ESA Discovery and Preparation – OSIP
Campaign on Remote Sensing of Plastic Marine Litter

Marine Litter Aggregation Forecast

Executive Summary Report

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Deep Blue Globe

Introduction

MARINE LITTER AGGREGATION FORECAST presents a new estimation of long-term global distribution of marine litter proceeding from land-based and from sea-based sources. Three studies are currently considered as a reference for floating marine litter global distribution. Maximenko et al (2012)[1]. applied a statistical model to adapt drifter trajectories from the Global Drifter Program and build a stationary matrix of probabilities of a drifter to move between adjacent cells of a ½º by ½º virtual grid covering the world ocean. This matrix was then used to simulate the expected transport of marine debris for 10 years, considering an initial uniform spatial distribution. Van Sebille et al (2012)[2]. developed a similar method, using the same drifter database, but considering a seasonal transit probability matrix and an initial marine litter distribution along the coasts scaled to local population density. Lebreton et al (2012)[3]. used a different approach based on the modelling of marine debris with a Lagrangian numerical model. The authors considered a detailed distribution of initial marine litter sources including main rivers, coastal cities and commercial shipping routes. As environmental forcings of the Lagrangian simulation the authors used a 6-year surface currents series from the global numerical HYCOM reanalysis looped 5 times for a total simulation period of 30 years. Results from the three studies (Figure 1) present variations, considering the differences in the adopted approaches. However, they found a common trend of marine litter accumulating in macro areas corresponding approximatively with the five subtropical ocean gyres, where converging currents seem to aggregate marine litter on the long run.

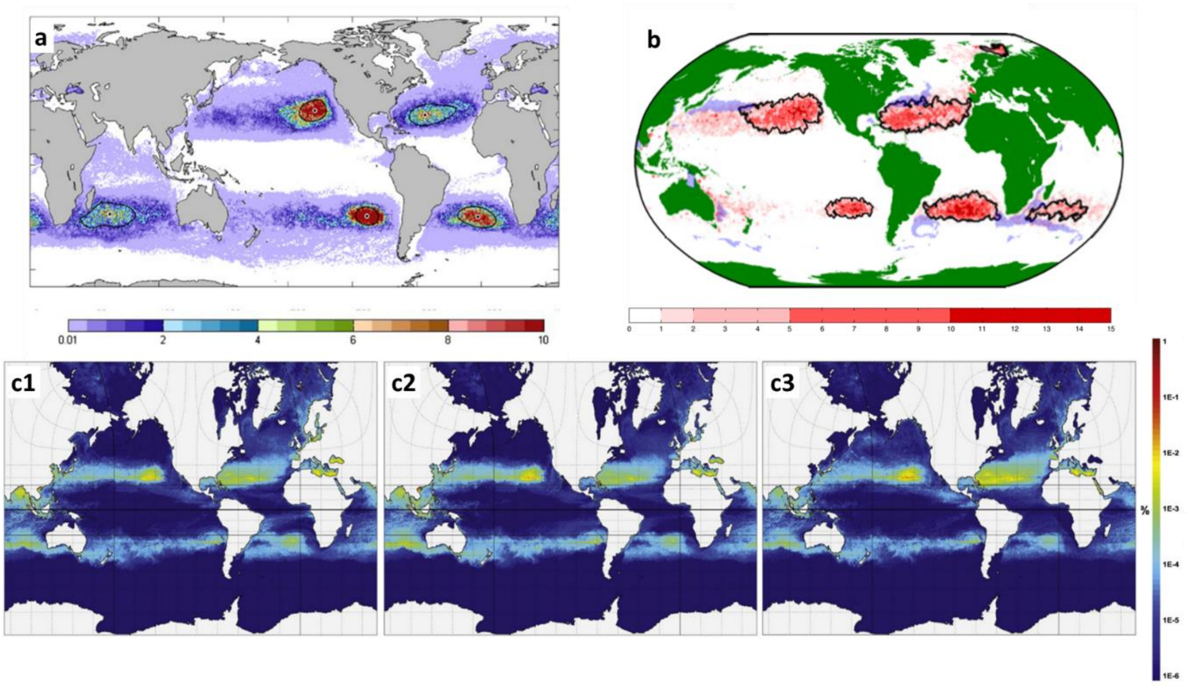

Figure 1. Floating marine litter global distribution from Maximenko et al. (2012) (a), Van Sebille et al. (2012) (b) and Lebreton et al. (2012) (c1: input from rivers; c2: input from coastal population; c3: input from shipping routes) (Adapted from Maximenko et al. (2012), Van Sebille et al. (2012), Lebreton et al. (2012)).

