Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research 53 (2014) 788–801

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

Lagrangian analysis of satellite-derived currents: Application to the North Western Mediterranean coastal dynamics

Jerome Bouffard [a,b,*], Francesco Nencioli [a,b], Romain Escudier [c], Andrea Michelangelo Doglioli [a,b], Anne A. Petrenko [a,b], Ananda Pascual [c], Pierre-Marie Poulain [d], Dalila Elhmaidi [e]

[a] Aix Marseille Université, CNRS/INSU, IRD, Mediterranean Institute of Oceanography (MIO), UM 110, 13288 Marseille, France
[b] Université de Toulon, CNRS/INSU, IRD, Mediterranean Institute of Oceanography (MIO), UM 110, 83957 La Garde, France
[c] IMEDEA (CSIC-UIB), Esporles, Spain
[d] OGS, Trieste, Italy
[e] Faculté des Sciences de Tunis, Campus Universitaire 2092 El Manar, Tunisia

Received 9 January 2013; received in revised form 6 December 2013; accepted 19 December 2013
Available online 30 December 2013

Abstract

Optimal interpolation methods for improving the reconstruction of coastal dynamics from along-track satellite altimetry measurements have been recently developed over the North Western Mediterranean Sea. Maps of satellite-derived geostrophic current anomalies are generated using these methods, and added to different mean circulation fields in order to obtained absolute geostrophic currents. The resulting fields are then compared to standard AVISO products, and their accuracies are assessed with Lagrangian diagnostics. The trajectories of virtual particle clusters are simulated with a Lagrangian code either with new current fields or with the AVISO ones. The simulated trajectories are then compared to 16 *in situ* drifter trajectories to evaluate the performance of the different velocity fields. The comparisons show that the new current fields lead to better results than the AVISO one, especially over the shallow continental shelf of the Gulf of Lion. However, despite the use of innovative strategies, some altimetry limitations still persist in the coastal domain, where small scale processes remain sub-sampled by conventional altimetry coverage but will benefit from technological development in the near future. Some of the limitations of the Lagrangian diagnostics presently used are also analyzed, but dedicated studies will be required for future further investigations.

Keywords: Lagrangian; Satellite altimetry; Mean dynamic topography; Coastal dynamics

1. Introduction

Coastal regions are characterized by a complex dynamics, often dominated by small, rapidly evolving structures at the mesoscale. In the open ocean, mesoscale dynamics plays a key role in modulating large-scale circulation and heat fluxes as well as in enhancing primary production (McGillicuddy et al., 2007). Such hydrodynamic processes are also crucial at coastal scales, where the associated currents are known to significantly influence water-mass mixing and exchanges between the continental shelf and the open ocean (Huthnance, 1995).

The high spatial/temporal variability and complexity associated with coastal mesoscale processes make them difficult to be studied with sparse *in situ* observations. Alternative options rely on exploiting satellite data specifically adapted to the coastal domain. Satellite altimeters are well adapted to observe open-ocean mesoscale structures (Fu et al., 2010) and represent an invaluable source of data that

* Corresponding author. Address: M.I.O. Institut Méditerranéen d'Océanologie, Campus de Luminy, Case 901, 13288 MARSEILLE cedex 09, Etg: 6, Bât: TPR2, France. Tel.: +33 491829108.
E-mail address: Jerome.Bouffard@univ-amu.fr (J. Bouffard).

0273-1177/$36.00 © 2014 COSPAR. Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.asr.2013.12.020

provides repetitive views of phenomena unachievable by other means (Fu and Chelton, 2001). Characterizing the influence of mesoscale dynamics on water-mass stirring, mixing and tracer transport based on satellite observations is still a challenging issue, and requires the development of diagnostics that combine 2D current fields coupled with Lagrangian tools.

Optimal interpolation of along-track altimetry Sea Level Anomaly (SLA) into 2D fields was originally based on the combination of 2 altimeter missions, which could not fully resolve dynamical features at scales of 10–100 km (Le Traon and Dibarboure, 2004, 1999). Nowadays, despite using 4 altimetry missions, the resulting AVISO regional maps (SSALTO-DUACS, 2006) may still smooth a large part of mesoscale signals, especially in the coastal domain where the spatial horizontal scales are known to be smaller and more anisotropic than in the open ocean.

