Response to discussion comments for manuscript "The Maxey-Riley-Gatignol equations for macroplastics in the North West European Shelf region"

Format:
Comments referee in black
Author's response in blue (with reference to line numbers in original version of manuscript)
Author's changes in the manuscript in red (with reference to line numbers in revised version of manuscript)

RC1: 'Comment on egusphere-2026-64', Anonymous Referee #1, 05 Mar 2026

The manuscript develops and applies a Maxey–Riley–Gatignol (MRG) formulation tailored to fully submerged buoyant macroplastics in the North-West European Shelf (NWES), implemented in Parcels and driven by Copernicus 1/36° hourly surface currents. The authors (i) derive a 2D slow-manifold form including Coriolis and non-Stokes drag, (ii) diagnose realistic particle Reynolds numbers, history-force magnitudes, and slow-manifold validity, and (iii) compare macroplastic trajectories against passive tracers for different drag regimes and temporal resolutions of the forcing. The topic is timely and relevant for both physical oceanography and marine litter modelling; the paper fits very well within Ocean Science.

Overall, I find the work potentially publishable after major revisions, mainly to (a) clarify and justify key modelling assumptions, (b) strengthen the connection to observations and practical macroplastic modelling, and (c) improve the structure and readability of the theory sections.

Major comments
Scope and physical realism of the configuration

1. Restriction to fully submerged particles and 2D surface flow

   The study considers "fully submerged buoyant macroplastics" forced only by 2D surface velocities, explicitly ignoring air–sea coupling and vertical structure. This is physically restrictive because:

   - Most macroplastics that are buoyant enough to remain near the surface will partially protrude into the air, so wind drag and wave-induced motions are non-negligible.
   - Using a single surface level (0.5 m) implicitly assumes vanishing vertical shear and no Stokes drift vertical structure, which is not true in the NWES, especially under strong winds and waves.

   The authors acknowledge windage and refer to BOM-type extensions, but in the main text the reader can easily lose track of what real macroplastic scenario is actually represented (e.g. fully submerged fishing gear vs bottles vs nets).

   Recommendation:

   - Sharpen the "physical scenario" paragraph in the Introduction: clearly state that the results apply to a very specific idealized class of fully submerged, nearly-surface macroplastics (and not to typical floating bottles or nets).
     Indeed, in our work we use an idealized model (spherical particles, no stokes drift and windage), that cannot and should not be expected to exactly reproduce the transport of actual

floating macroplastic objects. The focus on macroplastics in the introduction serves as a general motivation for why this work is needed. We tried to highlight this with the last sentence of the abstract ("This work is a first step towards including inertial effects in Lagrangian simulations of macroplastics in coastal regions with highly varying velocity fields"). Instead, the aim of this work is to systematically investigate how and whether the MRG equations differ from passive advection for (fully submerged) macro-sized objects at the surface in the coastal ocean, what forms of MRG work best, and which terms and formulations cause the largest differences. Note also that recent studies suggest that ocean currents are the biggest driver of the near-surface transport, where wind and waves are secondary effects (Medina-Rubio et al. 2026). Thus, we chose to solely focus on ocean currents in this work. In the revision, we try to make the aim and limitations of the current work more clear by rewriting the introduction in the following way:

Line 3-5: (abstract)
In this work, we tailor and test these equations, as well as their slow-manifold formulation, with non-Stokes drag to simulate fully submerged buoyant rigid spheres **representing idealized macroplastics** moving in 2D in the North West European shelf Region, where the flow is highly variable in space and time.
Line 20 – 26:
In our study, we investigate how inertia, added mass, and other effects that distinguish the motion of a rigid particle from a fluid element, affect the trajectories of **"idealized"** macroplastics. **Our idealized macroplastic particle is a buoyant rigid spherical particle that does not stick out of the surface. The aim of this work is to use these idealized particles to be able to study systematically how models can be improved based on existing theoretical frameworks of inertial rigid particles. However, the simulation of actual macroplastics would also require the effect of the shape (e.g. plastic bottles), flexibility (e.g. fishing nets), waves, and wind.**

Line 35:
The MRG equations use Newtons second law to find the velocity and position of a **rigid spherical** particle over time.

Line 46-47
As most macroplastic enters the ocean in coastal areas, we want to investigate the effect of the MRG terms on the trajectories of **idealized** macroplastics in coastal areas.

Line 52-54
First, we discuss the form of the MRG equations suitable to simulate **idealized** macroplastics in the NWES. Second, we use this form of the MRG equation to perform simulations of the **idealized** macroplastics in the NWES and investigate whether the MRG equation affect the particle trajectory compared to surface tracers.

- Add a short subsection in Discussion quantifying under what density/size combinations a macroplastic is realistically "fully submerged" while remaining in the surface model layer, and what that implies for the applicability of your results to field situations.
  As we use multiple idealized assumptions in this paper, we think it is better to discuss this in a narrative fashion in the discussion instead of finding a very specific range of almost neutrally buoyant macroplastics. To build intuition about which objects will stick out and how much, we include one specific example from BOM 2019. We think our work can serve

as basis for a complete MRG description for fully submerged buoyant macroplastic particles beyond the stokes regime. We tried to highlight the current limitation of our work this section in the discussion:

Line 515 - 522

There are two simplifications made in this work which have to be addressed before it can be applied for the simulation of actual macroplastic objects. Firstly, for objects at the surface, Stokes drift should be included. This can be done by adding this contribution to the velocity field. It is important to note that floating macroscopic objects in waves experience an enhanced Stokes drift (Calvert et al. 2024). This enhancement should be taken into account in a simulation of actual macroplastic objects. Secondly, in this work we assumed buoyant spherical particles that are at the surface but fully submerged. In reality, buoyant particles will stick out of the surface and thus will not only experience a drag force due to the ocean currents but also due to the wind as they partly stick out of the surface. A particle with B=0.68 and d=25 cm sticks out for 9.4 cm (Beron-Vera et al., 2019). Thus, a windage term has to be included for the trajectory computations of buoyant macroplastics in general.

To make a smooth connection to the next alinea, we also have rewritten that one slightly:

Line 523 - 527

~~In addition,~~The particle slip velocity will be affected by the windage, which we ignored in this study. ~~In reality, buoyant particles will not only experience a drag force due to the ocean currents but also due to the wind as they partly stick out of the surface.~~ In general, the wind and ocean currents are not aligned in a tidal region like the NWES, and thus the slip velocity of the particle with the ocean current will increase under the influence of the wind. This will lead to a higher $c_p(t)$ for the ocean drag force. Likewise, the drag force on the particle due to the wind will depend on the Re_p of the air, which will be influenced by the ocean current drag as this increases the slip velocity of the particle with the wind, increasing the air Re_p.

