A brief review of marine debris modeling at the regional and global scales

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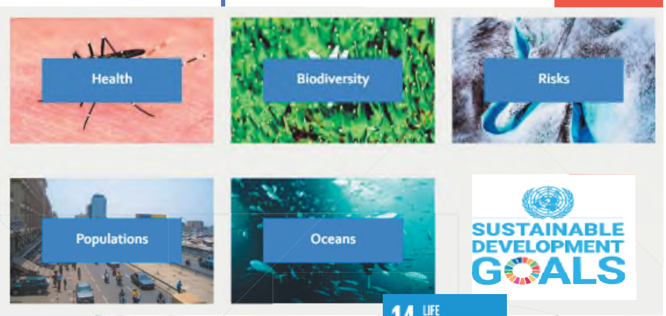
with inputs from Elodie Martinez, Bruno Blanke, Nicolas Grima, Thierry Huck, Gwenaele Jan, Guillaume Charria, Sebastien Theetten, Joël Sudre, René Garello, François Galgani, Laurent Le Breton, Erik van Sebille, Johnatan Gula, Fabrice Ardhuin…

APEC "Capacity Building on Global Marine Debris Monitoring and Modeling: Supports Protection of the Marine Environment"

Bali, Feb. 2020

What is IRD? A crucial player in providing scientific advice on the major challenges of development



Consult our entire annual report on

http://rapport.ird.fr/en.php

OUTLINE

GENERAL INTRODUCTION: a focus on the plastic crisis…

TAKE HOME MESSAGES:

We need to know the time variability of surface currents to adequately address the long distance connectivity and pathways,

We need to consider high-resolution horizontal currents (mesoscale at least) to estimate the time transfer on specific pathways,

We need to evaluate more accurately the source scenario (and the sinks) of surface floating litter to access the distributions at global and regional scales

SOME CONCLUSIONS AND PERSPECTIVES (in ocean modeling and observations)

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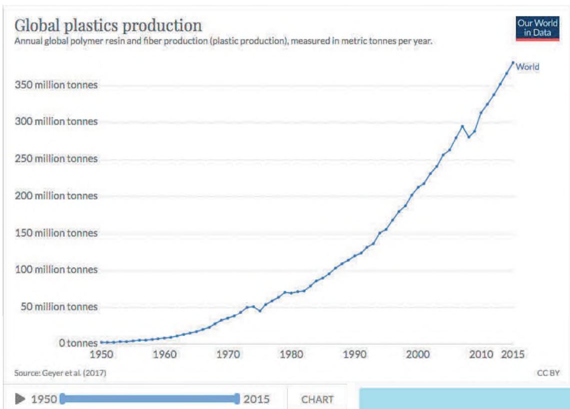


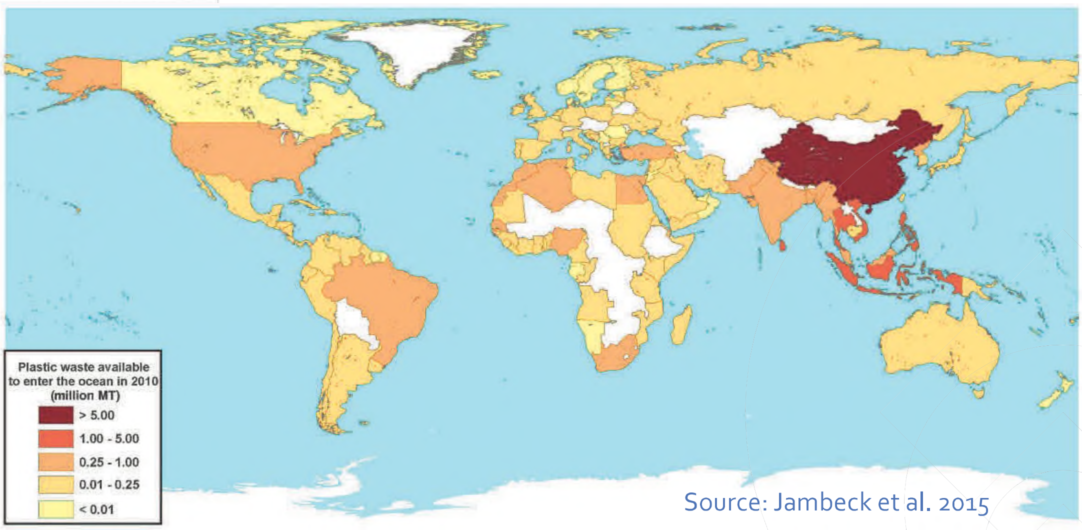
THE PLASTIC ISSUE

in 2018, 348 million tonnes of plastics production (Plastics Europe 2019)

55% are discarded in 2015 (not recycled, not incinerated)

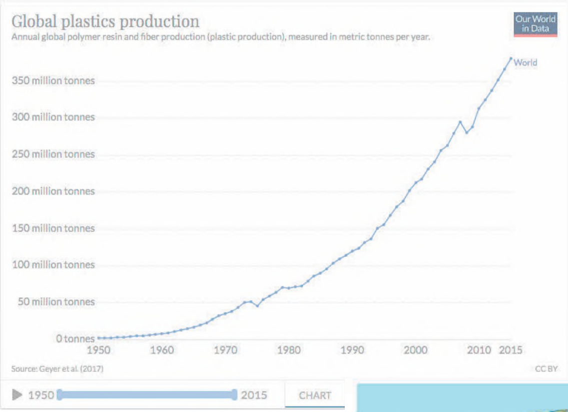
« 3% » enters into the oceans :
Global plastic waste that enters the ocean was around 8 million tonnes in 2010

Top-5: China, Indonesia, Philippines, Vietnam, Sri Lanka…



Source: Jambeck et al. 2015

Fig. 1. Global map with each country shaded according to the estimated mass of mismanaged plastic waste [millions of metric tons (MT)] generated in 2010 by populations living within 50 km of the coast. We considered 192 countries. Countries not included in the study are shaded white.



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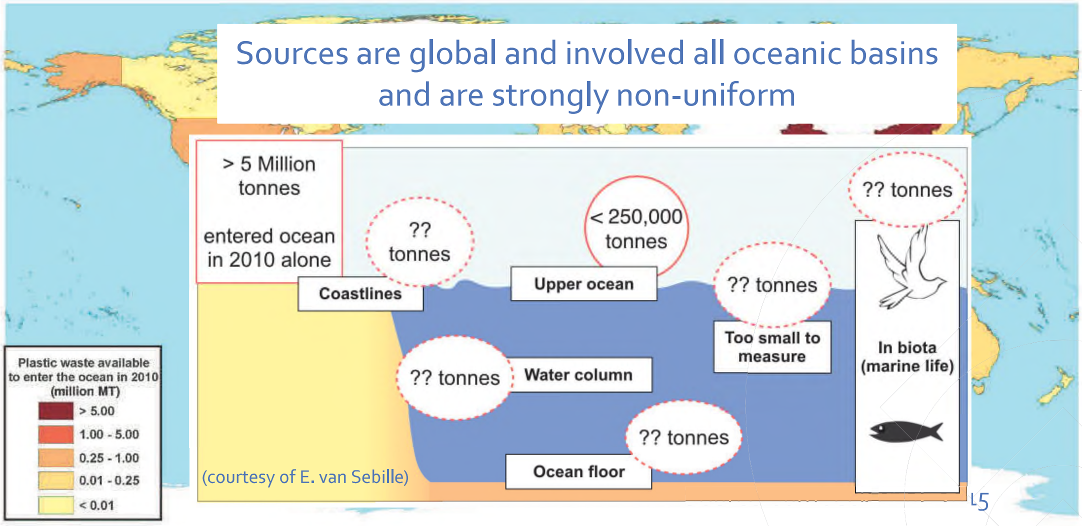

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5

THE PHYSICS OF THE (PLASTIC) DISPERSION IN THE OCEANS

HOW COMPLEX THE PROBLEM IS?

Source:
The physical oceanography of the transport of floating marine debris
van Sebille *et al.*, ERL, 2020

SCOR WG 153
Floating Litter and its Oceanic TranSport Analysis and Modelling (FLOTSAM)
Chair: S. Aliani
Period : 2018-2020

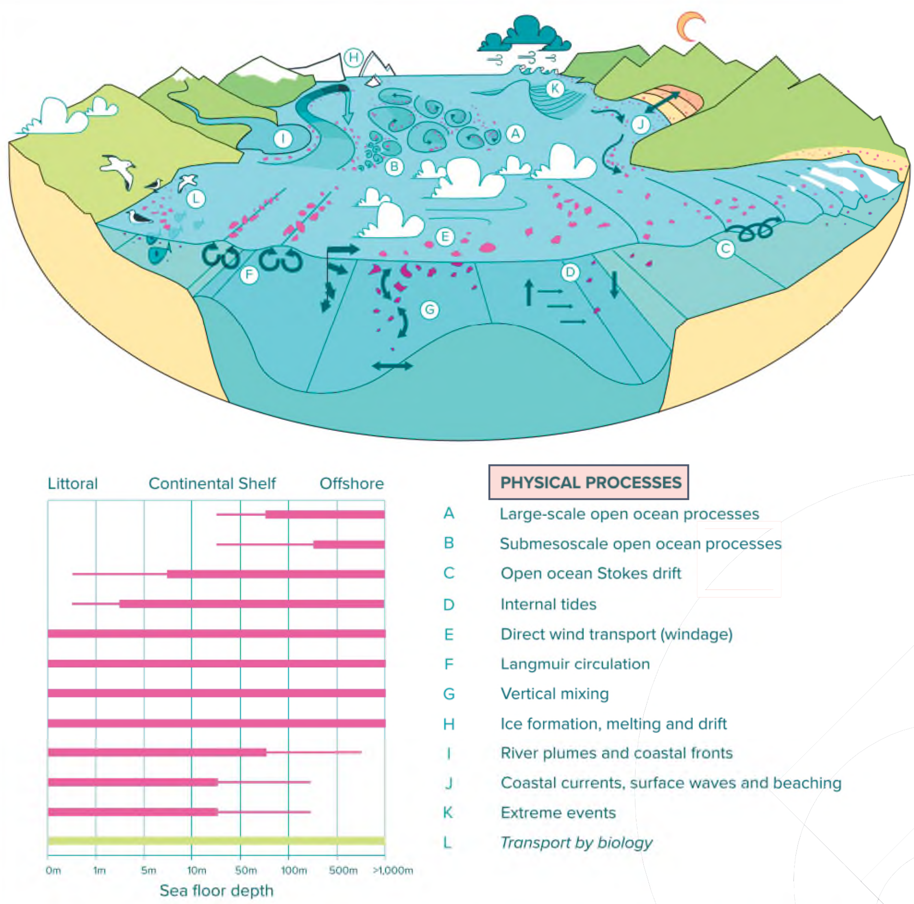


Figure 1. Schematic of the physical processes that affect the transport of plastic (pink items) in the ocean (top panel). The table (lower panel) identifies in which regions different processes are important. Thick pink lines in the table mean that the process is among the most important in that water depth, while thin pink lines mean that the process is only of secondary importance. Transport by organisms is not a physical process and therefore represented with a green line instead of a pink one.

OUTLINE

GENERAL INTRODUCTION: a focus on the plastic crisis…

<u>TAKE HOME MESSAGES</u>:

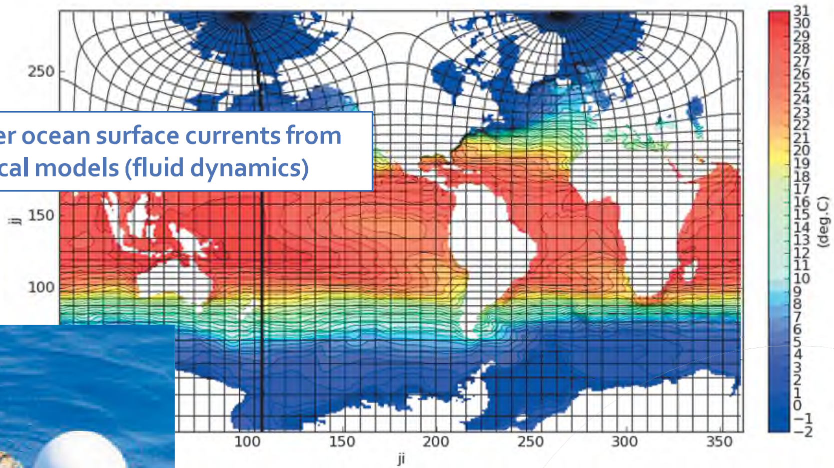
We need to know the time variability of surface currents to adequately address the long distance connectivity and pathways,

We need to consider high-resolution horizontal currents (mesoscale at least) to estimate the time transfer on specific pathways,

We need to evaluate more accurately the source scenario (and the sinks) of surface floating litter to access the distributions at global and regional scales

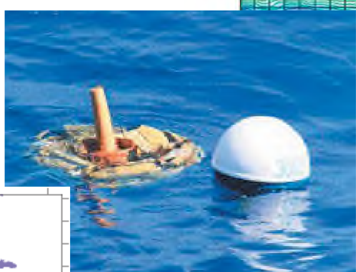
SOME CONCLUSIONS AND PERSPECTIVES (in ocean modeling and observations)

Lagrangian Pathways from surface currents

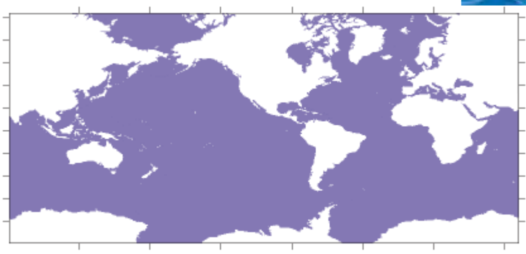


Consider ocean surface currents from numerical models (fluid dynamics)

