NEW HIDRALERTA PROTOTYPES: PENICHE, FARO AND QUARTEIRA

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Abstract.

Early Warning Systems are crucial disaster-risk-reduction strategies as they allow local authorities to prepare and implement in advance the necessary measures to avoid major destruction and risk for individuals and properties caused by storm events. HIDRALERTA is a forecast, early warning and risk assessment system for port and coastal areas that uses forecasts of sea-waves and water levels to evaluate overtopping/flooding events and risks associated with mooring of ships. The distinguishing feature of this system is that the risk assessment is based on specific parameters related to the actual risk being predicted, such as overtopping discharges, or the ship's mooring loads, and not only in met-ocean parameters. This work presents the latest prototypes developed for HIDRALERTA system: Peniche, Faro and Quarteira. These new prototypes contribute to reinforce the spatial coverage of HIDRALERTA system.

Keywords: Early Warning Systems, HIDRALERTA, Overtopping, Overwash

1. INTRODUCTION

Low elevation coastal areas host around 10% of the global population (United Nations, 2017). In many of these regions, extreme ocean events are threatening populations, infrastructures, and environmental assets. Moreover, climate change and population growth will exacerbate the risks. Thus, the authorities must possess tools to manage risks associated with coastal storms (namely wave overtopping and flooding impacts) and implement measures to mitigate those risks. A powerful and efficient tool for Disaster Risk Reduction (DRR) are Early Warning Systems (EWS) because they allow local authorities to prepare and implement in advance the necessary measures to avoid major disruptions and risks for individuals, properties and other assets (environmental, social, etc). EWS are also relevant as an

adaptative measure to anticipate the effects of climate change and agree with the goals of the 2030 Agenda. Specifically, EWS contribute to the United Nations Sustainable Development Goals (SGD) 8 "Promote sustained, inclusive and sustainable economic growth full and productive employment and decent work for all", 11 "Sustainable Cities and Communities" and 13 "Climate Action". Sea Level Rise (SLR) will contribute to increase the frequency and magnitude of flood events (Ranasinghe, 2016). Therefore, if adaptation measures to climate change are not implemented, vast new areas can be impacted by coastal floods while others will face an increase in flood intensity and occurrence.
HIDRALERTA system (Poseiro, 2019, Fortes et al., 2020, Pinheiro et al., 2020) is a forecast, early warning and risk assessment system for port and coastal areas and evaluates overtopping/flooding events and risks associated with mooring of ships. HIDRALERTA system provides forecasts with 72 hours of anticipation of both the sea wave characteristics and alert levels. The first prototype was developed for the port and bay of Praia da Vitória (Terceira Island, Azores) and is operating since September 2015. Since then, two new prototypes were developed and are operating in the Azores, for the ports of Madalena do Pico and of São Roque do Pico (both in Pico Island). In mainland Portugal, the prototypes for the ports of Ericeira and Sines, and for the coastal zone of Costa da Caparica were also developed and are under validation. This paper presents a brief description of HIDRALERTA system, followed by the presentation of the newest prototypes developed for Peniche, Faro and Quarteira.

2. HIDRALERTA SYSTEM

The HIDRALERTA system was developed in a python framework and it is accessible, to authorized users, from a web platform (www.aurora.lnec.pt, restricted access). It has a modular system that can be adapted to any port or coastal zone, and is divided into four main modules (Figure 1, port areas and Figure 2, coastal zones), namely:

Module I – Wave Modelling, to evaluate sea-wave characteristics at the study site. The offshore wave conditions (hindcast or forecast data) are provided by the ECMWF and Copernicus Marine Service. Then they are propagated to inshore and inside ports using numerical models: SWAN (SWAN Team, 2006) for the wave propagation from offshore to the vicinity of ports or coastal areas and DREAMS (Fortes, 2002) for areas where partial reflection plays an important role (having as incident boundary conditions the results from SWAN). Still-water-levels are predicted by adding astronomical tide levels (XTide model; https://flaterco.com/xtide/).

Module II is responsible for estimating the specific parameters that will be used to assess the risk, such as overtopping discharges, or the ship's mooring loads. It is divided in two sub-modules, Module IIa for port areas and Module IIb for coastal zones, as presented below.

