This work performs a suite of numerical simulations using LES to investigate the sensitivity of particle saltation processes to boundary layer thickness. The boundary layer thickness partly controls the spectrum of turbulent scales of motion (for a fixed wind shear), and thus controls (in some capacity) the turbulence fluctuation intensity and range of surface stresses experienced by the particles. I enjoy reading about work that focuses on the role of turbulent fluctuations in particle emission processes (rather than simply considering emission by the mean), as these fluctuations can be remarkably strong at high Reynolds number. Based on the authors' results, it certainly seems like the boundary layer thickness (and thus the Reynolds number of the flow) plays a meaningful role for the mass flux. I agree with the authors that more models should include the role of turbulent fluctuations in saltation processes, and including information about boundary layer height (and its consequences for turbulence intensity) is certainly one way to do that.

Authors' response: Thank you for your positive feedback and constructive comments on our work. You pointed out that the boundary layer thickness (i.e., Reynolds number) influences the mass flux by modulating turbulent scales and stress distributions, which is highly consistent with our numerical results. Your attention to the role of turbulent fluctuations in particle saltation processes is also one of the core motivations of this study. Below are our point-by-point responses to your comments.

I (cautiously) agree with the author's findings, but I am skeptical of the numerical method used in this work. The authors employ a standard wall-bounded flow setup, and since the horizontal boundary conditions are periodic, one might assume that a spectral (or hybrid spectral-finite difference) method would be more suitable than a second order centered difference scheme. The spectral method would preserve the finer fluctuations which may have a meaningful impact on the particle emission, one way or the other. For example, these fine scale features could decrease the coherence of the stress fluctuations, and may affect the author's results, but I am not certain.

Authors' response: We fully agree with your view that spectral methods may offer advantages over second-order central difference schemes under horizontal periodic boundary conditions. Their higher numerical accuracy in resolving fine-scale turbulent structures can enhance the accurate representation of particle emission processes. In response to your comments and within the context of this work, we would like to offer the following clarifications.

Our choice of the second-order central difference scheme is primarily motivated by its computational efficiency and robustness in large-scale parametric studies. As shown in Fig. 1(b), the mean velocity profiles are in good agreement with the logarithmic law. Fig. 2(b) further demonstrates that the Reynolds number dependence of the wall shear stress fluctuation is well captured across different boundary layer thicknesses. Furthermore, a more detailed validation of turbulence intensity and Reynolds stress for the sand-free flow by Jin et al. (2021) demonstrates favorable agreement with the spectral method simulations of Chung and Pullin (2009). These results suggest that the second-order scheme remains capable of capturing the key trends in turbulent statistical characteristics within the current parameter range.

This study aims to elucidate how boundary layer thickness influences the macroscopic behavior of near-threshold sediment transport—including threshold velocity, transport rate, and particle concentration—by modulating the turbulent scale, with particular emphasis on the role of large-scale coherent structures in regulating particle entrainment. While the fine-scale structures you noted may reduce the coherence of stress fluctuations—a point that certainly merits further physical exploration—our findings indicate that, under near-threshold conditions, particle entrainment is primarily governed by extreme stress events associated with large-scale structures whose characteristics are shaped by the boundary layer thickness (Pähtz et al., 2018). Although the second-order scheme introduces some numerical dissipation at fine scales, it has proven effective in capturing the statistical behavior and energy distribution of these large-scale structures (Wang et al., 2019; Feng and Wang, 2023; Jin et al., 2024).

The flow regime investigated here lies in the near-threshold region, where the friction

Reynolds number is moderate relative to that of high-Reynolds-number atmospheric boundary layers. Within this parameter space, the second-order scheme enables efficient, multi-parametric investigations at a manageable computational cost.

In summary, we acknowledge the theoretical advantages of spectral methods for resolving fine-scale turbulence and appreciate your constructive suggestion. In future work, we plan to incorporate spectral or higher-order schemes for comparative validation, aiming to systematically quantify the impact of numerical accuracy on the dynamics of particle entrainment and transport.

