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Storms impacts on a sandy beach including seasonal recovery: alongshore variability and management influences

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Abstract:
Despite a global context of shoreline retreat, coastal areas and in particular sandy coasts are increasingly attractive. To handle the problem of coastline retreat different management strategies are deployed and among them soft methods as windbreakers or hard ones as seawalls. But all those methods are known to interfere in the natural evolution of the beach/dune systems at different timescales. To underline potential influences of management strategies on erosion and recovery periods, high frequency DGPS surveys coupled with video images are recorded at a workshop-site exhibiting various management strategies, Biscarrosse beach (SW of France) from November 2015 until September 2016. Results for the winter 2016 highlight a global erosion of the beach associated to a dune foot retreat and an alongshore variability in the beach response to events. The same patterns can be observed during the seasonal recovery period (April to August), in particular a lag in the berm reconstruction in front of the seawall. The LVI (Longshore Variation Index) reflects possible sediment processes taking place between the different sections of the beach: while recovery seems to be dominated by cross-shore exchanges in the unmanaged section, longshore sediment processes seem to be the origin of the recovery in the managed section. This variability could be linked to a permanent rip current visible (98% of observation) in front of the seawall that could cause an offshore sediment export explaining both the lag in term of recovery timescale and the different sediment processes involved during the recovery period. During the erosion season, sediment exchanges between the beach and the dune are limited due to the presence of seawalls and beach erosion and dune retreat in the two ends on the wall accelerated.

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1. Introduction

Over the last decades, shore areas became more attractive, not only for tourism but also for the better way of life represented by an oceanic climate and water recreations. This increase in human activities implies a consequent economic benefit for coastal cities and the development of infrastructures directly build on the shore. In the contexts of global warming and shoreline retreat those infrastructures are threatened, as city's economic supply. According to PILKEY and HUME (2001), 80% of the world shoreline was in retreat ten year ago, associated with a lowering of beaches levels. Moreover, sandy coasts evolve at extreme event scales and even if beach recovery can take place over short period (few days), it is generally much longer (several weeks to months) while dune reconstruction based on wind sediment transport could even reach the decade. In order to restrict storm impacts on human activities and preserve natural areas as dunes, management strategies are deployed on seashores. After a study of the major issues of the sites, two types of strategies are preferentially developed depending on the desired effect (MICALLEF & WILLIAMS, 2002): soft and/or hard methods, sometimes as a step before thinking to a possible strategic retreat. The soft ones e.g. wind or wave breakers, pathway delimitations, revegetation of the dune or re-sanding are favored with the purpose to help the dune/beach system to resist to energetic conditions. Hard methods (e.g. seawalls and dykes) are used to anchor and fix the shoreline for a long term period. But, either hard or soft, each method has an impact on the system and modifies it, at its one timescale (ELLS & MURRAY, 2012). The general public generally considers that hard structures reduce the impact of winter storms seasons by inhibiting dune retreat, decreasing the risk of flood, *etc.,* and thus is benefiting to the beach system. However PILKEY and WRIGHT (1988) underlined that seawalls can degrade beaches in three ways: (1) passive erosion due to tendencies which existed before the wall was in place; (2) active erosion du to interaction of the wall with local coastal processes and (3) lost of accommodating place. Moreover, it can be supposed that fixing the dune foot or managing just a little part of a strait sandy shore could influence the "unprotected" part of the shore, especially in open and linear coast systems.

The Aquitanian coast is about 250 km of strait sandy beaches and dunes punctuated by different management strategies all along the shore. The National Network for shoreline observations Dynalit regroups 30 study sites in France with the purpose to understand storm processes in a context of global warming, and provide knowledge in term of coastal managing. During the exceptional winter 2013/2014, cluster of storms caused considerable damages on the Atlantic beaches and the associated dunes, impacting not only ecosystems but also the economy of the Aquitanian region (CASTELLE *et al.,* 2015). In this study the workshop site of Biscarrosse beach (SW of France) was chosen to understand the importance of beach management not only on the system's response to storms but also on beach recovery exploiting high frequency DGPS surveys and video dataset. According to ALMAR et al. (2009) and SENECHAL *et al.* (2015) the erosive trend decrease after February and Aquitanian beaches mostly recover the first month of summer (June and July). Thus, we only considered the period from January to September 2016 covering the maximum of erosion and the recovery period.

2. Methods

2.1 Field area

Biscarrosse beach, located on the Aquitanian coast in the South-West of France (Fig. 1), was chosen as a workshop-site by the National Network for shoreline observations Dynalit (SNO Dynalit). This double barred beach has previously been described as morphologically typical of the Aquitanian beaches (ALMAR *et al.*, 2009). Biscarrosse is a meso to macrotidal open sandy beach oriented about 280.5° from the North and fully opened to the North Atlantic swell. A strong seasonality in the wave climate is observed with significant wave heights that can exceed 10m during winter storms (from November to March). On average, the mean annual Hs is about 1.4m associated to Tp equals to 6.5s (BUTEL *et al.*, 2002), and the mean spring tide in this area is 3.7m against 1.8m during neap tide.

