3D hotspots of Marine Litter in the Mediterranean Sea: a modeling study

Javier Soto-Navarro[1] , Gabriel Jordá[2] , Salud Deudero[2], Carme Alomar[2], Ángel Amores[1] and Montserrat Compa[2].

[1]Mediterranean Institute for Advanced Studies (IMEDEA), Mallorca, Spain
[2]Spanish Institute of Oceanography, Mallorca, Spain

Background

- The Mediterranean Sea is one of the regions of the planet most affected by the pollution due to Marine Litter (ML).
- Observational studies cannot provide a synoptic analysis of the ML distribution over the basin due to the difficulties of the measuring campaigns, that limit the temporal and spatial coverage of the samples.
- Modeling studies are able to characterize the spatial distribution and time variability of the ML over the whole basin, although with important limitations.
- Up to now, and to our knowledge, only four studies have dealt with the analysis of the ML dispersion over the whole Mediterranean using modelled (Mansui et al., MPB, 2015, Macias et al., MPB, 2018 and Liubartseva et al., MPB, 2018) or drifter derived (Zambianchi et al., FES, 2017) current fields.
- All of then simulate 2D trajectories of floating particles over the sea surface and only Liubartseva et al. (2018) uses a realistic initial distribution of ML sources, the rest starting from a uniform distribution.

Objective

Analyze the 3D dispersion of ML over the Mediterranean Sea, characterizing the accumulation/dispersion regions, its temporal evolution and the vertical distribution of ML particles with different densities. To this aim, the current field of a very high Regional Circulation Model for the Mediterranean will be used as base to run a Lagrangian model that compute, for the first time, the 3D trajectories of ML particles with positive, neutral and negative buoyancies.

Modeling System

Regional Circulation Model (RCM)

NEMOMED36

Current field

Res: 1/36º x 1/36º ~ 3km

Z levels : 50

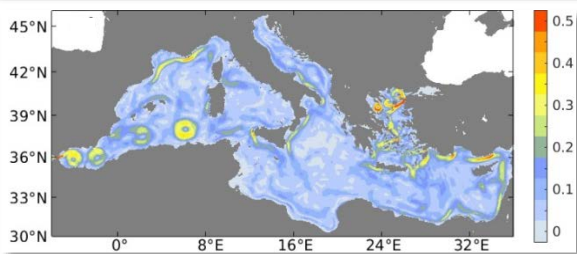
Atms. forcing: ARPERA

Initial cond.: MEDATLAS T/S

Rivers: RivDis dataset

Atl. Buffer zone: T/S Levitus, SSH reanalysis

Period: 2003 - 2013



Offline

Lagrangian model

Ichthyop 3.3

3D trajectories

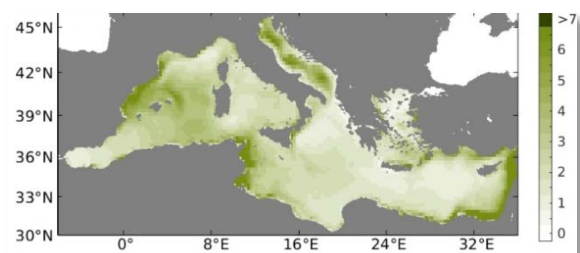
Runge – Kuta 4^{th} order

Horizontal diffusion

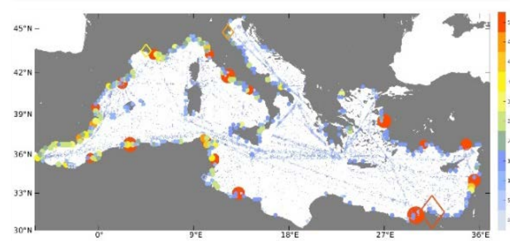
Boundaries behavior: Bouncing

Integration time step: 15 min

3D dispersion of ML over the Mediterranean Sea



- Realistic ML sources distribution: cities, rivers, ship lanes
- ML particles with neutral, positive and negative buoyancy

