DEVELOPMENT AND INTERACTIONS OF SURFZONE MORPHOLOGICAL PATTERNS: OBSERVATIONS AND MODELLING

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Abstract

Sandy coasts are highly dynamic environments, where many nonlinear processes interact at different spatial and temporal scales. To date, no models or physical formulations exist that can explain the interactions that have been observed in the field between different surf zone morphodynamic patterns. Similarly, longshore processes have so far been treated separately from cross-shore processes, which is unrealistic. The goal of this PhD research is to integrate the processes occurring at these different scales to gain basic understanding on the complexity of the coastal system. In particular, the aim is to investigate how coastal morphodynamic patterns in the surfzone are affected by the interactions with processes at different spatial and temporal scales. For that, a combination of field observations and morphodynamic modelling will be used. The field observations will be analysed in detail and provide the input for the morphodynamic models. In turn, the models will be used to reproduce and strengthen our understanding of the observed morphodynamic patterns in the field.

1. Introduction

The coastal system is a highly dynamic area where different physical processes act at several spatial and temporal scales. Characteristic scales vary from the slow evolution of large scale morphodynamic patterns (years and kilometres), passing through surf-zone sand bars (hours and hundreds of meters), to the fast motion of waves and sediment grains (seconds and centimetres). In particular, the processes driving sediment transport are still not fully understood and hard to predict accurately [1]. Also, boundary conditions (e.g. bathymetry and coastline) result in additional complexity to the system since they are continuously dynamic. On the other hand, human actions affect the coastal dynamics, which means that such activities are risky without a good knowledge of the coastal system. Thus, understanding the physics of the coastal system is not only a scientific challenge but also important from a societal and economical point of view.

Beaches dissipate much of the incoming wave energy by adopting different morphological configurations as a function of the wave conditions. The resulting beach profiles are commonly characterised by the presence of submerged sand bars. The dynamics of these sand bars is an important aspect of the overall behaviour of beaches since they efficiently dissipate wave energy. For 2D configurations, the sandbars are alongshore-uniform (Fig. 1a), whilst in a 3D configuration, with alongshore variability, the sandbars typically show an alongshore spatial periodicity (crescentic bars and transverse bars).

Crescentic bars (Fig. 1b) are characterised by undulations that typically show a rather uniform alongshore spacing ranging from tens of meters up to 2–3 km [11]. Strong seaward currents called rip currents concentrate at the deeper sections with shoreward return flows at the shallows. On the other hand, transverse bars are characterised by a nearly perpendicular or oblique orientation to the shoreline. Apart from sand bars, the shoreline often shows alongshore rhythmic features. Beach cusps (Fig. 2a) are alongshore rhythmic features at the coastline with a typical spacing of 1–50 m [11]. Megacusps (Fig. 2b) are shoreline undulations with an alongshore wavelength that is larger than that of beach cusps and they are typically linked to either transverse or crescentic bars. In case of megacusps linked to crescentic bars, sometimes they appear in phase (apices in front of rip channels), sometimes out of phase (embayments in front of rip channels) [13].

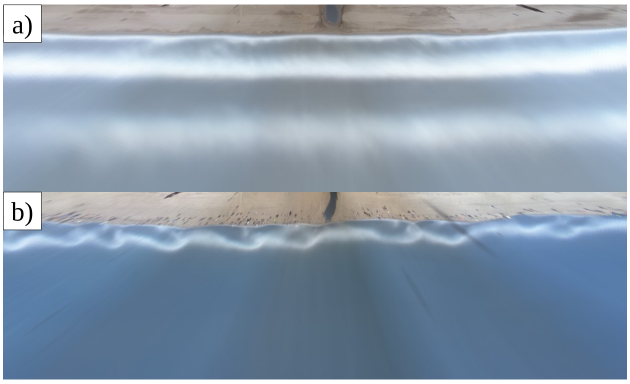

Figure 1. a) Planview image of a shore-parallel bar at Castelldefels, b) Planview image of a crescentic bar at Castelldefels. The white stripes indicate the dominant areas of wave breaking over the sandbar.

Traditionally, the different morphodynamic patterns have been studied separately and under idealized conditions. As a result, only a few recent studies cover the possible interactions between them and many questions remain unanswered [7]. Apart from that, there is a lack of model validations with field observations. To close this gap, there is a need for coastal studies that contain a) observations at large time and spatial scales with good time and space resolution and b) process-based modelling taking into account the interactions between longshore and cross-shore processes and between processes occurring at different temporal and spatial scales.

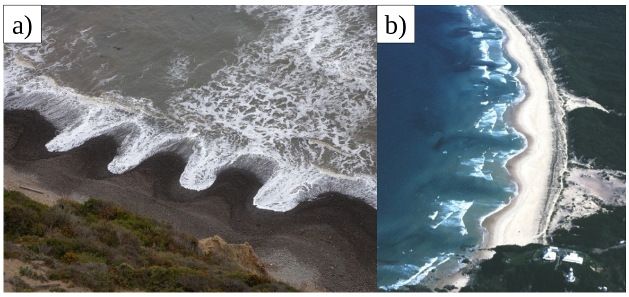

Figure 2. a) example of beach cusps (wavelength ~ 30 m), b) example of megacusps (wavelength >100 m).