Module IIa - Overtopping & Moored ships. The sea conditions obtained in Module I are used, for the ports prototypes, as input to the NN_OVERTOPPING2 (Coeveld et al., 2005), together with cross-section characteristics of the coastal structures, to obtain an estimate of the mean overtopping discharge, q, at each cross-section. The moored ships analysis is not considered in the present prototypes, so it will not be presented here.

Module IIb -Flooding Height & Overtopping. For coastal zones, flood levels are obtained by using empirical formulae (Poseiro, 2019), or the mean overtopping discharge is estimated with XBeach model (Roelvink et al., 2009).

Module III -Data Processing, through the comparison of the relevant computed values (overtopping discharge, maximum run-up) with pre-set thresholds. There are four risk levels (from 0 to 3, where 0 corresponds to the non-existence of risk and 3 corresponds to the higher level of risk). The evaluation of risk for overtopping is performed by dividing the study area into subareas that are defined considering the local characteristics as well as the activities that take place at the crest or at the leeside of the structure. Afterward, overtopping discharges are compared with pre-set thresholds to define the risk level. The activities cover the circulation of people and vehicles, ships, buildings, equipment and port structures. Each activity has an associated symbol, the colour of which changes according to the alert level (yellow for level 1, orange for level 2 and red for level 3).

Module IV -Alert System. This module creates and makes available, through a Web platform: 72-hour forecasts (with 3-hour interval in the case of Peniche and 1-hour interval in the cases of Faro and Quarteira) updated daily and all the results from the previous modules (including wave conditions, wave overtopping discharges and forces on the mooring system). The Web platform contains a set of functionalities and the user can highlight the alert maps that present the elements/activities that can be at risk. Those alert maps are built with the results obtained in module III. Module IV is also responsible for sending two daily bulletins (one for overtopping and one for moored ships) to the responsible authorities with the alerts for the following 72 hours. These bulletins also allow the continuous validation of the alert system, through the feedback received from the local authorities.

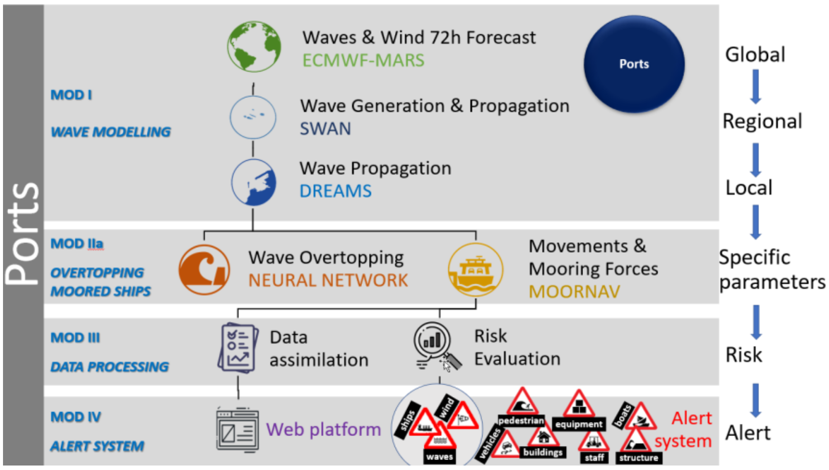

Figure 1- Port areas. Schematic representation of the HIDRALERTA system.

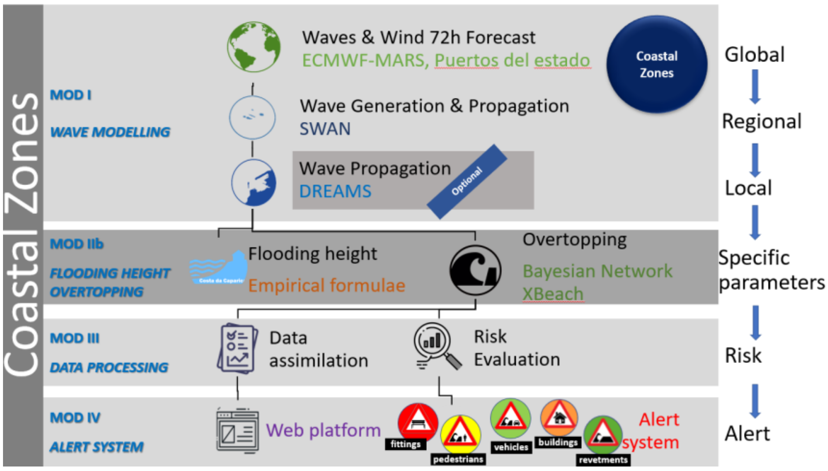

Figure 2- Coastal zones. Schematic representation of the HIDRALERTA system.

