SELF-ORGANIZED MORPHOLOGICAL PATTERNS IN COASTAL DYNAMICS

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Keywords: Coastal engineering, geomorphology, mathematical modelling, sandy beaches.

Summary: the meaning and significance of self-organization processes in coastal morphodynamics is presented. Two types of coastal self-organized patterns are discussed: crescentic bars in the surf zone and free shoreline sand waves emerging along coastlines where the wave incidence is very oblique to the shore. The coupling between wave breaking and bathymetry in the surf zone is presented as the mechanism which is responsible for crescentic bar formation. Numerical modelling illustrating this process is presented. Shoreline sand waves are described and numerical model results showing their growth and propagation are shown.

1. INTRODUCTION

The coast is one of the most dynamic environments of the Earth and at the same time has an enormous importance from a societal, economical and environment point of view. Indeed, a large fraction of the world population lives at the coast or near it and many economical activities as tourism, industries, fisheries, etc. take place at the coast. Also, many coastal areas as river deltas (e.g., Ebro Delta) are vital for the biodiversity. Therefore, knowing and understanding the physical processes that govern the dynamics of coastal morphology is a major research theme.

The coastal dynamical system has two basic components: i) an external forcing which is accomplished by waves, tides, coastal currents, wind, human intervention, etc. and ii) an internal dynamics which is governed by water motions in combination with the changing morphology, where the key point is the transport of sediment by the water (and air) motion. Although coastal morphodynamics is highly complex, from a conceptual point of view one can distinguish between forced processes and self-organized processes. In the forced processes the response of the system is simple dictated by external forcing and directly show the time and length scales of this forcing. For instance, if we built a groin perpendicular to a beach interrupting the dominant littoral drift, a sand accumulation will occur at the updrift side. The position and the shape of the sand deposit directly depend on the position and dimensions of the groin and the wave climate. This is an example of forced response. On the contrary, if a shore parallel bar develops rip channels and a crescentic shape, the shape, the exact location and the alongshore spacing of the rips has nothing to do (directly) with the wave forcing. They depend on the internal dynamics of the system: coupling hydrodynamics and morphology via the sediment transport. This is an example of self-organized response. From a practical or engineering point of view of predicting beach evolution, self-organized processes make the job much more difficult since the response of the system is then much more complex featuring patterns in time and space which are not directly predictable from the external forcing.

Examples of self-organized patterns in coastal morphology are ripple-marks, megaripples, beach cusps, rhythmic sand bars, shoreline sand waves and the sand waves and sand banks in the continental shelf. Our research group has been doing research on such patterns for the last 20 years. Here we will give a brief description of our research regarding two of such patterns: rhythmic sand bars and shoreline sand waves.

2. CRESCENTIC BARS AND RIP CHANNELS

Breaker bars are elongated sand deposits which run roughly parallel to the coast in the surf zone. They are important because they are a reservoir of mobile sand and they protect the beach from storms as most of the wave energy dissipates at the bar. Bars can be straight or they can feature undulations that are typically rhythmic (roughly periodic, with wavelengths typically in the range of a few hundred m up to 1-2 km at most) along the coast. In this case they are known as crescentic bars (see Fig. 1). The typical time scale at which they can form, evolve and disappear is of a few days. The most offshore segments of the undulations are deeper than the most onshore ones and are known as rip channels because seaward directed strong and dangerous currents (rip currents) concentrate in these channels. Rip currents severely affect beach safety for swimming and the rip channels are important for beach erosion, since they bring offshore an important amount of sand.

Figure 1: crescentic bar (indicated by the white foam of the breaking waves) with rip channels from Long Island, New York, USA. Taken from from Google Earth.

