A COMPARISON OF WAVE CHARACTERISTICS AT CAPARICA BEACH, PORTUGAL, USING IN-SITU AND TRANSFERRED WAVE DATA

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Abstract

The HIDRALERTA system is currently being implemented as a novel early warning system to assess the risk of flooding in coastal and port region areas. With forecasted sea wave conditions at coastal and port areas, the system is able to determine the effects of waves in terms of wave overtopping and flooding, to compare those results with pre-specified thresholds, to build alert maps, and, if necessary, to issue alert messages. The system will be applied to two case studies: Praia da Vitória harbor, in Terceira Island, Azores, and Caparica beach, near Lisbon. One of the major inputs of this integrated system is the characterization of sea wave conditions at the site of interest, so that both measured wave data and selected numerical models are used. Numerical models, however, should be calibrated for each area of application.

This paper is a contribution to get a better insight of the wave characteristics at one of those case studies, the Caparica beach, to provide adequate calibration of the mentioned numerical models. Therefore, two measurement campaigns were organized at that location, using several instruments. Data was collected and analyzed, then compared with those transferred from the Port of Lisbon wave buoy, by using numerical wave propagation models, which then enabled one to evaluate SWAN's performance and to calibrate some of its parameters. Thus, the paper describes the sea wave characterization using both in-situ data and transferred data from the Port of Lisbon wave buoy, and discusses the SWAN's strengths and weaknesses to simulate the wave conditions measured at the two above mentioned campaigns.

Keywords: warning and alert system; wave characterization, SWAN model

1. Introduction

The existence of a tool for planning and managing the short and long-term coastal and port areas is particularly important in the Portuguese coast, given its length, the known severity of the wave climate and the concentration of population and economic activities developed in those areas.

It is on this context that the HIDRALERTA (Fortes et al., 2013) system is being implemented. This integrated coastal management and port system aims to prevent emergencies and assist with the management, planning and long-term interventions in coastal and port structures. For that it uses a methodology for assessing the risk of flooding in coastal and port areas.

The HIDRALERTA system is primarily based on the forecasts of waves in coastal and port areas and in the calculation of the corresponding wave overtopping and flooding in those areas. The system consists in four modules, including a module for characterization of the sea waves. In this module, numerical models of wave generation and propagation, such as the

WaveWatch III (Tolman, 1999) and SWAN (Booij et al. 1999) models, are used, with the parameters of the latter ideally calibrated for each zone study.

The present work will discuss an evaluation of the performance of SWAN model (Booij et al., 1999), when applied to the Caparica beach area (one of the areas of study for HIDRALERTA system) by comparing the numerical results with in-situ measurements made at two field campaigns, and therefore this can be viewed as an extension of the work of Neves (2013).

In this paper we describe the study site, the in-situ measurement procedures, the application of SWAN model to the study area and the comparison between measured data and numerical simulations produced by SWAN.

2. Study location

The Caparica beach is located on the south of the mouth of the Tagus River, in the Almada municipality, just opposite to the city of Lisbon (Figure 1). The beach has a length of approximately 1.3 km, being confined in between two spurs (the north spur, 350 m long, and the south spur, 150 m long). The choice of this location was due to the following: a) this is a beach of sedimentary origin that presents a small dune system, yet very fragile, and where there is also a cohesive structure; b) the location is near a city where the risk associated with the occurrence of overtopping and flooding is of utmost importance to society; c) historical data of topographic, bathymetric profiles and waves are available for this site; d) also, it is a location where, on February 16th 2011, a serious overtopping and failure accident occurred, followed by an artificial sand feeding that, up to now, has worked quite successfully (Figure 1).

Figure 1. Location of the study area (Google Earth© 2014).

3. In situ measurements

3.1 Measurements at the APL wave buoy

The characterization of sea waves at the Caparica beach is performed based on data collected by the Port of Lisbon Authority (APL) wave buoy, located at the entrance of the Tagus estuary (Figure 2).

Figure 2. Location of the APL wave buoy and of the Caparica beaches (Google Earth© 2014)

The TRIAXYS directional wave buoy is located at 38 ° 37 '25" N, 9 ° 23' 09" W, at a water depth of 30 m (CD). There are data from this buoy between 1.10.2007 and 16.11.2012 (~ 6 years), but with extended periods of missing gaps. From 25.10.2012 to 01.19.2013 (~ 3 months) data are available on the internet, with records from 10 to 10 minutes. In this work we consider particularly relevant the following parameters: HS (significant wave height), TP (peak period) and DIR_TP (peak direction). Table 1 shows descriptive statistics of HS, TP and DIR_TP series, obtained at the buoy location.

