Review 1

Review to Monsoonal influence on floating marine litter pathways in the Bay of Bengal

General comments

This manuscript deals with the connectivity of floating macro-plastics released along the coast in the Gulf of Bengal. This region seems to be an under-sampled and under-studied area from a Lagrangian point of view. In this way, the results of this manuscript are of interest. The manuscript is clear and well written. The approach of initializing Lagrangian scenarios uniformly along the coasts to overcome the major uncertainties in source estimates is interesting. However, there are some limitations and important methodological points that need to be addressed to finalize the study before it can be published.

From the plastic problem point of view, I regret the country-by-country approach of this study, which leaves each country to its own responsibilities instead of promoting collaborative regional approach as it is recommended by scientists and NGOs in the context of current international negotiations for a treaty against plastic pollution. For example, countries upstream of watersheds share the responsibility for marine pollution, and measures must be discussed with continuity at borders to ensure fairness towards countries with long emitting and accumulating coasts (such as Myanmar designated in this study). A alternative in future work would be to segment the coasts according to ocean dynamics or sub-region land use or coastal types.

We recognise that reporting by country might overlook issues such as shared watersheds. It does also have advantages, namely making results directly comparable between studies and quantifying progress once measures are taken. Intentionally, the litter sources were all normalised in this study, rather than providing numbers of mass export between countries, so that the focus is on the efficiency of the marine pathways. This motivation has been added to the beginning of the discussion section (lines 306-309).

I suggest adding a limitations section to the methods and/or discussion. We understand that the authors use Ocean Parcels by activating the options already coded in the tool. However, the processes chosen and activated should be at least described and discussed, mentioning particularly their limitations. It is important to be able to interpret the results in the light of these uncertainties. The 2D approach, for example, that might over-estimate the beaching rates (no undertow for mass conservation as in 3D) should be discussed, as does the simple addition of Stokes drift to 2D Eulerian currents (no anti-Stokes force created contrary to coupled simulations).

A new subsection (“Model limitations”; lines 164-203) has been added to the Methods section, which substantially details the constraints of the model and datasets used. A note regarding the use of 2D surface velocities instead of a full 3D simulation has been included as follows (lines 201-203):

“The use of only surface velocities rather than running a 3D simulation further limits the movement of particles. However, despite the particle tracking simulations being limited to 2D, the hydrodynamic simulations were run in 3D and this mitigates some of these shortcomings.”

Since the advection kernel that is inbuilt in Parcels is central to the model’s operation, it is already discussed extensively in papers describing the model development. Instead of repeating what has been published elsewhere, we have referred the reader to the relevant citation. The diffusion kernel, which is not discussed in these articles, has now been described and the GitHub repository which houses the code for the two kernels used in this study has also been given a DOI and this is cited here so the reader can explicitly see how the kernels operate (lines 95-104):

"Advection of particles via surface ocean currents (detailed below) was included using an inbuilt OceanParcels kernel which uses a fourth-order Runge-Kutta advection scheme (Advection RK4, described in Lange and van Sebille, (2017)). Stokes drift velocities were included to account for the movement of particles resulting from wave motions by simple addition to surface current velocities. To account for sub-grid scale processes, diffusion is implemented as a random walk, through an inbuilt kernel known as DiffusionUniformKh. A diffusion coefficient of 100 m^2/s was chosen based on grid cell size (Peliz et al., 2007), as detailed below. The diffusion kernel combined this coefficient with a random variate calculated from a normal distribution with a mean of zero and standard deviation equal to the square root of the model timestep (see https://doi.org/10.5281/zenodo.14906471 where a copy of the advection and diffusion kernels used have been archived)."

Moreover, the manuscript is based on comparison of stranding between two simulations with different resolutions. Even if 2 km is a high resolution for regional approach, neither of the two runs has sufficient resolution to represent coastal and beaching processes, the dynamics in the coastal grid cells will still be very different (as mentioned by the authors in the section 4.3 but unfortunately not showed with figures). I suggest that the authors need to further clarify the particle release strategy in the two simulation, depending on the size of the grid cells, which is decisive for the comparison of beaching statistics (a figure zooming on coastal cells of both simulations with the particle release locations would be welcome, as well as one showing the final locations when they are considered beached in both simulations). This would illustrate how the resolution numerically constrain the release scenarios and beaching statistics, in addition to the representation of the dynamics.

