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MODELLING IMPACTS OF "JOHANNA SHORM" ON AN OPEN-BEACH WITH ECORS SIMULATORS

Olivier Morio[1], Thierry Garlan[2], Serge Suanez [3], Patrick Guyomard[2]

Abstract

Morphological and sedimentary dynamics processes on sandy beaches are not well understand. To better understand coastal processes on these highly complex environment, the ECORS system, led by French Oceanographic Office, have been developed and allow coastal short-term forecasting. Models formulations are complex and most of them are validate with laboratory data. Comparison between models results and field survey are not easy but necessary to improve a model. We reproduce in this paper the impacts of the "Johanna" storm (March 2008) on Vougot Beach (Finistère – France) using the SWAN-EPOC1DBeach modeling chain (still in development.) Dune erosion have been reproduced by modeling chain. Comparison of SWAN-ECPOC1DBeach model prediction with observations shows an overall good correlation. Dune erosion, sedimentary deposits and equilibrium beach profile are observed.

Key words: Modeling, beach profile, storm, erosion, dune, morphodynamics

1. Introduction

Even if hydrodynamics phenomena, like wave behavior, are relatively well understanding, scientific studies of sedimentary dynamics in its natural environment are also beginning. Sedimentary model are most of the time validate by laboratory study (swell canal test) but not by comparison with natural environment data.

Vougot beach is a macro tidal beach, located in the North of Finistère (France), which is frequently exposed to storms. This beach is formed by a massive dune complex 250 m to 400 m wide which was constructed during the Holocene (Guilcher and Hallégouët, 1991). It culminates at 13 m NGF in altitude (i.e. above sea level – asl). (The altimetric reference NGF – *Nivellement Général Français* – refers to French topographic data. In our case this reference is situated 3.5 m above the spring-tide low-water level). In March 2008, «Johanna» storm reached the North European coast and significantly impacted the beach and the dune system (Suanez and Cariolet, 2010). Developed for naval amphibious operations and led by the French Oceanographic Office, the aims of ECORS simulator is to predict short-term morphological evolutions of sandy coasts in order to better understand hydrodynamic and morphodynamic processes of these highly complex environments. In order to evaluate the validity of the modeling ECORS system, we tried to reproduce the impacts of the Johanna storm on Vougot Beach using one of the four morphodynamic models of ECORS : the SWAN-EPOC1DBeach modeling chain (still in development by University of Bordeaux I, France). We also compare model results with field survey results.

2. Environmental context

This first part of this paper focus on geological, sedimentary and morphological context of Vougot Beach.

[1]Internship at French Hydrographic and Oceanographic Office (SHOM), 2nd year student Master «Expertise et Gestion de l'Environnement Littoral», Institut Universitaire Européen de la Mer (IUEM), Plouzané (France).
[2]French Hydrographic and Oceanographic Office (SHOM), Department of Sedimentology, Brest (France)
[3]LETG-Géomer - UMR 6554 CNRS (IUEM, Plouzané, France).

2.1. *Study area interest*

The study area covers Vougot beach located in the municipality of Guissény. This town is situated on the north coast of Finistère (Brittany, France) (figure 1). Vougot beach presents several challenges and particular interest. In fact, it has been held in three different projects monitoring the risk of flooding of his coastal forehead. The study area was selected in partnership with the laboratory GEOMER -UMR 6554 CNRS- of the « Institut Européen de la Mer » (European Institute for Marine Studies – Plouzané, France), which monitoring this area since seven years. Observational data from the beach Vougot are consistent and the comparison with model results will be facilitated.

2.2. *Geomorphological and hydrodynamics setting*

The study area is characterized by large rocky outcrops. Vougot beach present a sandy foreshore where islets and reefs of migmatite (metamorphic rock) (Marcoux et al., 2004) emerging at low tide. Vougot beach is formed by a massive dune complex 250 m to 400 m wide which was constructed during the Holocene (Guilcher and Hallégouët, 1991). This dune, anchored on Zorn cliff, stretches over about 2 km in a southwest to northeast direction. It culminates at 13 m NGF in altitude (i.e. above sea level – asl). (The altimetric reference NGF – *Nivellement Général Français* – refers to French topographic data. In our case this reference is situated 3.5 m above the spring-tide low-water level). Over the last decades, the dune of Vougot beach has experienced erosion (Suanez et al..2010). The geological scheme (figure 2) present the main sedimentary and lithographic shape of the study area. At low tide, the intertidal beach surface can be exposed over more than 400 m. Macrotidal range of the area (reaching 8.5 m) explain this large surface.

Deep-sea wave rose characteristic are present on figure 3. Climatic wave data have been calculated by numerical model (Suanez et al., 2011). The principal offshore waves arriving in the Guissény area mostly come from a west-north-west direction. Islet and reef indeed waves diffraction and also relatively well protect Guissény shoreline. Coastal environment of Guissény is very complex and indeed multiple hydro-morphodynamics phenomena (“comet tails” formed at the lee of reefs and islets, waves deformations). (Suanez et al., 2011).

2.3. *“Johanna” storm characteristics*

2.3.1. *Meteorological observations*

The storm of 10 March 2008, named “Johanna”, hit the northwestern tip of Europe. On the evening of Saturday, March 8, 2008, two days before the storm reaches the west of France, low pressure area is born at Newfoundland (Pressure = 1010 hPa). The storm intensified during his journey along the 55th parallel north (Cariolet et al. 2010). The cold front of the depression reach the north coast of Finistère on march 10^{th} morning. Atmospheric pressure decreases, from 1000 hPa to 975 hPa. This pressure drop is accompanied by a change of wind direction (West-NorthWest), building to 20 $m.s^{-1}$. These weather conditions have influenced hydrodynamic conditions.

