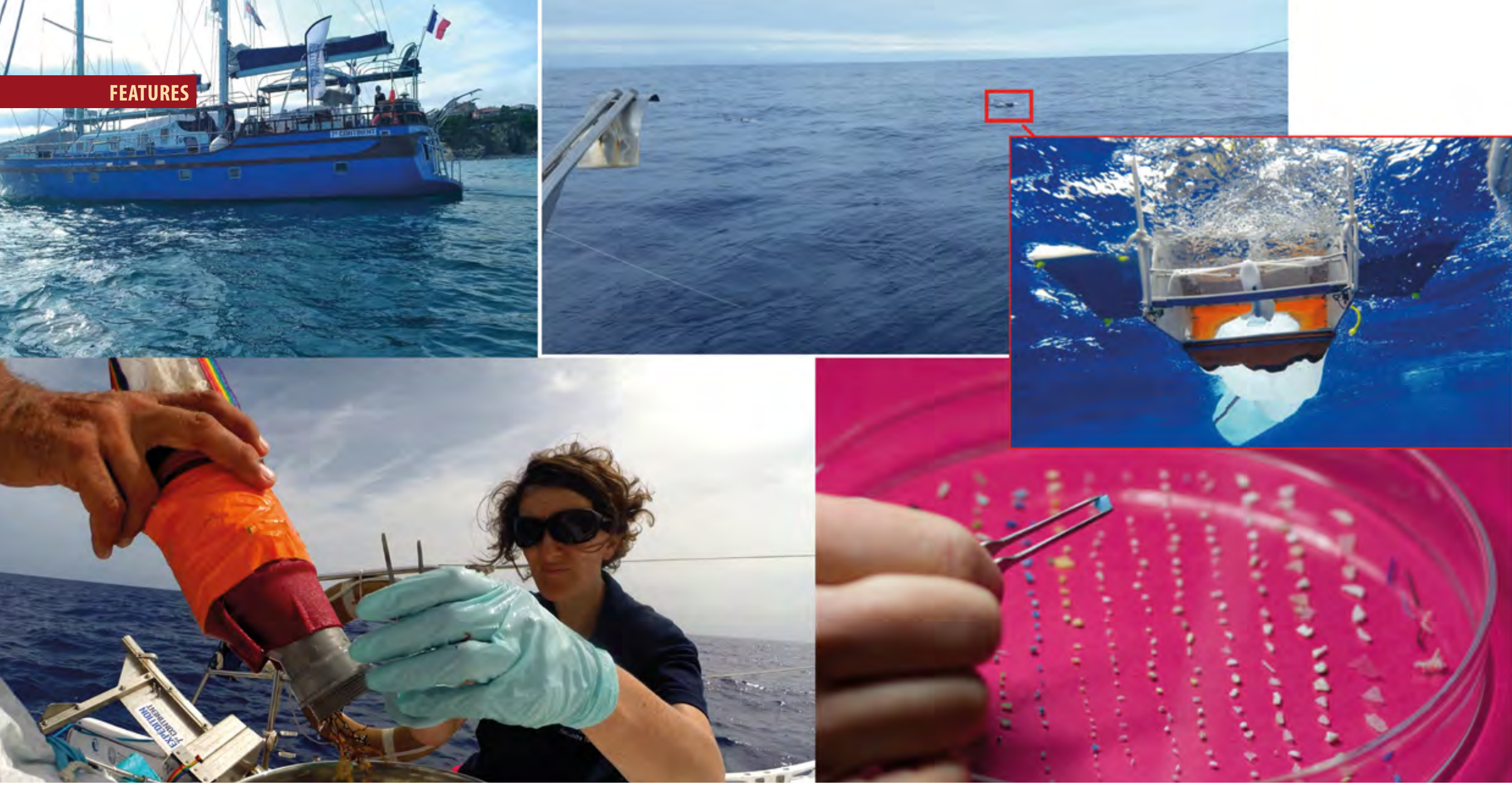

PLASTIC LITTER IN THE OCEANS. MOST OF IT HAS GONE MISSING, BUT IT MIGHT JUST BE TRANSFORMED… OR TRANSPORTED.

