Cuspat e shoreline relationship with nearshore bar dynamics during storm events – field observations at Sete beach, France.

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ABSTRACT


Cuspat e shoreline or megacusps, having alongshore lengths of 100-1000 m, are features widely described, and several theories were proposed for their formation and evolution (edge waves, self-organization). Their dynamics is often related with rip-currents migration, crescentic nearshore bars evolution, even if the relationship between shoreline rhythms and inner-bar pattern appears to be extremely variable. An Argus video monitoring system was deployed in 2011 at Sète beach (French Mediterranean). This microtidal wave-dominated environment is characterized by the presence of a double crescentic nearshore bar and a cuspat e shoreline with a 400 m wavelength. Wave climate is moderate at this site and most of the significant morphological evolution is observed during storm events. Monitoring of bar and shoreline evolution during two particularly energetic periods (autumn 2011 and spring 2012) permitted to evidence very different behavior in the coupling between bar and shoreline rhythms. Usually, a phase coupling is observed between bar shoals and a seaward bulge in the shoreline. However, during and just after an event, evolution and its timescale is variable for both morphologies, resulting in an apparent out-of-phase relationship. A storm group in autumn yields an important migration of the crescentic bar (200 m/day), due to an oblique wave incidence. However, shoreline cusps remained stable and migrated progressively during the storm fall. It took more than 10 days for the shoreline oscillations to recover a phased position with the bar shoals. In some occurrences, the bar placement was rapidly reversed by a new event with opposite wave direction, and no shoreline migration was observed, probably because time was not long enough to observed a significant displacement. During the spring’s storms, less energetic, a lower bar migration was observed (around 50 m), and a very small shoreline movement is seen, mostly due to the erosion of the flank facing incident waves. After this event, wave conditions decreased rapidly preventing any morphological evolution of both bar and shoreline. These observations indicate that the coupling between crescentic nearshore bars and shoreline rhythms is time-dependent, and a given period with significant energy on the falling storm is needed to recover a phased position of both morphologies.

ADDITIONAL INDEX WORDS: Argus Video system, alongshore migration.

INTRODUCTION

Cuspat e shoreline or megacusps, having alongshore lengths of 100-1000 m, are features widely described (Thornton et al., 2007), and several theories were proposed for their formation and evolution (edge waves, self-organization) (Masselink et al., 1997). The main question is on the cusp if they are formed by edge waves or self-organisation. Although significant progress has been made as to its origin using numerical models, the contribution made by field measurements has been very limited (Masselink et al., 1997). The process of self-organisation suggests that the feedback between the spreading movement Beach and the topography plays an important role (Masselink et al., 1997). Their dynamics is often related with rip-currents migration (Orzech et al., 2011; Castelle and Ruessink, 2011), crescentic nearshore bars evolution, even if the relationship between shoreline rhythms and inner-bar pattern appears to be extremely variable. Studies to assess their dynamics are very scarce (Orzech et al., 2011), but their role on dune erosion is important (Thornton et al. 2007) and would require more attention. In most cases, Video monitoring of bar dynamics was largely developed during the last years (Holman and Stanley, 2007). Such systems permit the observation of coastal morphologies during storm if the surf zone is not fully saturated and are thus particularly useful to determine storm responses (Van Enckevort and Ruessink, 2003). Such system was deployed at the Lido de Sète beach, along the french mediterranean coastline in 2011.

The study area is a narrow microtidal sandy barrier; Le Lido de Sète à Marseillan isolating a large lagoon complex (Thau Lagoon) from the Mediterranean Sea (Figure 1). This microtidal wave-dominated environment is characterized by the presence of a double crescentic nearshore bar (Certain and Barusseau, 2005) and a cuspat e shoreline with a 400 m wavelength (Figure 1). The mean shoreface slope of ~ 0.9 % and grain size about 200 μm for the

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nearshore bars (Certain et al. 2005). The inner bar is located between 80 and 170 m from the shoreline and its crest is around -2 m from the sea surface. The outer bar distance is between 250 m and 400 m with a crest depth around -4 m. Wave climate is moderate at this site and most of the significant morphological evolution is observed during storm events (Gervais et al., 2012). Mean tidal range is around 0.2 m and can reach 0.3 m during spring tides. Modal wave conditions are weak (Hs mean = 0.7 m; Tm mean ~ 4.5 s) but important wave episodes and storms in winter time are rather frequent. More than 3 events of Hs > 3 m per year occur in this region and annual return period for Hs is estimated at 4.3 m. Storm conditions (around Hs > 3 m and Tm > 7.3 s) are often associated with onshore wind and low atmospheric pressure that generate a storm surge which may reach 0.8 m above mean sea level in most extreme case (Gervais et al. 2012).