2.3.2. *Hydrodynamical observations*

At the peak of Johanna storm, an significant wave height (Hs) of 11,5 meters and a peak wave period (Tp) of 17 second are observed at the buoy n°02911 « Les Pierres Noires » (figure 4). This permanent buoy is the nearest buoy from the study area. According to Komar P.D. (1998) formulations, coastal Hs and coastal Tp waves values will be also important. Swell off direction are also correlated to wind direction. Water level observed at Roscoff tide gauge station (located at about 30 km from the area) reveal a storm surge due to Johanna storm. Observations at the buoy were supplied by CANDHIS service from National swell off database from the Institute for maritime and inland waterways (CETMEF-Brest) and tide prediction data were provided by the REFMAR service from SHOM.

3. The ECORS coastal forecasting simulator

3.1 ECORS project

ECORS program, developed by the French Defense (*Direction Générale de l'Armement - DGA*), is divided in two step : terrestrial and marine. The second one is led by the French Oceanographic Office and focus on marine environment for amphibious and naval operations. This marine step of ECORS contribute to a better comprehension of marine environment and its dynamics : waves, currents, beach morphology and sedimentary movements.
Coastal sea state quality and temporal variability of environment are poorly understood and are often limited to statics information (specific point in time). Coastal landing zone can be also limited. For example, the tridimensional dynamics, related to hydrodynamic condition, of sandy bars, often located in intertidal or subtidal zones, can prevent beach access. Born from five-years of theoretical research, field and laboratory experiments, and numerical models development, this theatrical simulator can be applied to the hydrodynamics and morphological processes understanding (in order to help amphibious operations), but also to coastal management and to improve numerical models.

3.2 The coastal forecasting simulator

3.2.1 Principles

The ECORS coastal forecasting simulator for sandy and gravelly beaches is an portable, autonomous and complete tool, available on every beaches in the world. This simulator is composed by three parts. First, the simulation environment that integrates a system of various models allows to calculate tide, swell off and coastal waves, currents, and morphology change of beaches. The second part concerns data space and workspace which centralized all data necessary for the operation of the simulator. Models are connected to the SHOM sedimentological and hydrographical databases. These databases allow to characterize coastal environment and their short-terms dynamics (from few hours to few weeks). The third part of ECORS simulator is its graphical interface ("QuantumGis" based) which is the component with which users interact with the simulator. These three components interact with each others to fulfill the desired functionality. This simulation is divided in two levels : ECORS first order model and ECORS second order model.

3.2.2 Modeling strategy of ECORS simulator

Figure 5 present the conceptual scheme, including different "environmental systems" and models, of ECORS analyze strategy. Three types of models interact themselves.

- ✓ *Swell off model*

Some forcing define this model : swell off conditions, tide data and coastal digital terrain elevation (extracted from multiple database like GEBCO, SHOM bathymetric database). Swell off model is generated by WaveWatch III™ modeling results, based on satellite measures and wave recorder data. Developed by "Météo-France" and "SHOM", modeling result provide swell data of 30 minutes mesh and with a 15 minutes time step over a decade (1998 to 2008).

- ✓ *Hydrodynamic model*

This model incorporates forcings from the wave model and external forcing such as tides data, the DTM and SHOM digital model of sediment. In this study, For swell off propagation in coastal area, SWAN model is used and SWAN output forced hydrodynamic component of EPOC1DBeach model for waves propagation on near shore area.

- ✓ *Morphodynamics model*

Morphodynamic model depend directly from hydrodynamic one. Beach morphology and sedimentary transports are managed by this model. An retroaction with the swell model create a cyclical modeling chain. In our case, EPOC1DBeach model compute morphology and sediment transports evolution.

3.2.3 ECORS first order models

The ECORS simulator first level is composed by simple first order models. These models allow to calculate the general characteristics of the targeted beach. The first level not use a surface approach of the

study area and is only based on some parameters (grain size data, statistical wave climatology data, tidal range, etc.) (Garlan et al., 2011). This first order modeling calculate many parameters like, equilibrium subtidal beach slope and profile model according to Bernabeu classical formulation (2003), Bernabeu formulation with tidal translate (2006) with tidal parameters (2006), Rectors and Dean-Moore formulations. Number of beach bars in subtidal area (according to Short and Aagaard formulation (1993), Iribarren number for break characterization, and so on , are also calculate.

3.2.4 ECORS second order models

The ECORS simulator second level integrates second-order models (in 2D and 3D). Models of this level require to have digital elevation models (DEM) which are based on depth data from different sources (soundings, multibeam echosounder data, charts, grided data), with heterogeneous quality and density of data (Garlan et al., 2011). Figure 6 present the conceptual model of ECORS simulator second level. Four morpho-dynamics models, coupled with hydrodynamic model, can be intend to use : SWAN-EPOC1DBeach (University of Bordeaux, France), SWAN-XBeach (Deltares, Nederland), SWAN-MARS-SEDIMORPH (Ifremer, France) and REFDIF-WENOHH- (

We focus this study on a second-order modeling with SWAN-EPOC1DBeach.

