



Typology of nearshore bar/shoreline couplings and impact on megacusps morphologies

Pierre FEYSSAT ¹, Raphaël CERTAIN ¹, Nicolas ROBIN ¹,
Jean-Paul BARUSSEAU ¹, Olivier RAYNAL ¹, Antoine LAMY ¹,
Bertil HEBERT ¹

1. CEFREM, UMR 5110, Université de Perpignan Via Domitia, 52 Avenue Paul Alduy,
66000 Perpignan, France.
pierre.feyssat@univ-perp.fr

Abstract:

Megacusps generally have wavelengths around hundreds of meters and amplitudes of up to tens of meters. These morphological characteristics are often a reflection of those of the nearshore bars facing them. Just as coupling relationships have been identified between the nearshore bar system, there are also coupling relationships between these bars and the shoreline, often between megacusps and crescentic bars. These coupling mechanisms are important because they influence the shape of the shoreline and can lead to changes in shoreline position with a possible lag effect. At our study site, coupling of the shoreline to the outer bar is observed in 51% of cases, in those moments it shows greater wavelength (≈ 450 m) and amplitude than when coupled to the inner bar (49% of observations) where the shoreline wavelength is then 200 to 450 m with smaller sinuosity amplitudes. The shoreline wavelength range is therefore wider when coupled to the inner bar. The increase in bar wavelengths correlates with those of beach sinuosities. Seasonality in the type of coupling is also visible, with a predominance of inner-bar/shoreline couplings in the summer period.

Keywords: Nearshore bars, Shoreline, Megacusps, Crescentic bar, Morphological coupling, Wave dominated, Microtidal, Gulf of Lions.

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1. Introduction

Beach megacusps generally have wavelengths around several hundred meters and amplitudes of up to several tens of meters (THORNTON *et al.*, 2007). These morphological characteristics are often a reflection of those observed on the opposing nearshore bars (WRIGHT & SHORT, 1984). Just as coupling relationships have been identified between the bars of the nearshore system, there are also coupling relationships between these bars and the shoreline, often between megacusps and crescentic bars (DE SWART *et al.*, 2022). These coupling mechanisms between crescentic bars and megacusps are important because they influence the shape of the shoreline and can lead to changes in shoreline position (THORNTON *et al.*, 2007) with a possible lag effect (DE SWART *et al.*, 2021). Although coupling between crescentic bars and megacusps has been regularly observed and forms an important part of Wright and Short's (1984) conceptual model, most current numerical models use a fixed shoreline (GARNIER *et al.*, 2008). Models in which shoreline and bars can evolve together generally show out-of-phase coupling where the horns of the two objects face each other (e.g. CASTELLE & RUESSINK, 2011), although these studies do not generally focus on these coupling interactions per se. To date, there is no consensus regarding the relationship between the type of bar/shoreline coupling and forcing conditions, particularly in multi-bar systems such as our study site.

With the aim of increasing knowledge on this subject, we focus here on the coupling between the shoreline and the nearshore bars of Leucate beach, in an attempt to determine the parameters controlling sinuosity and their relationship with the bar system.

2. Study area

The Leucate beach (2.8 km long) is described as intermediate ($\Omega=3.7$), with a permanent double crescentic nearshore sandbar system giving an undulating pattern to the shoreline (ALEMAN *et al.*, 2011). The inner bar is located around 200 m from the shore at a depth of between -1 and -2 m, with a wavelength of around 300 m. The outer bar is located around 600 m from the shore at a depth of around -5.5 m, with a wavelength of around 600 m (ALEMAN *et al.*, 2011, Figure 1b). Similar systems of double crescentic bars are found throughout the southern sector of the Gulf of Lions, approximately 65 km from Argelès-sur-mer to the south to Port-la-Nouvelle to the north (Figure 1a). The offshore wind (Tramontane) is dominant (60% of the time, speed up to $30\text{m}\cdot\text{s}^{-1}$, Figure 1c). The onshore wind is less frequent (30% of the time), significant wave heights (H_s) are generally low ($H_s < 1$ m for 75% of the time, Figure 1c), with a period of around 4 s. During storms (about 7–8 events are reported per year), H_s are higher than 2 m and can reach nearly 6 m with peak periods between 5-10 s. A certain seasonality can be observed in these forcing regimes: in summer, sea breezes are frequent, while late autumn, winter and spring are characterized by more violent

onshore wind events, punctuated by storms induced by sea winds. Although classified as a microtidal environment (tidal range < 0.30 m at mean spring tide), large variations in water level are possible in the Gulf of Lions during storm events (surge > 1 m).