2. Objectives and methodology

The aim of this PhD thesis within the MUSA project (Coastal morphodynamics: a multiscale approach) is to understand the development and interactions between surf zone morphodynamic patterns, combining observations with process-based modelling. Specific objectives are:

1. To better understand what beach conditions and processes are responsible for the formation, evolution and destruction of crescentic bars and megacusps.
2. To understand the role of the cross-shore dynamics into the development of crescentic bars and megacusps.
3. To understand the 'coupling' between crescentic bars, megacusps and the cross-shore dynamics of the bars.

This PhD project uses observational data from Castelldefels beach (located 20 km south-west of Barcelona) to study the dynamics in the field and to provide the morphodynamic models with relevant boundary conditions. The main part of the observational data consists of a long-term dataset of video images (October 2010-present), which is a cheap and nearly continuous method to monitor the beach and the nearshore with good time and space resolution (see section 3.3). The software SIRENA and ULISES [12] will be used for the image acquisition and processing, and the BLIM open source code [8] will be used for extracting bar positions. Apart from that, bathymetric data of the nearshore and the dry beach is measured a few times a year at Castelldefels. Moreover, offshore wave conditions will be taken from a wave buoy located in front of the harbour of Barcelona (see section 3.1). The obtained wave conditions will be propagated with two different available models, analysed and correlated to observations at the study site (see sections 3.2). Finally, a field campaign at Castelldefels beach will be held in March 2018 during a 7 days period, which will provide additional data regarding wave conditions, currents, turbidity, grain size and bathymetry at the study site.

Two available surf zone morphodynamic models, which solve the 2DH shallow water equations, the wave transformation and the bed evolution, will be applied to Castelldefels beach to validate their results and unravel the physical processes behind the development and interactions between patterns. The first one, called Morfo62, is based on linear stability analysis [10] and the second one, called Morfo70, solves the full non-linear equations, including shoreline evolution, and is being finished in the framework of the MUSA project.

Some preliminary work regarding crescentic bar observations at Castelldefels beach has already been carried out by the PhD candidate in the framework of an Erasmus Traineeship (March-July 2015) [5].

3. Preliminary results

3.1 Sources of offshore wave conditions

Given that offshore waves are the main forcing of the nearshore system, finding a reliable source for offshore wave conditions at Castelldefels beach is essential. A total of five sources are available, comprising two wave buoys and 3 large-scale wave models (see Fig. 3). The first buoy was located in front of the Llobregat delta, at a depth of approximately 40 m, and was part of the XIOM network [2] of the Catalan Government. Its location was ideal to capture all waves that also reach Castelldefels beach, but unfortunately it stopped operating in June 2009. The other wave buoy near Castelldefels beach is located in front of the harbour of Barcelona at a depth of 68 m and is managed by Puertos del Estado. This buoy started operating in March 2004 and measures until today.

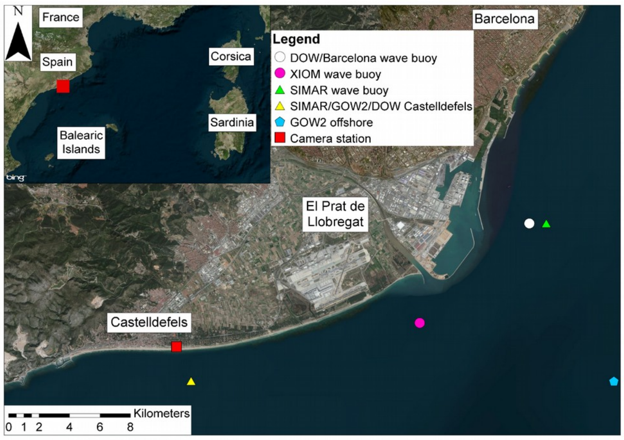

Figure 3. Location of Castelldefels beach and the various wave sources.

Apart from wave buoys, there are also large-scale wave models that provide wave conditions near Castelldefels beach. The SIMAR model, maintained by Puertos del Estado, has a data point directly in front of Castelldefels at a depth of approximately 20 m. Another point is located next to the Barcelona wave buoy. There are two other models, developed by IH Cantabria. One is called the DOW model [4] and has a data point in front of Castellde-fels, at the same location as the SIMAR model. The other

one, called the GOW2 model [9] has a coarser resolution compared to the DOW model and it also has a data point at the same location as the SIMAR and DOW models.
A detailed analysis of the five wave sources was conducted for the period 2004-2009 because all sources contain data in this timespan. The wave conditions measured by the XIOM buoy were taken as the 'true' wave conditions and the data from the other sources was compared to that of the XIOM buoy. To interpret the data, the corresponding RMSE and r^2 values were computed for the significant wave height and the wave angle. This analysis showed that the best source for offshore wave conditions that can be used to obtain data during the study period in at Castelldefels is the Barcelona wave buoy.

