Numerical ship-wave generation, propagation and agitation analysis, related with harbor downtime management

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ABSTRACT

The present study describes the works related with the numerical evaluation of waves generated by passing ships within the harbor. Ship-waves (or wake waves), are generated by the disturbance of the moving vessel, which delivers a set of oscillations that may interrupt or interfere the safe-mooring activities.

Since energy, shape and frequency of ship-waves depends on: speed, accelerations, track and geometry of the vessel; bathymetric contours; and wharf geometries, it is necessary to design a reliable tool that integrates all these characteristics.

Activities such (safe) loading/ unloading of materials/ passengers, navigation and sedimentary dynamics adjacent to harbour infrastructures (silting), are closely related with ship-wave generation and propagation.

Thus, this study presents a numerical alternative to characterize this forcing, to provide a new diagnosis system for any harbour manager. This will provide a decision tool based on a realistic harbour agitation study, forced by a ship travelling inside real basins, for any vessel/ operator/ route/ navigation protocol/ speed, etc.

Harbour managers will be able to evaluate the agitation effects, know and establish the speed limits, change routes, hours, and even the ship geometries and sizes, in order to satisfy the Port Authority safety limits and to improve the downtime records.

1. INTRODUCTION

In the present study, the main methodology for the numerical generation of ship-waves is described. The aim of this research is to obtain a robust and reliable system that predicts, in a realistic approach, the magnitude of the wave generated by the passing ships inside any port and harbour.

Ship-waves are first generated by the moving vessel and then propagated towards the port basin, channel and contours, and finally interacts with the berthing zones, breakwaters, and moored ships.

The numerical tool described here has been validated with several benchmark cases (laboratory) and in-situ measurements, obytaining very good predictions. Furthermore, the tool can be easely adapted/ integrated into any operational strategy designed for port management, as an individual module that allows the predictive knowledge of ship-waves, starting from a predefined selection (catalog) of trajectories, type of vessels and representative speeds taken from the whole vessel database (i.e. Automatic Identifycation System, AIS) of any port to be analyzed.

With this innovative product, a new predictive knowledge is established within any Port Athority in order to manage better any operation areas, docks and berthing areas to be analyzed, and that may be interpreted according to the operational conditions that each Port Authority considers.

2. METHODOLOGY

The methodology deals with the modification of a wave propagation numerical model, based on the non-linear and dispersive Boussinesq equations, by including the effect of the passing ship and the subsequent flow perturbation, propagation, and interaction with bathymetries docks AND basins.

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The numerical strategy requires the establishment of a complete working methodology: pre-processing and adaptation of the bathymetric, port and AIS data, in order to provide an easy-to-use, relocable and reliable tool ready to be applied in any real harbor at any stage: pre-design, design, construction, operation and modification (extension, improvement, etc.).

Hence the following tasks were developed:

i. A state-of-the-art review related with the mathematical and numerical generation of the waves generated by passing ships, in order to identify the best strategy that suits the numerical needs.

ii. Adaptation of the numerical tool to be used for a good ship-wave generation, taking into account the most relevant physical characteristics of the ship (speeds and geometries), as well as the spatial trajectories physics. This task involves an exhaustive validation process of the numerical tool using benchmark laboratory tests and field data.

iii. A detailed guideline to numerically assimilate the ship routes, sizes and speeds for an extensive catalogue of ships for any Port Authority is presented, based on realistic AIS databases. This catalogue is used in the following tasks.

iv. Run of the catalogue of ships with the numerical tool (once modified, adapted and validated), in order to obtain the corresponding characteristics of the shipwaves (individual wave heights and associated oscillation periods), at different pre-established control points and ship maneuvering areas.

Each task is described below.

2.1 Task 1. State-of-the-art review related to ship-waves generation and propagation

This section undertakes an exhaustive review of the state-of-the-art. In particular, a review is made of issues related to the numerical modeling of the phenomenon and the physical characteristics of ship-waves for its future use and assimilation within the research.

When a boat sails produces two types of ship-waves, some divergent and some transverse (see Fig. 1), the form and existence of these depends mainly on the speed at which the boat sails, distinguishing three speed types: sub-critical, trans-critical and super-critical defined by the Froude number *(1)* according to the ship length (*L*), the translation speed (*u*) and the acceleration of gravity (*g*).

$$F_{RL} = \frac{u}{\sqrt{g \cdot L}} \qquad (1)$$

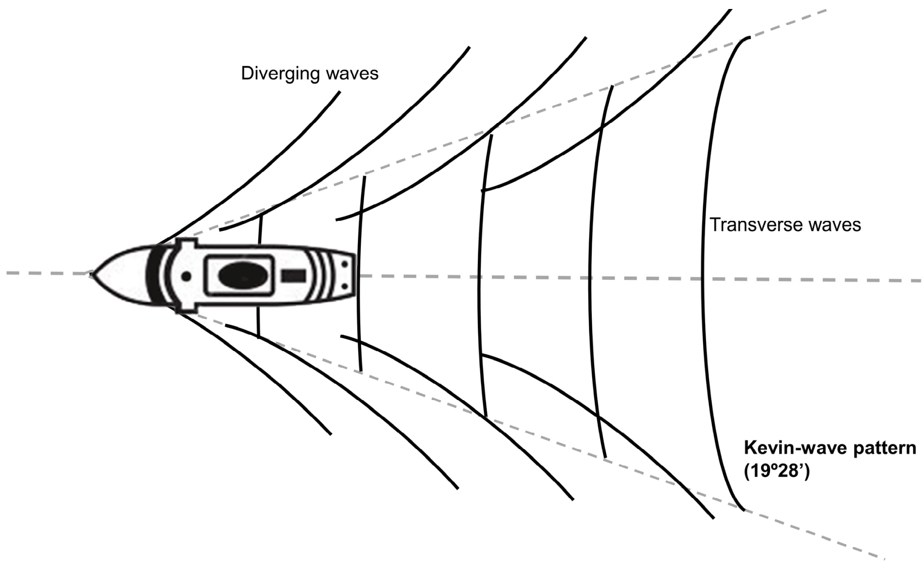


Figure 1: Ship-waves typical pattern and geometry

One of the fundamental documents to understand the generation and general characteristics of ship-waves is presented by McFarlane (2012), where it can be highlighted that the most relevant situation for the creation of ship-waves and therefore, on which the study should focus, is the trans-critical stage, because it is where there is more variation of the four characteristic parameters of the waves: its the period (*T*), the attenuation coefficient (*n*), the wave height constant (*γ*) and the angle between the direction of navigation and the line that intersects the transverse waves with the divergent ones (*θ=19º28'*).

The ship-wave trains (space-time propagated free-surface waves) contain very different types of waves. Within each group of waves, three types can be distinguished: Typea A, B and C. In order to understand the whole study, the difference between them must be understood (see Fig. 2).

