

Complex project

‘Realisatie van extra containerbehandelingscapaciteit in het havengebied Antwerpen’



Geïntegreerd onderzoek

Ontwerprapport 11: Simulatiestudie voor het verkeer ter hoogte van Duplexdok en Deurganckdok

23/08/2022



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DOCUMENTINFORMATIE

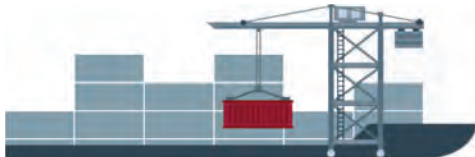
Naam project	Complex project 'Realisatie van extra containerbehandelingscapaciteit in het havengebied Antwerpen' (CP ECA)
Rapporttitel	Ontwerprapport 11: Simulatiestudie voor het verkeer ter hoogte van Duplexdok en Deurganckdok
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Projectnummer	21_043

VERSIEBEHEER

Versiedatum	Auteur(s) document	Doc.verantwoordelijke	Doc.screener
23/08/2022	Eloot, Katrien	Loyen, Reginald	Verwilligen, Jeroen

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Medegefinancierd door
de Europese Unie

Extra Containercapaciteit Antwerpen

Ontwerprapport 11: Simulatiestudie voor het verkeer ter hoogte van Duplexdok en Deurganckdok

Project Acroniem:	ECA
Project titel:	Complex project 'Realisatie van extra containerbehandelingscapaciteit in het havengebied Antwerpen'
Grant Agreement Nr.	2020-BE-TM-0086-S
Website:	www.cpeca.be
Versie:	1.0
Datum:	23 augustus 2022

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21_043_2
WL rapporten

Complex project: Extra containerbehandelingscapaciteit in het havengebied Antwerpen

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simulatiestudie voor het verkeer ter hoogte van
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simulatiestudie voor het verkeer ter hoogte van
Duplexdok en Deurganckdok

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D/2022/ 3241/182

This publication should be cited as follows:

Eloot, K.; Verwilligen, J. (2022). Complex project: Extra containerbehandelingscapaciteit in het havengebied Antwerpen: Deelrapport 2 – Geïntegreerd onderzoek – deel nautica: simulatiestudie voor het verkeer ter hoogte van Duplexdok en Deurganckdok. Version 4.0. FHR Reports, 21_043_2. Flanders Hydraulics Research: Antwerp

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Document identification

Customer:	Port of Antwerp-Bruges	Ref.:	WL2022R21_043_2
Keywords (3-5):	ULCS, toegankelijkheid, verkeerssimulaties, Duplex, realtime simulaties		
Knowledge domains:	Havens en vaarwegen > Manoeuvreegedrag > Oevers > Simulaties Havens en vaarwegen > Scheepsbeweging > Ontwerp Vaarweg en haven > Simulaties		
Text (p.):	82	Appendices (p.):	115
Confidential:	☒ No	☒ Available online	

Author(s):	Eloot, K.
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Control

	Name	Signature
Reviser(s):	Verwilligen, J.	Jeroen Verwilligen (Signature) Digitaal ondertekend door Jeroen Verwilligen (Signature) Datum: 2022.09.05 13:37:04 +02'00'
Project leader:	Eloot, K.	Getekend door: Katrien Eloot (Signature) Getekend op: 2022-09-01 16:25:28 +02:0 Reden: Ik keur dit document goed <i>Katrien Eloot</i>

Approval

Head of Division:	Bellafkih, K.	Getekend door: Abdelkarim Bellafkih (Sig) Getekend op: 2022-09-05 12:10:42 +02:0 Reden: Ik keur dit document goed <i>Abdelkarim Bellafkih</i>
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Abstract

The Duplex dock is a third alternative for the second tidal dock in the port of Antwerp area at the left bank. In 2021 a real time simulation study was executed to evaluate the accessibility of the Duplex dock for ultra large containerships of 430 m and 400 m of length. In this study the accessibility is further evaluated based on real time traffic simulations on four coupled manoeuvring simulators. The interacting containerships ranging from ULCS to smaller containerships and inland ships are executing head in/head out, inbound and outbound manoeuvres at different current conditions with strong wind of 5 or 6 Bft. The Duplex dock is evaluated as being accessible for up to 430 m ULCS with a required tug power of three 80 ton tugs for wind conditions of 6 Bft or unfavourable current conditions of flood during a head out outbound manoeuvre or ebb during head in inbound manoeuvre. Comparing the head in and head out manoeuvres shorter times to pass the dock/river zone are recognised for the head in manoeuvres.

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1 Introduction

This report discusses the traffic simulation study on four ship manoeuvring simulators for the accessibility of the Duplex dock (Figure 1), a new designed second tidal dock in the port of Antwerp-Bruges. In March 2022 real time simulations have been executed to examine the interaction between Ultra Large Container Ships (ULCS), smaller containerships or an inland ship.

In Eloot & Verwilligen (2021) the accessibility of the Duplex dock was analysed based on individual simulation runs with a 430 m or 400 m container ship with mainly head in manoeuvres to and from the dock. Compared to previous designs of the tidal dock (Boomerang and L-square) the layout of the Duplex dock seems to be more capable of also accepting head out manoeuvres. The turning of the dock entrance of Duplex dock towards the river (heading of 283 deg for Duplex and 299 deg for L-Square) gave the opportunity to also organise head out inbound and outbound manoeuvres. Therefore the traffic simulations in this report had as additional goal filling in the complete matrix of head in and head out manoeuvres at maximum flood or ebb tide during an inbound or outbound manoeuvre with 430 m or 400 m container ships.



Figure 1 – Duplex alternative for traffic simulations

In the L-square alternative of the second tidal dock a traffic simulation study on four ship manoeuvring simulators was completed in 2019 and reported in Eloot *et al.* (2020). The goal of the study was the examination of the dock mouth of the Deurganck dock as a bottleneck for the traffic to/from the river, Deurganck dock, Kieldrecht lock and second tidal dock.

Compared to the L-square traffic simulation study additional questions arose and are part of this report:

- *Head in or head out*: the turned alternative of Duplex (entrance closer to the river) gives an opportunity to choose head in or head out manoeuvres depending on current/tide and wind conditions. In the L-square simulations only head in manoeuvres were considered. On January 24th 2022 a presentation was given to (nautical) representatives of members of Alfaport and Voka where the circumstances to decide on head in or head out manoeuvres were discussed. It is mainly a time management decision based on avoiding meetings at certain locations on the river. Being able to choose for a head in or head out manoeuvre gives more flexibility for ships with an identical ETA to spread the passages on the river at for example CP (coordination point).
- *Two way traffic in Duplex for smaller container ships, interaction with inland ships*: Duplex has a dock width of 325 m, inclusive one mooring section for sea-going vessels downstream the bend or kink in the dock and a dock width of 350 m inclusive mooring zones at both sides upstream the bend (Figure 1). In the framework of the development of a capacity model for the port of Antwerp-Bruges (PoAB) by the company MACOMI, knowing which ship dimensions can meet each other before and upstream the bend of the Duplex dock and which ships can swing in the dock, is important. The interaction with inland ships, sailing in the docks or waiting at designed jetties in the northern area of the Duplex dock, is another goal of this simulation study. Therefore during one day inland skippers participated in the simulations.
- *Emergencies*: a question rose from shipping companies to examine emergencies in the Duplex dock: how will interacting ships react on failures of engines, rudder or thrusters, problems with tugs due to failure of tug lines or others or suddenly increased wind conditions.

Variations between head in and head out manoeuvres and interaction with inland ships are considered during the simulations in March 2022.

Emergencies will have to be part of another study for the Duplex dock and traffic simulations.

The simulations have been executed on March 7, 14 and 21 2022 with the cooperation of the Flemish and Dutch pilotage, tug captains from Boluda and Antwerp Towage and two inland skippers.

The report is subdivided in a description of the simulation setup and executed program in chapter 2, the analysis of individual runs (chapter 3.2) and scenario runs (chapter 3.3) in chapter 3 and the conclusions in chapter 4.

2 Simulation setup and program

The simulation setup and program starts from previous executed research. In Chapter 5 of Subreport 6 (Eloot *et al.*, 2018) an exploratory study was carried out into the traffic flow at the Deurganck dock where a junction is created for ships from the second tidal dock (TGD), the Deurganck dock (DGD) and the Kieldrecht lock (KIS). Taking into account the prognose for shipping in 2030 and the distribution of ship types and sizes over draught classes, it was estimated that for the total of 37 seagoing ships per day passing the junction with destination DGD, TGD and KIS, on average four (five every 15 days) ships (in both directions) are tide-dependent. This calculation to the number of tide-dependent ships is important because worst case, these ships will all pass the dock entrance close to each other due to the limited tidal window depending on their draft. Although in the L-square alternative only ULCS of 400 and 430 m were combined, it is rather conservative to assume that all tide-dependent vessels have a length of 400 m or more.

It was decided for this study to focus on four ULCS of 400 m and more during the first two scenarios of each simulation day (in 2019 four scenarios per day could be completed) and accept a larger variation in ship length (and draft) for the other two per day (combination of 400 m and smaller ships, for example those able to swing in the Duplex dock and inland ships).

For tidal dependency of entrance and departure manoeuvres a new development in the simulator software of Flanders Hydraulics Research (FHR) with dynamic changing tide, gave the opportunity to make a distinction between simulation runs with static tidal condition (for example maximum flood or ebb current as during all previous studies for the second tidal dock) and runs with dynamic tidal condition where the water level and current profile change in real time during the simulation.

The different parts of the simulation setup will be discussed in chapter 2.1, while the implemented ships in chapter 2.2 and the executed simulations program in chapter 2.3.

2.1 Simulation setup

2.1.1 General setup

The simulation environment is based on Figure 1 which was already implemented in the simulation study with individual runs in Duplex dock in Eloot & Verwilligen (2021). The turned Europe terminal (Eloot *et al.*, 2020b) was also available as this infrastructure should be available before the Duplex dock. Waiting jetties for inland ships had been added in the northern zone of the first stretch of the Duplex dock to be evaluated by inland skippers (Figure 2). Inland ships can moor at:

1. the first 480 m of the quay from the entrance;
2. the slope opposite to the quay wall downstream the bend with sufficient depth for the draft of the inland vessels and safety distance to passing sea-going vessels; the jetties were placed on the -10 m LAT depth line;
3. the end of the dock perpendicular to the quay walls.

More¹ navigation lines have been added to the Portable Pilot Unit (PPU) of the pilots so that also smaller ships can better distinguish quay walls and under water slopes, with:

- one 100 m out of quay wall line in the first part from entrance to bend and the quay wall itself;
- a slope intersection line between the vertical northern wall at the entrance of the dock and the slope in the kink;
- two 100 m out of quay wall lines in the second part of the dock and the quay walls themselves.

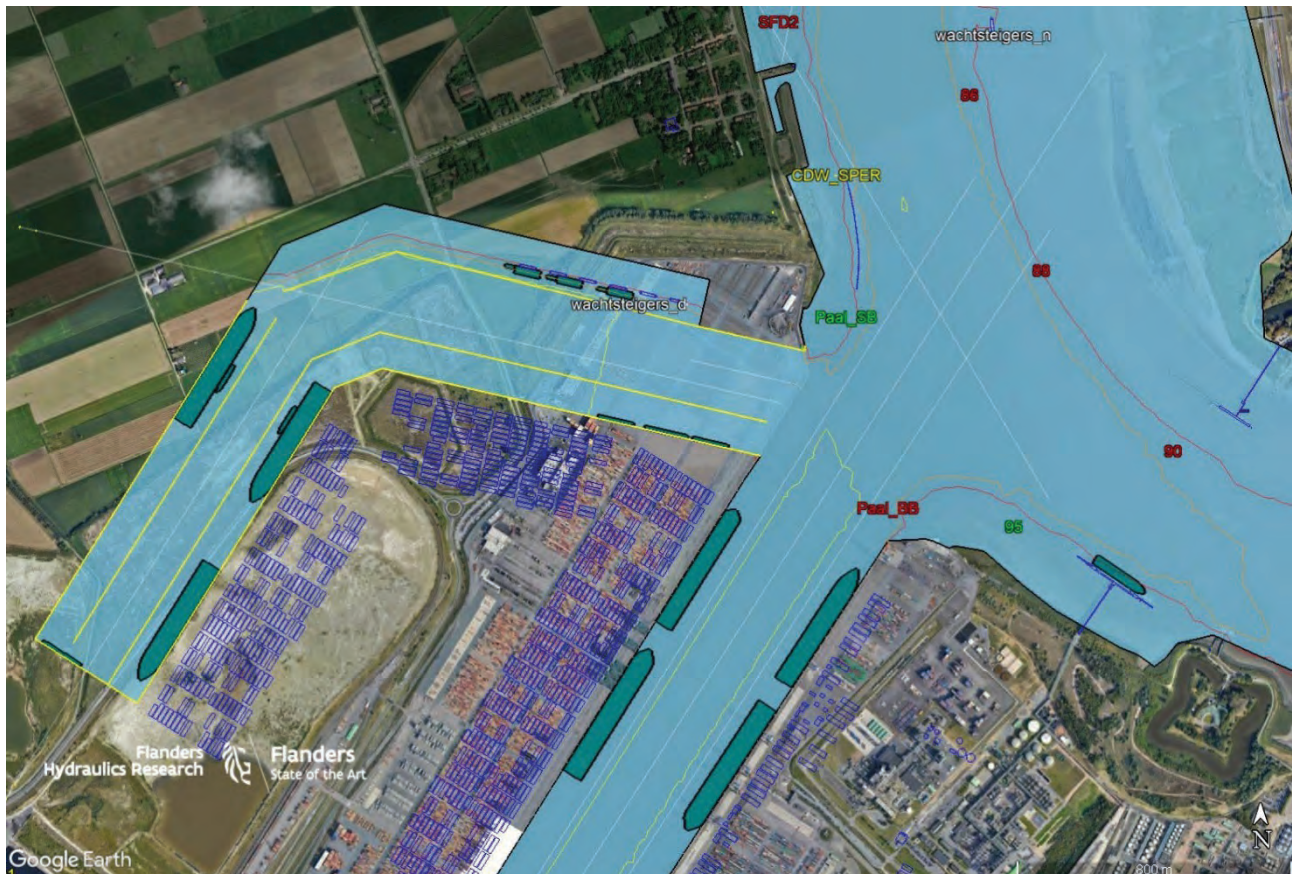


Figure 2 – Navigation lines (yellow) and waiting jetties (wachtsteigers_d) in the Duplex dock

For the traffic simulations four ship manoeuvring simulators (Figure 3) have been coupled so that they are acting in the same simulation environment:

- simulator SIM360+ (360 degrees projection screen);
- simulator SIM225 (225 degrees projection screen with extra screens for rear view);
- simulator SIM210 – Lara (inland simulator used within the project for sea-going and inland ships, 210 degrees front view with two extra screens for rear view);
- simulator SIM5 (desktop simulator with three computer screens for front view).

The simulator and the ship to be steered have been chosen as function of the manoeuvre to be applied. Especially for SIM5 with only a front view mainly head in manoeuvres have been chosen so that no rear view was necessary.

¹ The navigation lines at the quay walls have only been added during the simulation study.



(a) Simulator SIM360+, view of the stretch of Duplex dock upstream the bend



(b) Simulator SIM225, front view on the river nearby Deurganck and Duplex dock



(c) Simulator Lara, view of the stretch of Duplex dock downstream the bend with waiting jetties at northern under water slope



(d) Simulator SIM5, view of the stretch of Duplex dock upstream the bend

Figure 3 – Simulators implemented during the traffic simulations

In the framework of project 17_013 bathy, tide, current and wind data have been restructured in new data formats and corresponding query functionalities what will be shortly discussed in chapters 2.1.2 to 2.1.5.

situation. Without drastic changes to underwater structures and banks the entrance of DGD cannot be widened. Attention to the design of the underwater structures for the zone where the new entrance of the Duplex dock will come is necessary. In the conclusions based on the tracks of ULCS the distance between the northern wall of Duplex dock and the ship tracks is analysed what will help in designing the under water infrastructure for dredging.

2.1.3 Tide

The tide or water level original data are obtained from HD calculations in NAP with a conversion to TAW. Two tidal cycles (mean spring tide) had been chosen dating from March 24 to 25 2019 with the high water level at Prosperpolder at 04:39 or 17:04 UTM:

- data,..\\tide\\waterlevel\\Duplex_005_HwPros20190324_0439_water_level_2Dt\\
- data,..\\tide\\waterlevel\\Duplex_005_HwPros20190324_1704_water_level_2Dt\\

Based on the difference in a static or a dynamic tidal condition during the simulations the timePace parameter had to be set to 0 for constant static tide or 1 for dynamic tide. Additionally a starting time (e.g. - 3600 seconds before high water) can be chosen based on the timeStart parameter: e.g.

data,..\\tide\\Duplex_005_-01h00HWdyn_HwPros20190324_1704_2Dt.tide.v30.xml

- <timeStart>-3600</timeStart>
- <timePace>1.0</timePace>²
- <inputFields>
 <InputField
 href="..\\waterlevel\\Duplex_005_HwPros20190324_1704_water_level_2Dt\\Duplex_005_HwPros20190324_1704_water_level_2Dt.xml" />
 </inputFields>

The tidal curve and the current profile 50 minutes before high water, as calculated from the HD calculations, are shown in Figure 5.

In the L-square alternative the simulations were always executed with a constant static tidal condition. In the traffic simulations for the Duplex dock four simulation scenarios have been realised with a realistic time-dependent tide and current. The other scenarios were again with a constant static tidal condition to resemble the L-square traffic simulations. The constant tidal conditions preferably chosen were:

- Maximum flood: -00:54 to high water Prosperpolder with tidal level +5.34 m LAT
- Maximum ebb: +03:21 after high water Prosperpolder with a tidal level of +3.3 m LAT.

2.1.4 Current

The corresponding current data from HD calculations for the two tidal cycles selected in 2.1.3 are:

- data,..\\sne\\current\\Duplex_005_HwPros20190324_0439_current_3Dt\\
- data,..\\sne\\current\\Duplex_005_HwPros20190324_1704_current_3Dt\\

The HD calculations are in a three-dimensional (3D) field with vertical depth variation. As the current impacts the ships depending on their draft, an averaging of the 3D current field over the draft is executed for each ship in the traffic simulations.

² timePace = 1.0 (dynamic), timePace = 0.0 (static)

For the static or dynamic current identical parameters as for the tide can be chosen (timeStart and timePace):
e.g.

data,...\sne\Duplex_005_-01h00HWDyn_HwPros20190324_1704_3Dt.current.v30.xml

- <timeStart>-3600</timeStart>
- <timePace>1.0</timePace>
- <inputFields>

<InputField

href=".current\Duplex_005_HwPros20190324_1704_current_3Dt\Duplex_005_HwPros20190324_1704_current_3Dt.xml" />

</inputFields>

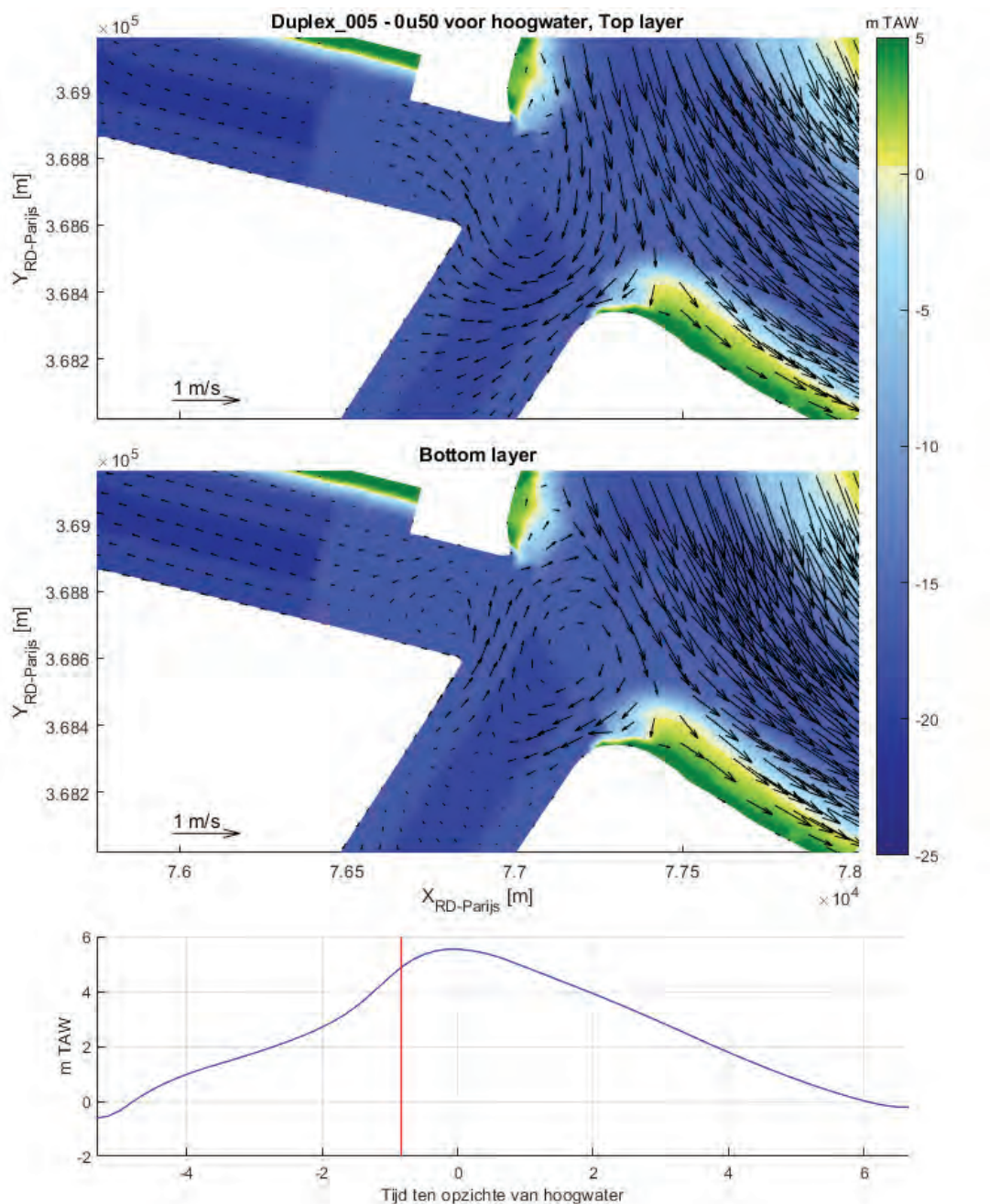


Figure 5 – Tidal curve and current profile at 00:50 before high water from HD calculations

As was done in previous simulations for L-square and Duplex an increase of the velocity magnitude with 15% (factor 1.15) was implemented to take into account a small underestimation of the HD calculations compared to measured current data. The metadata for currentVelocity give the opportunity to execute a transformation with scale, offset and rotation. Only the scale factor had been changed to 1.15 (Figure 6).

```
<?xml version="1.0" encoding="utf-8"?>
<InputField xmlns:xsd="http://www.w3.org/2001/XMLSchema" xmlns: xsi="http://www.w3.org/2001/XMLSchema-instance">
  <description>
    <components>
      <string>Component 1 ranges from -2.58447861671448 to 2.92588413818359</string>
      <string>Component 2 ranges from -1.92619681358337 to 2.94625663757324</string>
    </components>
    <mesh2D>Horizontal triangular mesh with 39684 vertices and 77366 triangles</mesh2D>
    <mesh2DX>X coordinate ranges from -10883.5284981101 to 7991.83875372133</mesh2DX>
    <mesh2DY>Y coordinate ranges from -5364.68262196705 to 13652.1948978379</mesh2DY>
    <vertical>Vertical dimension has 5 layers. Layer coordinates range from 0 to 1</vertical>
    <verticalReference>Vertical reference level = RELATIVE, Bottom level field = 'bathymetry', top level field = 'waterLevel'. Bottom coordinate = 1, top coordinate = 0</verticalReference>
    <time>Time dimension has 79 time frames. Time ranges from -21839.9999957532 to 24960.0000008941</time>
  </description>
  <key>currentVelocity</key>
  <metadata>
    <refLevel>none</refLevel>
    <refTime>HW_Proserpolder</refTime>
    <isTidal>true</isTidal>
    <interpolationTechnique>linear</interpolationTechnique>
    <transformation>
      <scale>1.15</scale>
      <offset>0</offset>
      <rotation>0</rotation>
    </transformation>
  </metadata>
</InputField>
```

Figure 6 – Input data structure for setting the metadata of the current field

2.1.5 Wind

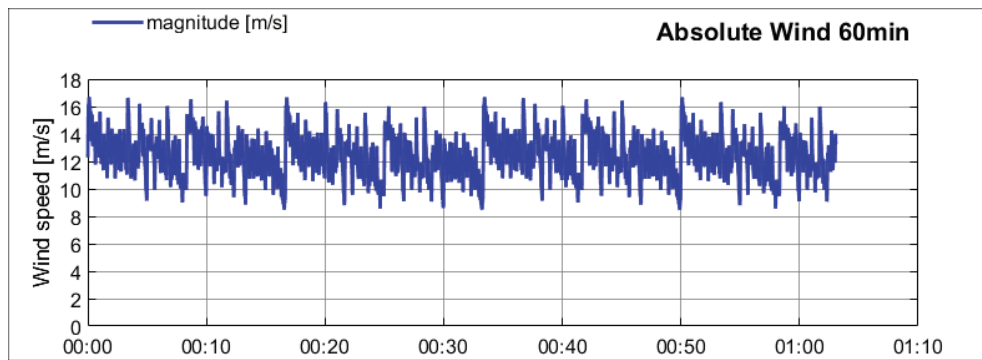
For the uniform wind field with variability in wind velocity and direction (wind gusts) a spectrum was used that resembles a Von Karman spectrum but based on a new structure. During the first and second simulation days (e.g. run M4 in Figure 7) wind fields with slightly different spectral definition in that new structure were implemented which have been improved during the last simulation day (run M5 in Figure 7). For M4 for all frequencies in the spectrum the same phase was applied while this phase was randomised for the simulation runs on the third day.

The input fields for a wind field of east 6 Bft are summarised in:

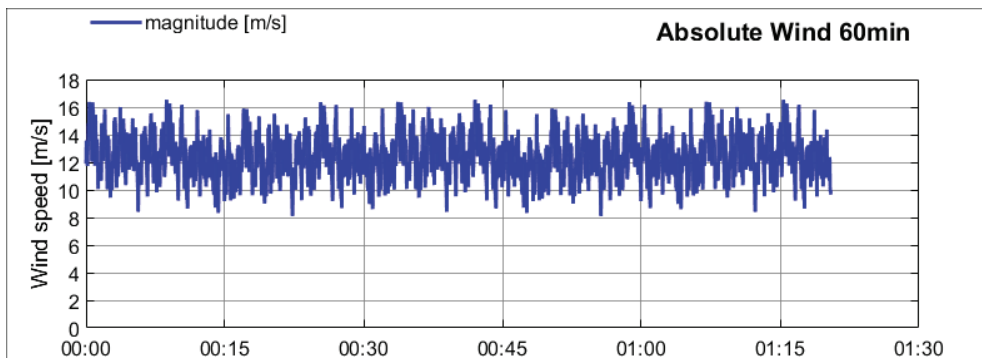
E.g. data,..\\win\\E6.wind.v30.xml

```
<timeStart>0</timeStart>
<timePace>0</timePace>
<inputFields>
  <InputField href=".\\wind\\E6_windMeanVelocity.xml"/>
  <InputField href=".\\wind\\airdensity_default.xml"/>
  <InputField href=".\\wind\\windSurfaceRoughness_3.xml"/>
  <InputField href=".\\wind\\windZeroPlaneDisplacement_default.xml"/>
</inputFields>
<inputWindSpectrum href=".\\wind\\windSpectrumInput_default.xml"/>
```

An example of a wind field time variation during two runs with northern wind 6 Bft are shown in Figure 7.



(a) Run M4



(b) Run M5

Figure 7 – Wind speed variation during a northern 6 Bft wind for run M4 and M5

For run M4 and M5 a distribution was calculated for the applied wind speed values during the complete simulation run, nevertheless with different execution time. The distribution over different Beaufort classes for mean 6 Beaufort wind is shown in Table 1. No important differences are seen between both runs with no wind speed values in the 4 and 8 Bft classes and a slightly larger percentage in the 7 Bft class for run M4 compared to run M5. If a theoretical comparison is made for a southwestern 6 Bft wind with an identical execution time the distribution over the Beaufort classes for “1 (identical) phase” or “randomised phase” is as in Table 1.

Table 1 – Wind distribution for two wind spectra applied during run M4 and M5

	4 Bft	5 Bft	6 Bft	7 Bft	8 Bft and higher
Wind speed [m/s]	5.5 – 8	8 – 10.8	10.8 – 13.9	13.9 – 17.2	> 17.2
Run M4	0%	14.8%	69.6%	15.7%	0%
Run M5	0%	15.4%	69.8%	14.8%	0%
“1 phase”	0%	15.8%	68.5%	15.7%	0%
“randomised phase”	0.1%	16.5%	65.5%	17.9%	0%

Wind sheltering due to cranes, containers or ships is not taken into account. Based on recent measurements of the port of Antwerp-Bruges they found that days with a predicted mean 6 Bft wind can have higher peaks during the day. Although wind conditions are strong with mean values of 5 and 6 Bft during the simulations, extreme weather conditions with abruptly increasing gusts to higher Bft classes were not applied during this study. It should be considered for further research on emergencies.

2.1.6 Target ships

Target ships have been selected from previous research with Duplex dock and based on AIS analysis of real tracks of ships to the port of Antwerp-Bruges. Especially smaller target ships were added to the simulator environment to model traffic on the Western Scheldt from the different locks and container terminals:

- Berendrecht (BS) and Zandvliet (ZVS) locks
- North Sea terminal (NZT)
- Europe terminal (EUT)
- Deurganck dock south and north quays (DGD_Z and DGD_N)
- Kieldrecht lock (KIS)
- Kallo lock (KAS)
- Boudewijn lock (BWS)

Although not all derived tracks have been used during the simulations, they are presented in the report as they could be used for other projects or pilot training related to the Duplex dock. Previous simulation tracks from the study on the Duplex dock were not added as these contain only tracks of ULCS while managing the steered ULCS from the simulator bridges was already a challenging task.

Different tracks have been selected:

- From previous simulations with ULCS in Duplex dock (Eloot & Verwilligen, 2021):
 - o Duplex_3 head in, inbound, flood, SW5
 - o Duplex_10 head out, outbound, ebb, W5
- From previous traffic simulations with ULCS to the Deurganck dock during the evaluation of the L-square dock (Eloot *et al.*, 2020a):
 - o 00_P1 Buoy 66 to mouth DGD
 - o 00_P3: buoy 89 to swinging and astern DGD North
 - o 00_P4: DGD south to buoy 82a
 - o 01_P3: Buoy 93 to swinging and aft DGD
 - o 02_P2: Buoy 81a to DGD swinging and astern
 - o 04_P1: Buoy 89 to DGD swinging and astern
 - o 07_P1: Buoy 93 to DGD swinging and astern
 - o 08_P3: Buoy 89 to DGD swinging and astern DGD North
- From AIS analysis executed in the framework of (Verwilligen *et al.*, 2021b) and (Verwilligen *et al.*, 2021a) a list is presented in Table 2 for outbound AIS tracks and Table 3 for inbound AIS tracks. The proposed ship from the simulator database to image the target ship is also added in the third column. In the fourth column a small remark on the scenario is added (e.g. when the ship executes a swinging manoeuvre).

In this AIS analysis the track is analysed and presented with chosen tolerances (position 2 m, heading 5 deg and time 60 s) with the speed as taken from the AIS track. In this way the analysed tracks have a realistic position (x,y), a realistic heading (psi) and a realistic speed for each selected target ship. Therefore also the main dimensions of the target ship in relation to the track are important and shown in the name of the track file. Some flexibility is still available to use tracks of larger vessels partially for smaller vessels. Tracks can be adjusted during the simulation to organize meetings with other manned vessels from the simulators.

An example of the use of target ships during run M3 is shown in Figure 8.

Table 2 – Outbound AIS tracks for target ships

Area	AIS Track	Ship from database	Scenario remark
BS	Afvaart_BS_id300_L180m_B300dm_own	Equinox agnandoussa	
BWS	Afvaart_BWS_id73_L209m_B300dm_own	Flaminia (32.2 m)	
BWS	Afvaart_BWS_id113_L180m_B300dm_own	Equinox agnandoussa	
DGD_N	Afvaart_DGD_N_id24_L396m_B590dm_own	Triple-Eirene	
DGD_N	Afvaart_DGD_N_id120_L399m_B600dm_own	Triple-Eirene	
DGD_N	Afvaart_DGD_N_id229_L203m_B250dm_own	Borchard (134.4 m)	Swinging end dock
DGD_N	Afvaart_DGD_N_id1426_L242m_B320dm_own	Trio container	
DGD_N	Afvaart_DGD_N_id1489_L237m_B320dm_own	Trio container	
DGD_Z	Afvaart_DGD_Z_id49_L400m_B590dm_own	Triple-Eirene	
DGD_Z	Afvaart_DGD_Z_id347_L294m_B320dm_own	Dozen express (300 m) City of Ghent (255 m)	Swinging end dock
DGD_Z	Afvaart_DGD_Z_id539_L366m_B480dm_own	UASC_Dubai	
DGD_Z	Afvaart_DGD_Z_id766_L292m_B320dm_own	Dozen express (300 m)	
EUT	Afvaart_EUT_id386_L294m_B320dm_own	Dozen express (300 m)	Swinging BS-ZVS
EUT	Afvaart_EUT_id441_L294m_B320dm_own	Dozen express (300 m)	Swinging Frederik
KAS	Afvaart_KAS_id283_L296m_B380dm_own	MSC Borgerhout (40 m)	
KAS	Afvaart_KAS_id347_L296m_B370dm_own	MSC Borgerhout (40 m)	
KAS	Afvaart_KAS_id460_L184m_B320dm_own	Autobus	Passing EUT east
KAS	Afvaart_KAS_id556_L218m_B270dm_own	Mandarine (28.4 m)	
KIS	Afvaart_KIS_id268_L214m_B320dm_own	Fidelio (227.8 m) Pauline (203 m)	
KIS	Afvaart_KIS_id755_L300m_B400dm_own	MSC Borgerhout	
KIS	Afvaart_KIS_id1020_L328m_B460dm_own	MSC Borgerhout	
NZT	Afvaart_NZT_id434_L364m_B510dm_own	UASC_Dubai	
NZT	Afvaart_NZT_id569_L304m_B400dm_own	MSC Borgerhout	

Area	AIS Track	Ship from database	Scenario remark
NZT	Afvaart_NZT_id592_L349m_B450dm_own	Sissi_Maersk	Swinging at depart
NZT	Afvaart_NZT_id628_L366m_B510dm_own	UASC_Dubai	
ZVS	Afvaart_ZVS_id642_L213m_B320dm_own	Rhone (173 m)	

Table 3 – Inbound AIS tracks for target ships

Area	AIS Track	Ship from database	Scenario
BS	Opvaart_BS_id556_L253m_B420dm_own	SKS Dionysus (45 m)	
BS	Opvaart_BS_id574_L230m_B370dm_own	Trio container (235 m)	
BWS	Opvaart_BWS_id26_L183m_B320dm_own	Brochard (22.5 m) Flaminia (209 m)	
BWS	Opvaart_BWS_id29_L200m_B300dm_own	Rhone (173 m)	
DGD_N	Opvaart_DGD_N_id47_L396m_B590dm_own	Triple-Eirene	
DGD_N	Opvaart_DGD_N_id116_L399m_B600dm_own	Triple-Eirene	
DGD_N	Opvaart_DGD_N_id377_L399m_B600dm_own	Triple-Eirene	
DGD_N	Opvaart_DGD_N_id389_L300m_B400dm_own	MSC Borgerhout	
DGD_Z	Opvaart_DGD_Z_id100_L363m_B460dm_own	UASC_Dubai (48 m)	
DGD_Z	Opvaart_DGD_Z_id454_L400m_B590dm_own	Triple-Eirene	
DGD_Z	Opvaart_DGD_Z_id723_L260m_B320dm_own	City of Ghent	Start dock
DGD_Z	Opvaart_DGD_Z_id726_L337m_B450dm_own	Sissi Maersk (352 m)	End dock
EUT	Opvaart_EUT_id183_L333m_B480dm_own	MSC Borgerhout (300 m)	Swinging BS-ZVS
EUT	Opvaart_EUT_id517_L294m_B320dm_own	Dozen Express (300 m)	
KAS	Opvaart_KAS_id146_L230m_B320dm_own	Trio container	Passing DGD East
KAS	Opvaart_KAS_id223_L240m_B380dm_own	Trio container	Passing DGD West
KIS	Opvaart_KIS_id165_L200m_B320dm_own	Flaminia (209.57 m)	
NZT	Opvaart_NZT_id278_L368m_B510dm_own	UASC_Dubai	

Area	AIS Track	Ship from database	Scenario
NZT	Opvaart_NZT_id472_L366m_B480dm_own	UASC_Dubai	Swinging SS
NZT	Opvaart_NZT_id544_L234m_B440dm_own	MSC Borgerhout (300 m) Trio container (32.26 m)	To North quay
NZT	Opvaart_NZT_id609_L366m_B510dm_own	UASC_Dubai	
ZVS	Opvaart_ZVS_id59_L219m_B380dm_own	Rhone (173 m)	
ZVS	Opvaart_ZVS_id568_L266m_B360dm_own	City of Ghent	

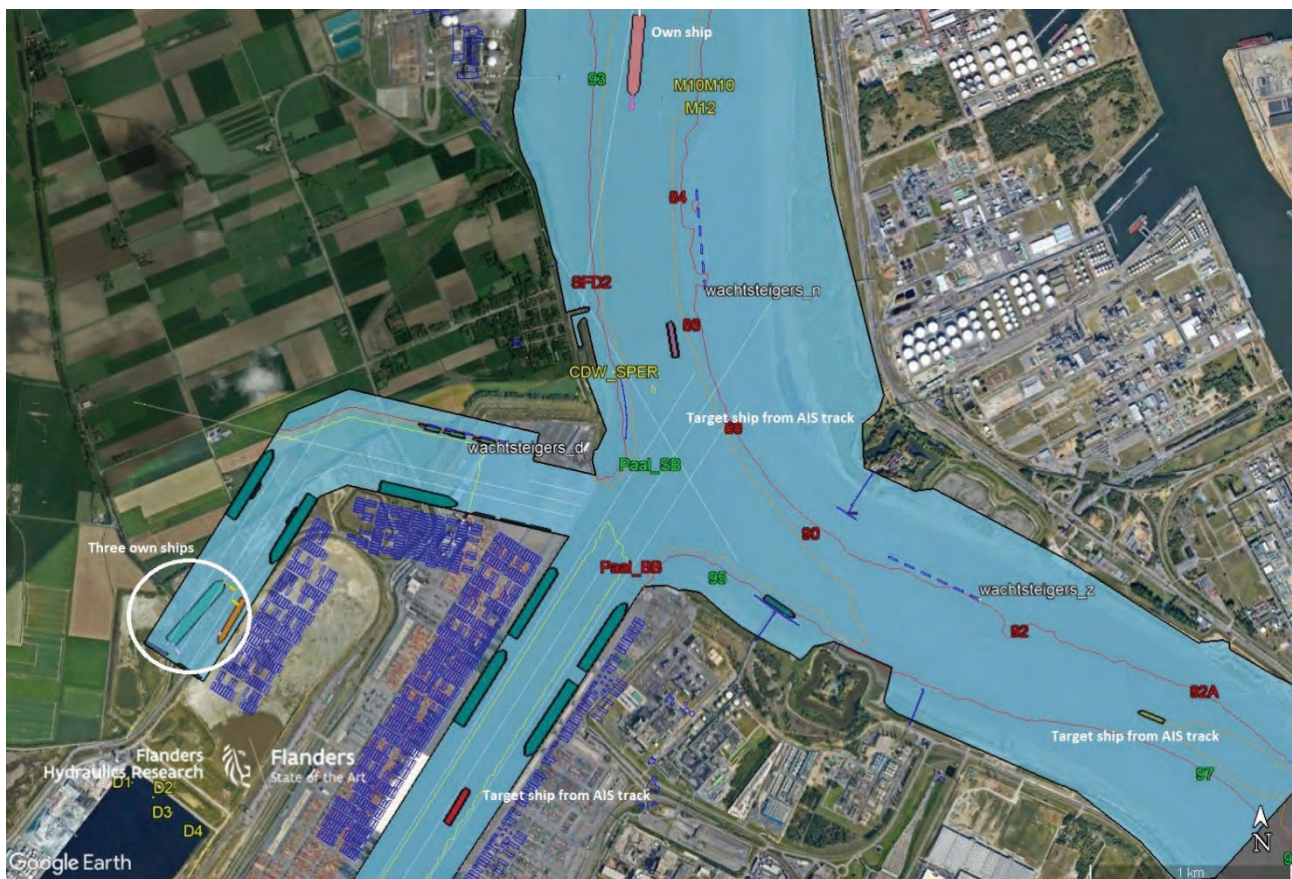


Figure 8 – Use of target ships from AIS tracks during traffic simulations with four ‘own’ ships steered from simulators, run M3

2.2 Ships

The design ship for the second tidal dock alternatives is a 430 m ULCS with a beam of 62 m (Appendix 1). In the simulation study for Duplex dock with individual simulation runs, a 400 m ULCS with a beam of 61.5 m had also been used. During the meeting with the members of Alfaport and Voka an illustration of Megamax and Gigamax container ships have been shared (Figure 9). Due to lack of information it was decided not to change the design ship (to a 425 m vessel with a beam of 66.1 m) but to take the width of a moored ULCS into account by implementing bunker ships alongside the ships (width of the design ship with bunker ship increase above 75 m).