Simulate the displacement of « fictive » drifters

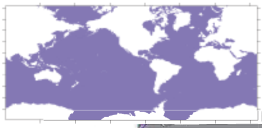


Consider a "release" scenario :
@t=0 c=1 on every model grid point



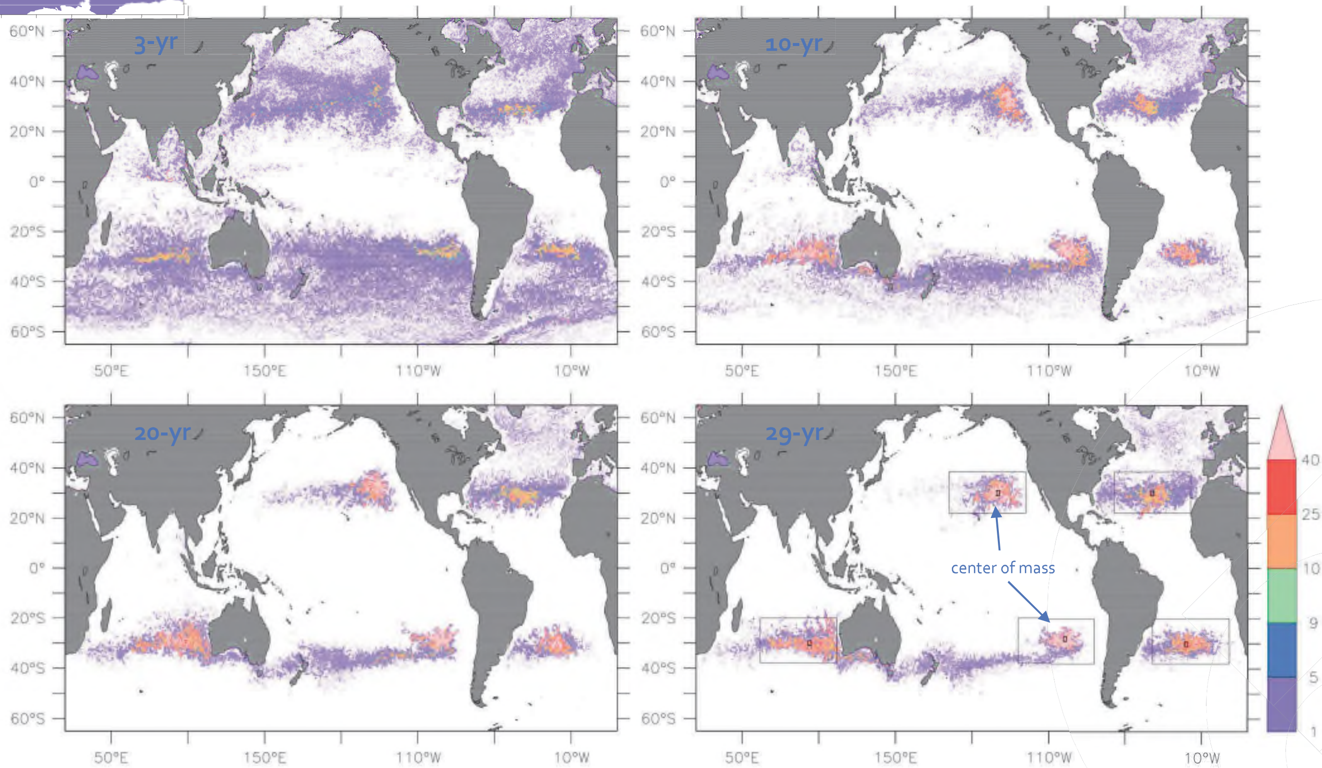
More details in Maes *et al.* GRL (2018):

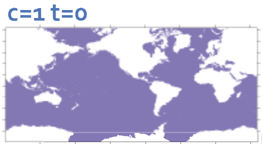
Advection of 1 million particles uniformly distributed (1/4°), daily surface currents during the 1985-2013 period (29-yr), C-GLORSv5 reanalysis on ORCA025 (NEMO) from CMCC



Lagrangian Pathways from surface currents

Time evolution of the particle concentration per ¼° grid cell





Lagrangian Pathways from surface currents

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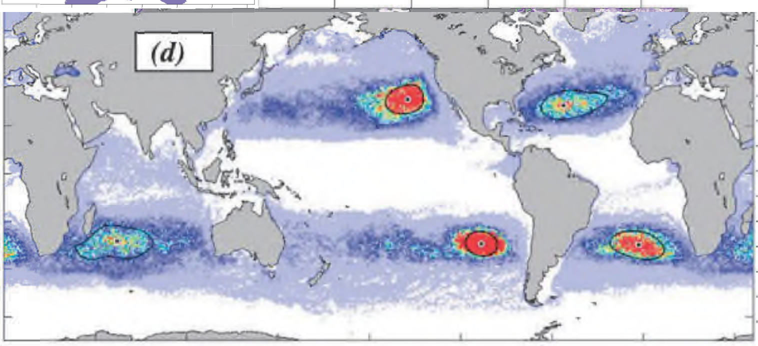
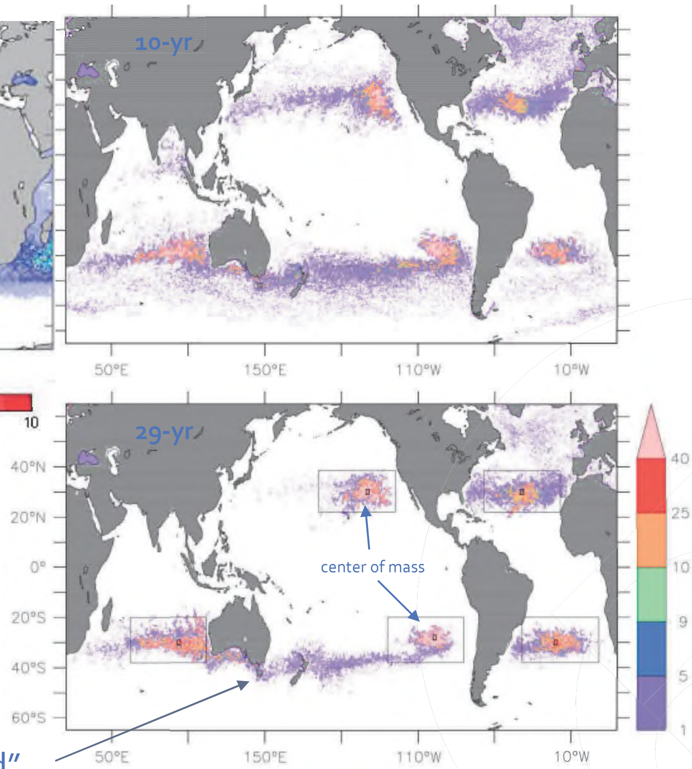


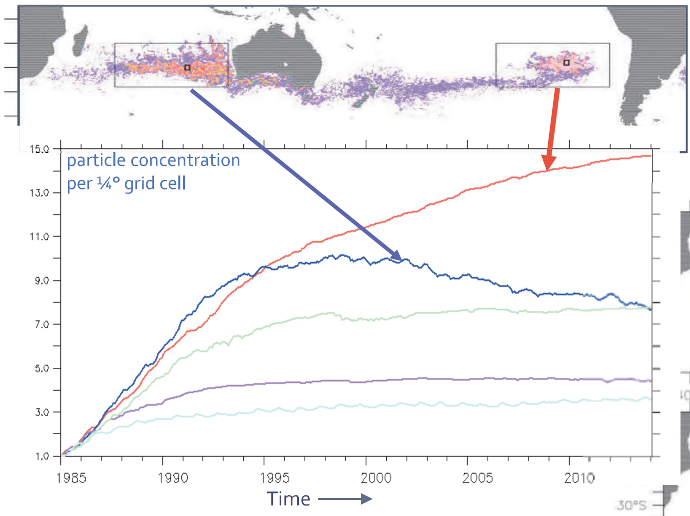
(Maximenko *et al.*, 2012)

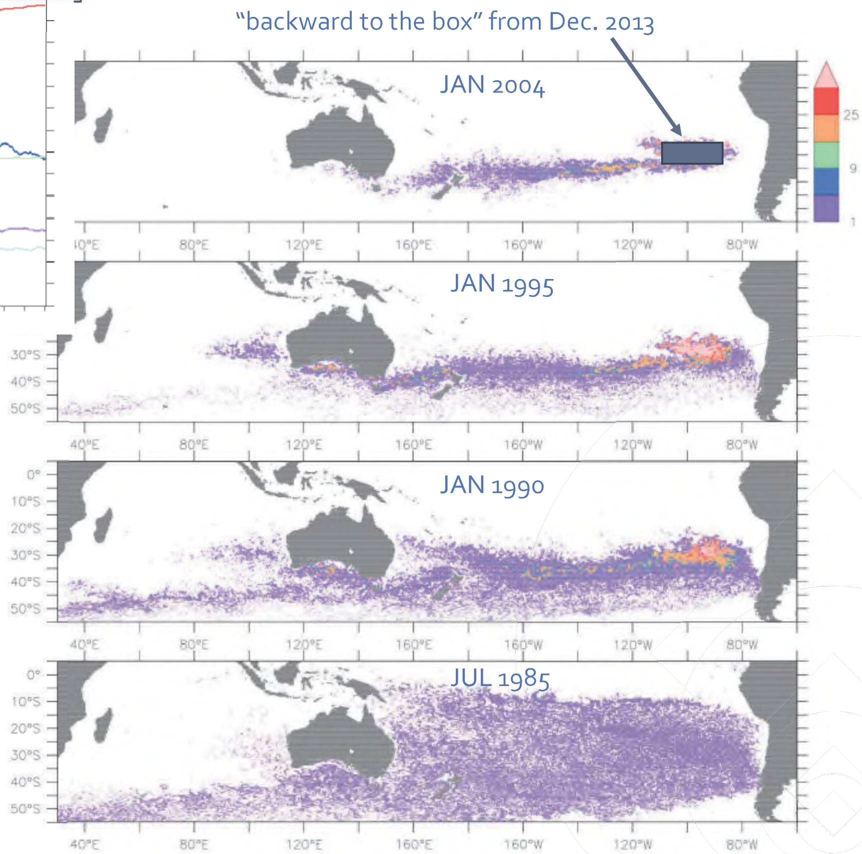


In the open sea, 5 accumulation zones are identified in the subtropical gyres by ocean models and drifter direct observations,

but these zones are *may be* not "disconnected"…

The super-convergence pathway





Note:
The eddy variability is essential to consider because experiments with mean currents only do not exhibit such pathway.

The full time variability is essential to be considered at the basin scales

OUTLINE

GENERAL INTRODUCTION: a focus on the plastic crisis…

TAKE HOME MESSAGES:

We need to know the time variability of surface currents to adequately address the long distance connectivity and pathways,

We need to consider high-resolution horizontal currents (mesoscale at least) to estimate the time transfer on specific pathways,

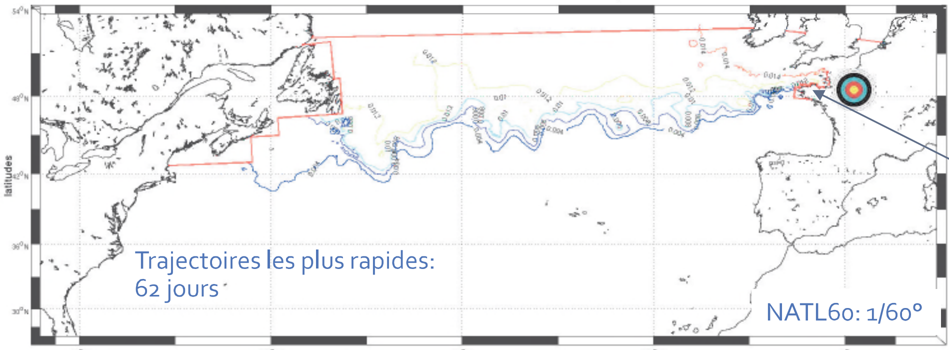
Case Study 1: 2 estimates of the time transfer

Case Study 2: « exit » routes from the core of subtropical gyres

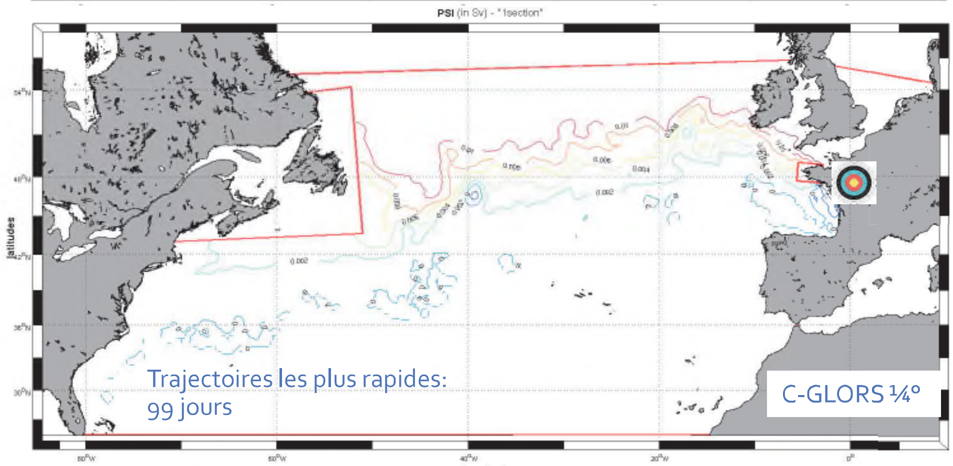
We need to evaluate more accurately the source scenario (and the sinks) of surface floating litter to access the distributions at global and regional scales

SOME CONCLUSIONS AND PERSPECTIVES (in ocean modeling and observations)

Case study 1: does a stronger turbulent ocean dynamics will reduce the time transfer?

