Changes in migration of intertidal dunes: from observation to modelling. Case of Somme Bay (NW France).

A. Imen TURKI *CNRS, UMR 6143 M2C, F-76821 Mont-Saint-Aignan, France - imen.turki@univ-rouen.fr* (corresp. author)

B. Sophie Le Bot *CNRS, UMR 6143 M2C, F-76821 Mont-Saint-Aignan, France – sophie.lebot@univ-rouen.fr*

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C. Nabil Kakeh *Department of Applied Physics, Universitat Politècnica de Catalunya-Barcelona Tech, Barcelona, Spain – nabil.kakeh@gmail.com*

D. Charlotte Michel *CNRS, UMR 6143 M2C, F-76821 Mont-Saint-Aignan, France – charlotte.michel2@univ-rouen.fr*

Field Code Changed

E. Robert Lafite *CNRS, UMR 6143 M2C, F-76821 Mont-Saint-Aignan, France – robert.lafite@univ-rouen.fr*

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ABSTRACT: Intertidal dune dynamic was investigated in the Somme bay (NW France) using a series of field surveys during a neap-spring tidal cycle: bed level measurements provided by Lidar techniques and energy conditions records of waves, tides and currents. Such observations have been used to quantify the dune migration and the sediment transport rates. The total dune migration can be decomposed into a simple translation component representing approximately 80% of the total movement and a rotation component which increases with the wave obliquity in respect to the coastline. Then, the net sediment transport was quantified from the observed migration rate and compared to the predicted bedload transport. The discrepancies between results suggest the sensitivity of dunes to the convolution between their morphological characteristics of height, length and asymmetry and the energy conditions. This convolution is addressed in a simple model that quantifies the dune response to hydrodynamic variables.

1. INTRODUCTION

Intertidal dunes largely cover sandy estuaries and coastal zones, and play an important role in their morphodynamic. Dune dynamic is very complex since they are sensitive to many sediment parameters and energy conditions. Previous studies have explored the dependence between the sediment transport and the dune migration rates (e.g. Masselink et al., 2009). This research uses field surveys conducted on intertidal dune fields to gain insight in their migration dynamic and the associated sediment transport fluxes under various energy conditions. Understanding this mobility was also explored to develop a simple model for dune response.

2. STUDY AREA

The Bay of Somme is a macrotidal estuary of the eastern English Channel (NW France) with an intertidal sandy area (excluding salt marshes and channels) of 42.5 km^2 (Figure 1). The bay is classified as a mixed wave-tide dominated estuary since it displays both wave-dominated (beach, dunes, tidal delta) and tide-dominated features (meandering tidal channels, salt marshes). Offshore waves are coming from SW quadrant (mainly swell) and NE quadrant (mainly sea). The area is characterized by semi-diurnal tides with mean neap and spring tidal ranges of 4.9 m and 8.5 m respectively; they can exceed 10 m during exceptional spring tides. The study dune field consists of a core of sinuous mean to large dunes with height and spacing varying between 0.2 and 0.6 m and 6 and 22 m respectively (Figure 1).

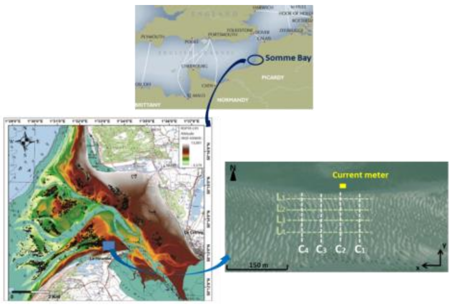

Figure 1. Location map of Somme bay and study dune field. Left: aerial LIDAR, April 2013. Right : Aerial photograph showing the survey lines in x direction (L1, L2, L3 and L4) and y direction (C1, C2, C3 and C4).

2.1 Field Survey

A survey was carried out during a neap-spring tidal cycle in January-February 2014. The maximum and the minimum tidal ranges were 11,1 and 8,3 m respectively.

Topographic measurements were conducted approximately every 3 days from 28/01 to 09/02 along a superficie of 2500 m^2, using a terrestrial laser scanner (TLS) with a high degree of accuracy. A digital elevation model (DEM) was produced with a 10-cm resolution (Figure 2). Lines were extracted from the DEM in the orthogonal (C1-C4; Figure 1) and parallel (L1-L4) directions with respect to the coastline. Dune morphological parameters were computed over the total data window. Dune migration rates have also been calculated.

Hydrodynamic conditions were measured during the whole neap-spring tidal cycle using punctual current meter and an ADCP instrument, to record the water sea level, flow velocities and wave conditions (height, direction and period) with a time resolution of 1 minute.

