

## GUIOMAR: Geo(graphical) User Interface for cOastal and MARine Modeling. Wave regime at Sines.

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### ABSTRACT

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GUIOMAR is an integrated system for coastal engineering modeling, developed with a commercial software of Geographical Information Systems (GIS). This system allows the utilization of both wave propagation models and of all the functionalities that are inherent to the GIS software, and it is being designed to help in the decision making process in coastal areas. GUIOMAR system is composed of three main components: a GIS commercial software, a set of modules/models of wave propagation and other pre and post processing algorithms programmed in FORTRAN<sup>™</sup>, and a Graphical User Interface (GUI) developed in VBA for ArcGIS<sup>™</sup>, which is responsible for the communication between the user and the system. At the moment, are available six wave propagation models and a program that automatically generates unstructured grids for the numerical models. In this paper, GUIOMAR structure and a general overview of its interface are presented. In order to achieve important information about the system operability, a test was made for an important Portuguese harbor. Sines harbor, at the southeast of Europe, 37° 57'N and 08° 53'W, is one of the main entrances in the Iberian Peninsula.

**ADDITIONAL INDEX WORDS:** Geographical Information Systems, GUIOMAR, Sines harbour

### INTRODUCTION

Coastal zones are very attractive regions for human settlement. The knowledge of the local wave climate is essential for a more supported coastal management. In order to meet these needs it is important to uprightly simulate real cases for the planning of current or emergency situations. Numerical wave propagation models represent, nowadays, a powerful tool to address problems in coastal engineering and in environmental studies such as water management. They give an important contribution in this ambit, due to their quickness, flexibility, and wide application range. Although these qualities allow the easy simulation of several scenarios, the models demand high quantities of data and originate high quantities of results for each case study.

Moreover, in order to achieve a decision about any intervention in coastal zones, it is necessary that the relevant information can be extracted from the enormous quantity of both model results and existent data. This has to be done in a clear, simple and quick way to enable a fast and supported decision.

So, creating a system that organizes the basic information to manage the models (such as bathymetries, harbour geometries, incident wave conditions, etc.), and that establishes quick and efficient working methodologies to deal with both data and model results, enables the user to have a quicker, simpler and more supported decision in terms of coastal problems and interventions.

The Geographical Information Systems (GIS) have huge potentialities to help in the accomplishment of the above mentioned, and are considered vital to understand the temporal and spatial complexity of natural hazards. This is due to their great

capacity to organize and interpret large amount of data and to extract information, hence, rapidly showing trends and patterns (essential to any decision-making process). In fact, GIS have become increasingly important in world-wide renowned institutions/companies that work in coastal engineering.

In order to fulfil these needs, ZÓZIMO et al. (2006) started the development of GUIOMAR system to be applied in studies of coastal hydrodynamic modelling at the Portuguese coast, by using ArcGIS<sup>™</sup>. The system has an interface that is responsible for the communication between the commercial GIS and the wave propagation numerical models. GUIOMAR System helps the user in having a quick, simple and supported decision in terms of coastal problems and interventions. However, some aspects of the operability of the system are still under development. For instance, to guarantee the robustness and liability of the system in the decision-making process, the errors that may be associated with its application have to be assessed, such as the ones related with the implemented computational algorithms, to the coupled functioning of numerical models, and to the interpolation between grids of different resolutions.

The present paper starts with a general description of GUIOMAR system, followed by the description of its application to the study case of the surrounding area of Sines harbour. Sines harbour is located in Portugal, at the west coast of Europe, 37°

57'N and 08° 53'W. This study case is an opportunity to test the system in a real situation. This work represents a step forward in the development of a robust system for the decision making process.

## GUIOMAR SYSTEM

### Main Developments

As a first approach to the system, tested the functionality of the ArcGIS™ software in the study case of sea wave propagation at Sines coastal area. For that test case, the numerical results were obtained with the model REF/DIF 1 (DALRYMPLE and KIRBY, 1991). The great potentialities of ArcGIS™ for the visualization and manipulation of data were confirmed.

To automate the process, SIMAR evolved to the GUIOMAR system (ZÓZIMO *et al.*, 2006). GUIOMAR facilitates the use of the wave propagation models in parallel with all the capabilities offered by the GIS environment. In fact, this system coordinates the use of mathematical models, including the input data management, the computational grid generation, and the geographic analysis of the results.

