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MONITORING SHORELINE ROTATION WITH A COASTSNAP SYSTEM AT THE MESOTIDAL EMBAYED BEACH OF LAFITENIA, FRANCE

A. DEBURGHGRAEVE¹, A. ROBINET¹, S. LECACHEUX¹, C. BOUVIER²
E. SIMON³, D. ROSEBERY⁴

1. BRGM, 24 Avenue Léonard de Vinci, Pessac, France. a.deburghgraeve@brgm.fr, a.robinet@brgm.fr, s.lecacheux@brgm.fr
2. BRGM, Direction Régionale Martinique, 97222 Fort-de-France, Martinique. c.bouvier@brgm.fr
3. CATIE, 33400 Talence, Nouvelle-Aquitaine, France. e.simon@catie.fr
4. ONF, 33520 Bruges, Nouvelle-Aquitaine, France. david.rosebery@onf.fr

Abstract: Shoreline position varies over a wide range of temporal and spatial scales in response to a variety of processes. The monitoring of its position changes requires availability of high-frequency observations over a long period. In this study, the low-cost crowd-sourced system CoastSnap (Harley *et al.*, 2019) is used to investigate the shoreline dynamics at the embayed beach of Lafitenia over a 9-months period. After the validation of CoastSnap images rectification thanks to *in-situ* surveyed data, a quantitative analyse of cross-shore position changes is undertaken using high tide waterline. The obtained results show apparent short time scale beach rotation for the first time at Lafitenia. This new shoreline mapping approach offers new perspectives to study short time coastal processes over long periods.

Introduction

Coastal areas are complex environments that act as a buffer, protecting biodiversity, human lives and settlements from strong waves and elevated water level. These land-sea interfaces are under an increasing pressure with both global mean sea level rise and a growing coastal population. Coastline position varies over a large range of temporal and spatial scales in response to a variety of forcing (Stive *et al.*, 2002). The understanding of processes driving these changes is critical for effective and sustainable management of the coastal zone and require frequent and long term data acquisition (Nicolae Lerma *et al.*, 2022).

Many measurement and observation methods are used by scientists and coastal managers for shoreline monitoring. Each one of them has its advantages and inconveniences. *In situ* methods such as DGPS surveying often provide high precision data but require significant logistic and available human operators (i.e. expensive and time consuming). For those reasons, it is difficult to maintain them over the long term on large spatial scale. Remote sensing techniques such as LiDAR also provide high precision data and can quickly cover wide areas

(Bossard V. *et al.*, 2020). However, its prohibitive cost and significant logistic remain limiting, especially for a frequent use. Video monitoring systems are frequently used to monitor shoreline dynamics at time scales from hours to years (Holman & Stanley, 2007). It has benefited from scientific advances in physic of the camera as an optical sensor to provide relevant shoreline monitoring data. Nevertheless, camera video stations require continuing energy supply and maintenance operations. Those requirements act as limiting factors in the deployment of cameras along coastlines. The use of satellite imaging to monitor costal dynamics has also strongly developed in recent years. Free access of both images and processing algorithms have made it a performant method suitable for shoreline monitoring at seasonal or decadal scale and at regional scale considering the wide areas covered by these images (e.g. Vos *et al.*, 2019). However, large pixel footprint plus a regular cloud cover can make satellite images unusable for high-frequency monitoring of individual beaches.

These above-mentioned weaknesses have encouraged scientists to keep exploring complementary alternatives. Following advances in video monitoring systems and worldwide smartphones growth, the CoastSnap system has been developed (Harley *et al.*, 2019). Its aims at providing a quantitative approach of shoreline mapping using crowd-sourced images taken from a fixed station overlooking the beach. Harley *et al.*, (2019) have successfully shown the capacity of CoastSnap to monitor the beach width of 2 Australian sandy beaches over a 1 km alongshore distance and a 7-months period of time. Besides providing high frequency data suitable to short time changes investigations, CoastSnap creates a link with local communities.

