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Typology of nearshore bars in the Gulf of Lions (France) using LIDAR technology

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ABSTRACT

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Nearshore bars are generally present on sandy coasts and play a significant role in wave breaking and exchange of sediments between the beach and the shoreface. The study area is located on the Languedocian coast in the Gulf of Lions (southern part of the French Mediterranean coast). This microtidal environment is classified as a wave-dominated coast. The sand coast displays different bar systems (single or multiple; straight or crescentic). The alongshore variability of bar morphology in the nearshore zone was investigated in August 2009 during one week, using a topo-bathymetric LIDAR data set (300 km2). LIDAR makes it possible to cover a large area in a very short time with a high resolution. The topo-bathymetric LIDAR offers the added benefit of morphological information about the beach-sea transition in very shallow water (below 1 m), data often difficult if not impossible to obtain with traditional techniques. The purpose of this paper is 1) to depict the distribution of bars and their characteristics along the 180 km coast of Gulf of Lions; 2) to update the classifications of bars typologies in Languedoc-Roussillon; 3) to pay particular attention to the description of the intricate inner system. Globally, cross-shore distribution of subtidal morphologies is characterized by an outer and an inner system. The outer system is crescent-shaped in the south and straight in the northern part with a distinctive regional delimitation. The inner system comprises an inner bar and, near the coast, a complex fluctuating bar called Low Bar Beach (LBB). Several intermediate states have been identified and added to the new classification proposed in this paper.

These results clearly emphasize the importance of LIDAR technology for a better understanding of bar behaviour and single and/or multi-bar beach organisation. They highlight the existence of several intermediate bar typologies and a complex LBB in connection with the inner bar, thus contributing to improving the existing classifications.

ADDITIONAL INDEX WORDS: *LIDAR, Crescentic bar, straight bar, Languedoc-Roussillon*

INTRODUCTION

Beaches have received a lot of attention in coastal sciences and engineering because of their environmental, recreational, residential and ecological importance. Nearshore bars are a common feature in sandy coasts and are significant reservoirs of sediment. These bars play a major role in wave breaking and exchange of sediments between the beach and the shoreface. So these large-scale features have strong consequences for beach stability both to the short and long terms (Lippmann and Holman, 1990).

For one or multi-bars systems, three main beach states (dissipative, intermediate and reflective) are identified in the literature (Wright and Short, 1984) in relation to environmental parameters. Intermediate beaches were further divided into four sub-states in relation to a decreasing energy provided to the system: longshore bar-trough (LBT), rhythmic bar and beach (RBB), transverse bar and rip (TBR); and low tide terrace (LTT) (Wright and Short, 1984; Lippmann and Holman, 1990; Short and Aagaard, 1993). However, these classifications represent a static and idealized vision of the nature. The processes associated with morphological changes within the intermediate beach state transitions are still poorly understood (Castelle *et al.*, 2007). Recently, additional states were identified in the inner system (Brander, 1999; Castelle *et al.*, 2007; Shand, 2007; Wijnberg and Holman, 2007; Ferrer *et al.*, 2009; Almar *et al.*, 2010; Castelle *et al.*, 2010b; Castelle *et al.*, 2010a; Robin *et al.*, 2010).

Identifying nearshore morphological characteristics in a multi-bar coast requires combined bathymetric survey (Certain and Barusseau, 2005; Ferrer *et al.*, 2009; Sénéchal *et al.*, 2009), photographic and satellite imagery (Barusseau and Saint-Guily, 1981; Lafon *et al.*, 2004) or video records (Lippmann and Holman, 1990; Wijnberg and Terwindt, 1995; Almar *et al.*, 2010). These data sets have their own spatial (alongshore magnitude, difficulty to obtain data in shallow water), temporal (alongshore uniformity) and accuracy limitations. Despite these methodological shortcomings, some conceptual classifications were proposed in literature (Wright and Short, 1984; Lippmann and Holman, 1990; Aagaard, 1991; Short, 1992; Short and Aagaard, 1993; Ferrer *et al.*, 2009) and result in single- and/or multi-bar beach change models. From another point of view, a lot of coastal research efforts are based on 2D morphological field and model studies carried out either in the alongshore or cross-shore direction assuming an alongshore uniformity (Grunnet and Hoekstra, 2004). Both approaches seem oversimplified. The airborne LIDAR (Light Detection and Ranging) technology can reduce some of these limitations and provides a full overview of features over large scale with good spatial and vertical accuracy (Guenther *et al.*, 2000).