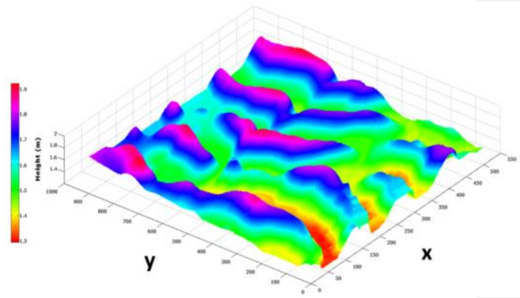

Figure 2. 3-D digital elevation model (DEM) of the intertidal dune field provided by Lidar (09/02/2014); x and y axis are orthogonal and parallel to the coast, respectively. Dune height varies between 1.3 m and 1.9 m (x and y axis are in pixels; 1 pixel =0.1 m)

2.2 Dune migration and sediment transport rates

The survey lines in X (L_1-L_4) and Y directions (C_1-C_4) were analyzed in order to investigate the spatial and temporal variability of dune morphological characteristics: orientation, height η , length λ and dune asymmetry. Then, the migration distance between the different surveys was calculated using a mathematical approach in order to determine the dune migration rates and its local gradient. In this method, the degree of change for every point of the topographic surface, based on local gradients in time and 2D space, is approximated. The objective is to calculate the migration vector M_r in two dimensions (x and y).

For any point of the topographic surface. Then, the migration rate V_{mr} can be approximated as:

$$V_{mr} = \frac{M_r}{\Delta t} = \left(\frac{\Delta Z}{M_r}\right)^{-1} \cdot \frac{\Delta Z}{\Delta t} \qquad 1$$

where M_r is the migration vector; V_{mr} is the migration rate and M_r / ΔZ is the local gradient.

In this study, the gradient in space ΔZ/M_r is expressed in both dimensions X and Y as shown below:

$$\left(\frac{\Delta Z}{M_r}\right)_{n,i,i+1} = \left(\left\{\begin{matrix}\frac{Z_{n+1}-Z_{n-1}}{X_{N+1}-X_{n-1}}\\ \frac{Z_{n+1}-Z_{n-1}}{Y_{n+1}-Y_{n-1}}\end{matrix}\right\}_i + \left\{\begin{matrix}\frac{Z_{n+1}-Z_{n-1}}{X_{n+1}-X_{n-1}}\\ \frac{Z_{n+1}-Z_{n-1}}{Y_{n+1}-Y_{n-1}}\end{matrix}\right\}_{i+1}\right).0.5$$

for any point X_n in two successive surveys at times t_i and t_{i+1} which is illustrated in Figure 3.a (1D case). Then, the local time gradient $\Delta Z/\Delta t$ is:

$$\frac{\Delta Z_{n,i,i+1}}{\Delta t_{i,i+1}} = \frac{Z_{n,i} - Z_{n,i+1}}{t_{i+1} - t_i} \qquad 3$$

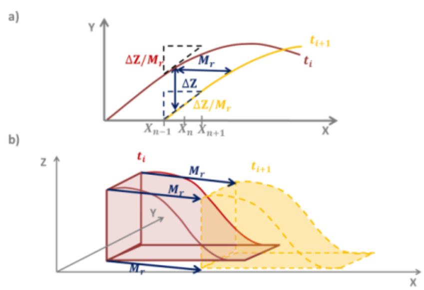

Figure 3. Approximation of the local gradient approach (a) to calculate the migration distance M_r, between t_i and t_{i+1}, which is decomposed in the two directions X and Y (b).

The migration distance was converted to migration rate per tide by considering the number of tides between successive surveys. In reality, this distance can be expressed in two directions and decomposed into 2 movements (Figure 3.b): a simple translation in the x direction of dune migration (parallel to the coastline) and a shift on the y direction orthogonal to the coastline. Both movements were investigated over the different field surveys together with the hydrodynamic conditions.

Finally, the rate of the sediment transport was calculated: (1) from the dune migration previously obtained (volumetric analysis), and (2) from measurements of the current velocities and sediment grain-size, using Soulsby's (1997) procedures. Here, only the component of the bedload transport is considered.

