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Simulation for climate change and indicator of vulnerability on four French sandy beaches

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***Abstract*— First, we established a procedure for binding three codes to simulate realistic or idealized climates. This procedure is validated in terms of hydrodynamics and morpho-dynamic evolution. These models have been used as part of a cycle of meteorological simulations describing the evolution of monthly events or hydrodynamic factors. Then, the vulnerability can be studied: the vulnerability of the coast will be defined and studied on the basis of in situ observations and model results will come from a set of simulations based on different scenarios (current and 2030). We will evaluate, for all four French sites, the parameter of vulnerability against this set of scenarios**

I. Introduction

The nearshore region frequently exhibits complicated motions. This complexity is perhaps particularly prominent in the changes that can take place in the morphology of many beaches.

On this nearshore region the climate change induced vulnerability is defined by the Intergovernmental Panel on Climate Change (IPCC) as the combination of sensitivity to climatic variations, probability of adverse climate change, and adaptive capacity. As stated by the IPCC (Watson *et al.*, 1997 [15]), the "*coastal systems should be considered vulnerable to changes in climate*". In these areas, amongst the most serious impacts of sea-level rise are erosion and marine inundation.

Within this context, the present paper will give the methodology for the modelling approach to analyse the vulnerability of several beaches on the French coast and, more particularly, on four beaches complementary in terms of hydrodynamic forcing. The coast of metropolitan France is composed of 30% sandy coasts and is potentially vulnerable. All these studies are involved in the VULSACO project.

All these assumptions should, of course, be systematically checked, the purpose of the exercise being to assess, through mid-term bathymetric evolution simulation. Then, vulnerability can be studied: the vulnerability of coast/beach will be defined and studied based on in-situ observations and model results will be taken into account as a modulator of the physical vulnerability.

The understanding of these processes needs, at this time the in situ data but also the development of models, mathematics and numerical codes. Hence, following the work of De Vriend (1987) [3] and De Vriend & Stive (1987) [4], we try to improve the classic quasi-steady procedure. This methodology for morphodynamic evolution is also used more recently in Smit *et al.* 2008 [12]. The 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 a few days to a few months). The coastal morphology evolution cannot be represented with average climatic conditions but needs to simulate such extreme events as storms and therefore, in a long term approach, the morphological evolution is the result of the combination of storm events and calm periods.

II. Description of the Beach

In this national programme we are looking at the climate change influence on four different beaches in France. These beaches are representative of linear sandy beaches of the coastal region. 31% of the French coastline is composed of sandy beaches. They are also representative of forcing and of various important factors.

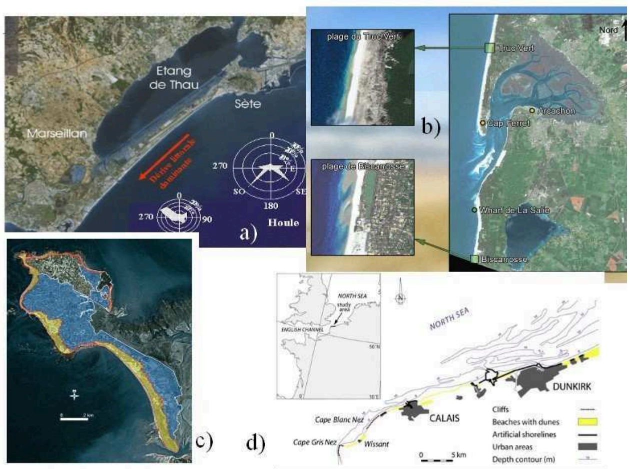

Figure 1. a) Lido de Sète, b) Truc Vert, c) Noirmoutier (in yellow the barrier beaches and in blue the flooding area) and d) Dunkirk (from Idier *et al.* 2007, [9]).

The four studied sites (see figure 1) were chosen to have complementarily hydrodynamic contexts (covering some of the possible hydrodynamic and wave conditions on the French metropolitan coast, Table 1):

1) Sète: The site studied is located in the northern part of the Lido de Sète. The beach is a linear sandy beach with one or two offshore bars. The tourism of this area and the local fisheries are important factors to be taken into consideration. Several measurement surveys have already been carried out on this site (PNEC programme), as well as numerous development studies.

2) Truc Vert: The site is characterized by its high exposure to waves from the Atlantic. There are rhythmic surf zone bars and their related morphodynamic self-organization. The system of bars/baïnes in the intertidal zone has already been studied in Castelle *et al.* (2006) [1].

3) Noirmoutier: On the coast of the Noirmoutier (Vendée) peninsula, a succession of three barrier beaches demarcating zones liable to flooding in the west can be observed: two in the north supported on reef flats and one (the longest) able to move in the south.