The aim of this paper is to provide a detailed and comprehensive distribution of bar morphologies on the wave dominated sandy coast of the Gulf of Lions (France) with LIDAR technology. The typologies are described introducing a new synthesis in accordance with conceptual models of the litterature (Wright and Short, 1984; Short and Aagaard, 1993; Ferrer *et al.*, 2009).

STUDY SITE

The study area is located along the *Languedoc-Roussillon* coastline in the Gulf of Lions (southern part of the French Mediterranean coast). It is a large unit that displays 200 km of coastline with a wide set of morphologies and coastal environments. The curviling coast is oriented North-South between Argelès and Cape Leucate and South-West to North-East between Cape Leucate and La Grande Motte (fig.1). The sand coast displays different bar systems (single or multiple; straight or crescentic) (Barusseau and Saint-Guily, 1981; Robin *et al.*, 2010).

The most frequent wind on the area is north-westerly; but north-easterly to south-easterly may prevail during winter storm conditions. The whole area is microtidal, and characterized by a very low tidal range (< 0.30 m at mean spring tide). Nevertheless, high water level variations are observed in response to set-ups and set-downs under the influence of wind and atmospheric pressure fluctuations. Under specific conditions, set-ups can reach 1 m near the shore (Certain, 2002) under the added action of waves. The significant wave heights (Hs) is generally low (Hs < 0.3 m for 75% of the time at Sète, fig.1) with a peak period between 3 and 4 s. Wave heights larger than 2 m are observed only 10 % of the time with peak period between 5-10 s; they come mainly from 140-220°N associated with sea breeze. The field site is typical wave dominated system (Certain, 2002).

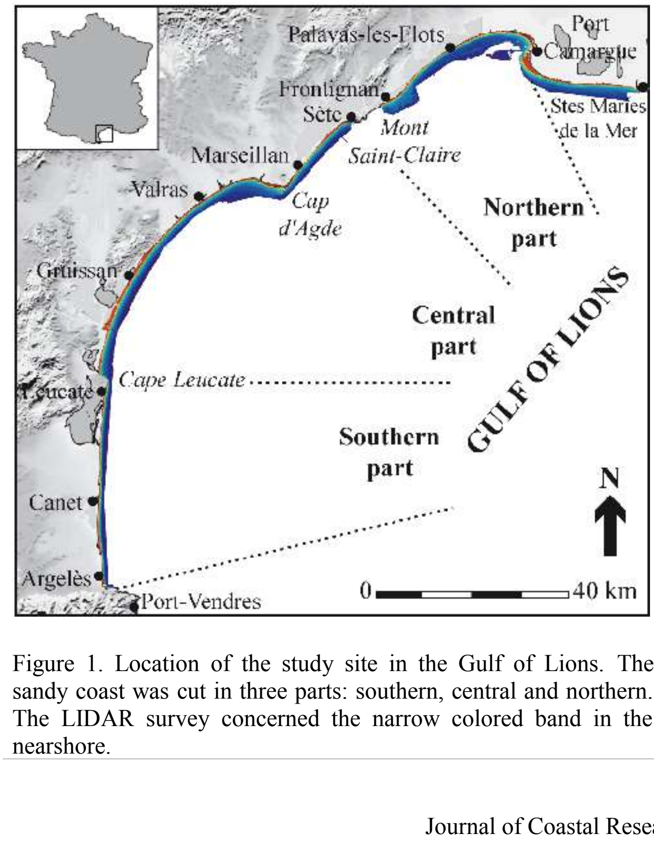

Figure 1. Location of the study site in the Gulf of Lions. The sandy coast was cut in three parts: southern, central and northern. The LIDAR survey concerned the narrow colored band in the nearshore.