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The balance between the leakage and abundance of plastic in the world's oceans remains a current topic of debate [1], which renders difficult the understanding of the cycle of plastic on Earth [2]. We discuss recent findings and their implications on the missing plastic waste paradigm.

▲ Crédits Marie Poulain-Zarcos, Vinci Sato ©Expédition Septème Continent

Oceanic plastic pollution is a major global issue: it is one of the 17 Sustainable Development Goals by the United Nations Organization (#14 "Life below water"), and one of the hot topics requiring stronger regulations according to the European Chemical Agency ("Microplastics"). In addition to many institutional and NGO initiatives to prevent more plastic to enter the environment, plastic pollution is also an important and active field of research gathering various research communities (biology, chemistry, ecotoxicology, economic and social sciences, oceanography and physics), with successful (online) gatherings of the MICRO community, leading to recommendations for policy makers [3]. A summary of the main results from the first observations of plastic in the middle of the Pacific in the early 1970s until the recent years can be found in [4].

Important knowledge gaps remain to be addressed quantitatively to better assess the extent and the impact of plastic pollution for marine life (quantity estimates, risk assessment, exposure rate). Here, we focus on the current state of understanding for the overall transport mechanism of plastic pollution in the oceans, as schematically described in Figure 1. The main challenge tackled here is to understand where the majority of floating plastic goes at sea.

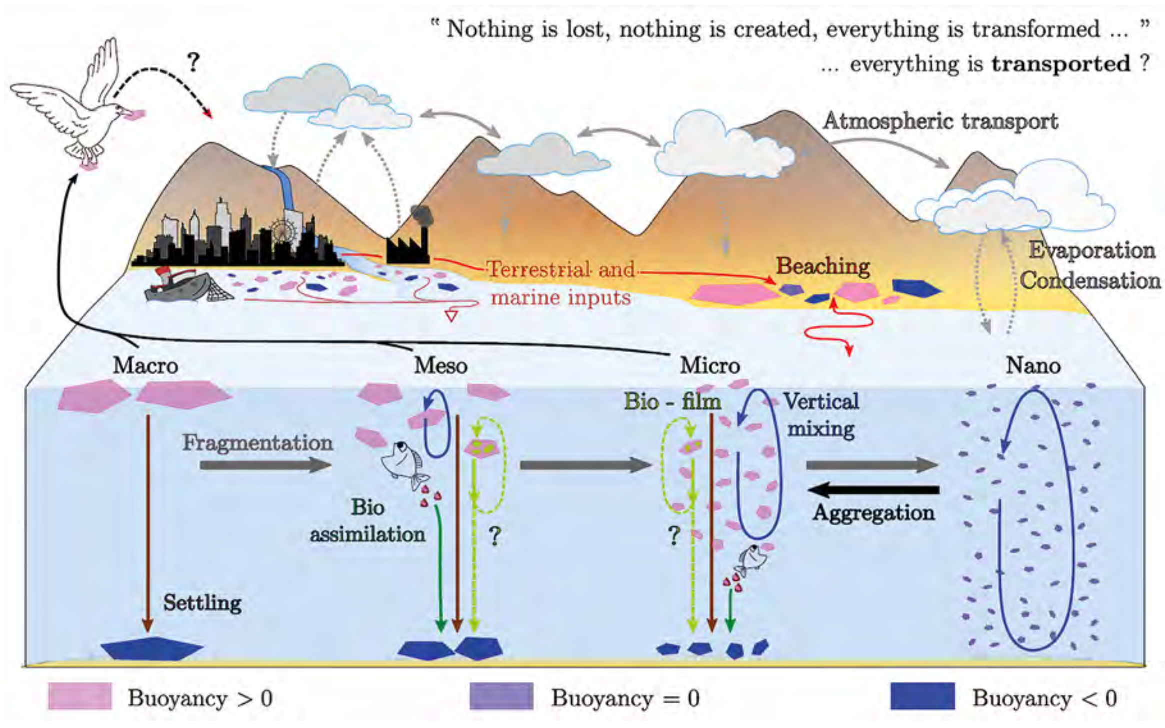
Plastic debris (or plastic litter) ending in the oceans come from various sources: rivers, coastal and offshore human activities, originating from mismanaged waste mainly [5], and more recently identified from airborne pollution [6]. The most recent estimates suggest that the mass of plastic entering the oceans was between 4.8 and 12.7 10^6 Tons for the sole year 2010, between 1.5 and 4% of the global industrial production [5]. Accumulation over the years could lead to figures 10 times larger.

