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NEW HIDRALERTA PROTOTYPES: PENICHE AND QUARTEIRA

NOVOS PROTÓTIPOS DO SISTEMA HIDRALERTA: PENICHE E 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 the 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 the HIDRALERTA system: Peniche and Quarteira. These new prototypes contribute to reinforcing the spatial coverage of the HIDRALERTA system.

Keywords: Early Warning Systems. HIDRALERTA. Overtopping. Overwash.

Resumo: Os sistemas de previsão e alerta precoce são meios cruciais de redução do risco, pois permitem que as autoridades locais se preparem antecipadamente e implementem as medidas necessárias para evitar elevados danos e riscos para pessoas e bens no decorrer de eventos de tempestade. O sistema HIDRALERTA é um sistema de previsão e alerta precoce para áreas portuárias e costeiras que utiliza previsões de ventos, agitação marítima e níveis de água para avaliar eventos de galgamento/inundação e riscos associados à amarração de navios. A característica distintiva deste sistema é que a avaliação de risco é baseada em parâmetros específicos relacionados com o perigo em causa, como caudais médios de galgamento ou forças

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nas amarras do navio, e não apenas em parâmetros mete-oceânicos. Este trabalho apresenta os mais recentes protótipos desenvolvidos para o sistema HIDRALERTA: Peniche e Quarteira. Estes novos protótipos contribuem para reforçar a cobertura espacial do sistema HIDRALERTA.

Palavras-chave-: Sistemas de previsão e alerta. HIDRALERTA. Galgamento. Inundação.

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 an increase in 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 the 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 on 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 the HIDRALERTA system, followed by the presentation of the newest prototypes developed for Peniche 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 onshore and inside the 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 into two sub-modules, Module IIa for port areas and Module IIb for coastal zones, as presented below.

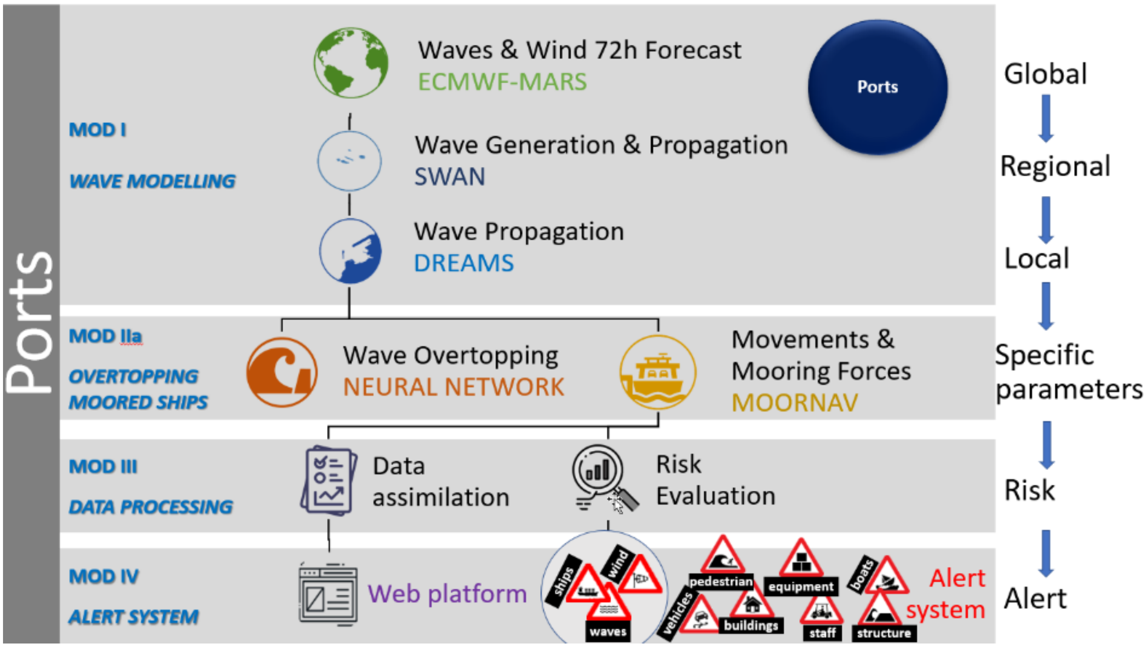
Module IIa - Overtopping & Moored ships. The sea conditions obtained in Module I are used, for the ports prototypes, as input to the NN_OVERTOPPING2 (COEVELD *et al.*, 2005), together with cross-section characteristics of the coastal structures, to obtain an estimate of the mean overtopping discharge, *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 the 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 exposed elements at the crest or the lee side of the structure. Afterwards, overtopping discharges are compared with pre-set thresholds to define the risk level. The exposed elements include the circulation of people and vehicles, ships, buildings, equipment, and port structures. Each exposed element 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).

