GMD-2021-400 Response to Reviewers

Title: ROMSPath v1.0: Offline Particle Tracking for the Regional Ocean Modeling System (ROMS).

Editorial/Reviewer comments are in black

Author responses are in purple

We thank the topical editor, executive editor, and editorial staff for their time considering the manuscript "ROMSPath v1.0: Offline Particle Tracking for the Regional Ocean Modeling System (ROMS)" for publication. We further thank Dr. Clavel-Henry and two anonymous reviewers for their comments, suggestions, and editorial notes on our manuscript. Their overall impression of the manuscript is positive, which we appreciate. After implementing most of the reviewers' suggestions we feel the paper is improved and ready for resubmission. We address the reviewers' comments point by point below, although not necessarily in the order we received them.

Editorial staff:

Please note that your reference list has not been compiled according to our standards. Please consider adjusting your reference list with the next revision of your manuscript.

We have adjusted the reference list to match the format described at https://www.geoscientific-model-development.net/submission.html#references.

Dr. Clavel-Henry Specific Comments:

L.93-94: In that statement, I am curious about one thing: what about ROMS models that have a small spatial extent and, somehow, have a less pronounced curvilinearity; thus, potentially small errors in the coordinate interpolation? Would the performance of ROMSPath be still better than LTRANS? That is something I would have liked to see discussed as it has significant consequences for the choice of the software.

Yes, a configuration for LTRANS is possible where ROMSPath and LTRANS show similar results. However, this requires careful consideration of domain size, location, study objectives, and choice of geographic reference as we noted in section 2.1. A systematic examination of the conditions when LTRANS output is close to ROMSPath output is outside the scope of this study.

L.338-339: Is it relevant to write about a result when neither the methods nor supporting graphs are shown? It confused me because I am not sure what you refer to by this statement. I suggest removing these two sentences or to provide an annex with methods, results, and discussion.

It is relevant in that the text addresses the questions posed about L.93-94 above regarding the sensitivity of LTRANS results to basic configuration concerns. An LTRANS simulation with a reference coordinate horizontally distant from the grid showed results extremely divergent from the run with a reference coordinate selected using the recommended criterion. But since the LTRANS manual recommends against configuring the reference point this way, we removed these lines.

"Figure 1: this figure should be put in a supplementary file. It is not a graph showing novelty and can be easily found on the website of ROMS. "

We moved the figure to supplementary Figure S1. Even though the information is available elsewhere, the coordinate system is a major change to the LTRANS code and therefore relevant.

Grouping some comments together---

"Table 1: 1) I need a rationale on why "2", "30", and "90" days transport duration and the particle number of "3285", "6000", and "32000" have been selected.

Additions were made to section 3.3

"2) For the vertical experience (i.e., Vert. LTRANS and Vert. ROMSPath), I got confused. Please, indicate the depth range and also indicate that the release is made of evenly distributed points along a segment instead of "Line" (For example: Evenly distributed points between X and Y depths). As for "Point", please, indicate the coordinates instead of "point."

Additions were made to section 3.3

Section 3.3: I think that you should add in each section if you used both the parent and child hydrodynamic models (i.e., DOPPIO and SnailDel) to track particles or just one of the hydrodynamic models. See below)

We clarify this in table 1 and in section 3.3.

Section 3.3: I think that you should add in each section if you used both the parent and child hydrodynamic models (i.e., DOPPIO and SnailDel) to track particles or just one of the hydrodynamic models. See below)

We attempted to make this clear in the table 1 caption, under the nested column. Nested=yes means both Doppio and Snaildel output is used. Nested = no means Doppio only. We added this detail to the caption. Also see below.

1. In line 286, you said you used the DOPPIO model for online tracking of particles (i.e., ROMSFloat). Did you also only use DOPPIO fields for particle tracking with LTRANS and ROMSPath?

   In this comparison, yes.

2. In sections 3.3.2 and 3.3.4, did you use DOPPIO and SnailDel, or just DOPPIO?

Both.