3. RESULTS

The dune migration has been computed in x-direction between the different surveys function of the local gradients $\left(\frac{\Delta Z}{\Delta t}\right)$ and $\left(\frac{Mr}{\Delta Z}\right)$. Results have shown that the total migration vector M_r is expressed by a component of translation, ΔR , and a shift component, $\Delta \gamma$. A statistical analysis of both components indicates that Δr ranges between 75-90% of the total migration vector and an amount between 10 and 22% describing the dune shift Δγ which seems to be more important during the surveys with high wave direction obliquity. An example of dune movement can be displayed in Figure 4. Using the migration and dune parameters (length and height), the rate of the 1-D net sediment transport was calculated between successive surveys. Computed values vary from $0.2m^2$ to $0.6m^2$ (per unit meter width) during 3 days between the surveys of 03/02 and 06/02 associated to eight spring tide cycles. Maximum values are recorded in the offshore direction where dunes are more dynamic and the energy is higher. Such values range between 0.03 m2 and 0.09 m2 (per unit meter width) between the 28/01 and 03/02 during eight neap tide cycles. The decrease of dune migration in x-direction from offshore (down-bay) to onshore (up-bay) was evaluated approximately to 0.03 m/tide during spring tide cycles. Similarly, the sediment transport rate decreases in the onshore direction.

Results suggest that the sediment transport responsible for the dune migration depends on the temporal variability of dune parameters for steady wave and tide conditions. When these conditions are changing, the two main factors, controlling the dune response between successive surveys, are the currents velocities and also the number of tides and the water level.

Measured transport rates have been compared to predicted values estimated from the application of Soulsby's (1997) procedures, function of current velocities, water level and tide range of tidal cycles.

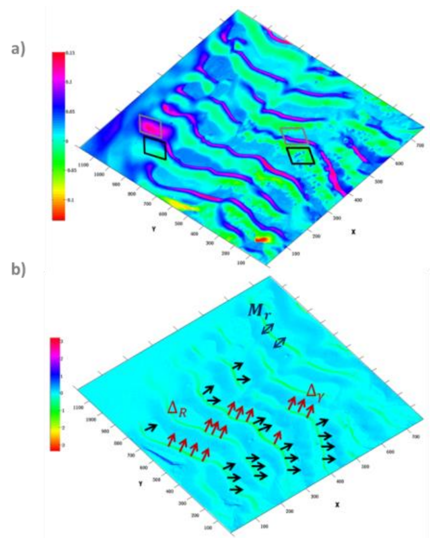

Figure 4. The local gradient shows the fluxes of erosion (black rectangle) and deposition (grey rectangle) between 03/02 and 06/02 (a). The migration vector Mr is composed of a translation ΔR and the shift component Δγ in the clockwise (black quivers) and counter-clockwise (red quivers) directions (b).

Such comparison has shown discrepancies between both approaches which increases for spring tide cycles. Predicted transport rates, relying only on tides, underestimates the observed transport, obtained by dune migration records, by a mean percentage of 20-30%. This underestimation is less significant if the measured transport rate would be calculated from a dune migration based only on the translation movement without the consideration of the dune shift which is strongly related the incident wave angle. Such results suggested the response of intertidal dunes dune (migration, sediment transport), in macrotidal coasts, is sensitive to: (1) morphological characteristics of dunes (height length, slope, sediment grain size) and (2) wave conditions, in particular the incident wave angle in the surf zone.
In this context, a new model is being developed basis on different physical approaches with the aim to calculate the dune migration $V_{mr}(t)$ as a function of the hydrodynamic conditions and the morphological characteristics of the dune. The model uses the convection equation

$$\frac{\partial \eta}{\partial t} = V_{mr}\frac{\partial \eta}{\partial x}. \qquad 4$$

The temporal change of the surface is calculated as the result of the local change of the sand flux which can be expressed as a function of energy conditions and the sediment grain size D_{50}. The variability η of is described by both components of rotation and translation. The dune height is related to the length λ and the slopes of dune faces α and β. Therefore mass conservation leads to:

$$\frac{\partial \eta}{\partial t} = \frac{1}{\rho_{sand}}\frac{\partial q}{\partial x} \qquad 5$$

Such approaches will be used also to characterize the equilibrium state of the dune.

4. CONCLUSIONS

The findings of this research have shown that the dynamic of intertidal dunes of the Somme bay is strongly related to energy conditions of tide cycles and coastal waves. They are also sensitive to their morphological parameters. Modelling dune migration, in particular its shift component is useful to understand the temporal dune evolution and its relation with the neighbor dunes (e.g. branching).

5. ACKNOWLEDGMENT

The authors are grateful to CNRS-INSU (EC2CO FORSOM), the DGA, the Regional Council of Haute-Normandie and “SFR SCALE” for their supporting to the research, and the members of the laboratory M2C involved in field measurements, in particular Julien Deloffre and Michel Simon.

6. REFERENCES

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