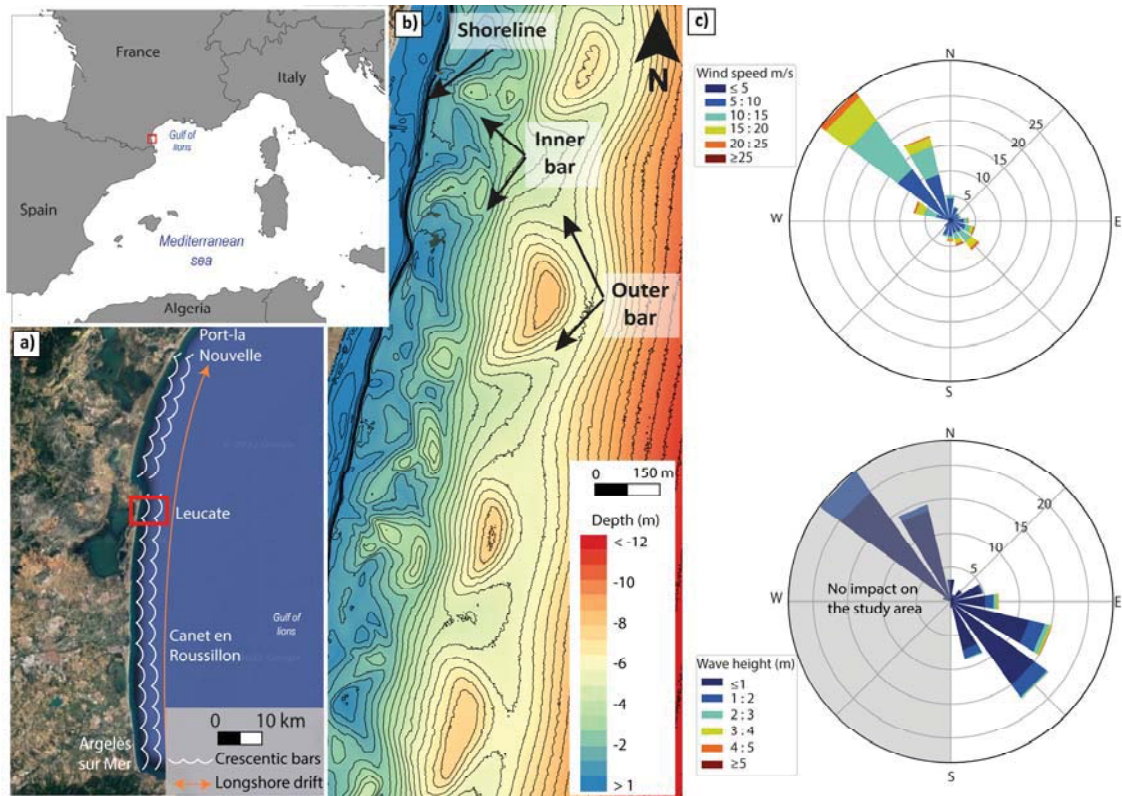


Figure 1. Nearshore bar typology in the southern area of the Gulf of Lions (a), topobathymetric map of the Leucate study site (b). Average forcing conditions at Leucate over the period from 2006 to 2021(c).

3. Methods

Hydro-meteorological forcing conditions are given by the Leucate swell buoy (Cerema) and by MétéoFrance for the wind (Leucate station). The nearshore area morphology is characterized by visual inspection using several data sources, such as: large spatial scale LiDAR (Litto3D campaigns), bathymetric surveys, satellite images (Landsat 5, 7, 8, 9, Sentinel 2), and occasional video surveys. Assuming that the shoreline is coupled to a bar of close wavelength, which imposes its mark on the shape of the shoreline through the hydrodynamic pattern it creates, it is attempted to determine the coupling relationships by comparing the wavelengths of the bars with that of the shoreline. For example, for a shoreline whose sinuosities have a wavelength of 450 m, with an inner bar having a wavelength of 400 m, and for an outer bar having a wavelength of 650 m, inner bar / shoreline coupling is assumed. According to the literature, there are three types of coupling (DE SWART *et al.*, 2022): out-of-phase (where the horns are facing

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each other), in-phase (where the patterns are expressed in parallel) and downwave (slight offset of the bar downstream of the drift current with respect to the coastline pattern, starting from an out-of-phase configuration).

