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Hydrodynamics over a microtidal double crescentic barred beach in low energetic conditions (Leucate Beach, France)

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ABSTRACT

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The south part nearshore zone of the Gulf of Lions coast (Mediterranean Sea) is characterized by a double crescentic sandbar system. During the winter 2007, a campaign of intensive hydrodynamical measurements (current profiles) was realized. During this campaign, based mainly on ADCPs, the maximal recorded wave height was 1.5 m. Four events were observed; two of those had northern incidence, one with southern incidence and a last one with frontal incidence. This paper proposes 3D hydrodynamical circulation maps over this microtidal bar system. The currents described reveals rip, bed-return and longshore currents strongly influenced by the wind-waves forcing and the bathymetry. At the apex of the oblique incidence events, the longshore component is the most important. The breaker zone is only located over the inner bar. During storm waning conditions, the cross-shore currents appear over the trough of the outer bar. The hydrodynamic circulation is then compared with other observations made in the literature.

ADITIONAL INDEX WORDS: *Wave, Current, Rhythmic Bar and Beach, nearshore zone, current profiles*

INTRODUCTION

Most of modern sandy coasts display nearshore bars organized in single or multi-bars systems. The morphological features are identified according to the usual bar classification of Wright and Short (1984) recently bettered (Ferrer et al., 2009; Ferrer, 2010). Investigations on Sandbars are important in the understanding of wave breaking and hydrodynamic circulation on the shoreface. The hydrodynamic circulation over a Rhythmic Bar and Beach (RBB) system is a complex pattern displaying craven by bed-return flows, rip currents (MacMahan et al., 2006) and longshore drift. Generally, hydrodynamic circulation is characterized in one point of the water column. The main objectives of this work are i) to characterize the hydrodynamic circulation in 3D based on ADCPs current profiles over a microtidal double crescentic barred beach under low and moderate energetic conditions, . ii) to portray the relative influence of both marine currents and wind. The originality of this study consist in the setting of instruments all over an outer crescentic feature. The recorded data increase the database of the hydrodynamical atlas for the Interreg European program BEACHMED-e.

SETTINGS

Leucate Beach (figure 1), lies in the Gulf of Lions (northwestern part of the Mediterranean Sea). This microtidal environment (mean tidal range lower than 0.3 m) is classified as a wave-dominated coast (annual mean of the significant wave height close to 0.6 m) with strong offshore and onshore winds. The shoreface is constituted by two bars with a RBB

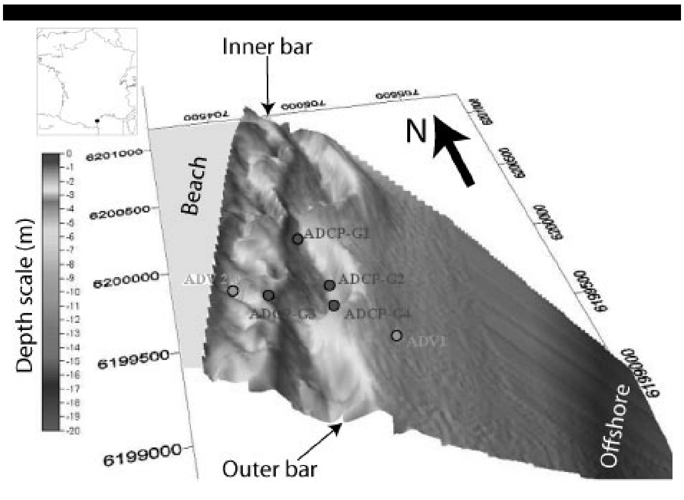

Figure 1. Bathymetric map of the study zone, showing the system of double bar of Leucate Beach and the position of the instruments during the hydrodynamic campaign (ADCPs in red and ADVs in green).

configuration. The outer bar is located at 500 m to the coast, has a wavelength of ~ 600 m and is between 4- and 7-m deep (Ferrer, 2010). The inner bar is located 150 m from the coast, has a wavelength of ~ 300 m and is between 1.5- and 2.5-m deep (Ferrer, 2010). The shoreline presents megacusps with horns distant of 600 m (Ferrer, 2010).

