Responses to reviewer #2

The manuscript presents a modeling study of the vertical distribution and trajectory of microplastics at three oceanic regions characterized by contrasted biological and physical properties. The study builds on the work in Lobelle et al. (2021), including improved parameterizations for vertical mixing and biofilm loss terms. The study is a good contribution to gain insight into the mechanisms driving the vertical transport of microplastics in the ocean. The manuscript is well written, with a clear structure. Therefore, I support the publication of this work.

We would like to thank reviewer #2 for their time. Their expert feedback has been very useful in order to improve our manuscript. We have responded to the minor comments below individually.

Some minor comments are given below:

The study is based on several model parameterizations and assumptions. The most important assumptions are discussed in Section 3.4 together with future potential developments. This section is quite pertinent, however, the model performance strongly depends on the calibration of a large number of parameters, a fact that may be further discussed or clarified :

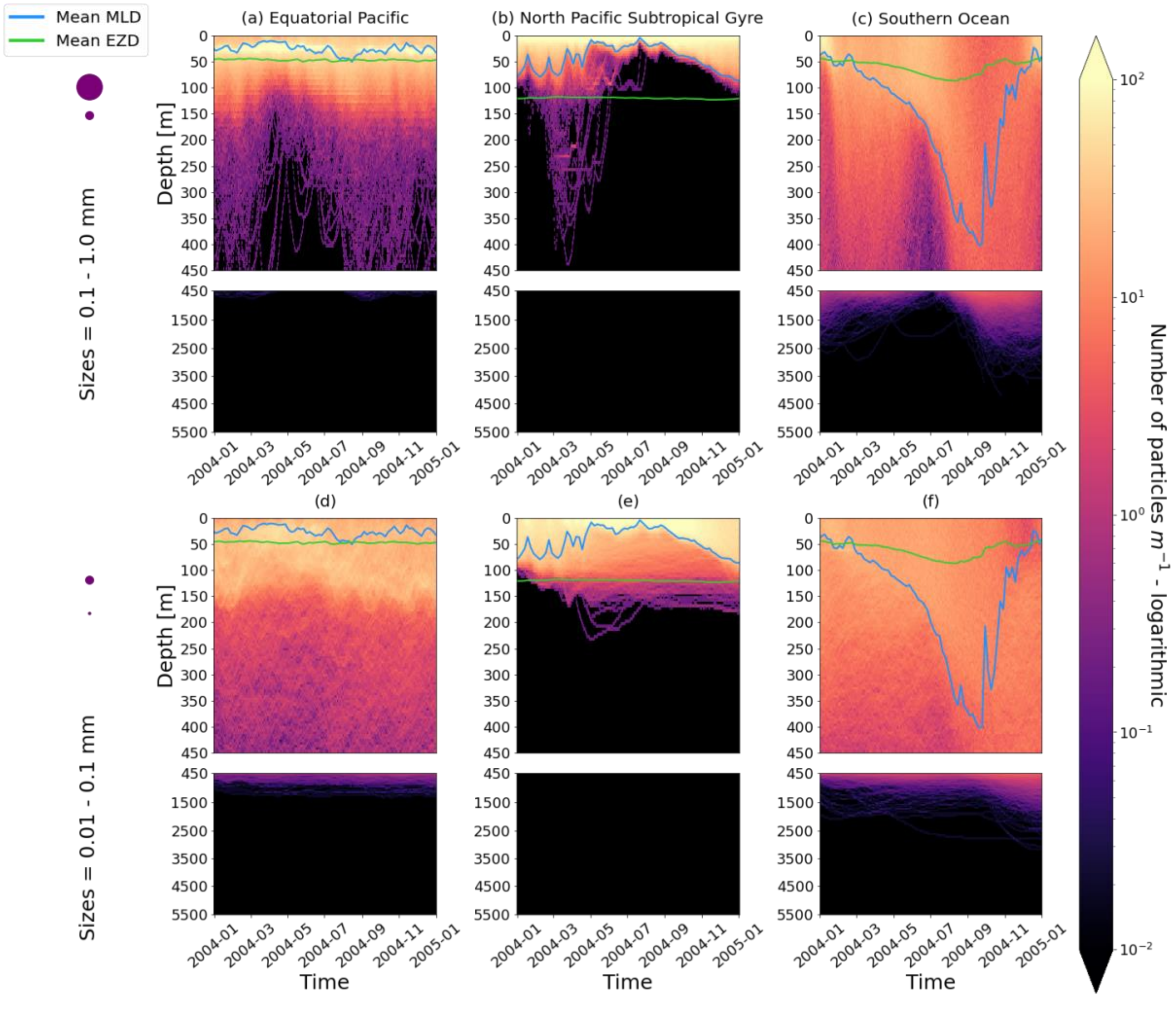
- **Parameters of mixing formulation: e.g. roughness scale, wave age, etc.**
- **Parameters of biofouling formulations: e.g. collision rate, growth rate, etc**
- **Would the combined use of a different plastic density and biofilm density change the results?**
- **How is the calibration/validation of NEMO-MEDUSA? Is it sensible to different parameterizations as well?**

