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# Long-term simulation with 2DH and 3D models for nourishment on Mediterranean beaches

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**ABSTRACT:** A modified 2DH morphodynamic and a 3D model was employed to simulate the evolution of large-scale features with major implications for beach nourishment. The study is focused on modeling the evolution of material artificially placed in different parts of the profile, extracting or adding material to the natural bars, and quantifying how the profile responds to different wave climates and nourishment placements. The simulated results were compared with field data from a Mediterranean beach.

## 1 INTRODUCTION

Examples of nourishment tests carried out on the near shore zone are few and far between in the relevant literature, compared to the many ones undertaken directly on the beach. SAFE, latest European project within the MAST program, acknowledges the absence of reference documents on this question, although such a technique could presumably constitute a less costly alternative (Hamm *et al.*, 2002).

The use of offshore bars to fight beach erosion, dating back to the 90th, was based on the fact that they represented a substantial reservoir of sediments. That theory turned out to be irrelevant, as beach nourishment requires coarser grain sizes. However, the essential role these bars can play in wave mitigation was evidenced by recent studies. Hence, working on reinforcing existing bars or even adding extra bars is a convincing approach, for they constitute a line of defence with no visual impact and are therefore environment-friendly. The method offers the added benefit of tapping abundant fine sands, easily available offshore, to build up the bars.

In addition, adequate depths in the inner shelf area would facilitate dredging and discharge operations and, the material reclaimed being usually clean, it can therefore be used directly without any processing. The core of the additional bar too could be made from marine mud, also easily available. All these assumptions should, of course, be systematically checked, the purpose of the exercise being to assess, through mid-term bathymetric evolution simulation, the consequences of the implementation of offshore bar nourishment and define the best location.

The understanding of these processes needs at this time the in situ data but also the development of models

and numerical codes. Hence, following the work of De Vriend (1987) and De Vriend & Stive (1987), we try to improve the classic quasi-steady procedure. Objectives of this work will be therefore to model and to simulate processes of sedimentary transport on sandy beaches with varied weather conditions in the medium term time scale (from few days to few months).

## 2 PROCEDURE AND DESCRIPTION OF THE BEACH

Certain & Barusseau (2006) show that morphodynamic evolution of offshore bars in a microtidal environment and bimodal moderate wave regime follows two different conceptual models, the main one being a seasonal pattern in line with the observed cycle of hydrodynamic conditions.

The morphological evolution in the near shore region, including its large-scale features, was first investigated using a combination of a commercial 2DH model and a Multi1DH model (Camenen and Larroudé, 2003, 2003b). Simulation of the wave-driven currents was carried out with Telemac, a finite-volume elements model, and the Sisyph sand transport module served to compute sediment transport rates and bed evolution. Since the sediment transport in the surf zone is mainly controlled by undertow, an undertow model (based on Svendsen, 1984) was added to account for that process.

These models were used in the framework of a simulated meteorological cycle describing the seasonal evolution of hydrodynamic factors. Results from monthly 2DH evolution simulations show a perfect fit with field data obtained on the “plage



Figure 1. Localization of the “plage de la Corniche” in Mediterranean sea and zoom on the study area with the creation of an artificial offshore bar.

de la Corniche” in Sète (Certain, 2002). Morpho-hydrodynamic feedback of a bar having undergone reinforcing is also examined (see Figure 1).

