Marine Pollution Bulletin 126 (2018) 191–196

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Anticyclonic eddies increase accumulation of microplastic in the North Atlantic subtropical gyre

Laurent Brach[a], Patrick Deixonne[b], Marie-France Bernard[b], Edmée Durand[c], Marie-Christine Desjean[d], Emile Perez[a], Erik van Sebille[e,f], Alexandra ter Halle[a,*]

[a] Laboratoire des Interactions Moléculaires et Réactivité Chimique et Photochimique (IMRCP), UMR CNRS 5623, Université Paul Sabatier-UPS, Bâtiment 2R1, 3ème étage, 118, route de Narbonne, 31062 Toulouse Cedex 09, France
[b] Expédition Septième Continent, Rue des Vanniers Domaine de Marie, 97224 Ducos, Martinique, France
[c] Mercator Océan, Parc Technologique du Canal, 8-10 rue Hermès, 31520 Ramonville Saint Agne, France
[d] Centre National d'Etudes Spatiales, 18 avenue Edouard Belin, 31401 Toulouse Cedex 4, France
[e] Grantham Institute & Department of Physics, Imperial College London, SW7 2AZ London, United Kingdom
[f] Institute for Marine and Atmospheric research Utrecht, Utrecht University, 3584 CC, Netherlands

ARTICLE INFO

Keywords:
Microplastic
North Atlantic subtropical gyre
Marine litter
Sea level anomalies
Mesoscale eddies
Satellite observations
Oceanic current models

ABSTRACT

There are fundamental gaps in our understanding of the fates of microplastics in the ocean, which must be overcome if the severity of this pollution is to be fully assessed. The predominant pattern is high accumulation of microplastic in subtropical gyres. Using in situ measurements from the 7th Continent expedition in the North Atlantic subtropical gyre, data from satellite observations and models, we show how microplastic concentrations were up to 9.4 times higher in an anticyclonic eddy explored, compared to the cyclonic eddy. Although our sample size is small, this is the first suggestive evidence that mesoscale eddies might trap, concentrate and potentially transport microplastics. As eddies are known to congregate nutrients and organisms, this phenomenon should be considered with regards to the potential impact of plastic pollution on the ecosystem in the open ocean.

1. Introduction

Because of the durability of plastic and the constantly increasing inputs, plastic debris is accumulating in every environment. Plastic debris is found inland even in remote places like deserts (Zylstra, 2013). In aquatic environments, plastic has been found in rivers (Bakir et al., 2014; McCormick et al., 2014), lakes (Faure et al., 2015; Eriksen et al., 2013a), bays (Schlining et al., 2013), gulfs (Phillips and Bonner, 2015) and oceans (Eriksen et al., 2014). While the denser debris accumulates in rivers and estuarine sea floors (Schlining et al., 2013), buoyant plastic mostly ends up in open oceans (Jambeck et al., 2015) where, after being transported over long distances, buoyant plastic debris tends to converge in subtropical gyres (Moore, 2008).

The impact of plastic pollution in the oceans affects the whole ecosystem. The direct effects are entanglement and ingestion. Plastic fragmentation results in a continuum of debris sizes (ter Halle et al., 2016), leading to microscopic and even nanometric fragments (Gigault et al., 2016). Thus ingestion concerns both the larger animals, like cetaceans (Lusher et al., 2013; Lusher et al., 2015), turtles (Schuyler et al., 2012), sea birds (English et al., 2015; Ryan, 2015; Wilcox et al., 2015), and the smaller ones, like fishes (Collard et al., 2015); even zooplankton are concerned (Cole et al., 2013; Cole and Galloway, 2015). It has been demonstrated that plastic ingestion can significantly alter the feeding capacity and decrease the reproductive output of organisms (Cole et al., 2015). Another effect is the transportation of invasive species across oceans, which could potentially affect the equilibrium of ecosystems (Goldstein et al., 2014; Zettler et al., 2013). There are also toxic chemicals associated with plastic debris since the plastic contains additives, persistent organic pollutants and heavy metals (Rochman et al., 2013a). The transfer of these substances into the food web when plastic debris is ingested by animals has already been demonstrated for certain organisms (Rochman et al., 2014a; Rochman et al., 2014b; Rochman et al., 2013b; Tanaka et al., 2013; Wardrop et al., 2016).

