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Modeling of Shoreline Evolution
Influence of Using Synthetic Series of Agitation

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ABSTRACT

The study of the evolution of the coastline, taking into account the use of synthetic series of agitation is an important analysis for science dealing with the coastal zone. The use of synoptic data of the wave climate for study or design of coastal areas is becoming a reality. The use of collection stations stationed offshore is not always feasible, due to errors in the data readings from the stations, due to the difficulty in accessing the data, or due to costs related to the whole data collection process.

This dissertation will be addressing this issue through mathematical simulations carried out in a stretch of the west coast of Portugal, Figueira da Foz - Costa de Lavos. The primary objective will be to simulate the evolution of the shoreline, by varying the order of classification of the wave climate offshore, and after analyzing the influence that this order has on the position of the coastline. Different simulation scenarios were created in order to represent as fully as possible any influence of the order of occurrence of wave events, in the position of the shoreline, by varying the sequential order of wave heights and directions.

The mathematical model responsible for simulating the evolution of the position of the shoreline will be the GENESIS model, while another model, STWAVE will accomplish the transformation of the wave climate from offshore to nearshore conditions. These two models are embedded in the CEDAS computer program, developed by Veri-Tech, which provides an interface platform for user-models.

Keywords: Modeling of the Evolution of a Coastline, Influence of Using Synthetic Series of Wave Climate, Figueira da Foz, Costa de Lavos, GENESIS, STWAVE.

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1. INTRODUCTION

The study of synthetic series of wave climate, in short, focuses on analyzing the influence of the order of events of agitation. This work aims to evaluate the behavior of the evolution of a shoreline varying wave climate conditions offshore.

To achieve that goal an extend of the Portuguese cost was modeled. This coastal extend reaches from the Figueira da Foz port to a local village, Costa de Lavos. Using the STWAVE model annual series of wave climate were propagated from offshore to nearshore conditions. The nearshore data was then used to model shoreline evolution, using the GENESIS model. This last mathematical model is responsible for simulating the position of the shoreline and allowed to produce the final results of this study. The main generator, by the GENESIS assumptions, of the variation of the shoreline evolution is the longshore transport. This type of transport depends essentially on three factors, waveform, beach and sediment characteristics.

Hanson, 1987, and *Le Mehaute, et al.,* 1983*,* produced studies where series of wave climate were used to simulate shoreline evolution. Both concluded that the order of the synthetic wave series influences the shoreline position after the simulation period, particularly wave direction. The big difference between their studies and the one present here is the application on a real coastal extend and the variation of more than one wave characteristic at the same time.

2. THEORY BASICS

2.1. CERC FORMULA

The CERC formula acts as the basis for the mathematical model GENESIS. This formula makes use of the energy flow method and can be written in the following way.

$$Q_l = K \left(\frac{\rho \sqrt{g}}{16\, k^{1/2}\, (\rho_s - \rho)\, (1-n)} \right) H_b^{5/2} \sin(2\alpha_b) \tag{2.1}$$

Where,

- Q_l – Longitudinal transport flow;
- K – Adimensional factor;
- k - Breaker index;
- ρ – Density of water;
- ρ_s - Density of sediment grains;
- g –Acceleration of gravity;
- n - In-place sediment porosity (. 0.4) [dimensionless];
- H_b - Wave height at breaking.

The CERC formula is as described above, proportional to wave height and wave direction at the breaker zone.

2.2. GENESIS

GENESIS, Generalized Model for Simulating Shoreline change was developed by the U.S. Army's Corps of Engineers. It's a numerical model that uses the single line theory, simulating coastline change on a region. The GENESIS is able to determine the advances and retreats of the shoreline, keeping its shape and moving perpendicular to the coast. Thus, by selecting a single point of the simulated coastline, one can determine the beach profile at that location, because it moves parallel to itself.

