

## Reviewer #1

### General Comments

#### Comment A1

This study applies an albedo-based drag partitioning approach to GEOS-Chem (v. 14.2.3) for simulating dust emission globally. The authors compare the simulated spatial and seasonal distribution of dust emission from the current albedo-based drag partitioning approach with those obtained from two existing dust emission schemes that used (1) an observation-based dust source function that masks out non-erodible area, and (2) a simplified vegetation roughness drag partitioning approach, and further validate against atmospheric dust observations and dust deposition observations. The comparison and validation lead to the conclusion that the albedo-based drag partitioning approach eliminates an empirical source function to constrain dust sources and avoids the need to tune dust emission models.

I generally appreciate the equifinality issue within dust modeling as raised by the authors, and the albedo-based drag partitioning approach appears as an encouraging alternative to the classic dust source function approach. However, I have several concerns about the present manuscript regarding (1) the applicability this new approach being overly stated, and (2) the deviates between the current and previous approaches being insufficiently explored. Given the uncertain outcome of my proposed additional work, I recommend rejection of the current manuscript and encourage resubmission.

#### Response

We thank the reviewer for their positive overview and we appreciate the recognition of the equifinality issue in dust modeling which we think is one of the major findings of this work which will greatly interest readers across a range of disciplines.

The reviewer has two major concerns which has led that person to recommend rejection and resubmission:

The reviewer's first main concern is not about the quality of our work, but that the applicability of the work is overstated. We do not share this perspective and we will illustrate how applicable the model is now and for future modelling. Fundamentally, we do not accept and find it unreasonable that (foreseeable) applicability of our work should be included in the review of our manuscript. We respectively remind the reviewer that the criterion of applicability is not listed in the [GMD review criteria](#).

We found the reviewer's second major concern difficult to understand as "the deviates between the current and previous approaches being insufficiently explored", but which we attempt to clarify below. Nevertheless, this comment appears to require some additional analyses comparing the albedo-based and other approaches to better demonstrate their differences and characteristics.

Given the unreasonable basis of the reviewer's first major concern and its inconsistency with this journal's assessment criteria, and that the second major

concern appears to requires some additional “exploration”, we do not share the reviewer’s perspective that these concerns warrant a judgement to reject our manuscript.

Below, we respond to the reviewer’s comments point by point to clarify the objectives of this study and present the additional analyses.

## **Major Comments**

### Comment A2

A main purpose of the current study seems to eliminate the use of dust source function because, according to the authors, (1) the source function is empirical and not physical, (2) it is static over time. While I agree with these two critiques about the present usage of dust source function, the present albedo-based drag partitioning approach has its own limitations by nature.

### Response

Nowhere in our manuscript do we state that the main purpose of the current study is to eliminate the dust source function because it is empirical. We repeat the well-established fact in many other dust papers, that the dust source function is empirical. It is clear from the original manuscript abstract alone, that we demonstrate that the use of a dust source function in a dust emission model is redundant compared with dynamic drag partitioning. The reviewer has incorrectly conflated the empirical nature of the dust source function with the redundancy of the function in the presence of adequate drag partitioning. To ensure other readers do not make the same mistake, that the basis for the dust source function being redundant is due to it being empirical, we delete the three uses of the word ‘empirical’ which precede the description of the dust source function.

We focus the remainder of this section on the substantive science of how / why the dust source function is redundant in the presence of adequate drag partitioning. In the last few sentences of the original manuscript Introduction (Line 90-95) of the original paragraph, we state clearly the rationale for the work:

“However, several studies have noted that the use of a dust source function can introduce uncertainties in modeled dust concentrations and fails to adequately represent the dynamic changes in dust source regions driven by processes such as vegetation dynamics, desertification, and land use/land cover change.

and state clearly our manuscript’s intention:

“We replaced the time-invariant source function used in the DEAD scheme with dynamic drag partition parameterization from albedo data and compared simulations driven by the new albedo parameterization against the standard configuration to assess how drag partition influences both the intensity and frequency of dust

emissions across major sources.”

Our original manuscript states clearly our concern that the use of source functions within the current DOD-based model evaluation framework may compensate for missing physical processes in a non-unique manner and mask deficiencies in dust emission parameterizations. The reasons are described below.

In current dust modeling studies, atmospheric dust observations such as DOD are commonly used to evaluate and constrain dust emission schemes. In practice, dust source functions effectively prescribe preferential spatial distributions of dust emissions. Such prescribed source regions can partially compensate for missing or simplified physical processes (e.g., drag partitioning) by empirically constraining the spatial distribution of emissions, thereby improving agreement between simulated and observed atmospheric dust fields.