Interested in these features, the Coastal Observatory of Nouvelle-Aquitaine region (France) decided to experiment the CoastSnap system at the embayed beach of Lafitenia (France) whose dynamics remain poorly known. In this study, CoastSnap images of Lafitenia were used to investigate the shoreline dynamics over a 9-months period. It has enabled to highlight short time beach dynamics that have not been identified yet with conventional measurement methods at Lafitenia. The study site is introduced in section 2, data and methods applied are presented in section 3, and results are presented and discussed in section 5.

Study site

The study was conducted at the open coast sandy beach of Lafitenia, located in Saint-Jean-de-Luz in southwest of France (**Erreur ! Source du renvoi introuvable.**). Bounded by two rocky headlands, this 350 m-long NW-facing embayed beach is exposed to high-energy waves generated in the North Atlantic Ocean. They propagate from W-NW sectors (average propagation is 307.3° TN) with an average significant wave height of 1.55 m and 10.9 s peak wave period measured at isobath 50 m. In this part of the Atlantic Ocean, atmospheric

depressions and storms are more intense during the November to March period. The tide is meso-tidal with amplitude usually ranging from 2.80 m to 3.75 m for neap and spring tides, respectively. The sand lie on a rocky bedrock that is apparent on the surface at both extremities of the beach. The beach is surrounded by medium size cliffs made of relatively instable alterite.

The CoastSnap station has been installed on 25th October 2021. It is located on top of the cliff, overlooking the beach of Lafitenia. The camera cradle is at an elevation of 37.8m FOD and provides a northeastward view of the beach extending to a distance of approximately 600 m alongshore. The important number of visitors and the proximity of the coastal trail ensure a minimum stream of contribution required for high frequency monitoring.

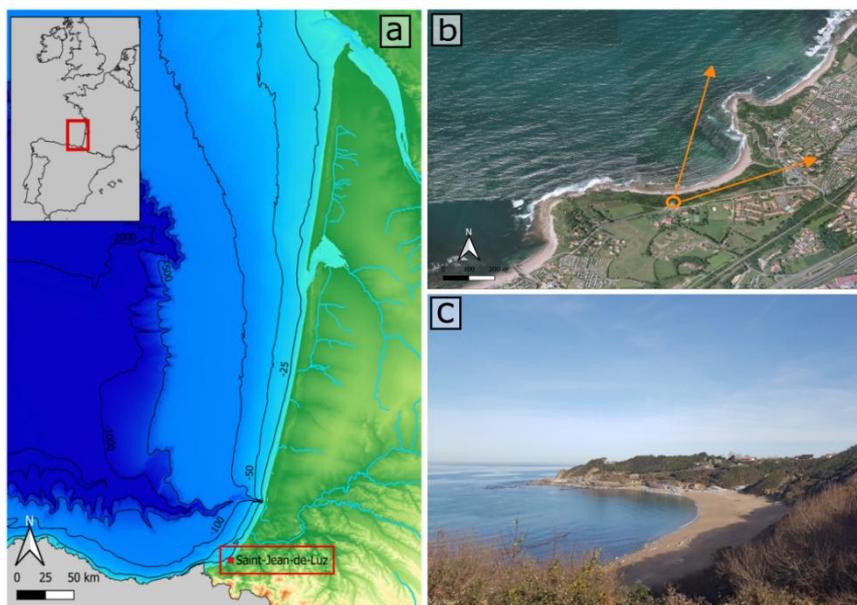


Figure 1: Location of the CoastSnap station used in this study. (a) The city of Saint-Jean-de-Luz in the southwest of France. (b) The embayed beach of Lafitenia and the CoastSnap station location. (c) Example of smartphone image taken from the station

Data & Methods

Input Data

Crowd sourced images are regularly acquired and shared by citizens since station installation. All those images are centralized on a unique database. Date and time of acquisition are systematically associated to each image to allow

retrieving the water level from astronomical tide prediction. The CoastSnap station enable to constraint both location and viewing angles of the image. These controlled parameters are combine with surveyed ground control points (GCP) to allow the rectification of each image in real world coordinates and quantitative analyses.

