# HIDRALERTA Project – A Flood Forecast and Alert System in Coastal and Port Areas

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**Abstract:** This paper describes the recent advances on the research project HIDRALERTA - "Flood Forecast and Early Warning System in Coastal and Port Areas", whose main objective is developing a system for forecasting, warning and assessment of risks associated with wave overtopping and flooding in coastal and port areas, supported by measurements/predictions of waves and water levels in these areas. The case study here presented is the port and bay of Praia da Vitória, at the Terceira Island, Azores. Methodologies and accomplishments of the HIDRALERTA project achieved so far, with the focus on its more relevant results, are herein described.

**Keywords:** warning system, wave conditions, wave overtopping, flooding, risk assessment

## Introduction

The wave overtopping/flooding evaluation in coastal and port areas is a very important issue in Portugal. In fact, due to the length of the Portuguese coastline, the severity of the sea conditions and the relevance of the coastal zone for socio-economic activities, it is important to study wave induced risks and, in particular, overtopping and flooding due to wave action. In Portugal, emergency situations caused by adverse sea conditions are frequent, endangering the safety of people and goods, with negative impacts for the society, the economy and the environment.

For these reasons, it is imperative to empower the national authorities with an adequate forecast and early warning system that allows the identification of emergency situations and enables the selection by the authorities of measures to avoid loss of lives and minimize damages.

Moreover, the forecast and early warning system also act as a long-term management tool since it can simulate the response to future scenarios related to climate changes, such as the increase of the mean sea level and/or of the storm severity, which will increase the probability of coastal flooding. Such a system it will contribute to complying with the directive 2007/60/CE from the EU of 2007-10-23 in what concerns the preparation by the member states of flooding risk maps before December 22$^{th}$, 2013 (Chap.III-Art.6-8) and of risk management plans, including forecast, alert and warning systems, before 2015-12-22 (Chap.III-Art.7-3). This framework does justify the HIDRALERTA project.

The work within this project consists in:

1. Creating a user-friendly tool, which follows Zózimo *et al.* (2008), that allows:

- Construction of risk maps that are decision-support tools for the authorities. These maps are constructed by considering either long-term series of sea-wave forecasts or predefined scenarios associated with climate change and/or extreme events;
- Real-time evaluation of overtopping/flooding emergencies, issuing warning messages to the authorities when the safety of people, goods or activities in these areas is likely to be at stake;

2. Development of a prototype system, HIDRALERTA system, in a *Web*GIS environment, for the port and bay of Praia da Vitória, Terceira Island, Azores, and for São João da Caparica beach, Costa da Caparica, Lisbon.

In the next sections, the HIDRALERTA system modules are described, as well as recent developments which have been made therein. One application case (port and bay of Praia da Vitória) is also presented.

## HIDRALERTA Methodology

The HIDRALERTA system encompasses four main modules, see Figure 1 and Poseiro *et al*. (2013a), namely I – Wave Characterization; II – Wave run-up / Overtopping; III - Risk Assessment and IV - Warning System. The system is developed in *Python* language and it is implemented in a *Web*GIS platform.

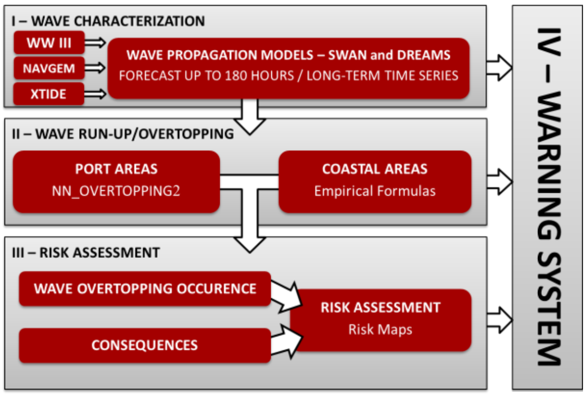


**Figure 1. Schematic representation of the HIDRALERTA system**

### *Wave characterization module*

The objective of this module is to determine 180-hours-in-advance sea wave characteristics, to be used by the warning system, and also to provide adequate handling of long term time series of wave characteristics for the definition of risk maps.