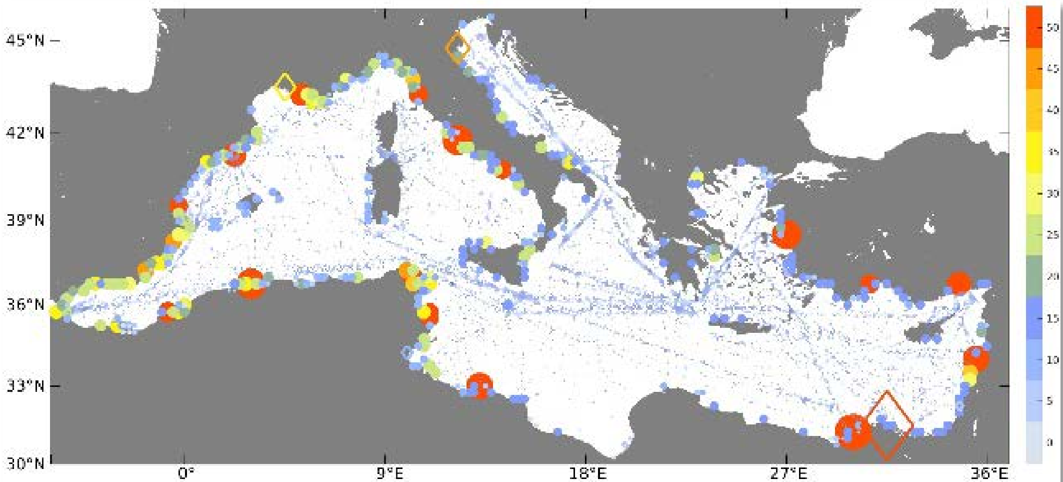


For more details see: Soto-Navarro et al. 2020. *Marine Pollution Bulletin.*

Doi: https://doi.org/10.1016/j.marpolbul.2020.111159

Simulations

Initial concentrations at the sources (kg·km^{-2})



ML sources distribution and initial concentrations:

Total ML: 100k tons. Cities:Rivers:Ship lanes → 50:30:20 %

Cities (circles): Proportional to the population. 480 with population > 25k inhabitants from http://www.citypopulation.de.

Rivers (diamonds): proportional to the average runoff. 15 major rivers data from ORCHIDEE River Model Flow.

Ship lanes (dots): Proportional to the maritime traffic. Data from https://www.marinetraffic.com/.

ML particles density:

Floating Particles (FP) → $\rho < \rho_{seawater}$ (vertical velocity = 0)

Neutral Particles (NP) → $\rho = \rho_{seawater}$ (vertical velocity given by the RCM)

Sinking Particles (SP) → $\rho > \rho_{seawater}$ (vertical velocity set to 10^{-3} m·s^{-1})

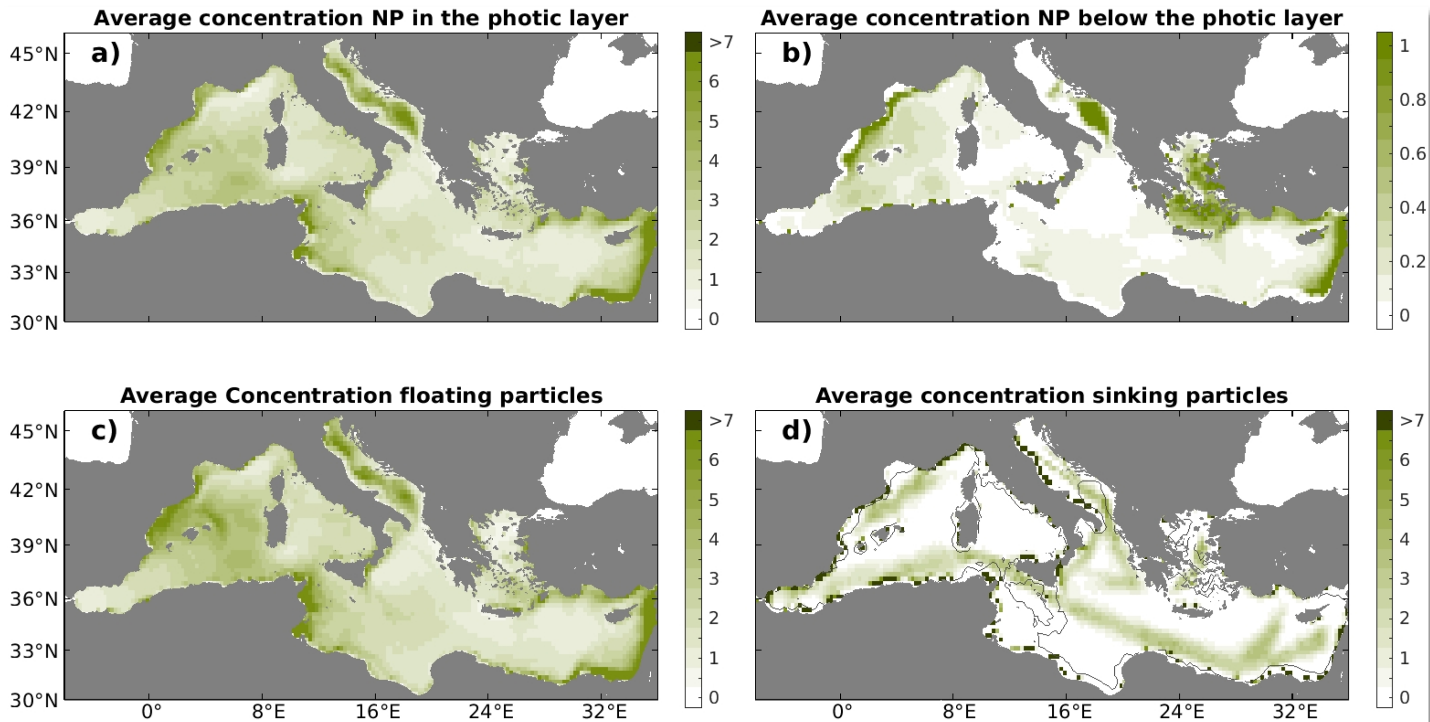
Integration period: 120 1-year long simulations, starting the first day of each month between 2003 and 2013, for each particle density.

