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High-frequency video observation of two nearby double-barred beaches under high-energy wave forcing

R. Almar†∞, B. Castelle†∞, B.G Ruessink‡, N. Sénéchal†∞, P. Bonneton†∞, V. Marieu†∞

† CNRS
UMR 5805-EPOC
33405, Talence, France
r.almar@epoc.u-bordeaux1.fr

∞ Université de Bordeaux
UMR 5805-EPOC
Talence, France

‡ Faculty of Geosciences
Utrecht University
P.O. box 80115
3508 TC Utrecht, The Netherlands
g.ruessink@geo.uu.nl

ABSTRACT

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Five weeks of hourly time-exposure video images were used to monitor the double-barred Biscarrosse Beach and Truc Vert Beach, both located on the sandy Aquitanian Coast, SW France. This study presents the first high-frequency observations of double-sandbar dynamics in meso-macrotidal settings during storm conditions. Although the sites are only 50 km apart and experienced similar wave and tide forcing, the observed total outer-bar migrations were much larger at Truc Vert Beach (Δcross~100 m, Δlong~350 m) than at Biscarrosse Beach (Δcross~50 m, Δlong~200 m). The distance between the inner bar and the outer bar was 150 m larger at Truc Vert Beach than at Biscarrosse Beach. We observed a simultaneous straightening of the outer-bar and an increase in the alongshore non-uniformities in the inner bar during the largest wave event (offshore significant wave height > 8 m), which may point to inner-outer bar interactions during extreme wave conditions.

ADITIONAL INDEX WORDS: *nearshore morphology, storm impact, crescentic bar, Truc Vert, Biscarrosse*

INTRODUCTION

Double sandbars systems are common morphological features along sandy, wave-dominated, micro- to meso-macro-tidal coastlines (RUESSINK *et al.*, 2003; CASTELLE *et al.*, 2007). Double sandbar systems often exhibit reasonably regular outer-bar crescentic patterns and inner-bar transverse bar-rip morphology. These three-dimensional (3D) features are often part of an accretionary, slowly onshore propagating, down-state sequence developing from an alongshore-uniform bar (WRIGHT and SHORT, 1984) following a storm event. Under high waves, the 3D features are reshaped into a straight bar, together with a rapid seaward migration. Investigating two contrasting micro-meso-tidal double-barred beaches, VAN ENCKEVORT *et al.* (2004) noted that the outer-bar crescent wavelength and amplitude variations over space and time were common. They also highlighted the strong non-linear behavior of both the inner and outer bars comprising commonly observed merging and splitting of individual crescents. These intrinsically nonlinear interactions were interpreted as an attempt of the crescentic bar to self-organize into a more regular pattern. More recently, several authors suggested that sandbar dynamics in double-barred beaches is potentially even more complicated than previously envisaged. For instance, RUESSINK *et al.* (2007) suggested that the outer-bar geometry and the distance between the inner and outer bars are critical parameters governing the morphological evolution of the composite double sandbar system. Using a non-linear morphodynamic model, CASTELLE *et al.* (2008) showed that the typical alongshore variability in inner-bar rip channels is indicative of a mixture of self-organization and morphological coupling rather than self-organization alone.

High-frequency (~ daily) information of double sandbar dynamics in high-energy meso-macro-tidal settings is, up to now, non-existent (CASTELLE et al., 2007). Two double-barred beaches are studied in this paper, Biscarrosse Beach (BB) and Truc Vert Beach (TVB), located about 50 km apart. We describe the behavior of BB and TVB during storm conditions over a 5-week period. Using video imagery techniques, we show that despite similar storm responses, the outer bars had contrasting migration amplitudes. In addition, the inner-bar cross-shore migration at both sites is found to be small despite offshore significant wave height Hs ranging from 1 to 8 m. We also suggest