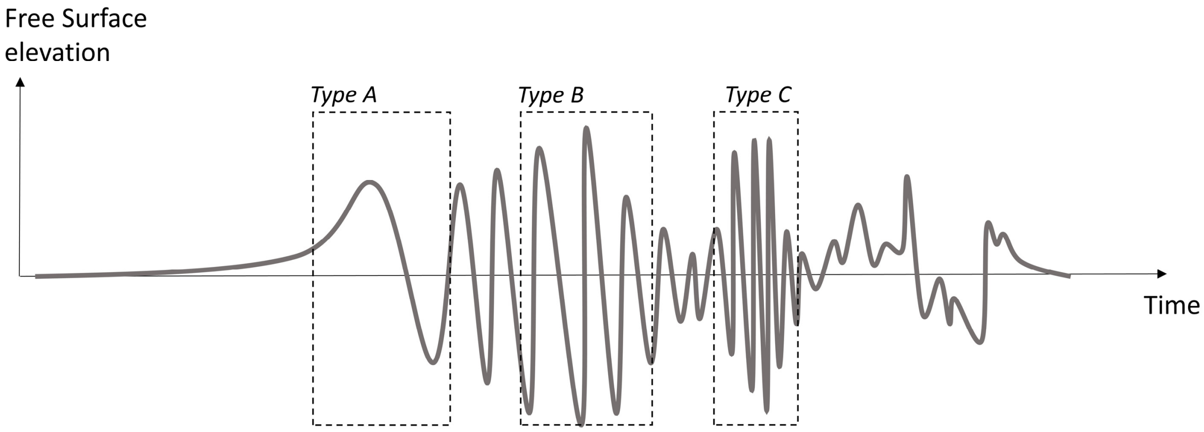


Figure 2: Ship-wave profiles A, B and C

Type A: is the wave with the longest period but the lowest height. Sometimes it can reach more height and with more energy. However, despite being the least high are those that have greater area under the trough since the period is longer, that is, the distance between peaks is larger and, therefore, have much more energy. These waves differ well in supercritical speeds, since the ridges are larger and their footprint is more noticeable.

Type B: they go after the waves A. They have a shorter period than the previous ones, although they are sometimes similar. What differentiates them from the previous ones is the increase in their height. They also have a lot of energy despite not being the wave with the highest height and period.

Type C: they are small divergent waves and reach the maximum height. They always follow waves A and B, and they have the shortest period. If it is in a sub-critical or trans-critical situation, the height is smaller.

Regarding the numerical modeling of the ship-wave generation phenomenon, the literature gathers different mathematical strategies that can be grouped into three large families: a) Analytical approaches, b) modeling with potential approximations, c) codes based on the theory called "thin ship "(TS), d) modeling based on Boussinesq approximations, and e) three-dimensional modeling with CFD (Computational Fluid Dynamics) models.

All the aforementioned approaches try with more or less success the adequate evaluation of the characteristics of the ship-waves for two well differentiated zones: 1. the field near the navigation line of the vessel where the funds can be considered deep and constant, and 2. the far field to the boat where the waves interact with the coastal or port areas with variable bathymetries.

Raven, (2000) and Kofoed-Hansen et al. (2000) indicate that the applied methods usually analyze these two zones individually and uncoupled, performing a post-coupling process to try to couple and give continuity to the process of generation-propagation-interaction of the shiop-waves throughout the domain (from the field near to the distant one).

The Raven analytical approaches (2000) are based on mathematical adjustments of empirical measurements in the field or laboratory, carried out under controlled situations of navigation and vessel geometry, with a limited number of typologies and bathymetries with a constant background. These basic formulations only offer a first outline of the wave heights and periods that can be expected for a standard vessel sailing at speeds with limited speed ranges that do not differentiate between the different subcritical to supercritical translation regimes. Analytics usually focus their range of application only to the near field and constant depths of propagation.

Approaches based on potential models proposed by Raven (2000) and Hughes (2001) often employ models that solve the free surface of the flow considering only the linear interactions within the flow. The surface of the water and the body or volume that defines the three-dimensional shape of the vessel is represented by a three-dimensional mesh of panels. The surface of the fluid is derived from obtaining the collapse and settlement of the fluid due to the pressures of the boat in motion and depending on the speeds of translation, the boat's own geometry and the weight or tonnage of each one of them. The generated subsidence propagates in the rest of the domain, initially at rest, solving the equations of the potential flow based on the initial perturbation, for constant background. This solution is not realized taking into account the temporary or transitory behavior of the propagation phenomenon of the ship-waves, so the results obtained are limited to a static photograph of the equilibrium state of the flow for any instant of time. This approach usually provides information about ship-waves very detailed and realistic in the area near the boat (near field) since it takes into account the detailed and three-dimensional shape of each floating body. However, the stationarity, the constant background limitation and the computational effort, which can be expensive (depending on the geometrical detail of the vessel and its size), make this approach move away from the needs of the current project.

Third, TS-type codes are based on the linear assimilation of Kelvin-type sources and sinks placed along the centerline of the vessel to represent the free surface. This approach is again limited to constant funds, linear behavior of the WW generated and waves with small amplitude compared to their lengths. These codes proposed by Havelock (1908), Mitchell (1898), Eggers et al. (1967), Gadd (1999), Molland et al. (2000), Tuck et al. (2001) and Doctors (1997), which solve the equations based on multiple integrations of each established source and sink, can only be applied at constant (not transient) translation speeds and preferably below the Froude critical regime and shallow depths. Finally, this type of approach usually shows instabilities for the evaluation of ship-waves in the far field, even with a constant background, either by numerical dissipation or by obtaining ship-waves height well above reality.

On the other hand, the codes based on the Boussinesq equations have focused primarily on the evaluation of ship-waves in the far field. That is, once the initial perturbations are generated in the near field, either with a potential model or a TS type. Kofoed-Hansen (1999, 2000) propose the use of models based on the Boussinesq equations for the subsequent solution of the far field. This coupling between models allows solving the wave propagation type WW over variable and complex backgrounds, taking into account the non-linear and transitory effects, interaction with port contours with complex geometries and even the evaluation of the hydrodynamics in the surf zone, currents in beach, break and approximate run-up, all in extensions of the order of kilometers.

This scheme of solution to the problem seems, therefore, the most appropriate for a correct evaluation of the effects of the ship-waves in the wharf or coast, especially if the objective is to evaluate fully and integrated large coastal areas. However, this coupling technique usually involves complex difficulties when trying to integrate the physical effects of the flow related to the propagation of the near field to the far field, and supposes simplifying hypotheses when generating the wave type ship-waves (constant bathymetry, constant velocity of the boat, straight trajectories, etc.). Therefore, if you want to make an easy assessment of ship-wave generation towards realistic boat traffic scenarios, this strategy can be a difficult and tedious numerical challenge.

For this reason, Chen and Sharma (1995) investigated the possibility of integrally solving the generation and subsequent propagation of ship-wave using Boussinesq models, managing, in a single step, the generation in the near field and its subsequent propagation to the field. far. This solution seems the best from the point of view of operational management to evaluate the characteristics of ship-waves in the quay and the coast. This strategy has been developed in depth by Jiang (2000) for vessels in motion, with variable trajectories and changing speeds. However, for this he used the simplified Boussinesq equations (weakly dispersive and non-linear).

This strategy has the disadvantages of having a poor spatial definition of the vessel geometry, because the mesh discretizations of the Boussinesq models for areas of the order of kilometers are usually not smaller than 5 m in general, so The digital boat generated is synthesized to polygonal or prismatic geometric shapes. However, Jiang et al. (2002) have shown that with an adequate validation process, the ship-wave generation in the near field can be calibrated with simplified ship forms.