Many of the comments above suggest a lack of clarity regarding the different model configurations in this manuscript. We made major changes to the description table and heavily edited section 3.3 for clarity.

Sections 4.1 and 4.2: the main result (or global outcome) from the tests should be put on the first line of the paragraphs. In these two sections, I had an introduction of the figures instead of the main findings.

We restructured sections 4.1 and 4.2 to reflect this suggestion.

Section 4.1: the results from ROMSPath being close to the online simulation ROMSfloat should be a valorised outcome of the manuscript. I expected a few comparisons with peer-reviewed studies that could have compared online and offline particle tracking simulations. Consider also my first comment (for L.93-94).

I am not entirely clear about what is meant by the term "valorised". But we can comment on comparison with other peer reviewed studies.

While there is extensive literature on Lagrangian analysis of ocean models (Beron-Vera and Lacasce, 2016; Chu et al., 2004; Van Sebille et al., 2018) there are a few studies directly comparing online vs offline particle tracking for the same model run (e.g., Wagner et al. 2019; Cassiani et al 2016). However, these studies compare offline particle dispersion or online tracer dispersion. Typically, the choice of offline vs. online is due to the practical considerations of computing time and storage space. We noted this in section 4.1 and added the references.

Cassiani, M., et al. (2016). "The offline Lagrangian particle model FLEXPART–NorESM/CAM (v1): model description and comparisons with the online NorESM transport scheme and with the reference FLEXPART model." Geoscientific Model Development 9(11): 4029-4048.

Wagner, P., et al. (2019). "Can Lagrangian Tracking Simulate Tracer Spreading in a High-Resolution Ocean General Circulation Model?" Journal of Physical Oceanography 49(5): 1141-1157

L.352-354: Please, note that this is a nonshown result that took half the paragraph of section 4.2. I think this result is interesting to have at least a supplementary figure and a short explanation of the method in 3.3.2.

We added a figure similar to Figure 5 as Supplementary Figure 2, with an LTRANS time step of 5s.

“Section 4.3.: 1) Considering the results relied only on visuals, I would have appreciated, in complementary, to have quantitative information such as a spatial aggregation index or the surface that contained 95% of particles at day X and per scenario. It would quantify the idea of “more horizontal dispersion”(L.366) and at least put some contrast between figures 6e and 6g.”

We added a dispersion coefficient to the panels in Figure 6, calculated based on Lacasce (2008). See new Figure 6. The particles’ dispersion coefficient increases in simulations that capture more small-scale dynamics, e.g. via nesting a better resolved grid or adding vertical and horizontal turbulence. This result is consistent with the description in the text in section 4.3

LaCasce, J. H. (2008). "Statistics from Lagrangian observations." Progress in Oceanography 77(1): 1-29.

“Section 4.3.: 2) Regarding the particles advected in the estuary with ‘Nest/No Turb’ but not with ‘No Nest/No Turb’, a small discussion would be welcomed. I don’t know the surface of the Delaware Bay but I easily guess that the resolution of the Doppio is too coarse for capturing the water circulation as the SnailDel can do. Hence the importance to do particle tracking simulation using the parent and child grid of hydrodynamic models in intertidal zones.

Yes, the Doppio resolution is too coarse (7km). We need the SnailDel resolution (1km) to resolve small scale features associated with the estuary. We have expanded the discussion of this point in section 4.3

“Figure 6: Please, be considerate of colour-blinded people and avoid having green and red on the same graph.”

Of course, thank you for pointing it out. We changed the figure.

Section 4.4: Here too, I would appreciate some elements of discussion including comparison with peer-reviewed studies. This is an interesting result, which, beyond including it as a Model development, can have consequences for particle modelling in shallow marine areas in the future.

It is long known that Stokes transport has an impact on coastal/estuarine circulation. We added discussion in a second paragraph in section 4.4, along with a number of references.

