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Upper beach reconstruction patterns after moderate storm events

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Abstract:
The wave-dominated beach barrier of Villeneuve-Lès-Maguelone extends between Palavas and Frontignan (Gulf of Lions, northernmost Mediterranean Sea), along a slightly natural sandy protected area characterized by typical and well-expressed morphologies. In the nearshore, the sea bottom shows one or two approximately rectilinear sand bars. In 2010-2011, we performed a 6 month-long monitoring (autumn 2010/late spring 2011) of a 500 meter-long segment along this sand barrier. We used RTK D-GPS offering centimeter resolution to acquire sets of elevation data on the beach and the upper shoreface. The study is innovative because a full morphologic monitoring was performed each time the wave/ wind conditions changed significantly. These changes were tracked in real-time thanks to a set of hydrodynamic equipments deployed at sea, including well-known DREAL buoys. We identify from well-documented data: (1) a beach reconstruction cycle at the shoreline after a moderate storm event (wave height at 3-4 m) and (2) how a sand bar in the nearshore migrates to the shoreline and drives the shoreline shift.

Keywords:
Shoreline – Swash zone – Morphological patterns – Beach reconstruction

1. Introduction

Barrier island systems arise from the intimate interaction of a nearshore domain (LIPPMAN & HOLMAN, 1990) and an emerged beach (SHORT, 1999) which are both constantly driven by the action of waves. However, the morphodynamics at their seaside

boundary -the shoreline- is not so well understood and is less documented (MASSELINK & PULEO, 2006).
Seasonal cross shore migration of sand bars in the surf zone (ELGAR *et al*., 2001) shows offshore tendency (up to 10 m/day) during storms and onshore tendency (only up to 1m/ day) during fair weather (CERTAIN & BARUSSEAU, 2005). SUNAMURA & TAKEDA (1984) relate from field observations the beach erosion (respectively the accretion) to a seaward (respectively landward) migration of sand bars in the the nearshore (surf and swash zones). In the meanwhile, many surf/ swash models try to characterize relationships between sand bars and dry beach (ELFRINK & BALDOCK, 2002); but usually, such models fail to predict onshore migration of inner bar to the shoreline (GALLAGHER *et al*., 1998). This lack of understanding derives also from the difficulty of data field acquisitions in swash zone and dry beach. This paper focuses on morphodynamics in the swash zone and at the shoreline, being the missing link between the surf zone sand bars and the dry beach.

2. Hydro-morphodynamic settings

The sand barrier (so-called "lido") of Villeneuve-lès-Maguelone is located in the Gulf of Aigues-Mortes and it is limited by Palavas-les-flots and the Cathedral of Maguelone peninsula to the East, the small town of Frontignan to the West, and the Rhone/ Sète canal to the North (figure 1a, 1b). The system is a typical 11 kilometer-long sand barrier. The distance from the shoreline to the lagoon ranges from 60 to 300 meters, with a maximum elevation at about 3 meters above mean sea level.
Regarding the hydrodynamics, tides range between 20 to 40 centimeters. Therefore, the shoreface is mostly controlled by currents and waves (LEREDDE *et al.*, 2007). To the beach scale, the hydrodynamics are driven by wave-current interactions with the nearshore sand bars (CERTAIN *et al.*, 2005). The dominant winds along the coast are Tramontane (northly to north-westerly, 36% of the wind day per year) and Mistral (north-easterly, 15% of the wind day per year) (ISEBE *et al.*, 2008). Remaining breeze (34%) and other winds blowing from land (15%) are known to have no significant influence on the littoral dynamics. Wave energy is moderate (at 88% of the time) with a mean significant wave height of 0.7 meter and a mean peak period of 5 seconds. The wave regime is characterized by three types of waves: waves from South-East (69%), waves from South (17%) and waves from South-West (14%). Storm waves (H_s>4 m with period of 5 to 10 seconds) represent 1 to 2% of time (AZERAD *et al.*, 2007).
In the shoreface, LIDAR imagery (2007, BEACHMED-E / CG34; 2009, DREAL LR/SO LTC see at *www.soltc.org*) clearly shows one to two sand bars whose geometries are not simple in the studied area. The cross-shore mobility of the sand bars is not known in this area, but it has been analyzed in adjacent spots for years (CERTAIN & BARUSSEAU, 2005; CERTAIN *et al.*, 2005; ALEMAN *et al.*, 2011). It is known to follow a NOP-NOM (Net Offshore bar Migration) like (SHORT & AAGAARD, 1993)