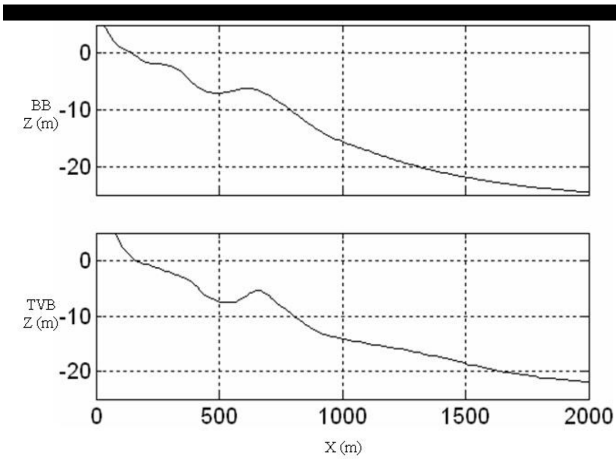

Figure 1. Surveyed alongshore-averaged depth versus cross-shore distance at (a) Biscarrosse Beach (BB) (June 2007) and (b) Truc Vert Beach (TVB) (February 2008). Both surveys were performed by SHOM ('Service Hydrographique et Oceanographique de la Marine').

the importance of inner-outer bar interactions during storm events.

FIELD DATA

Field sites

Our two study sites are the double-barred BB and TVB, both located on the Aquitanian Coast, SW France, facing the North Atlantic Ocean. BB and TVB are located respectively about 20 km to the north and 30 km to the south of the Arcachon Lagoon entrance and are far enough from this entrance to be wave-dominated environments. Coastlines at BB and TVB are aligned 8.5° and 10.8° from the N-S direction, respectively. The wave climate is similar at both sites with a mean offshore significant wave height (Hs) of 1.4 m and a corresponding mean period of 6.5 s (BUTEL *et al.*, 2002). The seasonal modulation of incoming wave energy is strong, with minimum energy during summer and recurrent storm waves during winter with maximum Hs of about 10 m. The Aquitanian Coast is exposed mainly to low-steepness, long-distance swells travelling from W-NW direction, resulting in a strong net southerly longshore drift of approximately 700,000 m^3 (MICHEL and HOWA, 1999). Although the effect of the Arcachon Lagoon on the hydrodynamics at BB is negligible, the southerly drift is locally affected by the Arcachon Lagoon and south-propagating large-scale sandbars associated with the ebb-tidal delta are often observed until BB location. The tide is semi-diurnal, with neap and spring tidal ranges of 2 and 5 m, respectively (i.e., meso-macro tidal range).

The sediment at the two sites consists of fine to medium quartz sand with mean grain sizes ranging from 200 to 400 µm (PEDREROS *et al.*, 1996). BB and TVB are mainly intermediate double-barred (see profiles in Figure 1) following the classification of WRIGHT and SHORT (1984). At both sites, the inner bar, which is observed in the inter-tidal domain, commonly exhibits a Transverse Bar and Rip (TBR) morphology with a mean rip spacing of about 400 m (LAFON *et al.*, 2002). The outer subtidal bar has been observed to be persistently crescentic at a narrow range of wavelengths of about 700 m (LAFON *et al.*, 2004).

Until recently, only low-frequency (monthly) observations were available. The absence of high-frequency (daily) observations, particularly during high-energy wave events, was an issue raised by CASTELLE *et al*. (2007) when elaborating a conceptual model of the double-barred beaches of the Aquitanian Coast.

Over the last 2 years, both BB and TVB have been recurrently ground surveyed and remotely monitored (satellite and video imaging), providing quantitative information on the high-frequency response of the two double-barred beaches.

Data

Digitised video images of both sites were obtained from automated video monitoring systems developed by the NIWA (COCO *et al.*, 2004). The BB permanent system was mounted in April 2007 on a 12 m pole. The TVB temporary system was mounted on a 8 m scaffolding during the ECORS 2008 experiment (SHOM-BRGM). Both systems were implemented on a high dune, about 12 m above Mean Sea Level (MSL).

