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Low Beach Bars: a discontinuous subtidal system of proximal bars within Mediterranean low microtidal crescentics systems

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Abstract:
The southern part of the Gulf of Lions, formerly described as a double crescentic nearshore bar, may exhibit a third bar closer to the coastline which we defined as Low Beach Bar (LBB). Locally, the inner bar (IB) horn may be less developed and retreated seaward, leaving a larger accommodation space between it and the coastline. This allows the growth of a third proximal system of sandy plateau or bar, framed laterally by two "classic" IB horns close to the coastline. The dynamic of the LBB is very reactive to changes of hydrodynamic conditions due to their positions in the very shallow water and responds along an increasing morphological continuum from sandy plateaus to disrupted RBB if the energy level increases. The LBB is distinct from other transitory proximal systems observed in the literature such as SPAW or Net Offshore Migration initiation due to its resilience over several years and lack of offshore migration to replace the IB. It does, however, appear to be able to merge and exchange sediments with the beach face.

Keywords: Nearshore bars, Low Beach Bar, Crescentic bar, Wave dominated, Microtidal, Gulf of Lions

1. Introduction

Nearshore bars are common on sandy coasts. They play a key role in wave breaking and sediment exchange between the aerial and submarine compartments of the beach. The intermediate beach category is divided into four sub-states: Longshore Bar-Trough (LBT), Rhythmic Bar and Beach (RBB), Transverse Bar and Rip (TBR) and Low Tide Terrace (LTT). These states are broadly observed at many sites, but transitory typologies are possible: hybrid TBR/RBB, disrupted RBB, linearisation of patterns (ALEMAN *et al.*, 2011; 2017; FERRER, 2010). The inner bar (IB) may locally be attached to areas of shoals against the coastline that extend the emerged beach face and may be organized into transverse or crescentic bars, depending on the dimensions of the rip circulation cells (DAVIDSON-ARNOTT, 2022). These shoals are rarely described in the literature and yet seem to be very present at these Mediterranean study sites in the form of Low-Beach

Bar (LBB). This is observed in the southern part of the Gulf of Lions (SE France), where the nearshore is classically described as having two crescentic bars, but locally a third proximal bar, the LBB, occurring adjacently to the coastline in very shallow water (< 1 m) can be observed (ALEMAN *et al.*, 2011). This bar has complex morphological patterns being sometimes a long plateau connected to the collision slope or small crescentic bars that may occasionally be connected to the IB.

The aim of this study is to 1) characterize the representativeness of LBB in the study area of the southern Gulf of Lion and 2) to describe their morphology and dynamics in detail, using a representative site (Leucate) as an example.

