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Modelling surface currents in the Eastern Levantine Mediterranean using surface drifters and satellite altimetry

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ABSTRACT

We present a new and fast method that blends altimetric and drifter positions data in order to predict the surface velocity in the Eastern Levantine Mediterranean. The method relies on a variational assimilation approach where a velocity correction is continuously obtained by matching observed drifter positions with those predicted by a simple advection model. The background velocity used in the advection of the drifters is the aggregate of a geostrophic and a wind-driven component and the velocity correction is constrained to be divergence free. The algorithm employs a sliding time window that assimilates at once and inside each frame, an entire trajectory of drifters. We show that with few drifters, our method improves the estimation of velocity in two typical situations: an eddy between the Lebanese coast and Cyprus, and velocities along the Lebanese coast.

1. Introduction

An accurate estimation of mesoscale to sub-mesoscale surface dynamics of the ocean is critical in several applications in the Eastern Levantine Mediterranean basin. For instance, this estimation can be used in the study of pollutant dispersion emanating from heavily populated coastal areas. Small scale and accurate surface velocity estimation near coastal areas could also benefit the study of the paths of alien Lessepsian species. A good knowledge of the surface velocity field is thus important but can be challenging, especially when direct observations are relatively sparse.

Altimetry has been widely used to predict the mesoscale features of the global ocean resolving length scales on the order of 100 km (Chelton et al., 2007). There are, however, limitations to its usage. It is inaccurate in resolving short temporal and spatial scales of some physical structures like eddies, fronts and filaments, which results in blurring these structures. Further errors and inaccuracies occur near the coastal areas where satellite information is degraded (within 20–50 km from land, see e.g. Cipollini et al., 2010); this is due to various factors such as land contamination, inaccurate tidal and geophysical corrections, inaccurate Mean Dynamic Topography and incorrect removal of high frequency atmospheric effects at the sea surface (Caballero et al., 2014).

To improve velocity estimation, especially near the coast, in situ observations provided by surface drifters can be considered (e.g. Bouffard et al. (2008); Ruiz et al. (2009)). Drifters follow the currents and when numerous, they allow for an extensive spatial coverage of the region of interest. They are inexpensive, easily deployable and provide accurate information on their position and other environmental parameters (Lumpkin and Pazos, 2007).

To illustrate the information provided by drifter data, we show in Fig. 1 the real-time positions of three drifters launched south of Beirut on August 28 2013. These positions can be compared to the positions that would have been obtained if the drifters were advected by the altimetric velocity field. We observe that unlike the corresponding positions simulated by the altimetric field provided by AVISO (see Section 2.1), the drifters stay within 10–20 km from the coast. The background velocity field shown in the figure is the geostrophic field predicted by altimetry and averaged over a period of 6 days. The drifter in situ data render a much more precise image of the local surface velocity than the

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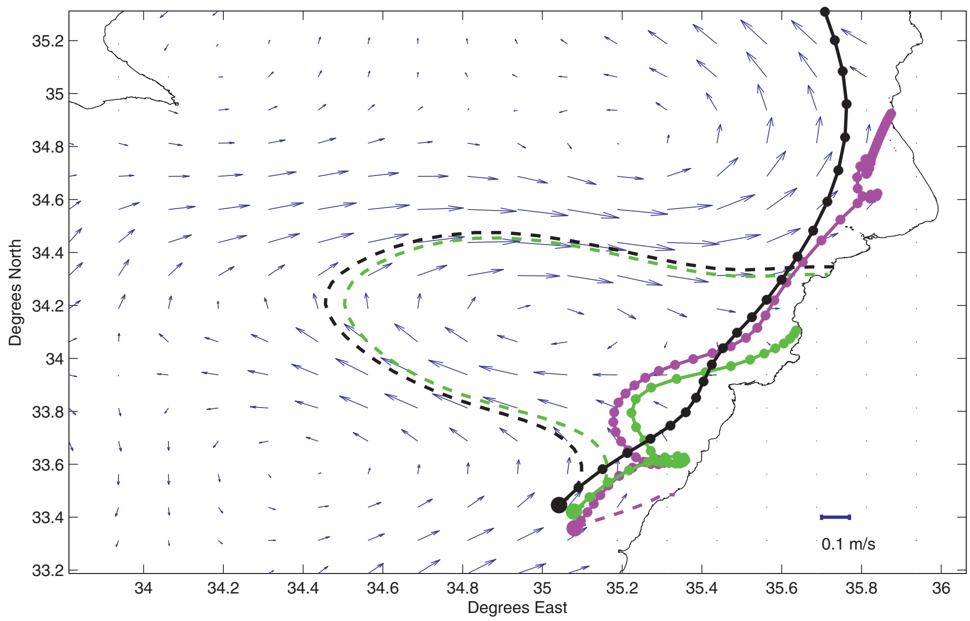