METHODS

A monthly bathymetric survey was performed for more than two years. In January-February 2007, an intensive hydrodynamic survey was carried out to complete the morphodynamic data set, over a zone including one entire outer crescentic feature (L ≈ 600 m) associated to two half crescentic features, and a cross-shore profile until the shoreline to the beach apron. The data was collected using 4 ADCPs (Teledyne RD Instruments Sentinel: 600 and 1200 Hz), 3 ADVs (Nortek Vector) from the GLADYS platform (figure 1) and 1 Datawell buoy in front of Leucate Beach, located at zone depth close to 40 m (DREAL LR). The acquisition was made with a frequency of 2 Hz, during 40 minutes with an interval of 3 hours. During this survey, no significant morphological changes were recorded.

RESULTS

Using the data of the Datawell buoy and the ADV located at the entry of the system, this study focuses on four hydrodynamic events (Table 1). Two of them had a northern incidence (oblique incidence), one was frontal and the last one came from the south (oblique incidence again). These events had significant wave height ($H_{1/3}$) between 0.7 and 1.5 m. During this campaign, the wave breaking was observed over the horns of the inner bar, defining a surf zone of 100 m wide for events with $H_{1/3} \geq 1$ m.

Table 1: Characteristics of the hydrodynamic events recorded during FEST1 campaign.

Day	Waves direction (°)	$H_{1/3}$ (m)	Period (s)
22/01/2007	140	1,2	6
24/01/2007	35	1	6
25/01/2007	50	1,5	7
30/01/2007	80	0,7	6

Southern oblique incidence

The 22/01/2007, the wind had an incidence of 150° and speed close to 10 m/s. $H_{1/3}$ reached a maximum value of 1.25 m, at 18PM, displaying a wave breaking mainly on the horns of the inner bar. At the maximum of the energetic conditions, the peak of the wave spectrum was 0.18 Hz with an energy density of 1.6 m²/Hz. No energetic peak was observed in the infragravity band of the wave spectrum.

The observed currents had northern direction and speed between 0.15 and 0.2 m/s in the water column and 10 and 15 cm/s near the bottom at the ADV3, at the coast (Figure 2). They displayed a major longshore component in the wind-waves direction (Figure 2). The bathymetric influence appeared in the shallow water (0, -3 m) displaying directional variations of the currents in the water column. The currents recorded with ADCP G1, located on the southern horn of the outer bar, showed a small cross-shore deviation to the coast during the maximum of the event. Simultaneously, the currents recorded with ADCP G4, located on the northern horn of the outer bar, showed an oblique direction following the morphology of the crescentic feature. The same