3.3 SWAN-EPOC1DBeach Model

3.3.1 Model selection.

In this study, Islets and reefs effects on wave diffraction is not considered. The current ECORS simulator model version not allow to fixe hard structures for littoral DTM. This fact explain also that we select an 1Dimension model. We also considering a profile which avoid reefs, at the North-east section of Vougot beach (figure 1).

3.3.2 Model setting

- ✓ *SWAN model*

SWAN is a third-generation wave model for obtaining realistic estimates of wave parameters in coastal areas, lakes and estuaries from given wind, bottom and current conditions. However, SWAN can be used on any scale relevant for wind-generated surface gravity waves. The model is based on the wave action balance equation with sources and sinks (Ris et al., 1994). The model is formulated in terms of action density N (energy density divided by relative frequency). The SWAN wave model formulation are detailed in Ris and al., 1994.

SWAN simulates the following physical phenomena (Holthuijsen et al., 1989; Ris, 1997) :

- Wave propagation in time and space, in banks, due to refraction and depth, frequency shifting currents and depth non-stationary.
- The generation of waves by wind (not activate on ECORS simulators).
- Nonlinear Interactions (both quadruplets and triads).
- Friction on the bottom, and depth-induced breaking.
- Blocking of waves by the current.

- ✓ *EPOC-1DBeach model*

1DBeach is a 1DH model (one horizontal dimension) which simulate the cross-shore beaches dynamics, including sand bars. Developed by the University of Bordeaux, the evolution of beach profile is based on a simple model which integrates an averaged phases approach and coupling wave, sediment transport and bathymetric evolution. This model allows to simulate the migration of sand bars to the edge or seaward through a parameterization of sediment flux perpendicular to the coast (Castelle et al., 2010). This parameterization considers the asymmetry of the wave and acceleration near the bottom. EPOC-1DBeach model is composed by a hydrodynamic module and sedimentary module.

The hydrodynamic model is defined by this following parameters :

- Variation of the wave energy flux
- Mean sea level variation of free surface is based the equation of conservation of momentum
- Energy flux associated to break
- Undertow current

- Long shore sedimentary flux
- Wave modeling
- Sedimentary equation of conservation

A detailed description of this morpho-dynamic model and formulation is presented in Castelle et al., 2010.

4. Field data, modeling data sources and modeling parameters initialization

Grain size analyses have been realized in may 2012 in order to characterized Vougot beach. These values have been obtained by using a *Beckman Coulter LS 13320* laser diffraction particle size analyzer, the density of the sediment was measured with an Helium pycnometer *(Accupyc II 1340)*, and porosity was then obtained from this measurement. We also consider for this study a homogeneous grain for all of the Vougot beach. The median particle size (D_{50}), average of all sediment sample analyze, is 0,438 mm, related to a fine sand. For sedimentary characteristic, we also forced models with a sediment porosity of 35%, a density of 2650 $Kg.m^{-3}$. Water physical and chemical proprieties are set up with statistics data from SHOM for a winter-ending season. Cinematic viscosity is defined as 0.0000011 $m^2.s^{-1}$, water density as 1021 $Kg.m^{-3}$ and temperature as 10.5 °C and salinity as 34.25 PSU. ECORS calculate gravity constant for this geographic position and assume it as 9.8199 $m.s^{-2}$. Figure 7 show coastal DEM for swell off propagation from points with valid swell data (two yellow points). SWAN model is forced by using WaveWatch III™ modeling results from ECORS database.

Three specific parameters are defined for SWAN-EPOC1DBeach models. Break slope is fixed to 0,1. For break energy dissipation model we use Ruessink et al. (2003) formulation including a true flag avalanche parameters.

5. Comparison between modeling survey and field survey

Backshore and intertidal beach dynamic are studied in order to validate the modeling results (figure 8). We forced EPOC-1DBeach model in order to reach the maximum sea level (Suanez and Cariolet, 2010). In fact, this morphodynamic model just considering set up phenomenon but not run up one and water elevation (storm surge due to low pressure). Or , Suanez et al. 2011 shows that these two phenomena have a major impact in the beach dynamics during Johanna storm. Suanez and al. (2011) calculate run-up via a semi theoretical approach using the basic equations established by Hunt (1959), Battjes (1971) and Holman (1986). The maximal run-up (set up + swash run up) reach 10.4 meters (dune crest) during Johanna storm (Suanez and al., 2011). So, characteristic water level in SWAN-EPOC1DBeach model have been modified by an external method (not implement in ECORS simulators). We simulate a maximum water level of 11.56 meters. (wave break included), corresponding to maximal tidal range.

Observations realized by Suanez and Cariolet (2010) show a major erosion of the dune toe. Comparison of EPOC1DBeach model predictions with observations show an overall good correlation (Figure 8). The major erosion of the dune toe is well modeled by model chain. Beach profile readjustment following these erosion phenomena on the nearshore to shoreface zone would therefore result in post-storm sediment transport between the upper intertidal beach and the lower intertidal beach–nearshore to shoreface zone. These processes have been particularly well described by Dean (1991).

However, due to the relative simplicity of models parameters and sedimentary dynamics equations, results under or over-estimate the real impact of a storm on the Vougot beach. Figure 9 show that volume variation modeling result during the storm are overestimated. They do not accurately reflect reality, but they show tendencies. In fact, sedimentary volume transport during Johanna storm is over-estimated by EPOC-1DBeach model. The 10 meters gridded DEM used for modeling smooth beach profile and not allow to reproduce the hard slope of dune. Moreover, the complex bathymetry of Vougot Bay, with the presence of rock reefs, explain probably most of the differences between modeling results and the reality and define the limits of the morphodynamic model.

