Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research 55 (2015) 1590–1603

ADVANCES IN SPACE RESEARCH
(a COSPAR publication)

www.elsevier.com/locate/asr

Heavy Guadalquivir River discharge detection with satellite altimetry: The case of the eastern continental shelf of the Gulf of Cadiz (Iberian Peninsula)

J. Gómez-Enri [a,*], R. Escudier [b], A. Pascual [b], R. Mañanes [a]

[a] *Applied Physics Department, University of Cadiz, Cadiz, Spain*
[b] *Instituto Mediterráneo de Estudios Avanzados (IMEDEA), CSIC-UIB, Illes Balears, Spain*

Received 8 June 2014; received in revised form 22 December 2014; accepted 29 December 2014
Available online 6 January 2015

Abstract

In situ water levels in the Guadalquivir River estuary mouth show the effect of strong river freshwater discharges on the monthly means of the sea level on a yearly basis. Accurate altimeter products oriented toward coastal zones are increasing the number of potential applications at different spatiotemporal scales. The present work is focused on the analysis of the sea-level variability in the eastern shelf of the Gulf of Cadiz (between North Africa and the southwestern side of the Iberian Peninsula), adjacent to the Guadalquivir River estuary. Sixteen years (1994–2009) of along-track and standard AVISO maps of sea-level anomalies (SLAs) have been used to generate a new high-resolution product with increased spatiotemporal resolution. The use of a bathymetry constraint and smaller correlation scales in the methodology developed to generate high-resolution altimeter products improves the characterization of the mesoscale signals in the coastal strip adjacent to the estuary due to strong river freshwater discharges. This has been confirmed by the analysis of along-track SLA data in the vicinity of the estuary. The daily evolution (2 weeks) of the sea level obtained in the event of December 2009 might be related to the river plume extension observed by optical Moderate Resolution Imaging Spectrometer (MODIS) images. The spatiotemporal distribution of the altimeter tracks available in the study area might compromise the mapping capabilities to capture coastal and fine-scale features.

Keywords: Coastal altimetry; Sea-level variability; River discharge; Gulf of Cadiz

1. Introduction

Radar altimetry has become a powerful source of accurate sea-level data in the open ocean (Fu and Cazenave, 2001), and more recently in the coastal fringe (Vignudelli et al., 2011). Indeed, coastal altimeter measurements have remained largely unexploited, due to several factors: wrong characterization of the geophysical corrections and inaccurate estimates of the distance between the satellite's center of mass and the mean reflected surface (*range*), and significant wave height (SWH). Near the shore, the radar footprint might be contaminated by land and/or calm water reflections complicating the retracking of radar waveforms, and hence the retrieval of the abovementioned parameters. Thus, sea-level anomalies (SLAs) and SWH have had limited use near the coast. A number of initiatives have been made in the last decade to improve the accuracy and availability of altimeter data in the coastal zone. They are applied to along-track measurements (Vignudelli et al., 2005; Roblou et al., 2007; Brown, 2010; Liu et al., 2012), including the use of coastal-oriented corrections and the review of the data recovery strategies near the coast (Vignudelli et al., 2003, 2005, 2011; Bouffard et al.,

* Corresponding author. Tel.: +34 956016071.
E-mail address: jesus.gomez@uca.es (J. Gómez-Enri).

http://dx.doi.org/10.1016/j.asr.2014.12.039
0273-1177/

2008a,b; Bouffard et al., 2010, 2012; Birol et al., 2010). In addition to this, a better along-track spatial resolution (from 1 to 20 Hz) might improve the extraction of finer scales in coastal areas (Vignudelli et al., 2011). Alternatively, some innovative techniques for the generation of high-resolution (HR, henceforth) gridded maps of SLA have been developed by Dussurget et al. (2011) and Escudier et al. (2013). They made qualitative and quantitative comparisons with independent observations confirming that the new altimetry HR gridded products improve the characterization of coastal and fine-scale features. Thus, the number of applications exploiting accurate coastal altimeter reprocessed data has increased exponentially in the past years (Vignudelli et al., 2011; Pascual et al., 2013; Bouffard et al., 2014, among others).

