ACCU-WAVES: AN OPERATIONAL SYSTEM FOR WAVE FORECASTS SUPPORTING SHIP NAVIGATION AROUND AND INSIDE SEAPORTS

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ABSTRACT

This paper presents a new Operational Forecast Platform (OFP) for prevailing sea conditions at very important ports worldwide (project Accu-Waves; http://accuwaves.eu/). The OFP produces reliable, high-resolution, predictions of wave characteristics in and around harboured coastal areas. Its goals are to support safer navigation, assist vessel approaching, enhance management of towing services, and bolster secure ship manoeuvring in busy ports around the globe. Hence, port managers and authorities can be assisted in timely predicting possible port downtime. Accu-Waves OFP is based on integrated, high-resolution, spectral wave modelling over the continental shelf and in coastal areas that incorporates data from global- and regional-scale, open-sea, wave forecasts as boundary conditions. The models' setup, coupling, validation, and application are presented and discussed, concerning 50 selected areas near and inside significant port basins. The platform provides three-day forecasts at three-hourly intervals. Exceptional cases of very high waves and rough sea conditions in representative ports are discussed reflecting the performance of the prediction system.

Keywords: operational forecasts, wave modelling, ports, harbours, navigation safety

1. INTRODUCTION

Seaport infrastructures provide access and marine services to global short sea shipping and the maritime industry in general, by feeding and supporting the supply-chains worldwide; 80% of the world trade volume is carried by port-to-port marine pathways. However, they are considered as endangered areas as they contain low-lying inland terrains (berths, wharf sheds, piers, bulkheads, and container terminals) and structures (breakwaters, piers, docks, jetties, dykes, and quays) exposed to sea level variation and wave attack, caused by extreme weather conditions. These can severely impact harbours' infrastructure and cause port service downtime. To address these issues, a new web-GIS OFP (https://accuwaves.eu/forecast/index.html#), called Accu-Waves [1], has been created. It relies on a modern automated setup [2] and delivery of three-day marine weather predictions (for wave characteristics, sea levels, currents, and winds) in very high resolution, based on a set of robust, integrated, numerical models [3], concerning areas near and inside 50 very important ports worldwide.

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2. METHODOLOGY

Accu-Waves OFP incorporates met-ocean data from global- and regional-scale, meteorological and open-sea wave forecasts as input and boundary conditions in order to automatically feed the integrated, high-resolution, spectral wave modelling suite.

2.1. Available Data (Atmospheric Input, Boundary Conditions, Field Observations)

The sequence of implementation components in Accu-Waves OFP comprises the retrieval of patrimonial, open-access, forecast input data from: a) NOAA (https://www.ncdc.noaa.gov/; meteorological forcing), b) Copernicus Marine Service (http://marine.copernicus.eu; hydrographic boundary conditions), c) national mapping agencies and Navionics (https://webapp.navionics.com/; bathymetric data), and d) Aviso+ (https://www.aviso.altimetry.fr/; tidal components of sea level). In situ observations of wave characteristics from sea-surface buoys in several ports (e.g., Algeciras - Spain, Antwerp - Belgium, Los Angeles - USA, presented herein) are gathered from available sources, namely Puertos del Estado (https://www.puertos.es/en-us), Copernicus, etc. These are used for wave model calibration and validation. A great effort was made to create a continuously updated inventory of solid boundaries inside ports to represent the fully or partially reflective boundary conditions in wave models.
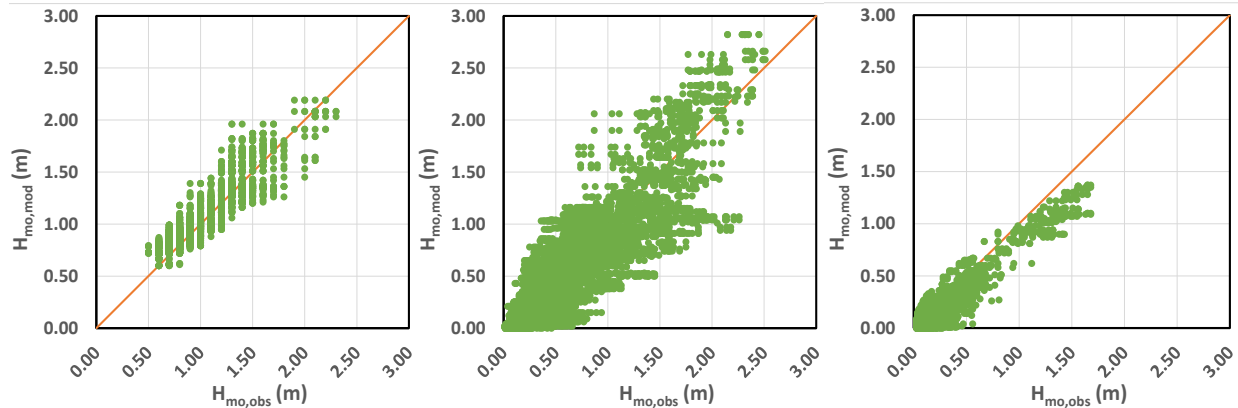
2.2. Numerical Models (TOMAWAC and WAVE-L)

