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# Modelling the transport and accumulation of floating marine debris in the Mediterranean basin

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ABSTRACT

In the era of plastic and global environmental issues, when large garbage patches have been observed in the main oceanic basins, this work is the first attempt to explore the possibility that similar permanent accumulation structures may exist in the Mediterranean Sea. The questions addressed in this work are: can the general circulation, with its sub-basins scale gyres and mesoscale instabilities, foster the concentration of floating items in some regions? Where are the more likely coastal zones impacted from open ocean sources?

Multi-annual simulations of advected surface passive debris depict the Tyrrhenian Sea, the north-western Mediterranean sub-basin and the Gulf of Sirte as possible retention areas. The western Mediterranean coasts present very low coastal impact, while the coastal strip from Tunisia to Syria appears as the favourite destination. No permanent structure able to retain floating items in the long-term were found, as the basin circulation variability brings sufficient anomalies.



## 1. Introduction

The problem of litter disposal and accumulation in the marine environment has recently become recognized by the international community and constitutes a major threat for the marine life. Since the 20th century the main sources of macro-waste in the ocean include land-based sources (UNEP, 2009), lost fishing gear and recreational fishing, but also illegal dumping from ships (Ramirez-Llodra et al., 2013). Despite some progress with regard to legislation, illegal dumping of litter combined with the transport of macro-waste from coastal areas and river discharge remains a major problem.

Litter can easily be mistaken as food by numerous animals and cause health complications or even death. Many studies on marine litter have investigated the ingestion of plastic items by marine animals, including for examples fishes (Carson, 2013), turtles (Lazar and Gračan, 2011), cetaceans (Baulch and Perry, 2014) or seabirds (Azzarello and Van Vleet, 1987; Ryan and Jackson, 1987). Fishing gear can become ocean pollutant as a result of accidental losses or dumping. Entanglement in derelict fishing gear is another important threat not only for marine mammals (Laist, 1997; Schrey and Vauk, 1987), but also for benthic biota (Chiappone et al., 2005). Floating macro-waste can also be a support to the marine life. Some invasive species take advantage of these potential rafts to travel over large distances and find new habitats (Aliani and Molcard, 2003; Barnes, 2002).

The economic impact of marine litter is clear. Beaching marine debris cause aesthetic problems, especially in touristic areas where they generally lead to a decline in tourist traffic and oblige the concerned municipalities to substantial cleaning costs. At sea, floating marine debris endanger the maritime traffic. Small items can block propellers and collisions are always possible with larger debris. In addition to that, litters trapped by fishing nets is becoming a recurring issue for fishermen (Takehama, 1990).

The common marine litter types found in the world's ocean are plastics, glass and metal (UNEP, 2009). Plastics items are the most abundant from the development of the world-wide plastic industry (Derraik, 2002) and account for more than 60% of total marine litter (Gregory and Ryan, 1997).

Their persistence property is the major reason why they are a significant threat for marine ecosystems. The natural decay of plastic items in the marine environment takes an extremely long time, generally estimated between hundreds and thousands of years (Barnes et al., 2009). During this time, plastics constitute a major source of chemical pollutants such as polychlorinated biphenyls (PCBs) and dioxins (Engler, 2012). In addition, the degradation process is accompanied by fragmentation of smaller pieces down to micro-plastics (microscopic particles of eroded plastics). These

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micro-particles are becoming more common in oceans and greatly impact trophic levels (Andrady, 2011; Cole et al., 2011).

Since the 90's, when an enormous spatial extension of floating debris in the North Pacific Ocean has been first observed (Moore et al., 2001), the problem of marine litter has become more and more advertised. The spatial distribution and accumulation of macro-waste from the world's ocean surface is driven by prevailing currents and winds, hydrography, anthropogenic activities (Ramirez-Llodra et al., 2013) and can significantly vary from a location to another. The main large oceanic aggregation patterns ("garbage patches"), characterised by high densities of marine debris are now quite well described and identified in the literature (Law et al., 2010; Moore et al., 2001).

Numerical modellings of floating marine debris (Martinez et al., 2009; Lebreton et al., 2012; Maximenko et al., 2012) have confirmed and explained the presence of accumulation structures in most of the main oceanic basins. Subtropical gyres are convergence areas where clockwise ocean currents act as a retention mechanism and prevent plastic debris from moving towards mainland coasts. This general circulation feature is directly correlated to the anticyclonic wind forcing and its associated Ekman transport. However, it is assumed that the accumulation structures are probably larger in the Northern Hemisphere where the population and the level of economic and industrial activities are higher (Lebreton et al., 2012). In addition, higher concentrations at mid-latitudes compared to polar regions have also been found (Barnes and Milner, 2005).

