"CHANNELING THE GREEN DEAL FOR VENICE"
Action n. 2019-IT-TM-0096-S
CEF Connecting Europe Facility

NAVIGATION SIMULATIONS

Fast-time simulations

Activity		**Phase 2**
Task		Fast-time simulations
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1. CONTENT

The final goal of the comprehensive set of undergoing activities is to quantify the impact along the Malamocco – Marghera Channel and surrounding areas induced by vessel transits in the Channel, to identify possible solutions aimed at minimizing the erosion processes that are now affecting the tidal flats surrounding the Channel, thus achieving sustainable navigation conditions. To match this ambitious goal, following Public Tender procedures, the Contract was awarded by Port of Venice to a Consortium led by DHI S.r.l. and formed by DHI A/S, Force Technology, HS Marine S.r.l., Cetena S.p.A. and Around Water.

The present document presents a fast-time simulation study to assess the existing Malamocco-Marghera access channel's capacity for different selected design ships including Cruise, Container and Bulk ships. The purpose of the fast-time simulations is to extract the most challenging situations (environmental conditions) to be used for the Full-Mission study.

With reference to the "*Capitolato Tecnico*" the present document forms the second part of the following deliverables:

9. *Relazione tecnica dei risultati delle simulazioni di navigazione realizzate mediante auto-pilota ("fast time simulations");*
12. *Elaborati grafici di sintesi per la rappresentazione dei risultati dei modelli di navigazione.*

2. INTRODUCTION AND OBJECTIVES

The present document presents a fast-time simulation study to assess the existing Malamocco-Marghera access channel's capacity for different selected design ships including Cruise, Container and Bulk ships.

The assessment should address a Container vessel, a Bulk carrier and a Cruise ship negotiating the existing Malamocco channel with respect to weather limits and channel width and depths.

The objective of the fast-time simulations is to extract the most challenging situations (environmental conditions) to be used for the Full-Mission study and to be used in the risk assessment.

A fast-time study was set up to assess the environmental limits and tracks for the existing Malamocco channel. The fast-time study was carried out in the period 2nd to 6th May 2022.

The layout of PoV Malamocco channel is shown in Figure 1 below. Data for the study were delivered by PoV and DHI srl.

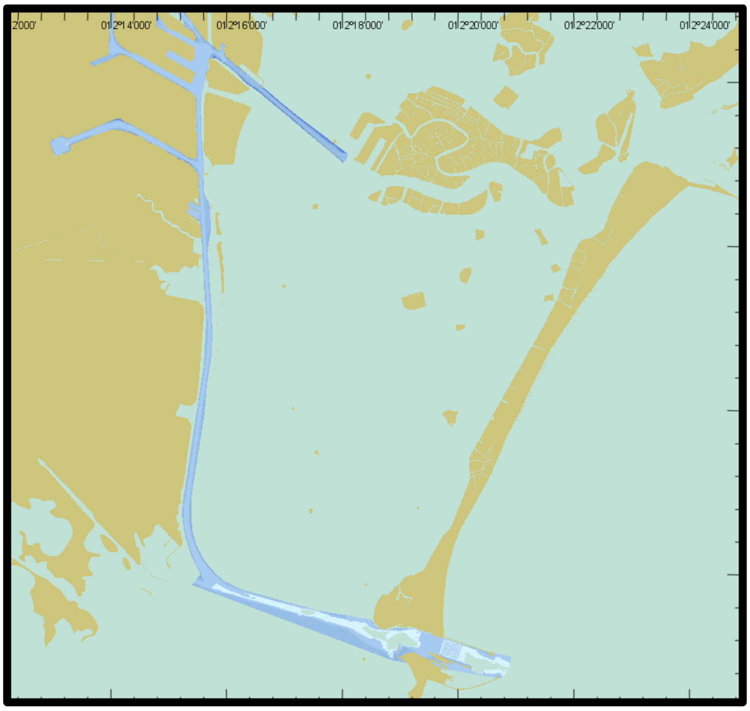


Figure 1 The Malamocco Marghera Channel.

The fast-time study for PoV had the following objectives:

- Evaluate the most challenging environmental conditions for negotiating the existing Malamocco channel.
- Extract the most challenging scenarios to be used for the Full-Mission study.

3. OBSERVATIONS

The fast-time simulations were carried out individually for the three selected design ships: a Container vessel, a Bulk carrier and a Cruise ship. Therefore, for each vessel, 20 scenarios were analysed, illustrated in Table 1. Each of them is characterized by different metocean conditions (wind speed, wind direction, current speed, current direction, tide level, etc.) and consider all the environmental limits imposed by the Port of Venice.

Results of NCOS simulations are used to find the met-ocean conditions to be tested. According to NCOS, the ships will not ground.

In every case the bathymetry of the channel combined with these environmental conditions influenced the performance of each ship.

Table 1 List of analysed scenarios.

Scenario	Departure Time and Date	WS mean (m/s)	WD mean	CS mean (kn)	CD mean
1	'20/01/2020 05:30:00 PM'	4.76	57.81	0.45	2.81
2	'15/09/2020 05:30:00 AM'	5.06	43.93	0.61	2.74
3	'25/03/2020 07:00:00 AM'	10.00	86.44	0.50	2.53
4	'10/03/2020 07:00:00 PM'	5.11	138.01	0.46	3.17
5	'06/04/2020 01:00:00 AM'	4.96	46.75	0.33	-177.00
6	'19/08/2020 01:30:00 AM'	5.30	36.99	0.46	-176.56
7	'30/11/2020 02:00:00 PM'	4.88	49.35	0.43	-176.54
8	'28/04/2020 04:30:00 AM'	4.59	140.72	0.37	-176.62
9	'06/05/2020 01:00:00 PM'	4.74	137.45	0.37	-177.11
10	'25/05/2020 04:30:00 PM'	4.41	-154.13	0.37	-176.68
11	'07/09/2020 06:30:00 AM'	13.17	84.81	0.09	-19.42
12	'25/12/2020 03:00:00 PM'	13.64	43.76	0.19	-2.22
13	'27/03/2020 04:00:00 AM'	10.13	88.47	0.26	-172.64
14	'05/04/2020 11:00:00 AM'	8.26	82.19	0.37	-176.47
15	'11/01/2020 08:30:00 PM'	3.63	62.87	0.75	2.81
16	'09/02/2020 07:30:00 PM'	3.82	-151.61	0.75	3.00
17	'24/07/2020 09:00:00 AM'	7.96	-35.39	0.70	2.84
18	'05/04/2020 05:00:00 PM'	3.91	74.18	0.43	2.51
19	'05/08/2020 07:00:00 AM'	6.19	47.04	0.41	1.81
20	'02/09/2020 06:00:00 AM'	5.93	57.40	0.46	1.95

The Cruise ship had no problems during the navigation. For the cruise ships, it was able to arrive almost at the end of the Malamocco – Marghera channel, and it grounded between Fusina and the entrance of the Industrial West Channel, in the north side of the channel (as Figure 2 shows). The duration of the navigation was approximately one hour for each run. Just a few cases (scenarios 11, 12, 13, 17) showed grounding after the curve in the south of the channel; in these scenarios the navigation lasted 24 to 40 minutes.

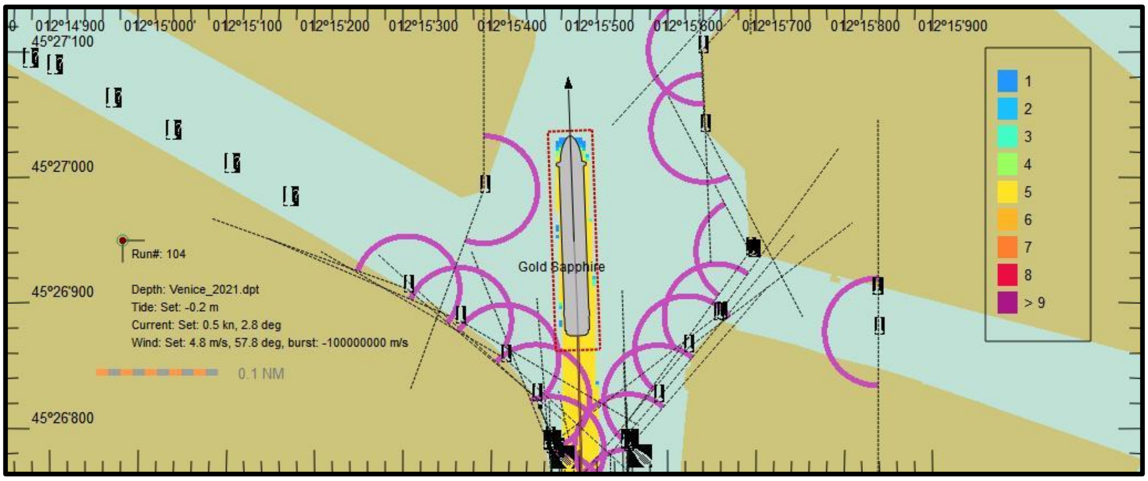


Figure 2 Scenario 1, Grounding of the Cruise ship in the northern part of the channel, between Isola delle Tresse (Tresse Island) and Canale Industriale Ovest (west industrial channel).

However, the navigation for the other two design ships were more problematic. Hence, for each simulation, as can be seen in Figure 3 and Figure 4, respectively, the Bulk ship and the Container ship grounded just after the main curve or within it in the south side of the channel. For this reason, the duration of the navigation was approximately between 23 and 45 minutes.

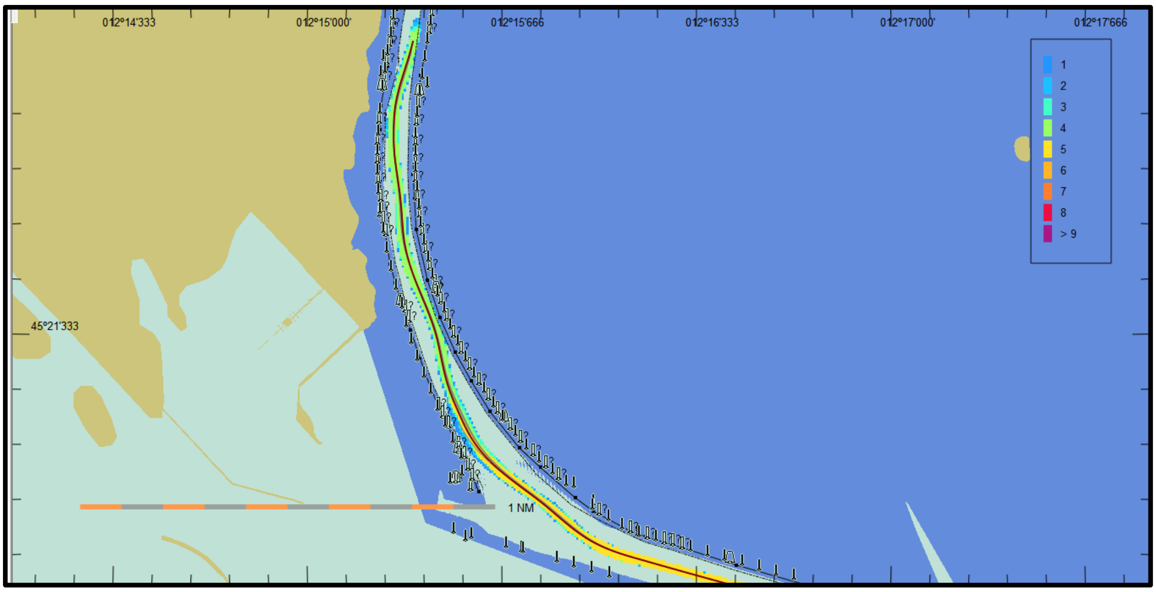


Figure 3 Scenario 7. Container ship grounding after the main curve in the south of the channel.