Numerical simulations run on the Central Node for Grid Computing (NCG) of the Portuguese Infrastructure for Distributed Computing (INCD), a 64-node high-performance computing facility. Currently, HIDRALERTA needs approximately 1 hour to generate the 72-hour forecast.

3. NEW PROTOTYPES

The recently developed prototypes of HIDRALERTA system, currently under validation, are Peniche, Faro and Quarteira.

3.1 Peniche

The Port of Peniche (Figure 3) is located on an isthmus on the south coast of Peniche city, about 1.5 miles from Cabo Carvoeiro in Portugal's, centre region. It was built in 1981 and is the westernmost port in Europe. This port is considered one of the main Portuguese fishing ports and is equipped with a marina, boat ramp, dock, shipyard, among other equipment. The port is protected by 2 breakwaters, the south breakwater (east) and the north breakwater (west).

Figure 3- Port of Peniche. Location and aerial views of the port.

The propagation from offshore to onshore is performed with SWAN model (Figure 4 a,b) with two nested grids with the following resolutions: 118 m in x and 149 m in y in the coarse grid and 32 m in the fine grid. The model includes physical processes as diffraction, triad and friction in both grids. The results from the finer grid are used as an input to DREAMS model (Figure 4c) that is responsible for defining the local wave characteristics. The boundary conditions implemented in DREAMS model (Figure 4c) are the generation-radiation condition at the open boundaries (A1 and A2 in Figure 4c) and total or partial reflection conditions, which are adequate for the solid boundaries of the study region, namely beaches, rocky cliffs, ramps, vertical walls and breakwaters.

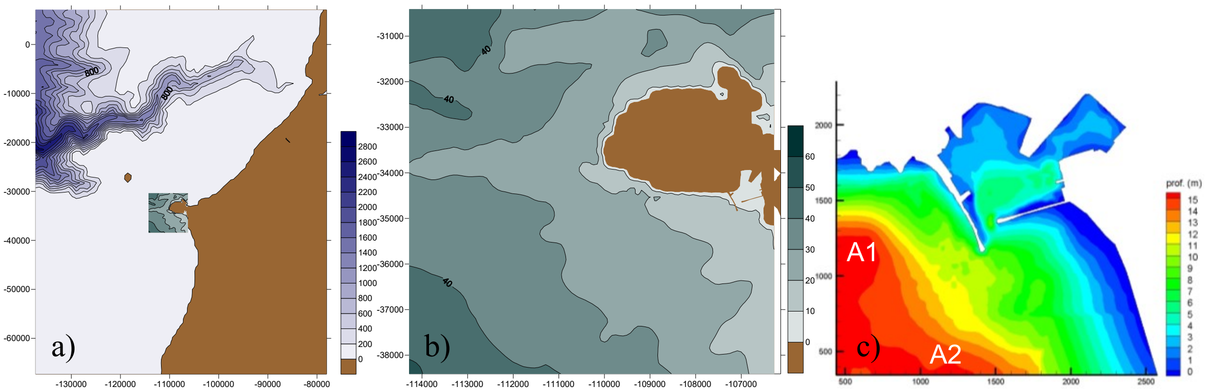

Figure 4- Port of Peniche. Bathymetry and coarse (a) and fine (b) grids nested domains for SWAN numerical model and bathymetry for DREAMS model (c).

The local wave conditions estimated with DREAMS model are the input data for the calculations with NN_OVERTOPPING2, which will provide the mean overtopping discharges. Figure 5a presents an aerial view of the west breakwater, which is the focus of the present version of HIDRALERTA prototype and Figure 5b presents the overtopping zones defined for the west breakwater. For the estimation of wave overtopping, eight points were defined along the structures toe (grey circles along the north breakwater, or west, in Figure 6e) whose wave characteristics were given by the results from the local wave model. The activities that were considered at each overtopping zone for the west breakwater are presented in Table 1. Figure 6 presents an example of some of the outputs that are available through the web platform, namely local wave conditions, wave overtopping discharges and the daily bulletin with the alert maps that present the elements/activities that can be at risk.