The empirical predictive formula for the longshore sand transport rate used in GENESIS is:

$$Q_l = H_{b\,sig}^2\, C_{gb}\, \left(a_1\, \sin 2\alpha_b - a_2 \cos \alpha_b \frac{\partial H_{b\,sig}}{\partial x}\right), \tag{2.2}$$

The nondimensional parameters a_1 and a_2 are given by,

$$a_1 = \frac{K_1}{16\left(\frac{\rho_s}{\rho} - 1\right)(1-n)\,(1.416)^{5/2}} \tag{2.3}$$

$$a_2 = \frac{K_2}{8\left(\frac{\rho_s}{\rho} - 1\right)(1-n)\, m\,(1.416)^{7/2}} \tag{2.4}$$

Where,

- K_1 and K_2 - Empirical coefficients, treated as calibration parameters;
- m - Average bottom slope from the shoreline to the depth of active longshore sand transport;
- ρ – Density of water;
- ρ_s - Density of sediment grains;
- C_{gb} - Wave group speed at the breaker line;
- α_b - Wave breaker angle relative to the shoreline;
- $H_{b\,sig}$ - Significant wave height at breaking.

The first term of the GENESIS empirical expression, $H_{b\,sig}^2\, C_{gb}\, (a_1\, \sin 2\alpha_b)$, is known as the CERC formula (equation 2.1), and accounts for longshore sand transport produced by obliquely incident breaking waves. The second term, $H_{b\,sig}^2\, C_{gb}\, \left(a_2 \cos \alpha_b \frac{\partial H_{b\,sig}}{\partial x} \right)$, is used to describe the effect of another generating mechanism for longshore sand transport, the longshore gradient in breaking wave height (U. S. Corp of Engineers, 2006).

GENESIS is able to simulate coastline evolution with an almost arbitrary number and combination of groins, jetties, detached breakwaters, beach fills, and seawalls. It also allows multiple wave trains to be input, but a trend in shoreline evolution must be evident. Throughout the simulation, the bottom slope remains constant and moves parallel to itself. Beyond the offshore closure depth the beach profile suffers no change and the longshore transport is only caused by wave and wave induced currents, taking no account for currents induced by local winds or tides.

3. Case Study

3.1. Spatial Domain

The grid for the GENESIS model was defined from south to north, forming a stretch 5600m long with a 25m spacing (Figure 3.1). This spacing was defined taking into account the groins present in the spatial domain, because in the model the structures must be defined at the nodes of the calculation grid.

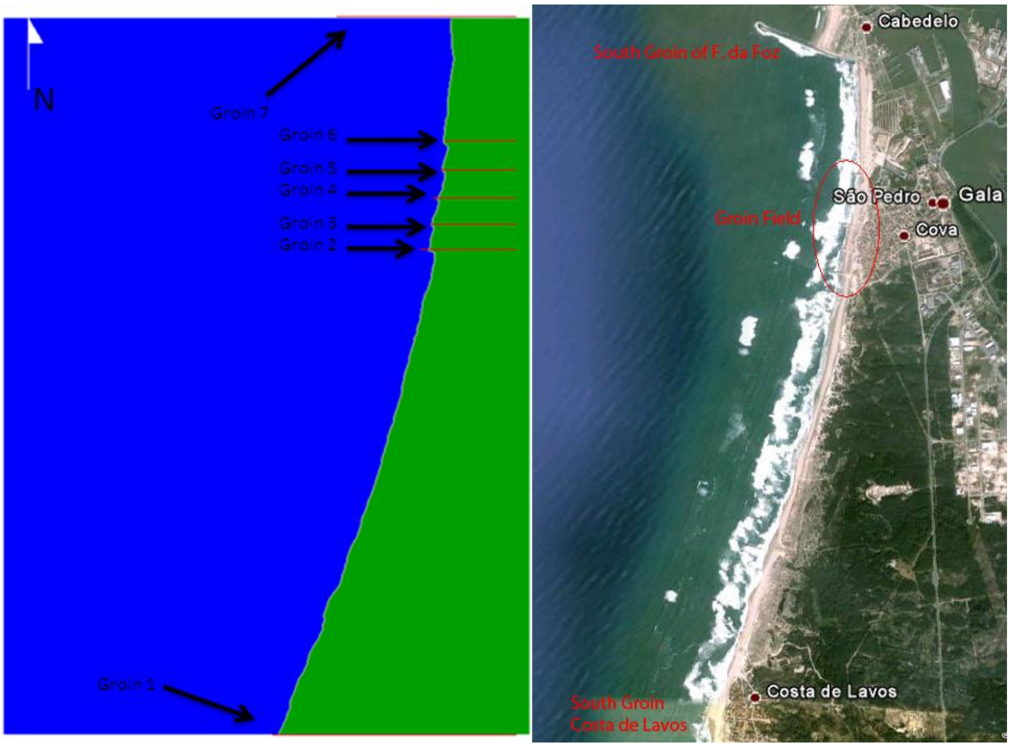


Figure 3.1 - Spatial domain and localization of structures

3.2. Modeling Scenarios and Wave Datasets

Different scenarios were created to be simulated with the NEMOS module. This module includes the GENESIS model, provided by the software CEDAS, which is developed by Verytech Inc. These same scenarios included a year of dataset and were numbered alphabetically. Their specifications are described in the following table.

