Comments to the manuscript with title “Exploring ship track spreading rates with a physics-informed Langevin particle parameterization” by McMichael et. al.

May 4, 2024

General comments

This manuscript investigates the aerosol spread rate from a point source using a “Lagrangian particle model governed by a Langevin stochastic differential equation to create a simplified framework for predicting the rate of spreading from a ship-injected aerosol plume in sheared, precipitating, and non-precipitating boundary layers”. The authors showed that “the stochastic particle-velocity representation can reasonably reproduce spreading rates in sheared, precipitating, and non-precipitating cases using domain-averaged turbulent statistics from the LES”. Using statistical physics to study aerosol-airflow interactions and the consequential aerosol-cloud interactions is very novel. The manuscript is also well-written. I recommend the publication of this manuscript with the following comments for the authors to consider.

My main conceptual comment is the scale problem. It is surprising to see that using *domain-averaged* turbulent statistics from the LES as input, the stochastic model can somehow reproduce the LES spreading rate. This is because the aerosols as tracers interact with turbulence below the Kolmogorov scales. How can the *domain-averaged* turbulent statistics that filter out the native small turbulence scales transport aerosols?

Specific comments

- The numerical diffusion term is not included in Eq.1. How to deal with the numerical stability without the numerical diffusion term for the continuity equation, which is a well-known issue in many applications?
- Do we expect a $-5/3$ power law for the LWP spectra? If so, is it related to the turbulence energy spectra? How to explain the deviation from the $-5/3$ power law in Fig.1(b). In addition, the LWP spectra appear to be Δx independent if I am not mistaken. What is the reason behind this?
- Taking the $\Delta x = 50$m-LES as a reference, the $\Delta x = 50$m-LES-hyperdiffusion produces about two times larger values of LWP (Fig.2a) and smaller z_{inv} (Fig.2d). However, it produces boundary-layer-averaged aerosol concentration well and R_{sfc} relatively well. This indicates the hyperdiffusion contributes more to the microphysical processes than to the macrophysical ones. What is the physical explanation of this observation?
- The LWP from the weak-shear LES exhibits filament structure compared to the control and strong-shear simulations in Fig.5. Is this because of the competition between the buoyancy force and shear (Richardson number)?

- It is interesting that the spatial plume evolution determines the spatial morphology of the surface precipitation rate, which should be taken into account for modelling shiptracks. Would this be one of the highlights of this study as well?
- The PM width differs the most to the LES width for the strong shear case (Fig.12 and Fig.14b). Is this because the Langevin equation can not represent turbulence well at strong shear?
- Why are the time evolution of TKE from the LES and PM so different for the control simulation in Fig.13?