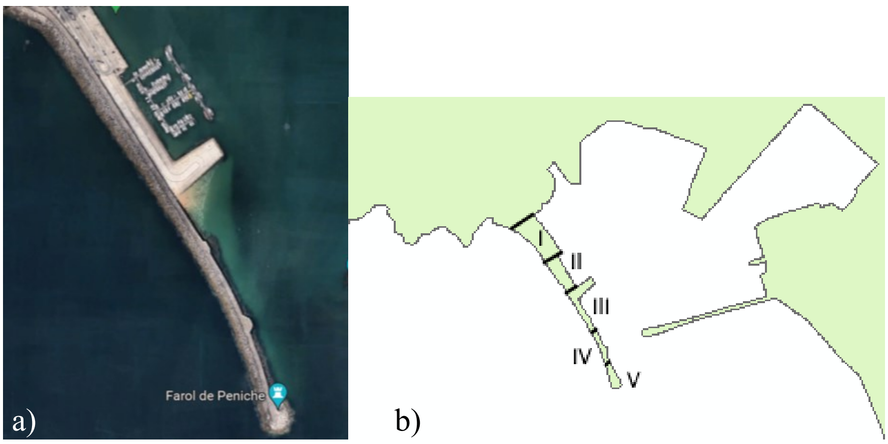

Figure 5- Port of Peniche. Aerial view of the west breakwater (a) and overtopping zones (b).

Table 1. Overtopping zones associated activities and mean discharge thresholds for each level of alert.

	Alert level				
	0	1	2	3	
Activity	Mean overtopping discharge (l/s/m)				Zone(s)
Unaware pedestrians	< 0.01	[0.01 – 0.02[	[0.02 – 0.03[	≥ 0.03	I to V
driving at low speed	< 10.0	[10.0 – 25.0[	[25.0 – 50.0[	≥ 50.0	I to III
promenade behind seawall	< 25.0	[25.0 – 100.0[	[100.0 – 200.0[	≥ 200.0	I to V
small boats	< 2.0	[2.0 – 5.0[	[5.0 – 10.0[	≥ 10.0	II