Finally, there are the CFD-type approaches (eg FLOW models, OpenFoam) that are responsible for solving the near field of the generation of the WW taking into account the completely three-dimensional flow around the vessel in motion, also considering the detailed geometry of the boat (of the order of millimeters). This strategy is analogous in area of influence and conditions to the panel method, with the fundamental difference that the solution of the flow is made using the Navier Stokes averaged equations (RANS) that solve the complete 3D flow, considering all the transitory effects, non-linear, viscous and turbulent. These models, in addition to being highly computationally expensive, are usually focused on the evaluation of the efforts in the structure of the vessel by the wave action generated and projected on it, the evaluation of the geometry for the optimization of the hydrodynamic and turbulent performance, and the optimization of competition prototypes. So, if you want to use this type of modeling in the creation of vessel and trajectory typology scenarios, it does not seem to be a recommendable strategy.

In summary, the state-of-the-art provides information on the characteristics of the ship-waves generated in the near field and the strategies for its evaluation and subsequent propagation to the far field. Once the conditioning factors of each of them have been analyzed, and based on the objectives of the study, the decision has been made to adopt the integral solution technique, using the Boussinesq model proposed by Jiang et al. (2002), extending its scope to a better definition of the numerical domain (a better spatial resolution) and to improve the processes of wave propagation towards the far field through the adaptation of the non-linear and dispersive Boussinesq equations. All this with the final objective of evaluating the general characteristics of the ship-wave type waves and their temporal evolution, including waves type A and type B waves (the highest in energy) previously discussed in different areas within any port, as well as the post-processing of said series in the form of histogram, spectral and general statistics charts of the individual waves of the record.

2.2 Task 2. Numerical model adaptarion towards a ship-wave generation strategy

IHCantabria has developed IH-BOUSS model, which solves the temporal patterns of wave propagation, transformation and agitation, within numerical domains of the order of kilometers with complex contours, on real bathymetries, through the use of regular meshes in finite volumes and solving the two-dimensional (2DH) patterns of velocities, pressures, and free surface, considering the processes of asomeration, refraction, diffraction, and run-up in beach and port structures, as well as the reflection and radiation of the waves.

In addition, the numerical model includes in its formulation the processes of energy dissipation by partial or total absorption of the contours, processes associated with wave breakage, bottom friction and turbulent effects.

One of the fundamental advantages of using the IH-BOUSS numerical model is that it is based on advanced capabilities to solve wave patterns on a numerical domain with real complex contours, considering a temporal evolution of these patterns, and how the waves propagates and interacts with port contours. This allows the evaluation of the general characteristics of wave trains on foot of the structure, inherently including the non-linear and transitory processes that this has experienced from its point of generation to the structure.

Following the methodology proposed by Jiang et al. (2002), the IHBOUSS model must follow an adaptation protocol in order to generate ship-wave in a simple, repeatable and reliable way, taking into account the following boundary conditions of the problem:

- Consider the different dimensions of the vessels to be analyzed (length, draft and beam).
- Take into account realistic trajectories of vessel movement: turns and accelerations.
- Consider a good spatial definition of the element that represents the digital vessel to be simulated.
- Be able to evaluate an extensive area of the order of 10 to 15 km, with a mesh resolution of the order of 2 m to be able to meet the dimensional needs of the bay of Algeciras and the geometries of the vessels, respectively.

- That the generated numerical domains are executed in competitive computational times in order to simulate at least a *N* number of reoresentative types of vessels / trajectories / speeds within the project (i.e. for the Alceciras study, a *N*=40 ships were selected and simulated).

- That the model adapted for the ship-wave is then tested to a rigorous validation process with instrumental, mathematical or analytical data to guarantee its reliability when generating the aship-waves.

Taking into account the different conditions mentioned above, the effort has been focused on this process of adapting the IH-BOUSS model for the creation of ship-waves. Basically, the adaptation of the numerical model has been based on the inclusion of a mobile "sink" element in the domain of the IH-BOUSS model, similar to the classical source function proposed by Wei et al. (1999) but considering only the state of negative oscillation below the mean sea level, and a prismatic volumetric form that can move freely through the numerical domain [*X, Y*], taking into account the instantaneous position *X* and *Y* for any instant temporal *Xi = f (Xi-1, ti); Yi = f (Yi-1, ti).*

Fig. 3 shows an example of the realistic trajectory for any vessel sailing at variable speed within a 500 x 1000 m domain. The spatio-temporal trajectory known a priori, therefore, can be adjusted to a mathematical function that defines it and that can be included in the model. In this way a faithful numerical representation of the real movement of the vessel and an easy assimilation of this behavior by the model is guaranteed, avoiding in this way tedious adaptations of trajectory reading and post-processing of these (for example, from the Raw Information System (AIS) data).

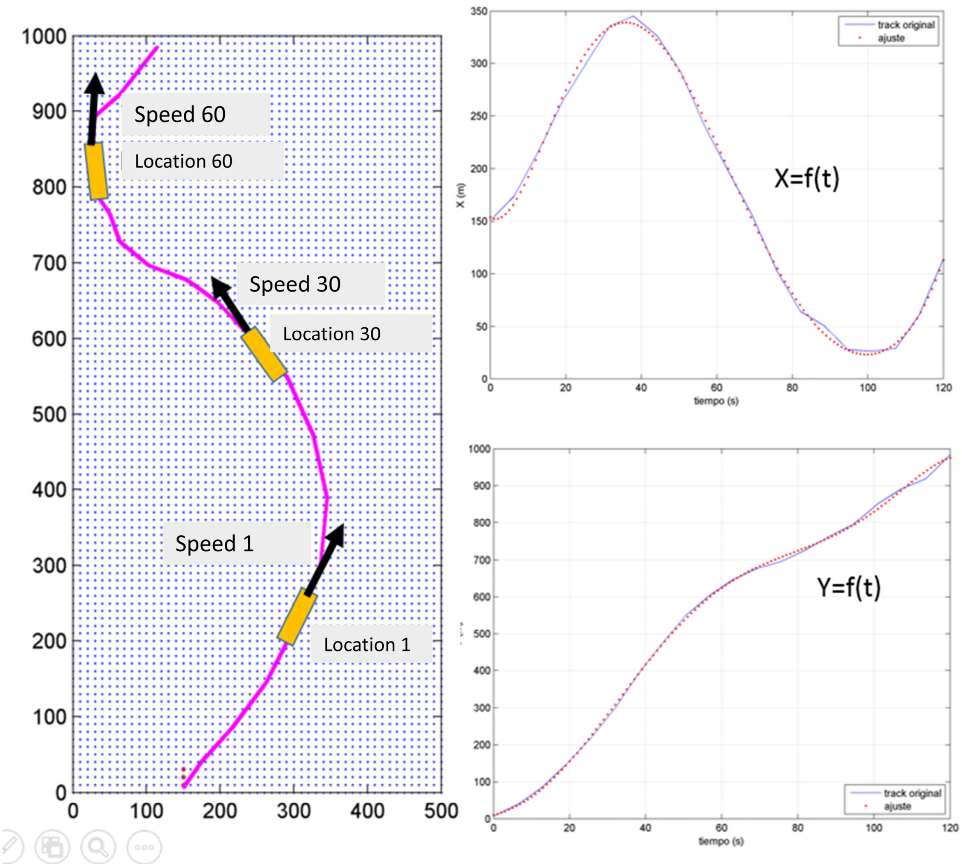


Figure 3: Ship trajectory assimilation within [X, Y], taking into account the ship speed and turns

