Response to Reviewer 1

This work evaluates future dust pollution by modeling different climate change scenarios that include changes in GHG and aerosol emissions using a global climate model. By including different SSP scenarios, they are able to assess different mechanisms, especially those that have counteracting effects on dust transport and deposition. The manuscript is well written and organized, but there are some aspects that can be improved prior to publication. Mainly, the novelty is not clear enough, the results are described more qualitatively than quantitatively, and lastly, there are not many comparisons of their results with other works. Below are some specific comments regarding these aspects.

We thank the reviewer for the constructive comments and suggestions, which are very helpful for improving the clarity and reliability of the manuscript. Please see our point-by-point responses to your comments below.

1) I suggest highlighting the novelties of the paper in the abstract, introduction, and summary. In the introduction, similar studies are mentioned. What are the main differences with those? Do your conclusions agree with all the mentioned studies?

Reply: The novelties of this study have been highlighted in the Abstract (L32-34), Introduction (L132-135, L162-173, L166-171), and Conclusion (L430-438).

Existing studies typically focus on dust flux responses to climate change under future scenarios, thereby examining only the combined effects of anthropogenic aerosols and GHGs, which also have yet to quantify dust response to future climate change for pursuing carbon neutrality goals (Zhao et al., 2023; Liu et al., 2024). In this study, the individual impacts of anthropogenic aerosols and GHGs reductions under carbon neutral scenario on dust emissions and concentrations over the dust belt of low- to midlatitudes in the Northern Hemisphere are investigated.

Our conclusions agree with all the mentioned studies. Dust emissions are significantly higher under high-emission scenarios than under low-emission pathways (e.g., Singh et al., 2017; Zhao et al., 2023; Liu et al., 2024; Gomez et al., 2023), consistent with our finding of reduced dust emissions in carbon neutral scenario relative to the high fossil fuel scenario. Moreover, the impacts of anthropogenic aerosol and GHGs mitigation on wind speed identified in this study are in accordance with previous findings (e.g., Lei et al., 2023; Ren et al., 2024; Sawadogo et al., 2019).

2) I suggest evaluating the title. I found it a bit generic, considering that there is a focus on specific regions, and that the selection of carbon neutrality scenarios is quite specific too.

Reply: We have now revised the title to "Impacts of reductions in anthropogenic aerosols and greenhouse gases toward carbon neutrality on dust pollution over the Northern Hemisphere dust belt". Considering that SSP1-1.9 has been widely used as the carbon neutrality scenario, it is not specified in the title.

3) The abstract has a clear message, but quantitative results could greatly support their statements.

Reply: Quantitative results have been added (L40-44) in abstract. For example, (i) Reductions in aerosols amplify surface downwelling shortwave radiation, convection and wind speed, thereby promoting dust emissions by 6–12% and concentrations by 4–20% over North Africa, the Central Asia Desert and East Asia; (ii) GHGs reductions diminish the land-ocean thermal contrast and wind speed, suppressing dust emissions by 6–15% and concentrations by 8–20% mainly over the Central Asia Desert and North Africa.

4) Experiment setup: As mentioned at the end of this Section, the model evolves in time. I don't completely understand when the simulations start and how fine the time resolution is, in terms of the prescribed aerosol concentration. Are all simulations initialized with the same aerosol conditions and only the emissions change in time (hourly?) and space, or do they also have different initial conditions? You can also tell us a bit more about how realistic the aerosol emissions are modeled, to better understand the simulation of these scenarios. Are anthropogenic emissions properly specified per region/country/city, and do they vary along the day? Another thing that I wonder is if the model is able to capture changes in vegetation, since it was mentioned as a possible agent in aerosol modification in the Introduction.

Reply: Equilibrium simulations are run for 100 years of the year 2060, with the initial conditions at the year 2060 level. The initial 40 years are considered as model spin-up period. The output data has a monthly temporal resolution. All simulations are initialized with the same aerosol and GHG conditions and only the aerosol emissions and/or GHGs concentrations change in time and space every month. The model is integrated every 30 minutes and the results are archived every month. Future emission inventories build on the Shared Socioeconomic Pathways, providing standardized multidimensional parameters (e.g., population, economy, technology, environment, institutions) and qualitative narratives at national/regional scales (van Vuuren et al., 2017; Kriegler et al., 2017; Fujimori et al., 2017; Calvin et al., 2017; Fricko et al., 2017).

This study aims to investigate the influence of meteorological factors on dust emission under future climate changes. In the model simulations, land use is held constant, thereby unable to account for potential vegetation changes. However, based on previous studies, we can reasonably assume the impact of vegetation dynamics on dust emissions. Notaro et al. (2006) employed a fully coupled atmosphere–ocean–land–ice model with dynamic vegetation to analyze future vegetation changes under continuously increasing CO_2 concentrations. Their results revealed an increase in tree cover across arid regions, such as the Sahel and the Middle East, along with a northward shift of the Sahel transition zone. Cramer et al. (2001) demonstrated that the physiological effect can facilitate forest expansion into savanna and grassland expansion into arid tropical regions. Furthermore, by using an asynchronously coupled system between the IAP-AGCM model and the biosphere BIOME3 model, Jiang et al. (2011) projected an increase in deciduous forests across tropical Africa under the A2 emissions scenario. Consequently, the vegetation changes may weaken the dust changes in the future. We have now added it in the manuscript.