Specifically, the GUIOMAR system has three main components: a commercial GIS software (ARCGIS™); a set of wave propagation models; and some pre- and post-processing programs in FORTRAN™ language. The modular nature of the system allows its expansion and easy upgrade, such as to include more advanced models or models that contemplate different physical processes. It is intended for the models to be managed independently, or in a coupled way.

In order to use the system a Graphical User Interface was built, that permits the communication between the GIS and the wave propagation numerical models. The entire user interface is built in VBA programming language for ArcGIS™ and permits: (i) the creation of the input files for the numerical models; (ii) the automatic visualization of the bathymetric data; (iii) to run several wave propagation numerical models; and (iv) the visualization of all the results in the GIS tool taking advantage of its 2D and 3D visualization facilities.

The wave propagation numerical models that are included in GUIOMAR system permit a different approach to each case according to the environmental characteristics. At this stage, six wave propagation modules/models are included: models based on the mild-slope equation, DREAMS (FORTES, 2002), REF/DIF1 (DALRYMPLE and KIRBY, 1991) and REF/DIF S (KIRBY and OZKAN, 1994); models based on the Boussinesq equation, FUNWAVE 1D and 2D (KIRBY *et al.*, 1998); and the spectral wave propagation model SWAN (BOOIJ *et al.*, 1999).

The program GMALHA (PINHEIRO *et al.*, 2006) is responsible for the unstructured grid generation.

The main capabilities of the system are to help in the correct use of the wave models and to support the decision making process in current coastal engineering studies and in emergency situations. The main limitations are related to the present stage of development, which does not include, for instance, the coupled functioning of models.

Figure 1 shows a diagram of the functioning of the GUIOMAR system. Although this structure could be implemented with any GIS software, it is being developed in ARCGIS 9.3™. This software was chosen because of its widespread use, years of utilization as commercial software, and due to the fact that it allows programming in VBA, which is an easy learning language.

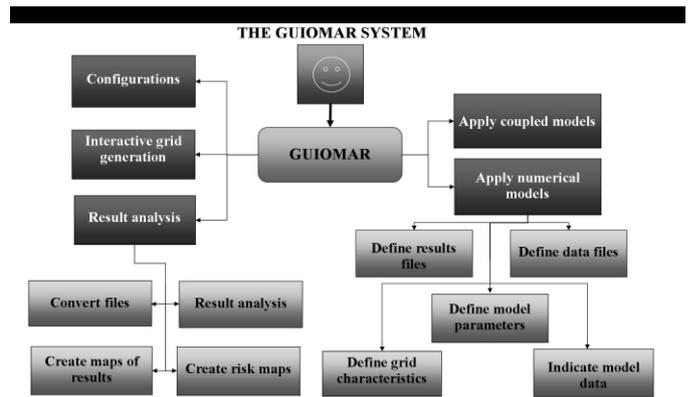


Figure 1. Diagram of the GUIOMAR system

### The Interface

After installing the GUIOMAR system, the user is empowered to access all its features through the ArcMap application (included in ArcGIS™). GUIOMAR is implemented as a new ArcMap extension (like for example 3D Analyst) (Figure 2).

At this stage, this extension enables automatic visualizations of the bathymetries, to run the numerical wave propagation models DREAMS, REF/DIF 1, REF/DIF S, FUNWAVE 1D, FUNWAVE 2D and SWAN (ZÓZIMO *et al.*, 2006), and to create unstructured grids with GMalha (PINHEIRO *et al.*, 2006).

In fact, once the user chooses which model wants to apply, he/she has access to several forms that help in the introduction and manipulation of data, in the application of that specific model, and in the visualization of data and results.

GUIOMAR enables either the introduction of new data for a certain test case or the import of existing data files. Consequently, the construction of new data sets is eased. To be imported, the data files have to be in the pre-defined format of GUIOMAR. For the correct importing of data files, a set of helps to the user will be created in future, to guide the user on the construction of data files for importing.

The construction of the input files occurs when the user applies the numerical model. The system is responsible for writing those files accordingly to the model format specifications. If there is any mistake in the data input in the forms, the user is notified by an error message, that is intended, in the near future, to indicate where the error occurred (for REF/DIF 1 model this functionality is in its final phase of implementation).

After the correct construction/import of the input files, the user can proceed with the application of the model. After that application, the results of the numerical models can be analyzed through the different forms developed for their visualization and post-processing.



Figure 2. Main menu of the GUIOMAR system.