4. Results and interpretation

4.1 Coupling between nearshore bar system and megacusps

In our observations, the proportion of coupling is balanced, with 51% of megacusps coupled to the outer bar and 49% to the inner bar. Couplings to the inner bar seem to be more prevalent in summer (Figure 2a). If we focus on the types of coupling for a single bar and their seasonal distribution, for the inner bar, the dominant coupling is out-of-phase (65%, Table 1), often present in the summer period when forcings are weaker (Figure 2b, d). In-phase coupling (19%, Table 1) is most often found in early summer (Figure 2b). Downwave types (16%, Table 1), which are higher-energy but mainly oblique swell forms, are more likely to be found outside the summer period, or during the latter, when small SE swells dominate the forcing (Figure 2b, d). We notice that the most common type of coupling when megacusps are coupled to the external bar (Table 1) is Downwave (51%, Table 1), which is found during the more energetic winter period (Figure 2c, d). In-phase coupling (32%, Table 1) is most often found outside the winter period between March and September (Figure 2c). Finally, out-of-phase coupling (17%, Table 1), which is not very well represented, is expressed in a minority, mainly in summer, autumn and early winter (Figure 2c). Although there appears to be a seasonal pattern in the distribution of coupling types, it may be difficult to draw clear conclusions about the relationship between offshore forcing conditions (wave height and direction) and the resulting type of bar/shoreline coupling. A wide dispersion of coupling types is observed, whether in relation to wave heights or direction (Figure 2). However, for inner-bar/shoreline coupling (Figure 2a), downwave appears almost exclusively for incidences of $+20^\circ$ to $+40^\circ$ (i.e. south-east) for low to medium-intensity swells ($<2\text{m}$). In-phase coupling is found for swells more normal to the beach (between 0° and 30°), for intensities that are always fairly low ($<2\text{m}$). In the most common case, out-of-phase coupling, swells sweep across the entire spectrum of possible directions between -20° and $+40^\circ$ (northeast to southeast), but unlike the other two, it can be observed in the -20° - 0° range (northeast), which generates powerful, frontal swells at the study site. As far as the outer bar/shoreline coupling is concerned (Figure 2b), it is much more difficult to observe trends, although out-of-phase and in-phase are only found in the 0° to $+30^\circ$ (east to south-east) quadrant of offshore wave propagation, while downwave can also affect the -20° - 0° (north-east) quadrant. Out-of-phase is concentrated on more frontal swells (between 0° and 20°), while the others dominate at higher incidence, particularly in the positive quadrant.