Changes in Biscarrosse beach morphology are both driven by a strong longshore drift orientated from the North to the South and poorly understood cross-shore exchanges. As presented by ANGNUURENG *et al.* (2017) Biscarrosse morphological response is relatively rapid at the seasonal timescale but also at the event scale. According to the WRIGHT and SHORT (1984) classification, this beach composed by medium sand, with a 350 µm median grain size (BA & SENECHAL, 2013), is defined as an intermediate beach mostly dominated by TBR and LTT states (PERON & SENECHAL, 2011). In 2009, ALMAR *et al* confirmed that the inner sandbar generally present a TBR type associated to wavelengths around 400m, but that all intermediate states could be reached. The outer bar currently presents a crescentic shape with a typical wavelength about 700m, but its geometry can be influenced by the wave incidence and exhibits asymmetrical trends (LAFON *et al.,* 2005; CASTELLE *et al.,* 2007).

Even if Biscarrosse beach is considered as a more “natural” environment compared to the other beaches, different management strategies were deployed on the beach/dune system. Indeed, Biscarrosse is a touristic hot point, and to be more accessible and attractive the back dune were covered by grass. Moreover, the southern part of the shoreline was fixed by a seawall while the northern part of the dune is only protected by windbreakers (Fig. 1).

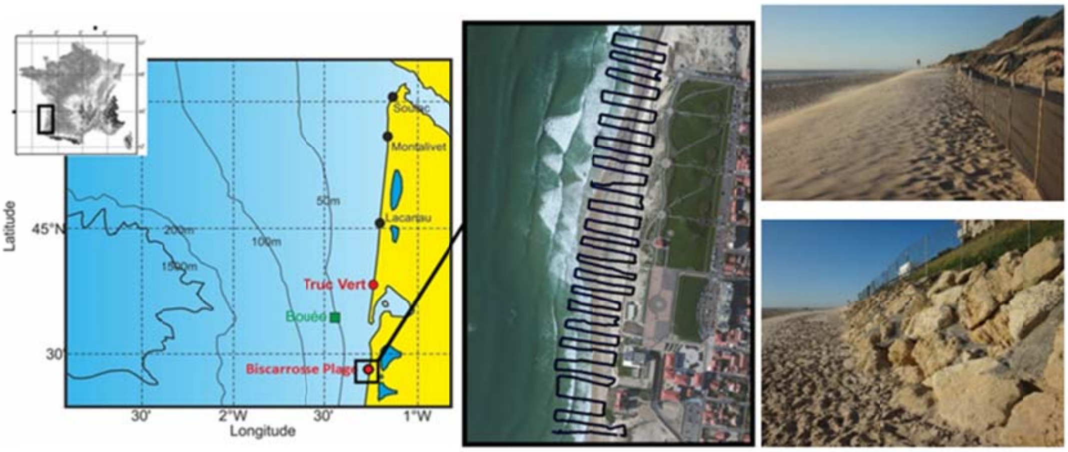

Figure 1: Biscarrosse beach location, surveyed transects and management strategies.

2.2 <u>DGPS surveys and barline extraction</u>

From November 2015 to November 2016, more than fifty DGPS surveys were recorded and analysed with the purpose to follow the dune/beach system evolutions at short timescales as storm events and access the impact of each storm even within a cluster. At least twice a week (Fig. 2, red crosses), 30 to 50 transects (depending on the presence of specific structures on the beach or not) are realised covering 700m of longshore beach from the dune to the low tide limit (Fig. 1).

To complete this dataset the inner barline position was monitored through a video system composed by four color cameras. The system CamEra deployed at Biscarrosse was primarily developed by the NIWA (New-Zealand) and then modified by V. Marieu (EPOC, France). Fixed on a 15m high pole it overlooks 2 km longshore and 1km of cross-shore coast and provides four images per hour (ALMAR *et al.*, 2009). The submerged surfzone sandbar is manually digitized using the method of predominant wave breaking detection on 113 rectified averaged images (LIPPMAN & HOLMAN, 1989; VAN ENCKEVORT & RUESSINK, 2001). Extractions are made following a fixed mean wave breaking coefficient (γ) determined by the equation (1) (DESMAZES, 2005) were Hs is the significant wave height and η the water level.

$$\gamma = Hs/\eta = 0.8 \quad (1)$$

Because of technical failures and poor images quality, the positions of the barline and RIP channels have not been registered during the first cluster of storm (2nd to 13th of January 2016) and the summer period (from June to September).