5) On model evaluation, are the comparisons with CALIPSO performed along a whole year or a specific timeframe, and is it for the whole domain or a region of the space?

Reply: For model evaluation, CALIPSO satellite observations are compared against simulations across the entire study domain (0°–60°N, 25°W–130°E) during March-May of 2017 - 2021, since that the data end in 2021.

6) How fine is the vertical resolution in order to observe PBL rising? If not fine enough, could this be a bias that enhances the surface wind strengthening?

Reply: The model has 30 vertical layers, from the surface to the top of the atmosphere. however, this resolution remains relatively low. Lindvall et al. (2012) evaluated the performance of PBL parameterizations in CESM using observations and reanalysis data across a range of near-surface parameters. Their results indicate that the model captures spatial patterns relatively well but systematically underestimates PBL height. Consequently, this simulated PBL bias may influence wind speed changes. We have now added the discussion about this potential bias.

7) The mechanisms that drive the observed changes are carefully explained, especially those with opposite trends, which seems to be the main strength of this work. However, these changes are not quantitatively described nor compared with other studies. For instance, in L348 “significant reductions” could be quantified in a

comparative way (as a % of the initial scenario, for example), in order to have a more complete description of their results.

Reply: Quantitative descriptions of dust flux changes and key meteorological drivers (e.g., wind speed) have been added to Section 3 and Section 4. For example, anthropogenic aerosol reductions in SSP1-1.9 relative to SSP5-8.5 amplify 10-m wind speed by 0.05–0.10 m s^{-1} across core dust sources (Figures 8a), driving intensified dust emission fluxes by 6–12% and near-surface concentrations by 8–16% in North and Central Africa (Figures 3c-d, Figures 4c-d). The GHGs reduction elevates relative humidity (Figure 10b), which raises the critical threshold wind velocity required for dust mobilization. It further reduces dust emission fluxes by 6–15% and atmospheric dust concentrations by 8–20% (Figure 4e-f), particularly in the North African and Central Asian source regions, even though the soil moisture slightly increases in some regions (Figure 10c).

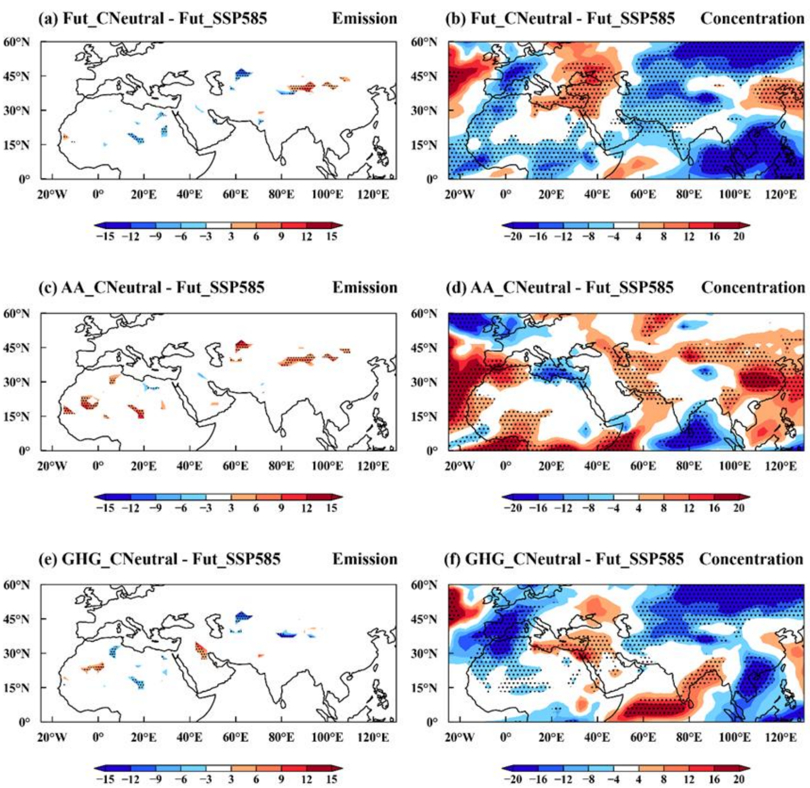

Figure 4. Spatial distribution of percentage changes in March–May mean (a, c, e) dust emissions (%) and (b, d, f) near-surface dust concentrations (%) in 2060 for

Fut_CNeutral (top), AA_CNeutral (middle), and GHG_CNeutral (bottom) compared to the Fut_SSP585 simulation. The stippled areas indicate statistically significant differences at the 90% confidence level based on a two-tailed Student's t-test.

8) Fig. 1: “autumn”

Reply: Revised.

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