Figure 1 has been updated to show the particle release locations with respect to the different coastlines in the CMEMS and ROMS models. This figure also now demonstrates the differences in coastal dynamics that are resolved by the different models as the backgrounds have been changed to show an ocean velocity snapshot for each of the models. Subfigures have also been included to show a small area in the southeast of the domain that has been enlarged to illustrate the differences in coastal dynamics. Moreover, a new figure has been added to Appendix A to show the final locations of particles that were considered beached on each of the coastlines so the proximity of the particles to the coast upon beaching can be seen more clearly. Additionally, the newly added "Model limitations" subsection discusses the challenge of resolving beaching processes at these model resolutions (lines 178-185):

"Regardless of the beaching method employed, the resolution of all these hydrodynamic models, including the two used in this study, are too coarse to fully capture all processes that are key to marine debris beaching. Fine-scale ocean dynamics such as submesoscale and microscale eddies near the coast contribute to litter accreting and washing ashore but are not represented even in the finer scale ROMS model we used to advect particles. Sub-grid scale tidal motions at the shoreline are also precluded, yet they would likely lead to higher beaching rates (Zhang et al., 2020), and slope at the coastline is not represented by either model. Additionally, the shape of the coastline, while much more realistic in the ROMS model versus CMEMS (Fig. 1), is still not refined enough to show the true morphology of the coast and misses many features such as estuaries which have been demonstrated to act as traps for floating debris (Duncan et al., 2020; Pawlowicz et al., 2019)."

Detailed comments

L33. "Despite the large uncertainties": this is very important in the current challenges of quantifying sources and monitoring plastic pollution in the marine environment, I suggest to add the orders of magnitude of these uncertainties here referring to the recent literature on the subject (interesting studies have followed the precursory but not up-to-date study by Jambeck et al., 2015).

While there are a large number of studies that have looked into this problem, we are only aware of one other that has reported a global estimate of plastic waste entering the ocean from (almost) all sources at the coast. Many others are not global studies and only focus on the sources of mismanaged waste to the ocean in small regions. A few only discuss pollution coming from rivers, and while this makes up the majority of input into the ocean, it does not encompass other litter sources as in the Jambeck et al. (2015) study. Additionally, our manuscript has taken the approach that river inputs to the ocean have been shown to not produce accurate source-to-sink estimates for floating marine litter. The most recent, similar estimate we can find (Borrelle et al., 2020) details waste finding its way to all aquatic environments, not solely the ocean. Therefore, order of magnitude error estimates based on studies that have looked at waste input to the ocean based on different criteria are not really possible to calculate. The estimate quoted from Jambeck et al. (2015) is one of two studies we are aware of that are relevant to our research and their estimate is purposely given as a range to indicate the uncertainty in the calculations.

We have instead emphasised the level of uncertainty by adding in details of other drastically different estimates to show how they can differ, but stress that they have estimated different things (lines 31-43).

"Jambeck et al. (2015) estimated that between 4.8 - 12.7 million tonnes of plastic entered our oceans every year (based on conditions in 2010), and that this could increase by an order of magnitude by 2025. Other studies have calculated significantly different estimates for how much plastic finds its way to the ocean. Lebreton and Andrady (2019) calculated a lower estimate of between 3.1 – 8.2 Mt of plastic entering the ocean each year, using a different dataset for solid waste generation but similar assumptions to that of Jambeck et al. (2015) about how much mismanaged waste within 50 km of the coast finds its way into the ocean. Several other studies have investigated slightly different questions and about how much plastic waste enters the oceans which have resulted in quite different estimates. Lebreton et al. (2017), Schmidt et al. (2018) and Meijer et al. (2021) calculated how much plastic is transported solely by rivers to the ocean, resulting in much lower values of 1.1 - 2.4 Mt/yr, 0.5 – 2.8 Mt/yr, and 0.8 – 2.7 Mt/yr, respectively. A subsequent study by Borrelle et al. (2020) found a significantly larger value of 19 – 23 Mt of plastic waste ending up in aquatic environments in 2016, however, this includes rivers and lakes rather than just the ocean. Despite the large uncertainties associated with these estimates, observations of so-called 'garbage patches' that have formed in the ocean's major gyres (Cózar et al., 2014; Eriksen et al., 2014) and reports of litter washing up on beaches (e.g. Shankar et al., 2023) confirm plastic pollution in the ocean is a vast problem."