Scenarios	Description	Simulation Period
Scenario A	The dataset is sorted in the order of increasing wave height (H).	20 years
Scenario B	The dataset is sorted in the order of decreasing wave height (H).	20 years
Scenario C	The dataset is sorted in the order of increasing incidence wave angle (θ).	20 years
Scenario D	The dataset is sorted in the order of decreasing incidence wave angle (θ).	20 years
Scenarios E, F, G	The datasets are distributed randomly.	20 years

These datasets were created from a study presented by Barata et al., 1996, in which they performed a statistic evaluation on a dataset recovered from a buoy located offshore of the Mondego Cape, establishing six representative waves, here described in the following table.

Wave Index	Height (m)	Period (s)	Direction (^{0})	Occurrence Frequency (%)
1	1,75	12	315	50
2	2,25	12	303,75	30,02
3	3,75	12	281,25	7,54
4	3,75	12	326,25	9,8
5	4,75	15	315	1,64
6	6,25	15	315	1

The frequency of occurrence is referred to a year of data recovery.

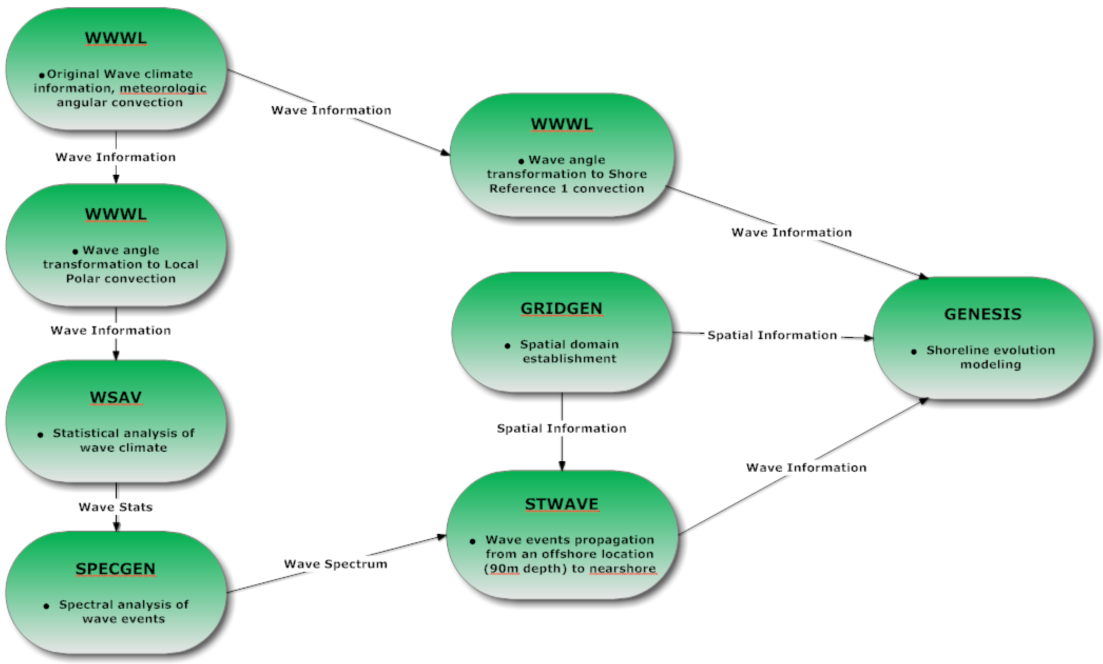
The total flow of sediments was also estimated by Barata et al., 1996. In their study they concluded that the resulting sediment flow had a North-South direction and a $1{,}3 \times 10^3\ m^3/year$ rate.

4. MODELING

4.1. MODELING PROCESS

The modeling process consisted in two big stages. One in which the six representative waves were propagated from offshore, from a depth of 90m, to a nearshore location, using the STWAVE model. The other stage consisted in modeling the shoreline evolution using GENESIS.