At a finer scale, regional seas have also been under investigation, like the Japan Sea (Yoon et al., 2010; Shiomoto and Kameda, 2005; Kako et al., 2011), China Sea (Zhou et al., 2011), Antarctic (Walker et al., 1997). A very recent work by Neumann et al. (2014) have focused on marine debris agglomeration in the southern North Sea, evaluating the windage effect and assuming different source regions. Indeed, semi-enclosed seas that are surrounded by developed areas, such as the Mediterranean Sea, are likely to have particularly high concentration of marine debris (Barnes and Milner, 2005). For the example of the Mediterranean Sea, several studies have already documented the beaching of macro-waste (Gabrielides et al., 1991; Golik and Gertner, 1992), their transport at the surface (Aliani and Molcard, 2003; Aliani et al., 2003) and accumulation on the sea floor (Galgani et al., 1995a; Galil et al., 1995; Pham et al., 2014; Ramirez-Llodra et al., 2013). Estimates of the average density of macro-litter at the surface of the Mediterranean Sea range from 1.2 items/km$^2$ (McCoy, 1988) to the huge value of 2000 items/km$^2$ (Morris, 1980). The latter value should however be treated with great caution, as only 60 surveys of 1 min were performed. A more reasonable estimate was recently given by Suaria and Aliani (2014) and still represents a total of 62.10$^6$ anthropogenic macro-litter items, assuming that the density stays constant over the basin. In this first large-scale survey of marine debris in the central and western part of the Mediterranean Sea (May–October 2013), a large spatial heterogeneity in litter distribution have been found. Still, little is known on the distribution and accumulation at global scale of floating marine litter in the Mediterranean Sea, which relative small size does not allow the formation of large gyres.

Numerical studies using ocean modelling received little attention and we have not been able to identify any modelling of floating marine debris specifically dedicated to the Mediterranean basin. In Lebreton et al. (2012) the Mediterranean Sea is included in their global ocean general circulation model and is indeed described as a potential high density marine debris region. Even though the low resolution of the model may not be appropriate to study regional seas, they have shown that semi-enclosed seas can be a preferential destination of the global marine debris sources, both terrestrial and maritime. The incoming Atlantic surface water and the high maritime traffic in the Mediterranean Sea are described as the main causes.

In the present paper, numerical simulations of the Mediterranean Sea are achieved with two different objectives. The first goal is to define how the general surface circulation in the Mediterranean Sea can foster the concentration of marine floating debris, leading to the formation of permanent garbage patches. To address this, we describe the spatio-temporal evolution of the macro-waste density from an homogeneous initial condition, using an ocean general circulation model coupled with a particle tracking model. Travelled distances are also investigated to get a global picture of the particle journeys. Finally, the second goal is to try to identify the coastal zones that are the most impacted from open ocean sources.

## 2. Materials and methods

In order to mimic the marine debris transport at the sea surface, virtual particles acting as Lagrangian tracers are introduced in a numerical circulation model. The simulation of the particles drift at the oceanic surface is performed in two stages: first, the ocean state and the velocity fields are computed with an appropriate ocean general circulation model (OGCM). Second, the drift of the virtual particles is computed by an advection model using the velocity fields computed from the OGCM.

### *2.1. Models*

For this study, the velocity fields has been extracted from high-resolution model simulations. The oceanic circulation model used is the NEMO model (Madec et al., 1998; Madec, 2008) in a regional eddy permitting configuration over the Mediterranean Sea (MED12 configuration, Beuvier et al., 2012; Lebeaupin Brossier et al., 2012a; Lebeaupin Brossier et al., 2012b; Brossier et al., 2013).

The numerical model solves the primitive equations assuming the hydrostatic equilibrium, the Boussinesq approximation and a free sea surface formulation. The domain is defined on a 1/12° "ORCA" grid (Madec, 2008) with 567 $\times$ 264 grid points covering the entire Mediterranean Sea from 30°N to 46°N and from 11°W to 36°E. A no-slip boundary condition is used at the coast and domain boundaries. The horizontal resolution ranges between 6 km and 8 km, while the vertical dimension is unevenly spaced with 75 Z-levels from the surface ($\Delta Z = 1$ m) down to the bottom ($\Delta Z = 135$ m). 22 levels are in the first 100 m to better represent the upper boundary layer and the topography is based on the ETOPO1 database (Smith and Sandwell, 1997). This MED12 configuration uses the MEDATLAS climatology as initial condition and is forced by the ALADIN-Climate atmospheric fields (Herrmann et al., 2011). The atmospheric data comes from the METEO-France center, and is available at 3 h intervals on a 10 km by 10 km grid. The resulting ocean model configuration allows to solve the mesoscale circulation, with a good representation of the surface mixed layer and a fully resolved wind driven circulation. The velocity fields are computed at each time step (12 min) and the outputs are daily averaged files from January 2001 to December 2010.

The computing of the general transport pathways is done using the Lagrangian off-line tool ARIANE to track the virtual particles. Marine debris are considered as passive surface particles advected by the currents computed from the model (MED12). The velocity used includes the Ekman drift, the baroclinic motion, the tidal and inertial currents as well as the Stokes drift induced by waves. Only the first level of velocity is considered as the lack of studies about degradation of plastic items or changes in their buoyancy, strongly limits appropriate attempts to represent their vertical movement. As a consequence, vertical movements are banned and particles are forced to stay just below the surface, which

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