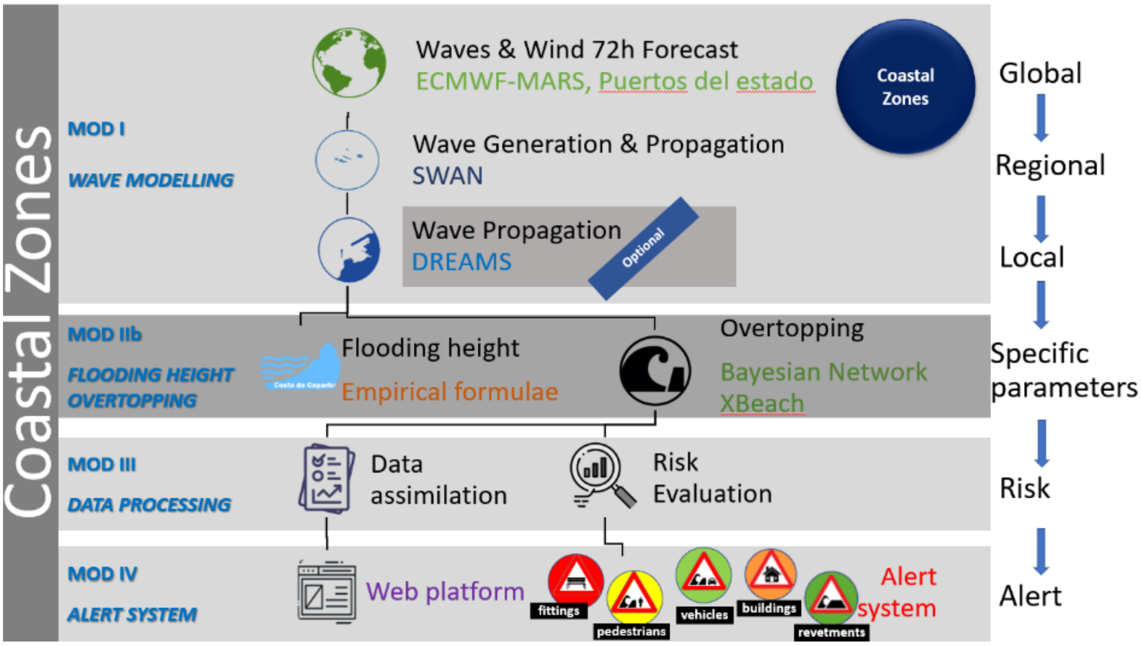
Module IV - Alert System. This module creates and makes available, through a Web platform, a 72-hour forecast (with 3-hour intervals in the case of Peniche and 1-hour intervals in the cases of Faro and Quarteira), which is updated daily. It also permits access to previous modules' results (including 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.



Source: From the authors.

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



Source: From the authors.

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 the HIDRALERTA system, currently under validation, are Peniche, Faro and Quarteira. The present paper focuses on the Peniche and Quarteira prototypes.