The following chart illustrates the modeling process from the beginning, within NEMOS module.



4.1 – Modeling chart procedure

The WWWL editor is used for specifying and editing a variety of record-oriented data types such as waves, winds, water levels (WWWL). This tool was responsible for the re-orientation of the wave data to suit the models specifications. The WSAV provides features for use in statistical analysis of series of wave events, graphically displaying the results of these analysis, and producing a representive group of wave events for use in simulations, this tool also served as a verification method for the annual dataset wave created for the scenarios, where the results from the WSAV tool had to be the same that Barata et al., 1996, reached. SPECGEN creates or imports half-plane energy density spectra suitable for use in STWAVE, which is responsible for wave propagation. The GRIDGEN tool was used to create the spatial domain to be used by the models. With this tool the STWAVE and the GENESIS grids were created.

4.2. GENESIS MODELING PARAMETERS

The shoreline was used as the initial condition for simulation reference. By definition the shoreline corresponds to the intersection of the mean sea level with the beach profile, i.e., corresponds to the line formed by topographic zero (ZT). According to data from the Hydrographic Portuguese Institute and Teixeira, 2006, this position is set at +2.0 referred to the hydrographic zero.

The following table summarizes all the parameters used in the GENESIS simulations.

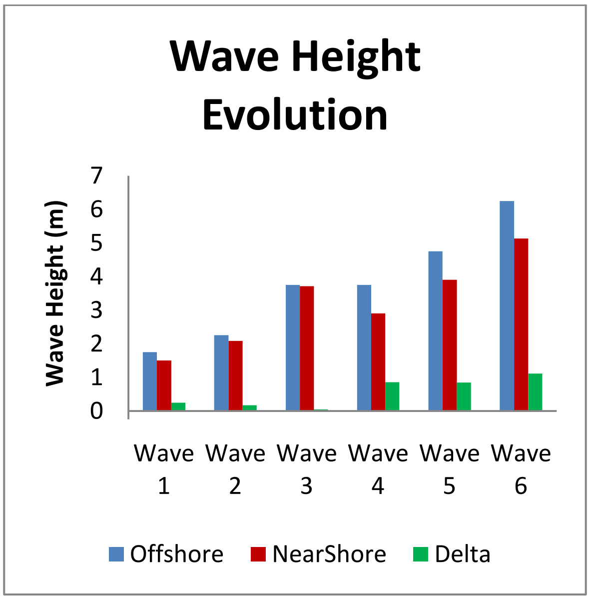
Closure Depth	12m	
Berm Height	4m	
Effective Grain Size	0,660mm	
Boundary Conditions	South	179m (Groin 1 length)
	North	1000m (80 m more than Groin 7 length)
Calibration Conditions	Bypass Conditions	Period: simulation duration
		Location: 300m from groin 7
		Total bypass rate: $148{,}4\ m^3/h$, which corresponds to $1{,}3 \times 10^3\ m^3/year$
	K_1 and K_2	0,13 and 0,10
	Angle offset	-9,5º

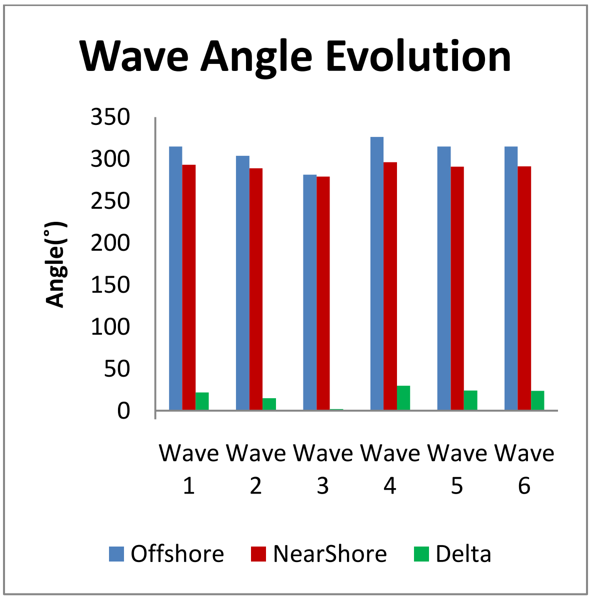
The closure depth was defined using an average from the Hallermeier, Birkemeier and the GENESIS definition equations. The berm height was set at 4m, referred to the mean sea level, this value was determined consulting surveys from INAG and confirmed by Teixeira, 2006. To characterize the average size of sediments in the study area, information provided by the National Information System for Coastal Resources, SNIRL, was used. Here the sediment size from the river mouth, Mondego, to Praia Velha de São Pedro de Moel, is classified as coarse sand to medium. An average from this classification was used for the Effective Grain Size. Both North and South boundary conditions were specified in the model as type, gated groin, this definition implies that the sediment flow is conditioned by a fictitious hatch. The length defined for each boundary condition allows sediment exit in both groins, but only in groin 1 is sediment entry allowed. The calibration data was obtained by recurring to preliminary simulations. To simulate the total flow in the spatial domain, a bypass condition was assumed at the North groin. The angle offset corresponds to a tool that allows wave angle translation, in order to obtain consistent results.