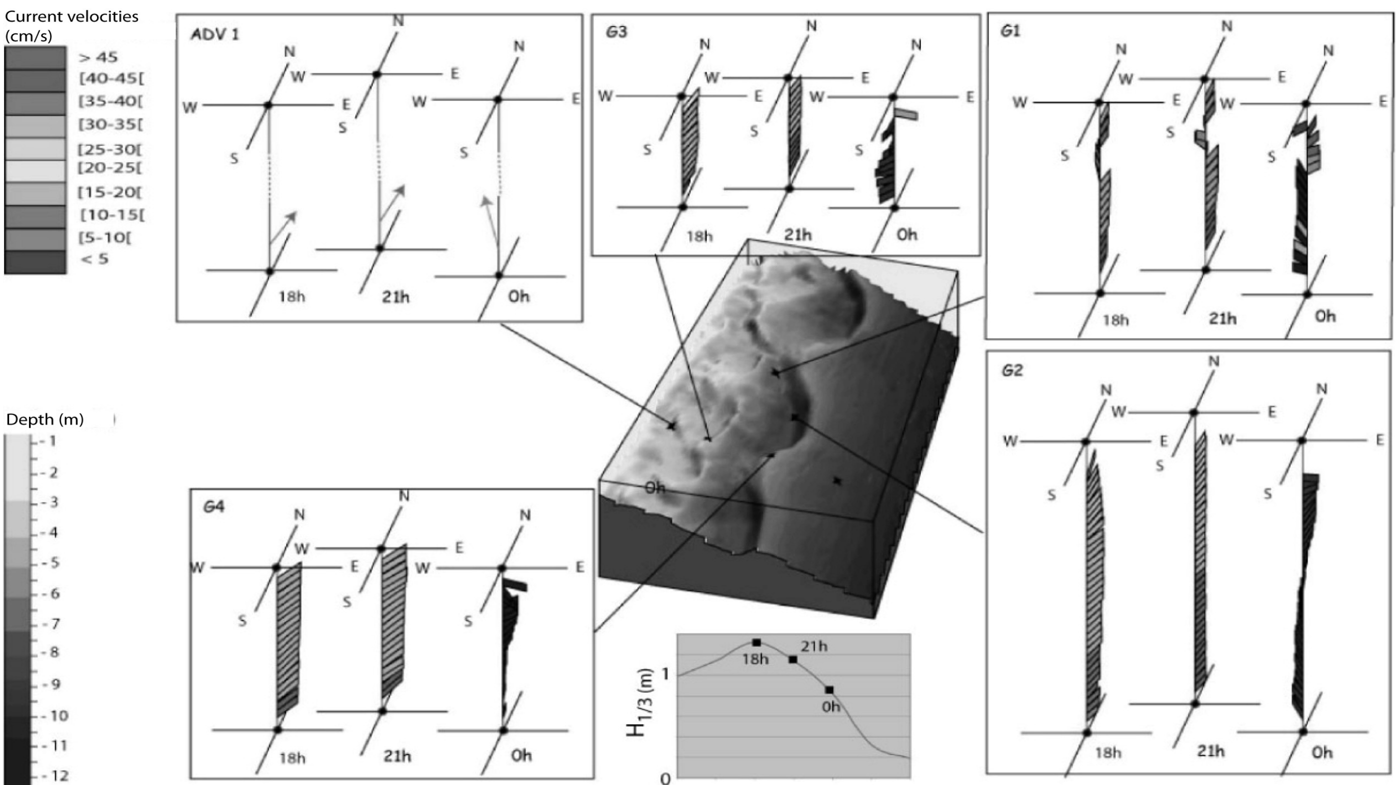

Figure 2. Hydrodynamic map of the current profiles over Leucate Beach bar system during the 22/01/2007 event, based on ADCPS measurements and ADVs.

component was observable at the ADCP G3, on the horn of the inner bar (Figure 2). During the storm waning conditions (21PM to 0AM), the currents were less intense and displayed a cross-shore component offshore in the upper part of the water column (ADCPS G2 & G4) (Figure 2).

Northern oblique incidence

The event of the 25/01/2007 was the most characteristic of the two events of northern incidence and is only presented in this study. The maximum of the event happened between 9AM and 12PM, $H_{1/3}$ had a maximum value of 1.5 m associated to northeastern wind with average speed of 15 m/s (Figure 3). This event was the most energetic with an energy density peak of 2 m²/Hz at a frequency peak between 0.15 and 0.20 Hz. In details, this wave spectrum displayed a small energy density peak, 0.4 m²/Hz, in the infragravity domain (0.075 Hz), more visible at 12 PM than 9AM.

