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Interactive comment on "The Parcels v2.0 Lagrangian framework: new field interpolation schemes" *by* Philippe Delandmeter and Erik van Sebille

Philippe Delandmeter and Erik van Sebille

p.b.delandmeter@uu.nl

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We would like to thank Dr Joakim Kjellsson for his careful reading and its constructive comments. Please find our replies below.

Philippe Delandmeter and Erik van Sebille

Summary

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Discussion paper

The paper describes the new version of Parcels, v2.0. The new version includes new interpolation schemes for tracing particles which allow for various vertical coordinates and staggered grids. As the paper presents these new and necessary features of Parcels I recommend it should be published, but only after some re-working of the text and also using a 3D test case rather than a 2D case.

Thank you. Please find our answers to your different comments below.

Major comments

The authors spend quite some time deriving and explaining the new interpolation schemes for z and s coordinates on staggered grids, which is a new feature of Parcels. I'm therefore a bit puzzled that the showcase in the Results section is only for surface drift. I would strongly recommend the authors to change the showcase to some example with subsurface 3D flow, so that we can see the z or s coordinates in action.

Following your comments and the ones from Dr Dagestad, we haved added a simulation with 3D passive particles in the North Sea to compare surface and 3D transport in the North West European continental shelf. In this run, the particles dynamics follow the NEMO 1/12° data, which are discretised on a curvilinear C-grid with z-levels.

The writing is in need of revising (see specific comments further down). In particular, I struggled with Page 6, Line 23 to Page 9 Line 20, which did not flow well and was at times confusing. This section needs a bit of re-writing and re-structuring. I also found Section 2.1.1 to be very abstract and I had to wait until Section 3 before the methods to be described in a more practical sense. I would strongly urge the authors to either put Section 3 directly after 2.1.1 or somehow merge the two sections so that the definitions of interpolation schemes are directly followed by how it is done in practice.

Section 2.1 introduced a lot of definitions and notations, which made it hard to read. Based on your comments (here and below), we have restructured the section to help the reader along with the construction of the interpolation schemes, highlighting the main four steps:

1. define a mapping between the physical cell and a unit cell;
2. compute the fluxes on the unit cell interfaces, as a function of the velocities on the physical cell interfaces;
3. interpolate those fluxes to obtain the relative velocity;
4. transform the relative velocity to the physical velocity.

Before we were describing the scheme by starting with what we want (the velocity at given x, y, z) and progressively building the variables we need, ending with the gridded input data. We have reversed that order for the 2D case, starting from what we have and reaching what we want. This structure follows the one in Section 3, that you commented as easier to understand. For the 3D case, we keep the original order since there is no point to introduce the different fluxes (U_0, U_{12}, U_1, V_0, ...) before motivating why we need them, but we keep referring to the four main steps of the interpolation. Section 3 is a validation of the schemes, and therefore appears after the complete description.

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Discussion paper

Minor overall comments

On the large scale I find that the authors over-use the word "different" as a synonym for "various", and I often found that the word could simply be omitted to make the paper easier to read.

We have removed the unnecessary occurrences of this word as well as others for an easier reading.

Parcels is referred to as being developed to meet the exa-scale challenge, when velocity fields and tracer fields become massive and traditional Lagrangian codes will struggle. However, none of the examples in the paper are what I would refer to as "very large data sets", and there are no results regarding Parcels run time, memory use etc. I would therefore change the focus a little bit and re-phrase the introduction and also throughout the paper to describe Parcels as flexible and user-friendly, which seems to be the big advantage of using Parcels, rather than focusing too much on computational efficiency.

The aim of Parcels is to build an efficient and flexible framework for Lagrangian ocean analysis (Lange et al., 2017). We simply remind this in the paper introduction, then do not insist on it since it is not the point of the paper.

Specific comments

Page 1:
Line 19: I would re-write to say "can, in turn, be used to analyse the global ocean dynamics given the flow field from the model." Followed by "The flow field can also be taken from observations, e.g. land-based measurement... "

We have modified the sentence.

Page 2:
Line 2: "and many other types", "etc." Line 26: "We then validate... "
Line 29: "the results."

Done

Page 5:
I'm wondering if Fig 2 is really necessary. The staggering of grids is also shown in Fig 3, and indices could also be added to Fig 3, thus making Fig 2 redundant.

Fig. 3 is already quite busy with other information. We preferred to not overload it, and keep the global indexing separately, in Fig. 2.