4) Dunkirk: The site is located between Dunkirk and the Belgian border. Dunkirk is on the boundary of a sedimentary layer stretching up eastwards to the Belgian border. Data is available concerning the following fields of study: morphodynamic, hydrodynamic and aerodynamic conditions. The system is complex with the presence of banks in the open sea which attenuate the energy of waves and protect the coast, but which also reduce sedimentary provisions towards beaches (by diminishing the intensity of oscillatory currents onshore)

TABLE I. SYNTHESIS OF THE MAIN HYDRODYNAMIC ENVIRONMENTS OF THE 4 SITES STUDIED

Number	Zone	Tide	Wave exposure	
1 - Sète	Mediterranean	Micro	High	
2 - Truc Vert	Figure 1. Atlantic coast (South)	Meso	High	
3 - Noirmoutier	Atlantic coast (North)	Macro	High	
4 - Dunkirk	Channel	Macro	Moderate	Geographical positioning

III. MODEL AND METHODOLOGY

Using the computer code 2DH Telemac, we set up a quasi-permanent binding calculations for the wave (wave modeling is done through the Artemis code that solves the equation of Berkhoff with process integration dissipation by wave breaking and bottom friction), for the calculation of the hydrodynamics and for the simulation of the sea bed evolution with a choice of sediment transport formulae (Camenen & Larroudé, 2003 [2]) (Fig. 2). The calculation chain Telemac is a complete model using the finite element method and allows the realization of various sedimentary hydrodynamic calculations.

The equations of the three modules are detailed in Hervouet (2007) [6]. This modeling methodology morphodynamics of sandy beaches is already validated in terms of mesh, time step and convergence in Falquès *et al.* (2008) [5] and Larroudé (2008) [10].

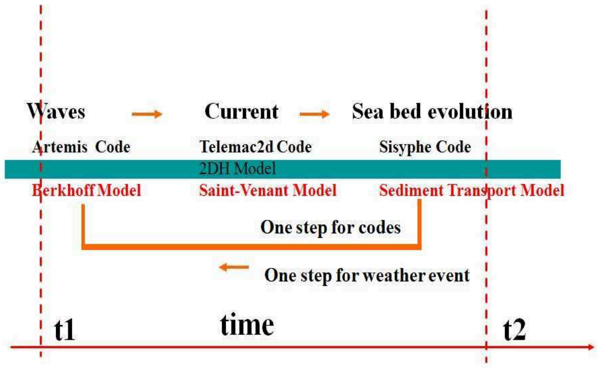

Figure 2. Technical drawing (Artemis-Telemac-Sisyphe: ATS) loop on a time step weather event (between t1 and t2) used in our simulations. For the Noirmoutier and Dunkirk site we used (Tomawac-Telemac-Sisyphe: TTS).

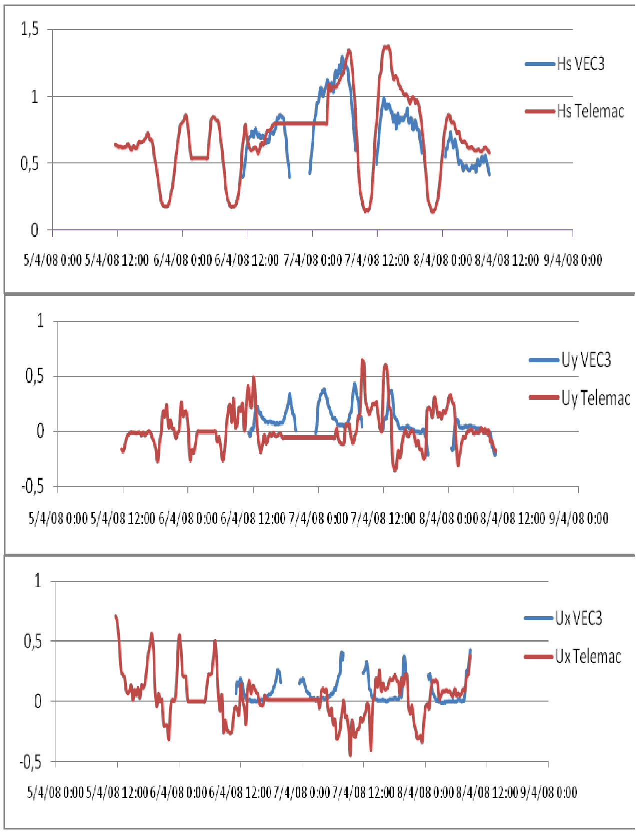

Figure 3. Comparison Hs, Ux (cross shore) and Uy (long shore) between the numerical values and in situ measurements on the device VEC 3 (all data in situ: EPOC Univ. Bordeaux.