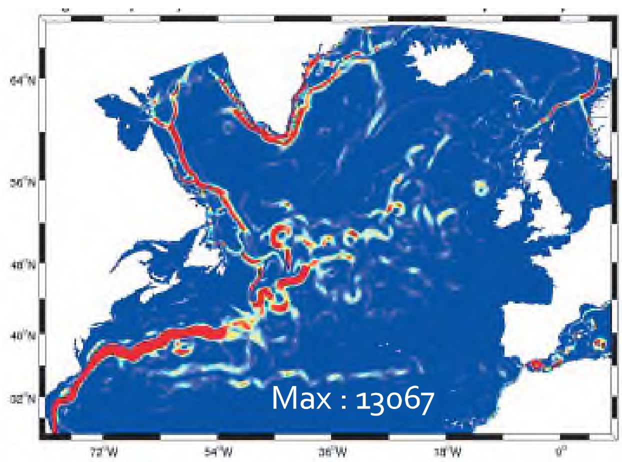


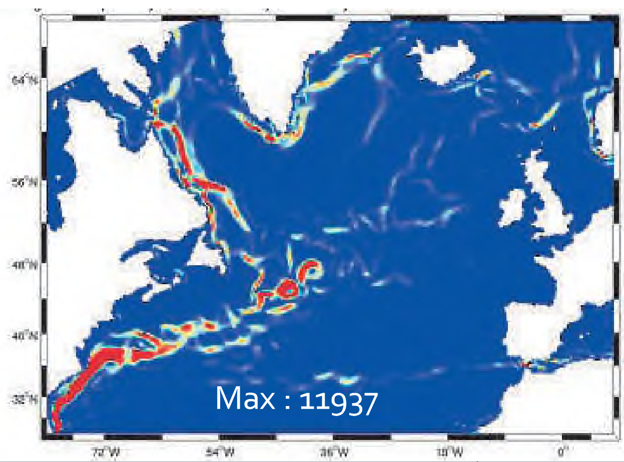
Fishing tags found on the beach in Brittany



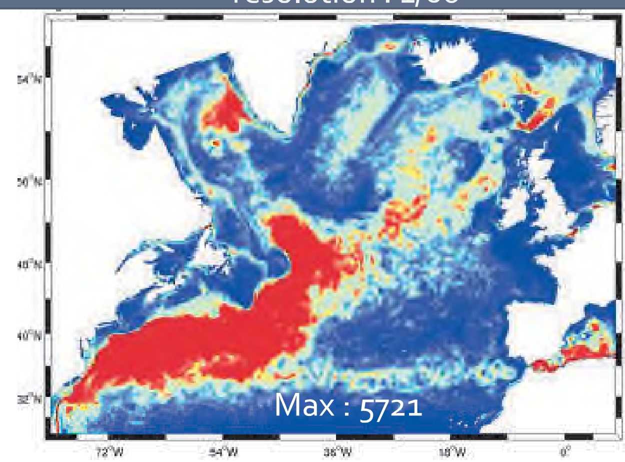
Source : T. PAVIET-SALOMON (2017, master2 report)

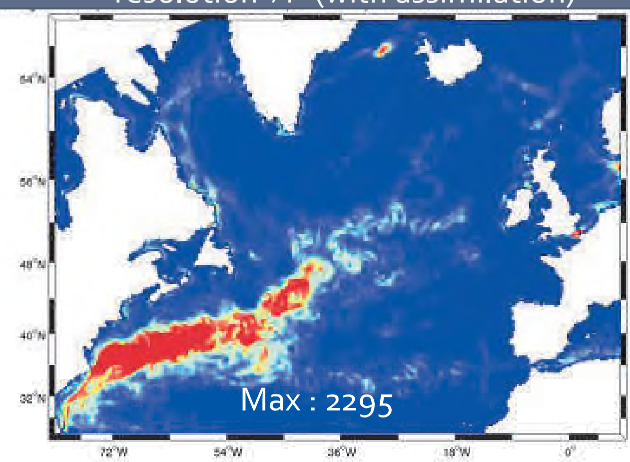
Mean Kinetic Energy & Eddy Kinetic Energy (cm²/s²)



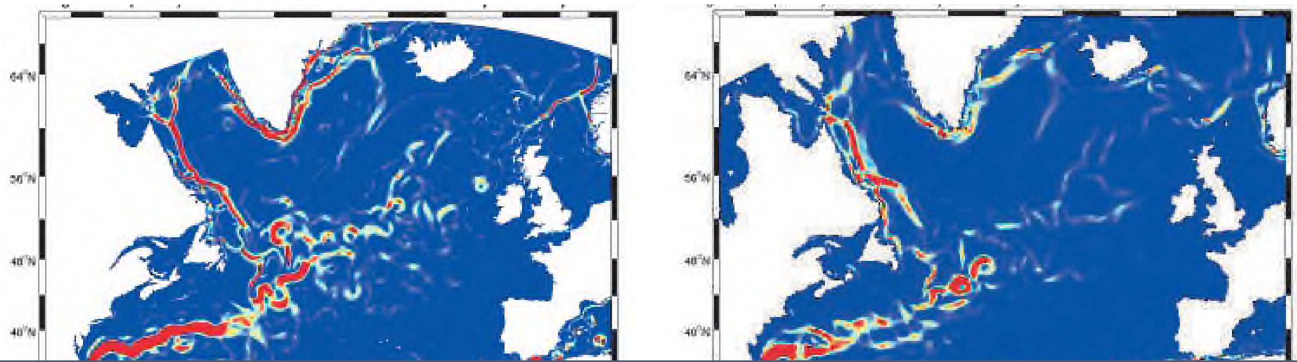


resolution : 1/60° | resolution ¼° (with assimilation)

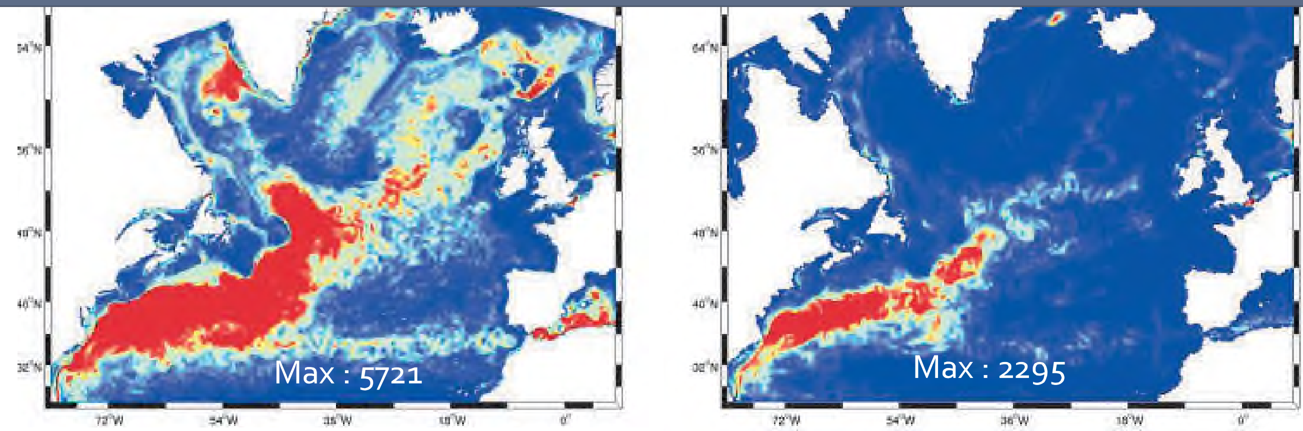




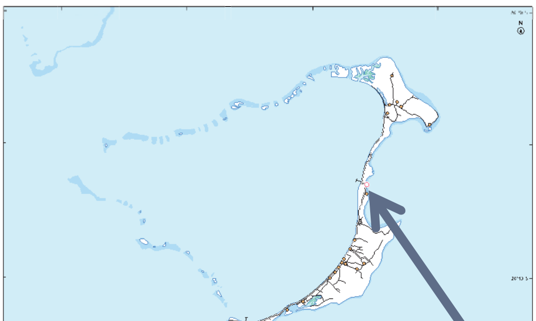
Mean Kinetic Energy & Eddy Kinetic Energy (cm²/s²)

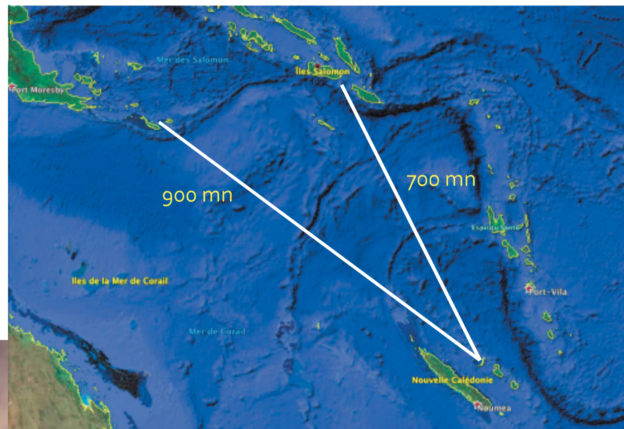


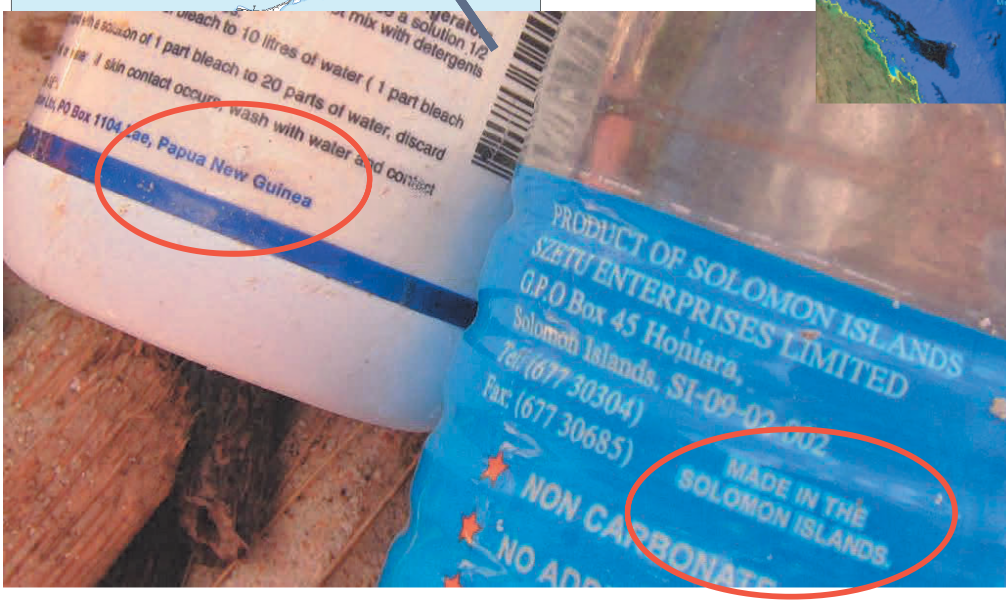
Time transfer depends on the energetics of the ocean dynamics (small scales as simulated by models matter)

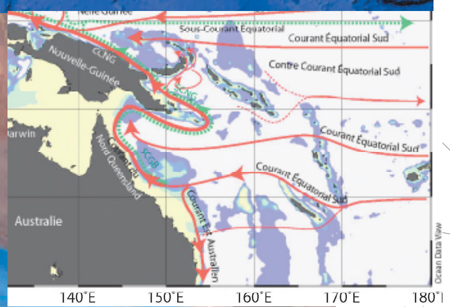


Case study 1: drifting of 2 plastic bottles









Connection will depend on the current features…

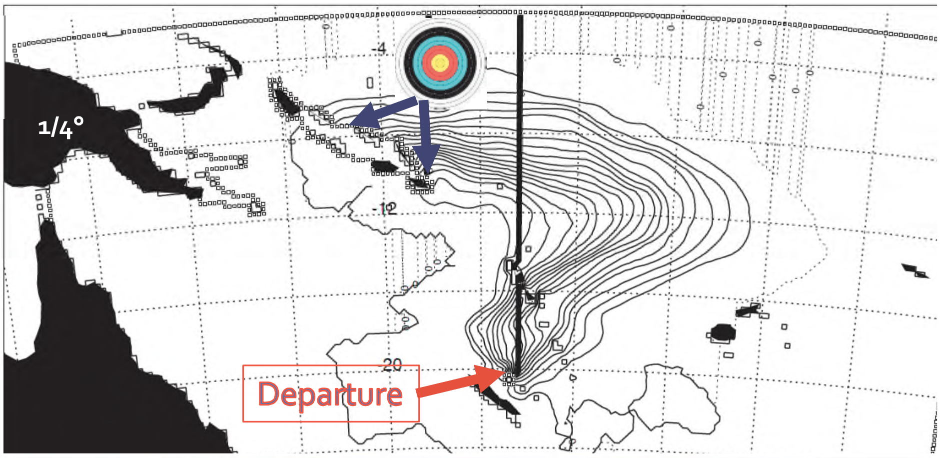
- Lagrangian stream functions for the connections calculated between Ouvéa Island and Solomon islands