6. Tables, Figures, Equations and References

3.1. *Figures*

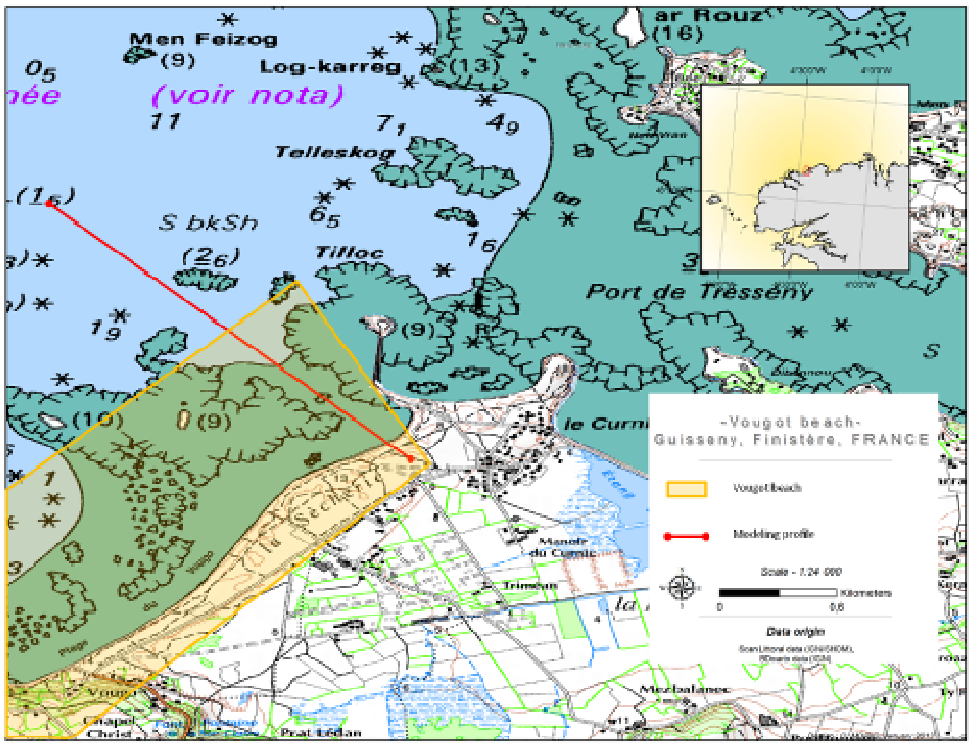

Figure 1. Geographical situation of Vougot beach and modeling profile– Guissény town, Finistère, France

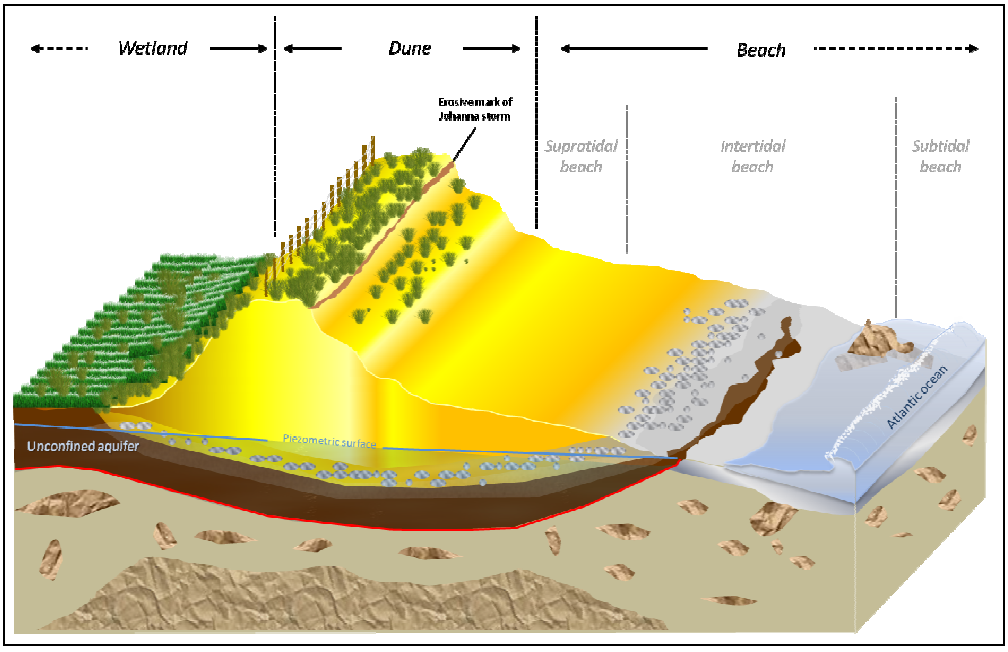

Figure 2. Hypothetic geological scheme of Vougot area.

