Geophysical Research Abstracts
Vol. 20, EGU2018-6480-1, 2018
EGU General Assembly 2018

Stochastic Lagrangian modeling the plastic marine debris in the Mediterranean Sea

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Two-dimensional Lagrangian framework has been established to track the transport and fate of plastic marine debris in the Mediterranean Sea, embracing the three environmental destinations: (i) the sea surface, (ii) coastlines, and (iii) the sea bottom. A statistically significant ensemble of $>10^{10}$ virtual particles is released from the largest coastal Mediterranean cities, rivers, and the most congested shipping lanes over 2013–2017. Transport of plastics is forced by the high-resolution sea surface kinematics provided by the Copernicus Marine Environment Monitoring Service. In addition to the sea surface currents, the sea surface Stokes drift that substantially deflects the pathways of plastics is taken into account. Daily analyses of ocean currents and waves at a horizontal resolution of 1/16° are used to force the plastic particles.

The Monte Carlo technique developed for the sedimentation of plastic debris allows a simple approximation with a small number of parameters. This method seems reasonable enough to overcome the significant uncertainty in formulation of vertical motion of plastics. The probabilistic nature of the beaching of plastics is also taken into consideration in a manner analogous to that applied to the beaching of oil droplets used in oil spill modeling. The statistics obtained demonstrate a good regression to the mean concentration of plastics at the sea surface and fluxes of plastics onto the coastline and sea bottom.

The mean particle half-life of 7–80 days allows the Mediterranean Basin to be defined as a dissipative system with respect to the plastics floating at the surface. This means that any long-term accumulation of plastics at the sea surface would be unlikely in the Mediterranean, in contrast to the global ocean. We indicate a substantial accumulation of plastics on the coastlines and sea bottom and that the former sink greatly dominates the latter one.

According to the model, the most contaminated areas are in the Cilician subbasin, Catalan Sea, and near the Po River Delta. Also, highly polluted local patches in the vicinity of sources with limited circulation are identified. In contrast, the Aegean Sea and coastlines of the Balkans are identified as relatively low-polluted areas. This phenomenon might be explained by a “filtering effect” of the complex coastlines composed of innumerable inlets and many small islands. However, such a long coastline requires local coastal inhabitants of Greece, Albania, Montenegro, Bosnia and Herzegovina, Croatia, and Slovenia to expend significant efforts towards cleanup.

Solution to the inverse problem, quantifying the national source-receptor relationships among the 19 Mediterranean countries, reveals that the plastic pollution of almost every country’s coastline is mainly caused by its own terrestrial sources of plastics.

Our model results can be used to fill gaps in monitoring of plastic pollution and optimize cleanup activities in the Mediterranean Sea. Additionally, the solution obtained could provide open boundary conditions for regional and coastal models of marine debris transport and fate.