Technical comments: All suggestions were implemented

L.37: I think it should be clearer that you are talking about online particle tracking. “at model run time” can be slightly confusing because both “hydrodynamics” fields and “particle trajectories” are from a model. In other words, at first read, it is not evident which type of model “at model run time” points to.

Hydrodynamics model is common usage for a 4-d primitive equation model. But we changed it to Hydrodynamic ocean model.

L.291 and L.292: “two similar runs” and “at the same location”. Please, remind your reader that your simulation parametrisations are similar to the previous test (section 3.3.1).

These runs are configured differently from those in the previous section. (3.3.1). We clarified the differences among model runs in the configurations section.

Reviewer 2 Specific Comments:

Line 101: Include a comparative analysis of the number of particles that run aground in order to support this claim.

Results have been added in section 4.1 for the cases of the LTRANS OTP vs ROMSPath OTP . In LTRANS, 34% of particles are identified as passing through a “Land” grid cell at least once, whereas in ROMSPath, only <0.01% of particles pass through “land” cells.

Lines 284-286, 291, 312: How was this specific method chosen? Was there sensitivity to using starting positions in different parts of the domain, for example? Were these based on dynamics or patterns observed in previous analyses?

This comment mirrors several comments by Dr. Clavel-Henry. The overall description of the various OTP model configurations lacks clarity and some detail. We added a number of comments in section 3.3 and expanded/changed Table 1.

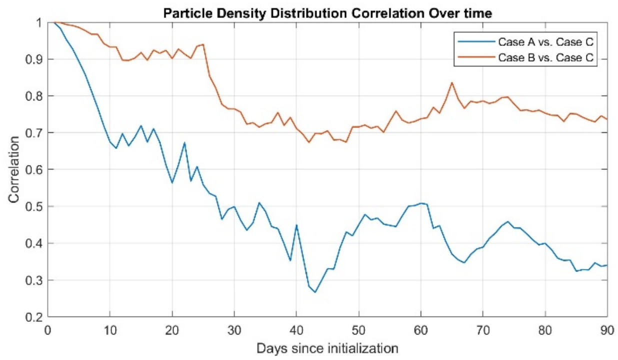
Line 329: What does it mean that “The ROMSPath OTP output is always closest to the ROMS floats output”? Is this at each time, on average, or also for each particle trajectory? Please specify and quantify this distinction.

Clarified this in the text. See Below

Line 340, Figure 4: Include additional quantitative support to summarize this comparison, such as dispersion, offshore transport, and trajectory of the center of mass.

Figure 4 is now Figure 3. Center of mass is shown in panels 4a and 4b, an additional figure quantitatively summarizing the primary result is added as new Figure 4. Following Simons et al, 2012. We calculated particle density distributions (PDD) for each model over time. Then the correlation coefficient between PDD’s. i.e. ROMSfloats to ROMSpath and ROMSFloats to LTRANS. The LTRANS correlation coefficient drops below .7 in 10 days. The ROMSPath stays above .9 for 25 days and stays above or around .7 for the remainder.

Simons, R. D., et al. (2013). "Model sensitivity and robustness in the estimation of larval transport: A study of particle tracking parameters." Journal of Marine Systems 119-120: 19-29.