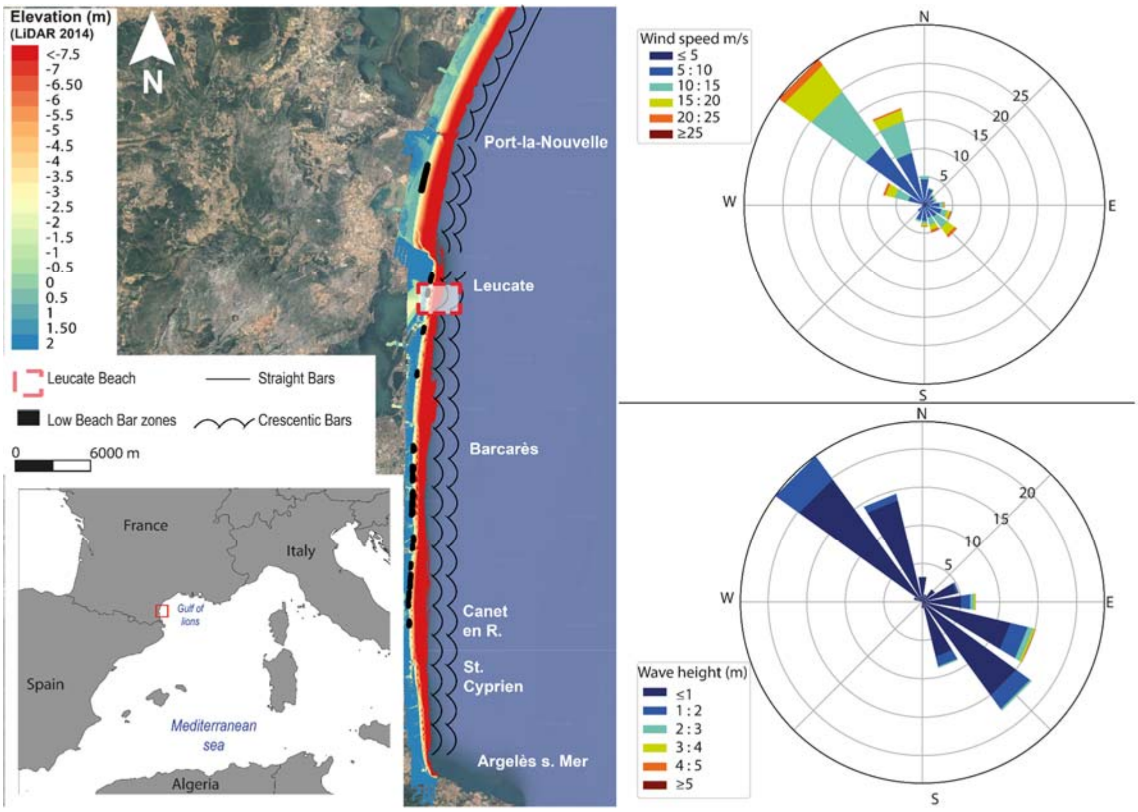

Figure 1. Study area and Leucate high-frequency study site, LBB sectors are represented in black and internal and external bar system typologies. On the right, average forcing conditions at Leucate over the period (2006-2021).

2. Study area

The southern part of the Gulf of Lions extends approximately 65 km from Argelès-sur-mer to the south to Port-la-Nouvelle to the north. The nearshore area presents a double RBB crescentic bar system (ALEMAN *et al.*, 2011) where LBB are present in a discontinuous manner over 13 km in total with longitudinal extensions ranging from 450 m to 2300 m long (figure 1). The offshore wind (Tramontane) is dominant (60% of the time, speed up to 30 m.s^{-1}). The onshore wind is less frequent (30% of the time) but can be accompanied by violent storms. Significant wave heights (Hs) are generally low (Hs < 1 m for 75% of the time), with a period of around 4 s. During storms, Hs are higher than 2 m and can reach nearly 6 m with peak periods between 5-10 s. It is a microtidal environment (tidal range < 0.30 m at mean spring tide) but large variations in water level are possible during storm events (surge > 1 m). The high frequency monitoring site of Leucate, used to describe in detail the morphodynamics of the LBB (figure 1), is typical of this southern area of the Gulf of Lions with a double RBB nearshore undisturbed by the presence of harbor structures.

3. Methods

To characterize the morphology of the shallow water area (depth ≈ 1 m to 10 m) on a large spatial scale, LiDAR data are used (Litto3D 2014). High-frequency monitoring of the Leucate site uses DGPS-RTK bathymetric and topographic surveys (Trimble R8s), but also by occasional video surveys. Hydro-meteorological forcing conditions are given by the Leucate swell buoy (CANDHIS) and by Météofrance for the wind.

4. Results and interpretation

4.1 Conditions for LBB development

LiDAR data show that the LBB are only located in areas of double crescentic bars in the South of the Gulf of Lions (figure 1). The slope of the upper shoreface is between 0.8° and 1.2°, locally 1.6° (figure 2a). Slopes too steep (>1.6°) or too weak (<0.6°) seem to be unsuitable for the development of these bars. The sediments that compose them have a D50 between 0.2 and 1.1 mm (figure 2a). Such bars are not found in areas disturbed by harbours or coastal defense infrastructure, river inlets areas seem unsuitable because they are too unstable. LBB are established in a band averaging 100 m seaward (exceptionally 200 m), between the shoreline (Shl.) and the IB (figure 2a). The length of the sections varies between 350 m and 2300 m (Figure 2b). LBB sectors are themselves enclosed by the adjacent horns of the IB that connect to the coastline (figure 2c).