However, atmospheric dust loadings are influenced not only by emissions, but also by the combined effects of transport and deposition under meteorological conditions. Previous studies have shown that regions with frequent high DOD are not always spatially consistent with observed dust plume hotspots (Chappell et al., 2023). Therefore, DOD alone may be insufficient to uniquely constrain the realism of dust emission processes, and improved agreement with atmospheric dust observations does not necessarily imply more realistic dust emissions (Shao et al., 2025). In this context, source functions may partially mask deficiencies in the representation of threshold-controlled dust emission physics, leading to equifinal agreement with atmospheric dust observations through different underlying emission mechanisms. As shown in our results, substantially different dust emission patterns among source regions can still produce similar climatological DOD distributions.

#### Comment A3

First, I would not call the present approach as “purely physical”, because (1) the aerodynamical shadow of roughness elements is empirically linked with surface albedo, and (2) the formulation of the present approach, e.g. equation (8), is semi-empirical.

#### Response

In our original manuscript there is no statement that includes the phrase “purely physical”. In our original manuscript, the drag partition is described (Lines 155-160) using the word “empirical”. In the original manuscript there is only one use of the phrase “physically based albedo drag partition parameterization”. In the revised manuscript, we have removed the phrase “physically based”.

We agree that the albedo-based drag partitioning framework remains semi-empirical because the relationship between aerodynamic sheltering effects and surface albedo is observation-constrained, and the parameterization itself includes empirical

components. Our intention was not to describe the approach as fully physical, but rather to emphasize that including drag partitioning effects provides a more physically relevant representation of momentum transfer between the atmosphere and the soil surface compared to simplified treatments that neglect spatial variability in surface sheltering effects.

#### Comment A4

Second, because of the semi-empirical nature of equation (8), it is hard to directly use it for predicting dust emission under climate change because to do so will require a radiative transfer module in the land model to calculate the surface albedo that accounts for the shadow of vegetation. In contrast, a more physics-based drag partitioning approach, e.g. as used in Leung et al. (2024), is more directly applicable in a climate or Earth system model than the present albedo-based drag partitioning approach.

#### Response

As we explained at the start of our responses, the applicability of a model is not a requirement of the GMD assessment criteria. Therefore comments on a model's applicability should not form the basis for the evaluation of the scientific basis for publishing a manuscript. It will hinder scientific development and is unreasonable to judge the quality of a manuscript based on a reviewer's perception / understanding of (foreseeable) application.

Most importantly for this review, this manuscript does not claim to demonstrate the applicability of the albedo-based drag partitioning approach for future climate change projections or fully coupled Earth system models. Rather, this work aims to evaluate the applicability of the albedo-based approach within chemical transport models during the satellite era, when satellite-derived albedo information is available. In addition, this study aims to highlight the potential equifinality issue in current dust modeling frameworks, where similar atmospheric dust loadings may arise from substantially different underlying emission mechanisms.

The fact is that our original manuscript has shown that a large-scale dust transport model of the type used in coupled climate modelling can host the albedo-based approach to drag partitioning. Furthermore, surface albedo is already a standard variable in land surface models (LSMs) and Earth system models (ESMs) because it is required for surface energy balance calculations. Therefore, the information required by the albedo-based approach is already available within these modeling systems. In this sense, the albedo-based framework could potentially be incorporated into larger-scale coupled models as described by Chappell et al. (2023). We accept that simplified drag partitioning approaches may currently be more directly applicable for future climate simulations.

#### Comment A5

If the authors refine the applicability of the current albedo-based drag partitioning

approach to chemical transport models that deal with air quality problems during the satellite era when albedo observation is available, I believe it is fair to say that the albedo-based drag partitioning is an encouraging approach for capturing the episodic and dynamical nature of dust emission. Therefore, I suggest to rephrase the entire manuscript to clearly state the applicability of the present approach. Yet, the relative performance of different dust emission modeling approaches should be further evaluated, which I will cover in the next section of my review.

#### Response

The reviewer's insistence that "applicability" should be central to the manuscript is inconsistent with the GMD assessment criteria. We do not share the reviewer's perspective on this point and have shown in our responses above that modelling applicability is not inherently in the interest of scientific (model) development. We have illustrated in our original manuscript that the albedo-based approach can be implemented in large-scale models. Our comments above, and previous publications on the albedo-based approach, illustrate that it is ultimately applicable to ESMs. We have used this discussion to revise the manuscript and illustrate the opportunity for applicability of the albedo-based approach for large-scale dust models. In our revised manuscript we have clarified that the immediate applicability of the albedo-based drag partitioning approach is within the context of chemical transport model applications during the satellite era, when satellite-derived albedo information is accurate, precise and widely available.