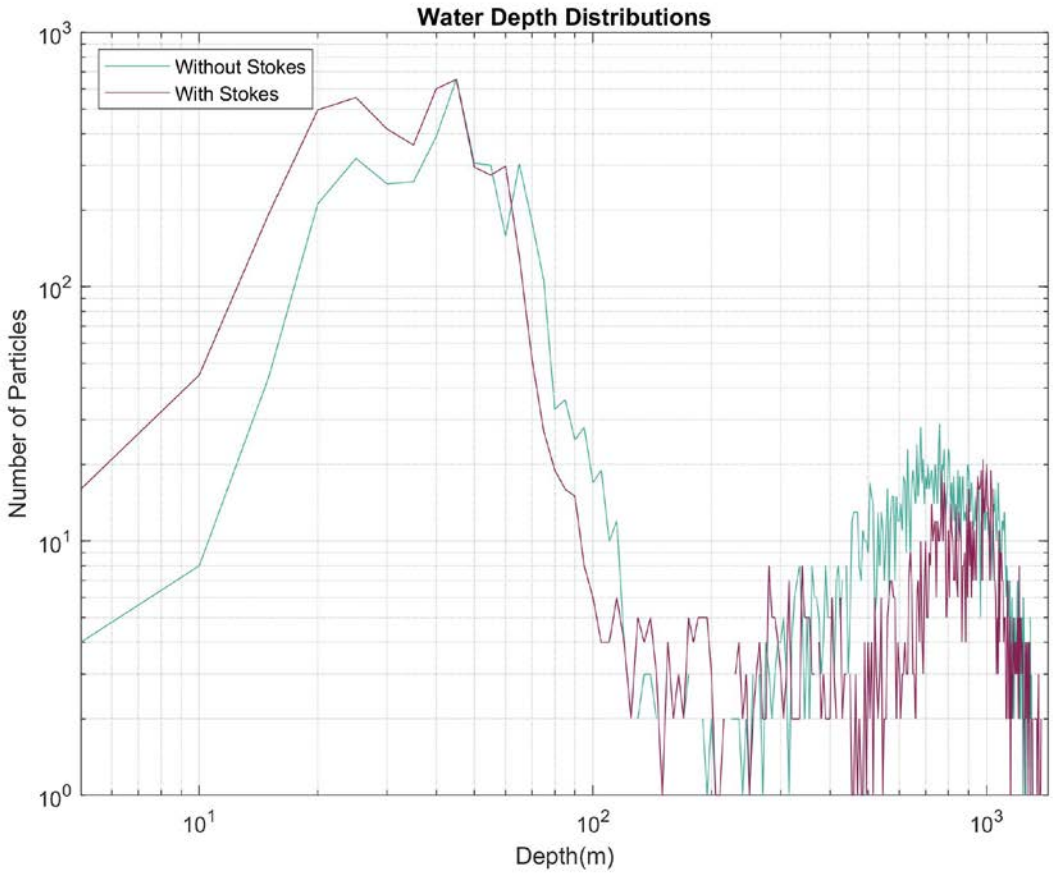
Lines 377-379: Comment on the implications, and how this compares across particle tracking models (note, this relates to the previous comment re: Line 340). For example, is there evidence to suggest that the increased dispersion apparent with including small scale hydrodynamics through nesting and turbulent parameterizations in ROMSPath simulations improves the accuracy of this model compared to other formulations?

A detailed skill assessment of ROMSPath is outside the scope of this study. Hence, and we are unable to measure the accuracy of the dispersion compared to observations. However, we added a quantitative measure of dispersion to figure 6 in the form of diffusivity calculated as described in Van Sebille et al. (2018). A description of the result is in section 4.3, supporting the conclusion that dispersion increases with nesting for this model configuration.

van Sebille, E., et al. (2018). "Lagrangian ocean analysis: Fundamentals and practices." Ocean Modelling 121: 49-75.

Line 393-394: It is hard to see from this figure that the particles tended to be closer to shore. Is there a statistic you can use for comparison, such as the mean distance from shore between the two, or the mean water depth of particles to test the significance of this observation?

The center of mass of the simulation with Stokes drift is approximating 9 km to the northwest of the simulation without stokes drift. Additionally, the percentage of particles in depths less than 50 m was 57% with Stokes drift and 38% without stokes drift. Comments to this effect are in section 4.4 along with a new figure (Figure 8). Figure 8 is a histogram of the particle water depth after 30 days.



Summary (i.e. Line 403): Can the authors comment on the results and features of ROMSPath in the context of other OPT applications (e.g. Lines 39-41), and in the context of previous works?

The manuscript describes improvements and new features to an existing OTP, and the summary focuses on highlighting those differences, i.e., LTRANS vs ROMSPath. However, we addressed aspects of this question in previous sections:

We added a few comments in section 4.1 comparing OPT models to online tracer advection.