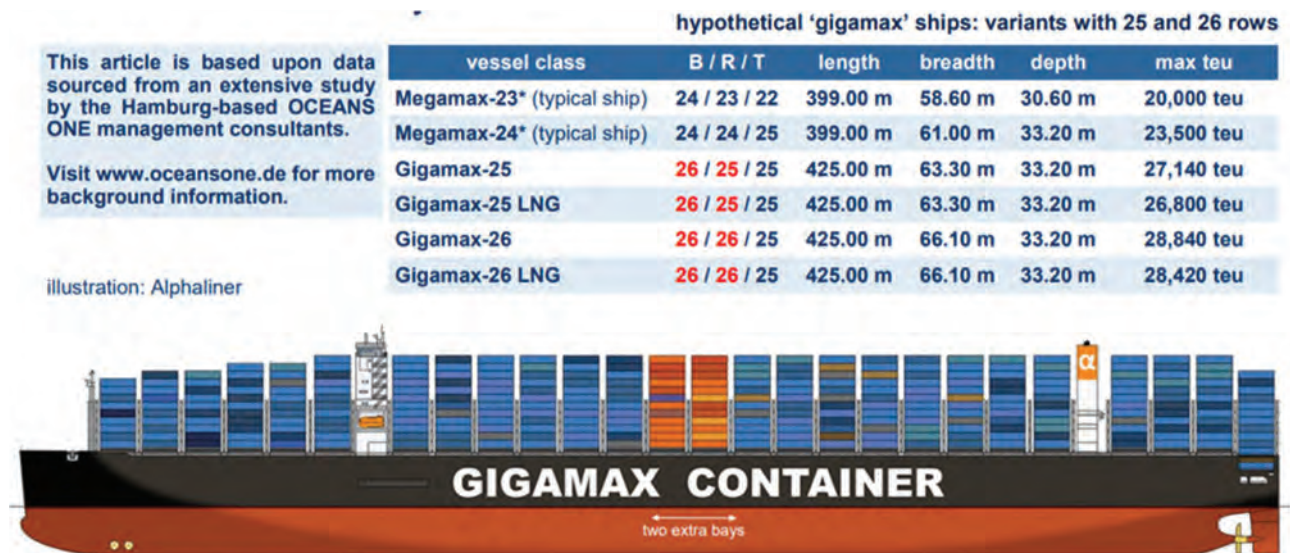


Figure 9 – Illustration of Alphaliner on Megamax and Gigamax container ships dimensions

Important for the comparison of the 430 m and 400 m vessel is that the 430 m ULCS had one bow thruster with a power of 3170 kW while the two bow thrusters of the 400 m ULCS (based on real data of (recent generation 400 m ULCS) had each 3000 kW power, which is almost twice the power of the bow thruster of the 430 m ULCS. This conservative approach for real ULCS of 425 m and higher has to be considered during the analysis of the simulations.

Simulations have also been executed with smaller container ships of length 367, 255 and 210 m and inland container ships such as a 135 m motorship and a 110 m and 191 m (with beam 22.8 m) push convoy. Details of these ships will not be given.

2.3 Simulation program

2.3.1 Description

Three consecutive Mondays: March 7, 14 and 21 2022, Flemish and Dutch pilots (two on SIM225 and SIM360+ and one on SIM5 and Lara, total of 6 pilots per day – 5 on March 14 and two skippers) simulated with the assistance of tug captains of Boluda and Antwerp Towage for the steering of the tug module.

The simulation parameters can be summarised as:

- Duplex alternative
- Tide and current: static or dynamic with focus on maximum flood and ebb conditions; a low water condition is interesting for a scenario with all ships tide-independent.
- Wind: the emphasis was on strong wind conditions of 5 and 6 Bft. The direction is varied per scenario.
- Ship (see §2.2): The draft for the ULCS could be varied between 12 m and 16 m for the 400 m vessels and 15 m or higher for the 430 m. Based on this restriction some scenarios at ebb tide are executed with the 430 m vessel at 15 m draft although the ship will not manoeuvre nearby Deurganck dock on the river in these circumstances (tide dependent).
- In- and outbound
- Head in or head out manoeuvre
- Destination: Duplex dock or DGD during inbound and Bath during outbound sailing, the inland vessel changes direction and destination during the simulation to introduce different manoeuvres and interactions with the other vessels.
- Number of tugs of which all are Azimuth Stern Drive tugs of 80 ton bollard pull for the ULCS and tugs with smaller bollard pull (e.g. 60 ton) for smaller containerships.

2.3.2 Simulation program

The executed simulation runs are presented in Table 4, Table 5 and Table 6 for respectively March 7, 14 and 21 2022.

Scenarios with only Ultra Large Container ships (ULCS) or for March 14th with three ULCS and one inland ship are named UX with player indicated as P1 to P4. On March 14th the inland ship was always player P3. Scenarios with multivariant ships of different sizes are named as MX with player indicated as P1 to P4.

The program is summarised based on:

- Scenario name: UX or MX
- Current/tide: for static and dynamic current/tide the start hour in the tidal cycle is indicated with addition of 'dyn' for dynamic tide.
- Wind speed in Bft scale and wind direction in compass rose
- Player P1 to P4
- Simulator used for each player
- Ship with length in m and draft in dm
- Inbound or outbound manoeuvre with start location such as B(uoy) plus number, NZT (North Sea Terminal), EUT (Europe terminal), DX (Duplex dock), DGD (Deurganck dock) and CP (coordination point)
- Head in (HI) or head out (HO) manoeuvre
- (Intermediate) Destination
- Number of tugs and bollard pull: F fore tug, A aft tug, P pusher and 80 or 60 ton.
- Planning before the execution of the scenario.

Table 4 – Overview of program Monday March 7 2022

Scenario	Current/Tide	Wind speed	Wind direction	Player	Simulator	Ship (L m / T dm)	IN/OUT	Head in/out	Destination	Tugs	Planning
U1	-1.0h to HW 5 Bft	NW		P1	SIM360	430/150	IN - B93	HO - HI	DGD - DX	F ³ 80 - A 80	Ship with shift to DX, head in, mooring end of dock
				P2	SIM225	400/142	IN - NZT	HO	DX	F 80 - A 80	First passing by mouth DGD - if 400 m/135 dm on river - astern
				P3	Lara	400/135	OUT - DX	HO	Bath	F 80 - A 80	Manoeuvre close to river - prevent space to Ineos
				P4	SIM5	400/150	IN - B79	HI	DX	F 80 - A 80	
U2	+3.3h to HW 5 Bft	NE		P1	SIM360	430/150	IN - B83	HO	DX	F 80 (P) - A 80	
				P2	SIM225	430/150	OUT - DX	HI	Bath	F 80 - A 80	Ship moored at section upstream bend N side
				P3	Lara	400/140	IN - EUT	HI	DX	F 80 - A 80 - A 80	Ship moor at section N side
				P4	SIM5	400/120	OUT - DX	HO	Bath	F 80 - A 80	Ship in section downstream bend
M1	-3.5h to HW 6 Bft	S		P1	SIM360	430/150	OUT - DX	HO	Bath	F 80 - A 80 - A 80	Start at quay downstream bend
				P2	SIM225	400/140	IN - NZT	HO	DX	F 80 - A 80 - P 80	Mooring upstream bend N side
				P3	Lara	210/110	IN - B89a	HI	DX	A 80	Swinging at quay - end of DX dock
				P4	SIM5	255/120	OUT - DX	HO	Bath	A 80	Meeting with 210 m in DX
M2	+1.0h to HW 6 Bft	N		P1	SIM360	430/150	OUT - DX	HO	Bath	F 80 (P) - A 80	Ship moored at section upstream bend end dock
				P2	SIM225	400/150	IN - CP	HI	DX	F 80 - A 80 - P 80	Ship moor upstream bend
				P3	Lara	367/131	IN - B93	HI	DX	F 80 - A 80	
				P4	SIM5	255/120	IN - NZT	HI	DGD	A 80	Pass waiting ship 367 m

³ F fore, A aft, P pusher tug, XX ton e.g. 80 or 60 ton.

Table 5 – Overview of program Monday March 14 2022

Scenario	Current/Tide	Wind speed	Wind direction	Player	Simulator	Ship (L m / T dm)	IN/OUT	Head in/out	Destination	Tugs	Planning
U3	-0.9h to HW	5 Bft	SW	P1	SIM360	430/150	IN - B93	HO	DX	F 80 - A 80	Moor end of dock, check distance tugs
				P2	SIM225	400/120	OUT - DX	HI	Bath	F 80 - A 80 – P 80	First leave the dock
				P3	Lara	110/35				none	Meeting with all ULCS in mouth/entrance; check end of dock if 430 m mooring
				P4	SIM5	400/150	IN - CP	HI	DX	F 80 (P) - A 80 (P)	Last ULCS entering DX
U4	+3.3h to HW	6 Bft	NW	P1	SIM360	400/131	IN - NZT	HO	DX	F 80 - A 80 - P 80	This ship can wait at Phenol before entering DX
				P2	SIM225	430/150	IN - B93	HO	DX	F 80 - A 80 - P 80	This ship can do a manoeuvre to DGD and then to DX, moor DX downstream bend
				P3	Lara	110/40				none	Meeting with all ULCS in mouth/entrance; check end of dock if 430 m mooring
				P4	SIM5	430/150	OUT - DX	HO	Bath	F 80 - A 80 – A 80	First this ship must leave DX
M3	-5.0h to HW dyn	5 Bft	E	P1	SIM360	400/131	IN - B93	HI	DX	F 80 - A 80	Ship will have to wait in DGD until DX free
				P2	SIM225	255/120	OUT - DX	HI-HO	Bath	F 60 - A 60	Swinging in bend
				P3	Lara	110/35				none	Moored end of dock at start, interaction, check waiting area
				P4	SIM5	400/131	OUT - DX	HO	Bath	F 80 - A 80	Moored end of dock west side, tugs
M4	-2.5h to HW dyn	6 Bft	S	P1	SIM360	430/150	IN - NZT	HO	DX	F 80 (P) - A 80 (P) - P 80	Moor first quay DX downstream bend
				P2	SIM225	367/145	IN - B93	HI	DX	F 60 - A 60	Meeting with 210 m in mouth
				P3	Lara	191/40				none	Meeting with all ships in mouth/entrance
				P4	SIM5	210/110	OUT - DGD	HO	Bath	none	Meeting with 367 m in mouth

Table 6 – Overview of program Monday March 21 2022

Scenario	Current/Tide	Wind speed	Wind direction	Player	Simulator	Ship (L m / T dm)	IN/OUT	Head in/out	Destination	Tugs	Planning
U5	-0.9h to HW	5 Bft	E	P1	SIM360	430/150	IN - NZT	HI	DX	F 80 - A 80	Ship moored south side bend DX, second ship
				P2	SIM225	430/150	OUT - DX	HI	Bath	F 80 - A 80	
				P3	Lara	430/150	OUT - DX	HO	Bath	F 80 (P) - F 80 - A 80	First ship to leave at flood
				P4	SIM5	400/131	OUT - DGD	HO	Bath	F 80 - A 80	Ship leaves DGD start end of dock
U6	+3.3h to HW	6 Bft	SW	P1	SIM360	400/131	IN - B93	HI-HO	DGD-DX	F 80 - A 80 - P 80	Ship first sails in DGD (wait for outbound ship) and then in DX astern
				P2	SIM225	430/150	OUT - DX	HO	Bath	P 80 (F) - A 80 - P 80	This ship first leaves DX
				P3	Lara	430/150	IN - NZT	HO	DX	F 80 - A 80 - P 80	Ship does direct manoeuvre astern
				P4	SIM5	430/150	IN - CP	HI	DX	F 80 - A 80 - A 80	Against the current, tugs!
M5	+4.0h to HW dyn	6 Bft	N	P1	SIM360	400/120	OUT - DX	HI	Bath	F 80 - A 80 - A 80	Ship first leaves DX and wait on river or DGD (see inbound)
				P2	SIM225	400/140	IN	HO	DX(1)	F 80 - A 80 - P 80	Passed by 210 m while mooring
				P3	Lara	210/110	IN	HI	DX	A 60	Follows closely 400 m, meeting with 255 m in bend DX, swinging at quay
				P4	SIM5	255/120	OUT - DX	(HI)-HO	Bath	A 60	Meeting with 210 m in bend DX (if HI, swinging in bend?)
M6	-3.5h to HW dyn	6 Bft	W	P1	SIM360	400/131	OUT - DX	HI	Bath	F 80 - A 80 - P 80	Moored west side dock south
				P2	SIM225	400/131	OUT - DX	HO	Bath	F 80 - A 80 - P 80	Moored west side dock north
				P3	Lara	367/145	IN - B93	HI	DX	F 80 - A 80	Meeting with ship in mouth while ship is waiting in entrance DX
				P4	SIM5	255/120	OUT - DGD	HO	Bath	none	Ship passes 367 m while in entrance

3 Analysis

The analysis is discussed on the one hand per individually performed simulation and on the other hand per scenario. The analysis is based on KMZ files which give an overview of the performed tracks of vessels (own and target AIS ships) and tugs in a Google Earth View (digital appendix to the report), feedback from the pilots (standardised and free in Appendix 3) and time charts per vessel/player (Appendix 4).

The analysis is based on a KMZ file per scenario on which the tracks of the ships and the assisting tugs in the scenario are represented and can be replayed. The description for handling these KMZ files is included in Appendix B. With these tracks one can see where the vessels and the tugs were located in relation to the hard infrastructure and the depth lines. On the KMZ following own ships are shown in colour according to the simulator:

SIM360	Red
SIM225	Orange
Lara	Blue
SIM5	Green

Target ships moving based on AIS tracks are in dark red or other colours.

The evolution of the time-dependent data is shown per ship in Appendix 4. In this way one can see how often maximum rudder angle is given, how many times maximum thrust is requested from the bow thrusters and from the tugs. If the requested control aids are large, it is clear that the manoeuvre is performed with little reserve. Taking into account that more difficult conditions (strong wind force 5 and 6 Bft and for some runs maximum flood or ebb current) were chosen to carry out the simulations with ships of at least 400 m, the deployment of the control means (rudder, thrusters and tugs) will in reality for the most part of the year be less than during the simulations. Interesting in the time graphs is the depth at the four corners of the ship (bow/stern and port/starboard side) to check the availability of enough keel clearance at all sides.

3.1 Standardised feedback

The standard feedback form that was answered per simulation run and per player is included in Appendix 3. The objective is to evaluate the pilot's findings on the execution of the manoeuvre (reserve) and on the difficulty level of the manoeuvre (moeilijkheidsgraad).

The scores are summarised for the ULCS of 430 and 400 m or for the smaller container ships. The discussion follows for flood and ebb current conditions. Almost all manoeuvres are executed to/from the Duplex dock. The simulation runs to/from the Deurganck dock are given in *italic*.

3.1.1 Flood current

ULCS

For flood current and ULCS of 400 and 430 m 18 runs have been executed with a static or dynamic flood current with (start) time between -5 hours to 54 minutes before high water Prosperpolder (HW). It was advised to take three tugs of 80 tons for a mean wind velocity of 6 Bft. For some particular manoeuvres (e.g. head out leaving the Duplex dock to the river) three tugs were also proposed even though the wind velocity was 5 Bft.

For all runs the difficulty was set to normal (score 2, Table 7) which means that no particular challenge was dedicated to the executed simulation runs. According to the reserve during the simulations on space and manoeuvring equipment (tugs, thrusters) mostly the reserve was enough (score 2) although for some runs with the 430 m vessel or at low water (-5h to HW) with 400 m vessels there was minimum reserve (score 3).

Table 7 – Standardised feedback for manoeuvres with ULCS at flood tide

Current	Ship	In-Out	Run_player (wind)	# Tugs	Reserve	Difficulty
-0.9h to HW	430 m	In	U3_P1 (SW5)	2 x 80 ton	2	2
	400 m	Out	U3_P2 (SW5)	2 x 80 ton ⁴	2	2
	400 m	In	U3_P4 (SW5)	2 x 80 ton	2	2
	430 m	In	U5_P1 (E5)	2 x 80 ton	2	2
	430 m	Out	U5_P2 (E5)	2 x 80 ton	3	2
	430 m	Out	U5_P3 (E5)	3 x 80 ton	3	2
	<i>400 m⁵</i>	<i>Out</i>	<i>U5_P4 (E5)</i>	<i>2 x 80 ton</i>	2	2
-1.0h to HW	430 m	In	U1_P1 (NW5)	2 x 80 ton	2	2
	400 m	In	U1_P2 (NW5)	2 x 80 ton	2	2
	400 m	Out	U1_P3 (NW5)	2 x 80 ton	2	2
	400 m	In	U1_P4 (NW5)	2 x 80 ton	2	2
-2.5h to HW dyn	430 m	In	M4_P1 (S6)	3 x 80 ton	3	2
-3.5h to HW	430 m	Out	M1_P1 (S6)	3 x 80 ton	3	2
	400 m	In	M1_P2 (S6)	3 x 80 ton	2	2
-3.5h to HW dyn	400 m	Out	M6_P1 (W6)	3 x 80 ton	2	2
	400 m	Out	M6_P2 (W6)	3 x 80 ton	2	2
-5h to HW dyn	400 m	In	M3_P1 (E5)	2 x 80 ton	3 ⁶	2
	400 m	Out	M3_P4 (E5)	2 x 80 ton	3	2

⁴ Plus pusher only at departure

⁵ A run in italic means that the destination or start was the Deurganck dock and not the Duplex dock.

⁶ Reserve is 3 but 2 for taking the bend in Duplex as the wind helps the manoeuvre.

Container ships with length ≤ 367 m

For the smaller container ships 10 runs have been executed of which three with inland ships. For these ships no evaluation was made because there is no restriction for the environmental conditions set during the simulations. In one condition with a 367 m vessel at S 6 Bft wind, the reserve is evaluated as minimum (score 3, Table 8). For the other conditions the reserve is enough or even more while the difficulty changes between normal (score 2) and smoothly (score 1) executed.

Table 8 – Standardised feedback for manoeuvres with smaller container ships at flood tide

Current	Ship	In-Out	Run_player (wind)	# Tugs	Reserve	Difficulty
-0.9h to HW	135 m	-	U3_P3 (SW5)	no	no restriction	
-2.5h to HW dyn	367 m	In	M4_P2 (S6)	2 x 60 ton	3	2
	191 m	-	M4_P3 (S6)	no	no restriction	
	210 m	Out	M4_P4 (S6)	no	2	2
-3.5h to HW	210 m	In	M1_P3 (S6)	1 x 80 ton ⁷	1 ⁸	1
	255 m	Out	M1_P4 (S6)	1 x 80 ton	2	1
-3.5h to HW dyn	367 m	In	M6_P3 (W6)	2 x 80 ton	2	2
	255 m	Out	M6_P4 (W6)	no	1	1
-5h to HW dyn	255 m	Out	M3_P2 (E5)	2 x 60 ton	2 ⁹	2
	135 m	-	M3_P3 (E5)	no	no restriction	

3.1.2 Ebb current

ULCS

For the ebb current comparable conclusions can be drawn as for the flood current discussed in 3.1.1. 15 simulations are reported in Table 9 with the current changing between 1 to 4 hours after HW. The simulation U4_P2 at maximum ebb tide and NW 6 Bft was evaluated as more than normal difficulty as the 430 m vessel had a draft of 15 m (not expected in reality for maximum ebb tide due to tidal restrictions downstream) and such a large vessel in lower under keel clearance and strong current is expected to manoeuvre with difficulty.

⁷ A 60 ton tug for the 210 m and 255 m container ship would have been sufficient.

⁸ During the swinging manoeuvre nearby the quay the quay was not visible, nor on the view as on the portable pilot unit so that contact with the quay occurred although this could be avoided in real life.

⁹ No reserve during the meeting.

The influence of the current becomes clear when the current condition ‘stil van hoog’ is applied with a small magnitude and changing direction at approximately 1.0h after high water condition and the difficulty is evaluated for run M2_P2 as smoothly executed. For the reserve the 430 m ULCS gets more score 3 (minimum reserve) while for the 400 m vessel at lower tide (4.0h after HW) this score is also given. For the other simulations at ebb enough reserve (score 2) is chosen.

Table 9 – Standardised feedback for manoeuvres with ULCS at ebb tide

Current	Ship	In-Out	Run_player (wind)	# Tugs	Reserve	Difficulty
+1.0h to HW	430 m	Out	M2_P1 (N6)	2 x 80 ton	2	2
	400 m	In	M2_P2 (N6)	3 x 80 ton	2	1
+3.3h to HW	430 m	In	U2_P1 (NE5)	2 x 80 ton	2	2
	430 m	Out	U2_P2 (NE5)	2 x 80 ton	3	2
	400 m	In	U2_P3 (NE5)	3 x 80 ton	2	2
	400 m	Out	U2_P4 (NE5)	2 x 80 ton	2	2
	400 m	In	U4_P1 (NW6)	3 x 80 ton	- ¹⁰	-
	430 m	In	U4_P2 (NW6)	3 x 80 ton	3	3
	430 m	Out	U4_P4 (NW6)	3 x 80 ton	3	2
	400 m	In	U6_P1 (SW6)	3 x 80 ton	2	2
	430 m	Out	U6_P2 (SW6)	3 x 80 ton	3 ¹¹	2
	430 m	In	U6_P3 (SW6)	3 x 80 ton	3	2
	430 m	In	U6_P4 (SW6)	3 x 80 ton	2	2
+4.0h to HW dyn	400 m	Out	M5_P1 (N6)	3 x 80 ton	3	2
	400 m	In	M5_P2 (N6)	3 x 80 ton	3	2

Container ships with length ≤ 367 m

5 runs have been executed with smaller container ships at ebb tide (after high water) and are summarised in Table 10. The reserve in run M5_P3 was restricted because of the strong interaction between the inbound sailing vessel and an outbound sailing ULCS. The entrance manoeuvre was influenced and the distance to the southern wall of Duplex dock while turning into the dock was minimal.

¹⁰ The scores were forgotten to give and only a feedback was captured in Appendix 3.

¹¹ 3 at departure but 2 after departure

Also for run M5_P4 swinging with a 255 m vessel in a restricted area of 285 m in between quay and moored vessels is not advised and should be avoided. For the other two runs with sea-going vessels the reserve is between large and enough. The difficulty was between smooth and normal.

Table 10 – Standardised feedback for manoeuvres with smaller container ships at ebb tide

Current	Ship	In-Out	Run_player (wind)	# Tugs	Reserve	Difficulty
+1.0h to HW	367 m	In	M2_P3 (N6)	2 x 80 ton	2	2
	255 m	In	M2_P4 (N6)	1 x 80 ton	1	1
+3.3h to HW	110 m	-	U4_P3 (NW6)	no	no restriction	
+4.0h to HW dyn	210 m	In	M5_P3 (N6)	1 x 60 ton	3	2
	255 m	Out	M5_P4 (N6)	1 x 60 ton	3 ¹²	2

3.2 Analysis for individual runs

In this chapter only individual runs of the sea-going containerships will be discussed and compared for following conditions:

- Flood: inbound and outbound to/from Deurganck dock. It is possible that the final destination of the inbound vessel is the Duplex dock but in some runs the Deurganck dock is used as intermediate waiting location.
- Flood: inbound manoeuvres (directly) to Duplex dock
- Flood: outbound manoeuvres from Duplex dock
- Ebb: inbound and outbound to/from Deurganck dock (also with final destination/start Duplex dock).
- Ebb: inbound manoeuvres (directly) to Duplex dock
- Ebb: outbound manoeuvres from Duplex dock

As head in and head out manoeuvres to the Duplex dock are executed a distinction based on this parameter gives additional background.

3.2.1 Manoeuvres to/from Deurganck dock at flood

A distinction can be made between ships with destination or departure the Deurganck dock (U5_P4, M4_P4, M6_P4) or ships that are temporarily using the Deurganck dock as waiting area before going to the Duplex dock (U1_P1, M6_P3, M3_P1). The individual runs are discussed starting with highest flood current to lowest current. An overview of the tug configuration¹³ for runs to/from Deurganck dock at flood are summarised in Table 11.

¹² 3 for the swinging manoeuvre and 2 for the rest of the simulation

¹³ The tug numbering is linked to the time graphs in Appendix 4 and in the dedicated figures in the report with tug 1, 2, 3 and 4.

Table 11 – Tug configuration for simulation runs to/from Deurganck dock at flood

Run	Ship (L m / T dm)	Current	HI/HO	Dock	Wind	Tug 1	Tug 2	Tug 3	Tug 4
U5_P4	400/131	-0.9h to HW	HO	DGD	E5	F 80	A 80	-	-
U1_P1	430/150	-1.0h to HW	HI	DX	NW5	F 80	A 80	-	-
M4_P4	210/110	-2.5h to HW	HO	DGD	S6	-	-	-	-
M6_P3	367/145	-3.5h to HW	HI	DX	W6	F 80	A 80	-	-
M6_P4	255/120		HO	DGD	W6	-	-	-	-
M3_P1	400/131	-5.0h to HW dyn	HI	DX	E5	-	-	A 80	F 80

Scenario U5 at maximum flood tide (-0.9h to HW) and easterly 5 Bft wind is for U5_P4 a scenario where the ship is leaving the Deurganck dock in a regular head out manoeuvre while following U5_P3 once on the river at a short distance and meeting with the ULCS U5_P1 (Figure 10). One fore and one aft tug have been used. The full track with the tug, bow thrusters use and speed variation is shown in Figure 11.

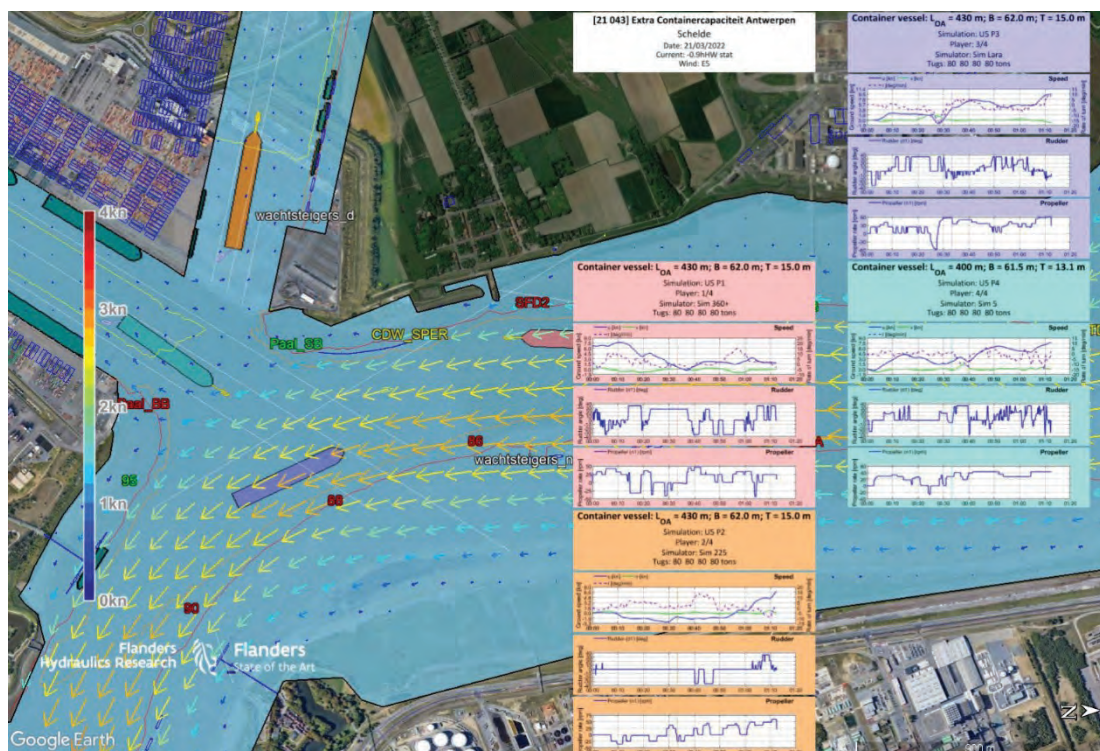


Figure 10 – Scenario U5 [minute 33]: U5_P4 (green) from Deurganck dock at -0.9h to HW

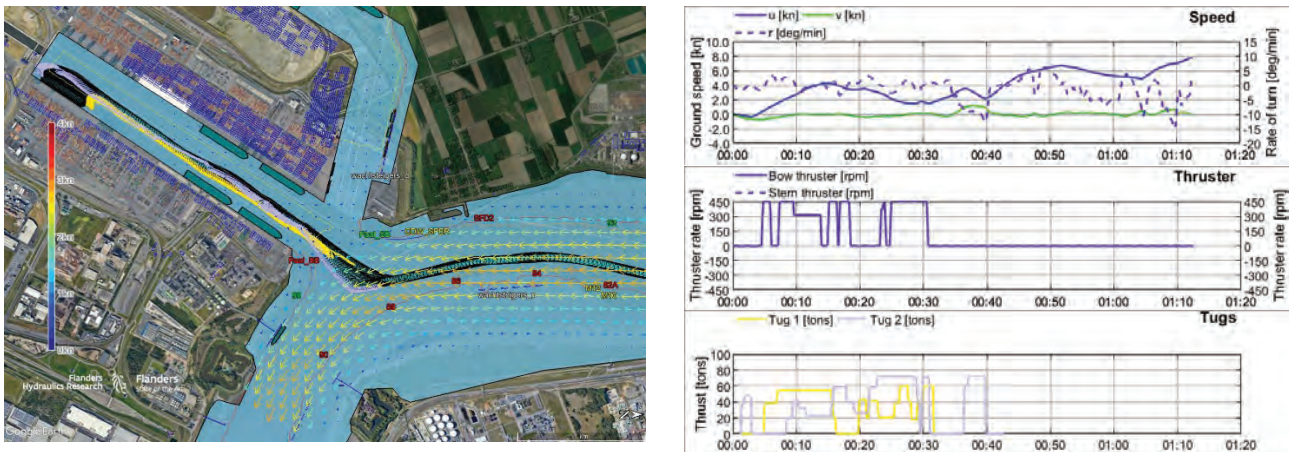


Figure 11 – Run U5_P4 [duration 0 to 52 min shown on map]: classical manoeuvre from Deurganck dock to the river¹⁴

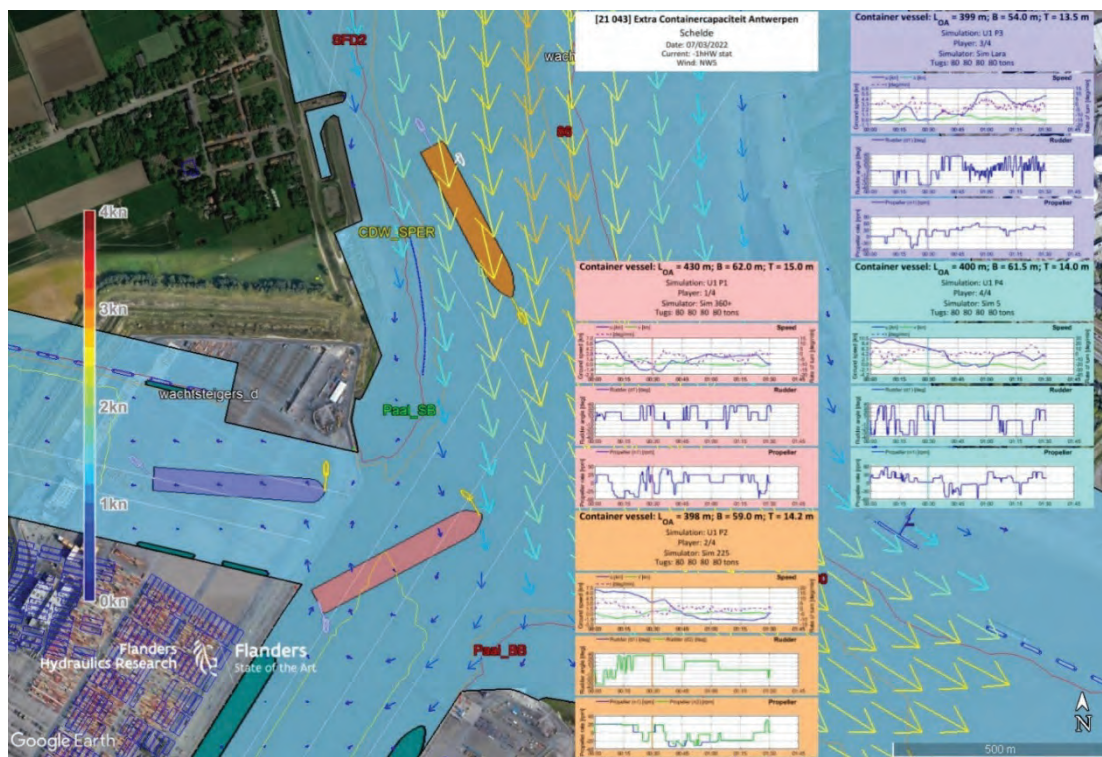


Figure 12 – Scenario U1 [minute 29]: U1_P1 (red) to Deurganck dock at -1h to HW

Scenario U1 at maximum flood current (-1.0h to HW) is for U1_P1 a scenario where U1_P3 has still to leave the Duplex dock before U1_P1 can enter the dock (Figure 12). U1_P1 executes a classical astern manoeuvre to Deurganck dock, waits in DGD so that the mouth between the entrance of Duplex and DGD is free and later enters the Duplex dock. The total manoeuvre shown in Figure 13 takes 112 min (from half way buoy 91-93 until alongside the quay at the end of the dock). The thruster and tugs fore and aft are used at maximum power during the swinging manoeuvre to DGD and the ship passes the quay closely. The thruster and fore tug are at maximum power during the turning manoeuvre into Duplex dock.

¹⁴ The stern thruster in the thruster's graph is a second bow thruster for the 400 m ULCS. This is for all figures in the report where a stern thruster is mentioned.

Remembering the reduced (half) power of the bow thruster of the 430 m ULCS (non-existing) compared to the 400 m recent generation ULCS, this maximum thruster use could be expected.

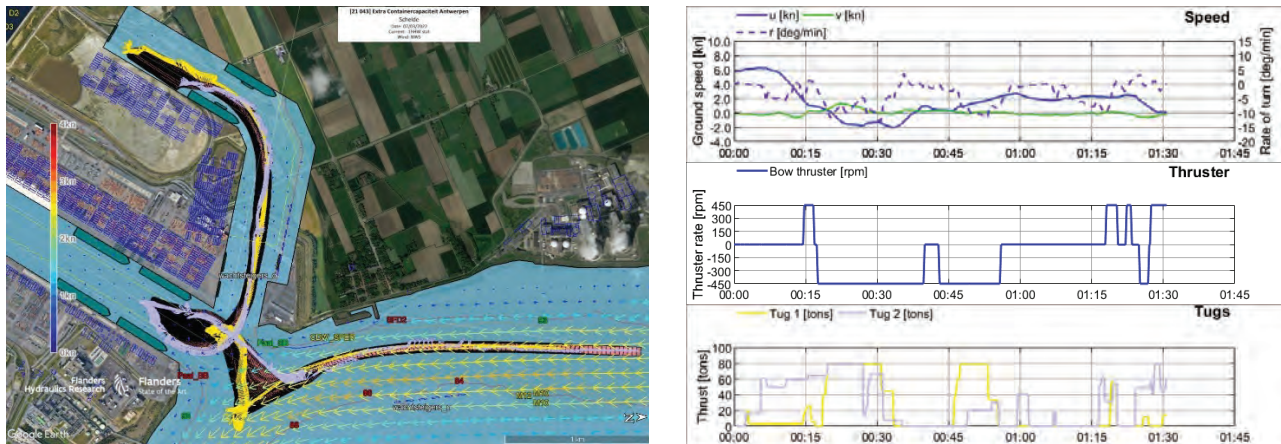


Figure 13 – Run U1_P1 [duration 112 min]: classical manoeuvre to Deurganck dock followed by a manoeuvre head in to Duplex dock

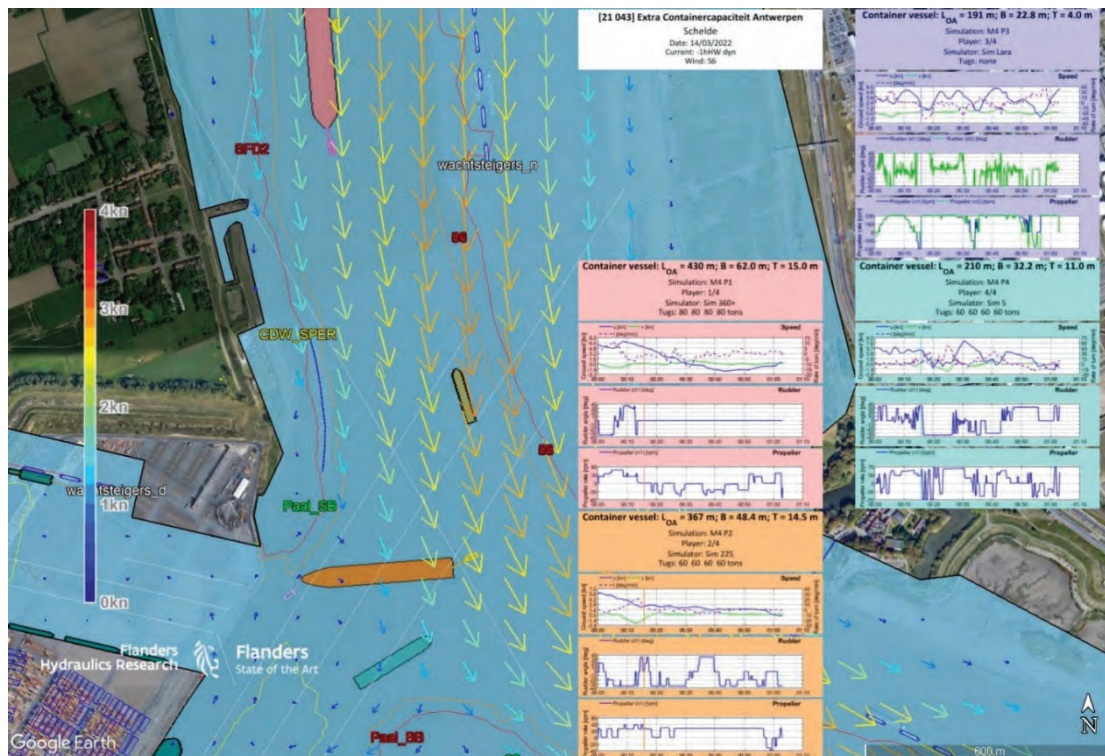


Figure 14 – Scenario M4 [minute 15]: M4_P4 (green) from Deurganck dock at -2.5h to HW

Scenario M4 with dynamic flood current starting at -2.5h to HW is for M4_P4 (Figure 14) a scenario where M4_P4 tries to pass by the head in incoming player M4_P2 while being in the mouth of DGD approaching the stronger current on the river. Consequently the ship is caught by the current and cannot fulfil a direct head out manoeuvre (Figure 15). Only by executing a unintended swinging manoeuvre over starboard the current can be compensated and the head out manoeuvre continues after finishing the swinging. The 210 m vessel obtains a rate of turn up to 50 deg/min during swinging with the thruster rate from time to time at maximum power to speed up the manoeuvre on the river.

In future the pilot should avoid this inconvenient manoeuvre by waiting longer in the protected Deurganck dock until the ULCS passed the DGD mouth, before sailing to the river with a heading more in line with the current.

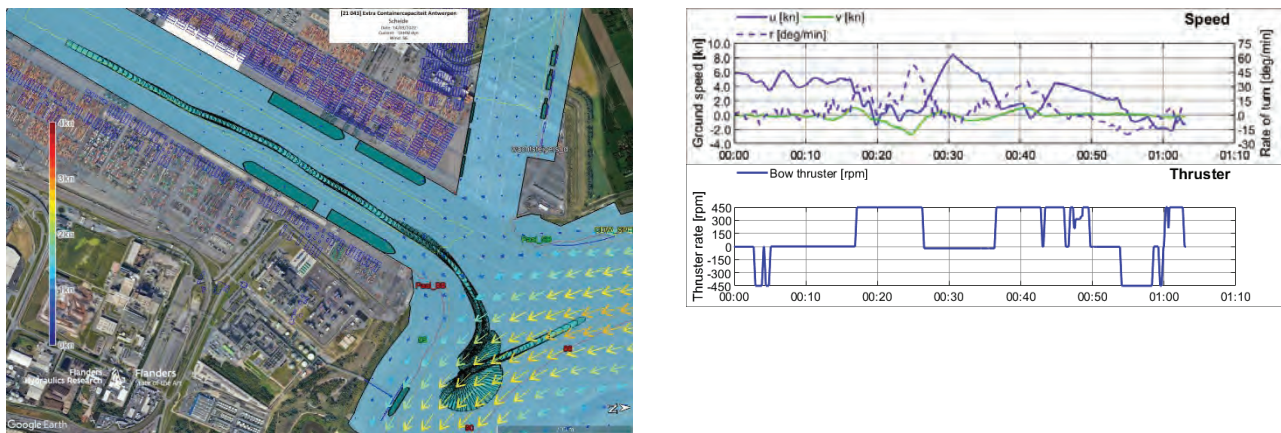


Figure 15 – Run M4_P4 [duration 0 to 30 min shown on map]: departure from Deurganck dock but due to a meeting with another vessel in the mouth the vessel is taken by the flood current

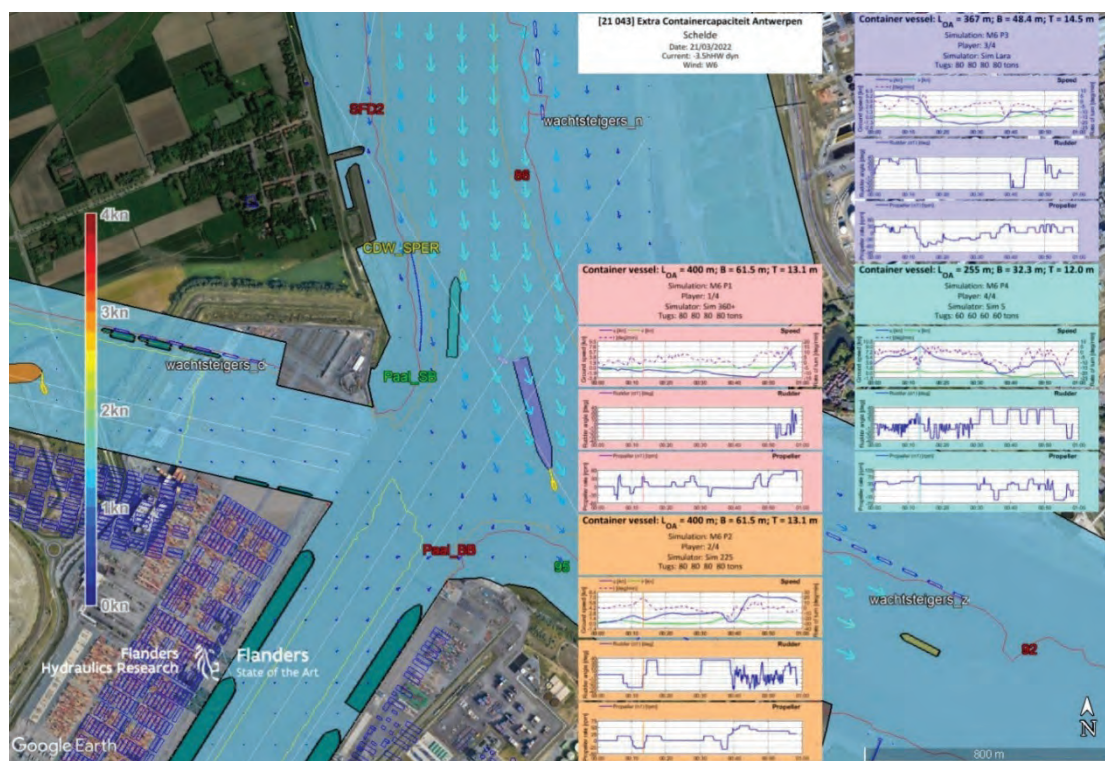


Figure 16 – Scenario M6 [minute 13]: M6_P4 (green) from Deurganck dock at -3.5h to HW and M6_P3 (purple) swinging astern to Deurganck dock followed by head in to Duplex dock

Scenario M6 (Figure 16) starts at -3.5h to HW with a reduced flood current and M6_P4 (Figure 18) is leaving the Deurganck dock at the green side while M6_P3 is preparing an astern swinging manoeuvre to Deurganck dock (Figure 17) followed by a turning to Duplex dock. The thruster is regularly used at maximum power while the fore tug has still reserve and the aft tug gives maximum bollard for less than 10 minutes.