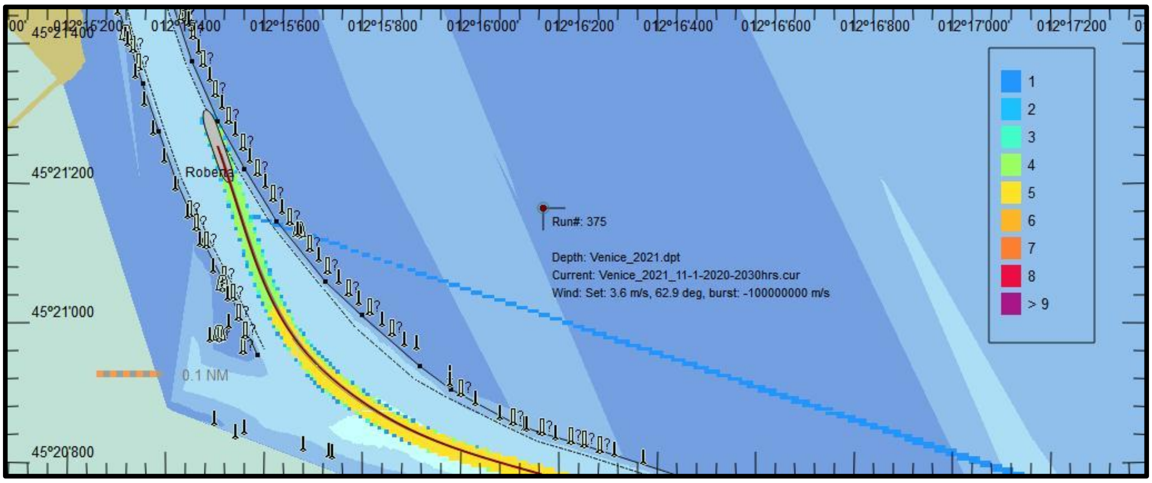


Figure 4 Scenario 15. The Bulk ship grounds in the proximity of the curve.

The observed phenomenon is probably due to the randomness factor (human behavior) and to the shallow water conditions which affect the simulation and in general characterize the area of the Malamocco – Marghera channel. Moreover, these conditions eventually led to various phenomena such as bank effect and/or squat (due to the low under keel clearance of the analyzed ships).

4. PREPARATIONS

4.1. Envrironment

PoV is located at the eastern coast of Northern Italy with access to the Adriatic Sea. The channel leading up to Fusina basin from the Malamocco entrance is influenced by wind, waves, tide and current. The following periods of current and tides were used during the fast-time study:

10-3-2020-1900hrs.cur	10-3-2020-1900hrs.tid
11-1-2020-2030hrs.cur	11-1-2020-2030hrs.tid
15-9-2020-0530hrs.cur	15-9-2020-0530hrs.tid
19-8-2020-0130hrs.cur	19-8-2020-0130hrs.tid
20-1-2020-1730hrs.cur	20-1-2020-1730hrs.tid
24-7-2020-0900hrs.cur	24-7-2020-0900hrs.tid
25-12-2020-1500hrs.cur	25-12-2020-1500hrs.tid
25-3-2020-0700hrs.cur	25-3-2020-0700hrs.tid
25-5-2020-1430hrs.cur	25-5-2020-1430hrs.tid
27-3-2020-0400hrs.cur	27-3-2020-0400hrs.tid
28-4-2020-0430hrs.cur	28-4-2020-0430hrs.tid
2-9-2020-0600hrs.cur	30-11-2020-1400hrs.tid
30-11-2020-1400hrs.cur	5-4-2020-0700hrs.tid
5-4-2020-1100hrs.cur	5-4-2020-1100hrs.tid
5-4-2020-1700hrs.cur	5-4-2020-1700hrs.tid
5-8-2020-0700hrs.cur	6-4-2020-0100hrs.tid
6-4-2020-0100hrs.cur	6-5-2020-1300hrs.tid
6-5-2020-1300hrs.cur	7-9-2020-0630hrs.tid
7-9-2020-0630hrs.cur	9-2-2020-0600hrs.tid
9-2-2020-1930hrs.cur	9-2-2020-1930hrs.tid

Figure 5 Period extracted for current and tide.

4.1.1. Bathymetry

The bathymetry derived from a post-processing of original data provided by Port of Venice. The post-processing was necessary to match the original data format and the format required by the simulator.

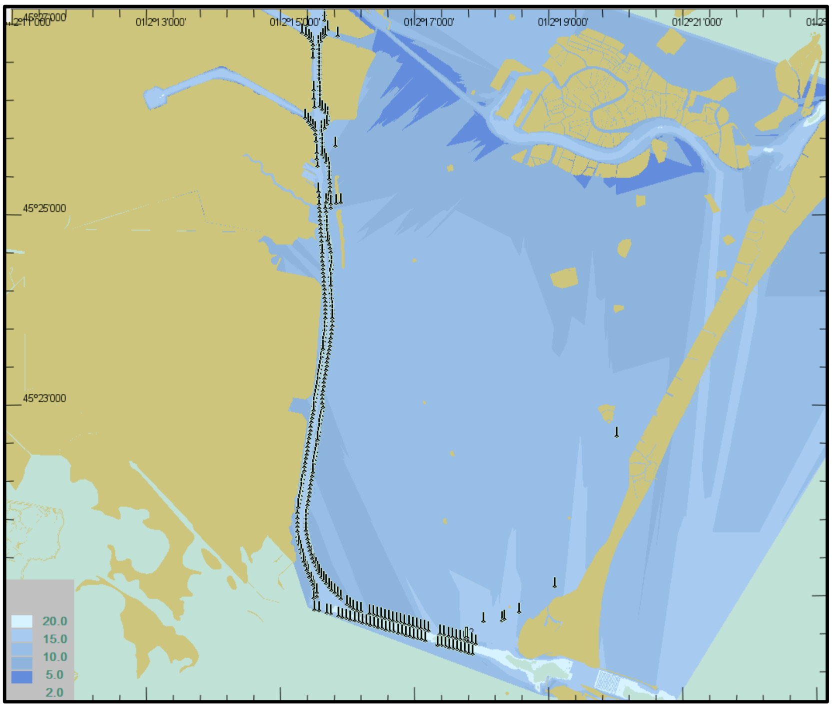


Figure 6 Bathymetry.

4.1.2. Wind

The magnitude of the wind was chosen based on information from DHI conducted NCOS simulations as statistic data.

Please note that the definition of wind speeds in the simulator is based on wind tunnel tests and are converted to a uniform wind speed in 10 metres height which is the normal meteorological definition. This wind speed may be different from the captain's observation of the ship's wind indicator. See Appendix B.

4.1.3. Current

For the simulations both ebb and flood currents for a year was delivered by DHI srl as "dfsu" files. From the dfsu files, different periods of 2 hours were extracted for the fast-time study. An example of the grid and the current is shown in below Figure 7 and Figure 8.

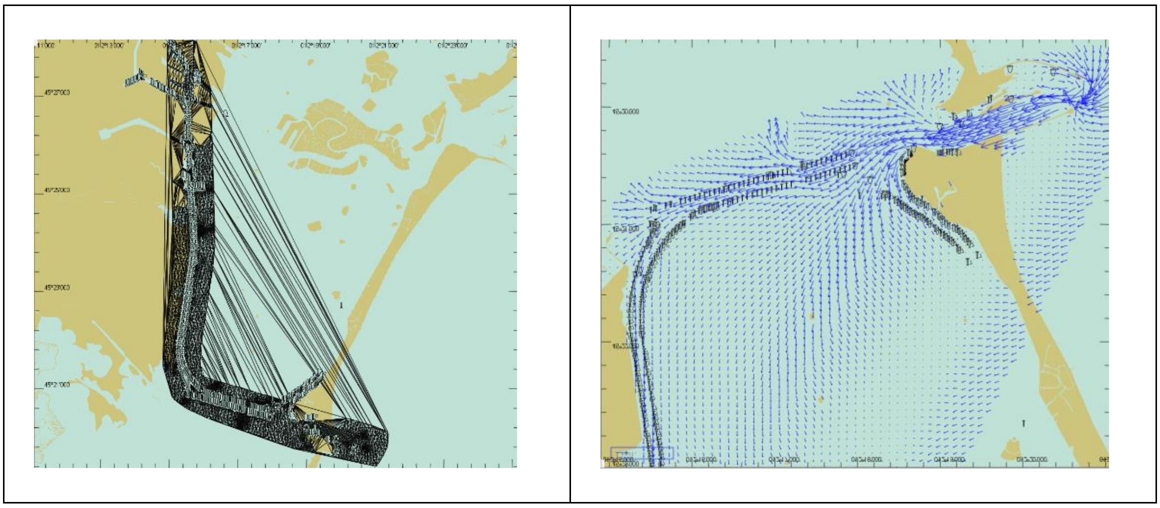


Figure 7 Example of current grid and arrow plot.

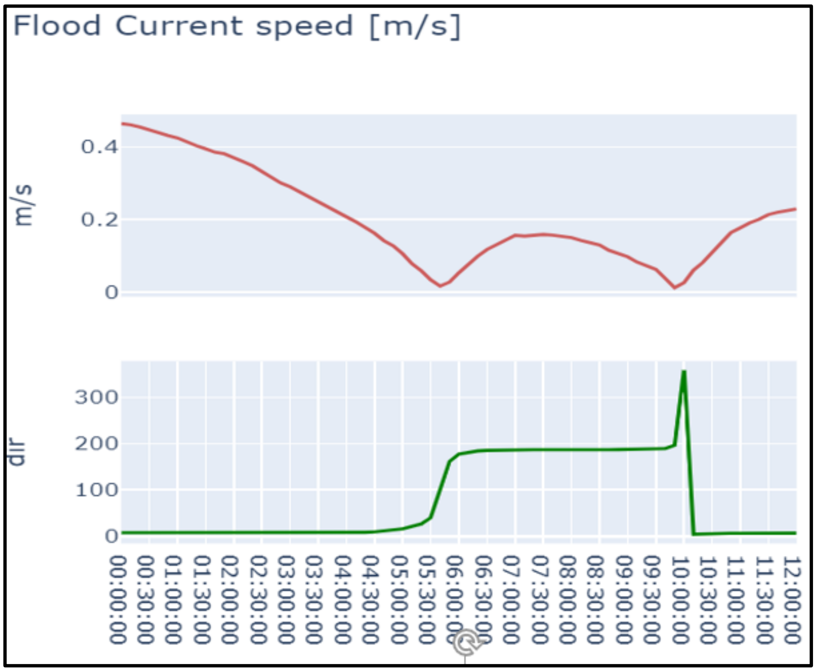
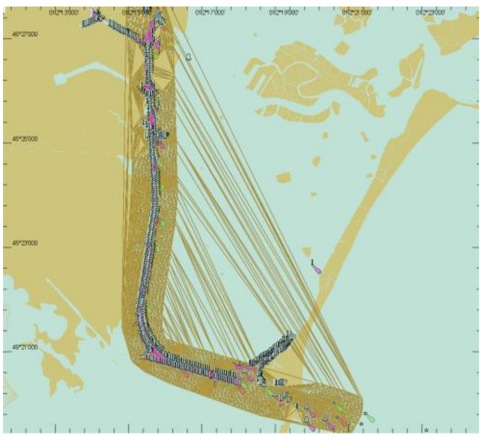


Figure 8 Current curve and direction for a 12-hour period. For fast-time a period of 2 hours was extracted.

4.1.4. Tide

For the simulations, tide was delivered by DHI srl as dfsu files. The grid for the tide files is shown in below Figure 9and Figure 10.



```
NODE-POINTS
 45 21 142.768 N  12 15 622.401 E
TIME-TABLE
0  -0.617414  -0.617414
600  -0.63902  -0.63902
1200  -0.656465  -0.656465
1800  -0.670878  -0.670878
2400  -0.682991  -0.682991
3000  -0.69131  -0.69131
3600  -0.695462  -0.695462
4200  -0.696255  -0.696255
4800  -0.692022  -0.692022
5400  -0.683084  -0.683084
6000  -0.671192  -0.671192
6600  -0.656689  -0.656689
7200  -0.637117  -0.637117
7800  -0.614244  -0.614244
8400  -0.587283  -0.587283
9000  -0.558239  -0.558239
```

Figure 9 Tide grid and a part of a point showing time (col 1) and elevation (col 2).

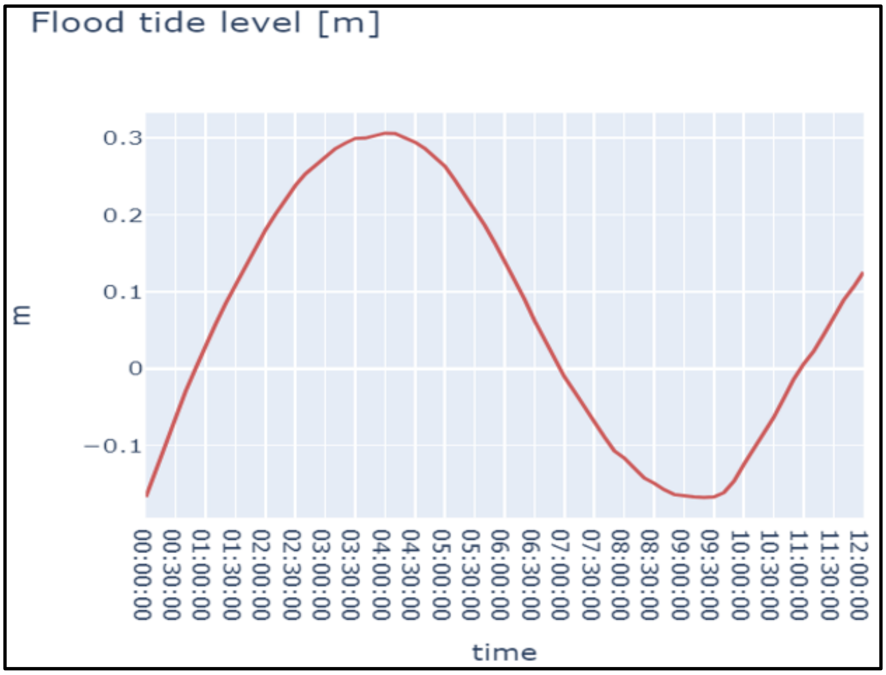


Figure 10 Tide curve for a 12-hour period. For fast-time a period of 2 hours was extracted.