L41. "with fewer looking at the connections of litter that 'beaches', or washes ashore, along coastlines": seems exaggerated, many studies have indeed focus on the gyres, well represented by the large-scale dynamics, whereas coastal processes are more complex but there is still a significant literature on Lagrangian tracking applied to plastic beaching issue. An updated state of the art would be welcome.

We have removed this text.

L42. “two-thirds […] is captured on coastlines”: I suggest to note the huge uncertainties in the statistics mentioned here given the resolution of the global models cited.

We have altered to wording of this sentence to make it clearer that these estimates are approximate and have explicitly noted the large uncertainties associated with them (lines 48-50):

“However, multiple recent studies have suggested that approximately two-thirds to three-quarters of all litter released in global model simulations may be captured on coastlines, though they note there are large uncertainties associated with these estimates (Chassignet et al., 2021; Chenillat et al., 2021; Lebreton et al., 2019; Onink et al., 2021).”

L59. “Lebreton et al. (2017), which have very high uncertainties”: others river input models have shown the sources of uncertainties in the mentioned reference, add citations

Citations which discuss the large uncertainties and some of the sources of uncertainty have now been included here.

L93. “Stokes drift […] wave motions”: How is added the effect of Stokes Drift on the 2D current fields? A simple addition is physically very different from a coupling process for example

We have clarified that the velocities were combined through simple addition (lines 97-98):

“Stokes drift velocities were included to account for the movement of particles resulting from wave motions by simple addition to surface current velocities.”

L95. “Windage […] trajectories”: for which macro-plastic size are these 1% consistent ? Is there a risk of obtaining excessively high drift velocities for particles by combining all these effects?

In response to this and a similar comment by another reviewer, the sentence referred to here has now been altered and this section has been updated to give more details of how we came to the decision to use a 1% windage coefficient in addition to Stokes and surface ocean velocities. This is an approach used in other studies (e.g. Chassignet et al., 2021; Isobe and Iwasaki, 2022) and is based on the physical processes that need to be considered for the movement of floating litter (Haza et al., 2019). While the effect of wind on the surface currents themselves is already included in the ocean current velocities used, the addition of windage takes into account the extra push that wind provides as a result of friction against the portion of marine debris that is not under the surface of the water. This is the reason the additional wind factor is necessary without ’double-counting’ the wind’s effect that one might suspect would lead to excessively high drift velocities. This explanation has been added to the text (lines 104-108):

“Windage is implemented in the model by applying 1% of the wind velocity to the particles’ trajectories. Following analysis of observations of the wind’s effect on undrogued drifters by Pereiro et al. (2018), this should describe all but very buoyant items of litter. While the effect of wind on the surface ocean currents is already included in the ocean velocities used in the particle tracking simulations, the addition of windage takes into account the extra push that wind provides as a result of friction against the portion of marine debris that extends above the surface.”

L114. “Particles […] locations.”: did the particles have exactly the same release lon,lat in both simulations given the different resolutions of coastal cells and the same distance to the land mask?

The particles did have exactly the same lat/lon release locations in both simulations, but as the shorelines were in slightly different locations in each model due to the resolution, the distance between the particles and the shoreline was different for particles in different locations in each model (i.e. some particles are further away from the coastline in the ROMS model than they are in the CMEMS model whereas some are closer, and vice versa). We have clarified that the mean and maximum distances stated were from the Natural Earth coastline and stated explicitly that the release locations were exactly the same in both simulations and the differences can now be seen in a figure (lines 133-140):

“Particle release locations were uniformly spaced around all major coastlines in the Bay of Bengal (Fig. 1). Particles were released on average 6 km from the Natural Earth coastline (naturalearthdata.com), with a maximum distance of 18 km in some locations. This distance was chosen to complement different coastlines from the two hydrodynamic models, ensuring no particles were released on land while also ensuring they were released on the continental shelf for both configurations; this ensured coastal dynamics rather than open ocean dynamics influenced the particles when they initiated their journeys. We chose to release the particles from exactly the same latitudes and longitudes in both simulations, but note this means their proximity to the coast will differ between the CMEMS and ROMS runs, due to the differences in hydrodynamic model resolution (Fig. 1c-d).”