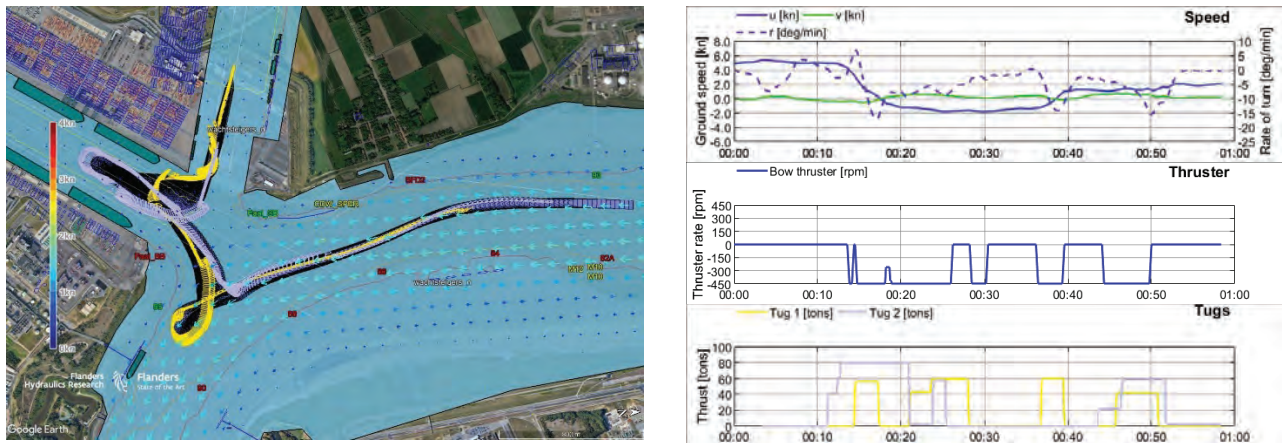


Figure 17 – Run M6_P3 [duration 58 min]: classical manoeuvre to Deurganck dock followed by a head in manoeuvre to Duplex dock

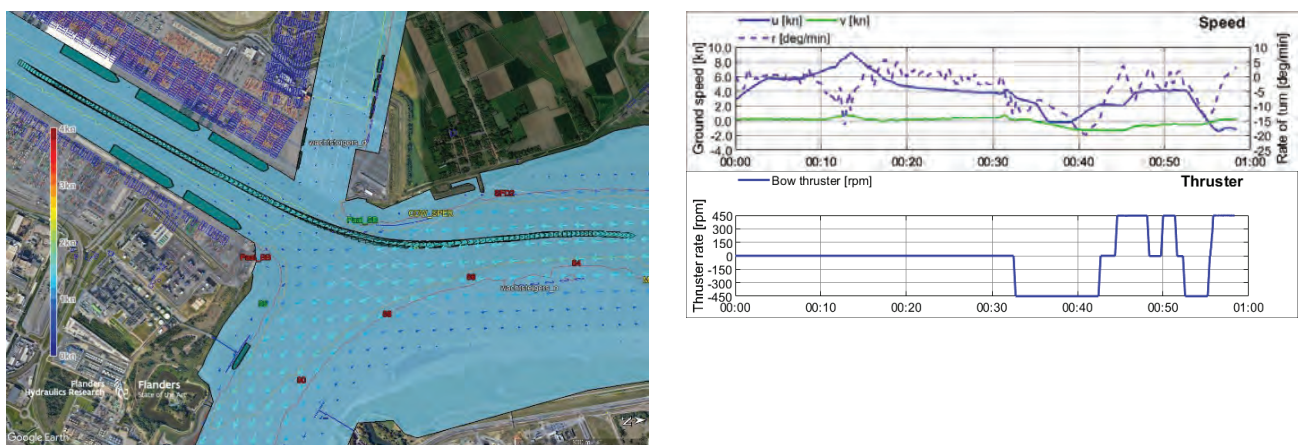


Figure 18 – Run M6_P4 [duration 0 to 19 min shown on map]: classical manoeuvre from Deurganck dock

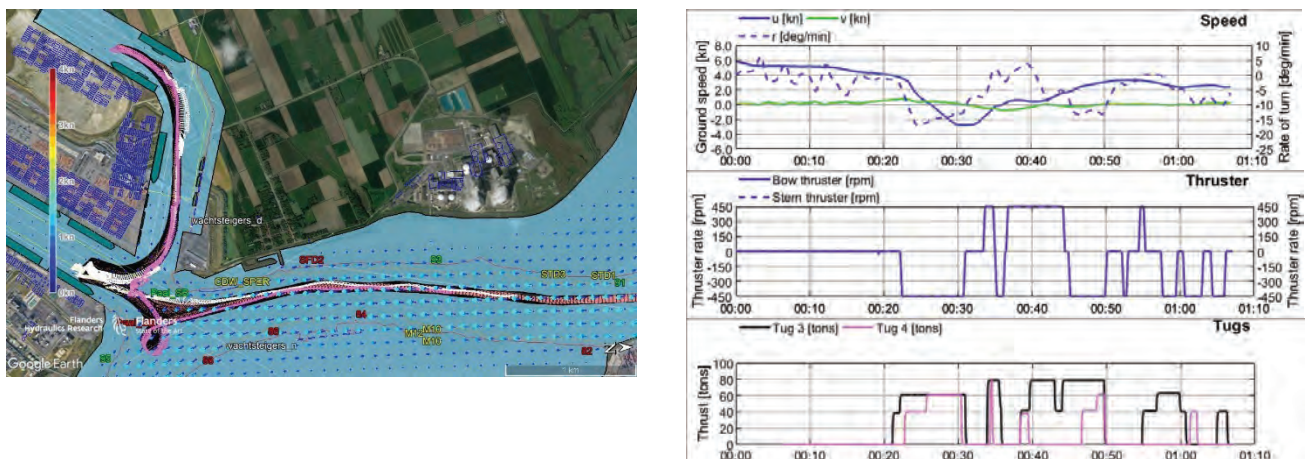


Figure 19 – Run M3_P1 [duration 67 min]: classical manoeuvre to Deurganck dock followed by a head in manoeuvre to Duplex dock

Starting at lower water (-5.0h to HW) M3_P1 in scenario M3 executes a classical swinging manoeuvre to DGD followed by a head in manoeuvre to Duplex dock. The manoeuvre is presented in Figure 19 and shows a very short distance with the aft ship and aft tug nearby the moored ship at the eastern quay in DGD. Compensating the easterly wind by sailing close to this quay gave this result. Turning into Duplex dock from DGD is counteracted by easterly wind while in the bend in Duplex dock the ship stern is helped by the wind while turning. The aft tug (tug 3) is used at maximum power to avoid collision with the moored ship in DGD and while turning into Duplex dock. Bow thruster use is regularly at maximum power while there is some reserve left on the fore tug (tug 4).

The swept paths with intermediate waiting at DGD are shown in Figure 20 (without tugs) with two white crosslines¹⁵ at the entrance of Deurganck dock and in the Duplex dock to validate the timing for the completion of the head in manoeuvre with blocking the mouth of the dock. The time needed for each run to pass the two crosslines is 35.2, 26.8 or 34.7 min for respectively run U1_P1, M3_P1 and M6_P3. M3_P1 (smallest draft) has the shortest time as it is the vessel that also went less far in the DGD while going astern.

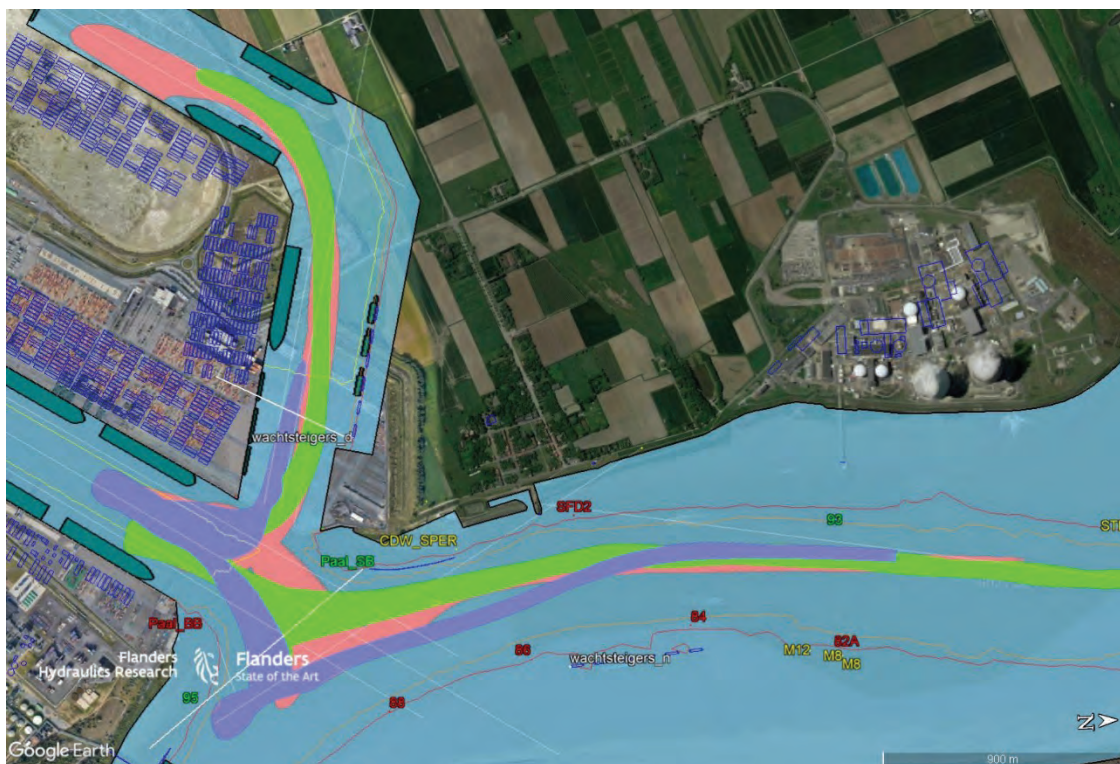


Figure 20 – Comparison of runs U1_P1 (red), M3_P1 (green) and M6_P3 (purple) for head in manoeuvre to Duplex dock with intermediate position in Deurganck dock at flood

¹⁵ The Lambert coordinates of the crosslines are based on (Verwilligen *et al.*, 2021a) and reported in Appendix 5.

3.2.2 Manoeuvres to Duplex dock at flood

The simulations to Duplex dock at flood tide are divided in the head in and head out manoeuvres.

Head in

An overview of the tug configuration for the head in runs is given in Table 12. The runs to Duplex dock discussed in 3.2.1 will not be repeated.

Runs U3_P4, U5_P1 and U1_P4 are executed at maximum flood (-0.9h or -1h to HW) with wind force 5 Bft (varying direction) and two 80 ton tugs. The swept paths of the ships without tugs are shown in Figure 21. Distances to infrastructure are acceptable. The use of tugs and thrusters for all runs (not in 3.2.1) in Table 12 is shown in Figure 22. Generally the required power of the fore tug is limited while the thruster is mainly used as steering device at the bow. There is still reserve on the fore tug and thruster combination while for the stern tug assistance is often required (also to maximum bollard pull) but acceptable. On Figure 21 the two white crosslines are shown at the entrance of Deurganck dock and in the Duplex dock, as in §3.2.1, to validate the timing for the completion of the head in manoeuvre with blocking the mouth of the dock. The times for U3_P4, U5_P1 and U1_P4 are 15.6, 10.1 and 10.0 min so that the run with the widest swept path in the dock mouth (largest effect of flood) increases the time with 50% compared to the other runs. Sailing closer to the current deflecting wall (CDW) helps in reducing the current effect and the time. The passing time is approximately one third of the time reported in §3.2.1 for a manoeuvre with intermediate waiting in DGD.

Run M4_P2 with a 367 m and M1_P3 with a 210 m vessel are presented in Figure 23 and smaller 60 ton bollard pull tugs are used or no tugs for the 210 m except for the swinging manoeuvre in the restricted area of the Duplex dock with moored ULCS at the opposite quay. Due to the southern 6 Bft wind M4_P2 comes close to the northern wall of the Duplex dock at the entrance and the aft tug (tug 1) has to counteract the wind effect at full power during at least 15 min. The time to pass the crosslines as for the other runs is 9.7 min for M4_P2 and 7.0 min for M1_P3 and thus smaller than for the ULCS.

Table 12 – Tug configuration for simulation runs to Duplex dock at flood and head in

Run	Ship (L m / T dm)	Current	Wind	Tug 1	Tug 2	Tug 3	Tug 4
U3_P4	400/150	-0.9h to HW	SW5	F 80 - P	A 80 - P	-	-
U5_P1	430/150		E5	F 80	A 80		
U1_P1 ¹⁶	430/150	-1h to HW	NW5	F 80	A 80		
U1_P4	400/150			F 80	A 80	-	-
M4_P2	367/145	-2.5h to HW dyn	S6	A 60	F 60	-	-
M1_P3	210/110	-3.5h to HW	S6	-	A 80	-	-
M6_P3	367/145	-3.5h to HW dyn	W6	F 80	A 80	-	-
M3_P1	400/131	-5h to HW dyn	E5	-	-	A 80	F 80

¹⁶ Simulations in grey are already discussed in 3.2.1 for Deurganck dock (intermediate location).

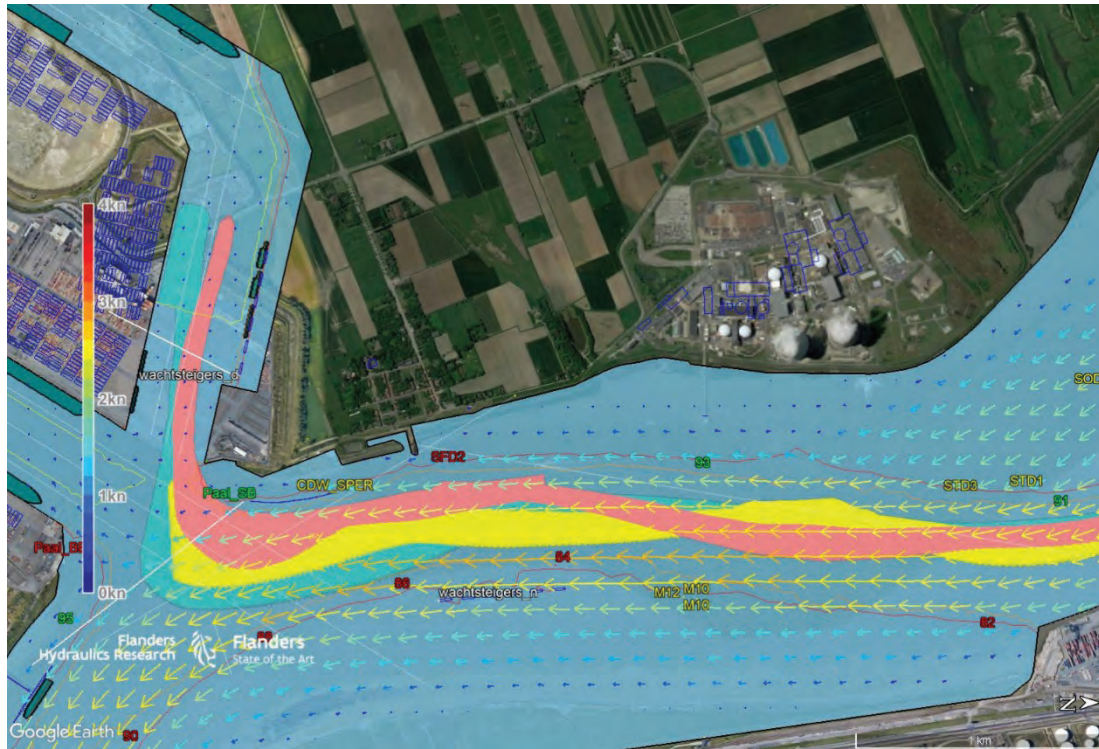


Figure 21 – Comparison of runs U3_P4 (green), U5_P1 (red) and U1_P4 (yellow) for head in manoeuvre to Duplex dock at maximum flood

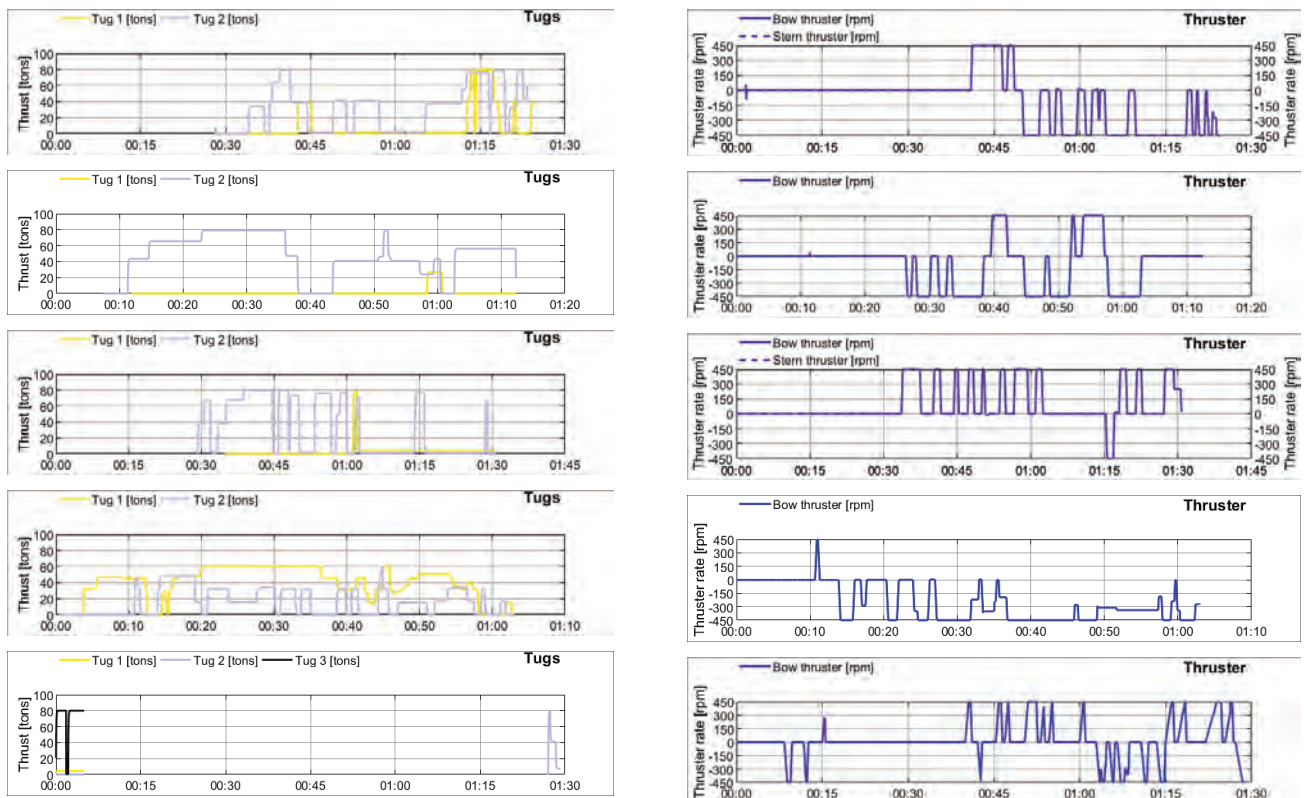


Figure 22 – Time variation of thrusters and tugs for (from top to bottom) runs U3_P4, U5_P1, U1_P4, M4_P2 and M1_P3

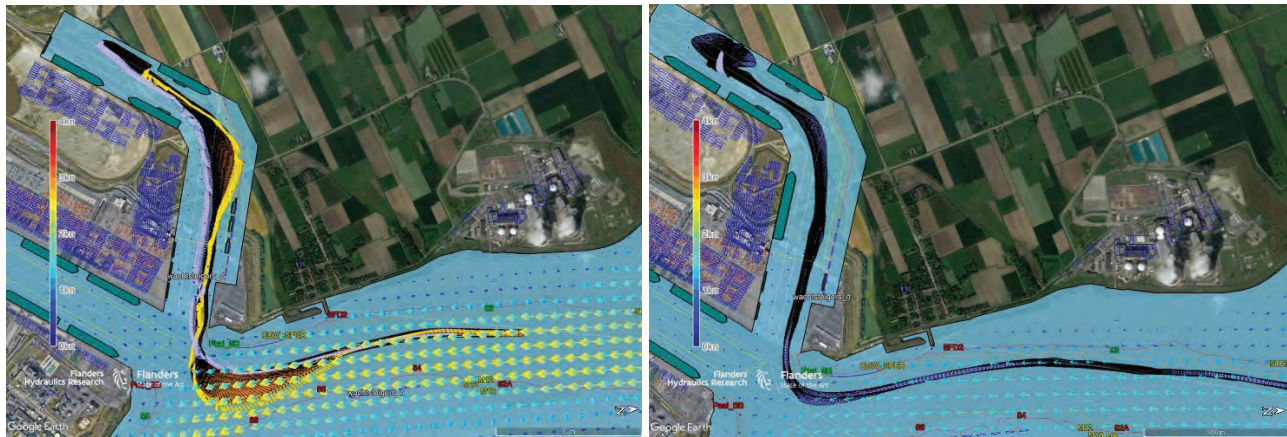


Figure 23 –Runs M4_P2 (left) and M1_P3 (right) for head in manoeuvres to Duplex dock at flood (-2.5h dynamic and -3.5h static to HW)

Head out

An overview of the tug configuration for the head out runs is given in Table 13.

Table 13 – Tug configuration for simulation runs to Duplex dock at flood and head out

Run	Ship (L m / T dm)	Current	Wind	Tug 1	Tug 2	Tug 3	Tug 4
U3_P1	430/150	-0.9h to HW	SW5	-	-	A 80	F 80
U1_P2	400/142	-1.0.h to HW	NW5	F 80	A 80	¹⁷	-
M4_P1	430/150	-2.5h to HW dyn	S6	P 80	-	A 80 - P	F 80 - P
M1_P2	400/140	-3.5h to HW	S6	F 80	A 80	P 80	

Runs U3_P1 and U1_P2 are executed at maximum flood (-0.9h or -1h to HW) with wind force 5 Bft (varying direction) and two 80 ton tugs. The swept paths of the ships without tugs are shown in Figure 25. Run U1_P2 went far upwards the river alongside the phenol jetty because the ship waited for an outbound sailing ship from Duplex dock to pass the mouth of Deurganck dock. The flood current and northwestern wind pushed the ship in the upwards direction what did not help in keeping the ship closer to DGD and the final destination of the Duplex dock (larger use of aft tug). U3_P1 and U1_P2 at 5 Bft wind are executed with a fore and aft tug, with required force and bow thruster use as shown in Figure 24. For both runs, only the aft tug has been used at maximum bollard pull, together with the bow thruster (less used in run U1_P2) while the fore tug is almost not used with a small required power (20 to maximum 40 ton). For run U3_P1 the head out entrance manoeuvre to Duplex dock is executed in one move where due to the stronger flood current, compared to runs M4_P1 and M1_P2 (Figure 26), a more easterly position in the DGD mouth is seen (also making space for outbound U3_P2 to pass). These runs M4_P1 and M1_P2 are both executed at S 6 Bft with three tugs as suggested. In run M4_P1 all tugs have been used at maximum bollard pull during a shorter (fore tug) or longer (aft tug and pusher) time of the run. The bow thruster (underpowered) is several times used at maximum power.

¹⁷ Tug 3 was not used during the simulation.

In run M1_P2 the current is less strong than in all the other head out manoeuvres at flood to Duplex dock. It can be seen in the required tug power. Only the pusher is temporarily working at maximum bollard pull while the other tugs give still some (aft) or more (fore) reserve. Only one bow thruster have been used in run M1_P2. The time between the passing of the white crosslines in Figure 25 and Figure 26 differs. For run U1_P2 where the ship is overtaking the mouth of DGD on the river, to keep the mouth free for other ships, the astern track from one to the other crossline takes almost 16.9 min. For run M4_P1 the time in between is only 14.5 min and caused by a passing of both crosslines with the stern (best alignment with the heading of the Duplex dock for astern motion) and a closer position to the Duplex dock. As in run M1_P2 the bow is first crossing the DGD crossline and the ship's heading is not yet turned to the heading of the Duplex dock the time between the crosslines is longer and 24.5 minutes. For run U3_P1 this time was 20 min.

The blocking of the dock mouth when executing a head out turning manoeuvre to the Duplex dock can take 20 to 25 min, while if this manoeuvre is executed in two steps, such as in run U1_P2 with first completely passing the dock mouth (to make the DGD entrance free for other ships), in the second step the passing of the DGD mouth to the complete entrance in the Duplex dock can take up to 17 min.

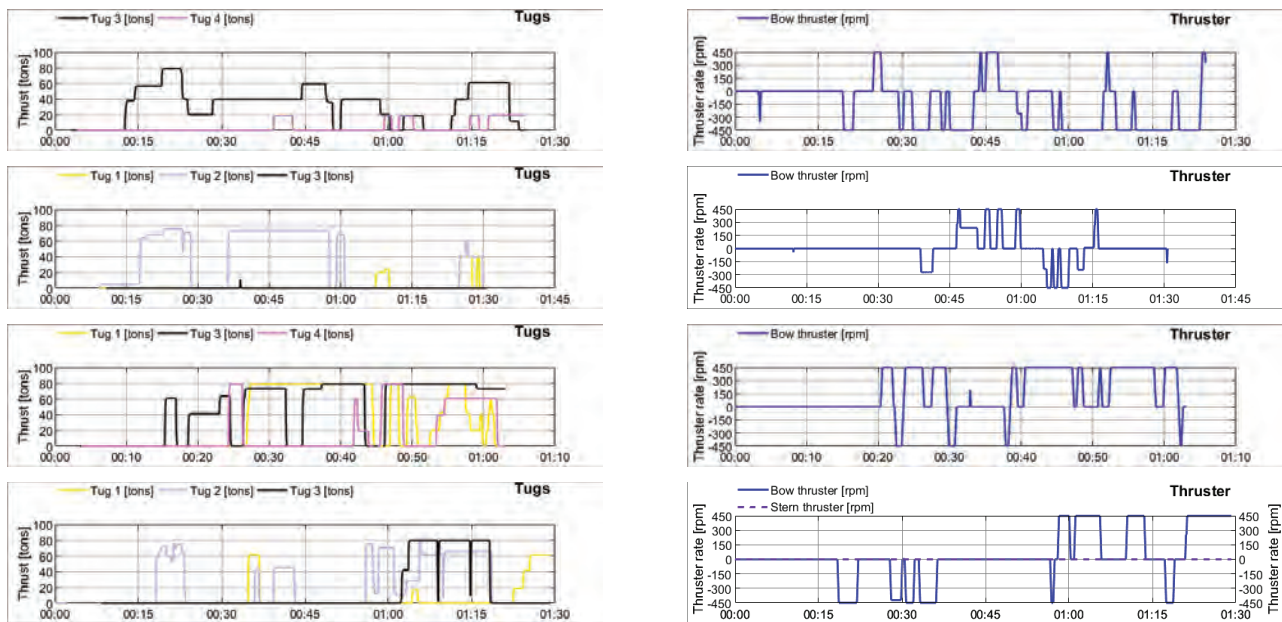


Figure 24 – Time variation of thrusters and tugs for (from top to bottom) runs U3_P1, U1_P2, M4_P1 and M1_P2¹⁸

¹⁸ The second thruster is a bow thruster instead of a stern thruster.

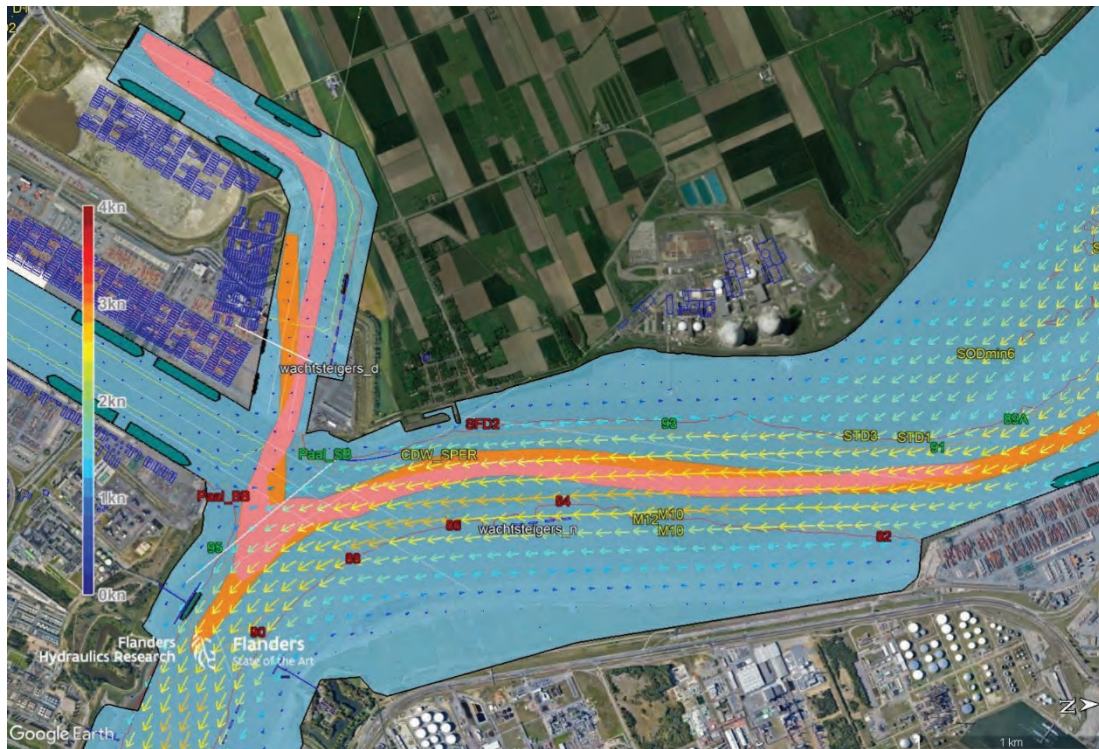


Figure 25 – Comparison of runs U1_P2 (orange) and U3_P1 (red) for head out manoeuvre to Duplex dock at maximum flood

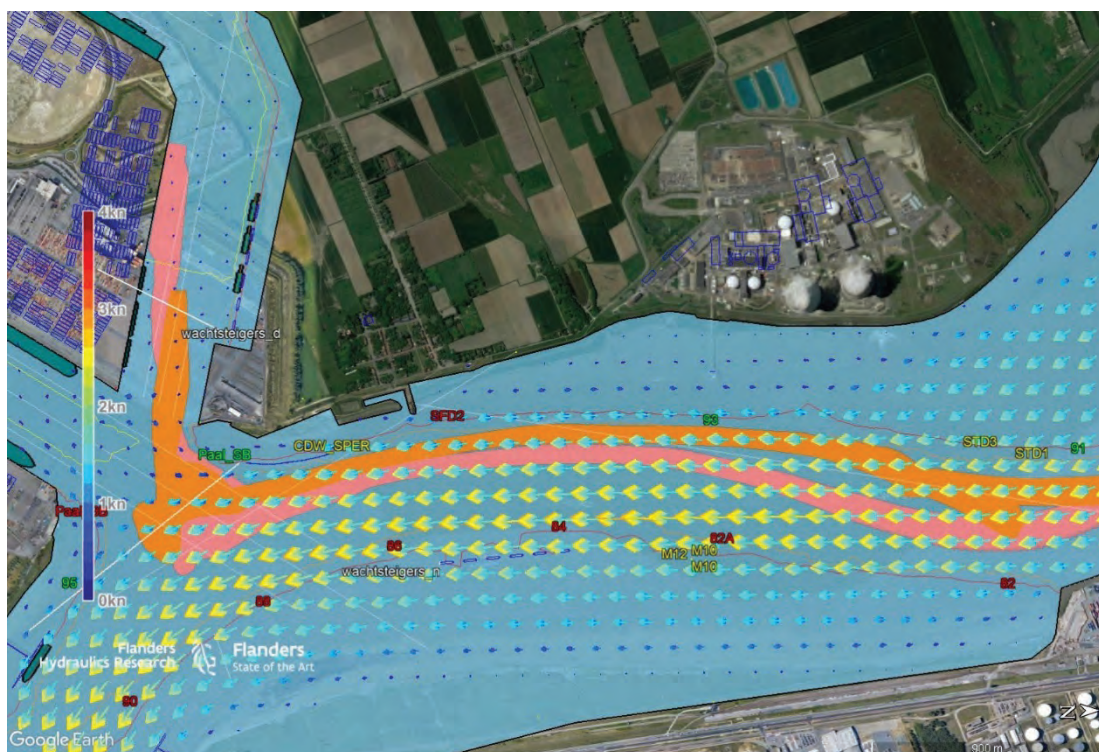


Figure 26 – Comparison of runs M1_P2 (orange) and M4_P1 (red, with current) for head out manoeuvre to Duplex dock at flood

3.2.3 Manoeuvres from Duplex dock at flood

The simulations from Duplex dock at flood tide are divided in the head in and head out manoeuvres. Special attention has to be given to head out manoeuvres at flood tide as the current is counteracting the turn to portside that a container ship leaving the Duplex dock and the mouth of DGD has to take.

Head in

An overview of the tug configuration for the head in outbound runs is given in Table 14.

Table 14 – Tug configuration for simulation runs from Duplex dock at flood and head in

Run	Ship (L m / T dm)	Current	Wind	Tug 1	Tug 2	Tug 3	Tug 4
U3_P2	400/120	-0.9h to HW	SW5	A 80	F 80	P 80	-
U5_P2	430/150		E5	F 80	A 80	-	-
M6_P1	400/131	-3.5h to HW dyn	W6	F 80	A 80	P 80	

Runs U3_P2 and U5_P2 are executed at maximum flood (-0.9h to HW) with wind force 5 Bft (varying direction). In both runs a fore and aft tug are used while in run U3_P2 an additional pusher is assisting during the astern turning to the Deurganck dock. Both runs are indeed characterised by a first astern turning from the Duplex to the Deurganck dock before with motion ahead crossing the mouth of the DGD (Figure 27, swept paths without tugs).

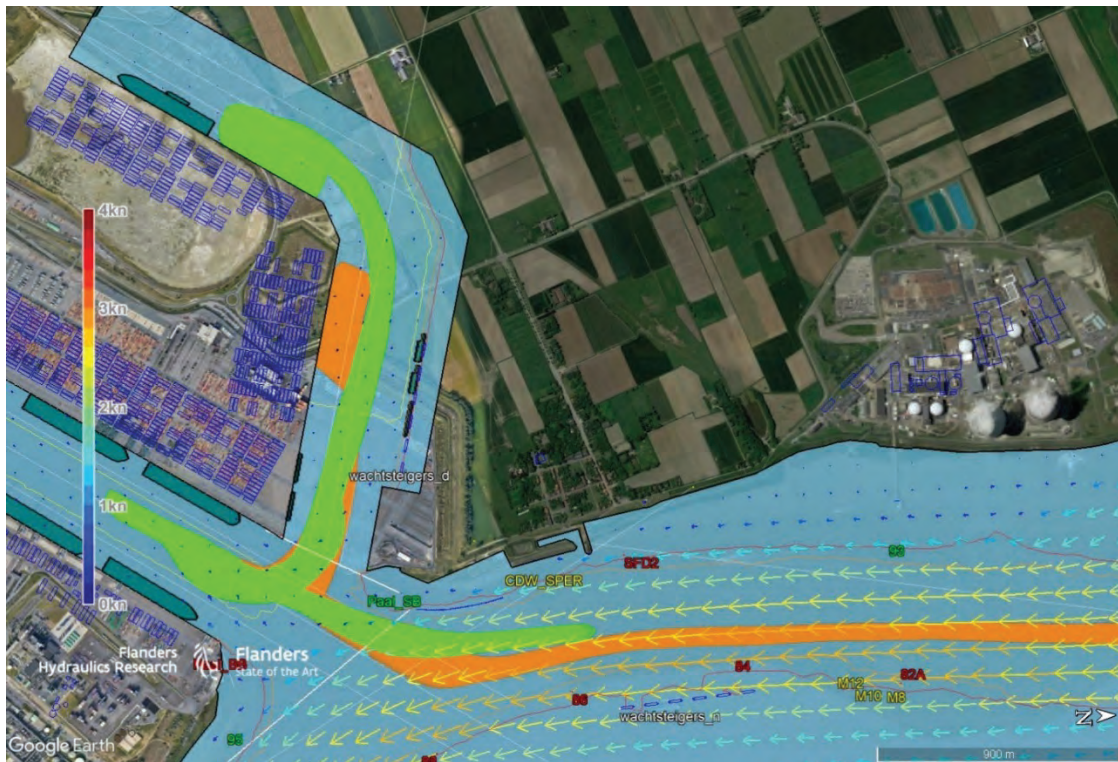


Figure 27 – Comparison of runs U3_P2 (orange) and U5_P2 (green, with current) for head in manoeuvre from Duplex dock at flood

The ULCS in run U5_P2 is going further astern in the DGD than run U3_P2 while the river crossing is more heading to the current so that the sway motion is for run U3_P2 more pronounced than for run U5_P2. Nevertheless the ULCS in run U3_P2 is more quickly at the red buoy side of the river. The time needed for crossing the white lines of the entrance of Duplex dock and DGD in Figure 27 is different with 11.2 min for U3_P2 and 30.5 min for U5_P2. The difference is caused by the scenario in which U3_P2 can immediately leave the mouth of DGD for the river after turning into DGD, while U5_P2 has first to wait for an incoming ULCS (U5_P1) before being able to leave the DGD for the river.

The use of tugs and thrusters is summarised in Figure 28. For run U3_P2 the pusher (tug 3) is pushing at starboard side astern with maximum bollard pull while bringing the aft in the DGD with also the aft tug (tug 1) assisting at maximum. Further on during the simulation the tugs are not used to bring the ship on the river (00:30 to 00:45). Use of tugs between 50 min and the end of the run is due to an additional swinging manoeuvre U3_P2 executed at the North Sea Terminal. The bow thrusters are assisting with the fore tug (tug 2) from time to time at maximum power. It is known that a head out manoeuvre from the DGD to the river requires a heading of which the direction is more aligned towards the current. In run U5_P2 the bend has to be taken in the Duplex dock what requires a maximum assistance with the aft tug (tug 2). Once turned with the fore and aft tug (both maximum) in the Deurganck dock both tugs are heading the ship towards the expected current on the river. Once on the river the tugs are not used anymore. The bow thruster is often used but is for the 430 m ULCS in run U5_P2 half the power of in run U3_P2. It is clear that at certain moments there is no reserve on the tugs and/or thrusters.

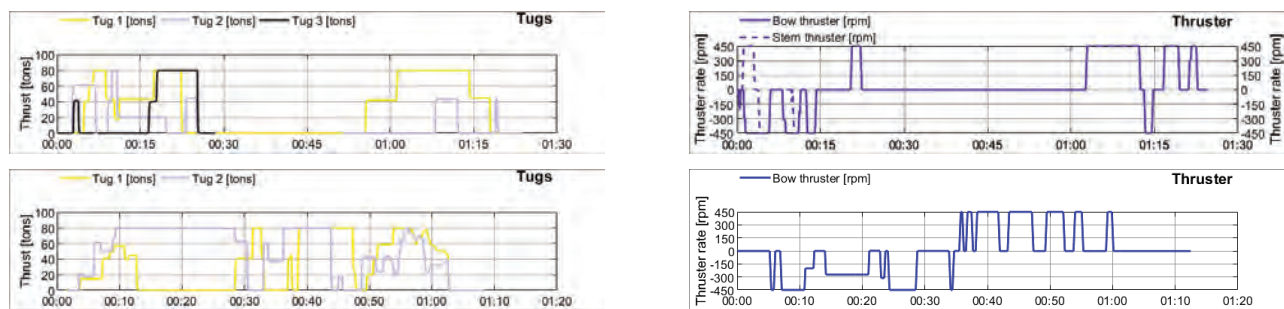


Figure 28 – Time variation of thrusters and tugs for (from top to bottom) runs U3_P2¹⁹ and U5_P2

In contrast with the outbound head in manoeuvres with an intermediate turning in DGD in run M6_P1 the ship is astern moving to the river from the Duplex dock entrance at a smaller dynamic flood current (varying between -3.5h to -2.5h to HW, Figure 29). The time needed to cross the white lines in Figure 29 (first point crossing is twice with the stern) is 8.5 min. In the crossing position on the river the mouth is then partially free but another 7 min is necessary to move the ship towards the red buoy line so that meetings with other vessels are possible on the river (min 00:50 to 00:57 with tug use). The pusher tug (tug 3) is only used when leaving the quay (westerly 6 Bft wind counteracting). The rest of the manoeuvre in the Duplex dock is assisted by a fore and aft tug. In the bend the fore tug is used at maximum power and the aft tug at 75%. While passing the mouth of DGD the tugs are not used, followed by assistance fore and aft for turning the ship on the river.

¹⁹ The second thruster is a bow thruster instead of a stern thruster, also for M6_P1.