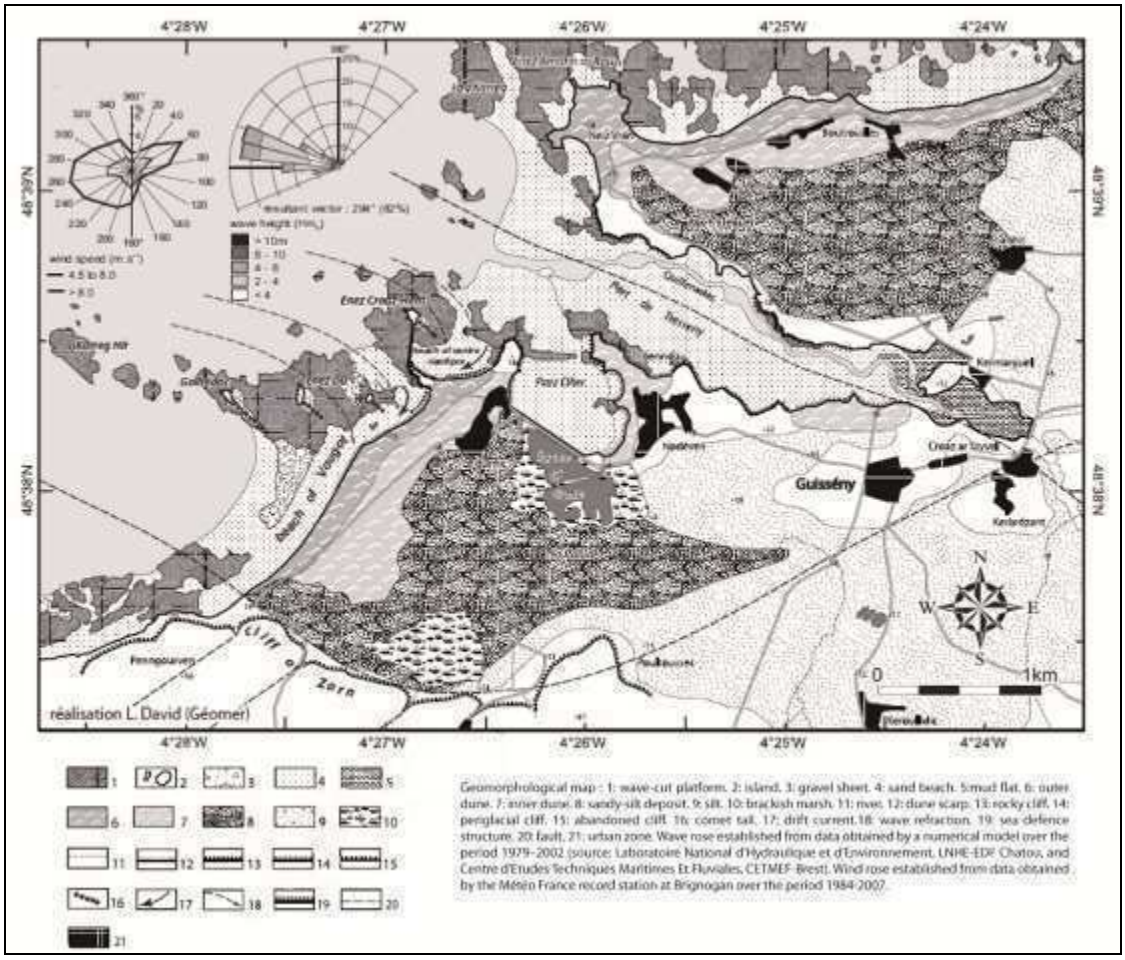

Figure 3. Geomorphological map of coastal area of Guissény town, centralize on Vougot beach (from Suanez et al. 2011)