### 3 THE CODES

The sedimentary evolution is modeling under the action of the oblique incident waves and is coupling with different numerical tools dedicated to the other process involved in the near shore zone. We can mention the following modules:

- module of wave with hold in account of the energy dissipation by surge (hyperbolic equation of extended Berkhoff), (LNHE, Artemis, 2002). The Artemis code (Agitation and Refraction with Telemac2d on a Mild Slope) solves Berkhoff equation taken from Navier-Stokes equations with some other hypothesis (little camber of the surface wave, little slope...).
- Main results are, for every node of the mesh, the height, the phase and the incidence of the waves. Artemis can take into account the reflection and the refraction of waves on an obstacle, the bottom friction and the breakers. One of the difficulties due to Artemis is that a fine mesh must be used to have good results when Telemac2d do not need such a fine mesh.
- module that calculates currents induced means by the surge of the waves, from the concept of radiation constraints gotten according to the module of waves, (LNHE, Telemac2d, 2002). Telemac2d is designed to simulate the free surface flow of water in coastal areas or in rivers. This code solves Barré Saint-Venant equations taken from Navier-Stokes equations vertically averaged. Then, main results are, for every node of the mesh, the water depth and the velocity averaged over the depth. Telemac2d is able to represent the following physical phenomena : propagation of long periodic waves, including non-linear effects, wetting and drying of intertidal zone, bed friction, turbulence, ...

- sedimentary module integrating the combined actions of the waves and the current of waves (2D or 3D) on the transport of sediment, (LNHE, Sisyphé, 2002),

The Sisyphé code solves the bottom evolution equation which expresses the conservation of matter using directly a current field result file given by Telemac2d. Four of the most currently empirical or semi-empirical formulas are already integrated in Sisyphé (Peter-Meyer, Einstein-Brown, Engelund-Hansen and Bijker formulas). We integrate two other ones which seem more appropriate to coastal sediment transport (Bailard, 1981 and Dibajnia-Watanabe, 1992). Main results are, for every node of the mesh, the bottom evolution and the solid transport.

- an hydrodynamic simplified model (called Multi1DH) use the following assumptions: a random wave approach, in a 1DH (cross-shore) direction. A offshore wave model (shoaling + bottom friction + wave asymmetry) is used with the break point estimation. The waves in the surf zone are modeled with the classic model of Svendsen (1984) with an undertow model (roller effect, Svendsen, 1984, Dally *et al.* 1984).The long shore current model is the Longuet- Higgins’s model (1970).

### 4 RESULTS

#### 4.1 Comparison for validation

Firstly we set up a procedure to use the coupled codes Artemis-Telemac2d-Sisyphé and especially we improved the treatment of the boundary conditions in order to be able to work on fields of calculations close to the coastal zone and equivalents in dimension for the three codes. We also used the Multi1DH code for the medium term simulations. These models were used for monthly simulations taking of account the weather conditions. These weather conditions are drawn from the data of ground for the period of November 2000 and are simplified in terms of height of swell, period of swell and direction by dividing the month into 9 significant periods (see Table 1). One can notice that the average height of the swells to broad during each period attenuated the weather events this November.

We obtain a good adequacy between numerical bathymetries after one month and those raised on the ground (see Figure 2).

We began simulations with a fattening of the zone of study at the beginning of November 2000 and we can compare the results obtained with model 2DH (waves, hydrodynamics and transport) and the model simplified Multi-1DH.

Secondly, we regarded as basic state a profile of the bathymetry of November 16, 2000, the P5 profile with  $X = 200$  m (distance longshore compared to the

Table 1. Simplified weather data: November 2000 ( $\Theta$  angle in degree in the trigonometrically direction reverses compared to the normal with the beach).

Temps (s)	Hs (m)	Tp (s)	$\theta$
0j à 1j 21h	0.244	7.45	25.475
1j 21h à 3j 12h	1.703	7.92	27.861
3j 12h à 7j 21h	0.351	7.13	28.094
7j 21h à 10j 9h	1.787	6.76	6.065
10j 9h à 18j 12h	0.222	6.2	3.97
18j 12h à 20j 3h	1.358	6.78	14.9
20j 3h à 24j 15h	0.251	7.03	14.33
24j 15h à 30j	1.259	6.27	-5

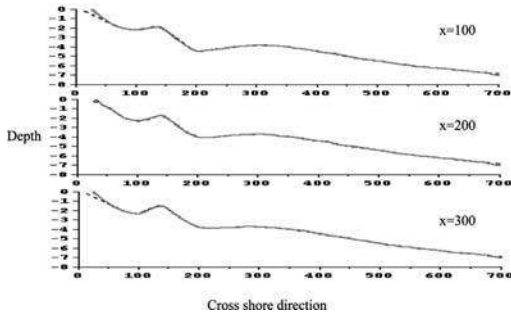


Figure 2. Sea bed for three location on the beach at the 25 November 2000, comparison between in situ data and numerical simulation after one month using the 2DH model with the meteorological model.