Number of particles: 41872 particles released at the beginning of each simulation. Total of more than $5\cdot10^{6}$ particles for each density.

For more details see: Soto-Navarro et al. 2020. *Marine Pollution Bulletin.*
Doi: https://doi.org/10.1016/j.marpolbul.2020.111159

ML spatial distribution

Average ML concentration (kg·km^{-2})

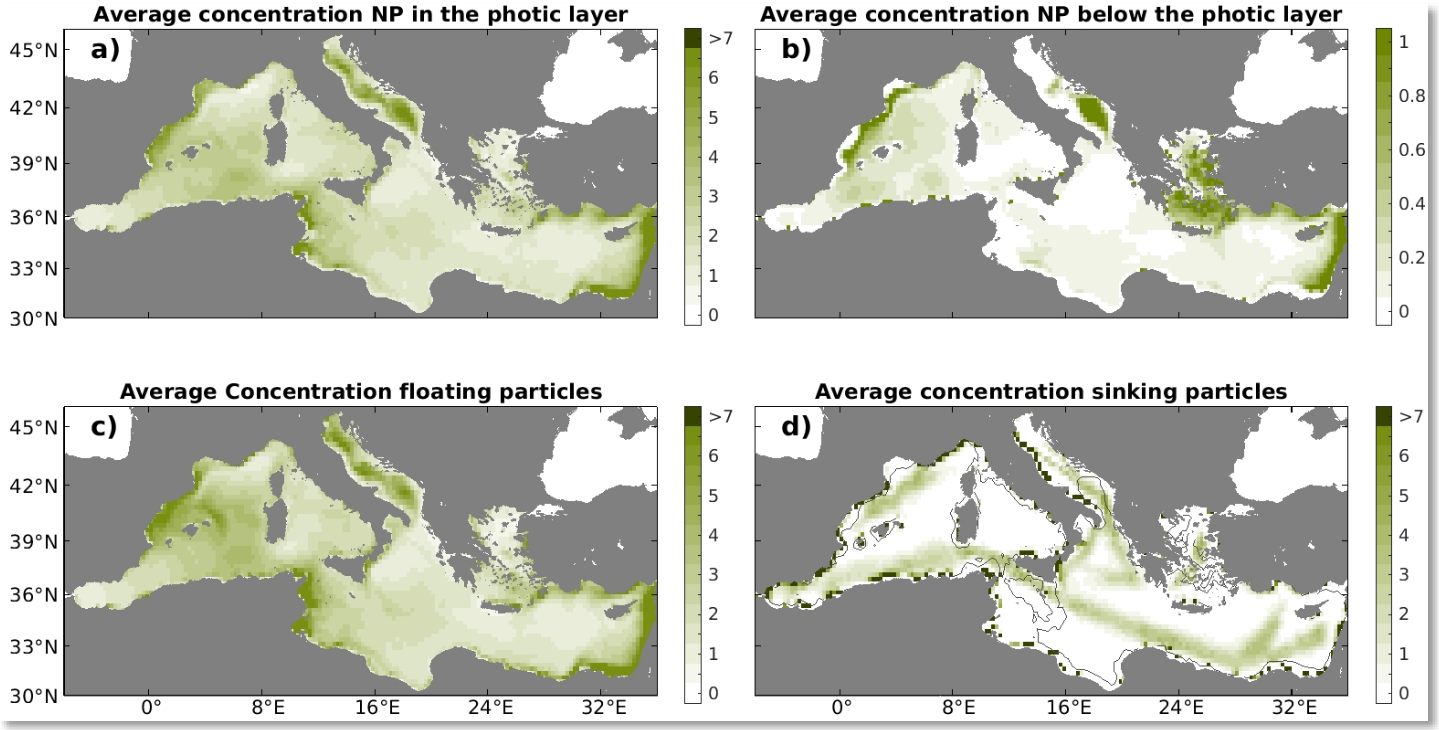


Neutral Particles:

- Average concentration 2.3 kg·km^{-2}, 80% of the NP above the photic layer
- Higher concentrations (> 6 kg·km^{-2}): Gulf of Lions, slope of the Iberian Peninsula, Sicily