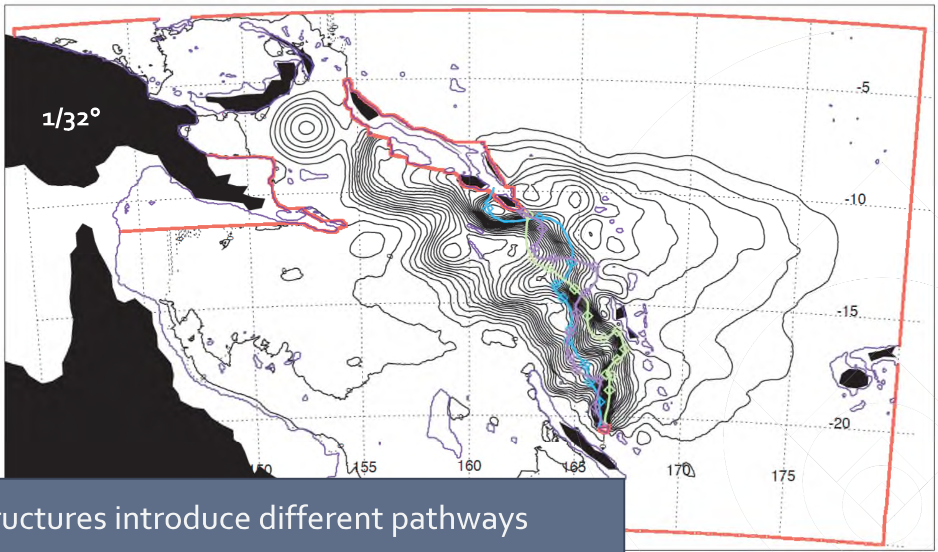
- Backward computation for the 2010-2011 period

- Initial release of 5 million of particles

- Fastest times for connection with Solomon islands :
  147-day (1/4)
  vs.
  52-d (1/32)

Source: Maes and Blanke, MPB 2015

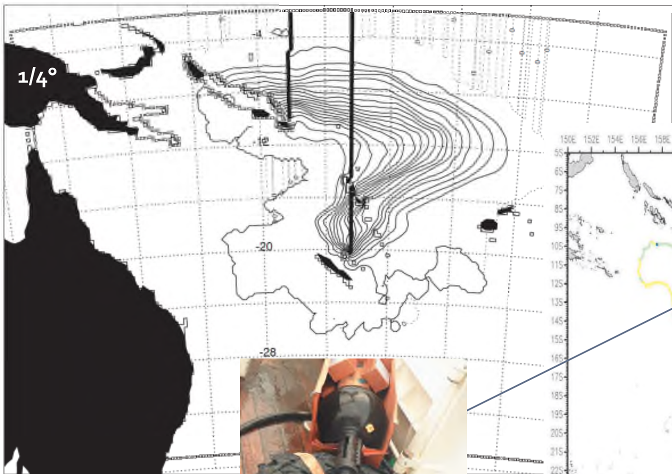




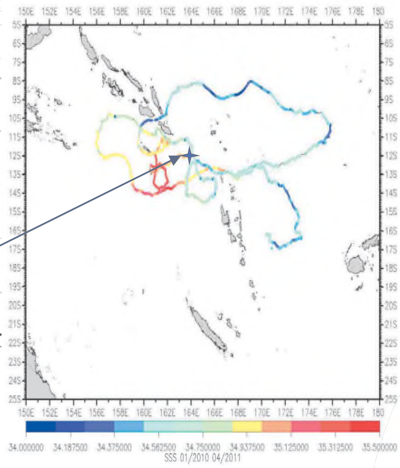
Small scale structures introduce different pathways

Meso- and sub-mesoscales introduce more possible pathways…

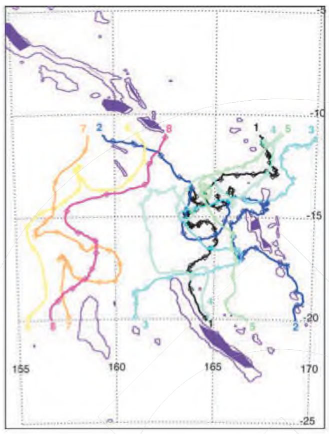
~10^6 particules



(Crédit photo: ©IRD C. Maes)



in situ obs.



but it does not mean that "low-resolution" models are wrong

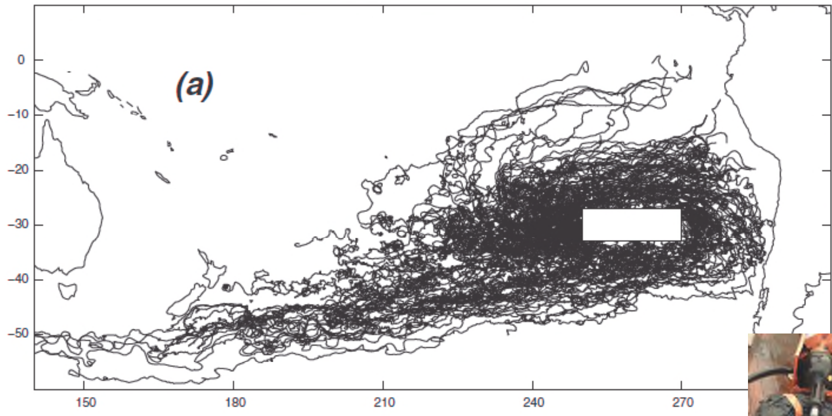
Case study 2: does subtropical convergence zones are totally isolated?

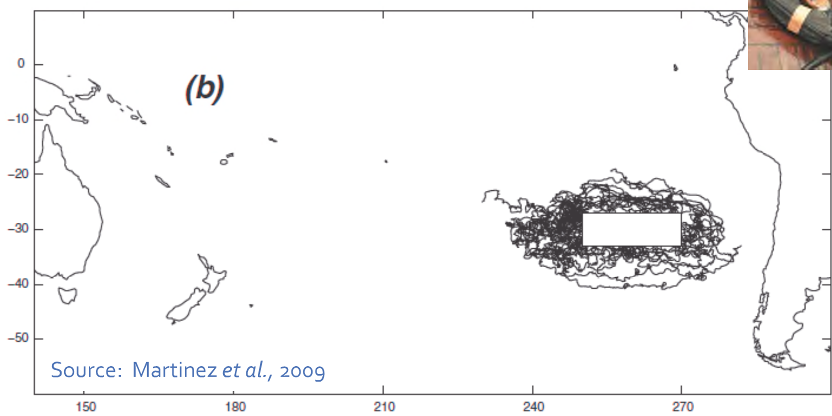
Segments of trajectories of "real drifters"

(a) before they entered

and

(b) after they left from area outlined by the rectangle (57 drifters) into the South Pacific gyre



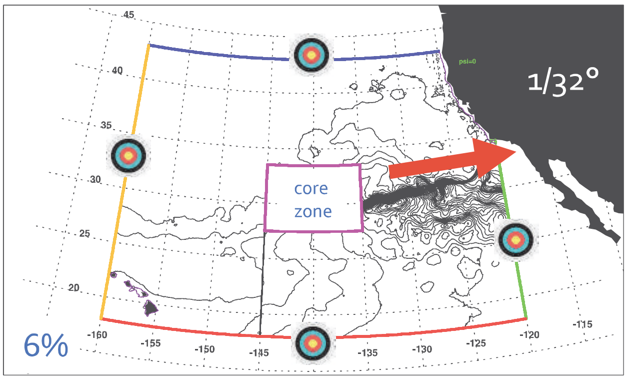


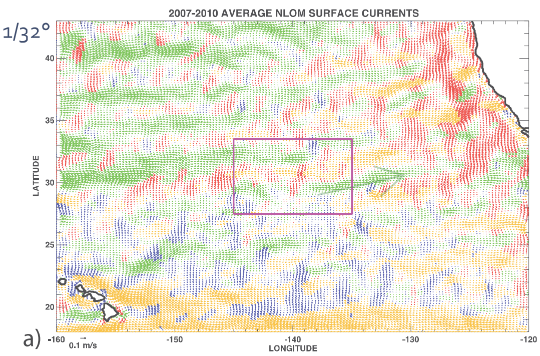
Source: Martinez *et al.*, 2009

Case study 2: revealing « exit routes »

(Maes et al. GRL 2016)

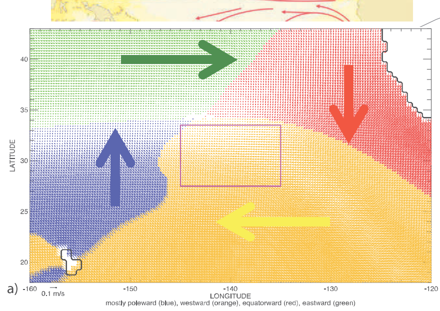
NO exit routes in the ¼° model, but it is present in models at 1/12° and 1/32°





Current striations are linked to the eddy pathways

Consider only the direction of current : the color code refers to the dominant direction of the flow: mostly poleward (blue), westward (yellow), equatorward (red), eastward (green)…



Based from GEKCO « satellite » currents (Sudre et al., 2013)

The subtropical convergence zones are not "isolated" systems or regions.

OUTLINE

GENERAL INTRODUCTION: a focus on the plastic crisis…

TAKE HOME MESSAGES:

We need to know the time variability of surface currents to adequately address the long distance connectivity and pathways,

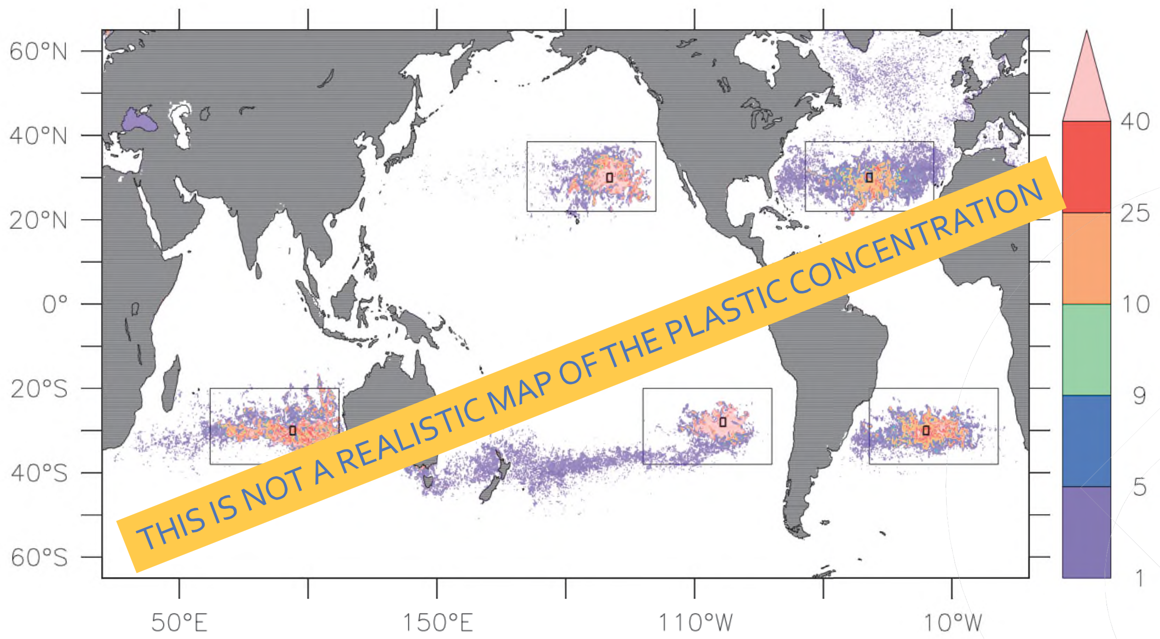
We need to consider high-resolution horizontal currents (mesoscale at least) to estimate the time transfer on specific pathways,

We need to evaluate more accurately the sources (and the sinks) of surface floating litter to access the distributions at global and regional scales

SOME CONCLUSIONS AND PERSPECTIVES (in ocean modeling and observations)

One comment

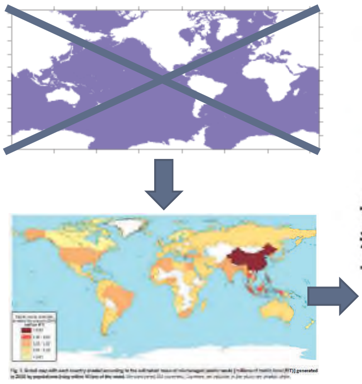
We need to evaluate more accurately the sources (and the sinks) of surface floating litter to access the distributions at global and regional scales

