Marine Pollution Bulletin 58 (2009) 1347–1355

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Floating marine debris surface drift: Convergence and accumulation toward the South Pacific subtropical gyre

Elodie Martinez [a,b,*], Keitapu Maamaatuaiahutapu [a], Vincent Taillandier [b]

[a] Laboratoire Terre-Océan, Université de la Polynésie Française, BP 6570 Faaa, Faaa 98702, Tahiti French Polynesia, France
[b] Laboratoire d'Océanographie de Villefranche (LOV), CNRS UMR 7093, Université Pierre et Marie Curie, BP 08, 06 238 Villefranche sur Mer, France

ARTICLE INFO

Keywords:
Surface currents
Satellite data
Lagrangian drift
Floating marine debris
Convergence zone
Accumulation area

ABSTRACT

Whatever its origin is, a floating particle at the sea surface is advected by ocean currents. Surface currents could be derived from *in situ* observations or combined with satellite data. For a better resolution in time and space, we use satellite-derived sea-surface height and wind stress fields with a 1/3° grid from 1993 to 2001 to determine the surface circulation of the South Pacific Ocean. Surface currents are then used to compute the Lagrangian trajectories of floating debris. Results show an accumulation of the debris in the eastern-centre region of the South Pacific subtropical gyre ([120°W; 80°W]–[20°S; 40°S]), resulting from a three-step process: in the first two years, mostly forced by Ekman drift, the debris drift towards the tropical convergence zone (~30°S). Then they are advected eastward mostly forced by geostrophic currents. They finally reach the eastern-centre region of the South Pacific subtropical gyre from where they could not escape.

1. Introduction

Floating marine debris (FMD) and other marine pollution threaten the livelihood of coastal communities. Coastlines are strewn with a myriad of light-weight plastic bags and other debris, marring the paradise image of the South Pacific, endangering shipping and human health as well as threatening marine life. It is estimated that each year around the world more than 100,000 sea animals, including turtles, die from eating or being caught in plastic bags and other debris (Wilks, 2006). Despite control measures, the amount of litter at sea is increasing (Ryan and Moloney, 1993) and the predominance of plastics varies between 60% and 80% of the total marine debris (Gregory and Ryan, 1997). Their durability in the marine environment is still uncertain but they seem to last from 3 to 10 years, and additives can probably extend this period to 30–50 years (Gregory, 1978).

Transport of particles by ocean currents is important in physical oceanography since the particles can be used as a tracer of the ocean circulation. Conversely, our knowledge of the ocean currents could help us find the trajectories of FMD in order to study polluting FMD (Kubota et al., 2005) or to study invasive species (Martinez et al., 2007). On a large scale, extensive studies of FMD have been carried out in the North Pacific Ocean. Wakata and Sugimori (1990) investigated surface drift simulations using ship drift data. Three high-density accumulation areas exist and one of these stagnates north of the Hawaii islands. The accumulation mechanism in this area was clarified by Kubota (1994), using surface currents calculated by combining Ekman and Stokes drifts and geostrophic currents. Stokes and Ekman drifts were derived from COADS ocean wind data, while geostrophic currents were derived from Levitus salinity and temperature data. Then Kubota et al. (2005), used monthly ERS winds and 5-day Topex/Poseidon sea surface height on a 1° grid in order to calculate surface current fields for the world ocean from 1993 to 1998. The Stokes drift effect on the motion of FMD was considered to be less significant than geostrophic currents and Ekman drifts. Focusing on the North Pacific, the authors showed that after a five-year drift FMD accumulate in specific high density areas such as the mid latitudes and north of Hawaii. A similar trend of mid-latitude convergence in other ocean basins as well as in the South Pacific Ocean has been reported by Kubota et al. (2005).

The present work is intended to characterize and quantify long-term drift of FMD in the South Pacific Ocean. This oceanic basin is insufficiently sampled by surface drifters, especially in its central part, to provide a suitable spatial coverage. Moreover, drifters almost never start their drifts from coasts but in the open ocean and they could not operate longer than three years. For our purpose, satellite data are more suitable mostly with the unprecedented 1/3°-spatial and 7-day temporal global coverage from 1993 to 2001. Considering the durability of FMD (10 years or more), it is possible with this data set to explore the long-term drift

* Corresponding author. Address: Laboratoire d'Océanographie de Villefranche (LOV), CNRS UMR 7093, Université Pierre et Marie Curie, BP 08, 06 238 Villefranche-sur-Mer, France. Tel.: +33 4 93 76 37 23; fax: +33 4 93 76 37 39.
E-mail address: martinez@obs-vlfr.fr (E. Martinez).

0025-326X/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.marpolbul.2009.04.022

of FMD in the South Pacific Ocean and to answer the question about the FMD fate after they reach the convergence region in the mid latitudes. Assessment of the impact of interannual variability due to ENSO (El Niño Southern Oscillation) is carried out. Our data set allows us to explore the effect of mesoscale structures on FMD drift. Such higher spatial resolution data set is particularly useful in the South Pacific mid latitudes where the SubTropical CounterCurrent (STCC) flows. The STCC is highly turbulent (Qiu and Chen, 2004) and should impact on drift trajectories.

This paper is organized as follows: in Section 2 data and processing procedures are presented. In Section 3, Lagrangian trajectories and trends in the South Pacific Ocean are identified. Comparisons with results calculated from the OSCAR (Ocean Surface Current Analysis-Real time) product are carried out. A summary and discussion are provided in Section 4.