4.2 Characterisation and typology of LBB

The analysis of LiDAR images over the study area allows us to appreciate the morphological variability of LBB (figure 3), which can be summarized as follows: a) A shallow (0.85m), unpatterned sandy plateau, attached to the coastline and extending from the beach face until it connects seaward to the horn of the retreated IB (figure 3a). The plateau ends laterally at the junctions to the coastline of the IB horns. This pattern accounts for 18% of the observed linear. b) A plateau extending the emerged beach face that is less developed and not connected to the horn of the retreated IB. The outer edge of the plateau can be cut by small oblique channels of a few tens of centimeters in depth and whose outlet affecting the IB can occasionally be blocked (figure 3b). This pattern is the least present in the observed area, 9%.

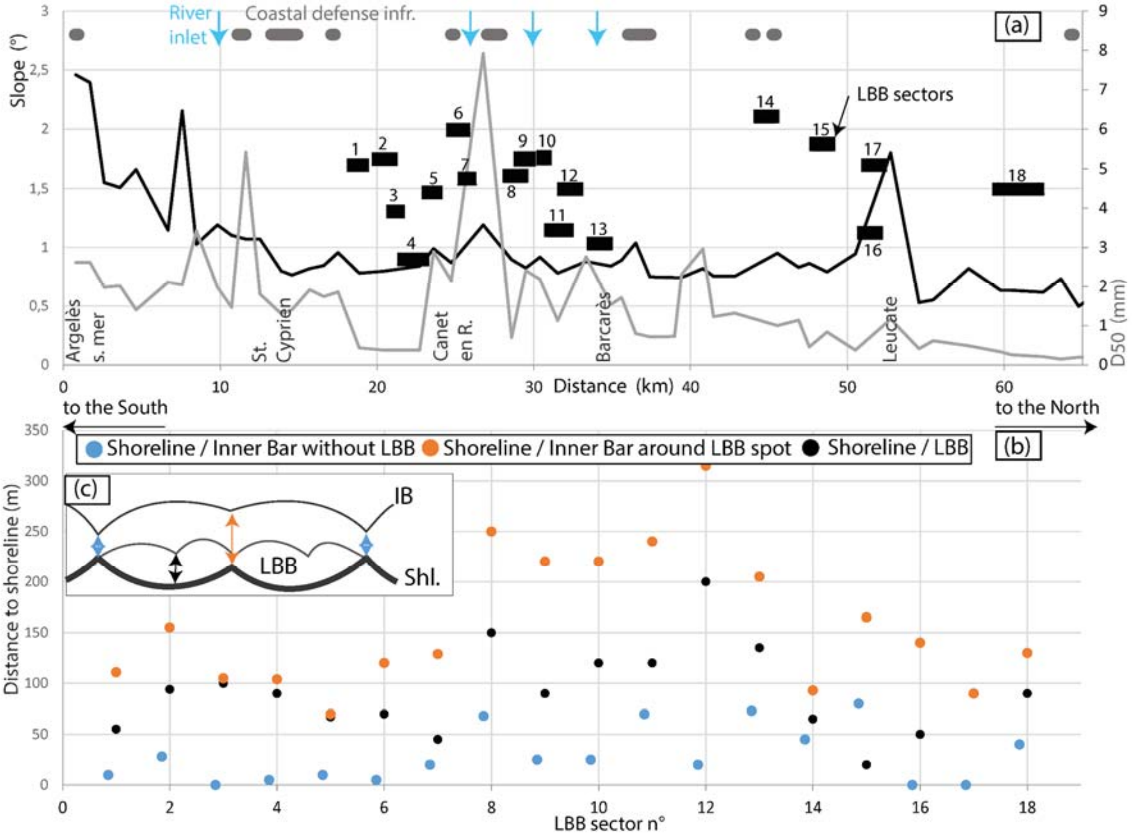

Figure 2. (a) Upper shoreface slope (black) and grain size (grey) from Aleman et al., 2015. LBB area slopes (black rectangles). Coastal defense infrastructures (grey rectangles) and rivers inlets (blue arrows). (b) Distance coastline to the IB on both sides of the LBB sectors (blue) and in the sectors with LBB (orange), distance from the coastline to the outer edge of the LBB (black). (c) Schematic positioning of the LBB and the measured parameters.

c) A small RBB pattern disconnected from the IB horn (figure 3c), but very close to the coastline (≈ 10 m), with a wavelength between 90 and 220 m and average depth around -1.16m. The horns interact with the coastline causing small progradations of the latter. These horns are generally either adjacent to the shoreline or separated by a small rip channel a few tens of centimeters deep. This pattern represents 37% of the observed line.
d) A disrupted RBB pattern at the embayments (figure 3d), close to the coastline (between 0 and 10 m), with a wavelength of between 60 and 180 m, where again the connections of horns can cause progradations of the coastline, the average depth is around -1.10m. This pattern represents 36% of the observed line.