[1] Maximenko, N., Hafner, J., & Niiler, P. (2012). Pathways of marine debris derived from trajectories of Lagrangian drifters. Marine pollution bulletin, 65(1-3), 51-62.
[2] Van Sebille, E., England, M. H., & Froyland, G. (2012). Origin, dynamics and evolution of ocean garbage patches from observed surface drifters. Environmental Research Letters, 7(4), 044040.
[3] Lebreton, L. M., Greer, S. D., & Borrero, J. C. (2012). Numerical modelling of floating debris in the world's oceans. Marine pollution bulletin, 64(3), 653-661.

Methodology workflow

Figure 2 shows a graphical scheme of the overall methodology of the project. As shown in the figure, the methodology is made up by two different though linked parts. The first part focuses on an AI model to produce realistic long-term series of met-ocean conditions. These met-ocean series is then used as an input of the second component of the methodology. This second part represents a common Lagrangian framework for the study of the drift of any floating drifting object in the ocean, such as an oil spill, marine litter, or even for search-and-rescue of humans or ships. Given an initial distribution of worldwide marine litter sources, a Lagrangian model is used to simulate the long-term floating marine debris distribution under the effects of the met-ocean driver series previously obtained with the AI model.

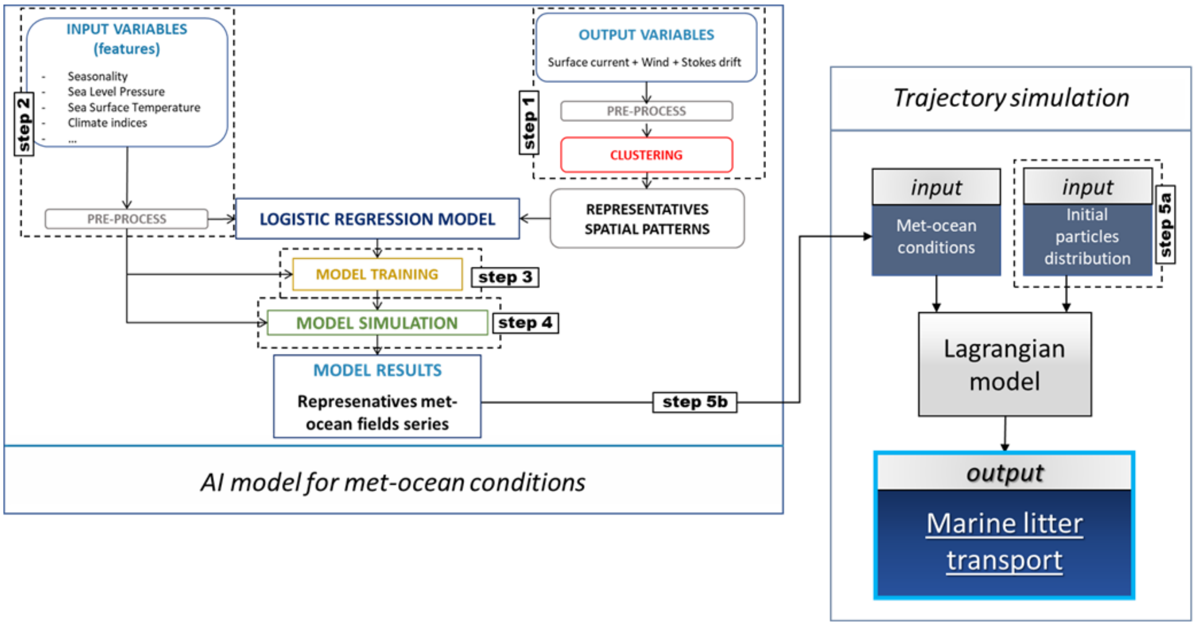

Figure 2. General scheme of the proposed methodology

Results

Distribution maps of marine litter concentrations were achieved by averaging the instantaneous concentrations (of mass for land-based scenario and of weighted particle abundance for sea-based scenarios) of the last five year of simulation, in a 0.5º virtual grid.