Previous studies in this area have (Barusseau and Saint-Guily, 1981; Barusseau et al., 1994) evidenced a rapid evolution and dynamics of the nearshore bars during storm events. Gervais (2012) described rapid bar migration and/or deformation of the inner bar that are driven by hydrodynamic conditions, but also by the initial morphology of the shoreface before the storm occurs. The general shape of the bars appears to be very stable with the permanent presence of small cusps in the northern part of the lido and larger cusps in the south. Rhythmicity in the shoreline are usually in phase with the inner bar, the seawards bulges in the shoreline being located in front of the bar shoals. Bar position is oscillating around a mean position at a seasonal timescale. At a larger timescale, the bars are following the well-described net offshore migration (Certain, 2002).

METHODS

An Argus video monitoring system (Holman and Stanley, 2007) was deployed in 2011 at Sète beach. The video monitoring system consists in 8 cameras installed on two 20 m height masts. The best hydrodynamics conditions for positionning the crest of the nearshore bar on the Argus images are under moderate waves (between 1 and 2 m) and low surge (below 0.2 m). Waves at 30 m water depth and water levels (in the harbor of Sète) are measured in the vicinity of the fieldsite by the regional government administration (DREAL-LR).

RESULTS

Hydrodynamic conditions

Figure 2 presents the hydrodynamics conditions from October 2011 to April 2012. Offshore waves during this monitoring period were moderate and the maximum Hs is around 3.6 m. However, several storm events were observed, with Hs ranging from 2.5 to 3.6 m. 5 events occurred in October and November 2011 and one event in April 2012. All storms events have wave from ESE except the event of 3-4 November with waves from the South. This last event had low waves but a quite important duration and thus an important cumulated alongshore energy. Storm surges were moderate during the autumn period, reaching 0.5 -0.6 m during the main storm peaks, and remained low during the winter 2012 period.

Inner bar dynamics

Monitoring of the bar crest permitted to analyze the changes in bar position and shape. During the most energetic period (autumn 2011), the shape of the inner bar remained constant with the presence of 3 well-developed cusps. However an important alongshore migration of the system was observed, reaching hundreds of meters in several hours. Cross-shore mobility was
conditions. The migration rate appears to be driven by the longshore energy of waves at the peak (Figure 4). Despite a quite important scatter in the data points, a clear tendency is observed. However, during the storm event with wave from south, the migration is higher than expected given the wave energy at the peak. This event was less energetic than others but had a longer duration, resulting in a higher cumulated energy than could eventually explain the higher migration rate.

**Shoreline cusps dynamics**

During fair weather conditions, a phase coupling is observed between the inner bar shoals and seaward bulges in the shoreline. Given the low energy storm conditions, it was possible to observe the evolution of the shoreline during the migration phases of the bar shoals. During the first event at the end of October 2011, the seaward bulges remained at the same position, despite a rapid and important migration of the bar shoals. This resulted in an apparent out of phase between the bar and shoreline (Figure 5). Shoreline cusps migrated progressively during the storm fall. It took more than 10 days for the shoreline oscillations to recover a phased position with the bar shoals. This recovering period was characterized by the presence of moderate wave conditions with significant wave height remaining over 2 m, and wave periods over 7 s. The mean wave direction remained constant.

During the spring’s storms, less energetic, a lower bar migration was observed (around 50 m), and a very small shoreline movement is seen, mostly due to the erosion of the flank facing incident waves. After this event, wave conditions decreased rapidly preventing any morphological evolution of both bar and shoreline.

**Beach and dune erosion**

During the entire monitoring period, erosion of the dune toe was observed only during one event, at the end of October 2011 (Figure 6). Given the moderate wave conditions, this was unexpected, because a 4 m Hs is usually necessary at this site to induce a set-up and run-up able to reach the dune (Gervais et al., 2012). This event was observed exactly when the bar shoals and the seawards bulges in the shoreline were out of phase (the bay of the bar in front of the bulges). Times series of pixel intensities evidenced that the maximal intensity of the swash zone was located higher on the (pre-storm) beach cross-shore profile located in front of the bar shoals, suggesting an eventual higher set-up over the shoals, that could have induced a higher maximal level reached on the aerial beach by the swash.

