High-frequency video observation of a geologically-constrained barred-beach: La Grande Plage de Biarritz (France)

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ABSTRACT


The Basque Coast (SW France) is a major international and national tourism destination that has been facing serious erosion issues over the last decades. Among all the embayed beaches of this section of coastline, La Grande Plage de Biarritz is one of the most attractive and busy location. In this paper 2.5 years of daily time exposure images are examined to study cross-shore sandbar behavior and location preferences of rips. Results show that the surfzone sandbar behavior strikingly contrasts with that commonly observed along open beaches as a result of geological constraints (headlands, offshore emerged rocks and rocky substratum). Non-surprisingly the sandbar rapidly migrates offshore during storms and slowly migrates onshore during subsequent lower wave energy conditions. But conversely with the general observation along open beaches, here sandbar three-dimensionality increases with increasing wave energy. Three distinct types of rip channels are found along the beach: (1) a topographic rip channel against the southern headland, (2) one or two controlled rip channel(s) that are presumably forced by both alongshore gradients in wave height caused by the offshore emerged rock and the rocky substratum in the intertidal domain and (3) a transient rip channel that forms at the southern end of the beach and subsequently migrates northward to merge with a controlled rip. Our high-frequency video-observation therefore goes with more general existing studies suggesting that geological inheritance is a major factor influencing beach type and surfzone sandbar dynamics.

ADDITIONAL INDEX WORDS: rip channels, Surfzone sandbars, topographic rip

INTRODUCTION

The Basque Coast (SW France) is of major interest from the perspective of both socio-economic activity and nearshore science as it is a major international and national tourism destination that has been facing serious erosion issues over the last decades. In this framework, restoring and maintaining beach amenity is a primary objective along this section of the French coastline. This is particularly true for La Grande Plage de Biarritz that is characterized by obvious geological constraints (GPB, Figure 1). Surprisingly, the dynamics of the Basque Coast beaches has only been scarcely documented in the literature (Abadie et al., 2008). The SW coast of France is characterized by high-energy open beaches that have received significant attention over recent years (e.g. Castelle et al., 2006; 2007; Sénéchal et al., 2009; Bruneau et al., 2009; Almar et al., 2010). From these past studies, beaches are known to be double-barred. The inner bar and the outer bar typically exhibit highly-dynamic bar and rip morphology and reasonably persistent crescentic patterns, respectively. In contrast with the open beaches, the Basque Coast sandy beaches are characterized by ubiquitous headlands and rocky substratum and much more complex surfzone sandbar behaviors that are poorly understood. Therefore, the Basque Beaches are presumably strongly geologically constrained and beach response is expected to contrast with that typically observed along the more northern open sandy beaches.
Only recently, geological factors have been identified as important constraints on actual beach state. For instance, encompassing a larger number of beaches along the Irish coast, Jackson et al. (2005) showed that inherited geological factors appear to be more important determinants of beach morphology than contemporary dynamics in most of the studied beaches. Similarly, Short (2006) assessed the role of waves, sediment and tide range in contributing to beach type encompassing all the Australian beach systems. In some cases Short (2006) indicated that geological inheritance was a major factor in defining beach type and rip channels. The existing studies only addressed beach state at a given times and, as far as we are concerned, did not address the high-frequency response of both the beach and nearshore sandbars to the persistent changes in tide and wave conditions. Only in embayed beaches with reasonably large distance between headlands surfzone sandbars have been intensively studied (e.g., Holman et al., 2006). The impact of headlands on rip location was limited. The present study aims at investigating strongly geologically-constrained surfzone sandbar evolution along a high-energy single bar embayed beach.

In this paper we present 2.5 years of daily time exposure images from GPB Beach to examine cross-shore sandbar behavior and location preferences of rips at this beach to assess geological constraints on surfzone sandbar dynamics and preferred rip channel locations.

STUDY SITE AND METHODOLOGY

La Grange Plage de Biarritz, France

GPB is a meso-tidal environment with semi-diurnal tidal regime and a mean spring range of 3.85 m. The beach is a 1.2 km long embayed sandy beach that is delimited by two major headlands and is characterized by two small (~50 m²) offshore emerged rock located between about 200 m and 400 m from the 0-m shoreline (Figure 1). The intertidal beach is relatively flat (1.5-2 %) and is composed of medium quartz sand. The beach is mostly single barred as a rather flat and inactive outer bar is observed about 500 m from 0-m level shoreline (Figure 1). GPB Beach faces NW and is predominantly exposed to Atlantic swells coming from the WNW direction, and also scarcely receives more variable locally-generated wind waves (Abadie et al., 2005). It has an annual average significant wave height and peak period of $H_s = 1.57$ m (up to 10 m during severe storms) and $T_p = 10$ s, respectively, which result in drastic changes in beach morphology.