3.1 Peniche

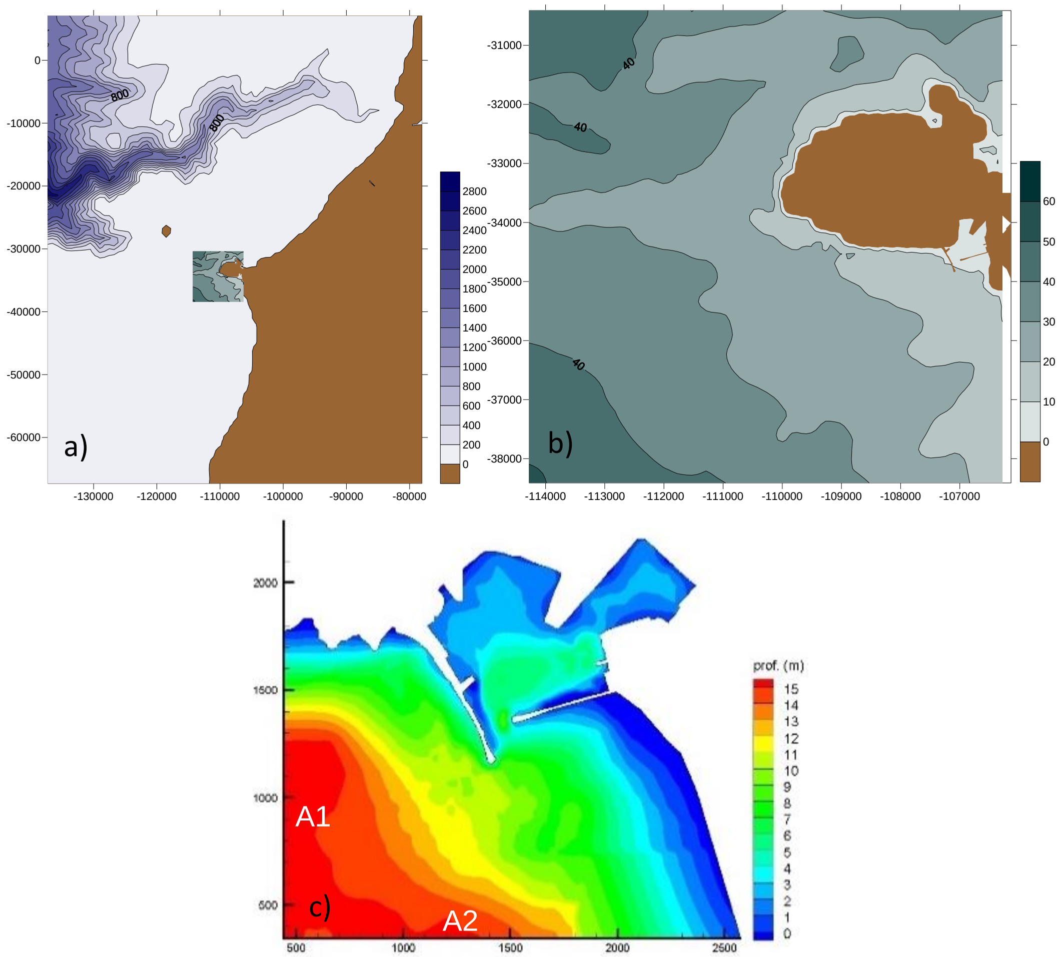
The Port of Peniche (Figure 3) is located on an isthmus on the south coast of Peniche city, about 1.5 miles from Cabo Carvoeiro in Portugal’s central region. It was built in 1981 and is the westernmost port in Europe. This port is considered one of the main Portuguese fishing ports and is equipped with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

The propagation from offshore to onshore is performed with the SWAN model (Figure 4a,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 such as diffraction, triad, and friction in both grids. The results from the finer grid are used as input to the DREAMS model (Figure 4c) that is responsible for defining the local wave characteristics. The boundary conditions implemented in the 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 3 – Port of Peniche. Location and aerial views of the port.

Source: Top left and right: GoogleEarth^{TM}, top right: From the authors, Bottom left: Marinas.com, Bottom right: Náutica Press.

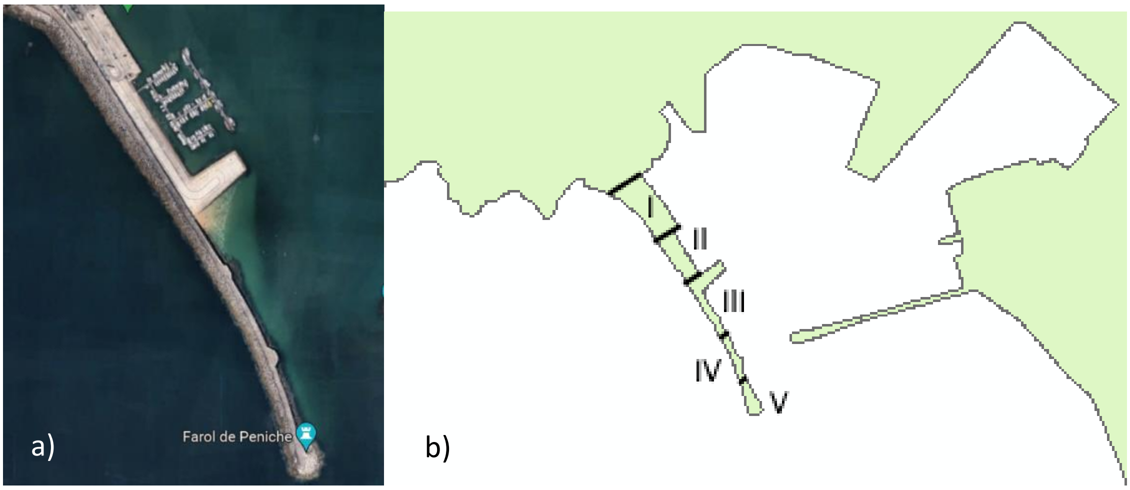
Figure 4 – Port of Peniche. Bathymetry for coarse (a) and fine (b) grids nested domains for the SWAN model, and DREAMS model (c).