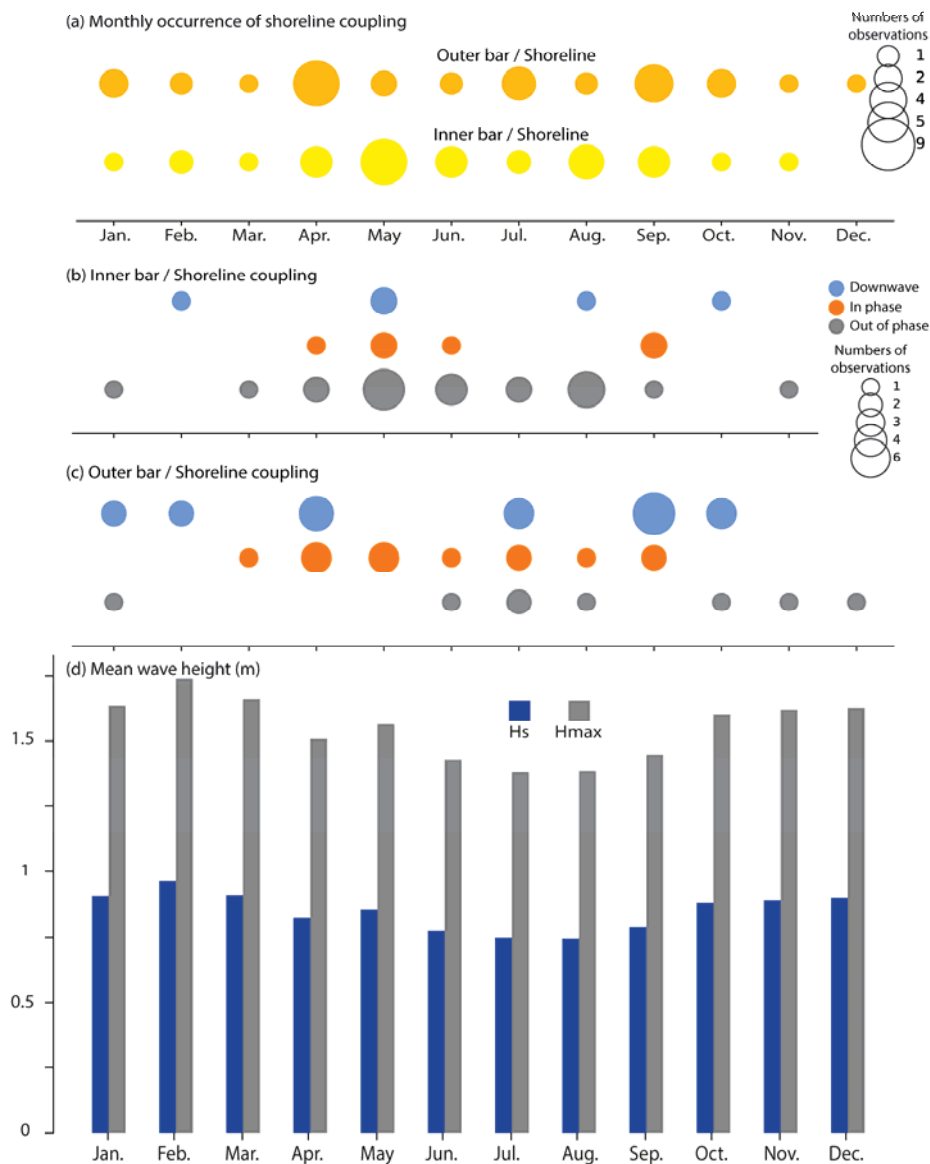


Figure 2. Observations of shoreline coupling with internal or external bar (a). Number of monthly occurrences of inner bar/shoreline coupling (b) and outer bar/shoreline coupling (c). Average monthly wave conditions over the study period (d).

Table 1. Proportion of each coupling type according to the bar to which the shoreline is coupled.

	<i>Outer bar</i>	<i>Inner bar</i>
<i>Downwave</i>	51 %	16 %
<i>In phase</i>	32 %	19 %
<i>Out of phase</i>	17 %	65 %

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4.2 *Coupling impact on shoreline morphology*

If we consider that the shoreline can only be coupled to one of the two bars, two situations emerge with regard to the impact of bars on shoreline morphology. If the shoreline is coupled to the outer bar ($L=450-650$ m), the wavelength of the beach megacusps will average around 450 m (Figure 3a), i.e. rather the low range of outer bar crescent size, but can approach their average size with wavelengths of 500 m to 600 m, following a linear relationship (Figure 3a). Overall, the greater the wavelength of the outer bar crescents, the greater the wavelength of the resulting megacusps.