We noted a potential transport pathway from the shelf to Delaware Bay in section 4.3 in the context of past literature.

We commented that implementing Stokes velocities in OPT has implications for tracer transport estuary-shelf exchange, larval transport/recruitment, and nearshore processes in section 4.4

Formatting Comments:

We implemented all the formatting comments.

Reviewer 3 Specific Comments:

While this project motivated the changes that were made to the code, it's not necessarily the most effective means for demonstrating the improvements. It would have been more informative to illustrate the results with simpler, idealized examples that are more easily diagnosed and transferrable to other applications. For example, the improvements in performance from splitting the advective and turbulence time steps will clearly provide model speed-up, but it'd be helpful to provide guidance on how much speedup users can expect for typical simulation parameters. Similarly, it is not surprising that using higher resolution grids will increase the resolved dispersion of particles, but it'd be useful to provide more context on how the increase in dispersion with nested grids compares with theoretical expectations."

"Among the stated aims are to "improve the model's efficiency, accuracy, and generality" [47-48], so that end, it would enhance the presentation to provide more generalizable examples of how these code updates improve the model. "

We agree that a broader analysis of the parameter space associated with the computational speed and model skill of ROMSPath, including a series of runs on idealized model grids for each model, would be valuable. However, as reviewer 3 notes, this work was motivated by a single project with specific scientific objectives. A larger study of type reviewer 3 recommends would be an independent investigation and is unrealistic given the available resources and time. The improvements illustrated in the manuscript are significant enough that we believe publication is warranted.

"The examples with initially vertically uniform particle distribution illustrate how particle dispersion depends on having the random walk algorithm coded correctly, but I am left wondering whether the clustering of particles near the pycnocline in the ROMSpath case has a physical basis due to flow characteristics or is instead some residual error (that is nevertheless a big improvement on the LTRANS result). "

Given the 4-d nature of these simulations, it is unlikely the minor increase in particle density seen in figure 5 are due to residual error. As the particles spread in space the vertical distribution of particles at any given horizontal point becomes less uniform. Further, even in the canonical case in Fig. 3 of Visser et al (1997), there are some random increases in particle density at the diffusivity minimum.

Visser, A. (1997). "Using random walk models to simulate the vertical distribution of particles in a turbulent water column." Marine Ecology Progress Series 158: 275-281.

is "OPT" a commonly used acronym? It's unfamiliar, and quick search did not turn up other instances of it. The added confusion to readers with creating a new acronym does not seem to be worth the savings in keystrokes or ink.

This acronym does not seem confusing to us. Offline and online particle tracking are terms used in existing literature (e.g. van Sebille et al, 2018) and it is natural to use an acronym for a phrase used repeatedly, such as "offline particle tracking". However, to minimize any confusion we will emphasize the acronym in the introduction, switching (line 38) “referred to as offline particle tracking (OPT)” to “referred to as offline particle tracking (hereafter designated as OPT for readability)”

van Sebille, E., et al. (2018). "Lagrangian ocean analysis: Fundamentals and practices." Ocean Modelling 121: 49-75.

Perhaps note in the abstract that the manuscript provides examples of the how the improvements affect the performance of the code?

We added a comment at line 15-16.

“that calculate particle trajectories for a variety of applications” can be deleted.

The text was removed.

[45] “It is not uncommon for users to modify OPT models to add novel processes for individual studies. Here, we describe alterations and additions to an existing OPT code, the Lagrangian TRANSport model (LTRANS), to add specific larval behaviour and improve the model’s efficiency, accuracy and generality.” These statements seem contradictory. If most users add their own processes and you are adding your own specific behavior, how does that improve generality? Please clarify.

It is not that the larval behavior itself adds generality, but as part of our project we added specific larval behavior while also improving generality, for example by adding functionality for nested grids and stokes drift and wet/dry cells. We clarified this in the text.

[195] is the Stokes drift necessarily output at the same times as the ROMS fields?