Due to the geometry of the coastline, the residual littoral drift is directed northward along the southern part (10 to 40,000 m^3/y) and towards the South-West along the northern part (10 to 100,000m^3/y) (Certain, 2002; Brunel, 2010). The presence of rocky headlands such as Mont St Clair at Sète, Cap d'Agde and Cap Leucate (fig.1) causes total or partial interruption of longshore sediment transports. Superficial sediments are well sorted fine to medium sands (125–320 µm). However, significant cross-shore variations are observed with a general seaward decrease of grain size (Jago and Barusseau, 1981). Longshore variations exist as well. The coarsest sediments are observed in the vicinity of deltaic mouths and localized rocky plateaus in the nearshore zone.

METHODS

A topo-bathymetric LIDAR survey of the *Languedoc-Roussillon* sand coast was conducted from August 24th to September 7th, 2009 at the request of the *Direction Régionale de l'Environnement, de l'Aménagement et du Logement Languedoc-Roussillon* (DREAL-LR). A technical and expertise assistance were operated by the *Service Hydrographique et Océanographique de la Marine* (SHOM), (Vanroye, 2009). This period was chosen because it comes after the several weeks long summer period during which coastal feature well stabilized.

The equipment deployed by EUROSENSE and FUGRO LADS Corporation is the LADS Mk II, hosted on a Dash 8-202 flying between 1200 and 2200 ft. The green laser (e.g. the bathymetric beam) frequency is 900 Hz for a minimal spatiaml resolution around 5 m and a swath width of 240 m. For this survey, the space between lines of flight was 220 m (overlap of 20 m between lines). Transversal flight lines at the coastline were also performed every 5000 m. The collected data extend from the eolian dune to a water depth of -20 m. The total area covered is 300 km^2 with 25 million measured points.

Three areas of bathymetric control were surveyed daily during the whole LIDAR campaign. The pre-validation of measurements was conducted by FUGRO LADS Corp. Furthermore, they made a post-processing of the full dataset including self-made-man corrections in Adelaide (Australia) that was subsequently controlled by the SHOM. Two local GPS stations were installed for the campaign. The tide was specifically monitored at two control points in Port-la-Nouvelle and Port Camargue harbours (fig.1).Tide data from SHOM (Port-Vendres, Sète and Saintes-Maries de la Mer (fig.1)) were used also.

RESULTS

The study area has been divided in three sections: the southern part from Argelès to Cape Leucate, the central part from Cape Leucate to Sète and the northern part from Sète to Port-Camargue (fig.1). The splitting was based on the general morphology of the sand bar systems: crescentic to the South, crescentic (inner Bar (IB)) and straight (outer bar (OB)) in the center and straight to the North.

From the observations performed by LIDAR, a conceptual model of typology of the *Languedoc-Roussillon* bar systems is presented in Figure 2. It enhances different classifications proposed in the literature (Wright and Short, 1984; Lippmann and

