Focus Earth

Shallow-Water Hydrography in Portugal Using ERS-SAR Data

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The capacity of Synthetic Aperture Radar (SAR) to image the sea-bottom topography in shallow waters is now well-known. Nevertheless, the difficulties associated with its quantification in terms of depth determination have in some way prevented the effective use of SAR imagery for bathymetry mapping. This article describes an approach for combining ERS-SAR and limited bathymetric survey data with the use of the Bathymetry Assessment System (BAS), developed by ARGOSS, for sea-bottom mapping in shallow-water areas. It focusses on the extraction of bathymetric information in the Tejo Estuary, in Portugal.

Introduction

The aim of hydrography is basically to chart the underwater topography. A precise knowledge of the sea-bottom features has great relevance mainly in shallow waters, where navigational safety must be assured at any cost. Ideally, one should have available a complete series of maps of the sea-bottom topography.

The surveillance of coastal and estuarine waters is an ambitious task. Large river estuaries, such as the Tejo Estuary, cannot be covered with a single hydrographic survey. In addition, some particularly critical areas need more frequent coverage, given that river estuaries are zones where changes are likely to occur frequently due to sediment transportation.

Remote sensing, mainly from space, can play an important role in the characterisation and monitoring of sea-bottom topography in shallow waters. It is now well known that Synthetic Aperture Radar (SAR) systems can, under favourable hydrodynamic and meteorological conditions, reveal patterns associated with bottom features. ESA's ERS remote-sensing satellites have provided SAR data in frames covering an area of approximately 100 km x 100 km. Although the basic information provided by ERS-SAR is only qualitative, in terms of bright and dark departures from the surrounding mean radar intensity, numerical models have been developed to quantify a SAR image in terms of depths. These models have been incorporated into the Bathymetry Assessment System (BAS), developed in the Netherlands by ARGOSS. BAS calculates the seabed topography based on ERS-SAR images and on a limited set of soundings (Fig. 1).

In the framework of an agreement between ESA and Portugal, a research project has been carried out using ERS-SAR data and the BAS tool to study bathymetric features visible in satellite images of the Tejo Estuary.

Background

In Portugal, the Instituto Hidrográfico (IHPT) is responsible for the production of the Official Nautical Charts (ONC). These charts are used for navigation purposes and cover the entire coast of Portugal on different scales. Harbour areas are shown on the largest scale. Lisbon harbour is covered by four charts on a scale of 1:15 000. This harbour is heavily used due to the highly favourable natural conditions offered by the Tejo Estuary, which covers an area of approximately 210 km^2. As in most major estuaries, the bottom morphology is subject to continual change. One of the most sensitive areas is the harbour entrance, where a dredged channel must be regularly maintained to ensure safe navigation.

The depth measurements used to produce the ONCs come from different sources, but always relate to the most recent survey performed in