## STUDY CASE

The objective of the study case presented here was to study and characterize the local wave regime of the area adjacent to Sines harbor. Being one of the main entrances in the Iberian Peninsula, Sines harbor is extremely relevant geographically. For this test case, SWAN (BOUJ *et al.*, 1999) model was applied to propagate the offshore wave measurements until the harbour entrance, followed by an application of DREAMS (FORTES, 2002) model to propagate the wave conditions from the entrance until the harbor interior. Notice that the need of these two models is related to their own limitations. Within the port, the wave reflection on its boundaries is one of the phenomena that determines the sea-waves characteristics and that it is not properly simulated by SWAN. Thus, there is the need to use the DREAMS model which takes into account this phenomenon but that can only be used in a small area due to the computational effort involved. The program REGIMES (PINHEIRO *et al.*, 2006) was used to establish the wave regime at defined points inside the harbour.

Figure 3 shows the bathymetry used to calculate the wave significant height, period, and direction. This bathymetry is based on a bathymetric survey made by the Hydrographic Institute of Portugal.

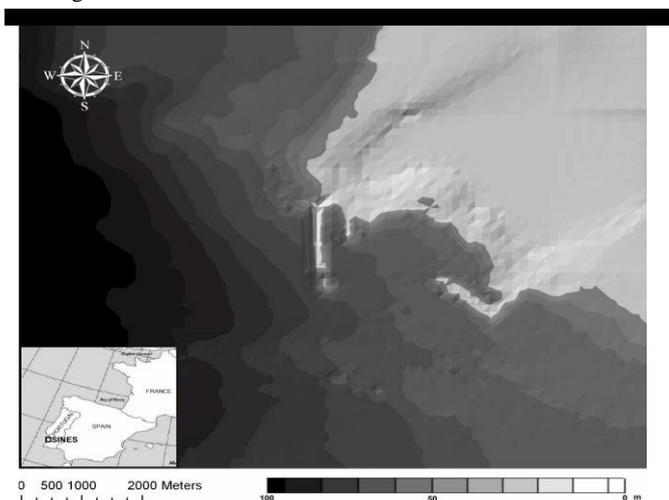


Figure 3. Sines. Bathymetry and localization.

## METHODOLOGY

### Definition of transfer matrixes

The buoy data comprises a set of 32807 records obtained between May 1988 and December 2002 by a directional wave buoy. The transference of this huge amount of data to inshore, by with SWAN and DREAMS models, involves a significant computational effort. Notice that the running time for each calculation of SWAN (each buoy data value) and DREAMS models is of around 45 minutes.

To overcome this difficulty, the methodology implemented consisted in determining a priori transfer matrix(es) for the study region, i.e., the values that relate the offshore sea-wave characteristics with the sea waves at a specific points inside the port.

Once the transfer matrix(es) is known, for each measured buoy wave data ( $H_s$ ,  $T_p$  and  $\theta$ ), the REGIMES program interpolates such condition using the transfer matrix(es) to estimate the sea-wave characteristics at the study point(s).

To establish the transfer matrix(es) from the buoy data, one has to define the ranges and the corresponding intervals of the significant wave height, average period and direction. This enables the definition of several trios of ( $H_s$ ,  $T_p$  and  $\theta$ ) equally spaced. Those values are the input wave conditions for which the SWAN and DREAMS models are applied. Based on these numerical results, the transference matrix is built at each point inside the harbour.

### Wave regime inside the harbour

16 SWAN observation points and 6 DREAMS observation points were defined and are shown in Figure 4.

The computational grids (Figure 4) were built in order to achieve the most quality results. SWAN and DREAMS computational grids were built through GUIOMAR system. The DREAMS finite element mesh was generated with the module for the grid generation GMALHA (PINHEIRO *et al.*, 2006).

Two SWAN grids with different resolutions were defined, namely a coarse and a nested grid, with a 80 and 40 meters spacing respectively. The DREAMS finite element mesh was composed by 300139 elements and 151669 nodes.

The calculations included a range of wave conditions, 810 in total, including significant wave heights ( $H_s$ ) from 0.5 to 9.5 m with 1 m step, periods ( $T_p$ ) from 4 to 20 s with 1 s step and directions ( $\theta$ ) from 180 to 360° (relative to north) with 20° step.