4.1.5. Banks

Banks are applied in the whole length of the channel and consist of a slope between to water depths.

4.2. Vessels

One Container vessel, one Bulk carrier and one Cruise ship were used in the study. The main particulars for the ships are given in Table 2.

Table 2 Main particulars.

Ship No.	Name	Ship Type	Description	Load Con.	LOA m	Lpp m	Bmld m	Tf m	Ta m	Displacem	Prop.	Rudd.	Bow thrst.	Stern thrst.
3644	"Gold Sapphire"	Cruise Ship	294 m	S	294.0	261.0	32.2	8.3	8.3	50453	2F	2	3	3
3481	Roberta	Bulker	51.000 DWT	L	200.0	191.0	32.2	11.0	11.0	55690	1F	1	1	0
3601	"Atlas"	Container Ship	2.680 TEU	L	215.6	206.2	32.2	11.0	11.0	48571	1F	1	1	0

5. FAST-TIME SIMULATIONS

5.1. Methodology

The SimFlex4 system can run both fast-time and real-time simulations. Fast-time simulations are used to produce quantitative results.

As part of the fast-time simulations, the ship is controlled by the FT numerical navigator. The methodology for the numerical navigator is briefly described in section 5.2.

FT's fast-time simulator was used to control the ship under various environmental conditions during arrival to PoV in the Malamocco channel. The ship model is six degrees of freedom manoeuvring model. The time domain simulations included the squat and bank effect.

The fast-time simulations are set up by applying a route to the ship in question. The route consists of a number of waypoints. For each waypoint the speed and heading are applied, thereby making a route for the ship to follow with speed and direction.

5.2. Numerical navigator

A so-called numerical navigator controlled the ship. The numerical navigator is basically a track controller. When the ship passes the different waypoints, the autopilot is commanding the heading and the speed of the next leg in the route. When the turn is completed, a fuzzy controller is used to adjust the autopilot heading and handle settings in order to get back to the track. This is, in short, the FT numerical navigator strategy to follow a track.

Human behaviour is introduced in the form of randomness so when a scenario is repeated, the outcome differs a bit. In the Venice case, we assume the pilot is concentrated and on high alert so the parameters are set to give small variations. Mainly the distance to the waypoints or the wheel over point are used to give the variation.

5.3. Scenarios

The scenarios set up for the fast-time study are as shown in the above Table 1. The scenarios are derived from the NCOS simulations conducted by DHI srl. The scenarios are selected to NCOS successful transits. The main difference between NCOS and fast time simulation is the dynamic behaviour and that extra effects such as banks are included in the fast-time results. NCOS stays perfectly on the preferred track whereas in fast-time the ship is pushed by the environmental effects.

The scenarios consist of an own ship to which a route is applied. Environmental conditions are then applied to the scenarios such as wind, current, waves and tide. Each scenario is repeated 5 times and variated due to the behaviour of the numerical navigator.

5.4. Assessment of model accuracy

The applied model can be considered a state-of-the-art simulation model in the time domain. There are, however, some modelling uncertainties and assumptions that need to be addressed in order to be able to evaluate the conclusions and recommendations.

The ship model is an accurate manoeuvring model with accurate mass and moments of inertia. The effect of shallow water on the hydrodynamic forces has been estimated using empirical methods from the literature. The motion of the ship is dominated by inertia effects which are accurately modelled, meaning that any uncertainties in hydrodynamic forces have small influence on the obtained motion.

When carrying out a ship simulation study, one should always bear in mind that a simulator is only a model of real life and not real life itself. By using a ship manoeuvring simulator, a large number of assumptions are made that in smaller or larger scale reduce the accuracy, or in other words how close the simulated scenarios are to real life. There will always be a discrepancy between the simulated/modelled world and real life. Hence, the goal is to always stay conservative when carrying out simulations and to know to what level a given assumption will impact the outcome and the conclusions. In other words, the purpose of the use of a ship manoeuvring simulator has to match a sufficient accuracy and detail level with the data provided.

Within ship maneuvering simulators, it is a mandatory requirement that all calculations should be done in a frequency high enough to replicate real behavior. If this requirement is not respected, the behavior of the navigator controlling the vessel will become unrealistic. The real-time requirement is at the same time a constraint in terms of the modelling accuracy. For example, the physics of waves propagating from deep water to shallow water can be modelled quite accurately by use of wave modelling tools. However, despite plenty of computer power, such tools take days to calculate just an hour of real-time wave action which clearly conflicts with the real-time requirement.

As a consequence of the above, the waves in the simulator are calculated in a more “real-time” manner, meaning that a wave spectrum is used to simulate the waves with input Hs, Tp, direction and ship speed. To change the wave conditions during the simulation, a new input is needed which is done either by applying a wave map or by using event lines.

Wave forces and motions are in SimFlex modelled in real time based on output from the FT OMEGA program. OMEGA uses a panel description of the hull form and potential theory to calculate wave coefficients. Given a spectrum, the wave height, period, direction, and ship speed, the wave forces and hence the motions can be calculated in real time.

Another source to lack of accuracy is data. A ship maneuvering simulator can never be better than the input data provided. Using the waves again as an example, only if the local wave conditions in an area, for example the area close to the port entrance, are well defined either by physical measurements or by use of other more accurate wave modelling tools, a satisfactory level of accuracy can be obtained.

Another example is the ship model. The generation of a ship model can be based on data from other similar vessels (type and size), physical model tests in a towing tank and sea trials. A model based on all three types of data will give the most accurate ship model obtainable. But still well-known sources of errors are known. There are scaling effects when doing model tests. Sea trials are rarely done in shallow water and always under influence of wind, current, and waves although typically attempted to be completed in calm weather.

All assumptions made, whether being a result of the accuracy of data or being a consequence of the level of mathematical modelling, will in the end limit the accuracy of the obtainable results. Hence, a ship manoeuvring simulator can provide conclusions and recommendations only to a certain level where each assumption made should be considered carefully. As an example, if groundings are experienced during a simulation, the ship manoeuvring simulator can only indicate that there is a problem bearing in mind that the results must be expected to be conservative. We call this qualitative evaluation; hence, the simulator cannot quantify how often it will happen.

In the grounding situation, more accurate data and tools will be necessary to evaluate the risk and thereby also to address the means to avoid such groundings.

6. DATA ANALYSIS

6.1. Track plots and time series

The results of the simulations are track plots, statistics and time series of a number of parameters. For these fast-time simulations, it has been chosen to only examine the track plots in the form of swept area (area covered by the ships outline) for each scenario. The track plots are show in Appendix A.

6.2. Coordinate system

The motions are given in the coordinate system of the ship which is a right-hand coordinate system with surge positive forward, sway positive towards starboard (SB) and heave positive down. Heel is positive for SB side down, pitch for bow up and yaw for the bow rotating towards SB.

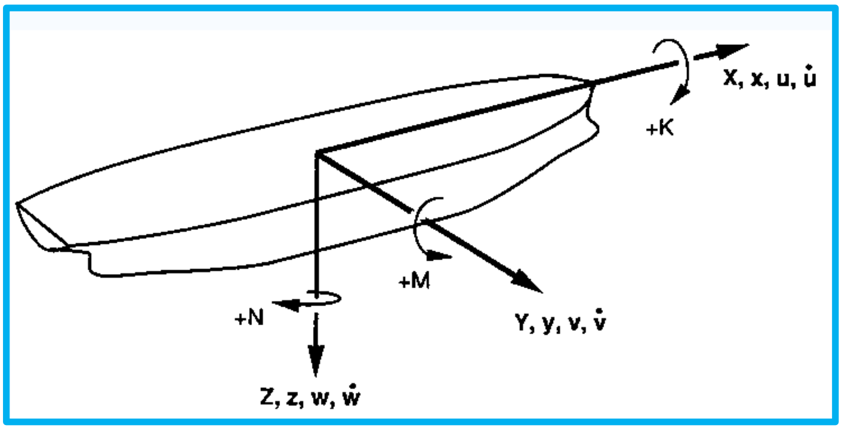


Figure 11 Coordinate system.

7. CONCLUSIONS

7.1. Assumptions

The conclusions in this report only apply to the chosen vessels and conducted runs in the pre-selected environmental conditions.

The scenarios (routes and environmental conditions) are developed based on the NCOS output and the experience of the FT's senior captains.

7.2. Results in general

The simulations showed that both the Container ship and Bulk carrier grounded in or just after the bend in the channel. The Cruise ship was able to reach Fusina basins The simulator is conservative and does not include soft bottom so a bottom touch will result in a grounding.

Note that all selected scenarios start lower than mean sea level, and one result could be that approaching the channel shall not be done in this worst scenario condition which shall be investigated during the real-time simulations.

The fast-time results show that the bend should be further investigated during the real-time simulations.

APPENDICES

APPENDIX A
TRACK PLOTS

CRUISE SHIP

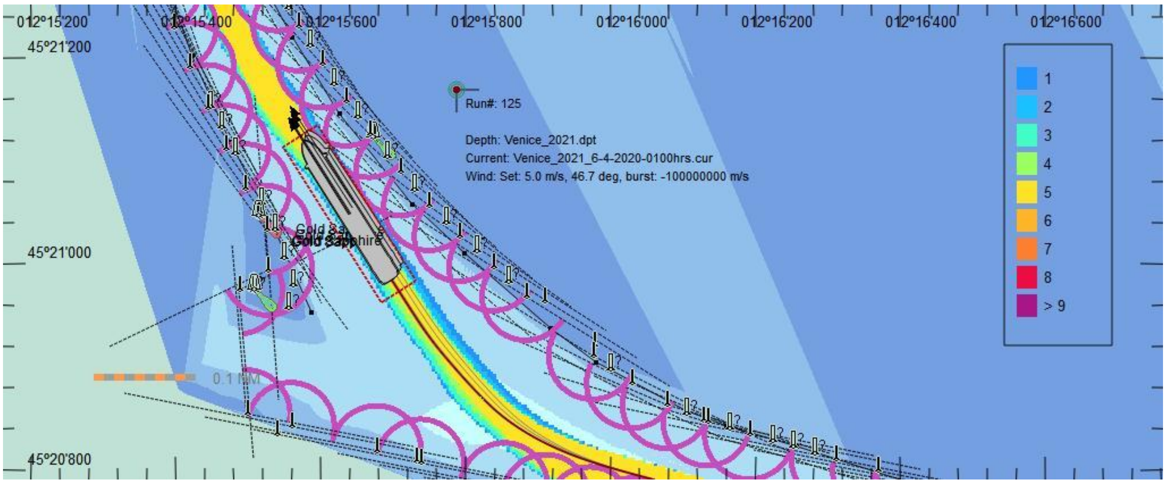


Figure 12 Scenario 5. No grounding in this chart. This is the main curve of the channel (in the south), which became quite narrow and due to shallow water effect, the navigation can be affected by these conditions.

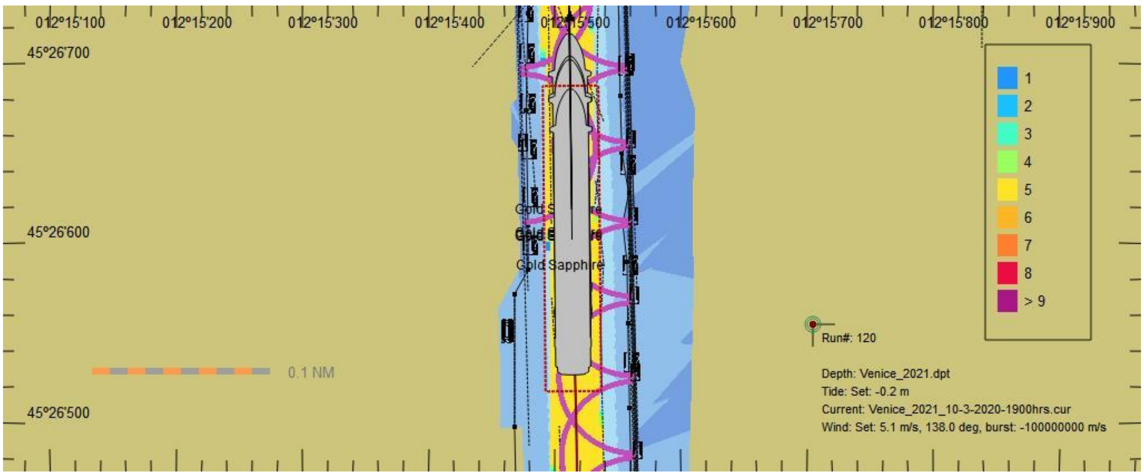


Figure 13 Scenario 4. No grounding here. However, as can be seen, the channel is narrow, and the navigation can be affected by Bank effects.