2. 2D slow-manifold vs full 3D Maxey–Riley in shelf seas
The analysis and simulations are 2D, using surface velocities and 2D MRG/SM-MRG equations. However, tidal and wind-driven flows in the NWES have substantial vertical shear, and the Stokes number and effective Rep can differ with depth.
In this work, we have the application to buoyant macroplastics in mind, which is why we used 2D flows. Important to note is that for macroscopic objects with a density different than water, the particles will have a significant sinking or rising velocity. For our research, we performed a simple back-of-the-envelope calculation to calculate rising velocities from the force balance between the drag force and buoyancy force (see fig below) and find that typical rising velocities are larger than 0.25 m/s (Figure 1) which is much larger than typical oceanic vertical velocities.

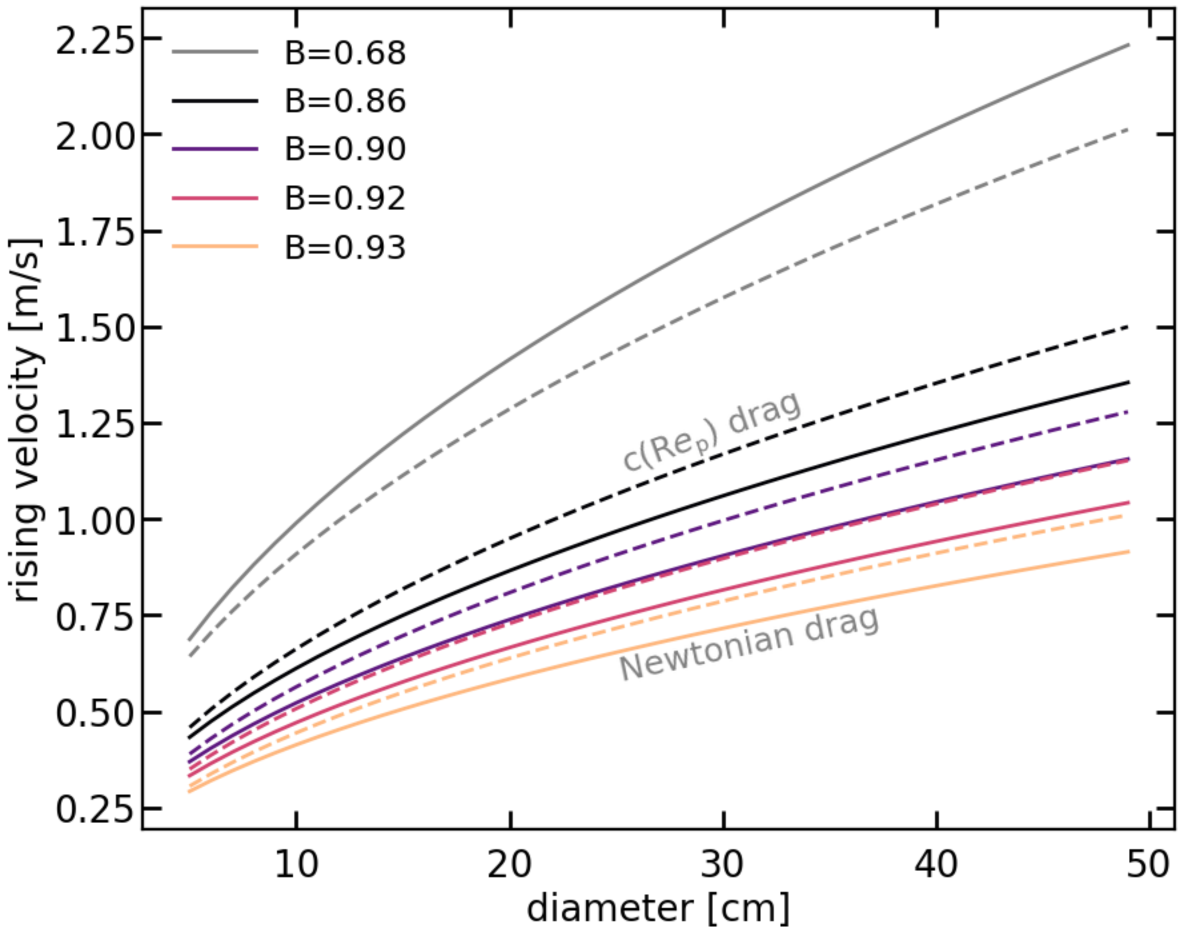


Figure 1: rising velocity for spherical particles with different buoyancies. The buoyancies used are indicated in the legend. The grey one is the value used in this work and the range shows values typical for pure polypropylene (PP) and polyethylene (PE). The solid lines show the results from Newtonian drag force and the dashed line show the rising velocities calculating using a drag force with a Reynolds number calculated from the rising velocity.

Thus, we expect that our particles will quickly rise to the surface and remain there. Note also that most microplastics enter the ocean near the surface. In the case that the particles have the same density as the water surrounding them (e.g. B=1 in the equations), a lot of the "correction" terms in MRG equations vanish and thus we expect that the particles follow the flow.

The terms associated with effect of vertical shear on the horizontal transport are not included indeed, because the vertical velocities are much smaller than the horizontal velocities at the surface. To check the size of these terms we did a small Eulerian analysis where we compared the size of $w_f \frac{du_f}{dz}$ with $u_f \frac{du_f}{dx}$ and $v_f \frac{du_f}{dy}$. We unfortunately had to perform this analysis for a slightly different region and for daily resolution. The copernicusmarine services changed the model used for the simulation of the NEWS on 1/1/2026 which means that the model data we used in our simulation can no longer be downloaded from copernicusmarine. We only have the datasets saved for horizontal currents and not the vertical currents. To work around this, we chose to use the Iberia–Biscay–Ireland (IBI) area instead (https://doi.org/10.48670/moi-00027) which was simulated with the same model as we used in our work (run by NOW/Nologin Spain). The reason to use this model instead of the new met-office model is because the vertical resolution is much higher, in the IBI model the surface layer has a thickness 1 meter while in the new NWES model the surface layer has a thickness of 3 meters. Even though this analysis is thus in 3 ways not optimal (i) daily instead of hourly data (ii) regional extend slightly different (missing Northen part) and (iii) different time window as new data can only be downloaded up to 2 years prior to now we still think it gives an estimate for the typical values.

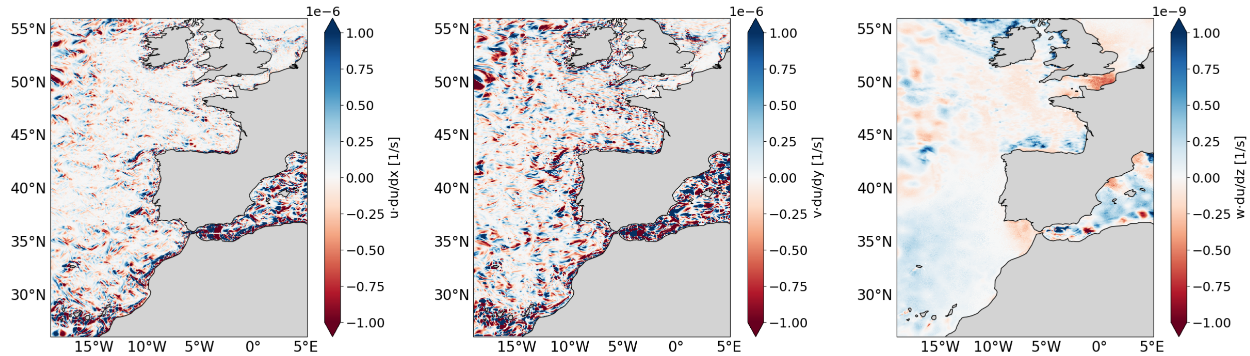


Figure 2 Magnitude of different spatial terms in the material derivative where the horizontal shear terms times the horizontal velocities are are 2 or 3 orders larger than the vertical shear term times the vertical velocity.