Table 1. Descriptive statistics of HS, TP and DIR_TP series, obtained at the buoy location for period 1.10.2007 to 16.11.2012.

Statiistics	HS (m)	TP (s)	DIR_TP (°)
Mean	1.26	10.7	280.0
Median	1.04	10.5	284.5
Mode	0.88	11.8	284.1
Standard deviation	0.72	3.0	28.4
Variance	0.52	8.8	806.8
Kurtosis	4.60	0.02	29.2
Assimetry	1.94	0.04	-4.2
Range	5.91	18.1	359.6
Minimum	0.28	1.9	0.1
Maximum	6.19	20.0	359.7
Number of values	29418	29418	29418

From the obtained results, it is apparent that the wave propagation regime is characterized by:

- Wave heights HS between 0.28 and 6.2 m, with average 1.26 m, being the most frequent range between 0.5 m and 1.5 m;
- Peak periods, TP, from 1.9 s to 20 s, with a mean of 10.7 s;
- Wave directions, DIR_TP between 0° and 360°, occurring mostly in the range between 240° and 320°. At this location there is still a range between 0° and 100° with high peak periods, although with few occurrences.

3.2 In-situ measurements

The two campaigns of in-situ measurements on the Caparica beach involved elements of the National Laboratory of Civil Engineering (LNEC), the New University of Lisbon (UNL), the University of Algarve (UAlg) and the Faculty of Sciences of the University of Lisbon (FCUL). They were held on 11 to 15 April 2010 (Campaign 1) and 29 and 30 October 2012 (Campaign 2). The objective of the campaigns was to obtain hydrodynamic and morphological data to test and validate the numerical models as well as to improve the understanding of the dynamics of the surf and its influence on sediment transport and morphodynamics of beaches. In the two campaigns a number of acquisition instruments, such as Pressure Transducers (PT), Electromagnetic Current Meters (ECM), differential-GPS and an Acoustic Doppler Current Pressure (ADCP) transducer, were used. Figure 3 shows some details of the placement of equipment in the respective support structures for Campaign 1.

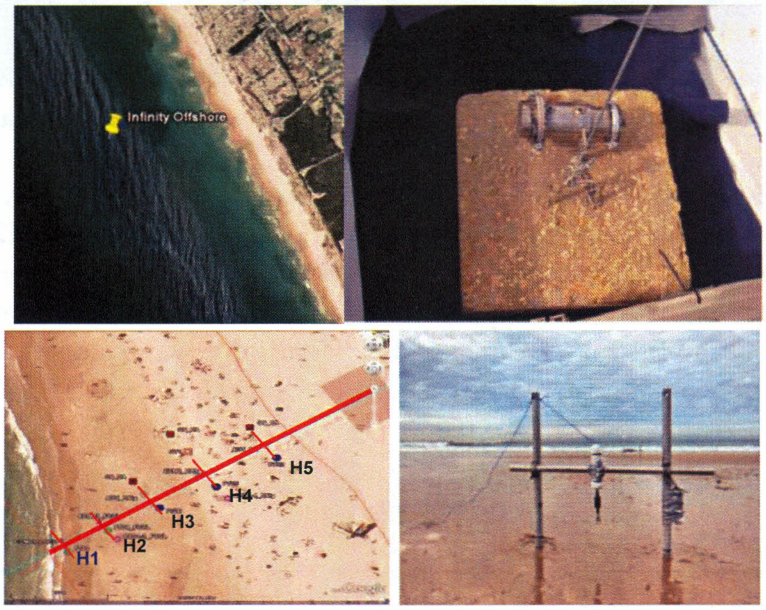

Figure 3. Some aspects of the instrumentation placement: for Campaign 1 (above) and for Campaign 2 (bottom)

In this figure one can observe the INFINITY equipment placement (figure on the top), at a position named PT00 (see Figure 2), with coordinates 38 ° 37 '27.89 "N, 9 ° 14' W', and water depth -7.6 m (CD). This was the location considered for the comparisons made with the numerical model SWAN. Wave parameters for the in-situ measured data were obtained through time and spectral analyses.