Video monitoring

In September 2007, a CASGAE video system (Rihouey et al., 2009) was installed at GPB at about 30 m above the mean sea level. The station includes four N-NW facing cameras (only three are used in this study). The data of interest here are 10-min time exposure images collected each daylight hour spanning about 700 m of GPB. Time exposure images were rectified into real world Cartesian coordinates through mathematical projection onto a horizontal plane located at mean sea level and further transformed into local beach alongshore $x$ and cross-shore $y$ coordinates.

In this study 2.5 years of daily time exposure images from October 3, 2007 to April 27, 2010 were examined to study the sandbar dynamics. To both minimize breakerline variability and gather continuous dataset of images we used low neap-tide level images only. Provided wave breaking was sufficiently pronounced to create an alongshore continuous breakerline, from each plan view image the bar crest location was manually detected from the breaking-induced intensity peak alongshore. In this way a matrix $Y(x,t)$ was constructed with $Y$ the bar crest position sampled at time $t$ and alongshore location $x$. Time series of the alongshore-averaged sandbar position $D(t)$ was computed as the alongshore average of each $D(y)$. In addition, the standard deviation $std$ of $Y$ was computed to give a measure of how well the surfzone sandbar was three-dimensional. Figure 2 shows an example rectified time-exposure image of GPB with manual detection of the location of both the rip channels and the bar crest geometry.
Offshore significant wave height $H_\text{s}$, peak period $T_\text{p}$, and direction were obtained from the global model WaveWatch3 (WW3, Tolman, 1991), at the coordinate 2°30'W 44°N. Time series of tidal elevation was estimated from tidal harmonic propagation. During this period, the averaged significant wave height and peak period were 1.95 m and 9.8 s with maximum values of 12 m and 18 s, respectively.

**RESULTS**

Observation of surfzone sandbar evolution at GPB shows highly-complex and dynamic behavior throughout. From the 2.5-year evolution, 3 recurring surfzone sandbar morphologies can be extracted (Figure 3). During low- to moderate-energy wave conditions, surfzone sandbar varied from a reasonably alongshore-uniform geometry with absence of any significant rip channel (Figure 3a) to a much more three-dimensional, rippy, configuration (Figure 3b). Shoreward of the emerged rock in Figure 1, two rip channels were commonly observed at $x \approx -20$ m and $x \approx 80$ m for both reasonably low-energy conditions (Figure 3b) and high-energy wave conditions (Figure 3c). This alongshore location $-20 \leq x \leq 80$ m also corresponds to the presence of a rocky substratum in the intertidal domain that is typically covered (uncovered) by sand during accretive (erosive) periods. Figures 3b shows a typical high-energy bar and rip morphology with two narrow and deep rip channels shoreward of the immerged rock in Figure 1 at $x \approx -20$ m and $x \approx 80$ m. In contrast to Figure 3b, no additional rip at $x \approx -250$ m is observed. The behavior of this additional, transient, rip channel will be discussed in more details later in this paper.

Figure 4 shows the 2.5-year time series of the GPB Beach dataset. Incoming waves were strongly seasonally modulated with low- to moderate-energy waves during spring and summer ($H_\text{s} < 2$ m) with only occasional wave events with $H_\text{s} > 2.5$ m (Figure 4b). During autumn and winter, waves were almost systematically of high-energy type with common storms with $H_\text{s} > 3$ m and occasional severe storms with $H_\text{s} > 5$ m (about 4 to 8 per year). These persistent changes in wave conditions together with persistent changes in tidal ranges (Figure 4b) drove drastic changes in surfzone sandbar morphology and rip channel location.