In the revised manuscript, we have therefore rephrased the relevant discussions to clarify the current application of the approach and to offer the opportunity for application to future climate projections or fully coupled Earth system models.

Within this scope, our results show that, after calibration of the total dust emission magnitude, the albedo-based drag partitioning approach produces climatological atmospheric dust fields comparable to those from conventional dust modeling approaches. The present results are therefore sufficient to demonstrate the applicability of the albedo-based framework in chemical transport model applications. Evaluating the performance of the albedo-based approach in such applications is beyond the scope of the present study.

#### Comment A6

Which dust source function do you actually use in Exp 1? What is it based off? While the authors state it is the default GOCART setting and cite the Ginoux et al (2001) paper, they also mention that it is "based on the geographical distribution of atmospheric dust". But indeed the dust source function used in the GOCART default setting was not from atmospheric dust, but from surface topography and has a physical foundation in terms of sediment cumulation (Ginoux et al. 2001). I believe the default DEAD model use the same or similar idea for generating dust emission model (Zender et al. 2003). Please check the dust source function used in your Exp 1

and clarify its empirical or physical foundation.

#### Response

In Exp 1, we used the default dust source function implemented in the DEAD dust emission scheme within GEOS-Chem, which follows the formulation of Ginoux et al. (2001). Consistent with the reviewer's comment, this source function is based on surface topographic depressions that preferentially accumulate fine sediments, rather than being directly derived from atmospheric dust distributions.

We agree that our original description of the source function was inaccurate. In the revised manuscript we have corrected and clarified the description accordingly.

#### Comment A7

In Exp2,  $z_0$  is obtained at what temporal scale? I see a subscript  $m$  in equation (4) but not on line 123. Are they the same thing? Leung et al. (2024) used similar, simplified vegetation drag partitioning formulation, but aerodynamical roughness length above canopy is updated with dynamical vegetation. They show good performance of the dust emission scheme when compare the day-to-day variation in DAOD with multiple sources of observation. So I wonder if the vegetation drag partitioning in your Exp2 reflects the dynamical nature of vegetation, or is it set static? If it is currently set static, could you follow the approach of Leung et al. (2024) but use satellite observation to derive a dynamical vegetation drag partitioning and compare it with your albedo-based drag partitioning approach? Do you still get the conclusion that Exp2 overly flatten the seasonal cycle of dust emission.

#### Response

In Exp. 2, the drag partitioning parameter is prescribed as a globally uniform constant and does not vary temporally, following the original implementation of the DEAD scheme (Zender et al., 2003). The  $z_{0,m}^s$  in Eq. (4) and the  $z_0^s$  in Line 123 refer to the same variable, and the text in Line 123 has been corrected for consistency.

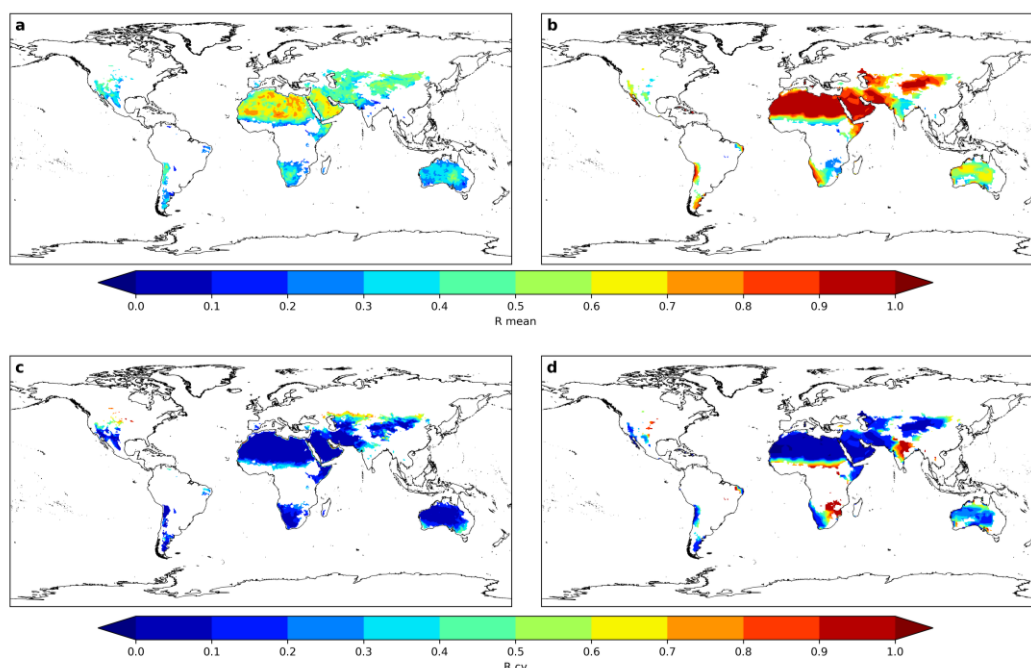
We thank the reviewer for suggesting a comparison with vegetation-based drag partitioning approaches. We agree that the implementation in Leung et al. (2024) provides an informative comparison framework. Similar to the albedo-based approach used here, their scheme explicitly reduces the surface friction velocity from  $u_*$  to  $u_{s*}$ , rather than representing drag partitioning solely through an increase in the threshold friction velocity as in many previous studies. We note however, that the use of planform (viewed at nadir) vegetation cover has little to do with the later cover afforded by the obstacles at the land surface. Furthermore, the photosynthetic description of the vegetation is poor in arid and semi-arid regions and will not adequately represent the non-photosynthetic vegetation that produce roughness elements.

