PLASTOCS - Plastic Transports in the Oceans: Concentrations, Sources and sinks

Projet LEFE-GMMC en partenariat renforcé avec Mercator 2023-2025

CONTRAT N°23141-MO-GMMC-PLASTOCS entre MERCATOR OCEAN et le CNRS

Contrat N° 269661 CCR PLASTOCS pour le CNRS-DR17

Rapport intermédiaire à mi-parcours – 12/06/2024

pages 1-16 : Présentation aux journées LEFE GMMC du 11/6/2024

page 17 : Publications

PLASTOCS - Plastic Transports in the Oceans: Concentrations, Sources and sinks

Thierry Huck, Christophe Maes, Bruno Blanke, Florian Sévellec, Raphaël Bajon, Patrice Bellec, Nicolas Rascle, (LOPS), Nicolas Grima (LMAP), Camille Richon (>LEMAR), Lisa Weiss (>IGE), Gwenaele Jan (>eOdyn), Xavier Couvelard (>SHOM)

Simon van Gennip, Stéphane Law Chune (Mercator)

projet "ouvert" : Julien Jouanno , Patrick Marsaleix (LEGOS), Yann Ourmières (MIO)

Projet LEFE-GMMC en partenariat renforcé avec Mercator 2023-2025

> présentation mi-parcours aux journées LEFE GMMC 11/6/2024 AM (visio)

Plan de travail

WP1 global

WP1.1 Simulations lagrangiennes à l’échelle globale 2D et 3D

WP1.2 Validation

WP1.3 Comparaison des approches lagrangiennes et eulériennes et complémentarité (Ariane, Parcels, NEMOTOP)

+ Processus de dispersion/concentration au fond de l'océan (Jonathan Gula, Clément Vic)

WP2 régional

WP2.1 Océan Indien (Christophe Maes, Lisa Weiss)

WP2.2 Golfe de Gascogne (Gwénaele Jan)

+ Méditerranée (Lisa Weiss)

WP3 processus

WP3.1 Couplage océan-vagues et dérive de Stokes (Stéphane Law Chune, Nicolas Rascle)

WP3.2 Vitesses verticales (Camille Richon)

WP3.3 Mélange vertical

+ Interactions avec la biogéochimie (Camille Richon)

WP1.3 Comparaison des approches lagrangiennes et eulériennes : méthode

Question : influence du mélange sous-maille sur la dynamique, notamment verticale ?
(... est-ce qu'on peut faire du lagrangien en 3D sans prendre en compte le mélange vertical ?)

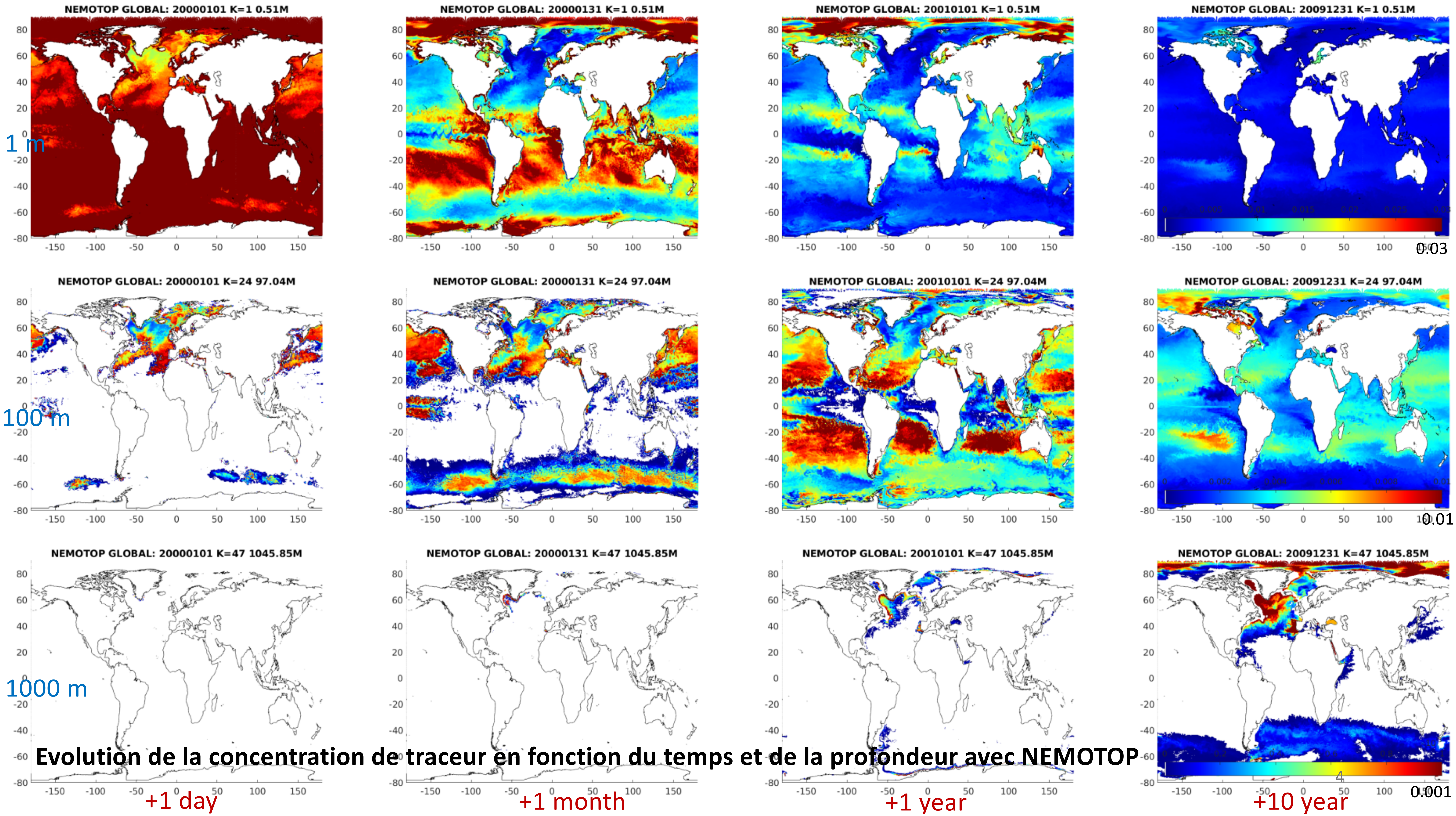
- Suivi de traceurs initialisés de manière uniforme en surface par une méthode eulérienne (NEMOTOP module traceur passif de NEMO) et lagrangienne (Ariane)

  - mêmes champs de vitesses (et mélange pour NEMOTOP) journaliers issus d'une simulation NEMO-eORCA025 IMHOTEP au 1/4° pendant 10 ans

  Ariane : initialisation de particules en surface au milieu de chaque point de grille
  NEMOTOP : initialisation d'un traceur passif à 1 dans la couche de surface, 0 ailleurs