Source: From the authors.

The local wave conditions estimated with the DREAMS model are the input data for the calculations with NN_OVERTOPPING2, which will provide the mean overtopping discharges. The present version of the HIDRALERTA system was developed specifically for the west breakwater of Peniche, for which five zones were considered for the overtopping analysis (Figure 5a and Figure 5b). The division into different overtopping zones has considered the structure's characteristics. For the estimation of wave overtopping, the wave characteristics were given by the results from the local wave model (Figure 6) at eight points defined along the structure’s toe (grey circles along the west breakwater, in Figure 7). The considered exposed elements that were considered at each overtopping zone for the west breakwater were “Unaware pedestrians”, “Driving at low speed", "Promenade behind seawall", "Small boats" and "Driving at low speed". For those exposed elements, mean overtopping discharge thresholds were defined for each of the alert levels (Table 1). The outputs that are available through the web platform are the offshore and local wave conditions (Figure 6), the wave overtopping discharges (Figure 7), the alert levels and the daily bulletin with the alert maps that present the elements that can be at risk (Figure 8).

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



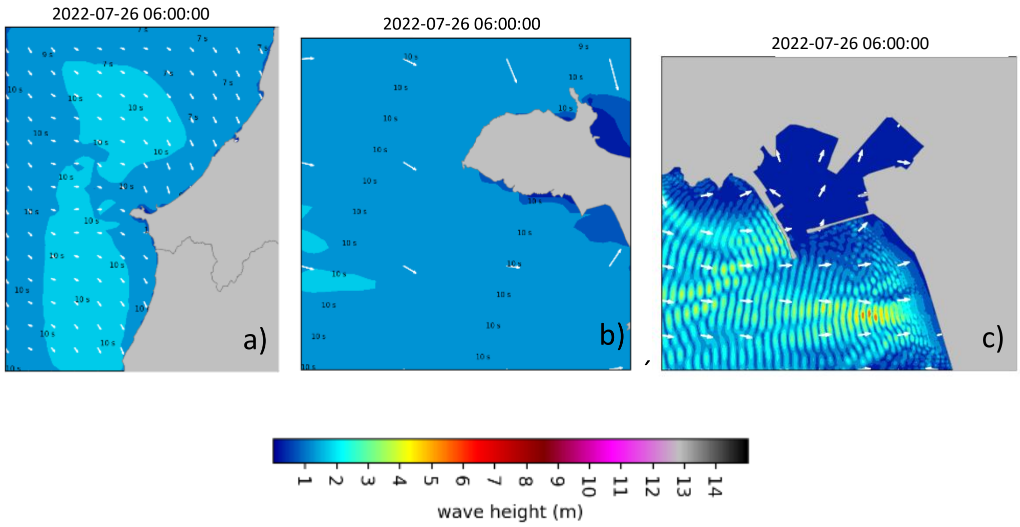
Source: a) GoogleEarth™, b) From the authors.