2.3 <u>Hydrodynamic data</u>

The tide dataset was extracted from the tide model developed by the SHOM institute. The offshore waves were extracted from the WaveWatch3 model provided by Previmer in about 50 m deep offshore of the Cap Ferret sandy spit (Fig. 1, green square). In 1994, DOLAN & DAVIS defined a storm event not only as a threshold of significant wave height but also in term of storm duration. At Biscarrosse beach, and more generally on the Gironde coast, high hydrodynamic conditions are qualified as storm events if Hs exceed 4m ($H_{95\%}$) during a complete tide cycle (ANGNUURENG *et al.,* 2017). Moreover, a cluster is characterized as a succession of at least two or three storms separated by each other by calm conditions (under the storm threshold) inferior to 5 days.

3. Results

3.1 Hydrodynamic conditions

The figure 2 presents the hydrodynamic conditions experienced during the studied period. The maximum significant wave height (Hs) was 7.3 m and the mean Hs was about 1.9m. The mean Tp (peak period) was about 11s with a maximum of 18s reached in March. Positive values of the wave angle relative to the shore (incidence) symbolise waves coming from the North while negative values are waves from the South. Waves were generally reaching the coast with a North or normal incidence.

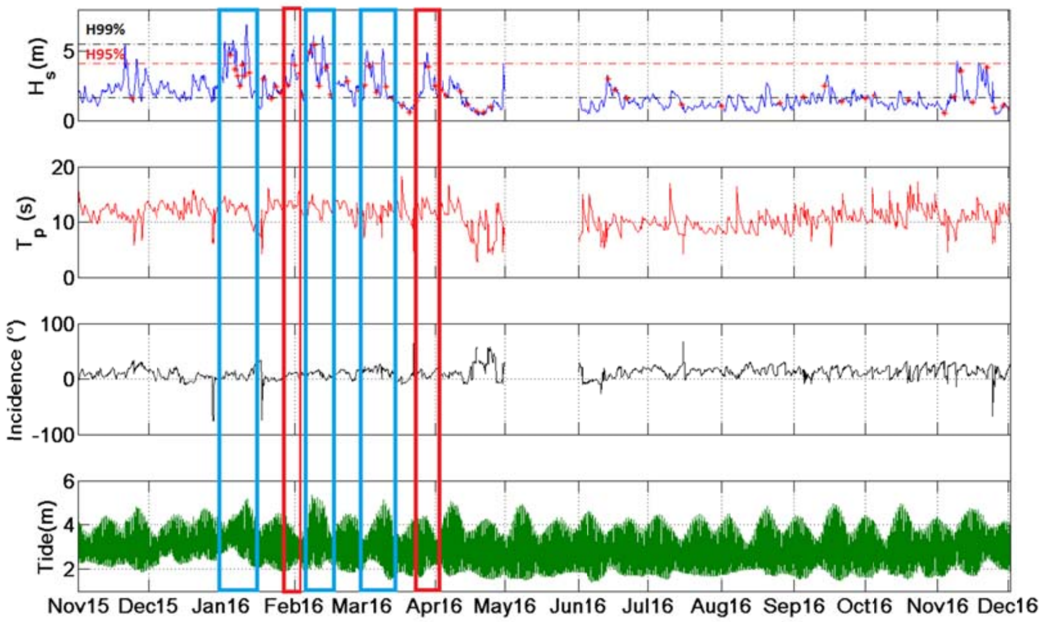

Figure 2. Hydrodynamic conditions: significant wave height (Hs), peak period (Tp), wave incidence and tide. Red boxes highlight the individual storm events and the blue boxes the storm clusters.

According to the previous definition, the winter 2015/2016 (from November to March) is characterized by 10 storms (Fig. 2), but as the DGPS surveys start in January the first storm (middle of November) is not taken into account in this study. The first storm considered began the 2nd of January 2106 with a maximum Hs of 6.1 m and a duration over 20 hrs. During the second one that hit Biscarrosse, from the 4th to the 7th January, waves reached 6.5m associated to a mean Hs of 5 m. The third one occurred from the 11th to the 12th January and the maximum Hs was 7.3 m. But, it defers from the two previous ones by its storm apex correlated to a spring tide period. In view of the tiny interval between two consecutive storms (< 5 days), those three events could be considering as a same cluster. Thus the winter 2016 is composed by three clusters respectively made up by 3 and 2 storms, and two single events (Fig. 2, blue and red boxes).

3.2 Morphological evolutions

3.2.1 General overview: erosion/recovery

On the Aquitanian coast, beaches are mostly wave dominated and the climate is clearly marked by a calm summer season and an energetic winter one (Fig. 2). First results of DGPS surveys at Biscarrosse beach show a classic cycle of erosional trends during winter versus recovery period during summer (Fig. 3). Indeed during the winter 2016 characterized by surveys from the 5th of January to the 4th of April a lowering of the upper beach zone about 1 m is observable, while the intertidal zone general balance looks stable. Moreover, in the figure 3 the supratidal beach is eroded (-2 m) corresponding to a major dune foot retreat. During the recovery season, we observe an accretion of the supratidal and the upper beach between, on average, 1 and 2 m typical of the signature of the berm reconstruction. Besides 3D structures representative of beach cusps are visible on the berm, as well as an erosion of the intertidal beach. This suggests a sediment transport from the intertidal to the supratidal zone in order to feed the berm. The last panel of the figure 3 illustrates the morphological evolution of the beach from January until September 2016 covering the erosive and the entire recovery periods. During this period the upper beach gained big volumes of sediment but the supratidal beach (between -40 and -60 m in cross-shore direction) lost sand because of dune retreat.