Regarding the inclusion of the new source function represented by the ship, different tests and approximations have been made, finding that the inclusion of a rectangular prism representing the vessel in motion is more than enough to generate realistic and suitable ship-waves type waves. It is true that the near field (very close to the boat), possibly lacks sufficient detail to be able to consider a flow well represented in this area. However, the results so far found and validated indicate that once the initial disturbance in the flow (originally at rest), the ship-weaves manages to adopt realistic forms and speeds consistent with the phenomenology studied. The assimilation of the typical dimensions of a boat (the minimums for its correct definition: beam or beam (*W*), draft or draft (*d*) and length (*L*)) in the rectangular numerical prism that has been included in the model IH-BOUSS.

Fig. 4 to 6 show preliminary results of different validation examples so far carried out, considering container type (general dimensions) and Ferry, sailing under different geometric characteristics.

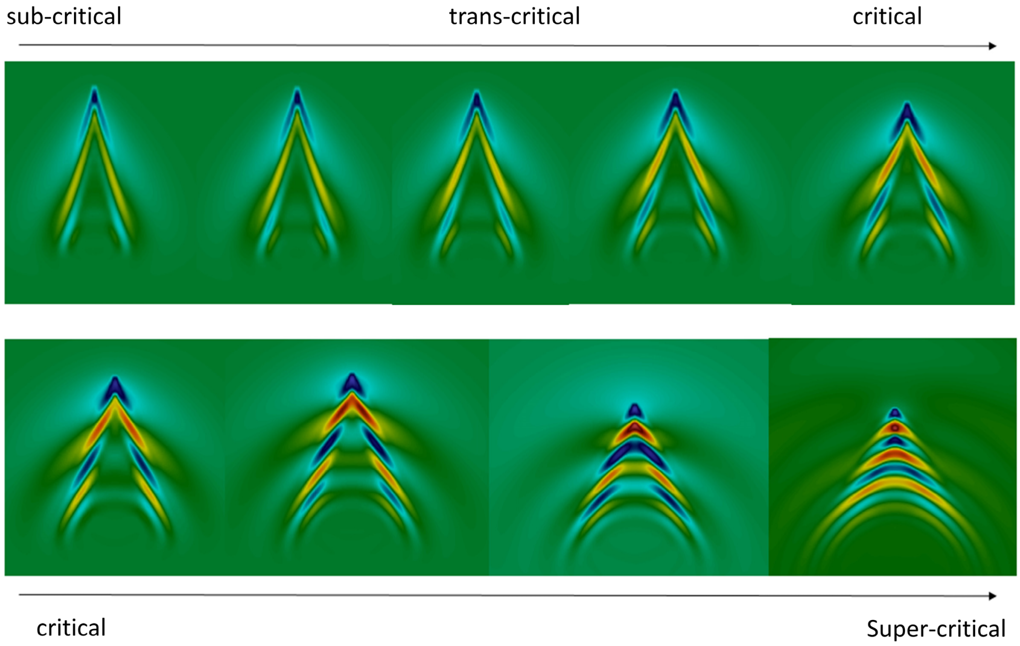


Figure 4: Ship-wave behavior example generated by IH-BOUSS model for different critical regimes (Froude numbers)

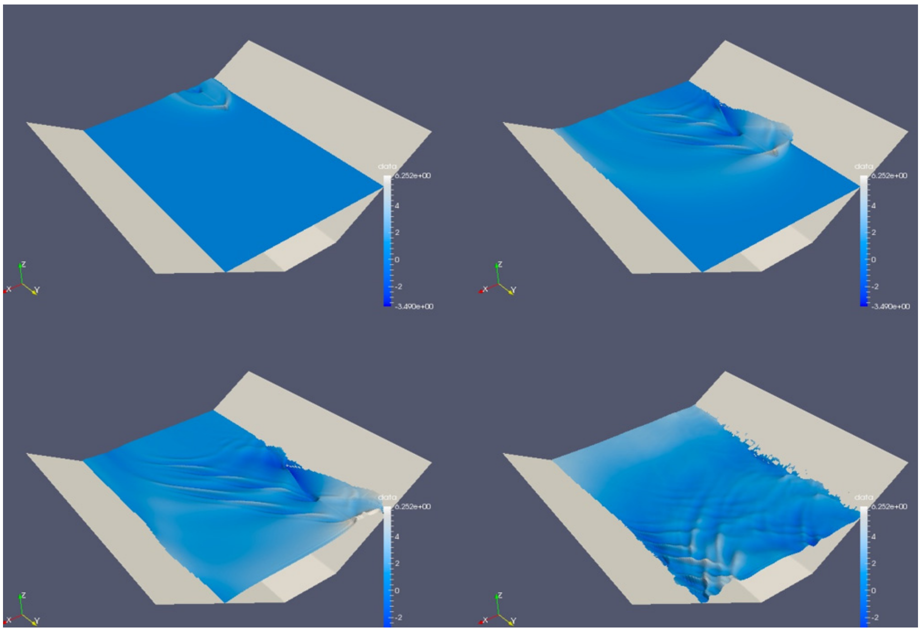


Figure 5: Ship-wave example generated with IH-BOUSS model for a ship travelling along a inner waterway and ship-wave run-up generation