Recommendation:

- In the Theory or Methods, explicitly state that you approximate macroplastic motion as constrained to the surface layer, and briefly discuss how vertical shear and vertical excursions would affect the Stokes number and the balance between drag, Coriolis, and history forces.
  We made this approximation explicit by adding this text in the theory section:
  Lines 86 - 90
  These particles have a rising velocity of more than 1 m/s in a quiescent fluid and thus we use only the surface currents in this work. This means that we ignore the buoyancy force, the vertical terms associated with the Coriolis effect and the effect of vertical shear on horizontal transport. In the MRG equations the vertical shear shows up in the term $w_f \frac{du_f}{dz}$, and thus the effect of vertical shear term is much smaller than the horizontal shear term, as the first scales with the vertical fluid velocity (which is small).

Treatment and interpretation of drag and Reynolds number

3. Use and meaning of c(Rep) and cp(t)
   The paper nicely shows that Rep in the NWES is typically O(10^2–10^3), justifying non-Stokes drag and motivating the use of the White (1991) drag correction. The numerical experiments with fixed c(Re_p^In) and with time-varying cp(t) are informative, but some aspects are unclear:
   - The ensemble-average argument that c(Re_p^In)⟨Re_p^M⟩ is constant is elegant; however, it is effectively diagnostic, calibrated on the same flow used for the simulations. It would be useful to clarify that this is not a universal relationship but a practical property of the particular NWES flow statistics.
     The specific value of $r = c\left(Re_p^{In,ref}\right)\langle Re_p^{M,ref}\rangle$ is indeed a particular property of the studied area. However, the method developed here is not NWES specific. To use this for other regions, one should do a simulation to determine the region specific r. The relation in equation (31) can then be used to estimate the region-specific average Reynolds number (i.e. finding Re_p for which $Re_p = r/c(Re_p)$.
   - The physical meaning of cp(t) for a deformable, non-spherical macroplastic is questionable. The drag law and Rep used are for rigid spheres.

   Recommendation:

- Emphasize that all drag parameterizations assume spherical rigid particles and briefly discuss how non-sphericity and flexibility could alter both the effective drag law and the interpretation of Rep, perhaps referring to Sunberg et al. (2024) more explicitly.
  We now clearly state in the introduction that we consider rigid spherical particles in this work by adding
  Line 23
  Our idealized macroplastic particle is a buoyant rigid spherical particle that does not stick out of the surface.
- Where you argue that cp(t) "better captures reality" because drag should depend on the instantaneous boundary layer, clearly separate what is physically desired from what is actually supported by available drag data for macro-scale, irregular plastics.
  Indeed, the phrasing "better captures reality" might be a too strong statement. As there are - as far as we know - no measurements on the drag regime/boundary layer for macro-scale objects in sea conditions. Instead, the point is that we base the coefficient on the sea state, which clearly varies over time, so the boundary layer can vary as well. An open question indeed remains what the local boundary layer is and whether it depends on sea state, or whether it is, for example, always completely turbulent and we should instead consider Newtonian drag.
  We changed this statement by:
  Line 342 - 446
  ~~We expect that flexible drag correction factors better capture reality, as the drag force a particle experiences depends on the particle boundary layer.~~ **The flexible drag correction factor captures the idea that when a particle experiences different sea-state conditions, the particle boundary layer might change and thus the form of the drag force can also change.** The timescale of this particle boundary layer is much less than the typical oceanographic timescales, and thus the particle boundary layer changes over time resulting in a drag force regime that changes over time. **Additional observations are needed to confirm whether this happens in reality.** ~~However~~

4. Sensitivity to cp(t) and temporal resolution of forcing
   One of the most interesting results is that, for flexible cp(t), trajectories differ more from tracers when using daily-averaged currents than when using hourly currents, contrary to naïve expectations. The explanation—that coarse temporal averaging reduces velocity extremes, hence underestimates cp and drag—is plausible, but currently somewhat qualitative.

   Recommendation:

- Strengthen this point by adding a small diagnostic figure or table showing distributions of |uslip|, Rep, and cp(t) for hourly vs daily forcing, to demonstrate quantitatively that Rep is systematically lower in the daily case.
- Clarify whether this effect is robust across seasons and subregions (shelf vs slope). If not, explain where it is strongest.
  We agree with the reviewer that we can strengthen this point by showing this explicitly. As |uslip|, Re_p and cp(t) do directly depend on the slip velocities and no additional factors (such as particle size or density) are varied in this work, we only show Re_p. We plotted the measured Reynolds number per particle averaged over September 2023. We show the particles on their starting position and color them according to their measured average Reynolds number. We do this for the simulations for which we used hourly fieldsets, as well as for the simulations for which we used daily fieldsets. In addition, to show how Rep varies over time, we show the ensemble averaged measured Reynolds number as function of time. We did take tidal averages to reveal long term trends. The first day is 1 September 2023.

Interestingly, this plot reveals the strong effect of the spring-neap cycle on Rep for the hourly dataset.

We add these plots to figure 4 in the paper:

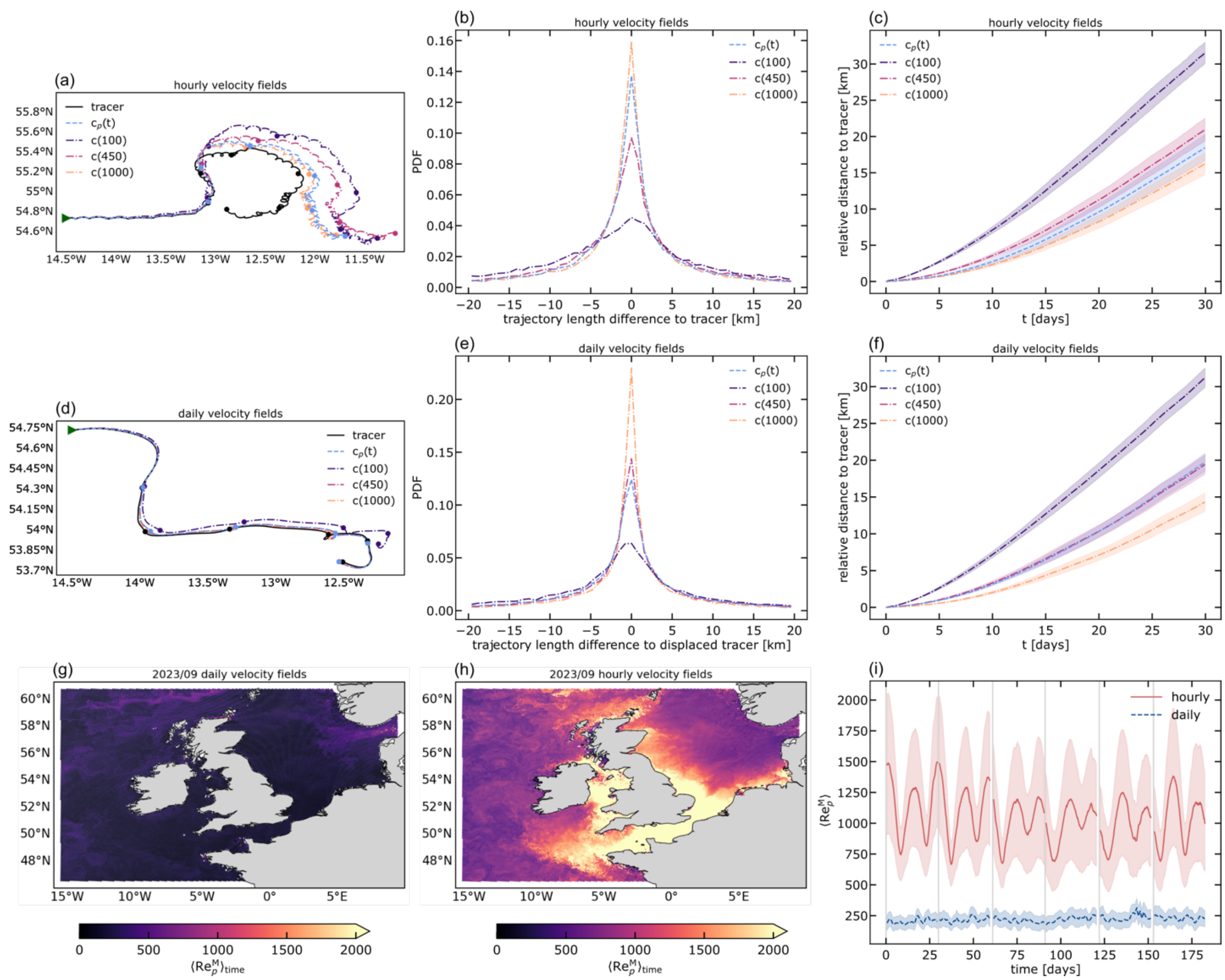


Figure 3 new version figure 4 paper

We extend the caption of figure 4

Fig 4 caption

In panels (g)-(i) we plot the measured Reynolds numbers for simulations with $c_p(t)$. In panel (g) and (h) we show the spatial distributions of the measured Reynolds number per particle averaged over September 2023 for (g) hourly and (h) daily velocity fields. The particles are shown at their starting position and colored according to their $\langle Re_p^M \rangle_{time}$ as indicated by the colorbars below the plots. In panel (i) whe show the tidal averaged $\langle Re_p^M \rangle$ over time for hourly and daily velocity fields as indicated in the legend. The grey lines indicate the start of the monthly simulations.

In addition, we extend the description in the results with

Lines 458 - 467

To visualize the effect of the temporal resolution on the simulations with flexible $c_p(t)$, we show the measured Reynolds number in Fig.4(g)-(i). In Fig.4(g) and Fig.4 (h), we show the measured particle Reynolds number per particle averaged over September 2023. The particles are shown at their starting location and colored according to their $\langle Re_p^M \rangle_{time}$. For the simulations with the hourly fieldsets, we measure much higher values of $\langle Re_p^M \rangle_{time}$. The maxima are found on the continental shelf, where the tides dominate. However, even off the shelf, we find higher values in the simulations with hourly resolutions. In Fig.4 (g), we show how $\langle Re_p^M \rangle$ varies over time for daily and hourly fieldsets, where day 0 is the 1st of September 2023. The ensemble averaged value is always much higher for the hourly fieldsets. In addition, the $\langle Re_p^M \rangle$ for the hourly resultion fieldsets has the spring-neap cycle clearly imprinted on it while this signal is not present in $\langle Re_p^M \rangle$ for the fieldsets with daily resolution.

We make the discussion align with the fact that we show the measured Reynolds number here
Line 506-507:
Without these extreme values, ~~the slip velocity a particle experiences~~ **the measured Reynolds number of the particle decreases**, and thus $c_p(t)$ is underestimated, resulting in an underestimation of the drag force.

- Explicitly state the implication for practitioners: using MRG-type models with cp(t) on temporally smoothed currents is not conservative and can bias particles toward less flow-following behaviour than in reality.
  In the discussion, we tried to highlight this in lines 495-498 (original manuscript)
  "This means that one should take care when implementing the MRG equation with flexible $c_p(t)$ as used in this paper. Even the high-resolution field used here is still averaged over 1 hour. In addition, small scale features of the flow are not resolved due to the finite spatial resolution. Thus, the variations in the velocity will be even higher in the real NWES, which most likely results in larger values for $c_p(t)$ and thus particles that are more flow-following."

  To make this statement more explicit we changed it to:
  Line: 510-513
  This means that one should take care when implementing the MRG equation with flexible $c_p(t)$ as used in this paper. Even the high-resolution field used here is still averaged over 1 hour. In addition, small scale features of the flow are not resolved due to the finite spatial resolution. Thus, the variations in the velocity will be even higher in the real NWES, **which means that the MRG equations with flexible $c_p(t)$ as used in this paper can bias particles toward less flow-following behavior than in reality**.

History force: methodology and robustness of the "negligible" conclusion

5. Two-bracket estimate (Mei/Adrian vs Basset–Oseen) and parameter range
   The manuscript uses two estimates for the history force: Mei/Adrian kernel (likely an overestimate) and Basset kernel truncated at the Oseen time (likely an underestimate). Both suggest that history accelerations are at least an order of magnitude smaller than drag and Coriolis at Rep ≥ O(10^2), leading to the conclusion that history can be neglected. This is an important result, but some aspects should be tightened:
   - The Mei/Adrian kernel is only validated for microscopic particles at Rep up to ~O(10^2), in different flow configurations, and for B > 1; here you apply it to 25 cm buoyant particles with B < 1.

- The approximation for the Oseen-truncated Basset kernel assumes slowly varying slip over t , which may break down near strong tidal accelerations.
  As the largest Oseen time is 24 seconds (95%-percentile for Rep = 1000) while tidal timescales are on the order of hours, we think this approximation is fine even in strong tidal accelerations.