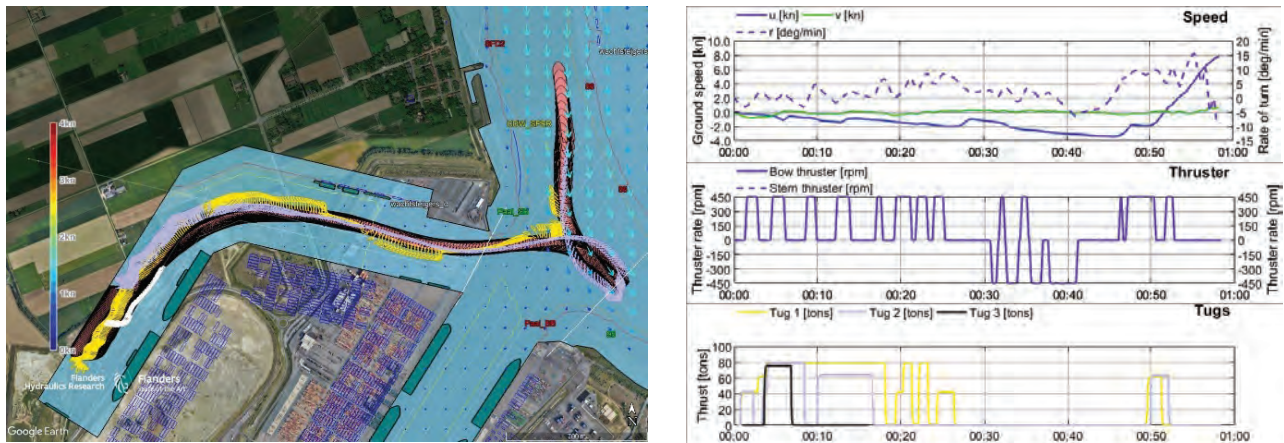


Figure 29 – Run M6_P1 [duration 58 min]: head in outbound manoeuvre from Duplex dock to the river at flood (-3.5h to HW dynamic)

Head out

Seven outbound head out manoeuvres have been executed at flood and are summarised in Table 15 with the chosen tug configuration.

Table 15 – Tug configuration for simulation runs from Duplex dock at flood and head out

Run	Ship (L m / T dm)	Current	Wind	Tug 1	Tug 2	Tug 3	Tug 4
U5_P3	430/150	-0.9h to HW	E5	F 80 - P	A 80	-	F 80 ²⁰
U1_P3	400/135	-1h to HW	NW5	F 80	A 80	-	-
M1_P1	430/150	-3.5h to HW	S6	F 80	A SS 80	A PS 80	-
M1_P4	255/120			-	A 80	-	-
M6_P2	400/131	-3.5h to HW dyn	W6	F 80	P 80	A 80	
M3_P2	255/120	-5.0h to HW dyn	E5	F 60	A 60	-	-
M3_P4	400/131			F 80	A 80	-	-

Run U5_P3 and U1_P3 have been executed at maximum flood (-0.9h and -1.0h to HW) with wind force 5 Bft (varying direction). The swept paths of the two ULCS are shown in Figure 30. Both vessels start at the quay in the first stretch of the Duplex dock with one fore and one aft tug (Figure 32). The northwesterly wind requires more tug assistance at start than the easterly wind as expected. Bow thrusters are also helping at maximum power from time to time while leaving the Duplex dock. U5_P3 is sailing at a larger speed than U1_P3 so that the ship is not heading more to the north in line with the current when crossing the DGD entrance at the river. The fore tug was repositioned from the bow to the portside aft as pusher.

²⁰ This tug is only used on the river as two tugs did not fulfil.

Without a fore tug the ship is first pushed by the current as the (underpowered) bow thruster cannot change the heading of the bow and an additional fore tug (tug 4) is attached to the bow. With all these three tugs at U5_P3 at maximum bollard pull the ship can be turned on the river. Run U1_P3 is characterised by a slow and smoother manoeuvre from Duplex dock to the mouth of DGD so that from min 00:40 to 00:50 maximum power of the bow thrusters with shortly half power of the fore tug and maximum bollard pull of the aft tug brings the ship more in line with the current on the river. The time needed to cross the two white lines on Figure 30 is nevertheless similar for both runs (18 min for U1_P3 and 19.9 min for U5_P3) due to the required speed to execute the different manoeuvres.

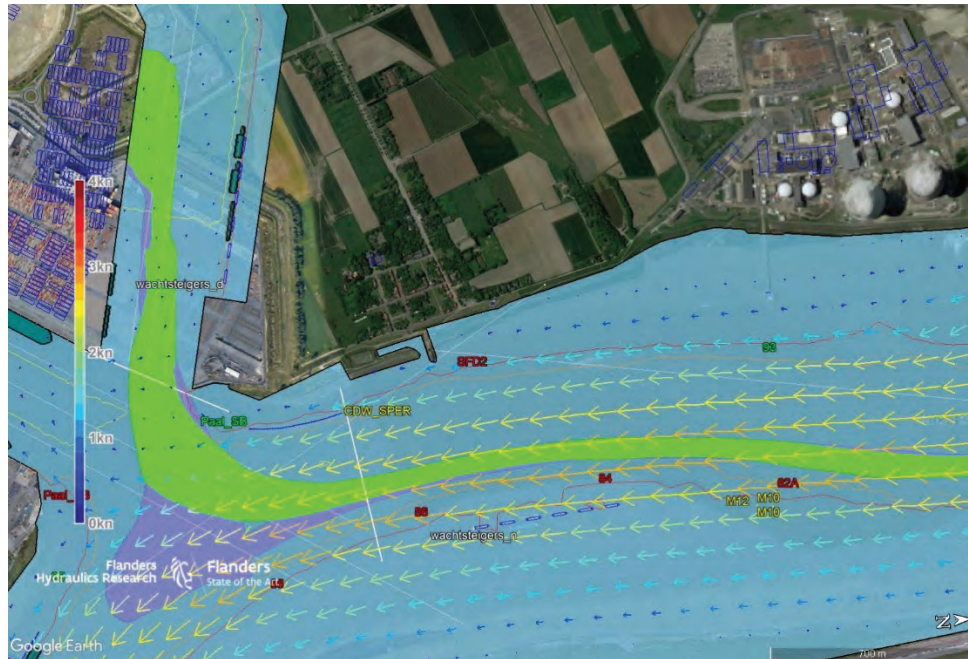


Figure 30 – Comparison of runs U5_P3 (purple, with current) and U1_P3 (green) for head out manoeuvre from Duplex dock at maximum flood

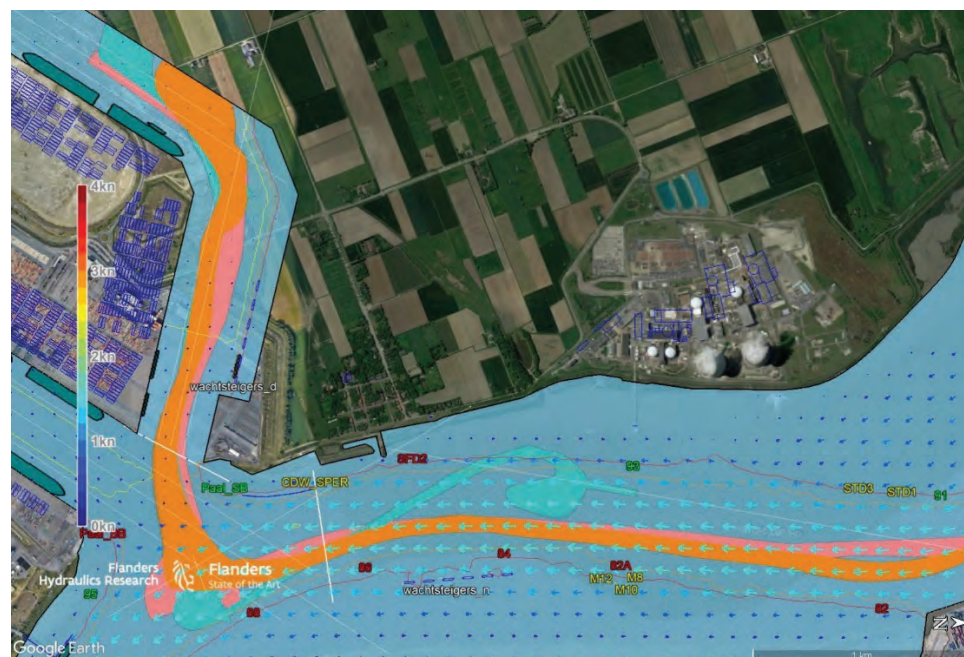


Figure 31 – Comparison of runs M1_P1 (red), M1_P4 (green) and M6_P2 (orange, with current) for head out manoeuvre from Duplex dock at flood

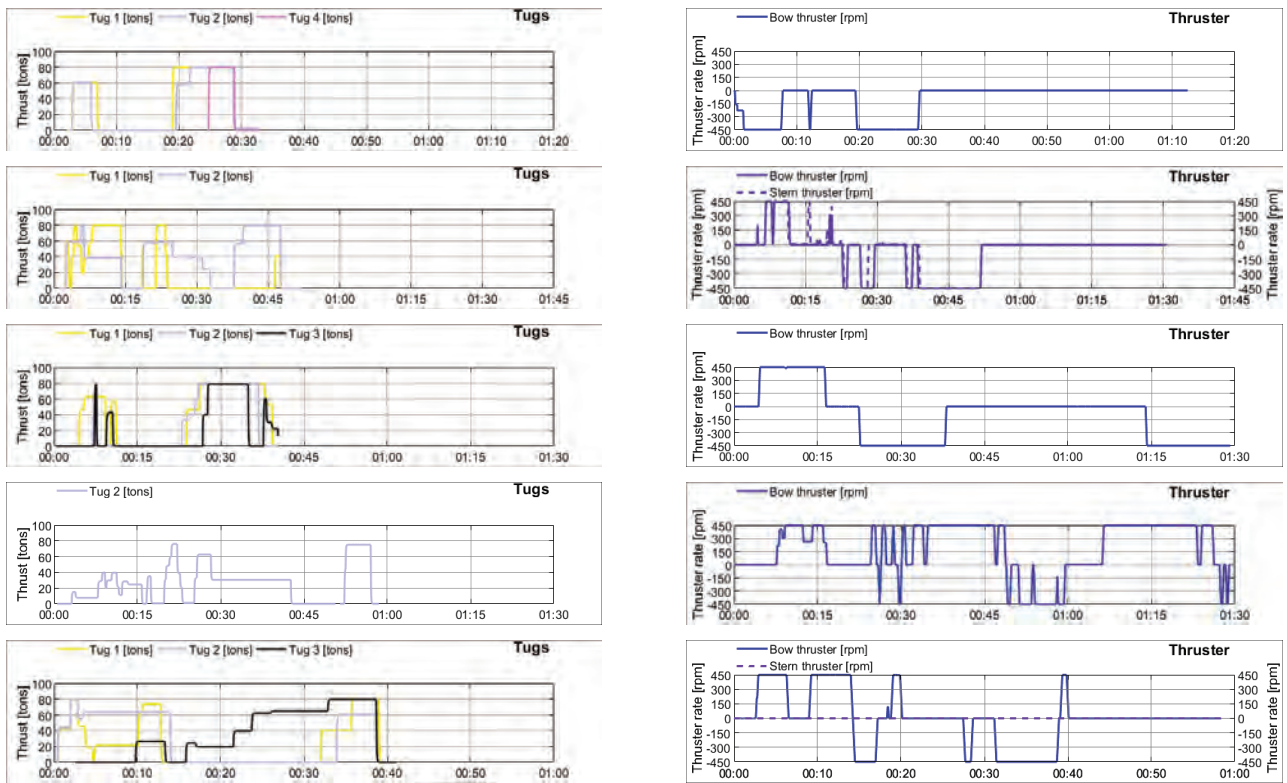


Figure 32 – Time variation of thrusters and tugs for (from top to bottom) runs U5_P3, U1_P3, M1_P1, M1_P4 and M6_P2

For the runs M1_P1, M1_P4 and M6_P2 with smaller flood current (starting at -3.5h to HW) the swept paths are presented in Figure 31. All ships take the bend in Duplex dock whereas M6_P2 comes closer to the quay at the first stretch of Duplex dock downstream the bend but no ships are moored at that quay in scenario M6. M1_P1 is using three tugs with one fore tug (tug 1) and two aft tugs (tug 2 and 3). The bow tug is mainly used for taking the bend in Duplex (min 0:05 to 0:12) together with the bow thruster while during the head out manoeuvre (even at lower flood current) from the dock mouth to the river (min 00:25 to 00:35) all tugs are using maximum bollard pull to counteract the current (also maximum power for the bow thruster). It is difficult to succeed in turning the ship against the current and red buoy 88 can just be avoided. Heading with the ULCS almost perpendicular to the current while leaving the dock introduces difficulties. M1_P1 executes also a swinging manoeuvre at the North Sea terminal at the end of the scenario. M1_P4 is a smaller 255 m vessel but experiences a comparable behaviour between the mouth of DGD and the river as the ULCS M1_P1. This vessel only uses an aft tug. From minute 00:50 to 00:60 90% of the aft tug bollard pull is used to turn the ship from the entrance of Duplex dock to the river (red buoy line). The vessel also ends up close to buoy 88. As no fore tug is considered the bow thruster operates often at maximum power. The reserve is restricted. In run M6_P4 three tugs are used but with one fore tug (tug 1), one aft tug (tug 3) and one pusher (tug 2). The pusher is only used in the bend in Duplex dock (until min 00:13) and during the turning on the river (until min 00:38) with rather 60 ton. The fore and aft tug are also working in the bend in Duplex together with maximum power for one bow thruster (the other is not active) and during the final turning of the ULCS on the river in front of the mouth a fore tug, one bow thruster and aft tug are at full power while the pusher still has some reserve.

The time needed to turn the ship between the white cross lines on Figure 31 is 21.5 min for M1_P1 but can be reduced for the smaller M1_P4 to 12.2 min and for the smoother manoeuvre with the ULCS M6_P2 to 14.7 min. This smoother manoeuvre with another tug configuration can save some time.

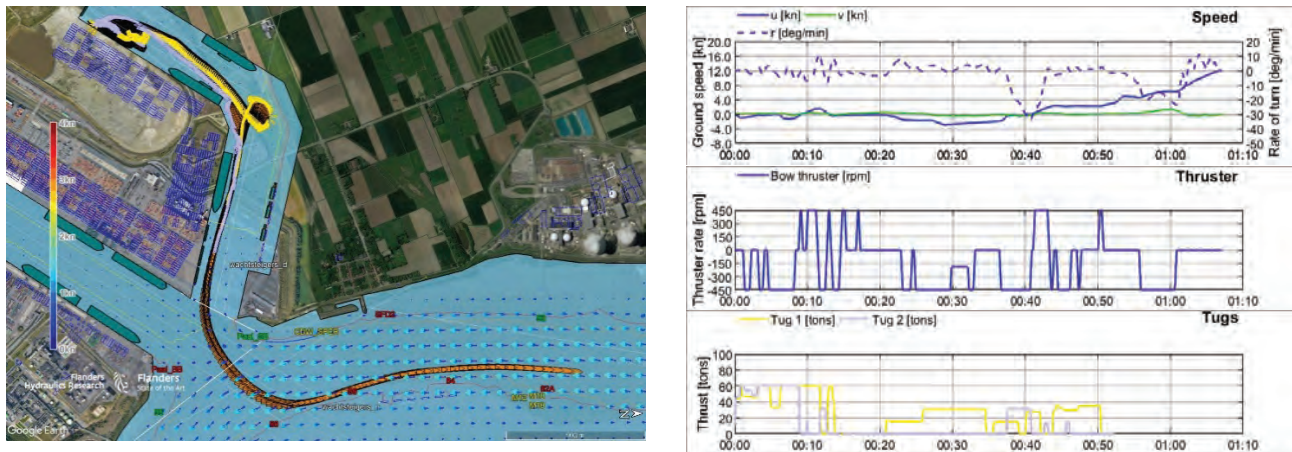


Figure 33 – Run M3_P2 [duration 67 min]: head in outbound manoeuvre from Duplex dock to the river at flood (-5.0h dynamic to HW)

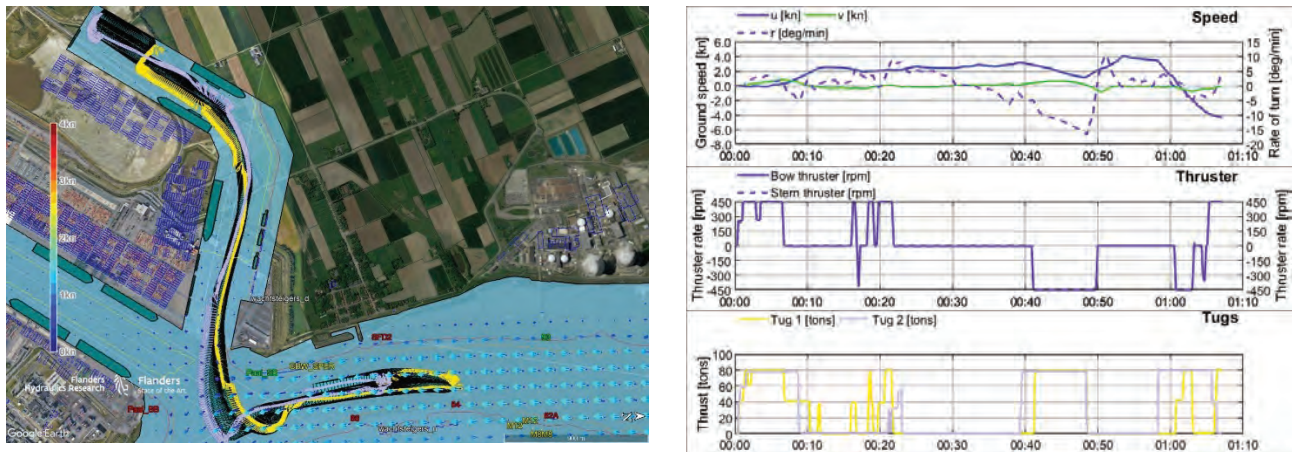


Figure 34 – Run M3_P4 [duration 67 min]: head in outbound manoeuvre from Duplex dock to the river at flood (-5.0h dynamic to HW)

In scenario M3 two outbound head out manoeuvres from the dock to the river are executed. M3_P2 and M3_P4 are moored at opposite quays at the end of the dock. M3_P4 first leaves the dock, followed by M3_P2. Run M3_P2 starts with a head in astern motion from the end of the Duplex dock to the bend where a swinging manoeuvre is executed (Figure 33). The vessel length of 255 m seems to be large to swing in the bend as for the pilots it was difficult to position the vessel at a safe distance from the inner side of the bend (quay) and the outer side (sloped bank). Two tugs of 60 ton have been used and despite the maximum bollard pull²¹ required to keep the vessel alongside the quay while the other vessel is leaving, only reduced tug power is used for the rest of the manoeuvre. The bow thruster is more often and with more power (maximum) assisting the manoeuvre. From the bend in Duplex to the mouth of DGD the vessel is too close to the southern quay of the first stretch of Duplex dock. There was enough space so the position could have been adjusted.

²¹ Partially needed because of misunderstandings of the tug captain in the use of the tugs on the tug console.

The tugs are released before the ship leaves Duplex dock so that the full manoeuvre through DGD and to the river is executed without tugs. The longitudinal speed is 4 to 6 knots and the vessel cannot counteract the effect of the reduced flood current (the efficiency of the bow thruster is low at higher velocity) so that the vessel ends up sailing over buoy 86. Even for smaller containerships and low tide with small flood current the outbound manoeuvre to the river needs an adapted manoeuvre (tug – speed – heading).

Run M3_P4 starts also at the end of the dock and this ship leaves first the Duplex dock (Figure 34). The vessel has an inclined position nearby the bend in the stretch between the moored vessels with bunker ships so that the bow and the stern reach outside the navigation lines (closer than 100 m to the quay). This should have been avoided by positioning the ship more in the middle of the bend. The tug assistance in the bend is restricted. In the first stretch downstream the bend the vessel is following the middle section and at minute 00:40 when the ship leaves the DGD mouth for the river, both fore and aft tug and the bow thrusters are assisting at maximum power to turn the ship against the current and the easterly wind. No reserve is available. The longitudinal speed had to be reduced from 3 to 1.5 knots to avoid coming too close to the red buoy line on the river. The rest of the manoeuvre was not a regular manoeuvre as the pilots are stopping the vessel to start a swinging manoeuvre on the river.

Five of seven head out outbound manoeuvres resulted in points of attention due to the lack of reserve on tugs or bow thrusters or coming too close to the red buoy line on the river. A preference could therefore be given to a head in manoeuvre compared to a head out manoeuvre. Nevertheless, as the wind conditions were always strong with 5 to 6 Bft it is expected that with enough tugs (e.g. U5_P3 three tugs from the start) or adjusted speed the manoeuvres can be executed smooth and safe. Training on the specific manoeuvres is necessary. For moderate wind conditions more reserve will be available.

3.2.4 Manoeuvres to/from Deurganck dock at ebb

The runs to or from Deurganck dock at ebb are summarised in Table 16. Two runs (M2_P3 and U6_P1) have as final destination the Duplex dock but the Deurganck dock is used as intermediate location so that the passing of the mouth of Deurganck dock is from the river to Deurganck dock.

Table 16 – Tug configuration for simulation runs to/from Deurganck dock at ebb

Run	Ship (L m / T dm)	Current	HI/HO	Dock	Wind	Tug 1	Tug 2	Tug 3	Tug 4
M2_P3	367/131	+1.0h to HW	HI	DX	N6	F 80	A 80	-	-
M2_P4	255/120		HI	DGD		-	A 80	-	-
U6_P1	400/131	+3.3h to HW	HO	DX	SW6	F 80	A 80	P 80	-

Scenario M2 (Figure 35) is a scenario where four ships are following each other at short distance. M2_P3 (367 m) is using the entrance of Duplex dock to turn with the stern to the Deurganck dock as M2_P1 (430 m) is still in Duplex dock and a meeting cannot be organised in this dock. M2_P4 (255 m) follows M2_P3 but will wait on the river for entering the Deurganck dock, until M2_P1 left the mouth of DGD, and will meet M2_P3 in the DGD. For M2_P4 this is an entrance manoeuvre to DGD, executed without any difficulties. For M2_P3 using the Duplex dock entrance for the swinging manoeuvre into the DGD is an interesting new possibility if the Duplex dock will be present and is shown in Figure 36 for the total run. A 80 ton fore and aft tug are used with still reserve on the tugs and only maximum bollard pull at the stern tug to bring the stern into the DGD after swinging with the bow in the Duplex dock and at the fore tug to align the ship in the DGD for the meeting with M2_P4.

The bow thruster is at maximum power from time to time during the complete run but for 10 minutes between 00:50 and 1:00 for taking the bend in Duplex dock. There is still reserve at the bow because the bow tug is then not used. The manoeuvres of M2_P4 with only one 80 ton aft tug are summarised in Figure 37. The ship has to pass by the mouth of DGD to let another ship leave the dock and turns to the dock on the river (maximum bollard pull of tug 2 at 00:22 and the bow thruster). When the inbound sailing M2_P3 is aligned in DGD M2_P4 passes by and later on executes a swinging manoeuvre in the Deurganck dock (tug and thruster assistance).

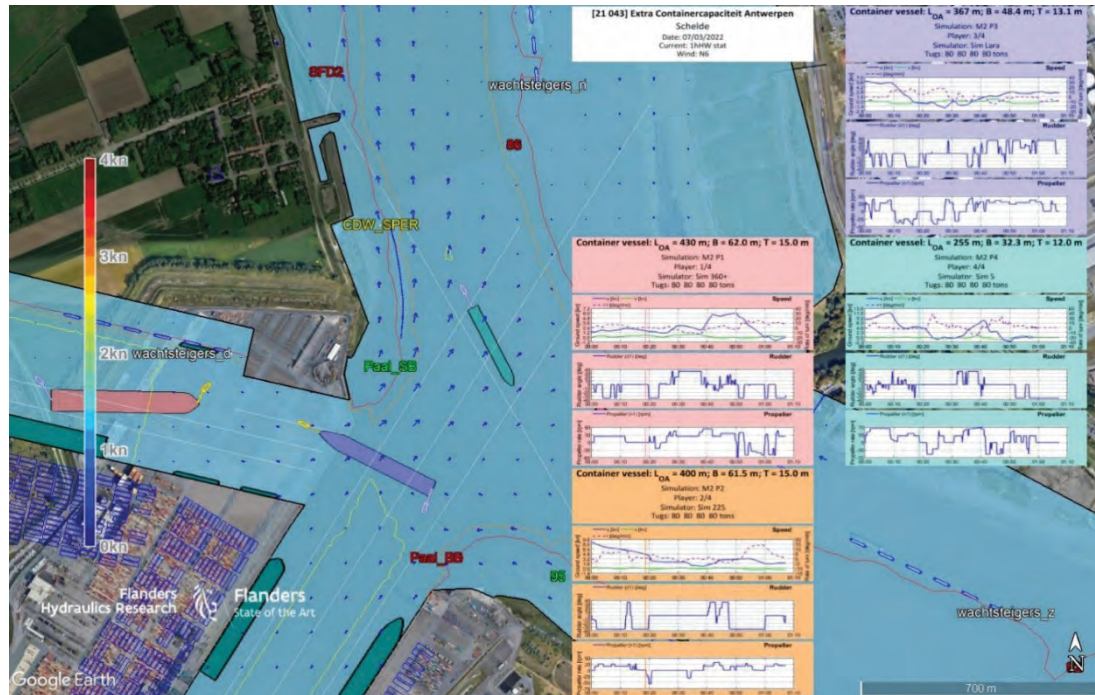


Figure 35 – Scenario M2 [minute 18]: M2_P3 (purple) and M2_P4 (green) to Deurganck dock at +1.0h to HW

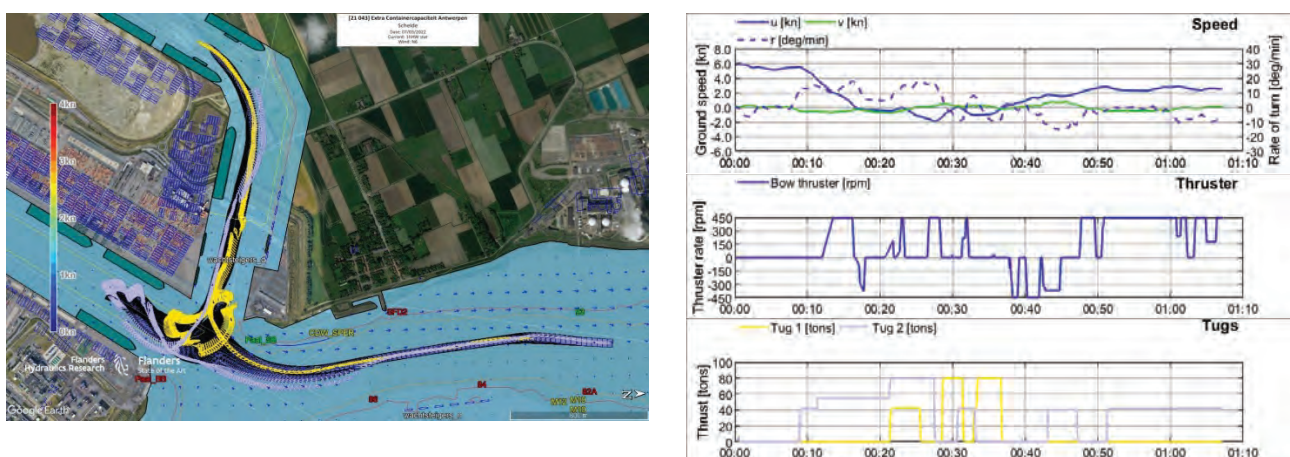


Figure 36 – Run M2_P3 [duration 67 min]: entrance Duplex dock used for swinging astern to Deurganck dock, followed by entrance manoeuvre to Duplex dock

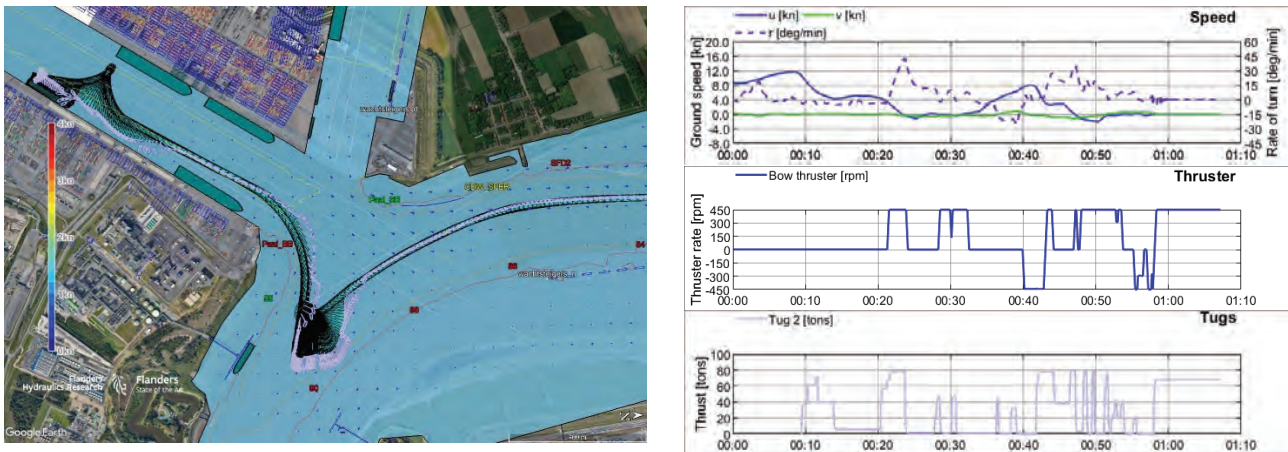


Figure 37 – Run M2_P4 [duration 67 min]: waiting on the river to turn into Deurganck dock, meeting and swinging at the quay

Run U6_P1 uses the DGD for a head in manoeuvre to the dock followed by an astern swinging manoeuvre to the Duplex dock outside of the ebb current on the river (Figure 38). The bow thrusters are used frequently with maximum power during a longer time when turning astern in the Duplex dock and counteracting the southwesterly wind. The tug configuration is a fore and aft tug with a pusher at the portside aft. The aft tug and pusher are most used. There is still some reserve on the tugs. The ship was alongside the quay at 1:15 and was for the rest of the scenario kept there using all means although in real life the ship should have been moored.

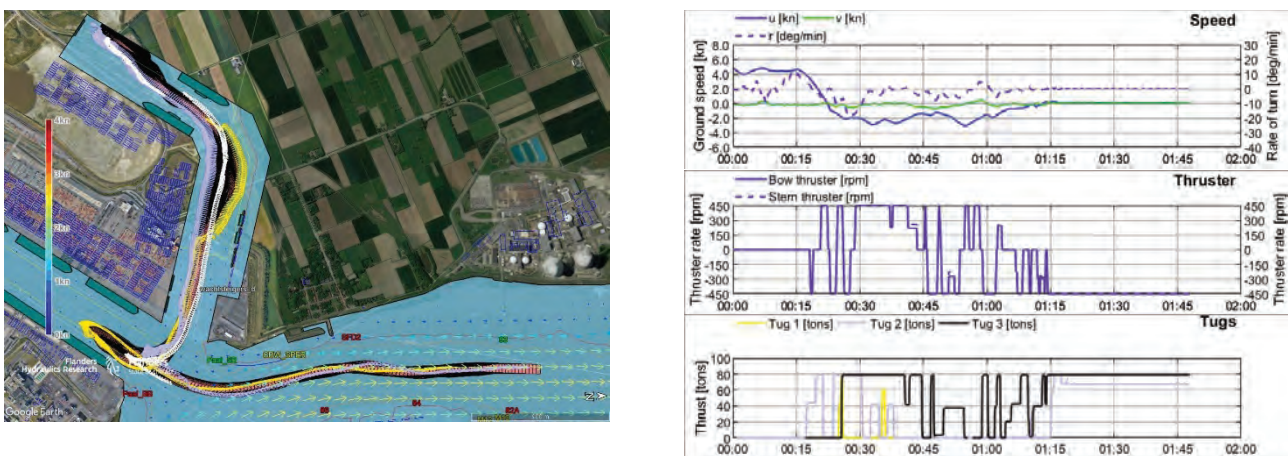


Figure 38 – Run U6_P1 [duration 75 min]: head out inbound manoeuvre to Duplex dock with the entrance of Deurganck dock used to execute a swinging manoeuvre at ebb

3.2.5 Manoeuvres to Duplex dock at ebb

The simulations to Duplex dock at ebb tide are divided in the head in and head out manoeuvres. Ebb tide is a more difficult condition for an inbound manoeuvre compared to flood as the current is counteracting the head in manoeuvre to the Duplex dock.

Head in

Five head in manoeuvres to the Duplex dock at ebb tide are summarised in Table 17. The simulations are discussed in increasing time after high water (low – maximum – low ebb). M2_P2 is a direct head in manoeuvre at small ebb tide 1.0h after HW (Figure 39). Three tugs have been used although there is still

reserve on all tugs. Maximum bollard pull is never used although the wind force is a northerly 6 Bft. One bow thruster and the aft tug are mainly used to approach the mouth of DGD while during the turning into the Duplex dock the pusher is also assisting at starboard side astern. At the end of the simulation the pusher is relocating at the portside closer to the midship section. The time to cross²² the two white lines in Figure 39 (identical to a direct head in manoeuvre at flood) is 11.2 min and thus comparable to the values at maximum flood tide (10 to 15 min, at flood the current helps the turning into the dock). M2_P3 is already discussed in §3.2.4 and the time needed for the same crossings is 40.5 min as the ship is first turning astern to DGD and then again turning to Duplex dock, thus almost three times longer than a direct manoeuvre.

Table 17 – Tug configuration for simulation runs to Duplex dock at ebb and head in

Run	Ship (L m / T dm)	Current	Wind	Tug 1	Tug 2	Tug 3	Tug 4
M2_P2	400/150	+1h.0 to HW	N6	F 80	A 80	P 80	
M2_P3	367/131 ²³			F 80	A 80	-	-
U2_P3	400/140	+3.3h to HW	NE5	F 80	A SS 80	A PS 80	-
U6_P4	430/150		SW6	F 80	A SS 80	A PS 80	-
M5_P3	210/110	+4.0h to HW dyn	N6	-	A 60	-	-

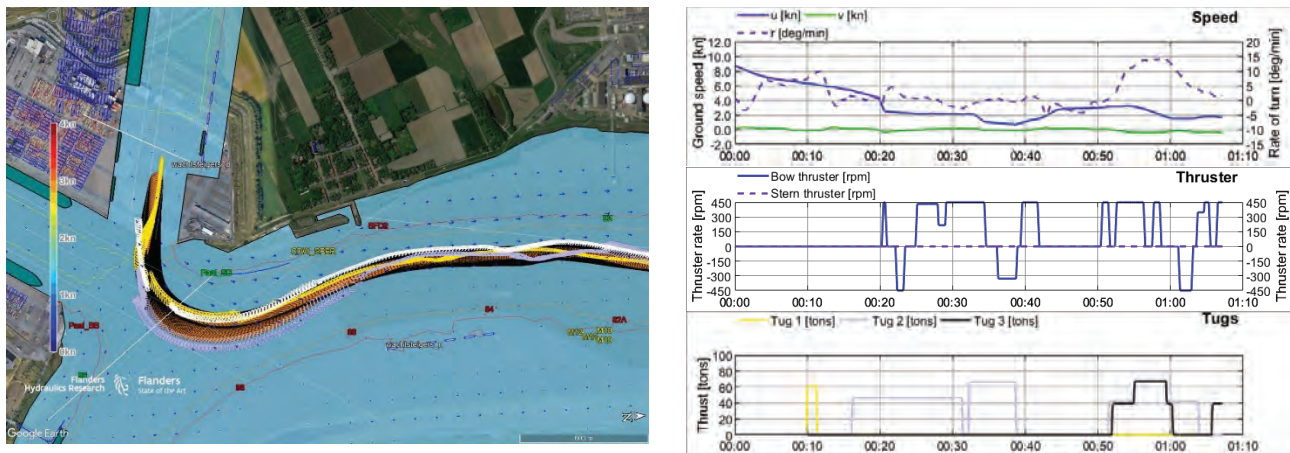


Figure 39 – Run M2_P2 [duration 67 min]: head in inbound manoeuvre to Duplex dock at minimal ebb current

Two runs have been executed at maximum ebb tide (3.3h after HW) with the same tug configuration more specifically one fore tug and two stern tugs (Figure 40). The swept paths of the two runs are more or less identical from the river to the Duplex dock although the wind is different with respectively NE 5 Bft and SW 6 Bft, so that the current is determining the path. The time variation of the thrusters and tugs is summarised in Figure 41. The turning into the dock happens from 00:55 for U2_P3 and is clearly seen at 1:30 for U6_P4. Both aft tugs are used (partially at maximum bollard pull) while the bow thrusters are delivering the required power at the bow and the fore tug is not used. The time needed to execute the turning manoeuvre between

²² The second line in the Duplex dock was not crossed but the time with the shortest distance was taken.

²³ Simulations in grey are already discussed in 3.2.4 for Deurganck dock (intermediate location).

the two white crosslines in Figure 40 is 13.5 min for U2_P3 and 15.7 min for U6_P4 what corresponds to the longer time needed for the direct head in turning into the Duplex dock at flood. So with two strong aft tugs the counteracting ebb current can be compensated. There is shortly no reserve at the aft tugs.

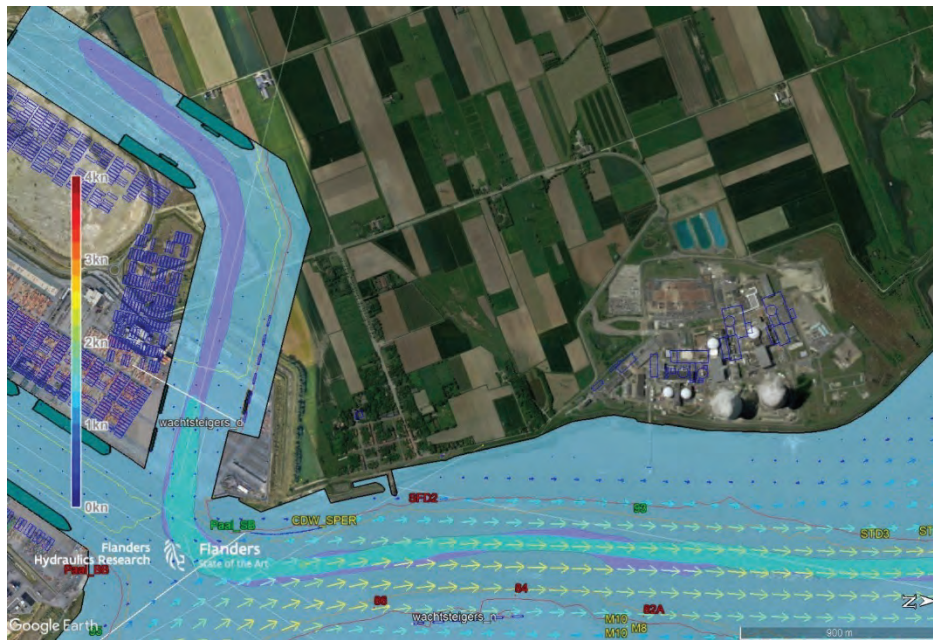


Figure 40 – Comparison of runs U2_P3 (purple, with current) and U6_P4 (green) for head in inbound manoeuvre to Duplex dock at maximum ebb

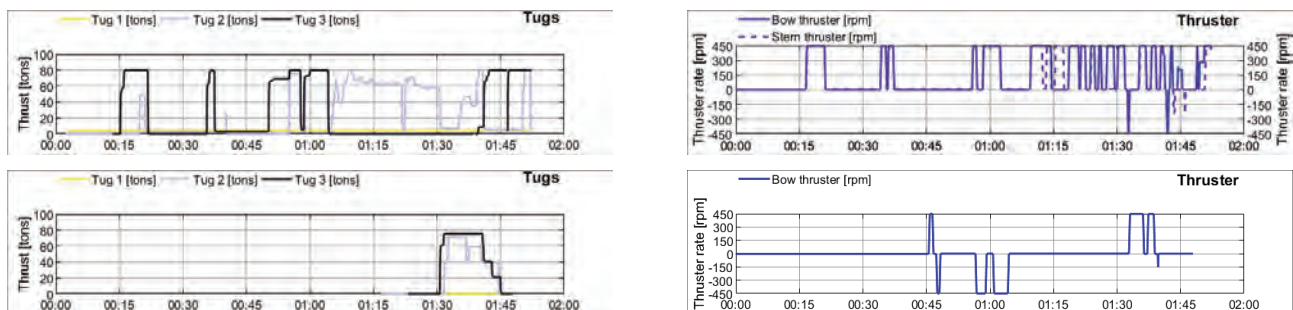


Figure 41 – Time variation of thrusters and tugs for (from top to bottom) runs U2 P3 and U6 P4

Run M5_P3 has been executed at a start condition for the tide of 4.0h after HW with a dynamically varying tide. This 210 m vessel uses one tug at the aft (Figure 42). The turning into the mouth of DGD and Duplex dock is disturbed by a meeting with M5_P1 alongside the current deflecting wall and the passing of M5_P2 during the astern head out manoeuvre so that the ship could only be turned into Duplex dock nearby the southern corner. A collision with the dock was avoided. The speed had to be decreased from 5 to lower than 2 knots (00:37 till 00:40). Then the ship is meeting M5_P4 in the bend of Duplex dock and although no real problem occurs meeting should be avoided in narrow spaces with strong (wind) conditions (N 6 Bft). The 210 m vessel executes a turning manoeuvre in the second stretch of the dock but the aft tug does not succeed in keeping a safe distance to the moored ship. The swinging should better be executed along the free quay wall where the ship has to moor. The bow thruster is assisting during the turning into Duplex dock and the swinging manoeuvre. The time to pass the two crosslines in Figure 42 is 9.0 min. This is lower than for the ULCS in other conditions, although the turning was not a smooth manoeuvre.