Oblique 10-minute time-exposure video images were collected hourly during daylight hours from the March 6 to April 9, 2008. The advantage of the time-averaged exposure images is that they remove visual features related to individual waves, enhancing features that tend to be related to the underlying bathymetry (LIPPMANN AND HOLMAN, 1989; HOLLAND *et al.*, 1997). For the present work, only low tide images were selected. The images were projected to ground coordinates using standard photogrammetric methods (HOLLAND *et al.*, 1997). The images were projected to MSL which introduces a photogrammetric error caused by the differences in the real elevation of the sea level and MSL. The selected images were transformed into a 2x2 m grid, extending 1.2 km and more than 2 km in the cross-shore (X) and alongshore direction (Y), respectively. The grid origins (X=0; Y=0) at two sites were set to the video system location. Spatial resolutions in the bars area were about 1-10 m in the cross-shore and 5-20 m in the alongshore direction, with the higher values with increasing distance to the camera.

Subsequently, the bar crests locations were digitalized by manually tracking the cross-shore location of the image intensity

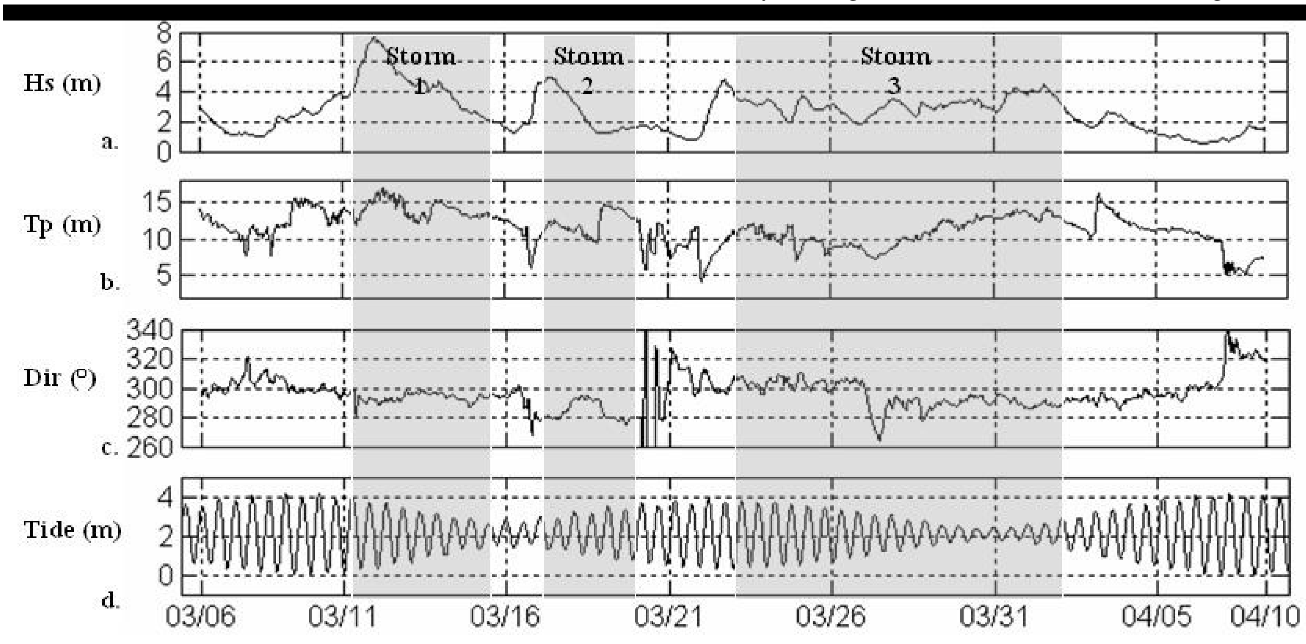

Figure 2. Offshore (a) significant wave heigth Hs, (b) peak period Tp, (c) peak direction and (d) tide level. The 3 grey zones stand for storm episodes.