**DISCUSSION**

Cuspate shorelines are observed along many coastlines. Their dynamics is complex and even if their association with nearshore bars is obvious (Thornton et al., 2007), phased /out-of-phased relationships are observed (Orzech et al., 2007) and difficult to explain. The video monitoring at the Lido de Sète beach permitted to assess the dynamics of both bars and shoreline during moderate energy storm events. The survey evidenced a very rapid alongshore migration of the inner bar cusps. The migration rate is driven by wave obliquity and alongshore wave energy. This kind of longshore migration was already described in others environments (Van Enckevort and Ruesink, 2003). However, that was unexpected at this site where the bars are considered to be very stable in time. This rapid displacement of the bar have never been observed in the past despite a long term monitoring of the bar deformation using classical bathymetry means.
Figure 3. Evolution of the bar position during the most energetic period in October and November 2011. White areas indicate the parts of the bar close to the beach (bar horns), and darker areas indicate the bar bays. Wave characteristics (Hs and wave incidence) are reported on the left to correlate storm events and alongshore migration of the bar. 0° wave incidence coincides with South-east incoming waves.
The relationship between bar cusps and cuspate shoreline can be driven by various parameters (water level, self-organisation, ...). At the Lido de Sète beach, both morphologies are usually in phase (seaward bulges in the shoreline in front of the bar shoals/horns). Monitoring of bar and shoreline evolution during two particularly energetic periods (autumn 2011 and spring 2012) permitted to evidence very different behaviors in the coupling between bar and shoreline rhythms. Usually, a phase coupling is observed between bar shoals and a seaward bulge in the shoreline. However, during and just after an event, evolution and its timescale is variable for both morphologies, resulting in an apparent out-of-phase relationship. A storm group in autumn yielded an important migration of the crescentic bar (200 m/day), due to an oblique wave incidence. However, shoreline cusps remained stable and migrated progressively during the storm fall. It took more than 10 days for the shoreline oscillations to recover a phased position with the bar shoals. In some occurrences, the bar displacement was rapidly reversed by a new event with opposite wave direction, and no shoreline migration was observed, probably because time was not long enough to observed a significant displacement. During the spring’s storms, less energetic, a lower bar migration was observed (around 50 m), and a very small shoreline movement is seen, mostly due to the erosion of the flank facing incident waves. After this event, wave conditions decreased rapidly preventing any morphological evolution of both bar and shoreline. These observations indicate that the coupling between crescentic nearshore bars and shoreline rhythms is time-dependent, and a given period with significant remaining energy on the falling storm is needed to recover a phased position of both morphologies. The reason for this behavior is not explained here, and further monitoring will be required to fully document this dynamics.

The impact of this behavior on the erosion of the dune is interesting. As documented by Thornton et al. (2007), a relationship between the cuspate shoreline embayment and the location of dune erosion is clear. This is apparently also the case at the Lido de Sète during most energetic storms that induce erosion of the dune toe that is clearly located in front of the inner bar shoal and the shoreline embayment. However, during the storm event of October 2011, wave conditions remained moderate, and were not expected to yield impacts on the dune. The observed impacts are supposed to have been generated by the particular out-of-phase

Figure 5. Evolution of the bar and cuspate shoreline position during the storm event in November 2011. Successive images illustrate the coupling in phase and out-of-phase between bar shoals and seaward bulges in the shoreline.

Figure 6. Impact of the 24/10/2012 storm event on the dune system of the Lido de Sète beach. A) rectified Argus image showing the nearshore bar pattern and the inundation of the aerial beach; B) video snapshot image from camera 6, and C) field photo of the impact on the dune toe and wooden stacks.
coupling between the bar and shoreline. It is hypothesized here that in this area, wave energy was less dissipated by the inner bar, and thus inducing a higher breaking at the beach that could have produced higher set-up and run-up, able to reach the dune toe.

CONCLUDING REMARKS

Video monitoring of the Lido de Sète beach permitted to document morphological evolution during two energetic periods in autumn 2011 and spring 2012. Moderate conditions allowed the observation of bar dynamics and the evolution of the cuspy shoreline.

Our dataset indicates that these moderate wave conditions induce an important and rapid migration of the inner bar that was not described before at Sète beach. The coupling between crescentic nearshore bars and shoreline rhythms is time-dependent during storm events, and a given period with significant energy on the falling storm is needed to recover a phased position of both morphologies.

This dynamics plays apparently a role on wave dissipation, and maximum run-up reached on the beach, and on the occurrence and location of erosion spot on the dune system.

These preliminary observations will be pursued to better understand the coupling between bars and shoreline and the consequence on beach and dune erosion during storms.

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LITERATURE CITED