model or similar, including seaward shifts during storms, and landward shifts during beach reconstruction under fair weather conditions. However, the shoreline shows seasonal to higher frequency landward and seaward shifts controlled by wave climate (SABATIER *et al.*, 2008). Those are within the scope of this paper.
Along the shoreline itself, the swash zone shows a 10 centimeters to 1 meter high berm (figure 1d) with a moderate slope (3.5%) and a usually well-expressed 5 to 40 centimeters high beach step (figure 1e). Beach cusps (figure 1f) occur also intermittently.

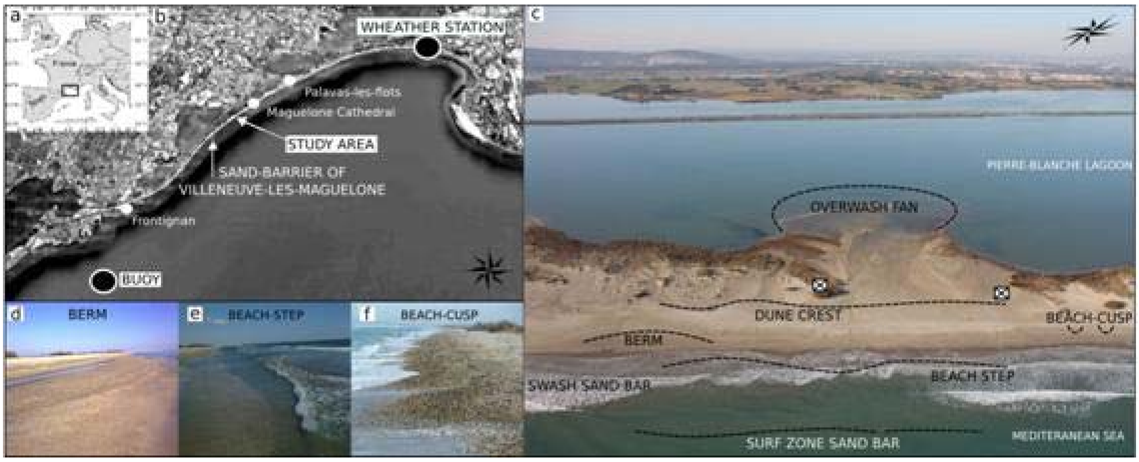

Figure 1. Location and presentation of the studied area. (a) Location map of the Gulf of Lions (GOL, north-western Mediterranean Sea, France); (b) Location map of the Gulf of Aigues Mortes (GAM, north-western GOL) with location of lido de Villeneuve-Lès-Maguelone and study area. Hydrodynamic and meteorological data used in this study were obtained from the buoy of Sète and the anemometer of La Grande Motte; (c) an oblique aerial photograph of the main geomorphic features in the study area with the definition of morphologic features used in the text; (d) a berm; (e) a beach-step and (f) a beach-cusp.