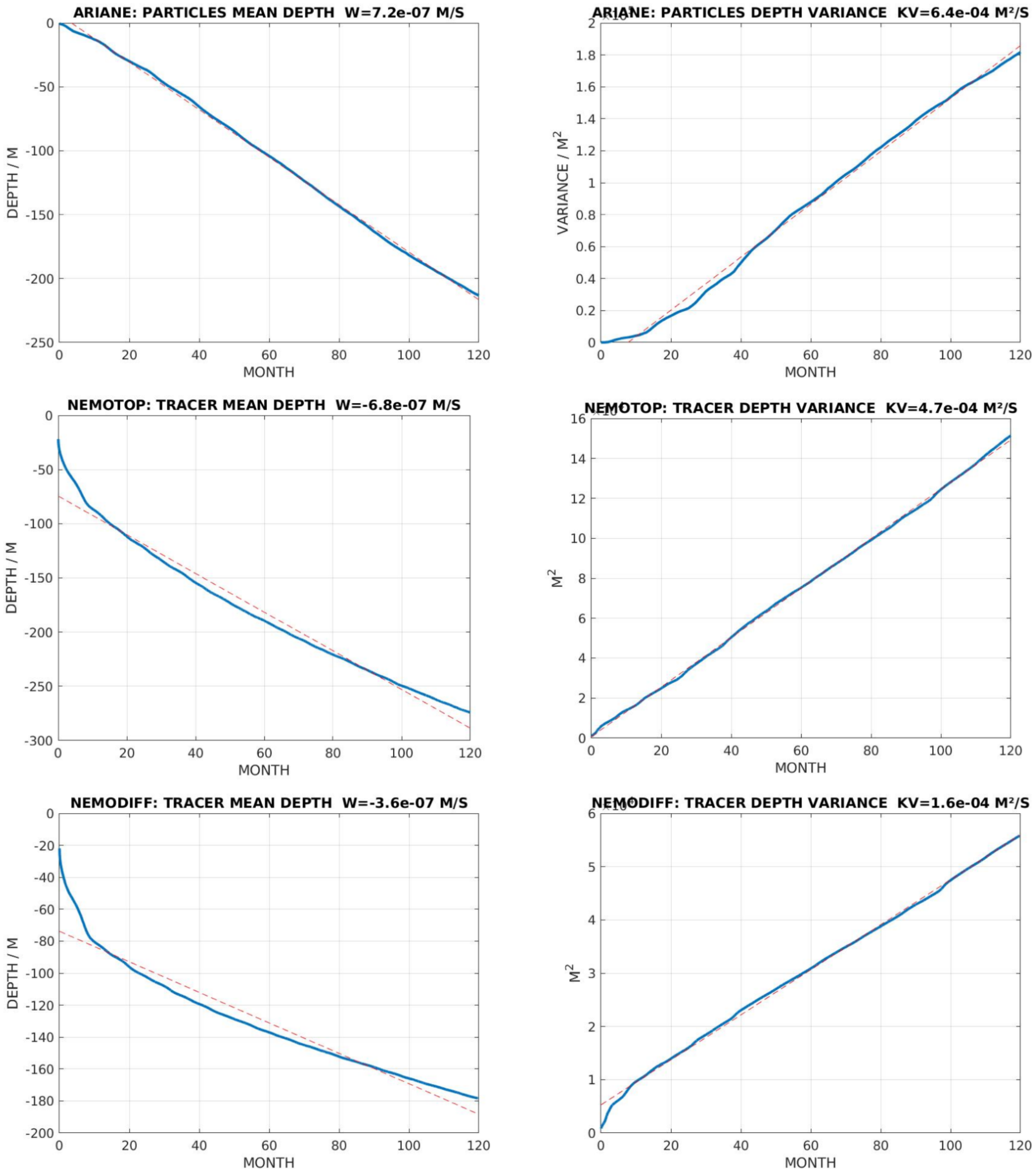
  Diagnostics > suivi de la profondeur moyenne des particules / distribution de traceurs et de la variance de profondeur

> stage M2 d'Anne Gaymard en 2023 au LOPS : Comparison of advective and diffusive processes for the vertical dynamics of microplastics. Encadrement : T. Huck, F. Sévellec, C. Talandier, B. Blanke, C. Richon. Financement ISblue.



Evolution de la concentration de traceur en fonction du temps et de la profondeur avec NEMOTOP

WP1.3 Comparaison des approches lagrangiennes et eulériennes : résultats



Profondeur moyenne des particules / distribution de traceurs (à gauche) et variance de profondeur (à droite) en fonction du temps pour

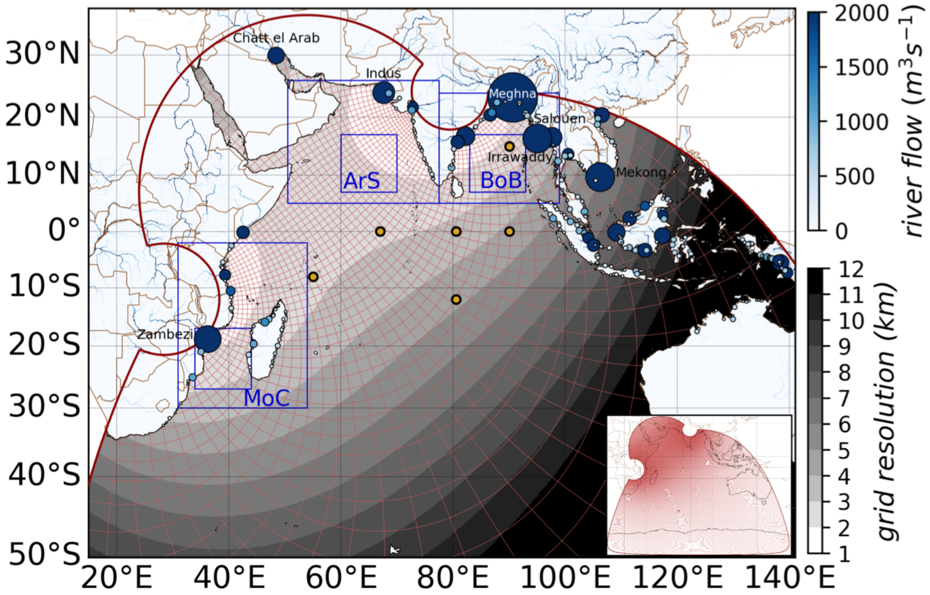
- Ariane (lagrangien) (en haut)
- NEMOTOP (eulérien) = advection + diffusion (au centre)
- NEMODIFF = NEMOTOP avec diffusion seulement (en bas)

> temps courts (jours) : approfondissement rapide en eulérien dans la couche de mélange (inexistant en lagrangien)

