Detection of Submerged Sand Bars in the Ebro Delta Using ASTER Images

R. Rodríguez-Martín and I. Rodríguez-Santalla

Abstract

Deltas are complex systems that can be affected by the alteration of any factors that interfere in their dynamic. Knowledge of these systems allows managers and scientists to model and establish the ecosystem state. This study is focused on the sand bars located in the Ebro delta coast. These sand bars constitute a natural sediment deposit to protect the beaches from wave erosion. Over the last 20 years, their detection has been based on the record of the maximum intensity shown by waves breaking over them. The methodology uses satellite images to detect the sand bars depending on the pixel value. Although is not possible to validate the results, their coherence allows where new investigation lines to be explored. The methodology used will allow increased frequency of monitoring in large areas while reducing costs.

Keywords

Submerged bars • Ebro delta • ASTER • Remote sensing

1 Introduction

Delta coasts are dynamic sedimentary formations found in the transition from terrestrial to marine environments. As a result delta coasts are affected by processes related to this environmental transition giving the delta coast an importance from environmental and economical aspects.

The bars are accumulations of submerged sediments and represent sedimentary formations located off the coastline, less than 10 m deep with a very dynamic morphology. The bars are formed by the action of intense waves that create effective return currents.

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The importance of the bars is that they are a reserve of sediment which protects the coastline against erosion from storms. It is important to know their characteristics for the study of the hydrodynamics of the surf zone, for the beach morphology study and for the protection of the coast (Ojeda et al. 2008).

Lippman and Holman (1989) pioneered the use of video cameras for the detection of submerged bars. This was done taking advantage of the high light intensity that waves produce breaking over the crest of sand bars. This technique has been widely used, studied and improved. With this technique it has been established that the relationship between the position of the bars and the maximum intensity varies with the studied area (Ribas et al. 2010). This relationship depends on the tide level, the significant wave height (Ojeda et al. 2008) and the beach profile (Plant and Holman 1998). The best results are obtained with the average of images taken every second over 10 min (Lippman and Holman 1989). This approach lacks the synoptic view of satellite sensors and in addition requires study in situ and

Y. Huang et al. (eds.), *New Frontiers in Engineering Geology and the Environment*,
DOI: 10.1007/978-3-642-31671-5_16,

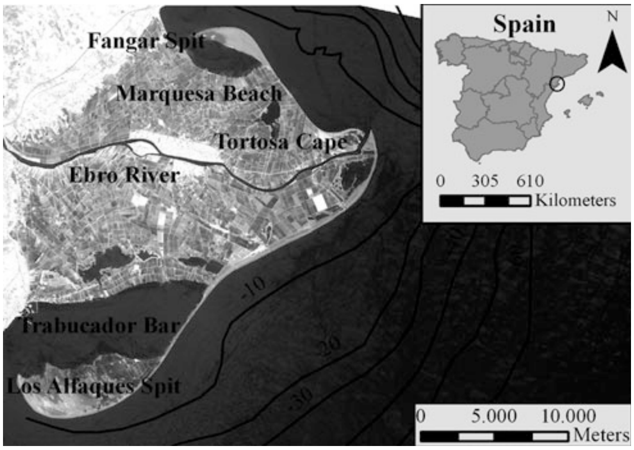

Fig. 1 Location map of the ebro delta. ASTER image

maintenance of video recording equipment, which leads to high cost.

On the other hand, the signal received by a satellite sensor in the coastal zone has low reflectivity in the visible range (Chuvieco 2010). The reflectivity increase due to the foam generated by breaking waves and also by the influence of the sea floor, especially where there are sand bars (Gould and Arnone 1997).

2 Field Site and Data

The Ebro Delta is on the Mediterranean coast of the *Comunidad Autónoma de Cataluña* (Spain) (Fig. 1). It is the most important coastal delta of the Iberian Peninsula, and is a microtidal delta currently dominated by waves (Jiménez and Sánchez-Arcilla 1993).

The most intense waves occur from October to March. The main incident wave comes from the east, and diverges at the Cape of Tortosa, creating two currents: one to the North and the other to the South (Garcia 1982). The longitudinal transport allows the formation of beach ridges that favor the growth of spits. The greatest erosion is concentrated in Cape Tortosa, while the main deposition is located at the end of El Fangar spit situated in the north hemidelta, and in the Los Alfaques spit, in the south hemidelta (Rodriguez 1999).

In this analysis four ASTER images are used which cover the area of the Ebro Delta: 07/06/2003, 01/07/2006, 08/10/2007 and 7/28/2010. The images of 2003, 2006, and 2010 correspond to the period in which the waves were less energetic, whereas, the image of 2007 includes the result of strong waves.