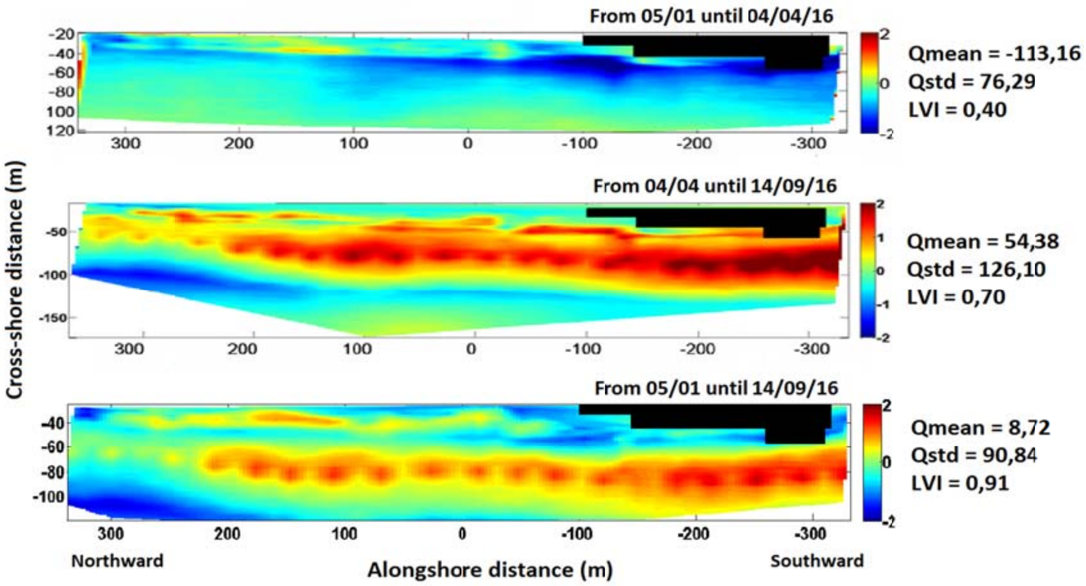

Figure 3. Morphological evolution of Biscarrosse beach. Fist panel: winter season. Second panel: summer season. Third panel: All seasons.

3.2.2 Intra-season response: overall

During the winter 2016 different storms occurred and the morphological evolution of Biscarrosse beach differs from one storm to the other one. The figure 4 presents changes in the beach morphology after every potential erosive event during this winter. At the end of some events, a sediment transport from the dune/supratidal beach to the intertidal seems to take place (E1, E3 and E4, Fig. 4). In contrast, the direction in sediment exchanges looks reversed when it results from event E2 and E5 (Fig. 4). Thus some events could be considered as erosive whereas others as recovery periods despite energetic conditions (Hs > 4 m) in each case. So, even if the residual result of the winter 2015/2016 is a general erosion of the beach and the dune (Fig. 3, top panel), this erosion is not an accumulation of sediment loss in response at each phenomenon as recovery periods also occurred during this winter.

Biscarrosse beach is a tourist hotspot and at the end of winter, a dune foot re-sending is structured and visible in the topographic maps (Fig. 5, 1st panel). At the end of April, the lower part of the northern beach is eroded (<-1 m) while the higher part is accreted (+1 m, Fig. 5). Indeed the sediment eroded seems to supply the berm reconstruction in the supratidal zone. At the beginning of June, the berm reconstructs all along the beach except in front of seawalls (south beach) and, in the north, it is associated with 3D patterns corresponding to beach cusps. In the southern end of the beach the berm is fully rebuilt only at the end of July and at this time the sediment supply seems not just come from the intertidal beach but probably from a longshore transport too. During August, the berm is maintained and even amplified in the South, and migrates onshore. At the end of summer (September) beach cusps are well developed on the berm with a wavelength measured around 20 m. Considering the beach recovery as the berm reconstruction, there is a lag in the recovery of the southern part of the beach compared to the northern one.