3. Methodology

3.1 Field surveys

Six month-long field works were conducted from January to July 2011 on the sand barrier of Villeneuve-Lès-Maguelone to investigate its morphodynamics, and resulted in 28 distinct surveys of the full beach (figure 2a).
All the field campaigns follow the same field protocol, with the acquisition of: (1) the survey area of a 320 m (alongshore) × 220 m (cross shore) zone (figure 1c), including an over-wash fan, the swash zone and the associated upper shoreface (some meters seaward in the water) ; (2) four profiles measured at the exact same location through time. One of them is cross shore (from the sea to the lagoon across the wash-over fan)

and three others are longshore, one profile on the beach and two profiles on the overwash fan; (3) precise localization of peculiar geomorphic markers, such as beach cusps, berm, beach-steps, vegetation boundaries and their change through time. In this study, we choose the beach step as being the exact location of the shoreline.

These data sets were acquired with a D-GPS Trimble R8 which offers Real Time Kinematic (RTK) and vertical and horizontal resolution about 2 cm (Z) and 5 cm (X,Y). The Conic Conform projection Lambert III South (geographical version) was used to store the data. With a small chariot trolley pulled on the beach, the trail of the operator follows a regular pattern, with lines 10 meters apart along which points are acquired at a regular distance of about 1 m. The geolocalization of specific geomorphic features was performed at a spatial resolution of about 0.5 m. The four profiles and underwater measurements were acquired with points spaced 1 to 5 meters apart. The shoreline itself was delineated with at set of points 10 meters apart.

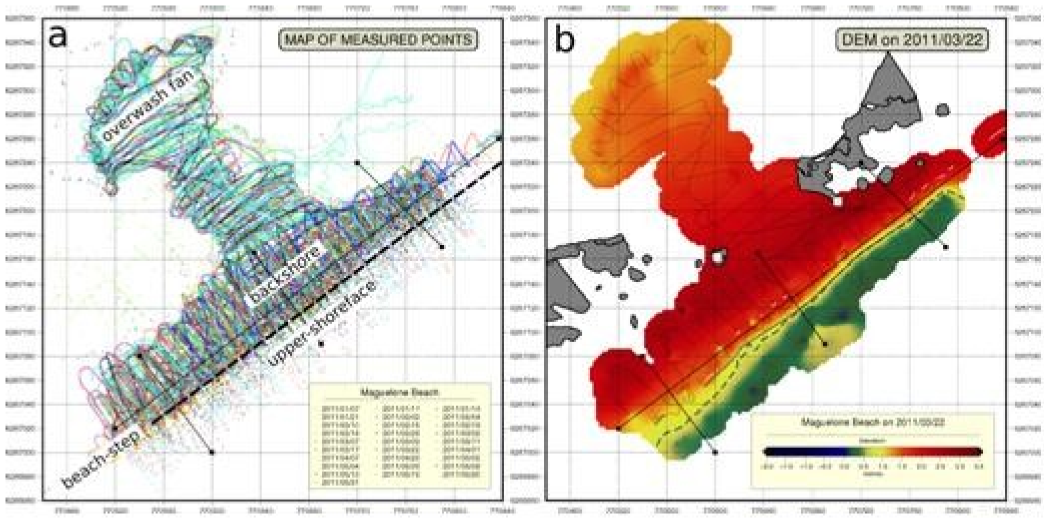

Figure 2. Altimetric data acquired from January to July 2011.a) Map of the dataset and names for the distinct beach zones used in this study. Profiles extracted from the DEM (Digital Elevation Model) for morphologic analysis are represented by solid black lines. b) example of a DEM.

3.2 <u>Data processing</u>

The altimetric data were analyzed with Bash scripts on the basis of GMT tool box (WESSEL & SMITH, 1998; WESSEL, 2010).