Figure 3 shows the obtained global distribution of floating marine litter from land-based sources, as concentrations (kg/km^2), considering a windage of 1%. Main concentrations at sea are found in the Asia-Pacific region, excluding Australia and New-Zealand areas, and in northern and mid Indian Ocean. Concentrations obtained here range between 100 kg/km^2 and 1 T/km^2 (see Figure 3 for the exact value distribution). Other important accumulation areas are found in the North Atlantic, with concentration of up to 500 kg/km^2 and in the North Pacific with concentration of up to 200 kg/km^2. In most of the Mediterranean Sea results oscillate between 1 and 50 kg/km^2. Other major accumulation regions are shown in the South Atlantic (between 1 and 30 kg/km^2) and South Pacific (1 to 5 kg/km^2). Similar concentrations, although with a more spread distribution, are observed in the southern Indian Ocean, and between the upper North Atlantic and Kara Sea up to the Arctic Ocean. An interest finding is the presence of decent marine litter concentration throughout most of the Southern Ocean, ranging between 1 g/km^2 - 2 kg/km^2. A particular accumulation area (2 kg/km^2) is found in the Bellingshausen Sea, at the west of the Antarctic Peninsula. The map also shows marine litter concentrations on coasts. Since the focus of this project was to identify marine accumulation areas, we did not include in the work process specific methods and parameters required to accurately assess particle beaching. However, we considered convenient to keep in our simulation with those particles that reached land cells (considered beached) and include them in the concentration maps provided, so to also contribute with the information of which coasts have higher risk of suffering marine litter pollution, based on our analysis. In this respect, highest values are obtained on almost all Asian coasts, being also remarkable on eastern sides of Africa and middle South America, on northern edge of the Gulf of Guinea and southern boundary of the Mediterranean Sea. Less intense coastal concentrations are obtained on the European Atlantic coasts, on both side on Central America and eastern side of North America and western coasts of Oceania.

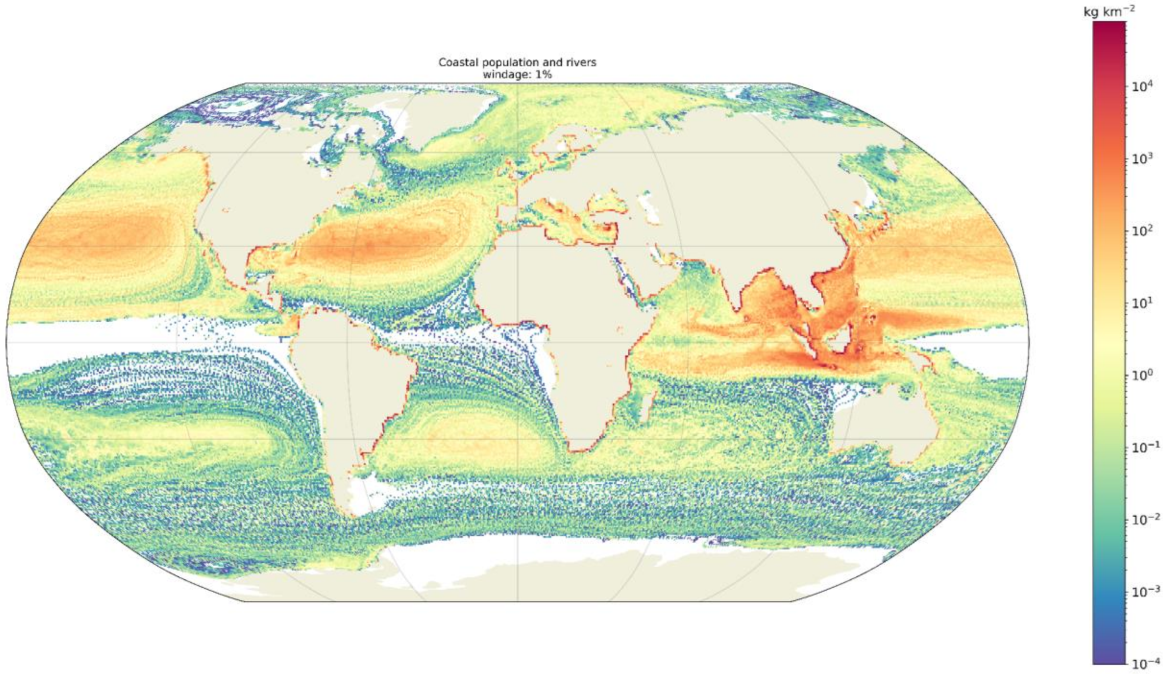

Figure 3. Concentration of floating marine litter proceeding from land-based sources, considering a windage of 1%.

If we consider in the simulation a higher value of the windage parameter equal to 3% the resulting concentration distribution is shown in Figure 4. Although such a windage value is, in our opinion, less representative in a global marine litter long-term analysis, we think that this simulation can be helpful to understand the effect of wind in the global marine litter distribution. Most major accumulation areas are confirmed, although highest concentrations drop by between one to two orders of magnitude. The most significant change is observed in the South Atlantic, where marine litter presence almost disappears while in the Southern Ocean concentrations increase of three orders of magnitude, suggesting a key role of the wind in the accumulation in the Southern Ocean.

Results obtained when considering as sources areas of demersal fishing activities are shown in Figure 5. In this case, given the lack of knowledge about the distribution of quantities involved, results are shown as weighted percentage of particle presence (weight is given by the intensity of fishing activity at the origin particle location). Major aggregation areas are found in the North Pacific (with also the highest density), North and South Atlantic, between upper North Atlantic and Arctic Ocean (with local major densities around southern coast of Greenland) and, to a lesser extent, in the South Pacific and Indian Ocean (local highest densities in the upper and mid basins).