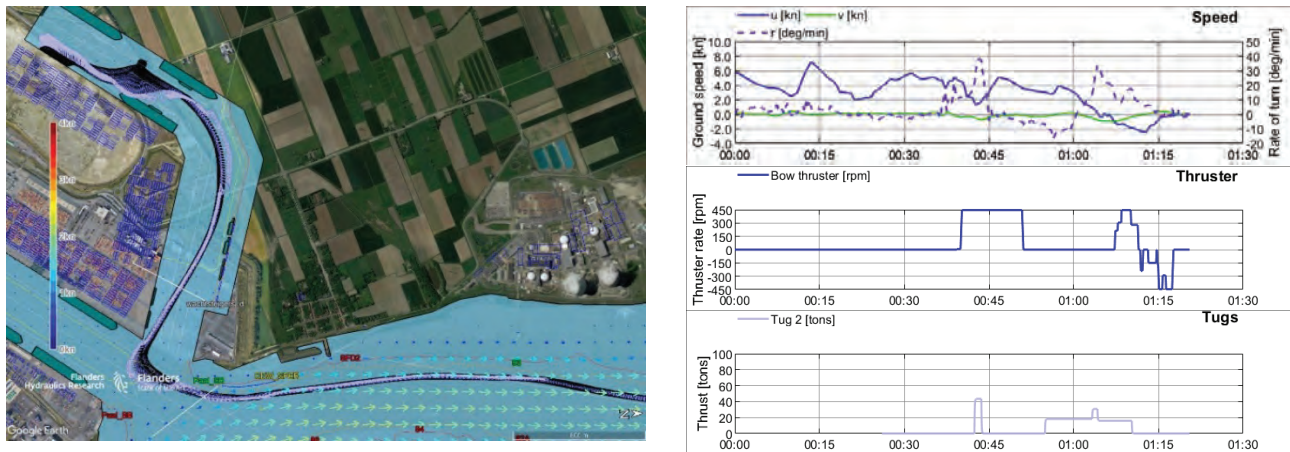


Figure 42 – Run M5_P3 [duration 80 min]: head in inbound manoeuvre to Duplex dock at ebb

Head out

Four head out manoeuvres to Duplex dock have been executed at maximum ebb tide (Table 18). A fifth starts at 4.0h after HW with a dynamically varying tide and current. The tug configuration for U2_P1 at a northeasterly 5 Bft wind consists of two tugs fore and aft while for runs U4_P1, U4_P2 and U6_P3 at 6 Bft an additional pusher is added. The swept paths of all four runs at maximum ebb tide are presented in Figure 43. A difference is seen between the tracks on the river nearby the DGD mouth with shorter (U4_P1) to longer (U4_P2) turning paths. Between buoys 91 and 93 the swept paths of U2_P1 and U4_P1 are wider due to zero speed position keeping while waiting for meetings and planning with the other ULCS. The time to cross the white lines on Figure 43 is 17.4, 18.4, 17.1 and 18.4 for respectively U2_P1, U4_P1, U4_P2 and U6_P3 and thus almost the same for all runs despite the wind direction and force. This time was also seen in a head out inbound manoeuvre at flood tide (U1_P2) although other runs at flood showed more difference in time. This difference between ebb and flood can be contributed to the composition of the inbound manoeuvres from river to Duplex dock. The northern crossline lays in the middle of the total manoeuvre to be executed so that an overall evaluation for all conditions will be reported in the conclusions in chapter 4.

Table 18 – Tug configuration for simulation runs to Duplex dock at ebb and head out

Run	Ship (L m / T dm)	Current	Wind	Tug 1	Tug 2	Tug 3	Tug 4
U2_P1	430/150	+3.3h to HW	NE5	F 80 - P	A 80	-	-
U4_P1	400/131		NW6	F 80	A 80	-	P 80
U4_P2	430/150			A 80	F 80	P 80	-
U6_P3	430/150		SW6	F 80	A 80	P 80	-
M5_P2	400/140	+4.0h to HW dyn	N 6	F 80	A 80	P 80	-

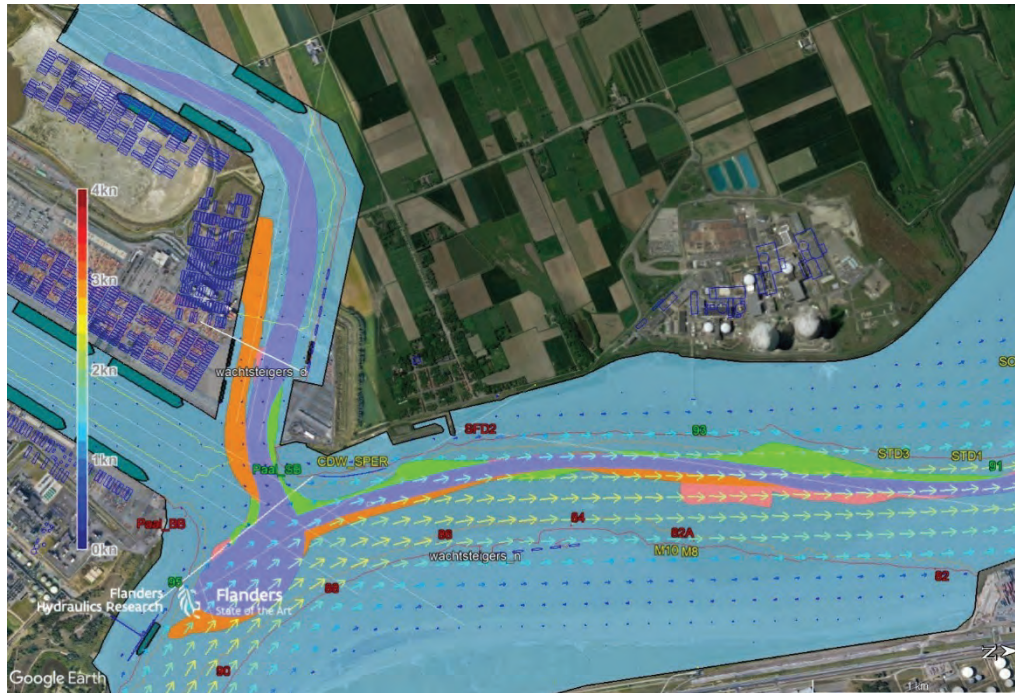


Figure 43 – Comparison of runs U2_P1 (red, with current), U4_P1 (green), U4_P2 (orange) and U6_P3 (purple) for head out inbound manoeuvre to Duplex dock at maximum ebb

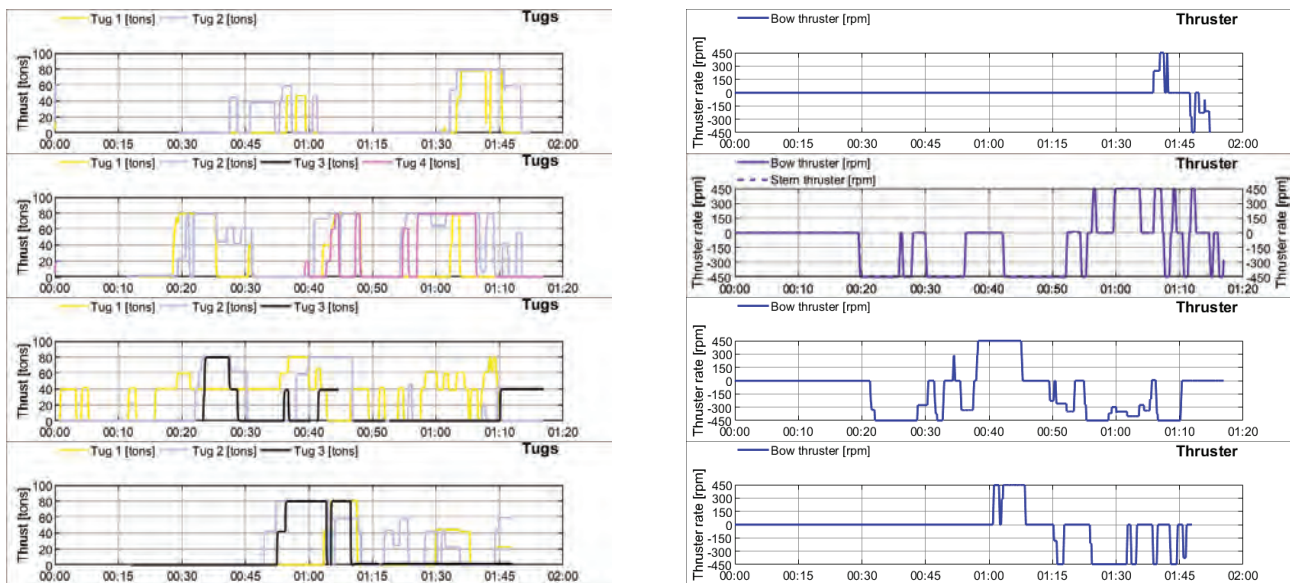


Figure 44 – Time variation of thrusters and tugs for (from top to bottom) runs U2_P1, U4_P1, U4_P2 and U6_P3

The tug configuration in run U2_P1 is with a fore and aft tug while approaching the DGD mouth on the river to counteract the NE wind, followed by a change of the fore tug to a pusher portside aft while turning in the mouth. During this turning with the stern to Duplex dock maximum bollard pull of both tugs and maximum power of the (underpowered) bow thruster is used. For run U4_P1 when turning into the dock an additional pusher is assisting at the portside aft to bring the stern in the Duplex dock. At a certain moment (between 1:00 and 1:05) all tugs are assisting at maximum bollard pull and the bow thrusters are also at full power.

This gives no reserve. The pusher had also to leave the position at portside because there was not enough space for the tug between the northern quay of Duplex dock and the ship. More effect of the northwesterly wind was expected. It seems that in run U4_P2 the pusher has not been used in a correct way on the simulator (towing at a push point) so that the manoeuvre is probably disturbed by unintended tug assistance. Only between minute 00:20 and 00:30 the pusher assisted correctly at starboard side at the bow to counteract the motion towards the phenol jetty. The ship is coming close to the inland ships moored at the southern quay. More distance should be kept. In run U6_P3 while turning astern through the DGD mouth to Duplex dock first the aft tug and pusher are assisting at maximum bollard pull and later the fore tug and pusher. The (underpowered) bow thruster delivers maximum power several time intervals but in this run some reserve on tugs and real bow thrusters was available.

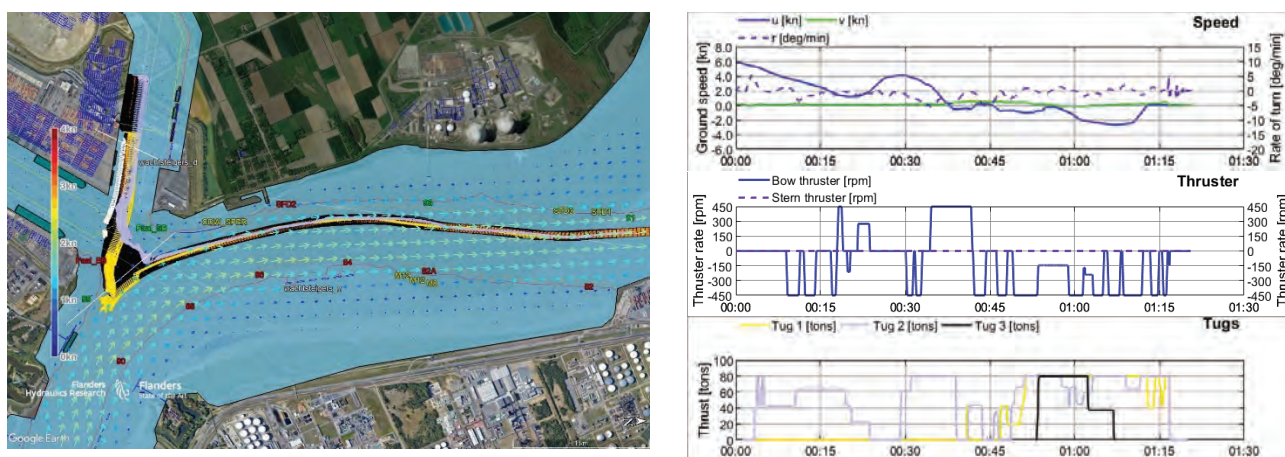


Figure 45 – Run M5_P2 [duration xx min]: head out inbound manoeuvre to Duplex dock at ebb

Run M5_P2 (Figure 45) is executed at a lower ebb tide starting at 4.0h after HW and with a northerly 6 Bft wind. The manoeuvre is smoothly executed with only the aft tug used for the approach to the DGD mouth from the river. Due to the N 6 Bft wind the vessel is at low position nearby buoy 95. The fore tug starts then helping the bow thrusters to counteract the wind and finally an additional pusher is assisting at the starboard side to prevent the ship from swaying to the inland ships under the northerly wind. The time to pass the crosslines is 27.8 min. This time is much longer (plus 10 min) than for the other head out inbound manoeuvres at maximum ebb tide due to the planning with meeting of M5_1 and letting M5_P3 pass at the stern before going astern to Duplex dock.

3.2.6 Manoeuvres from Duplex dock at ebb

The manoeuvres from Duplex dock at ebb tide are divided in the head in and head out manoeuvres. The ebb current helps the head out outbound manoeuvre by turning the ship's bow to port while leaving the dock.

Head in

Two runs have been executed, U2_P2 at maximum ebb tide and M5_P1 at a dynamic tide starting at 4.0h after HW (Table 19).

Table 19 – Tug configuration for simulation runs from Duplex dock at ebb and head in

Run	Ship (L m / T dm)	Current	Wind	Tug 1	Tug 2	Tug 3	Tug 4
U2_P2	430/150	+3.3h to HW	NE5	F 80	A 80	-	-
M5_P1	400/120	+4.0h to HW dyn	N6	F 80	A 80 M	A 80 PS	-

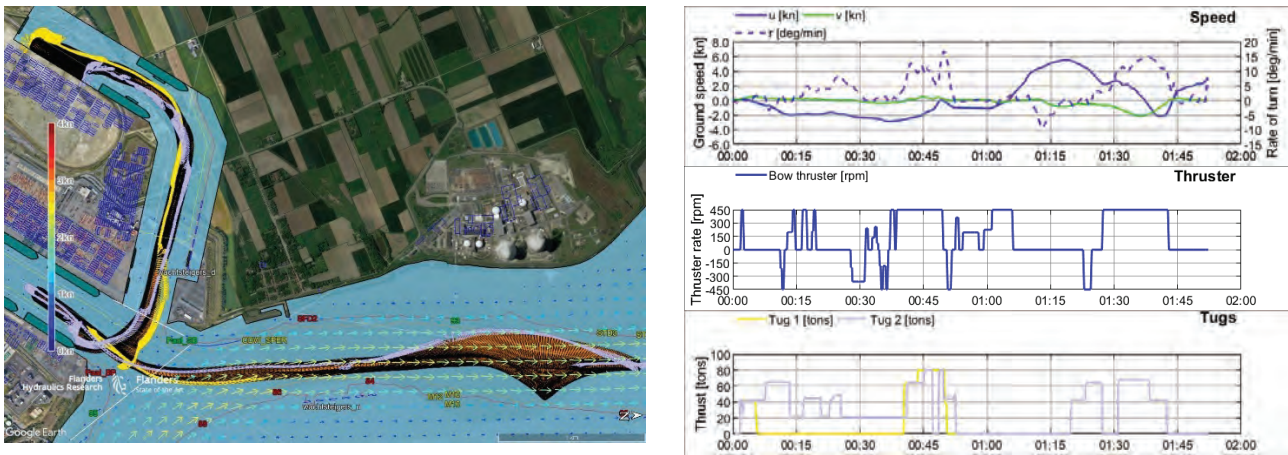


Figure 46 – Run U2_P2 [duration 112 min]: head in outbound manoeuvre from Duplex dock to the river at ebb (+3.3h to HW)

In run U2_P2 a 430 m ULCS is leaving the Duplex dock head in starting from the quay at the end of the Duplex dock (Figure 46). The ship passes the moored ships with bunker ships and the bend with one fore and one aft tug. Leaving the Duplex dock the ship goes astern to DGD with an easterly position intending to compensate for the northeasterly wind but almost collides with the moored vessel at the eastern quay in DGD. Consecutively the ship waits in DGD for U2_P3 entering Duplex dock. The time passing the two crosslines gives 32.6 minutes what is comparable with the time needed at flood for run U5_P2. There is still reserve on the fore and aft tugs and the bow thruster. At the end of the simulation the ship executes a swinging manoeuvre with one aft tug between buoy 93 and 82.

In run M5_P1 a 400 m ULCS leaves the quay in the first stretch of the Duplex dock and executes an astern motion to the river, assisted by three tugs, one fore and two aft tugs (Figure 47). The two aft tugs are used at 50 to 100% bollard pull with maximum bow thruster power to bring the ship at the entrance of Duplex dock. This assistance is followed by one aft tug with the fore tug and bow thrusters lining up the ship on the river. There is still reserve on the tugs, less on the bow thrusters. The time to pass the cross lines is 6.8 min what is comparable to the 8.5 min time in flood conditions for run M6_P1. The ship executed a swinging manoeuvre on the river nearby buoy 82 what is not part of this research but an exercise for the pilots themselves.

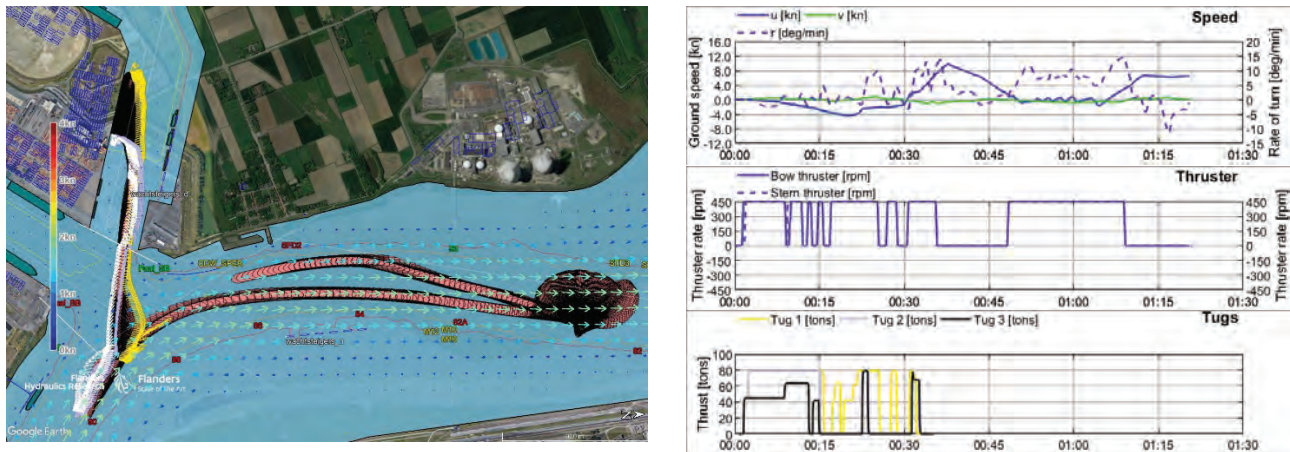


Figure 47 – Run M5_P1 [duration 80 min]: head in outbound manoeuvre from Duplex dock to the river at ebb (+4.0h to HW dynamic)

Head out

Five outbound head out manoeuvres have been executed at ebb and are summarised in Table 20 with the chosen tug configuration.

Table 20 – Tug configuration for simulation runs from Duplex dock at ebb and head out

Run	Ship (L m / T dm)	Current	Wind	Tug 1	Tug 2	Tug 3	Tug 4
M2_P1	430/150	+1.0h to HW	N6	F 80 - P	A 80	-	-
U2_P4	400/120	+3.3h to HW	NE5	F 80	A 80	-	-
U4_P4	430/150		NW6	F 80	A 80	A 80	-
U6_P2	430/150		SW6	P 80 - F	A 80	P 80	-
M5_P4	255/120	+4.0h to HW dyn	N6	-	A 60	-	-

Run M2_P1 at 1.0h after HW (very small current) starts between the moored vessels in the second stretch of the Duplex dock (Figure 48). The vessel is only assisted by a fore and aft tug despite the northerly 6 Bft wind. Taking the bend in Duplex dock (min 00:03 to 00:11) the tug assistance is still acceptable while taking the bend from the entrance of the Duplex dock to the river the fore tug is repositioned to a pusher at the portside aft and maximum bollard pull is required from both tugs together with maximum bow thruster power. No reserve is available. An additional third tug as proposed from 6 Bft on for these ULCS could help. The time to pass the two crosslines in Figure 48 is 12.4 min while for the more difficult manoeuvre at flood the time was 18 to 20 min.

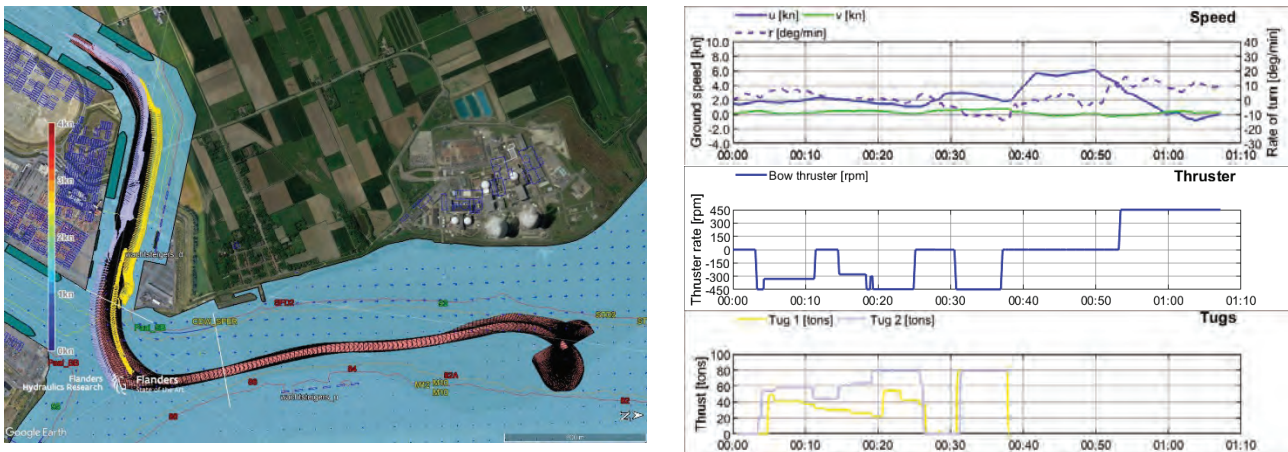


Figure 48 – Run M2_P1 [duration 67 min]: head out outbound manoeuvre from Duplex dock to the river at minimal ebb (+1.0h to HW)

Three head out outbound manoeuvres have been executed at maximum ebb tide (Figure 49). Only U4_P4 starts upwards of the bend in Duplex dock. The swept paths show less reserve in space in the bend for run U4_P4 partially due to the northwesterly wind and for U6_P2 nearby the moored inland ships at the southern quay. The swept paths in the DGD mouth while executing the turning manoeuvre to the river give a closer path to the northern quay wall of Duplex dock for run U4_P4 and a more eastern path in the DGD mouth for run U2_P4. The time between the two crosslines is 13, 9.2 and 12 min for respectively U2_P4, U4_P4 and U6_P2 with the shortest time for run U4_P4 most westerly crossing the entrance of DGD mouth and influenced by a northwesterly wind that helps the turning. The tug configuration in each run is summarised in Table 20. In run U2_P4 only two tugs are used at a northeasterly 5 Bft wind. The head out manoeuvre from the Duplex dock to the river is concentrated from min 0:00 to 0:25 where there is still reserve on the tugs and the bow thrusters. The pilots decided to do three consecutive swinging manoeuvres in the lock mouth of Berendrecht and Zandvliet lock, astern to the Europeterminal and in front of the North Sea terminal which manoeuvres should not be considered for this specific report. In run U4_P4 two aft tugs and one fore tug are assisting the 430 m ULCS while taking the bend in Duplex dock but the rest of the simulation has been executed with one fore and one aft tug. Turning on the river with only two tugs and an (underpowered) bow thruster requires all devices at maximum power for almost five minutes. There is no reserve. At the end of the simulation a swinging manoeuvre was executed in front of the North Sea terminal. For run U6_P2 the manoeuvre from the quay at a southwesterly 6 Bft wind starts with two pushers and one aft tug. While approaching the entrance of Duplex dock the pusher fore takes the line but has not been used anymore while the aft tug and the pusher assist both at maximum power together with maximum bow thruster. There is no reserve for three minutes.

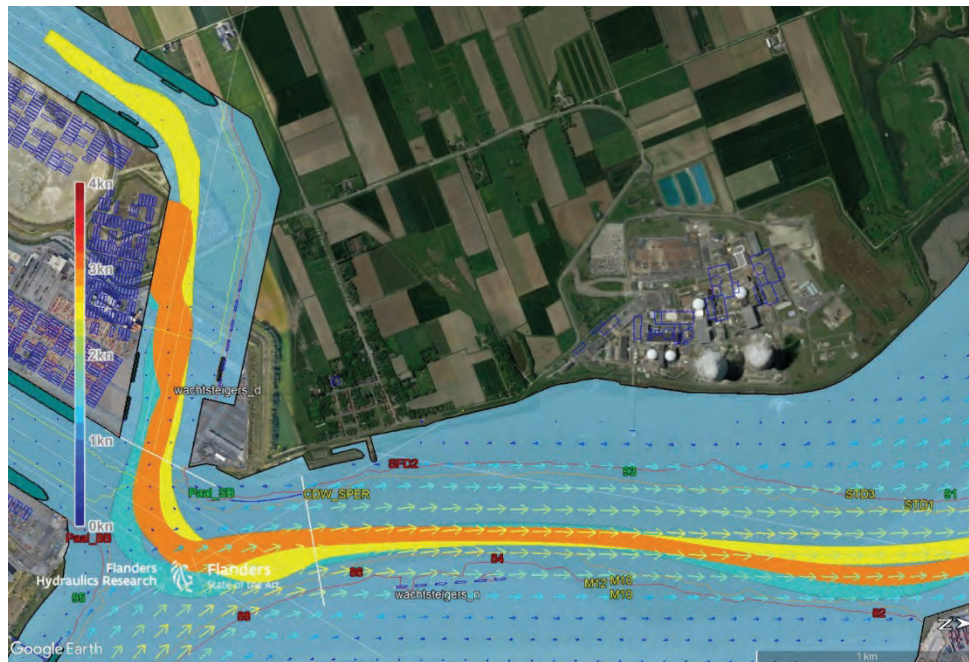


Figure 49 – Comparison of runs U2_P4 (green, with current), U4_P4 (yellow) and U6_P2 (orange) for head out outbound manoeuvre from Duplex dock at maximum ebb

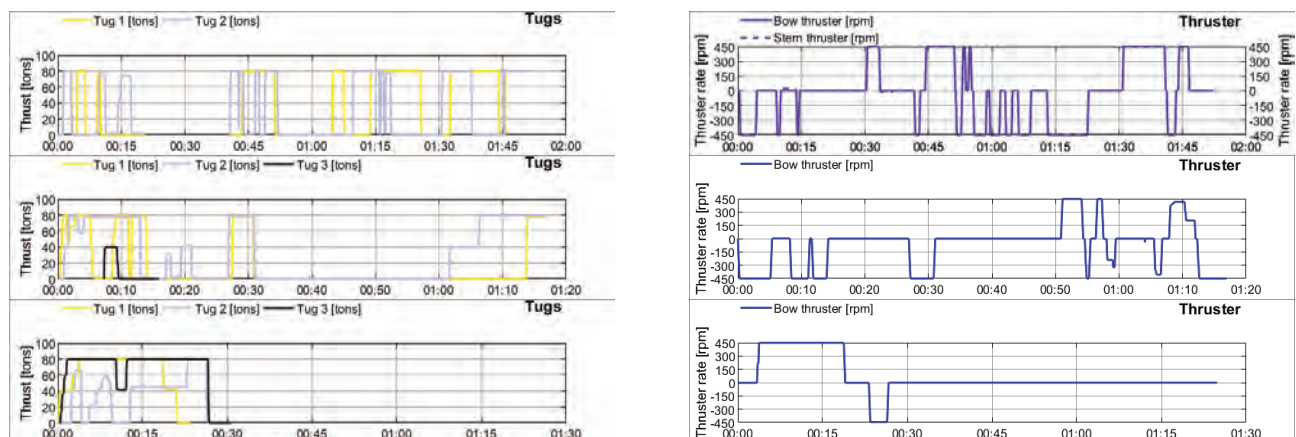


Figure 50 – Time variation of thrusters and tugs for (from top to bottom) runs U2_P4, U4_P4 and U6_P2

In run M5_P4 a head in swinging manoeuvre is first executed at the quay at the end of the Duplex dock with a 255 m vessel, but as the ship length with aft tug is too large for the area with moored ULCS at the opposite quay, the swinging manoeuvre should be executed elsewhere (necessary dock width of 350 m) or the ship should have to leave the dock astern. Due to the swinging the vessel leaves the dock as a head out outbound sailing ship without any tug assistance. The manoeuvre at a dynamic tide starting 4.0h after HW is a smooth manoeuvre. The simulation was ended before the second crossline was passed so that the time from the first line to the end of the simulation was 5.8 min.

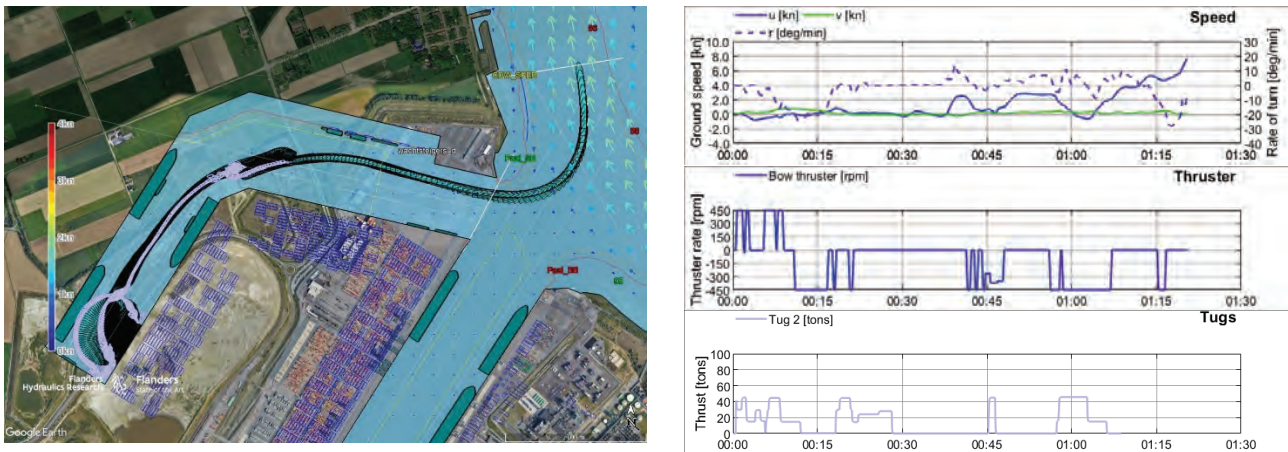


Figure 51 – Run M5_P4 [duration 80 min]: head out outbound manoeuvre from Duplex dock to the river at ebb (+4.0h to HW dynamic)

3.3 Analysis per scenario

Besides the analysis of individual head in or head out manoeuvres to and from Duplex dock it is also interesting to evaluate the interaction of the containerships in the different scenarios. This evaluation was first made for the L-square alternative in Eloot *et al.* (2020). An important difference with the scenarios in the L-square dock is that all manoeuvres to and from the dock were head in manoeuvres. Secondly since 2019 additional research has been executed, such as the study on fairway widths in Verwilligen *et al.* (2021a) for the Portgenie capacity model built by Macomi for the port of Antwerp-Bruges. These studies will give an adapted evaluation of the simulations in the L-square and the Duplex dock. The output of the real time simulation studies in both alternatives will be evaluated based on the new developments for the capacity model and will be reported in the framework of project 21_044 and not in this report. Thirdly on March 14th inland skippers were sailing on simulator Lara so that in the U type simulations with ULCS four or three were interacting with each other.

The aim of the analysis per scenario for the Duplex dock is twofold and more precisely:

- to describe the sequence of the ULCS in following configurations (scenario UX):
 - o more ULCS inbound than outbound: chapter 3.3.1
 - o two ULCS inbound and two ULCS outbound: chapter 3.3.2
 - o less ULCS inbound than outbound: chapter 3.3.3
 with or without the inland ship as interacting vessel;
- to describe the sequence in scenarios MX with additional focus on manoeuvres such as swinging or meetings in Duplex dock and others: chapter 3.3.4.

3.3.1 More ULCS inbound than outbound

Four scenarios with ULCS have been executed with more ULCS coming inbound than outbound (U1, U3, U4 and U6). U1 and U3 are at flood tide and U4 and U6 at ebb tide. For U3 and U4 one ship is the inland motorship or push convoy.

Each scenario is summarised in a descriptive table with following parameters:

- the player in het scenario (P1, P2, P3 or P4);
- the ship (length/draft);
- the start position: the buoy or dock (Deurganck dock DGD or Duplex dock DX, with first stretch DX(1) or second DX(2)) or tidal terminal;

- the intermediate position: if the ship is holding at approximately zero speed at a certain area;
- the end position: the buoy or dock or the terminal such as for the start position;
- time on river: the time the ship (first crossing with bow or stern) has passed at the river from the start or end position until the crossline 0290_ (Appendix 5). The crossline is further away from the DGD mouth to give the possibility to the outbound ship to align more or less to the red buoy line on the river between DGD and Europeterminal;
- time dock/river (Figure 52): time at the zone in between the Duplex dock (3010_2GTD01_West_430) or Deurganck dock (2020_EntranceDGD_North) and the crossline on the river 0290_. This zone is much larger than the zone used in the evaluation of the L-square alternative but is chosen here to detect the difference between head in and head out manoeuvres;
- time in dock: the time the ship is in Duplex or Deurganck dock;
- total time of the scenario: total duration of the simulation;
- meetings: the players (ships) are mentioned with the time stamp in the simulation and the location. Situations where ships are in each other's vicinity in DGD mouth at non-parallel courses are not considered. Only interacting ships steered by the pilots are considered. Meetings with target ships and moored ships are not reported. Meetings will be discussed in a separate chapter 3.3.5.

For the understanding of the descriptive tables it is best to combine them with the KMZ Google Earth views of the simulations.

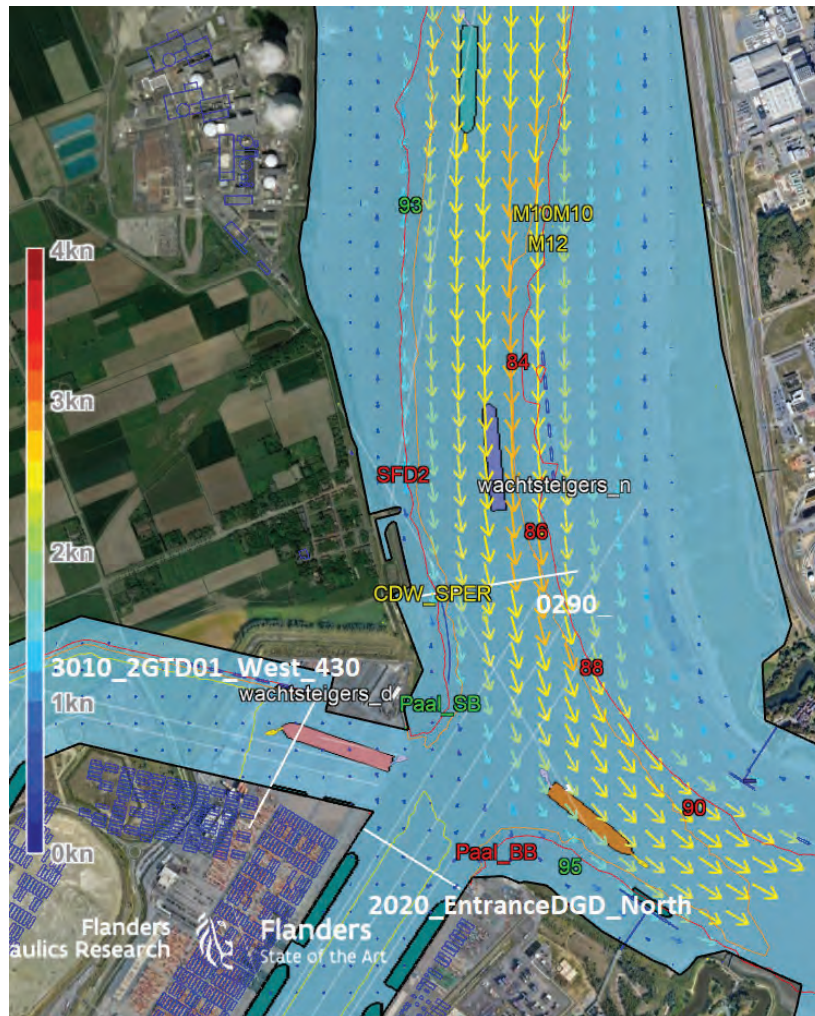


Figure 52 – Definition of zone between crosslines 0290_ and 3010_2GTD01_West_430 (scenario U1 at min 58) for Duplex dock and 2020_EntranceDGD_North for Deurganck dock

The scenario U1 with three inbound ULCS and one outbound at flood tide is given in Table 21. The sequence of the vessels can be checked based on the start position and the outbound tracks are filled in grey. An indication of an intermediate position reveals measures taken to adjust the meetings of vessels or passages of certain areas. Bringing ships closer to each other can request adjustments of the speed during the passages but can give opportunities to handle the different ships in a time-space optimisation. Interesting are the time indications and especially the time needed to pass the zone from river to dock and vice versa. For U1_P4 the shortest time of 13 min is measured and based on a direct head in inbound manoeuvre without adjusting the passing due to planning with other vessels. U1_P1 is a head in inbound manoeuvre but via the DGD with a total time of 48 min. This time is more or less identical with the time needed for U1_P2 to execute a head out inbound manoeuvre to Duplex with a swinging manoeuvre in DGD mouth. The distance between the tugs of U1_P4 and U1_P1 was too small in the DGD mouth but U1_P1 could have adjusted the speed to leave space for the outbound sailing U1_P4.

The direct head out outbound manoeuvre from Duplex to the river (U1_P3) gives a duration of 36 min with 12 min waiting time in the Duplex dock entrance. This corrected time is less than two times the one for the direct head in manoeuvre of U1_P4. The flood current counteracts the outbound manoeuvre what explains the longer duration. The time to travel with the 430 m vessel (U1_P1) from a position fully in the Duplex dock to the end of Duplex takes 33 min.

Table 21 – Scenario U1 with three inbound and one outbound ULCS at flood tide and NW 5 Bft

Run	Parameter/player	P1	P2	P3	P4
U1	Ship (length, draft)	430 m / 150 dm	400 m / 142 dm	400 m / 135 dm	400 m / 150 dm ²⁴
	Mooring in dock	Head in DX	Head out DX	Head out DX	Head in DX
	Start position	Buoy 93	Buoy 87	DX(1) ²⁵	Buoy 79
	Intermediate position	DGD	no	DX entrance	Buoy 93
	End position	End DX(2)	DX(1)	Buoy 87A	Entrance DX
	Time on river	9 min	27 min	36 min	77 min
	Time dock/river	48 min	49 min	36 min	13 min
	Time in dock	33 min	14 min	18 min	-
	Total time scenario	1h 30 min			
	Meetings	(P3, P4) at min 64 (buoy 93)			

²⁴ Outbound sailing ships are filled in grey so that a distinction can be made with the inbound sailing ships. The direction of execution changes with the inbound sailing ships first passing the river while the outbound sailing ships start in a dock.

²⁵ DX (1) means Duplex dock in first stretch downstream the bend and DX (2) means Duplex dock in second stretch after/upwards the bend.

A comparable scenario with three inbound and one outbound ULCS but now at ebb tide (U6) is summarised in Table 22. The shortest time between dock and river is obtained for the head out outbound manoeuvre of U6_P2 with 20 min where the current helps the turning manoeuvre. To leave space for this ship, U6_P1 entered first head in the DGD and could immediately turn head out to Duplex dock in 24 min (Figure 53). This is not significantly more than the 22 min needed for the direct head in inbound manoeuvre of U6_P4 where the ebb current counteracts the turning to starboard while entering Duplex from the river. The mooring direction is nevertheless different (head out versus head in). Executing the head out inbound manoeuvre on the river and in the DGD mouth gives a time of 32 min for U6_P3. Compensating current and wind makes it more difficult than in U6_P1. Two tracks from the entrance to the end of Duplex dock are available with a time duration of 40 and 38 min (more than in scenario U1) for respectively U6_P1 and U6_P3 (difference in wind force compared to the 33 min for U1_P1).

Table 22 – Scenario U6 with three inbound and one outbound ULCS at ebb tide and SW 6 Bft

Run	Parameter/player	P1	P2	P3	P4
U6	Ship (length, draft)	400 m / 131 dm	430 m / 150 dm	430 m / 150 dm	430 m / 150 dm
	Mooring in dock	Head out DX	Head out DX	Head out DX	Head in DX
	Start position	Buoy 93	DX(1)	Buoy 87	Buoy 74
	Intermediate position	DGD	no	no	Buoy 93
	End position	End DX(2)	Buoy 66	End DX(2)	DX(1)
	Time on river	9 min	55 min (B66)	42 min	86 min
	Time dock/river	24 min	20 min	32 min	22 min
	Time in dock	40 min (quay)	10 min	38 min	-
	Total time scenario	1h 48 min			
	Meetings	(P2, P3) at min 35 (buoy 84) and (P2, P4) at min 43 (buoy 82)			

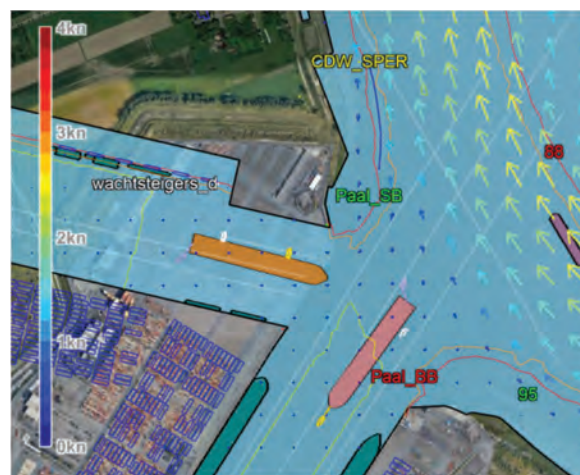


Figure 53 – Scenario U6 with interacting head out outbound sailing U6_P1 (red) and head out outbound sailing U6_P2 (orange)

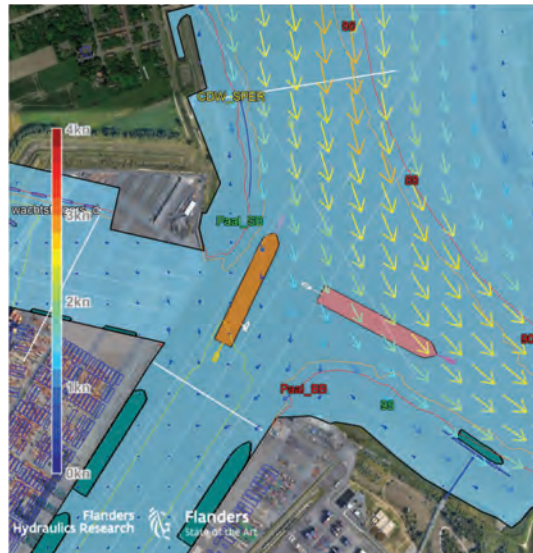


Figure 54 – Scenario U3 with interacting head in outbound sailing U3_P2 (orange) and head out inbound sailing U3_P1 (red)

Table 23 – Scenario U3 with two inbound and one outbound ULCS at flood tide and SW 5 Bft (plus inland ship)

Run	Parameter/player	P1	P2	P3	P4
U3	Ship (length, draft)	430 m / 150 dm	400 m / 120 dm	110 m / 3.5 dm	400 m / 150 dm
	Mooring in dock	Head out DX	Head in DX	-	Head in DX
	Start position	Buoy 91	DX(1)	DGD	Buoy 74
	Intermediate position	River (DGD)	DGD	-	-
	End position	End DX(2)	NZT	End DX(2)	DX(1)
	Time on river	15 min	52 min	-	44 min
	Time dock/river	31 min	21 min	-	21 min
	Time in dock	38 min	11 min	-	19 min
	Total time scenario	1h 24 min			
	Meetings	(P2, P3) at min 10 (DX(1)), (P2; P4) at min 38 (buoy 84), (P1, P3) at min 60 (bend DX) and (P3, P4) at min 66 (DX (1))			

Scenario U3 has two inbound and one outbound ULCS while an inland ship is moving around in the Duplex and Deurganck docks (Table 23). The scenario is also at flood tide as U1 but with different wind condition (SW instead of NW). Although U3_P1 and U3_P2 are coming together in/nearby the DGD mouth a fluent and short interaction is executed (Figure 54). The head out inbound sailing U3_P1 only stays for 31 min in the dock/river zone although it has to wait some minutes for the head in outbound U3_P2 that uses the DGD as an intermediate location to turn outside of the current on the river. It seems clearly favourable to organise

as much as possible manoeuvres outside of the strong current zones by using the different stretches of Duplex and Deurganck dock. U3_P4 executes a direct head in inbound manoeuvre, without interference from other vessels, and needs 21 min to pass the dock/river zone. The southwesterly wind is more counteracting the turning manoeuvre than the northwesterly wind in U1. U3_P1 sails to the end of Duplex dock and needs 38 min what is comparable with the 33 to 40 min in U1 and U6. Several meetings with the inland ship (U3_P3) have been organised in Duplex dock, also with U3_P1 in the bend but this do not really change the time needed to pass Duplex dock compared to the runs without interacting inland ships.