4. Application of SWAN model

This section describes the application made with the SWAN model in order to evaluate the performance of the model for the area under study. In situ measured data were compared with results of the numerical model according to the following methodology:

- at point P1 (wave buoy location), -30 m (CD), for period from 01.10.2007 to 16.11.2012 without considering wind field in numerical calculations;
- at point PT00 (pressure transducer location), -7.6 m (CD), for period from 12 to 15 May 2010 (Campaign 1) without considering wind field in numerical calculations;
- at point P1 (wave buoy location), -30 m (CD), for period October 29 to 30 2012 (Campaign 2), considering a wind field in the numerical calculations.

4.1 Initial conditions

The implementation of the SWAN model requires the introduction of different databases concerning the physical variables that characterize the bathymetry, the wave conditions, the winds and the tides.

Offshore wave conditions were estimated by the 3rd wave generation and propagation model WaveWatch III (Tolman, 1999). These estimates were defined in terms of HS, TP and DIR_TP parameters, obtained every three hours, for the period from 01.10.2007 to 16.11.2012, Poseiro (2013) at point "WaveWatch III", see Figure 4.

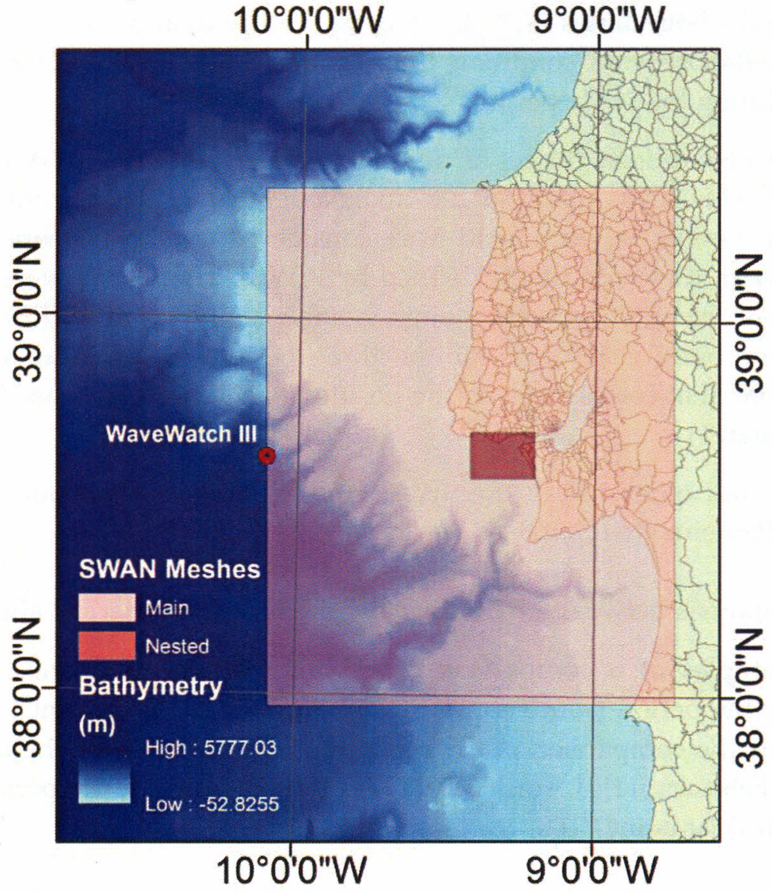

Figure 4. SWAN computational domains and location of WaveWatch III estimates.

With regard to winds, and only for Campaign 2 (from 29 to 30 October 2012), regional wind data at 10 m were used, provided by FNMOC's NOGAPS model (Bayle, 1992) - horizontal (U) and vertical (V) components, with a spatial resolution of 1°. Four points of wind data were considered in the calculation domain of SWAN.

For the tide level, one used the values provided by the Cascais tide gauge. Note that these values already contain the storm surge component, as result of variable weather conditions, including variations of the atmospheric pressure and the action of strong and sustained winds.

4.2 Computational model and simulation characteristics

The computational domain of the numerical model SWAN was discretized by means of two rectangular grids, see Figure 4. The larger grid (SWAN 1st mesh) is 153 km long and 120 km wide and is made of square cells, 250 m-wide. The medium grid (SWAN 2nd mesh) is 13.7 km long and 19 km wide and is made of square cells, 50 m-wide.