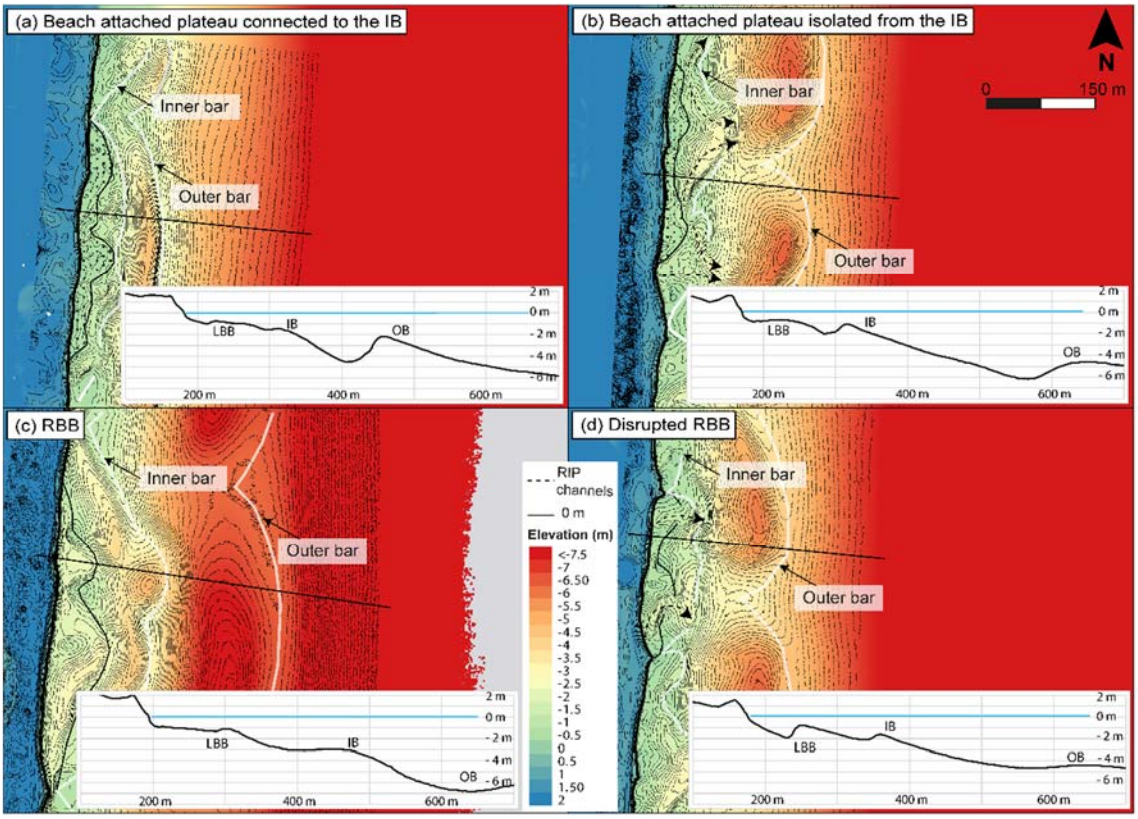

Figure 3. LBB typologies (crest in black) observed on the 2014 LiDAR, a) Beach attached plateau locally connected to the IB (crest in white), b) Beach attached plateau isolated from the IB, c) RBB partially connected to the coastline, d) RBB with disrupted embayments.