The distribution of marine litter coming from main commercial shipping routes is shown in Figure 6, as well in weighted percentages. Here, the most important accumulation area is found in the North Atlantic, with densities of at least one order of magnitude higher than the rest of the basins. Important accumulations are found in the Southeast Asia seas, in the North Pacific and between upper North Atlantic and Arctic Ocean. Relative low densities found in areas with high shipping activities , such as the Mediterranean Sea, could be explained by the beaching experimented by the particles.

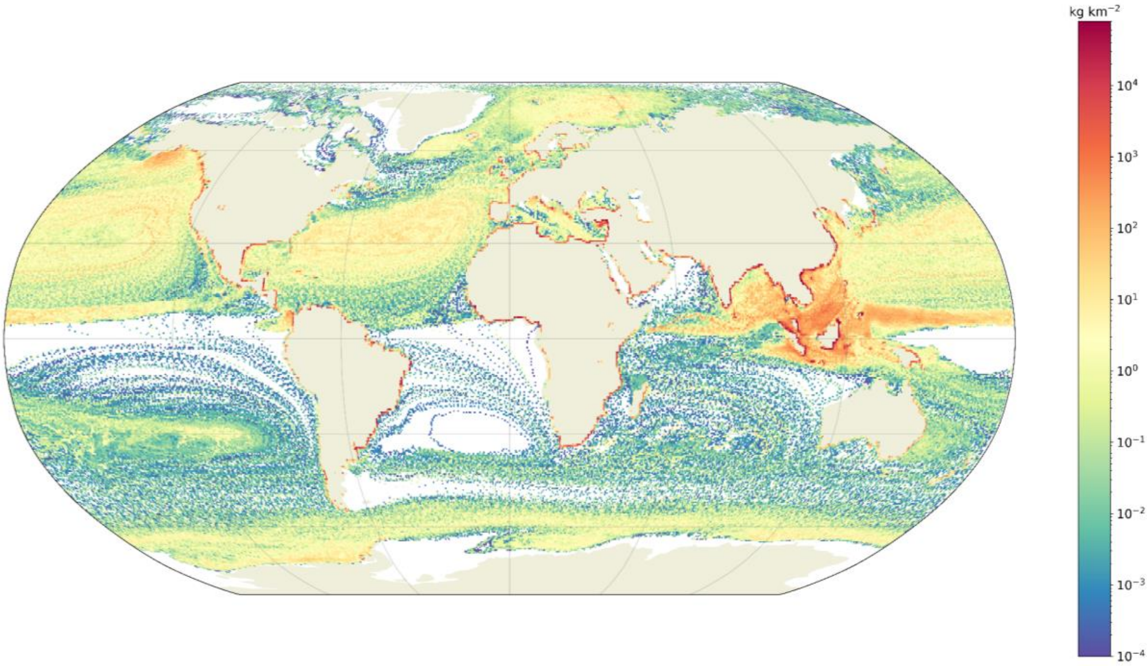

Figure 4. Concentration of floating marine litter proceeding from land-based sources, considering a windage of 3%.

