Deep-Sea Research Part I 124 (2017) 73–92

Contents lists available at ScienceDirect

Deep-Sea Research Part I

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

An improved near-surface velocity climatology for the global ocean from drifter observations

Lucas C. Laurindo[a,*], Arthur J. Mariano[a], Rick Lumpkin[b]

[a] Rosenstiel School of Marine & Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149, USA
[b] NOAA/Atlantic Oceanographic and Meteorological Laboratory, 4301 Rickenbacker Causeway, Miami, FL 33149, USA

ARTICLE INFO

Keywords:
Near-surface velocity climatology
Ocean drifters
Gauss-Markov estimation
Drifter slip bias
Error analysis

ABSTRACT

This work updates the methods of Lumpkin and Johnson (2013) to obtain an improved near-surface velocity climatology for the global ocean using observations from undrogued and 15-m drogued Global Drifter Program (GDP) drifters. The proposed procedure includes the correction of the slip bias of undrogued drifters, thus recovering about half of the GDP dataset; and a new approach for decomposing Lagrangian data into mean, seasonal and eddy components, which reduces the smoothing of spatial gradients inherent in data binning methods. The sensitivity of the results to method parameters, the method performance relative to other techniques, and the associated estimation errors, are evaluated using statistics calculated for a test dataset consisting of altimeter-derived geostrophic velocities subsampled at the drifter locations, and for the full altimeter-derived geostrophic velocity fields.

It is demonstrated that (1) the correction of drifter slip bias produces statistically similar mean velocities for both drogued and undrogued drifter datasets at most latitudes and reduces differences between their variance estimates, (2) the proposed decomposition method produces pseudo-Eulerian mean fields with magnitudes and horizontal scales closer to time-averaged Eulerian observations than other methods, and (3) standard errors calculated for pseudo-Eulerian quantities underestimate the real errors by a factor of almost two. The improved decomposition method and the inclusion of undrogued drifters in the analysis allows resolving details of the time-mean circulation not well defined in the previous version of the climatology, such as the cross-stream structure of western boundary currents, recirculation cells, and zonally-elongated mid-ocean striations.

1. Introduction

A global climatology of surface ocean currents is desirable for a variety of applications. For example, the statistical moments of the ocean velocity (mean, variance, and covariances) are used in the study of linear geophysical instabilities, ocean energetics, and the turbulent transport of tracers and heat. In a Lagrangian framework, the fluctuations around the mean are used to infer eddy diffusivities and decorrelation time scales. Besides the investigation of the underlying ocean dynamics, the statistical description of the surface circulation is also relevant for ship routing, search and rescue operations, and for predicting the dispersion and transport pathways of biogeochemical tracers and of pollutants such as oil, microplastic, and floating marine debris.

The drifters of the Global Drifter Program (GDP) currently provide the most accurate set of measurements of the near-surface ocean velocities at global scales (Lumpkin and Pazos, 2007; Maximenko et al., 2013). However, observations are scattered in space and time and often autocorrelated in both dimensions, making their decomposition into mean and fluctuating components a non-trivial exercise. A common approach involves ensemble-averaging data selected within spatial bins (e.g. Niiler, 2001; Fratantoni, 2001; Jakobsen et al., 2003; Reverdin et al., 2003; Maximenko et al., 2009; Zhurbas et al., 2014), however, this method has a number of associated biases whose effects are difficult to diagnose (Mariano and Ryan, 2007). A particularly important source of uncertainty lies in the choice of bin size, whose definition involves a trade-off between the statistical reliability of the results and the resolution of the horizontal scales of the mean flow. Specifically, larger bins select more data points, which leads to a higher statistical significance of the estimates, however they smooth horizontal variations of the mean at scales smaller than the bin. Conversely, smaller bins better resolve spatial gradients, however the use of less data points increase the estimation errors. The bin size choice, therefore, influences the estimation of the mean, consequently also affecting the residuals and thus second moment statistical properties (Fratantoni, 2001; LaCasce, 2008; Koszalka and LaCasce, 2010).

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[*] Corresponding author.
E-mail addresses: llaurindo@miami.edu (L.C. Laurindo), amariano@miami.edu (A.J. Mariano), rick.lumpkin@noaa.gov (R. Lumpkin).

http://dx.doi.org/10.1016/j.dsr.2017.04.009
Received 13 September 2016; Received in revised form 8 April 2017; Accepted 9 April 2017

Furthermore, while most studies based on binning methods employed fixed-sized bins, a consequence of this practice is obtaining pseudo-Eulerian estimates whose statistical reliability vary in space. To avoid this issue, Koszalka and LaCasce (2010) proposed selecting data in clusters covering unequal areas but with a similar number of observations. Notably, the application of this technique to GDP data in the Nordic seas resolved features of the time-mean circulation with scales ≤10 km in well-sampled regions (Koszalka et al., 2011). However, the number of observations per cluster prescribed in that work results in an average selection radius of 75 km ($\sim 0.67^\circ$ latitude and ~ 1.3–1.8° longitude, in their study area), meaning that horizontal velocity gradients at mesoscale ranges are smoothed out when considering typical ocean sampling densities.