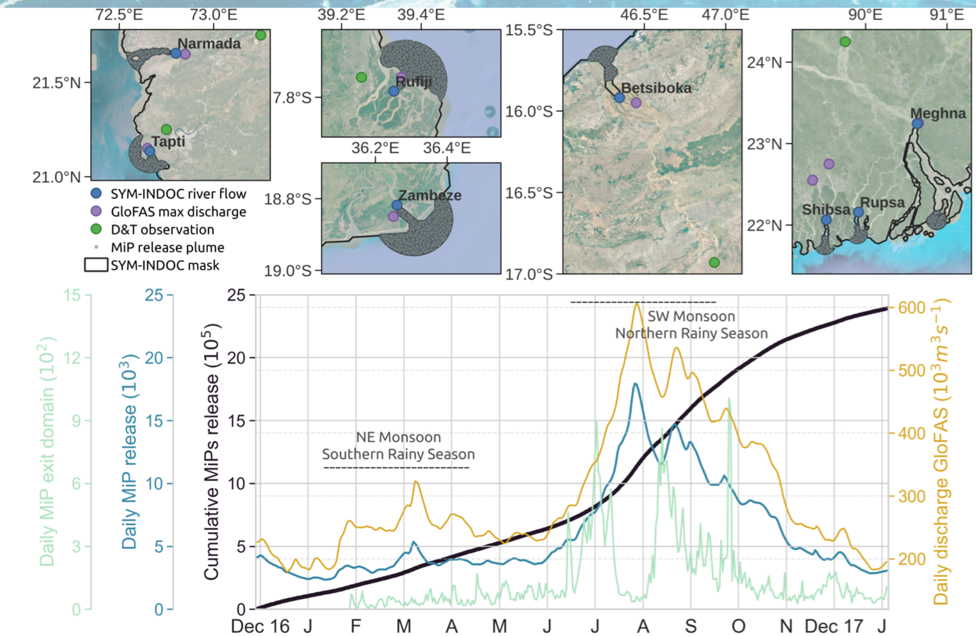
> temps longs (années) : comportement surprenamment similaire, avec un approfondissement plus rapide et une dispersion verticale légèrement plus importante en lagrangien ? à comprendre...

Attention aux échelles verticales différentes à droite :
2e5 en haut, 16e4 au milieu, 6e4 en bas.

WP2 Dispersion des MPs dans l'Océan Indien : méthode

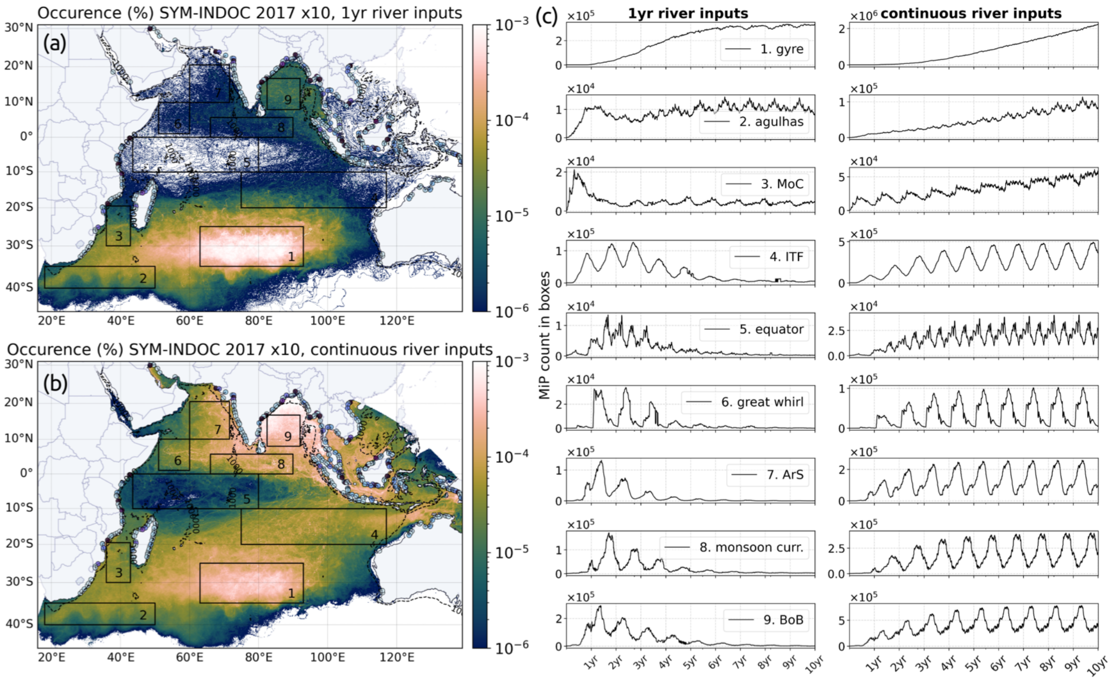


- dev **regional config.** hydrodynamic model **SYMPHONIE**
- Telescopic **grid** (3000x2800) 1 to 23 km - GEBCO21 with manual verif. for river, islands, straits - 60 VQS verti. lev.
- **Forcing** atm ERA5 - ini and obc GLORYS - tide FES2014 - 414 daily river discharges > 100 $m^3 s^{-1}$ GloFASv4 - Stokes drift WAVERYS
- **Validation** SST, SSS, SLA, rivers with RAMA buoys, OSTIA, CCI, ALTI, HydroSHEDS, D&T clim.
- Run **5 years 2016-2020** (looped)



- SYMPHONIE **Lagrangian** module - RK2 scheme
- MP **vertical rising velocities** (0.1 to 100 mm s^{-1}) for 3D floating trajectories (from Waldschläger & Schüttrumpf 2019)
- **Vertical turbulent diffusion** (from Guizien et al. 2012)
- MP **river source scenario** (from Weiss et al. 2021) with river basins GIS (HydroSHEDS), population densities (CIESIN18), daily discharges (GloFAS)
- **Daily MPinputs** (2.4 million particles / yr)