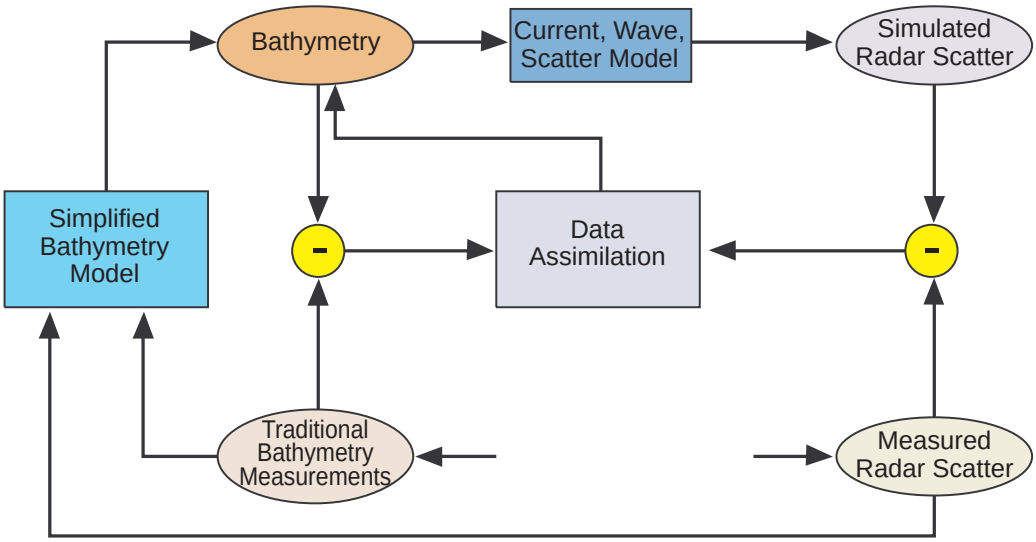

Figure 1. The Bathymetry Assessment System (BAS) is an intelligent interpolator that computes water depths between transects of echo soundings (survey lines) based on the grey-tone variations in Synthetic Aperture Radar (SAR) images. These variations are modelled taking water currents and winds into account also

the respective area. Each ONC has its own compilation history, which influences the level confidence in the information in the chart.

Access to up-to-date bathymetric information would represent a unique opportunity for the verification of existing maps, and would also help in establishing adequate planning of hydrographic surveys.

The opportunity to investigate these issues arose during a one-year traineeship granted by the Portuguese Government and ESA to one of the authors, J. Robalo. As a result, a research project was set up with the aim of demonstrating the potential of ERS-SAR in imaging sea-bottom topography in shallow-water areas. As a case study, the Tejo Estuary area was selected for a preliminary assessment of the feasibility of applying ERS-SAR images and the BAS in order to extract bathymetric information.

Project area and mapping methodology

The project area corresponds to the section of the Tejo Estuary represented in the Portuguese ONC 26306. Using the BAS for bathymetry modelling requires further input. Data have to be collected from different sources and include: ERS-SAR images, soundings, and tidal and meteorological data. Moreover, all data have to be geo-referenced into a unique grid system.

Data

The ERS-SAR Precision Images (PRI) were supplied by ESA. Several were analysed from a set available at ESRIN. It was not possible to make a selection based on the most favourable hydro-meteorological conditions because relevant information in the form of image quick-looks was not available. The two ERS-2 images eventually selected were acquired on 14 June and 23 August 1998 (Figs. 3 and 4).

The location accuracy of the ERS-SAR PRI product is assumed to be 100 m in the range direction and 200 m in azimuth, which was not good enough for the purposes of this project. More precise geo-referencing of the two SAR images was achieved using a set of ground control points (lighthouses, towers, etc.), obtained from IHPT.

The soundings used in the project were digitised from the bathymetric contour lines represented in ONC 26306. Tidal predictions were obtained from IHPT and the Instituto de Meteorologia provided wind information, recorded at Lisbon Airport, close to the Tejo Estuary.

SAR image interpretation

The principles of seabed and current interaction and its manifestation as surface roughness are explained in Figure 2. In the data of 14 June (Fig. 3), the hydrodynamic and meteorological conditions at the time of recording seemed to be more favourable for the imaging of seabed topography. Compared to the acquisition of 23 August (Fig. 4), low-wind (dark) areas are less evident and tidal

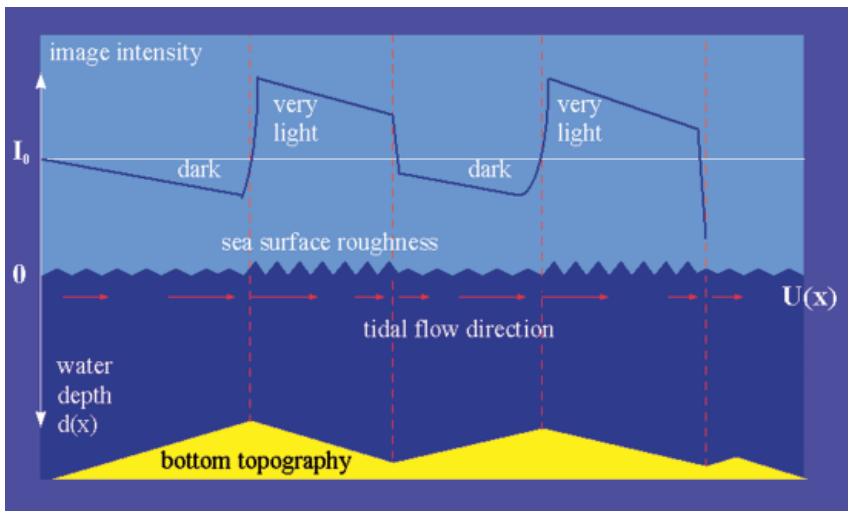

Figure 2. The principles of seabed and current interaction and its manifestation as surface roughness. In a SAR image, any changes in this surface roughness are visible as variations in backscatter values and hence as different grey tones