Another source of uncertainty is due to the fact that drifters do not perfectly track the horizontal flow. Differences between the measured velocities and the actual current velocities, an effect known as slip, are caused by wind drag on the drifters surface float and wave-induced phenomena, such as Stokes drift and drifter self-propulsion by wave surfing. GDP drifters include a drogue centered at 15-meter depth that minimizes the wind and wave-induced bias, however that also introduces another component to the slip via the vertical velocity shear between the surface float and the subsurface drogue. Despite the complex nature of the processes driving the slip motion, the drogued design of GDP drifters is calibrated to yield a predominantly downwind slip of less than $\sim 0.1\%$ of the 10-m wind speed, for winds up to 10 m/s (Niiler et al., 1995). An assessment of the GDP dataset by Lumpkin et al. (2013) showed that more than 50% of the available data previously believed to be from drogued drifters are actually from instruments that had lost their drogues, a condition that changes the sampling level from 15-m to the surface, and renders their trajectories more sensitive to wind and wave effects, increasing the slip to about 0.7–1.6% of the 10-m wind speed (e.g. Pazan and Niiler, 2001; Poulain et al., 2009; Peng et al., 2015b).

Nearly-global maps of the mean surface ocean circulation calculated from drifter observations using bin-averaging were presented by Niiler (2001) and Maximenko et al. (2009). Considering that these fields were biased by undrogued drifter data, and seeking to reduce the smoothing effect of data binning, Lumpkin and Johnson (2013) produced a global climatology using drogued-only observations and a new binning method that simultaneously models spatial and temporal variations. However, since the exclusion of undrogued data significantly reduces the observational density in many oceanic areas, Lumpkin and Johnson (2013) selected data within relatively large bins (specifically within ellipses oriented by the variance of the binned observations, with areas equivalent to 2° radius circles) to obtain statistically significant estimates homogeneously distributed throughout the oceans. Although the use of large bins better resolves large-scale circulation patterns, it has the potential to significantly smooth coherent structures at mesoscale ranges, such as the large cross-stream velocity gradient associated with western boundary currents.

Based on these considerations, this study applies a first-order correction to the slip of undrogued drifters by referencing their velocity estimates to 15-m using a formulation proposed by Pazan and Niiler (2001), and describes a new estimation method designed to further reduce the smoothing effect of data binning, in order to generate a new comprehensive velocity climatology at 15-m depth (hereafter referred to as “near-surface”) of the global ocean. The mean fields obtained using the proposed approach recover well-known large-scale circulation features, and resolve coherent structures at mesoscale ranges whose visualization was only possible by time-averaging surface velocities indirectly inferred from satellite observations (e.g. Lagerloef et al., 1999; Maximenko et al., 2009). A thorough description of the circulation in light of the new results, including its seasonal variations and kinetic energy distribution, will be the subject of an upcoming publication. Here, focus is given to describing the proposed method and to analyzing its associated uncertainties.

This work is organized as follows. Section 2 describes the datasets, the correction of drifter slip bias, and the method proposed for the decomposition of Lagrangian data into mean, seasonal and eddy components. Section 3 presents the results of sensitivity tests to method parameters and an error analysis, describes the improvements of the new climatological fields relative to the results of Lumpkin and Johnson (2013), and briefly describes prominent new features observed in the obtained global maps. Finally, Section 4 summarizes this study and its conclusions.

2. Methods

2.1. Data description

2.1.1. Position/velocity observations from surface ocean drifters

This analysis uses position and horizontal velocity data from both undrogued and 15-m drogued drifters of the Global Drifter Program (GDP). This dataset is archived and distributed by the Atlantic Oceanographic and Meteorological Laboratory of the National Oceanic and Atmospheric Administration (AOML/NOAA, http://www.aoml.noaa.gov/phod/dac/index.php). Its generation involves the quality control of the raw drifter position fixes, and their subsequent interpolation via kriging along their trajectories to regular 6 h intervals, at which the u and v velocity components are calculated by 12 h centered differencing the kriged positions (Hansen and Poulain, 1996). The GDP dataset obtained for this study comprises more than 29 million, six hour position/velocity estimates scattered throughout the worlds ocean, from February 1979 to June 2015. About 56% of the available data points are from undrogued drifters.

Fig. 1 shows global distribution maps of the data obtained by drogued, undrogued and both types of drifters (top, middle and bottom panels, respectively), in observation days per square degree. The density of data obtained by drogued drifters is usually higher close to continental contours and to traditional deployment sites, such as the western North Atlantic, the western and eastern North Pacific, the tropical Pacific, Sea of Japan, and near the Antarctic Peninsula, while the distribution of data from undrogued instruments marks time-averaged convergence zones in the interior of the subtropical gyres, notably highlighting garbage patches in the eastern South Pacific, and within the subtropical gyres of the Atlantic ocean. These characteristics arise because (a) the probability of drogue loss increases as a function of drifter age, with about 30% (90%) of these instruments losing their drogues within the first 3 months (1.5 years) of operation (Grodsky et al., 2011); (b) a time scale of months to years is required for drifters deployed near coastal areas to travel to the interior of the gyres, meaning that instruments sampling these regions tend to be older and thus more frequently undrogued; and (c) the drifters ultimately tend to move away from time-averaged divergence areas, such as the equatorial region, and to accumulate at convergence zones, such as the interior of subtropical gyres. While Ekman convergence plays a role in this effect, Beron-Vera et al. (2016) demonstrated that the main mechanism driving the accumulation of undrogued drifters at large-scale convergence zones is the combined action of wind and currents on finite-sized floating objects.

2.1.2. Altimeter-derived geostrophic velocity fields

Altimeter-derived surface geostrophic velocity (GV) fields are produced by the *Segment Sol Multimissions d'Altimétrie, d'Orbitographie et de Localisation Précise* of the Data Unification and Altimeter Combination (SSALTO/DUACS), and were obtained from the Archiving, Validation and Interpretation of Satellite Ocean Data (AVISO, http://www.aviso.altimetry.fr/duacs/). For its generation, regularly-gridded sea-surface height (SSH) fields are initially obtained by merging data from two altimetric satellites with different sampling characteristics. One is from the TOPEX/Jason missions, with a 315 km equatorial ground track separation and a 9.9156 days global sampling