Full topography of the beach was acquired using DGPS measurement on July 12th 2022 to validate the spatial accuracy of waterlines extracted from rectified images. In addition, beach profiles measured annually at spring since 2009 by the Coastal Observatory of Nouvelle-Aquitaine (Nicolas Lerma *et al.*, 2022) along three cross-shore transects within the embayment are used to compute the average beach slope (see section Methods). Astronomical tide levels are computed using tide harmonics derived from a time series of water levels simulated offshore Lafitena by 10-m depth. Water levels are obtained from a regional-scale hindcast realized by the French Research Institute for Sea Resources (IFREMER) using the MARS2D hydrodynamic model (Lazure and Dumas 2008). Waves conditions are extracted from a wave hindcast realized by IFREMER using the WAVEWATCH III wave model (Roland and Ardhuin 2014).

Methods

To facilitate further processing, images are aligned on unique reference image. This alignment step is undertaken using Adobe Photoshop as suggested in Harley *et al.* (2019). This set of images is then rectified using CoastSnap algorithms. Image rectification is a usual treatment that turns an oblique image with pixel coordinates, into a geo-referenced horizontal plan view with real world coordinates (e.g. Bouvier *et al.*, 2017). That transformation enable quantitative assessment of distances. However, it requires specifying the rectification altitude beforehand to be undertaken. Only points that are actually located on this rectification plane could be properly situated within the rectified image. In this study, water level at the time of image acquisition, provided by astronomical tide prediction, is used as rectification elevation. Geographical coordinates of each waterline are then obtained manually by digitizing on rectified images.

To assess the accuracy of the rectification, the digitized waterlines are compared to the tide corresponding contours computed from the measured beach topography (Figure 2). This comparison is undertaken using waterlines from 7 images acquired on July 11th and July 12th 2022. Wave energy offshore Lafitena was very low on these 2 days ($H_s < 0.5\text{m}$). As it is the main factor driving short-term beach changes, the beach configuration can be considered as spatially identical as when topography was acquired (see Input Data section). Cross-shore positions were compared along a series of profiles. The overall obtained RMSE

and determination coefficient are respectively 3.86 and 0.79.

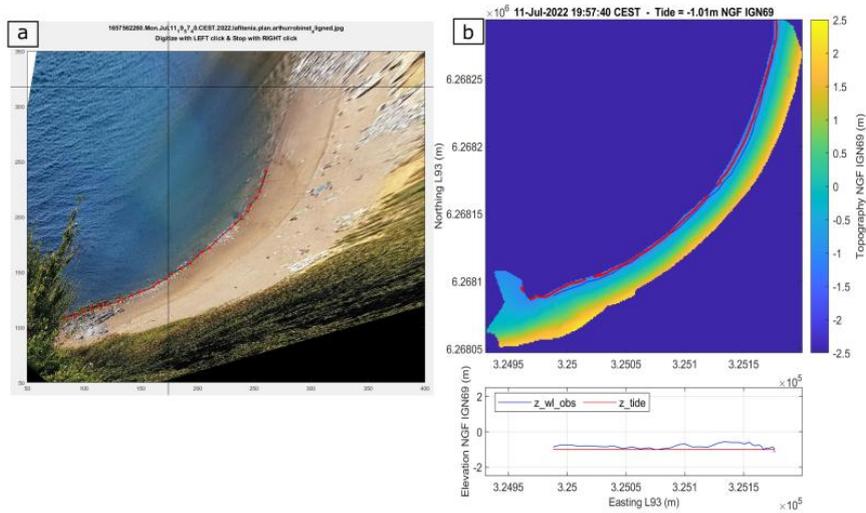


Figure 2: (a) Waterline digitalization on rectified image. (b) Digitized waterline position (blue line) compared with the corresponding contour computed from beach topography (red line)

Mean high waterline (Boak and Turner, 2005) is used as a proxy of the shoreline as Lafitena is a mesotidal beach. Indeed, the mean high waterline was shown to be a relevant shoreline proxy to study event-scale to inter-annual shoreline variability for such tidal regime (Castelle *et al.*, 2014). Consequently, every low or mid tide images have been put aside in this study to keep only high tide images. Besides, when several images were acquired within a small period of time (e.g. few days) only the image exhibiting the lowest swash excursion is kept to reduce the difference between total water level and astronomical water level. This results in a set of 65 images between October 2021 and August 2022 from which high tide waterline can be extracted.