Plastics with a great diversity of shapes, sizes, types and colors end up in the environment, reflecting the many sources of this pollution. The heavier plastics are rapidly integrated in sediments whereas the lighter plastics are transported over long distances and have long times of residency at the sea surface. Floating plastic is slowly transformed into altered material (due to UV radiation and mechanical constraints) that lead to fragmentation into smaller and smaller pieces. The weathered plastic debris loses its mechanical properties and is more subject to erosion and fragmentation [7], as illustrated in Figure 2. Deep chemical and morphological modifications drastically modify its physico-chemical properties, the potential increase in toxicity is still unknown.

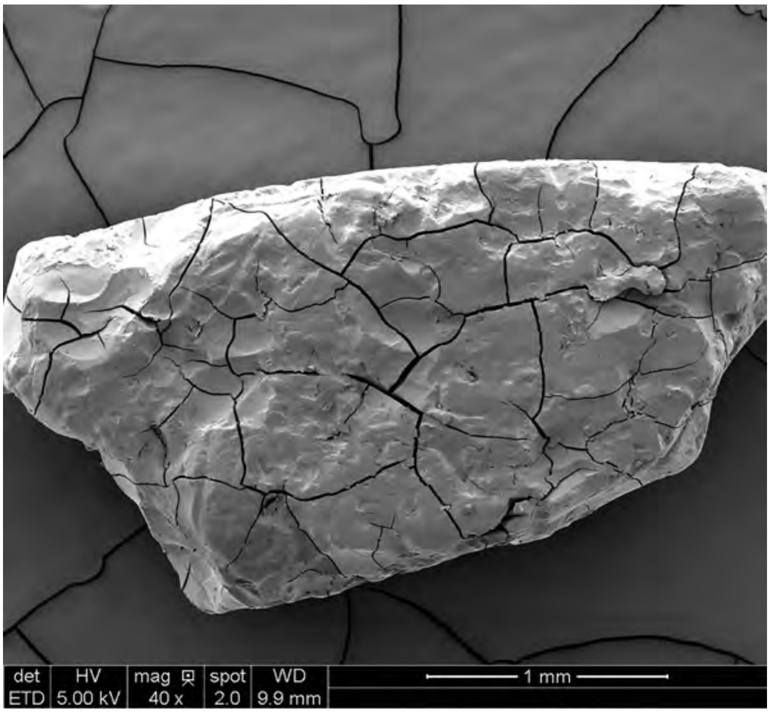
To assess the amount of floating plastic litter, samples are collected at the sea surface with neuston nets [4]. Samples cover a continuum of sizes ranging from large macroscopic debris (>5mm) to microplastics (between 25µm and 5mm). Even nanoplastics (<25µm) are found when collecting water samples [8]. Nevertheless, interpreting this continuum in terms of mass distribution is usually complex, because (i) samples analysis has not been consistently performed for this goal, (ii) the diversity of debris' shapes prevent from easily matching sizes to mass, and (iii) the smallest (and lightest) pieces with dimensions smaller than 300µm (mass smaller than 1mg) are more likely to be transported everywhere in the oceans. An example of the vertical distribution of microplastics in the range of depths [0-300]m is illustrated in Figure 3. Other processes can also affect the distribution of plastic particles, more than just fragmentation, we discuss them in the following.