L122. “we could be applied […] future”: this perspective may be little excessive, the number of particles released per day seems low and the question of statistical representativeness of the diversity of possible trajectories is not addressed (“500 coastal locations every day, […] with 182,500 particles released in total”). The authors should add a statistical sensitivity test to show that the number of particles released is sufficient to represent the diversity of particle fates in the studied region (i.e. increase the number of particle releases and see if it changes or not the connectivity statistics, taking into account the spatial and temporal variability of the dynamics - in the same way they have done the temporal resolution sensitivity analysis described in Appendix A).

We acknowledge the importance of testing the sensitivity of the results to the number and distribution of released particles. While we have not conducted an additional sensitivity test, the consistency of the patterns observed across both simulations suggests that the conclusions are robust to variations in particle release parameters. In addition, we ensured that the particle release strategy followed established practices in similar studies to achieve statistically representative connectivity patterns. Our approach to the number of particles released per day is in line with, or in excess of, all other studies of this nature cited in the manuscript. van der Mheen et al. (2020a) released a similar number of particles to our study (~200,000 in total over the course of a year) in the northern Indian Ocean, which was a larger geographical area that included the Arabian Sea, adjacent to the Bay of Bengal. Irfan et al. (2024) released far less than this in their study of the Bay of Bengal because they chose to release particles monthly. This low frequency results in a total number of particles that is an almost 10 times lower than our study over their 10 year run (~200,000). Many global studies have used a range of larger numbers of total particles released per year but considering the geographical coverage is so much larger, our statistical robustness is greater. Examples include: Lebreton et al. (2012): ~120,000 - 500,000 per year; Chassignet et al. (2021): ~350,000; Chennilat et al. (2021): ~240,000; Onink et al. (2021): ~600,000 per year. Many of these global simulations have also used monthly releases as opposed to our more frequent daily releases. It should also be noted that many studies have released different numbers of particles depending on the assumed amount of litter entering the ocean from a given location and this changes throughout the year (e.g. Chassignet et al., 2021) meaning that in some locations, a single particle is released per month to represent a small amount of litter.

The manuscript has been updated to give some of these examples which has set the precedent for our method (lines 140-143):

"A particle was released from each of the 500 coastal locations every day for a year, with 182,500 particles released in total. The number of released particles is consistent with other particle tracking studies conducted in the Bay of Bengal and on a global scale (e.g. Chassignet et al., 2021; Chenillat et al., 2021; Lebreton et al., 2012; van der Mheen et al., 2020a)."

L150. Are the 100 particles really released at exactly the same position and at exactly the same time? So why do the 100 differ from one another?

Diffusion is implemented as a random walk at each time step which leads to the differences. We have clarified this in the manuscript (line 222):

"Note that the random-walk diffusion causes each of the 100 particles to take a slightly different path."

Figure 2. It would be interesting to be able to see the weekly particle clouds (like Fig. 2b) for each D1-4 drifter trajectory in the supplementary materials, to see the spread associated with the statistics in Fig. 2c (for each of the two simulations). Also, does Fig. 2b correspond to CMEMS or ROMS advection? Please specify.

A figure has been added to Appendix C to show the validation comparisons for each model and each drifter. The caption for Figure 2 has been altered to identify that the images in Fig. 2a&b are from the ROMS run but that the CMEMS figures and the rest of the drifters for both runs can be seen in Appendix C.

L192. It would be welcome here to have, for example, a current map to understand why the exit patterns are different, and based on the bibliography of dynamics in the region, which seasonal pattern is predominant over the years. I did not find the corresponding circulation analysis in the Discussion section.

The different currents can best be seen through the supplementary animations. The particles can be seen leaving the domain as the seasons progress. Readers have now been pointed towards these animations when outlining the differences in CMEMS and ROMS simulations. Additionally, we have included extra details in the post-monsoon section of the Results that this season dominated the year-long simulation in terms of total escaped particles (lines 271-277):

"The number of remaining particles leaving the domain was also higher than the monsoon and pre-monsoon seasons combined (CMEMS: 27%, ROMS: 15%) by a substantial margin, making the particle-exit pattern from this post-monsoon season dominant across the full simulation for the CMEMS and ROMS cases. The majority of these particles left the domain through the southwestern boundary towards the Arabian Sea (CMEMS: 19%, ROMS: 10%), a smaller portion leaving through the southern open boundary (CMEMS: 7%, ROMS: 3%), and relatively few leaving though the southeastern boundary into the Strait of Malacca (1%) in each case. These groupings are reflected in the particle-exit pattern for the full simulation in both cases."