4.3 <u>LBB dynamics</u>

During the event scale monitoring carried out at the Leucate site, all of the LBB typologies described above were observed over several years of survey. The bar system stayed globally at the same position along the shoreline. Because of their small size and shallow depths, changes in LBB typology occur rapidly even for low wave heights (figure 4). During the summer period there are mainly beach-attached plateaus locally connected to the IB (figure 3a) creating some continuity between the IB and the shoreline. The plateaus disconnected from the retreated IB horn (figure 3b) are found for slightly more energetic periods. These first two typologies are common when Hs≤ 0.6m, especially in summer. The commonly observed RBB (figure 3c) develops as a result of medium-energy forcing (Hs< 1.5m) that will reorganize the pre-existing sandy plateau. Finally, the high-energy (Hs≥ 1.5m) form is a disrupted RBB (figure 3d), embayments are broken by rip channels that are directed towards the IB embayments. This typology is more likely to be observed during the winter just after storms.

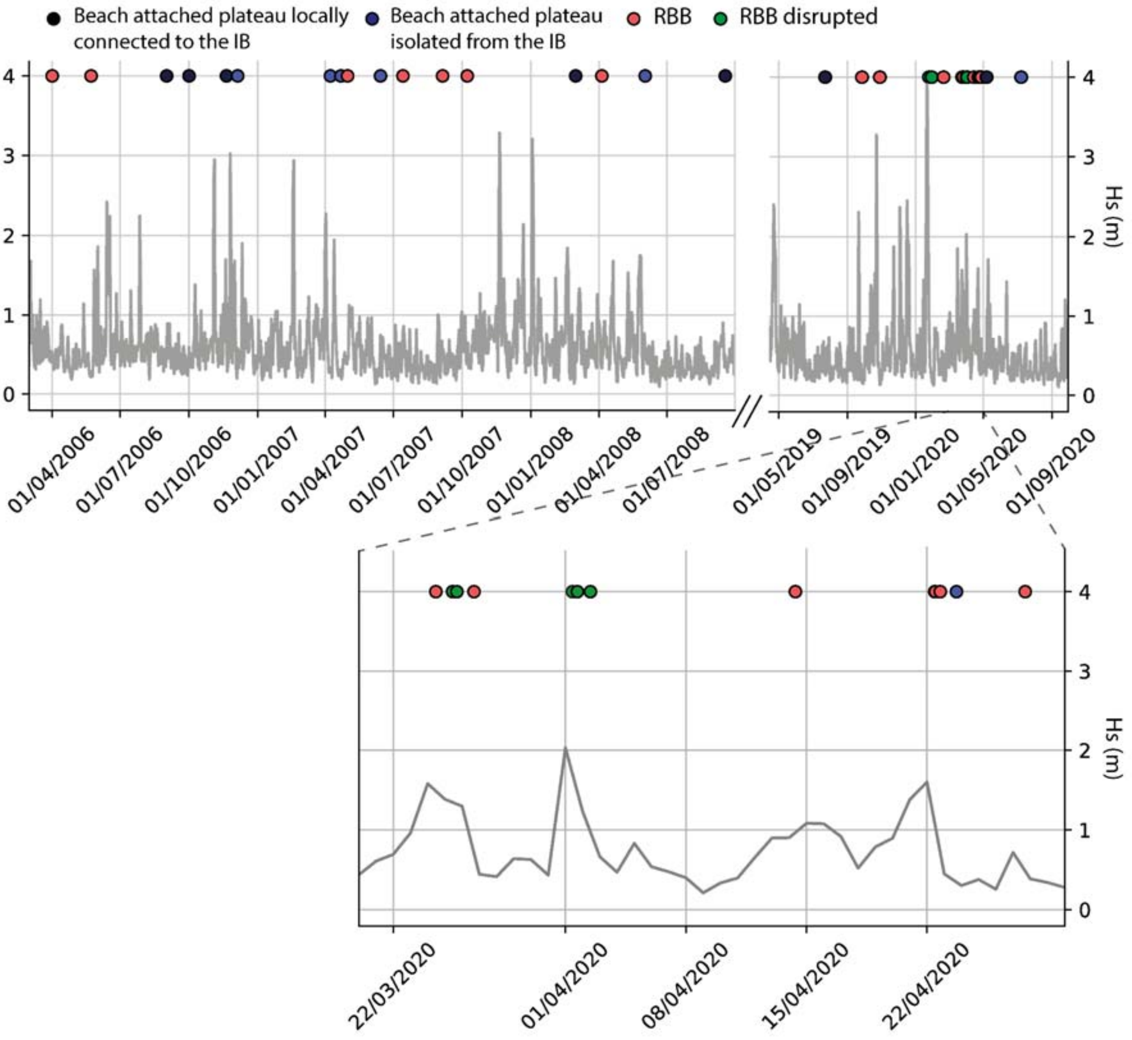

Figure 4. Event-based observation of LBBs on Leucate beach according to daily Hs (m) conditions (top); zoom on the high frequency video monitoring carried out in 2020 (bottom).

5. Discussion

5.1 Conditions for development and sustainability of LBB systems

In order to develop, LBB seem to require: a sufficient accommodation space between a crescentic IB and the shoreline (150 to 200 m); an average slope of the upper shoreface (between 0.8° and 1.2°); rather coarse sediments ($0.6<D_{50}<1.1$ mm) and an area without infrastructures (harbour jetties, breakwaters, groynes).

The presence of LBB is constant over time in areas favorable to their development. High frequency monitoring shows the presence at the same place of a LBB system over a long period exceeding one year in Leucate, even if the LBB states can change. This is related to the relative stability of the IB horns allowing an adequate accommodation space over long periods (FERRER, 2010).

5.2 LBB state change depending on the energy level