Low-resolution (LR, hereinafter) ($1/3° \times 1/3°$) gridded weekly maps of SLA routinely produced by AVISO (Archiving, Validation, and Interpretation of Satellite Oceanographic data, http://www.aviso.oceanobs.com/) have been used in the past to study the sea-level variability over continental shelves at different time scales (Volkov et al., 2007; Saraceno et al., 2008; Gómez-Enri et al., 2012; Laiz et al., 2013; Caballero et al., 2014). In particular, Gómez-Enri et al. (2012) analyzed the effect of sporadic and heavy Guadalquivir River discharges in the sea level of the eastern continental shelf of the Gulf of Cadiz. They concluded that these events could explain up to 50% of the variance of the daily mean sea level recorded by a tide gauge in the estuary mouth. Unexplained variance was found in the nearest LR altimeter point to the estuary (at 25 km to the mouth in the 50-m isobath). This could indicate that the river runoff effect is restricted to the estuary mouth and along a small fringe near the coast. More recently, Laiz et al. (2013) demonstrated that LR weekly maps of SLA were unsuitable for the analysis of the Guadalquivir River sporadic discharges, due to the lack of altimeter data in the vicinity of the estuary mouth.

Nencioli et al. (2011) showed that LR maps could not resolve small and coastal features because of the smoothing applied to the data merging and interpolation. Dussurget et al. (2011) improved the temporal and spatial resolution of LR maps from weekly to daily and from $1/3° \times 1/3°$ to $1/16° \times 1/16°$ Mercator grid, respectively. They added the short-scale signals to this HR product from the along-track data. More recently, Escudier et al. (2013) presented a new approach for the generation of HR maps of SLA that clearly improves the characterization of mesoscale signals in the coastal strip by adding a bathymetry constraint.

This work focuses on the capabilities of this new daily HR product (Escudier et al., 2013) to capture coastal and mesoscale processes. We present some examples of how these maps are able to show the daily evolution of a freshwater plume in the eastern continental shelf of the Gulf of Cadiz, after heavy discharges from the Guadalquivir River estuary. This has been confirmed by the analysis of the SLA signal observed in the altimeter tracks available in the vicinity of the estuary. The paper is organized as follows. We present in Section 2 the study area with Section 3 devoted to the data sets used (the daily means of in situ water levels, river discharges, and altimeter-derived SLA) and methodology. The sea-level response to heavy river discharges from daily to monthly time scales is analyzed using in situ tide gauge data in the mouth of the Guadalquivir estuary. We then focus on two events of heavy freshwater river discharges (from March 2001 to December 2009) analyzing the spatiotemporal distribution of the satellite SLA in the surrounding continental shelf of the river estuary mouth. We discuss the importance of the number and distribution of altimeter tracks in the study area during one strong event of river discharges (December 1996). The final remarks and conclusions are outlined in the last section.

2. Study area

The Gulf of Cadiz is located between North Africa and the southwestern side of the Iberian Peninsula. It connects the Atlantic Ocean with the Mediterranean Sea through the Strait of Gibraltar. Its continental shelf is located approximately within the 100-m isobath. It is divided into two halves by Cape Santa María: the western and eastern continental shelves. On the eastern side (Fig. 1), the Guadalquivir River, the Tinto-Odiel system, and the Guadiana River are the main tributaries. The Guadalquivir River is the main contributor of freshwater discharge into the eastern shelf affecting the hydrology of the surrounding area (Prieto et al., 2009). The estuary has an extension of about 110 km between the mouth at Sanlúcar de Barrameda and the Alcalá del Río dam.

The river discharge has been identified as the main forcing agent of the hydrology inside the Guadalquivir estuary (Díez-Minguito et al., 2012; Navarro et al., 2012). Díez-Minguito et al. (2012) pointed out the lack of knowledge on the exchange of water masses between the continental shelf and the river. Several works have reported a strong decrease in salinity in the estuary mouth during episodes of strong river discharges (González-Ortegón and Drake, 2012; González-Ortegón et al., 2010; Navarro et al., 2012). This might indicate that the main effect in the adjacent continental shelf is an elevation of the sea level due to the less dense freshwater over the sea level. Prieto et al. (2009) analyzed the importance of heavy river discharges, together with the wind regime, in the triggering of phytoplankton growth on the shelf. In addition, the coastal warm surface countercurrent flowing near the shore westward (spring–summer) and eastward (late autumn to early winter) over the eastern continental shelf (Stevenson, 1977; Relvas and Barton, 2002; García-Lafuente et al., 2006; Criado-Aldeanueva et al., 2009) could also be affected by these episodes. In summary, little is known about the sea-level change in the adjacent eastern continental shelf due to heavy discharges of freshwater from the Guadalquivir River estuary.