The bottom computational grids at the region adjacent to study area were based upon the bathymetric dada provided by the Portuguese Hydrographic Institute (IH) and the LIDAR coastal data were provided by the Portuguese Terrestrial National Institute (DGT).

The model was run for the following conditions: a) SWAN version 40.72, with no currents, in stationary mode; b) a directional JONSWAP frequency spectrum defined in 24 components, from 0.04 to 2.0 Hz, with logarithmic distribution and a directional discretization covering 270°, in 90 intervals; c) a constant wave breaking coefficient of 0.65; d) an adapted JONSWAP spectral shape with a bottom friction coefficient of 0.067 m^2s^{-3}; e) Offshore wave conditions defined by WWIII at the boundaries W, N and S of the first grid, at point "WaveWatch III", see Figure 4; f) for each offshore wave condition, the considered tide level was the one observed in Cascais tide gauge during the study periods.

Based upon the above conditions, the set of simulations made with the SWAN model included the period of 11 to 15 May 2010, 1 October 2007 to 6 November 2012 and from 29 to 30 October 2012 (for this latter period, a wind field was considered in the numerical calculations), considering the offshore wave conditions defined by WWIII. The results were obtained across the calculation domain including specific points, notably point P1, at 3°37'26" N, 9°23'10" W, where the APL wave buoy is located, for the three periods. Numerical results were also obtained at point PT00, that corresponds to the position of the pressure transducer, from 11 to 15 May 2010 (Campaign 1).

For a more efficient and quick use of the SWAN model, a special software for the models' interface was used (Pinheiro et al. 2007).

5. Comparative analysis between in-situ measurements and numerical simulations

Figure 5 shows examples of a comparison of HS values measured and obtained by the numerical model for the period from February 11 to April 1, 2012, at point P1 (without wind field). Figure 6 shows the comparison of HS measured and obtained by the numerical model for the period from February 11 to April 1, 2012, at point P1, and for the period from 12 to 15 May 2010 (Campaign 1), at point PT00.

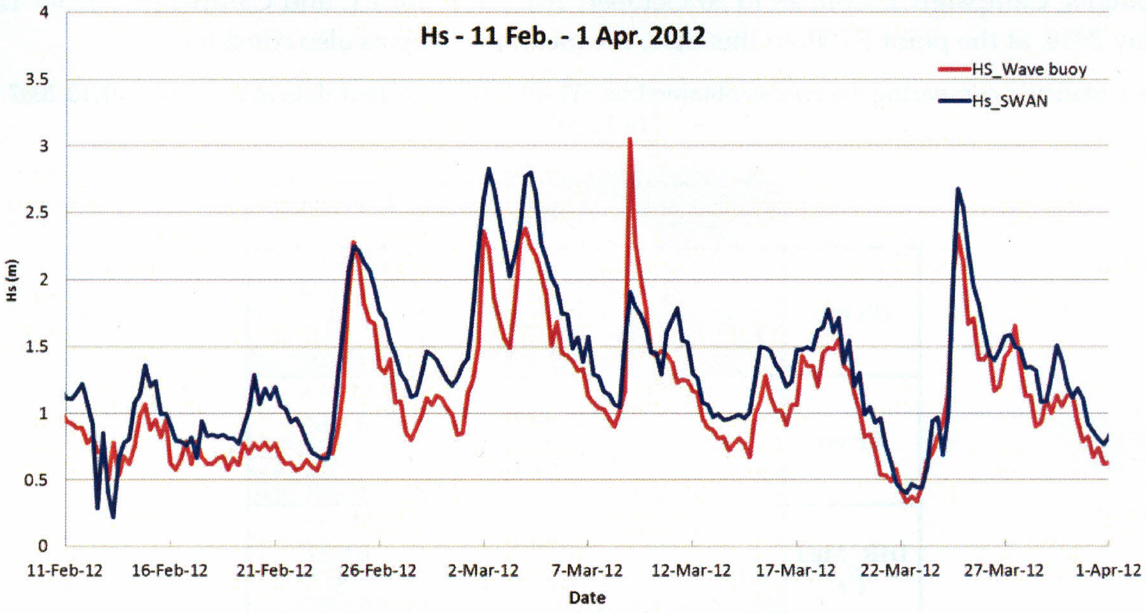

Figure 5. Comparison of SWAN's numerical simulations and in-situ measured data from 11st February 2012 to 1st April 2012, at point P1