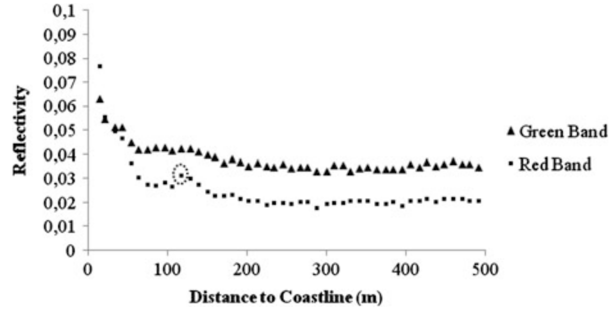

Fig. 2 Profile No. 43 of ASTER image of 2006, bands of red and green. The re-marked point has the highest intensity in the area where the bar is expected to be found

3 Methodology

The methodology seeks to transfer the experience acquired from the use of video cameras to the satellite images. This presents a set of problems and limitations. Satellite images show the state of the sea surface in a single instant; therefore it is impossible to have an average of 600 images for a 10 min period. This may not be a great problem taking into account that the spatial resolution of ASTER is 15 m and the fluctuations due to changes in wave height with the actual position of the bar's crest can be collected at the same pixel, or adjacent. The column of water between sensors and ground can be five times higher with a video camera than with ASTER because the angle of incidence of a video camera is around 80 and 21.3° in ASTER (Abrams and Hook 2007).

Due to the lack of accurate bathymetry, we could not validate the results. Therefore, we should consider this project as an exploratory technique.

3.1 Preprocessing and Processing

The preprocessing was carried out following instructions from Abrams and Hook (2007). The image of 2003 was georeferenced over an orthophoto of PNOA (Plan Nacional de Ortografía Aérea). The other took as a reference the 2003 image. A mask was done using the NIR band, with the goal of using only the sea within 500 m of the coast.

Bars were digitized visually for each date. Subsequently, lines perpendicular to the coastline were generated obtaining profiles according to the red and green bands. The position of the sand bar was assigned repeating the same steps in each profile: (1) observing the area where it was expected; and (2)

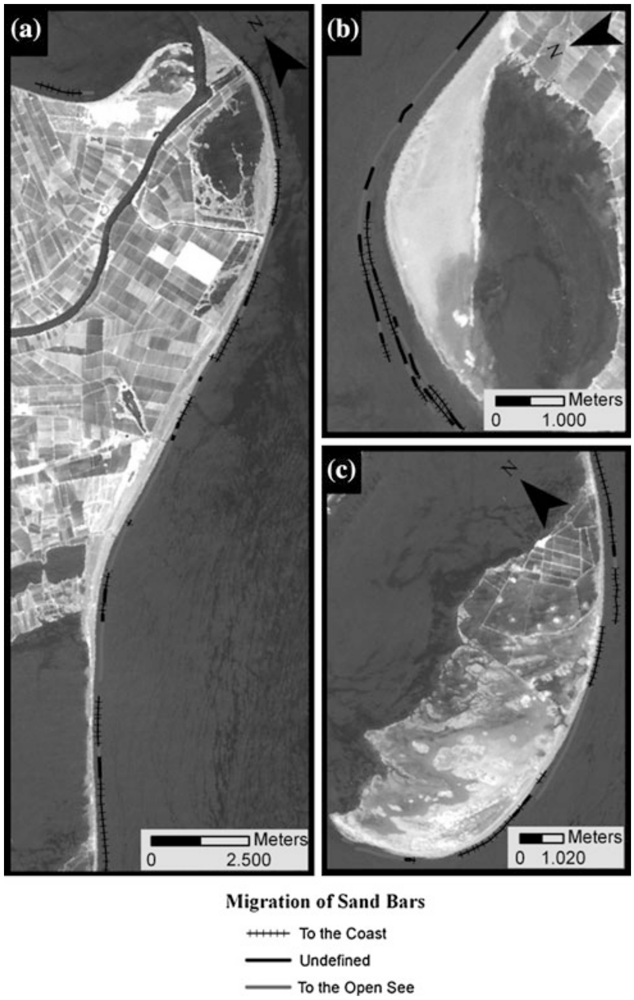

Fig. 3 Direction of migration of the bars. **a** Cape Tortosa and Trabucador Bar (2003–2006), **b** Spit of the Fangar (2006–2007) and **c** Spit Alfaques (2007–2010)

choosing the maximum relative point (Fig. 2). These points were used to digitalize the bars.

4 Results and Discussion

Fourteen bars were digitalized manually and are present in each of the four images. For their detection 247 lines perpendicular to the coastline were generated at irregular intervals (median: 204 m, maximum: 1223 m and minimum 15 m).

Visual analysis of 988 profiles showed that it was easier to select maximum reflectivity points with the red band (Fig. 2). The percentage of common points was relatively high (62.0–75.8 %).

The extension of the sand bars is very irregular (9–558 m). Their presence is not constant for the four dates as a consequence of the complex dynamic of the bars.