Strait, Gulf of Gabes, Adriatic Sea and slopes of the Levantine basin from Egypt to Tukey.
- Lower concentrations (< 1.5 kg·km^{-2}): Alboran, southern Tyrrhenian and Ligurian Seas. North Aegean, northern Ionian and central Levantine basin.

ML spatial distribution

Average ML concentration (kg·km^{-2})



Floating Particles:

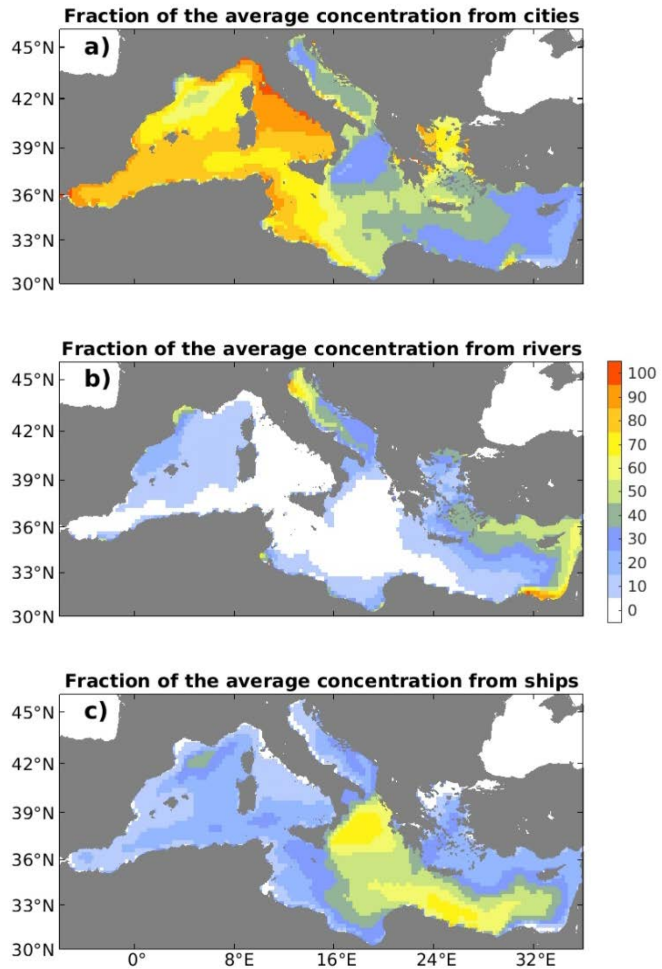
- Similar distribution than for the NP, with slightly higher concentration in the Balearic Sea.

Sinking Particles:

- Rapidly reach the seafloor very close the position of the source, with no time to spread.

