Review of “Dynamic characteristics of snowfall particles in atmospheric turbulent boundary layer and its effect on dust wet deposition” by Zhang et al.

This study employs a Delayed Detached-Eddy Simulation (DDES) coupled with a Lagrangian particle tracking method to investigate the motion of snowfall particles within an atmospheric turbulent boundary layer. The authors analyze how turbulence influences the relative motion between snow particles and air, identifying a critical dimensionless parameter ($\alpha_d = 0.2$). The results suggest that for ($\alpha_d < 0.2$), horizontal relative motion dominates, significantly enhancing the swept volume and, consequently, the potential for dust wet deposition compared to gravitational settling alone.

The manuscript addresses an interesting and complex problem in atmospheric physics, the interplay between turbulence and precipitation scavenging. The use of DDES to resolve the turbulent wind field represents a sophisticated approach compared to standard RANS models often used in this field. The identification of the transition threshold at $\alpha_d = 0.2$ offers a potentially valuable metric for parameterizing wet deposition in larger-scale models.

Please note that my evaluation focuses on the physical interpretation of the snowfall dynamic characteristics, the experimental design regarding particle physics, and the implications for dust wet deposition. As I am not a specialist in Computational Fluid Dynamics or hybrid RANS/LES modeling, I have not critically assessed the numerical implementation of the DDES model, the specific grid convergence strategies, or the stability of the solution. My comments regarding the methodology are restricted to its physical justification and consistency with atmospheric principles.

While the trajectory analysis appears rigorous, I have concerns regarding the physical simplifications made for the snow particles, specifically the assumptions regarding particle shape and collection efficiency, which likely lead to an overestimation of the deposition flux. These issues should be addressed before publication.

Major comments

1. In Section 3.3, the calculation of the dust collection amount assumes that "snow grains can fully collect all dust particles along their trajectories, i.e., the collection efficiency $e_s = 1$". This is a very strong assumption that likely leads to an overestimation of the removal rate. Collection efficiency can be governed by aerodynamic effects (Brownian diffusion, interception, and inertial impaction). For the Aitken mode dust mentioned in the text, flow streamlines around the falling snow particle may carry aerosols away from the collector surface, resulting in efficiencies well below 1.0. Could the authors explicitly discuss the magnitude of uncertainty introduced by this assumption. The results should

perhaps be framed as "maximum potential encounter volume" rather than actual "collection amount."

2. The study simplifies snowfall particles as spheres with a density of 340 kg/m3. While this simplifies the Lagrangian tracking, natural snow particles (dendrites, plates, aggregates) exhibit different drag coefficients and terminal velocities compared to spheres. This aerodynamic difference directly affects the calculation of Vt and the critical parameter α_d. A discussion is needed on how non-spherical drag would alter the α_d threshold. Would complex shapes be more or less susceptible to the horizontal entrainment described in this study?

3. The manuscript defines the relative motion distance Sr as the product of the relative velocity and the suspension time Td. While this metric is useful for comparing cases, it is essentially a proxy for the "swept volume" or "effective path length." The text essentially equates longer suspension time in turbulence with higher deposition. However, if a particle is trapped in a vortex, it may be "sweeping" the same volume of air repeatedly (which has already been scavenged), rather than encountering fresh dust. Please clarify if the model accounts for the depletion of dust in the local trajectory of the snow particle, or if it assumes the dust concentration remains constant regardless of how many times the snow particle passes through a specific eddy.

Specific comments:

1. Some figure captions can be enhanced by defining the variables/parameters in the figure. For instance, Figure 17, the readers have to read through the manuscript to understand the meaning of Q, Q1, and Q3. And the meaning of the lines in Figure 8.
2. Line 71: the statement here should be softened, as the two research categories described do not fully encompass all possible approaches. Additional types of studies may exist.
3. Line 148: Add a comma before "and."
4. Figure 6: What do in panel (b) mean?
5. Equations 18 and 19. Please elaborate on why this particular functional form was chosen. A brief justification or reference would help readers better understand the reasoning behind these expressions.
6. Equation 20, Please check whether a bar is missing over the variable on the right-hand side of the equation?

7. In Figure 14(a) and the y-axis label, the word "Verticle" is misspelled. It should be corrected to "Vertical."