In scenario U4 two inbound and one outbound ULCS are interacting with a push convoy travelling through Duplex dock (Table 24). U4_P4 meets the push convoy in the bend of Duplex dock but nevertheless only needs 18 min to travel from a mid position in the centreline of Duplex dock in the second stretch to the crossline in Duplex dock. Then the ULCS continues with a direct head out outbound manoeuvre (13 min to travel the dock/river zone) while U4_P2 is waiting on the river nearby DGD mouth to execute a head out inbound manoeuvre. The passing time in the dock/river zone is long with 41 min (see also U1_P1 and U1_P2). This time can be split up in 11 min to travel from the crossline at the river to the waiting area nearby buoy 95, 9 min waiting at buoy 95 (mouth free) and then 21 min to pass the DGD mouth to the crossline in Duplex dock. U4_P1 also executes a head out inbound manoeuvre but only needs 26 min to pass the dock/river zone as no other ULCS have to be taken into account and the ebb current is assisting the astern motion. The pilot also tried to turn as close as possible to the northern corner of the Duplex dock to save time.

The time the ULCS are spending on the river were not discussed but the information can also be interesting to check how the planning of ULCS could be optimised to organise the necessary meetings along the river, terminals and in the docks.

Table 24 – Scenario U4 with two inbound and one outbound ULCS at ebb tide and NW 6 Bft (plus inland ship)

Run	Parameter/player	P1	P2	P3	P4
U4	Ship (length, draft)	400 m / 131 dm	430 m / 150 dm	110 m / 4.0 dm	430 m / 150 dm
	Mooring in dock	Head out DX	Head out DX	-	Head out DX
	Start position	Buoy 87	Buoy 93	DGD	Mid DX(2)
	Intermediate position	Buoy 93	River (DGD)	-	-
	End position	DX(1)	DX(1)	End DX(2)	NZT
	Time on river	49 min	10 min	-	46 min
	Time dock/river	26 min	41 min	-	13 min
	Time in dock	2 min	17 min (quay)	-	18 min
	Total time scenario	1h 17 min			
	Meetings	(P3, P4) at min 14 (DX bend), (P3, P2) at min 37 (mouth), (P1, P4) at min 39 (buoy 84), (P3, P1) at min 43 (buoy 86), (P3, P1) at min 60 (mouth)			

3.3.2 Two ULCS inbound and two ULCS outbound

Only one scenario (U2) has been executed with two ULCS inbound and two outbound at ebb tide. No comparison with other scenarios in Duplex dock is possible. Scenario U2 is summarised in Table 25.

The two outbound sailing ships have different starting positions and U2_P2 is moored head in while U2_P4 is moored headout. U2_P4 can immediately start from the quay and pass the dock entrance for the river in 17 min. U2_P2 has to leave the quay, pass the bend in Duplex and approach the crossline in Duplex dock in astern motion (35 min). The ULCS then sails astern to the DGD to leave space for the inbound heading in U2_P3 that needs 25 min to sail the dock/river zone in one move (ebb tide, counteracting current). The DGD mouth is then free for U2_P2 to leave the dock for the river with a total time in the dock/river zone of 41 min. U2_P1 can as final ULCS pass the DGD mouth with a turning to an astern motion in the dock/river zone which passage needs 24 min. Consequently, the time U2_P3 and U2_P1 needs to pass the dock/river zone is the same while there heading is different.

U2_P3 travels to the end of Duplex dock in an ahead motion at a northeasterly 5 Bft wind and needs 43 min to come along the quay while U2_P2 starts at the end of the dock in an astern motion and needs 35 min to pass with the stern the crossline in Duplex dock. There is nevertheless a difference of one ship length between both timings as the first point crossing the line is taken as reference. 400 m distance is at a speed of 1 m/s travelled in 6.7 min what explains the difference. The travel time in ahead or astern motion is therefore almost the same in Duplex dock.

Table 25 – Scenario U2 with two inbound and two outbound ULCS at ebb tide and NE 5 Bft

Run	Parameter/player	P1	P2	P3	P4
U2	Ship (length, draft)	430 m / 150 dm	430 m / 150 dm	400 m / 140 dm	400 m / 120 dm
	Mooring in dock	Head out DX	Head in DX	Head in DX	Head out DX
	Start position	Buoy 74	End DX(2)	Buoy 89	DX(1)
	Intermediate position	Buoy 93	DGD	-	-
	End position	DX entrance	Buoy 82	End DX(2)	Buoy 87 ²⁶
	Time on river	88 min	36 min	44 min	88 min
	Time dock/river	24 min	41 min	25 min	17 min
	Time in dock	-	35 min	43 min	7 min
	Total time scenario	1h 52 min			
	Meetings	(P3, P4) at min 29 (buoy 84), (P1, P2) at min 82 (buoy 84)			

²⁶ Three swinging manoeuvres executed in between DGD and NZT

Table 26 – Scenario U5 with one inbound and three outbound ULCS at flood tide and E 5 Bft

Run	Parameter/player	P1	P2	P3	P4
U5	Ship (length, draft)	430 m / 150 dm	430 m / 150 dm	430 m / 150 dm	400 m / 131 dm
	Mooring in dock	Head in DX	Head in DX	Head out DX	Head out DGD
	Start position	Buoy 87	Front DX(2)	DX(1)	End DGD
	Intermediate position	Buoy 84	DGD	-	-
	End position	DX(1)	Buoy 86	Buoy 85	NZT
	Time on river	46 min	1 min	36 min	69 min
	Time dock/river	17 min	41 min	26 min	17 min
	Time in dock	9 min	30 min	10 min	26 min
	Total time scenario	1h 12 min			
	Meetings	(P1, P3) at min 40 (buoy 84), (P1, P4) at min 46 (buoy 86)			

3.3.3 Less ULCS inbound than outbound

Only one scenario has been executed with three ULCS outbound and one ULCS inbound, U5 at flood tide and E 5 Bft (Table 26). No comparison with other scenarios in Duplex dock is possible. The time stamps at min 23 and 40 during the simulation are shown in Figure 55. Both U5_P2 (head in) and U5_P3 (head out) leave the quay at the start of the simulation. The difference in time spend in the dock to the crossline in Duplex dock (30 min for U5_P2 and 10 min for U5_P3) is due to the starting position but also the manoeuvre necessary to leave the quay. U5_P2 has to first bring the ship to the centreline of the second stretch of Duplex dock before heading astern to the bend in Duplex while U5_P3 can immediately sail to the dock entrance with only inland ships moored in ahead motion. U5_P4 starts at the end of Deurganck dock and needs 26 min to travel to the crossline in Deurganck dock. U5_P3 is executing a direct head out outbound manoeuvre in the dock/river zone in 26 min with a difficult manoeuvre once on the river to counteract the flood current. This manoeuvre is followed by the head out outbound manoeuvre from DGD of U5_P4 in 17 min. The head in outbound manoeuvre of U5_P2, where the ULCS first turns with the stern in the DGD, takes longer (41 min) than the head out outbound manoeuvre of U5_P3 but is comparable with other tracks of ships that have to wait until other ULCS passed the dock/river zone (e.g. U1_P1). The head in inbound sailing U5_P1 had to wait a bit at buoy 84 to manage the interactions with the other ULCS but can pass finally the dock/river zone in 17 min, what is the same time as for the head out outbound sailing U5_P4 from DGD.

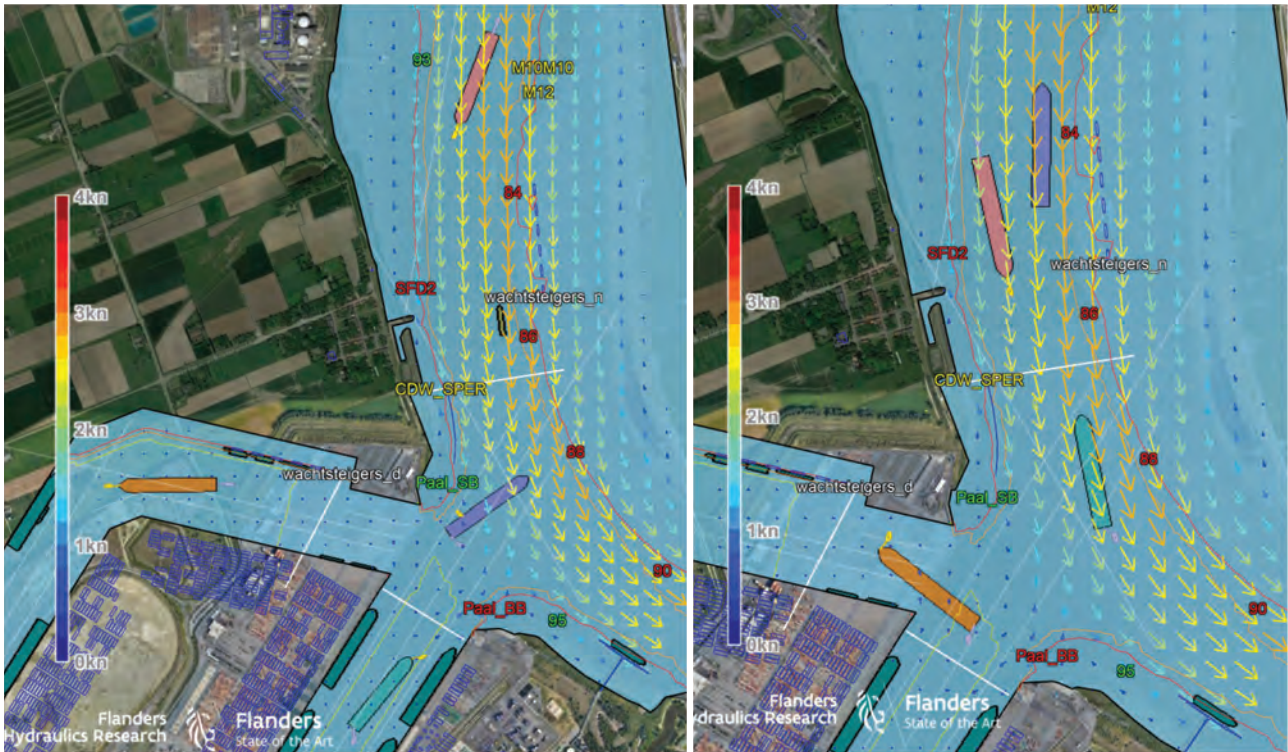


Figure 55 – Scenario U5 with three outbound and one inbound ULCS at flood tide and E 5 Bft (left min 23, right min 40)

3.3.4 Multivariant ships

For the scenarios with multivariant ships first the scenarios themselves will be discussed followed by special attention to specific manoeuvres in the Duplex dock (swinging, meeting).

Scenarios

Scenario M1 has two inbound (400 m and 210 m) and two outbound ships (430 m and 255 m) at flood tide and S B Bft. M1_P1 is at the start of the simulation already in the centreline of the second stretch of the dock while M1_P4 is still at the quay. Both vessels are sailing head out outbound. M1_P1 passes the dock to the crossline in 18 min and needs 26 min to execute a direct head out turning to the river against the flood current. This is for example comparable with U5_P3. M1_P4 will wait in the bend of Duplex dock to organise a meeting with M1_P3 in the first stretch of Duplex dock. This explains why the time in the dock is 48 min. Once both ships passed by (meeting at the crossline in Duplex dock) M1_P4 needs 15 min to travel the dock/river zone although some manoeuvring was necessary to counteract the flood current. The meeting ship M1_P3, that can always enter and leave Duplex dock ahead thanks to its length (see simulations with swinging manoeuvres to be discussed), needs 11 min to pass the dock/river zone. At the end it executed a swinging manoeuvre in front of the quay which was difficult to execute as the Duplex dock quay walls were not available on the electronic chart of the PPU while this will surely be the case in real life. The last incoming ship is the ULCS M1_P2 that executes a head out swinging in the dock/river zone which takes in total 30 min.

Table 27 – Scenario M1 with two inbound and two outbound containerships at flood tide and S 6 Bft

Run	Parameter/player	P1	P2	P3	P4
M1	Ship (length, draft)	430 m / 150 dm	400 m / 140 dm	210 m / 110 dm	255 m / 120 dm
	Mooring in dock	Head out DX	Head out DX	Head in DX	Head out DX
	Start position	Mid DX(2)	Buoy 87A	Buoy 89A	Mid DX(2)
	Intermediate position	Buoy 88	Buoy 82	Buoy 93	Bend DX
	End position	NZT	DX entrance	End DX(2)	Buoy 93
	Time on river	45 min	58 min	37 min	26 min
	Time dock/river	26 min	30 min	11 min	15 min
	Time in dock	18 min	1 min	41 min	48 min
	Total time scenario	1h 29 min			
	Meetings	(P1, P3) at min 41 (buoy 88), (P3, P4) at min 48 (DX entrance), (P1, P2) at min 52 (buoy 84), (P4, P2) at min 62 (buoy 88)			

Table 28 – Scenario M2 with three inbound and one outbound containerships at minimum ebb tide and N 6 Bft

Run	Parameter/player	P1	P2	P3	P4
M2	Ship (length, draft)	430 m / 150 dm	400 m / 150 dm	367 m / 131 dm	255 m / 120 dm
	Mooring in dock	Head out DX	Head in DX	Head in DX	Head in DGD
	Start position	Start DX(2)	Buoy 85A	Buoy 93	Buoy 89
	Intermediate position	-	Buoy 93	DGD	Buoy 90
	End position	Buoy 82	DX(1)	Bend DX	DGD
	Time on river	26 min	50 min	7 min	15 min
	Time dock/river	22 min	17 min	44 min	24 min
	Time in dock	19 min	-	16 min	28 min
	Total time scenario	1h 07 min			
	Meetings	(P3, P4) at min 40 (DGD) and (P1, P2) at min 45 (buoy 84)			

Scenario M2 is characterised by three inbound and one outbound sailing containerships at minimum ebb tide and N 6 Bft. The ULCS M2_P1 starts nearby the bend in the second stretch of Duplex dock. It takes 19 min to pass the crossline and 22 min to sail the dock/river zone. In the meantime M2_P3 was approaching the DGD mouth before M2_P1 left the dock and used the Duplex entrance (for placing the bow) to execute a swinging manoeuvre with the stern entering DGD and awaiting the meeting with M2_P4 (Figure 56). This is the reason why the passing of the dock/river zone takes 44 min. Finally M2_P3 sails till the bend in Duplex dock in 16 min. The indirect manoeuvre of M2_P4 for entering the DGD explains the travel time of 24 min between the crosslines at the river and DGD. M2_P4 executes a swinging manoeuvre in DGD. Finally M2_P2 executes a direct head in manoeuvre to Duplex dock and needs 17 min to cross the dock/river zone. The time is not necessarily different at this minimum ebb tide but strong wind condition compared to the other scenarios with stronger current.

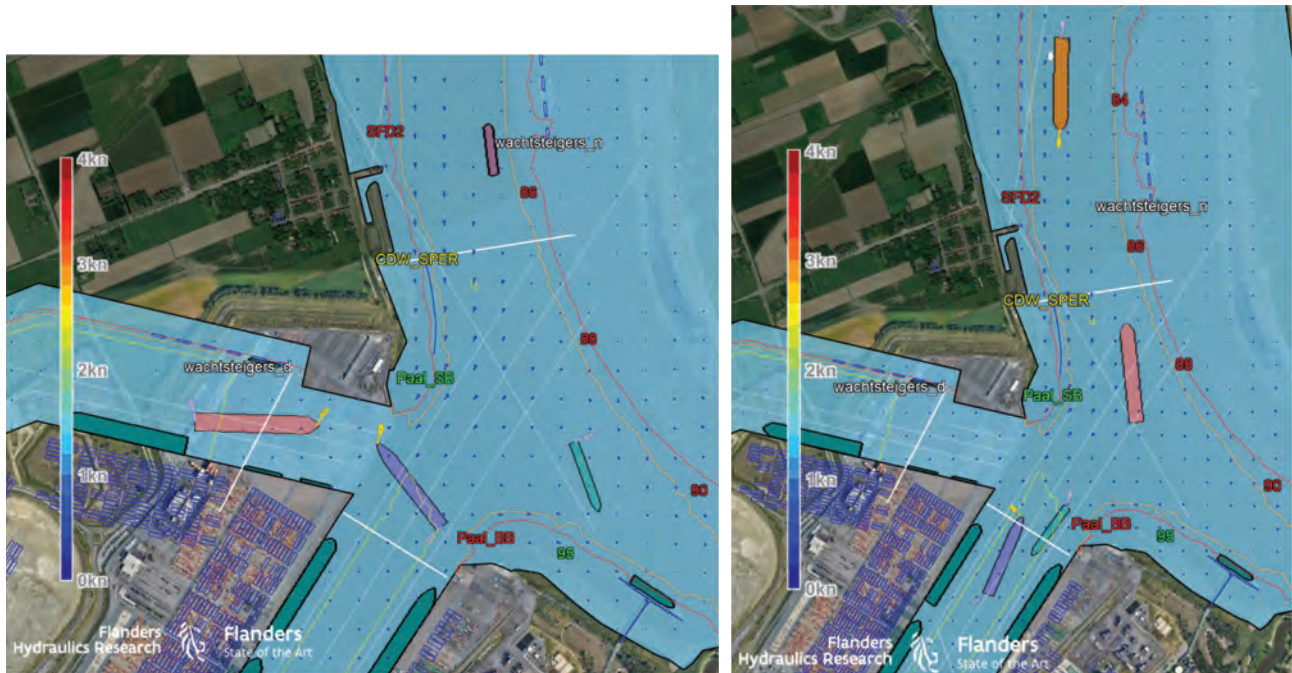


Figure 56 – Scenario M2 with three inbound and one outbound containerships at minimum ebb tide and N 6 Bft
(left min 23, right min 39)

Scenario M3 is with an inland ship moving through Duplex and Deurganck dock with one inbound and two outbound sea-going containerships at increasing flood tide and E 5 Bft (Table 29). At the start of the simulation M3_P3 (inland), M3_P4 and M3_2 are at the end of Duplex dock. The largest ship M3_P4 leaves first and passes the dock to the crossline in 33 min followed by a direct head out outbound manoeuvre with 19 min in the dock/river zone. In the meantime M3_P1 entered the DGD mouth and executed a swinging manoeuvre astern to DGD to wait for the entrance of Duplex dock. The time of M3_P1 in the dock/river zone was 32 min. When passing the dock entrance a meeting with M3_P2 is prepared but the distance between the meeting and moored ships is not feasible. M3_P2 has a time from the end of the dock to the crossline of 52 min. Some problems occurred also at the start of the simulation with the tug assistance and the ship had to wait for the departure of M3_P4 and M3_P3. M3_P2 executes a head out outbound manoeuvre and crosses the dock/river zone in 9 min, the shortest time with a 255 m containership. The time for M3_P1 to sail from the crossline in Duplex dock until the zone upstream the bend is 17 min.

Table 29 – Scenario M3 with one inbound and two outbound sea-going containerships and an inland ship at flood tide and E 5 Bft

Run	Parameter/player	P1	P2	P3	P4
M3	Ship (length, draft)	400 m / 131 dm	255 m / 120 dm	110 m / 35 dm	400 m / 131 dm
	Mooring in dock	Head in DX	Head in DX	-	Head out DX
	Start position	Buoy 91	End DX(2)	End DX(2)	End DX(2)
	Intermediate position	DGD	-	-	
	End position	Mid DX(2)	Buoy 93	End DX(2)	Buoy 84
	Time on river	17 min	5 min	-	14 min
	Time dock/river	32 min	9 min	-	19 min
	Time in dock	17 min	52 min	-	33 min
	Total time scenario	1h 06 min			
	Meetings	(P3, P4) at min 30 (DX(1)), (P3, P1) at min 36 (DGD), (P3, P1) at min 44 (DGD), (P3, P2) at min 48 (DX(1)) and (P2, P1) at min 53 (DX(1))			

In scenario M4 two inbound (to Duplex) and one outbound sea-going ship (from DGD) were interacting with a sailing push convoy in the docks. The plan was that M4_P2 and M4_P4 should meet in the DGD mouth to check if such vessels can meet at this space (Figure 57). So M4_P2 executes a regular direct head in inbound manoeuvre to Duplex dock with a time of 15 min in the dock/river zone during flood tide and S 6 Bft. The meeting M4_P4 ship does not disturb the entrance of the ULCS M4_P2 as the smaller M4_P4 has to take the ULCS manoeuvring into account. Nevertheless for M4_P4 the following sailing on the river is not successful as the flood current cannot be overcome and the vessel executes a swinging manoeuvre over starboard on the river (Figure 57). M4_P4 should have been waiting in the DGD until the DGD mouth was completely free to execute the outbound sailing to the river. The time M4_P4 therefore needs to sail from the crossline in DGD to the crossline on the river is 19 min what long is for a 210 m vessel. This meeting should in real life have been avoided. M4_P1 is then executing a swinging manoeuvre to Duplex dock astern which takes 27 min in the dock/river zone. The time to sail from the crossline in Duplex dock to the first quay in the first stretch of Duplex takes 17 min as the ship has to counteract the southerly 6 Bft wind. M4_P2 travels in 40 min from the same crossline to the end of Duplex dock with an overtaking manoeuvre by the push convoy in the bend of Duplex included.

Table 30 – Scenario M4 with two inbound and one outbound sea-going containerships and an inland push convoy at flood tide and S 6 Bft

Run	Parameter/player	P1	P2	P3	P4
M4	Ship (length, draft)	430 m / 150 dm	367 m / 145 dm	191 m / 40 dm	210 m / 110 dm
	Mooring in dock	Head out DX	Head in DX	-	Head out DGD
	Start position	Buoy 89A	Buoy 93	DX(1)	End DGD
	Intermediate position	-	-	-	-
	End position	DX(1)	End DX(2)	DX(2)	_27
	Time on river	19 min	8 min	-	12 min
	Time dock/river	27 min	15 min	-	19 min
	Time in dock	17 min	40 min	-	32 min
	Total time scenario	1h 03 min			
	Meetings	(P3, P4) at min 10 (DGD), (P4, P2) at min 16 (DGD mouth), (P1, P4) at min 30 (buoy 88) and (P3, P2) at min 43 (bend DX)			

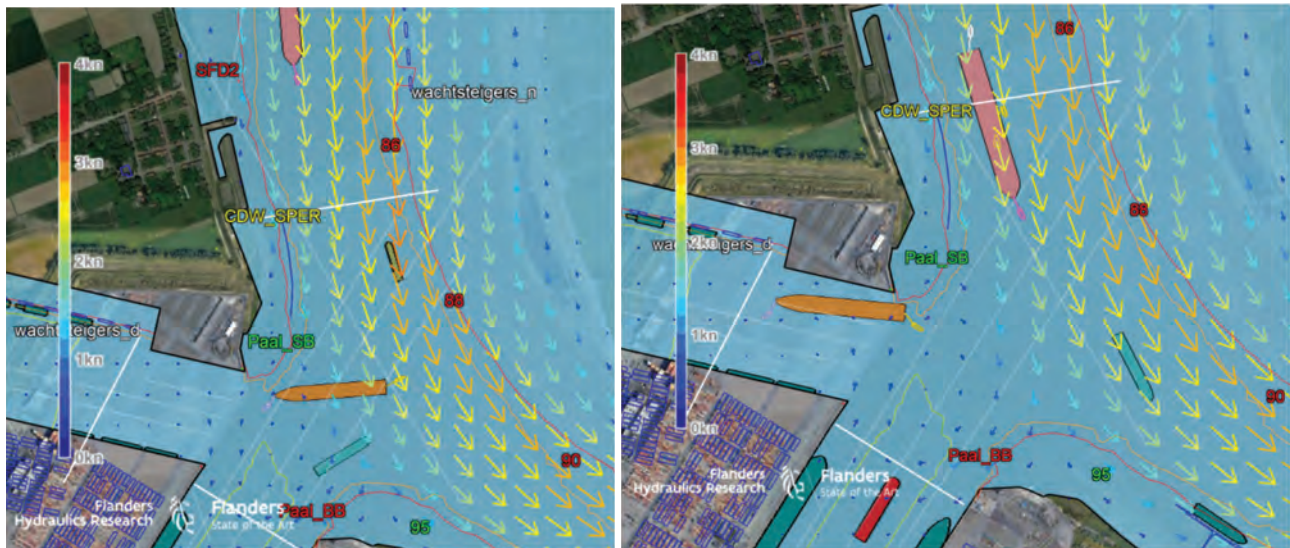


Figure 57 – Scenario M4 with two inbound and one outbound sea-going containerships and an inland push convoy at flood tide and S 6 Bft (left min 15, right min 21)

²⁷ M4_P4 executed different manoeuvres on the river after leaving the Deurganck dock for the river.

Table 31 – Scenario M5 with two inbound and two outbound containerships at ebb tide and N 6 Bft

Run	Parameter/player	P1	P2	P3	P4
M5	Ship (length, draft)	400 m / 120 dm	400 m / 140 dm	210 m / 110 dm	255 m / 120 dm
	Mooring in dock	Head in DX	Head out DX	Head in DX	Head in DX
	Start position	DX(1)	Buoy 91	Buoy 87A	End DX(2)
	Intermediate position	-	-	DX(2) ²⁸	-
	End position	- ²⁹	DX(1)	End DX(2)	Buoy 88
	Time on river	43 min	27 min	35 min	-
	Time dock/river	24 min	38 min	12 min	8 min
	Time in dock	13 min	25 min	33 min	72 min
	Total time scenario	1h 20 min			
	Meetings	(P1, P2) at min 34 (buoy 88), (P1, P3) at min 37 (buoy 86), (P2, P3) at min 40 (DGD mouth), (P3, P4) at min 56 (bend DX) and (P2, P4) at min 70 (DX(1))			

In scenario M5 (Table 31) are two ships outbound sailing from Duplex dock and two inbound to Duplex dock with ebb tide and N 6 Bft. M5_P1 leaves the quay in DX(1) at the start of the simulation and M5_P4 executes a swinging manoeuvre at the quay to change the head in to a head out. Later on the plan is that M5_P4 will meet with M5_P3 in the bend of Duplex dock so that the time of M5_P4 in the dock is long (72 min). When M5_P1 approaches the dock entrance after 13 min, it takes 24 min to sail from the crossline in the dock to the crossline on the river. The pilots decided not to wait on the river at the DGD mouth and M5_P2 decided to continue the head out approach to the DGD mouth so that both ships are meeting each other at the river in front of the DGD mouth. This is a stable but close manoeuvre. M5_P2 is then waiting at the position nearby the DGD mouth until M5_P3 passes the stern of the ship for entering the Duplex dock. Due to a consecutive meeting of M5_P3 with M5_P1 and M5_P2 the ships encounters ship-ship interaction forces hindering the entering manoeuvre to the Duplex Dock. In real life these meetings before entering the Duplex dock should have been avoided by adjusting the timing of ship interactions and leaving more space for M5_P3. The time M5_P3 needs to pass the dock/river zone is still short and only 12 min. M5_P2 follows with a time for passing the dock/river zone that is much longer and 38 min. M5_P3 travels in 33 min from the crossline in Duplex dock to the end of the dock with an acceptable meeting with M5_P4 in the bend. Finally the 255 m vessel M5_P4 can pass the dock/river zone in an ahead motion in only 8 minutes which is 1 minute better than the shortest time until now and can be dedicated also to the ebb tide which helps the ship turning.

Scenario M6 (Table 32) was a test case for two outbound ships at the western quays in the second stretch of Duplex dock with one heading in (M6_P1) and the other heading out (M6_P2). The other two ships were smaller with a head out outbound M6_P4 coming from DGD and a head in inbound M6_P3 to Duplex dock.

²⁸ The ship was waiting in DX(2) for planning a meeting with M5_P4 in the bend of Duplex dock.

²⁹ The ship executes a swinging manoeuvre on the river at buoy 82 and returns to the DGD mouth.

First the two ships in Duplex dock leave. It takes 24 min to leave the quay until the crossline in the dock for M6_P2 and 14 min more or a total of 38 min for M6_P1 laying deeper in the Duplex dock. This ship is also moving astern. The time to pass the dock/river zone is nevertheless identical for both ships and counts 20 min. M6_P2 can counteract the smaller flood current in a direct head out manoeuvre. Before both ships passed the DGD mouth the incoming M6_P3 and the outcoming M6_P4 from DGD met each other green to green on the river between the current deflecting wall and buoy 88. M6_P3 is then executing a swinging manoeuvre with the stern to DGD to leave space for the two outbound sailing ships. This waiting gives a time for M6_P3 of 47 min in the dock/river zone. M6_P4 only needs 5 min to pass the crossline in DGD and on the river.

Table 32 – Scenario M6 with one inbound and three outbound containerships at flood tide and W 6 Bft

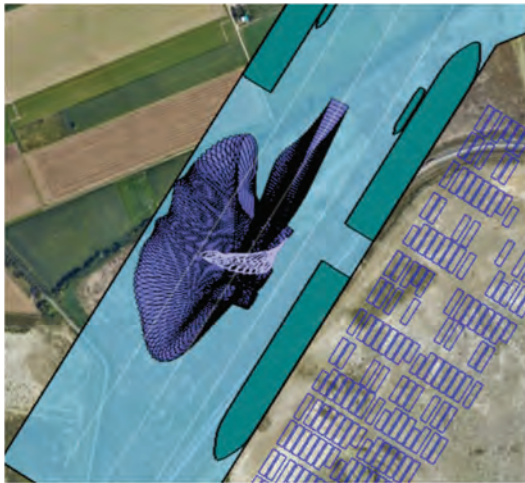
Run	Parameter/player	P1	P2	P3	P4
M6	Ship (length, draft)	400 m / 131 dm	400 m / 131 dm	367 m / 145 dm	255 m / 120 dm
	Mooring in dock	Head in DX	Head out DX	Head in DX	Head out DGD
	Start position	End DX(2)	Start DX(2)	Buoy 93	DGD
	Intermediate position	-	-	DGD	-
	End position	Buoy 86	Buoy 91	DX(1)	_30
	Time on river	-	14 min	8 min	44 min
	Time dock/river	20 min	20 min	47 min	5 min
	Time in dock	38 min	24 min	3 min	9 min
	Total time scenario	58 min			
	Meetings	(P3, P4) at min 12 (buoy 88)			

Swingings in Duplex dock

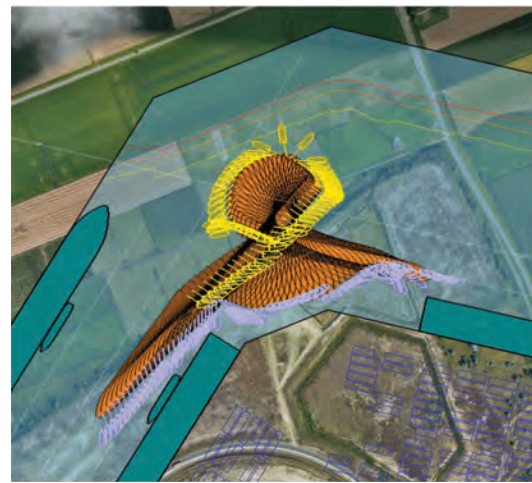
Besides of the full description of the scenarios some swinging manoeuvres in the Duplex dock will be analysed to evaluate the possibilities for ships to swing in the dock. Swinging manoeuvres with 210 m and 255 m vessels have been executed in the bend or the second stretch of the Duplex dock. The Duplex dock is 325 m wide at full depth in the first stretch and 350 m in the second stretch. The bend is 300 m at full depth.

All swinging manoeuvres in the Duplex dock are presented in Figure 58. A ship length of 255 m was not expected to be able to turn in the Duplex dock if ships are moored nearby the swinging area and that is proven with the tracks of M3_P2 (moored ships close by the bend) and M5_P4 (no space for ship and aft tug if a ship is moored at the opposite quay). A 210 m vessel should be feasible to swing but even then at strong wind conditions as 5 and 6 Bft the space is restricted. In M1_P3 the pilot had no indication of the quay wall on the PPU so he came too close. M5_P3 shows that in a full Duplex dock with wide ULCS moored at both sides a swinging nearby the quay does not leave much space for the assisting tugs in strong wind conditions. Training through ship manoeuvring simulations will help in deciding in which conditions a swinging manoeuvre with a maximum 210 m vessel is still possible.

³⁰ The ship executes several manoeuvres on the river between the Europe terminal and buoy 93.



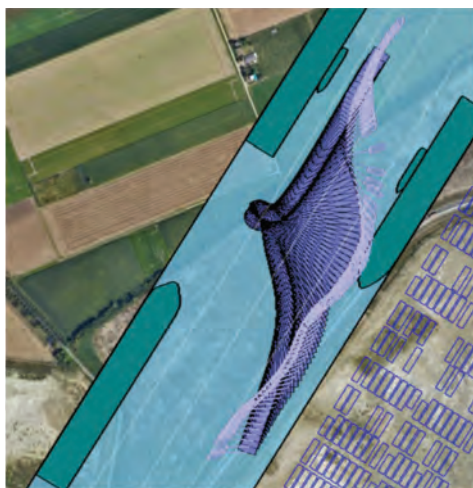
M1_P3 (210 m)



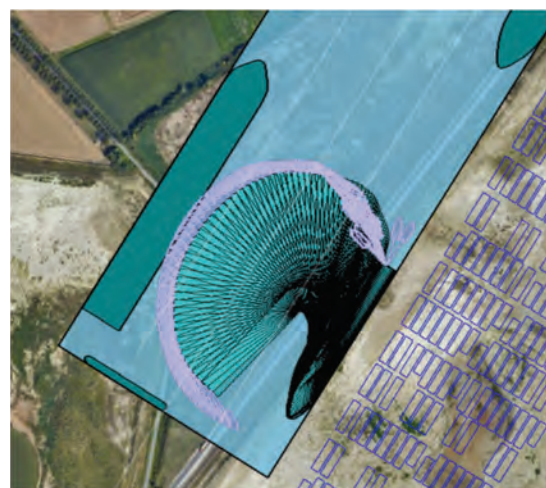
M3_P2 (255 m)



Livestream image of M3_P2 (255 m)



M5_P3 (210 m)

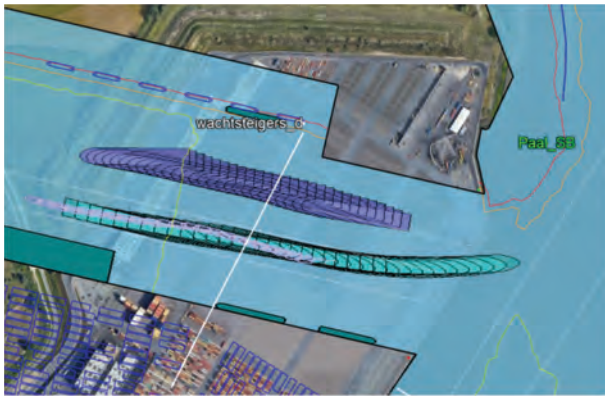


M5_P4 (255 m)

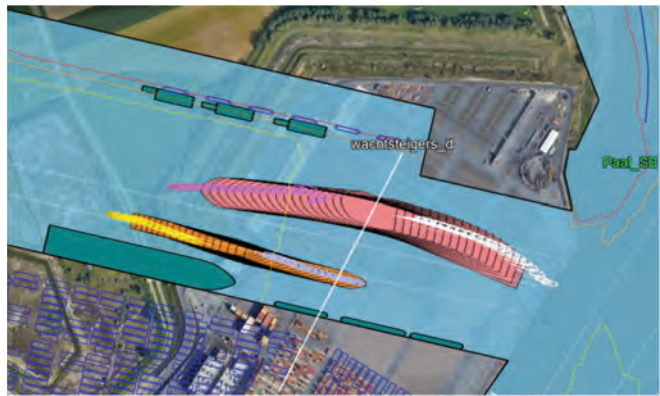
Figure 58 – Swinging manoeuvres in the bend and second stretch of Duplex dock

Meetings in Duplex dock

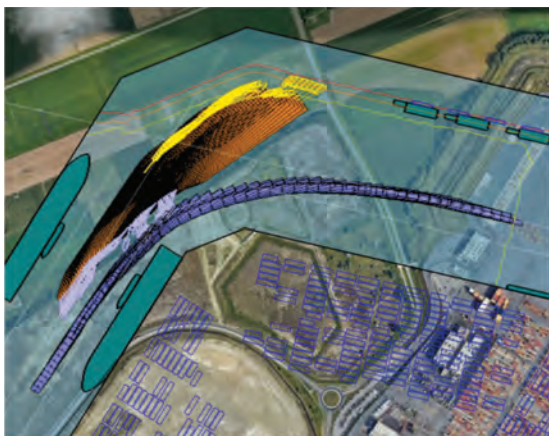
A second question was the organisation of meetings in the Duplex dock so that for some ships the Duplex dock can be considered as a two-way dock. Based on the analysis in chapter 3 it is clear that the second stretch does not leave much space for meetings if (wide) moored ships (with bunker ships) are present at both sides of the dock. Therefore no meetings were organised in the second stretch. The meetings in the first stretch of the Duplex dock downstream the bend are shown in Figure 59. Panamax wide ships can meet in the first stretch of the dock (M1 – P3 and P4) when a ULCS is moored downstream the bend. A combination of a ULCS with another sea-going small vessel should better be avoided (M3 – P1 and P2). With inland ships meetings for ULCS are realistic (U3 – P3 and P4). Meetings have also been executed in the bend. In strong wind conditions this could better be avoided (M5 – P3 and P4) with Panamax vessels but it is expected that in more favourable situations this will be done. Also for meetings between ULCS and inland ships in the bend (M4 – P2 and P3, U3 – P1 and P3, U4 – P3 and P4) the same conclusion can be drawn. Inland container ships with 5 container rows high also undergo negative effects in strong wind conditions so that some precautions should be taken to organise a meeting.



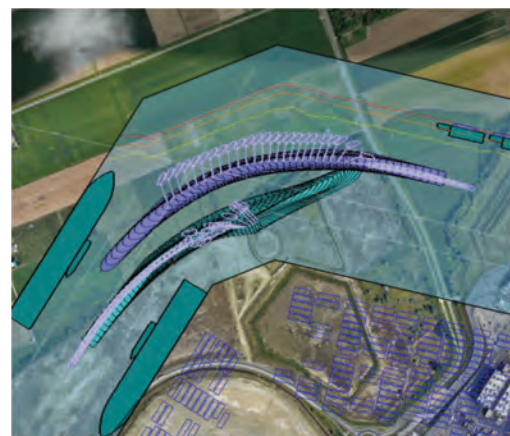
M1 – P3 (210 m) and P4 (255 m)



M3 – P1 (400 m) and P2 (255 m)



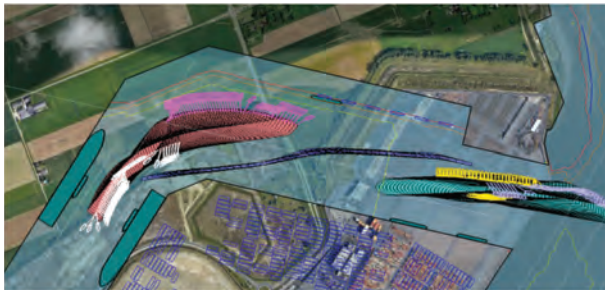
M4 – P2 (367 m) and P3 (191 m)



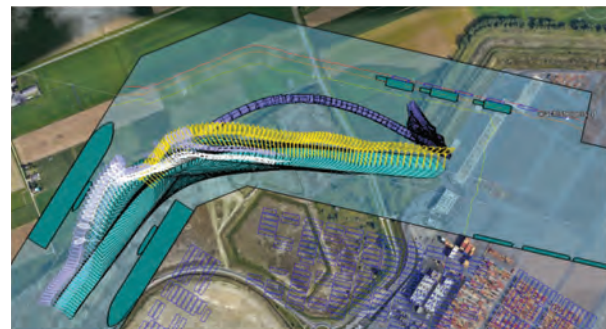
M5 – P3 (210 m) and P4 (255 m)



Livestream image M4 – P2 and P3



U3 – P1 (430 m), P3 (110 m) and P4 (400 m)



U4 – P3 (110 m) and P4 (400 m)

Figure 59 – Meetings in Duplex dock with sea-going and inland ships

3.3.5 Meetings

The meetings of ships on the river to be organised due to the traffic handling of four or three sea-going containerships concentrate between buoy 88 and buoy 82 on the river (for a summary see Table 27 to Table 32 for the MX scenarios and the meetings with ULCS in the UX scenarios in Table 21 to Table 26). One meeting was also happening in the Deurganck dock and two in the DGD mouth. Only the meetings between ships steered from a simulator are discussed. The positions of the ships during the meetings are visualised so that the distance between the ships and the heading are clear.