Page 6:
Line 15: "in the cells, and interpolating"
Line 16: "formulation. For instance, such interpolation"
Line 18: While I enjoy citations, it it enough to just cite Jonsson et al. 2015 (the Tracmass code) and Doos et al 2017 (a thorough model description paper).

Done.

Line 23: If I understand this section correctly, you calculate fluxes on the cell faces, then interpolate fluxes to particle position, and then interpolate cell face area to the particle position, and divide flux by area to find velocity? The section starts by defining the velocity and ends by defining the Jacobian, which makes it a bit confusing for the reader to follow how velocities are interpolated from the model grid to the particle position. It would make more sense to start by defining the fluxes U,V, then how they are

interpolated to the particle position, and then describe how velocities are found. Line 24: "(Fig 2b). Velocities are not found by linear interpolation but, like in finite-volume schemes, they are approximated by linearly interpolating the fluxes (U0,U1,V0,V1) at the cell faces (fig 3b) and dividing by the cell face area."
Line 26: Should it be ". . . the velocity and any position (x,y) is derived as a function..."?

The interpolation schemes consist in (1) building a mapping between the physical and the unit cell; (2) computing the fluxes on the cell edges (in 2D) or faces (in 3D); (3) interpolating the relative velocity using the fluxes and the Jacobian of the transformation; (4) transform the velocity to the physical coordinates. We have rewritten the section to highlight the important parts of the interpolation process, reordering the description as you suggested.

Page 7:
Line 5: These are the velocities on the model grid? The section should end with an expression for how u,v are found. Line 9-11: The last two sentences seem out of place. Instead, you could add ", where indices are chosen to conform with the NEMO model (Madec et al)" on Page 6, Line 24. Line 17: l is the model vertical index? Conforming with NEMO model?

Those were the relative velocities. After the restructuring of the section, we now end with the expression for u and v as you suggested. The comment on the NEMO indexing was also moved following your comment. Yes, we use NEMO conforming indexing in both horizontal and vertical directions. l was the vertical index, since k was used somewhere else, but we have changed it such that we use the more common i, j and k notations for the grid indexing.

Page 8:

Line 1: what is meant by "do not resolve exactly a uniform velocity"? Do you mean "do not result in a uniform velocity"
Line 6: remove "different"

We meant that if the C-grid field was representing a uniform velocity, it was not possible to obtain for all x, y and z that velocity while interpolating the field with a linear interpolation scheme in 3D. We have reformulated that sentence.

Page 9:
Line 5: "and their respective fluxes are"

Done

Line 6: I like this Table. Could you do the same thing for the 2D case and also add to Fig 3? It would be a lot shorter, but I think it could be informative.

For the 2D case, the situation is much easier since there are only 4 fluxes, and the Jacobians reduce to the simple edge length. We have added the 2D computed fluxes definition in new Eq. 7.

Line 9-12: Replace with "We can compute the fluxes through grid faces [12,13,14,15] (in blue, Fig 4), [16,17,18,19] (in red), and [8,9,10,11] (in green) using the continuity equation. The flux through [12,13,14,15] is..."

We have reformulated that sentence.

Line 13-14: Is this only for fixes z coordinates? In the case of z or σ coordinates, the cell thickness varies in time which must be taken into account. If the time-varying part is taken into account here, please explain how.*

Thank you for pointing that comment. Indeed, this is only valid for a fixed mesh. For a moving mesh, the mesh expansion should be added to the continuity equation, which we don't do in Parcels. We have added this note to the document, with also a reference to Kjellsson and Zanna 2017, that quantifies the error induced if a moving mesh is assumed as fixed.

Line 16: What does the "+" superscript mean? What is the difference between U+ and U?

There is an important difference between U_{12} and U_{12}^{+}. U_{12}^{+} corresponds to the flux going through the physical interface. From this flux, the velocity u_{12} is computed as the flux U_{12}^{+} divided by the interface area, which corresponds to the Jacobian evaluated at $\eta = 0.5$, $\zeta = 0.5$. Then as for the other interfaces, the flux to be interpolated U_{12} is the product of u_{12} with the Jacobian $J_0^{2D,f}(0.5, \eta, \zeta)$. This distinction results from the fact that the Jacobian varies as a function of the relative coordinates. Volume is not distorted evenly within the cell. For a rectangular parallelepiped, the Jacobian is constant all over the cell and $U_{12} = U_{12}^{+}$.