Table 2. Weather data simplified for the three cases of storm ( $\Theta$  angle in degree in the trigonometrically direction reverses compared to the normal with the beach).

	Temps	Hs (m)	Tp (s)	$\theta$
TS	24 h	1 m	6,5 s	0° et 20°
FS	24 h	2,5 m	7 s	0° et 20°
ES	24 h	4 m	10 s	0° et 20°

beginning of the zone of study). This approach will enable us to more easily compare the models of calculation used by the various partners of the program. For these simulations we agreed to consider three cases of climatic conditions (see Table 2): Traditional Storm (TS), falling from Storm (FS) and Exceptional Storm (ES). The whole of simulations was carried out with the model multi1DH and the results will be presented in the continuation. We also made some calculations with the chain of Artemis-Telemac2d-Sisyphus code.

For case FS, the swells do not have effects on the internal and external bars. For simulations TS the swells erode the internal bar but does not seem to attack

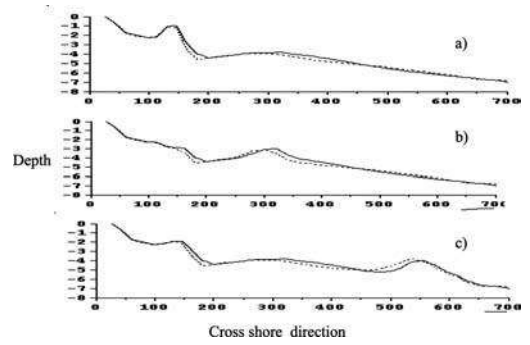


Figure 3. Sea bed evolution on 24 hours calculated with the multi-1DH model for three location of nourishment: a) on the inner bar, b) on the offshore bar and c) with the creation of new bar offshore.

to a significant degree the beach and the external bar. Only a longer-term erosion of the internal bar can be prejudicial with maintains of beach.

The case of the exceptional storms will be used to us as a basis to present the differences obtained with the model multi1DH between different the option from recharging. The case, on the basic profile of November 16, 2000, shows us an erosion of the bars internal and external with a transport of these bars towards the broad one and thus one can consider a weakening of the protection of the beach (see Figure 3). The internal bar is eroded of approximately 10 m and the external bar of 40 m, the deposit with broad with a maximum of 25 m but is very spread out.

These values are indicative to be possibly compared with other simulations but cannot be used as quantitative values for real estimates of the quantities of sands put moving. We will further see they is values are still strongly dependent on the models and in particular on the formulas of sedimentary transport.

#### 4.2 Long term simulation

The good accuracy of this first result allows us to create a methodology of simulation for longer time scale. We are looking now with the coupled codes Artemis-Telemac2d-Sisyphus, the morpho-evolution of the beach with and without nourishment. The aim is to find the best way of create the simplified meteorological model from the in-situ data. In the study presented in the paper, we show the first step of this methodology which is to compare seasonal simulation with different script of meteorological event during each season. The principal question is do we have to cut out each hour, day . . . Each meteorological event has time duration issued from the data. The Figures 4 and 5 show the importance of the storm in the destruction of the off-shore nourishment bar. The major modification of the sea bed is numerically obtained because the time loop