To address the reviewer's suggestion that further compare the albedo-based and vegetation-based drag partitioning approaches, we implemented an additional

experiment (Exp4) in GEOS-Chem following the formulation described in Leung et al. (2024). In this experiment, drag partitioning is calculated using vegetation area index (VAI) data from GEOS-Chem, with monthly temporal resolution and an original spatial resolution of  $2^\circ \times 2.5^\circ$ , and we also removed the source function.

This sensitivity experiment is included here in response to the reviewer's suggestion and is not intended to be a comprehensive intercomparison of vegetation-based and albedo-based drag partitioning schemes.

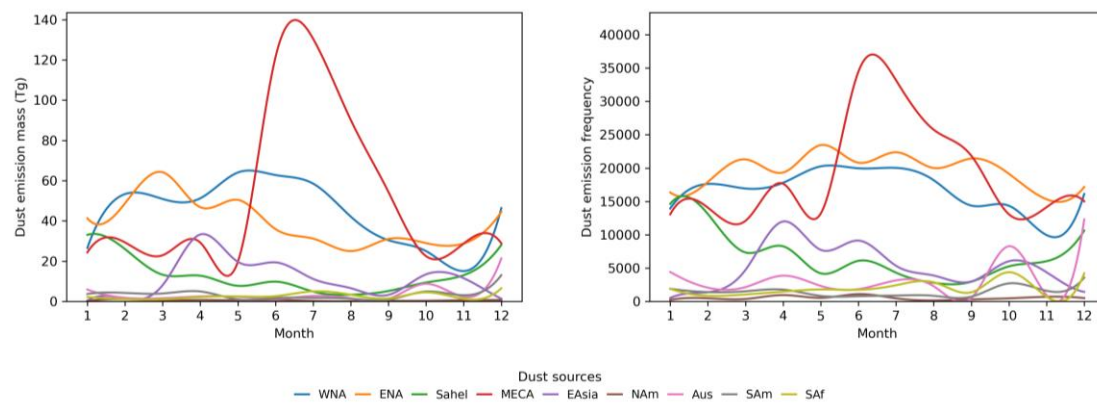
Figure SA1 (below) compares the annual mean (a, b; top row) and coefficient of variation (c, d; bottom row) of the drag partition  $R$  (defined as the ratio between  $u_{S*}$  and  $u_*$ ) derived from the albedo-based (left column) and VAI-based (right column) approaches. Results are shown only for areas with simulated dust emissions. The albedo-based approach generally produces smaller  $R$  and more heterogeneous patterns than the VAI-based approach, especially over arid desert regions. This difference mainly arises because the albedo-based approach implicitly accounts for the combined sheltering effects of multiple roughness elements, including vegetation and rocks, whereas the VAI-based approach only represents planform photosynthetic vegetation effects. Compared to the albedo-based approach, the VAI-based drag partitioning also exhibits stronger temporal variability, particularly in vegetated regions such as India, southern Africa, and Australia. The implications of these differences between drag partitioning parameterizations merit further investigation but are beyond the scope of this study.



**Figure SA1: Drag partition ( $R$ ) from albedo-based (a & c) and vegetation-based (b & d) approaches.**

Figure SA2 presents the simulated monthly dust emission totals (after global emission totals calibrated to  $2000 \text{ Tg yr}^{-1}$ ) and emission frequencies for major dust source

regions from the VAI-based experiment. The results show that vegetation-based drag partitioning is also able to effectively suppress unrealistic dust emission frequencies, for example over Australia during October–February. This suggest that the overly flattened seasonal cycle of dust emission totals and emission frequency in Exp2 is largely consistent with the absence of drag partitioning, which provides an important physical constraint on dust emission processes. The similarly flattened emission frequency in Exp1 indicates that this limitation is also present in that configuration. However, in Exp1, the use of the dust source function modifies the magnitude of dust emissions, which leads to an inconsistency between emission totals and frequency seasonality and therefore hides the underlying effect of the missing drag partitioning.