L243. The fact that beaching is predominant in the vicinity of source points in all literature studies at these modeled resolution does not confer an element of validation since none of these studies allows the representation of realistic beaching. I would advise more nuance with regard to the numerical limitations in these assertions, especially as the study's beaching criterion is rather simplistic.

We have added a caveat to this paragraph to address the limitations of modelling studies on this scale to effectively simulate beaching processes (lines 312-315):

"This is consistent with previous modelling studies in the region (e.g. Chassignet et al., 2021; Chenillat et al., 2021) and is unsurprising given that the resolution of global or regional-scale models is insufficient at the coast to implement realistic beaching processes and instead, simpler beaching methods are employed in this study and others."

L267. The quantification of connectivity between countries seems totally linked to particle emission scenarios, the argument brought by the authors at the end of the section is in fact central to the differences observed compared to Chassignet et al., 2021 and should be mentioned right at the beginning of the paragraph: the sink differences should be discussed in relation to the differences in sources of the cited publication (in term of quantity and location).

This paragraph has been moved to the beginning of the discussion about comparisons to the results of Chassignet et al. (2021) so that readers can keep this in mind when we discuss the similarities and differences of our findings.

L282. I was not able to see the Supplementary animations. I suggest that this section 4.2 could be illustrated by one or two figures of ocean circulation to help understand the different seasonal pathways discussed and the importance of simulation resolution for the study of connectivity.

Figure 1 has been updated to reflect other comments by yourself and the other reviewer and now shows the differences in resolution between the CMEMS and ROMS simulations (e.g. smaller eddies are resolved in the ROMS simulation). Animations are available alongside the preprint under Assets > Supplement. These animations show seasonal pathways far more clearly than a set of static figures would as the journeys of the particles clearly show the pathways of currents at different times of the year.

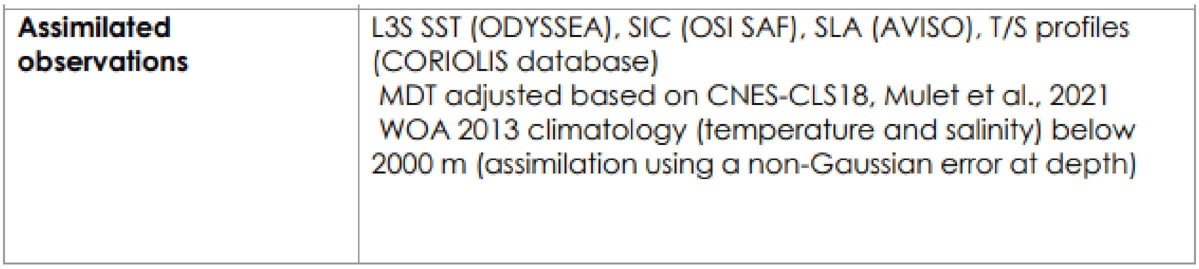
L335 - 339. The assumptions made here should be illustrated by coastal zoom circulation maps (eddies and/or offshore current) at the two simulation resolutions used. Otherwise remove as unfounded.

Figure 1 has been updated to show a snapshot from each model for the whole domain and a zoomed in area around Indonesia and Thailand which demonstrates that the higher resolution ROMS velocities capture smaller scale features that could not be resolved in the CMEMS model. An example of coastal currents eddying off the northern tip of Indonesia are depicted in the snapshot chosen. The comparison shows that these features are present but not as well resolved in the CMEMS data. The text referred to here has been updated to point towards this new figure (lines 428-429):

"An example of the difference in the level of detail of coastal currents and mesoscale eddies resolved by each of the models can be seen in Fig. 1c-d."

L341. Has the CMEMS product assimilated the drifters' profiles? If so, it's normal that the CMEMS simulation corresponds better to the observations even if its resolution is coarser.

No, we do not believe the drifter velocities have been assimilated. The CMEMS product has only assimilated data related to sea level, sea ice concentration and/or thickness, SST, and data from in-situ TS profiles from the sources listed below. It is possible that other observations from the drifters may have been included in some of the products listed here, but velocities would not have been assimilated based on the information provided in the product manual:



Assimilated observations	L3S SST (ODYSSEA), SIC (OSI SAF), SLA (AVISO), T/S profiles (CORIOLIS database) MDT adjusted based on CNES-CLS18, Mulet et al., 2021 WOA 2013 climatology (temperature and salinity) below 2000 m (assimilation using a non-Gaussian error at depth)

We have updated the information in the manuscript to include this detail (in the Methods, lines 213-215):

"This is an important consideration given that the CMEMS simulations include data assimilation (for sea level, temperature and salinity) and would therefore be expected to provide more accurate offshore currents than the ROMS velocities."

