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Geoscientific Model Development Discussions

Interactive comment on "A Lagrangian Advection scheme with Shape Matrix (LASM) for solving advection problems" *by* L. Dong et al.

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Dear Dr. Kaas,

Thank you for your thorough review and constructive comments! The interparcel mixing is really the key part of a successful Lagrangian method as you previously pointed out. The followings are our responses to your questions.

1. It is not clear what physical principles were used to set the specific cut-off value of $\mathcal{D}_i$, and the actual reduced value of γ_m."5" seems as a completely ad hoc choice.

Response: The current mixing setup in LASM is learned from the HEL scheme proposed by you, and the choice of the parameters is based on the test cases that we have conducted. The object is to make LASM perform well in both the deformation test

case and the barotropic ones.

2. Nature is not discontinuous in terms of mixing. Parcels in the real world mix gradually and the mixing increases gradually with the deformation rate. This must be discussed. What is of even more concern is the factor by α which the major parcel axis will be shrunk after mixing has taken place. I cannot understand why α is not a function of the degree of mixing that has actually taken place. I also don't understand what has motivated the actual choice (e.g., $\alpha = 0.05$). If there is no link between α and the mixing one can introduce anything from too excessive or too weak mixing, all depending on the parameter choices.

Response: The mixing in LASM is not discontinuous. The value of α controls how the mixing is gradual. One parcel may be mixed with its surrounding parcels continuously (in several time steps) if the deformation persists. The effect of changing α is depicted in Fig. 13, where the larger α causes more burrs at the edge of the slotted cylinders because too many amount of tracer mass is mixed at a time. But the setup of α remains open to question. As you mentioned, it could be a function of the mixing degree (or deformation rate). By doing this, the amount of mixing could be more consistent with the real one and more objective. Thank your for bringing such a good idea to us. We will work on this important topic in the future.

3. Aliasing is the misinterpretation of unresolved scales on the resolved scales. ... Hence, to avoid the gradual build up of aliasing in a Lagrangian model one must introduce spatial mixing. Considering the specific type of mixing in LASM it is not clear to me how one can be certain to avoid aliasing. In particular, I am here thinking about the situation where the degree of disorder $\mathcal{D}_i$ is low, i.e. the mixing threshold m is very large (up to 100). As far as I can see the mixing in LASM will not eliminate aliasing. So I should like the authors to discuss this issue some depth (at least to convince me). See also comments below.

Response: It is our belief that the aliasing in the Lagrangian methods is related to the

fact that the real shape of the parcels is not simulated explicitly, so the remapping is isotropic which is not correct in the deformative flow. In addition, the chaotic flow deformation makes the simulation of the parcel shape even harder. So we firstly described the parcel shape by a linear deformation matrix (linear assumption) learned from the finite mass method. This can reduce the aliasing as much as possible when the disorder degree of the flow is low. The deformation test cases showed the effectiveness of such discretization. That is in the low degree of disorder cases, LASM can handle the deformation without the interparcel mixing. But when the flow deforms disorderly as in the barotropic test cases, the linear assumption degenerates quickly. Lots of needle form parcels appeared. That is when the interparcel mixing should be active to compensate for such degeneration of the linear assumption to the parcel shape. In spite of this, we currently could not be sure that the aliasing is eliminated at all. The interparcel mixing must be more physically based and be more adaptive (e.g., better parameter formula as pointed in the previous question), so that the minimum mixing is introduced to ensure the aliasing is suppressed and the numerical diffusion error is as low as possible. We will add more discussion on this in the revised manuscript.

4. Page 4830, line 18. It is suggested to change “model” to “modeling”.

Response: Adopted.

5. Page 4830, line 18. What about cloud water and cloud ice?

Response: Adopted.

6. Page 4830, line 21. Grammar

Response: “though many other aspects also affect” → “although many other aspects also affect the results”.

7. Page 4831, line 19. “is disbennifit” → “is a problem”.

Response: Adopted.

8. Page 4831, line 24. “... so least resolution”: Wrong grammar plus I cannot see that purely Lagrangian (without explicit interparcel mixing) schemes have any diffusion at all.

Response: “Contrarily, Lagrangian schemes have so least numerical diffusion that the interparcel mixing needs to be implemented explicitly,” → “Contrarily, Lagrangian schemes have no numerical diffusion, and the interparcel mixing needs to be implemented explicitly”.

9. Page 4832, line 15. “into needle form”: in the real world they are not deformed into needles but rather into irregularly shaped thin filaments (i.e. they are often also strongly bended) Maybe you can find a better word than needles?

Response: This “needle” word is first mentioned in Klingler et al. (2007) as: “The ability of the mass packets to deform arbitrarily with the flow and to change their size, shape, and orientation is the reason for the high accuracy of the finite mass method, but can also lead to serious problems when particles become sharp needles or degenerate in another way.” And we also observe such abnormal shape of the parcel when the parcel shape is not constrained. So we think it might be better to keep this word.

10. Page 4833, line 16. “... aliasing error as much as possible...”. I cannot see that this is related to aliasing. Only mixing can be used to reduce aliasing in this type of model. Maybe you can explain this in more detail to bring the thoughts of the reader in the right direction.