This work allows to apprehend the variability of the LBB morphologies, which can be classified by increasing order of energy (figure 5) and schematized as follows: a) Beach attached plateau without pattern locally connected to the IB, which is the low energy form; b) With increasing energy, this plateau will be cut on its external edge by small oblique channels generally oriented towards the IB horn which will detach the LBB; c) The pattern then tends toward a small RBB disconnected from the retreated IB horn; d) if the energy increases significantly, this RBB pattern will deform and break up at the embayments (figure 6a). It appears that some of it may then migrate toward the shoreline at the end of the storm as forcing conditions decrease, creating a new berm by welding to the coastline that replaces the one destroyed during the peak of the storm (figure 6b). These different LBB typologies interact as a function of forcing conditions, their small size and shallow depths allow them to readjust very quickly.

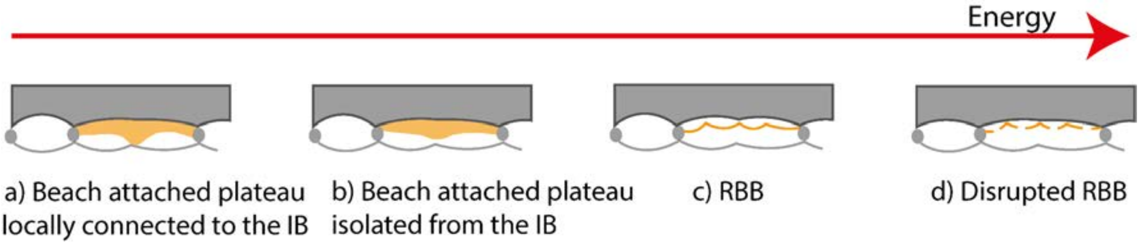

Figure 5. Conceptual model of LBB (in orange) morphodynamics.

5.3 Comparisons with other proximal systems

The organization of proximal shoals has already been observed by some authors (ALEMAN *et al.*, 2011; DAVIDSON-ARNOTT, 2022) without going as far as a detailed characterization. However, their presence and their possible implications in the exchanges between emerged and submerged beaches require a better understanding of their dynamics. LBB have morphologies close to what is described in bar classifications (SHORT & WOODROFFE, 2009), but their evolution is constrained laterally by longshore connections of the IB horns with the shoreline and offshore by the retreated IB horn (figure 2c). This induces the lack of offshore bar migration (NOM) as observed for slightly oblique bar sites in the central part of the Gulf (ALEMAN *et al.,* 2017). They are therefore not similar to SPAW, which are pieces of bars moving between bar systems (WIJNBERG & HOLMAN, 2007). LBB are more resilient systems that existed and could be monitored locally and continuously at the Leucate site during the two and a half years of high frequency monitoring.

