MONITORING TOPOGRAPHY OF COASTAL LAGOONS USING SATELLITE RADAR ALTIMETRY

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ABSTRACT

Satellite radar altimetry was initially designed to measure the marine geoid. Thanks to the improvement in the orbit determination from the meter to the centimeter level, this technique has been providing accurate measurements of the sea surface topography over the open ocean since the launch of Topex/Poseidon in 1992. In spite of a decrease in the performance over land and coastal areas, it is now commonly used over these surfaces. This study analyzes the ability of satellite radar altimetry to retrieve for the very first time the topography of the intertidal zone in coastal lagoons.

Index Terms— Radar altimetry, Coastal altimetry, Topography of the Intertidal zone

1. INTRODUCTION

Coastal regions represent only 5% of Earth’s land area, yet their societal and economical importance are larger than their surface area suggests [1]. A common feature of coastal systems are coastal lagoons, occupying 13% of coastal areas worldwide [2]. These ecosystems provide important services and societal benefits (e.g., food provision, recreational, water regulation, etc.), however their subsistence is threatened by global climate change [3]. Understanding the physical dynamics of these systems is of great importance in order to direct the planning and implementation of coastal management strategies in coastal lagoons.

In the need for a better understanding of lagoons’ dynamics, satellite radar altimetry measuring the variation of the surface elevation could be a very useful tool providing key information, especially for non-monitored areas. However, using altimetry in coastal regions remains a great challenge (see [4] for more details). Despite some shortcomings, recent improvements in processing techniques extended, the capabilities of altimeters in coastal areas [5].

In this study, retrievals of the intertidal zone topography using radar altimetry are presented for the Arcachon Bay.

3. STUDY AREA

The Arcachon Bay (44°40′N, 1°10′W) is a mesotidal shallow semi-confined lagoon, located in the southeast of the Bay of Biscay (Figure 1). The total lagoon surface (174 km^2) is composed of channels (57 km^2) that drain the intertidal area (117 km^2). The main channels have a maximum depth around 20 m and are extended by a complex network of secondary channels [6]. The tidal cycle is semi-diurnal with a weak diurnal inequality. The tide amplitudes vary from 0.8 to 4.6 m for neap and spring tides respectively. The Arcachon Bay connects to the Atlantic Ocean through two narrow passes of 1–1.5 km width and around 12 km long. The two passes are separated by the Arguin Bank. Important seawater exchanges, reaching up to 384.106 m^3 occur during each tidal cycle [7]. Freshwater inputs from small rivers and groundwater are coming mostly from the Eyre River and the Porges Canal, located south-east and north of the Bay respectively (see Figure 1). They represent more than 95% (73% and 24% respectively) of the total annual freshwater inflows [8]. The intertidal area is composed of a mix of muddy and sandy material [6]. A large zone of 70 km^2 of the mudflats in the inner lagoon is covered with Zostera noltii seagrass [9].

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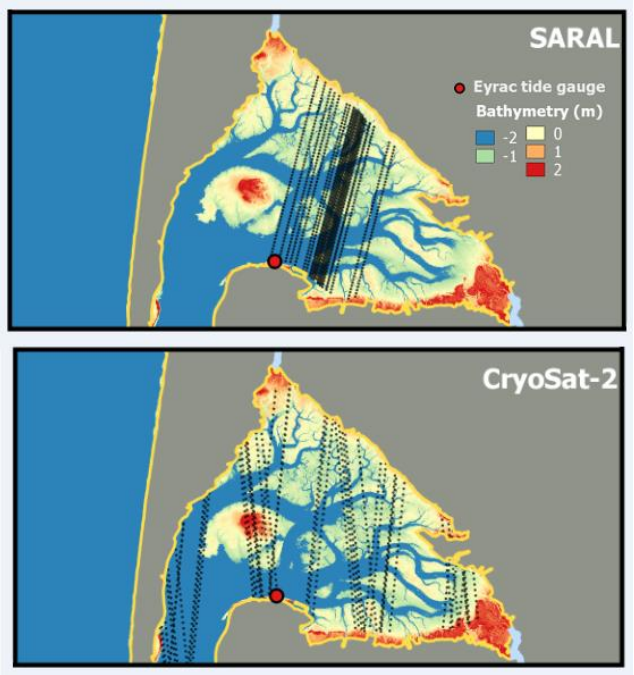

Figure 1. SARAL (top) and CryoSat-2 (bottom) ground-tracks over the Arcachon Bay.

3. DATASETS AND METHODS

Altimetry data used in this study correspond to the following missions: SARAL and CryoSat-2. SARAL (Satellite for Argos and ALtika) is a CNES-ISRO (Centre National d'Etudes Spatiales - Indian Space Research Organization) joint-mission that was launched on 25 February 2013. It is the first altimeter to operate at Ka-band (35.7 GHz). Its accuracy is expected to be about 1 cm over ocean. In coastal regions, it is expected to provide measurements significantly better than those from the previous Ku band missions due to the reduced footprint size provided by Ka-band [13].