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
driving at low speed	< 10.0	[10.0 – 25.0[	[25.0 – 50.0[	≥ 50.0	I to III

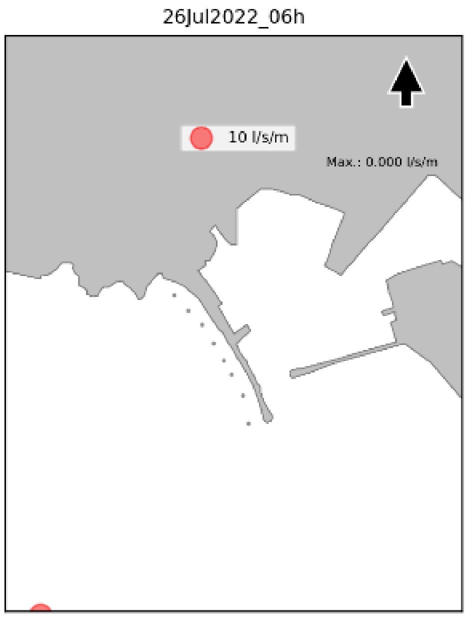
Source: From the authors.

Figure 6 – Wave conditions at the west coast of the mainland central region of Portugal (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.



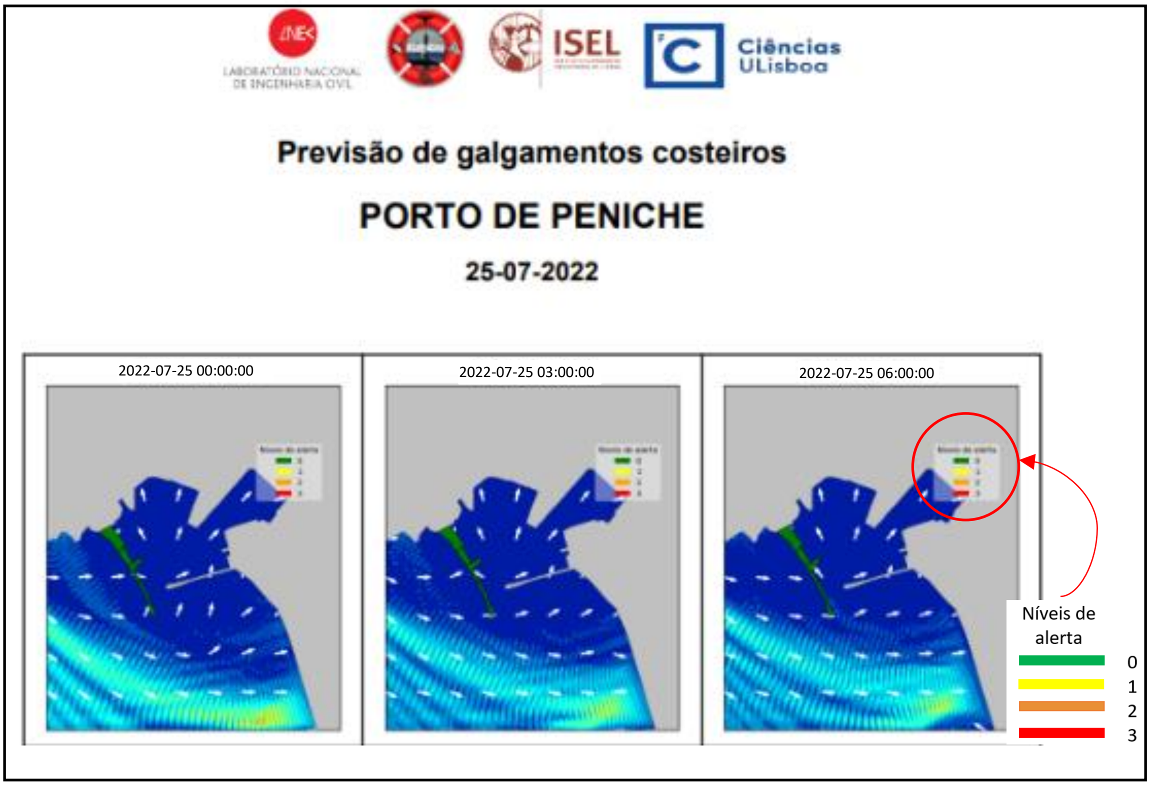
Source: From the authors.

Figure 7 – Overtopping results (grey circles) in the eight points defined along the toe of the structure.



Source: From the authors.

Figure 8 – Daily bulletin with the alerts forecast.



Source: From the authors.

3.2 Quarteira

The new prototype developed for Quarteira has a similar structure as the one for Peniche, except that the overtopping risk is evaluated using a Bayesian Network trained with a dataset of numerical model results from a set of synthetic sea states. Quarteira is located on the southern coast of Portugal (Figure 10). The study area 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. The beaches 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.