peaks in the alongshore direction. Following VAN ENCKEVORT and RUESSINK (2003), a matrix X(t,Y) was constructed for each bar, consisting of bar crest locations as a function of time t and alongshore distance Y. Due to the absence of wave-breaking across the outer bar during low-energy wave conditions, the inner-bar position is usually more frequently measured than the outer bar. Actually, the intense wave forcing during the 5-week period made the outer-bar position measurement available throughout the study period, except during the final period of calm conditions (Hs < 2 m).The bar crest data was used to estimate the overall cross-shore position of the bar through the alongshore-averaged bar-crest location <X>. In addition, the corresponding standard deviation S of each X(Y) was computed, which is an indication of how well crescentic or rip patterns are developed.

Offshore significant wave height, peak period and direction were collected by a waverider buoy moored in about 20 m depth, located about 1 km seaward of the ECORS08 experiment area. Wave and tide conditions were assumed to be the same at BB. Tide was computed from tidal harmonic propagation (SHOM, Figure 2d).

RESULTS

The results discussed below were obtained from a 5-week period from March 6 to April 9, 2008, during the ECORS08 campaign. This period comprised a 3-storm sequence, including a 10-year return storm, and ended with 9 days of lower-energy waves (Figure 2).

Prior to the first storm, the outer bars at both sites were characterized by well-developed crescentic patterns with the horns almost welded to inner bars (Figures 3a, b). The outer bar cross-shore standard deviation was larger at TVB (~100 m) than at BB (~50 m). Inner bars were rather alongshore-uniform at both sites. A very energetic storm (Hs > 8 m, T >16 s) storm event hit the coast from March 10 to 12. During this 10-year return storm, an outer-bar up-state transition, from crescentic to alongshore-uniform, was observed, which is highlighted by vanishing S values (Figs. 4b, f). The outer bars rapidly migrated seaward: the TVB outer-bar migration (~100 m) was larger than that of BB (~50 m, Figs. 4a, e). Only a small seaward migration (< 20 m, Figures 4c, g) was observed for the inner-bar whereas the alongshore non-uniformities increased (increasing S in Figs. 4d, h)