Before we process the full data sets, two types of interpolations were compared in order to build DEMs (Digital Elevation Model). Akima interpolation (AKIMA, 1979) was selected as it curves and highlights the morphologies whereas TIN (Triangulated Irregular Network) method minimizes the convexity and flattens the geomorphic features such as the observed beach cusps. The Akima method is based on a

combination of harmonic representations optimization of the surface towards a minimal curvature. The Akima algorithm used to process the data (STOOCH tools) was tuned with a search radius set at 15 meters and a tension parameter set at 0.35.
The following types of graphs were created: (1) plot of cross shore elevation profiles; (2) for each campaign, a colored altimetric map of the DEM including visible boundaries of vegetation (that did not change through time during the field works) and the localization of typical features (shoreline, beach cusp,...) in order to switch easily from map to map, and to achieve basic comparisons (figure 2b); (3) maps of the altimetric differences between two consecutive campaigns to quantify the morphologic changes at the DEM scale; (4) plots of the still sea level changes through time. Indeed, the beach step is supposed to occur at a constant elevation along the 400 m long segment of beach. In that zone, from the measured locations of the beach step (that is the shoreline), elevations were extracted from the DEM and a mean shoreline elevation was calculated. This process results in two distinct shoreline concepts: a) the line created directly from the points measured on the beach-step and b) the line extracted from the DEM, and made of points of same elevation (that of the mean beach step). To illustrate the shoreline dynamics in relation with morphodynamic changes, calculated shorelines from DEM (described previously) were drawn on the maps of altimetric differences.

4. Results

The detailed analysis of all data and derived graphs has revealed a sand supply cycle from the nearshore to the upper beach including shoreline shifts. Six successive steps are identified in this cycle. STEP 1 is the input of sand in the upper shoreface. The incoming sand can be shaped in bars or immersed beach-cusps pointing to the beach. STEP 2 is the migration of this sand stock close to the actual beach step. This results in a shoreline shift (STEP 3) and the creation of a second shoreline (concomitant beach step) seaward the current one. The migration is (1) homogeneous along the shore if the amount of incoming sand is significant; (2) irregular, describing 10-100 meter-long oscillating patterns, if the incoming sand volume is low. STEP 4 is the total fusion of the incoming sand with the previous shoreline resulting in its disappearance. STEP 5 is the nourishment of the berm and the upper beach. STEP 6 corresponds to the final regularization of the shape of the shoreline. From January to June, seven distinct morphologic cycles were observed (figure 3). Although all steps are not well-expressed for each cycle, they always occur in the strict same order as described above.
Beyond the morphologic cycle, we promote also two distinct scenarios at the origin of the sand supply in the upper shoreface (beginning of STEP 1; figure 3). During significant storms, sand is directly taken from inner bars. In a second time after the storm apex, some of this sand migrates to the beach to input a morphologic cycle. In this case, observations show that the nourishment of the beach is negligible and the

cycle does not characterize beach reconstruction. Conversely, long fair-weather periods trigger the STEP 1 of the morphodynamic cycle described above with provision of significant sand volumes to the beach. This corresponds to the regular inner bar migration to the shoreline. It is a typical beach reconstruction process.