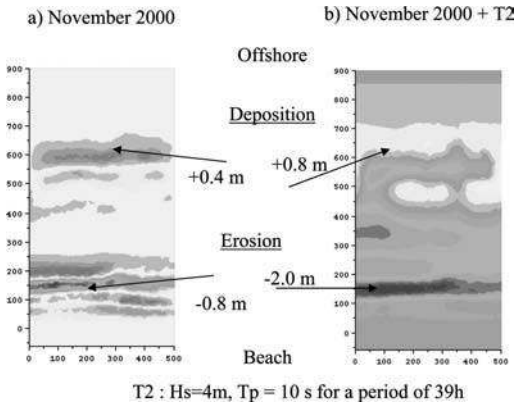


Figure 4. a) Sea bed evolution for a monthly simulation from the 04 11 to the 25 11 2000 with nourishment and b) the same with a storm of 39h (initial on left, final on right).

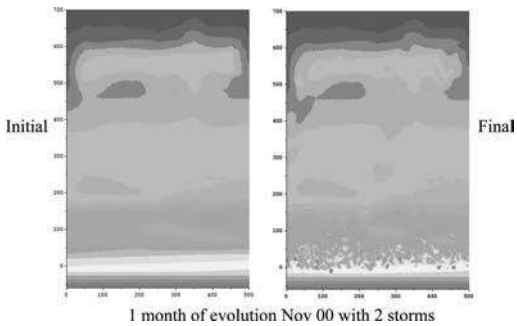


Figure 5. Iso-bathymetry of a monthly simulation from the 04 11 to the 25 11 2000 with nourishment and with a 2 consecutive storms (initial on left, final on right).

of the coupled codes Artemis-Telemac2d-Sisyphé is shorter than the time duration of the storm. The principal criteria to cut out could be the current velocity du to the waves. Indeed, when we have calm weather condition (e.g. small waves height) the feedback between the hydrodynamics and the sea bed evolution could be longer.

Some results show the numerical difference du to number of hydro-sedimentary loop we simulate for the same monthly or seasonal modeling. The differences are very important in the very near shore region and close the beach. The Figure 6 shows a complete year of simulation (the 4 seasons) with nourishment and with a cut out of 48 events. The simulation took 24 hours on a 2.36 GHz processor. The aim is to find in the same time the best accuracy of the yearly sea bed evolution and the lowest computational time. The other main goal is to be able to predict the best placement of the nourishment bar to protect the beach over five to ten years.

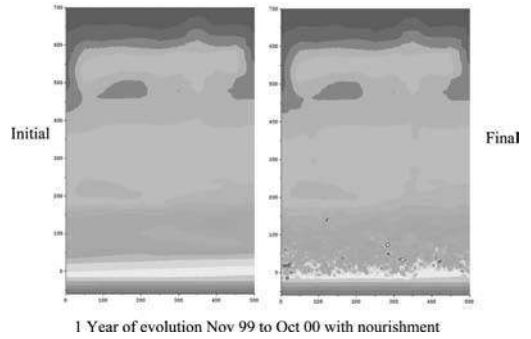


Figure 6. Iso-bathymetry of a yearly simulation from November 1999 to October 2000 with nourishment (initial on left, final on right).

## 5 CONCLUSION

The interesting thing of this study is that we can compare our numerical results to the in-situ data. Then, it could be easier to modulate time steps to have the most realistic results. A modified 2DH morphodynamic model was employed to simulate the evolution of large-scale features with major implications for beach nourishment. The study is focused on modelling the evolution of sea bed and artificial material in the near shore region, extracting or adding material to the natural bars, and quantifying how the profile responds to different wave climates and nourishment placements. The simulated results were compared with field data from a Mediterranean beach over storm, monthly and yearly time scale. The results are good in term of quality and also in term of quantity for the velocity field du to waves. The first 3D simulations are in good agreement with the current data. The next step of the study is to simulate a large amount of seasons from the year 1994 to 2005 to be able to elaborate a criterion for the meteorological cut out. The second goal is to predict the next five years with different nourishment placement to have a good strategy for the beach protection.

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