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Coastal bathymetry estimation using an ensemble of Synthetic Aperture Radar images from Sentinel-1

L. Lamas[1], J. P. Pinto[1], P. Vilar[1], A. Moura[1]

[1] *Instituto Hidrográfico, Rua das Trinas, 49, 1249-093 Lisboa. Portugal*

Abstract
In this study, coastal bathymetry is estimated with a wave ray-tracing algorithm using wave parameters retrieved from Synthetic Aperture Radar (SAR) images acquired by the Sentinel-1 satellites. The method relies on the long swell wave's detection by SAR imagery and the wave's properties adjustment to the underwater topography, which can be mathematically related using the linear dispersion relation.
The ray-tracing algorithm tracks the shoaling waves until the wave breaking zone, using the wavelength and wave direction retrieved from the 2D directional spectra applied at consecutive sub-images. Then, by inverting the linear wave dispersion relationship, the depth is calculated based on the mean wavelength obtained for each sub-image and maintaining the wave period retrieved at the first offshore position, which is computed using a mean depth from an independent bathymetric source.
The output of the algorithm is a bathymetric model that results from the interpolation of the depth computed at each tracking position to a uniform grid and the results are compared with bathymetric information from the General Bathymetric Chart of the Ocean. The use of a monthly ensemble of SAR images, instead of individual ones, to reproduce the bathymetry near Aveiro, Portugal, resulted in a smoother topography with lower relative errors, suggesting that the final bathymetric model retrieved from SAR should result from a combination of SAR images.
The methodology presented here to infer the bathymetry using space-borne SAR imagery can be useful to retrieve the mean bottom topography (especially in remote areas where the traditional hydrographic surveying methods are not performed regularly) and to reproduce new underwater structures, such as banks, reefs or bars, which are important to detect for the safety of navigation.

Key words: *Coastal Bathymetry, Synthetic Aperture Radar Data, Wavelength, Wave Direction, Earth Observation*

I. INTRODUCTION

The knowledge of the water depth, specifically in coastal areas, is of crucial importance for a vast range of scientific, economic and societal fields. Accurate bathymetric information is imperative for the forecasting of the sea-state and coastal dynamics over shallow waters. Safety of navigation, fishing activities, offshore energy production, etc., all require precise information about underwater topography. The most accurate solution to retrieve bathymetric information is provided through traditional hydrographic surveying techniques, yet, these methods are time consuming, very costly and not regularly performed, especially in remote areas. The global bathymetry at 1 km resolution is already known and available through multiple different datasets (e.g. General Bathymetric Chart of the Ocean: GEBCO), however, those datasets also depend on in-situ data which can be out of date, especially in coastal areas where the hydrographic surveys are not performed often, or regions where the bottom floor changes rapidly due to, for example, the presence of energetic storms. The increasing advances in remote sensing technologies provided a natural solution for the development of methodologies that estimate the bottom depth ([1]; [2]; [3]; [4]; [5]; [6]; [7]; [8]; [9]; [10]). The use of SAR images acquired from satellites to derive the bathymetry can be particularly useful for many coastal applications, since satellites provide images globally, with high spatial and temporal resolution, and SAR sensors are independent of daylight and weather conditions.
A theory for bottom depth estimation using SAR imagery was first proposed by [1], which showed that the variation of strong currents detected by the SAR images could be related with the bottom topography. Other SAR-based methodologies have been proposed since, some of which use wave-current interactions [2], tidal currents [6] or directional changes of refracting waves [7]. In this study, the coastal bathymetry is derived with a ray-tracing algorithm (RTA) through wave parameters retrieved from SAR images from the Sentinel-1 satellites, following a similar methodology as proposed by [8] and [9]. The estimation of bathymetry through this method relies on the detection of long surface gravity waves and how the wavelength and direction are modified as the waves propagate towards the shore, which can be related to the bottom topography. The bottom depth estimated is compared against the bathymetry information provided by GEBCO. The methodology proposed here is tested for a region near Aveiro on the northwestern coast of Portugal and the results are discussed regarding the use of individual versus combined SAR images.

II. CONCLUSIONS

The bathymetry from SAR can be retrieved typically for depths between 10 to 100 m, depending on the long waves' length and breaking depth, which are specific to the sea state at the time of the sensing and the topography of the area of interest. In the case study presented here, the bottom depth estimated near Aveiro spanned between 20 and 100 m.

This study showed that using individual SAR images results in errors of the order of 10 to 20%, similar to previous studies ([8]; [9]) while using an ensemble of images can reduce this error to 5%. Fewer images in the ensemble resulted in higher relative error of the final bathymetric model. The topography near Aveiro at depths between 20 and 100 m are unlikely to change considerably in a monthly timescale, at least considering the spatial scales obtained by the SAR derived bathymetry. Apriori knowledge of the morphodynamics of the bottom floor for the area of interest is crucial in order to use the best timescale for the ensemble. For example, the time between images used in the ensemble should be reduced for places where the seabed changes often.

The bathymetric estimation using SAR might not be accurate enough to retrieve the absolute depth at a specific location, but can add useful information about the mean bottom topography (especially in remote areas where the traditional hydrographic surveying methods are not performed regularly) and can be used to detect new underwater structures, such as banks, reefs or bars, important to consider for the safety of navigation.

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