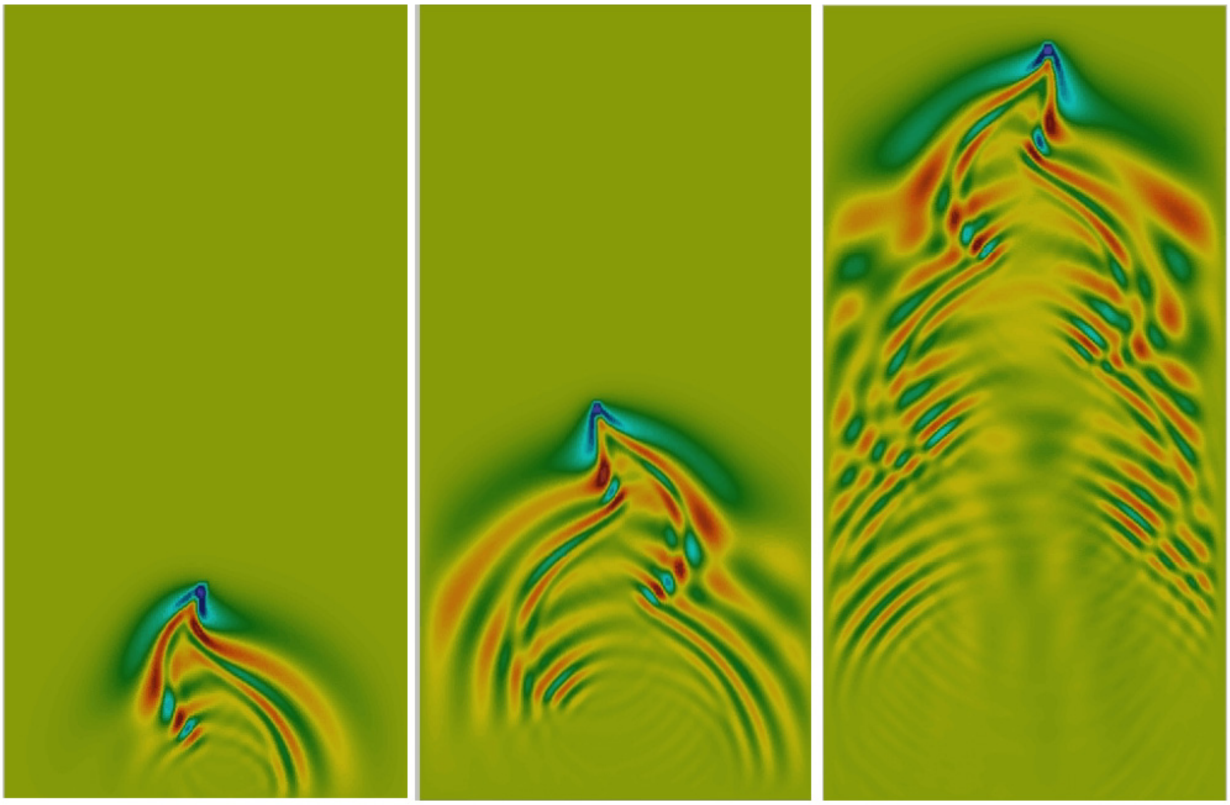


Figure 6: Ship-wave example generated with IH-BOUSS model for a ship travelling along a sinusoidal path with acceletarions

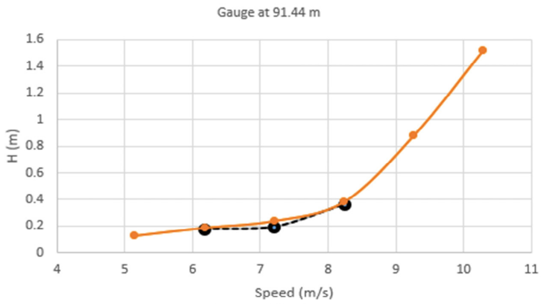
2.3 Task 3. Numerical model validation

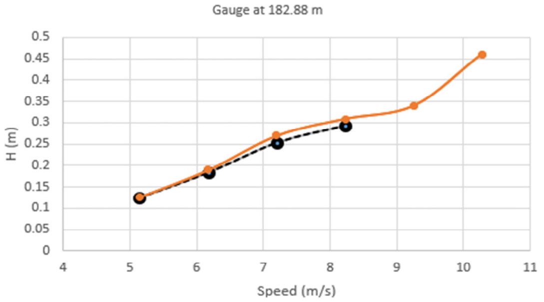
The prismatic and rectangular shape included in the IH-BOUSS model shows numerically a good numerical stability and fairly qualitatively adequate results according to the previous observations made in the literature. However, during the validation process, it was observed that the wave heights and periods (type B mainly) showed a general tendency to be overpredicted, regardless of the speeds and the type of vessel analyzed.

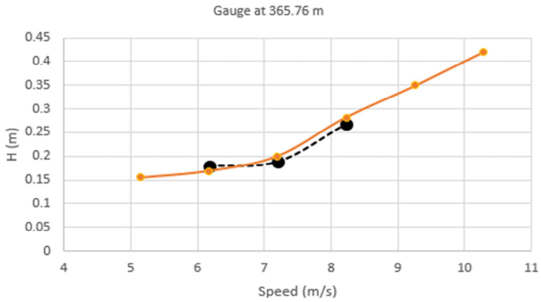
For this reason and based on the instrumental comparison information used to validate the model, we have chosen to impose some adjustment coefficients for each numerical dimension of the rectangular prism α, β, and γ, which multiply the real dimensions: length (L), draft (d) and sleeve (W) respectively.

Figure 5 shows an example of the validation results for two type vessels (containers and Ferry) and for values of $\alpha = 0.6$, $\beta = 0.25$, and γ, = 1.0. These parameters seem to adequately adjust the measurements of the wave height (type B) and their respective periods. In addition, they remain constant regardless of speeds, types of boat and bathymetric levels. So it seems that the final and final adjustment values will be around the aforementioned values. With this validation and with the calibration coefficients set, a second round of validation is carried out considering instrumental data for different vessels, mainly related to a high-speed ferry typology (se an example of the validation task in Fig. 7).

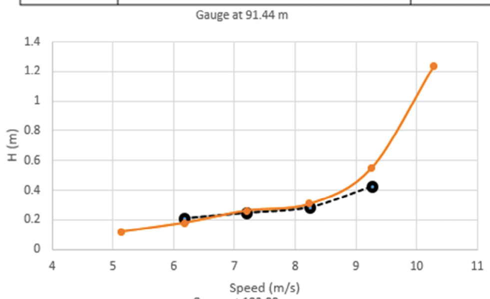
V (m/s)	Yakima measured (ft) 91.44 m	182.88 m	365.76 m	Yakima measured (m) 91.44 m	182.88 m	365.76 m	Yakima modeled (m) 91.44 m	182.88 m	365.76 m
5.14		0.41			0.124968		0.13	0.126	0.155
6.17	0.59	0.6	0.59	0.179832	0.18288	0.179832	0.19	0.19	0.169
7.2	0.65	0.83	0.62	0.19812	0.252984	0.188976	0.24	0.27	0.2
8.23	1.2	0.96	0.88	0.36576	0.292608	0.268224	0.387	0.308	0.282
9.26							0.88	0.34	0.35
10.28							1.52	0.46	0.42

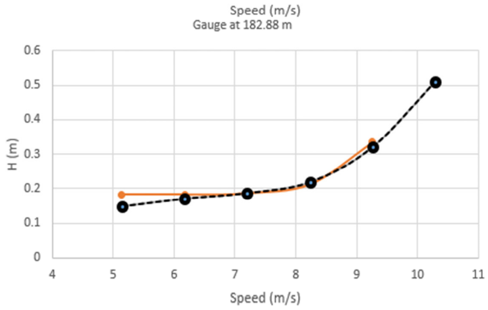






V (m/s)	Washington measured (ft) 91.44 m	182.88 m	365.76 m	Washington measured (m) 91.44 m	182.88 m	365.76 m	Washington modeled (m) 91.44 m	182.88 m	365.76 m
5.14	0.6	0.6	0.58		0.18288		0.12	0.15	0.15
6.17	0.7	0.6	0.55	0.21336	0.18288	0.16764	0.18	0.172	0.16
7.2	0.81	0.61	0.55	0.246888	0.185928	0.16764	0.26	0.188	0.161
8.23	0.94	0.7	0.65	0.286512	0.21336	0.19812	0.31	0.22	0.21
9.26	1.4	1.1	1	0.42672	0.33528	0.3048	0.55	0.32	0.3
10.28							1.24	0.51	0.41





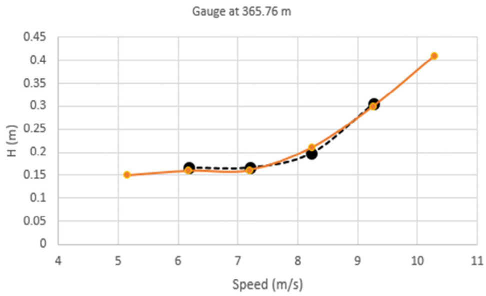


Figure 7: Wave height (type B) validation for a Fast-Ferry ship (Yakima, Washington State Ferries & (Sealth, Washington State Ferries).