WP2 Dispersion des MPs dans l'Océan Indien : résultats

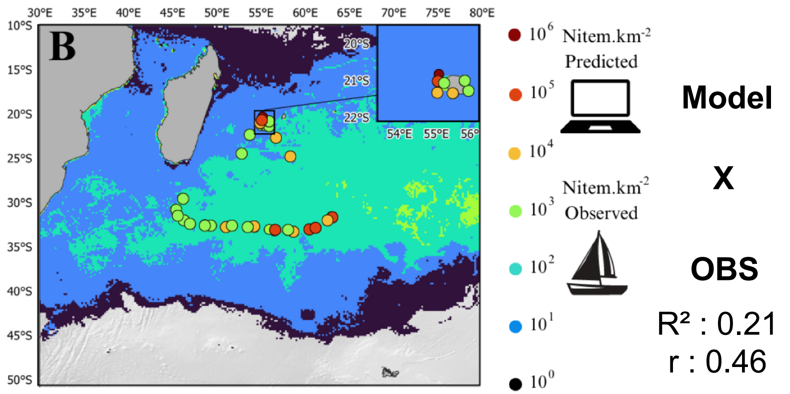


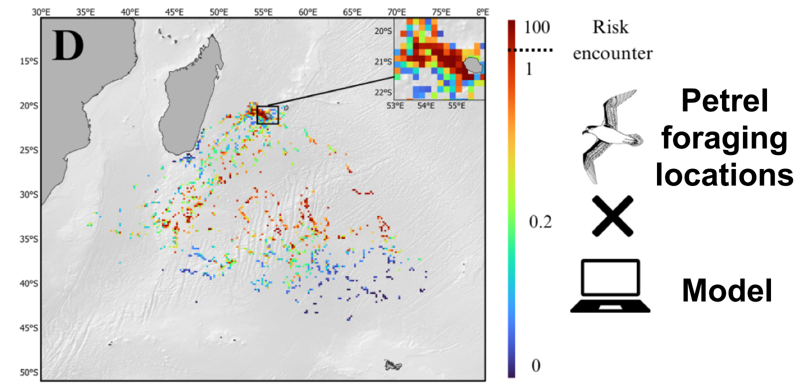
correlation R	1. Gyre	2. Agulhas	3. MoC	4. ITF	5. Equator	6. Somali	7. ArS	8. Monsoon curr.	9. BoB
Salinity	-0.87	0	0.53	0.33	-0.41	-0.82	-0.18	0.61	0.40
Relative Vorticity	0.79	0.20	-0.18	-0.58	-0.59	0	0.29	-0.25	-0.79
Vorticity^2	0.63	-0.17	0.58	0.97	-0.35	0	0.32	0	0.15
Kinetic Energy	0	0	-0.54	0.88	0	0	0.25	0	-0.32

> Weiss et al. (in prep for Geoscientific Model Development) **High resolution modeling of the Indian Ocean circulation to study the Lagrangian dispersion of riverine plastic debris**

Lisa Weiss, postdoc IRD LEGOS-LOPS, avec M. Hermann, P. Marsaleix, M. Bompoil, T. Duhaut, C. Maes

Plastic ingestion risk hotspots





Thibault et al. (submitted to Marine Environmental Research) **Seabirds as bioindicators of plastic pollution in the tropical Western Indian Ocean: a multifaceted approach**

WP2 Golfe de Gascogne

- expériences lagrangiennes avec Ariane avec particules issues des 4 principaux fleuves Seine Loire Gironde Adour
- courants issus de simulations numériques du Golfe de Gascogne avec Mars3D sur la période 2001-2010
- confrontation aux comptages de macro déchets sur 46 plages coordonnés par le CEDRE (MSFD/OSPAR)
- la comparaison aux données d'échouage reste un exercice difficile, d'autant plus qu'une partie des plastiques échoués sur nos côtes proviennent d'ailleurs

Gwenaele Jan (SHOM > eOdyn), Guillaume Charria, Christophe Maes, Nicolas Grima (LOPS), Camille Lacroix, Silvère André (CEDRE)

River input dispersion of floating neutral particles in the Bay of Biscay
How reliable is a regional ocean model?

Gwenaële Jan [1], Camille Lacroix[2], Guillaume Charria[3], Christophe Maes[4], Silvère André[2], Nicolas Grima[5]
[1]Shom, LOPS; Gwenaele.Jan@shom.fr [2] Cedre; Camille.Lacroix@cedre.fr [3]Ifremer LOPS; Guillaume.Charria@ifremer.fr [4]IRD, LOPS; Christophe.Maes@ird.fr [5]Cnrs, LOPS; Nicolas.Grima@univ-brest.fr

Framework

The riverine contribution of marine debris represents a part to be considered in the mass balance of plastic in the ocean. Numerical modelling completes the observation that should has to be regular and dense. These 2 approaches constitute a key to understand the main pathways followed by particles in the ocean. The numerical result has to be able to be confronted with the observation, which remain sparse, as well as facing the defined hypothesis about the source of particles function, seeding the model. This study examines this issue by questioning the correlation between model and observation and its observability. How to establish a robust comparison criterion that is the most adapted to these 2 types of data, statistically independent?

Materials and method
Observations

- 3 years of beach macro-litter counting at 46 stations distributed along the French coastlines (Fig.1) from January 2019 to December 2021. Part of France national beach litter monitoring program, coordinated by Cedre and conducted in the context of the European Marine Strategy Framework Directive (MSFD) and OSPAR Convention (Lacroix et al., 2022).
- Data are collected using the OSPAR/MSFD monitoring protocol, ensuring regular sampling at the same locations and a harmonized counting method on these sites (Galgani et al., 2013; OSPAR, 2020 ; Cedre and partners)

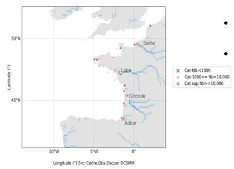


Fig.1: In situ counting of macro plastic over 46 stations located along the French Atlantic Channel coast, over time period: 01 January 2019 - 31 December 2021. Povided by Cedre. The stars locate the particles river inputs.

Numerical model

- Current fields are from Mars3D numerical experiments over 2001-2010 (Charria et al. 2017)
- Lagrangian code is ARIANE (Blanke et al. (*1997*)

From Lagrangian and ocean dynamics model outputs, a particle tracking model approach (PTM) allows tracking and the analysis of the marine particles' pathways, convergence, shear, outflow zones and stranding coastal areas. The distribution scenario is built considering the river flows from the 4 main sources considered. 1 million particles are released over 5 years, every week. Release function follows a barycentric distribution around each river mouth.

Criterion is defined for a set of selected sub-regions of interest (R.O.I). Areas A,B,C (Fig. 2). Its normalization by the number of measurements over the full time period and for all regions of the domain is expressed as a Relative Comparison Criteria (RCC). IRCC is for in situ RCC whereas MRCC is for Model RCC

$$RCC = \frac{\left[\frac{N_{partic.}}{km^2}\right]_{per R.O.I}}{\left[\frac{N_{partic.}}{km^2}\right]_{allregions}}$$

The 2 criteria, model vs. observation, are compared . The question we ask here is whether the MRCC able to be robust enough to be used as an indicator of major pathways of neutral lagrangian particles like macro plastics?

Result: RCC derived from in situ data vs. RCC from model for stranding concentration

3 regions represent 3 basins with distinct dynamics:) the Channel (area A), the Celtic Sea (area B) and the Bay of Biscay (area C) (Fig.2)

MRCC and IRCC, model versus observed stranding criterion, indicates a relative correlation, considering the hypothesis and uncertainty from both model and in situ data. In Celtic sea (area B), model and observation provide a stranding concentration that differs from 3.3 %. In BoB (C) this difference is 15.0 %. This is not insignificant but given the assumptions and the heterogeneity between the sampled observations and the numerical concentrations, it is encouraging. Difference on stranding in the Channel (region A) is partly due to the fact that this tidal region is located near the North model boundary so that particles carried out of the domain, are not re-circulating by some inflow.