Plastics at sea are rapidly colonized by a large diversity of microorganisms that form a biofilm on their surface [10]. Biofouling may decrease the buoyancy of most of the plastic debris by different processes. Microbial biofilms alone are sufficient to cause the sinking of small microplastic debris with surface area to volume ratios below 100, which correspond to thin plastic films, fragments or filaments with diameters less than 50µm [11]. For larger debris biofilms, they induce a decrease in hydrophobicity that favors the sink below the surface even though the pieces are still buoyant. It also facilitates adhesion of invertebrates, mainly calcifying organisms, and it could also alter the palatability of plastics, thus increasing ingestion by marine organisms and egestion of plastic together with fecal pellets that may sink together with plastic pieces [4]. Finally, biodeterioration processes occur on plastics that are part of the fragmentation process described earlier.

Other non-biological processes can make plastic pollution leave the sea surface. Waves and wind surface mixing put plastic debris in suspension in the water column. Theoretical models have been developed to correct surface mass concentrations of microplastics according to the sea state [12], that are valid for plastics • • •



◂ **FIG. 1:** Schematic view of various pathways for plastic debris in the ocean based on their properties, density and size.



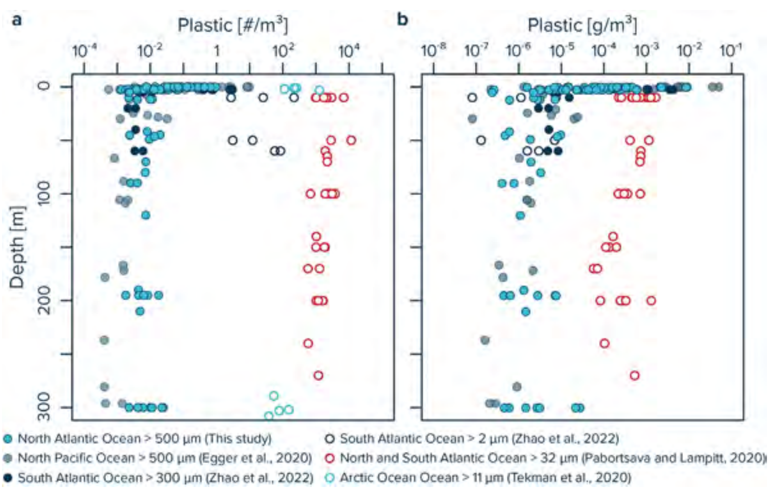
▲ **FIG. 2:** Infrared Image of a plastic piece collected in the North Atlantic Ocean.

larger than ~1 mm, resulting in a vertical distribution a few meters below the sea surface. Smaller plastic debris are mixed deeper (*cf.* Figure 3), where new oceanic processes can modify their transport, such as Langmuir cells for instance [13]. Recent studies have highlighted the importance of the beaching process, resulting in a permanent deposition along the coastlines. This process is difficult to calculate hence hardly estimated or taken into account [14]. Its consideration, based on a probabilistic approach due to the lack of data, could lead to a completely new design of the plastic accumulation maps (Figure 4).