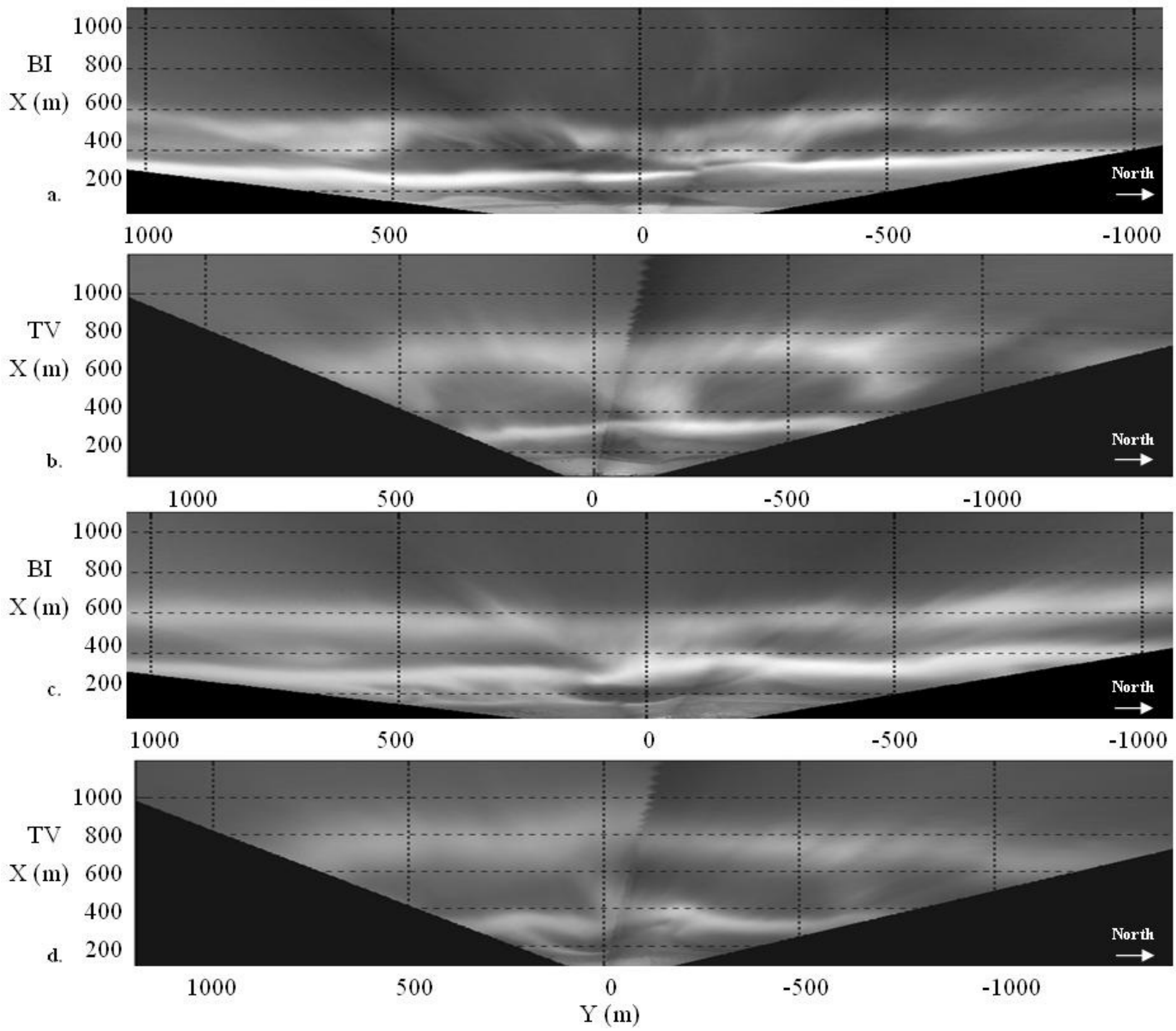

Figure 3. Planview images on the 8th of March 2008 at (a) BB and (b) TVB and on the 22nd of March at (c) BB and (d) TVB.