3.2 Wave transformation

To obtain the wave conditions at 20 m depth in front of the video station of Castelldefels, the data from the Barcelona wave buoy must be propagated from its location at 68 m depth.

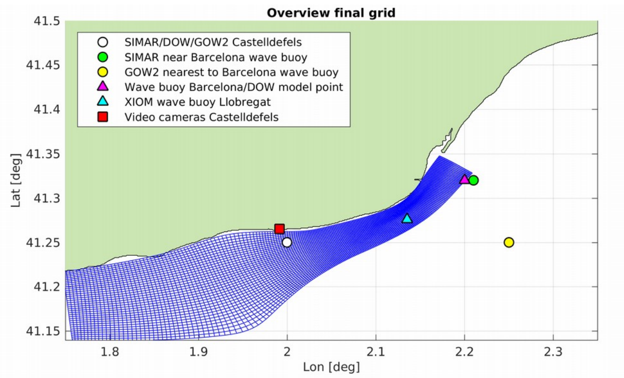

Figure 4. Overview of the SWAN grid.

For this, a wave model called SWAN [3] was set up covering the area around Castelldefels (Fig. 4). The grid follows the coastline and the 68 m depth contour and is forced with the wave conditions of the Barcelona buoy. Output model points are defined in front of Castelldefels and at the location of the XIOM buoy. Apart from SWAN, the waves were also propagated using linear wave theory (assuming parallel depth contours).
Using both methods, the data from the Barcelona buoy was propagated to the location of the XIOM buoy. The results of both methods were then compared to the measured data of the XIOM buoy. The comparison showed that both methods gave nearly the same results.

3.3 Calibration of video images

The video system at Castelldefels consists of 5 cameras that cover a 180° overview of the shoreline. Each daylight hour, all the cameras produce one snapshot, one time-exposure and one variance image. Time-exposure images clearly show the dominant areas of wave breaking as white stripes of foam. Since waves generally break over shallower areas, these white stripes are a good proxy for the location of the submerged sandbars [6].

When dealing with camera systems, the images are recorded in pixels. However, to quantify bar characteristics, data is needed in real world coordinates. This transformation requires intrinsic and extrinsic calibration of the cameras. For this, the x, y and z coordinates of ground control points (structures that are easy to detect in the raw images) are measured with a dGPS and the pixels in the raw images that correspond to the ground control points are detected. The pixels corresponding to the horizon are also detected. Using this information, a specific available software called ULISES [12] can georeference, rectify and merge the raw images into a planview of the shoreline with a pixel resolution of 0.5 m and a size of 1000 by 300 m (Fig. 1). This type of calibration needs to be repeated every time the cameras are moved or after some time (half a year at most). For now, existing calibrations in the years 2010-2014 have been checked and new calibrations until 2016 have been added. Once the planviews of the study period are obtained, BLIM code will be used to extract the bar lines [8].

4. Working plan

A detailed working plan with the tasks and the time schedule is provided in Table 1. A summary is given here:

- 2017-2018 (18 months): Data acquisition of wave conditions, sand bars, shorelines and bathymetries of Castelldefels beach. Finish calibrations of camera system.
- 2018-2019 (24 months): Data analysis of wave conditions, sand bars and shorelines of Castelldefels beach.
- 2019-2020 (24 months): Modelling wave propagation, and sand bars and shoreline evolution at Castelldefels beach.

5. References

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	I				II				III				IV			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Task 1: Data acquisition																
1.1: Obtain offshore wave conditions from various sources																
1.2: Finish all calibrations of the camera system and make planviews																
1.3: Build a 6-year data set of inner and outer sand bars																
1.4: Build a 6-year data set of shorelines																
1.5: Extract barline and shoreline positions from available bathymetries																
Task 2: Data analysis																
2.1: Analyse and compare wave conditions from all available sources																
2.2: Visual analysis of planview images																
2.3: Quantification of cross-shore bar and shoreline dynamics																
2.4: Analyse crescentic bar events																
2.5: Analyse events of megacusps																
2.6: Analyse coupling between sandbar, shoreline and cross-shore dynamics																
Task 3: Modelling																
3.1: Wave propagation using SWAN and linear wave theory																
3.2: Apply available linear model Morfo62 to developing patterns																
3.3: Apply available non-linear model Morfo70 to developing pattens																
3.3: Apply available non-linear model Morfo70 to coupled patterns.																
Task 4: Dissemination																
4.1: Papers																
4.4: Conferences																
4.3: Project meetings																
4.4: Thesis writing																

Table 1. Working plan for the four years of the PhD project. The red line represents the actual situation.