Floating marine plastic debris converges in subtropical gyres (Law et al., 2010; Eriksen et al., 2013b; Goldstein et al., 2013; Van Sebille, 2015). Some convergence areas have been much more surveyed than others, e.g. the western North Atlantic Ocean (Law et al., 2010; Moret-Ferguson et al., 2010) and the eastern North Pacific Ocean (Goldstein et al., 2013; Law et al., 2014). The southern hemisphere has been studied far less (Eriksen et al., 2013b; Cozar et al., 2014). The vast

---

* Corresponding author.
E-mail address: ter-halle@chimie.ups-tlse.fr (A. ter Halle).

https://doi.org/10.1016/j.marpolbul.2017.10.077
Received 3 August 2017; Received in revised form 25 October 2017; Accepted 26 October 2017

majority of the sea surface has not been surveyed for plastic pollution and there is an evident lack of experimental measurements at sea. By means of circulation models, the weight of the global plastic debris floating at sea has been estimated at several hundred thousand metric tons (between 90,000 and 250,000 metric tons) (Cozar et al., 2014; van Sebille et al., 2015). These estimates correspond to only 1% of the global plastic waste input into the ocean in 2010 (Jambeck et al., 2015). There is an obvious need to better understand where plastic debris is located at sea. This is a crucial step toward assessing the severity of the impact of plastic pollution on marine life.

Because ocean motion is complex and variable, it is difficult to determine precisely the boundaries of subtropical gyres (Froyland et al., 2014) and we do not know, in real time, exactly where plastic particles are located and how they are distributed inside the accumulation areas. Simulations and models exist and are good indicators for a global approach (Eriksen et al., 2014; Maximenko et al., 2012; Lebreton et al., 2012). A recent article comparing existing models concluded that distributions of plastic within gyres were in relative agreement even if methods and inputs were different (van Sebille et al., 2015).

It has often been reported that the amount of plastic collected in trawls can show large variability, sometimes up to an order of magnitude within only a few tens of kilometers, but this has never been rationalized (van Sebille et al., 2015). Knowing that eddies (vortices of 50 to 200 km in diameter that are ubiquitous in the ocean) can trap and transport fluid parcels including nutrients, chlorophyll, and zooplankton (Flierl, 1981; Early et al., 2011; Chelton et al., 2011), we set out to test the hypothesis that plastic distribution at the sea surface could be partly attributed to the presence of eddies. Traditionally, the paradigm is that anticyclonic eddies (clockwise in the Northern Hemisphere) capture material drifting at the surface, while cyclonic eddies (anticlockwise in the Northern Hemisphere) tend to expel material (Chelton et al., 2011). However, the mechanisms are complex and some studies have shown that cyclonic eddies can also capture material very effectively (Froyland et al., 2014; Haller and Beron-Vera, 2013; Beron-Vera et al., 2016).

Satellites providing near-surface information on ocean physics and biology are the only practical means of obtaining dense, global observations of the open ocean. But the direct observation of plastic debris in oceans is not yet possible via satellites since methods like remote sensing cannot observe small particles of plastic directly because of the instrument resolution. Moreover, concentrations of microplastics are not high enough to modify the backscatter signal of the sea surface detectable by RADAR (used for monitoring hydrocarbon spills for instance). In this study, we propose to correlate satellite observations with in situ microplastic concentrations.

During the sea campaign Expedition 7th Continent in June 2015, we performed in situ measurements while navigating around and across two individual cyclonic (CE) and anticyclonic eddies (AE) in the North Atlantic gyre. The localization of the eddies was beforehand determined by current forecasts. This paper is organized as follows the in situ measurements have been correlated with SLA values, then thank to the use of an algorithm we identified structure coherent eddies in the area sampled and the plastic distribution was discussed with respect of these structures. The aim of this study is to rationalize in situ microplastic surface concentrations with the altimetry data and model surface currents that are available globally at daily resolution.