5. RESULTS

5.1. STWAVE RESULTS

After the STWAVE simulation the six representative waves were propagated. The following two graphics show the evolution of those waves.





5.1 – Wave Height Evolution Graphic

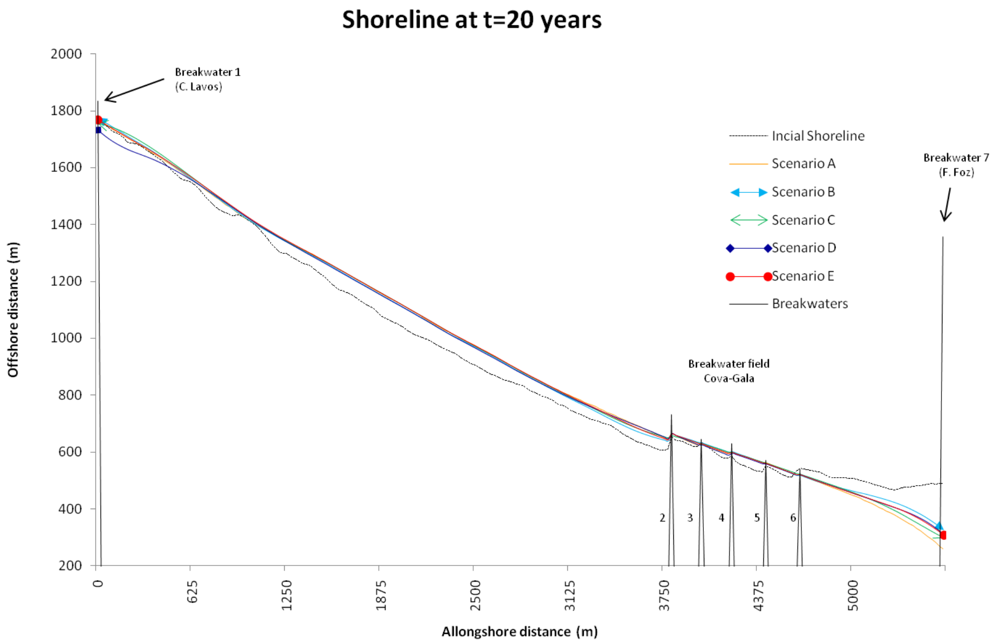
5.2 - Wave Angle Evolution Graphic

Taking in consideration the graphics in the figures 5.1 and 5.2, they show an evident decrease of wave height and a perpendicular wave orientation towards the shoreline (270º), after the wave propagation process.