[1] Jin T, Wang P, Zheng X. Characterization of wind-blown sand with near-wall motions and turbulence: From grain-scale distributions to sediment transport[J]. Journal of Geophysical Research: Earth Surface, 2021, 126(8): e2021JF006234.

[2] Chung D, Pullin D I. Large-eddy simulation and wall modelling of turbulent channel flow[J]. Journal of fluid mechanics, 2009, 631: 281-309.

[3] Pähtz T, Valyrakis M, Zhao X H, et al. The critical role of the boundary layer thickness for the initiation of aeolian sediment transport[J]. Geosciences, 2018, 8(9): 314.

[4] Wang P, Feng S J, Zheng X J, et al. The scale characteristics and formation mechanism of aeolian sand streamers based on large eddy simulation[J]. Journal of Geophysical Research: Atmospheres, 2019, 124(21): 11372-11388.

[5] Feng S J, Wang P. The influences of boundary layer thickness on the characteristics of saltation sand flow–A large eddy simulation study[J]. Aeolian Research, 2023, 60: 100853.

[6] Jin T, Wang P, Cao B. Transport characteristics of aeolian sand near different thresholds[J]. Catena, 2024, 247: 108541.

Overall, I found that the captions of almost every figure lacked the information necessary to properly interpret the figures. I think that the authors should consider revising the captions to include more relevant information about the figures, such as reminding the reader what each symbol means.

Authors' response: Thank you for your valuable suggestion. We have revised and supplemented all figure captions in the revised manuscript to include necessary explanatory information, aiming to help readers better understand the figures. The specific modifications include:

(1) Clarifying the meaning of different colors, line styles (e.g., solid, dashed, and double-dash-dotted lines), and arrows used in each figure, with explicit references to the quantities they represent—such as wind velocity, boundary layer thickness, and the mean and variance of particle diameter;
(2) Providing clear definitions of key symbols, including the density ratio s, resultant velocity V_p, the von Kármán constant κ, and the value of parameter B (e.g., B=5.5 in a straight channel);
(3) Noting in the caption of Fig. 9 that the line styles and colors are consistent with those used in other figures (e.g., Figs. 5 and 8), to facilitate cross-referencing.

These revisions have been clearly marked in the updated manuscript for your convenience. We sincerely appreciate your insightful comments, which have helped us improve the presentation of our work.

Specifically regarding figure 6, the particles almost appear to be stacked in columns, i.e. they seem far too organized. Can the authors explain this phenomenon? I assume the particles are able to move horizontally, as they mention that the particles have horizontal boundary conditions, but this figure makes me think that they only mover vertically.

Authors' response: In Fig. 6, the visual appearance of "column-like stacking" of particles is primarily attributed to the following reasons:

Under near-threshold transport conditions, the wind velocity is relatively low (θ_*=0.0032 in Fig. 6), and particles are mainly entrained by fluid and rebound motions.

Localized high instantaneous shear stresses play a significant role in lifting particles, making their vertical movements more pronounced, while horizontal motions are less intuitively visible in instantaneous snapshots. In fact, the horizontal velocity of particles is clearly represented—particle colors in Fig. 6 indicate their velocity magnitude, and together with the vertical profiles of mean horizontal particle velocity shown in Fig. 5, this confirms that particles do move in the horizontal direction, with streamwise velocity being dominant. Furthermore, Fig. 6 primarily displays the instantaneous particle distribution in the streamwise–vertical plane, where projection effects in the spanwise direction enhance the visual impression of vertical continuity.

One major point I have is that the Reynolds number is probably what matters here, not the boundary layer height independently. The authors mention as much when they reference that the boundary layer height (which increases the Reynolds number) controls the spectrum of turbulence scales. I think this article would benefit from a passage discussing the dynamical importance of the Reynolds number, and how the boundary layer height is actually only one part of the story (the other two being viscosity, and the wind velocity, or friction velocity).

Authors' response: Actually, as you pointed out in your comment, the boundary layer thickness itself is not an independent parameter, but rather regulates the multi-scale structure of turbulence by affecting the friction Reynolds number $\mathrm{Re}_\tau = u_* \delta / \nu$, thereby modulating near-wall turbulent statistics and particle transport processes. However, in this study, the friction velocity u_* and kinematic viscosity ν are fixed in the discussion, so the variation in the friction Reynolds number directly corresponds to the change in boundary layer thickness.

