar elevation ranges in a season/location have been mixed in order to define this mean DRE. Which is of course (Dust mean DRE) the outcome (the number) that the scientific community would like to have in the end, in order to assess dust effects on climate.

As the reviewer surely understands, the domain is complex and structured studies could be useful for the community to quantify individual effects and to understand their complex response to realistic changes of basic atmospheric and solar parameters.

So, it is probably not possible to use our results for an overall assessment of the e.g. Saharan dust effect on Earth – atmosphere balance, but it can help scientists dealing with measurements and models in related experiments, to focus on the most uncertain aspects of dust parameterizations needed for radiative forcing studies. And most probably, eventually, to indirectly help improving global or regional models too.

The conditions are not realistic for using them to directly retrieve a (regional or global) mean DRE, however they are meaningful when compared with actual measurements at related experiments (e.g. see Otto et al., 2007). Such studies are not dealing only with a mean DRE assessment and its modelling parameterization but also with other aspects. E.g., evaluating satellite-based data that need ground-based measurements and detailed dust optical properties for a certain location and a certain solar elevation in order to be meaningful for validation or radiative closure studies.

We have tried to make all the above clearer, especially in the introduction and the conclusion sections (see e.g., lines 600-613 at the summary and conclusions section).

Finally, a possible answer to this comment has been provided also from rev 3 that we point again here :

"The paper has to be understood and evaluated as an advance for radiative transfer simulations in atmospheres containing dust aerosols but not about generalities concerning dust aerosol DRE, in contrary to the wrong understanding of anonymous author of RC2 comment. In this way, the paper answers and quantifies some open questions of radiative transfer in atmosphere containing dust aerosols, a domain that needs such kind of detailed and structured studies, since the difficulty of parametrizing the radiative transfer equation in radiative transfer models for the case of dust aerosol is contained in the lack of order of magnitude and on the unknowledge about the influence of the different parameters (especially RI, size distribution and shape). Therefore, this study is a significant advance in this topic thanks to the clarifications and the quantifications that it brings."

For example, one of the main conclusions is that "At the top of the atmosphere (TOA) close to dust sources, the underestimation of size issues an underestimation of the direct warming effect of dust of ~18 - 25 W/m2, for dust aerosol optical depth (DOD) of 1 at 0.5 μm". What is the meaningfulness of the DRE 18 - 25 W/m2? Is it a regional mean value? Is it instantaneous value or diurnally averaged? How could a modeler compare their DRE simulations to such DRE values reported in this study?

We agree that most of the studies targeting a regional mean DRE value, use a certain DRE scale that would have a meaning for more global radiative forcing assessment. So, in our case percentage changes have more meaning. However, absolute solar radiation changes in a focused radiative transfer modeling sensitivity study is exactly what it is defined. It is the difference in W/m^2 among two defined runs. Which is not, and it does not have to be, comparable with model simulations of a modeler interested in a mean dust DRE. However, maybe a modeler could think that for example, diurnal or seasonal patterns of e.g. AOD, or size through transport, or RI, would affect the mean DRE due to the different response to solar elevation but that will not happen based on the size. And then prioritize the efforts towards dealing with such issues. So, someone can improve more his/her models towards less uncertain results linked with spatiotemporal assumptions of dust properties and their variability.

As a suggestion for revision (should the authors consider resubmission), I would recommend the study to set up the case studies in a more realistic and meaningful context that hopefully can be compared to the model simulations or other observations studies quantitatively.

As it is already stated in the original version of the manuscript (lines 111 - 114) and explained above: "It is important to clarify at this point that our study aims to contribute towards the understanding of how the dust optical properties parameterization in models affect the calculated dust DRE under different atmospheric and land surface conditions, rather than providing quantitative estimates of the (local or global) dust radiative effects."

