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Seasonal and interannual variability in the Gulf of Cadiz: Validation of gridded altimeter products

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ABSTRACT

Nine years of gridded multi-mission altimeter products have been validated in the Gulf of Cadiz. The comparison was performed using two tide gauges deployed in the mouths of two estuaries: the Tinto–Odiel system and Guadalquivir River. The averaged seasonal cycle of the sea-level – corrected for atmospheric pressure effect – obtained from the two tide gauges and their closest altimeter points showed good agreement, correlation coefficients being about 0.95 (at both stations). The variability about the mean seasonal cycle observed in the altimeter data is about half that obtained from the tide gauges. The year-to-year analysis of the seasonal cycle confirmed the level of agreement between the two datasets, and indicated lower amplitude errors in the estimate of the annual harmonic (only significant at 95% confidence level in most of the years) in the altimeter data. The estimation of the annual component is affected by sporadic heavy river discharges only observed in the tide-gauge records. In those cases the river flow explained more than 50% of the variance associated with the daily mean sea-level.

1. Introduction

Excluding the semidiurnal and diurnal tides, and the sub-inertial meteorological fluctuations over periods of a few days, the seasonal cycle is the main factor responsible for sea-level variability. A better understanding of the contribution of non-tidal processes to the sea-level oscillations on seasonal time scales is useful for a better knowledge of interannual and inter-decade oscillations, and also for analysis of long-term trends (Tsimplis and Woodworth, 1994). A more in-depth monitoring of the seasonal sea-level variability in the coastal areas could be helpful for many coastal applications such as marine life studies, shoreline developments (processes like erosion of beaches), studies of land movement, estuaries (Rossiter, 1967), and definition of extreme sea-levels and coastal-hazard zones. The interannual sea-level oscillations give information about the year-to-year variability of the oceanic conditions and can be used to describe ocean dynamics (Srinivas, 2002).

The main contributors to the seasonal and interannual variability are basically oceanographic (e.g. ocean heat content and circulation), meteorological (e.g. piling-up of water due to local wind fields, changes in the surface atmospheric pressure field) and hydrological (e.g. changes in river runoff regimes) forcings (Tsimplis and Woodworth, 1994). In addition, astronomical tides can be considered as a minimal forcing factor and thus negligible in comparison with the others (Pugh, 1987). Most of these primary forcings affecting the ocean occur at seasonal frequencies (Bell and Goring, 1998). The seasonal cycle and the relative contribution of each of the above-mentioned factors has been analyzed in the past at sites all around the world (Sultan et al., 1995; Bell and Goring, 1998; García-Lafuente et al., 2004; Srinivas and Dinesh Kumar, 2006; Marcos and Tsimplis, 2007; Vinogradov et al., 2008, and others).

Traditionally, all the studies mentioned have used time series from tide gauges deployed at continental boundaries and in shallow waters; this has precluded any attempt to perform a regional analysis of the seasonal cycle. Since 1992, radar altimeter missions have provided sea-level observations of high accuracy and precision. The spatial and temporal resolution of the altimeter records is mainly defined by their orbit. In general, the along-track measurements provide near-global coverage of sea-level observations with high accuracy and precision, and thus are suitable for analysis of the seasonal and interannual variability of the sea-level.

To our knowledge, only a few studies have combined in-situ and along-track altimeter data for analysis of the seasonal cycle in coastal areas. Fenoglio-Marc et al. (2005) analyzed the sea-level change along the Spanish coasts at interannual to inter-decade

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time scales. They combined Topex/Poseidon (T/P) altimetry data and tide gauges and found very good agreement (correlations of about 0.7) between the two datasets. Han and Huang (2008) compared T/P and tide-gauge data in the Bohai, Yellow, and East China Seas, estimating correlation coefficients of 0.98 (amplitude) and 0.99 (phase) between T/P and tide-gauge annual cycles. More recently, Vinogradov and Ponte (2010) used up to 345 tide gauges and T/P data, and estimated global correlations in annual amplitude and phases of 0.84 and 0.92 respectively.

In addition to the along-track altimeter measurements of the sea-level oscillations, global sea-level anomaly maps made from high-resolution gridded multi-mission altimeter data (Aviso, 2010) are also available. The study described here was intended to validate these gridded maps of sea-level measurements by analyzing the mean seasonal cycle and its interannual variability. The validation has been performed using two tide gauges deployed in the Gulf of Cadiz (GoC, hereinafter) in the vicinity of two estuaries: the Tinto–Odiel and Guadalquivir systems, respectively. Secondly, an investigate has been made of how extreme changes in river runoff regimes might affect the estimation of the seasonal cycle (on a yearly basis).