Recommendation:

- Make the limitations of both approximations more explicit; clearly label the "history < drag, Coriolis by ≥1–2 orders of magnitude" as a robust order-of-magnitude inference, rather than a precise quantitative result.
  We now emphasize that this should be seen as an order-of-magnitude argument by adding:
  Line 351-352:
  To estimate the importance of the history force, we ~~measure the~~ **make an order-of-magnitude estimation based on the diagnosed** particle slip velocities in simulations.
  Line 379-380:
  To ~~quantify~~ **estimate** how important the history force is for the motion of the particle, we compared the magnitude of the acceleration due to the history force in Eq. (3) to the other terms in the equation for c(10), c(100), c(1000), and $c_p(t)$.
  Line 400-403
  Because Re_p in our case is > 100, and because **- based on our order-of-magnitude estimation -** even the Mei/Adrian history integral is at least an order of magnitude smaller than the other terms in the MRG equation for this parameter regime, we conclude that the history force only plays a secondary role in our system.

Consider showing a time series of the different acceleration contributions for a few representative particles (shelf, slope, weak-flow interior) to illustrate that history remains small across dynamical regimes.

We made a new Figure S2 (see also below); as one can see, the history force remains small everywhere.

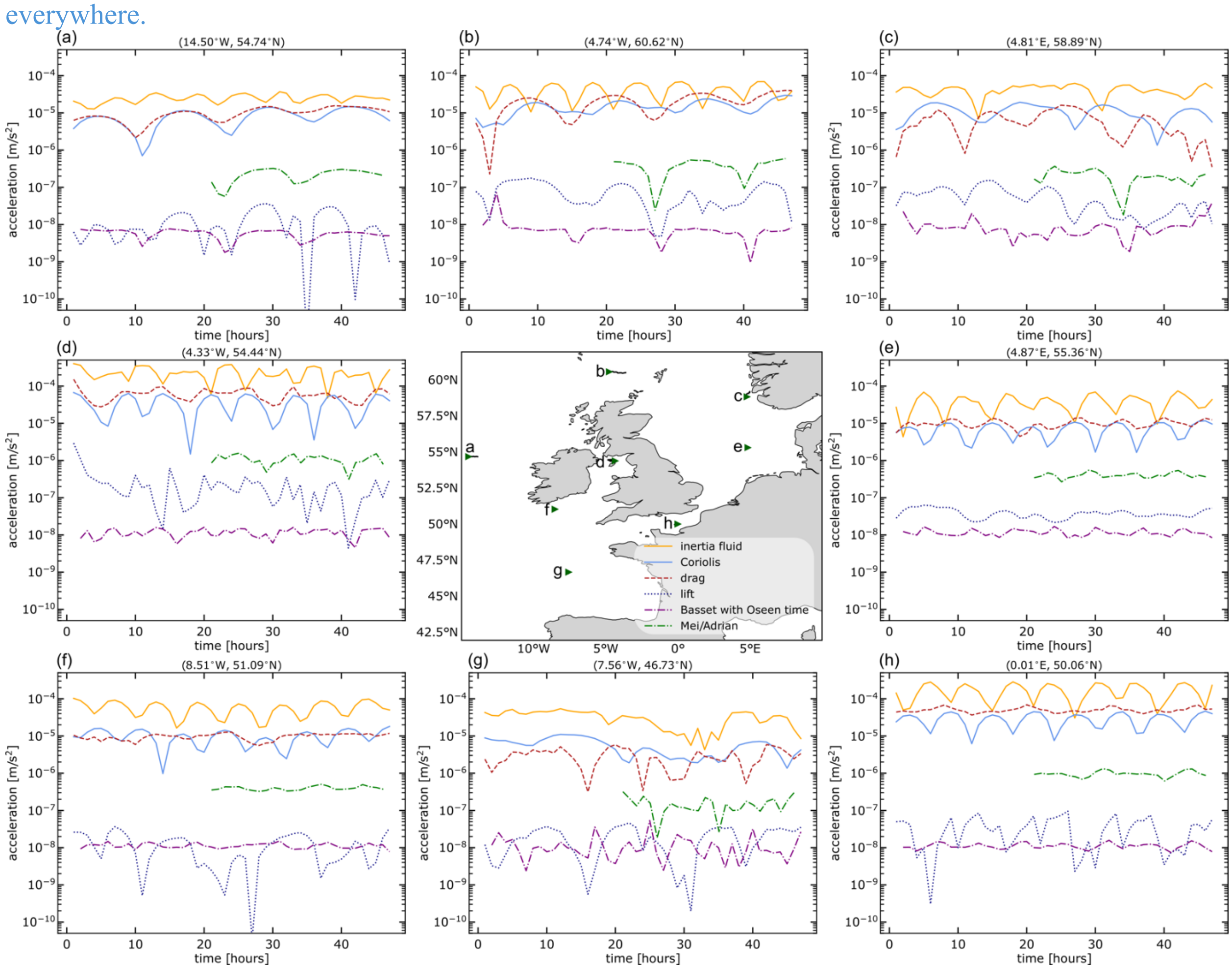


Figure 4 Si Fig 2: Acceleration of different terms in Eq. (3) as function of time for a selection of particles at different positions in the NWES for simulations with $c_p(t)$. The central panel shows the locations of the selected particles, which are labeled with the letter corresponding to their panel. The colors represent different terms as indicated in the legend in the central panel. The starting position of each particle is given on top of each panel.

And added the following reference in the main text

Line 389-391:

The history acceleration is small across different dynamical regimes. In SI Fig. S2, we show the different acceleration terms as function of time for variable $c_p(t)$ for a selection of particles in different locations in the NWES.

- It would be useful to briefly comment whether there are plausible parameter ranges in the NWES (e.g. smaller particles, different B) where history might become non- negligible.
  It is unfortunately very difficult to estimate without doing the full simulations for different particle sizes. In general, the history term becomes more important for small, light particles (as the history term for the acceleration of the particle scales with $\frac{1}{(1+2B)d}$, see Eq (3). Although the size is more important than the buoyancy, as the size term does not vanish for $B \rightarrow 0$. In addition, the Reynolds number becomes smaller as particle radius decreases, and so the Oseen time becomes larger and thus Basset history term has to be taken into account over a longer time. However, the Stokes relaxation time also decreases with decreasing particle size, causing faster relaxation towards the fluid flow making the MRG equations less

relevant for very small particles.. How these effects exactly balance would need to be investigated with simulations. We therefore cannot add a statement at this moment to the paper about this.