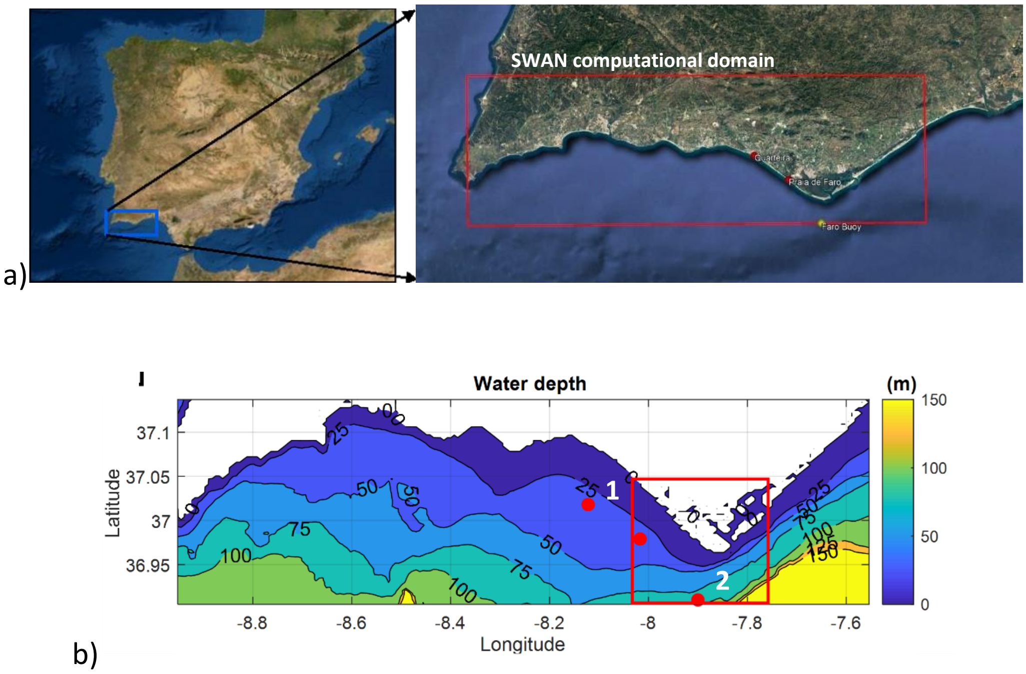
To create comprehensive information to train the Bayesian Networks (BNs), a numerical framework that computes wave overtopping was coupled with a risk model to identify risk conditions induced by a set of synthetic sea states or events. The considered input variables of the synthetic sea states were 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 the inclusion in the analysis of two types of events: 1) storm events characterized by *Hs* larger than 3 m and 2) swell events with *Hs* lower than 3 m and *Tp* larger than 13 s. 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). The mean overtopping discharges obtained with XBeach were extracted at different locations of the profile, depending on the exposed element (pedestrians, vehicles (cars) and properties (Figure 10). 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.

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 on GARZÓN *et al.* (2023) and displayed in Table 2. The mean discharge simulated by XBeach was used to establish risk conditions using these limits. The risk was defined among the 5 storms within each bin based on the worst-case scenario.

The Bayesian Networks developed for Quarteira are fed daily with the forecast obtained from Puertos del Estado in the location of the Faro-Costeira buoy and give the risks associated with coastal flooding for pedestrians, properties, and vehicles.

Some of the outputs that are available through the web platform are the offshore (Figure 11) and local wave conditions, the alert results and the daily bulletin with the alert maps that present the exposed elements (pedestrians, vehicles or properties) that can be at risk (Figure 12).

Figure 9 – SWAN computational domain and location of Quarteira (a), XBeach model offshore boundary and Faro-Costeira buoy (b).



Source: Top left and right: adapted from GoogleEarth™ image, Bottom: From the authors.

Figure 10 – Overview of the Quarteira site (a). The red box highlights the three beaches within the alert system: eastern (b), central (c) and western (d). The black line indicates the used cross-shore profiles, and the coloured squares indicate the locations where the risks were assessed: blue (pedestrians) and red (vehicles and buildings).