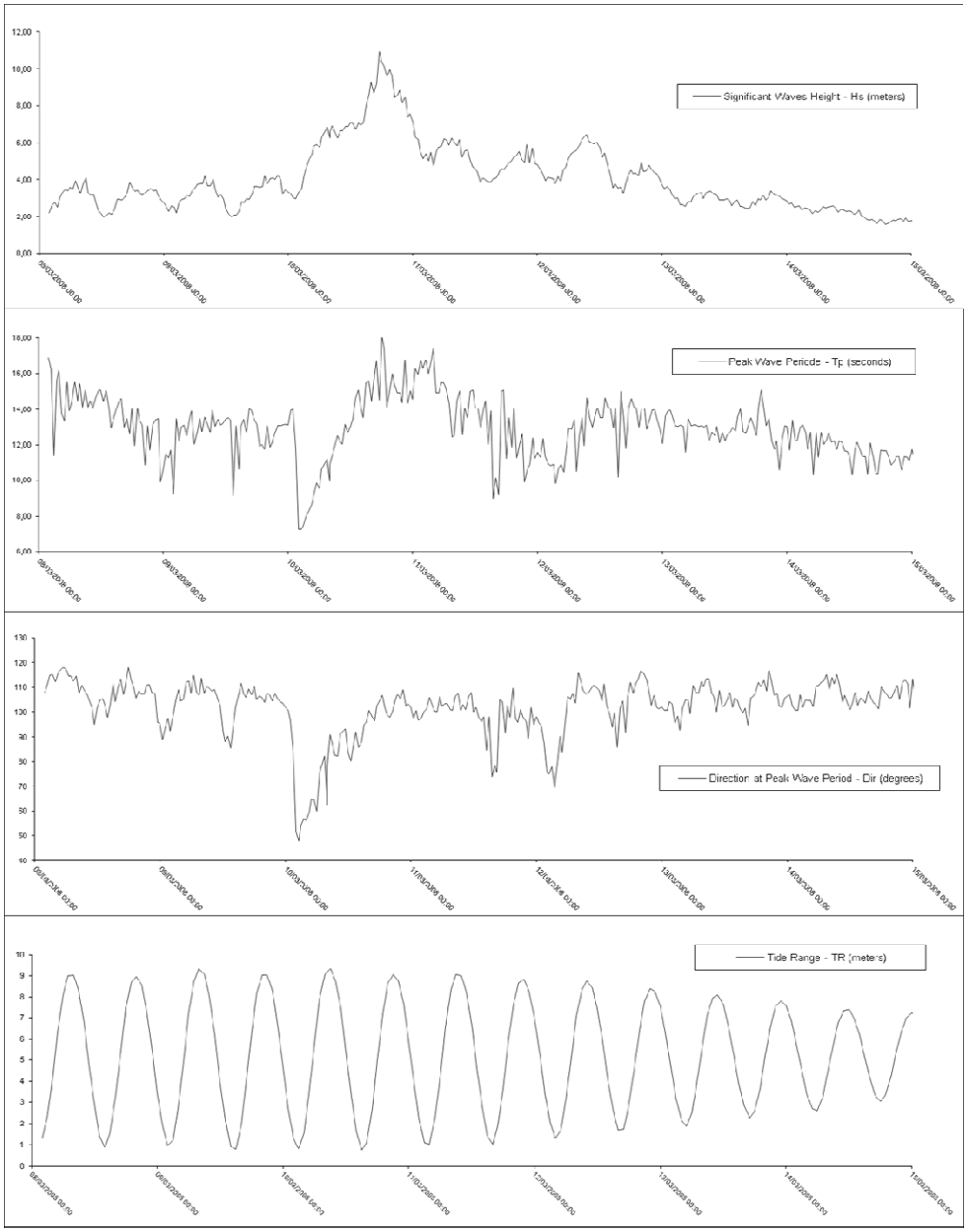

Figure 4. Hydrodynamical data during Johanna storm and apply to SWAN-XBeach models

The observations of Roscoff are the property of SHOM and are available on the REFMAR website (refmar.shom.fr) Swell off data are extract from swell off national data base CANDHIS. Measures have been realized by a collaboration between PREVIMER and CETMEF.

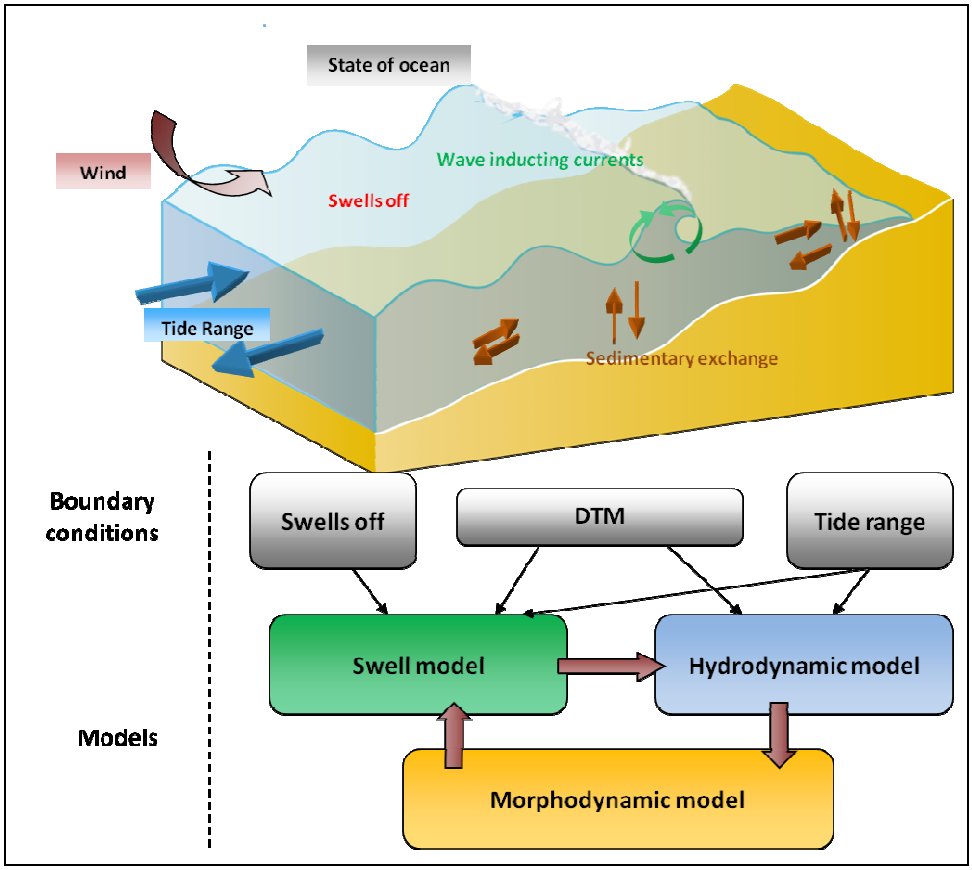

Figure 5. Conceptual scheme of ECORS modeling strategy (from Garlan et al., 2011, modified)