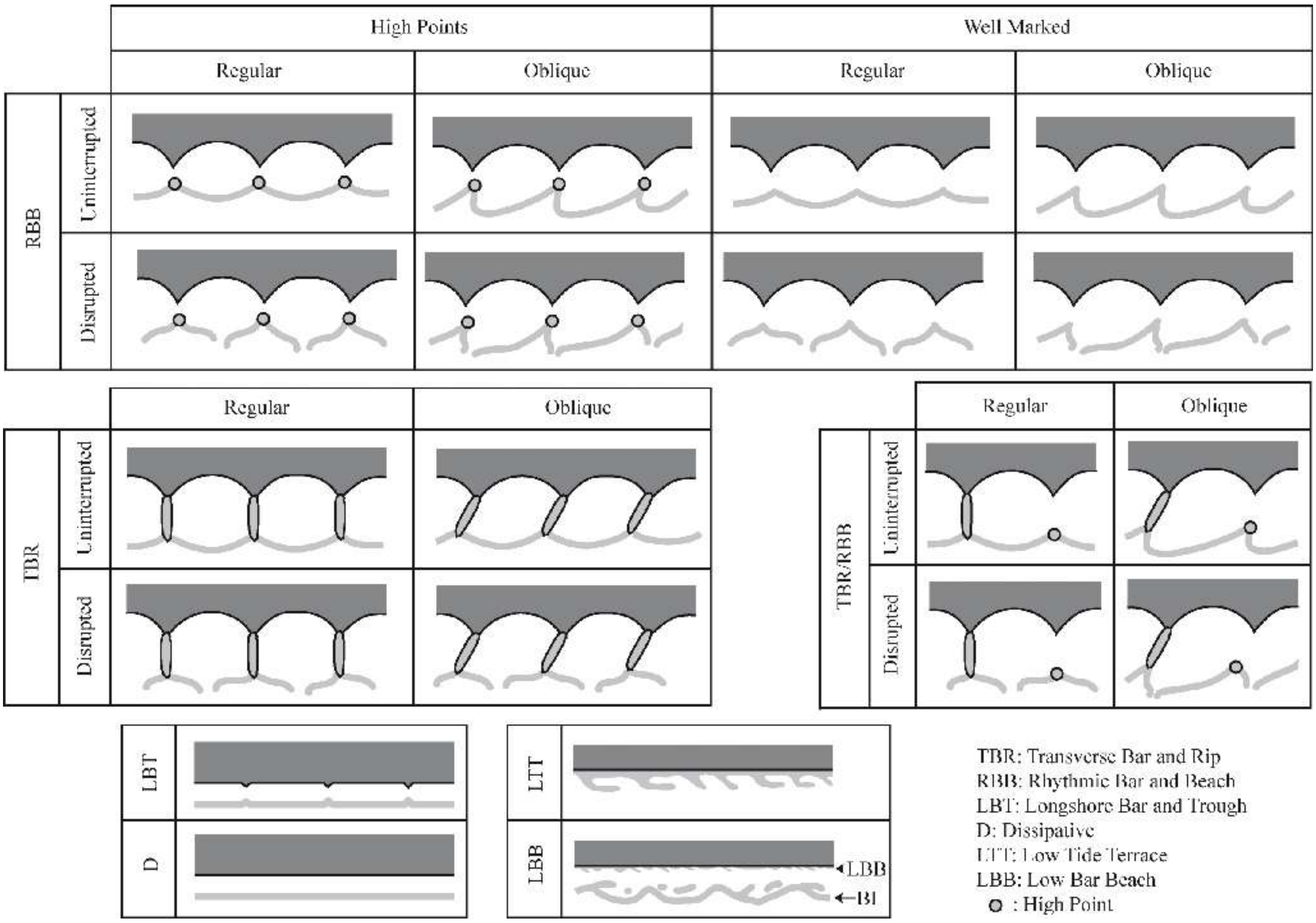

Figure 2. General classification of bar typology observed in *Languedoc-Rousillon*, France (modified from Wright and Short, 1984 and Ferrer *et al.*, 2009). This classification is given for the inner bar, but is also applicable to the outer bar.

Holman, 1990; Short and Aagaard, 1993; Ferrer *et al*., 2009). The classical terminology was used (TBR, RBB, LBT, LTT and D geometry) but some features have been added to give a more accurate description. For crescentic bars, a crescent presents normally two horns. A configuration transition (TBR/RBB) appears when one of the horns of a crescent is connected to the coast or to the previous bar and not the other one (fig. 2). Depending on their orientation with respect to the coast, the crescents can be oblique or regular and can be disrupted or not by rip channels (Ferrer *et al.*, 2009). The RBB typology includes *High Points configurations* when the horn is an important depocenter and *Well Marked configurations* when the horn and the bay have the same sizes (fig. 2 and 3).

A third bar called Low Bar Beach (LBB) was added in this classification. It appears in very shallow waters (< 1m) and is always connected to the shoreline (fig. 2 and 3). This bar displays complex features with a long platform that extend the beach and small transverse bars that can occasionally be connected with the IB (fig. 3a). Its offshore extent is only a few tens of meters unlike LTT inner bars that reach 100 to 150 m (fig. 2). Its presence in shallow water was easily identified with airborne LiDAR while its observation was difficult with conventional techniques. This bar was identified over 25 km of coastline, mainly in the central part

Table 1: Number of each type of crescentic bars for the southern part (from Argeles to Cap Leucate) and central part (from Cape Leucate to Sète). The northern part is not shown because the bar system is almost linear. (IB: inner bar, OB: outer bar).