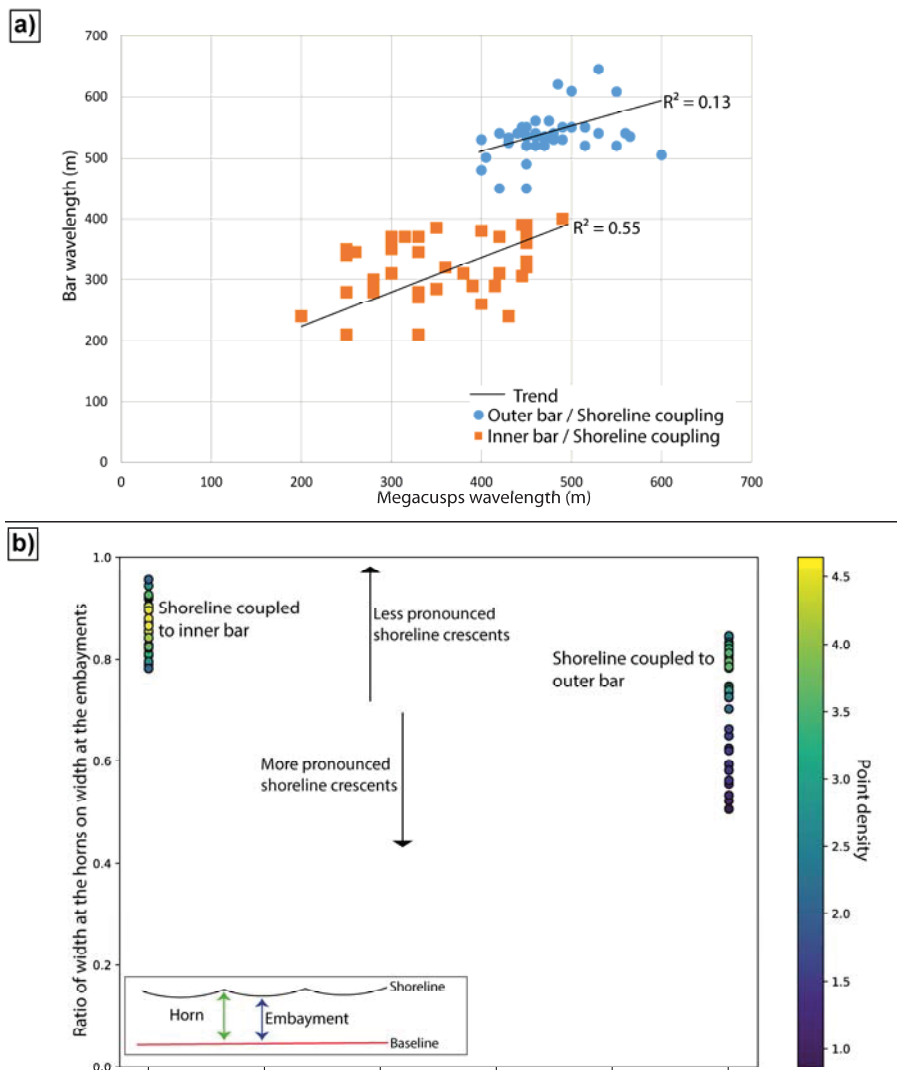


Figure 3. a) Shoreline wavelength plotted against the wavelength of the bar to which it is coupled: inner bar coupling (orange), outer bar coupling (blue). b) Ratio of beach width at a horn or bay as a function of whether the shoreline is coupled to the inner bar (left) or the outer bar (right). The closer the value is to 1, the more linear the morphology. Color indicates point density, with blue indicating few points and yellow more.

On the other hand, megacusps may be more pronounced as they point further out to sea (Figure 3b) in the event of coupling with the outer bar. If the shoreline is coupled to the inner bar ($L=200-400\text{m}$), the megacusps pattern may be less pronounced (Figure 3b) and its wavelength may be of the order of 250 to 400 m, also following a linear relationship, better expressed than for the inner bar. We also note that the range of possible wavelength values is greater when the coastline is coupled to the inner bar (200m to 400m) than when it is coupled to the outer bar (Figure 3a). Finally, there is a zone of overlap in shoreline wavelengths where between 400 and 450 m, it can be coupled to both the inner and outer bar (Figure 3a); the difference is then expressed in the amplitude of the megacusps, which will be more pronounced when coupled to the outer bar.

5. Discussion

5.1 Type of coupling according to forcing conditions

The downwave coupling is predominantly expressed on the outer bar (51%) and little on the inner bar (16%). This can be attributed to a swell that is often oblique and of medium to high intensity at the entrance to the system, generating a sinuous drift current on the bar that overrides the rip-cell circulations, resulting in a slight downstream offset of the bar horns in relation to the beach megacusps (MACMAHAN *et al.*, 2010). Out-of-phase coupling is largely expressed for the inner bar (65%) and very little for the outer bar (17%). As this type of coupling develops during low-intensity waves, favoring two-cell circulation (COCO *et al.*, 2020). This is often the case on the inner bar, since this is where the low-intensity swell hits, and is protected during the most energetic episodes by the filtering effect of the outer bar. As the outer bar is deeper and unprotected, it is only activated during the most energetic conditions. Finally, medium- to high-intensity frontal swells create in-phase couplings, logically more common on the outer bar (32%) subjected to offshore swells than on the more sheltered inner bar (19%), this time favoring single-cell circulation (DE SWART *et al.*, 2022). In conclusion, the bar/shoreline coupling mechanisms at Leucate broadly follow the process hypotheses described in the literature.