ML spatial distribution

Contribution of the different sources to the average ML concentration (%)



Western Mediterranean:

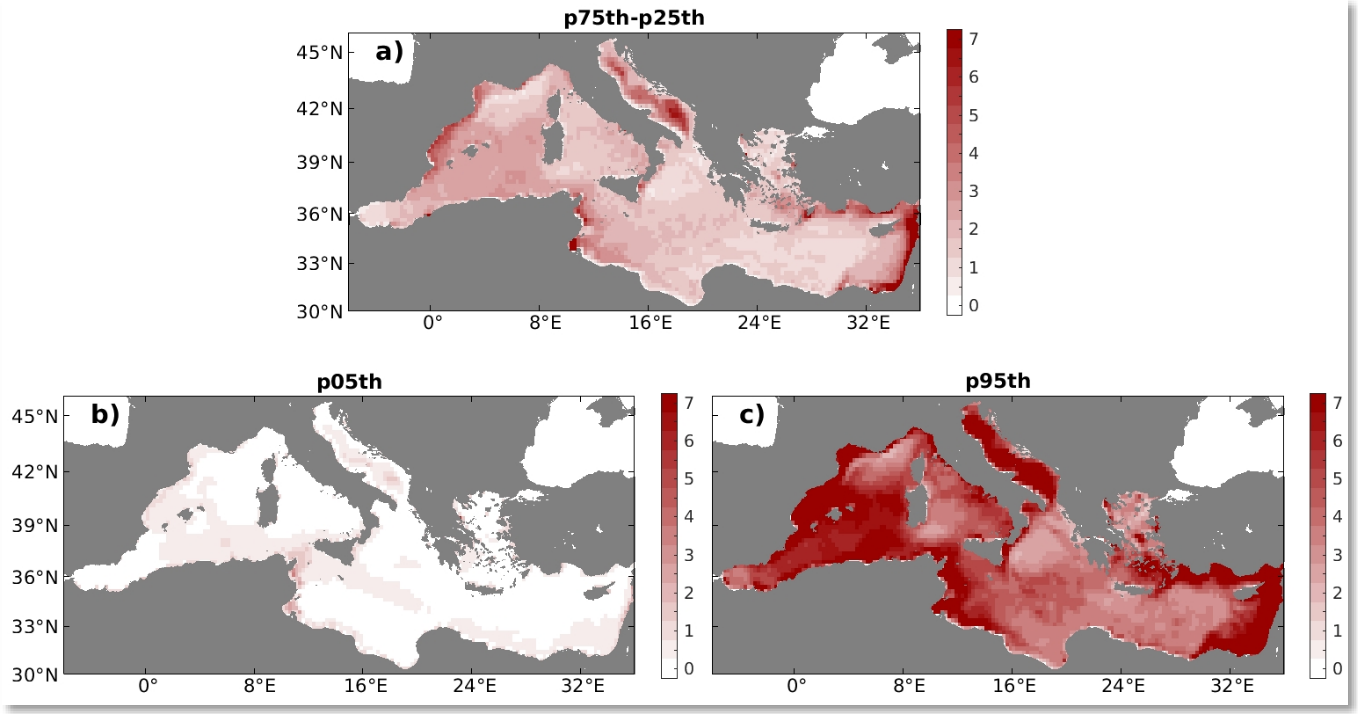
- Cities contribution higher than 60 %.
- Rivers contribution lower than 20% except on the Rhone mouth.
- Ship contribution uniform and lower than 30%.

Eastern Mediterranean:

- Cities contribution only higher than 50% in the Strait od Sicily, Gulf of Gabes and northern Aegean.
- Po and Nile rivers contribution higher than 50% in the Adriatic Sea and the Levantine basin.
- Ship lanes contribution reaches 60% in the Central Levantine basin and the Ionian Sea.

Temporal variability of the ML concentration

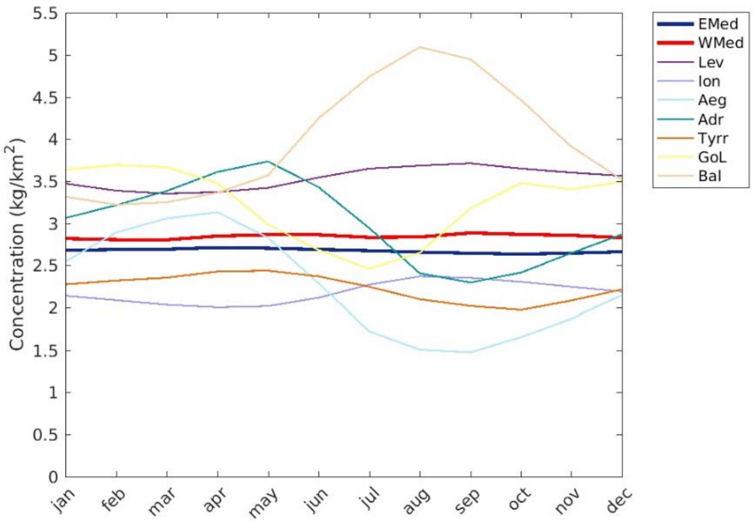
Quantiles of the ML concentration (kg·km^{-2})



- The regions with the highest variability are those with the highest average concentrations: The Northern Current area, Gulf of Gabes, Adriatic Sea and the northeastern coast of the Levantine basin.
- In the central Western Mediterranean, Adriatic Sea, southern Aegean and Levantine basin the concentration oscillates between 1 and 6 kg·km^{-2}.
- Lowest variability in the northern Aegean, northern Ionian and Tyrrhenian seas, ranging between 0.5 and 2.5 kg·km^{-2}.