2.4 Task 4. AIS database pre-process

Regarding the pre and post-process work of the AIS database (provided by any Port Authority), a brief description of the work carried out and final products produced is presented below. From now on, the explanation and description will be based on the Port of Algeciras experience (developed by IHCantabria the Algeciras Bay-Port Authorty, APBA).

The APBA provided the AIS information in .CSV (raw comma-separated values) format for two years of measurements, in 2014 and 2015. This information requires an intense process of analysis and pre-processing to be appropriate to the study. Specifically, the numerical model needs to be forced with information about the trajectories, type of vessels (geometry and general dimensions) and translation speeds of these, for a finite catalog of simulations (N=40). Thus, it has been necessary to establish an automated reading protocol of the raw AIS series that allows obtaining as a first fundamental product, a disaggregated database for each individual ship that has sailed within the Bay of Algeciras between 2014 and 2015. From this form, by having individual files that describe the boats and their navigation history in a specific way, it will be possible to make an intelligent selection of the catalog of 40 simulations that represent, in the best possible way, the casuistry of generation and propagation of ship-waves within the study area. This task has focused on the pre-processing of AIS information in order to obtain the individualized files for vessels mentioned above. To this end, a series of MATLAB© programs has been carried out that allow the automatic reading of the two large families of CSV files for each year. The ultimate goal is to have information broken into individual files of each type of vessel (see Fig. 8), which will include all data related to them (names, international identifiers, dimensions, spatial and temporal position, etc.).

Once the execution of both programs, 8126 files are obtained corresponding to the same number of individual vessels that have sailed within the Bay of Algeciras in the years 2014 and 2015. The obtaining of these files supposes the completion of the pre-process work and the beginning of the post process, where the representative cases (40) to be simulated by the IHBouss model are obtained and that in turn will be dumped in the operational system of evaluation of the waves type ship-waves according to the typologies or cases that the port manager considers within the finite catalog. Figure 6 shows an example of the graphic representation of the spatiotemporal trajectories of four different vessels, once their data has been separated into individual files. Once the pre-selection has been defined and in line with the APBA after its presentation in project control meetings, the final selection of 40 cases based on the possibility of repeating the type of vessels is made, in order to give more weight to those boats that obtained the most weight in the pre-selection. In this way it is ensured to cover a wider spectrum in the spatial effects of the most important vessels for the APBA.

2.5 Task 5. Numerical run of N selected ships and post-process

This section summarizes the results obtained after the execution of the final catalog of the N=40 events, as well as the post-treatment of the wave series type ship-waves obtained in the whole numerical domain. In the first place, the numerical domain is defined where vessels will pass from their entrance through the Bay of Algeciras to their different destinations in docks and anchorage areas. For the design of the numerical domain it is important to point out that the extension of the bay should be considered in the same simulation, in order to capture numerically the ship-waves generated by the passage of a vessel from one end of the Bay to the other. Therefore, it is decided to create a domain with a resolution of 3 x 3 m for the whole Bay considering the following spatial box (in UTM coordinates).

$$Xmin = 279761.3033;\ Ymin = 3998912.3298;\ Xmax = 288598.9463;\ Ymax = 4006805.3941$$

The final numerical mesh has 2946 x 2632 nodes in each of the orthogonal directions. Fig. 9 shows the final bathymetric and numerical domain proposed for the simulations.

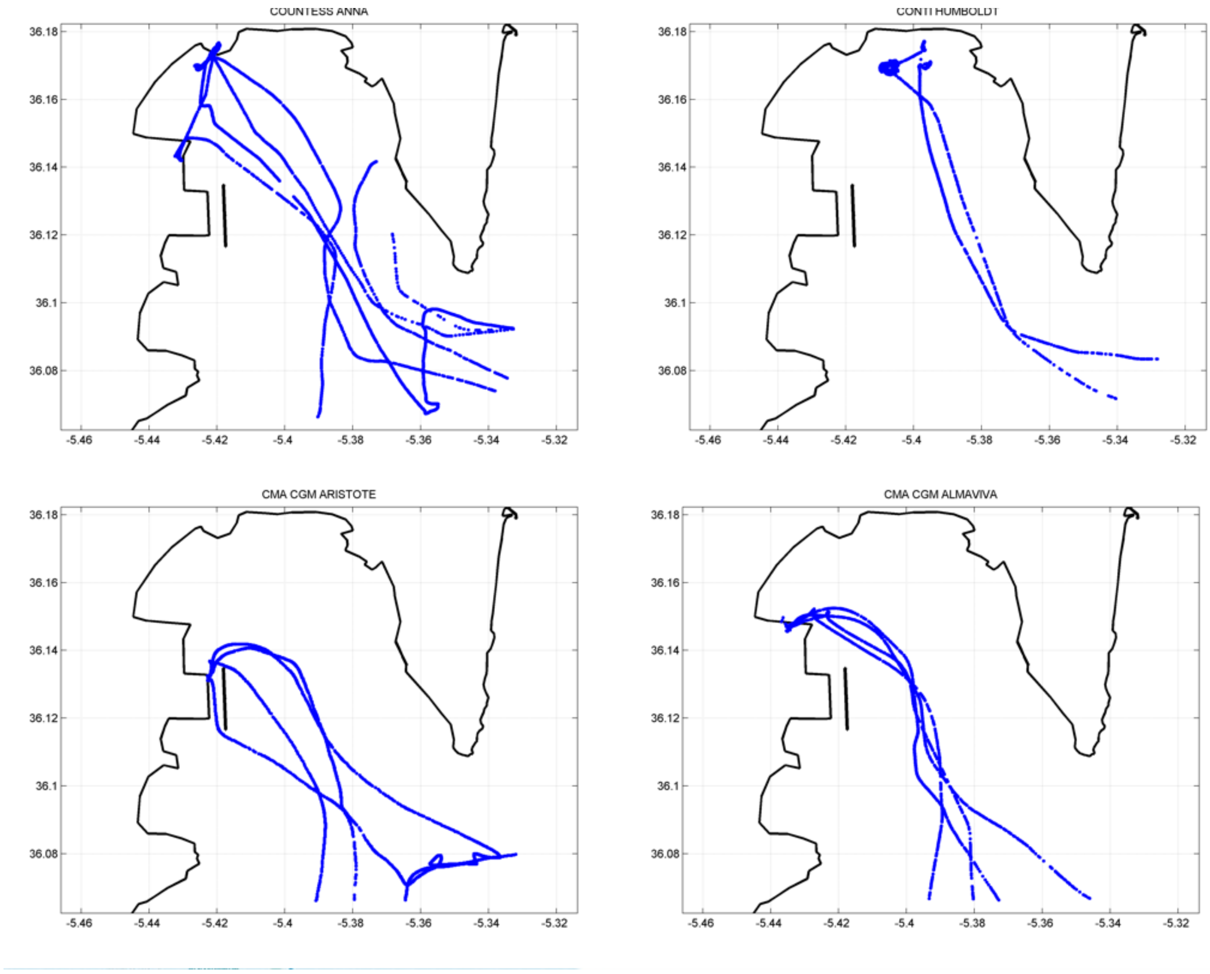


Figure 8: Example of 4 individual ships isolated from the whole 2-year AIS database