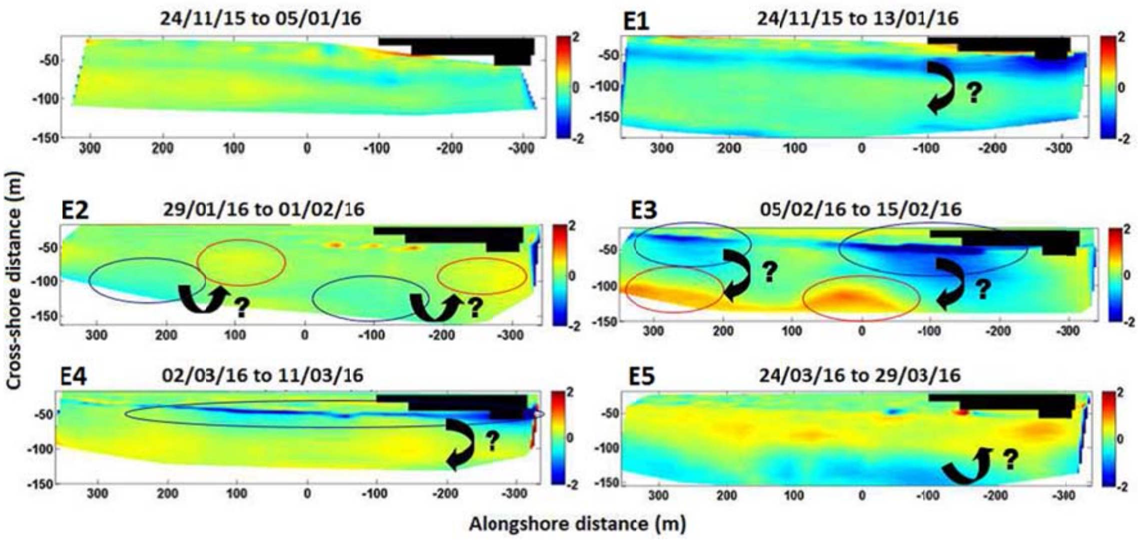

Figure 4. Topographic surveys of winter 2015-2016. E=Event.

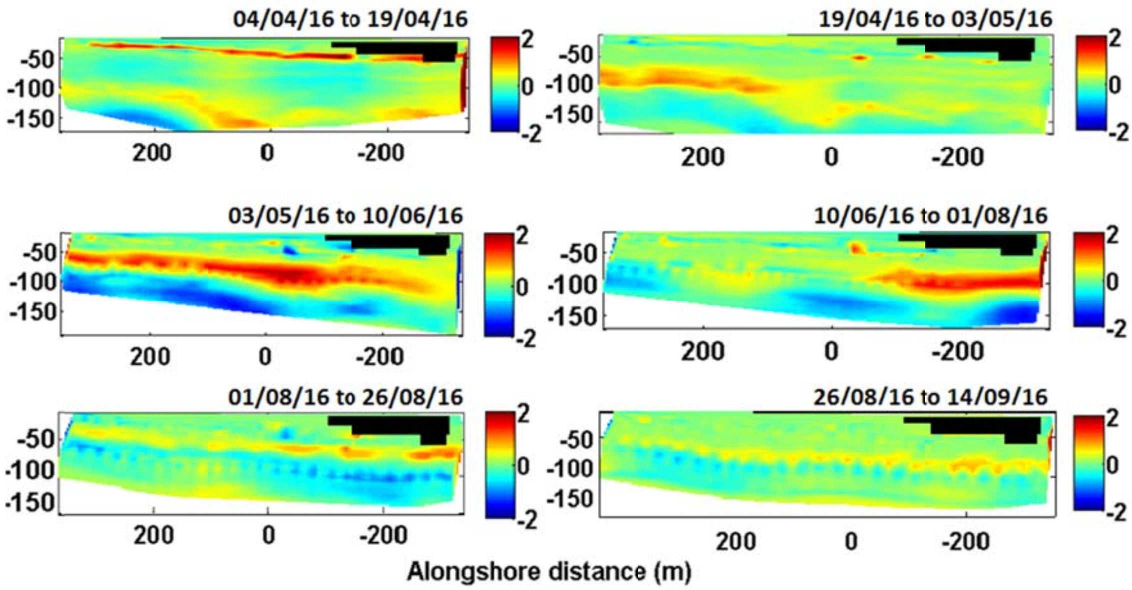

Figure 5. Topographic surveys of Biscarrosse beach for the summer 2016.

3.2.3 Alongshore variability

In 2017, Burvingt *et al*. proposed a Longshore Variation Index (LVI) to qualify the alongshore variability in beaches response to events (Eq. 2).

$$LVI = \frac{Qstd}{|Qmean| + Qstd} \qquad (2)$$

Where *Qstd* is the standard deviation calculated to quantify the amount of variation of all the net volumetric change values (*dQcross* determined for each cross-shore transect), and |*Qmean*| is the absolute value of the mean of *dQcross* values. A LVI = 1 means that the longshore sediment transport is dominant while a LVI = 0 implies a cross-shore transport dominance.

The longshore variability during the winter period (Fig. 3) does not look significant with a low LVI (0.4) implying a dominance of the cross-shore sediment exchanges. However, the high LVI calculated for the recovery period and the entire seasons (0.7 and 0.91 respectively) suggest an alongshore sediment transport dominance.