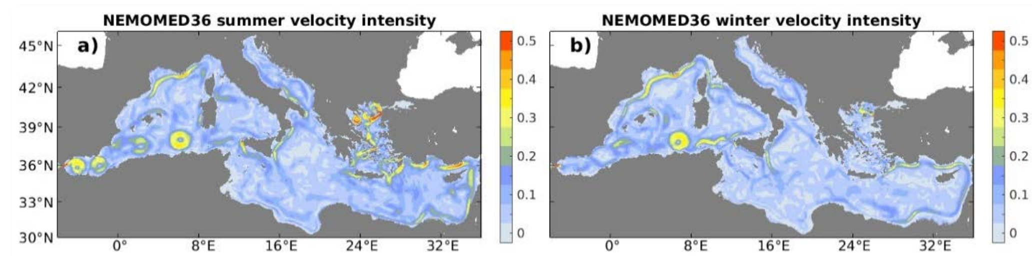
Temporal variability of the ML concentration

Seasonal cycle of the ML concentration at the different sub-basins (kg·km^{-2}).



EMed: Eastern Mediterranean
WMed: Western Mediterranean
Lev: Levantine basin
Ion: Ionian Sea
Aeg: Aegean Sea
Adr. Adriatic Sea
Tyrr: Tyrrhenian Sea
GoL: Gulf of Lions
Bal: Balearic Sea

Average summer and winter RCM velocity field (m·s^{-1})



- The seasonality is the result of the particles redistribution between the different sub-basins due to the currents variability.
- EMED and WMED seasonal variability negligible.
- Summer weakening of the Northern current favors transport of particles from the GoL area (minimum in July) to the Balearic Sea (maximum in August).
- Summer strengthening of the Adriatic and Aegean currents favors their ventilation, decreasing the ML concentration (minimum in August – September).
- The Ionian Sea and the Levantine basin receive the ML leaving the Aegean and Adriatic in the summer, increasing their concentration (maximum in August – September).