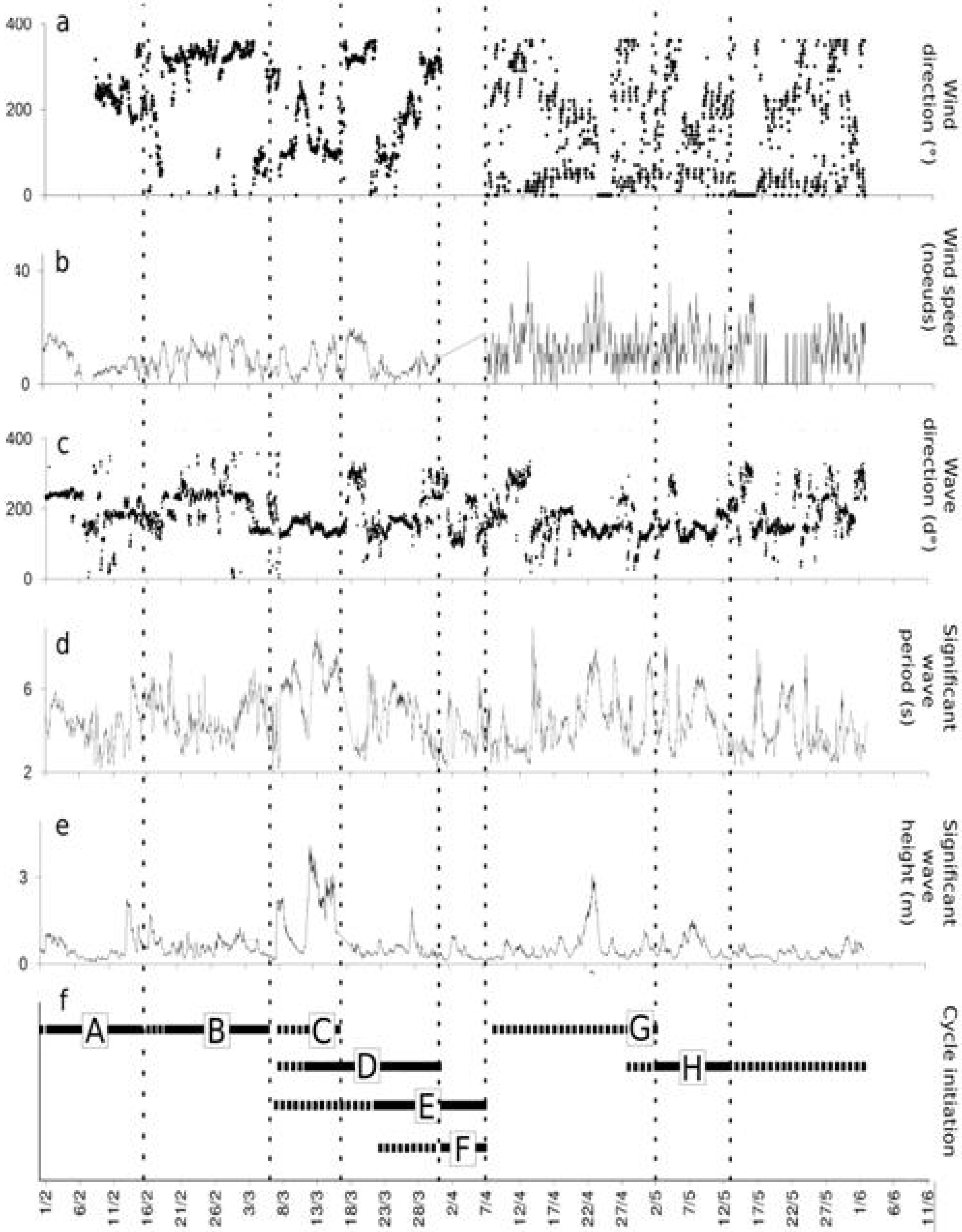

Figure 3. Beginning of morphological cycles A to H faced with hydrodynamical and meteorological forcings from January 1st to June 16th, 2011. Waves are from Sète buoy (DREAL LR/SO-LTC), 6 km off the shoreline in 40 m of water depth (03°46.777'E, 43°22.290'N (WGS-84).a to e illustrate the forcings and f Extension (horizontal line) and end (vertical dashed line) of each cycle.

5. Conclusion

Supported by solid field measurements, this study describes a sand migration process from the nearshore to the emerged beach through a buffer zone at the shoreline. This field survey contributes to fill the gap between sand bar and emerged beach dynamics during storms and fair weather periods. Now, we plan to reproduce exactly the same experiment in Villeneuve-Lès-Maguelone over the period 2012-2013, and we extend the survey to other field sites. Indeed, in the frame of KUNSHEN ANR Project, we intend to describe the morphological evolution of the barrier island of Wan-Tzu-Liao, located South-West Taiwan, following the same methodology. In this area, wave energy can be ten times higher, and H_s up to 12 meters in the nearshore can occur during typhoon events (HSU *et al*., 2007). Comparison between dynamics in the Mediterranean Sea and in Taiwan may result in the generalization of the morphological cycle presented in this study to extreme forcings.

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