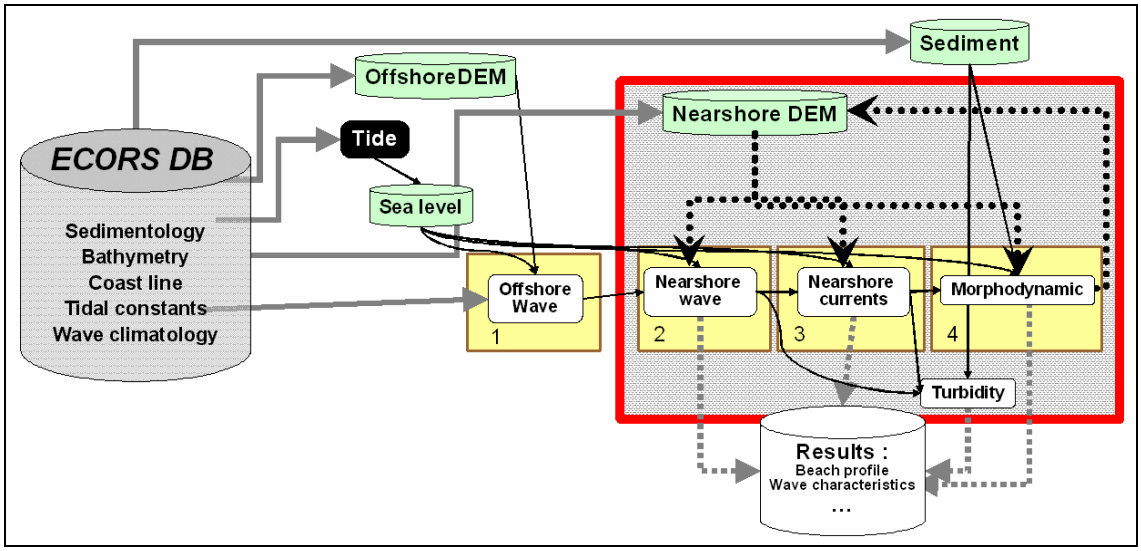

Figure 6. The conceptual model of ECORS simulator second level (from Garlan et al., 2011).

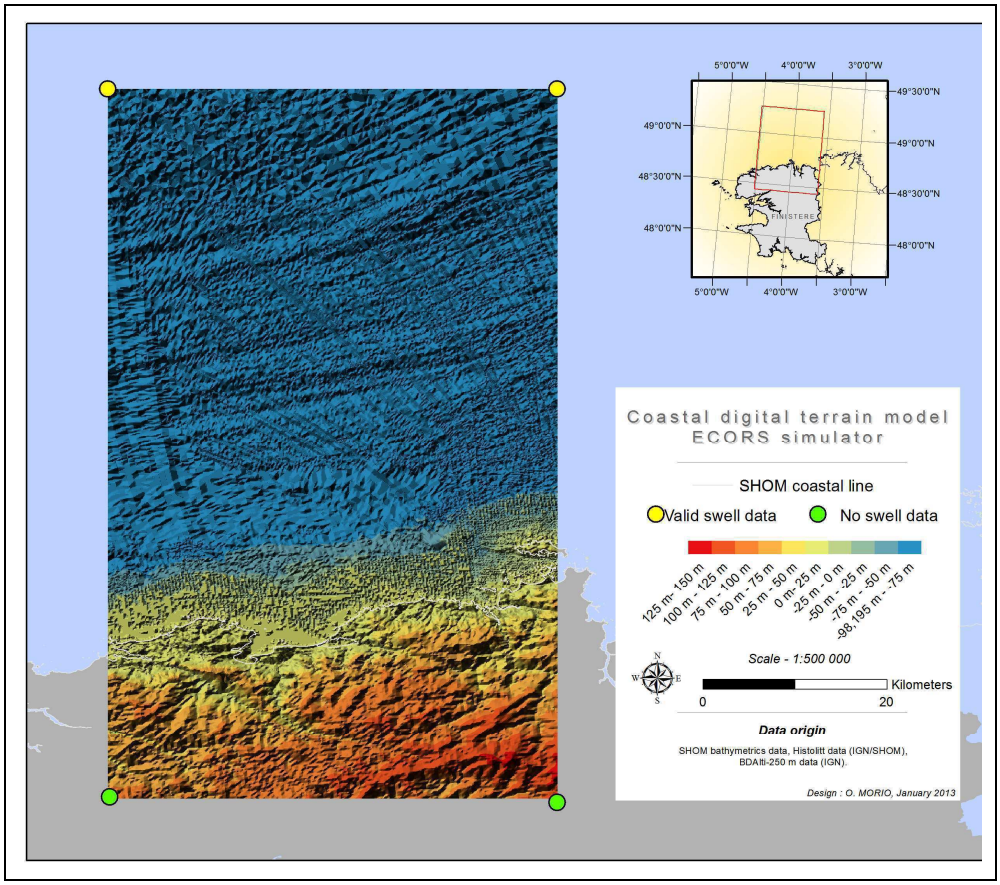

Figure 7. Coastal Digital Elevation Model for swell off propagation.