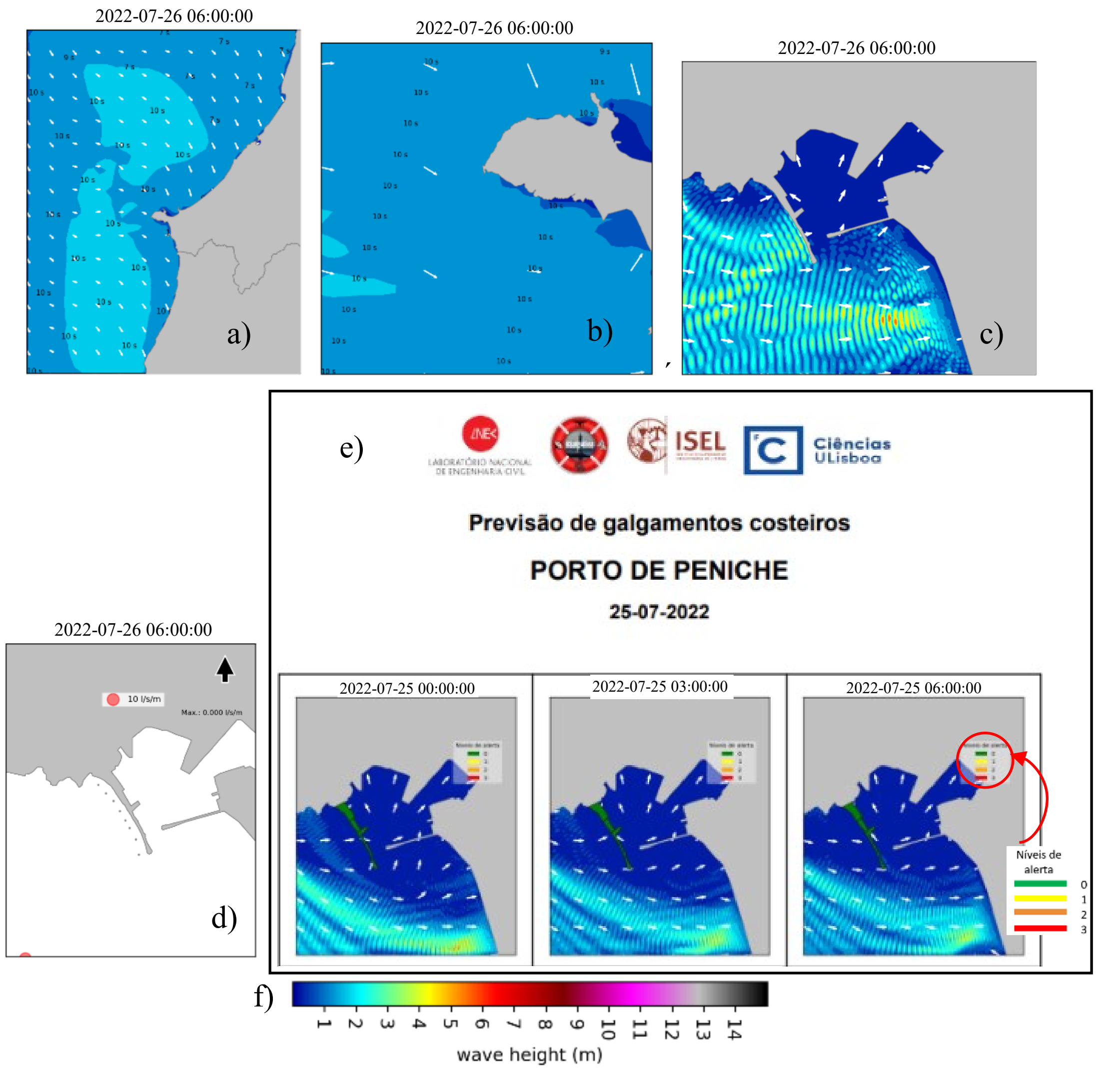

Figure 6- Wave conditions at the west coast of the mainland centre region (a), near the isthmus of Peniche (b) and at the vicinity and inside the Port of Peniche (c), where the wave heights are in colours, wave directions in arrows and wave periods in numbers, overtopping results (grey circles) in the eight points defined along the structures toe (d), daily bulletin with the alerts forecast (e) and colour scale of the wave heights (f).

3.2 Faro and Quarteira

The new prototypes developed for Faro and Quarteira have a similar structure as Peniche, except the overtopping risk is evaluated using a Bayesian Network trained with a dataset of numerical model results from a set of synthetic sea states. Praia de Faro (Figure 7) is a natural open sandy beach located in the Peninsula of Ancão, a narrow sand barrier that separates the Atlantic Ocean and a coastal lagoon. The ocean front is partially stabilised with rocks or naturally protected by the dune. The dune elevation varies, with higher elevation at the western portion of the study area, while at the central and eastern parts, the dune is almost destroyed by urban development. The central part is periodically overwashed. Quarteira is located ten kilometres NW from Praia de Faro. The study area (Figure 8) consists of a set of three sandy beaches with a total longshore length of 900 m that are laterally limited by 150 m long rock armoured groins. They are limited at the backside by a promenade with an elevation ranging from 6 to 8 m above MSL. Several touristic facilities are located beyond the promenade including restaurants, hotels and supermarkets.
To create comprehensive information to train the Bayesian Networks (BNs), a numerical framework that computes wave overtopping was coupled with a risk model to identify risk conditions induced by a set of synthetic sea states or events. The considered input variables of the synthetic sea states were significant wave height (Hs), peak wave period (Tp) and total water level (TWL). The synthetic sea states were built by combining a wide range of these three input variables. Then, the variables defining the synthetic sea states were discretized in bins of 0.5 m and 1 s for the wave parameters, and in bins of 0.25 m for TWL. This discretization of the wave variables allowed to include in the analysis two types of events: 1) storm events characterized by Hs larger than 3 m and 2) swell events whose Hs is lower than 3 m and Tp is higher than 13 s.