Yes, and the same spatial grid. It requires front end processing of stokes velocities into the correct format. We added a comment in section 2.5.

[232] Do the details of the Doppio implementation on data assimilation and nudging matter for ROMSpath? If not, suggest removing for clarity.

In as far as the hydrodynamics are being used as ROMSPath input, yes. We are using Lopez et al. (2020) as a primary reference for the DOPPIO hydrodynamic model setup. Lopez et al. (2020) did not use nudging and nesting, so we need to describe these differences.

López, A. G., et al. (2020). "Doppio – a ROMS (v3.6)-based circulation model for the Mid-Atlantic Bight and Gulf of Maine: configuration and comparison to integrated coastal observing network observations." Geoscientific Model Development 13(8): 3709-3729.

[245] Similar to the previous comment, it’s not clear if the details on the time stepping are important for ROMSpath (e.g., recommended output interval) or specific to the goals of this

science project. For this manuscript the focus should be on the former, and the latter would be more appropriate for a manuscript reporting on the scientific results.

Time stepping details are very important for reproducibility. Typical ROMS output is saved hourly or 3 hourly, due to disk space constraints. We saved hydrodynamic data every 12 minutes and used that as input to ROMSPath.

[331] As with OPT, “CM” is unnecessary, and is more a source of confusion than clarity.

CM is not used often so does not warrant an acronym, so we removed it.

[334] “LTRANS OTP fails to reproduce the off-shelf transport” Why is that? What aspect of the code modifications led to this improvement?

This is explained in section 4.1 (Coordinate system), describing the results comparing LTRANS, ROMSPath and ROMS floats. ROMSPath reproduces off-shelf transport by ROMS floats because it uses the ROMS eta/xi coordinate system, whereas LTRANS does not because of the error introduced in the LTRANS grid transformation.

[Fig 4] It's confusing to have the center of mass line on all 3 plots since the rest of the info in each panel is just a snapshot in time, whereas the line represents the trajectory over time. It’s also hard to distinguish the center of mass lines from the dots. Suggest removing the center of mass lines since, as noted in the text, it is not a particularly good metric as the particles get strained out.

While the center of mass is not the best metric, it is still useful to see where the center of mass paths diverged. It is informative to see these paths in figures 4a and 4b, although they are unnecessary in other panels.

[353] Why does decreasing the advective time step mitigate the clustering problem in LTRANS?

Good question, most likely it’s that the error introduced in the turbulence parameterization scales with the time step. So, a larger timestep gives a larger error. We illustrate this in a Supplemental Figure S2.

[354] “numeric[al] efficiency…tens of thousands of particles” It'd be worth quantifying the speedup in efficiency gained by splitting the turbulence and advection steps, assuming an appropriate ratio for them. Presumably it depends on how computationally expensive the advection and turbulence calculations are? Does it depend on the number of particles, or just become more noticeable with increasing numbers of particles?

The speed change is difficult to quantify. Depending on the configuration we saw speed changes from 20% increase in speed to a 4000% increase. We added text to this effect in the last section. The increase in speed depends on the system I/O speed as well as turbulence calculations, but it also becomes more noticeable with more particles, which translate to longer computation times.

[Fig 5] As mentioned above, ROMSPath also appears to have clustering near the turbulence minimum, but much less so. If LTRANS were run with the correction to the sign error in the code, would it give a result similar to ROMSPath, or are there other factors contributing to the difference?

If the error correction were implemented in LTRANS, the clustering issue would be somewhat mitigated. However, clustering also results from having a turbulence time step that is too large. Using a small time step in LTRANS results in long computation times, whereas the split time-stepping in ROMSPath enables a smaller turbulence while also improving computation speed.

[393] "wave swell was onshore during this time period" Isn't swell usually onshore, and increasingly so as it approaches the coast? Perhaps the idea is that the wave direction was aligned with main axis of the estuary?

The wave field over time is variable over the width of the shelf, and not all of the domain of interest is in very shallow water. It seemed prudent to be specific about the direction of the waves for this test case.