During the peak of this event, the currents values oscillated between 0.3 and 0.5 m/s and were directed to the south all over the water column, in the same direction as the wind propagation (Figure 3). The velocities of the currents were maximum over the inner bar and decreased offshore. The bathymetric influence was less important on the hydrodynamic circulation than for the event of southern incidence. When the energetic conditions decreased, a cross-shore component appeared in the lower part of the water column and over the outer bar with current velocities about 0.1 m/s (ADCPs G1, G2, G4) (Figure 3). At the coast, the velocities of the currents were higher (0.4 to 0.5 m/s) than the southern incidence case. The longshore component was always important but a small deviation was observable near the coast. This cross-shore component could be interpreted to the bed-return current (Figure 3).

Frontal incidence

This event had an eastern incidence. The maximum happened at 9AM, $H_{1/3}$ had a maximum value of 0.7 m associated to northeastern light wind with average speed of 5 m/s. The wave spectrum displayed two wide energetic peaks at frequencies between 0.17 and 0.2 Hz, with an energy density peak of 0.65 m²/Hz.

During the apex of this event, the currents had low velocities, between 0.05 and 0.1 m/s. In the water column, a longshore component was linked to the wind incidence and not to the wave incidence. Close to the bottom, near the ADCP G4, the major component was cross-shore and directed offshore. The ADVs located to the coast showed a more important cross-shore component than the longshore one. This cross-shore component seemed to be more developed than in the precedent oblique energetic events, even if $H_{1/3}$ was higher.

INTERPRETATION

The storms with oblique incidence and low to moderate energy ($H_{1/3}$ lower than 2 m) displayed mainly longshore currents directed in the same direction of incidence waves and wind.

At the entry of the system (ADV 1), on the outer slope, the longshore currents appeared at the maximum of the storm. They