2. Data and methods

2.1. Satellite derived high spatial resolution sea surface currents

Surface oceanic currents are calculated from sea level anomaly (SLA) and sea surface wind satellite data products from January 1993 to January 2001 in the South Pacific Ocean ([5°N; 60.5°S] and [139.5°E; 70.5°W]). SLA data are extracted weekly from the combined TOPEX/POSEIDON (T/P) (Fu et al., 1994; Stammer and Wunch, 1994) and ERS-1/2 (Ducet and Le Traon, 2001) data on a 1/3° grid. SLA data are added to the Levitus mean annual climatological dynamic height referred to 1000 m depth (Levitus et al., 1992) to calculate the surface geostrophic currents. Geostrophy is established from the standard f-plane geostrophic balance with a special attention near the equator where the coriolis parameter is equal to zero. As in the method presented by Lagerloef et al. (1999), geostrophy varies smoothly from a β-plane formulation at the equator to an f-plane formulation at mid latitude, with the transition occurring at ~2°–3° latitude. The transition is interpolated with Gaussian weighted functions.

The Ekman current is calculated from a parametric model of the purely wind-driven response (Pond and Pickard, 1983). About 10 m-high wind fields are measured by the ERS-1/2 scatterometers and provided by PODAAC (Physical Oceanography distributed Active Archive Center). Wind fields are linearly, temporally and spatially interpolated to fit the 7-day interval, 1/3° gridded field of T/P-ERS SLA from January 1993 to January 2001. At the equator, Ekman current vectors are considered as 3% of the wind vectors to make a smooth transition with conventional wind currents calculated for higher latitudes (Chen et al., 1999; Lagerloef et al., 1999).

Surface circulation features in the South Pacific Ocean are described with a good resolution (Le Traon et al., 2003) from 1993 to 2001, every 7 days on a Mercator 1/3° grid as the sum of geostrophic and Ekman currents, and will be referred as the *High Resolution (HR)* total, geostrophic and Ekman fields.

2.2. HR mesoscale filtered field

A degraded version of HR field is also used in this study to investigate the sensitivity to mesoscale current structures. The mesoscale patterns are filtered out from the original HR fields. Keeping the same meshgrid, the mesoscale filter has consisted in applying a moving spatial average over a radius equal to 200 km.

2.3. OSCAR sea surface currents

The OSCAR sea surface currents are provided by NOAA (http://www.oscar.noaa.gov), on a 1° resolution grid, weekly from 1993 to 2001. This product is constructed from the TOPEX/Poseidon sea surface heights, scatterometer winds, and both Advanced Very High Resolution Radiometer and *in situ* sea surface temperatures (Bonjean and Lagerloef, 2002). It is representative of the surface layer (upper 30 m depth).

With a 1° spatial resolution, OSCAR surface currents will be referred as the *Low Resolution (LR)* product compared to the HR product presented in Section 2.1.

2.4. Eddy kinetic energy

The weekly Eddy kinetic energy is calculated using altimetry data (Jakobsen et al., 2003; Martins et al., 2002; Ducet and Le Traon, 2001): EKE = $1/2[(u_g')^2 + (v_g')^2]$, where u_g' and v_g', respectively, are the zonal and meridian components of the geostrophic anomaly field. This anomaly field is obtained removing the 8 year (1993–2001) average to the weekly geostrophic fields.

2.5. The Lagrangian drift

FMD are assumed to be transported by the sea surface currents derived from satellite data (Sections 2.1–2.3). Their trajectories are then represented by the successive positions $r = (\lambda, \varphi)$ that FMD cross by during the 8 years period of interest (1993–2001) inside the Southern Pacific Ocean.

In numerical practice, the advection of a passive particle inside a 2D velocity field can be described by a solution of the non-linear ordinary equation $\frac{dr}{dt} = \boldsymbol{u}(\boldsymbol{r}, t)$, with the initial condition $\boldsymbol{r}$ (to). This equation is classically and accurately resolved using the 4th order Runge–Kutta scheme for the integration of the time derivation, and a bilinear interpolation in space for the velocity term $\boldsymbol{u}(\boldsymbol{r}, t)$.

Its discrete formulation requires the specification of a time step which duration is to be consistent with the spatial resolution of the velocity field. Given a 1/3° resolution at most for the ocean surface currents data, the time step is fixed at 1 day in order to account for the local velocity structures along the FMD motion. With an average motion of 20 km per day, the FMD trajectory would be sampled in each mesh of the velocity field and so forced by all the surrounding velocity values (see Taillandier et al., 2006 for detailed discussion).

The FMD are represented by a large population of numerical particles that are homogeneously distributed at the initial time of the experiment. The distribution of this population over the South Pacific Ocean is computed weekly but the outputs are considered with a periodicity of a month. Each month, the number of numerical particles is computed inside each 1° × 1° bin covering the whole basin. The number of numerical particles which have not moved during this 1 month period is also performed to quantify a rate of disappearance of the population. This distribution at the initial and final times is also extracted for each simulation.

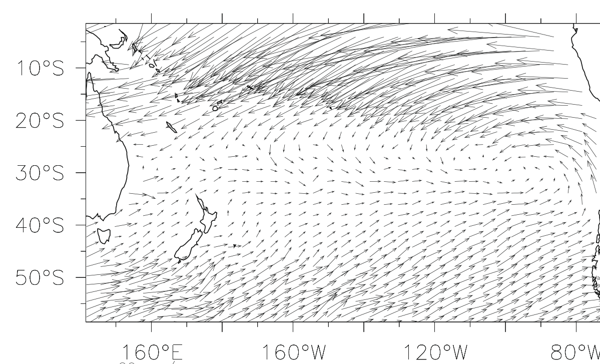

Fig. 1. Mean surface current from January 1993 to January 2001.