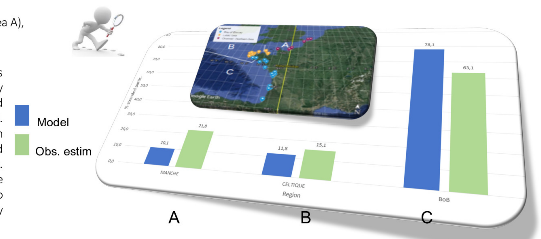
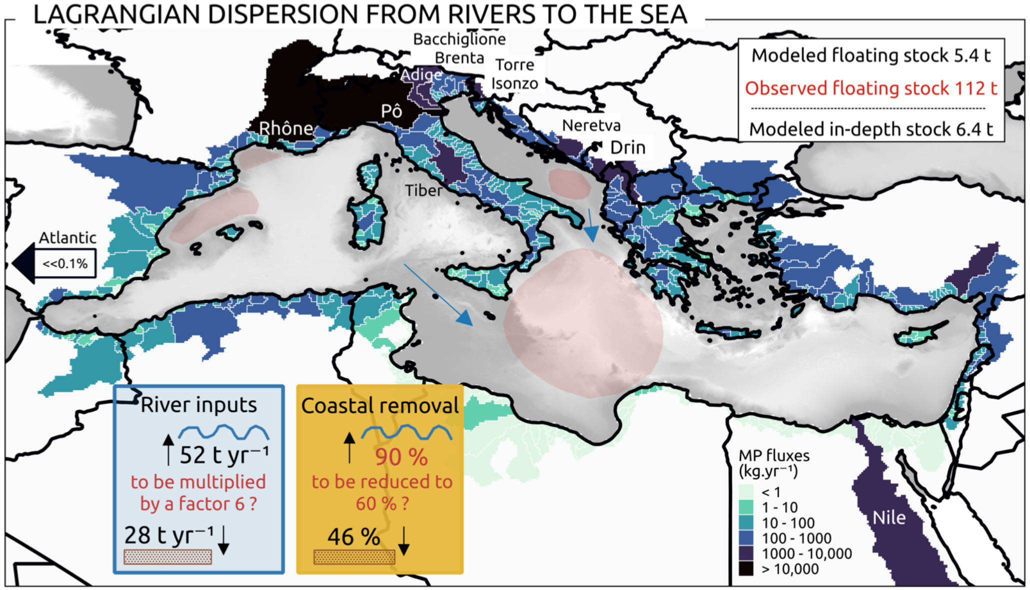


Fig.2: Histogram of percentage of stranded particles from system ocean numerical model + lagrangian code (MRCC) face to the observation of in situ counting particles in reference to OSPAR methodology (IRCC).

Additional points: A total of 55.72% of the particles drift before beaching, 43.08% leave the domain, and 0.37% remain offshore and do not run aground on the coasts. 0.24% remain in a coastal band, between the coast and 1-km from the coast and not moving particles represent 0.59% of the total number of particles, meaning immediately stranded.

References:
- *Blanke, B., Raynaud, S., 1997. Kinematics of the pacific equatorial undercurrent: An Eulerian and Lagrangian approach from GCM results. J. Phys. Oceanogr. 27, 1038–1053.*
- *Charria, G.; Theetten, S.; Vandermeirsch, F.; Yelekç, Ö. Audiffren, N., 2017. Ocean Sci., vol. 13, pp.777–797*

WP2 Dispersion des MPs en Méditerranée

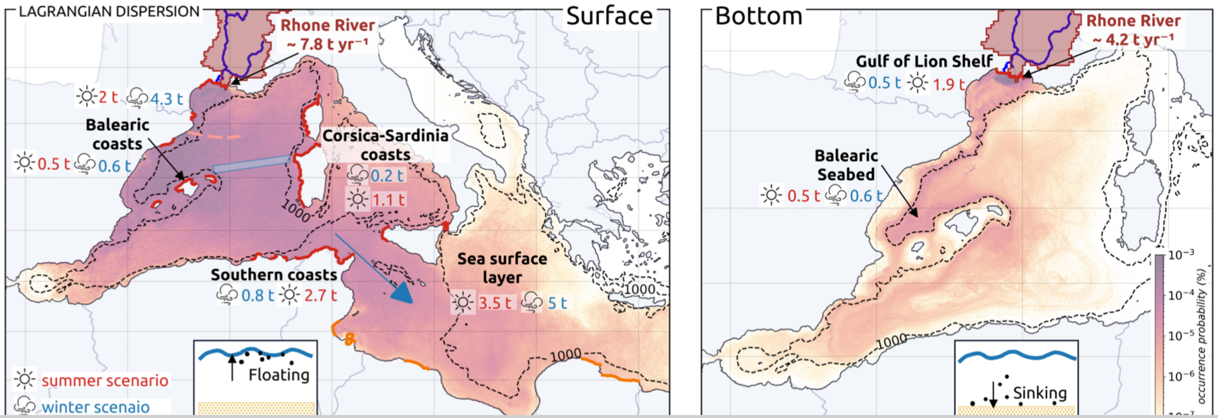


Weiss et al. (under review in ESPR) **From source to sink: Part 1. Characterization and Lagrangian tracking of riverine microplastics in the Mediterranean Basin**

- Ocean modeling & Lagrangian tracking with SYMPHONIE
- **Source scenario** 80 t yr^{-1} / 682 10^9 MPs (Weiss et al. 2021)

► model MP inputs for 9988 rivers outflows at global scale and 549 at the MED scale are provided in geospatial vector data

- 65% **floating** and 35% **sinking** particles
- 10 main rivers account for 52% sources
- Observed vs Modeled floating stocks
- **Stranding** and **shelf retention** statistics



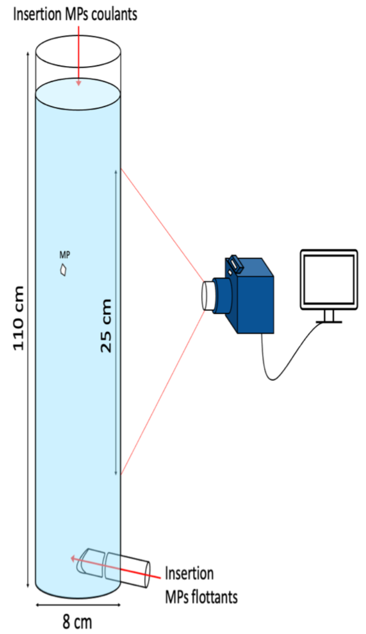
Weiss et al. (under review in ESPR) **From source to sink: Part 2. Seasonal dispersion of microplastics discharged in the NW Mediterranean Sea by the Rhone River in southern France**

