This paper studies the effect of the boundary layer thickness on several properties of windblown sand using a LES-based model. It is first shown that increasing boundary layer thickness leads to a widening of the probability distribution of the wall shear stress (Fig. 2), as expected. It is then shown that, as a consequence of the widening, two distinct thresholds of aeolian sand transport decrease (Fig. 3). Likewise, vertical profiles of the mass flux, particle volume fraction, horizontal velocity, and others are also affected (Figs. 4-9). The strength of this study is to look at the effect of a quantity, the boundary layer thickness, that is often being ignored as a sand-transport-influencing factor by the community, even though it may arguably play an important role. In fact, I only know a few studies to have looked into this ever. The main weakness of this study is the methodology used to model the motion of the particle phase. It uses the same aerodynamic entrainment and splash models as the one by Anderson and Haff (1991), which is problematic for a variety of reasons (explained below). Furthermore, the particle phase model does not resolve the bed as a whole and it seems to neglect collision between particles. Both have been shown to be quite important in recent years (explained below). This being said, I still think overall this study can be valuable, since the observed boundary layer thickness effects are quite interesting. However, more data analyses are needed, especially in what regards transport intermittency (see below), and I also think the authors should make sure their definitions of the "rebound threshold", and the conclusions they draw from it, are consistent with the definition of this threshold in the literature (which I think it is not, see below).

Authors' response: Thank you for taking the valuable time to review our manuscript and for providing such insightful and constructive comments. These suggestions are crucial for further improving our study, and we will address them point by point below.

Methodology concerns

By now, numerous research groups, for the purpose of simulating aeolian sand transport, have moved to using coupled CFD-DEM simulations that resolve the particle phase, including many layers of the bed, at the particle scale. Given that such simulations are

Authors' response: We are greatly inspired by your in-depth analysis regarding the advantages of using the Discrete Element Method (DEM) over traditional splash functions in simulating aeolian sand transport.

First, we fully acknowledge the significant advantages of the DEM method highlighted in your comments. As revealed by the studies you cited (Jia and Wang, 2022; Tholen et al., 2023; Wang et al., 2024; Lester et al., 2025), DEM can explicitly resolve particle-scale interactions and realistically capture collective effects, which is crucial for accurately understanding splash dynamics under natural conditions (i.e., non-static beds). In contrast, traditional splash functions based on static-bed, single-particle

impact assumptions—such as the Anderson and Haff (1991) model—cannot describe these complex phenomena. Moreover, the empirical parameters they rely on often lack a clear physical basis. The works you mentioned, such as Lammel et al. (2017) and Comola and Lehning (2017), indeed provide a more physically sound framework for modeling splash on static beds.

Second, we fully recognize that coupled CFD-DEM simulations represent the cutting edge of current research in this field. However, a key challenge hindering their application remains the limitation in computational domain scale. To achieve particle-scale resolution, typical CFD-DEM simulations—including the studies you cited—often employ relatively small computational domains. For instance, the three-dimensional domain in Jia and Wang (2022) has a side length of only 50 times the particle diameter, and the streamwise dimension in Tholen et al. (2023) is approximately 1000 times the particle diameter. While such scales are highly effective for studying the micro-mechanisms of particle-bed interactions, they are insufficient for accommodating and resolving the large-scale and very-large-scale turbulent structures within the boundary layer.

The primary objective of this study is to systematically investigate how the atmospheric boundary layer thickness, as a macroscopic parameter, influences the bulk statistics of aeolian sand transport. The boundary layer thickness primarily affects the spatiotemporal distribution of wall shear stress by modulating the large-scale coherent structures within the flow field. To reliably capture these large-scale flow structures, which play a crucial role in transport dynamics, the streamwise computational domain length is set to 8π times the boundary layer thickness—a scale typically used for studying large-scale structures in turbulent boundary layers. Given such an extensive domain, conducting fully particle-resolved CFD-DEM simulations under current and foreseeable computational resources is prohibitively difficult, if not unrealistic.

Therefore, to balance physical fidelity with computational feasibility, this study employs a simplified particulate model based on a splash function. We acknowledge

that this approach parameterizes the complex particle-bed interactions. However, given our primary objective—to elucidate the macroscopic influence of boundary layer thickness—this simplification constitutes a necessary and acceptable compromise. It enables us to concentrate computational resources on resolving the large-scale flow structures and their coupling with the particulate phase.

In response to your valuable suggestions, we have implemented the following revisions in the updated manuscript:

(1) In Section 2, we have explicitly discussed the simplified nature and limitations of our employed particle collision model (splash function), and by directly citing the relevant literature you mentioned on DEM advantages and static-bed splash function improvements (e.g., Jia and Wang, 2022; Tholen et al., 2023; Lammel et al., 2017; Comola & Lehning, 2017), we have demonstrated our awareness of these limitations and our understanding of recent field advancements.