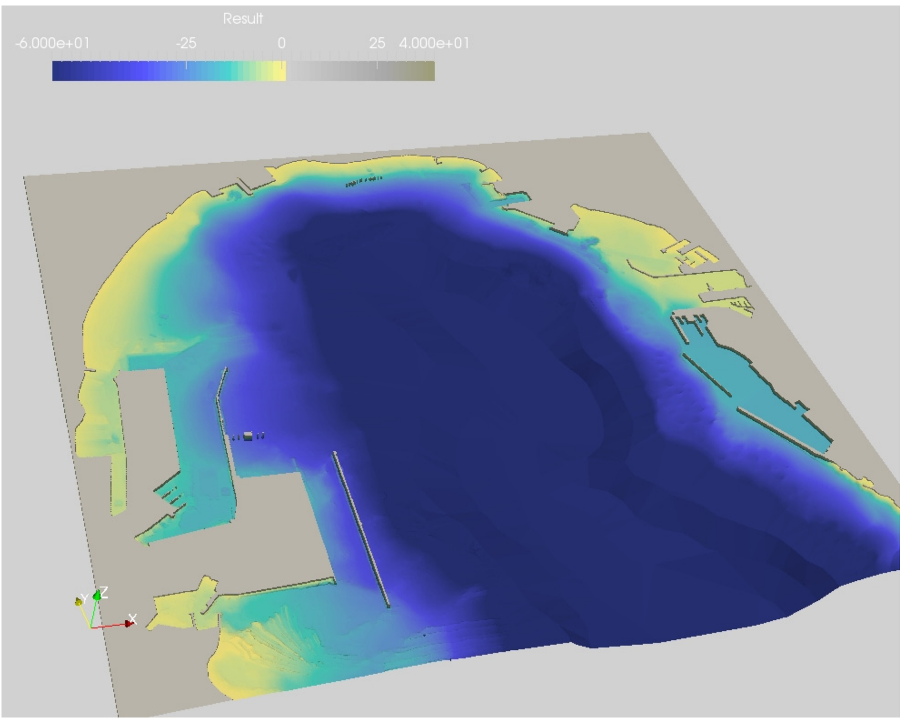


Figure 9: Numerical domain and bathymetry used in the APOBA domain and adapted for IH-BOUSS model

Each of the *N*=40 simulations has been executed in parallel using 16 processors, obtaining satisfactory final results, finding an absolutely stable behavior of the numerical tool, showing wave heights type ship-waves realistic and within the ranges observed in the literature, a propagation of these waves towards the adequate port contours and very competitive computational times (3 to 4 days of simulation as a mean for durations of events of 1 hour of ship trajectories).

Once the simulations are finished (see Fig. 10), two types of numerical results are collected: a) temporary maps of free surface in all the numerical domain, and b) temporary series of free surface in 83 control points arranged in different areas of operational interest.

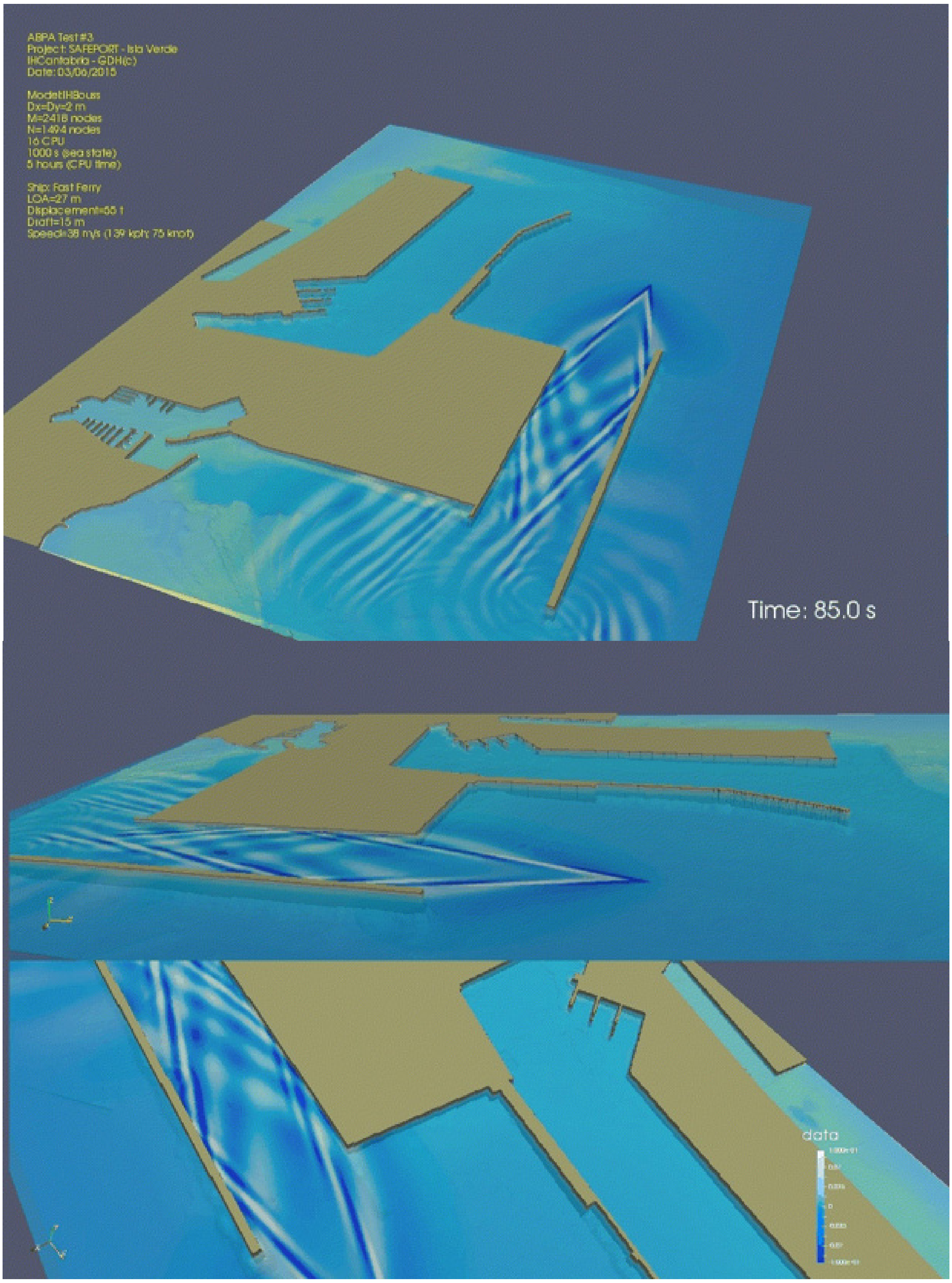


Figure 10: Example of a snapshot for a Fast-Ferry navigating inside APBA's Port (3 different views)