For the warning part, the HIDRALERTA system is able to determine sea wave characteristics inside a given port or at a certain location on the coast by using numerical models for sea wave propagation. The use of one or more numerical models for the propagation depends on the study region characteristics and on the phenomena involved in the propagation. The numerical models used by the system are the nonlinear spectral model of generation and propagation of waves in coastal areas, SWAN (Booij *et al.*, 1999) and the linear mild-slope model of wave propagation in port areas, DREAMS (Fortes, 2002) which will be replaced later by the nonlinear Boussinesq model BOUSS-WMH, Pinheiro et al. (2011).

The implemented procedure is as follows: SWAN is forced by the 180-hours-in-advance sea wave characteristics estimated by WAVEWATCH III (Tolman, 1999), a numerical model for sea wave prediction at a regional level, and by the wind fields, also at a regional level, as well as tide levels, obtained respectively from NAVGEM (Whitcomb, 2012), and XTide (Flater, 1998) models. XTide provides astronomical tide levels, so it was considered a constant storm surge to obtain te final tide level. WAVEWATCH III estimated offshore wave conditions and the wind field, obtained from NAVGEM, are both provided through The Fleet Numerical Meteorology and Oceanography Center (FNMOC). FNMOC delivers forecast wave data from WAVEWATCH III up to 180 hours and historic data since September 2003 until the present, with a 1º resolution. It also delivers wind data from NAVGEM up to 180 hours and historic data since January 2004 until the present, with a 0.5º resolution. Then, these values are transferred to the coast using the SWAN model and finally into the harbour basins (where the reflection effects are important) with the DREAMS model.

For the risk assessment, the system uses the long time series estimated either by the WAVEWATCH III model or, preferably, by *in-situ* measurements, although the latter is not common since only a few locations exist with wave buoys and even when they exist, there usually are important gaps in the data records that precludes its use in practice. In both cases, the wave characteristics are to be transferred by SWAN and DREAMS (or BOUSS WHF) models, following the above procedure.

Recent developments in this module consisted of: a) Establishment of an automatic download procedure (Poseiro, 2013) for the 180-hours-in-advance sea wave predictions of WWIII (FNMOC), with tides being provided by the XTide model and winds being provided by NAVGEM model (FNMOC); b) Coupling of WWIII, SWAN and DREAMS models and validation of each module, as well as its coupling through comparison with *in-situ* measurements. To this effect, campaigns for measuring waves in Costa da Caparica, like the one that took place on October 29th, 2012, and campaigns for construction of beach profiles, like the one that took place on April 29th and 30th, 2014, are to be used to feed the system; c) Automation of processes for creating layouts generated by the numerical models as well as creation of files with values obtained for each parameter at each point; d) Development of an ARTMAP neural network with fuzzy logic (Santos, 2013) to be tested for determining the wave propagation conditions inside ports which can substitute the use of wave propagation numerical models in some cases.

*Wave run-up/overtopping module*

The objective of this module is the determination of wave run-up/overtopping on coastal and port areas. In the HIDRALERTA system, wave run-up/overtopping determination follows two different approaches, in case of port or coastal areas.

For port areas, the tool NN_OVERTOPPING2 (Coeveld *et al*., 2005) is employed and it is based on neural network modelling. This tool was developed as part of the CLASH European project (Crest Level Assessment of coastal Structures by full scale monitoring, neural network prediction and Hazard analysis on permissible wave overtopping) to predict Froude-scaled mean wave overtopping discharges, *q*, and the associated confidence intervals for a wide range of coastal structure types (such as dikes, rubble-mound breakwaters and caisson structures). The input needed to run NN_OVERTOPPING2 includes the wave/water level conditions in front of each structure and its geometrical characterization. For coastal areas (simple beaches or beaches with coastal defence structures), empirical formulas are applied to evaluate wave run-up/overtopping. The formulas applied for wave run-up evaluation are presented at Neves *et al*. (2013). The flood levels are obtained by adding the wave run-up estimation to the astronomical tide level and the storm surge.

Recent advances consisted in developing *Fortran* programs to implement the empirical formulas in order to couple both these formulas and the neuronal network tool with numerical models as well as to automatically display the results. The new neural network tool, of the ARTMAP type with fuzzy logic, to calculate the overtopping of maritime structures (Santos *et al*., 2013) is being further developed to become an alternative to the NN_OVERTOPPING2 tool, especially for small mean overtopping discharges. In addition, new formulations have been developed for estimating run-up and overtopping at seawalls built on land and in very shallow water (Mase *et al*., 2013), which will also be incorporated in the system.