Figure 4c shows the time evolution of rip channel alongshore locations. Two preferred locations of rip channels at $x \approx -20$ m and $x \approx 80$ m that were touched upon above are confirmed in Figure 4c as these two rip channels are almost persistently seen during autumn and winter. During spring and summer these two rips are occasionally observed and can even remain almost throughout (see for instance in 2009 in Figure 4c). Two other rip channels are also preferably observed at the locations $x \approx 150$ m and $x \approx 250$ m during autumn and winter seasons (Figure 4c, see also in Figure 3c). The two rip channels tend to merge into a single rip channel during spring and summer. An additional rip channel at
The seasons at alongshore locations. Additional rip channels are also observed throughout the year. Two high-energy rip channels tend to merge during low-energy conditions. It is found that variations in sandbar migration (O(10 m/day)) are observed to be about one order of magnitude larger than the typical onshore migration rate (O(1 m/day)). It is also found that, overall, variations in the alongshore migration rate can be reasonably small (~2 m/day during summer 2009, Figure 4c) to substantially high (~10 m/day during spring 2008, Figure 4c). Figure 4d shows the alongshore-averaged sandbar cross-shore position D with its superimposed standard deviation. Consistent with existing observations of cross-shore sandbar behavior along both open and embayed wave-dominated sandy beaches (e.g., Ruessink et al., 2007), high-energy wave conditions drive a rapid offshore migration of the sandbar, while slow onshore migration is observed for decreasing wave energy. The typical offshore sandbar migration (O(10 m/day)) is observed to be about one order of magnitude larger than the typical onshore migration rate (O(1 m/day)). It is also found that, overall, variations in the alongshore-averaged sandbar cross-shore position D do not exceed 50 m (150 m ≤ D ≤ 200 m in Figure 4d). More surprisingly, standard deviation of the cross-shore sandbar position increases with increasing wave energy (Figure 4d) which goes against typical observations along open beaches. This behavior confirms the observation of increasing number of observed rip channels during autumn and winter (Figure 4c) as well as the typical time exposure images of GPB given in Figure 3.

This seasonal modulation of rip channel characteristics is emphasized in Figure 5 that shows rip current occurrences as a function of longshore location with discrimination of the autumn-winter and spring-summer periods. During autumn and winter two preferred occurrences are clearly observed at x ~ -20 m and x ~ 80 m. In contrast, the highest number of rip channels observed during spring and summer occurs in between, that is, at x ~ 30 m as the two high-energy rip channels tend to merge during low-energy conditions. Additional rip channels are also observed throughout the seasons at alongshore locations x ≥ 100 m.

DISCUSSION AND CONCLUSIONS

In this paper we examined 2.5 years of daily time exposure images at GPB Beach to study cross-shore sandbar behavior and location preferences of rips. In agreement with the general observation along wave-dominated open sandy beaches, the sandbar rapidly migrates offshore during storm and slowly migrates onshore during subsequent lower wave energy conditions. But conversely with the general observation along open beaches, here sandbar three-dimensionality increases with increasing wave energy as a result of geological constraints. The high-frequency video-observation of GPB Beach therefore goes with more general studies (Short, 1996) suggesting that geological inheritance can be a major factor influencing beach type and surfzone sandbar dynamics.

Three distinct types of rip channels are found along GPB Beach. (1) A topographic rip channel that was observed against the southern headland. This rip channel was hardly detectable throughout the study because of the limited camera view field. However, field observations suggest that this rip channel is actually present most of the time at GPB. (2) One or two controlled rip channel(s) were almost persistently observed at -20 m ≤ x ≤ 80 m. The(se) feature(s) are presumably forced by inshore horizontal circulation driven by alongshore gradients in wave height due to wave energy shadowing from the offshore emerged rock. This morphologically-coupled origin may therefore be similar to that observed in double sandbar system (Castelle et al., 2010) when the outer crescentic bar is well developed. The rocky substratum located at this alongshore location in the intertidal domain may also have an important role that could not assessed in this paper. (3) A transient rip channel that forms at the southern end of the beach and subsequently migrates northward to merge with a controlled rips. This systematic northward migration was readily non-affected by offshore wave angle to the shore (not presented in this paper). We suspect that this type of rip channel is common along embayed beach despite, as far as we are concerned, it has not been touched upon in the literature so far.

Of note, the preferred locations for the three types of rip channels discussed in this paper show high alongshore variability in rip spacing which goes against what would be expected from models of longshore standing wave motions trapped within the pocket beach (e.g., Bowen and Inman, 1971). In addition, no free rip channel was observed during this study. As a result all the rip channels are suspected to have a geological, forced, origin.

At this stage it is difficult to discriminate the influence of the offshore rock and rocky substratum to the dynamics of the two forced rip channels in the -20 m ≤ x ≤ 80 m region, nor the mechanisms responsible for the formation and subsequent evolution of the transient rip channel. A larger dataset together with the combination of numerical modeling and accurate field assessment of the rocky substratum topography may help in better understanding GPB Beach dynamics and highly-geologically constrained beaches in general.

LITERATURE CITED

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