2. Materials and methods

2.1. 2015 North Atlantic sea campaign routing

The sea campaign Expedition 7th Continent took place in the western North Atlantic subtropical gyre between 15 and 30°N and 55 and 65°W from 28th May to 16th June 2015 (Fig. 1). The boat was guided day by day from Toulouse (France) using Copernicus Marine Environment Monitoring Service portal (CMEMS, http://marine.copernicus.eu). The CMEMS data was referenced as GLOBAL_ANALYSIS_FORECAST_PHYS_001_002 (global ocean analysis and forecast model) and was available daily with a resolution of 1/12°. Our area of interest was mapped every day to forecast the following day's surface currents and sea surface height (SSH). In the area to be explored, SSH was between 3 and 40 cm and we planned to sample the whole range of SSH and to explore two mesoscale eddies. We tried to allocate sampling time evenly over the whole range of SSH but this was limited by logistical considerations, mainly the navigation speed and weather conditions.

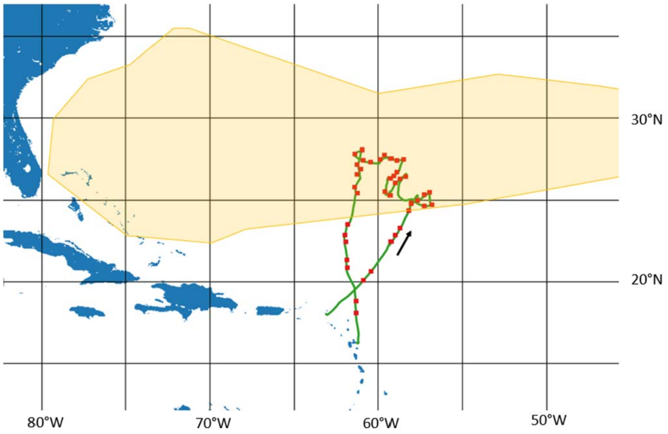

Fig. 1. Map of subtropical North-Western Atlantic Ocean. The route of the boat is represented by the green line, the red squares mark the location of each net tow and the yellow shading corresponds to the plastic accumulation area according to Lebreton et al. (Lebreton et al., 2012). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.2. Net tow sampling

On the sailing vessel Guyavoile, net tows were conducted using Neuston nets with a standard mesh size of 300 μm. Plastics were collected in a 0.5 m × 0.4 m rectangular frame fitted with a 2 m long net. The net was equipped with a mechanical flow meter (Digital Flow Meter Model 438,110, Hydro-bios, Altenholz Germany), from which sea surface concentrations could be calculated and expressed as the number of pieces per square kilometer. The plastic debris was collected from the surface-layer at a depth of 0–20 cm. Tow durations were set to 30 min and were all undertaken while the vessel was travelling at a speed of 1 to 2.5 knots. The wind speed was measured with an anemometer fixed on top of the mast at 27 m. The Beaufort number was deduced from the wind speed measurements. The captain estimated the sea state of each sampling period. During this 17-day long campaign, 41 nets were towed. The date, GPS location, Beaufort number and sea state for each net tow is reported in Table SI 1.

2.3. Microplastics sorting, counting, weighing and preservation

On the boat, the contents of the tows were filtered on 300 μm sieves. Most of the plastic debris was removed with tweezers and stored at − 5 °C in glass vials. The remaining mixture of plankton and the smallest plastic debris was stored in flasks in a formol/sea water solution (5% vol formol) to preserve the plankton for identification and numbering. Under laboratory conditions and using a binocular microscope (magnification by 5 and 10), the small plastic debris was manually separated from natural matter with forceps. The remaining sample was inspected again on a glass plate. The plate was placed successively on top of white, black and red paper in order to sort out all the plastic debris. Sargassum was carefully inspected as plastic lines were often entangled in it. Microplastic is defined as plastic debris with a size below 5 mm (Arthur et al., 2009). In this study, plastic debris were sampled using a mesh size of 300 μm. All plastic debris was