L360. Even with Stokes drift and windage included in the study, coastal processes are not represented: put more nuance in this sentence. Moreover, Stokes drift seems to be added by simple addition with the Eulerian current fields: here again, this is a strong limitation to be discussed. In coupled simulations, Stokes drift forcing creates a feedback from the current fields called anti-Stokes force that attenuates the total current compared to the total current obtained by adding the Eulerian current and Stokes drift without coupling at each time step.

The limitations set by the simple addition of Stokes drift velocities to those of the Eulerian currents has been addressed in the limitations section added to the methods, as detailed above. We have altered the wording in this sentence to make it clearer that wind and waves are not the only drivers of beaching, just contributors. Additionally, we have added a caveat to the end of the paragraph to state that coastal processes responsible for beaching are not resolved in the models used in this work (lines 453-460):

"Their model did not feature key mechanisms thought to promote the beaching of floating particles, such as windage or Stokes drift, instead assuming a beaching probability. Winds and waves are likely to have a large effect on beaching probabilities; Stokes drift, for example, has been found to reduce the residence time of particles in simulations in the Black Sea as well as increasing beaching rates by up to 75% (Castro-Rosero et al., 2023). Onink et al. (2021) found that not including Stokes drift in their global model reduced the trapping of particles near the coast and reduced beaching by 6-7%. Additionally, Irfan et al. (2024) found increases in beaching rates of 5% when Stokes drift was added to their model and a further 9% when windage was included. It is important to note, however, that neither model used in this study is able to fully resolve all the coastal processes that are likely to influence beaching rates."

L380-383 Same remark as in the method section. To ensure that the conclusions drawn from the study's Lagrangian simulations can be extended to different cases by weighting the particles according to various source scenarios, I suggest adding a sensitivity test in the appendix showing that the number of particles released is sufficient for the connectivity obtained to be statistically representative: a comparison of the spread and connectivity of clouds composed of different numbers of particles with slightly different time and space initialization should be added (with a histogram as in Fig. 2c for example).

In our simulations, we ensured that the particle release strategy followed established practices in similar studies (van der Mheen et al., 2020a; Irfan et al., 2024; Lebreton et al., 2012; Chassignet et al., 2021; Chennilat et al., 2021; Onink et al., 2021), as detailed above, to achieve statistically representative connectivity patterns. While we have not conducted an additional sensitivity test, the consistency of the patterns observed across both simulations suggests that the conclusions are robust to variations in particle release parameters.

Following similar comments from another reviewer about the likelihood of our results being weighted with updated pollution estimates, we have removed the text here emphasising the future applications of the model as a tool that could be reused with newer, more accurate weightings applied to our results. Therefore, while we agree this sensitivity analysis would be very interesting to investigate, this piece of work would be a very large undertaking that is outside the scope of this paper, especially given the lack of emphasis now given to the future weightings, and would not add enough value to the manuscript to justify the work.

L400. “Our simulations [...] litter.” This recommendation is far too vague and should be removed: targeting the entire Myanmar coast is illusory, and the study offers no way of targeting smaller coastal transect suitable for the scale of a beach litter observation.

We have removed this sentence.

L404-405. Same comment as above, the present connectivity study remains interesting, but the scale of the coastline considered here is not suitable as support for policy decisions and beach cleaning operations (which requires a link to finer scales). I suggest nuancing the last two sentences or removing them.

The point about needing finer scale research to influence policy decisions and targets for beach cleaning is valid. Following other comments from yourself and another reviewer, this paragraph has been removed from the conclusions section.

Appendix A. L433. “The differences in sink locations [...] negligible”: I would put more nuance into this kind of statement, the connectivity presented here is calculated between very long lengths of coastline, if smaller transects had been taken into account for the connectivity study, the differences might be higher.