Figure 3 shows comparisons with in-situ data (here the Truc Vert, see Idier *et al.* (2011) [9]) for other sites see Maspataud *et al.* (2010) [11] and ANR-Vulsaco reports. The physical presentation of the sites is described in Vinchon *et al.*, 2008 [14].

IV. RESULTS

We will present two ways of looking at possibly the vulnerability of beaches by analyzing the results of simulations of different scenarios.

The first method is based on the method described in Idier *et al*. (2006) [7]. We will initially look at the maximum grain size mobilized with a simpler approach. Indeed the calculation of the stress at the bottom will be estimated only from the velocity of the simulations after coupled waves-tides and/or waves only after the site. It also determines the critical Shields using the equation proposed by Soulsby and Whitehouse in Soulsby (1997, p105 [13]). Then there is the maximum size of grain mobilized by inverse method (see results in Tables II to V).

TABLE II. RESULTS OF THE MAXIMUM DIAMETER MOBILIZED (M) WITH THE INVERSE METHOD OF SÈTE SITE

Site 1: Sète	**Baseline scenario**	**Storm surge (Ss) +120%**	**Hs +10% Ss +120%**	**Incidence (–10°) Ss+120%**
Point 1.1	0.00583	0.00584	0.00590	0.00580
Point 1.2	0.00580	0.00580	0.00580	0.00580
Point 1.3	0.00581	0.00581	0.00580	0.00580
	Case 1	Case 2	Case 3	Case 4

TABLE III. RESULTS OF THE MAXIMUM DIAMETER MOBILIZED (M) WITH THE INVERSE METHOD OF TRUC VERT SITE

Site 2 : Truc Vert	**Baseline scenario**	**Storm surge (Ss) +120%**	**Hs +10% Ss +120%**	**Incidence (–10°) Ss+120%**
Point 2.1.1	0.04307	0.02389	0.024122	0.03466
Point 2.1.2	0.04776	0.05012	0.041834	0.04778
Point 2.1.3	0.00657	0.00708	0.006945	0.00742
Point 2.2.1	0.02329	0.02635	0.025837	0.05493
Point 2.2.2	0.00847	0.00874	0.008820	0.00785
Point 2.2.3	0.00713	0.00734	0.007563	0.00721

TABLE IV. RESULTS OF THE MAXIMUM DIAMETER MOBILIZED (M) WITH THE INVERSE METHOD OF NOIRMOUTIER SITE

Site 3 : Noirmoutier	**Baseline scenario**	**Storm surge (Ss) +120%**	**Hs +10% Ss +120%**	**Incidence (–10°) Ss+120%**
Point 3.1	0.00585	0.00588	0.00588	0.00588
Point 3.2	0.00591	0.00597	0.00596	0.00596

TABLE V. RESULTS OF THE MAXIMUM DIAMETER MOBILIZED (M) WITH THE INVERSE METHOD OF DUNKIRK SITE

Site 4 : Dunkirk	**Baseline scenario**	**Storm surge (Ss) +120%**	**Hs +10% Ss +120%**	**Incidence (–10°) Ss+120%**
Point 4.1	0.00893	0.00603	0.00605	0.006155
Point 4.2	0.00719	0.00682	0.00719	0.006610

In these tables the columns represent the four scenarios: baseline scenario for each site is the scenario constructed from current data and a simulation case where premium is increased by 120%, an event that we change the height of significant waves at 10% off and if you change the direction of the swells offshore. We make calculations of maximum grain size mobilized within a few points along cross-shore profile at each site (see Figure 4).

This criterion is to be confirmed by the analysis of all the simulations, but it does not seem completely relevant to the vulnerability or not the beach.

It can be completed by the second method in this paper: the analysis of the temporal evolution of cross-shore profiles for each site for the same scenarios presented above. This criterion is not convincing at sites where tidal currents are predominant (Noirmoutier and Dunkirk). For these sites where we are less convinced by the relevance of our results with our morphodynamic simulations TTS. Figure 5 shows that the study on thesea bed evolution of cross-shore profile can be complementary to a vulnerability study by conventional indicators. Indeed we see the influence of the increase of the storm surge, the change in direction for the incident wave or the increase of the significant height of waves on the evolution of multiple profiles on the site of the Truc Vert. This influence could be important and we also analyze that these sea bed evolution are very dependent of the choice we made on the sediment transport formula. These results have to be completed with further study.

V. CONCLUSIONS

This work allowed us to validate and improve our procedures for calculating the evolution of morpho-dynamic calculation chain Telemac. We show in this paper a simplified approach of first calculating the data as an indicator of vulnerability of sandy beaches. This approach shows the limits and must be complemented by a full analysis of simulations of different scenarios and a more classical approach of the evaluation indicators.