*Risk assessment module*

The objective of this module is the evaluation of the overtopping/flooding risk. Risk assessment is based upon the concept of risk level given by Risk level = Probability level x Consequences level, this is, risk level is the product of the probability level associated with the exceedance of a pre-set threshold for the mean overtopping discharge per unit length of the structure crest (or for the flood level) by the consequences level associated to such exceedance (Raposeiro, *et al.*, 2010).

For assessing the risk of overtopping or flooding in a given port or coastal area, the procedure followed is: a) to evaluate the nature of the activities developed in the area sheltered by the structure (or beach) and the impact of the overtopping/flooding on the safety of people and infrastructure; b) to establish the thresholds for the allowable mean overtopping discharge (or for the flood level) for each type of structure (or beach) and activity; c) to assess the probability level of occurrence of these discharges (or flood levels); d) to assess the consequences level; e) to assess the risk level.

The thresholds for the allowable mean overtopping discharge are set based on existing recommendations (Pullen *et al.*, 2007), which take into account the nature of the activities in the area sheltered by the structure (or beach), the characteristics of the overtopped structure and the need to ensure the safety of people and infrastructure located in this area. The thresholds for the flood levels are related to the topography of the area (crest levels of the beach/dune). The probability levels associated with the exceedance of a pre-set threshold for the mean overtopping discharge/flood levels are defined according Raposeiro *et al*., (2010). The consequences of overtopping/flooding have been estimated using a methodology that allows a simple qualitative evaluation of the consequences level associated with hazardous events in the area under study (Raposeiro *et al*., 2010).

However, in that methodology there is no prioritization or allocation of weights to the different environmental, economic and social aspects that can be important for a given study area in the occurrence of hazardous events that exceed pre-set thresholds. In order to complement the qualitative method to get the consequences level, Poseiro *et al*. (2013b) applied a methodology developed by Antunes (2012) and Craveiro *et al*. (2012) based on a multi-criteria analysis that enables a spatial analysis, a classification and an assignment of weights to each of the aspects that characterize a given study area. This methodology for the establishment of the consequences map consists on the construction of a spatial index of human pressure on the port/coastal area through the application of the Analytic Hierarchy Process (AHP).

Recent developments include the application of AHP method in the port and bay of Praia da Vitória (Azores), and the application of Coastal Vulnerability Index and Hazard Assessment to obtain Coastal Risk in sandy beaches with and without coastal defence structures in Costa da Caparica (Lisbon) by using a geo-referenced database and the multi-criteria analysis.

*Warning system module*

The objective of this module is to assess and disseminate warnings of sea-wave overtopping to the authorities. The system integrates all the information that is required from, and generated by, the methodology components. It is made of two components: the data evaluation that integrates and processes the data from the remaining modules and the user interface. Whenever wave run-up/overtopping exceeds a pre-set threshold in a specific area, it sends warning messages to the authorities.

The warning system deals with the following tasks: a) Data acquisition from the data sources; b) Trigger the wave overtopping determination component; c) Store risk assessment results; d) Disseminate current warning conditions through the following channels: Website, Twitter account, and Email; e) Maintain the zone characterization, using a map with the overtopping consequence layer and threat areas;

The data evaluation component assumes an emergency occurrence whenever the overtopping / flooding threshold is exceeded in one or more sections of the analysed structures. This identification of an emergency situation thus leads to the generation of graphs, charts and reports, which are then transmitted to the interaction component and presented to the user who will evaluate the situation. The user interaction component is materialized in a web application, in which the whole warning system is parameterized. The application is designed for use in traditional and mobile web browsers adapting the information in accordance with the characteristics of the client's device.

Recent developments include the integration of both components of the warning system. A first version is presented in Sabino *et al*. (2014). The data evaluation component consists of a series of *Python* scripts that engage all models and automate all the procedures for the operation of the system. Additionally, the web interface is being designed using public domain tools: the web development platform *Django* (also based on *Python*), for the development of interactive component; and the database management system *Postgre*SQL (with the *Post*GIS spatial extension).