The positions of the bars, for each date, were compared with those closer in time. The RMS (Root Mean Square) of the differences, using the results of the red or green bands, was very low (0.47–0.59). The results of the migration of the bars are very similar and given that the visual analysis of the profiles showed greater variability with the red band, the results showed from now on will be exclusively for this band.

The magnitude of the movements of the sand bars has an error derived from the geometric correction: 3, 7 and 8 m for the periods 2003–2006, 2006–2007 and 2007–2010 respectively, this being the sum of the RMS of the images compared, except for the period 2003–2006, in which the error is due only to the image of 2006 and so the image of 2003 was taken as reference. There is no guarantee that differences of less than the error for each interval are actually due to changes in the position of the bar.

From 2003 to 2006, submerged bars migrated to the shore on an average of 8 m along the Ebro Delta. This general movement was not observed in some bars, such as Alfaques Spit, Cape Tortosa or the Trabucador bar (Fig. 3a). The highest specific migration to the coast (higher than the standard deviation minus the mean, < -60 m), occurred in the Tortosa Cape and Trabucador bar meanwhile the bars that move away from the coast are mostly situated in Los Alfaques spit.

From 2006 to 2007 average migration for the entire study area was 7 m to open sea. Only in three bars situated on the spits of the Alfaques and Fangar (Fig. 3b) was the mean motion towards the coast. The highest specific migration to the coast (< -23 m) in this period was found in the two spits and in Trabucador bar.

Among the images of 2007 and 2010 (Fig. 3c), half of the bars have an average of movement toward open sea of low intensity. The general computer shows a widespread retreat of 9 m.

Annual rates of migration were calculated to compare the intervals. It is relevant to remember that migration is not a unidirectional process. In Ojeda et al. (2008) variations of the same magnitude as in this study can be found, even occurring in a few days. There are movements of up to 69.8 m in 9.7 days (7.2 m/day) after a heavy wave storm. In the medium or long term rates may indicate a trend which can show the presence of a causal factor and its intensity.

The annual migration rates in intervals 2003–2006 and 2007–2010, for the whole Ebro Delta, are of the same intensity and direction, −3 m/year. On the other hand, for 2006–2007 the rate is doubled and changes direction 6 m/year. Images of 2003, 2006, and 2010 correspond to the low wave station, while the 2007 image has already been affected by high energy waves, which move the bar seaward, explaining the positive sign of the migration rate and that its magnitude was more than twice other intervals.

Jimenez (1996) and Rodriguez (1999) have observed how the redistribution of the sediments differs from an inflection point in the direction of both spits depending on the predominant wave direction. Aside from the inflection point, erosion is the dominant process and the bars recess of the bars while on the other side, the opposite phenomenon occurs. This phenomenon can be observed in the periods 2003–2006 and 2007–2010, while it is reversed for 2006–2007 due to the influence of strong waves. For the interval 2003–2006, in El Fangar spit this trend is not observed and there is a general advance of the bars to the coast, possibly due to the retention of sediments after the construction of a breakwater at the beginning of the spit.

The bars, present in front of the Marquesa Beach, Cape Tortosa and Trabucador Bar (Fig. 3a) have a similar behavior to the rest of areas of marine events. In Cape Tortosa, the bars show a tendency to back away due to the predominant wave incidence. Submerged bars in front of the Trabucador Bar tend to move to the continental body which was noted by Rodriguez (1999) from 1957 to 1998.

5 Conclusions

The sensitivity of the results of analysis is a function of (1) RMS of the geometric correction (2) spatial resolution (3) number of profiles obtained and (4) satellite trajectory, due to the assignation of the bar location to the center of the pixel.

The results of migration of the sand bars show how sensitive they are to coastal dynamics and human influence.

To establish a criterion to choose the dates of images and the sensor is the objective of the study and the timescale. ASTER provides a good cost-resolution ratio. However, the spatial resolution could be insufficient in short term studies, unless there are important changes between the two images.

Although results have not yet been validated, the analysis of literature that uses the methodology and consistency of results opens up new lines of research aimed at validating and improving the process, and also increases the knowledge in the subject matter. Repeating the methodology in a coastal area for which we have an accurate bathymetry could be the answer to: What wavelength and width of images give the best results? What proportion of high reflectivity values is to be fount on the bars, due to (1) a lower water column, to (2) the foam, to (3) the suspended sediments and to (4) the roughness of the waves? Is it possible to develop a computer program that automates the process?

Verifying the methodology would not be too expensive if an already existing accurate bathymetry were used, having only to buy the satellite image closest to the bathymetric survey. This minimal investment could help to reduce future costs, giving a synoptic view and generate fundamental information rapidly for coastal managers and scientists.

Acknowledgments This work was carried out under the project "Determination of morphodynamic relationships and sediment transfer mechanisms in the beach-dune system and its variation under different climatic scenarios. Application to the Ebro River delta system" funded by the Ministry of Science and Technology of the Spanish State.

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