Deurganck dock

The meetings in Deurganck dock (mouth) are shown in Figure 60. The ship length of the interacting vessels was varying between 400 and 210 m. Only the meeting in scenario M2 is evaluated as realistic. The meetings in the dock mouth in scenarios M4 and M5 should be avoided in real life.

The non-parallel meetings of the manoeuvring ULCS in the DGD mouth are not considered in this evaluation of meetings as they are part of the traffic handling of the ULCS in the different stretches of Duplex dock, Deurganck dock and the river sections, connecting to the DGD mouth, and because of the positive evaluation of the pilots on the manoeuvres of ULCS in the vicinity of each other. Only in scenario U1 the tug captains considered the distance left for the assisting tugs too small but the pilots could have left more space for each ULCS. For all the other scenarios the meetings between the ULCS were acceptable in real life.

It can be concluded that although in the planning some space should be kept between consecutive or interacting ULCS for Deurganck dock and Duplex dock, unforeseen circumstances that bring the ULCS closer to each other can be handled with the dock entrances and river space nearby DGD mouth.

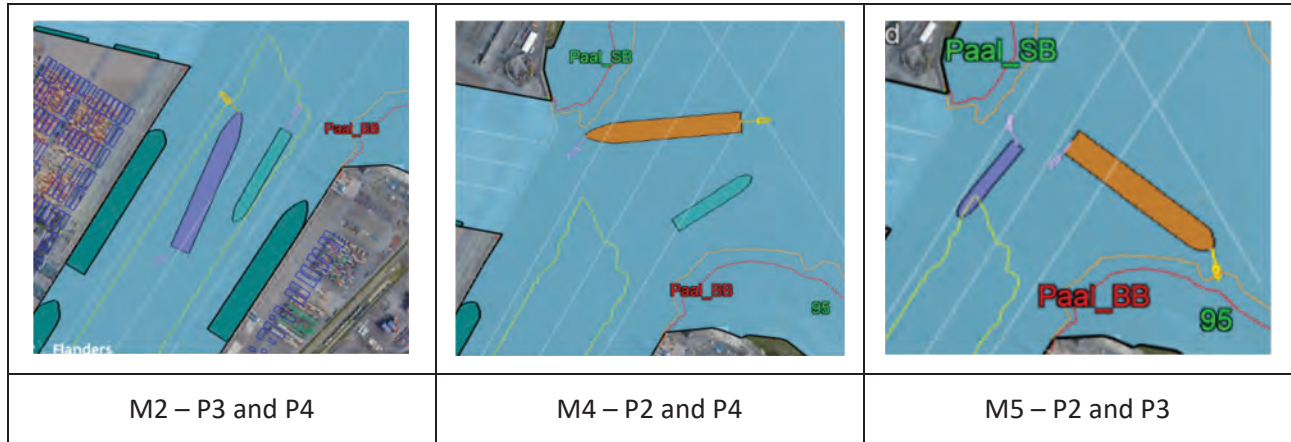


Figure 60 – Meetings in Deurganck dock (mouth)

Buoy 88

In comparison to the scenarios executed in the L-square alternative where only one meeting was occurring between buoys 86 and 88, now five meetings are happening at buoy 88 thus nearby the DGD mouth (Figure 61). This could be related to the Duplex entrance which is closer to the river and the combination of head out and head in manoeuvres instead of only head in manoeuvres in the L-square alternative. All meetings, except in scenario M5 where both ships are close to each other but still controllable, were smoothly executed.

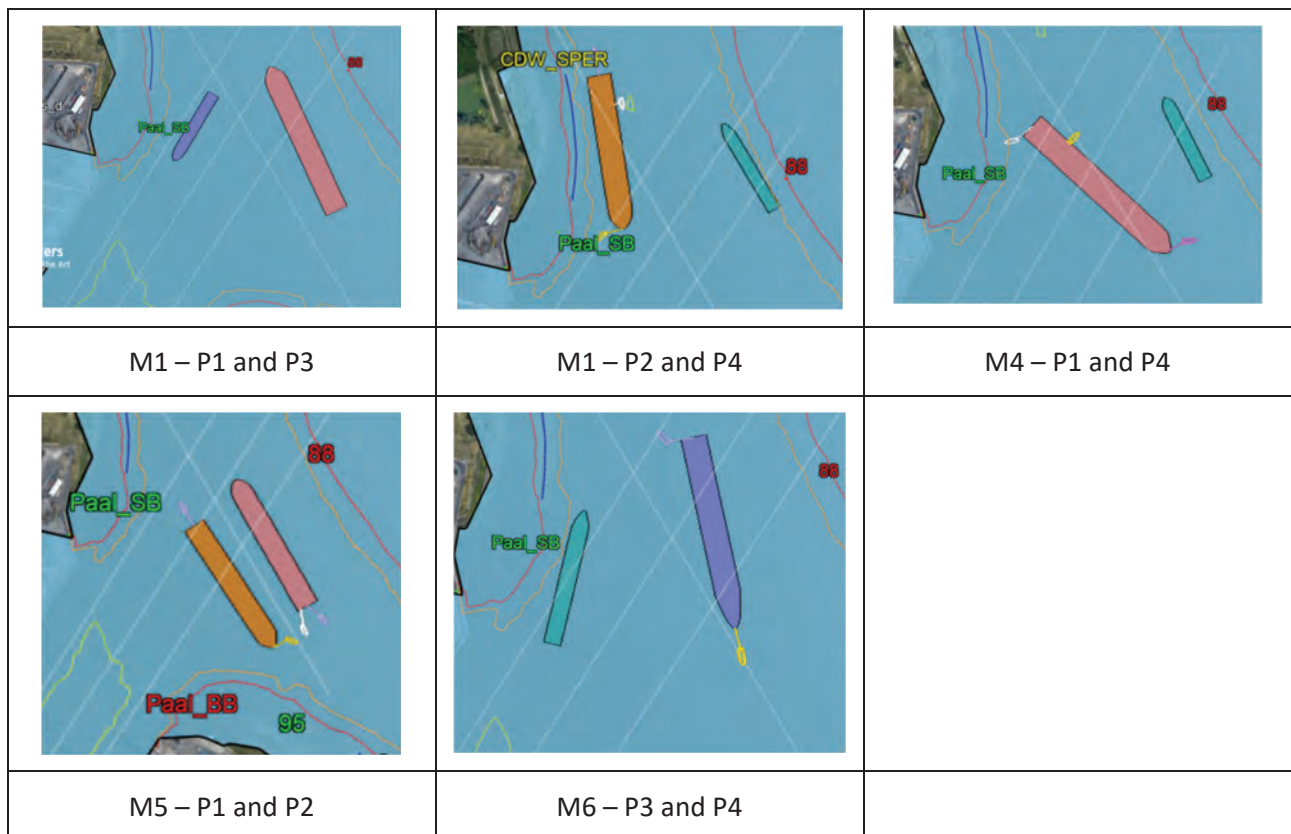


Figure 61 – Meetings at buoy 88 nearby the Deurganck dock mouth

Buoy 86 – 88

Only one meeting happens in between buoy 86 and 88 in scenario M5 (Figure 62). The meeting was for the smaller containership P3 (purple) a bad experience as the interaction forces on the vessel were large and effected the consecutive turning to Duplex dock manoeuvre. The meetings in scenario M5 between buoy 86 and DGD mouth should have been avoided by planning the ships further out of each other.

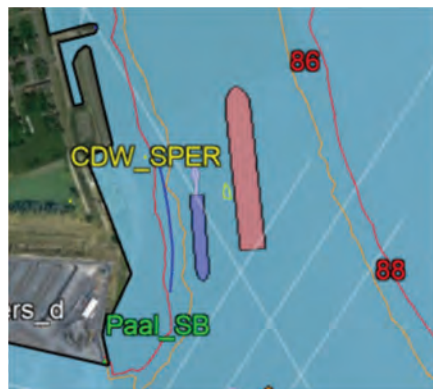


Figure 62 – Meeting in scenario M5 between P1 and P3 between buoys 86 and 88

Buoy 84 – 86

Two meetings occur between buoys 84 and 86 (Figure 63). Although the distance between the ships is only one ship beam in scenario M2, no particular remarks are made.

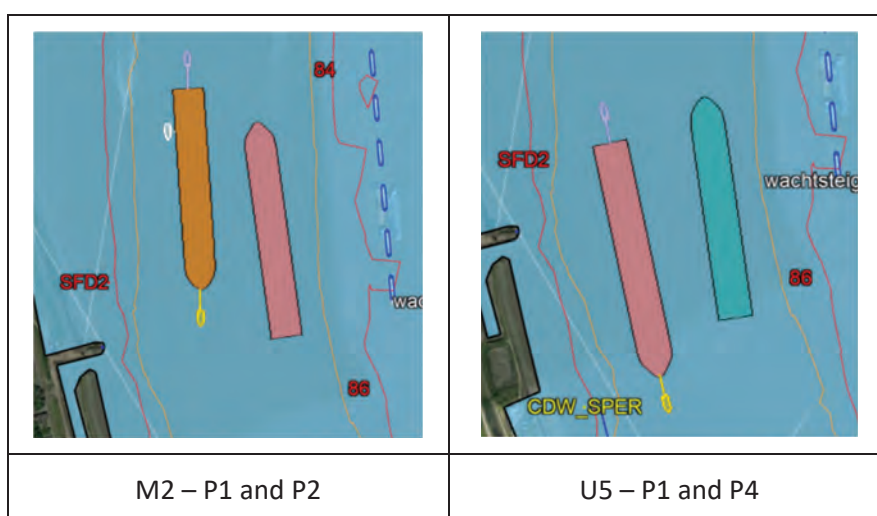


Figure 63 – Meetings between buoys 84 and 86

Buoy 93 or buoys 82A and 84

Most meetings happen in between buoys 84, 82A and at the opposite side of the river at buoy 93 (Figure 64). Most of the time the distance between the ships is more than two ship beams but in scenario U2 (between P3 and P4) and U3 this distance is even smaller than one ship beam. This should be avoided as the pilot also mentioned that in scenario U3 (U3_P4) the meeting was the most difficult manoeuvre of the executed exercise.

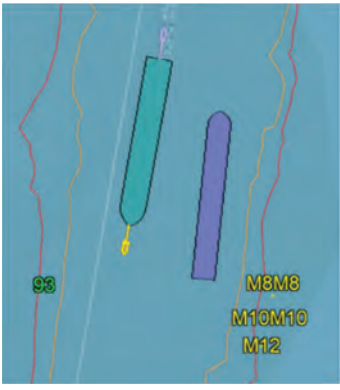
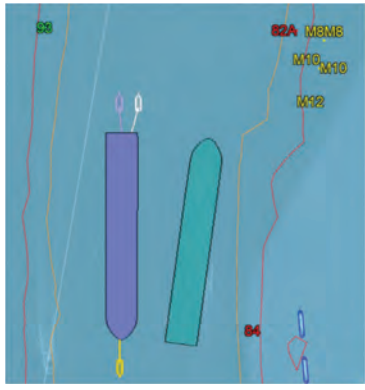
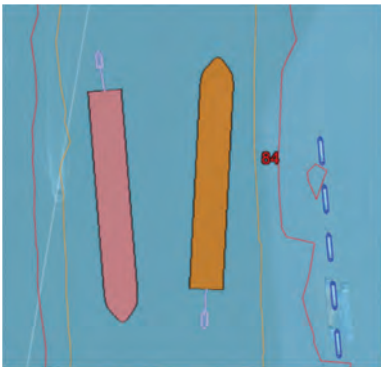
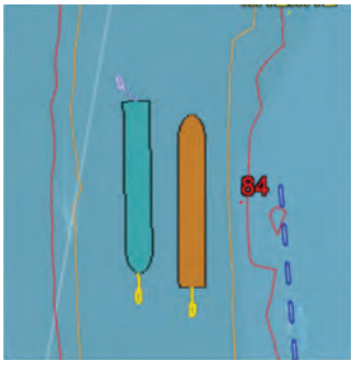
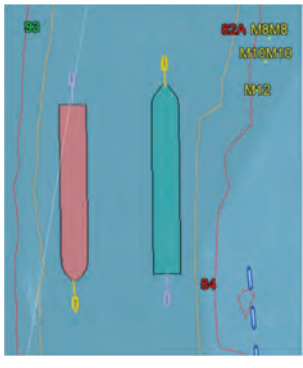
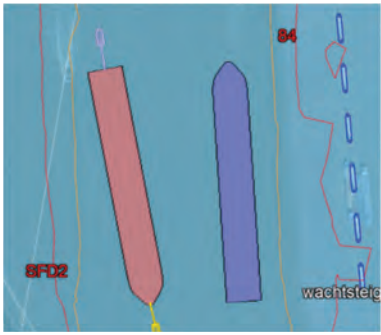
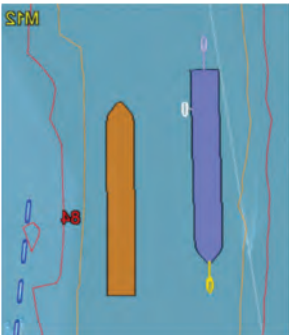
		
M1 – P1 and P2	U1 – P3 and P4	U2 – P3 and P4
		
U2 – P1 and P2	U3 – P2 and P4	U4 – P1 and P4
		
U5 – P1 and P3	U6 – P2 and P3	

Figure 64 – Meetings between buoys 84, 82A and 93

Buoy 82

One meeting is executed at buoy 82 and alongside the southern part of the Europe terminal (Figure 65). Thanks to the lack of moored ships at the southern half quay of the Europe terminal this meeting occurs without any problems.

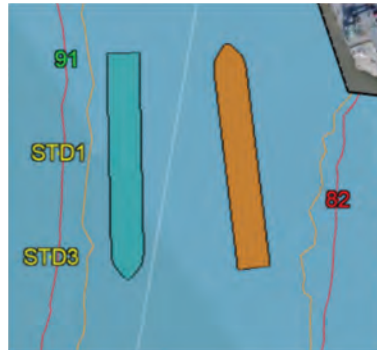


Figure 65 – Meeting in scenario U6 between P2 and P4 at buoy 82 nearby the Europe terminal

4 Conclusions and future work

For the second tidal dock of the port of Antwerp-Bruges three alternative designs are available: Boomerang, L-Square and Duplex dock. The nautical accessibility of each of these alternatives have been examined through real time simulations on ship manoeuvring simulators and for the L-square dock a real time traffic simulation study has been executed in 2019 and reported in Eloot *et al.* (2020).

On March 7th, 14th and 21st 2022 pilots of the Flemish and Dutch pilotage, tug captains of Boluda and Antwerp Towage and inland skippers performed 12 scenarios in the Duplex dock alternative (Figure 1) with four interacting containerships in an environment between the bend of Bath and the Deurganck dock and Duplex dock. For each scenario two ships (Ultra Large Container Ships) were handled from the full mission bridge simulators for sea-going vessels (SIM360+ and SIM225, Figure 3) while the third ULCS, smaller or inland containership was steered from the (inland) simulator Lara and a fourth ULCS or smaller containership from a three screens wide, compact simulator (SIM5).

Individual simulation runs with one simulator to evaluate the accessibility of Duplex dock were already executed in 2021 and reported in Eloot & Verwilligen (2021) but the full matrix of inbound/outbound, head in/head out and maximum flood/ebb current was not fulfilled yet. While all scenarios to the L-Square dock were executed as head in manoeuvres, the turning of the dock entrance of Duplex dock towards the river (heading of 283 deg for Duplex and 299 deg for L-Square) gave the opportunity to also organise head out inbound and outbound manoeuvres. The question now arises how the dock layout influences the nautical accessibility. Other questions gained also attention as how to organise meetings with smaller containerships in the Duplex dock. Due to its dimensions (325 m in the dock entrance and first stretch with a southern quay wall and a northern wall or bank, 300 m at full depth in the bend or kink, 350 m at the second stretch with quay walls at both sides) meetings between wider containerships than Panamax sized ships cannot be organised in contrast with the Deurganck dock (450 m at the entrance and 400 m at the end). Another question was the execution of swinging manoeuvres with smaller ships in Duplex dock.

12 simulation scenarios with four players gave 48 simulation runs with a diversity of containerships such as the 430 m (x 62 m) design ship for the dock, a 400 m ULCS, containerships of 367, 255 and 210 m and an inland motorship of 135 m or push convoys of 110 or 191 m. The wind was varied in direction but with strong wind speeds of 5 or 6 Bft. Half of the scenarios have been executed at a static maximum flood or ebb tide while the other simulations are with static (constant during the simulation) or dynamically changing tide in more moderate current conditions. To increase the interactivity during the simulations non-steered target ships based on real AIS tracks of different types of vessels had been added to the simulation. In this way the traffic density in the simulation process was improved with ships coming from the Kieldrecht lock, Kallo lock or other areas on the Western Scheldt.

The full program executed at the three simulation days is summarised in Table 4, Table 5 and Table 6. The parameters involved resemble the parameters for the L-Square dock traffic simulation study but the main difference of head in and head out manoeuvres does not make a direct comparison possible.

In the standardised feedback of the pilots, summarised in chapter 3.1, for manoeuvres with the 430 m ULCS the evaluation is often 'executed with minimum reserve' while for the 400 m vessel 'enough reserve' is available. This reserve is based on the manoeuvring space and environmental conditions but also on the use of steering devices like tugs and bow thrusters. It clearly reveals that more difficulties are present when a 430 m vessel at strong wind and current conditions has to sail to, from and in the dock. Training on ship manoeuvring simulators can help in getting familiar with the new dock and once real 425 m or longer ships are sailing to the Flemish harbours their manoeuvrability can be compared with the predicted behaviour of the simulation ship.

The manoeuvring guidelines, given preliminary in the first report on the accessibility of Duplex dock in Eloot & Verwilligen (2021), can be confirmed. For wind conditions of a mean 5 Bft at least two 80 tons tugs are necessary for ULCS while from 6 Bft on three 80 tons tugs are required of which one can operate as pusher (in standby condition). Generally at least one fore and one aft tug are taken. For some specific manoeuvres an additional third tug is proposed, independent of the wind:

- Inbound head in with maximum ebb current: two aft tugs
- Outbound head out with maximum flood current: two fore tugs

During the traffic simulations this tug configuration was not always followed as the current was not necessarily maximum while passing the DGD mouth, so that more possibilities are available (e.g. a pusher instead of a second fore tug at flood). It is also clear that with the ULCS of 430 m at 6 Bft wind force there are more time intervals during the simulations where all steering power of the tugs and the underpowered bow thruster (a recent generation of 400 m ULCS has double power for the bow thrusters) is used. An evaluation of the available tugs and their bollard pull in the port will be necessary to decide on the maximum wind speed accepted at the different locations. The 6 Bft wind class gives indeed a range of mean wind speeds between 10.8 and 13.9 m/s so that the maximum wind speed for the accessibility of 430 m could be decreased to a value within this range lower than 13.9 m/s. It has to be said also that most of the simulations were successful with for the others only minor difficulties.

The different manoeuvres to and from the Duplex dock with head in or head out mooring are fully described in chapter 3.2 with the analysis of the individual runs. Evaluating the dock layout based on these runs it can be concluded that:

- in general the Duplex dock is accessible for ULCS up to 430 m length and 62 m beam until wind force 6 Bft (a limit in this range can be set based on the available tug power). The four stretches around the DGD mouth (up/downwards the river, DGD entrance and Duplex dock entrance) give interaction possibilities between four containerships close to each other (Figure 66). The turned dock entrance closer to the river gives the opportunity to use this dock entrance for swinging manoeuvres outside the river and thus with more gentle or negligible current. This can give new procedures for vessels with Deurganck dock as destination or when an intermediate location for an ULCS to/from Duplex dock is needed. Meetings in DGD mouth depend on the current and wind but it can be advised to avoid a meeting in the dock mouth itself if the meeting disturbs the preferable manoeuvre of one of the interacting ships while approaching the docks or the river and if adjusting the speed of the interacting ships is possible.



Figure 66 – Scenario U5 with four ULCS at short distance from each other on the four stretches around the DGD mouth

- the first stretch of the Duplex dock, from the entrance to the bend, with a width of 325 m at full depth and inland ships moored at the first 480 m, gives the possibility to accept meetings between Panamax sized vessels if an ULCS is moored at the southern quay downstream the bend but also a meeting between an ULCS and Panamax sized vessel if no containership is moored at that quay.
- the bend of Duplex dock with 300 m at full depth is restricted so that meetings between vessels are not desirable (between inland and sea-going ships depending on environmental conditions and vessel dimensions) and while turning in the bend it is convenient to take into account that with moored vessels at both sides of the second stretch of the Duplex dock, there is only 350 m minus twice 100 m (navigational safety zone for moored ships with gantry cranes) or thus 150 m waterway width available (Figure 67).

An overview of all simulation runs to/from the second stretch are shown in Figure 67:

- o for head in inbound: U1_P1, M3_P1, M4_P2, M1_P3, M2_P3, U2_P3
- o for head out inbound: U3_P1, U6_P1, U6_P3, U2_P2
- o for head in outbound: U5_P2, M6_PA, M3_P4
- o for head out outbound: M1_P1, M1_P4, M6_P2, M2_P1.

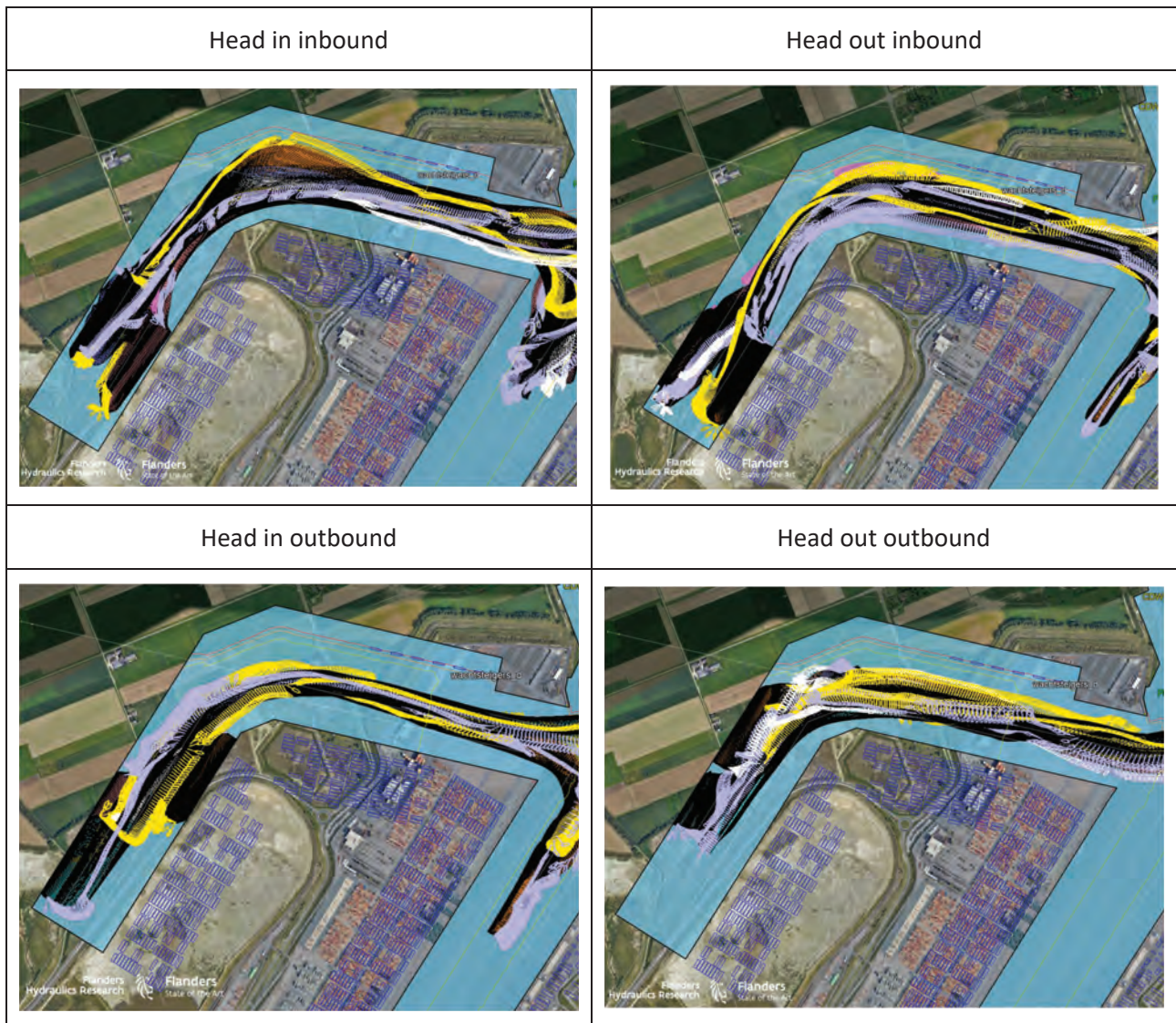


Figure 67 – Swept paths of individual simulation runs with tugs to/from the second stretch of Duplex dock

An increase of the dock width from 350 m to 450 m such as for the Deurganck dock at entrance is desirable but not realistic in the framework of the project area that ends at the Engelsesteenweg.

- swinging in the dock itself should be possible with vessels of maximum 210 m length in the bend and with moored ships at one quay in both stretches and with a 255 m vessel in the 350 m dock stretch with no vessels moored.
- the jetties for inland ships above the northern bank slope in the first stretch of the Duplex dock should be placed over a length of maximum 550 m from the upstream corner of the northern dock wall and so that for three rows of ships moored to each other (expected width of maximum 50 m in total) the vessels should not extend outside the continuation of the northern wall at the dock entrance.
- at the end of Duplex dock inland ships can be handled if the distance of the sterns of moored ships at adjoining quay walls is at least 70 m.
- the northern wall at the entrance of the Duplex dock should be designed so that dredging is easily executed and the desired depth of the dock entrance (also side in Deurganck dock) can be reached at a distance of 25 to maximum 50 m from the wall and dock corner. In Figure 68 all tracks of 430 m and 400 m ULCS (without tugs) is shown. The full black area reveals the zone where most ships manoeuvred. A distance of about 50 m is kept. Nevertheless the smallest distance between the northern wall and a track was 15 m.

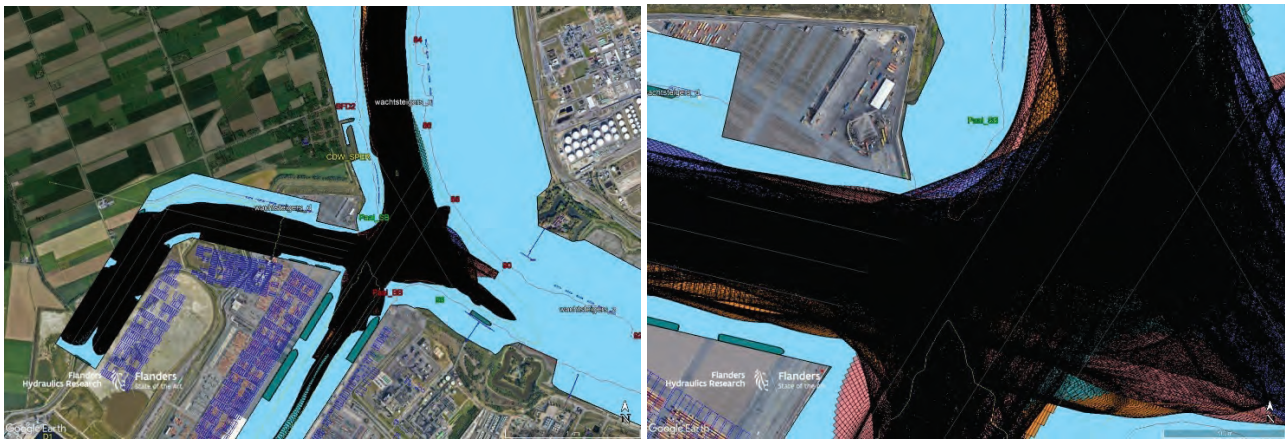


Figure 68 – Zone at Duplex dock entrance for dredging based on tracks of 430 m and 400 m ULCS

Evaluating the possibilities of head in and head out manoeuvres to Duplex dock in chapter 3.3 an analysis is made based on the scenarios UX (maximum flood or ebb tide) with a time evaluation for the passage of the dock/river zone (Figure 52) of ULCS. An overview is given in Table 33 with minimum and maximum registered values for the different runs. The shortest time intervals are for the four conditions of inbound/outbound and flood/ebb seen for the head in manoeuvre compared to the head out manoeuvre. This corresponds to the qualitative evaluation made in Eloot & Verwilligen (2021) for head in and head out manoeuvres what is repeated in Figure 69.

Table 33 – Time intervals with minimum and maximum for ULCS at maximum flood or ebb tide

	Head in	Head out
Inbound flood	13 - 21	31 - 49
Inbound ebb	22 - 25	24 - 32
Outbound flood	21	26 - 36
Outbound ebb	(24) ³¹	13 - 20

Head out	Flood	Ebb
Inbound	☹️	☹️
Outbound	☹️	😊 (400 m)
Head in	Flood	Ebb
Inbound	😊	😊 (400 m) ☹️ (430 m)
Outbound	😊 (400 m) ☹️ (430 m)	☹️

Figure 69 – Overall evaluation for head in and head out manoeuvres for Duplex alternative (430 m and 400 m ULCS) from Eloot & Verwilligen (2021)

The findings described in this report do already contribute to the required inputs necessary for the improvement of the Portgenie capacity model developed by Macomi and commissioned by the port of Antwerp-Bruges but some specific analysis dedicated to the definitions and the specific methodology of that model can still be made using the data from these real time simulations. This work will be done in the framework of project 21_044.

As stated in the conclusions of Eloot & Verwilligen (2021) an additional simulation study with emergencies can give more insight in a risk-analysis of the operations and is planned for the second half of 2022 for real time simulations to/from Duplex dock in relation to Deurganck dock and the traffic on the Scheldt. The pilots already stated that following situations could be examined:

- Passing Duplex dock in an outbound manoeuvre with gradually increasing SW wind towards the DGD mouth
- Leaving Duplex dock at lower wind classes without tugs.

³¹ Scenario M5, run M5_P1 with smaller ebb tide.

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Appendix 1: Pilot card 430 m en 400 m ULCS

Pilot card 430 m op 62.0 m ULCS

CON430_620 PRINCIPLE CHARACTERISTICS

based on fast-time simulations

Name	Con430_620_160.SHI
Project	16_117 CP ECA

Main Dimensions

L _{OA}	[m]	430
L _{PP}	[m]	409
B	[m]	62
T	[m]	16
M	[ton]	263734
A _{wind frontal}	[m ²]	2728
A _{wind lateral}	[m ²]	15932

Propeller

#	[-]	1
n _{max}	[1/s]	1.56
CPP		No

Thruster

Bow thruster	[-]	1
Total Power	[HP]	4250
Stern Thruster	[-]	-
Total Power	[HP]	-

Rudders

#	[-]	1
d _{max}	[°]	35
Time from +35 to -35	[s]	23



Manoeuvring speeds				
	RPM	UKC=100%	UKC=20%	UKC=10%
	[-]	[kn]	[kn]	[kn]
Manoeuvring Full Ahead	60	16.4	14.0	12.6
Half Ahead	48	13.1	11.2	10.1
Slow Ahead	36	9.8	8.4	7.6
Dead Slow Ahead	24	6.4	5.6	5.0

Stopping specifications			
	Time		Distance
	[s]	[min]	[m]
From Man. Full Ahead to Full Astern	604	10.07	2380
From Slow Ahead to Slow Astern	915	15.25	2027

Turning specifications			
	Advance	Transfer	Tact Diam
	[m]	[m]	[m]
UKC = 100%			
Full Ahead	1380	872	1879
Slow Ahead	1375	874	1874
UKC=20%			
Full Ahead	1614	1252	2489
Slow Ahead	1494	1139	2296
UKC=10%			
Full Ahead	2156	1838	3640
Slow Ahead	1966	1635	3266

Pilot card 400 m op 61.5 m ULCS

Con400_615 PRINCIPLE CHARACTERISTICS

based on fast time simulations

Name	Con400_615_160.shi
Project	00_107

Main Dimensions

LOA	[m]	400
L _{PP}	[m]	383
B	[m]	61.5
T	[m]	16.0
m	[ton]	266,699
A _{wind frontal}	[m ²]	2,885
A _{wind lateral}	[m ²]	16,304

Propeller

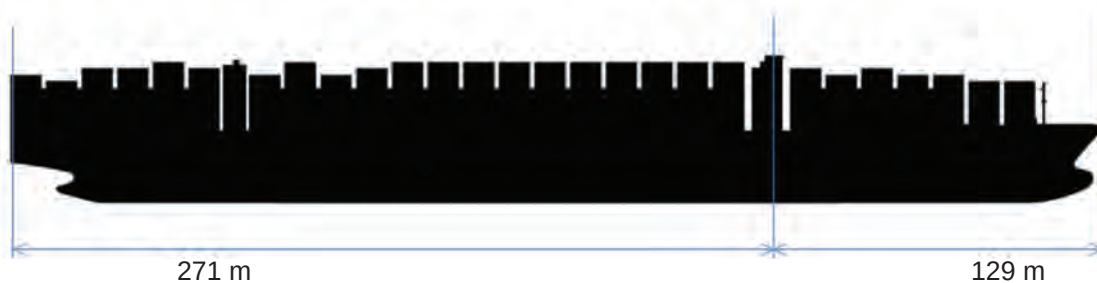
#	[-]	1
n _{max}	[1/s]	1.24
n _{min}	[1/s]	0.28
CPP		No

Thruster

Bow thruster	[-]	2
Total Power	[kW]	2 x 3000
Stern Thruster	[-]	-
Total Power	[kW]	-

Rudders

#	[-]	1
α _{max}	[°]	35
Time from +35 to -35	[s]	26



Manoeuvring speeds					
	RPM	UKC=150%	UKC=35%	UKC=20%	UKC=10%
	[-]	[kn]	[kn]	[kn]	[kn]
Sea Full Ahead	74.3	21.49	-	-	-
Manoeuvring Full Ahead	55.6	16.07	13.83	-	-
Half Ahead	45.4	13.09	11.29	10.59	9.15
Slow Ahead	35.8	10.23	8.89	8.32	7.22
Dead Slow Ahead	26.6	7.39	6.55	6.10	5.34
Minimum	17.0	4.20		3.60	3.30

Stopping specifications			
	Time		Distance
	[s]	[min]	[m]
From Man. Full Ahead to Full Astern			
From Slow Ahead to Slow Astern			

Turning specifications Portside			
	Advance	Transfer	Tact Diam
	[m]	[m]	[m]
UKC = 150%			
Full Ahead	1176.3	-662.7	-1420.8
Slow Ahead	1139.7	-659.3	-1416.1
UKC = 35%			
Full Ahead	1224.6	-848.6	-1712.2
Slow Ahead	1201.0	-839.8	-1698.3
UKC=20%			
Half Ahead	1212.9	-923.0	-1805.9
Slow Ahead	1195.8	-911.1	-1781.4

Turning specifications Starboardside			
	Advance	Transfer	Tact Diam
	[m]	[m]	[m]
UKC = 150%			
Full Ahead	1176.0	678.9	1457.3
Slow Ahead	1149.8	673.2	1450.2
UKC = 35%			
Full Ahead	1105.2	753.3	1524.7
Slow Ahead	1079.0	739.8	1493.9
UKC=20%			
Half Ahead	1256.6	957.4	1829.5
Slow Ahead	1229.0	929.5	1785.5

Con400_615 PRINCIPLE CHARACTERISTICS

based on fast time simulations

Name	Con400_615_120.shi
Project	00_107

Main Dimensions

LOA	[m]	400
L _{PP}	[m]	383
B	[m]	61.5
T	[m]	12.0
m	[ton]	194,920
A _{wind frontal}	[m ²]	2,987
A _{wind lateral}	[m ²]	17,030

Propeller

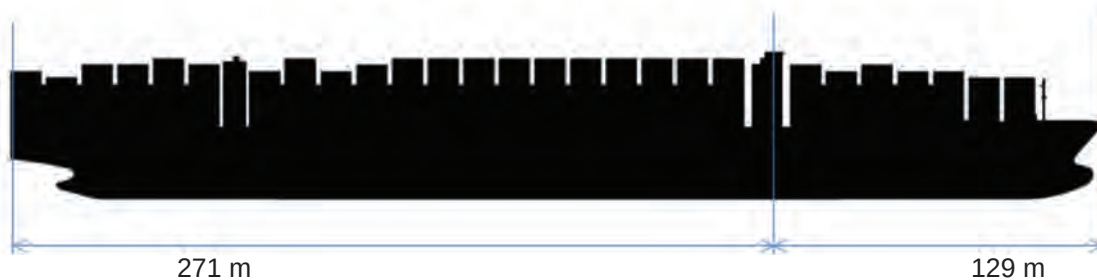
#	[-]	1
n _{max}	[1/s]	1.24
n _{min}	[1/s]	0.28
CPP		No

Thruster

Bow thruster	[-]	2
Total Power	[kW]	2 x 3000
Stern Thruster	[-]	-
Total Power	[kW]	-

Rudders

#	[-]	1
d _{max}	[°]	35
Time from +35 to -35	[s]	26



Manoeuvring speeds					
	RPM	UKC=150%	UKC=35%	UKC=20%	UKC=10%
	[-]	[kn]	[kn]	[kn]	[kn]
Sea Full Ahead	74.3	22.72	-	-	-
Manoeuvring Full Ahead	55.6	17.00	14.04	-	-
Half Ahead	45.4	13.88	11.46	11.07	9.93
Slow Ahead	35.8	10.92	9.03	8.72	7.83
Dead Slow Ahead	26.6	8.02	6.71	6.44	5.81
Minimum	17.0	4.74	4.21	3.91	3.60

Stopping specifications			
	Time		Distance
	[s]	[min]	[m]
From Man. Full Ahead to Full Astern			
From Slow Ahead to Slow Astern			

Turning specifications Portside			
	Advance	Transfer	Tact Diam
	[m]	[m]	[m]
UKC = 150%			
Full Ahead	1245.6	-681.6	-1430.0
Slow Ahead	1211.1	-680.8	-1420.1
UKC = 35%			
Full Ahead	1217.8	-874.0	-1807.5
Slow Ahead	1197.8	-869.7	-1797.2
UKC=20%			
Half Ahead	1298.2	-1012.5	-1969.9
Slow Ahead	1284.8	-1001.1	-1951.9

Turning specifications Starboardside			
	Advance	Transfer	Tact Diam
	[m]	[m]	[m]
UKC = 150%			
Full Ahead	1152.6	660.5	1383.9
Slow Ahead	1132.5	658.2	1382.2
UKC = 35%			
Full Ahead	1173.5	856.4	1758.8
Slow Ahead	1152.2	839.6	1730.7
UKC=20%			
Half Ahead	1241.2	953.1	1824.8
Slow Ahead	1219.0	931.7	1784.2

Appendix 2: Manual for KMZ tracks

The simulations can be replayed with animation in Google Earth based on the attached KMZ files. A short manual describes the actions and possibilities.