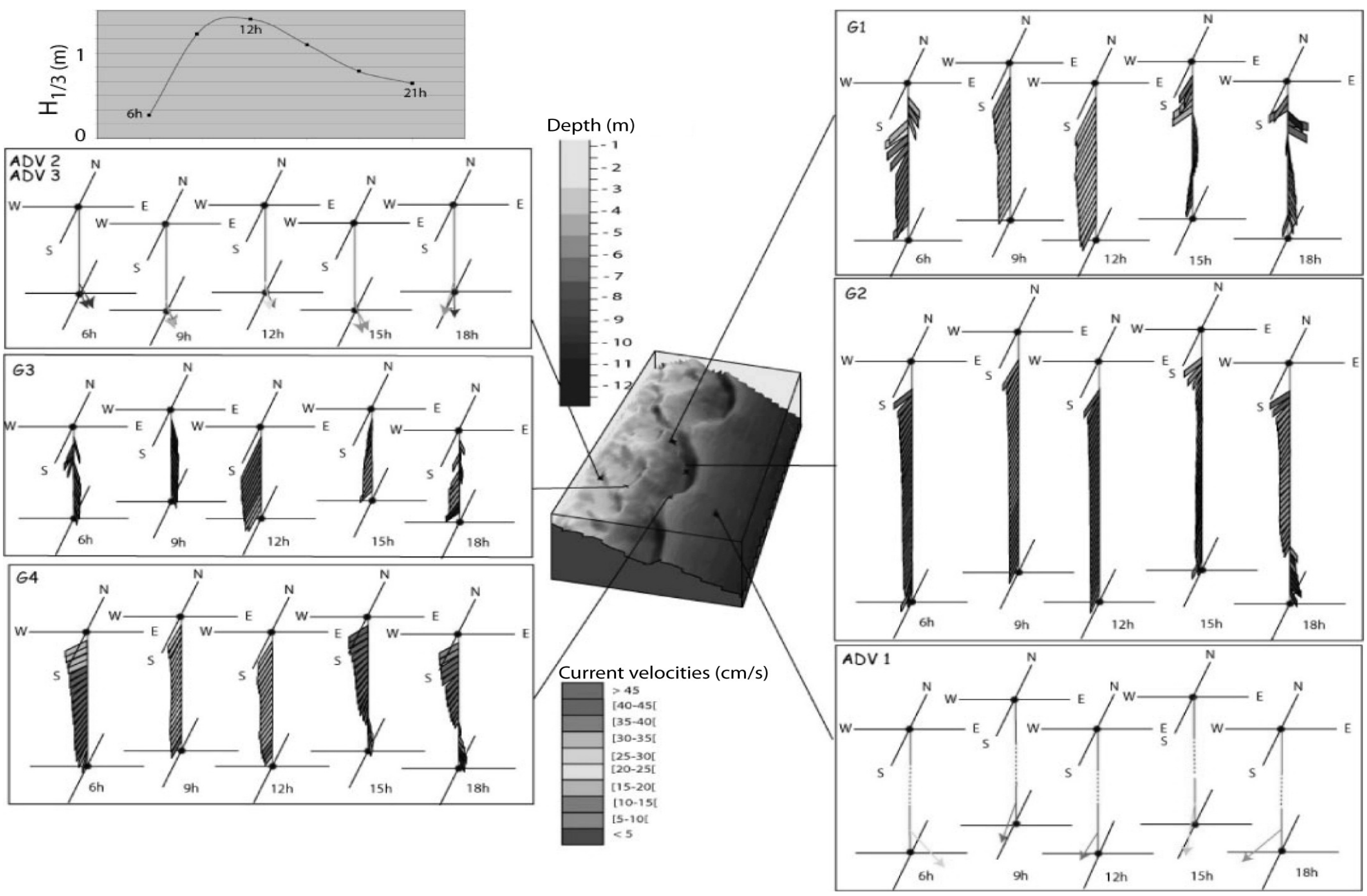

Figure 3. Hydrodynamic map of the currents profiles over Leucate Beach bar system during the 25/01/2007 event, based on ADCPS measurements and ADVs.

were observed over the outer bar system too, outside the surf zone. The inner bar system circulation was however controlled by waves breaking and longshore drift. The outer system seemed more controlled by wind than waves. The velocities of the currents were relatively uniform all over the water column, maybe linked to the wind forcing. Near the bottom, the currents were less intense, maybe due to the friction forces or the decreasing influence of the wind.

Bed-return flows were observed near the bottom and directed offshore in front of the horn of the outer bar. These currents decreased during the storm waning conditions. At 22/01/2007 and 25/01/2007, the bed-return flows were more important in the second event. These currents were also under the influence of the morphology of the inner bar. They were more intense in the channeled structures of the inner bar, in the trough.

Low energetic rip currents were observed. They were more significant during the storm waning conditions and not during the maximum intensity of the event. Using the position of the instruments, it is not possible to determine if the current intensities were more important over the inner bar or the outer bar and where they developed.

No infragravity waves were recorded certainly due to the low energetic conditions during the campaign. The small peak recorded during the northern incidence event was the only mark of infragravity. The energy density peak was too small to have a significant role on this system. The role of the infragravity waves in the intensity variations of the currents (McKenzie, 1958; Chappell & Wright, 1978) cannot thus be analyzed in this study.

To resume the hydrodynamic circulation during low to moderate energetic events within microtidal wave dominated site, the maximum velocities were recorded in the surf zone, over the inner bar system. The two components, longshore and cross-shore, were expressed at different moments. At the maximum of the event, the longshore component appeared in the longshore drift. During the storm waning conditions, the cross-shore component of the rip currents was more important. Bed-return flows were more intense near the coast (ADV 2 and ADV 3). The bathymetric influence can be felt in the structuration of the bed-return currents. The hydrodynamic circulation over the outer bar was not very active during this campaign. The wind seemed to influence the longshore circulation. This circulation was moreover relatively uniform in the water column.

DISCUSSION

Rip-currents

The recorded significant wave heights during the campaign do not allow the observations of intense rip currents over the outer bar. The position of the instruments over the inner bar does not allow a detailed interpretation of the hydrodynamic processes at the coast.