As for CryoSat-2 mission, it was launched on 8 April 2010 by ESA. This mission is dedicated mainly to polar observations. However, its acquisitions can be useful for ocean and inland monitoring [10]. The mission's main payload consists of a radar altimeter, SIRAL (Synthetic Aperture Interferometric Radar Altimeter), operating at Ku-band (13.575 GHz) in three different modes: Low Resolution Mode (LRM), Synthetic Aperture Radar mode (SAR), and Synthetic Aperture Interferometric mode (SARIn) [11]. It should be noted that for our study region and period, CryoSat-2 operated in SAR mode. Bathymetry datasets and water levels from tide gauges were used to validate altimetry measurements.

The principle of radar altimetry is the following: the altimeter emits a radar pulse and measures the two-way travel-time from the satellite to the surface. The distance between the satellite and the Earth surface – the altimeter range (R) – is thus derived with a precision of a few centimeters. The satellite altitude (H) referred to an ellipsoid is also accurately known from orbitography modeling. Taking into account propagation delays due to interactions of electromagnetic wave in the atmosphere and geophysical corrections, the height of the reflecting surface (h) with reference to an ellipsoid or a geoid can be estimated [12], [13].

The methodology adopted has the following steps: (i) Processing of altimetry data (to obtain surface heights) using the Multi-mission Altimetry Processing Software (MAPS) that is commonly used for the selection of valid altimetry data and their processing over land and ocean [14]–[17]; (ii) Referencing all data to a common datum (mean seal level) for comparison purposes; (iii) Extraction of the topography of the intertidal zone under the altimeter ground tracks; (iv) Filling the topography with water using tide gauges measurements made at the same time of the satellite passages in order to discriminate between submerged and emerged points of measurements. For each grid point of the bathymetry dataset, the grid point is considered submerged if the water level is higher than the bathymetry, emerged if not (see Figure 2). This discrimination was made in order to use only emerged points for comparison with altimetry measurements.

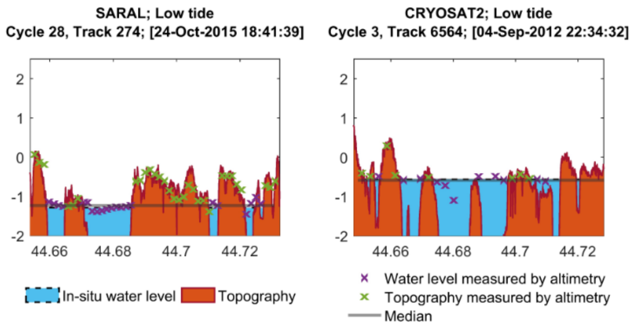

Figure 2. Examples of SARAL (left) and CryoSat-2 (right) along-track profiles of altimetry height over water (purple crosses) and land (green crosses) at low tides; the topography under the altimeter ground track is represented in brown and it is filled with water (in blue) using leveled tide-gauge records.

4. RESULTS

Depending on their overflight time, radar altimetry missions acquired observations of the lagoons all over the tidal cycle. During low tide, they provide observations of the surface topography of the intertidal zone. Topography profiles were extracted along the altimetry ground tracks in the intertidal zone of the bays. They were filled with water using the record from tide-gauge data corresponding to the altimeter overflights and they were compared with the along track profiles of altimeter height.

Figure 1 presents examples for one crossing of SARAL (left) and one crossing for CryoSat-2 (left) over the Arcachon Bay at low tides. The two missions show relatively good correspondence with in situ measurements.

For topography comparisons all measurements from every cycle were used. Figure 2 shows all the passages (cycles) of SARAL and CryoSat-2 over the Arcachon Bay. Figure 3 presents topography comparisons between the in-situ bathymetry data and altimetry measurements for SARAL (left) and CryoSat-2 (right). Excellent comparison results are obtained for SARAL and CryoSat-2. The slopes and intercepts obtained for the two missions are very close to 1 and 0. Good correlation coefficients (R) were obtained as well (R~0.71 for SARAL and 0.89 for CryoSat-2) along with an RMSE lower than 44 cm (RMSE~23 cm for SARAL).

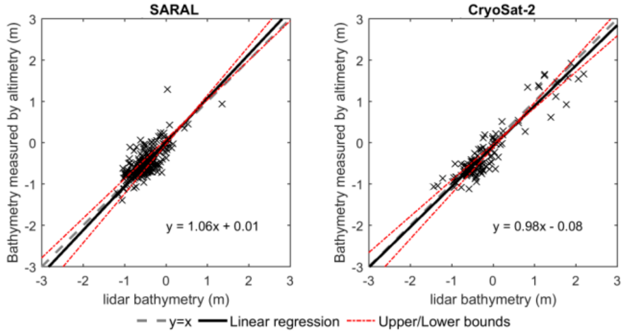

Figure 1. Comparisons between in-situ bathymetry and Altimetry-based topography measurements for SARAL (left) and for CryoSat-2 (right).