We thank the reviewer for this comment. It is true that our model includes many parameters and though some have been tested for sensitivity purposes, it is almost impossible to test the full combination of a range of values for each parameter. Furthermore, most of the parameters are chosen following previous studies (either based on observations or models), which are referenced throughout the Methods section. We also ran some initial tests (not shown) to isolate the specific terms that showed a small effect on the results (e.g. plastic and biofilm density, in Appendix Figures B1 to D1). Finally, since this is a *process* study, we do not aim to get each parameter exactly right (since that is in fact impossible without validation through observations); we have therefore focused on defining the dependencies between terms and simulating the processes that dominate a particle's movement in the ocean over time and the vertical space.

To focus on the first bullet point, the roughness scale is based on Zhao et al. 2019 (and they state that the roughness scale is quite small at sea, where it mostly affects Kz at the surface, and then the rest of the profile is dominated by other terms). For the wave age, we have added the following specification: L153 "*Assuming a constant wave age for a fully developed wave state…*"

Parameters such as collision rate did not affect the results in our initial tests, however since we do not show these results, we agree that mentioning the need for further sensitivity analyses is appropriate in Section 3.4: L423-425 "*Lastly, further sensitivity analyses can be carried out regarding the collision rate, growth rate and other parameters that the model performance relies on, since analysing the full combination of all ranges of parameters was beyond the scope of this study.*"

Furthermore, we have added a supplementary figure (Fig. C2; see below) using a different plastic density (closer to the density of seawater; 1020 kg/m3 - representing rigid polyamide). The following has been added: L116-120 "*For the 1020 kg/m^3 simulations in the NPSG (Fig. C2b and e), the majority of the larger particles mix completely to the base of the MLD (as opposed to 920 kg/m^3 particles mostly staying close to the sea surface). The smaller 1020 kg/m^3 particles on average resurface slower after being mixed down to 200 m in spring (as opposed to 920 kg/m^3 particles that quickly resurface). Particles representing other sizes in other regions with a density of 30 and 1020 kg/m^3 produce very similar results to the 920 kg/m^3 particles.*" By simulating these three particle densities, the full range of floating ocean plastic is represented in our study.



Regarding the biofilm density, we have used 2 densities that are ‘realistic’ seeing as the one is based on the original Kooi et al. (2017) model (1388 kg/m3) and the other on observations (1170 kg/m3) by Amaral-Zettler et al. (2020). Any other densities have not been suggested in the literature.

Finally, regarding the validation of NEMO-MEDUSA, the global scale performance of the model has been evaluated in Yool et al. (2013) and Yool et al. (2021). While these comprehensive evaluations have taken place at low resolution, its performance at high resolution is traceable and very similar, although somewhat improved. Yool et al. (2015) includes a more limited evaluation at both low and high resolution. We have amended the manuscript to note these evaluations: L131-133 “*The biogeochemical performance of NEMO-MEDUSA has previously been extensively validated at low resolution in the studies of Yool et al. (2013) and Yool et al. (2021), with traceability at higher resolution demonstrated in Yool et al. (2015).* ”

Kooi’s model seems to depend on water physical parameters such as temperature, salinity, viscosity. Did this work consider the seasonal and spatial variability of these parameters or are they just affecting the biofouling parameters in NEMO-MEDUSA? If so, how do they affect the spatial differences of the vertical distribution of particles between the three regions?

