Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research xxx (2017) xxx–xxx

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

Validation of CryoSat-2 SIRAL sea level data in the eastern continental shelf of the Gulf of Cadiz (Spain)

J. Gómez-Enri [a,*], S. Vignudelli [b], P. Cipollini [c], J. Coca [a,d], C.J. González [a]

[a] University of Cadiz, Av. Republica Saharaui, s/n, 11510, Puerto Real, Cadiz, Spain
[b] Institute of Biophysics, National Research Council, Via Moruzzi, 1, 56024 Pisa, Italy
[c] National Oceanography Centre, European Way, SO14 3ZH Southampton, United Kingdom
[d] University of Las Palmas, c/Juan de Quesada, 30, 35001 Las Palmas de Gran Canarias, Spain

Received 30 January 2017; received in revised form 20 October 2017; accepted 24 October 2017

Abstract

We present the validation of sea level measurements taken over the eastern shelf of the Gulf of Cadiz (southwestern Iberian Peninsula) by the European Space Agency CryoSat-2 satellite's SIRAL altimeter in SAR mode. Time series of sea level anomaly (SLA) at 20-Hz posting rate (corresponding to approximately 350 m along the satellite track) are compared against sea level measurements from two tide gauge stations located along the Spanish coast of the study area. Due to the long repeat cycle of CryoSat-2 (369 days), data selection is performed by including all the tracks falling in a radius of 50 km from the location of the tide gauge stations. Then, time series of SLA are formed during the observational time period (August 2010–December 2014) by taking the altimeter measurements located at growing distances from the coast (1, 3, 5, 10, 15 and 20 km) as well as around four isobaths (10, 25, 50 and 75 m). The validation of AltiKa's SARAL altimeter 20-Hz data, using its two 35-day-repeat ground tracks available in the area is also presented. Overall, CryoSat-2 20-Hz SLAs selected in the coastal strip from 3 to 20 km agree well with data from the western station (Huelva) with *rmse* ranging from 11.4 to 6.4 cm. The analysis at the eastern station (Bonanza) yields *rmse* ranging from 16.8 to 14.6 cm. The comparisons made with CryoSat-2 20-Hz SLAs are in agreement with the *rmse* estimated using AltiKa 20-Hz SLAs at distances to the coast higher than 5 km, and much better in the 1–5 coastal band. The differences in quantity of SAR mode data observed at the two stations and in their agreement with the tide gauges can be explained by (1) the more complex coastal morphology around Bonanza station with the altimetry tracks almost parallel to the coast; (2) the noisier hydrodynamics around Bonanza station due to the presence of the estuary mouth of the Guadalquivir River; and (3) residual (uncorrected) tidal signals in the Bonanza gauge record. We conclude that the quality of SAR altimetry is comparable or even slightly better than conventional altimetry, thus qualifying SAR data for exploitation in oceanographic studies and sea level monitoring. An example is the analysis made of the surface signal due to a heavy Guadalquivir River discharge event.

Keywords: Satellite SAR altimetry; Tide gauge; Validation; Applications

1. Introduction

The launch of the European Space Agency (ESA) satellite CryoSat-2 carrying the Synthetic Aperture Radar (SAR) Interferometric Radar Altimeter (SIRAL, henceforth) in February 2010 marked a milestone in satellite altimetry as the first spaceborne instrument with SAR

* Corresponding author.
E-mail addresses: jesus.gomez@uca.es (J. Gómez-Enri), vignudelli@pi.ibf.cnr.it (S. Vignudelli), cipo@noc.ac.uk (P. Cipollini), josep.coca@uca.es (J. Coca), carlosjose.gonzalez@uca.es (C.J. González).

https://doi.org/10.1016/j.asr.2017.10.042
0273-1177/

altimetry capability. Compared to conventional pulse-limited altimetry, SAR altimetry, also known as delay-Doppler altimetry (Raney, 1998), has the potential to provide a better along-track resolution and a higher Signal-to-Noise ratio (SNR). The SIRAL instrument operates in one of three modes: SAR, SAR-interferometric (SARin) and Low Rate Mode (LRM); the mode of operation is selected over different regions according to a Geographical Mode Mask (ESRIN-ESA, 2012). The SAR mode is enabled on sea-ice zones and some selected marine areas, including coastal zones (as the study area investigated in this work). The SARin mode is enabled over ice-sheet margins, small ice caps and mountain glaciers. Finally, the conventional LRM mode is enabled over the open oceans, continental ice sheets and all the land areas not covered by the other modes (ESRIN-ESA, 2012). ESA is generating and distributing CryoSat-2 Ocean Products derived from the LRM measurements, with the addition of Pseudo-LRM (PLRM) measurements over the SAR mode zones.[1] These products have now been comprehensively validated (Calafat et al., 2017) and confirm the value of CryoSat-2 for oceanography and climate studies.