INSTITUT MEDITERRANI D'ESTUDIS AVANÇATS

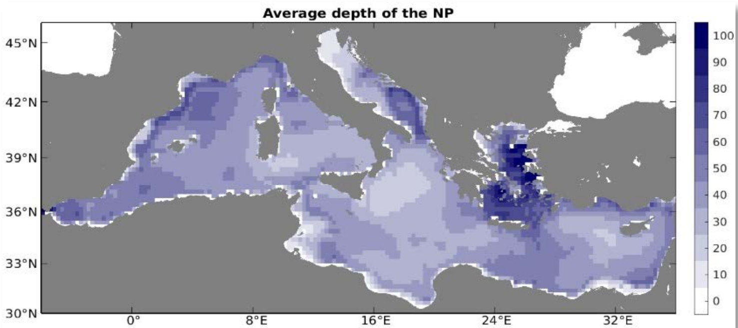
imedea.uib-csic.es

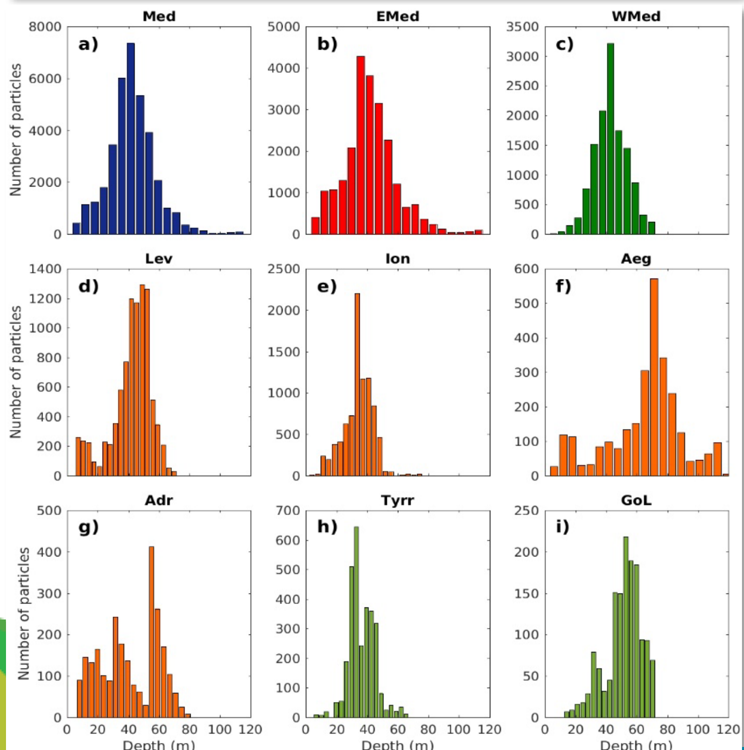
IMEDEA CSIC Universitat de les Illes Balears

EGU General Assembly

Vertical distribution of the ML neutral particles

Average NP depth and histograms of the average depths distribution in the different sub-basins (m).

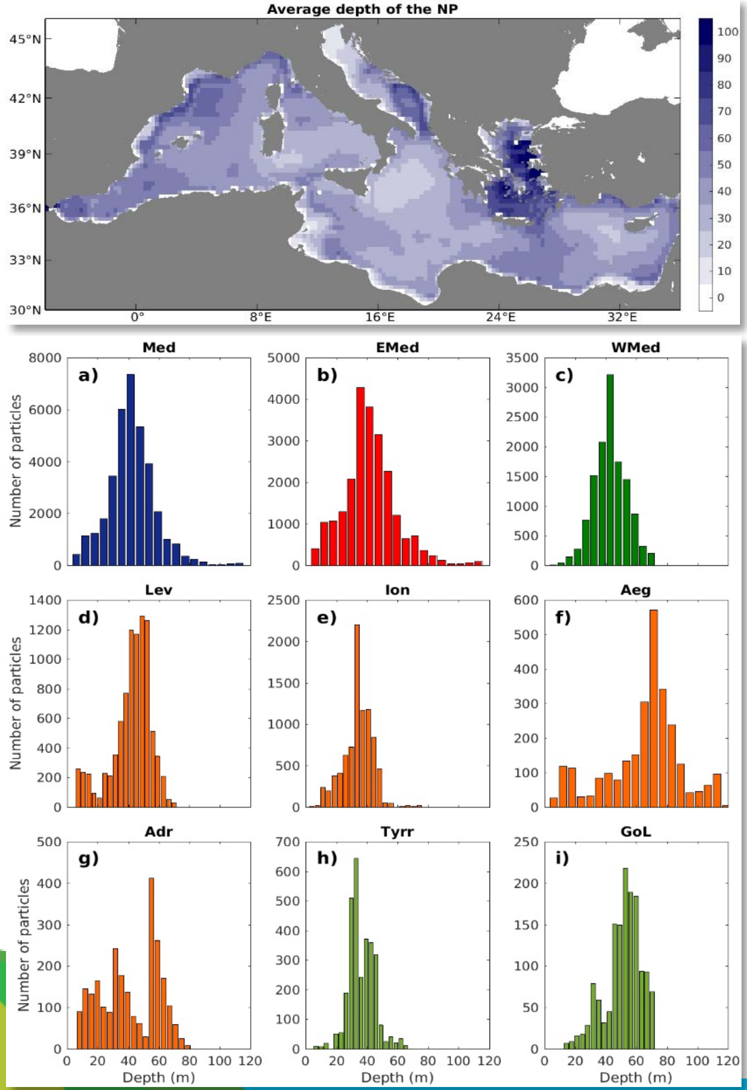




- The average NP depth over the basin is 35 m.
- Rather homogeneous depth distribution in the WMED [20 - 50] m
- More heterogeneous average depth distribution in the EMED [10 – 90] m.
- Histograms show that in the WMED particles rarely exceed 60 m depth, only in the Gulf of Lions.
- Large amounts of particles reach depths higher than 60 m in the EMED. In particular in the Adriatic and the Aegean seas.
- NP spread between the surface and ~120 m depth in one year of integration.

Vertical distribution of the ML neutral particles

Average NP depth and histograms of the average depths distribution in the different sub-basins (m).