In winter 2016, for the first hydrodynamic event (E1, Fig. 4, as an example) an alongshore variability in the beach response to events is noticeable. The southern end of the dune (negative values along the longshore transect) is fixed by seawalls (black boxes, Fig. 4) and the erosion resulting from the E1 is more significant in this part of the beach. In order to quantify those observations, four transects are extracted from the DGPS surveys (A, B, C, D, Fig. 6). In the northern end of the beach (A, Fig. 6) a lowering about 1 m of the supratidal beach is visible after the passage of the fist event (13/01/16). As explained before, the second event provoked an erosion of the intertidal beach (-50cm maximum) and a recovery of the upper beach (+50cm maximum). After the third one (15/02/16), the dune foot retreated 10 m onshore and the beach reached its profile of maximum erosion for this winter. The 11th of March, an accretion of the dune foot is remarkable, but it is due to a previous dune resending (24/02/16) and is not natural. However, the intertidal beach recovered providing sediment to accrete the supratidal zone under the effect of the waves of the last storm (29/03/16).

The beach dynamic to events in front of seawalls (C, Fig. 6) is rather different than in the north. The erosion provoked by the first storms equals more than 2m against the wall, and between 1m and 20cm all along the beach profile. After the 1st of February an accretion of the beach around 20cm in response to the second energetic event is visible. But, the main difference is the absence of erosion or accretion after the third event (E3). The beach profile is stable until the passage of the E4, the beach part against the wall eroded about 1 m while the intertidal zone accreted. As for the north, the supratidal beach profile rose about 50 cm after the last storm of winter.

In the southern beach, just at the seawalls south end (D, Fig. 6), the first event caused an erosion of the beach around 1m and dune foot retreat close to 20m. The beach profile is stable in this zone even after the second event, contrarily to the other parts of the beach (A and C). After the E3, there is an accretion of the beach profile (+1 m) and an offshore movement of the dune foot. In March, the events provoked a massive erosion of the beach (- 1 m) and an increase of the dune slope.

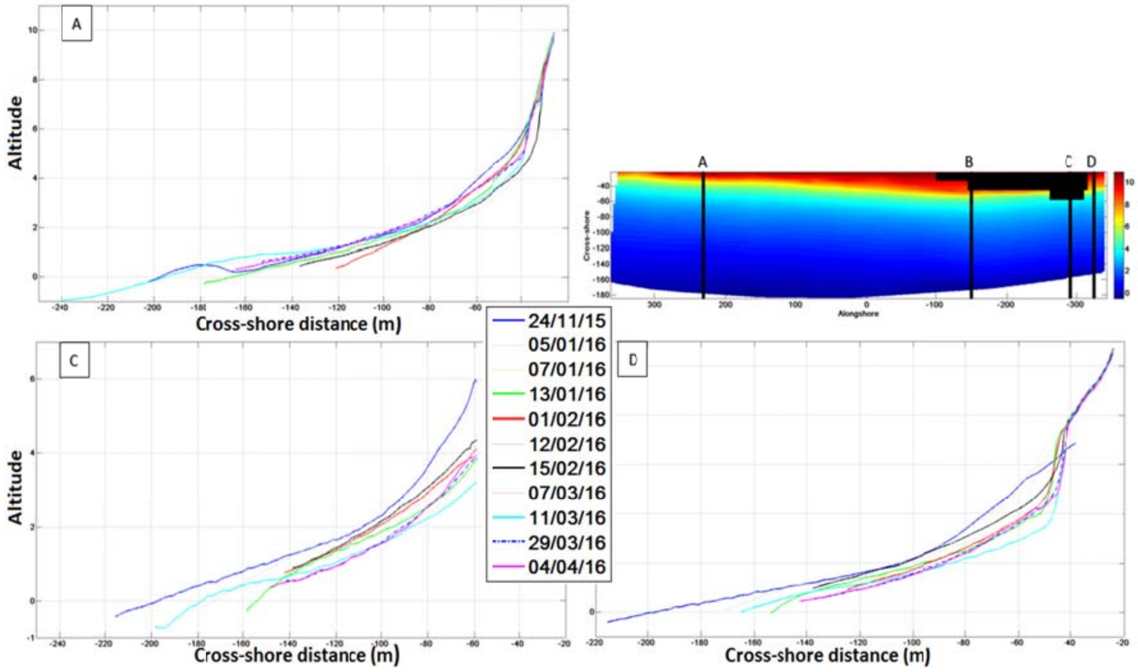

Figure 6. Cross-shore profiles extracted from DGPS surveys. A= North; C= in front of seawalls; D= South, after seawalls – Winter period.

Similarly, two cross-shore profiles were also extracted to compare the alongshore variability in the recovery of the two ends of the beach (Fig. 7). The profile A represents, as previously, the north of Biscarrosse beach. At the beginning of April, the profile A is already curved in the intertidal zone. This sediment seems to supply the gradual berm elevation, and then migration toward the dune, until rise an amplitude around 2 m the 1st of August. The end of summer is marked by an erosion of the berm that could be explained by energetic conditions (Hs > 2 m) and an erosion of cusps horns (*e.g.* MASSELINK *et al.,* 1998; DEHOUCK, 2006). In the south (profile D, Fig. 7) the intertidal zone began to recover around the 17th of May. During the month of June, the supratidal zone accretes, but unlike the north, the intertidal zone does not look to be a source of sediment for the berm reconstruction. At the end of August, the berm is fully rebuilt and migrates 10m toward the dune with an amplitude about 2m (as in the north). The profile of the 14th of September seems to show an expansion of the berm peak that could be linked to cusps formation/ migration, and a transition from bays to horns.