**Figure SA2: VAI-based modelled monthly total dust emissions (left column) and dust emission frequency (right column) for different dust source regions with drag partition from vegetation.**

#### Comment A8

If my understanding is correct, a key strength of the albedo-based approach is that the albedo field updates daily, which reflects the dynamical nature of soil erodibility. However, the current comparison on the simulated dust fields between the three experiments, as well as the simulated versus observed dust fields, mostly focus on the climatological scale. Could you show some extreme cases that are successfully captured by your albedo-based drag partitioning approach but missed by the other two schemes? Can you also show the statistics for all three schemes regarding their performance on extreme dust outbreak events?

#### Response

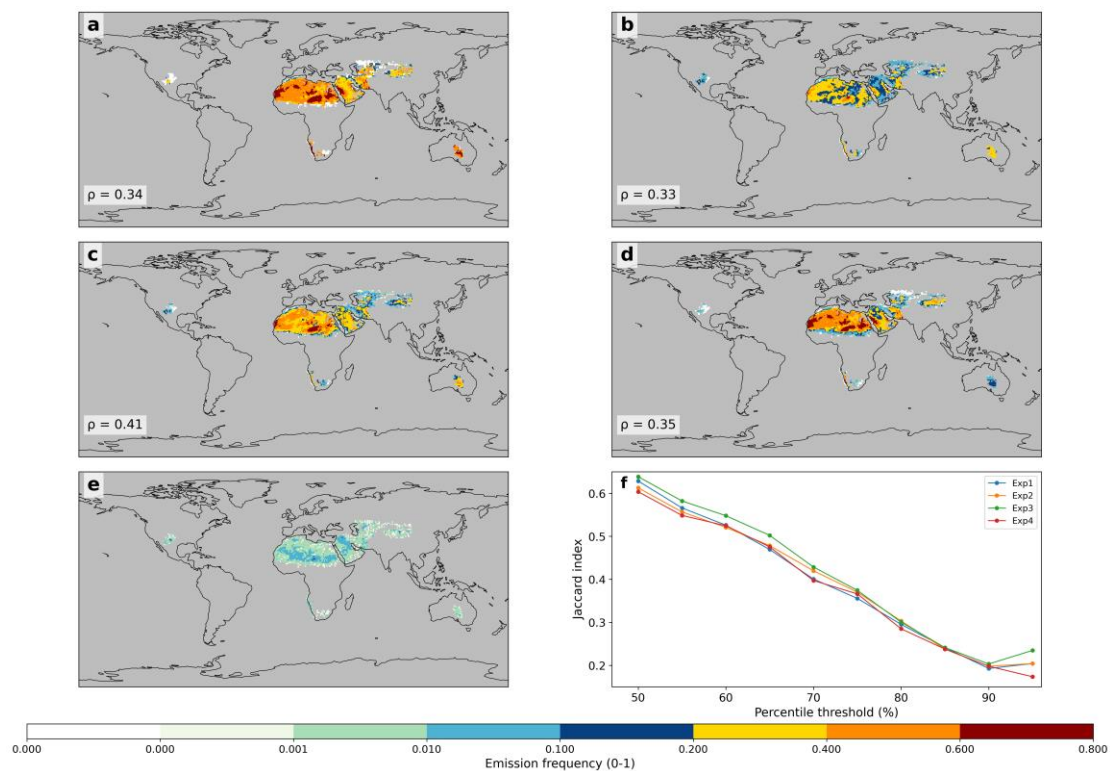
There are many strengths of the albedo-based approach:

1. Wherever there is albedo information the drag partition can be produced including the use of prognostic albedo in ESMs.
2. Currently, we have global albedo coverage at 500 m pixel resolution, but methodologies already exist to produce <30 m albedo which enables drag partition at those resolutions.
3. Since those satellite data are updated frequently this enables the drag partition to update frequently. In the presence of abrupt change e.g., wildfires, deforestation etc. the drag partition can monitor these changes.
4. Typically albedo changes seasonally and consequently the drag partition changes seasonally.