The sea level and current conditions in coastal areas are also provided as input to the wave simulations by a 2-D hydrodynamic model for barotropic circulation (High Resolution Storm Surge, HiReSS) that considers the synoptic scale meteorology and astronomical tides [4], operating in forecast mode [2, 3]. TOMAWAC (Model A; http://www.opentelemac.org/) is a 3rd generation, phase-averaged, directional, spectral wave action model that simulates the generation and propagation of wind-induced irregular wave fields on high resolution, triangular, finite element meshes. It is applied on coastal areas in the vicinity of ports, reproducing the irregular wave shoaling and depth-limited breaking, energy dissipation due to white-capping and bottom friction, non-linear wave-wave interactions, etc. The model can also capture the wave-current interaction processes around port and coastal protection structures [5]. WAVE-L (Model B) is based on the hyperbolic mild-slope equation, and simulates the transformation of wave fields with very high resolution (dx=2m) inside ports with rapidly varying bathymetries. It includes shoaling, refraction, diffraction, reflection from structures, energy dissipation due to wave breaking and bottom friction in a combined way [6]. The proposed evolved version of the model can cope with quasi-irregular wave generation in a peripheral mode with lateral incident wave propagation by any direction with the help of surrounding sponge layers; an advanced approach to incorporate partial and full reflection from structures is also followed [4]. The numerical scheme is based on a fast, explicit, staggered-grid solver to account for demanding computational times of simulations with $5 \cdot 10^6$ cells.

3. RESULTS

3.1. Models' Validation

Figure 1 and Table 1 present features for the validation of Model A in operational forecast mode against field data of significant wave height, H_{mo} or H_s, in the ports of Algeciras, Antwerp and Los Angeles. The very good performance of the wave model, shown in the scatter diagrams of H_{mo}, is corroborated by the very high values of Pearson Correlations, Willmott Skill Scores, and Hit-Rate-of-Percentiles Index [4], and small errors (<8%) of model results against field data derived from wave buoys in the three port basins.

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Figure 1. Scatter diagrams of comparisons between values of H_{mo} (m) from Model A simulation outputs (mod) and wave-buoy field data (obs) for the ports of Los Angeles (left), Antwerp (middle), Algeciras (right).

Table 1. Quantitative features of validation for Model A performance metrics in the three regions of Figure 1: Pearson Correlation, Willmott Skill Score, Hit-Rate-of-Percentiles Index, Root-Mean-Square-Error to $H_{mo,obs}$ Maxima.

Port	Pearson Correlation	Willmott Skill Score	HRP-Index	RMSE/$H_{mo,obs,max}$
Los Angeles	0.91	0.95	1.00	5.9%
Antwerp	0.90	0.94	1.00	7.8%
Algeciras	0.88	0.91	0.99	7.4%

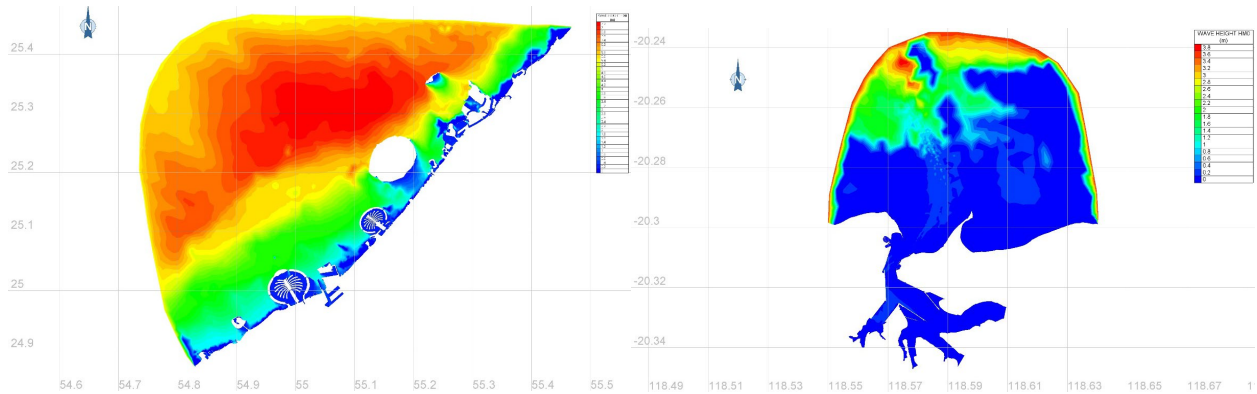## 3.2. Wave Propagation in Coastal Areas and Wave Agitation at Ports