(2) In section 4, we have explicitly stated: a logically crucial and necessary step is to adopt the CFD–DEM framework—under conditions that can resolve large-scale flow fields while incorporating realistic particle–particle and particle–bed interactions—to verify, refine, and extend the findings obtained in this study based on a macroscopic parameterized model.

Once again, thanks for your insightful feedback, which has greatly enhanced our understanding of methodological developments in this field and will significantly improve the depth and rigor of our manuscript.

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Aeolian transport thresholds

The authors use the terms "rebound threshold" and "impact entrainment threshold", which were first introduced by Pahtz and Duran (2018, doi: doi.org/10.1029/2017JF004580), as far as I know. These authors also discussed these thresholds more thoroughly in a 2020 review paper (Pahtz et al, doi: 10.1029/2019RG000679). It seems to me that, while the present authors adapt the same definition of the impact entrainment threshold (threshold of continuous transport), the manner in which they obtain the rebound threshold differs from the original definition. They seem to extrapolate the intermittent transport rate to vanishing transport, which I infer from Fig. 3. By contrast, Pahtz et al. (2020) state that the rebound threshold results from the extrapolation of the continuous transport rate to vanishing transport. For this reason, I suggest the authors to use a different terminology. In addition, I think the authors should, if possible, also compute the actual rebound threshold. This requires dealing with intermittency in a more sophisticated manner (see below).

Authors' response: The issues regarding the use of the term "rebound threshold" and its comparison with the work of Pähtz et al. (2020) are crucial for clarifying concepts and improving the presentation of our study. We fully agree with the reviewer's analysis and summary of the relevant literature. Below is our point-by-point response and

clarification regarding this comment.

In this study, we define the rebound threshold as the critical Shields number at which the observed saltation movement transitions from an intermittent state to a complete cessation. This aligns with the method inferred from Fig. 3 (marked as the data points of rebound threshold).

We agree with the core physical definition of the rebound threshold cited from Pähtz and Durán (2018) and Pähtz et al. (2020) in your comment: "the minimum fluid shear stress required to sustain continuous rebound of particles on the bed." The physical picture is as follows: when the fluid shear stress exceeds this threshold, the energy gained by particles from the airflow during saltation is sufficient to compensate for the energy lost during collisions with the bed, thereby sustaining stable, continuous rebound motion. Below this threshold, particles cannot maintain energy balance, and their motion will decay and eventually cease. This is precisely the physical critical condition that our study focuses on. Therefore, in terms of physical essence, the rebound threshold used in this work is consistent with the definition in the literature by Pähtz et al. (2020), both referring to the critical hydrodynamic condition required to maintain continuous rebound motion of particles.

We note that, as mentioned in the review by Pähtz et al. (2020), rebound threshold can be estimated through two approaches: (a) gradually reducing the shear stress until intermittent transport ceases, or (b) extrapolating the (continuous) transport rate to zero. The method adopted in this study corresponds precisely to the first approach (a) described above, that is, determining this threshold by directly observing the cessation point of intermittent transport.

We understand the distinction you highlighted: namely, Pähtz et al. (2020) emphasize the definition of rebound threshold through extrapolating the continuous transport rate to zero (method b). Although the specific operational approach to determining this critical state differs, the corresponding physical state—the critical point at which

sustained rebound motion of particles can or cannot be maintained—remains the same. Furthermore, to ensure terminological consistency with our team's previous related research (Jin et al., 2024) and to avoid potential confusion among readers, we prefer to retain the term "rebound threshold" in this study.

Meanwhile, we attach great importance to your suggestion regarding the clear distinction of methods. We have added an explicit clarification in the revised manuscript (section 3): "The rebound threshold in this study refers to the critical condition determined by observing the complete cessation of intermittent saltation motion. Its physical essence is consistent with the critical Shields number defined by Pähtz et al. (2020), which signifies whether sustained particle rebound can be maintained. It should be noted that the determination method differs from the one that estimates the threshold by extrapolating the continuous transport rate to zero."

For the research objectives of this study, defining the threshold by observing the cessation of transport intermittency offers clear physical intuitiveness and operational feasibility. It effectively captures the abrupt transition from "presence" to "absence" of particle motion. More importantly, as illustrated in Fig. 3 and discussed in the main text, the saturated transport rate curves for different boundary layer thicknesses are very close to each other once above the impact entrainment threshold. This indicates that, within this range, the influence of boundary layer thickness on the steady-state continuous transport rate is minimal. If the rebound threshold were defined by extrapolating the continuous transport rate to zero, the values for different boundary layer thicknesses would likely show extremely small differences, or might even be indistinguishable. This would obscure the significant physical phenomenon revealed in Fig. 3, which is one of the core findings this study aims to reveal and elucidate. Therefore, employing the current method based on the observation of intermittency better highlights the focal points of this research and the novel patterns discovered.