Yes, the biofouling model in this work is dependent on physical seawater properties and includes their variability in time and space as provided by the NEMO-MEDUSA output. This is now described slightly clearer in Section 2.3 and 2.4: L180-181“*rho_{sw} is the ambient seawater density [kg/m3] derived from NEMO-MEDUSA's temperature and salinity fields that vary in 3D time and space*”. And L234-235 “*where T is the MEDUSA temperature field [C] that varies in 3D time and space (see Fig. F1 for the graphical relationship of the respiration rate and seawater temperature).*”

We have made the impact of this dependency slightly clearer at the beginning of Section 3.4 (Model assumptions and future model developments), for example, with the following sentences: L391-393 “*... the model relies strongly on the assumption that biofilm respiration depends only on temperature. After a particle is biofouled and sinks, continued respiration is the main mechanism for defouling, which in turn leads to the oscillation of the microplastic. Such behaviour is still theoretical and has never been experimentally observed.*” Furthermore, the length of oscillations are dependent on the temperature of water because respiration generally is the dominant term below the MLD (Fig. 5). This has also been added in the text: L385-387 “*It should also be noted that since respiration is the dominant process below the MLD in general, and respiration is dependent on temperature (Eq. 8), the oscillatory behaviour of particles is dependent on the surrounding water temperature (Appendix F).*”

The vertical velocity of the particle (w_s) is dependent on the surrounding seawater density, where the regionally averaged MLD is an indication of the stratification of the water. This has been made clearer in the text as follows: L275-278 “*In general, in regions with more mixing (and less stratification), a particle that is moving vertically will be less affected by sudden changes in density and can sink deeper (for example, in the SO), whereas in regions with less mixing (more stratification), the opposite occurs and particles tend to sink to shallower depths (for example, in the NPSG)*”.

Unless I am mistaken, the discussion of results from Appendix D is quite light. Given that the oscillatory behavior of microplastics has not been observed yet, it may be interesting to elaborate on this scenario that may also represent a "realistic" situation.

We agree with the reviewer that the results from Appendix D are limited. We must mention that although this could seem like a more ‘realistic’ scenario, without any observations regarding what happens to biofilms below the EZD, this is just one potential model. We do not wish to focus too much on this model since we are simply presenting one alternative (or adaptation) to the Kooi model and further work should be done to expand and test it further.

We have added a sentence, however, to introduce the model in the Methods firstly: L242-244 “*These biofilm gain and loss terms result in an oscillatory behaviour of the particles due to the biofilm’s gain causing an increase in overall density and sinking followed by the biofilm’s loss and decrease in density which leads to rising. We also propose an alternative scenario where biofilm cells remain attached in the dark (see full description in Appendix D).*”

We have also added a sentence in the Results section: L321-324 “*Across all regions, the sensitivity analysis simulating the denser algal cell wall that remains attached after the biofilm is dead shows that oscillations still occur (Fig. D1). For the smaller size class, particles can reach deeper depths and longer oscillations, however the larger size class remains unchanged. Since this phenomenon has never been experimentally observed, we suggest one alternative approach for the biofilm dynamics.”*

Line 25: A new study published in Science (Weiss et al., 2021) reformulates the calculation of plastic fluxes and shows that there may not be this huge amount of “missing plastic”. Weiss, L., Ludwig, W., Heussner, S., Canals, M., Ghiglione, J.F., Estournel, C., Constant, M., Kerhervé, P. (2021). The missing ocean plastic sink: Gone with the rivers, Science, 373 (6550), 107-111

It is true Weiss et al. (2021) suggest that the Jambeck et al. (2015) study overestimates the amount of plastic entering the oceans. However, regardless of the plastic influx into the oceans, the simulations in Onink et al. (2021) would still produce the same results regarding the fraction that ends up on beaches or coastal waters. We have included this in the introduction as follows: L28-L30 “*Although a recent study by Weiss et al. (2021) suggests that Jambeck et al. (2015) overestimates plastic fluxes from rivers to oceans by two to three orders of magnitude, this would not affect the fraction of the total that ends up close to the coasts from Onink et al. (2021), for example. Following these approximations, around 20-30 % of ocean plastic debris is unaccounted for and could either be in the water column or on the seafloor.*”

References

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