Fig. 1. Real drifters deployed on 28 Aug. 2013 (shown in $-o$) versus synthetic trajectories simulated using the AVISO field (shown in $--$). The velocity field shown is the AVISO field, averaged over 6 days from 28 Aug. 2013 to 3 Sept. 2013.

altimetric one. In fact, drifters are not only able to correct inaccuracies of altimetry in predicting the geostrophic part of velocity near the coast, but they are also likely to predict ageostrophic components in these areas. In these coastal regions, shallow water dynamics may be driven by winds, inertia, vertical variations, upwelling, and buoyancy fluxes (Berta et al., 2015). This additional information can be obtained only along the path following the drifters trajectories, whereas other types of data relaying partial information about the velocity (e.g. altimetry) may be available in a wider area. The main focus of this work is to optimally blend several sources of data to obtain an accurate estimate of the surface velocity field in the Eastern Levantine Mediterranean.

From the application point of view, the idea of using drifters for velocity estimation has been successfully applied to several basins, for example in: the Gulf of Mexico (e.g. Carrier et al., 2014; Muscarella et al., 2015; Berta et al., 2015), the Black Sea (Kubryakov and Stanichny, 2011; Stanichny et al., 2015) the North Pacific (Uchida and Imawaki, 2003), and the Mediterranean Sea (Taillandier et al., 2006b; Poulain et al., 2012; Menna et al., 2012). The work of Menna et al. (2012) focused on the Levantine basin, where large historical data sets from 1992 to 2010 were used to characterize the surface currents. The specific sub-region which lies between the coasts of Lebanon, Syria and Cyprus is however characterized by a scarcity of data in the study of Menna et al. (2012). In the present work, we use in addition to the data sets used in Menna et al. (2012), more recent data from 2013 to study this particular sub-region.

From the methodological point of view, combining altimetric and drifter data has been done using statistical approaches, when extensive data sets are available. In order to improve Eulerian velocity estimation, a common method is to use simple regression models to combine three sources of data: altimetry, wind speed, and drifter positions. In this approach, drifter velocities are computed from positions using finite differences which makes these methods pseudo-Lagrangian. Ekman-wind induced velocities are computed from wind speed data using simple regression models (e.g Poulain et al., 2009). When large data sets are available, these methods produce an unbiased refinement of the geostrophic circulation maps, with better spatial resolution. (e.g. Poulain et al. (2012); Menna et al. (2012); Uchida and Imawaki (2003); Maximenko et al. (2009); Niiler et al. (2003); Stanichny et al. (2015)). Approaches like the ones described above assume heavy spatial coverage of the area of interest as well as fine enough sampling observation times of the drifters.

A variety of other methods have been explored to improve estimates of the Eulerian velocity field by assimilating Lagrangian information into operational ocean models. One common approach is to directly use the position information relayed by in-situ observations to modify a dynamical model state, predicted by complex physical models. The two main categories of data assimilation methods that are widely used in this context are either variational ones, based on optimal control theory, or statistical ones based on optimal statistical estimation. Sequential methods, relying on optimal interpolation or the Kalman filter, have been tested successfully in the context of blending in-situ position data and several types of operational models, such as idealized point vortex models (Kuznetsov et al., 2003), General Circulation Models with simplified stratification (e.g. Molcard et al., 2005; Özgökmen et al., 2003). In the variational assimilation approach, velocity corrections are obtained by minimizing an objective function measuring the difference between observations and their corresponding model variables. The gradient of this objective function is computed by integration of the adjoint model. Variational methods relying on adjoint computations and that take into account the temporal variation of the observations are called 4D-Var. These have been historically developed in the framework of atmospheric data assimilation (Courtier et al., 1994; Le Dimet and Talagrand, 1986), and later applied to assimilating in-situ data for correcting Eulerian velocity models (e.g. Kamachi and O'Brien, 1995; Mead, 2005; Nodet, 2006).

Another approach that fits in the 4D-Var framework is to assimilate drifter derived velocities, instead of positions, into an operational ocean model. Examples include the recent works of Carrier et al. (2014) and Muscarella et al. (2015). In these studies, the authors showed an improvement in forecast skill in model velocity, salinity, and SSH fields when velocities derived from drifters, as