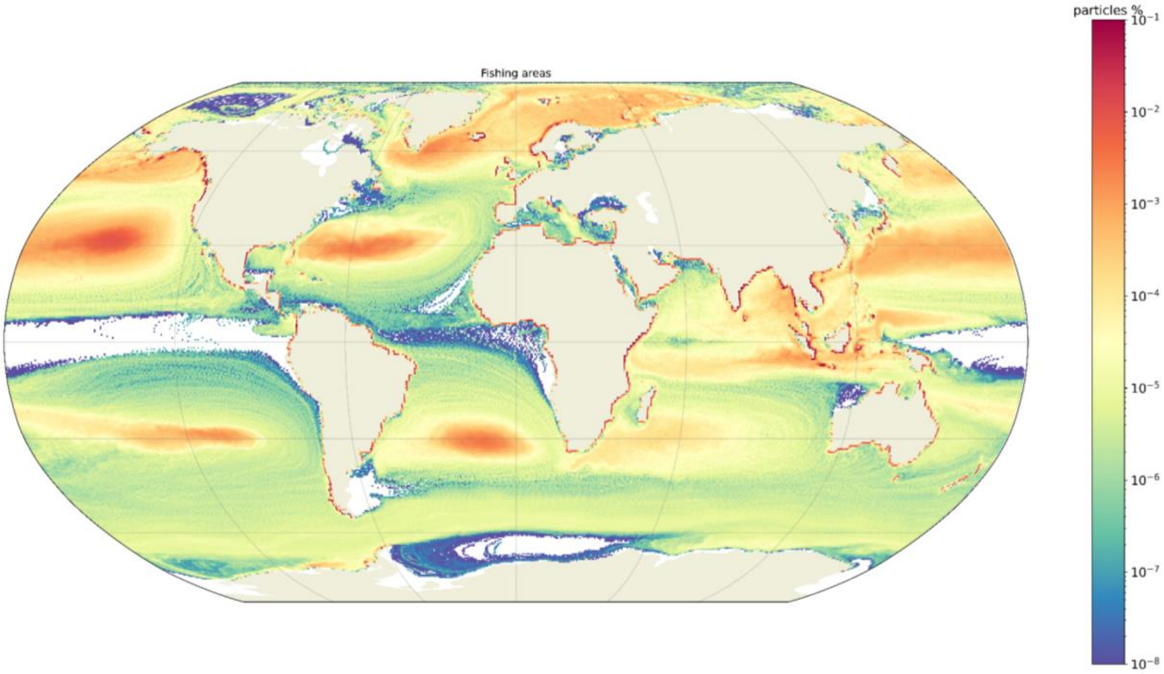

Figure 5. Distribution of floating marine litter proceeding from demersal fishing activities.

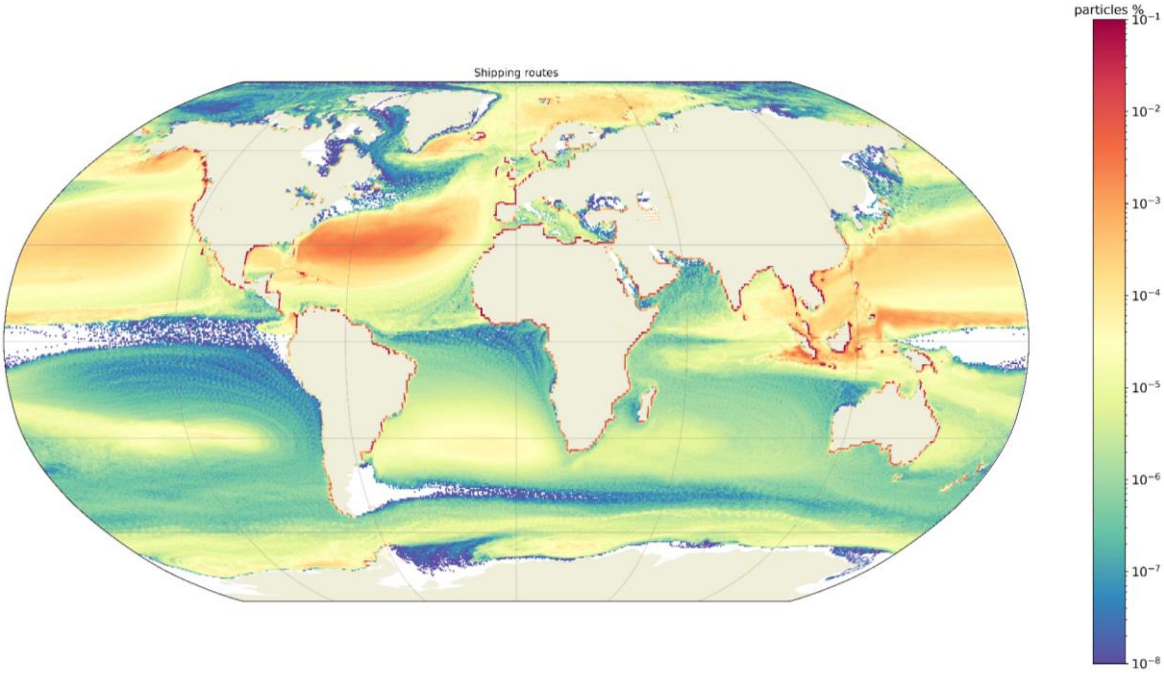

Figure 6. Distribution of floating marine litter proceeding from commercial shipping routes.

Discussion

As shown Figure 7, garbage patches are not steady but oscillate under the evolution of environmental dynamics. This is why we opted to provide our results as an integration in time., by averaging the simulated distributions over a period of five years (last five years of simulations).

By doing so, the marine litter distribution maps proposed are not related to any specific date but are representatives of an overall long-term situation.

Concentrations of marine litter from land-based sources so obtained are in agreement with standardized observed concentrations by Van Sebille et al.(2012) (Figure 8). As shown, the two databases are comparable both in term of spatial distribution and quantitively. However, a marked anomaly is observed with the transect of the southern Bay of Bengal, where standardized observations do not exceed 100 g/km^2 while our results show for the same region concentrations of approximately 1 T/km^2, actually the highest concentrations obtained. However, important marine litter accumulations in this region are supported by other numerical experiments. This is hard to explain but the scarcity of observations in the area, especially if compared to other region like North Pacific or North Atlantic, is an issue and disposing of a more robust and standardized ground truth dataset of the area could surely help to better understand the picture. At the same time, several recent studies are presenting evidence that in the Asia-Pacific area ocean pollution for marine litter is a reality, asking for a careful control of the situation.