It was not taken into account the phenomena associated with the wind and currents. It was admitted a JONSWAP spectrum, with a

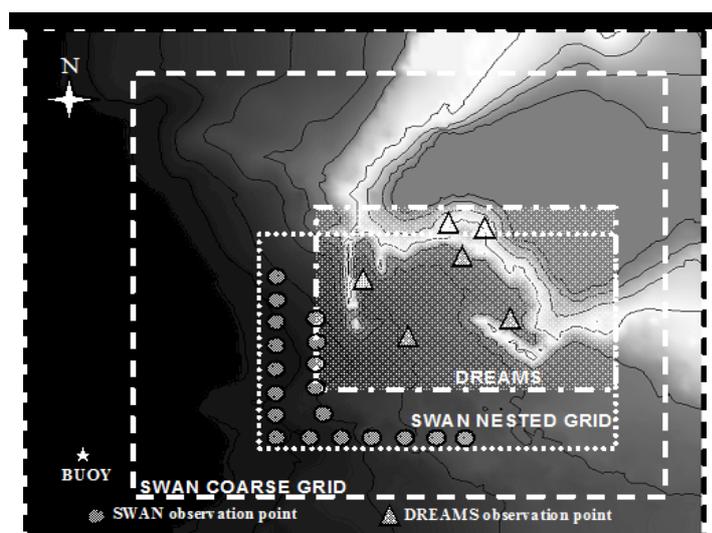


Figure 4. SWAN and DREAMS Grids and the points.

coefficient  $\gamma=3.3$  and a directional cosine square function. The frequency was discretized in 23 intervals from 0.04 to 1 Hz. The direction resolution was of 20°.

All the conditions mentioned above were set in the GUIOMAR system dialog boxes presented on Figure 5.

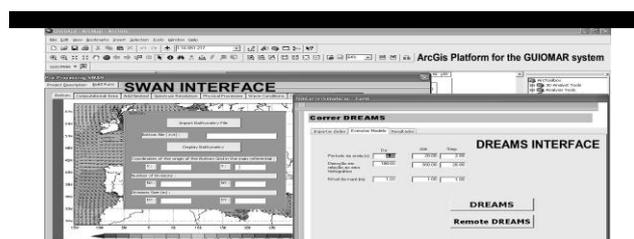


Figure 5. GUIOMAR: SWAN and DREAMS interfaces.

### RESULTS AND DISCUSSION

In order to summarize the results, 4 points of interest were defined, chosen with the intention of showing the wave regime evolution from outside the harbor zone until the small fishing port (Figure 6). The chosen points were: SWAN observation point 16 (outside the harbour zone) and DREAMS observation points 1, 3 and 5 (harbour entrance, small fishing port entrance and inside the small fishing port).

Table 1 and the following Figures (7, 8, 9 and 10) present the results for each chosen point. It is easy to observe the wave regime because the number of occurrences for each main event of a wave regime is represented. The results are presented by the number of events for each variable range at each point.

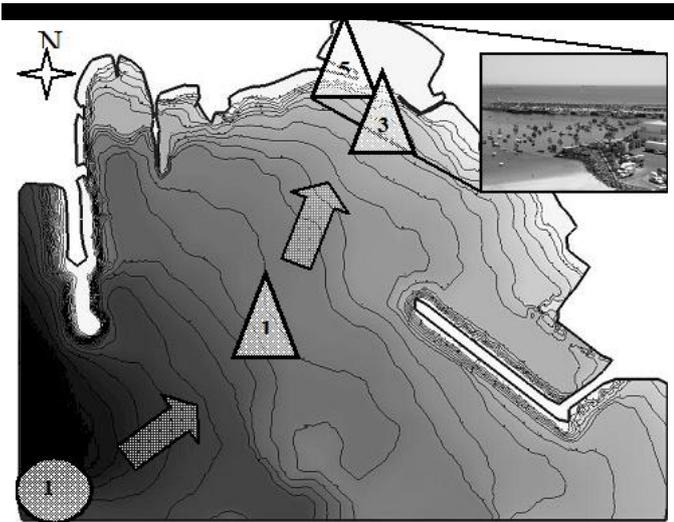


Figure 6. DREAMS mesh and chosen points.

Table 1: Maximum, minimum and average for each variable at each point.

Hs (m)	Point 16	Point 1	Point 3	Point 5
MAX	6.08	4.29	3.57	0.24
AVERAGE	1.51	0.6	0.19	0.01
Tp (s)	Point 16	Point 1	Point 3	Point 5
MAX	16.00	16.00	16.00	16.00
AVERAGE	6.90	6.90	6.90	6.90
$\theta$ (°) (N)	Point 16	Point 1	Point 3	Point 5
MAX	351.00	270.00	230.00	142.00
AVERAGE	292.00	241.00	212.00	125.00

Results show a clear evolution between point n.º 16 and point n.º 5. In terms of Hs, the values present a maximum of 6.08 m outside the harbor, of 3.57 m inside the harbor and of 0.24 m inside the small fishing port where the values are considerably lower. In every point, inside and outside the harbor zone, the periods (Tp) do not vary considerably.