Response: As mentioned in question 3, we think the shape of the parcels is not simulated explicitly causes the wrongly isotropic remapping (e.g. the spotty pattern in the tracer density on the mesh), so the tracer mass may be remapped onto the wrong grids, which may generate noises and thus the aliasing. By simulating the shape explicitly, such aliasing can be reduced largely when the flow deformation is not much disorder, for example in the deformation test case that has large deformation rate. Otherwise, we will need the interparcel mixing to compensate for the degenerated linear assumption

to the parcel shape as in HEL.

11. Page 4834, line 4. "... of deformation matrix, the ..." → "... of the deformation matrix, and the ...".

Response: Adopted.

12. Page 4834, equation (4). You write that this equation is an ordinary differential equation. But the âĂÍdivergence operator includes partial derivatives?

Response: Adopted.

13. Page 4836, line 5. "not" → "no".

Response: Adopted.

14. Page 4836, line 17. "despite" → "spite".

Response: Adopted.

15. Page 4838, line 1. "for other" → "for the other".

Response: Adopted.

16. Page 4838, line 25. "defomration" → "deformation".

Response: Adopted.

17. Page 4839, line 2-3. "aliasing error without using ... schemes.". I can see that this is the essence of the paper. I am however, not sure I understand how one can avoid introducing a certain amount of mixing to avoid the aliasing. Also, as far as I can see, the mixing will be more or less independent of the particular parcel shape formulation one uses. The mixing only depends on the deformation rate (or equivalently on the Lyapunov exponent) of the flow/problem. Use should discuss this statement in more detail to clarify what the magic is. From a theoretical point of view, I simply don't understand how a special shape formulation of individual parcels can reduce aliasing.

Response: This is related to the above question 3 and 10. LASM simulates the shape of the parcels explicitly by using the linear deformation matrix. This turns the isotropic remapping as in other Lagrangian schemes to the anisotropic remapping which should be more realistic. When the flow deformation is in order, the aliasing error in LASM is low without using the interparcel mixing, because the linear assumption to the parcel shape is sufficient. But when the flow deforms disorderly, the mixing must be used as in other Lagrangian schemes to suppress the strong aliasing error.

18. Page 4839, line 24. "In future," → "In the future,".

Response: Adopted.

19. Page 4841, line 27. A γ_m value of 100 seems to be exceptionally high (then parcels are indeed needles). I can see that γ_m is reduced when the degree of disorder is large, but still it seems that a γ_m value of, e.g., 5 is very large. With such large numbers it is obvious that you will minimize the mixing dramatically and therefore, in the validation tests, obtain results, which are similar to an almost unmixed Lagrangian model. However, I am not convinced that the values used for γ_m, $\mathcal{D}_i$, and α are consistent with the mixing limit that must be introduced to avoid aliasing. The γ_m, $\mathcal{D}_i$, and α values seem to be chosen on an ad hoc basis.

Response: The 100 γ_m is currently chosen to not interrupt the evolution of the parcel shape when the flow deformation is in order as in the deformation test cases. In those cases, it is normal that the parcels are deformed into long ellipses. But in the more real barotropic flows, the parcels can never evolve into long ellipses, because the interparcel mixing is active to control the parcel shape when the disorder degree is high. The γ_m value of 5 is a testing result. When it is larger, unacceptable results are observed, and when smaller, the excessive diffusion is observed. Nevertheless, it is open to questions that the optimal values of these parameters may be in the different forms. We will add more discussion about this in the revised manuscript.

20. Page 4841, line 14. Another related issue: I would guess that α should depend

on the length of the time step, or rather by the actual amount of mixing that has been imposed for the particle in question.

Response: Thanks for providing another good idea! We will consider this in the future work.

21. Page 4844, line 1. “in future” → “in the future”.

Response: Adopted.

22. Page 4844, line 3. “are summaries” → “can be summarized as”.

Response: Adopted.

23. Page 4845, line 13. “be in the real” → “be in a real”.

Response: Adopted.

24. Page 4845, line 16. Why not use (semi) analytical trajectories to check the importance of errors in trajectory calculations?

Response: At first, we thought it would be better to reveal the performance of LASM as in a real application, where the flow velocity is discretized on the mesh. But it seems that it is better to use analytical velocity when testing. We will try our best to do some extra experiments with analytical velocity.

25. Page 4847, text around Fig. 10. Please provide mixing parameters γ_m, β_1, β_2.

Response: We have added the reference to Table 1 where those parameters are listed.

26. Page 4850, line 12. What is meant by “apparent” in this context?

Response: The “apparent” means there is almost no interparcel mixing in the deformation test cases, when the values of the parameters are chosen as in Table 1. Only several times mixing occurred near the Poles due to the convergence of the grids in lat-lon mesh.

27. Page 4851, text around Fig. 15 At a first glance the LASM transport scheme seems to perform quite well. It is of course not surprising that the noise level is reduced when the number of parcels is increased. However, as hinted above, my general fear is that the amount of inter-parcel mixing in LASM is generally to low to avoid the build up of noise over time due to some kind of aliasing. I think it is very important to perform some longer simulations with the model (e.g. 10 days) to see what happens with noise in the long run in a realistic geophysical flow. The same comment applies to the simulations shown in Fig. 17.

Response: The current form of the interparcel mixing of LASM may not be the final form. We will continue to improve it based on the physical consideration. Meanwhile, we will conduct a long run (10 days) of the second barotropic subcase to see the performance of LASM.

28. Page 4852, line 8. “chaostic” → “chaotic”

Response: Adopted.

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