In this study, an automatic classification of cycles was performed to discriminate between submerged and emerged cycles. An automatic process was also envisaged to classify each measurement point, using the backscattering coefficient that tends to increase for land-dominated areas. However, an important limitation was encountered during the automating process. During low tides, some altimetry points above water showed as well high backscattering coefficients, which complicated the separation of emerged and submerged points using the backscattering coefficient parameter. The high values of the backscattering coefficient obtained for water at low tides is most likely due to smoother water surfaces in the channels than in the bay, caused by the reduced wave activity. This reduced roughness increases the specular reflection and thus the power received by the sensor (the backscattering coefficient). An example is shown in Figure 4 (left) for the cycle 20 of SARAL. The backscattering coefficient of water in large channels (zone 5 and zone 3) is lower than the backscattering coefficient of water in narrow channels (zone 4 and zone 2) showing values that match land-dominated areas (zone 1).

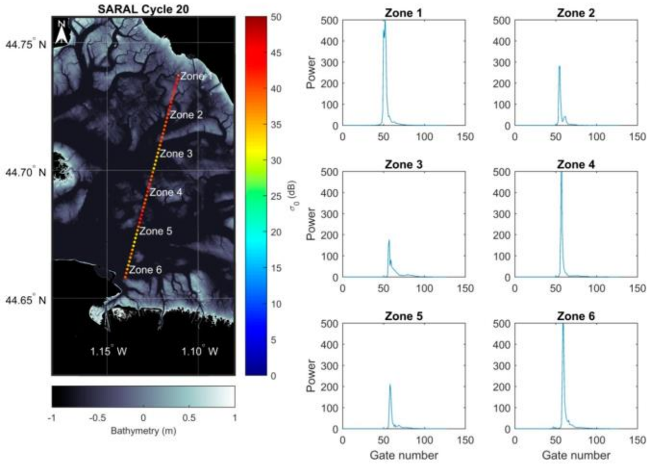

Figure 4. Spatial variation of the backscattering coefficient for SARAL (cycle 20) at low tide along with the corresponding waveforms of the indicated zones.

At low tides, SARAL (Figure 4) shows peak shaped waveforms while CryoSat-2 (Figure 5) shows mixed shaped waveforms. CryoSat-2 was the only mission that flew over the “ile aux oiseaux” sandbank (Figure 1 bottom). Some altimetry measurements made by CryoSat-2 underestimated the elevation of topography in this area. It is very likely that the cause of the high discrepancy is due to the penetration of the electromagnetic wave in the dry soil (long time after high water). Typical ocean waveforms were not observed for low tides even in areas dominated by water.

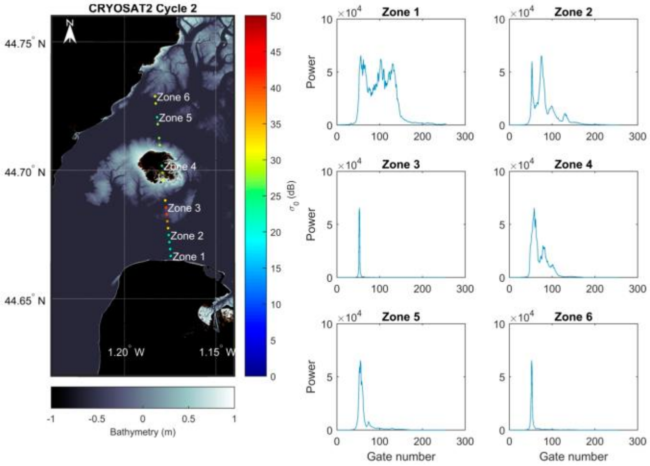

Figure 5. Spatial variation of the backscattering coefficient for CryoSat-2 (cycle 2) at low tide along with the corresponding waveforms of the indicated zones.

5. CONCLUSIONS

This study is the first to demonstrate the capabilities of altimetry to retrieve the topography of the intertidal zone in a coastal lagoon. More details can be found in [18]. Despite the major difficulties encountered in coastal areas by the altimeters, new techniques used by current missions like

SARAL (the use of Ka-band frequency [19]) and CryoSat-2 (operating in SAR mode for some regions) proved to be very accurate even in complex environments like the Arcachon Bay.

The most important limitation lies in the large footprint of altimeters. This coarse resolution prevented us from automatically discriminating land from water using intrinsic altimetry parameters like the backscattering coefficient or waveforms peakiness. However, we were able to discriminate acquisitions made during low tides from the ones made during high tides, because at the scale of the bay good contrast between low and high tides was obtained by the backscattering coefficient and the peakiness.

While altimetry was able to monitor the topography of the bay, caution must be taken when using altimetry data to retrieve topographic variations in similar environments. Dry sandy features are most likely problematic due to the important penetration depth of electromagnetic waves in such mediums. It is recommended to use this approach in areas exposed frequently to water.

This work is an initial step toward the use of future high resolution altimetry missions like SWOT (Surface Water and Ocean Topography) to monitor the topography of various coastal features.

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