5. Over longer time periods albedo changes with secular variation e.g., invasive species, CO<sub>2</sub> fertilisation promoting shrub growth over grass growth etc. consequently drag partition changes.
6. Measurements of albedo on the ground, on meteorological stations, from drones etc. are well-known to match satellite albedo and similarly drag partition can be produced across these scales.
7. Albedo is linearly additive with area and consequently once the albedo is at the desired scale it can then be used to produce drag partition which overcomes the non-linear scaling problem associated with sub-grid scale heterogeneity of scaling the equation.
8. We recently developed dynamic entrainment threshold (Zhou et al., 2026) using the albedo-based approach which provides the same opportunities for dust emission modelling.

To better illustrate the differences between the albedo-based and classic approaches, we have added additional analyses comparing simulated dust emission frequencies with satellite-observed dust plume source frequencies (Hennen et al., 2024).

Figure SA3 shows the simulated emission frequencies for 2016 from (a) default DEAD scheme with source function, (b) DEAD scheme with removed source function, (c) albedo based approach, (d) VAI-based approach, together with the observed dust emission frequency (e) derived from multi-year satellite plume observations. The simulated emission frequency was calculated as the fraction of days with nonzero dust emission relative to the total number of days in 2016.



**Figure SA3: Dust emission frequency from (a) default DEAD scheme with source function, (b) DEAD scheme with removed source function (c) albedo based approach, (d) VAI-based approach, and (e) dust plume observations (Hennen et al., 2024), and the well-known (f) Jaccard (1901) index varying with frequency thresholds. Gray areas in panels (a–e) indicate locations where no dust-plume emission-frequency observations are available (rather than zero observed frequency) and are therefore excluded from the comparison.**

To further evaluate whether the models capture the observed dust emission hotspots, we also calculated the Spearman spatial correlation ( $\rho$ ) and the Jaccard index under different frequency thresholds. The well-known Jaccard (1901) index (cf. Fletcher and Islam, 2018) was calculated by converting the emission frequency spatial fields into binary hotspot masks using different percentile thresholds and then quantifying the overlap between observed and simulated hotspot regions.

The results show that the albedo-based approach (Figure SA3 c) produces the highest Spearman correlation and generally higher Jaccard index values across most thresholds compared to the other experiments. These results suggest that the albedo-based approach better captures the spatial distribution of satellite-observed dust plume hotspots, a type of evaluation that has received limited attention in previous dust modeling studies. When considering these analyses, it is important to remember that satellite-observed dust plume source frequencies are available not automated and represent data where studies have been conducted. Therefore the geographical distribution of observed dust plumes should not be understood as a geographically complete and definitive description.

The reviewer suggests that our manuscript focuses on the climatological scale. This is correct and consistent with our intention to demonstrate the applicability of the albedo-based approach to large-scale modelling and its performance.

Following the reviewer's suggestion, we have also conducted an additional event-based evaluation to present the performance of the four experiments in detecting dust events (Figure SA4), with observed DOD  $> 0.2$  (Ginoux et al., 2012) used to define dust events. For extreme dust outbreak events, we use the 80th (DOD  $> 0.51$ ) and 99th (DOD  $> 1.5$ ) percentiles of all observed dust events as thresholds. These results will be incorporated into a revised version of the manuscript. The DOD observations were obtained from the MIDAS dataset, and only grid cells with nonzero source function values were included in the analysis in order to exclude regions far from major dust sources and are temporally consistent with the simulation period. The evaluation includes CSI, Bias, POD, and SR metrics for the different experiments.