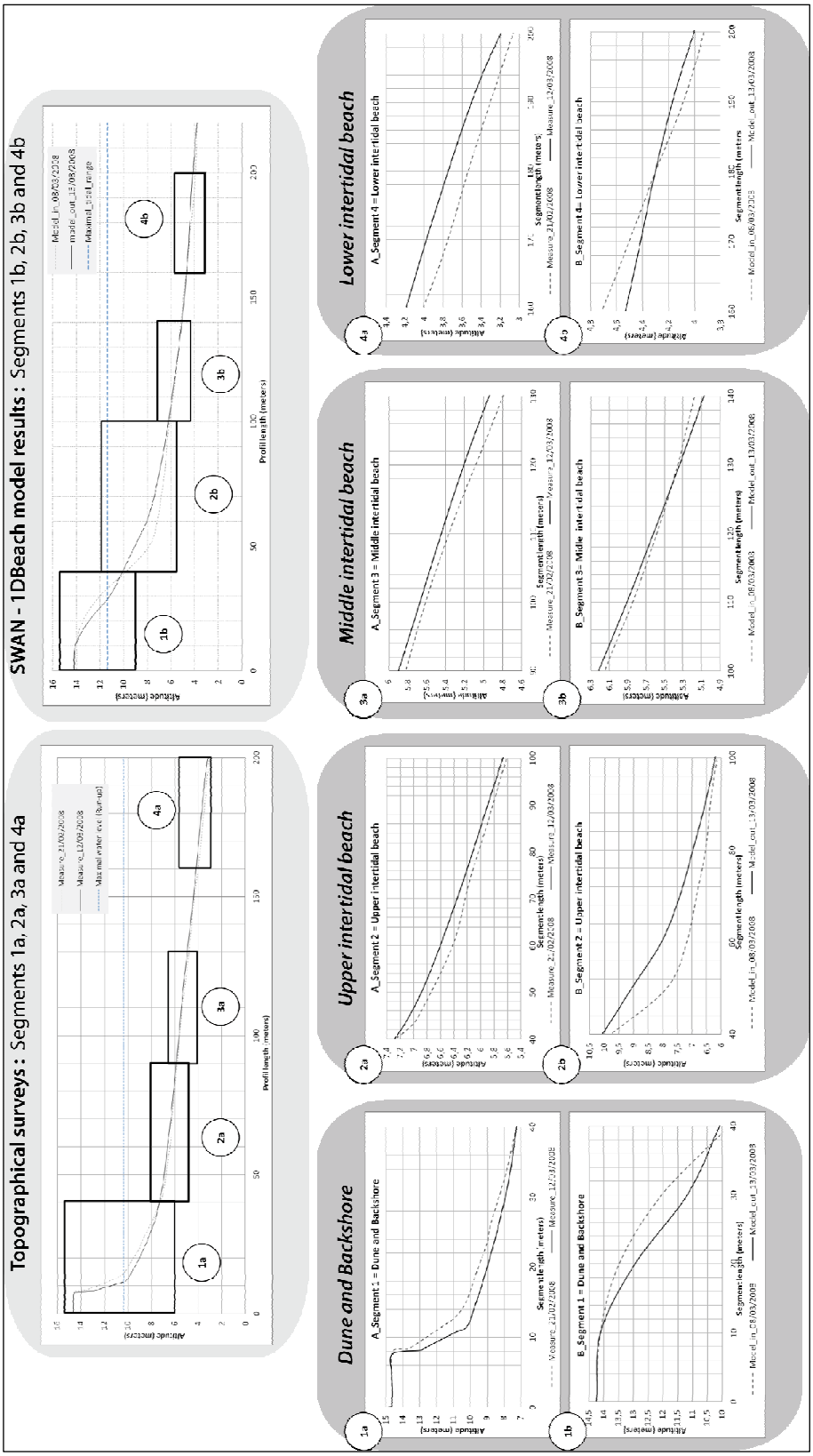

Figure 8 : Comparison between topographical surveys and modeling results of the impact of Johanna storm on Vougot beach.

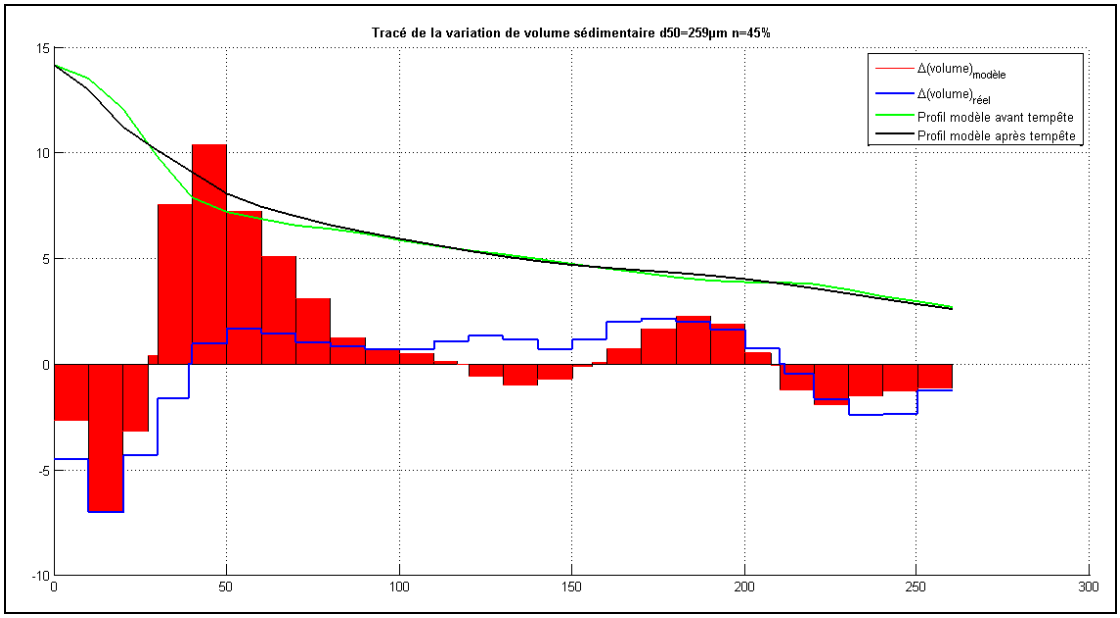

Figure 9: Volume variation of sediments during Johanna storm along modeling profile

3.2. *References*

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