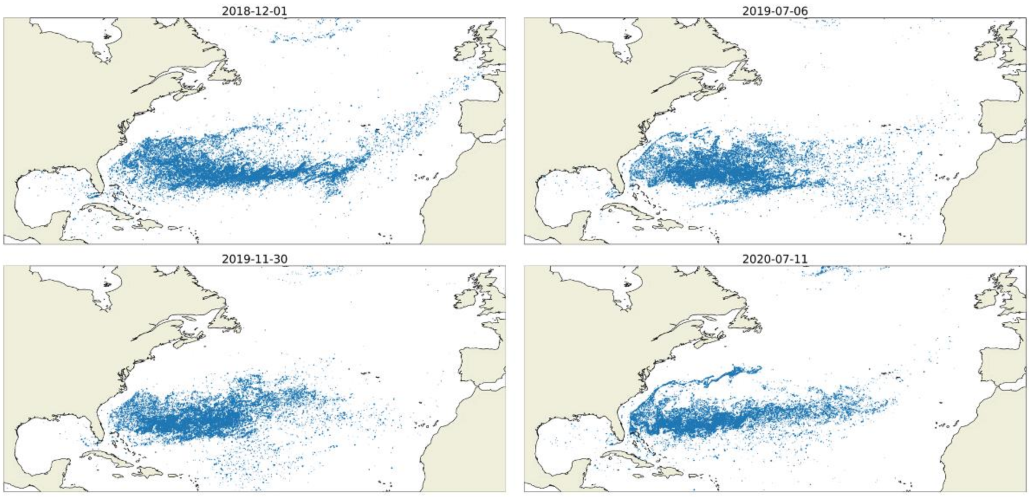

Figure 7. Snapshots of particle distribution in the North Atlantic during the land-based scenario simulation, at an approximate 6-month interval. Particle diameters are proportional to the logarithm of the associated mass.

Comparing our results with those of Maximenko et al.(2012), Lebreton et al.(2012) and Van Sebille et al. (2012) is not straightforward since in any of these studies mass concentrations are computed. However, several analogies can be found, such as the location and shape of different major accumulation areas. In particular, Van Sebille et al.(2012), observed the formation of a marine litter patch in the Barents Sea, which partially support our finding of an intermediate (in intensity) accumulation area between upper North Atlantic and the Arctic Ocean. As previously mentioned, Lebreton et al.(2012) also obtained a clear marine litter aggregation area in the Asia-Pacific area (Figure 1). This is likely due to the incorporation of more representative sources respect to other studies.

The presence of significant concentration in most of the Southern Ocean (1 g/km^2-2 kg/km^2, Figure 3) has never been found in a numerical study before. Nevertheless, our findings agree with the concentrations observed along a transect in the Drake Passage (Figure 8). Antarctic area has always been considered as one of the most pristine areas of the ocean being relatively free of plastic pollution. However, recent studies (Bessa et al., 2019; Waller et al., 2017; Waluda et al., 2020) are showing evidence of plastics and microplastics in animal life, deep-sea sediments and surface waters around the Antarctic, showing the importance of a better understanding of the extent of marine litter across the whole Southern Ocean.