As every selected image is acquired potentially at different stage of tide near the mean water level, waterlines have to be adjusted to this reference elevation to carry out a relevant comparison of their cross-shore position. A linear tidal correction is applied using water levels from tide data and measured beach face slope to translate each waterline to a reference elevation (Vos *et al.*, 2019) and use it as an estimate of the shoreline. The beach face slope used in this study is obtained by cross-shore averaging the data surveyed over the last ten years between isobaths 1.5m and 3m as we focus on the high tide area. An average slope of 12.5%, considered as homogenous in longshore direction, is thus calculated and used to adjust every waterline position to the baseline

Lafitena beach exhibits distinct alongshore curvature that complicates the explicit definition of longshore and cross-shore directions and so the characterization of its dynamic. In these circumstances, a solution enable to remove the initial curvature of the beach and to facilitate further data processing (Harley *et al.*, 2008). It consists in using a log-spiral function fitted to the beach planform to transform Cartesian data into longshore-cross-shore coordinates system. In our study case, the beach planform is estimated by computing the average of high-tide waterlines along transects placed perpendicular to the local beach orientation. Thanks to this method, waterlines are projected in a new coordinates system and can easily be resampled with a regular step all along the longshore axis defined by the log-spiral baseline.

A linear fit of each shoreline (derived from the digitized waterlines as described above) in alongshore/cross-shore referential is also performed in order to compute the time series of angle between the overall shoreline direction and the alongshore axis (hereafter referred to the shoreline angle).

Results and discussion

The timestack of the shoreline cross-shore position (Figure 3a) exhibits complex patterns of change over a 9-month period, with alternating periods of beach accretion (yellow color) and erosion (blue color) in relation to the log-spiral baseline. Interestingly, the shoreline cross-shore fluctuations often show opposite directions of shoreline translation at both extremities, creating an apparent beach rotation. This is clearly visible between end of January and mid-February, with a 5 to 10-m shoreline advance at the south extremity of the beach (alongshore distance \approx 250 m) synchronized with a 15 m retreat at the north extremity. Overall, the movements amplitude appears to be slightly more important during the first half of the time period (November to April) whereas a net decrease in shoreline fluctuations is observed starting from May.

Computing the time series of shoreline angle relative to the alongshore axis (Figure 3b) also highlights the occurrence of clockwise and anti-clockwise beach rotations at the scale of days to weeks with angle values ranging from -4° to $+6^\circ$.

In addition to these changes occurring at week scale, a seasonal pattern seems to emerge over those 9 months (Figure 2b). The winter period is made up of clockwise and anti-clockwise rotations of large amplitude while the summer period is characterized by reduced-amplitude and slower rotations with a beach remaining in anti-clockwise rotated state (negative shoreline angle).

Analysis of incident waves conditions (Figure 3c) usually helps understanding

conditions under which these beach rotations develop (e.g. wave intensity or direction shift). The strong seasonally modulated wave climate of Lafitenia is likely to have a straight influence on the above mentioned seasonal trend. Larger shoreline orientation shifts could be related with the winter energetic wave climate, whereas the observed shoreline stability over the last 4 months could be seen as a result of the fair wave conditions. On shorter timescale (days), it is hard to say at what point the few large beach rotation observed in November or February (Figure 3a, b) are linked to peaks in wave energy and/or direction shifts. Longer time series of data would be necessary to establish consistent relations at both week and season scales and to increase the understanding of this beach rotation process.

CoastSnap rectified images enables to undertake quantitative insights about shoreline changes. Shoreline advances and retreats at Lafitenia are calculated using data such as waterline positions and the average beach slope whose accuracy could still be improved. Waterline positioning should be improved by carrying out *in situ* sensitivity study and integrating the effect of swash excursion while digitizing. The hypothesis of an homogeneous beach slope could also be reconsidered, especially in the alongshore direction.