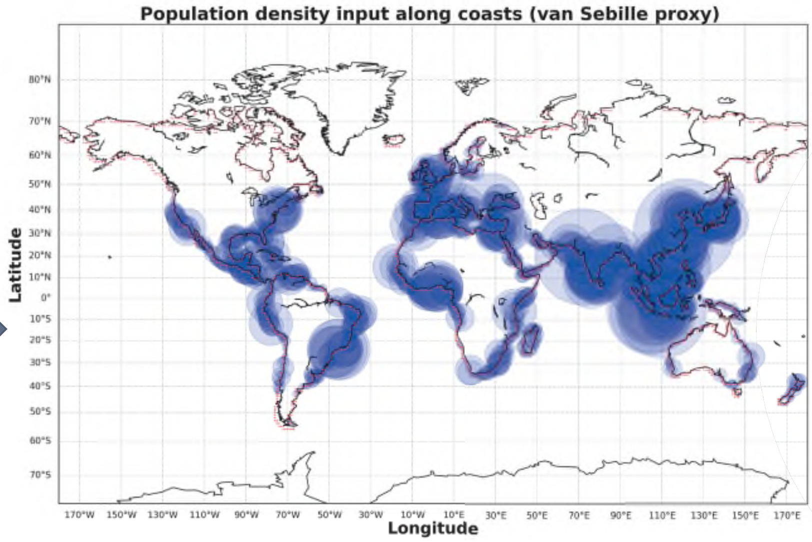


Application to the real problem

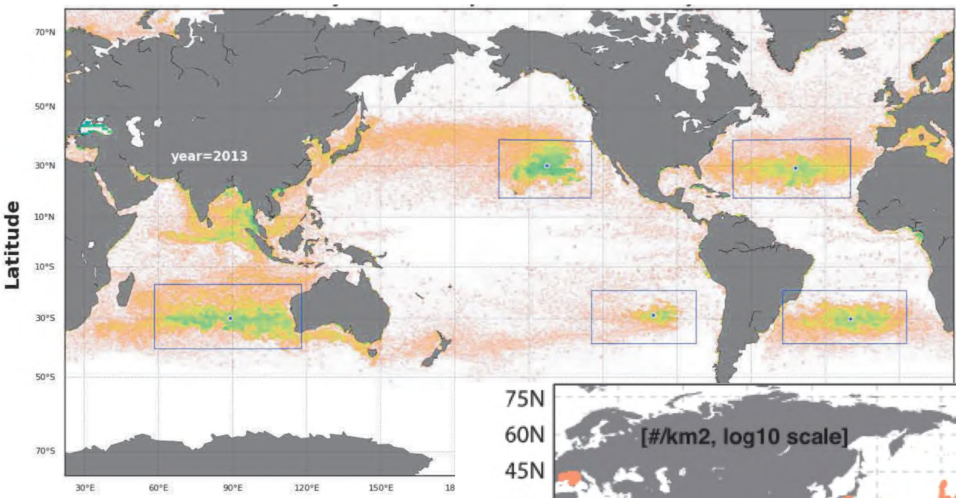
- GOAL: Evaluate the « realistic » input scenarios (van Sebille et al. 2015 vs. Lebreton et al. 2017) of marine litter (microplastics or whatever small floating material or debris)

- FOLLOWING A SIMPLE APPROACH:
    - Consider 1 million particles along the coasts (first ocean point in the model adjacent to land mask)
    - Dispersion by surface currents over the 1985-2013 period
    - Release operated every year but limit the age of particles to 20-yr
    - Source =



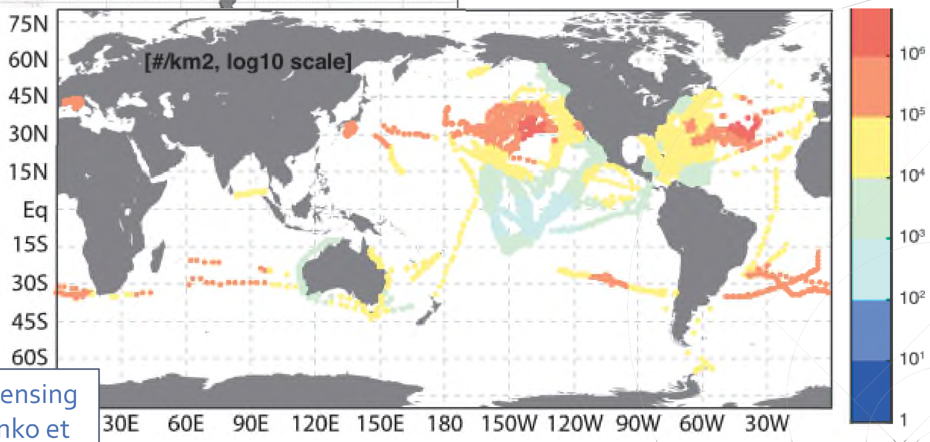


Application to the real problem: a simple approach



Preliminary results of particle concentration with continuous sources (along coasts) and '*conceptual*' sinks (finite life span)

Can we compare to observations?



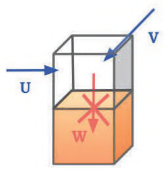
Microplastic count of all surface trawl data (van Sebille et al. 2015)

New initiatives for *in situ* and remote sensing observations such as IMDOS (Maximenko et al., OCEANOBS'19, 2019) are required.

Application to the real problem: can we diagnosed the beaching?

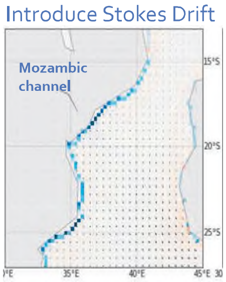
Source: C. Weber (2019, master2 report)

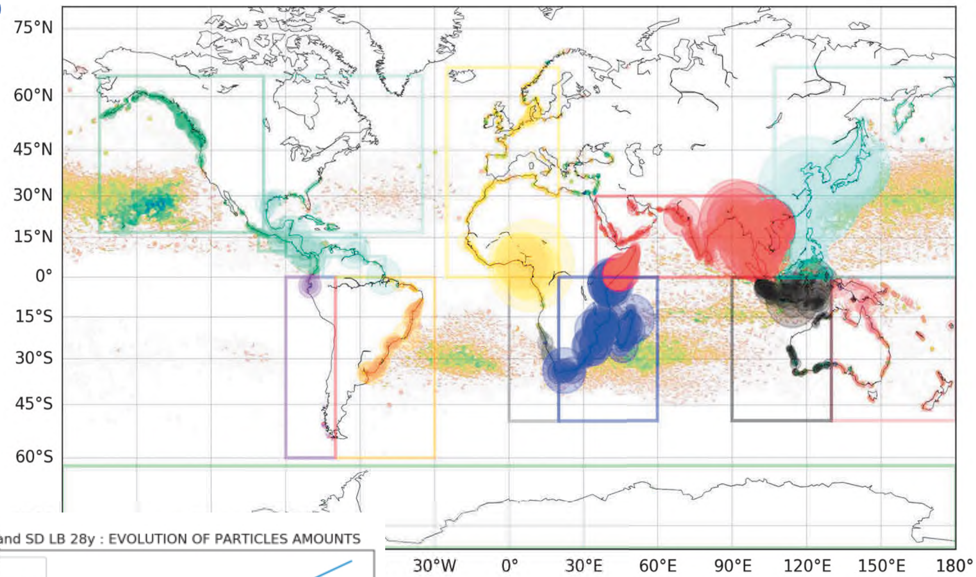
Surface u,v

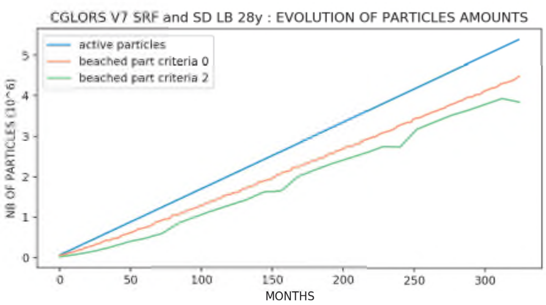


Sources: main rivers

Introduce Stokes Drift







1 particle is "beached" when it stays in the same grid point along coasts for 1-yr period

It could represent as far as 60-80% of the annual release in the oceans

SOME CONCLUSIONS AND PERSPECTIVES

We need to know the time variability of surface currents to adequately address the long distance connectivity and pathways,

Consider temporal variability in currents (high resolution to include tides)

Examine the physics relevant to the dispersion problem (divergent process)

We need to consider high-resolution horizontal currents (mesoscale at least) to estimate the time transfer on specific pathways,

Examine the impact of the small scales in current for different regions : offshore, continental shelf, littoral

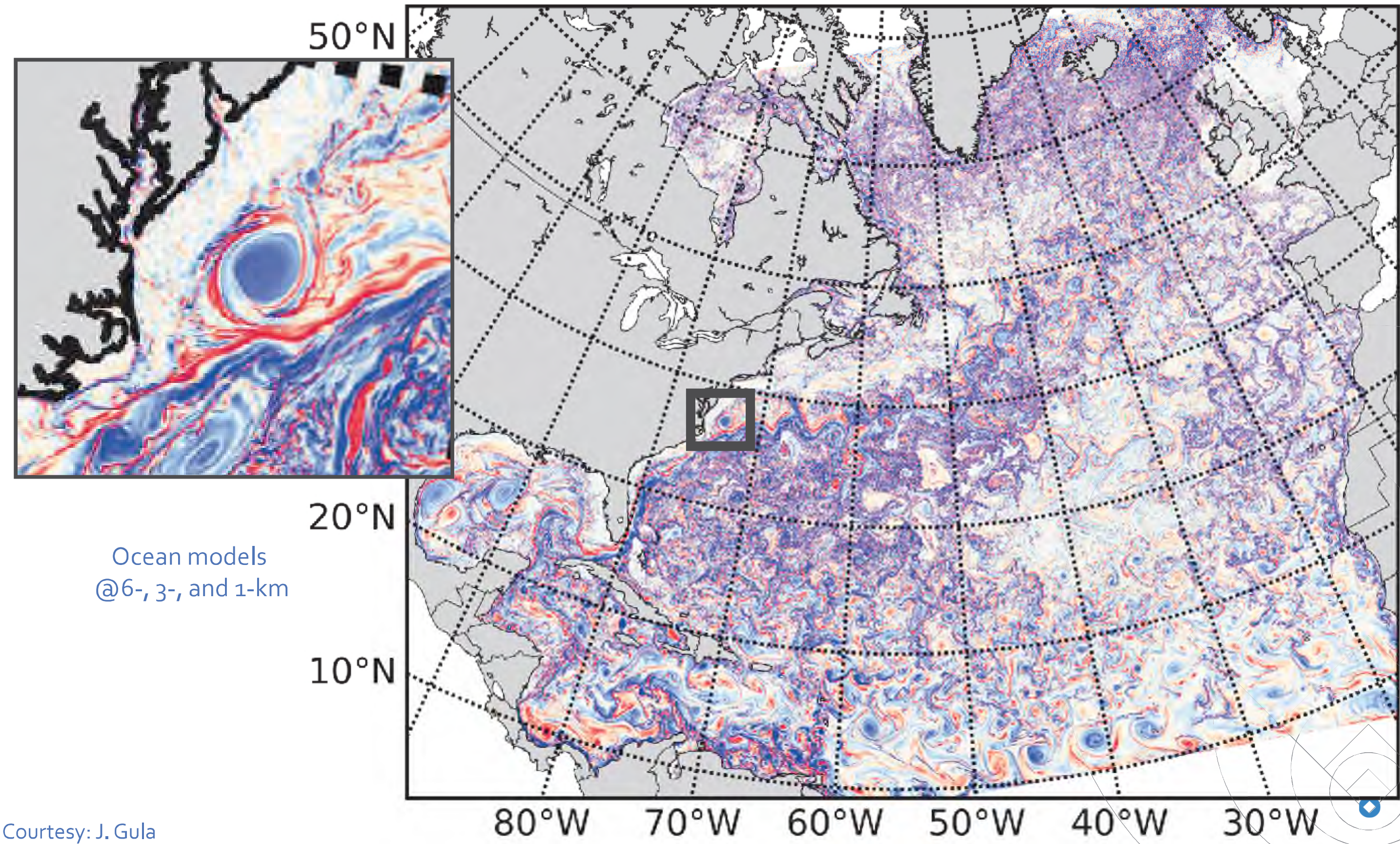
We need to evaluate more accurately the source scenario (and the sinks) of surface floating litter to access the distributions at global and regional scales

Elaborate different scenario and evaluate their variability (from land and in the ocean)

Consider the other aspects implying in the plastic cycle life (sinks? biota?)

ET POUR DEMAIN…

some high resolution grids for ocean bassin scale models



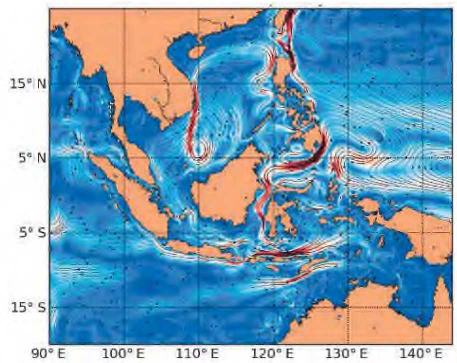
Ocean models
@6-, 3-, and 1-km

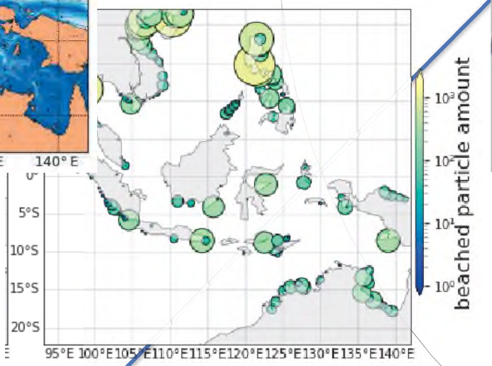
Courtesy: J. Gula

Horizon 2020-2021:

Monitoring and modelling the circulation of marine debris in Indonesia

IRD (LOPS-LEGOS-MIO-LOCEAN) - KPP – AFD
CLS – Mercator





FINAL MESSAGE

New satellite missions are needed to measure directly the motions at the ocean surface, namely currents and waves, and their relation to winds, for a wide range of applications from sub-kilometer scales to the global ocean circulation.

Such key observations will stimulate modeling studies for a better understanding of dispersion at sea and will provide background for predictions and applications.