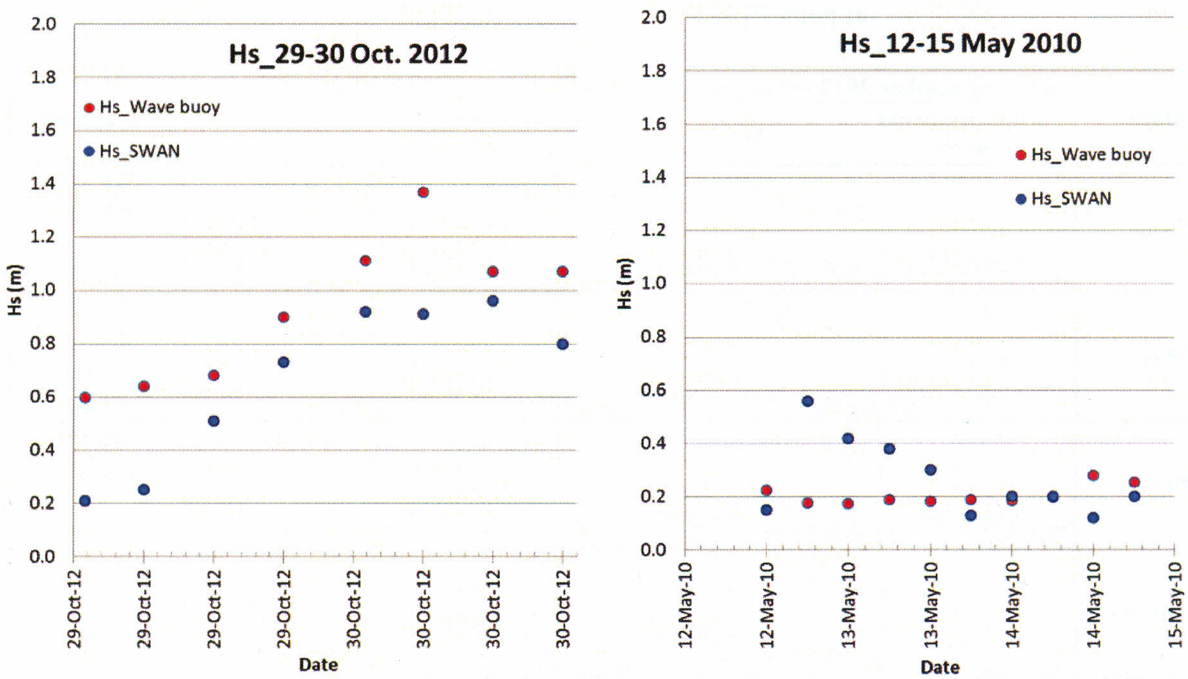

Figure 6. Comparison of SWAN's numerical simulations and in-situ measured data from, from 29 to 30 October, 2012 (Campaign 2), at point P1, and from 12 to 15 May 2010 (Campaign 1), at point PT00

Based on the results obtained by SWAN numerical model (HS, TP and DIR_MED, mean direction) and the in-situ measurements at P1, for period from 01.10.2007 to 16.11.2012, the following statistical parameters were obtained: mean, mean square error (RMSE), scatter index (SI) and bias (BIAS), shown in Table 2.

Similarly, the same statistics are shown in Table 3 for the periods of the two measurement campaigns: Campaign 2, from 29 to 30 October, 2012, at point P1, and Campaign 1, from 12 to 15 May 2010, at the point PT00. In this case, the mean period was also considered.

Table 2. Statistics comparing the results obtained by SWAN and measured data at PT1, from 01.10.2007 to 16.11.2012

	Measurements at PT1	SWAN	Parameter
HS (m)	1.275	1.490	MEAN
	0.348		RMSE
	0.273		SI
	0.216		BIAS
TP (s)	10.753	8.674	MEAN
	2.825		RMSE
	0.263		SI
	-2.079		BIAS
DIR_Med (º)	279	302	MEAN
	40.589		RMSE
	0.145		SI
	22.996		BIAS

Table 3. Statistics derived from the comparison of the results obtained by the SWAN model and data provided by the buoy at point P1, from 29 to 30 October 2012, and by the INFINITY pressure transducer at point PT00, from 12 to May 15, 2010.