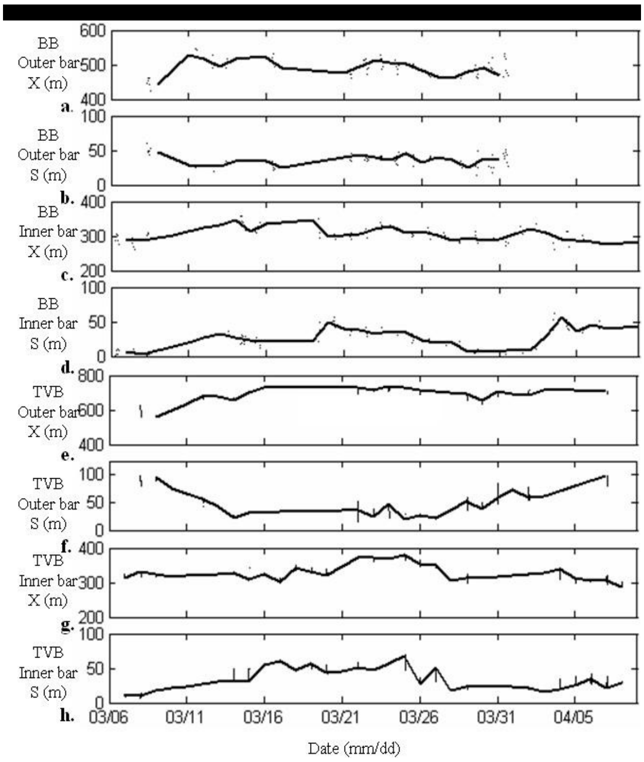

Figure 4. Time series of outer (o) and inner bar (i) crest lines alongshore-averaged cross-shore position (<X>) and standard deviation (S): (a) $\langle X_o \rangle$ BB, (b) S_o BB (c) $\langle X_i \rangle$ BB, (d) S_i BB, (e) $\langle X_o \rangle$ TVB, (f) S_o TVB, (g) $\langle X_i \rangle$ TVB, (h) S_i TVB.

with the development of large-scale (~700 m) alongshore features. After a rather short period of lower-energy waves, the coast was exposed to a second, less energetic, 1-day storm (Hs > 4 m, T >12 s) on March 16, generating shore-normal incident waves (Fig. 2). Its impact on the dynamics of both double sandbar systems was limited. Alongshore-averaged cross-shore positions and standard deviations did not vary significantly (small variations of S and <X> compared to the first storm, Fig. 4). The following 5-day recovery period allowed the development of short-scale (~300 m) inner-bar non-uniformities (S reached maxima dataset values).

Following this calm period, a third storm (Hs > 3 m, T > 10 s) hit the coast from the March 21 to 31, which constitutes a very uncommon long period of high energy waves for this stretch of coastline. Initial (22nd) alongshore-uniform geometry of the outer bar at both sites is shown in Figures 3c, d. During this 10-day period of high-energy waves, albeit of lower energy in comparison to the two previous storms, the TVB outer bar developed crescentic patterns (down-state transition, increasing S in Fig. 4f) while, in contrast, this did not happen at BB (non-varying S in Fig. 4b). The impact of this storm on the inner bars was quite similar at the two sites with pre-existing non-uniformities that almost vanished (decreasing S in Figs. 4d, h). Following this 3-storm sequence, a low-energy wave period occurred from April 1 to 9 (Hs < 2 m, Fig. 2). During this period, the outer bars were inactive at both sites whereas the inner bars developed non-uniformities (S ~ 50 m, Fig. 4d, h).

The mean position of the outer bar over the study period indicates that the TVB outer bar (~700 m) was located further offshore than at BB (~550 m). In contrast, inner-bar positions were similar (~300 m). Thus, the distance between the bars was substantially larger at TVB (400 m) than at BB (250 m).

To examine outer-bar behaviour in more detail, the alongshore migration of the non-uniformities was derived by sandbars crest position. The wave angle with respect to shore-normal (15°, Figure 2) and the exceptionally high-energy waves during the first storm induced an outer-bar southward migration of about 150 m and 100 m at TVB and BB, respectively. Obviously, the second storm had little effect on the alongshore migration with shore-normal waves (~0-5°). During the third storm, the combination of oblique incidence (W-NW 15-20°) and long duration resulted in an about 200 m southward migration at TVB and 100 m at BB, respectively.

The total observed alongshore migrations over the 5-week period were ΔY~350 m southward for the outer bar at TVB and only ΔY~200 m at BB. Alongshore-averaged cross-shore migrations were ΔX~100 m seaward for the TVB outer bar and ΔX~50 m at BB. Estimated maximum alongshore migration rates for the outer bar were about 50 m/day at TVB and 20 m/day at BB. The total inner-bar alongshore-averaged cross-shore migrations were very small at both sites (< 10 m/day).