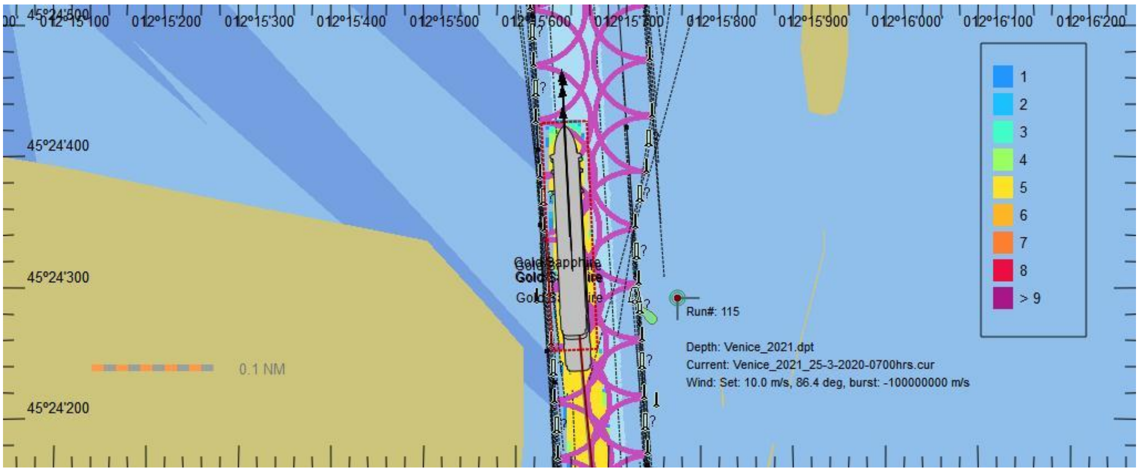


Figure 14 Scenario 3, grounding in proximity of Motte di Volpego.

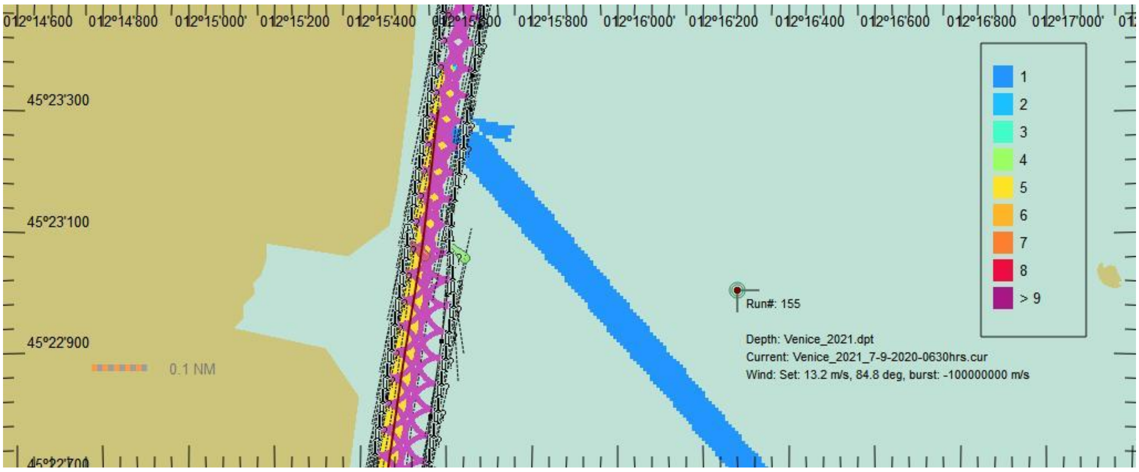


Figure 15 Scenario 11. The vessel grounds just after the curve probably due to bank effect. Duration of the navigation around 30 minutes.

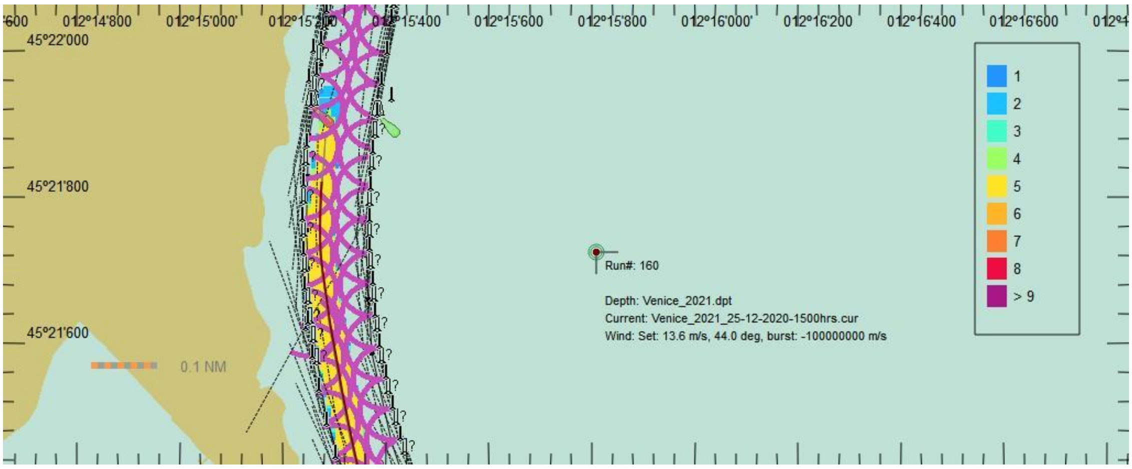


Figure 16 Scenario 12. Grounding after the curve. Duration of the navigation approx. 33 minutes.

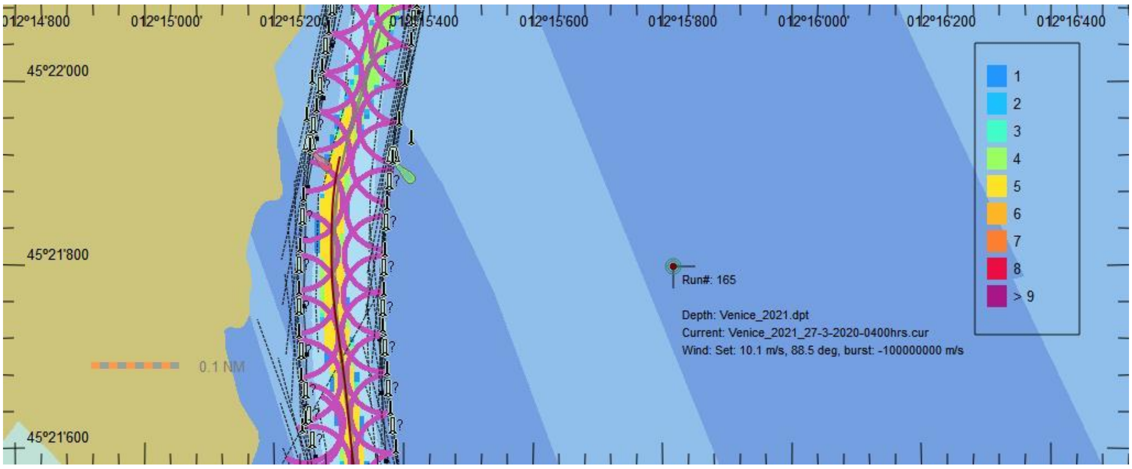


Figure 17 Scenario 13. Grounding after the curve. Duration of the navigation approx. 40 minutes.

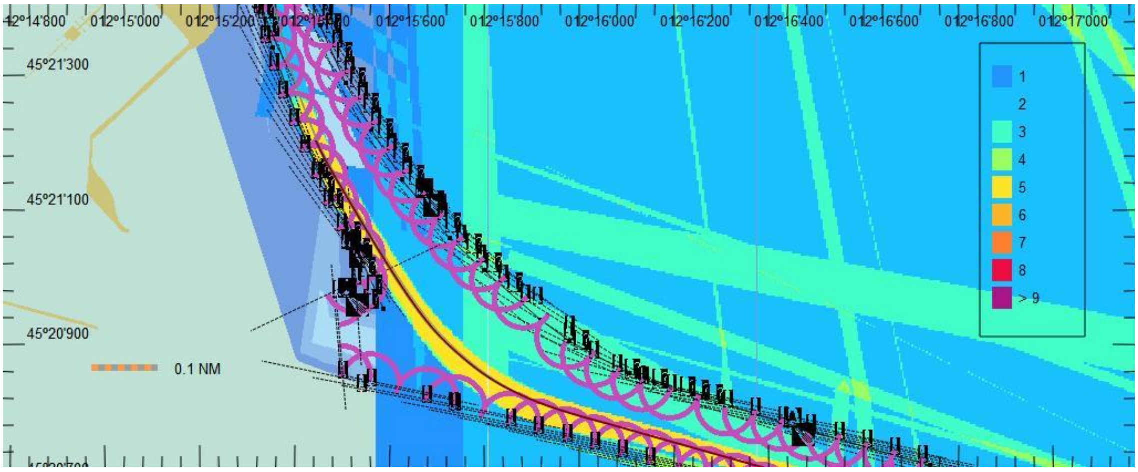


Figure 18 Scenario 17. Grounding after the curve. Duration of the navigation approx. 25 minutes.

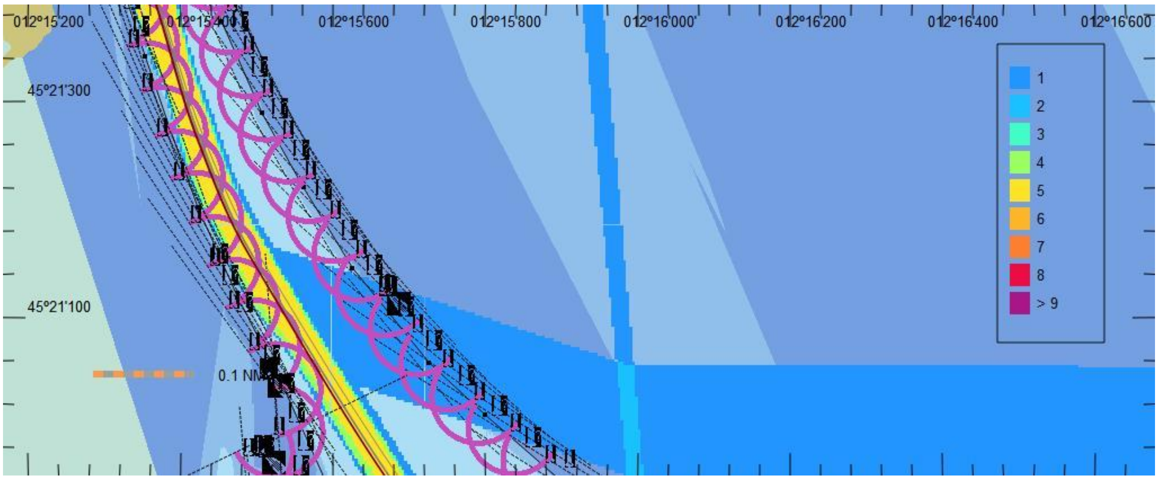


Figure 19 Scenario 20. The track of the vessel is close to the shallowest part of the channel, which can cause bank effect and, in some cases, the grounding of the Cruise ship, as scenarios 11, 12, 13 and 17 show.