Slow-manifold validity and link to existing inertial-particle theory

6. Slow-manifold error and its dependence on ε and c(Rep)

   The slow-manifold reduction is justified for ε/c(Rep) ≪ 1, and the paper presents skill scores > 0.97 for MRG vs SM-MRG trajectories for c(Rep) ≥ c(100) and cp(t). This is a strong and useful result, but some connections to the theory could be clearer:

   Recommendation:

   - When discussing Fig. 3, explicitly relate the observed skill scores to the magnitude of ε and ε/c(Rep) in your NWES configuration, and connect this to Haller & Sapsis (2008) and Rypina et al. (2024) more concretely (e.g. "for ε ≈ 0.3 we still find RMS separation of only X km after 2 days").
     Trying to quantify the actual simulations with a single ε value is difficult. The ε is an estimate based on a single velocity. In the NWES, there is a large range of velocities and length scales in the flow. It is thus hard to argue which single value of ε would represent the entire system. This is why we do not rely on a ε/c(Rep) value argument here but instead use the skill score to investigate the performance of the slow-manifold. To highlight this, we edited the text in the following way (the value of epsilon slightly changed here as we choose to use the average velocity of the NWES instead and as lengthscale use the length over which a particle traveling at the average velocity would be displaced by the M2 tide)
     Line 406-408:
     ~~We find a maximum value of ε = 0.32 and a minimum value of ε/c(1000) = 0.013. However, the fluid flow can change faster than the timescale given by L/U .~~
     For the average velocity of 0.25 m/s, we find a value of ε/c(0)=0.29, which reduces to ε/c(1000)=0.011. However, there is a wide range of fluid flows and lengthscales in the NWES, which can change faster than the timescale given by L/U.
   - It would help to mention whether the remaining ~1–3% mismatch between MRG and SM-MRG trajectories is dominated by particular regions (e.g. strong tidal fronts) or times (spring-neap transitions).
     It is not possible to give one simple answer to this, and thus we cannot add a simple statement about this in the manuscript. For these short simulations, the mismatch is dominated by specific locations in space as can be seen by fig 3(a) where the separation distance smoothly increases over time. In addition, we found that the skill score converged over time. Which regions in the remaining 1-3% mismatch depends on the drag correction factor used. In Figure 5 (below), we show the skill score per particle after 48 hours for a selection of drag correction factors used. Per drag correction value, there are spatial patterns present but these vary between the different drag correction factors. As there are clearly different drivers for

different drag correction factors it is not possible to add a conclusive statement on this in the manuscript.

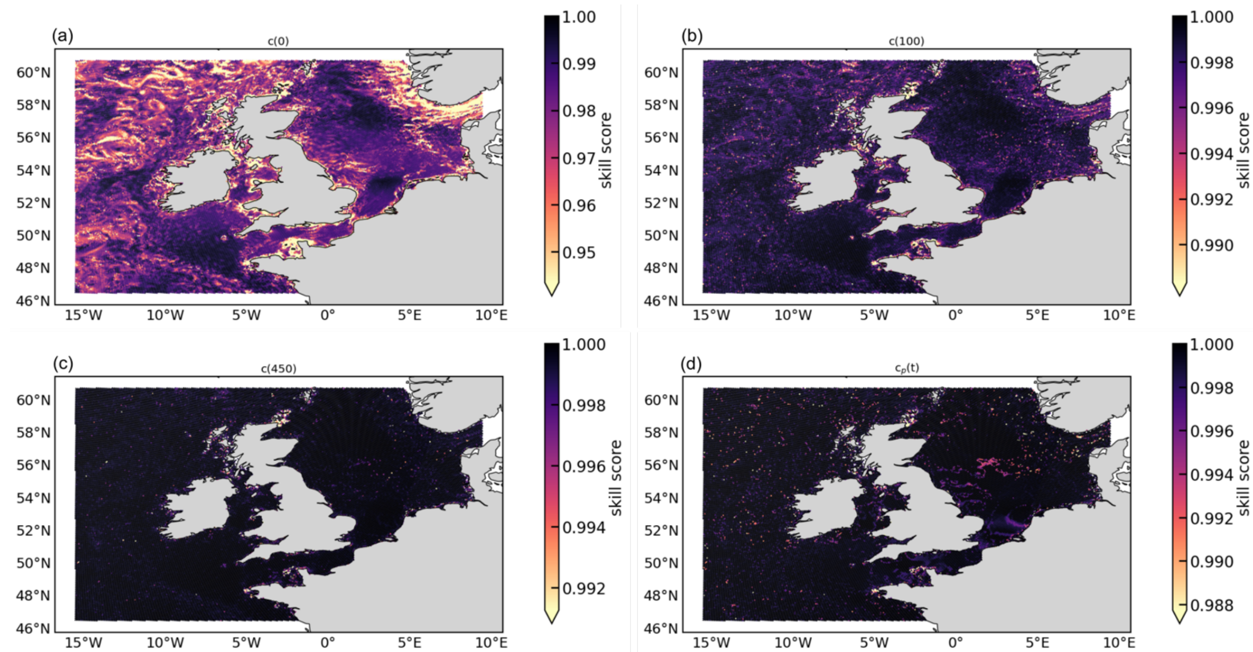
- 

*Figure 5 Skill score value per particle after 48 hours as indicated by the colorbar. The colorbar ranges between 1-2*STD and 1 for each plot. The different panels show a selection of the different drag coefficients used (a) c(0), (b) c(100), (c) c(450) and (d) flexible $c_p(t)$.*

Connection to observations and macroplastic applications

7. Lack of observational or empirical constraints
   The paper is purely modelling/theoretical, which is acceptable, but the Introduction and Discussion emphasise macroplastics and cleanup strategies. Currently there is no attempt to link the diagnosed macroplastic behaviour (e.g. Rep, slip velocities, dominance of Coriolis forcing) to observed macroplastic distributions, drifter data, or beaching statistics in the NWES.
   The scope of our manuscript is indeed purely modelling/theoretical. However, we want to emphasize the applications to plastic in the introduction and discussion to make people aware that one should take care in using the MRG for simulating macroplastics or other macroscopic objects in the ocean.
   Recommendation:
   - Add at least a qualitative discussion comparing your simulated drift characteristics (e.g. typical slip speeds, length scales, timescales) to those of MetOcean Stokes drifters or other macro-scale drifters in the NWES, which you already use for parameter choices.
     We show in the paper that the difference between tracer particles and our idealized macroplastics simulated with the MRG equations is very small due to the Reynolds number. Thus, comparing our simulated trajectories to observations will not add anything extra with respect to comparing surface tracer particles to observations. Therefore, we think that an additional comparison with observational characteristics (given the fact that we ignore wind and waves) would not add to this work.
   - If possible, mention what kind of observational datasets (e.g. drifters, camera-based macroplastic tracking, beach litter time series) could be used in future work to test the predicted near-tracer behaviour and the relative importance of Coriolis vs gradient forcing.

We find that the difference between tracer particles and MRG particles is very small if one takes into account the higher Reynolds number regime. Thus, we do not expect that one can observe MRG effects in any of the observables. We therefore end the conclusion with the recommendation to not use the MRG equations for macroplastics but instead use a leeway-type model: line 505-509 in original manuscript: "We thus expect that in reality the drag correction factor is even larger than found in the simulations with hourly velocity fields, and thus the particle trajectory will be completely dominated by the drag forces of the wind and ocean currents (including Stokes drift). Hence, instead of using the flexible cp(t) SM-MRG equation, we think an adjusted leeway-type formulation would be most suited to simulate macroplastics in the NWES. If one wants to use the MRG equations there should be a measurement of the state of the boundary layer around the particle for the different sea states.