DISCUSSION AND CONCLUSIONS

In this paper, we have presented preliminary results of daily cross-shore and alongshore behaviour of two double sandbar systems under extreme wave conditions in a meso-macro-tidal settings. This dataset was adequate to explore knowledge gaps highlighted in the review of CASTELLE et al. (2007), who proposed a conceptual model of TVB from existing sparse inner-bar surveys, satellite images during fair weather conditions and visual observations during winter storms. Most of the results presented herein corroborate this conceptual model. For instance, it is confirmed that only a severe storm, and not only a typical winter storm, is required to induce a straightening of the outer bar. It is also confirmed herein that, with offshore significant wave height smaller than 3 m, the outer bar remains inactive. Furthermore, as pointed out in CASTELLE et al. (2007), the influence of the tidal range on double-sandbar dynamics is still poorly understood. Our dataset thus deserves further analysis to determine the role of tidal range on sandbars response to storms in a meso-macro tidal setting.

The beach state transitions expected from WRIGHT and SHORT (1984; also assumed in CASTELLE et al., 2007) in relation to wave forcing were not systematically observed in our inner-bar data. In particular, during the first high-energy wave event, the inner-bar alongshore non-uniformities became more pronounced, while a straightening (as observed for the outer bar) would have been expected. The imagery shows that during the first storm outer-bar horns split into two sections and that the increase in the inner-bar large-scale non-uniformities was associated with the welding of the landward section of outer-bar horns to the inner bar. The previously underestimated role of coupling and interactions in double systems have been recently highlighted using both observations (RUESSINK et al., 2007; CASTELLE et al., 2007) and non-linear morphodynamic modelling (CASTELLE et al., 2008) as well. Although these earlier observations and modelling efforts dealt with down-state transitions only, our observations suggest that inner-outer bar interactions are relevant to up-state transitions as well.

The distance between inner and outer bars was about 400 m at TVB and 250 m at BB which represents some of the largest observed values at double-barred beaches (~230 m at Noordwijk, Netherlands and ~100 m on the Gold Coast, Australia, VAN ENCKEVORT *et al.*, 2004). The TVB outer-bar offshore migration reached 30-50 m/day during high-energy wave conditions on the March 11-12, which was close to the highest observed values at other sites (10-50 m/day, VAN ENCKEVORT *et al.*, 2004). These observations are not surprising given that BB and TVB were exposed to an exceptionally high-energy wave period comprising a 10-year return storm.

At both TVB and BB, the inner-bar standard deviations strongly varied with changing wave forcing without any large cross-shore migration. This result corroborates the recent findings of RUESSINK *et al.*(2000) who showed that, using a EOF technique, the inner-bar short-term signal was more affected by alongshore non-uniformity development than alongshore-averaged cross-shore migration. The small cross-shore migration rates point to the protecting role of the outer-bar on the inner-bar and the beach.

The observed contrasting behaviour of the double sandbar systems at TVB and BB sandbar systems could be explained from further investigations. Some key points could be found in a difference of nearshore bed slope or in the presence of offshore bathymetric features. Sandbar volumes could be computed as some results in the literature have shown that bars with smaller volume respond more quickly (SMIT *et al.*, 2008). Unfortunately, both BB and TVB can be considered as remote beaches, and undertaking detailed bathymetric at both sites at the same time (necessary for accurate comparison) is objectively a challenging and costly task. A bed sediment collection at the two sites would be also interesting: Although the sites are only 50 km apart and have similar wave and tide forcing, sandbar migration amplitudes were different. Our observations highlight the complexity of the short-term dynamics of double-sandbar systems. With our data we can further examine previously identified knowledge gaps on the Aquitanian Coast beaches, and explore double sandbar systems in general, including the inner-outer bar interactions during storm events that may result in outer-bar straightening and inner-bar non-uniformities.

LITERATURE CITED

BUTEL R., DUPUIS H. and BONNETON P., 2002. Spatial variability of wave conditions at French Atlantic coast using in-situ data, *Journal of Coastal Research*, SI 36, 96-108.

CASTELLE, B., BONNETON, P., DUPUIS, H. and SÉNÉCHAL, N., 2007. Double bar beach dynamics on the high-energy meso-macrotidal French Aquitanian Coast : A review. *Marine Geology,* 245, 141-159.