BULK CARRIER

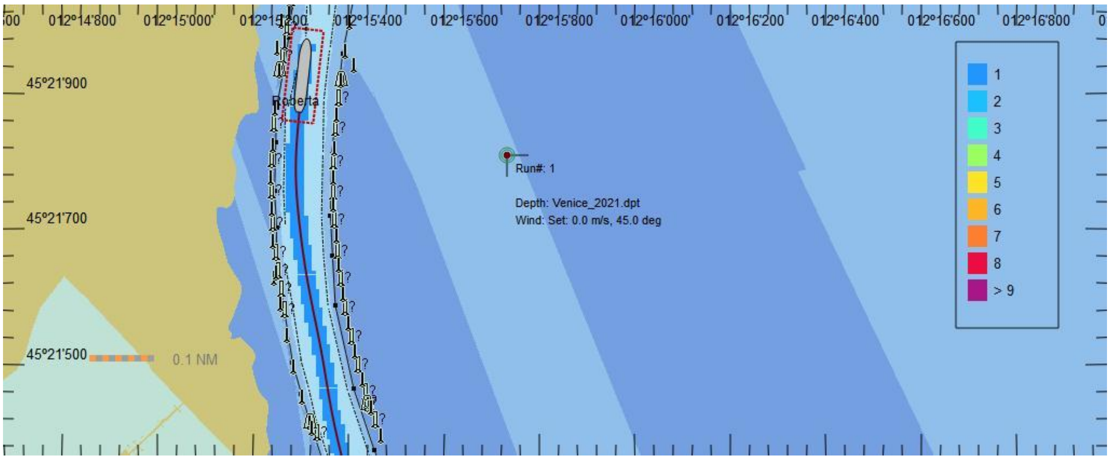


Figure 20 Basic scenario. No wind, no tide, no current. Duration 1h.

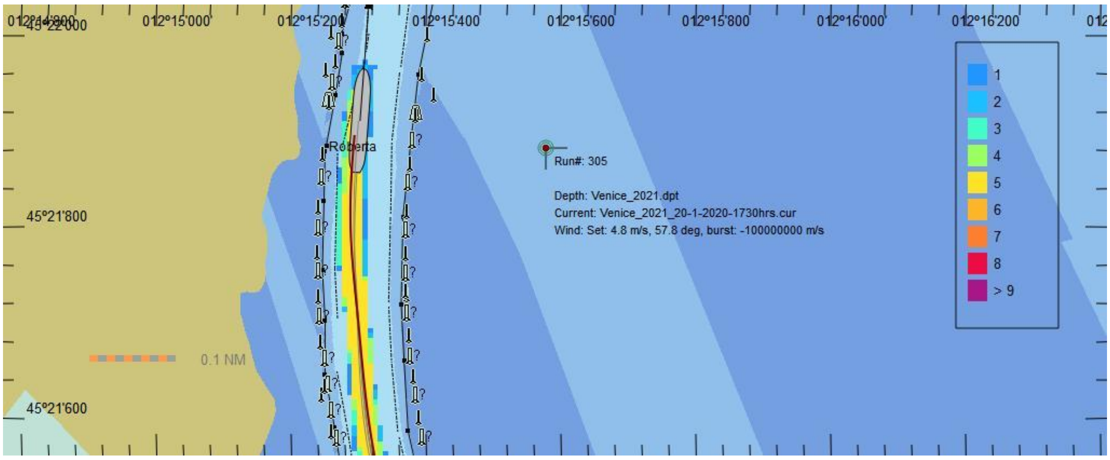


Figure 21 Scenario 1. Grounding after the curve probably due to the shallow water effect.

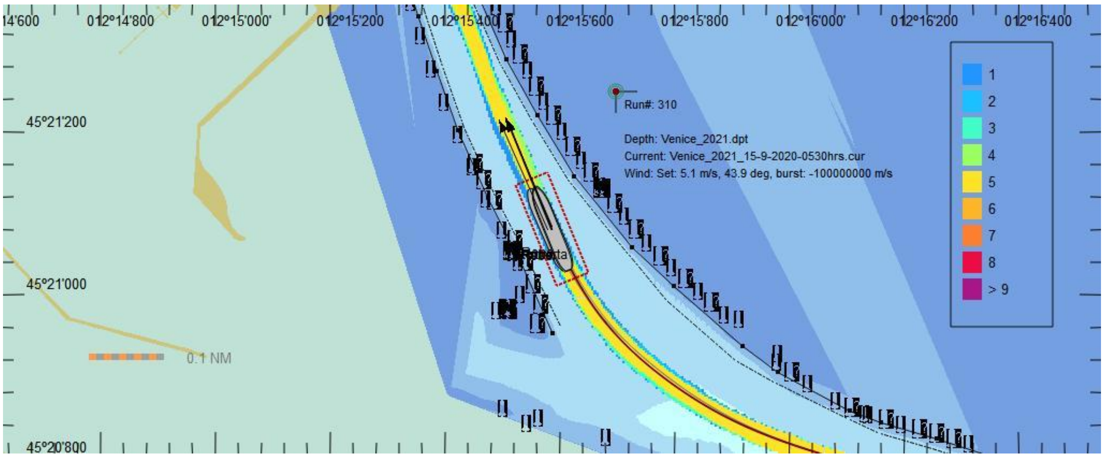


Figure 22 Scenario 2. In this case, the vessel ground after the curve, but this chart shows the behaviour of the Bulker in the curve.

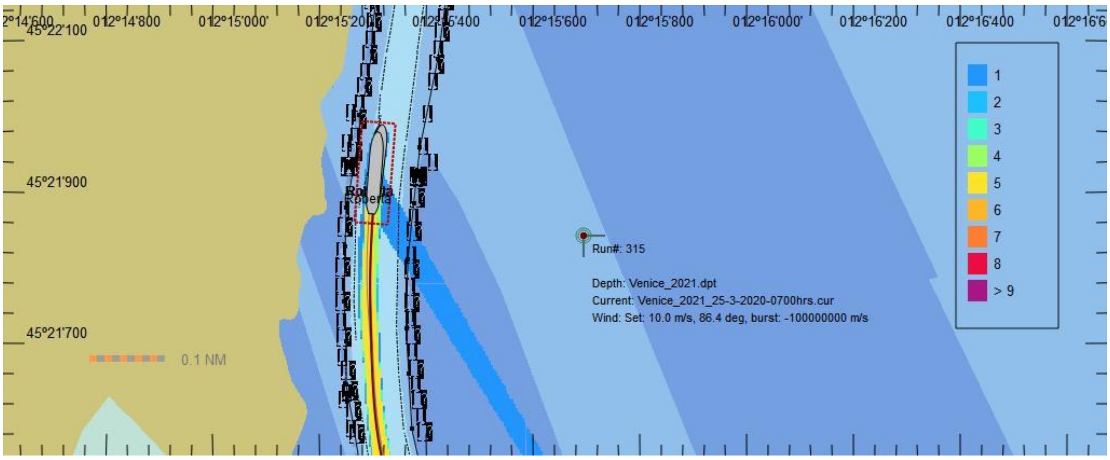


Figure 23 Scenario 3. The Bulker grounds after the curve probably due to bank effect.

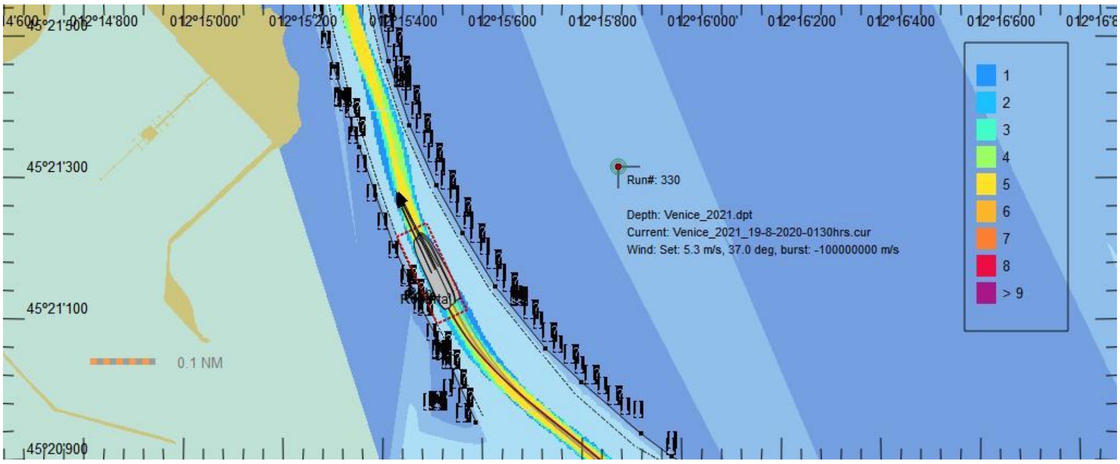


Figure 24 Scenario 6. In this chart the shallow water effect is already visible in the track of the vessel when it approaches the end of the curve.

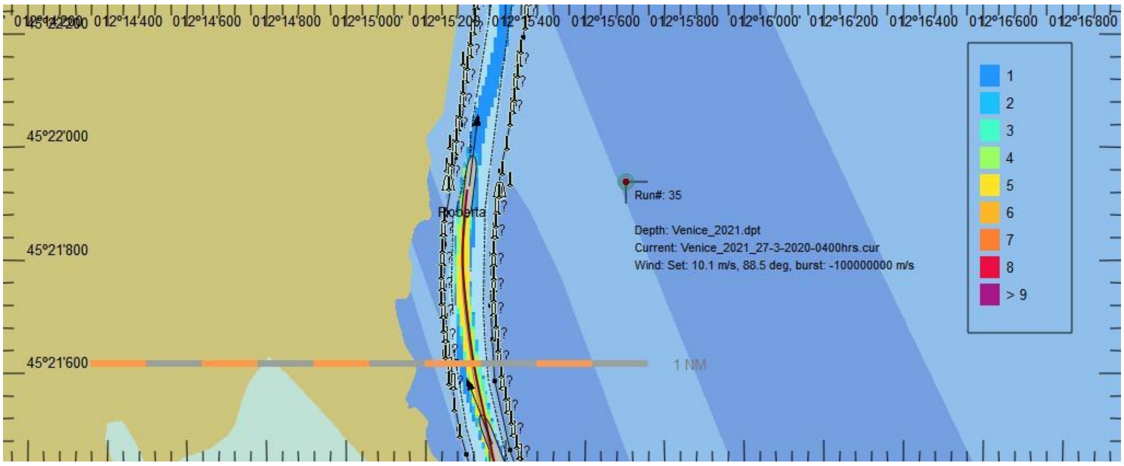


Figure 25 Scenario 13. Vessel affected by the bank effect grounds after the curve.

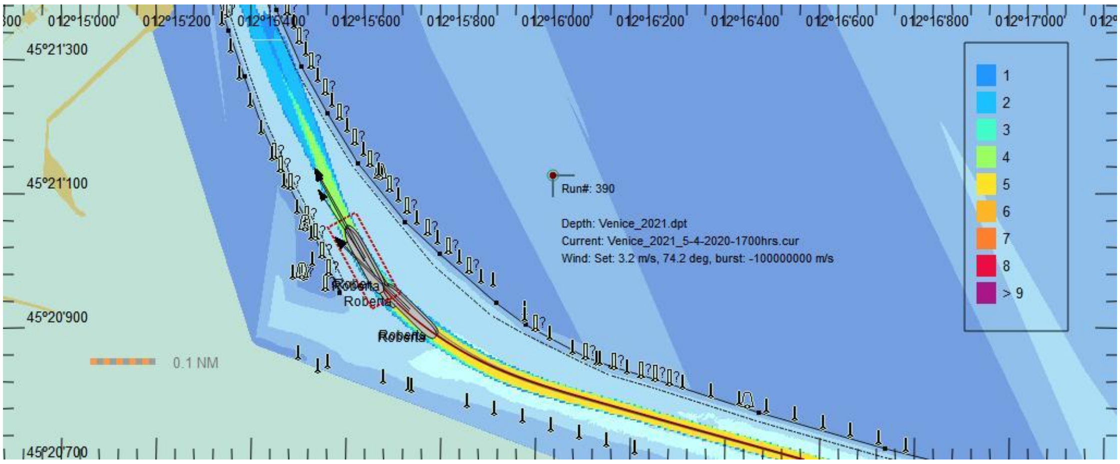


Figure 26 Scenario 18. The Bulker grounds within the curve due to shallow water.