We have altered this statement to make clear that the coarse resolution of the polygons used for connectivity calculations has contributed to our conclusion that the differences between the hourly and daily results were negligible (lines 520-523):

“Considering the aim of this study was to quantify connections between just six countries in such a large domain, as opposed to a more granular breakdown of the region, the differences in sink locations between the hourly and daily runs for each case (CMEMS and ROMS) were found to be negligible. Therefore, daily forcing was determined to be adequate to provide accurate results for the final experiment.”

Figure A1. Rather than giving the difference between the two connectivity matrices for each simulation, give the percentage error

The difference between the numbers of particles that were released from and beached on a given country in each simulation (hourly versus daily) is given in this figure. This provides an estimate of the margin of error that occurs in the separate simulations. As the values are given as a percentage of the number of particles released from each country, we would argue this figure already shows the percentage error. As this format remains consistent with the other connectivity matrices in the manuscript, we have opted to keep this figure in its original format.

References

Borrelle, S. B., Ringma, J., Law, K. L., Monnahan, C. C., Lebreton, L., McGivern, A., Murphy, E., Jambeck, J., Leonard, G. H., Hilleary, M. A., Eriksen, M., Possingham, H. P., De Frond, H., Gerber, L. R., Polidoro, B., Tahir, A., Bernard, M., Mallos, N., Barnes, M., and Rochman, C. M.: Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution, Science, 369, 1515–1518, https://doi.org/10.1126/science.aba3656, 2020.

Castro-Rosero, L. M., Hernandez, I., Alsina, J. M., and Espino, M.: Transport and accumulation of floating marine litter in the Black Sea: insights from numerical modeling, Frontiers in Marine Science, 10, 1213333, https://doi.org/10.3389/fmars.2023.1213333, 2023.

Chassignet, E. P., Xu, X., and Zavala-Romero, O.: Tracking Marine Litter With a Global Ocean Model: Where Does It Go? Where Does It Come From?, Frontiers in Marine Science, 8, 667591, https://doi.org/10.3389/fmars.2021.667591, 2021.

Chenillat, F., Huck, T., Maes, C., Grima, N., and Blanke, B.: Fate of floating plastic debris released along the coasts in a global ocean model, Marine Pollution Bulletin, 165, 112116, https://doi.org/10.1016/j.marpolbul.2021.112116, 2021.

Cózar, A., Echevarría, F., González-Gordillo, J. I., Irigoien, X., Úbeda, B., Hernández-León, S., Palma, Á. T., Navarro, S., García-de-Lomas, J., Ruiz, A., Fernández-de-Puelles, M. L., and Duarte, C. M.: Plastic debris in the open ocean, Proceedings of the National Academy of Sciences, 111, 10239–10244, https://doi.org/10.1073/pnas.1314705111, 2014.

Delandmeter, P. and van Sebille, E.: The Parcels v2.0 Lagrangian framework: new field interpolation schemes, Geoscientific Model Development, 12, 3571–3584, https://doi.org/10.5194/gmd-12-3571-2019, 2019.

Duncan, E. M., Davies, A., Brooks, A., Chowdhury, G. W., Godley, B. J., Jambeck, J., Maddalene, T., Napper, I., Nelms, S. E., Rackstraw, C., and Koldewey, H.: Message in a bottle: Open source technology to track the movement of plastic pollution, PLOS ONE, 15, e0242459, https://doi.org/10.1371/journal.pone.0242459, 2020.

Eriksen, M., Lebreton, L. C. M., Carson, H. S., Thiel, M., Moore, C. J., Borerro, J. C., Galgani, F., Ryan, P. G., and Reisser, J.: Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea, PLoS ONE, 9, e111913, https://doi.org/10.1371/journal.pone.0111913, 2014.

Haza, A. C., Paldor, N., Özgökmen, T. M., Curcic, M., Chen, S. S., and Jacobs, G.: Wind-Based Estimations of Ocean Surface Currents from Massive Clusters of Drifters in the Gulf of Mexico, Journal of Geophysical Research: Oceans, 124, 5844–5869, https://doi.org/10.1029/2018JC014813, 2019.

Hinata, H., Ohno, K., Sagawa, N., Kataoka, T., and Takeoka, H.: Numerical modeling of the beach process of marine plastics: 2. A diagnostic approach with onshore-offshore advection-diffusion equations for buoyant plastics, Marine Pollution Bulletin, 160, 111548, https://doi.org/10.1016/j.marpolbul.2020.111548, 2020a.