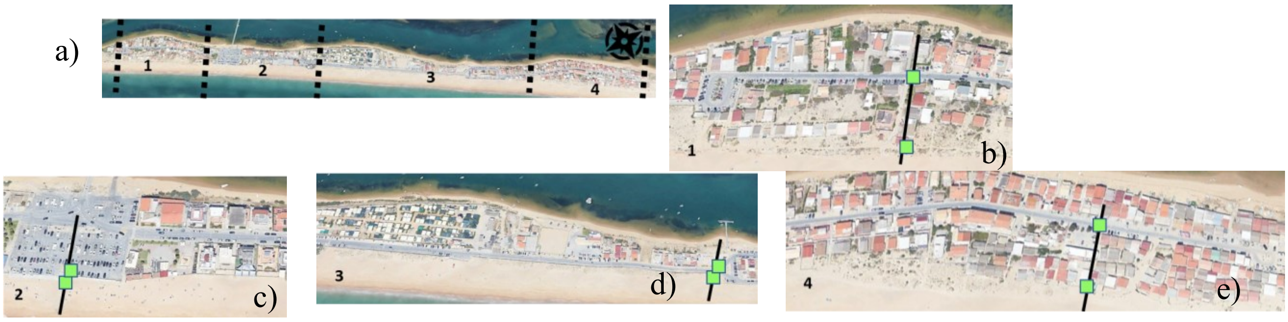

Figure 7- Praia de Faro. Overview of the four sections of the study area (a): western (b), parking lot (c), central (d), eastern (e). Black lines indicate the cross-shore profiles of XBeach model and the green dots the locations where the risk was evaluated.

These events were implemented in SWAN (Figure 9), which downscaled the wave conditions from the Faro Costeira Buoy location (~ 100m depth) to 25-30 m depth, where XBeach (one-dimensional ‘non-hydro’ model, Roelvink et al., 2009) simulated nearshore wave processes and run-up incursions (Figure 9). To better account for the stochastic effects of the wave overtopping process and obtain risk probability information associated with each storm condition, each bin of the BNs was trained with five synthetic storms, with their Hs, Tp and TWL values randomly selected. So, for each bin, five results were obtained.

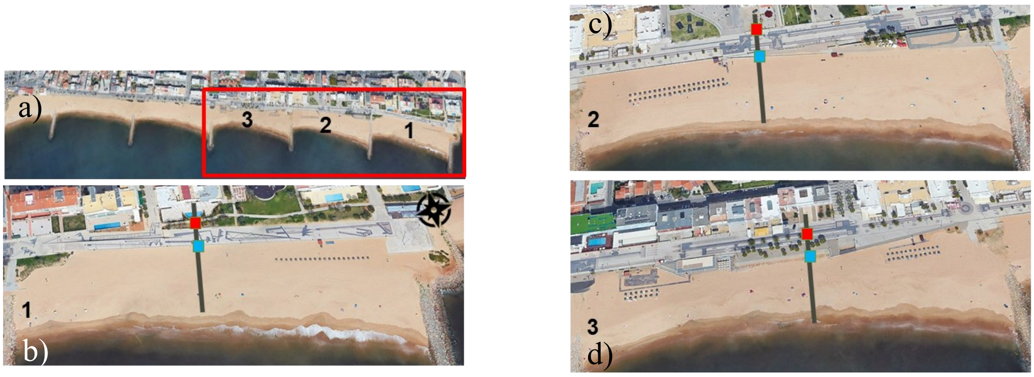

Figure 8- Overview of the Quarteira site (a). The red box highlights the three beaches: eastern (b), central (c) and western (d). Black line indicates the cross-shore profile, and the coloured squares indicate the locations where the risks were assessed: blue (pedestrians) and red (vehicles and buildings).

Regarding the risk model used to create the training data, the tolerable overtopping limits for pedestrians, vehicles (cars) and properties (potentially weak elements like doors and windows) are based in Garzón et al. (2022) and displayed in Table 2. Using these limits, the mean discharge simulated by XBeach was used to establish risk conditions. Among the 5 storms within each bin, the risk was defined based on the worst-case scenario.
The Bayesian Networks developed for Praia de Faro and for Quarteira are fed daily with the forecast obtained from Puertos del Estado in the location of Faro-Costeira buoy and gives the risks associated with coastal flooding for pedestrians, properties and vehicles.
Figure 10 presents an example of some of the outputs that are available through the web platform, namely local wave conditions, alert results and the daily bulletin with the alert maps that present the elements/activities (pedestrians, vehicles or properties) that can be at risk.