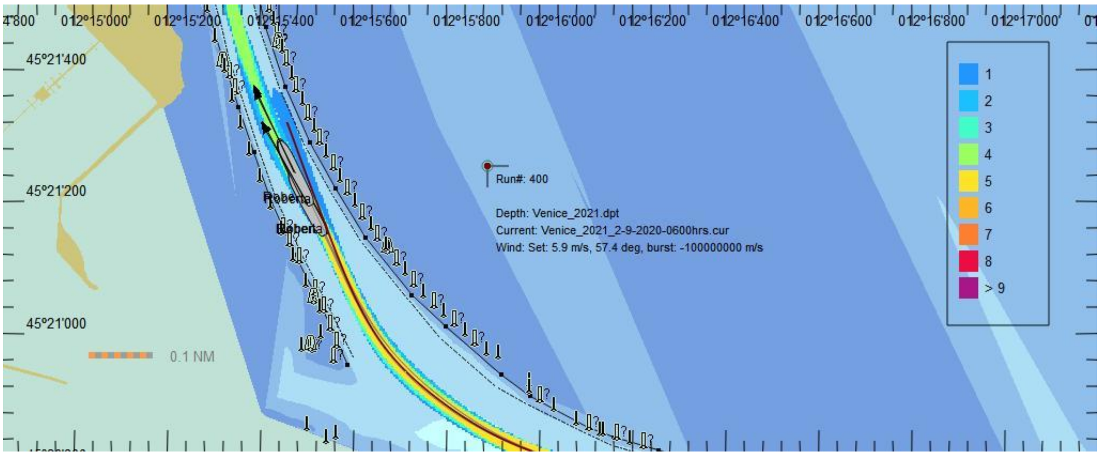


Figure 27 Scenario 20. Last scenario, the vessel grounds in proximity of the curve after approx. 30 minutes from the beginning of the navigation.

CONTAINER VESSEL

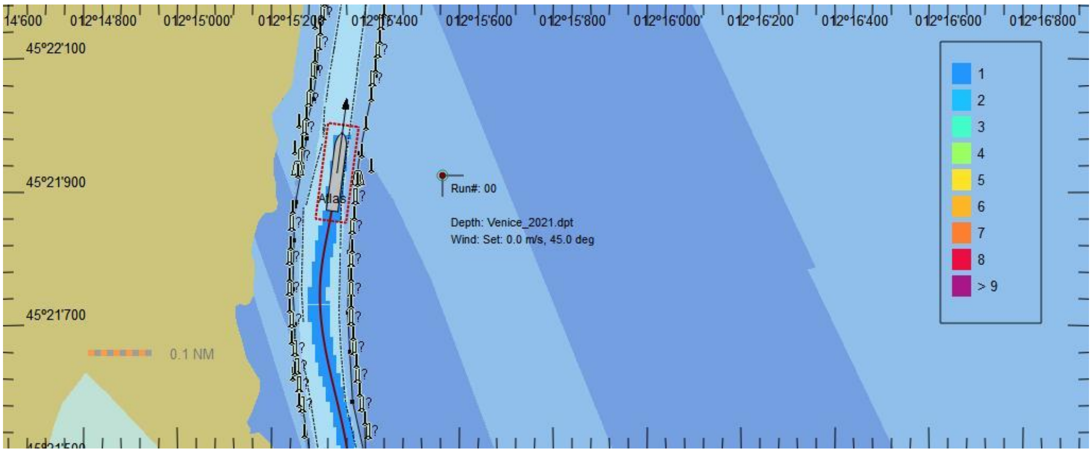


Figure 28 Base scenario.

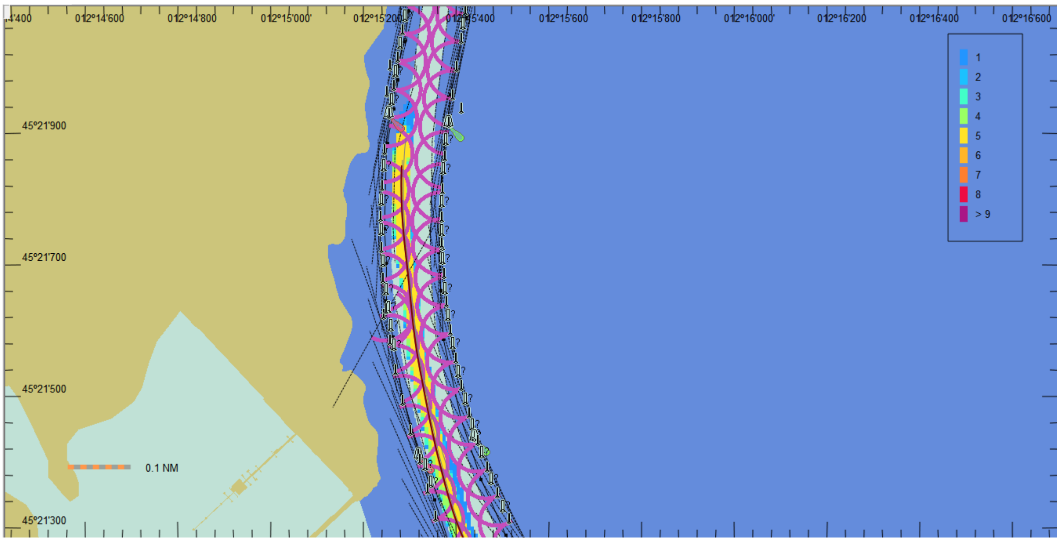


Figure 29 Scenario 1. Grounding after the curve.

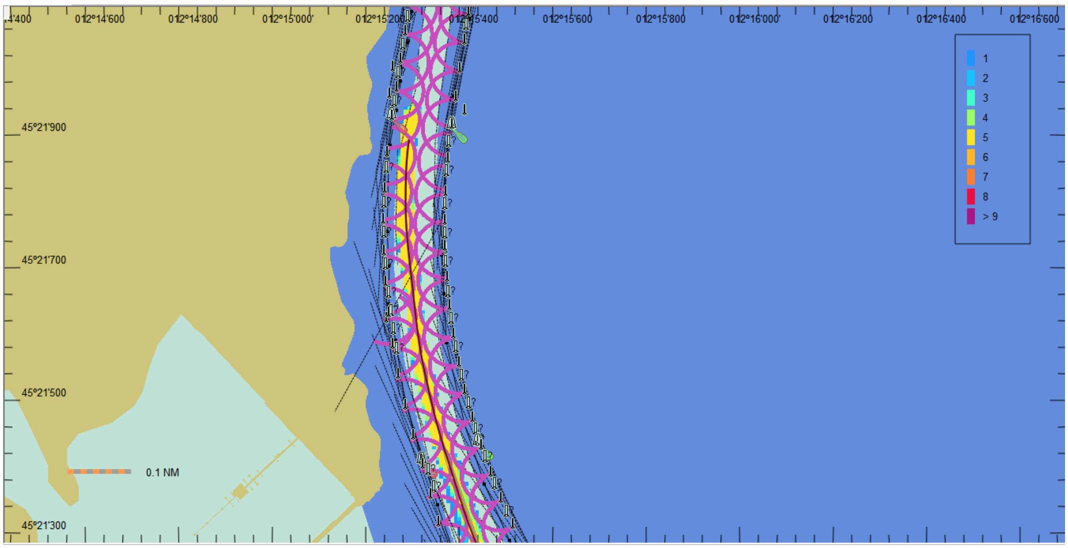


Figure 30 Scenario 2.

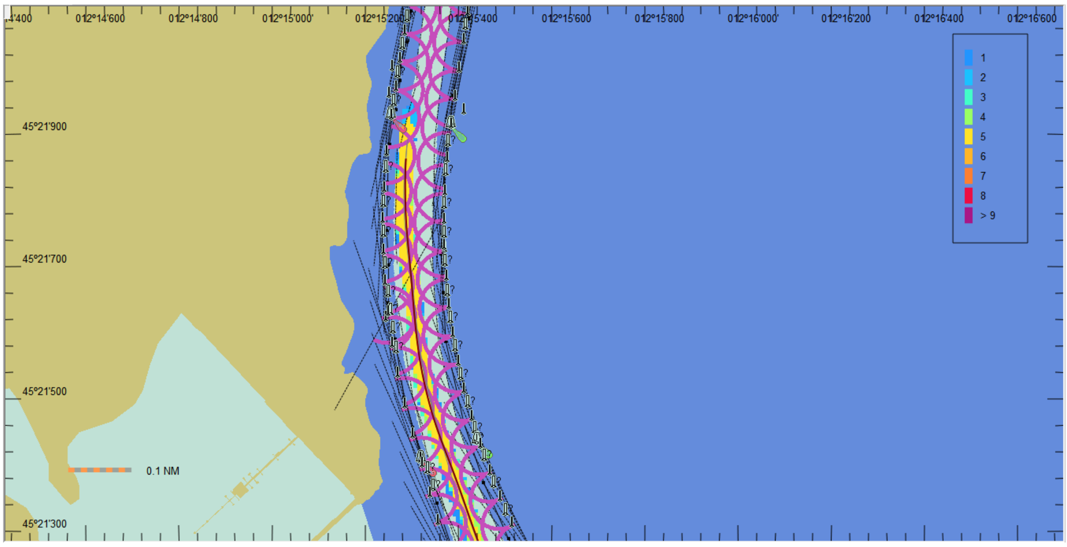


Figure 31 Scenario 3.

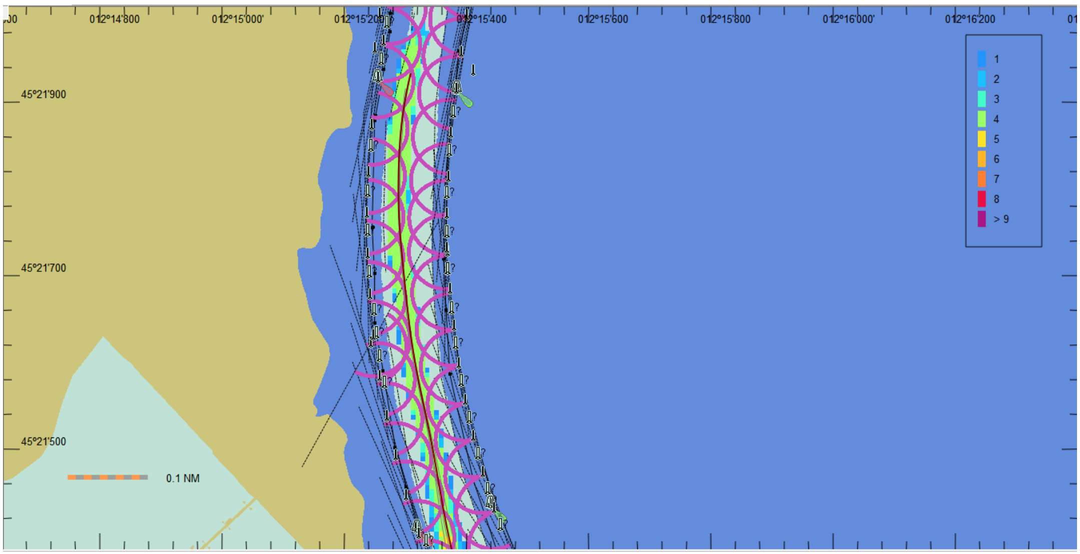


Figure 32 Scenario 4.

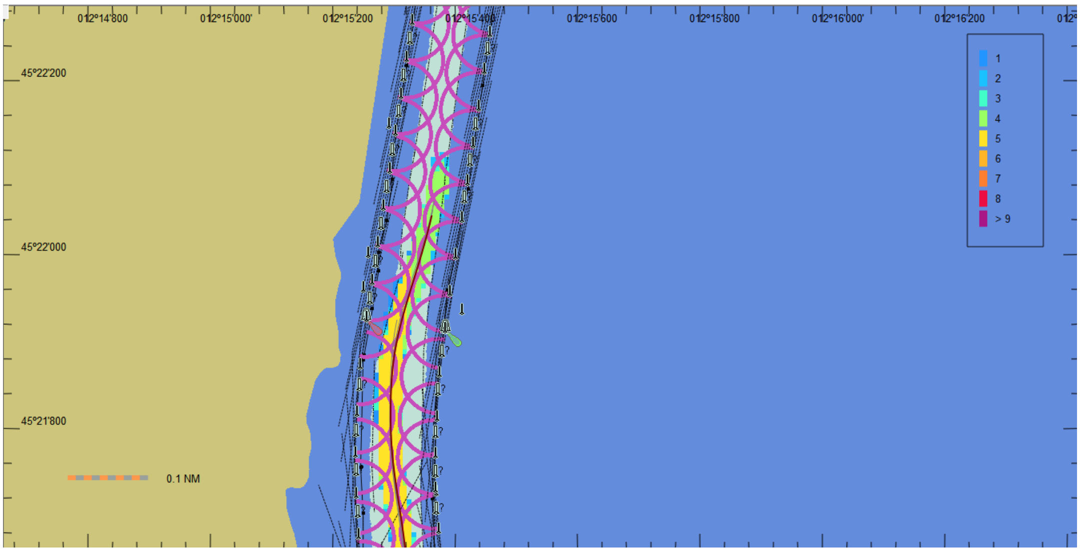


Figure 33 Scenario 5.