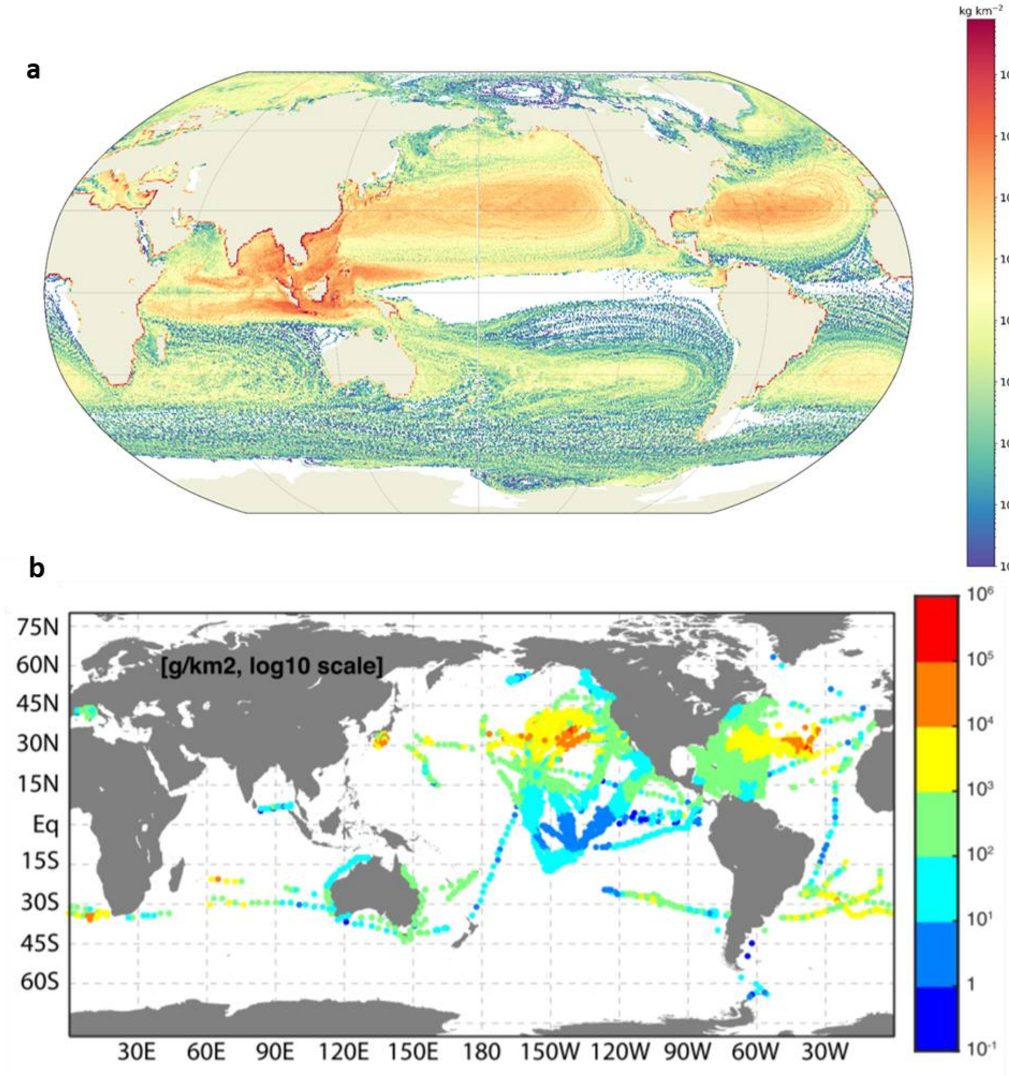

Figure 8. Comparison between marine litter concentration obtained in this project (a) (same data shown in Figure 3 but centred at 180º longitude for easier comparison) and standardized observational data by Van Sebille et al. (2015) (b, Source: Van Sebille et al. (2015))

With the aim of better understanding the reasons of the concentrations obtained with our simulations in the Southern Ocean, we ran a simulation of land-based marine litter by only considered surface currents from our met-ocean pattern simulated series. It is worth to highlight that this only represent a numerical experiment to explore the effect of currents in our simulations, but it does not represent a concentration distribution of debris particle advected only by currents (as particles suspended in the water column). To achieve the latter, we should re-apply our methodology from the first step only considering current data, clustering current data series, found relevant features for a LR (Logistic Regression) model of current patterns, and so on. The marine litter concentrations obtained are shown in Figure 9. Concentration of floating marine litter proceeding from land-based sources obtained by omitting effect of wind and Stokes drift in the simulated met-ocean patterns. Note that this is a numerical experiment and do not represent an estimation of current-driven marine litter. In this case no presence of marine litter is obtained in the Southern Ocean, while concentrations in Southern Hemisphere major accumulation areas increase, especially in the South Atlantic and southern Indian Ocean (by four orders of magnitude). The results of this experiment suggest that wind and waves could play an important role in the spreading of marine litter between Southern Hemisphere macro accumulation areas, especially the ones in South Atlantic and Indian Ocean, and the adjacent Southern Ocean. The results we obtained with 3 % value of windage (Figure 4) support this hypothesis by showing a shift of concentrations between South Atlantic – Indian Ocean and Southern Ocean with respect to the 1% windage case (Figure 3). Similar findings are also described by Van Sebille et al.(2012) with the authors obtaining, in the long run, the dispersion of the South Atlantic and the Indian Ocean patches and suggesting a possible interaction with the Southern Ocean.