## Hydralerta system: Application to Praia da Vitória

The port of Praia da Vitória is located on the east coast of the Terceira island in The Azores archipelago, Figure 2a. Both breakwaters that protect the harbour define a roughly rectangular port basin with about 1 km x 2 km. For this port, the system was applied in the two possible components: warning (modules I, II and IV) and risk assessment (modules I, II and III), both for the overtopping phenomenon.

The warning system is running permanently for Praia da Vitória. The sea-wave characterization module runs every day to predict 180 hours of wave characteristics at the port entrance and into the port, together with wind field and tide level predictions. Every 3 hours, the system creates a layout with significant wave height and angle of wave attack, Figure 2b. Once the wave characteristics in the port are available, every 3 hours, the second module, which predicts the run-up/overtopping associated to those wave characteristics, is applied. For each set of wave/water level characteristics, NN_OVERTOPPING2 provides information on mean wave overtopping discharge, *q*, Figure 2c, for each of the studied cross-sections of the structures. If the mean overtopping discharge exceeds the pre-set threshold, a warning is issued, Figure 2d. The *Web*GIS is presented at Figure 2e.

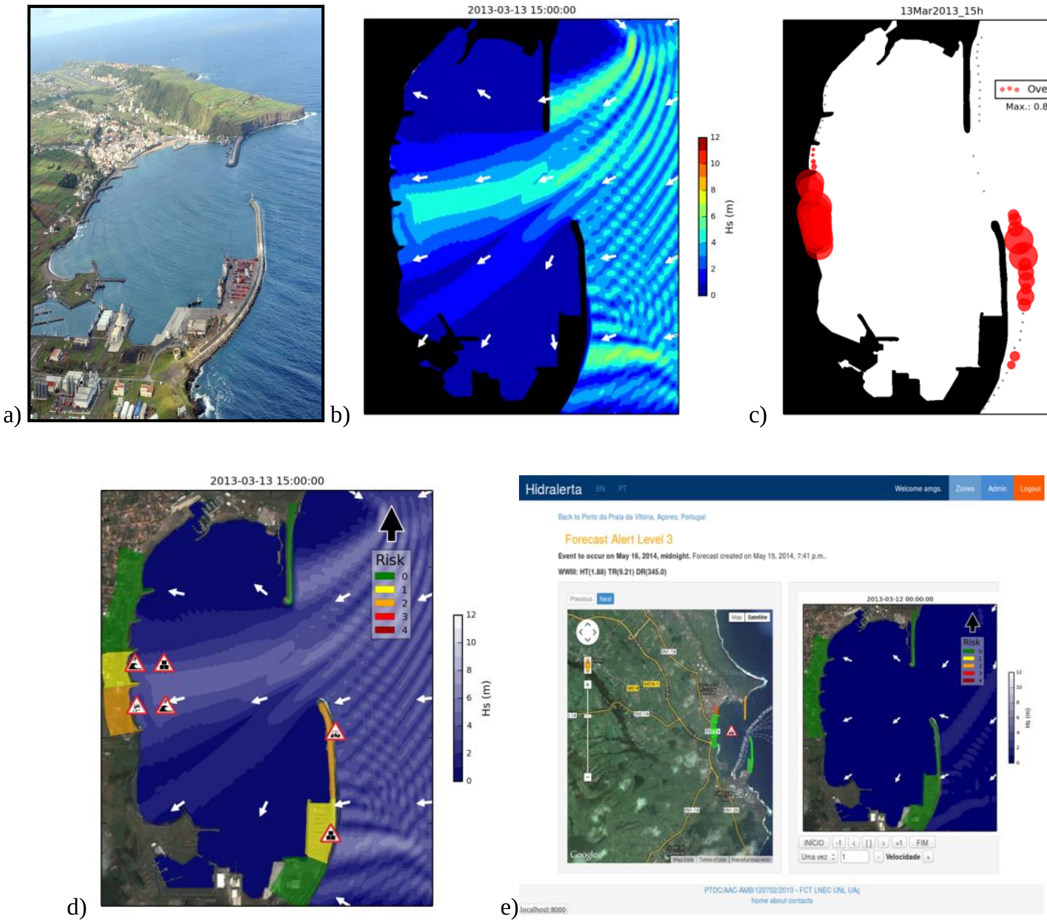


**Figure 2. a) Praia da Vitória aerial view; b) Module I: DREAMS; c) Module II: NN_OVERTOPPING2; d) Module IV: Warning map generated; e) *Web*GIS**