The paper is organized as follows. Section 2 gives an overview of the study area with some emphasis on its eastern side. The datasets used are presented in Section 3. The following section is devoted to: (1) validation of the mean seasonal cycle obtained with altimeter data; and (2) analysis of the effect of strong river discharges on the estimation of the seasonal cycle. Finally, a short summary and the conclusions are presented in the last section.

2. Study area

The GoC (Fig. 1) is a basin delimited by the southwest coasts of the Iberian Peninsula (northern boundaries), the Strait of Gibraltar (eastern boundary) and the Atlantic coast of Morocco (southern limit). Its continental shelf is approximately delimited by the 100 m isobath where the shelf slopes down into the continental slope. It is divided by Cape Santa Maria (CSM, see Fig. 1) into two basins with different circulation characteristics (García-Lafuente et al., 2006). West of the cape the shelf is narrow and does not have major inputs of continental fresh waters. East of the cape, where this study is focused, the shelf is wide (around 50 km) and is subject to discharges from major rivers like (from west to east) the Guadiana, Tinto–Odiel and Guadalquivir (Fig. 1), that imprint signatures on the surrounding waters in terms of sea surface temperature, suspended sediments, chlorophyll concentration, etc. In this respect, the Guadalquivir river dynamics are reported to affect the surface circulation over the eastern continental shelf (see García-Lafuente and Ruiz (2007) for a thorough review). Although the average discharge rate of this river is about 105 m^3/s, the *normal* rate is about 25 m^3/s through the year, but it can reach values as high as 1000 m^3/s, for periods of days, in spring and autumn (Díez-Minguito et al., 2009).

3. Datasets and methods

3.1. Tide gauge

Two tide gauges situated along the coast of the GoC were used in this study. The first one, "Bonanza" (BN), is located in the mouth of Guadalquivir river (Fig. 1) at 36°48′14″N − 6°20′10″W. It is a permanent station of the Spanish tide-gauge network REDMAR (Red de Mareográfos de Puertos del Estado: http://www.puertos.es), and it is also included in the Permanent Service for Mean Sea-Level (PSMSL) global network. BN is an acoustic sonar gauge measuring the sea-level at a sampling period of 5 min. This instrument has an accuracy of 2.5 mm and a resolution of 10 mm, assuming a 5 m tidal range and a 1-min integration period for the averaged measurements (ESEAS-RI, 2006). The sea-level is

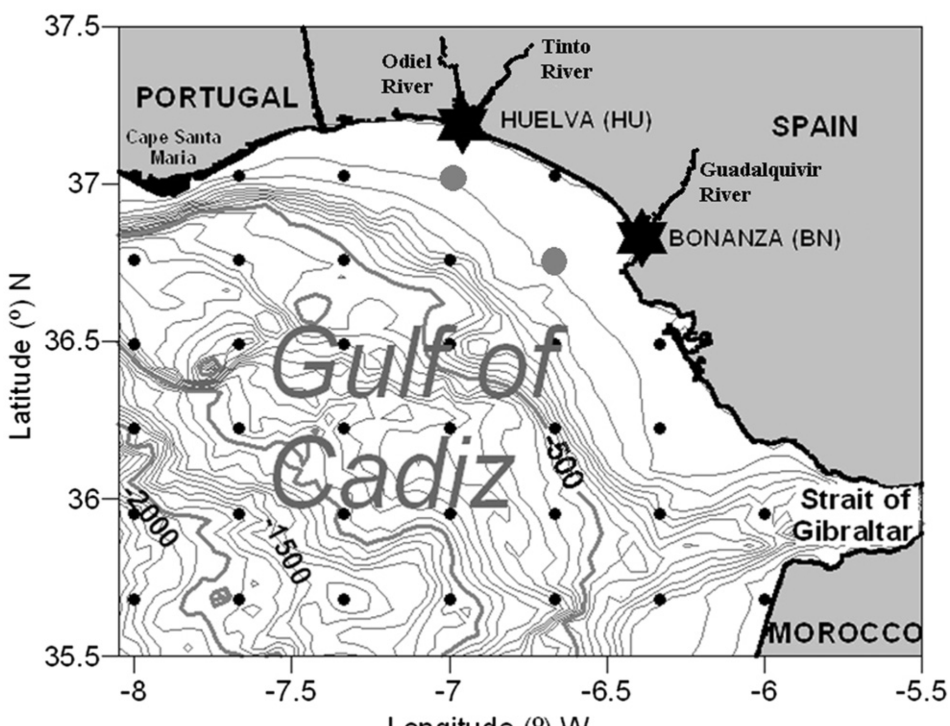

Fig. 1. Location of the study area: the Gulf of Cadiz, southwest Iberian peninsula. The position of the tide gauges "Bonanza" and "Huelva" are denoted by black stars. Also shown are the positions of the valid altimeter measurements (black dots), while the gray dots show the location of the closest altimeter points to the tide gauges used for comparison.