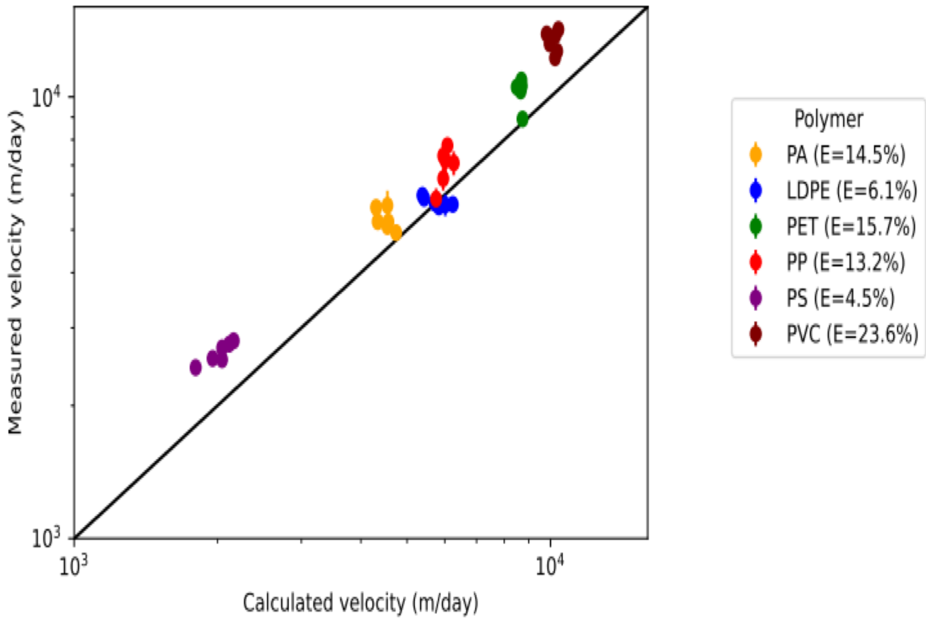
- Mesoscale and sub-mesoscale drive the MP dispersion, with strong seasonal variability, from the Gulf of Lion to the frontal zone
- High retention of sinking MPs (up to 50%) in the Gulf of Lion near the mouth, accentuated in winter

Lisa Weiss, en collaboration avec CEFREM et LEGOS: C. Estournel, P. Marsaleix, W. Ludwig, JF Ghiglione, M. Constant, G. Mikolajczak

WP3.2 Influence of MP morphology on vertical velocity

- Lab measurement of MP vertical velocity
- Good agreement with theoretical velocities (Zhiyao et al., 2008)

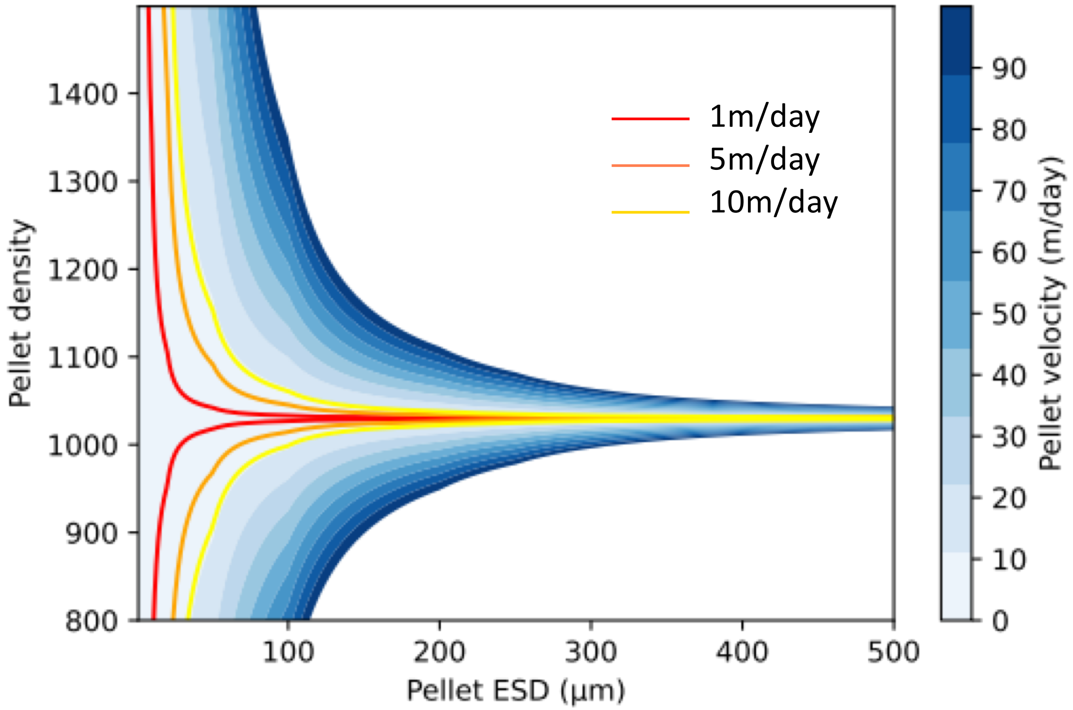




Measurements with industrial pellets (Ø ~3mm)

(Richon et al., *in prep*)

WP3.2 Influence of MP morphology on vertical velocity



- Lab measurement of MP vertical velocity
- Good agreement with theoretical velocities (Zhiyao et al., 2008)
- Description of the theoretical morphological space of neutral MP
- → Small MP and/or MP with density close to seawater

(Richon et al., *in prep*)

WP3+ Distribution and potential impacts of MP on ocean biogeochemistry

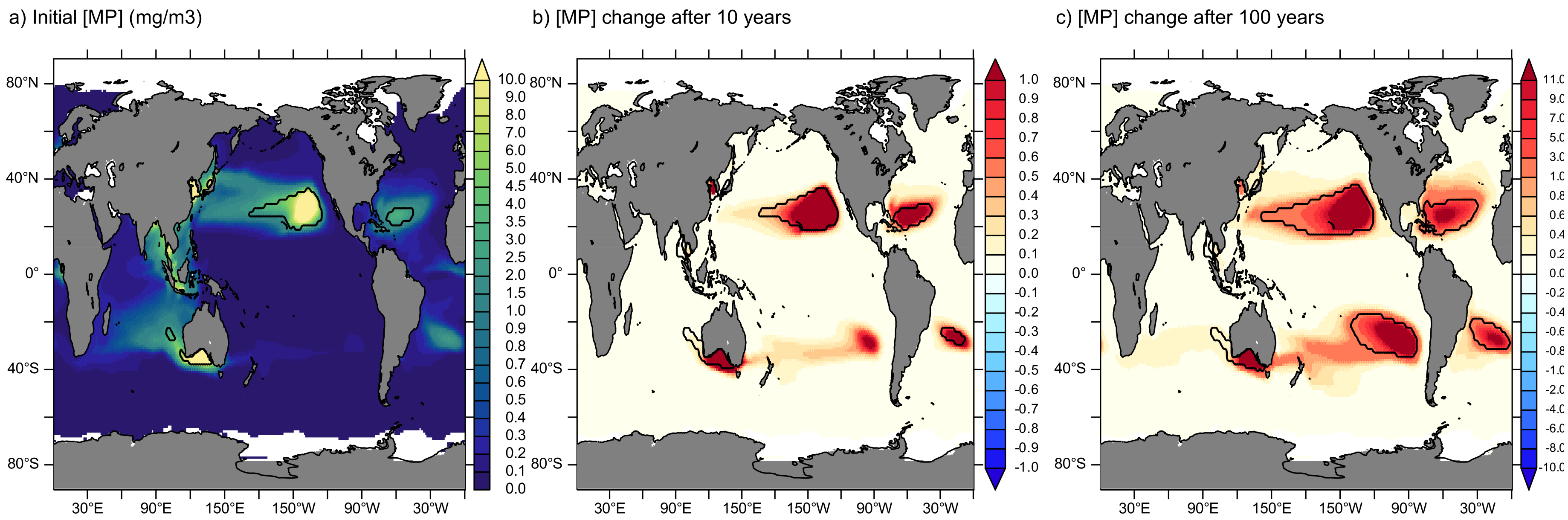
- Experimental evidence of MP impacts on zooplankton grazing rates (-25 to -75 %, Yu et al., 2020)
- Modeling MP impacts on grazing