For a long time it was believed that the crescentic patterns were forced by edge waves, i.e., nearshore trapped low frequency waves propagating along the coast. A much more plausible assumption that has now become widely accepted is that crescentic bars are self-organized patterns emerging from an instability of the straight bar. Our research group has been pioneering in this paradigm shift (Falqués et al., 2000). Essentially, waves break more on the shallow areas than on the deeper. If an irregularity in bed level arises along an initially straight bar, the more intense breaking will cause an shoreward current at the shallow and a return seaward current at the deep. These currents will transport sediment and will deposit sand at the shallow and remove sand from the deep. In this way, a positive feedback arises and the perturbation of the alongshore uniform bathymetry will grow together with the rip current circulation. This is essentially the physical mechanism which is responsible of the deformation of a straight bar into a crescentic bar. In Figure 2 we show a numerical simulation of this process with our morphodynamic model morfo55 (Garnier et al, 2008). This model describes the wave transformation from deep water over the changing bathymetry of the surf zone, the currents generated by the breaking waves, the sediment transport by the currents and, by keeping track of the gradients in sediment flux determines the bed level evolution.

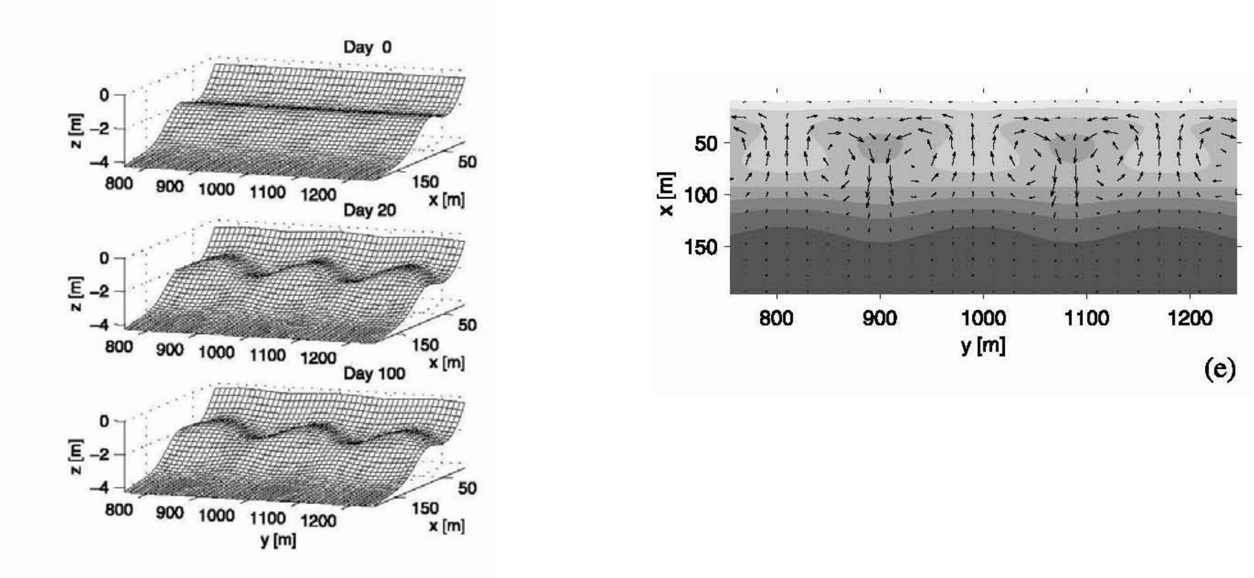

Figure 2: numerical simulation of the formation and evolution of a crescentic bar with the morfo55 model (from Garnier et al., 2008). Left: 3D view of the bathymetry; right: plan view of the bathymetric contours and the rip current circulation.

3. SHORELINE SAND WAVES

Shoreline sand waves are shoreline undulations that can occur at different length and time scales and can be generated by different causes. Here we will focus on self-organized sand waves that emerge from a morphodynamic instability in case of very oblique wave incidence. Their wavelengths are larger than those of crescentic bars, typically in the range of a few km's. The characteristic time scales are also much larger, of the order of a few years. If there is a dominant wave incidence direction they propagate downdrift at celerities of hundreds of m per year (Falqués and Calvete, 2005). Figure 3 shows an example from the SW coast of Africa (Namibia).