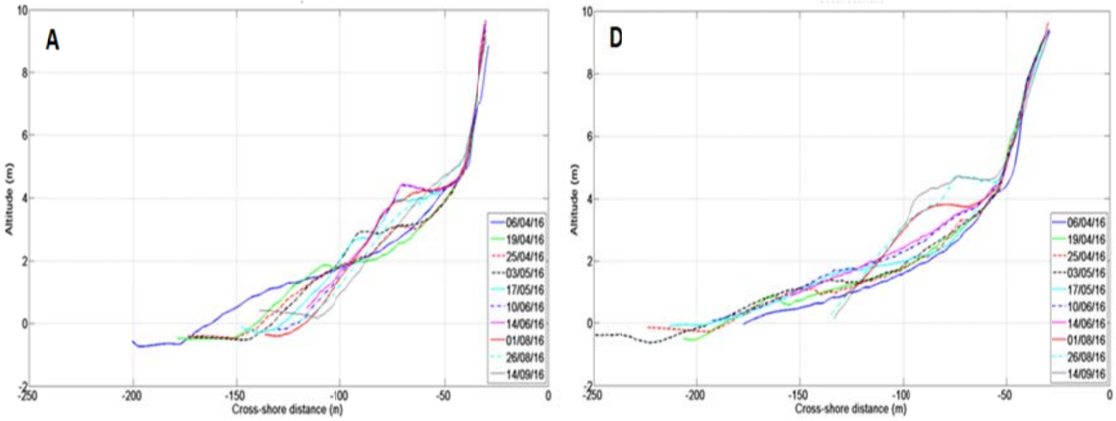

Figure 7. Cross-shore profiles extracted from surveys. A = North; D = South, after seawalls – Summer period.

4. Discussion

4.1 <u>Seasonal morphological variations</u>

Previous studies (e.g. MASSELINK *et al.,* 2006; PRICE & RUESSINK, 2008; ALMAR *et al.*, 2009) suggest that the beach morphology, the wave energy and the tide are key components to govern the intensity, duration and type of wave processes influencing the beach cross-shore profile. In winter 2016, all the clusters were associated to spring tides allowing access to the dune foot and the supratidal beach, generating important erosions. But according to our results, the beach also experienced recovery periods during energetic conditions. This could be linked to a neap tide period associated to Hs inferior to 5 m and moderate storm duration.

Following the seasonal erosion period, the decrease of the hydrodynamic conditions allow the waves to bring the sand back to the beach and initiate the recovery. Commonly the inner bar is moving to the beach in summer and supplies sediment for the berm reconstruction (ALMAR *et al.*, 2009). At Biscarrosse beach, the northern end undergoes a classical recovery and the sediment available in the intertidal beach is pushed by the waves and accumulated in the supratidal zone to form the berm. In the south, the recovery is not only driven by cross-shore sediment transfers but probably also by longshore migrations. Indeed, from May until August 2016 the LVI (equation 2) supports the idea of the dominance of the alongshore sediment transport (Table 1) that corresponds to the berm rebuilding in the southern beach. Besides this alongshore variability in the beach response to environmental conditions, it is important to notify that the berm is quite stable even during more energetic conditions (Hs > 2 m) unlike the observations of MASSELINK *et al.* (2006).

Table 1. LVI for the summer season

Period	***LVI***
04/04/16 to 19/04/16	*0.67*
19/04/16 to 03/05/16	*0.81*
03/05/16 to 10/06/16	*0.99*
10/06/16 to 01/08/16	*0.94*
01/08/16 to 26/08/16	*0.70*
26/08/16 to 14/09/16	*0.80*