$$If \frac{[MP]}{[food_j]} > \alpha :$$

With α = 0.5*

Constant MP inputs (rivers) for 100 years

$$Tot.Grazing = (\sum_j grazing_j \times 0.5)$$



Camille Richon, ISblue postdoc Fellowship, LOPS

* Sensitivity tests on α were performed

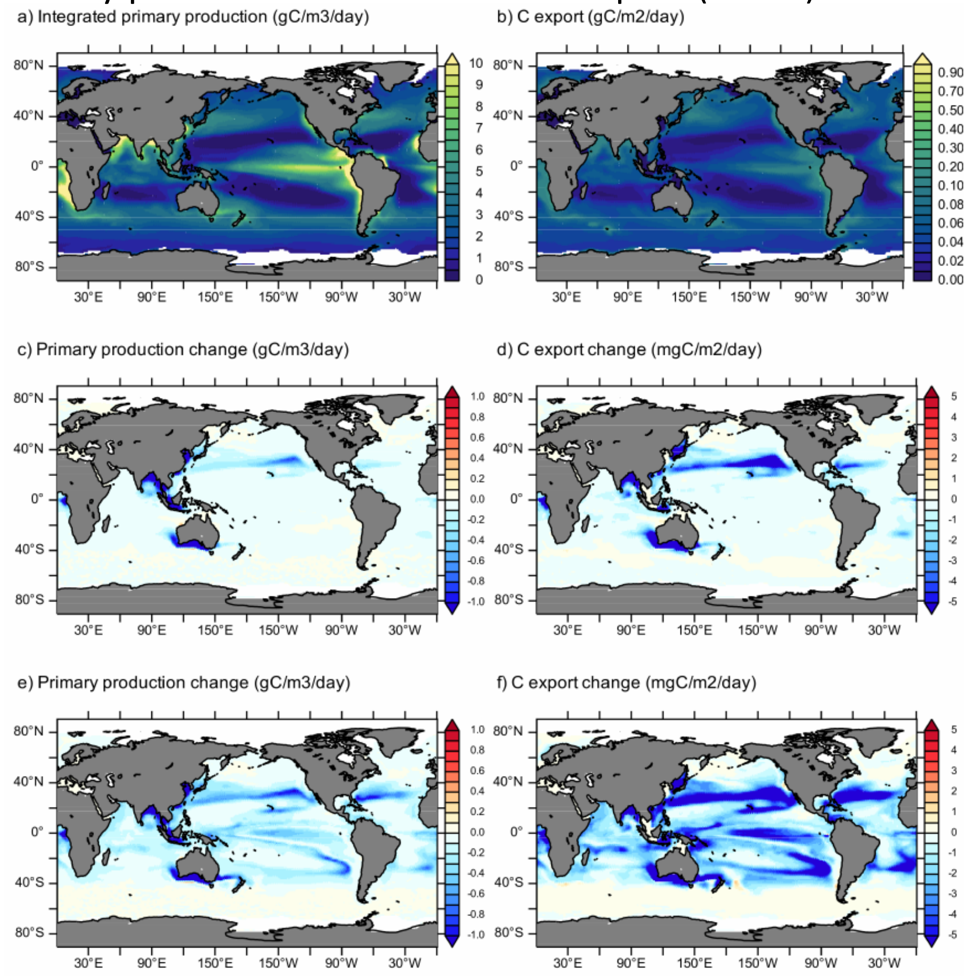
WP3+ MP impacts on grazing lead to feedbacks on whole surface C cycling

Primary production | C export (100m)

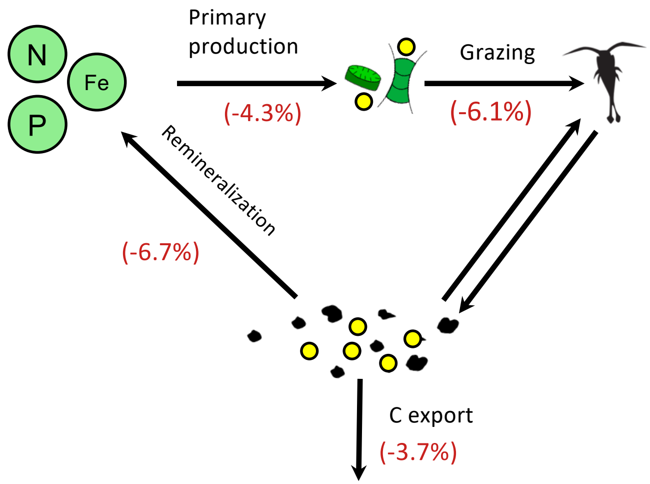
CTL

EXP-CTL (Short term)

EXP-CTL (Long term)



MP impacts on surface PP and C export (0-100m)



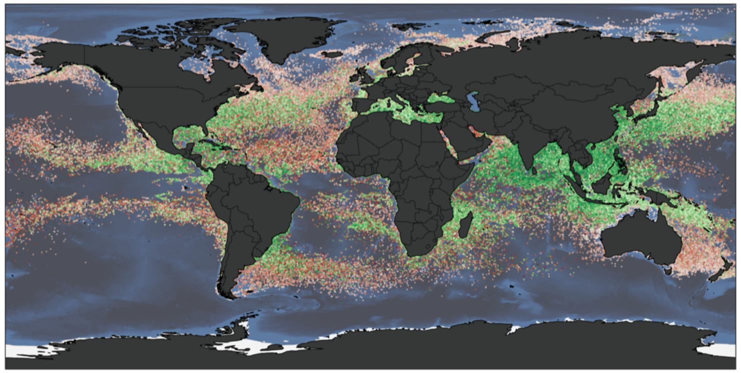
MP impacts on C cycling:

- Limited to most contaminated regions on ST (mostly oligotrophic)
- Spread to ~ mid latitudes on LT
- Slight increase in C fluxes in the high latitudes (f-ratio)

Ocean plastics: From modelling to decision making

Case study for Digital Twin of the Ocean

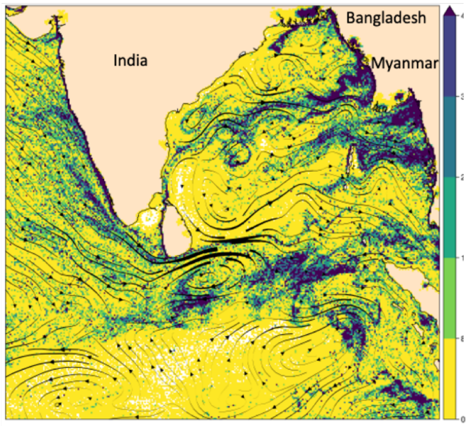
1. Lagrangian transport of plastics in the ocean