Nevertheless, we agree with your suggestion that the core role of the Reynolds number should be more explicitly articulated in the manuscript, clarifying how boundary layer thickness, friction velocity, and viscosity jointly determine the friction Reynolds number and subsequently influence turbulence structures and sediment transport behavior. Accordingly, we have added the following passage at the beginning of Section

3 in the revised manuscript:

"It should be noted that the boundary layer thickness δ does not affect turbulence structures in isolation, but rather acts through the friction Reynolds number $\mathrm{Re}_\tau = u_*\delta/\nu$. Under the same friction velocity u_* and ν, a larger δ corresponds to a higher Re_τ, which supports larger-scale turbulent eddies and richer multi-scale interactions. Therefore, the boundary layer thickness effects observed in this study are essentially manifestations of Reynolds number effects under near-threshold transport conditions."

We thank you again for this important insight, which has helped enhance the scientific depth and clarity of our manuscript.

Minor comments and typographical errors: The authors use the word "intermittency" many times. That has a specific meaning in the turbulence literature, and could easily be misunderstood. The authors should consider using the word "variability" as it seems to be what they mean, based on my reading.

Authors' response: We thank the reviewer for the careful observation and professional suggestion. We agree that the word "intermittency" carries a specific meaning in turbulence research and may indeed lead to confusion.

In this manuscript, we use "intermittency" primarily to describe the following two phenomena:

(1) Temporal intermittency of the transport process: under near-threshold wind conditions, sand transport exhibits an intermittent burst-like pattern—brief periods of intense activity separated by longer quiescent intervals (as stated in the Introduction: " characterized by intermittent bursts of intense activity separated by quiescent periods").

(2) Spatial intermittency of particle distribution: the non-uniform spatial distribution of particles, which we quantify by defining the "particle spatial occupancy" (α_p) (Section 3, Fig. 7 and related discussion).

Nevertheless, we also recognize that, from the perspective of strict turbulence terminology, "intermittency" typically refers to the non-Gaussian statistical characteristics of small-scale turbulent structures in both time and space. To avoid ambiguity, we will adjust the relevant expressions in the revised manuscript as follows:

When describing the discontinuity of transport activity, we will continue to use "intermittent" or "intermittency," as these terms are widely accepted in geomorphology and aeolian physics for describing such phenomena (e.g., Stout and Zobeck, 1997; Carneiro et al., 2015). When describing the fluctuating or variable nature of particle distribution, we will adopt the term "variability" as suggested, to more accurately reflect its statistical fluctuation characteristics and avoid confusion with the turbulence-specific meaning of "intermittency."

The specific revisions have been marked in the manuscript.

[7] Stout J E, Zobeck T M. Intermittent saltation[J]. Sedimentology, 1997, 44(5): 959-970.

[8] Carneiro M V, Rasmussen K R, Herrmann H J. Bursts in discontinuous Aeolian saltation[J]. Scientific Reports, 2015, 5(1): 11109.

Line 132: is u(x_p) the filtered velocity (i.e. what comes right out of the LES?), or is the sampled velocity re-constructed.

Authors' response: $\tilde{u}(x_p)$ is the filtered fluid velocity at the particle location interpolated with a third-order Lagrange scheme. We have already stated this in the original text.

Line 238: "Increasing"

Authors' response: We have made the revisions as suggested. Thank you for your reminder.

The particle spatial occupancy: isn't this just the concentration? Is it markedly different?

Authors' response: "Particle spatial occupancy" is indeed related to concentration, but there are distinct differences between the two in terms of definition and physical meaning.

Particle volume fraction (concentration) is defined as the ratio of particle volume to the grid volume. It reflects the amount of particle material per unit volume and is an intensive quantity. In this manuscript, Fig. 5(b) presents the vertical profile of the particle volume fraction. Particle spatial occupancy (α_p) is defined as the ratio of the number of grid cells containing particles to the total number of grid cells. It reflects the extent or coverage of particle distribution in space and is a geometric quantity. It measures "how much space the particles occupy," rather than "how many particles are in each space."