		TBR						**RBB**										**TBR/RBB**						**ALTOT**
		Regular		Oblique				High Points				Well Marked						Regular		Oblique				
								Regular		Oblique		Regular		Oblique										
		co.	di.	co.	di.	*total*	%	co.	di.	co.	di.	co.	di.	co.	di.	*total*	%	co.	di.	co.	di.	*total*	%	
PartSouthern	**IB**	29	7	4	-	***40***	47.6	7	-	-	-	15	3	5	-	***30***	35.7	9	1	4	-	***14***	16.7	**84**
	OB	26	-	3	-	***29***	33.7	5	-	1	-	16	-	5	-	***27***	31.4	28	-	2	-	***30***	34.9	**86**
PartCentral	**IB**	21	-	4	-	***25***	19.7	33	-	49	-	5	-	-	-	***87***	68.5	8	-	7	-	***15***	11.8	**127**
	OB	1	-	-	-	***1***	2.8	2	-	-	-	28	-	-	-	***30***	83.3	5	-	-	-	***5***	13.9	**36**

IB: inner bar, OB, outer bar, co.: continue, di.: disrupted

Table 2: Extension and percentage of each type of bar for the central part.

		Crescentic	Straight
IB	km	66.9	11.4
	%	*85.4*	*14.6*
OB	km	10.1	68.2
	%	*12.9*	*87.1*

IB: inner bar, OB: outer bar

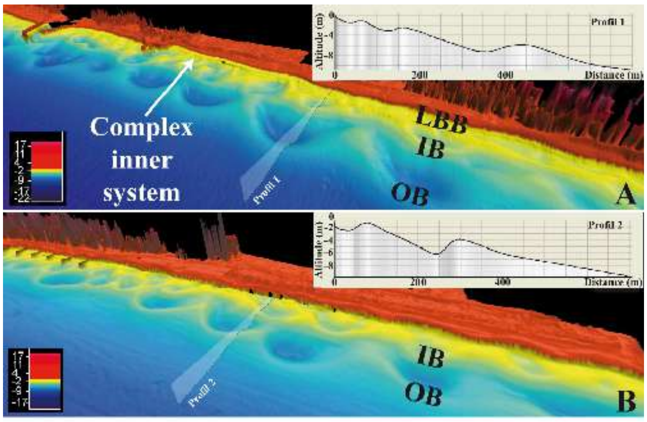

Figure 3. LIDAR imagery of *Languedoc-Roussillon* system bars in the Barcarès-Leucate region. (A) TBR/RBB outer bar and complex inner system with RBB inner bar exhibiting *High Point configuration* and LBB. (B) TBR regular and RBB outer bar displaying *Well Marked configuration* and TBR.

of the study area (between Leucate and Sète), but also occasionally in the South (fig. 1). Its complete description will be the subject of future study. Generally, it is difficult to draw a distinction in the inner system between the two bars due to the presence of remnants old bars. These remnants form high points that can connect to the horns of the bars.

In the southern part (40.5 km of coastline), the inner bar (IB) and the outer bar (OB) are crescentics (fig. 3). The inner bar type alternates between TBR (47.6%) and RBB (35.7%) with many transitions forms TBR/RBB (16.7%) (tab. 1). Eleven disrupted bars were identified in this section, principally between Canet and Cape Leucate (fig. 1). The rip channels disruptions exhibit no preferred orientation. To the South of Canet, and along this segment strictly, the IB is LTT over 4.7 km of coastline. 23 LTT bars were identified with an orientation towards the north in relation with the dominant littoral drift. The outer bar typology is equally distributed between TBR, RBB and TBR/RBB. Only 15.5% of the bars are oblique or dissymmetric with no specific geographical location.

In the central part (78.3 km), the inner bar is mainly crescentic (85.4% of the coastline). Straight bar configuration is observed on 11.4 km (14.6% of the coastline) (tab. 2). For the crescentic configuration, the IB is principally RBB (68.5%) or TBR (20%) with 47% of oblique configuration (tab.1). Unlike the inner bar, the outer bar displays mainly a straight configuration (87.1% of the coastline) (tab.2). The morphology is LBT or D. Only 36 regular crescents (83.3% of RBB) were observed and located to the North vicinity of Cape Leucate. In general, neither inner nor outer bars are disrupted.