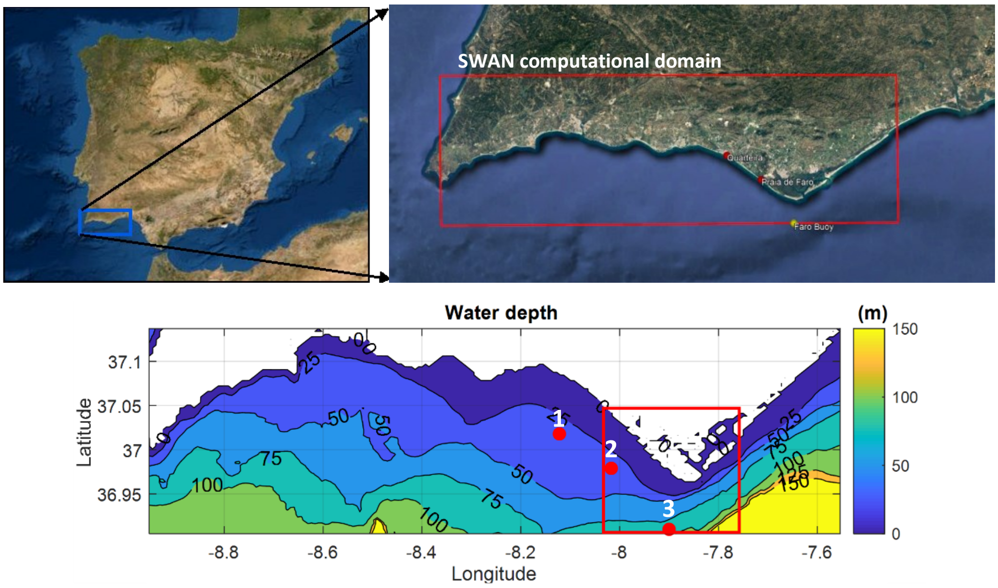

Figure 9- SWAN computational domain and location of Quarteira (1) and Praia de Faro (2) XBeach model offshore boundary, and Faro-Costeira buoy (3).

Table 2. Receptors, symbols and mean overtopping discharge thresholds for each level of alert.

Receptor	*Symbol (colour varies according to alert level*	*Green*	*Yellow*	*Orange*	*Red*
		Mean overtopping discharge (l/s/m)			
Pedestrian		0	] 0 -0.1]	] 0.1 – 1.0]	> 1.0
Recreational facilities & buildings		<1.0	[1.0 – 2.5]	]2.5 – 10]	> 10.0
Vehicles		<0.5	[0.5 – 1.5[	[1.5 – 5]	> 5.0