Specific / technical comments

Below are more detailed comments that may be useful when revising.

1. Abstract

i. The abstract is clear but quite dense for a non-specialist; consider adding one sentence explicitly summarising the main methodological advance ("we derive and test a slow-manifold MRG formulation with non-Stokes drag for macroplastics in a realistic shelf-sea flow").
We wanted to be careful with the claim that we derived the equation, as all elements used here are already derived and/or used in earlier work. The main advantage here is that we combine developments made in separate works. This is why we prefer to use the word "tailor" in line 3. We made the main methodological advance explicit as you suggested adding this in the abstract.
Line 3 -5
In this work, we tailor and test these equations, as well as their slow-manifold formulation, with non-Stokes drag to simulate fully submerged buoyant rigid spheres representing idealized macroplastics moving in 2D in the North West European shelf Region, where the flow is highly variable in space and time.

ii. It may be worth specifying in the abstract that the particles are fully submerged and that wind effects are not accounted for.
We tried to emphasize this indeed by using "fully submerged macroplastics" in line 4

2. Section 2.1, Eq. (1)

i. You state that Faxén corrections are ignored because gradients are on scales much larger than the macroplastics. It would help to quantify this: e.g., typical horizontal shear scale L ≫ d = 0.25 m, so Faxén terms are smaller than X.
As we have a model with 1 km resolution, the minimum length-scale of the horizontal scale is 1km which is much larger than the particle diameter. We made this more explicit in the text by adding:
Line 74 - 75
In this work, the minimum lengthscale of the gradient of the flow is 1 km while we consider particles with a diameter of 25 cm.

Clarify whether you entirely ignore vertical components of Coriolis and flow, or only project onto the horizontal plane. We entirely ignore it. We did clarify this by adding
Line 87 - 90:
These particles have a rising velocity of more than 1 m/s in a quiescent fluid and thus we use only the surface currents in this work. This means that we ignore the buoyancy force, the vertical terms associated with the Coriolis effects and the effect of vertical shear on horizontal transport.

In the MRG equations the vertical shear shows up in the term $w_f \frac{du_f}{dz}$, and thus the effect of vertical shear term is much smaller than the horizontal shear term, as the first scales with the vertical fluid velocity (which is small).

ii.

3. Section 2.2 (Drag force)

i. White (1991) drag law is used up to Rep < 10^5. Your Rep values reach ~O(10^3); that's fine, but it may be helpful to mention any known deviations for rough or deformable objects in this range.

As far as we are aware, there is no clear study on drag coefficient for deformable objects such as ghost-fishing nets. There is work on the drag coefficient of bubbles but that is not relevant to macroplastics. There is work on the drag experienced by fishing nets (e.g. Tang et al 2018), but these are attached to a frame and cannot reshape themselves. We thus cannot make any statements at this point on deviations for deformable plastic objects. We added the following information on the effect of non-spherical shapes and surface roughness:

Lines 111-120

Real macroplastic objects can be non-spherical and non-smooth. These factors affect the functional form of the drag correction factor used. For non-spherical particles, rescaling factors that depend on the shape of the particle can be used to map the drag correction factor to the correction factor of spherical particles (Ganser, 1993; Condo-Colcha et al., 2026). Important to note is that these relations are based on setting particles, where the particles orient their largest-cross sectional area perpendicular to the direction of motion. The orientation of floating objects is strongly affected by the presence of the fluid-air interface and thus for floating non-spherical objects these relations have to be adjusted to account for this effect. Increased surface roughness affects the drag coefficient at higher Reynolds numbers. The transition towards a fully turbulent regime shift to lower Reynolds numbers for particles with a rough surface and the drag coefficient in the turbulent regime depends on the surface roughness. However, for not-fully turbulent regimes considered in this work surface roughness does not significantly affect the drag correction factor (Achenbach, 1974).

ii. When you estimate Rep ≈ 867 from the geostrophic balance example, you rely on U = 1 m s^{-1}; please justify that this is representative of strong tidal currents in your NWES product.

This number is indeed a quite ad-hoc order of magnitude estimate. To have a clearer motivation for the choice of U, we changed it to the average speed in the NWES for the period between 1 September 2023 and 1 March 2024 which is 0.25 m/s. This gives a Reynold number estimate of 399. We adjusted the text in the following way

Lines 127 - 130

~~If use a typical tidal flow velocity of 1 m/s~~ **If we use the typical surface flow velocity averaged over the NWES domain and simulation period considered in this work (U=0.25 m/s),** we can numerically solve this equation for Re_p For this value of U we find $Re_p = 399$ which corresponds to a drag correction factor of c(399)=12.4, which is clearly outside the Stokes regime.

We also changed this value when calculating epsilon to be consistent throughout the manuscript. For the lenghtscale we keep the L=U*T_{M2} /4 with T_{M2} the tidal period. This changes the value of ε to 0.29 and ε/c(1000) = 0.011.

Lines 218 - 220

For d=25 cm, **U = 0.25 m/s** and **L=2.8 km (displacement by the M2-tide of a particle traveling with the mean velocity)** we find ε=0.29<1

Lines 406 - 408

For the **average velocity of 0.25 m/s** we find a **value ε/c(0) =0.29**, and this reduces to **ε/c(1000) = 0.011**. However, in the NWES there is a wide range of fluid flows and lengthscales present which can change faster than the timescale given by L/U.

4. Section 2.3 (History force)

i. When introducing t_d, t_O, and t_Mei/Adrian, the discussion is quite long; consider adding a small schematic/table summarizing the timescales for d = 0.25 m and d = 0.025 m to make the scaling argument more transparent.
we added a table with the values and changed the text.

diameter	t_d	t_O	$t_{Mei/Adrian}$
2.5 cm	$5 \cdot 10^2$ s	40 s	60 s
25 cm	$5 \cdot 10^4$ s	0.3 s	$9 \cdot 10^2$ s

Table 1 Diffusion, Oseen and Mei/Adrian timescale associated with the history term for a particle with a diameter of 2.5 cm and a particle with a diameter of 25 cm.

Lines 183 - 185

~~If we compare the diffusion time, Oseen time and the cross-over time for a particles of d=25 cm with Re_p and u_{slip} as found using geostatic balance (Eqs.~\eqref{eq:u_slip_steady_state} and \eqref{eq:v_slip_steady_state}), we find that there is a difference of multiple orders of magnitude between the timescales: t_d=5 10^4 s, $t_{Mei/Adrian}$ = 5 10^2 s and t_O =6 10^{-2} s.~~

In Tab. 1, we show the diffusion time, Oseen time, and the cross-over time for two different particle sizes using the geostatic balance (Eqs. (7) and (8)) with the average surface velocity of the NWES to determine the slip velocity and particle Reynolds number. For macroscopic particles we find that there is a difference of multiple orders of magnitude between the timescales.