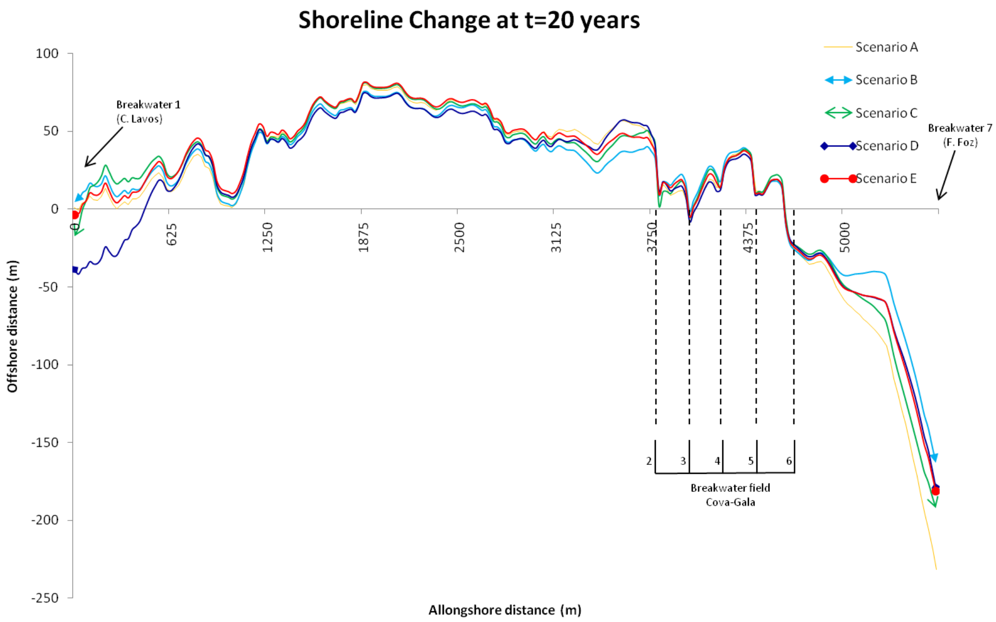
5.2. GENESIS RESULTS

Different plots were made during the total period of simulation, 20 years. These plots were made to determine the differences in the shoreline evolution during the simulation, so, in order to evaluate those differences plots were made at the 2th, 4th, 6th, 12th and 20th year. The analysis reveals an evolution of the shoreline towards an equilibrium position. In fact, as the simulation period increases the differences between the different shorelines decrease. For simulation periods between 12 and 20 years few are the changes in the coastline, in some cases the simulated shorelines coincide. This trend turns out to be valid for any scenario simulated.

The following analysis focuses only on the last plot made at the 20th year, the last simulation year. The randomly distributed scenarios (scenarios E, G and H) only registered small changes near the groins, displaying an overall coincidence of simulate shorelines. Taking that into account, the next graphics displayed in figures 5.3 and 5.4 only display the scenario E, which can be taken as representative of the other random scenarios.



5.3 – Simulated shoreline position after 20 years



5.4 – Shoreline change after 20 of simulation

From the graphics displayed above it can be stated that all the scenarios, except scenario D, show accumulation within the breakwater 1 and 2. In all scenarios there is accumulation of sediment in the breakwater field of Cova-Gala (breakwater 2, 3, 4, 5 and 6), and erosion further north, between the breakwater field and breakwater 7. In the vicinity of breakwater 1 it is the scenario D that turns out to be the one that shows the greatest setback of the shoreline and scenario B the greatest advance. Toward the breakwater 7, it is the scenario A that shows the greatest setback of the shoreline, however, the scenario B is still the one that produces the greatest advance of the shoreline. The scenario E can be taken as the average of all the other scenarios.

Need to be said that the results here presented are only valid, and highly influenced by the parameters imposed in the GENESIS model. Thus the big setback verified in the vicinity of breakwater 7 is due to the bypass conditions set at that location.

6. CONCLUSIONS

The obtained results point to a trend in shoreline evolution to find an equilibrium position as the simulation period increases. These results suggest that an appropriate discretization of the simulation period is important and that in this case study periods exceeding 12 years suffer little change in the simulated coastline.

The construction of random series of events of incident waves produces results, which in its own scale, can be considered as identical. A series of synthetic waves distributed randomly throughout the simulation period may, as shown, be taken as a baseline for an average of the other scenarios considered.

The study presented here concludes that the use of representative wave climate of agitation can be used to build synthetic series. However, it is safer to use random series built on representative waves.

It appears that the conclusions reached by *Le Mehaute, et al., 1983,* e *Hanson, 1987*, are here supported. As both stress sensitivity in the evolution of the shoreline when varying the order of series of synthetic wave climate, as well as the simulation period, where the greater, the more the coastline will tend to equilibrium position.

In a future study it would be interesting to analyze simulations with data directly recovered from the buoy that is without any statistical analysis and a subsequent comparison with the study here conducted, which could take into account financial aspects relating to costs, comparing the advantages and disadvantages of using "original" data or processed data. Such analysis would only be sustainable if in the same period existed the same boundary conditions as the study here concluded.

7. REFERENCES

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