Values	29 to 30 october 2012 – Campaign 2		12 to 15 may 2010 – Campaign 1		Parameter
	Measurements at P1	SWAN	Measurements at PT00	SWAN	
HS (m)	0.930	0.661	0.206	0.266	MEAN
	0.295		0.172		RMSE
	0.317		0.8333		SI
	-0.269		0.060		BIAS
TP (s)	7.600	6.695	8.816	7.243	MEAN
	2.082		1.743		RMSE
	0.274		0.198		SI
	-0.905		-1.574		BIAS
TM02 (s)	4.138	3.078	8.449	6.718	MEAN
	1.396		1.814		RMSE
	0.337		0.215		SI
	-1.060		-1.731		BIAS
DIR_MED (º)	251	241			MEAN
	46.236				RMSE
	0.184				SI
	-9.882				BIAS

From the analysis of Figure 5, one can observe a good agreement between the results of the SWAN model and measured data for HS at point PT1. The same was found for the peak period and the wave direction, although, for these parameters, more discrepancies were found between measured and numerical values, especially for the direction parameter.

Table 3 shows that both the significant wave height and the peak period have not significant deviations (BIAS). However, the mean direction shows much higher differences (~ 23 °). The shown low values of RMSE and SI for HS and TP indicate a better performance of SWAN for these parameters.

For the situation in which calculations were performed considering the wind field (from 29 to 30 October 2012), at point P1, Figure 6, the model results agrees better with observed data for the calculations performed without wind, so that one can infer the importance of a correct wind field definition (with appropriate reservations), and that the model is best suited for HS and TP calculations (lower values of RMSE).

For point PT00, at -7.6 m (CD) water depth, the model results also agree with measured data, with a quite good agreement for HS and a good agreement for TP, as can be seen by observing the obtained low values of RMSE.

6. Conclusions and future developments

The present work aimed to analyze the performance of the SWAN model on the Caparica beach, near Lisbon. The SWAN model is one of the models included in the HIDRALERTA alert system, which is being implemented for this region.

Comparisons between numerical results obtained with SWAN and wave buoy data and between SWAN results and results of in situ field campaigns were made for this paper.

A good agreement was found between SWAN's results and measurements, both in general terms and orders of magnitude of the significant wave heights and periods for the considered time spans, and for the two locations. As to wave directions, the model does not adequately reproduce the observed refraction for this particular region. The inclusion of the wind field clearly contributes to a better agreement between measured and numerical results.

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References

Bayler, G. and H. Lewit. (1992). The Navy Operational Global and Regional Atmospheric Prediction System at the Fleet Numerical Oceanography Center, Weather and Forecasting, Vol. 7, No. 2, June.

Booij, N., Ris, R.C. e Holthuijsen, L.H. (1999). A third-generation wave model for coastal regions, Part I, Model description and validation. J. Geog. Res., C4,104, 7649-7666.

Fortes, C.J.E.M.; Reis, M.T.; Poseiro, P.; Capitão, R.; Santos, J.A.; Pinheiro, L.P.; Rodrigues, A.; Sabino, A.; Rodrigues, M.C.; Raposeiro, P.D.; Ferreira, J.C.; Silva, C.; Simões, A.; Azevedo, E.B. (2013). The *HIDRALERTA project – An early warning system to assess the risk of flooding in coastal and port region areas.* 8th JPECP, AIPCN/PIANC, 10-11 October (in Portuguese).

Neves, P. (2013). *Flood risk evaluation for the Costa da Caparica area.* M.Sc. thesis, FCTUL, 120p (in Portuguese).

Pinheiro, L., Fortes, C.J.E.M., Santos, J.A., Fernandes, L. e Walkley, M. (2011). Boussinesq-type numerical model for wave propagation near shore and wave penetration in harbors. MARTECH 2011, 10-12 May, Lisbon.

Poseiro, P. (2013). *A set of procedures for executing HIDRALERTA system: Development of Applications using Python.* LNEC. Lisbon (in Portuguese).
(https://sites.google.com/ site/pedroposeiro/docs/Report_Hidralerta_Pedro_23052013.pdf)

Tolman, H. (1999). User Man. and Syst. Doc. WAVEWATCH-III.