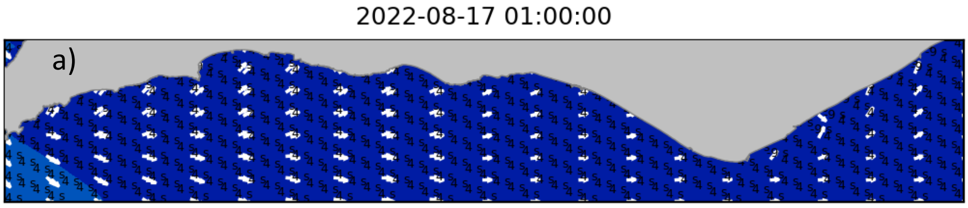
Source: Adapted from GoogleEarth™ image.

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

Receptor		Green	Yellow	Orange	Red
	Symbol (colour varies according to alert level	*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

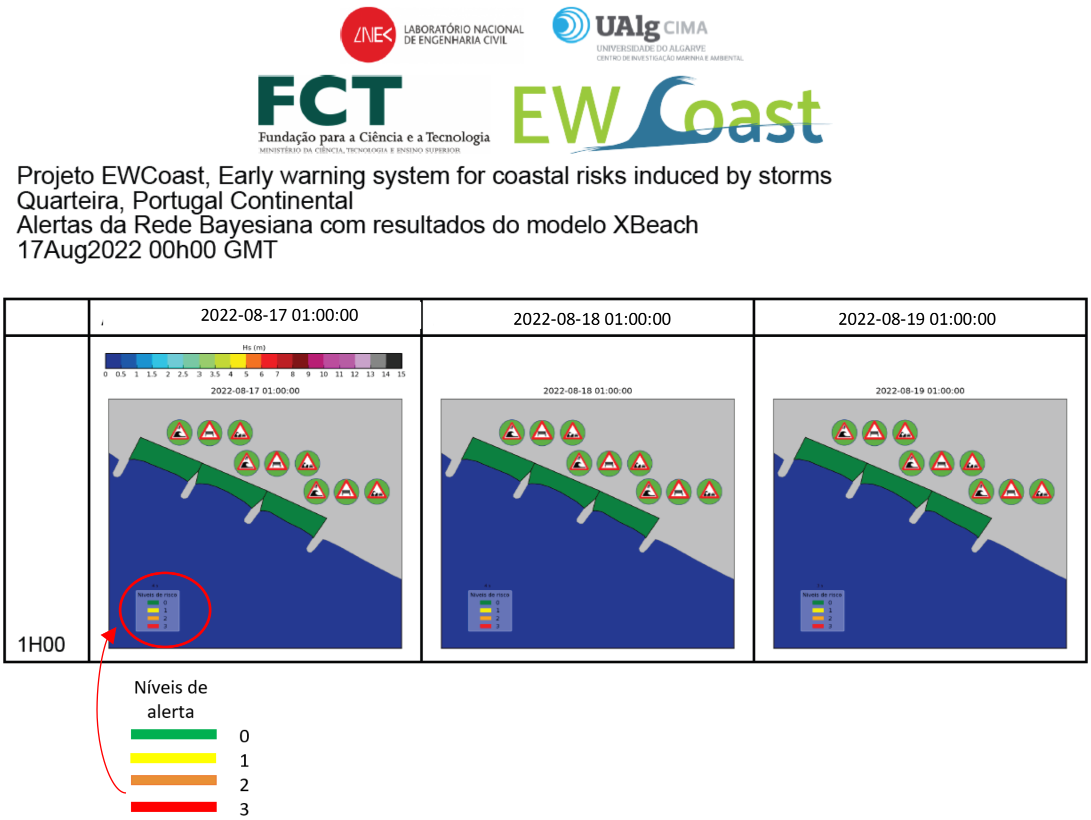
Source: From the authors.

Figure 11 – Wave conditions (wave heights in colour, directions in arrows) at the Algarve coast.



Source: From the authors.

Figure 12 – Daily bulletin with the alerts forecast for Quarteira.



Source: From the authors.

4. CONCLUSIONS AND FUTURE DEVELOPMENTS

The new HIDRALERTA prototypes are running operationally every day providing forecasts for the following three days. They are now being tested and validated, with the alerts that are issued being compared with local records to assess their agreement with real conditions. As to future developments, the implementation of the alert systems for erosion and flooding risks for other areas such as Praia de Faro has been completed, and their validation phase started in September 2022.

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