5.2 Impact of coupling types on shoreline morphology

Regarding the impact of couplings on shoreline morphology, several observations emerge from our work. The shoreline shows megacusps whose amplitude and wavelength (between 300 m and 600 m) can vary greatly, but are always present. Periods of linear shorelines are not observed, as they are at other Mediterranean sites (e.g. DE SWART *et al.*, 2022). This persistence of the crescentic pattern is related to the persistence of the same pattern in the nearshore bars. Here, the shoreline is coupled to the outer bar in a large proportion (51% of observations), which is rather exceptionally

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described in previous studies (GOLDSMITH *et al.*, 1982). It then shows a greater wavelength and amplitude (Figure 4a) than when coupled to the inner bar (Figure 4b). In addition, there is an overall linear relationship between the increase in bar wavelengths and sinuosity wavelengths. This is in line with studies showing a strong correlation between megacusps wavelengths and those of bars with which they are coupled (e.g. GOLDSMITH *et al.*, 1982).

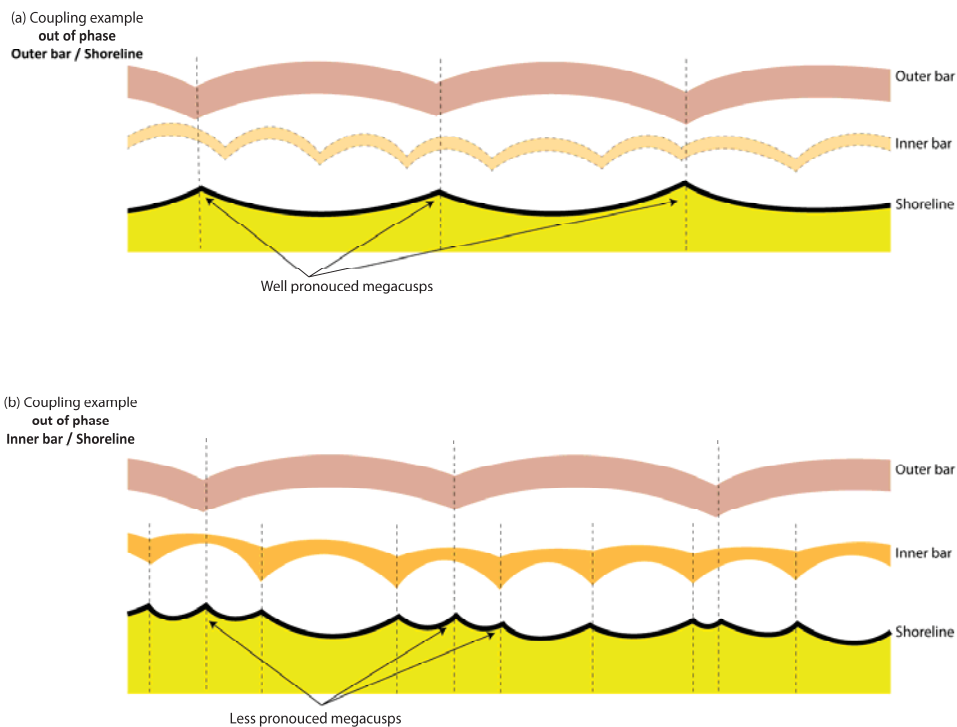


Figure 4. Out-of-phase coupling between a) the outer bar and the coastline; b) the inner bar and the coastline at the Leucate site.

5.3 Possibility of simultaneous of shoreline coupling with both bars

To simplify the analysis, only the coupling of one bar with the shoreline has been retained. However, the relationships could be more complex, and the shoreline could be controlled both by the outer bar, which would impose large, well-marked crescentic patterns (Figure 4a), and by the overlapping advances of shorter wavelengths controlled by the inner bar (Figure 4b). This configuration could be observed at the end of winter, with the establishment of large megacusps during major storms and the start of secondary sinuosities linked to weaker spring and summer forcing. The results also show that the point clouds in Figure 3a overlap at wavelengths between 400 and 500 m, suggesting that beach sinuosities in this range may be related to either the inner or outer bar. This work remains to be done.

6. Conclusions

The shoreline / outer bar coupling is observed in 51% of cases on Leucate beach, in these moments it shows a longer wavelength (≈ 450 m) and amplitude than when coupled to the inner bar (49% of observations) where the shoreline wavelength is then 200 to 450 m with lower sinuosity amplitudes. The shoreline wavelength range is therefore wider when coupled to the inner bar. The increase in bar wavelengths correlates with those of beach sinuosities. Seasonality in the type of coupling is visible, with a predominance of internal bar/shoreline couplings in the summer period. However, further work is required on several aspects, in particular on the possible simultaneous control of several bars on shoreline morphology, as well as the impact of coupling type on the beach (impact on sediment budgets) or the dunes (impact on dune foot erosion).

7. References

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