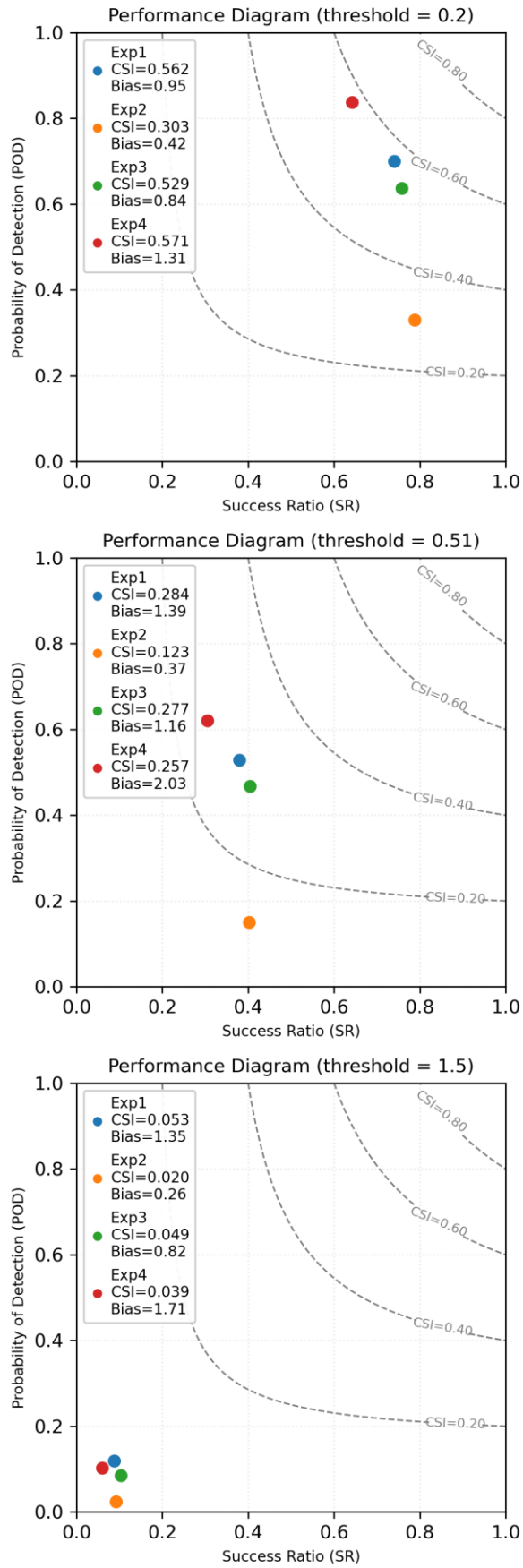


Figure SA4. Performance diagrams of the four experiments (same as Figure SA3).

For all dust events ( $DOD > 0.2$ ), Exp2 exhibits substantially lower POD and CSI values than the other experiments, indicating that the absence of effective drag partitioning strongly limits the model's ability to capture dust outbreak events. In contrast, Exp1 and Exp3 show comparable performance, with similar CSI values and balanced POD and SR statistics, suggesting that the albedo-based drag partitioning approach can reproduce major dust events without relying on a prescribed dust source function. Exp4 achieves the highest POD but also shows a substantial positive bias, indicating frequent false alarms and an overestimation of dust event occurrence.

As for 80th percentiles of dust events ( $DOD > 0.51$ ), the skill of all experiments decreases, reflecting the increasing difficulty of reproducing stronger dust outbreaks. Nevertheless, Exp1 and Exp3 continue to exhibit similar performance, with CSI values substantially higher than those of Exp2. Exp4 maintains the highest POD but also displays the largest positive bias (Bias = 2.03), suggesting that many of the detected events are associated with overprediction.

For the most extreme dust events ( $DOD > 1.5$ ), CSI values decrease considerably for all experiments, indicating the inherent challenge of simulating rare and intense dust outbreaks. Despite the overall reduction in skill, Exp1 and Exp3 still outperform Exp2 and maintain comparable CSI values. Exp4 again exhibits strong overprediction (Bias = 1.71) without a corresponding improvement in CSI, suggesting that its higher detection rate is achieved at the expense of a large number of false alarms.

Overall, these results demonstrate that the albedo-based drag partitioning approach (Exp3) achieves a detection skill comparable to the traditional source-function-based scheme (Exp1) across a wide range of event intensities, including extreme dust outbreaks, while substantially outperforming the experiment without drag partitioning (Exp2). In contrast, the vegetation-based approach (Exp4) tends to overestimate dust-event occurrence despite achieving relatively high detection rates.

We are currently undertaking additional case-study simulations to further evaluate the performance of the albedo-based approach during extreme dust events.

#### Comment A9

When you do comparison between model and observation, are all the observational datasets restricted to the year 2016? At least for dust deposition from Albani et al. (2014), it is unlikely that the observational data covers year 2016. I think the temporal match is necessary for model-observation comparison, especially in terms of the extreme events as I proposed in my previous comment.

#### Response

Most of the dust  $PM_{10}$  concentration and deposition datasets from Albani et al. are compilations of long-term observations with varying observational periods, and therefore were used only as climatological constraints in our evaluation.

Other evaluation datasets, including DOD observations from AERONET and MIDAS,

as well as PM<sub>10</sub> concentration observations from the SDT network, include data for 2016 and are therefore temporally consistent with the model simulations.

We agree that temporal consistency is important for evaluating short-term variability and extreme dust events. Therefore, the observational datasets used in the event-based evaluations described in our response to Comment A8 were selected to match the simulation period. In the revised manuscript, we have further clarified the temporal coverage and intended usage of each observational dataset.

### **Minor Comments**

#### Comment A10

None of the three approaches show dust emission over high latitudes (Bullard et al. 2016). Is it due to the color bar that has a cut-off at 0.1 or high-latitude dust sources are omitted by all three approaches?