The northern part (69.4 km) is different from the previous ones. To the West, the system presents a double straight bar configuration (LBT or D). Eastward, 13 crescents were identified near Palavas-les-flots (fig. 1). Along the Gulf of Aigues-Morte (between Palavas-les-Flots and Port-Camargue), the bar system displays one bar (16.8 km, 24.2% of the coastline) then no bar (8.2 km, 11.8% of the coastline) to the eastern end near Port-Camargue (fig. 1). In this part of Gulf of Lions, the erosion is strong and the sandy prism is reduced; the bedrock comes through at 3-5 meters of water depth.

DISCUSSION

The global distribution of bars (crescentic or straight, one or multi-bars) along the *Languedoc-Roussillon* coast by LIDAR technology is consistent with previous studies performed by Barusseau and Saint-Guily (1981) with partial aerial photographic data and summarized by Certain (2002). These features were also identified thanks to classical typologies classification (Wright and Short, 1984; Lippmann and Holman, 1990; Short and Aagaard, 1993; Ferrer *et al.*, 2009), in spite on the fact that they depict static and idealized states. News states were identified in the existing literature (Brander, 1999; Castelle *et al.*, 2007; Shand, 2007; Wijnberg and Holman, 2007; Ferrer *et al.*, 2009; Almar *et al.*, 2010; Castelle *et al.*, 2010b; Castelle *et al.*, 2010a; Robin *et al.*, 2010). This work completes these observations and proposed a new synthesis of the bar typology.

The inner system shows complex morphologies. It consists of one (inner bar) or two bars (inner bar and low bar beach) and can presented different representations. This is confirmed by Ferrer *et al.*, (2009) that observed during three years on lower spatial scale (Leucate beach, fig.1) similar morphologies to those proposed in figure 2. Although, the Lidar 2009 does not allow to have a dynamic vision of the system, the configurations remain for a significant time. Ferrer *et al.*, (2009) shows that these new states are in fact, transition stages between idealized stats of Shorts and Aagaard classification's. They can persist over long time scales, several months for the inner system to several years for the outer system. State changes resulting from the Hs threshold (1.5m between RBB and disrupted RBB or 2.5m between oblique TBR and oblique RBB for example) but also the direction of waves. In most energetic environments, the transitions of these states seem to be faster (Castelle *et al.*, 2007; Sénéchal *et al.*, 2009; Almar *et al.*, 2010; Gervais *et al.*, 2010). Thus, this study highlights for microtidal environments with low annual wave heights as *Languedoc coast*, the importance that must play these new states on wave propagation, current circulation and exchange of sediments between the beach and the shoreface. These morphologies must be taken into consideration for better understanding of system evolution and its eventual modeling. The next LiDAR survey in 2011 will bring some answers on their dynamics at a large spatial scale.

The 3D pattern of the bar system displayed in the Gulf of Lions discards the 2D approach generally followed previously for field and model studies under the longshore uniformity assumption (Grunnet and Hoekstra, 2004). The close vicinity of various patterns precludes also the only effect of causes like coastal orientation and wave regime (Hs, direction). Other factors must be evoked like the rapidly variable sediment reservoir available revealed by seismic surveys (Certain *et al*., 2005), the average slope of the shoreface, the granulometry of the sandy prism and the substratum morphology (Akouango, 1997). Particularly, regions deprived of sufficient sedimentary stocks can be very sensitive such in the Gulf of Lions (Certain, 2002; Certain *et al.*, 2005; Brunel, 2010). The slope values may also explain locally the number of bars present and especially the appearance of a third bar when the slope is low (Akouango, 1997). Similarly, the particle size influences the number and organization of the bars because it determines the shear stress necessary for the movement of the sediment (Akouango, 1997; Aleman, 2009). These parameters remains to correlate to propose a classification and explanation of the different features highlighted in this study. This concept diverges from the current classifications which are based solely on morphological and hydrodynamic parameters.

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