The validation of SAR–mode observations over the various SAR–mode patches is ongoing. A global assessment has recently been carried out by Boy et al. (2017), but still there is scope for detailed regional and coastal validation studies, as in the coastal zone, SAR altimetry holds particular promise by virtue of its increased resolution and SNR. Some of those studies have appeared already: Fenoglio-Marc et al. (2015) analysed the quality of the geophysical parameters derived from SAR and LRM modes in the German Bight, while Passaro et al. (2016) have cross-calibrated CryoSat-2 SAR–mode height with Envisat reprocessed using coastal altimetry techniques in the Indonesian Seas. This paper aims at contributing to the validation of SAR altimetry data from CryoSat-2 by assessing sea level data in the coastal strip of the eastern shelf of the Gulf of Cadiz (Spain). The Gulf of Cadiz and the adjacent Strait of Gibraltar have been already used for the validation of coastal altimetry, by Caballero et al. (2014) for Envisat significant wave height (SWH), and by Gómez-Enri et al. (2016) for sea surface height (SSH) from Envisat and AltiKa, so this paper is complementary to those validation studies.

The validation of geophysical parameters retrieved from radar altimeter satellite missions (sea level, significant wave height and wind speed at the sea surface) is a common exercise that the altimetric community makes to assess the performances of the various altimeters and the suitability of the measurements for oceanographic applications. The quality of the retrieved parameters has been assessed since the beginning of the missions, from the NASA/CNES Topex-Poseidon (Picaut et al., 1995; Mithcum, 1998; Birol and Delebecque, 2014) and its successors Jason-1/2 (Ménard et al., 2003; Vincent et al., 2003; Woodworth et al., 2004; Bonnefond et al., 2011; Passaro et al., 2015; among others) to the ESA Envisat RA-2 (Faugere et al., 2006; Passaro et al., 2015; Gómez-Enri et al., 2016).

The specific objective of this paper is to validate time series of Sea Level Anomaly (SLA, i.e. the anomaly of the sea surface height with respect to its temporal mean) from CryoSat-2 SIRAL operating in SAR mode near the shore. The sea level data were obtained from an ESA web service (see Section 3.1.1 for details) designed to process on line and on demand CryoSat-2 SAR data at a high posting rate (20 Hz, corresponding to approximately 350 m along the satellite track). We compare the satellite-derived time series of SLA with the water levels of two tide gauge stations (Huelva and Bonanza) located in the Spanish coast of the Gulf of Cadiz. The altimeter data at 20 Hz are selected considering the tracks available in a radius of 50 km from the location of the tide gauge stations, and forming time series for the analysed time period (August 2010–December 2015) with the radar measurements located at growing distances[2] to the coast (1, 3, 5, 10, 15 and 20 km) as well as around four isobaths (10, 25, 50 and 75 m). The time series of altimeter data, one for each distance or isobath, are then compared against those from the in-situ stations.

The paper is organised as follows: the study area is presented in Section 2, followed by a description of the data sets (Section 3) and methods (Section 4). In Section 5, the validation of CryoSat-2 SIRAL SLA using in-situ data is shown at the six distances to the coast and four bottom depths mentioned above. We also included in this section the validation results of AltiKa SARAL 20-Hz data using the two tracks available in the area, and a study of the impact of a high-discharge event from the Guadalquivir River on the altimetric data. Section 6 summarises the main results and presents the conclusions.

2. Study area

The validation of CryoSat-2 SIRAL data was made over the eastern shelf of the Gulf of Cadiz (*East_GoC* hereinafter) (Fig. 1). SIRAL operates in SAR mode in this area. *East_GoC* is located between the Iberian Peninsula and the Atlantic coast of Morocco connecting the North Atlantic Ocean and the Mediterranean Sea through the Strait of Gibraltar, and its continental shelf is around 50 km wide following the 200–m isobath. The Guadalquivir River is the main tributary in the zone; other rivers worth of note are the Tinto-Odiel system and the Guadiana.

The surface circulation of the Gulf of Cadiz has been deeply analysed in the past. Its strong seasonality is linked

[1] PLRM data are generated from SAR mode data in a way that yields waveforms conforming to the LRM echo model, and that can therefore be processed as the LRM waveforms, at the cost of higher level of speckle noise, i.e. lower measurement precision than conventional LRM.

[2] "Distance to coast" in this study refers to distance of closest approach, as opposed to along-track distance.

Please cite this article in press as: Gómez-Enri, J., et al. Validation of CryoSat-2 SIRAL sea level data in the eastern continental shelf of the Gulf of Cadiz (Spain). Adv. Space Res. (2017), https://doi.org/10.1016/j.asr.2017.10.042