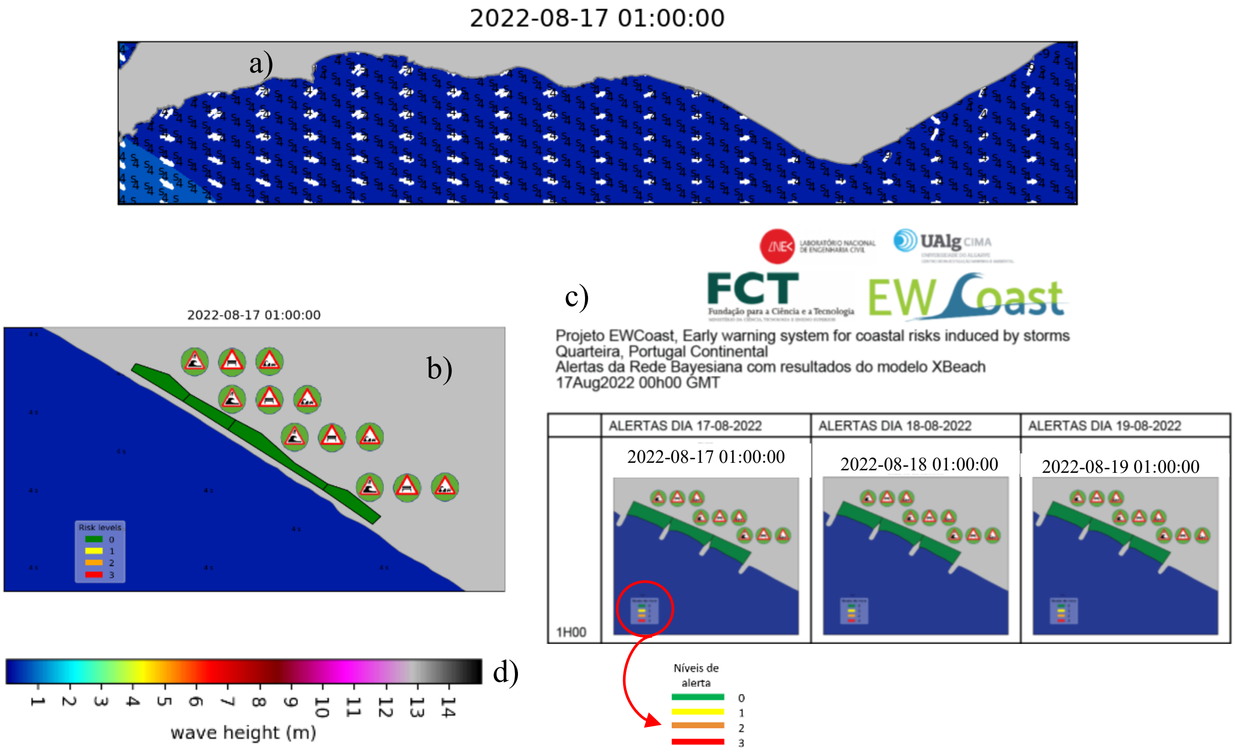

Figure 10- Wave conditions (wave heights in colour, directions in arrows) at the Algarve coast (a), alert results for Praia de Faro (b), daily bulletin with the alerts forecast for Quarteira (c) and colour scale of the wave heights (d).

4. CONCLUSIONS AND FUTURE DEVELOPMENTS

The new HIDRALERTA prototypes are running operationally every day providing forecasts for the following three days. They are now under the tests and validation phases, where the alerts that are issued will be compared with local records to assess their agreement with real conditions. As to future developments, the implementation of the alert system for erosion risks for Praia de Faro has already started and its validation phase is expected to start in September 2022.

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REFERENCES

Coeveld, E. M., van Gent, M. R. A. e Pozueta, B. (2005). Neural Network: Manual NN_OVERTOPPING2, CLASH WP8 – Report BV.

J. L. Garzon, Ó. Ferreira, M.T.Reis, A. Ferreira, C.J.E.M. Fortes and A.C. Zózimo (2022). Conceptual and quantitative categorization of wave-induced flooding impacts for pedestrians and assets in urban beaches. Scientific Reports (submitted).

Fortes, C. J. E. M. (2002). "Transformações Não Lineares de Ondas em Zonas Portuárias. Análise pelo Método dos Elementos Finitos", Tese de Doutoramento, IST-UL, Lisboa.

Fortes, C. J. E. M., Reis, M. T., Pinheiro, L., Poseiro, P., Serrazina, V., Mendonça, A., Smithers, N., Santos, M. I., Barateiro, J., Azevedo, E. B., Salvador, M., Reis, F. V. (2020). The HIDRALERTA system: Application to the ports of Madalena do Pico and S. Roque do Pico, Azores. Journal of Aquatic Ecosystem Health & Management, DOI: https://doi.org/10.1080/14634988.2020.1807295

Pinheiro, L., Fortes, C., Reis, M. T., Santos, J., Soares, C. G. (2020). Risk forecast system for moored ships, vICCE (virtual International Conference on Coastal Engineering).

Poseiro, P. (2019). "Forecast and Early Warning System for Wave Overtopping and Flooding in Coastal and Port Areas: Development of a Model and Risk Assessment", Tese de Doutoramento, IST-UL, Lisboa.

Ranasinghe, R. (2016). Assessing climate change impacts on open sandy coasts: A review. Earth-Science Reviews, 160, 320–332.

Roelvink, D., Reniers, A., van Dongeren, A., van Thiel de Vries, J., McCall, R., & Lescinski, J. (2009). Modelling storm impacts on beaches, dunes and barrier islands. Coastal Engineering, 56(11–12), 1133–1152.

SWAN TEAM (2006). Swan User Manual version 40.51. Department of Civil Engineering and Geosciences, Delft university of Technology, Delft, The Netherlands, 111 pp.

United Nations (2017). The Ocean Conference, United Nations, New York, 5-9 June 2017. Factsheet: People and Oceans. Retrieved from https://www.un.org/sustainabledevelopment/wp-content/uploads/2017/05/Ocean-fact-sheet-package.pdf in 18 February 2022.