Irfan, T., Isobe, A., and Matsuura, H.: A particle tracking model approach to determine the dispersal of riverine plastic debris released into the Indian Ocean, Marine Pollution Bulletin, 199, 115985, https://doi.org/10.1016/j.marpolbul.2023.115985, 2024.

Isobe, A. and Iwasaki, S.: The fate of missing ocean plastics: Are they just a marine environmental problem?, Science of The Total Environment, 825, 153935, https://doi.org/10.1016/j.scitotenv.2022.153935, 2022.

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., Narayan, R., and Law, K. L.: Plastic waste inputs from land into the ocean, Science, 347, 768–771, https://doi.org/10.1126/science.1260352, 2015.

Lange, M. and van Sebille, E.: Parcels v0.9: prototyping a Lagrangian ocean analysis framework for the petascale age, Geoscientific Model Development, 10, 4175–4186, https://doi.org/10.5194/gmd-10-4175-2017, 2017.

Lebreton, L. and Andrady, A.: Future scenarios of global plastic waste generation and disposal, Palgrave Commun, 5, 1–11, https://doi.org/10.1057/s41599-018-0212-7, 2019.

Lebreton, L., Egger, M., and Slat, B.: A global mass budget for positively buoyant macroplastic debris in the ocean, Sci Rep, 9, 12922, https://doi.org/10.1038/s41598-019-49413-5, 2019.

Lebreton, L. C. M., van der Zwet, J., Damsteeg, J.-W., Slat, B., Andrady, A., and Reisser, J.: River plastic emissions to the world's oceans, Nat Commun, 8, 15611, https://doi.org/10.1038/ncomms15611, 2017.

Lebreton, L. C.-M., Greer, S. D., and Borrero, J. C.: Numerical modelling of floating debris in the world's oceans, Marine Pollution Bulletin, 64, 653–661, https://doi.org/10.1016/j.marpolbul.2011.10.027, 2012.

Meijer, L. J. J., van Emmerik, T., van der Ent, R., Schmidt, C., and Lebreton, L.: More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean, Science Advances, 7, eaaz5803, https://doi.org/10.1126/sciadv.aaz5803, 2021.

van der Mheen, M., van Sebille, E., and Pattiaratchi, C.: Beaching patterns of plastic debris along the Indian Ocean rim, Ocean Science, 16, 1317–1336, https://doi.org/10.5194/os-16-1317-2020, 2020.

Onink, V., Jongedijk, C. E., Hoffman, M. J., Van Sebille, E., and Laufkötter, C.: Global simulations of marine plastic transport show plastic trapping in coastal zones, Environ. Res. Lett., 16, 064053, https://doi.org/10.1088/1748-9326/abecbd, 2021.

Pawlowicz, R., Hannah, C., and Rosenberger, A.: Lagrangian observations of estuarine residence times, dispersion, and trapping in the Salish Sea, Estuarine, Coastal and Shelf Science, 225, 106246, https://doi.org/10.1016/j.ecss.2019.106246, 2019.

Peliz, A., Marchesiello, P., Dubert, J., Marta-Almeida, M., Roy, C., and Queiroga, H.: A study of crab larvae dispersal on the Western Iberian Shelf: Physical processes, Journal of Marine Systems, 68, 215–236, https://doi.org/10.1016/j.jmarsys.2006.11.007, 2007.

Pereiro, D., Souto, C., and Gago, J.: Calibration of a marine floating litter transport model, Journal of Operational Oceanography, 11, 125–133, https://doi.org/10.1080/1755876X.2018.1470892, 2018.

Schmidt, C., Krauth, T., and Wagner, S.: Correction to Export of Plastic Debris by Rivers into the Sea, Environ. Sci. Technol., 52, 927–927, https://doi.org/10.1021/acs.est.7b06377, 2018.

Shankar, V. S., Purti, N., Ramakrishnan, S., Kaviarasan, T., Satyakeerthy, T. R., and Jacob, S.: A new hotspot of macro-litter in the Rutland Island, South Andaman, India: menace from IORC, Environ Sci Pollut Res, 30, 82107–82123, https://doi.org/10.1007/s11356-023-28024-8, 2023.

Zhang, Z., Wu, H., Peng, G., Xu, P., and Li, D.: Coastal ocean dynamics reduce the export of microplastics to the open ocean, Science of The Total Environment, 713, 136634, https://doi.org/10.1016/j.scitotenv.2020.136634, 2020.