This has been confirmed by recent studies which evidenced that Map of SLA (hereafter (M)SLA) still lack enough of the temporal and spatial resolution and/or accuracy required for the detection of small mesoscale features (horizontal scales of less than 50 km; Bouffard et al., 2012). Furthermore, Nencioli et al. (2011) have identified inconsistencies between surface transport patterns derived from altimetry in the western Gulf of Lion and the *in situ* structures detected through an adaptative sampling strategy, which combined ship-based ADCP velocities and Lagrangian drifter trajectories. Finally, using glider measurements, Pascual et al. (2010) as well as Bouffard et al. (2010) also highlighted limitations of standard AVISO gridded fields in characterizing coastal mesoscale dynamics.

In order to improve altimetry gridded fields, a series of alternative methods have been recently developed. For example, Gaultier et al. (2013) have exploited the information from oceanic submesoscale structures retrieved from tracer observations of sea surface temperature, in order to improve the characterization of mesoscale dynamics from altimetric (M)SLA. Dussurget et al. (2011) successfully applied another technique consisting in removing the large scale signals (~100 km) from along track altimetric data and then mapping and adding the residual with an Optimal Interpolation (OI) with regionally adjusted correlation scales.

Another critical aspect for the reconstruction of coastal mesoscale dynamics may concern the inaccuracies of the Mean Dynamic Topography (hereafter MDT) associated with the marine geoid. Although the marine geoid component dominates the altimetry signal, it is not known well enough to be removed independently. Therefore, a temporal mean altimeter height is usually constructed from several year-long time series and subtracted to eliminate the geoid component. This procedure removes not only the geoid component but also any current component with a non-zero mean. So, a MDT, i.e. the non static component of the stationary sea surface height, is generally added to the (M)SLA in order to derive absolute geostrophic currents. The AVISO products in the Mediterranean Sea typically use the MDT from Rio et al. (2007).

The analysis of satellite-based mesoscale dynamics and its impact on horizontal mixing and transport properties in the coastal domain requires not only the use of new satellite-derived fields but also relevant diagnostics in order to evaluate them. None of the previous studies (Dussurget et al., 2011; Gaultier et al., 2013; Escudier et al., 2013) have focused on the quantification of the combined impact of different OI methods and MDT products on altimetry-based approaches. This paper addresses this issue by applying an improved Lagrangian diagnostics to several satellite-derived velocity fields, regionally adapted to the North Western Mediterranean basin.

The major dynamical feature of the North Western Mediterranean (hereafter NWMed) is the so-called "Northern Current" (hereafter NC). As shown on Fig. 1, this density current arises from the junction of the Eastern and Western Corsica Current (respectively ECC and WCC on Fig. 1) and flows westward initially along the coast of the Ligurian Sea, and then along the continental slope of the Gulf of Lion, until it reaches the Balearic Sea (Millot, 1991). The NC is marked by a strong seasonal variability (Gostan, 1967). Over the Gulf of Lion (hereafter GoL), NC intrusions can bring open Mediterranean water onto the continental shelf, depending on the stratification and wind conditions (Millot, 1990; Gatti, 2008; Petrenko et al., 2005, 2008; Poulain et al., 2012b). Another key aspect related to the NC dynamics concerns the development of baroclinic and barotropic instabilities. These favor the development of coastal mesoscale structures such as meanders and eddies arising along the NC external and internal border, forced by strong wind events and/or bottom topography irregularities (Millot, 1991).

The NC mean position is within 50 km off the coast (Petrenko, 2003), where radiometer and altimeter footprints may encounter the coastline and corrupt the raw along-track remote-sensed signals (Anzenhofer et al., 1999; Strub, 2001). However, recent advances in altimetry data processing can be used to characterize small scale signals in coastal regions, specifically over the NWMed (Vignudelli et al., 2003, 2005; Bouffard et al., 2008a,b, 2010, 2011, 2012). Birol et al. (2010) analyzed ADCP current measurements and satellite across-track current anomalies at different locations on the NWMed shelf edge. The results indicated good altimeter performances at seasonal time scales, confirming that improved coastal along-track altimetry is reliable to observe low frequency variations of the NC dynamics. Along-track data have also allowed to observe the NC intrusions over the GoL continental shelf for the first time (Bouffard et al., 2011) and to characterize the inter-annual (Bouffard, 2007; Birol et al., 2010) and intra seasonal (Bouffard et al., 2008b) variability of coastal currents.

Despite such major advances in coastal altimetry (in the NWMed as well as in many other areas; refer to Vignudelli