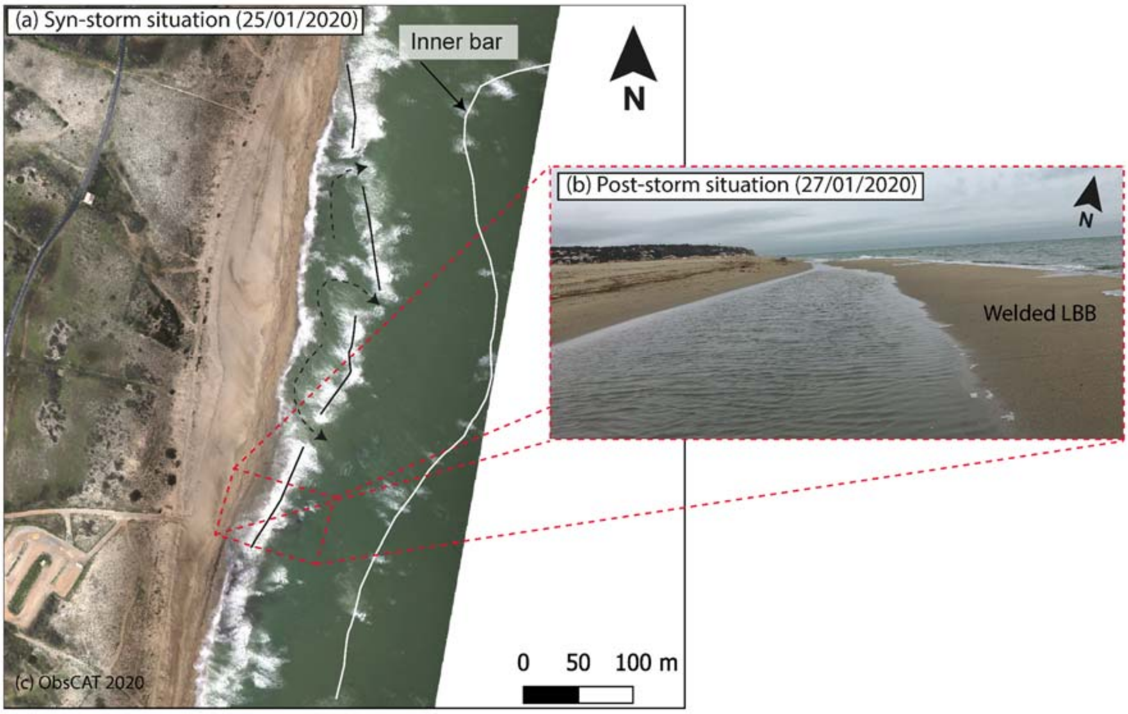

Figure 6. a) Syn-storm disrupted LBB (black) during vanishing storm conditions (25/01/2020) b) Post-storm, LBB welded locally to the shoreline (27/01/2020)

The slope of the nearshore, on average around 1°, also appears to be an important controlling factor. In other distinct microtidal environments with very gentle slopes (<0.6°), low energy and excessive sediment (e.g. coastal lagoon), the establishment of LBB seems to give way to the presence of transverse finger bars connected to the coastline (FALQUES *et al.,* 2021). The role of waves obliquity in the dynamics of LBBs seems less marked than for the rest of the nearshore bars system. LBB dynamics may be dominated by currents recirculation loops induced by wave transformation over the outer and the inner bars (FERRER, 2010).

6. Conclusions

This study illustrates that LBB are highly reactive to changes in hydrodynamic conditions due to their position in very shallow water and respond along an increasing morphological continuum from plateaus connected to the shoreline, to RBB and disturbed RBB if the energy level keeps increasing. They then seem to be able to merge with the beach face. This illustrates the importance of considering LBB morphologies, which appear to be fairly widespread, for improving the understanding of the functioning of Mediterranean microtidal environments with crescentic bars. Indeed, these beaches formerly described as two-bar systems can be locally considered as three-bars systems. Although modest in size, the presence of LBB inevitably disrupts the circulation of this area and the interactions between the coastline and the inner bar while participating in sedimentary exchanges. This aspect remains to be quantified in detail, as does the feeding of these systems by the offshore wind transport common in the study area.

7. Acknowledgements

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