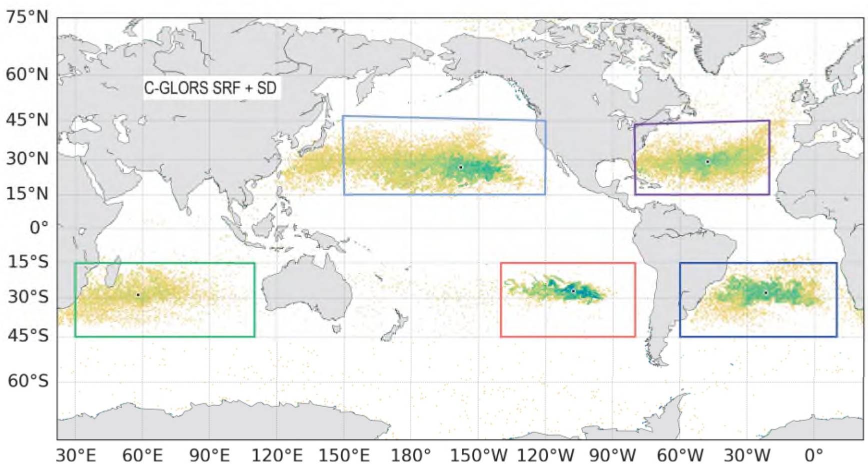
SCOR WG 153
Floating Litter and its Oceanic TranSport Analysis and Modelling (FLOTSAM)
Chair: S. Aliani
Period : 2018-2020

Christophe.Maes@ird.fr

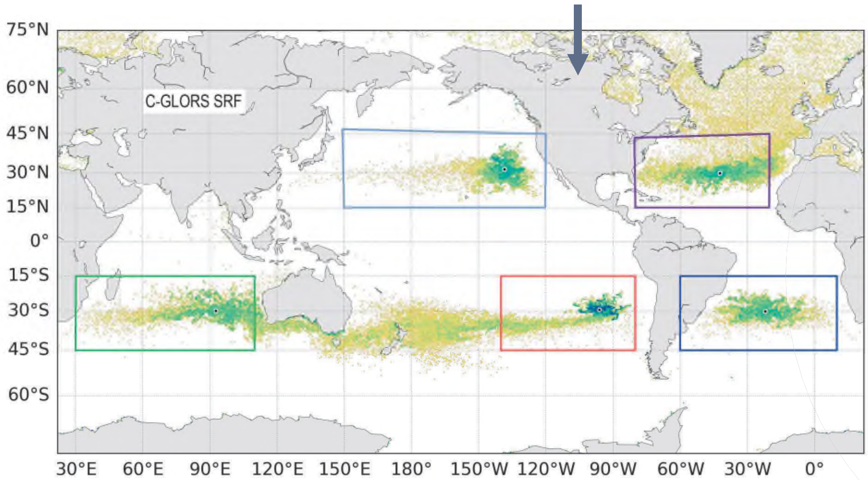
Crédit photo: Tracey Williams, LOST AT SEA

ADDITIONAL

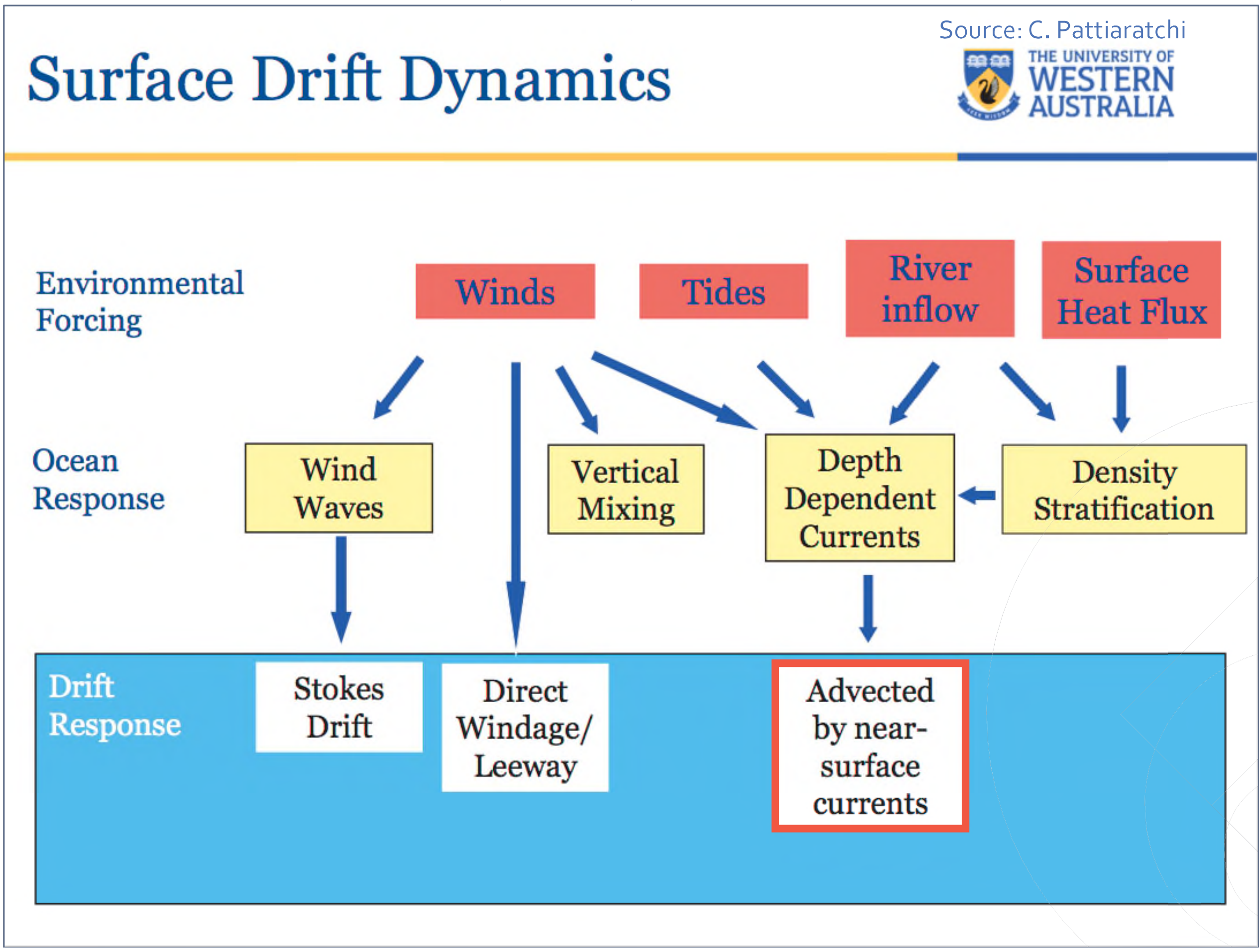
Dobler et al., 2019, MPB



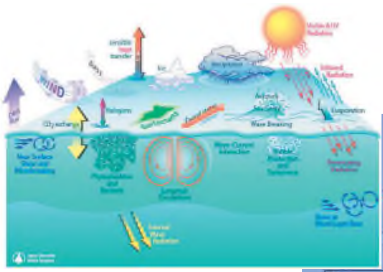
Uniform release scenario, dispersion is done under current and Stokes drift due to the waves



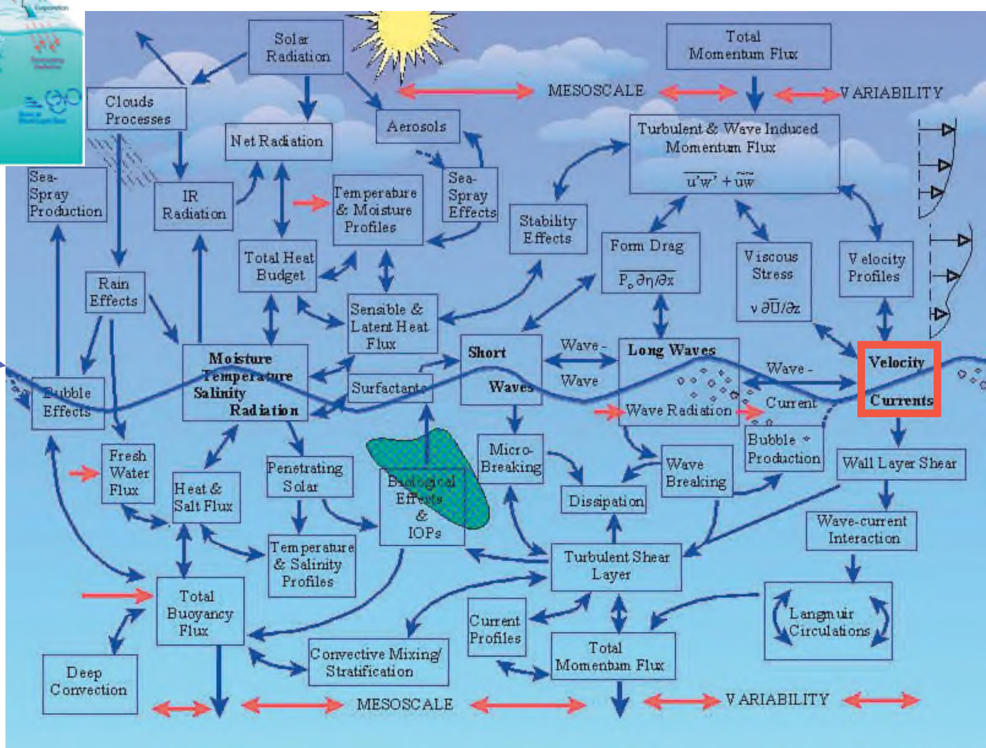
THE PHYSICS OF THE (PLASTIC) DISPERSION IN THE OCEANS



THE PHYSICS OF THE (PLASTIC) DISPERSION IN THE OCEANS
HOW COMPLEX THE PROBLEM IS?

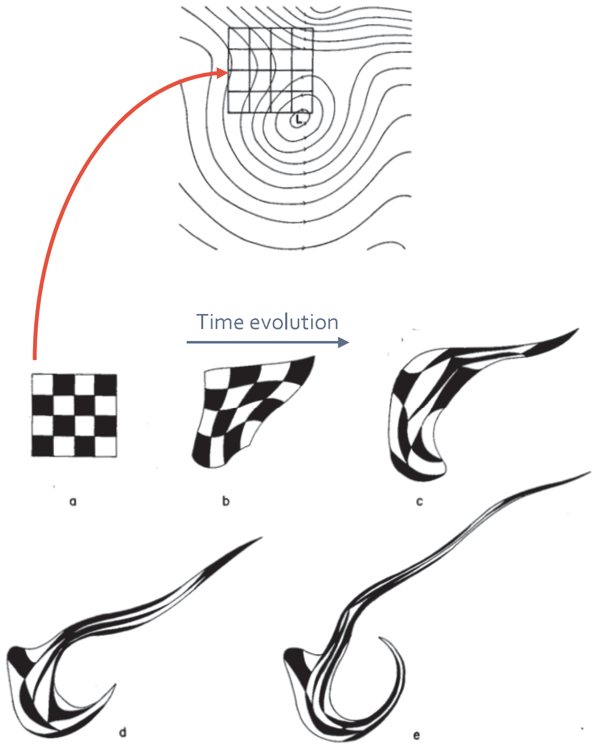


Ocean interface



Source: WHOI graphics

DISPERSION OF ANY MATERIAL AT SEA : A STIRRING TO MIXING PROBLEM AS WELL AS BEING FAMILIAR FROM ADDING CREAM TO COFFEE…



Welander (1955)

Fig. 2. Deformation of a fluid surface.

Evolution of a tracer in turbulent flows (C. Eckart paradigm, 1948): at first, during the stirring phase, the variance of the scalar gradient is increased, and later, during the mixing phase the molecular diffusion dominates and the strong gradient disappear (homogeneous final state).

Meeting report (2001) from P. Mueller and C. Garrett: « Stirring and mixing in a stratified ocean is the physics that need to be parametrized in ocean models. Challenging open problems remain at all levels, from very fundamental to highly applied aspects. »

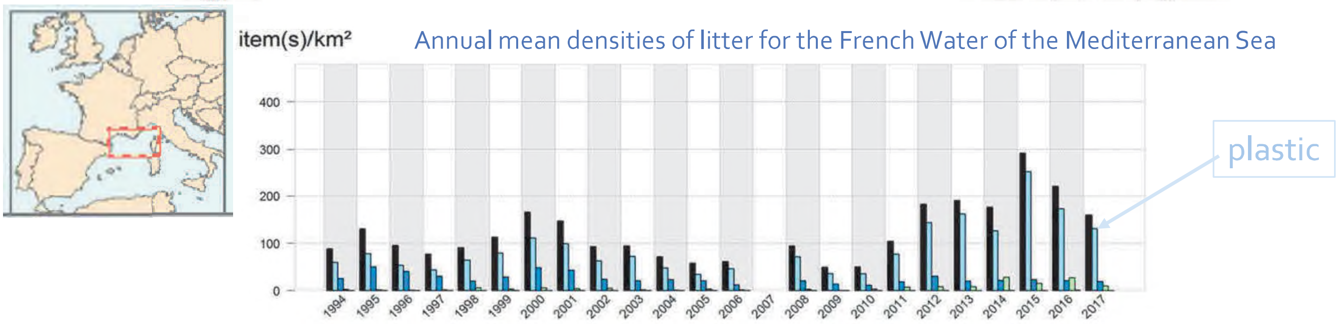
In the following, we will considered the plastic & litter dispersion at global and regional scales,
& hereafter, focus will be set on the knowledge of surface currents

WHERE GO THE PLASTICS IN THE OCEANS?