The risk assessment of Praia da Vitória permits the construction of risks maps in this bay. In the qualitative risk evaluation, it was considered a five-year period with sea-wave data from 2008 to 2012, as well as the effects of local wind and the astronomical tide level. The methodology described in Poseiro *et al*. (2013a) was applied to eight structures along the port and bay of Praia da Vitória, from D1 to D8 (Figure 3a). Example of a risk map is presented at Figure 3b, which shows the regions where mitigation measures are to be implemented. The AHP methodology (Poseiro *et al*. 2013b) was employed to generate the consequences map (Figure 3c).

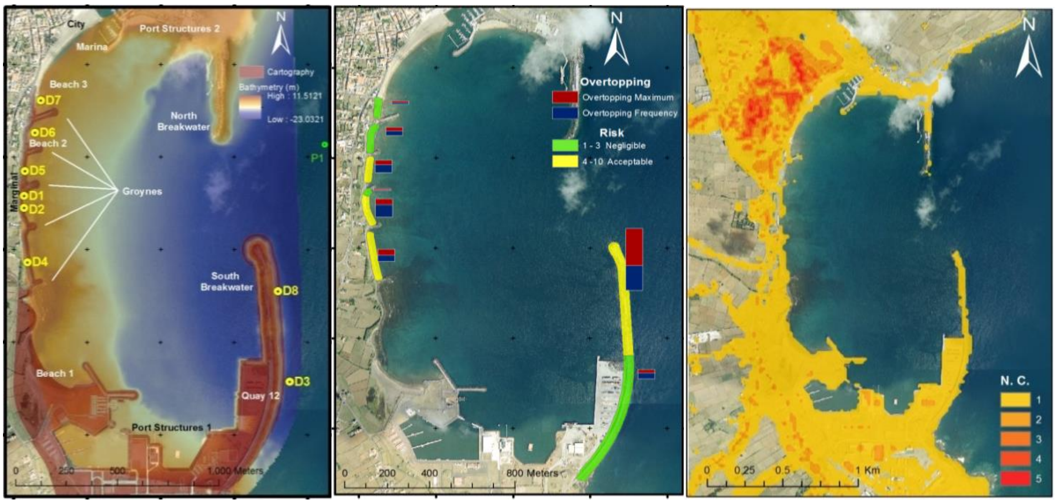


**Figure 3. a) Main structures of Praia da Vitória; b) Risk map; c) Consequences map (AHP)**

## Conclusions

This communication describes the recent developments of the HIDRALERTA system, a novel system currently being implemented as an early warning application and also to assess the risk of flooding in coastal and port regions. The system, implemented in a *Web*GIS environment, follows the basic idea of using wave forecasts (up to 180 hours) to calculate the effects of waves on the coast, particularly in terms of wave overtopping and flooding. Once wave overtopping and flooding are evaluated, they are compared with pre-defined thresholds, to build warning maps and risk maps, and, if necessary, to issue warning messages.

Here we have described the application of the system to the Praia da Vitoria bay, in Terceira Island, Azores. It shows that HIDRALERTA system has the potential to become a useful tool for the management of coastal and port areas, due to its fast and efficient capacity to effectively issue warning and to evaluate risks. In the framework of the HIDRALERTA project, the system has also been applied to low-line areas, namely sandy beaches and dunes systems under pressure and higher vulnerable to climate changes impacts such as Costa da Caparica, either as a warning system or as a risk evaluation tool, but it can be easily extended to other locations. In fact, it has been applied to other Portuguese locations, such as the ports of Ponta Delgada (Azores) and Sines, and the Praia da Galé coastal area.

At this point, the project is developing: : a) the replacement of the DREAMS linear wave model by the BOUSS-WMH nonlinear wave model; b) carry out overtopping tests on physical models for other types of structures, being the data produced within these tests used in evaluating the performance of empirical, neuronal network or numerical tools; c) improve the methodology for constructing maps of consequences; d) create maps to enable illustration of the spatial distribution of successive volume thresholds, which will be complemented maps of consequences, and consequently maps of risk of overtopping/flooding; and finally, e) set suitable levels (thresholds) to issue a warning.

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