Finally, the results for the directions clearly show a shift of the wave crests when entering the harbor, as expected: outside the harbor the main direction is of about 292° north, while inside the harbor it turns to 212° north and finally inside the small fishing port the main direction is of about 125° north.

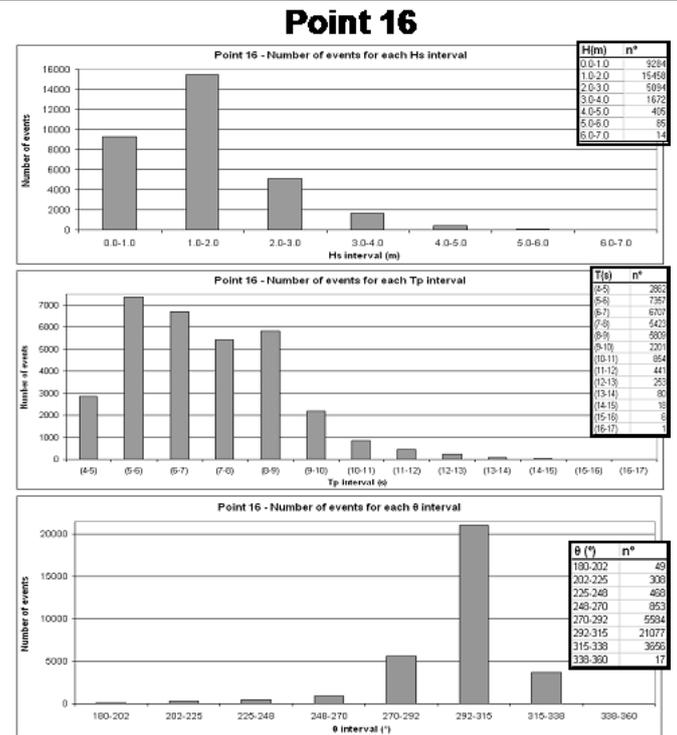


Figure 7. Point number 16: Number of events for each class of significant wave height (Hs), period (Tp), and direction (θ).

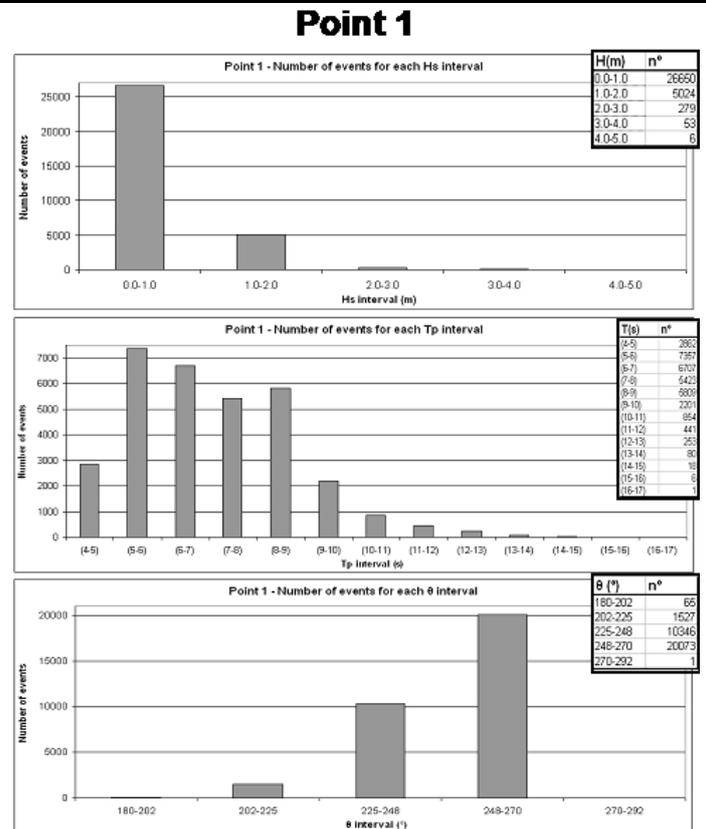


Figure 8. Point number 1: Number of events for each class of significant wave height (Hs), period (Tp), and direction (θ).