We explained this in the revised manuscript (page 10, line 13).

Page 10:
Line 5: "four grid objects"
Line 13: "which should not be used for C-grids"
Line 16: "... describe the new objects which were added..." Line 27: "... regions, which may overlap or not... "
Line 28: remove "different"
Line 29: "... order in which they ..."

Thank you, done.

Page 11:
Line 3: "... is the velocity given in ..."

Done.

Page 13:
Line 5: "... transported through... "
Line 10-13: "... studies have focused on marine littler in the southern part of the North Sea (Neumann) and have included diffusion and wind drift to their model as well as used a higher resolution."

Done.

Line 23: "NEMO-N006" is not a standard I am familiar with, at least it does not ship with NEMO v3.6. Are you referring to the ORCA0083-N006 simulation, which is similar to ORCA0083-N001 used by Grist et al 2014 and Kjellsson and Zanna 2017?
Line 26: "... at horizontal resolutions of nominally 1/4 and 1/12."
Line 26: What is the vertical coordinate used, i.e. which interpolation scheme is used here?

Yes, we use the ORCA0083-N006 and ORCA025-N006 models. The models use 75 z-layers, with the variables distributed on a C-grid. We have added those informations in the manuscript.

Page 14:
Line 7: Full disclosure: this is the reason why I'm often sceptical about CMEMS data for particle modelling. All data is interpolated from the model grid to some other grid and not necessarily in a conservative way. Could you say a few words here about how this interpolation was done by CMEMS. Would you get identical results if the CMEMS

data came on the native C-grid from the NEMO model?
Line 9: "...data, which will be ..."
Line 10: Again, which vertical coordinate is used? Is this also interpolated by CMEMS?

When transposing a field from a C to a A-grid, one should be particularly careful to preserve some properties, such as conservation, consistency and the boundary conditions. But even if those properties hold, information will be lost and one cannot generally obtain the same solution by interpolating the original C field and the A-transformed one, whatever being the transposing method (in CMEMS all the quantities are interpolated on the tracer grid).

So yes, we agree with you that when available, the original grid should always be used for Lagrangian modelling. However, many data are provided as a A-grid, like in CMEMS, and Parcels can also interpolate such datasets. The North West shelf reanalysis data are discretised on a z-level mesh, but we only use the surface surface field from this data set.

Line 28-29: After "(Gutow 2018).": "Here we distinguish two flow types, the first based on NEMO and CMEMS data which has impermeable boundary conditions at the coast, and the second which includes Stokes drift and diffusion thus allowing beaching."

Done

Page 15 Line 5: "...advection." Line 6: "...are run, where if the particle beaches, it stops moving."

Done

Page 16:

Line 5: what is meant by "travelled at least once by a cell"? That the cell has been visited by at least one particle?

You're right, this sentence is not precise. We mean that for each cell, we computed the fraction of particles that have visited it at least once. We have reformulated this sentence in the revised manuscript.

Line 10: remove "different"

Done

Line 15: "... no validation of mesoscale dispersion has been done for those simulations there... ". I am fairly sure Andrew C has done some validation (AMOC strength, AABW volume etc.), but probably not for particle dispersion near the grid scale.

By validation, we meant "validation for MP simulations". Even if the model was validated for climate quantities, this validation does not hold for particle modelling, especially at coastal scales. The sentence was reformulated to avoid any confusion.

Line 20-22: I don't fully understand this sentence. By "differences generated in the first year" you mean "within the first year we see more transport into the Kattegat and Skaggerak leaving fewer particles for transport along the Norwegian coast"? There are some differences along the Norwegian coast and Barents Sea (less deep blue regions for Fig 6c).

The NWS do not cover latitudes further North than 65°N, which are reached after around one year by the particles travelling to the Arctic. So basically, most of the differences between run (a) and (c) result from the first year dynamics, since further North both run do only interpolate NEMO 1/12° data. We explained that better in the revised manuscript (page 17, line 23).

Line 27-28: "... how adding diffusion impacts the face of MP."
Line 28: "reduced by 68%" is in relation to NEMO 1/12?

Yes, we precised it in the manuscript.

Page 18:
I don't understand the caption of the figure. Do you mean "fraction of particles visiting each different region at least once" or "for each grid cell, fraction of particles that have visited that grid cell".?

See previous comment about the same confusion in the main text. The caption was reformulated.

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