Despite the low energetic conditions, the event recorded the 22/01/2007 at Leucate Beach, low intensity rip currents were observed in storm waning conditions over the trough of the outer crescentic features, as the model described in the bibliography (Van Rijn, 1998; Wright & Short, 1984; Short, 1999, MacMahan et al., 2010). The intensities (0.05 to 0.5 m/s) are less significant than those of others studies (Masselink & Hegge, 1995; Aagaard et al., 1997; Froidefond et al., 1990).

This type of currents can be responsible of small bathymetric variations, despite their low intensity (MacMahan et al., 2006; MacMahan et al., 2008). In this site, the rip-currents could be responsible of the crest break of the inner bar bay (Ferrer et al 2009).

Bed-return currents

The event of the 25/01/2007 showed bed-return currents, directed offshore over the trough of the outer bar, and surface currents directed to the north showing the influence of the association of waves and wind sea incidences which can disable the generation of rip currents (Sonu, 1972).

The values of the observed bed-return flows (0.1 to 0.2 m/s) are compatible with those described in the results of other studies from numerical modeling (Sallenger et al., 1983; Haines & Sallenger, 1994; Masselink & Black, 1995). These currents seem to be maximal over the horns and the crest of the sandbars, where the water column is shallower and the waves break (Greenwood & Osborne, 1990; Osborne & Greenwood, 1990; Smith et al. 1992; Smith, 1994).

Longshore currents

The longshore drift in the surf zone is less important than the one described in the previous studies on other sites but the low energetic conditions are the explanation. This current is well known by experimental or numerical modeling (Bowen & Inman, 1969; Longuet-Higgins, 1970a and 1970b) in the upper water column or the surface (Abadie et al., 2006; Silva et al., 2007). In Leucate beach, the velocities are maximum over the crest of the inner bar where the depth is minimum in agreement of the theory developed by Thornton & Guza (1986, 1989) but in disagreement with the in-situ measurements (Greenwood & Sherman, 1986; Smith et al.; 1993) where the maximal intensities are observed over the trough of the bar systems as at Sète (Certain and Barusseau, 2005).

In this study, moderate longshore currents are also observed outside the surf zone due to onshore wind oblique forcing. All over the water column, they do not undergo directional variations at the maximal intensity of the event and seem to be uniform. Maybe under low energetic conditions, the currents induced by wind are an important factor of the longshore component generation in the upper part of the water column. We can note that the current velocities are maximum in shallow water zone or in the upper part of the water column for depth higher than -6 m. The intensities decrease with depth. When the wind intensities decrease, the current velocities decrease too.

CONCLUSION

These original results highlight the prevalence in the circulation of the longshore current link to the swell incidence and the stability of the bathymetry under low energetic conditions. The onshore oblique wind seems also to have a strong impact on the general hydrodynamic circulation on the shoreface as longshore currents are also observed offshore the surf zone. The low intensities of the events do not allow the observation of strong rip and bed-return currents over Leucate Beach system (outer bar in particular, located 450 m offshore at -8 m deep), so the comparison with other systems are difficult to realize even if obtained several currents profiles simultaneous is clearly new.

Despite the low energetic conditions, the interpretative scheme of the hydrodynamic circulation over Leucate Beach system correspond to those described in the literature (Van Rijn, 1998 ; Castelle et al., 2010 ; MacMahan et al., 2010). However, the superimposing of two crescentic inner and outer bars keep the system more complex than those described in the bibliography. On the inner bar, the currents directed to the open sea in the bay can disrupt the crest of the crescentic bar creating channeled structures and new beach state (Ferrer et al., 2009).

PERSPECTIVES

The results will now be used to calibrate numerical modelling as SHORECIRC (Bujan, 2009) and to create hydrodynamic maps of the circulation under high energetic conditions. To validate this numerical model, a new survey seems to be necessary to record hydrodynamic circulation under high energetic conditions ($H_{1/3}$ between 1.5 and 5 m).

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