#### Response

All three approaches in our original manuscript, as well as the VAI-based experiment added in this response, do not generate dust emissions over high-latitude regions during the simulation period. Therefore, the absence of high-latitude dust sources in the figures is not caused by the color scale threshold, but reflects the behavior of the current model configurations.

We agree that high-latitude dust is an important component of the global dust cycle. The reviewer's comment presumes that the dust models are adequate. It is clear from the information we provide in our Discussion that there remain many limitations to dust emission modelling which will ultimately require adjustments to large scale dust models. An additional possible reason for the absence of high-latitude dust emissions in our simulations is that the snow cover mask in GEOS-Chem may be overly restrictive, which suppresses dust emission from these regions under the current model configuration.

#### Comment A11

In Fig. 8, all three experiments show remarkable similarity, probably because of the log transformation. I also notice that a lot of these sites are located far away from dust sources. These sites are probably less relevant for evaluating dust emission.

#### Response

As described in our response to Comment A9, most of the available PM<sub>10</sub> concentration and deposition flux observations are long-term climatological datasets whose observational periods do not necessarily match the simulation year. Therefore, these datasets are used in Fig. 8 primarily as climatological constraints.

In addition, these observations are generally based on dust-specific measurements or

compositional analyses, such that the reported PM<sub>10</sub> or deposition values represent the dust component rather than total aerosol mass. Therefore, even stations located far from major dust source regions can still provide useful constraints on the large-scale transport and deposition behavior of the simulated dust cycle.

#### References:

Chappell, A., Webb, N. P., Hennen, M., Schepanski, K., Ciais, P., Balkanski, Y., Zender, C. S., Tegen, I., Zeng, Z., Tong, D., Baker, B., Ekström, M., Baddock, M., Eckardt, F. D., Kandakji, T., Lee, J. A., Nobakht, M., Von Holdt, J., and Leys, J. F.: Satellites reveal Earth's seasonally shifting dust emission sources, *Science of The Total Environment*, 883, 163452, <https://doi.org/10.1016/j.scitotenv.2023.163452>, 2023.

Fletcher, S. and Islam, M. Z.: Comparing sets of patterns with the Jaccard index, *Australasian Journal of Information Systems*, 22, <https://doi.org/10.3127/ajis.v22i0.1538>, 2018.

Ginoux, P., Chin, M., Tegen, I., Prospero, J. M., Holben, B., Dubovik, O., and Lin, S.-J.: Sources and distributions of dust aerosols simulated with the GOCART model, *Journal of Geophysical Research: Atmospheres*, 106, 20255–20273, <https://doi.org/10.1029/2000JD000053>, 2001.

Ginoux, P., Prospero, J. M., Gill, T. E., Hsu, N. C., and Zhao, M.: Global-scale attribution of anthropogenic and natural dust sources and their emission rates based on MODIS Deep Blue aerosol products, *Reviews of Geophysics*, 50, <https://doi.org/10.1029/2012RG000388>, 2012.

Hennen, M., Chappell, A., Webb, N. P., Schepanski, K., Baddock, M. C., Eckardt, F. D., Kandakji, T., Lee, J. A., Nobakht, M., and von Holdt, J.: A new framework for evaluating dust emission model development using dichotomous satellite observations of dust emission, *Science of The Total Environment*, 912, 169237, <https://doi.org/10.1016/j.scitotenv.2023.169237>, 2024.

Leung, D. M., Kok, J. F., Li, L., Mahowald, N. M., Lawrence, D. M., Tilmes, S., Kluzek, E., Klose, M., and Pérez García-Pando, C.: A new process-based and scale-aware desert dust emission scheme for global climate models – Part II: Evaluation in the Community Earth System Model version 2 (CESM2), *Atmospheric Chemistry and Physics*, 24, 2287–2318, <https://doi.org/10.5194/acp-24-2287-2024>, 2024.

Prospero, J. M., Collard, F.-X., Molinié, J., and Jeannot, A.: Characterizing the annual cycle of African dust transport to the Caribbean Basin and South America and its impact on the environment and air quality, *Global Biogeochemical Cycles*, 28, 757–773, <https://doi.org/10.1002/2013GB004802>, 2014.

Zender, C. S., Bian, H., and Newman, D.: Mineral Dust Entrainment and Deposition (DEAD) model: Description and 1990s dust climatology, *Journal of Geophysical Research: Atmospheres*, 108, <https://doi.org/10.1029/2002JD002775>, 2003.

Zhou, Z., Chappell, A., Zhang, C., and Song, H.: Satellite retrieved soil surface dynamics reduce the extent and frequency of sediment flux with implications for early warning systems, *Commun Earth Environ*, 7, 259, <https://doi.org/10.1038/s43247-026-03368-4>, 2026.