We however tried to follow the suggestion and address this comment by further analyzing the sensitivity of our results to surface temperature over the desert, as well as the effect of surface albedo (by performing simulations for the same size distribution over the two surfaces). The results are discussed in Section 3.2.2 while two new graphs have been added in the Appendix (Figures A3 and A4)

In comparison with several previous modeling studies (e.g., a recent one by Li et al. 2022) or the observations studies (e.g., Song et al. 2022), this study seems to be rudimentary and lack novelty. As mentioned above, the setup of the case studies is too simple. Moreover, the main conclusion from this study seems to be identical to previous ones (e.g., Li et al. 2021, 2022, Song et al. 2022). So, the novelty and significance of this study are quite questionable. They should be clearly explained and justified.

Indeed, there are other recently published studies that deal with the same problems as sensitivity studies without mentioning mean DRE regional assessments. It is true that especially the Song et al. study, which presents similar findings to our study, appeared at the time of the submission of this work. This led us to the inclusion of spectral irradiance aspects, focus more on the physical mechanisms that control the radiative transfer processes and also create section 4 that exactly deals with this aspect comparing our findings with the findings of other studies pursuing similar aspects.

One of the new aspects included in this study is the spectral simulations that, as discussed in Otto et al., (2007), are very useful for experimental campaigns where spectral dependence of different aerosol properties could play a significant role relative to the propagation of the spectral and total solar radiation through the dust layer.

E.g. what is the mean spectral lidar ratio variability in an area as large as the Sahara that must be used in order to include space lidars in model inputs aiming for a mean dust DRE? And what is the spectral AOD dependence effect on SW radiation in this whole area when the only source of information is satellite-based data dealing with mainly one AOD wavelength? Such uncertainties affect significantly the DREs calculated at larger scales using such data, and studies such as the present contribute towards the better understanding of their impact.

Finally, we see our study as an independent verification of part of the Song et al., 2022 findings that have been conceived, of course with different set ups and assumptions. In addition, we tried to interpret with physical mechanisms some of the aspects concluded here.

In paragraph 4 we have added, already in the original version of the manuscript, some aspects pointing out differences and new findings of our study compared with the ones mentioned here.

Several places of the paper are confusing and/or misleading. For example, in most previous studies (e.g., Kok et al. 2017, all of Ryder et al. papers) dust particle size distribution was described in terms of dust geometrical diameter whereas this study uses radius. Although this is not physically wrong, making it difficult to compare this study with previous ones. In Fig. 13 to Fig. 16, the comparison of LW DRE with SW DRE at different SZA is confusing because the LW DRE is independent of SZA. A more meaningful comparison is the diurnally averaged DRE.

Probably the radius or diameter aspect is a detail, but we used it mostly as it is the input in the RT models. Since we are not aiming to directly compare with models dealing with mean DRE we believe that it can reasonably stay as is. We do agree that LW DRE representation with SZA is confusing. We mentioned this in the captions and in the text but we kept it in the graphs for visual comparison with the SW in each case.

Finally, the overall quality of the paper seems to fall short of the ACP standard. The paper has many typos and many references are missing (e.g., Ryder et al. 2021, Gutleben et al., 2019; 2020, Dubovik et al., 2006 to name a few)

References:

Li, L., Mahowald, N. M., Kok, J. F., Liu, X., Wu, M., Leung, D. M., Hamilton, D. S., Emmons, L. K., Huang, Y., Sexton, N., Meng, J., and Wan, J.: Importance of different parameterization changes for the updated dust cycle modeling in the Community Atmosphere Model (version 6.1), Geosci. Model Dev., 15, 8181–8219, https://doi.org/10.5194/gmd-15-8181-2022, 2022.

Li, L., Mahowald, N. M., Miller, R. L., Pérez García-Pando, C., Klose, M., Hamilton, D. S., Gonçalves Ageitos, M., Ginoux, P., Balkanski, Y., Green, R. O., Kalashnikova, O., Kok, J. F., Obiso, V., Paynter, D., and Thompson, D. R.: Quantifying the range of the dust direct radiative effect due to source mineralogy uncertainty, Atmos. Chem. Phys., 21, 3973–4005, https://doi.org/10.5194/acp-21-3973-2021, 2021.

Kok, J. F. et al. Smaller desert dust cooling effect estimated from analysis of dust size and abundance. Nat Geosci 10, 274–278 (2017).

We tried to improve the document quality and included the suggested (as well as few more, recent) references in the introduction.