

The authors highly appreciate the exhaustive review provided by both the reviewers that has significantly improved the quality of the manuscript.

In particular, we thank the reviewer# 1 for his/her current valuable comments that definitely will improve the manuscript. For clarity, changes/modifications are highlighted in purple in the revised version of the manuscript. In addition, some minor mistakes (mistypes, misspellings, missing references, word repetitions, format changes, ...) have been observed in the manuscript, and then they have also been corrected (shown in orange) in the revised version of the manuscript.

Report #2

Reviewer #1's comments:

The authors addressed most of my concerns and suggestions, with an improvement for the manuscript. However, the reviewer considers that the core question has not been fully addressed.

The added text convincingly demonstrates that accurate representation of the dust size distribution is important for estimating dust direct radiative effects (DRE), and that current climate models suffer from biases in the relative proportions of fine and coarse dust. These points are well supported by the cited literature. However, what has not been justified is why computing DRE for fine and coarse modes "separately" is physically preferable — or necessary — compared to computing DRE for the total dust population as a whole using the complete size distribution and corresponding optical properties.

From a radiative transfer perspective, the physically rigorous approach would be to integrate extinction across the full shortwave and longwave spectrum using the continuous dust size distribution along with associated optical and microphysical properties (complex refractive index across SW and LW, non-spherical particle shape, etc.). The separation into fine and coarse modes at an arbitrary cutoff diameter is a modeling convention, not a physical requirement. The arguments presented in the revised text — that fine and coarse dust have opposing radiative effects and that optical properties are size-dependent — are arguments for correctly resolving the size distribution, not necessarily for splitting it into two discrete populations and treating them independently.

The authors are therefore encouraged to provide a more physics-based justification for their methodological choice. For example, are the observational inputs inherently mode-resolved, making the separated treatment a data-driven necessity? Or can the authors provide a quantitative sensitivity analysis from their own simulations demonstrating that the separated approach yields meaningfully

different DRE estimates compared to a bulk treatment? Addressing any of these points would substantially strengthen the motivation for the study's core methodology.

Author's response:

We agree that radiative transfer calculations can in principle be performed using the full continuous size distribution. In our study, however, the separation into fine and coarse modes is motivated by the observational retrievals and is used as a diagnostic framework to investigate size-dependent radiative effects. We have clarified this point in Section 1, adding a paragraph (page 3, lines 98–110) in the revised manuscript.

“From a radiative transfer perspective, the most rigorous way to estimate DRE would be to integrate the optical properties over the full particle size distribution. In this work, however, the separation between D_f and D_c is not introduced as a radiative-transfer requirement but arises naturally from the observational framework used. The polarization lidar methodology allows the retrieval of vertically resolved extinction profiles separately for fine and coarse dust particles (Tesche et al., 2009; Mamouri and Ansmann, 2014, 2017), as stated before. Treating these two modes independently therefore provides a direct way to propagate the observationally constrained dust components into the radiative transfer calculations. In addition, separating the D_f and D_c modes offers a useful diagnostic framework for interpreting the size-dependent radiative effects of mineral dust. D_f tends to dominate SW scattering, while D_c plays a more important role in LW emission and absorption, leading to potentially different or even compensating contributions to the total DRE. Analysing both modes separately therefore allows for a better understanding of how different parts of the size distribution contribute to the overall radiative impact. Finally, this separated-mode approach also enables a direct comparison considering the total dust as a whole. In this study, the DRE obtained by summing the contributions from D_f and D_c particles is compared with the DRE computed using the total dust population, allowing for assessing the sensitivity of the radiative effect to the size-mode resolved representation of dust.”

Moreover, other paragraphs along the manuscript have been revised, and modified if needed, to provide an improved version of the manuscript taking into account the concerns and suggestions of the reviewer. In particular:

- The following paragraph “Recent research has demonstrated that radiative transfer models must handle fine and coarse modes separately to accurately represent the radiative effect of mineral dust” (page 2, lines 66-67 in the previous

version of the manuscript) has been modified as follows: “Recent research has demonstrated that separating the dust population into fine and coarse modes provides a useful framework to analyse size-dependent radiative effects” (page 2, lines 66-67 in the revised version of the manuscript).

- The following paragraph “Sicard et al. (2014) found that a clear distinction between dust modes is critical for the reliable estimation of longwave radiative forcing” (page 2, lines 67-68 in the previous version of the manuscript) has been modified as follows: “Sicard et al. (2014) found that a clear distinction between dust modes is suitable for the reliable estimation of longwave radiative forcing” (page 2, lines 66-67 in the revised version of the manuscript).
- The following paragraph “When considered collectively, these studies demonstrate that fine and coarse dust must not be treated as a single, homogeneous aerosol population if radiative accuracy is to be preserved. The two modes differ not only in abundance and lifetime but also in their optical characteristics and radiative impacts. Thus, explicitly separating fine and coarse modes in radiative transfer models is crucial to reduce persistent biases in estimates of dust radiative forcing” (page 2, lines 79-82 in the previous version of the manuscript) has been replaced by: “It should be highlighted that the two dust modes differ not only in abundance and lifetime but also in their optical characteristics and radiative impacts. Thus, separating the dust population into fine and coarse modes provides a useful framework to analyse size-dependent radiative effects.” (page 2, lines 78-81 in the revised version of the manuscript).
- The following paragraph “The optical and microphysical properties were reported in López-Cayuela et al. (2023), and the DRE in the SW range can be found in López-Cayuela et al. (2025)” (page 2, lines 85-86) has been modified as follows: “This event was well characterized in López-Cayuela et al. (2023), which analysed the vertical behaviour of the optical and microphysical dust properties using polarization-sensitive lidar measurements from five Iberian lidar stations, separating the dust into its fine (D_f) and coarse (D_c) components following the methodology of Mamouri and Ansmann (2014, 2017). The DRE analysis in the SW range can be found in López-Cayuela et al. (2025).” (page 2, lines 84-87 in the revised version of the manuscript).