O. Gerigny, et al.

Marine Pollution Bulletin 146 (2019) 653–666

Annual mean densities of litter for the French Water of the Mediterranean Sea



1012

P.G. Ryan et al. / Environmental Pollution 238 (2018) 1008–1016

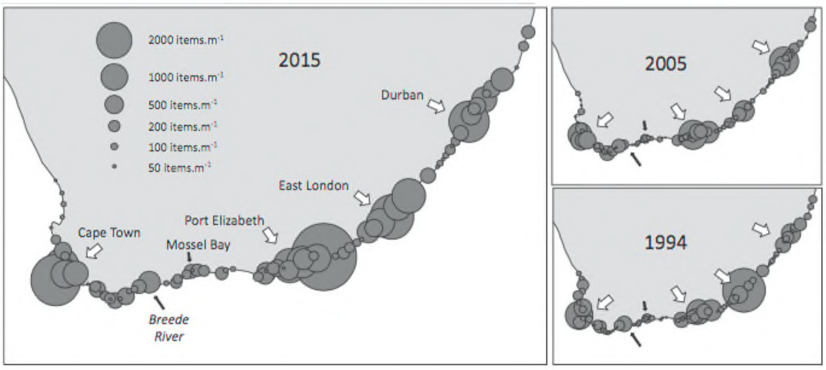


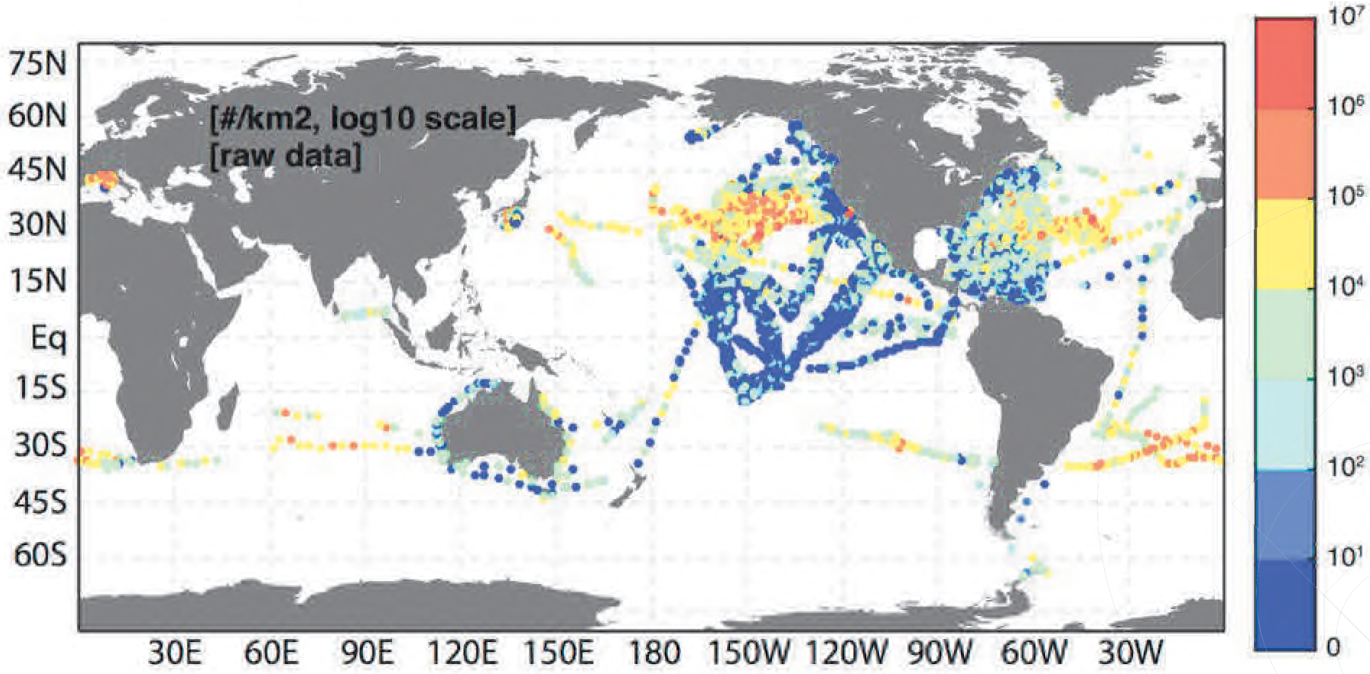
Fig. 4. The abundance of mesodebris on 82 South African sandy beaches in the austral winters of 2015, 2005 and 1994 in relation to the location of four urban-industrial centres, Cape Town, Port Elizabeth, East London and Durban (white arrows), and other local sources (black arrows).

82 beaches sampled
focus on mesodebris (1-25 mm)
99% of items are plastics

« Sample year had no effect on mesodebris abundance, indicating that there has been little change in the amounts of mesodebris over the last two decades. »

WHERE GO THE PLASTICS IN THE OCEANS?

A Global inventory of small floating plastic debris
(van Sebille et al. 2015)
Figure S1: Map of the raw, non-standardized data.



SCIENTIFIC REPORTS

OPEN

Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic

Received: 17 October 2017
Accepted: 5 March 2018
Published online: 22 March 2018

L. Lebreton[1,2], B. Slat[1], F. Ferrari[1], B. Sainte-Rose[1], J. Aitken[3], R. Marthouse[3], S. Hajbane[1], S. Cunsolo[1,4], A. Schwarz[1], A. Levivier[1], K. Noble[1,5], P. Debeljak[1,6], H. Maral[1,7], R. Schoeneich-Argent[1,8], R. Brambini[1,9] & J. Reisser[1]

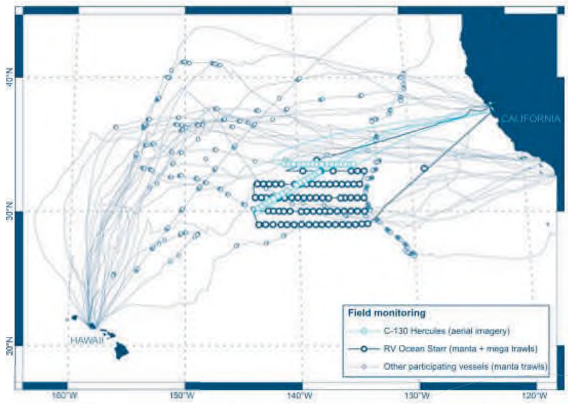


Figure 1. Field monitoring effort. Vessel (grey and dark blue lines) and aircraft (light blue lines) tracks and locations where data on buoyant ocean plastic concentrations were collected (circles). Grey circles (n = 350)

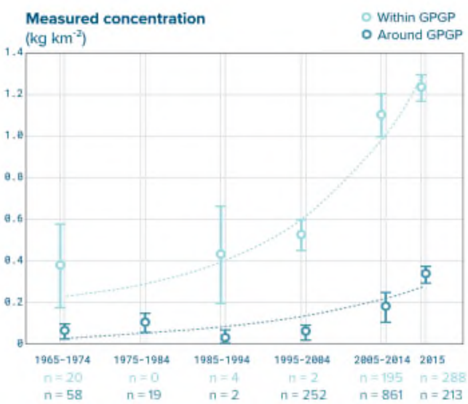
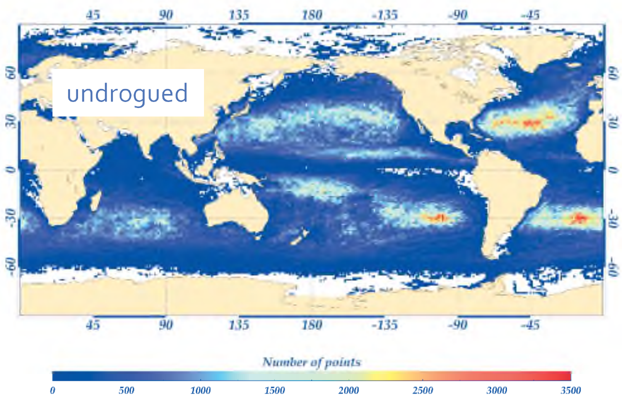


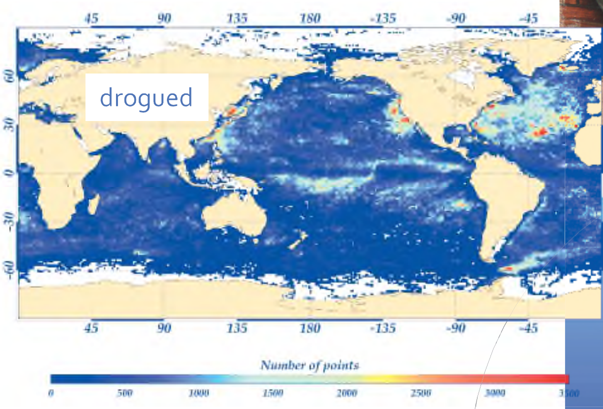
Figure 6. Decadal evolution of microplastic concentration in the GPGP. Mean (circles) and standard error (whiskers) of microplastic mass concentrations measured by surface net tows conducted in different decades, within (light blue) and around (dark grey) the GPGP. Dashed lines are exponential fits to the averages expressed in g km^{-2}: $f(x) = \exp(a*x) + b$, with x expressed in number of years after 1900, $a = 0.06121$, $b = 151.3$, $R^2 = 0.92$ for within GPGP and $a = 0.04903$, $b = -7.138$, $R^2 = 0.78$ for around the GPGP.

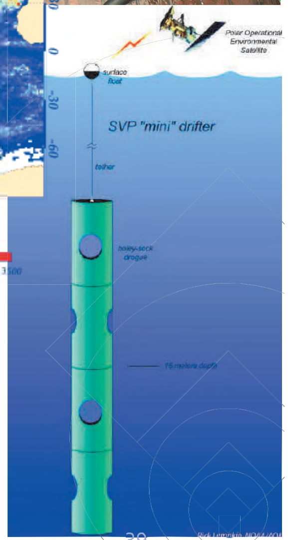
DO WE REALLY KNOW THE OCEAN SURFACE CURRENTS?

For centuries, surface currents were inferred from bottles and drifting objects, and in the 1980s the World Climate Research Program initiated the global array of SVP drifters (drogued at 15 m depth)

Density of current observations based on the SVP program on 1°x1° coverage







Mean seasonal climatology is OK, but daily and near real time observations are based on 1200-1300 active buoys (~80% of 5°x5° coverage for 60°N-60°S)

Variability of large scale currents (200-km wavelength and 15-day period) is depicted by satellite altimetry and vector winds from scatterometer. This leaves important observation gaps (Ardhuin *et al.*, 2019).

SURFACE CURRENTS: WHICH DEPTH DO WE NEED TO CONSIDER?

Deployment of 3 types of surface buoys near the Frigg Field in the northern North Sea (Christensen et al., 2018)

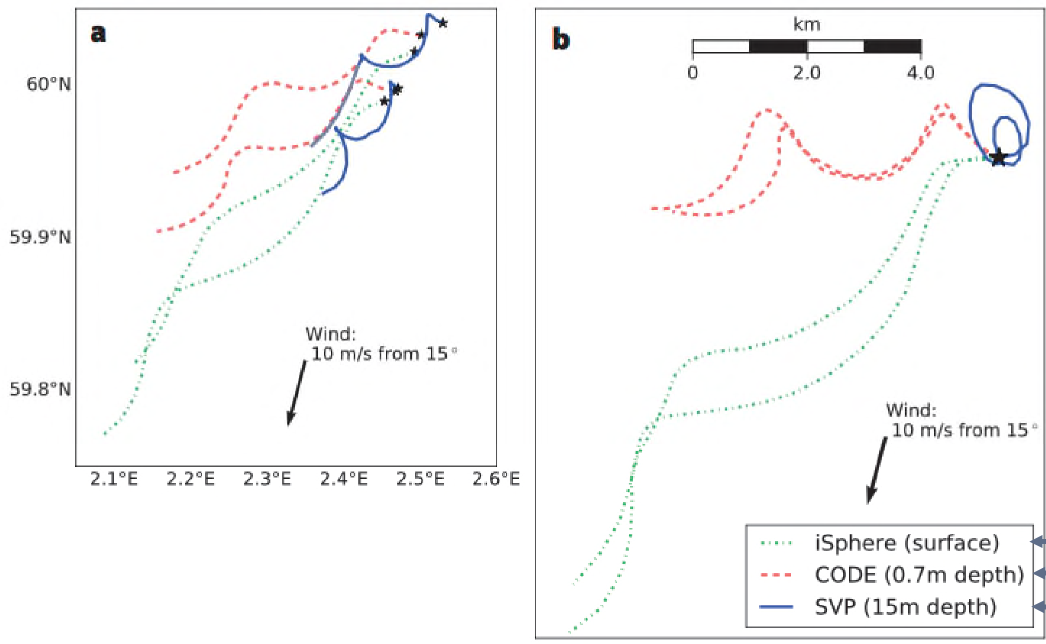
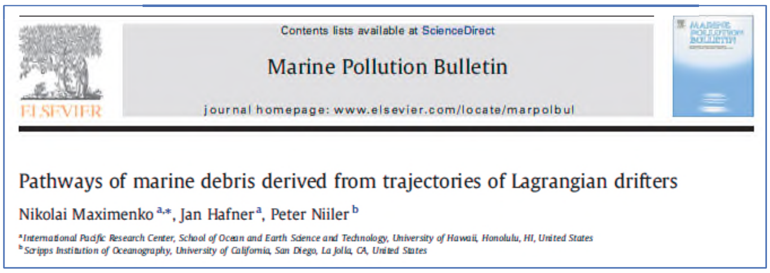


FIGURE 1. Trajectories from three different types of drifters as observed during the Norwegian Clean Seas Association's oil-on-water exercise in June 2018: iSphere (green dash-dotted line, 0 m depth), CODE drifters (red dashed line, 0.7 m depth), and SVP drifters (blue solid line, 15 m depth). One of the SVP drifters lost its drogue, after which the line is gray. The trajectories are plotted for two full inertial periods totaling 27.6 hours. Panel (a) shows the actual trajectories, while panel (b) shows the trajectories with the average displacement of one of the SVPs removed and using the same initial position for all units.