2.6 Task 6. Final results and data sheets obtained for operational port managers

As part of the elaboration of the data-results of each of the 40 simulations carried out, summary-sheetsare made that collect and show the general information of each one of the simulations (see Fig. 11), integrating the following data:

- General information on the geometry of the selected vessel, name, identification keys, photograph and start and end dates of the selected path.
- A general map of the Bay of Algeciras that includes all the AIS events recorded for the vessel selected for each of the 40 events (blue dots) and the selected trajectory in the individual event that has been simulated (red dots).
- Instantaneous velocity chart (knots) of the event / vessel selected showing four spatial positions *A*, *B*, *C* and *D* to help its identification on the map of the Bay of Algeciras (see Fig. 11).
- Two graphs that define the time-space evolution of the selected trajectory for each event, showing the time vs. the position *X* (UTM) and *Y* (UTM). Likewise, the adjustment of the 10-degree polynomial used to force the numerical model is included. The 4 guide points *A*, *B*, *C* and *D* are also included.
- A zoom of the general map of the Bay of Algeciras centered on the selected control point, where the trajectory for the event to be analyzed is included, the points closest to the chosen position and the selected trajectory in the individual event that has been simulated (red dots).
- Instantaneous velocity chart (knots) of the selected event / vessel showing four spatial positions *A*, *B*, *C* and *D* to help its identification on the map of the Bay of Algeciras (analogous to that observed in the "*A*" type sheet).
- Graph of the instantaneous distance of the event / vessel selected according to the analysis point, showing also the four spatial positions *A*, *B*, *C* and *D*.
- Temporary free surface graphic registered numerically at the selected control point.
- Wave height (*H*) and period (*T*) histograms of each individual wave recorded at the selected control point.
- Joint plot of *H* vs. *T* to observe the distribution of wave heights and their relation to periods.
- Two graphs that define the time-space evolution of the selected trajectory for each event, showing the time vs. the position *X* (UTM) and *Y* (UTM). Likewise, it includes the adjustment of the polynomial of degree 10 used to force the numerical model and the 4 orientative points *A*, *B*, *C* and *D*.

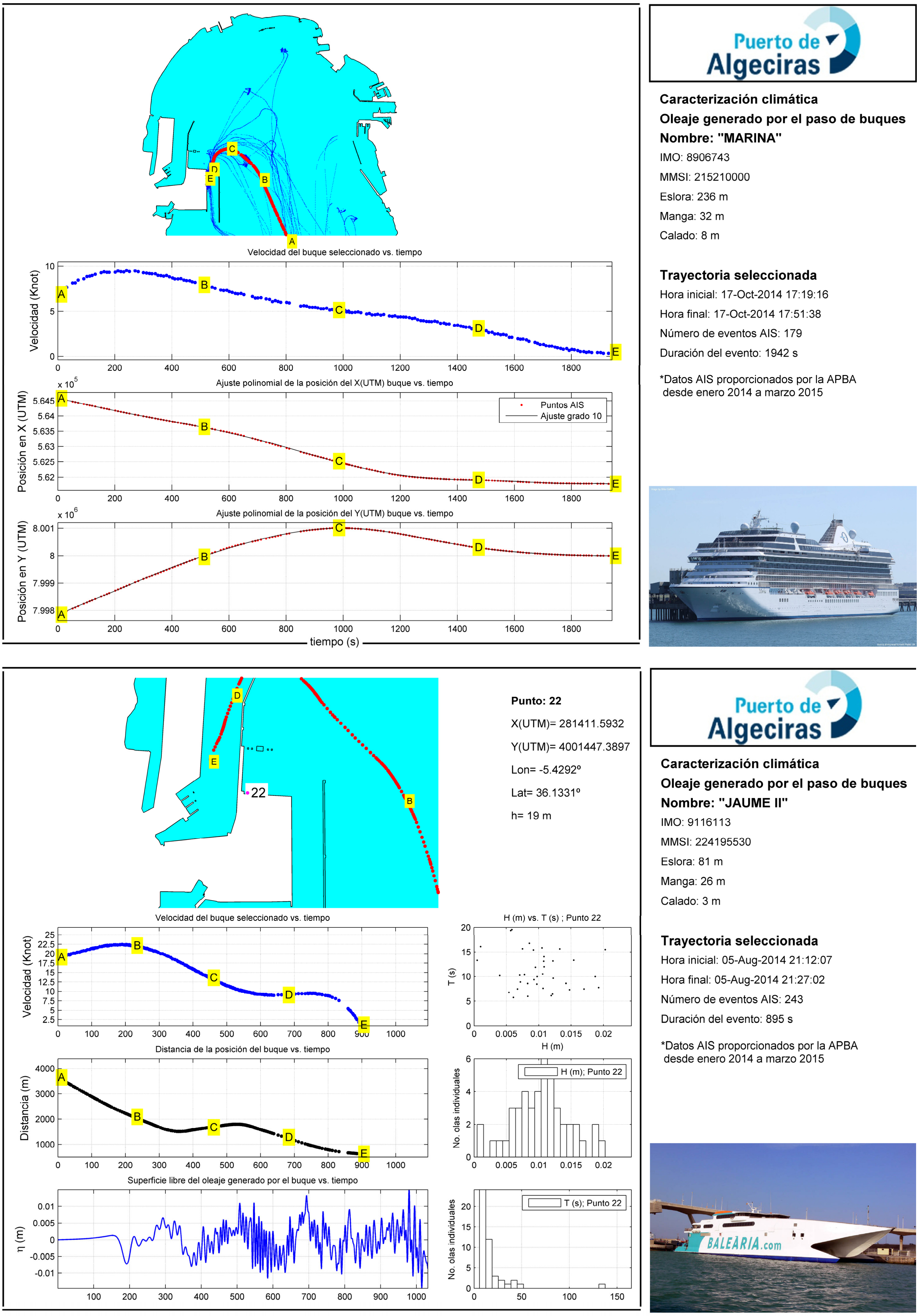


Figure 11. Data-sheed example (in Spanish) for 2 different ships and control point #22.

3. CONCLUSIONS

A complete ship-wave predictor system has been successfully obtained. Ths system is able to evaluate the waves generated by the passing of the vessels, in a realistic, reliable and computationally agile way. This development allows the generation of products of direct exploitation and exploitation by any power authority that requires to know the response of its facilities to this type of forcing.

This innovative approach opens a new way of study this phenomena considering important improvements comparted to the tradictional-lmited approaches.

As an example, the system is actually integrated into Algeciras Port met-ocean strategy.The APBA has exploited this new knowledge through the adaptation of an innovative operational system for calculating the waves generated by the passage of vessels (shyp-waves) in different locations pre-established by the APBA and for a finite number of vessels (catalog of 40 types of boats / speeds / trajectories).

This new information will allow any Port Authority to know, quantify, diagnose and manage its different areas of special operational interest in relation to the existing ship-wwaves daily in its port environment.

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