4.2 Alongshore variability

Morphological changes at Biscarrosse beach in 2016 were characterized by a longshore variability whatever the season. The overall overview for January to September (Fig. 3) is represented by a LVI of 0.91 indicating a longshore sediment transport dominance that could explain the beach response and the general sediment gain in the southern part of the beach. Previously the interaction between sandbars and the beach were described as a parameter to take into account when looking at the beach response to storms (*e.g.* CASTELLE *et al.,* 2007; VAN DE LAGEWEG *et al.,* 2013). On the Aquitanian coast the inner bar mostly presents a Transverse Bar and Rip morphology (LAFON *et al.,* 2002) associated with downdrift oriented Rip channels. Extraction of Rip channels from video images gave us an idea of the position of rips and the percentage of observation of the different channels (Fig. 8). According to our observations, one channel seems to be permanent (98% of observation whatever the season) and is located in front of seawalls in the south beach. The presence of a permanent rip channel could cause an export of sediment offshore toward the subtidal sandbar. In this case, the sediment is not available for the recovery explaining why the cross-shore transport is negligible during the southern berm reconstruction. Moreover, it also could explain the accentuation of the erosion of the beach in the south during the three clusters (e.g. CASTELLE *et al,* 2015). The stability in the position of this rip channel could be linked to the presence of the seawalls (TAIT & GRIGGS, 1991). The negative interaction between structures and beach/dune system has been previously classified into three categories: a beach width reduction, passive erosion and/ or active erosion (e.g. PILKEY & WRIGHT, 1988). At Biscarrosse during winter, an active erosion of the system is visible partially resulting from the seawalls position. The presence of hard construction limits sediment exchanges between the dune and the beach inhibiting the beach recovery following successive storms. There is also an “end-of-wall effect” defined by an important erosion of the two ends of the seawall (Fig. 9), impacting the dune slope and foot retreat as shown in the paragraph 3.2.2 (PLANT & GRIGGS, 1992; BASCO, 2006). Moreover, the fact that the rocks composing the wall were directly on the supratidal beach implies that the balancing zone is reduce. Indeed lots of exchanges are visible between the upper and lower parts of the beach (however the sense) and the balancing zone is a necessary space for the beach to adapt its profile to hydrodynamic events. Limiting this zone results in a lowering of the beach. Additionally, seawalls also look to impact the recovery timescale by restricting cross-shore sediment transport (DAVIS & ANDRONACO, 1987).

Thus the alongshore variability of Biscarrosse beach response to seasonal trends is simultaneously in relation with natural and anthropogenic factors.

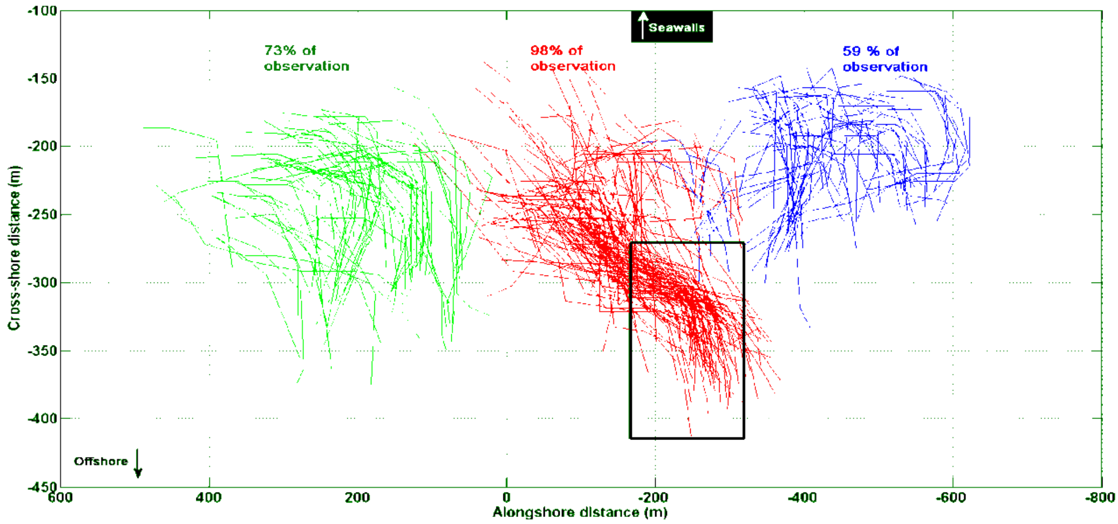

Figure 8. Rip channels positions and percentages of observations of each channel.

Figure 9. End-of-wall effect at Biscarrosse beach, January 2016.

5. Conclusions

High frequency DGPS surveys and video images of Biscarrosse beach are used in this study to identify the potential impact of management strategies on the beach/ dune system. Results confirm that morphological changes during winter (January to March) are driven by the beach morphology, the duration of storms, the wave energy and the tide. In this way recovery can take place even during winter and storm conditions. Seasonal recovery began in April in the northern part of the beach by a progressive accumulation of sediment in the upper beach supplying the berm reconstruction. But, the combination of seawalls and a permanent rip current in front of those structures, located in the south of Biscarrosse beach, generates a strong alongshore variability in the beach response to seasonal trends, erosion as recovery. Indeed, during winter the acceleration of the erosion of the beach and the dune retreat on each end of the walls are visible because of seawalls, and an offshore sediment transport supposed linked to permanent rip currents. During recovery periods, cross-shore sediment transports toward the beach are limited and berm rebuilding is mainly managed by longshore sediment transports, explaining the lag in the beach response compared to the north.

In this study, it appears that both naturals (hydrodynamic conditions, sandbar positions, *etc*…) and anthropogenic factors are driving the morphological evolution of Biscarrosse beach. But, we cannot deny the impact of seawalls on the alongshore variability of the beach response at different timescales.

6. Acknowledgements

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