CASTELLE, B., RUESSINK, G., BONNETON, P., BRUNEAU, N., MARIEU, V., 2008. Modeling of coupled and noncoupled behavior of a double sandbar system: self-organization and morphological forcing. *Proceedings of the 31st International Conference on Coastal Engineering* (Hamburg, Germany, ASCE), in press.

COCO, G., BRYAN, K., PAYNE, G., 2004**.** The next Era for Cam-Era, Coastal news.

HOLLAND, K.T., HOLMAN R.A., LIPPMANN T.C., STANLEY J.and PLANT, N.G., 1997. Practical use of video imagery in nearshore oceanographic field studies. *IEEE Journal of oceanic engineering*, Vol. 22, No. 1.

LAFON, V., DUPUIS, H., HOWA, H. and FROIDEFOND, J-M, 2002. Determining ridge and runnel longshore migration rate using spot imagery. Oceanologica Acta 25, 149_158.

LAFON, V., DE MELO APOLUCENO, D., DUPUIS, H., MICHEL, D., HOWA, H. and FROIDEFOND, J-M., 2004. Morphodynamics of nearshore rhythmic sandbars in a mixed-energy environment (Sw france) : i. mapping beach changes using visible satellite imagery. Estuar. Coast. Shelf Sci. 61 (2), 289-299.

LIPPMANN, T. C., and R. A. HOLMAN,1989. Quantification of sand bar morphology: A video technique based on wave dissipation, *J. Geophys. Res.*, 94(C1), 995–1011.

MICHEL, D. and HOWA, H., 1999. Short-term morphodynamic response of a ridge and runnel system on a mesotidal sandy beach. J. Coast. Res. 15, 428-437.

PEDREROS, R., HOWA, H. and MICHEL, D., 1996. Application of grain size trend analysis for the determination of sediment transport pathways in intertidal areas. Marine *Geology*. v135. 35-49.

RUESSINK, B.G., I.M.J. VAN ENCKEVORT, K.S. KINGSTON and M.A. DAVIDSON, 2000. Analysis of observed two- and three-dimensional nearshore bar behaviour. *Marine Geology*, 169, 161-183.

RUESSINK, B.G., WIJNBERG, K.M., HOLMAN, R.A., KURIYAMA, K. and VAN ENCKEVORT, I.M.J., 2003. Intersite comparison of interannual nearshore bar behaviour. *Journal of Geophysical Research*, 108, doi:10.1029/2002JC001505

RUESSINK B.G., G. COCO, R. RANASINGHE, and I.L. TURNER, 2007. Coupled and noncoupled behavior of three-dimensional morphological patterns in a double sandbar system. *Journal of Geophysical Research*, 112, C07002, doi:10.1029/2006JC003799.

SMIT, M.W.J., S.G.J. AARNINKHOF, K.M. WIJNBERG, M. GONZÁLEZ, K.S. KINGSTON, H.N. SOUTHGATE, B.G. RUESSINK, R.A. HOLMAN, E. SIEGLE, M. DAVIDSON and R. MEDINA, 2008. The role of video imagery in predicting daily to monthly coastal evolution. *Coastal Engineering*, 54, 539-553.

VAN ENCKEVORT, I.M.J. and B.G. RUESSINK, 2003. Video observations of nearshore bar behaviour. Part 1: alongshore uniform variability. *Continental Shelf Research*, 23, 501-512.

VAN ENCKEVORT, I.M.J., B.G. RUESSINK, G. COCO, K. SUZUKI, I.L. TURNER, N.G. PLANT and R.A. HOLMAN, 2004. Observations of nearshore crescentic sandbars. *Journal of Geophysical Research*, 109, C06028, DOI:10.1029/2003JC002214.

WRIGHT, L.D., and SHORT, A.D., 1984. Morphodynamic variability of surf zones and beaches: a synthesis. Marine Geology, 56, 93-118.

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