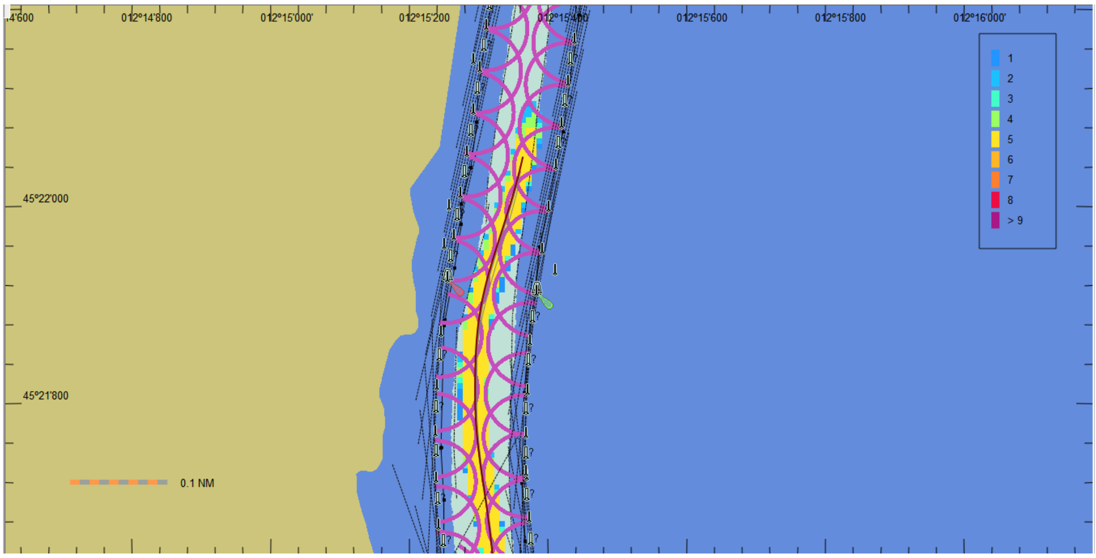


Figure 34 Scenario 6.

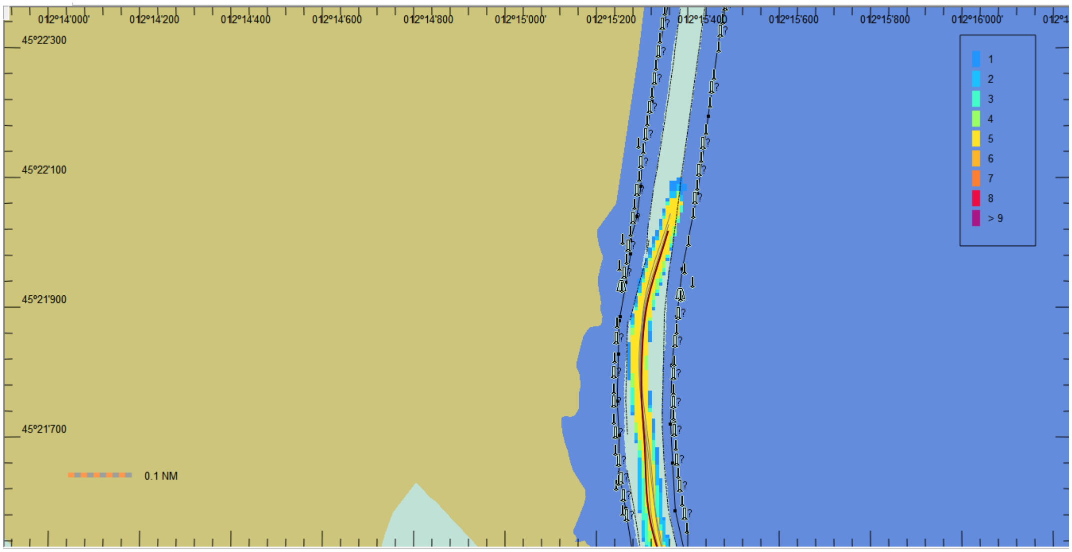


Figure 35 Scenario 8.

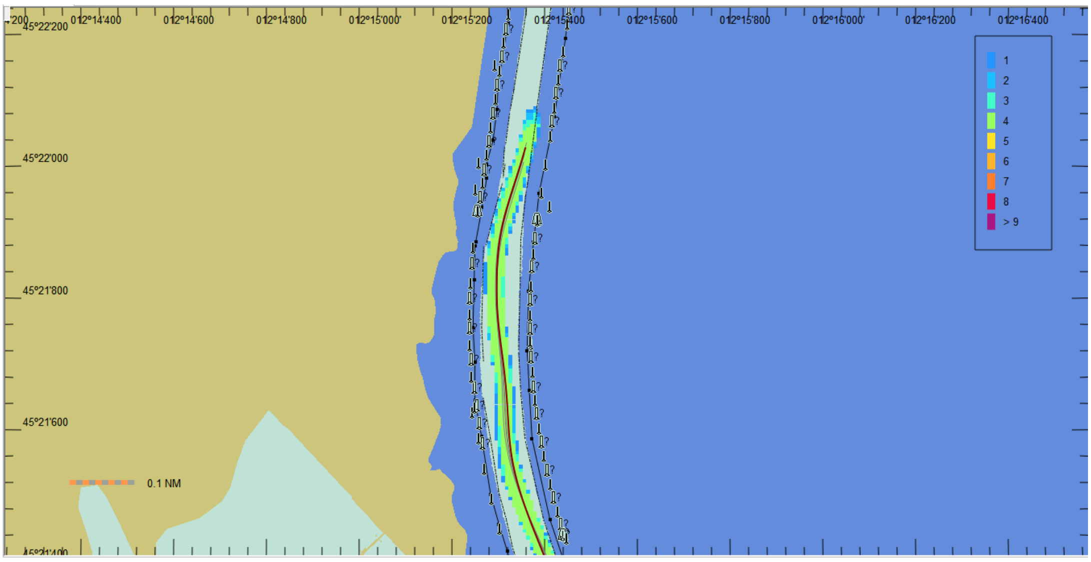


Figure 36 Scenario 9.

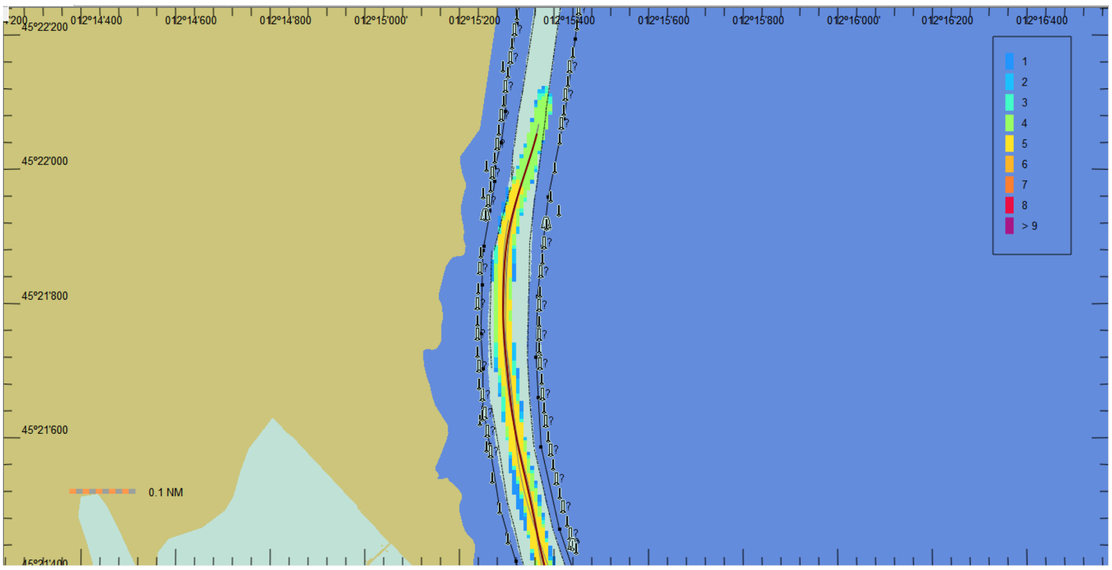


Figure 37 Scenario 10.

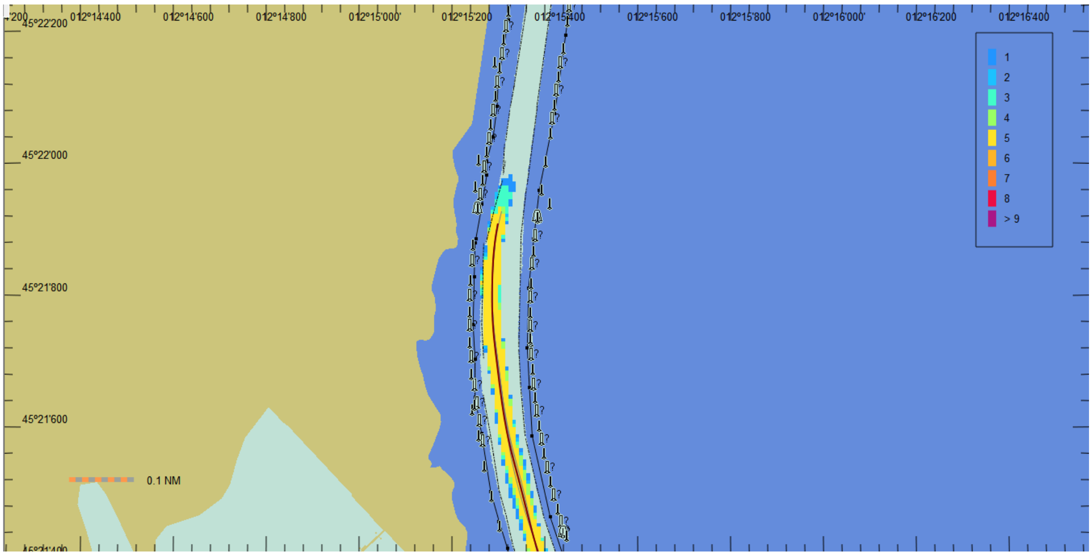


Figure 38 Scenario 11.

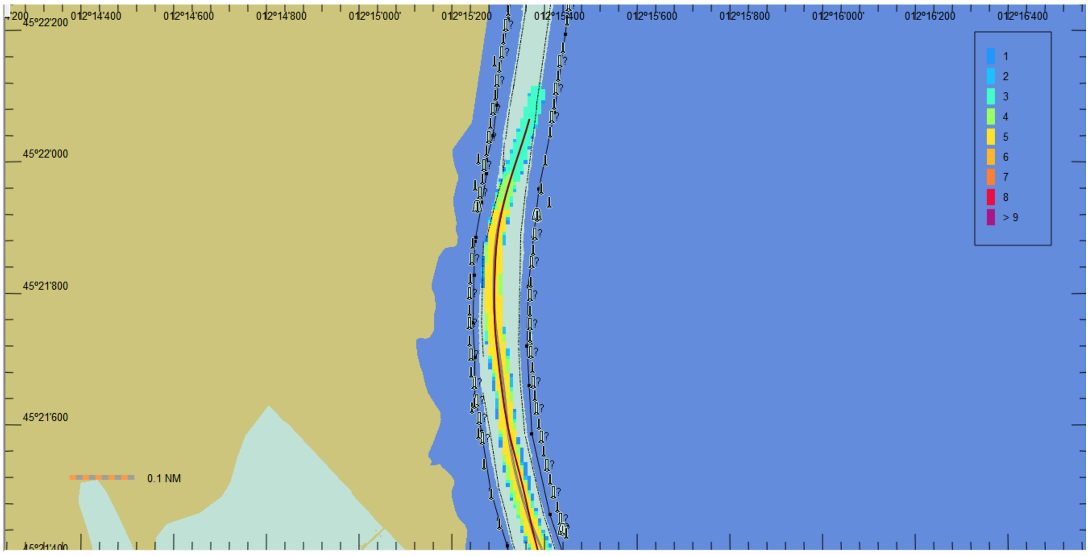


Figure 39 Scenario 13.