designed for oil spill tracking
coastal app. + Deepwater Horizon
WCRP

Trajectories shown for 2 intertial periods (~27.6 hr)

Pathways from Lagrangian Drifters


Contents lists available at ScienceDirect
Marine Pollution Bulletin
journal homepage: www.elsevier.com/locate/marpolbul

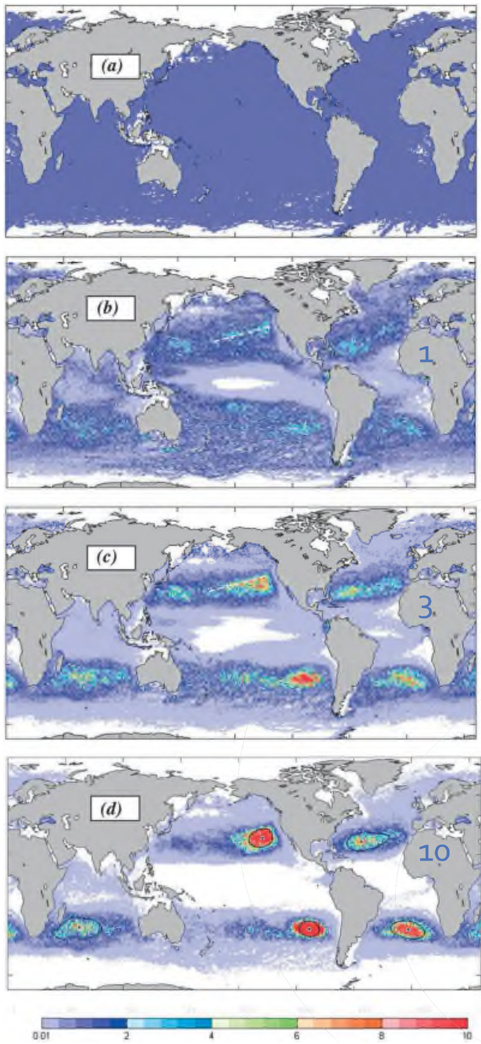
Pathways of marine debris derived from trajectories of Lagrangian drifters

Nikolai Maximenko [a,*], Jan Hafner [a], Peter Niiler [b]
[a] International Pacific Research Center, School of Ocean and Earth Science and Technology, University of Hawaii, Honolulu, HI, United States
[b] Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA, United States

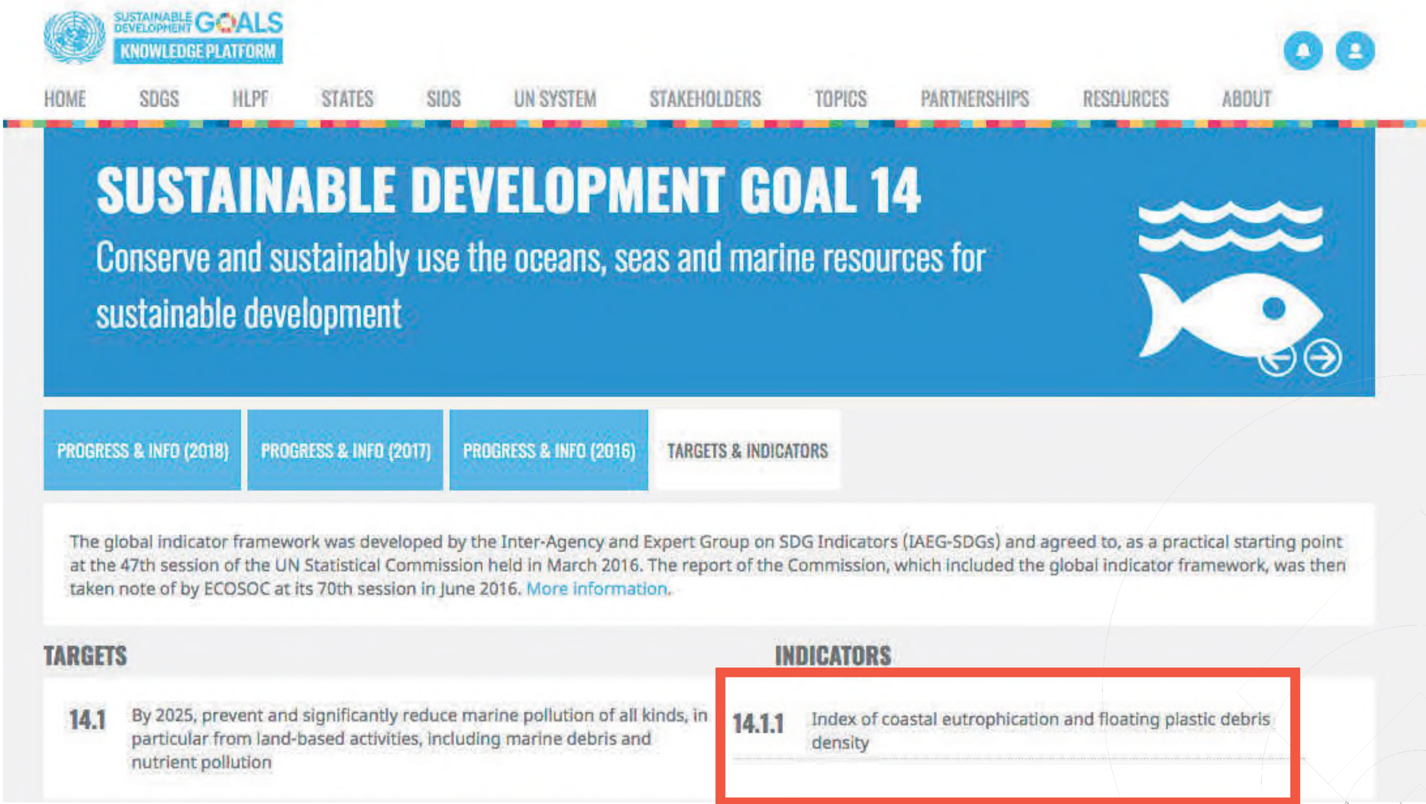
A probabilistic model is developed based on global set of trajectories of satellite-tracked Lagrangian drifters…

…the total number of data is small along the equator. Similarly, density is also low in many regions of coastal upwelling. On contrary, not many drifters were released in the five subtropical regions…

More generally, ocean currents are known to exhibit various modes of interannual and decadal variability, so that validity of the assumption of statistical stationarity can be questioned. The goal of the model, presented in this paper, is to provide a global view and simple general concept explaining the pattern and dynamics of the areas of marine debris aggregation in the World Ocean.



PART II: PLASTIC POLLUTION IN THE OCEANS: A PROBLEM AT GLOBAL SCALE

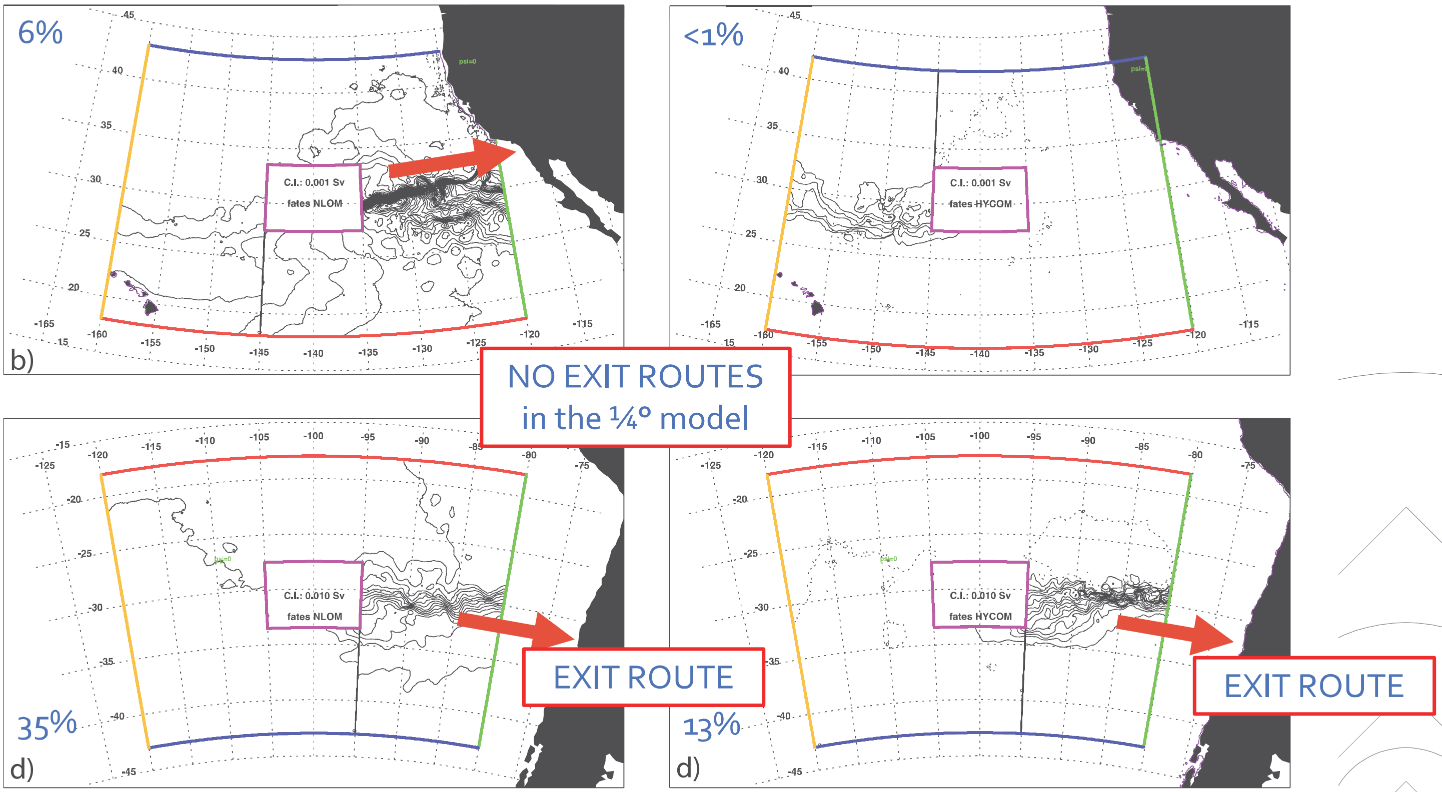


A DIRECT OBERSVATION FROM THE OCEAN BOTTOM

Courtesy of F. Galgani (IFREMER)

Case study 2: revealing « exit routes »

(Maes et al. GRL 2016)



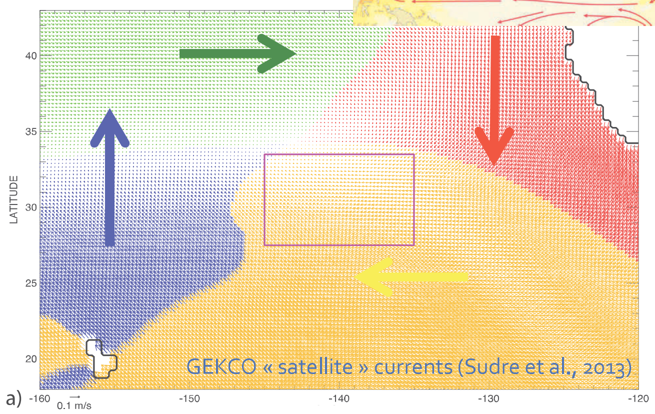
NLOM (1/32°) **HYCOM (1/12°)**

Fates of surface drift: impact of high-horizontal resolution (based on 6 and 10 million particles)

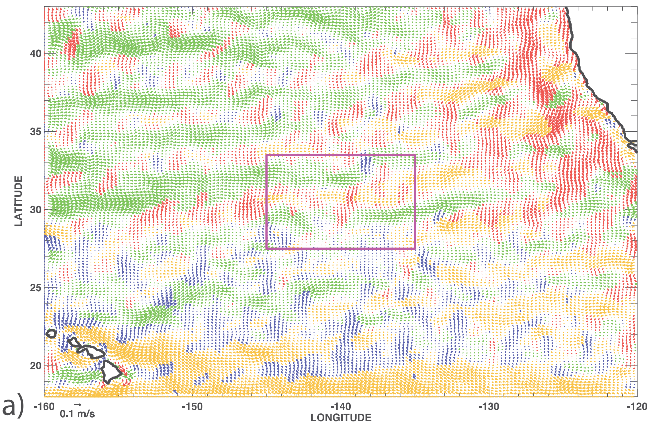
Case study 2: small scale structures in current matter…

Direction of current in the subtropical North Pacific convergence zone

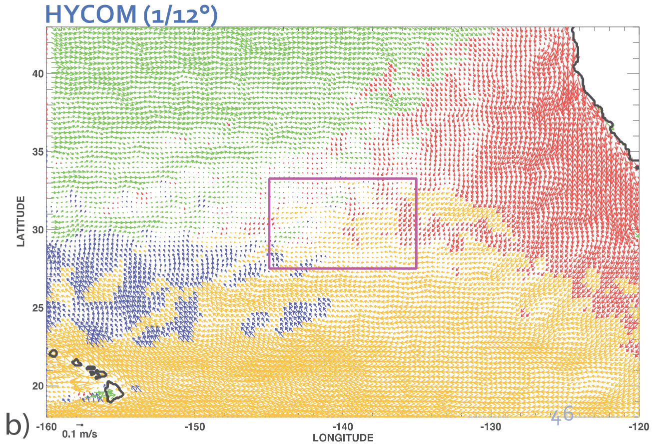
The color code refers to the dominant direction of the flow: mostly poleward (blue), westward (yellow), equatorward (red), eastward (green)…



NLOM (1/32°)



HYCOM (1/12°)



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