Reply to Referee #2 Yonggang Liu

We appreciate the constructive and detailed comments from the reviewer. Below we reply to each point they raise (black) and explain how we intend to revise the manuscript (blue).

Xie et al. develop and tune a new offline dust emission model, DUSTY, based on which and the climate simulations they have carried out previously, a continuous model-derived timeseries of global dust emissions over the whole Phanerozoic is established. The simulation results provide quantitative insights into significant fluctuations in dust emissions during this Era. Notably, the study highlights the dominant influence of non-vegetated areas on dust emissions. The authors further investigate the mechanisms underlying the hydrological variations, governs the aridity the distribution non-vegetated areas. The findings demonstrate that paleogeography serves as the primary driving force behind dust emission variations, while the role of CO_2 is found to be marginal. The comparison between the simulated region of dust emission and the distribution of evaporite sediment records is not bad given the uncertainties in so many boundary conditions and model parameters. The manuscript provides new knowledge to both geologists and paleoclimatologists and clearly written in general, I recommend publication after a relatively minor revision.

Major comments

1. More detailed comparison should be made here of the 15_MMM and 0Ma simulations, which are crucial for tuning and evaluating the model. Although the model parameters of the DUSTY model have been optimized by maximizing the Arcsin Mielke score and the global mean emissions are the same, significant differences still exist between Figures 1a and 1b. For example, the dust emission in the middle of Eurasia and South America is seriously underestimated while that over Australia is highly overestimated. Are they due to biases in the simulated climate, vegetation or dust parameterization? The implication to the simulated distribution of dust emission in other periods should also be discussed.

   The comparison between the tuning target (Figure 1a) and the tuned pre-industrial simulation (Figure 1b) indicates that the DUSTY model can represent the general spatial distribution of dust emissions. However, biases exist in the detailed distributions. In Figure 1a, dust emissions have hotspots in regions such as the eastern Sahara and central Asia. In contrast, Figure 1b shows emissions more evenly distributed, lacking standout areas with high emissions. This discrepancy is largely due to the absence of detailed morphology and particle size representation in our models. These factors are crucial for capturing small-scale areas with frequent dust activation, such as the eastern Sahara. Because we force the DUSTY model to match the global mean emission rate of the target, the average emission in each sub-area is enhanced in the absence of hotspots. This leads to overestimation in regions like Australia and western Sahara. While vegetation should not be attributed to the bias in this comparison because, in the standard pre-industrial simulations the vegetation is from observations instead of simulated from TRIFFID (described in line 166 -169 in the original manuscript).

Further, in terms of the simulated dust field in paleo time slices, our model is expected not able to simulate small-scale areas with standout emissions, and will overestimate the emission rate over the broader areas as well. Additionally, the paleo simulations involve greater uncertainty in vegetation and topography compared to the standard pre-industrial run, which introduces additional biases into the simulated dust emission fields.

We will add the above discussion to the revised manuscript.

2. The absence of land plant colonisation before 410Ma implies that the inclusion of vegetation cover during 541-410Ma in this study may have resulted in an underestimation of dust emission during this period. The influence of this effect on the major conclusions of their study should also be discussed.

   The TRIFFID vegetation scheme, coupled with the GCM, employs a simply representation of terrestrial vegetation, incorporating five plant functional types that cover a broad climate range. These plant types do not go extinct and can regenerate under suitable conditions. This simplification introduces a bias for early Paleozoic periods before the colonization of land plants, resulting in our simulations predicting both bare soil and vegetation where, in reality, there would have been only bare soil. Consequently, this leads to an underestimation of dust emissions during those period.

   This issue explains the poor consistency with evaporite records in the time slices before the Devonian (Figure 9 and Figure A6), along with biases potentially introduced by GCM simulation and DUSTY parameterization. A more quantitative evaluation of the sensitivity of dust emissions to dynamic vegetation can be achieved through parallel simulations excluding the TRIFFID model. Sensitivity tests in Liu et al. (2020) demonstrate that including dynamic vegetation can lead to up to a fourfold underestimation of dust emissions in the Precambrian, highlighting the significant impact of non-existent land vegetation.

   We will add this discussion to the limitations in Section 5.2 and address the higher uncertainty before land plant colonization in Section 4.1, describing the paleo dust emission results, as well as in the Conclusion section in the revised manuscript.

Specific Comments

Line 45-48: May add "glaciogenic rock powder" or other equivalent expressions.

Yes, will add “more abundant sediment availability” and reference in the corresponding paragraph.

Line 188-190: is the global mean the average over all the land or over the regions with nonzero dust emission?

The global mean is calculated over the entire global area, including both land and ocean. This approach ensures consistency when comparing the means across different time slices and avoids confusion arising from variations in the total land area over time.

Line 189: 'C1' should be changed to 'C2'. This correction is also required in Table 1.

Thanks for pointing this out! They will be corrected in the revised manuscript.

Line 230: It should be added here that the results are from the S2 series of experiments.

Sure, we will clarify the experiment series name at the beginning of introducing paleo results in the revised manuscript.

Line 282-285: How was the value of 0.8 mm/day chosen here? The bracket at the end of Equation 10 needs to be removed.

The value of 0.8 mm/day is chosen based on studies that have shown that sediments, such as evaporites and weathered sandstones, form under precipitation conditions below this threshold, indicating an arid environment. This is an approximation referenced from Watson et al., 1992; Price et al., 1994; Cecil et al., 2003; and Craggs et al., 2012. We will add a justification for this value in the revised manuscript.

And the extra bracket will be removed.

References:

Cecil, C. B.: The Concept of Autocyclic and Allocyclic Controls on Sedimentation and Stratigraphy, Emphasizing the Climatic Variable, https://doi.org/10.2110/pec.03.77.0013, 2003.

Craggs, H. J., Valdes, P. J., and Widdowson, M.: Climate model predictions for the latest Cretaceous: An evaluation using climatically sensitive sediments as proxy indicators, Palaeogeography, Palaeoclimatology, Palaeoecology, 315-316, 12–23, https://doi.org/10.1016/j.palaeo.2011.11.004, 2012.

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Warren, J. K.: Evaporites through time: Tectonic, climatic and eustatic controls in marine and nonmarine deposits, Earth-Science Reviews,98, 217–268, https://doi.org/10.1016/j.earscirev.2009.11.004, 2010.