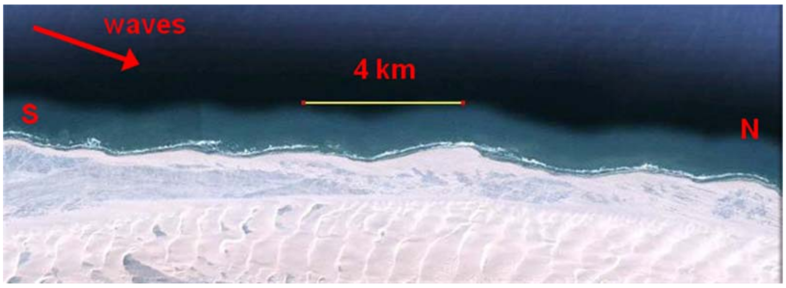

Figure 3: shoreline sand waves along the coast of Namibia. Taken from Google Earth.

We here show a numerical simulation of their formation with our Q2D-morfo model. This model is similar to morfo55 but does not resolve the hydrodynamics, it computes sediment transport directly from the waves by a parameterization. In this way it is appropriate for long term simulations at large length scales, which would be prohibitive with a model like morfo55 (2DH model). It belongs to the N-line model-type used in coastal engineering.

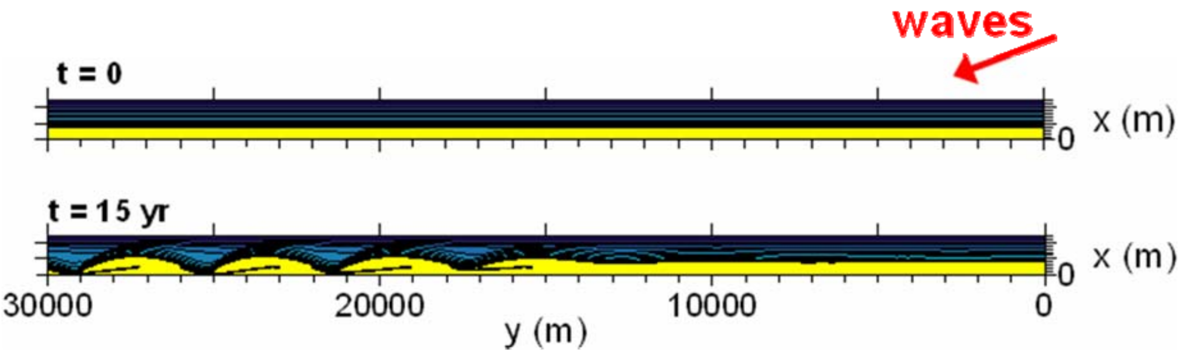

Figure 4: numerical simulation of the formation and propagation of shoreline sand waves with the Q2D-morfo model.

4. CONCLUSIONS

This type of studies is not meant to make predictions for particular situations with engineering interest but to gain knowledge on the fundamental physical processes. Thus, our goal is to understand why these patterns form, which are the wave conditions and the underlying morphology that determine their occurrence, which is the main features of their shape, which is their characteristic length and time scale and where it comes from, which is their propagation celerity, etc. This type of knowledge can then be used by coastal engineers to better design beach nourishments to mitigate beach erosion, since nourishment can interact with bars or can trigger the formation of sand waves or to foresee which impact a coastal structure can have on the adjacent beaches. Large scale sand waves can be associated to the so-called erosional hot-spots that can develop at the bays of the sand wave. One of the main difficulties we encounter is the lack of systematic experimental data on bar and sand wave dynamics to test our self-organization theory. Detailed bathymetric surveys, sometimes very frequently or during long periods of time are required. Also, laboratory experiments on these morphological features have not been done yet. However, the modern improvements of the experimental techniques to monitor beach morphology like video-monitoring of beaches, satellite images, lidar surveys, differential GPS, etc. make us feel optimistic regarding the development of this research theme in the near future.

RFERENCES

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