In summary, our use of the term "rebound threshold" is based on its consistency in physical essence and its alignment with our previous work. At the same time, we have

fully incorporated your suggestion in the revised manuscript to more clearly articulate the specific method used in this study to determine the threshold and to explicitly distinguish it from other methods in the literature, thereby avoiding potential misunderstandings among readers.

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Intermittency definition

I find the authors' quantity "particle spatial occupancy", alpha_p, to be a very poor measure of intermittency. As far as I understand, it represents the ratio between the number of numerical grid cells occupied by at least one simulated particle (which represents many particles at the same time) and the total number of grid cells. The problem with this definition is that it depends strongly on the grid cell size. In particular, in the limit of zero grid cell size, alpha_p becomes zero everywhere and therefore meaningless, since the probability to find a point within an interval of measure zero is zero. This conflicts with a basic requirement of any numerical simulation: that any result obtained from it should converge in the limit of zero grid size.

A much better way to define intermittency is through bursts of overall activity, e.g., see Carneiro et al. (2015, doi: 10.1038/srep11109), Martin and Kok (2018, doi: 10.1029/2017JF004416), Comola et al. (2019, doi: 10.1029/2019GL085739). For example, the latter two studies looked at the fraction of time, fQ, at which aeolian transport is active, defined through a non-zero overall particle count over a period of 2s

Authors' response: We agree with the reviewer that α_p, defined in the original text as the ratio of grid cells containing particles to the total number of grid cells, exhibits dependence on grid size. Theoretically, α_p loses its meaning when the grid size approaches zero. We acknowledge that the initial manuscript failed to adequately clarify the applicability and scope of this metric.

As noted by the reviewer, defining intermittency by the fraction of time during which saltation is active, denoted as f_Q—as employed in methods such as those by Martin and Kok (2018) and Comola et al. (2019)—is a more widely accepted quantitative standard in the field of aeolian physics. However, when applying this criterion to our large-scale macroscopic computational domain simulations, we encountered specific challenges that affect the effectiveness of f_Q in distinguishing the influence of different boundary layer thicknesses: even when the wind speeds approach the rebound threshold—defined by the cessation of intermittent transport—the fraction of time during which saltation is inactive across the entire large-scale computational domain remains very small. Consequently, the derived f_Q remains persistently near unity, limiting its ability to resolve the variations in transport intensity close to the threshold.

Therefore, the conventional alternative is to define f_Q by detecting the transport time series at a single point (e.g., the center of the computational domain), as seen in Jin et al. (2024). However, this approach suffers from two issues: (1) its results still depend, to some extent, on the size of the local observation grid; and (2) more importantly, it fails to capture the global differences in transport spatial structure induced by varying boundary layer thicknesses. For instance, in our simulations, at the comparably lowest

wind speed ($\theta_* = 0.0032$), conditions with a thinner boundary layer ($\delta = 1.0\ m$) may exhibit pronounced local intermittency (lower f_Q), whereas conditions with thicker boundary layers ($\delta = 5.0\ m,\ 10.0\ m$) could sustain higher levels of spatially uniform transport across the entire computational domain, leading to higher f_Q values that may even approach unity. In such cases, relying solely on single-point f_Q would make it difficult to effectively distinguish and quantify the fundamental influence of boundary layer thickness on transport dynamics.

The primary purpose of introducing α_p in this study is not to provide a universal quantitative standard for intermittency, but rather to use it as a qualitative tool to contrast the spatial dispersion or clustering trends of particle transport under different boundary layer thicknesses. Under a consistent grid resolution, the relative variation of α_p with respect to boundary layer thickness or wind speed can effectively reveal key differences in transport spatial structure—such as whether transport is concentrated in a few active "streamers" or widely dispersed—which is one of the core concerns of this study.

We fully accept the reviewer's critique that our original presentation may have equated α_p directly with "intermittency intensity," which is insufficiently rigorous. In the revised manuscript, we have revised the description of α_p, clearly stating its role in characterizing the spatial inhomogeneity of transport, noting its dependence on grid size, avoiding its direct association with the physical concept of "intermittency intensity," and conceptually distinguishing it from time-based metrics such as f_Q defined in Martin and Kok (2018). We believe that this clarification will make the analytical framework of the manuscript more rigorous and the argument more persuasive.

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