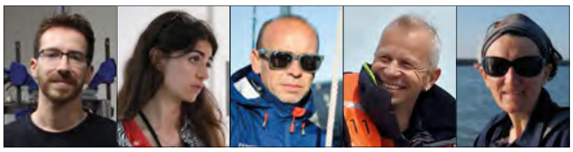
Ultimately, how to estimate the global concentration of plastics? Ocean general circulation models (OGCM) are used, by introducing virtual particles mimicking plastics that are either neutrally or positively buoyant. They can estimate the amount of plastic drifting on the sea surface and predict the main areas of accumulation. At the ocean-basin scale, these areas turn out to be the center of the main large systems of circulating ocean currents, called gyres. These gyres result from a coupling between wind-induced shear at the sea surface and the Coriolis force. However, OGCMs can hardly account for all the oceanic processes that transport plastic debris because of the wide variety of spatial (from mm to thousands of km) and temporal (from seconds to months) scales of oceanic processes [13]. Actual OGCMs parameterized for plastics transport are valuable tools to get general patterns of accumulation and transport processes at the ocean-basin scales, filling the gaps of insufficient in-situ campaigns. The remaining identified issues of such numerical methods are the lack of high resolution processes as described before, that can lead to a bias on the global concentrations. Furthermore, the initial conditions regarding the quantity and the spatial distribution of plastics inputs are still poorly known, imposing simulation scenarios to remain more qualitative than quantitative. Recent works try to explain the mismatch between plastic inputs and estimated global plastic concentrations, by considering more processes such as beaching, Stokes drift, vertical transport, *etc.* General consensus is far from being reached.

For now, the current global mass estimates of the floating plastic pollution based on surface samples alone are of the order of 0.1 to 0.2 10^6 Tons [4], whereas recent global mass estimates for the upper ocean ([0-300m]) suggest that this `hidden' contribution to plastic pollution (away from the surface) could reach 11 to 21 10^6 Tons [9]. The mass of plastic pollution trapped at the oceanic floors is estimated using the proportion of industrial production of plastic denser than seawater. As we make progress on these estimates for the plastic cycle, the hidden part of plastic pollution has significantly decreased but remains a key issue; it seems most likely to be transported everywhere in our environment, depending on the scale at which we search for it. ■

▼ **FIG. 3:** Recently measured depth concentration profiles in oceanic gyres for different plastic sizes (from [9])



About the Authors



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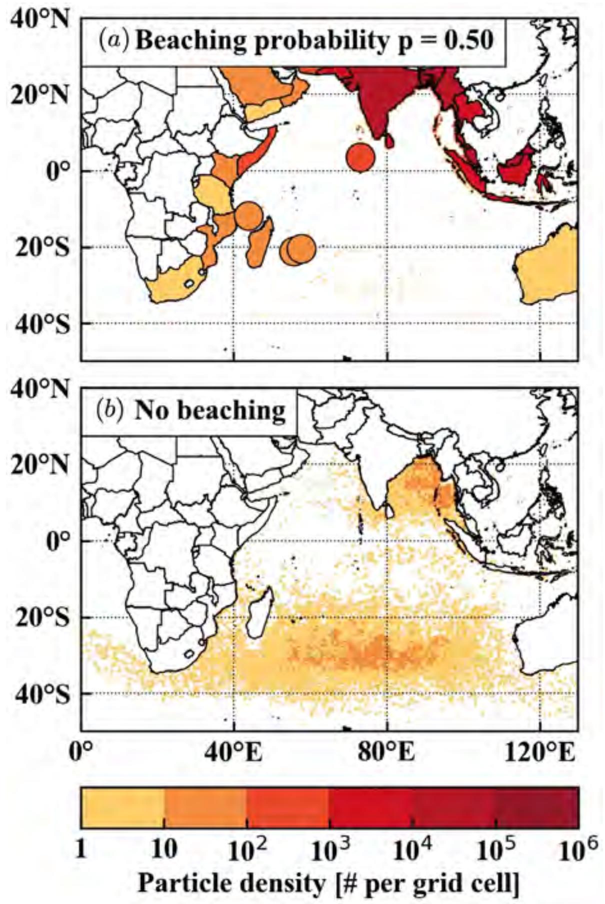

▲ **FIG. 4:** Density of beached particles per country or island and density of particles in the ocean for particles released from river source locations in the Northern Hemisphere Indian Ocean after 21 years of simulation with (a) a beaching probability of 50 % and (b) no beaching (adapted from [14]).

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