Limitations to be considered in the interpretation of the results:

i. The figures represent average values, but there is a small fraction of NP that sink deeper than 120 m.

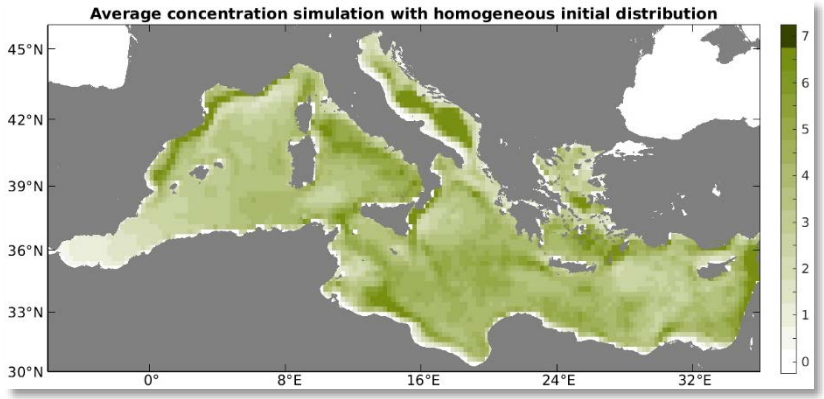
ii. The 1-year integration period is not enough for the NP to spread along the whole water column.

iii. The basin stratification also limits the depths reached by the NP.

iv. Vertical diffusivity is not included in the model

Comparison with previous studies

Average ML concentration from a simulation starting from a uniform particle distribution (kg·km^{-2})



Uniform initial distribution Simulation:

- 1 particle every three RCM grid point.
- 47942 particles I each run.
- 120 1-year simulations starting the first day of each month, between 2003 and 2013.

Previous studies:

Manusui et al. MPB 2015 → MNS15
Macías et al. MPB 2019 → MCS19
Zambianchi et al. FES 2017 → ZBC17
Liubartseva et al. MPB 2018 → LBS18

- MNS15, MCS19 and ZBC17 initial uniform ML distribution.
- Similar experiment performed for comparison.
- MNS15 use the same RCM (NEMOMED), lower resolution.
- MCS19 lower resolution configuration of GETM RCM.
- Better agreement with MNS15 → significant role of the RCM and the atmospheric forcing in the final spatial distribution of ML.
- ZBC17 used a current field derived from drifter observations.
- Better agreement with ZBC17 than MNS15 → improvements achieved by increasing the horizontal resolution.
- LBS18 use realistic distribution of ML sources. Lower resolution version of the NEMOMED GCM for the current field. Beaching and sedimentation processes included.
- Good agreement with LBS18 in the Western Mediterranean. More discrepancies in the Eastern basin, particularly in the Aegean Sea.

Conclusions

- The accumulation/dispersion areas of the floating and neutral particles are very similar although in the latter the particles are distributed across the upper 120 m with an averaged depth of 35 m.
- The highest concentrations of neutral particles are found in the Catalan continental shelf, the proximities of the Strait of Sicily and the Gulf of Gabes, the Adriatic Sea and the easternmost slope of the Levantine basin. For the floating particles large concentrations are also found in the Balearic Sea.
- The particles with negative buoyancy rapidly sink and reach the seafloor close to their sources, with no time to disperse.
- The higher variability in the ML concentration is observed in the regions of higher average concentration for both neutral and floating particles.
- There is a moderate seasonal variability of the ML concentration that redistribute the ML particles among the different sub-basins as a consequence of the seasonality the RCM current field.
- The comparison among different studies suggests that the main limitation of the modeling studies is linked to the lack of accurate information about the amount of ML released into the sea from different sources.

Future work

- Include the effects of population fluctuation in the coastal areas due to, for instance, the touristic seasonality, as well as the seasonal variability of the river discharge.
- Improve the model representation of the vertical displacements, through the inclusion of the vertical diffusivity and extending as much as possible the integration time. In this way the vertical displacements of the NP will be more accurately represented and the particles will have enough time to spread along the whole water column, leading to a better estimate of the cumulative effects of ML in the deeper layers.
- The results presented in this work can also be used in the design of field campaigns to study marine litter distribution. The sampling strategies should consider at least the seasonal variability of each region (i.e. by sampling in different seasons in places with strong seasonality). Also, if the campaign aims at a quantification of the total amount of plastics, measurements of the vertical distribution of the ML would also be necessary, in particular across the photic layer.