Figure 3. ERS-SAR PRI image of the project area acquired on 14 June 1998, including the mouth of the Tejo Estuary. Sea-bottom-related features can be seen in terms of bright and dark departures from the surrounding mean radar intensity. It is not possible to quantify these patterns directly in terms of depths. To extract bathymetry information, the Bathymetry Assessment System (BAS) must be used

current seems to be swifter. This is confirmed by a white area near the Vasco da Gama bridge, inside the Estuary. It is the result of a strong interaction between the tidal current (ebb flow) and the bridge pillars, rendering the water surface rougher than elsewhere. On the image of 23 August, this effect is not visible, indicating that the tidal current (flood flow) was weaker.

Bathymetric maps

Two bathymetric maps with a grid resolution of 50 m were generated by the BAS, using a different radar image for each map. These bathymetric maps, based on the ERS-SAR images of 14 June and 23 August, are shown in Figures 5 and 6, respectively. The bathymetry contour lines corresponding to 0, 2, 5, 10, 15 and 20 m as generated by BAS are shown in black. For a visual verification, the digitised contour lines from the ONC are shown in red.

There is a strong similarity between the two maps generated by the BAS. The bathymetry

Figure 4. ERS-SAR PRI image of the project area acquired on 23 August 1998. Sea-bottom-related features can be observed with the same generic pattern as those in Figure 3. Dark patches are related to low-wind areas, but they could also represent tidal flats

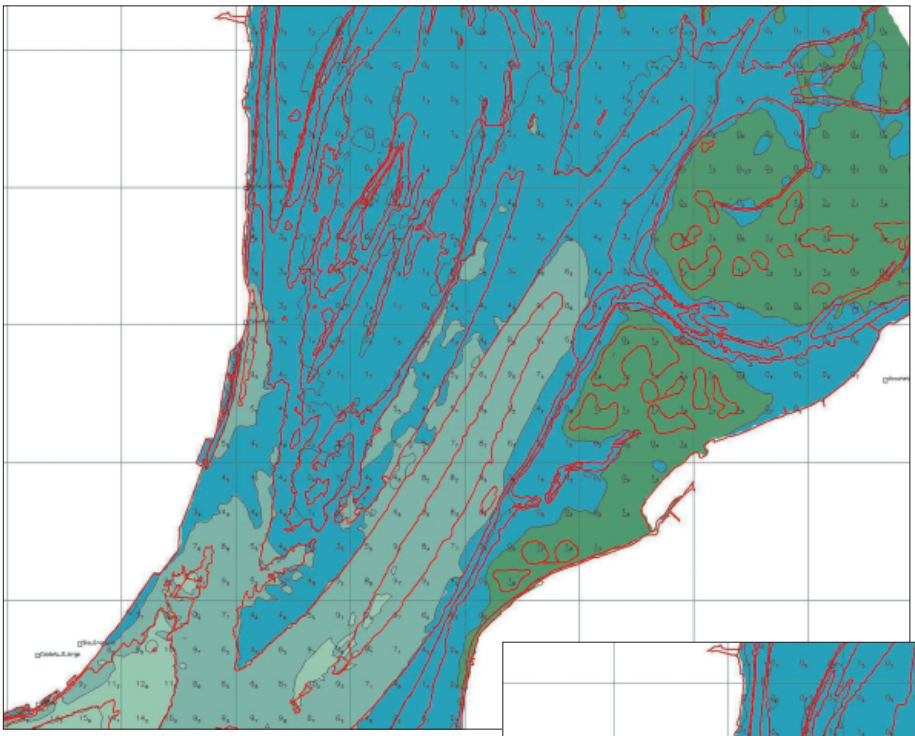

Figure 5. A bathymetric map generated by the BAS, based on the ERS-SAR image of 14 June 1998. Grid resolution is 50 m, and the red lines are contours digitised from the Nautical Chart

contour lines show a similar general pattern in corresponding locations, although many more details are visible in the map based on the 14 June SAR image.

