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Coastal SAR and PLRM altimetry in German Bight and West Baltic Sea

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Abstract

Unlike previous altimetric missions, the CryoSat-2 altimeter features a novel Synthetic Aperture Radar (SAR) mode that allows higher resolution and more accurate altimeter-derived parameters in the coastal zone, thanks to the reduced along-track footprint. The scope of this study is to quantify regionally the skills of CryoSat-2 SAR altimetry for distances to coast smaller than 10 km, during the mission lifetime and at different time scales. The validated geophysical altimeter parameters are the sea surface height above the ellipsoid, the significant sea wave height and wind speed, all computed at 20 Hz. These have been compared to in situ and regional model data along the coasts of German Bight and West Baltic Sea during a time interval of almost six years, from July 2010 to March 2016, to investigate both instantaneous and seasonal behaviour.

From CryoSat-2 FBR (Full Bit Rate) data, a Delay-Doppler processing and waveform retracking tailored specifically to the coastal zone has been carried out, by applying a Hamming window and zero-padding, using an extended vertical swath window in order to mitigate tracker errors. Moreover, a dedicated SAMOSA-based coastal retracker (here referred to as SAMOSA+) has also been implemented.

Since one of the highest remaining uncertainties in the altimeter parameters estimated in coastal shallow waters arises from residual errors in the applied range and geophysical corrections, innovative and high resolution solutions for ocean tide model, geoid, mean sea surface and wet tropospheric correction have been selected. As CryoSat-2 SAR and LRM (Low Rate Mode) modes are not collocated in time, in order to quantify the improvement in the coastal zone with respect to pulse-limited altimetry, 20 Hz PLRM (pseudo-LRM) data from CryoSat-2 FBR were built and retracked, adopting the ALES adaptive sub-waveform approach, with a numerical Brown-based retracker, here referred to as TALES.

The cross-validation proves the good consistency between PLRM and SAR sea level anomaly in the coastal zone. The regional ocean model (BSH) shows the highest agreement with the SAR sea level anomaly, with a standard deviation of the differences (stdd) of 24 cm, whereas the corresponding value with respect to PLRM is 55 cm. Distance to coast plots show that land contamination begins to affect sea level and wave measurements at 2 km from the coast in SAR and at 3.5 km in PLRM TALES. The analysis of monthly mean time-series shows that SAR Altimetry is able to measure the sea level monthly mean in the coastal zone of the region of interest, during the

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entire mission, more precisely than PLRM. The cross-validation against in situ data also proves the higher accuracy of SAR SAMOSA+ compared to PLRM TALES in the coastal zone, with average SLA stdd of 4.4 cm and 8.4 cm respectively.

Keywords: SAR altimetry; Coastal altimetry; In situ validation; Sea level; Retracking; CryoSat-2

1. Introduction

The objective of this paper is to quantify the capacity of the novel SAR (Synthetic Aperture Radar) altimetry concept in measuring the coastal dynamic topography processes when a special tailoring of both the Delay-Doppler processing and the SAR waveform retracking is carried out and when the state of the art auxiliary data and range and geophysical corrections are used.

This work is meant to be a continuation of the work carried out in the open sea (i.e. distance to coast larger than 10 km) by Fenoglio-Marc et al. (2015a). That previous study has shown that over open sea the SAR and PLRM (pseudo-LRM) altimetric measurements feature a good level of consistency between each other and against in situ data, SAR mode data having, anyhow, a higher level of precision. In the present study, we focus instead essentially on the coastal zone, defined here as the band of 0–10 km from the coast. Our goal is to assess the capacity of SAR altimetry to bring the altimetric measurements closer to the coast, in comparison to collocated PLRM pulse-limited altimetry, when a tailored coastal processing is used for both the SAR and pulse-limited altimetry.

In the first place, we emphasize the importance of having an accurate global altimetric dataset in the coastal zone: this is a highly dynamic and lively part of the marine environment, where processes and interactions between sea and land occur very quickly and at very short scales. The coastal zone plays a key role in the life of millions of people, being that more than 10% of the Earth population live in the low-elevation coastal zone area (Neumann et al., 2015) and hence potentially exposed to the effects of sea level rise, global warming and climate change. It is therefore mandatory to develop tools and techniques to monitor the sea level rise in the coastal zone, to include in the near future the coastal data in the global sea level budget and to demonstrate that coastal altimetry data can contribute effectively to the monitoring of regional sea level trends. The importance of coastal altimetry has been indeed recognized by the major space agencies, which have been supporting research and development (R&D) in the field. Thanks to this effort, progress has been achieved in the last years in the frame of projects such as ALTICORE (Lebedev et al., 2008), COASTALT (Cipollini et al., 2009), X-TRACK (Roblou et al., 2007), PISTACH (CLS Report, 2015), eSurge (Cipollini et al., 2012) and CP4O (Cotton, 2015). These projects aimed at improving conventional and SAR altimetry and at improving the range and geophysical corrections (in particular the wet tropospheric path delay and ocean tide) in the coastal zone. In particular, in the COASTALT project, a coastal-enhanced wet tropospheric correction, designated Global Navigation Satellite Systems (GNSS) derived Path Delay (GPD), was developed (Fernandes et al., 2010, 2015; Fernandes and Lázaro, 2016) that has been subsequently selected as the default wet tropospheric correction in the sea level calculation for the Sea Level CCI (Climate Change Initiative) project (Ablain et al., 2015).

In the last years, relevant advancement has been achieved in the field of pulse-limited waveform retracking (i.e. the process of extracting the geophysical altimetric measurements from the received waveform) in the coastal zone by adopting a sub-waveform retracking approach (as Guo et al., 2010, RED3 in CLS Report, 2015, Idris and Deng, 2012) and an adaptive sub-waveform retracking (as ALES in Passaro et al., 2014). The latter authors succeeded in mitigating the impact of land contamination (off-nadir returns from the land synchronous with nadir return from the ocean, see (Vignudelli et al., 2011) and bright targets (as wetlands, mud flats, reefs, etc.) on the retrieved coastal measurements, by retracking only a subset of the waveform. Despite these advances in conventional altimetry, due to the novelty of the SAR altimetry mode, not much work has yet been carried out in the field of SAR coastal retracking.

In spite of its importance for climate change monitoring, dedicated coastal retracking is not yet integrated in the operational altimetry Payload Data Ground Segment (PDGS), coastal datasets are being produced only on a prototypal basis (see http://www.coastalt.eu/#datasets for available coastal datasets), there is still no general consensus on the optimal approach to process altimetric measurements in coastal zone (Vignudelli et al., 2011), and the sea state bias in coastal zone is still a major issue (Cipollini et al., 2010). Consequently, most altimetry data collected in coastal zone over the last 25 years are still largely unexploited or flagged as invalid in the ground segment altimetric products.

Here, we briefly introduce the concept of SAR altimetry and highlight its differences with respect to conventional pulse-limited altimetry. The main difference between these two measurement modes is related to the frequency used to transmit the pulses, which is called the Pulse Repetition Frequency (PRF). In pulse-limited mode, transmitted and received pulses are interleaved, i.e. pulses are received and transmitted continuously and reflections from the