Although related, these two quantities are not equivalent. For example, near the wall, α_p may approach 1 (almost all grid cells contain particles), while the particle volume fraction may still be very small (very few particles in each grid cell); Conversely, if particles cluster together, the particle volume fraction may be locally high, but α_p could be very small.

Therefore, α_p is primarily used to quantify the spatial heterogeneity of particle distribution (i.e., whether particles are uniformly dispersed throughout the flow field), whereas the particle volume fraction reflects the vertical distribution of transport intensity. In Section 3, we employ both parameters precisely to characterize particle motion under near-threshold transport conditions from different perspectives.

Line 362: Perhaps it's worth mentioning that the maximum magnitude of the fluctuations occur in the buffer layer and this is a well recognized phenomenon, i.e.

u_rms is maximal around y^+ = 10-20 and has some influence from outer layer motions (i.e. the boundary layer height). This can be seen in many papers on wall-bounded turbulence i.e. fig 4 in Smits et. al (2010) 10.1146/annurev-fluid-122109-160753

Authors' response: The phenomenon you mentioned—that the maximum streamwise turbulence intensity occurs in the buffer layer ($y^+ \approx 10-20$) and is modulated by outer-layer motions—is indeed a well-established conclusion in wall-turbulence research, as clearly illustrated in Fig. 4 of Smits et al. (2010).

It should be noted that what we discuss in Line 362 of our manuscript is the vertical distribution of particle velocity fluctuations, rather than fluid velocity fluctuations in single-phase turbulence. As inertial particles, their velocity fluctuation characteristics differ fundamentally from those of the fluid. Nevertheless, the near-wall peak location of particle velocity fluctuations still has certain similarities with that of fluid velocity fluctuations—both occur in the near-wall region.

However, this study employs wall-modeled large-eddy simulation, in which the wall-normal distance of the first grid point corresponds to $y^+ > 30$. This means we are unable to resolve the flow details within the buffer layer ($y^+ < 30$), and therefore cannot directly observe the peak of fluid velocity fluctuations at $y^+ \approx 15$. The particle velocity fluctuation profiles presented in this manuscript are statistically obtained on the resolvable grid scales, and their near-wall peak location is constrained by the grid resolution, reflecting the overall response of particles in the near-wall region.

That said, we fully agree with your insight regarding the modulation of near-wall fluctuations by outer large-scale motions. In Fig. 8 and the associated discussion, we have already pointed out that an increase in boundary layer thickness enhances the amplitude of near-wall particle velocity fluctuations, a phenomenon closely related to the intensification of outer large-scale structures and their influence on the inner region. We have also cited Smits et al. (2010) to strengthen the depth and completeness of this discussion.

[9] Smits A J, McKeon B J, Marusic I. High–Reynolds number wall turbulence[J]. Annual Review of Fluid Mechanics, 2011, 43(1): 353-375.

Line 368: I'm having trouble following this part. Please revise.

Authors' response: Thank you for your correction. This refers to the description of mass flux fluctuations in Fig. 8(b). To make the description clearer, we have revised the text accordingly and added "Fig. 8(b)" at the relevant position to specify the subject.

I'm unclear on the meaning of the cyan arrow in figure 9(b).

Authors' response: The cyan arrow in Fig. 9(b) is intended to indicate the trend of the particle size probability density distribution as the wind velocity increases (from θ_* =0.0032 to 0.0043). Specifically, as the wind velocity increases, the probability density of larger particles decreases. This arrow is included to help readers intuitively understand this trend. We have supplemented the figure caption with a relevant explanation to make the figure clearer and more comprehensible. Thank you again for your valuable comment.

Line 385-386: I can't quite follow the inline math. Please revise.

Authors' response: Since the mean and variance of particle diameter follow the same trend under different boundary layer thicknesses, we have rewritten the relational expression of their magnitudes as follows: $d_{p,\ \delta=1.0\ m} > d_{p,\ \delta=5.0\ m} > d_{p,\ \delta=10.0\ m}$.