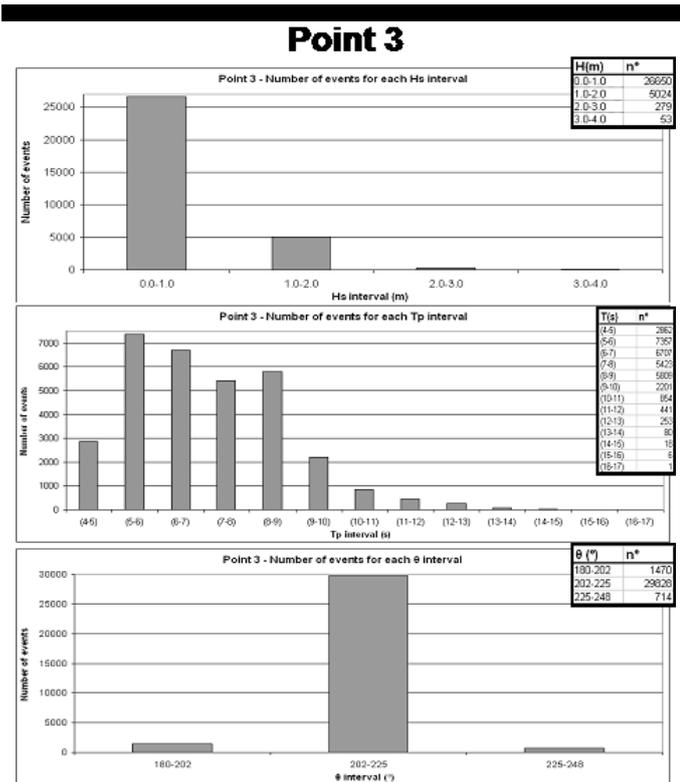


Figure 9. Point number 3: Number of events for each class of significant wave height (Hs), period (Tp), and direction (θ).

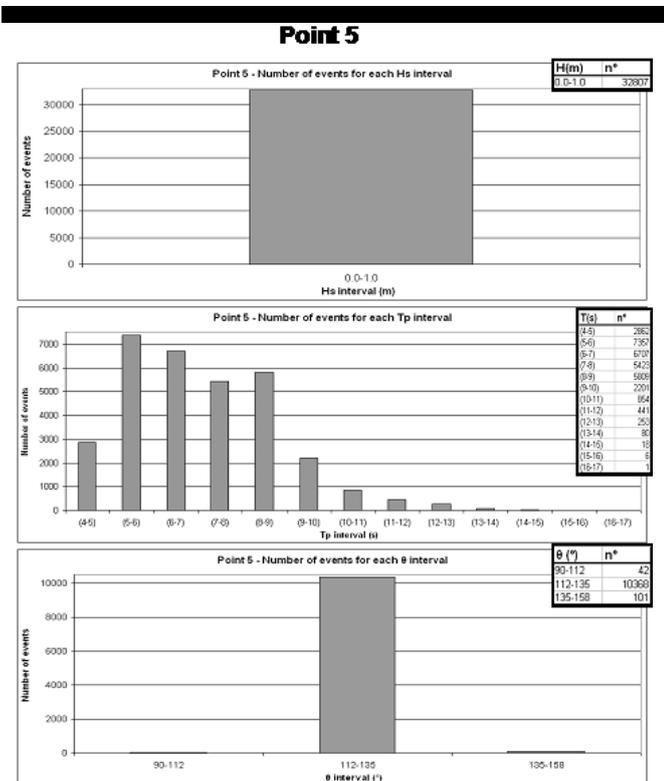


Figure 10. Point number 5: Number of events for each class of significant wave height (Hs), period (Tp), and direction (θ).

### FUTURE DEVELOPMENTS

The main developments projected for the short term are the following:

1. Coupled application of models through the interface. Due to the complexity and diversity of the phenomena involved in the wave propagation in coastal areas and to the large study dimensions, it does not exist one model that can describe the wave transformation from deep to shallow waters;
2. The implementation of procedures for the interactive definition of domain boundaries and respective characteristics to be used by GMALHA program.

Additionally, improvements related with the numerical models interfaces should be made, such as the definition of helps to the user and the display of error messages related with the wrong introduction of data as well as the conclusion of the automatic visualization of the results.

These tasks will contribute to the development of a reliable system, characterized by easy management, robustness and precision in decision-making processes.

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