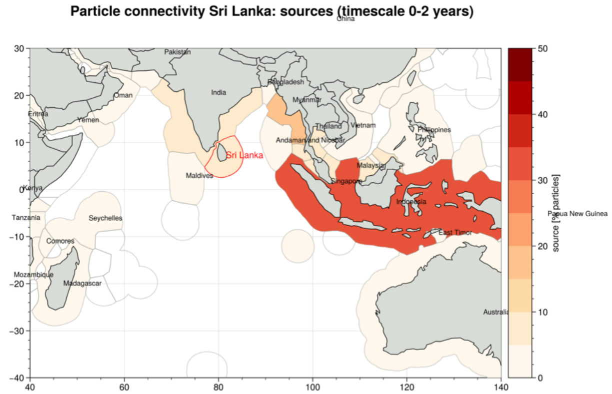
- River discharges (Lebreton 2019)
- Coastal discharges (Meijers 2021)

Model: 6h-Ocean real time surface currents +
Stokes drift from wave model (2010-19)
Plastic particles: passive buoyant particles

2. Monitoring plastic abundance,



… and quantifying exposure



3. Enable users to assess What if scenarios:
Evaluate impact of plastic removal action plans
e.g. focus on coastal vs riverine?

EDITOModelLab

Perspectives

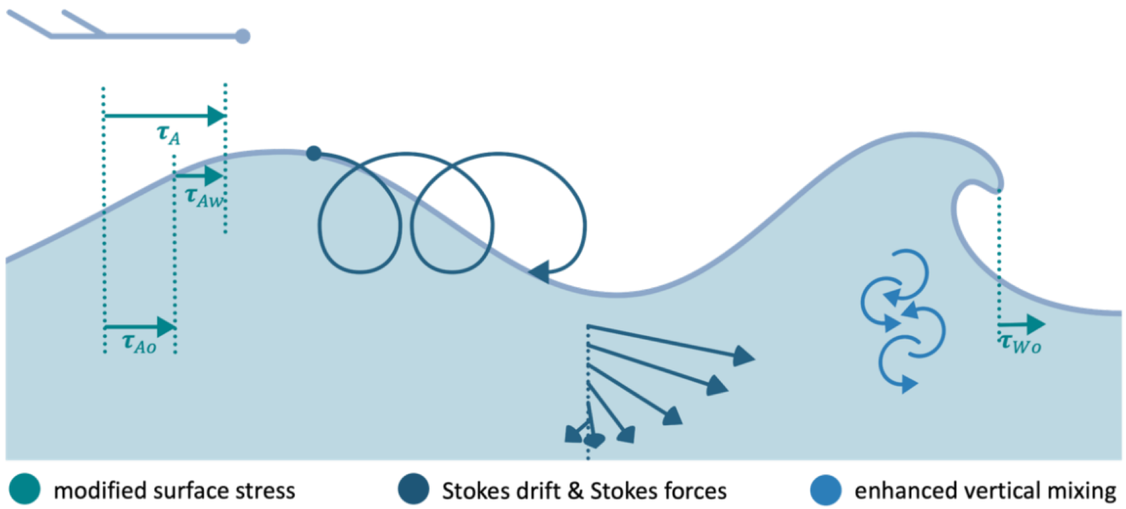
- Improve understanding and representation of ocean processes (from global to very local) on plastic drift, and impact of interactions with atmosphere and waves

- Better representation of plastic input through rivers (flux, seasonality, …)

- Extend understanding to all types of plastics (beyond simply buoyant).

LEFE-GMMC PLASTOCS contributes to improving understanding of plastic dynamics in the ocean and provide the tools necessary for better monitoring of ocean plastics

WP3.1 Couplage avec les vagues



- utilisation de simulations océaniques et couplées océan-vague globales au ¼° réalisées par Stéphane Law-Chune à Mercator sur plusieurs années
- comparaison aux résultats obtenus précédemment avec les simulations de Xavier Couvelard

Table 2: Performed types of Lagrangian surface dispersal simulations. For each simulation type we employed a different combination of velocity fields from the non-coupled (superscript nc) and coupled (superscript c) model experiments, which represents a different combination of the theoretical non-wave-driven and wave-driven velocity components.

Lagrangian simulation type	**Lagrangian velocity components**	
	theoretical components	**employed modelled velocity fields**
old standard	$u_L = u_{Enw}$	$u_L = u_E^{nc}$
basic approximation	$u_L = u_{Enw} + u_S$	$u_L = u_E^{nc} + u_S^c$
best guess	$u_L = u_{Enw} + u_{Ew} + u_S$	$u_L = u_E^c + u_S^c$
sensitivity simulation	$u_L = u_{Enw} + u_{Ew}$	$u_L = u_E^c$

Source : Rühs et al. 2024 EGUsphere

Publications

Bajon, R., T. Huck, N. Grima, C. Maes, B. Blanke, C. Richon, X. Couvelard, 2023: Influence of waves on the three-dimensional distribution of plastic in the ocean. Marine Pollution Bulletin, 187, 114533, doi:10.1016/j.marpolbul.2022.114533.

Richon, C., Kvale, K., Lebreton, L., Egger M., 2023: Legacy oceanic plastic pollution must be addressed to mitigate possible long-term ecological impacts. Micropl. & Nanopl. 3, 25, doi:10.1186/s43591-023-00074-2.

Richon, C., T. Gorgues, M. Cole, I. Paul-Pont, C. Maes, A. Tagliabue, C. Laufkötter, 2024: Model exploration of microplastic effects on zooplankton grazing reveal potential impacts on the global carbon cycle. Environ. Res. Lett., in press, doi:10.1088/1748-9326/ad5195.

Publications en cours

Capuano, T.A., M. Hermann, D. Dobbler, A. Koch-Larrouy, L. Weiss, C. Maes, 2023: River freshwater effects on the South-East Asian ocean dynamics. Geoscience Letters, submited.

Jan, G., C. Lacroix, G. Charria, C. Maes, S. André, N. Grima, 2024: River input dispersion of floating neutral plastics in the Bay of Biscay, North-East Atlantic. Journal of Marine Science and Engineering, in revision.

Weiss, L., et al., 2024: From source to sink: Part 1. Characterization and Lagrangian tracking of riverine microplastics in the Mediterranean Basin. Environmental Science and Pollution Research, submitted.

Weiss, L., et al., 2024: From source to sink: Part 2. Seasonal dispersion of microplastics discharged in the NW Mediterranean Sea by the Rhone River in southern France. Environmental Science and Pollution Research, submitted.

Weiss, L., et al., 2024: High resolution modeling of the Indian Ocean circulation to study the Lagrangian dispersion of riverine plastic debris. Geoscientific Model Development, in preparation.

Rapports

Gaymard, A., 2023: Comparison of advective and diffusive processes for the vertical dynamics of microplastics. Rapport de stage de M2 EDSML/POC, UBO, encadrement T. Huck, F. Sévellec, C. Talandier, B. Blanke, C. Richon.