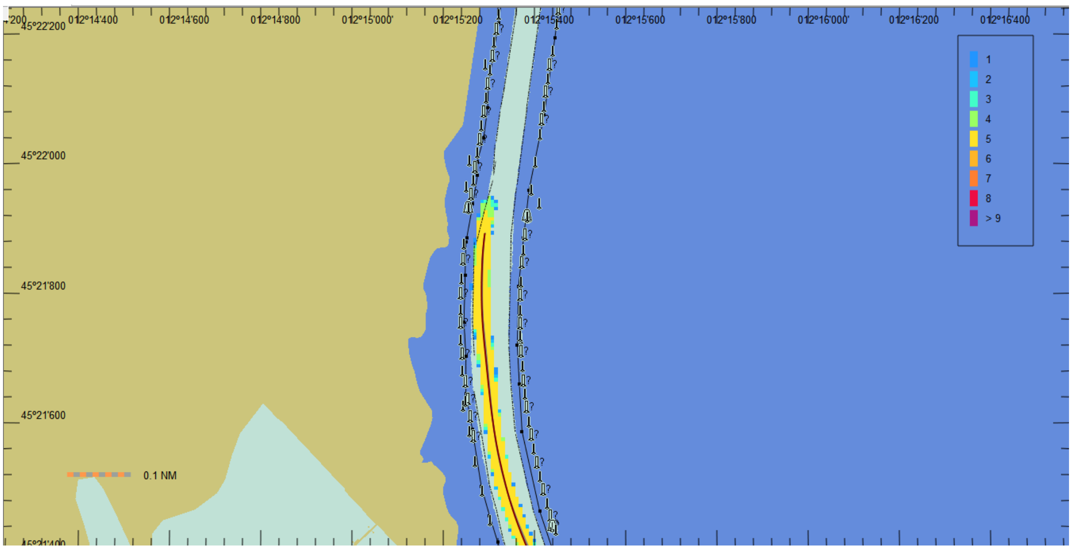


Figure 40 Scenario 15.

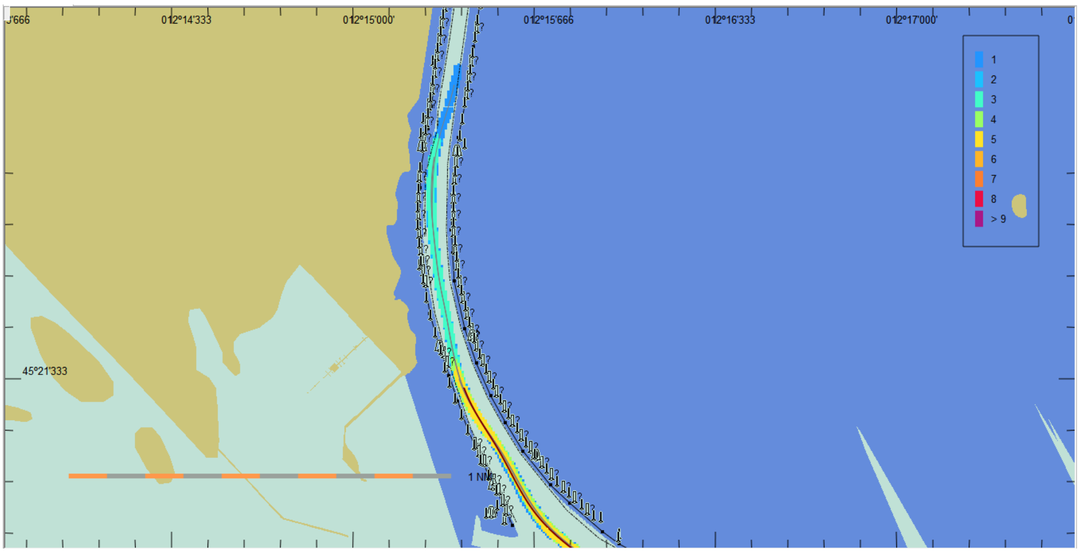


Figure 41 Scenario 18.

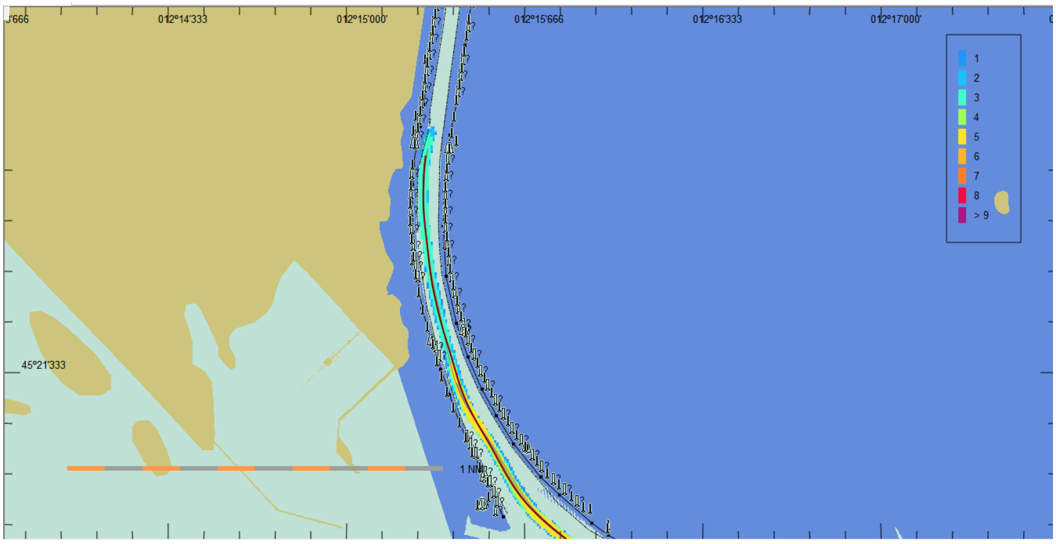


Figure 42   Scenario 19.

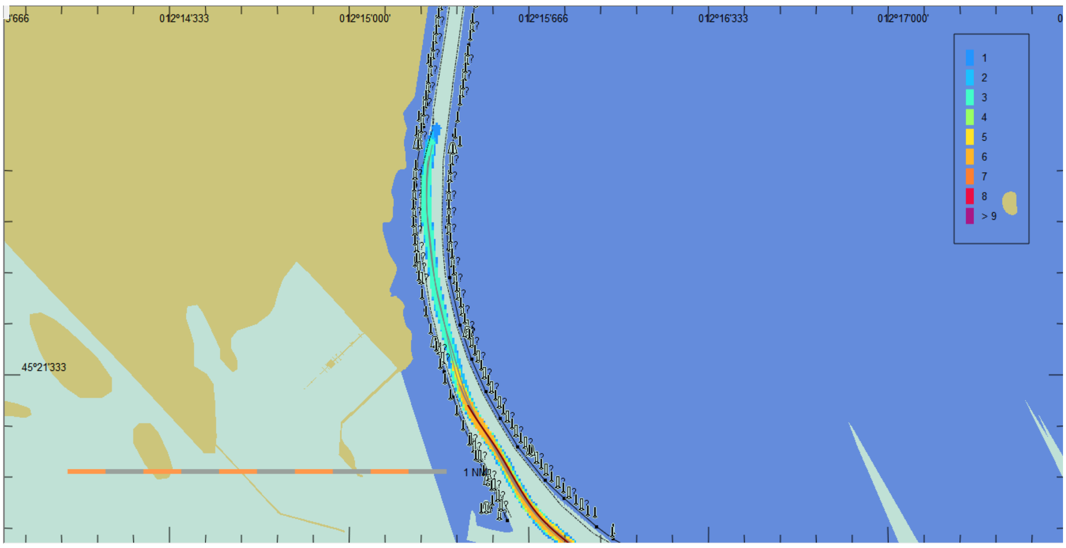


Figure 43   Scenario 20.

APPENDIX B

WIND DEFINITIONS IN SIMULATOR

Wind definitions in the simulator

Wind definitions in relation to the simulators wind speed indicator versus the vessels wind speed indicator.

In the simulator the wind speed is given in "meteorological wind speed". This wind speed is not equal to the wind speed read from the wind indicator of the ship. As a tentative comparison the following facts and assumptions can be given:

Wind indicator registers the wind speed e.g. at 35 meters' height.

Coefficient for calculating wind forces in the simulator refers to wind speed at 10 meters height and a mean value of a 10-minute sampling period.

Wind information from meteorological sources should refer to wind at 10 meters height.

Read-out from a wind indicator will typically refer to the mean value of a 5 second sampling period.

The variation of the mean wind in the height z above ground level is found by the formula:

$$u_z = u_{10} \times \left(\frac{z}{10}\right)^{\alpha}$$

u_z = Wind speed in a certain height

u_{10} = Wind speed at 10 meters height

α = Power constant (0,12 over sea, 0,16 over land, 0,28 over town).

z = Wind speed indicator height above the surface

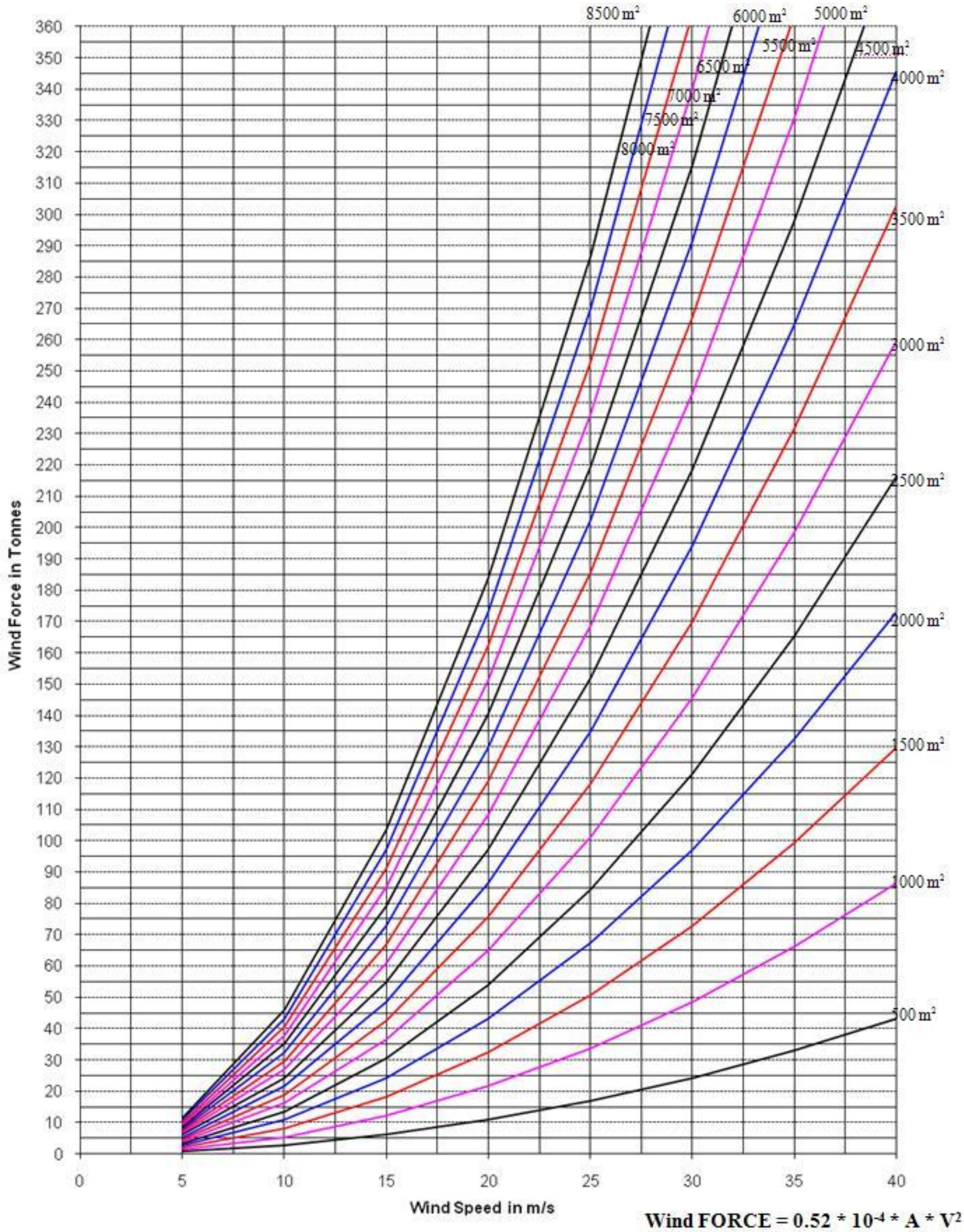
Using Engineering Sciences Data Unit (ESDU) 72026 we find the following ratio between

“Max 5 second wind” and “mean 10 minutes wind” equal to 1,25.

Example:

Wind read out on wind indicator (on vessel, height 35 m) =		25 m/s
10 min. mean wind at e.g. 35 m height = 25 / 1,25 =		20 m/s
10 min mean wind at 10 m height = $20 / \left(\frac{35}{10}\right)^{0,12}$	=	17,2 ms

This means that what the navigator correctly reads as a wind speed of 25 m/s corresponds to a “meteorological” wind speed of 17,2 m/s.



Wind FORCE = $0.52 * 10^{-4} * A * V^2$
A = Beam Wind area in m^2
V = Wind speed in m/s

Approximate wind forces; standard formula used by navigators.