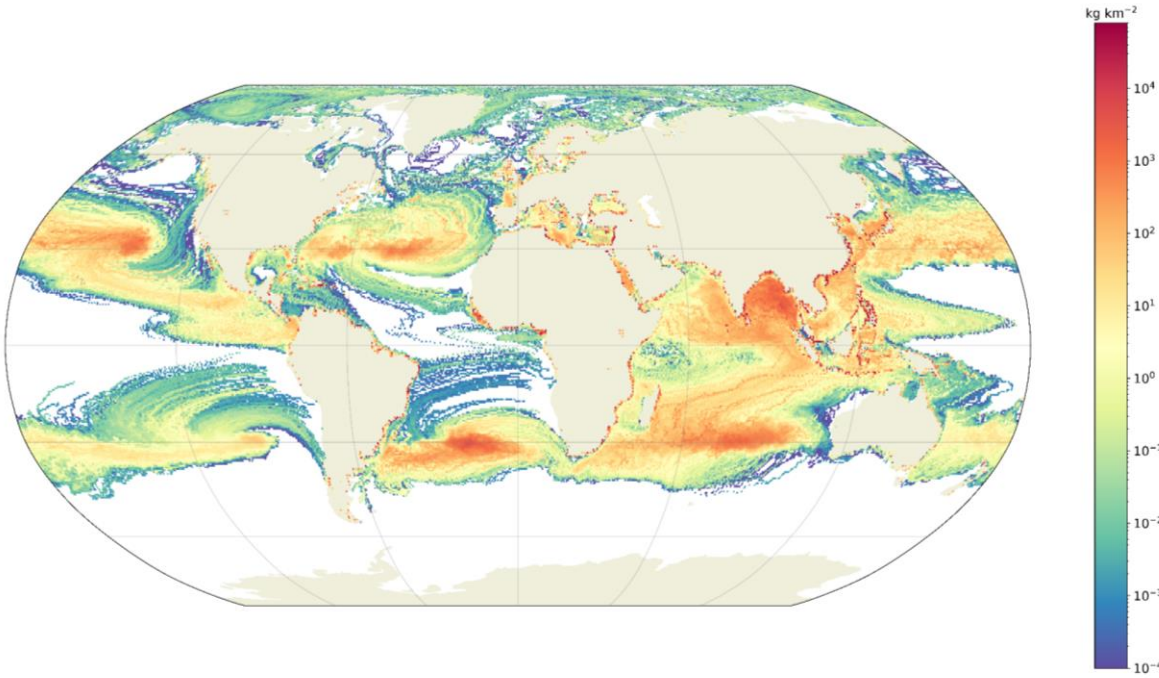

Figure 9. Concentration of floating marine litter proceeding from land-based sources obtained by omitting effect of wind and Stokes drift in the simulated met-ocean patterns. Note that this is a numerical experiment and do not represent an estimation of current-driven marine litter.

Conclusions

In the present document the methodology and the results of the project are presented and discussed. We achieved a new estimation of long-term global distribution of marine litter proceeding from land-based sources (provided as mass concentration) and from sea-based sources (provided as relative abundance). As a key component of our methodology, an AI model based on clustering techniques and LR modeling is used to produce long-term climate-based series of surface currents, wind and Stokes drift, subsequently used to force a Lagrangian model. Main conclusions of the project can be summarized as follows:

- Main floating marine litter concentrations from land-based sources are found in the Asia-Pacific marine region (excluding the Australia- New Zealand area), with values ranging between 100kg/km2 and 1 T/km2. Concentrations of up to 500 kg/km2 are found in the North Atlantic and of up to 200 kg/km2 in the North Pacific. In most of the Mediterranean Sea concentrations range between 1 and 50 kg/km2. Other major accumulation regions are found in the South Atlantic (between 1 and 30 kg/km2) and South Pacific (1 to 5 kg/km2). Similar concentrations, although with a more disperse distribution, are found in the southern Indian Ocean and between upper North Atlantic and Kara Sea up to the Arctic Ocean. Concentrations between 1 g/km2 - 2 kg/km2 are found in the Southern Ocean, particularly in the Bellingshausen Sea.

- Marine litter contamination coming from demersal fishing activities result spread worldwide with higher densities corresponding approximately with the North and South Pacific and North and South Atlantic gyres, between upper North Atlantic and Arctic Ocean and the Asia-Pacific seas.
- Marine litter associated to commercial shipping routes mainly converge towards the North Atlantic. Important accumulation areas are also found in the Southeast Asia seas, the North Pacific and between upper North Atlantic and Arctic Ocean. Southern Hemisphere results less affected by this type of debris source.
- Experiments realized varying the relative effect of the considered dynamics suggest that marine litter presence in the Southern Ocean is due to particles escaping from Southern Hemisphere accumulation areas, especially from the South Atlantic and the Indian patches.
- The obtained results compare favorably with worldwide collected observations of marine litter, even in the Southern Ocean, supporting the project findings.
- Our results, like several recent studies do, suggest that more investigations and monitoring missions are needed in the Antarctic region.
- Highest concentrations of marine litter found in the Asia-Pacific marine region (excluding Australia-New Zealand area) are partially confirmed by previous studies, and not supported by very scarce observations available in the area. A more extensive local ground truth database should help to better understand the actual situation of this region.