Review on article egusphere-2024-825

This study proposes a novel approach for efficiently computing the transport of high-dimensional information of aerosol particles. It solves the evolution of particle number concentration using the finite volume method and calculates the transport of particles probabilistically based on the flux. This method has been thoroughly analyzed and tested in one-dimensional cases, and preliminary tests of two-dimensional and three-dimensional cases have also been presented. The paper is well-structured and easy to read. Despite the drawback of numerical diffusion affecting the mixing ratio of tracers, this approach is valuable for understanding the transport of aerosol particles. In addition, it could also help develop a Lagrangian particle tracking scheme in regional models. Therefore, it is suitable for publication in Geoscientific Model Development. I hope the comments provided below will contribute to the further improvement of the paper prior to its acceptance.

General Comments

I do not believe the flux-based approach is essentially different from particle-based Lagrangian tracking schemes. For example, a recent study has applied a quantization approach—similar to methods used in machine learning—to particle advection, effectively reducing computational costs and memory usage by quantizing particle positions within a cell (Matsushima et al., 2023). They round the positions of advected particles to the nearest possible locations within a cell, but it is also possible to use stochastic rounding instead of rounding to the nearest. Furthermore, the level of quantization can be optimized for the scientific objectives. Conversely, your method could also reconstruct Lagrangian particle trajectories probabilistically. I suggest investigating the impact of numerical diffusion more clearly by examining the variance in particle distribution, specifically how many particles move significantly faster or slower than the mean flow field. Such evaluations, particularly in two-dimensional test cases, could help clarify how your scheme differs from exact Lagrangian particle tracking.

The impact of resampling within your scheme requires further improvements. There are concerns that over time, the high-dimensional information held by particles may degenerate into overly similar states due to repeated resampling. Please consider adding a test case where 2–3 tracers are internally mixed to assess such effects on attribute-space dynamics. A simple yet effective analysis could compare the differences between the initial and final distributions in attribute space, providing insights into the extent of particle degeneracy. In addition, please provide details on variations of areas in each cell and atmospheric density and the results for the vertical cross sections of the tracer mixing ratio for the three-dimensional case to clarify the range of applicability of your scheme.

The dependency of the number of computational particles on the results is well presented in your scheme. However, convergence with respect to space and time resolution is not addressed. Additionally, it would be beneficial to specify the Courant number used in your test cases and discuss the limits of the Courant number that your scheme can accommodate.

Specific Comments

L152: The extension to multiple dimensions could be more clearly improved. In your method, unlike methods such as the corner transport upstream method or the conservative semi-Lagrangian method (Lin et al., 1996), it appears that you assume particles do not move in diagonal directions. Is my understanding correct? If so, would it be more reasonable to employ a flux that better aligns with the actual transport of particles?

L300: To check whether the schemes can be applied to simulate the mixing process, it would be better to adopt a swirling shear flow and a steeper initial condition like those of a cosine bell-type distribution and verify how well the tracer filament structures are preserved (see p.264 in Durran 2010).

References

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- Durran, Dale R. Numerical methods for fluid dynamics: With applications to geophysics. Vol. 32. Springer Science & Business Media, 2010.