Note that we again changed U from 1 m/s to 0.25 m/s and thus the values also change. In addition, we found a mistake in calculation of the diffusion time for the small particle, which is now corrected (500 s instead of 13 s)

ii. Clarify whether you include the f × (u_f − u_p) term inside the history integral in the numerical evaluation or whether it is approximated separately; this could matter for fast inertial oscillations.
We include this term inside the history integral in the numerical evaluation.

5. Section 3.1–3.2 (Numerical integration)

i. The modified RK4 scheme for second-order ODEs is correct but slightly heavy to read. Consider moving the full algorithm derivation to an Appendix and keeping only a short description in the main text.
We see this point and moved the description of the adjusted RK4 integration scheme and finite differences to the SI and adjusted the text accordingly

Line 257 - 264

We use the same scheme for advecting the plastic particles with the SM-MRG equation, for which we wrote a custom Parcels kernel. We solve the full MRG equations using a RK4 scheme adjusted for 2nd order differential equation (Gould et al., 2007), which we describe in detail in SI Sec. 1.1. To calculate the material derivative of the fluid field at the location of the particle, we use finite differences in both space and time as described in SI Sec. 1.2.

The numerical integration timestep was set such that the particle samples the velocity grid accurately and the MRG equations are numerically stable. This resulted in a timestep of dt=10 s for advection with the MRG equations and a timestep of dt=5 min for advection with the SM-MRG equation.

And added the extended description to the SI

6. Boundary treatment and coastal interactions

i. Particles within one grid cell of the coast are displaced normal to the coast by 1 m s^{-1}·dt. This is a strong and somewhat ad hoc rule that can impact trajectories near shore where macroplastics accumulate and beach.

ii. Please discuss how sensitive your results are to this displacement magnitude and whether it can artificially affect Rep and cp(t) estimates near the coast.
Thank you for pointing this out. Upon closer investigation, the displacement artificially affects the Rep and thus cp(t) value near the coast at the moment the particle is moved (making the Rep value spike). We decided to change the boundary condition. We now delete particles from the simulation if they almost beach. This almost beaching is defined as when a particle comes within < 0.1 Δx from the coast, where Δx is the grid spacing. As a result, the mean Rep measured value changes from 512 to 509. We adjusted the information about the boundary condition
Lines 271 - 273
To exclude the effect of stuck particles at the coast, we deleted particles from the simulation when they come closer than 0.1 grid cell from land.

7. Metrics for trajectory comparison

i. The choice of trajectory length difference, relative distance, and skill score is appropriate. It might help to give a short physical interpretation of typical values (e.g. ⟨D⟩ = 30 km after 30 days corresponds to ~1 km/day separation).
We see the point, however as the separation is not linear in time the 1km/day is not the best statement. We hope that by showing it over time it gives some feeling that the increase is very slow.

ii. In the skill score definition, you only show the case α vs β symmetrically; clarify which type is used as "reference" in your figures (tracer vs MRG vs SM-MRG).
The MRG is always used as reference, we clarified this in the text
Line 309
In this definition type α is the reference particle, *i.e.* the skill score it normalized by the trajectory length of type α particles.
caption fig 3
The MRG particles are used as refence particles (type α).
Line 416 - 417
To quantify whether the trajectories of the MRG particles and SM-MRG particles are significantly different, we use the skill score as introduced in Eq.19, where we use the MRG particles as reference (type α).

8. **Figures**

i. Fig. 1: In panel (a), consider plotting the full range including c(0)=1 point and then using an inset to zoom the region of interest; currently the omission may confuse readers.
We adjusted the panel to also show the c(0)=1 point. The inset is not needed.

ii. Fig. 2: PDFs of accelerations use log axes and multiple colours; the legend is dense. Consider splitting into two panels or adding small insets focusing on the history-force distributions to highlight the relative magnitudes more clearly.
It is indeed a dense figure. It is not about the absolute value of the different terms but rather about their relative magnitude. Splitting the different terms over different panels/insets would make it more difficult to directly compare the magnitude of the different terms, thus we decided to keep all lines together in one figure.

iii. Figs. 4–5: The example trajectories are helpful. You might add markers at 5-day intervals to indicate how phase differences accumulate over time.
Yes that we can do. We added markers every 5 days in fig 4(a), (d) and 5(a).

9. **Discussion and conclusions**

i. The Discussion section is thoughtful and touches on many relevant points, but it is long and could be more sharply structured (e.g. subsections "Implications for macroplastic modelling", "Limitations of our approach", "Future extensions").

ii. The final recommendation that a modified leeway-type formulation may ultimately be more appropriate than fully fledged MRG for macroplastics in the NWES is very important; you might want to state this more prominently and earlier in the Discussion, as it is a key "take-home message" for applied users.
We added subsections, indeed the final recommendation is one of the main points we like to highlight, we think that ending the paper with this statement highlights its importance. We hope that this is clearer now it has its own subsection. Subsections added:
Line 499:
Limitations of the flexible drag correction factor
Line 514:
Extensions of the model
Line 528
Implications of the large drag forces for macroplastic modeling

10. **Code availability and reproducibility**

i. Code is made available via GitHub, which is excellent. Please ensure that the repository includes:
   a. A configuration file or notebook reproducing the main experiments (including cp(t) vs fixed c(Rep) cases).
   b. Scripts for computing the history-force diagnostics and skill scores, not only the forward advection.

We now cleaned up the GitHub repository, where the history force and skill scores are included and the readme file clearly indicates what can be found where.

Recommendation

I recommend major revision. The manuscript is scientifically sound and potentially impactful, but the presentation and interpretation of key assumptions (drag law, fully submerged 2D particles, history force approximations, cp(t) sensitivity to temporal resolution) need to be clarified and more clearly framed in terms of applicability to real macroplastics in the NWES. Addressing the points above will significantly improve the paper's robustness, clarity, and usefulness both for inertial-particle theorists and for practitioners modelling marine macroplastics.

We thank the reviewer for these kind words. Additionally, we added 2 references we did not see when writing the original manuscript but think are relevant to this work:

Line 103 - 105:

Here, we approximate the drag force in the transient regime by introducing a drag correction factor to the Stokes drag, similar to the work of DiBenedetto et al. (2022) and Davidson et al.(2023).

References:

Tang H, Xu L, Hu F (2018) Hydrodynamic characteristics of knotted and knotless purse seine netting panels as determined in a flume tank. PLOS ONE 13(2): e0192206. https://doi.org/10.1371/journal.pone.0192206

Medina-Rubio, J., Nussbaum, M., van den Bremer, T. S., and van Sebille, E.: Using surface drifters to characterise near-surface ocean dynamics in the southern North Sea: a data-driven approach, Ocean Sci., 22, 49–74, https://doi.org/10.5194/os-22-49-2026, 2026 .