Figure 2 presents the evolution of H_s fields in the coastal areas around the harbours of Jebel Ali (United Arab Emirates) and Port Headland (Australia) based on Model A simulations of extreme wave conditions' scenarios with H_s=6m and 4m, for north-westerly and northerly winds, respectively. Respective wave height maps of Model B simulation results are shown in Figure 3 for Algeciras and Buenos Aires ports under high wave conditions, H≈2m, for easterly to south-easterly winds, respectively.

4. CONCLUSIONS

A modern OFP, built on an integrated wave modelling suite of very fine resolution, is presented herein to account for reliable, detailed predictions of wave conditions in and around 50 globally significant ports. Accu-Waves is a prototype tool that can assist in safer shipping operations and port navigation management. The system incorporates external data from global-scale met-ocean forecasts and offers a downscaled processing of complex numerical data within automated parallel execution frameworks. Proper validation of the integrated models' performance was achieved. Therefore, Model A implementations offer useful information about port approaches and certified navigation pathways for ships calling to ports, while Model B offers very high resolution representation of wave fields (e.g. standing waves, refraction or shadow regions, etc.) redefining the OFP paradigm for port areas. It is built in MarineTraffic's web-GIS app and provides an intuitive interface for coastal- and port-scale data query.

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Figure 2. Maps of Model A results for significant wave height H_s (m) in Jebel Ali (left) and Port Headland (right) coastal areas with port approaches during extreme wave conditions, H_s = 6m and 4m, for north-westerlies and northerlies, respectively.
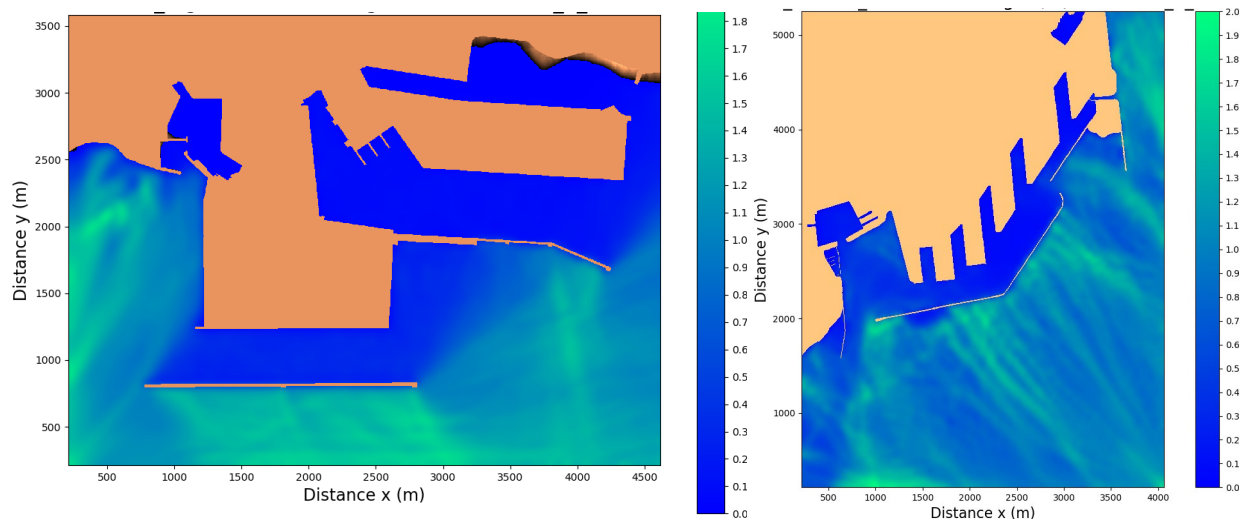
Figure 3. Maps of Model B, very fine resolution results, for pseudo-spectral wave height H (m) in Algeciras (left) and Buenos Aires (right) ports during high wave conditions, H≈2m, for easterly to south-easterly winds, respectively.

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