ACKNOWLEDGEMENT

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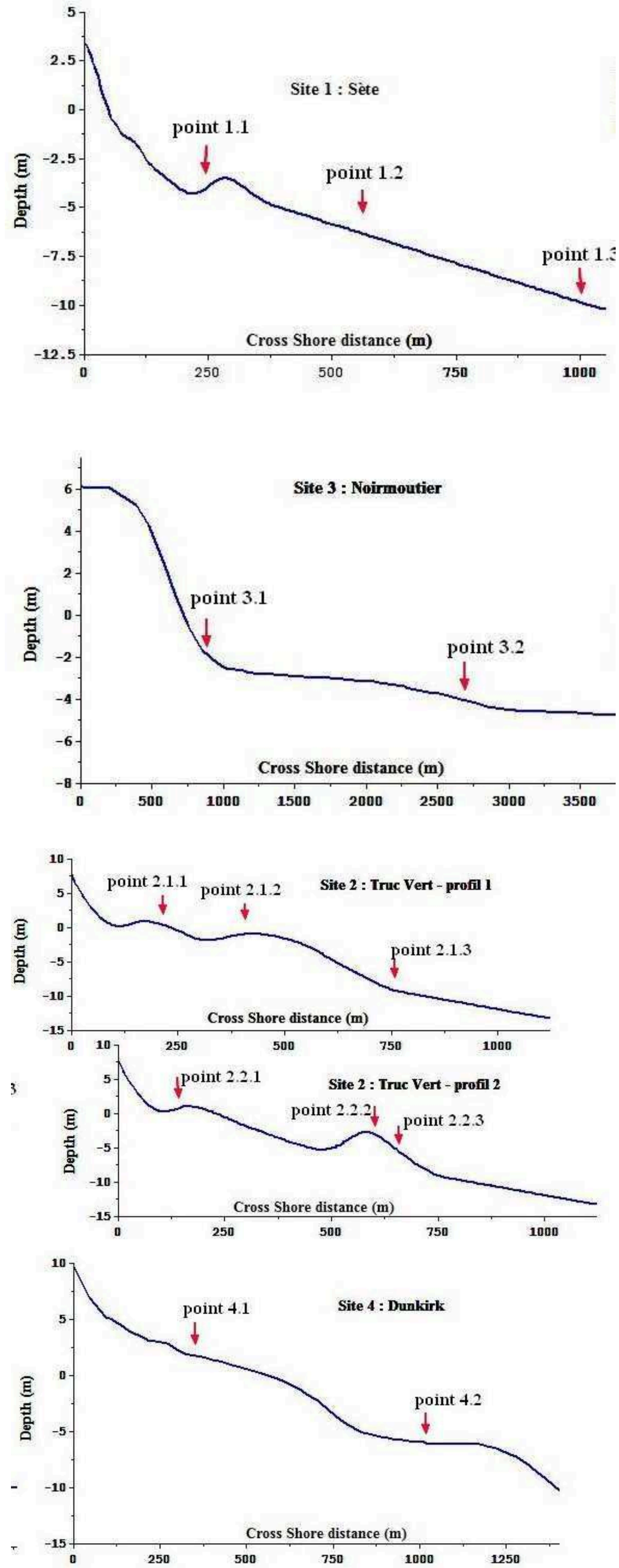

Figure 4. Cross-shore profiles of the four sites used for this study with the position of points used for calculations of maximum grain sizes.

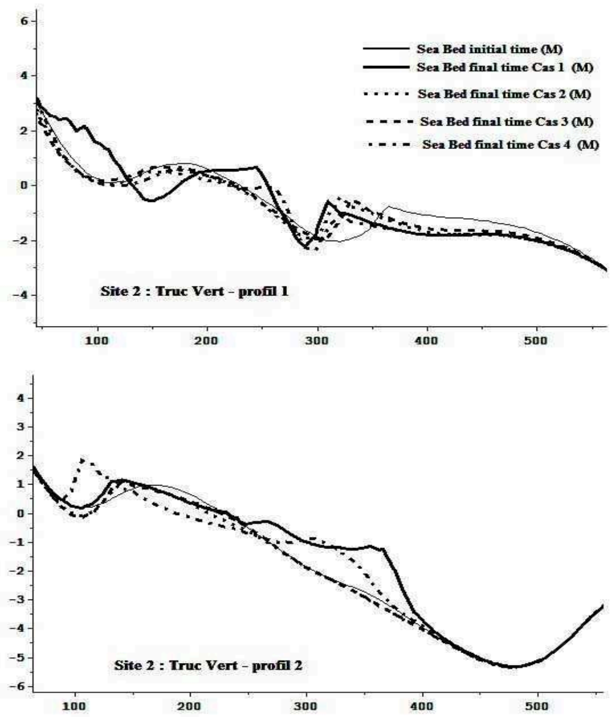

Figure 5. Profile cross shore of the Truc vert site for the four scenarios of the Table III.

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