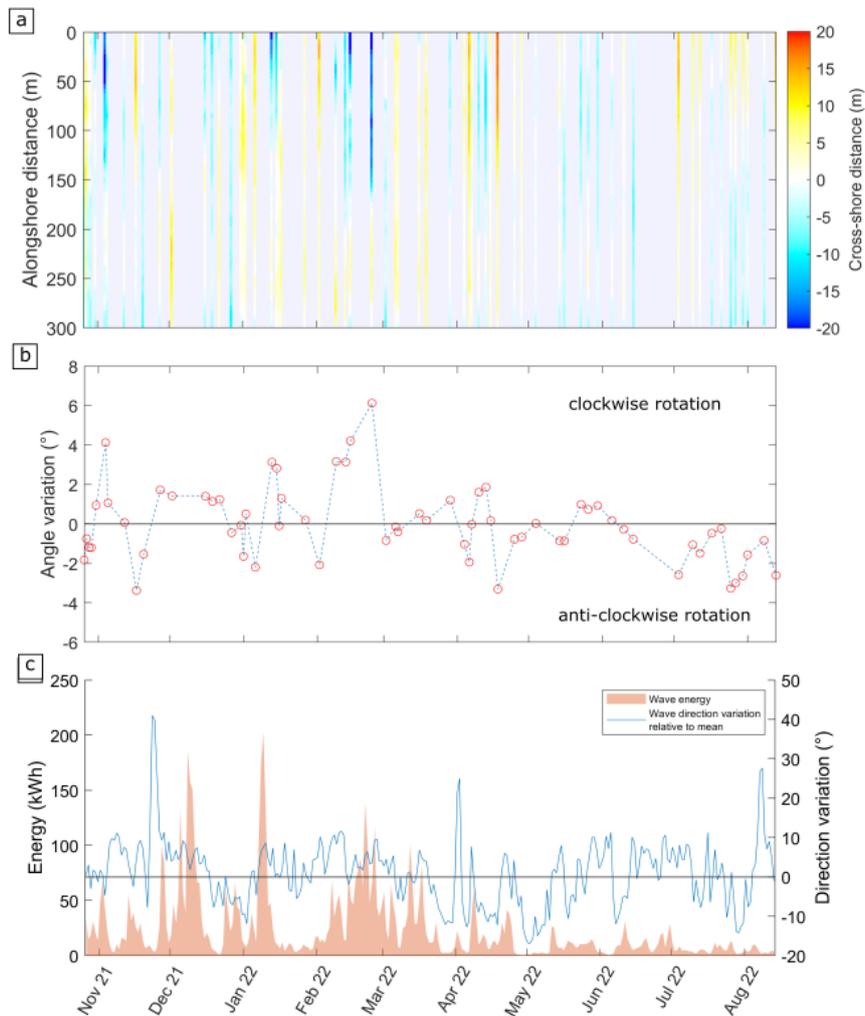


Figure 3: (a) Shoreline timestack showing the cross-shore distance to the baseline as a function of time and alongshore distance. (b) Time series of beach angle with respect to the baseline angle; clockwise rotation at Lafitenia means that the beach gets more north oriented (c) Daily-averaged wave conditions offshore Saint-Jean-de-Luz (MARC, IFREMER)

Conclusion

The installation of a CoastSnap station at Lafitenia has enabled to characterize for the first time beach rotations occurring at this embayed beach. The high-

frequency dataset, made up of 65 crowd-sourced images acquired over a 9-months period, was used to detect and to quantify shoreline changes at short time scales (from day to season). Cross-shore dynamic of shoreline shows interesting patterns, with notable opposite movements of extremities. Despite some approximations, it is possible to obtain the shoreline position at a reasonable precision (see section Method). Future work will be carried out to better relate wave forcing to the shoreline dynamics. This will require continuous supply of citizen's contributions.

Acknowledgements

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