Comparison of BAS map and nautical chart

A visual inspection shows that there is a fair resemblance between the BAS maps and ONC 26306 (black and red contour lines). A statistical analysis indicates that for the 'best' map (based on 14 June image), the difference is less than 85 cm, when applying a confidence level of 95%.

Conclusions

Hydrography can benefit greatly from the use of remote-sensing-based methods. The combined use of ERS-SAR and limited survey data, introduced into the Bathymetry Assessment System, may be very helpful for shallow-water hydrography. Bathymetric maps with a reasonable level of accuracy can be produced, which provide an instantaneous overview of a vast area. The method presented here can be used very successfully for:

- an overall verification of existing nautical charts
- the detection of problem areas with fast-changing bottom morphology, where hydrographic surveys should be carried out more frequently
- improving bathymetry maps of areas where only coarse surveys are performed.

The quality of the information content of the SAR images used is an important factor in determining the accuracy of the depth maps generated by the BAS. Favourable hydrometeorological conditions are crucial for sea-bottom imaging by SAR. A wide choice of images acquired under different conditions is therefore required, and the availability of quick-look images is essential for cost-effective selection and would certainly stimulate this type of data application considerably.

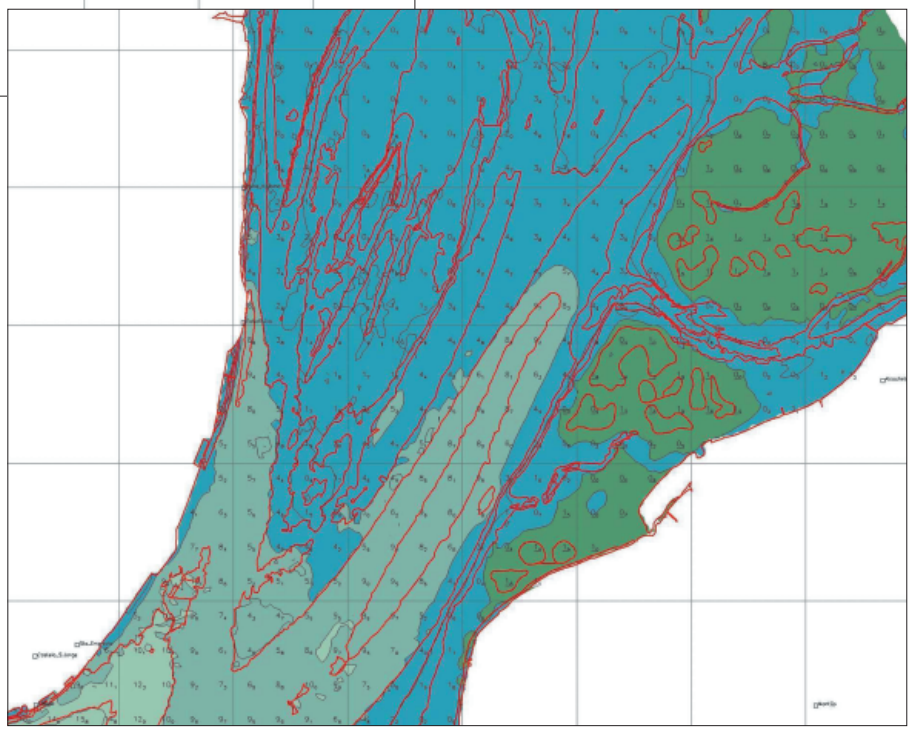

Figure 6. The BAS-generated bathymetric map, based on the ERS-SAR image of 23 August 1998. The calculated bathymetry contour lines agree with those depicted in Figure 5, but much more detail is visible in that map due to the better quality of the feature representation in the SAR image used

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