Install Google Earth (the version used for the images in this manual is a Dutch version)

Go to Windows Explorer or the KMZ files attached to the report and double click on a selected KMZ file:

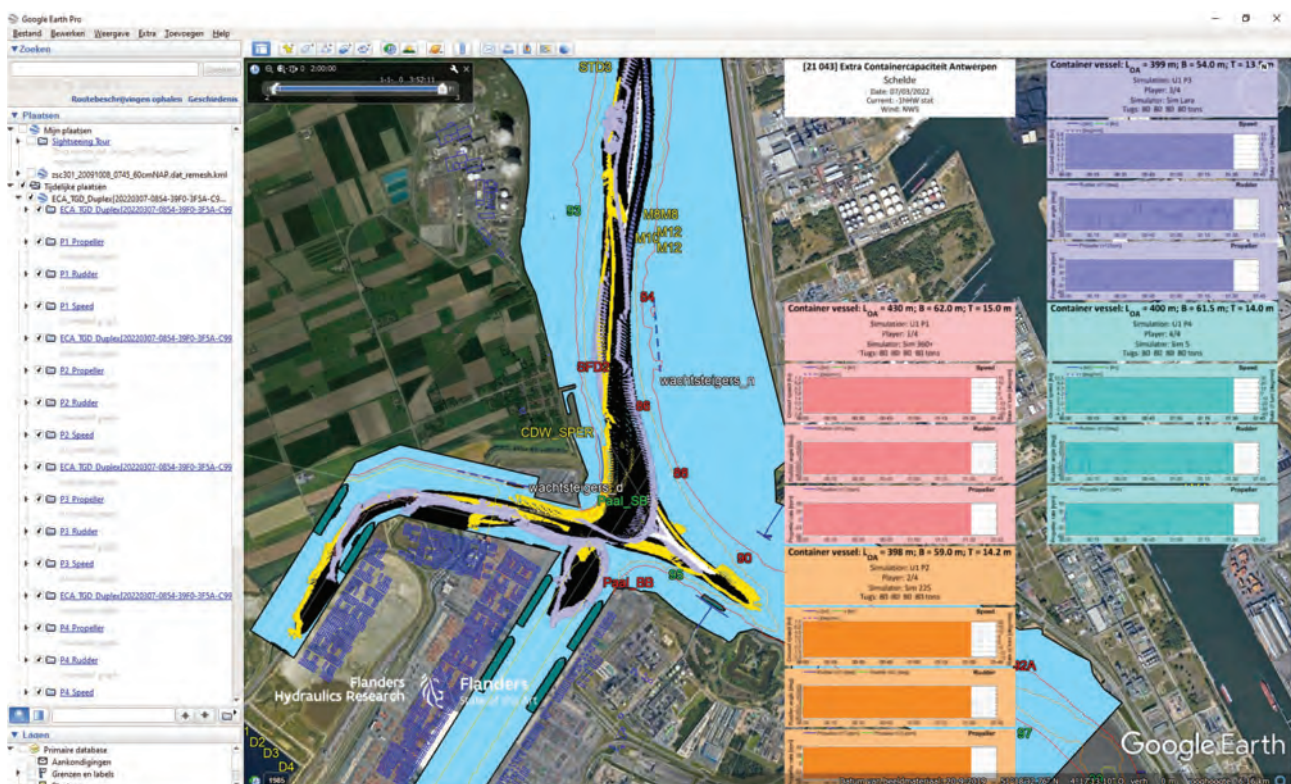
e.g. U1_[20220307-0854-39F0-3F5A-C994DB5F_Manoeuvring.kmz

All players P1 to P4 are presented with also the target ships if available. On the KMZ own ships are shown in colour according to the simulator:

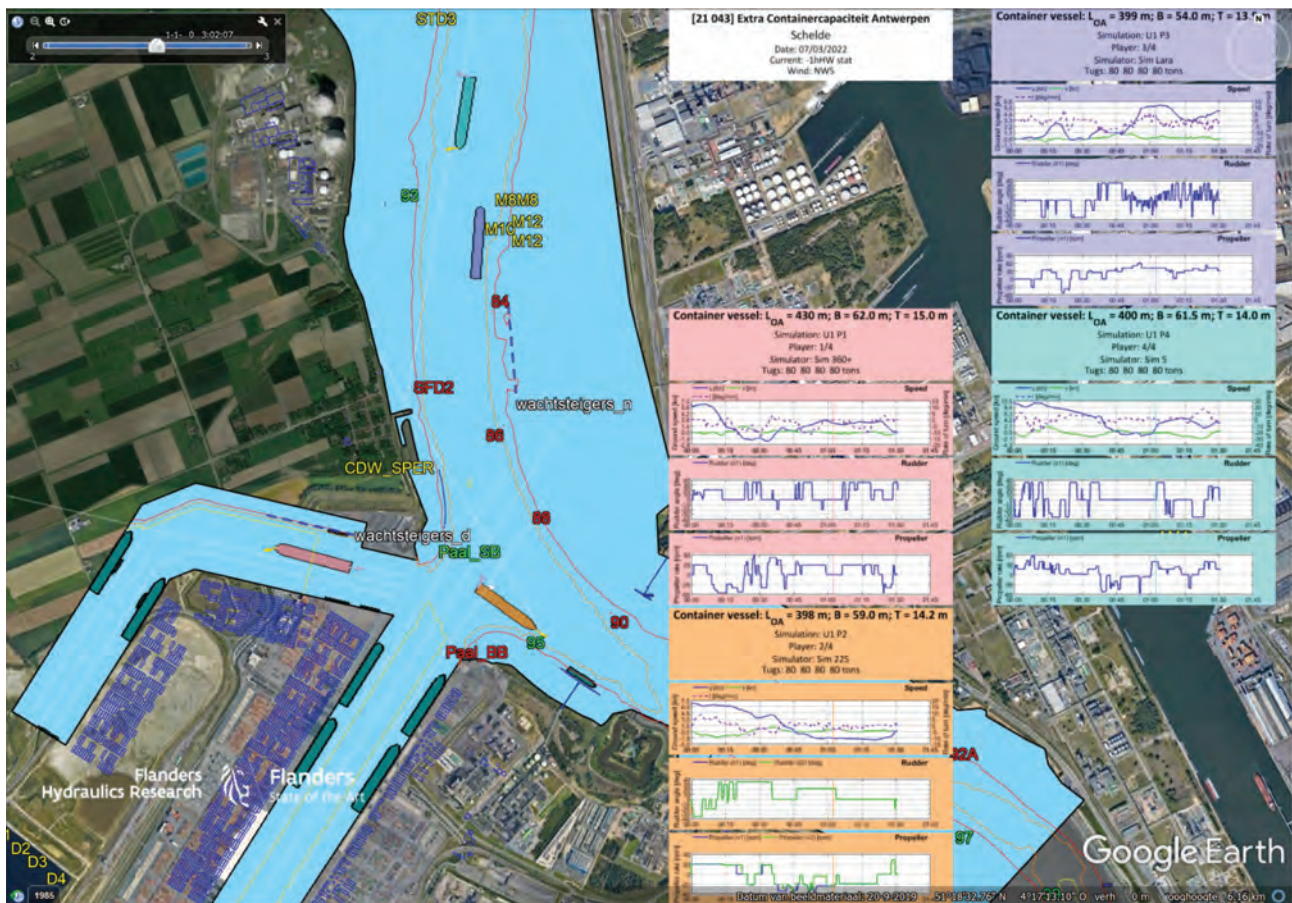
SIM360	Red
SIM225	Orange
Lara	Purple
SIM5	Green

Target ships moving based on AIS tracks are in dark red or other colours.

The KMZ file with animated graphs and animated simulation can be seen in the temporary locations at the left pull down menu. On the main screen the location is seen with the simulation data on top of it and the overlay graphs (right column with time graphs). You can tick on or off the different overlay graphs in the left pull down menu.



The overlay graphs are light red, orange, purple or green (depending on the simulator) on top of the different series in the graphs because the animation is presented from the start to the end of the simulation. If you use the slider on the top left location, you can go back and forward on the graphs and also on the track.



To clearly focus on the track of each player you can select the pull down list of the animated simulation. Player P1 has the most information included (target ships with trajectories, moored ships, environment, etc.) while the other players have specific information on their manoeuvre.



In the pull down list of the animated simulation there is also a PLAY button for each player, by double clicking on this button the simulation replays with a vertical line on the overlay graphs to show where you are in the graphs for the presented player on the Google Earth view. In the left corner below, the play button is presented and can be used for increasing the replay speed.



The following graphs are shown on the Google Earth presentation:

The longitudinal speed component (u), the lateral speed component (v) and the rate of turn (r) of each player. The rudder angle ($d1$) with a minimum of -35 degrees (to starboard) and a maximum of 35 degrees (to port) for sea-going ships. The inland ships have larger rudder angles but only the angles in the -40 to 40 degrees range are shown.

The propeller rate ($rn1$) with a minimum depending on the player (harbour full astern) and a maximum (harbour full ahead).

On the Google Earth overview are the red lines the depth lines at -10 m LAT, the orange lines the depth lines at -14.5 m LAT and the yellow lines at -18.0 m LAT.

Appendix 3: Feedback

Standard feedback form

[21_043] Duplex

Beoordeling reserves

1. gelukt met veel reserve
2. gelukt met voldoende reserve
3. gelukt met weinig reserve
4. ten einde gebracht met incidenten (geen schade)
5. niet gelukt met schade
6. niet gelukt / opgegeven

Moeilijkheidsgraad op de simulator

1. het werd vlot uitgevoerd
2. het werd normaal uitgevoerd
3. meer dan normale moeilijkheid
4. het was moeilijk
5. het was uiterst moeilijk, riskant
6. onuitvoerbaar

Individual feedback per player

U1_P1	Met twee sleepboten de con430 bedienen ging, soms zelfs wat marge. 8 à 9 deg ROT. Vooruit slaan om het Duplex dok in te draaien. Voorbij de knik heel dicht bij de afgemeerde schepen met bunkers. Sleepboten regelmatig weinig kracht. 1.5 à 2 knoop in het dok.
U1_P2	Wachten aan phenol was wel ok, misschien iets te dicht. Lang achteruit moeten kloppen en achterboot driekwart, het schip was een dubbelschroever, bij een enkelschroever zouden twee achterboten vastgemaakt zijn om het schroefeffect te compenseren. Derde sleepboot is hier niet gebruikt.
U1_P3	Loods dacht dat de con430 head in het DGD zou ingaan. Gesukkel met de boegschroef op Lara (bediening “reversed”). Surplacen ging om te wachten tot de con430 voldoende in DGD lag. Heel traag de monding ingaan maar achterboot moet vol staan. Ontmoeting ok. De sleepboten zaten zeer dicht bij elkaar in het DGD.
U1_P4	Indraaien van het dok gaat vanzelf met de vloed, surplacen aan Frederik met sleepboten, voorbij Frederik ontmoeting aan trage snelheid maar manoeuvre uitgevoerd zoals gepland, 4.5 knopen nodig om de monding en het dok in te draaien, de kapiteins zullen moeten wennen aan deze manoeuvres. Boegschroef gebruikt bij indraaien maar geen voorsleepboot. Met bakboord roer stutten in ingang.
U2_P1	Wachten op de rivier is comfortabeler tegenstrooms. De afspraak met SIM225 was ok. Sleepboten aantal ok. Sleepboot naar achter laten duwen owv groot te verwachten schroefeffect. Sleper terug naar voor om af te meren.
U2_P2	Dit schip gaat als tweede het Duplex dok uit. Het gaat achteruit het DGD in om daar te wachten tot de eerste opvarende het Duplex dok in is. Bij dit achteruit gaan wordt zeer dicht bij een afgemeerd schip gevaren. Het schip gaat aan de Frederik rond als extra manoeuvre gekozen door de loods. Opmerking loods: ROT bij uitkomen Duplex, achteruit DGD, ROT viel van 12 naar 6.8 (alles stond er op), nakijken wat er gebeurde, hierdoor dicht bij afgemeerde schip. Verder als verwacht, ook uitvaren dok. Ontmoeting ok. [Opmerking te onderzoeken: duwer gaf geen 80 ton, slepers nakijken (instelling, kracht)]
U2_P3	Voorboot niet gebruikt, twee achterboten bijna vol (een achter is niet voldoende bij eb). Met twee afgemeerde schepen in Duplex toch krap, je hebt niet veel over. De kraanmannen gaan dit niet leuk vinden. Eens van stroom één boot nodig.
U2_P4	Dit schip gaat er eerst uit. Loods doet nog een extra zwaaimanoeuvre aan NZT om de uitgebreide kade te onderzoeken. Met de eb snelheid maken en dan snelheid afbouwen om met SIM360 te passeren. In monding aan zuidkant, snelheid 2-3 knopen, vooraan niets gebruikt. Zuidkant opgezocht, snel aan de rode kant.
M1_P1	Bij het aanlopen van de knik komt het achterschip zeer dicht tegen de bunker aan. Bij het op stroom komen (zelfs er voor) slechts 8 deg ROT, alle sleepboten stonden op maximum, maar de stroom liet geen mogelijkheid tenzij misschien een voorsleepboot laten duwen, dus twee vooraan. Er wordt voorgesteld om in het vervolg de snelheid tussen 1 en 1.5 knoop te houden en niet hoger te laten oplopen bij op stroom komen.
M1_P2	Op de rivier moeten wachten, monding in, twee achterboten lang moeten trekken en duwen bij indraaien monding, achteruit naar dok, maar de ROT bleef weer laag.

M1_P3	Bij opstarten waren er nog sleepboten vastgemaakt aan het schip van de vorige simulatie. Deze verstoorde het manoeuvre. Sleepboten gedeactiveerd. Het indraaien van dok ging goed, dus zonder sleepboten. De ontmoeting met de City of Ghent lukt in het eerste deel van het dok. De boegschroef gaf zeer traag toeren. Doordat op de PPU de kade van het dok niet is aangegeven (enkel navigatielijnen 100 m uit de kade) is de loods even tegen de kade gegaan bij het zwaaien. Zwaaien met deze lengte is ok maar met achterboot bij deze wind. [de achtersleepboot was te zwaar voor dit schip, beter 60 ton in het vervolg] Waarschijnlijk was er technisch conflict tussen bediening simulator en bediening sleepboten - werd ontdekt tijdens volgende run.
M1_P4	Ontmoeting is ok, bij op stroom komen had de loods gedacht om indirect te werken met de achtersleepboot, maar dit kon niet met de sleepboot die voorzien was in de simulatie. De snelheid was 5 knopen. Niet elke sleepbootkapitein doet dat, op voorhand melden is nodig. Loods deed nog een zwaaimanoeuvre op rivier.
M2_P1	Bij het naar buiten varen met twee achterboten en noordenwind verwacht om ROT te kunnen opbouwen, rond 10 deg ROT. Knik was ok. Hoek gemaakt om de wind te compenseren wachtend op de UASC Dubai die met de boeg in de ingang van Duplex draaide. Indien het schip had moeten stoppen voorbij de knik dan zou een derde boot nodig geweest zijn. Extra zwaaimanoeuvre op de rivier.
M2_P2	Zoals verwacht, voorboot niet gebruikt.
M2_P3	Met de boeg in de ingang van Duplex dok draaien kan standaardmanoeuvre worden om naar DGD te gaan bij de vloed (niet bij de eb). Verlopen zoals verwacht.
M2_P4	Ruimte geven aan de grote jongens.
U3_P1	Opmerking sleepbootkapitein, bij ingang DX bij het oplijnen naar de lichtenlijn tijdens het achteruit varen beter voorsleper gebruiken (grotere hefboom) dan achtersleper. Eerst afspraak met uitvarende dat zij wachten aan de phenol maar dat ging niet lukken voor de con430 en daarom HMM achteruit in het DGD gedraaid en daaruit vertrokken. Con 430 dieper in Duplex dok wanneer tweede opvarende het Duplex dok ingaat. Con 430 en 135 m binnenschip ontmoeten elkaar in de knik. Voor binnenschipper krappe indruk van de knik. Stel een combinatie leeg met vijf lagen dan heeft een binnenschipper ook ruimte nodig. In knik had con 430 1.7 kn achteruit, waarbij gang moet gehouden worden.
U3_P2	Wegblazen van de kant bij starten door zuidwesten wind, daarna onder controle. Ze hebben nooit hun manoeuvre moeten onderbreken voor de con430. Vlot met ruimte in DGD achteruit, en dan vertrekken bij vloed. Opmerking dat bij HI zoals in deze simulatie je meer mogelijkheden hebt om een plaats te vinden voor wachten (Deurganckdok of rivier).
U3_P3	135 m schepen hebben vaker breedtes van 15 en 17 m en dubbelschroeven! Myzaquazo is een model met enkelschroever. Voor de wachtsteigers zou er ruimte moeten zijn aan de buitenzijde om met 3 bredere schepen langzij te kunnen liggen, dus bijvoorbeeld 3 x 15 m = 45 m en dan zeker nog binnen de hoek blijven met de muur aan de ingang. Communicatie door binnenschippers in realiteit altijd via Centrale Zandvliet, volgens loodsen staat in de regelgeving dat een directe communicatie tussen binnenvaart en zeevaart moet plaatsvinden zoals tijdens de simulatie. Op het einde van het dok afmeren met dwarse wind 6 Bft zal moeilijker zijn naarmate meer containers op het schip aanwezig zijn maar met 70 m tussen de afgemeerde ULCS en de dwarse kaai zou het genoeg moeten zijn.

U3_P4	Geen probleem, mekaar kruisen op de Frederik is het moeilijkste. Gang maken en wat bij zetten. Manoeuvre indraaien vlot, iets te ver op de rivier, voorboot gebruiken om de boeg goed te houden. Indraaien met 1.5 kn, was nodig om voldoende ruimte te laten voor de andere schepen.
U4_P1	[Schip zat dicht bij de hoek van het Duplexdok waardoor er terug aandacht moet zijn om bij aanleg van het dok een onderwatertalud te voorzien dat gemakkelijker kan gebaggerd worden op diepte, dus niet zoals de overstaande zijde van het DGD]] NW6 schip is enorm loefgierig zodat het schip twee keren op de rivier in de groene kant is gekomen. Fel vertraagd op de rivier om de eerste opvarende en dan de passerende autobus de ruimte te geven. Sleepboot aan BB duwen om zo snel met achterschip uit stroom (dit is een ander manoeuvre dan de eerste opvarende). Bij invaren ingang van het dok meer effect van de wind verwacht maar vrij gebleven van de muur. Ook met achterboot nog naar stuurboord dus zeer loefgierig schip.
U4_P2	Vrij veel ruimte gelaten voor afvarende schip. Stroom heeft meer effect dan de wind, alle kracht van de sleepboten nodig om met een s-bocht er in te gaan. Beter in de zwaaicirkel in achteruit gaan zoals de tweede opvarende. Dus in het vervolg ook mogelijk om een ander manoeuvre uit te voeren met eerst achteruit naar DGD en dan naar DX. 6 Bft is moeilijk voor deze ULCS (met pieken naar 7). Met Duplexdok twee strekkingen in plaats van één voor Deurganckdok. Wachten en weer oplijnen in het eerste deel van het dok, alles nodig om het manoeuvre onder controle te houden, beter om meer uit stroom aan te lopen. In realiteit zou de loods door de slechtere positie van het schip besloten hebben om terug naar buiten te gaan en een nadelige s-bocht zoals in de simulatie te vermijden.
U4_P3	Het duwkonvooi van de schipper is uitgerust met rotatable propellers in straalbuizen (type Deseo, Tripoli). De boegschroef reageert trager dan in werkelijkheid. Het manoeuvreren in de omgeving van de knik en het tweede deel van het dok wordt door de binnenschippers ook als krap ondervonden. De schipper had bij start geen bediening. In realiteit wordt het effect van de wind veel gevoeld. Effect van stroming (bijvoorbeeld aan de steigers Galgenschoor) is in realiteit ook groter.
U4_P4	Schip in dok direct bij simulatie, NW 6 Bft zeer moeilijk, geen ruimte met de ULCS en bunkerschepen, sleepboten tegen de bunkerboten, misschien nog iets verder doorvaren en stoppen en door de wind laten rondvallen. Met NW 5 zal dat vlotter gaan. Op stroom komen zonder slepers gestart maar niet snel genoeg door de stroom en daarom slepers toch laten helpen. Het opvarende schip liet de volledige cirkel vrij. Nog even achteruit geven bij het op rivier komen wat niet optimaal is. Dit had met het vroeger inzetten van de slepers kunnen verholpen worden.
M3_P1	Met lichte vloed standaardmanoeuvre, in het Deurganckdok wachten is vechten tegen de wind, stilleggen is dus niet aangewezen, invaren in het DX dok, nog altijd vechten tegen de oostenwind waarbij het schip verzet wordt, het binnenschip is tussen de zuidelijke hoek van de ingang van het Duplexdok doorgedaan maar ze zou dat in de realiteit niet doen bij oostenwind (bij een andere niet nadelige windrichting wel). Er werd door de loods afgesproken om aan bakboord te passeren om te vermijden om aan lager wal te geraten (door plaats maken voor binnenschip). In de knik draait de wind het achterschip en goede positie tussen de afgemeerde ULCS.
M3_P2	Probleem met actie van de duwende sleepboten bij start van de simulatie. Hierdoor werd het schip achteruit geduwd en nadien naar de verkeerde kant geduwd. De loodsen kozen er voor om na deze acties toch de simulatie te laten verder lopen. Over bakboord gezwaaid in de knik omdat dit gevraagd was. Maar eigenlijk nadat het eerste afvarende schip was vertrokken zou er eerder ter plaatse van de ligplaats gezwaaid worden (aangezien geen schip aan de overstaande kade). In de knik was er 20 m vooraan en 80 m achteraan (tot talud). Een ontmoeting zoals uitgevoerd in

	het eerste deel van het dok zouden ze in realiteit niet doen omwille van te korte afstanden tot kranen en (binnen)schepen.
M3_P3	Geen collision voor het binnenschip bij start simulatie (en ook einde), het schip gaat door de kade, te onderzoeken.
M3_P4	Het schip vertrekt als eerste van de kade achteraan het Duplexdok. Ruimte tussen de afgemeerde schepen is te kort. Het achterschip moet op de lichtenlijn gehouden worden tot je voldoende ver voorbij de bunkerschepen bent. Met boegschroef en voorboot het voorschip goed houden. Met oostenwind opsturen maar achterboot geen ruimte om te werken nabij de bunkerschepen. Voor de rest ging het vrij vlot. Op stroom komen met 1 knoop vloed, met drie knopen snelheid, dat had dan met lagere snelheid gemoeten. Na wenning zal dat kunnen lukken. Niet met alles vol er in. Weinig reserve met een 430 m schip in de knik en op de rivier.
M4_P1	Manoeuvre zoals gepland maar de wind is zeer sterk, de stroming kan je met inscheren doodvaren, dus zoals gepland in de monding maar dan bij lage snelheid wordt het effect van de wind groot en beïnvloedt het manoeuvre. Drie duwende sleepboten gekozen om het schip achteruit in het DX dok te brengen.
M4_P2	Twee 60 ton sleepboten zijn te weinig, achteraan zeker 80 ton, in de monding van het DGD was het ok, maar in de ingang Duplex te weinig. Dus zeer traag varen. Boegschroef heel veel moeten gebruiken, in knik, ging maar traag en weinig reserve in slepers en boegschroef, de ontmoeting zou de binnenschipper in realiteit niet gedaan hebben, eerder wachten.
M4_P3	Ook voor 4 barges is het smal in het tweede deel van Duplex indien aan beide zijden schepen zijn afgemeerd en er nog een ander schip passeert. In realiteit zouden ze die ontmoeting niet gedaan hebben. De knik is ook voor de binnenschippers voor ontmoetingen krap, dus de combinatie van zeevaart en binnenvaart vereist een goede communicatie (en rechtstreeks soms ook met het schip) - blokkanaal voorzien zoals binnen in de haven (in plaats van kanaal 12)
M4_P4	Schip verplicht om stuurboord uit te wijken omdat het achterschip van de opvarende naar Duplexdok uitzwaait, maar daardoor in de vloedstroom gekomen. Vermijden om een grote inkomer te kruisen in de monding, dus beter wachten in het Deurganckdok. Maar bij sterke wind zou je dan na vertrek wel beter een achterboot behouden om de snelheid onder controle te houden. [Daarna voerde de loods nog een zwaaimanoeuvre uit en vervolgens achteruit naar het dok]
U5_P1	Grote uitdaging, vaart minderen en wachtplaats, aan Frederik, Doel, en daar is het smal. Windverhaal bij het invaren, trage snelheid om met oostenwind achter naar de knik te gaan, dus trage snelheid bij het invaren. Heel erg op het gemak.
U5_P2	Sleepboten naar bakboord tegen de wind, snelheid aanpassen aan de andere schepen, met bakboordzijde van het schip in de 100 m lijn houden, 1.5 en 2 knopen achteruit, achteruit DGD in, anticiperen met de oostenwind, ingang goed vrijhouden voor de opvarende, daarna vooruit geven, boten nog even vasthouden, achteraf misschien achteruit op stroom en wat sneller?
U5_P3	Derde sleepboot werd maar vastgemaakt toen het schip volledig op stroom was. Gestart met twee sleepboten voor en achter, voorboot wijzigt naar duwer achteraan BB. Door oostenwind naar punt Duplexdok, dus snelheid behouden, op stroom dan een derde voorboot gebruikt. Nu in een vloeiende beweging naar buiten, de volgende keer iets meer in de monding in het DGD rechtdoor en dan ter plaatse zwaaien en positioneren om uit te varen.

U5_P4	Achterboot vastgehouden bij op rivier komen om sneller naar de rode kant te gaan en het achterschip tegen de wind in te houden. In het Deurganckdok moeten wachten tot eerste afvarende uit Duplex op stroom weg was en dan zo goed mogelijk volgen. Ontmoetingen ook met afgemeerde schepen aan Europaterminal en Noordzeeterminal.
U6_P1	De sleepboten niet gebruikt om Deurganckdok in te varen, meer last verwacht van de wind, duwer nadien vol, manoeuvre goed te doen, de wind helpt twee keren (indraaien dok en eerste deel dok), manoeuvre vergelijken met de volgende opvarende. Met SW 6 helpt de wind ook bij het nemen van de knik.
U6_P2	Bij vertrek alle sleepboten gebruiken bij die SW 6. Schip bleef vooruitlopen, een beetje stroom, maar in realiteit niet verwacht. Voor de rest vlot, naar midden Deurganckdok om de zwaai goed te kunnen maken. Ontmoeting aan Frederik met opvarende liep goed. Meer dan gebruikelijk roer in Bath, te wijten aan het model van het 430 m schip dat een moeilijk manoeuvreerbaar schip is.
U6_P3	Zoals verwacht goed aan de groene kant aankomen en dan achteruitslaan, door de wind is de boeg weg. Misschien meer reserve kunnen bouwen door de tweede boot ook achter vast te maken in plaats van te duwen. (sleepbootkapitein nuanceert, dit hangt af van de diepgang van het schip en het effect van het schroefwater, je kan ook aan de lijn slepen door een langere lijn te gebruiken om meer effect te hebben.) De knik lukte met die wind ook goed, even ruimte maken voor de voorsleper aan de wachtsteigers om van stuurboord naar bakboord te gaan.
U6_P4	Drie boten, voorboot zo goed als niet nodig, twee achterboten, vol nodig, afstand tot CDW, 3 knopen SOG om de bocht naar het dok te nemen. Ontmoeten ging goed, zonder sleepboten, sleepers aan Doel vastgemaakt, alles onder controle. [sleepbootkapitein, vol trekken tot 15 min kan afhankelijk van de snelheid van het geassisteerde schip]
M5_P1	1 (= vol) + 0.75 voor achterboten, voorboot ook vol, achteruit naar de rivier, manoeuvre eerder waarbij opvarende afwaarts CDW wacht om zo het manoeuvre te doen. Te onderzoeken in het manoeuvreermodel: terwijl schip aan het deinzen is en dan vooruit geeft met stuurboord roer, gaat het achterschip nog meer naar de rode kant of dus bakboord (HMM 400 of ook con 430).
M5_P2	Heel lang met maar twee sleepboten gewerkt, te weinig voor 6 Bft. Uiteindelijk werd er een derde duwende sleepboot aan toegevoegd.
M5_P3	Twee keren interactie met het afvarende schip (belangrijke interactie) waardoor met toeren correctie moest gegeven worden. Daardoor was de snelheid opgelopen en ging het opdraaien in het dok niet vlot maar geen extreme situatie.
M5_P4	Zwaaien in ruimte tussen afgemeerd schip geeft slechts 285 m, voor een schip van 255 m is dat te weinig. Ontmoeting met andere schepen in de knik alleen in zeer gunstige omstandigheden. Er is in het tweede deel weinig plaats, twee feeders van 150 m zullen dat wel kunnen doen in de knik en opwaarts. Afmerende schepen passeren ging goed en rivier opvaren ging goed, stroming en wind helpen.
M6_P1	Deel in dok was normaal, bij het achteruit op stroom komen meer effect van de wind verwacht. Opvarende Triple Eirene werd gebruikt om het schip naar rode kant te dwingen.
M6_P2	Het ging redelijk vlot, maar het tweede deel van het Duplexdok is krap. Flink wat stroom dus achteruitslaan om de snelheid er uit te halen. Maar het ging.

M6_P3	Volgens plan, twee sleepboten om achteruit in Deurganckdok te gaan maar omdat het schip 14 m diep lag wel meer achteruit moeten geven met de machine. Alles onder controle om vanuit Deurganckdok het Duplexdok in te draaien.
M6_P4	Beste oplossing om in de monding van het dok te ontmoeten met de opvarende. De afvarende uit het Duplexdok heeft zich een beetje moeten aanpassen.

Appendix 4: Time graphs

The time graphs are given in chronological order. The following parameters are shown:

Sheet 1:

- Speed over ground in knots: longitudinal u and lateral v component and rate of turn r in deg/min
- Rudder angle in degrees: positive to port, negative to starboard
- Propeller rate in rpm: positive ahead, negative astern
- Thruster rate in rpm: positive motion to starboard, negative motion to port
- Thrust of tugs in tons: required bollard pull

Sheet 2:

- Current speed in knots: longitudinal u_c and lateral v_c component and rate of turn r_c in deg/min
- Relative wind speed in m/s and direction to bow of vessel in degrees
- Absolute wind speed in m/s and direction to north in degrees
- Water depth at port (P) or starboard (S) and fore or aft.

Container vessel: $L_{OA} = 430$ m; $B = 62.0$ m; $T = 15.0$ m

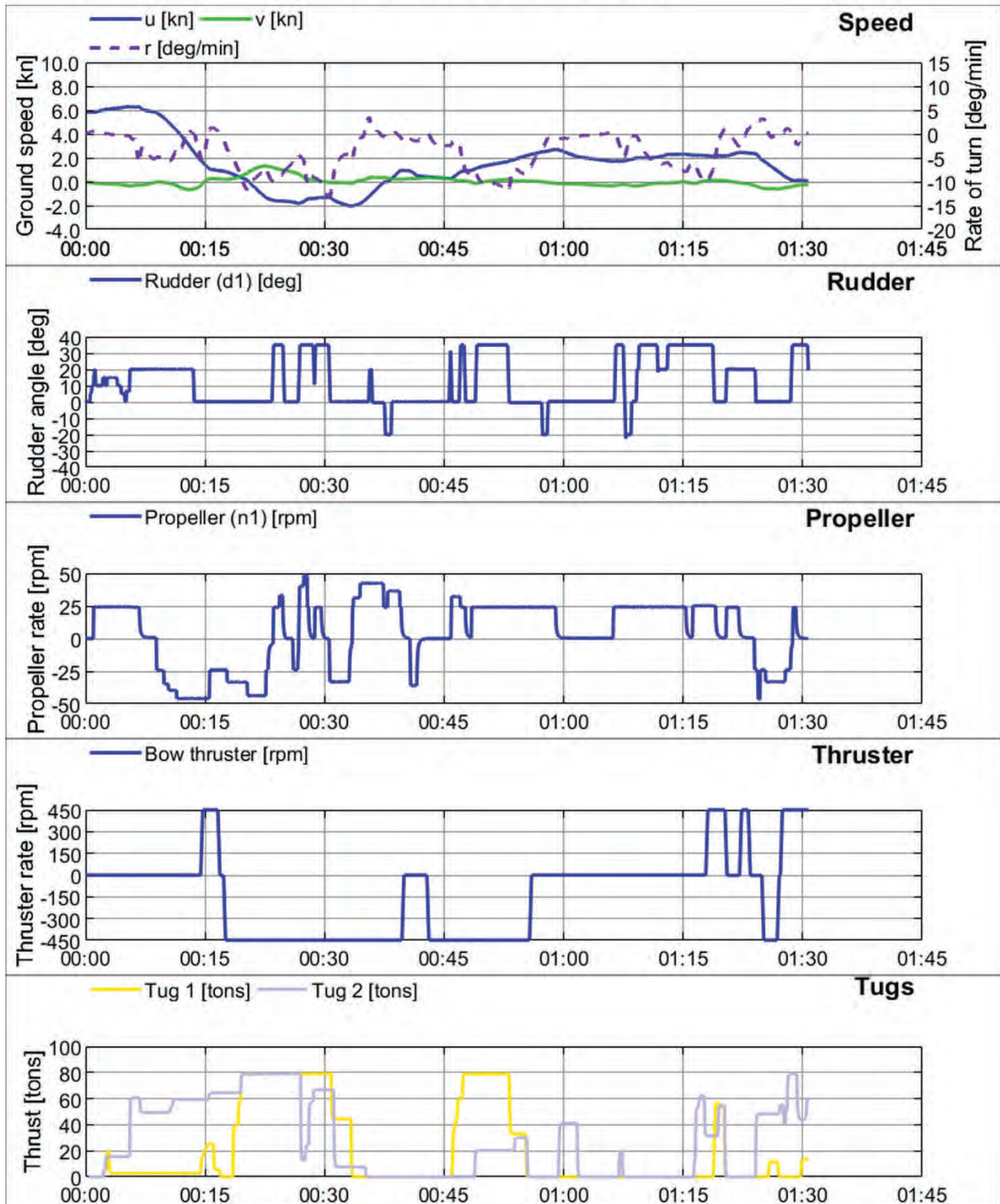
Simulation: U1 P1

Time: 08:57:09

Player: 1/4

Simulator: Sim 360+

Tugs: 80 80 80 80 tons



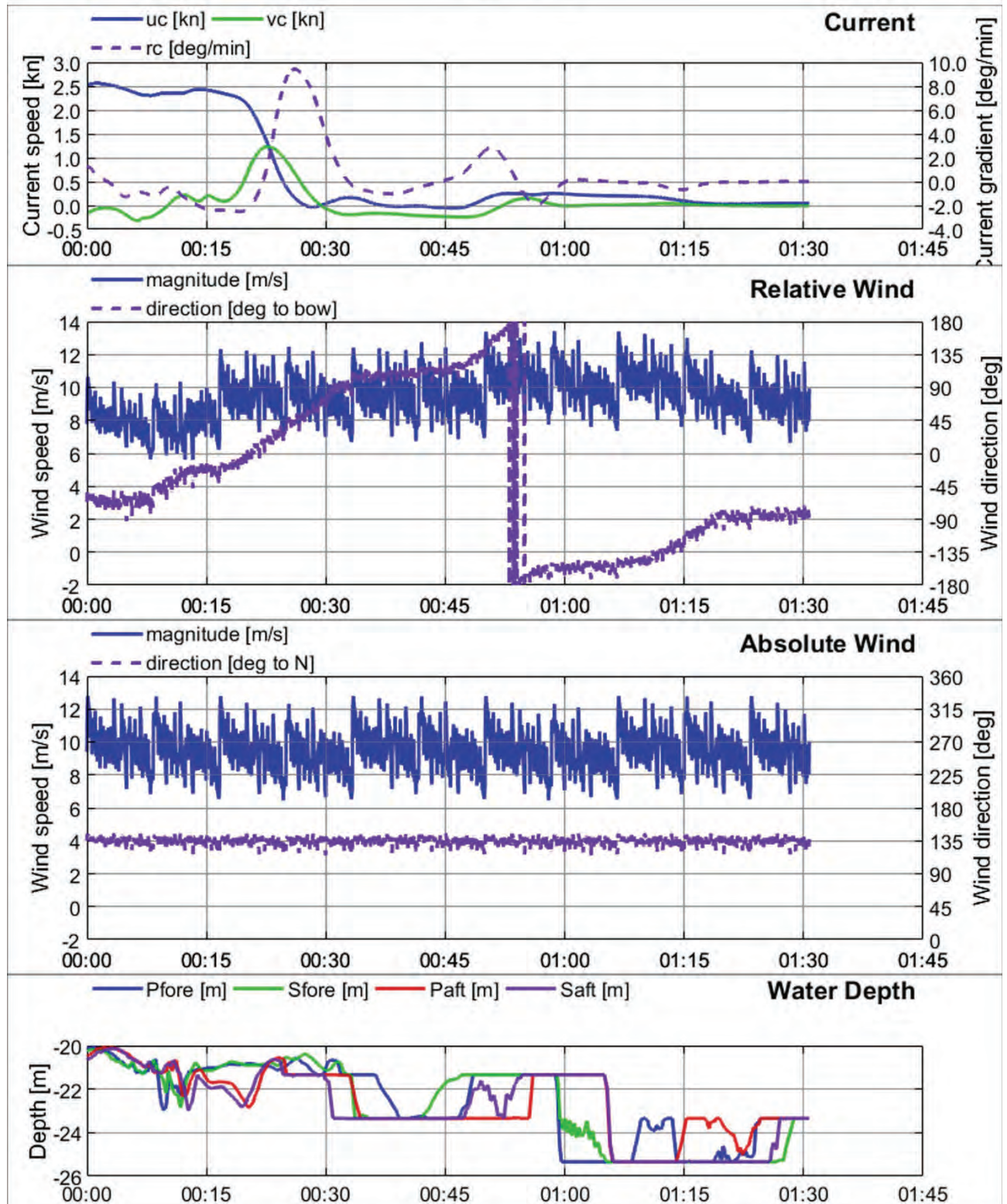
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 07/03/2022

Current: -1hHW stat

Wind: NW5



Container vessel: $L_{OA} = 398$ m; $B = 59.0$ m; $T = 14.2$ m

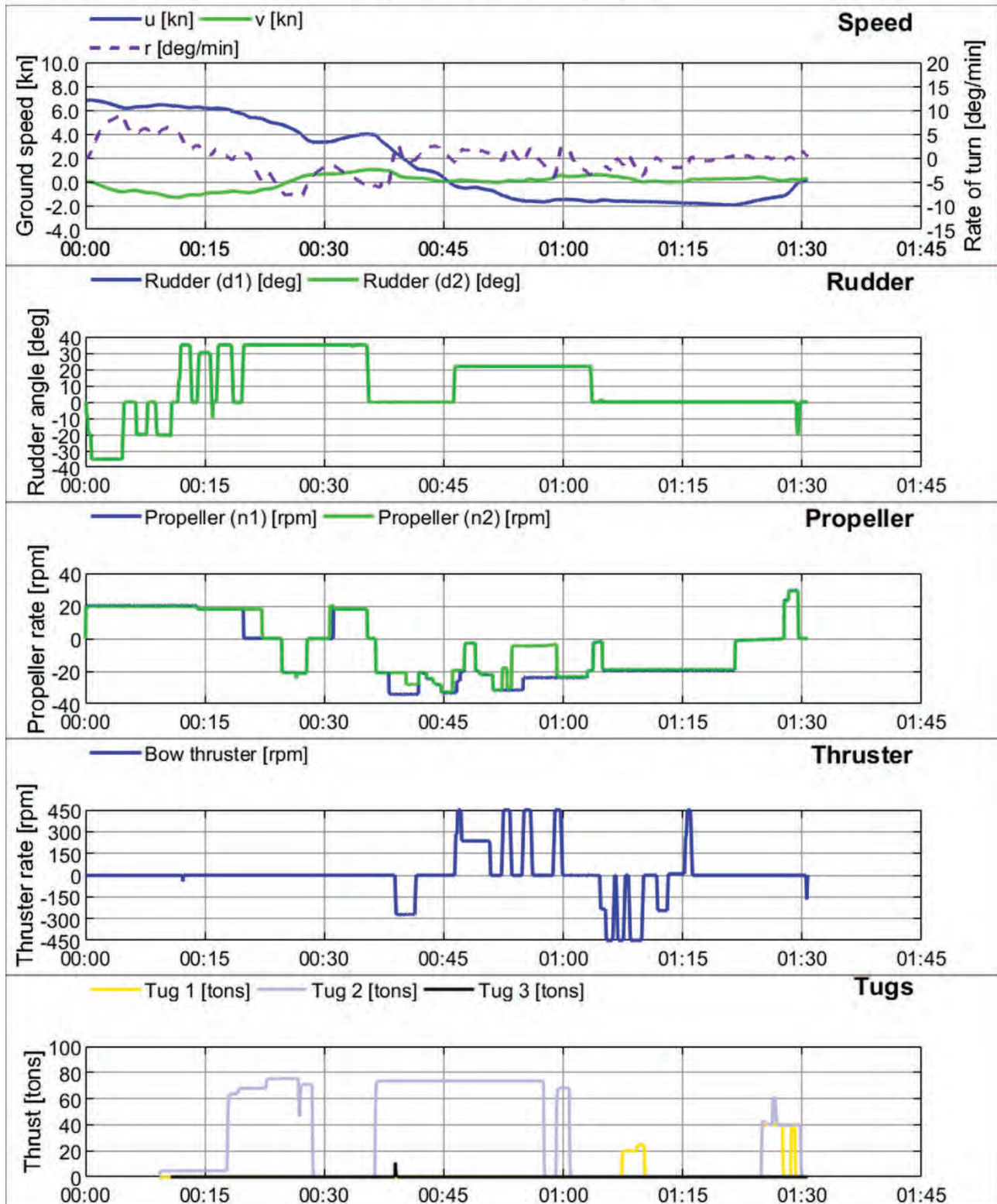
Simulation: U1 P2

Time: 09:01:04

Player: 2/4

Simulator: Sim 225

Tugs: 80 80 80 80 tons



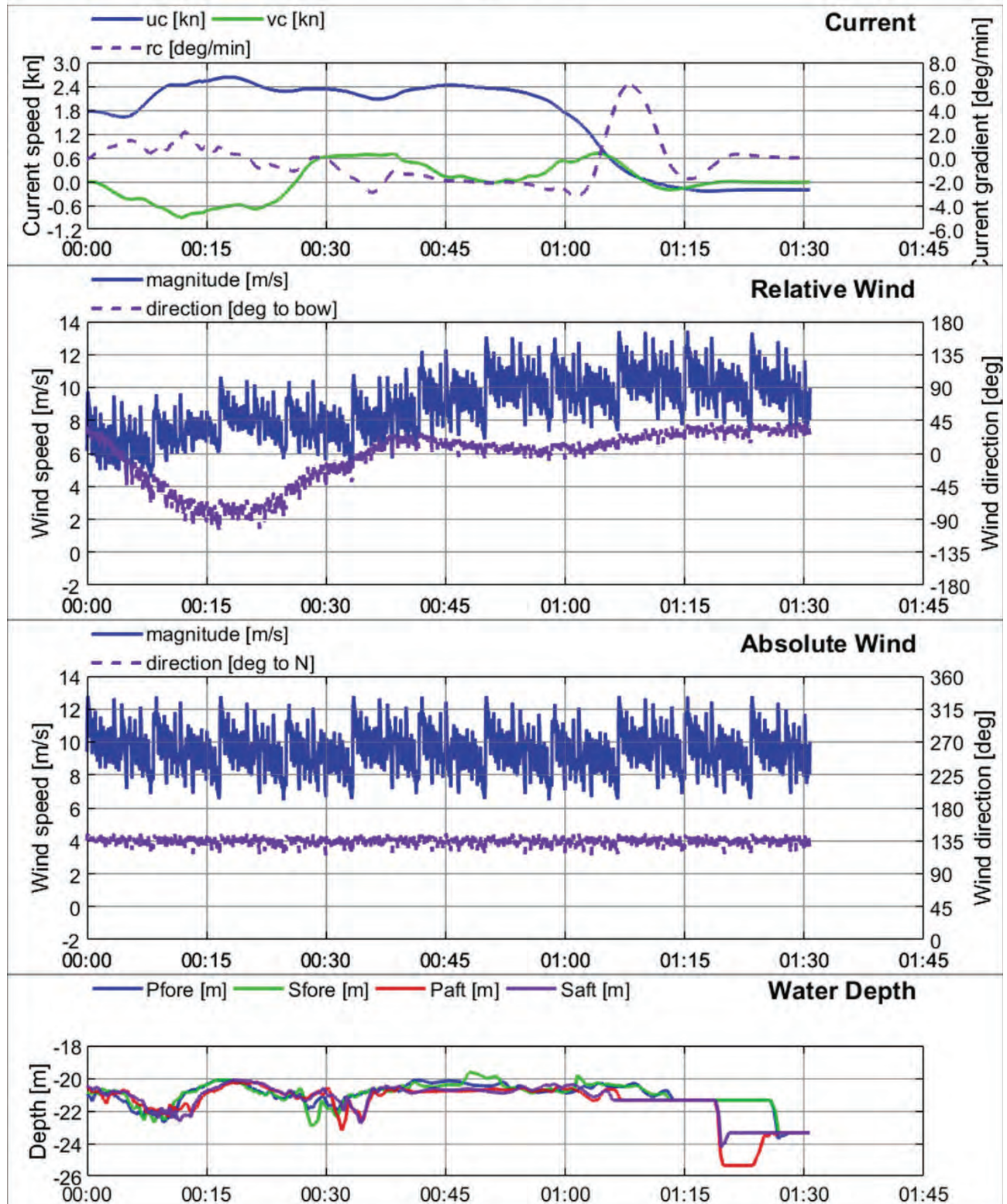
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 07/03/2022

Current: -1hHW stat

Wind: NW5



Container vessel: $L_{OA} = 399$ m; $B = 54.0$ m; $T = 13.5$ m

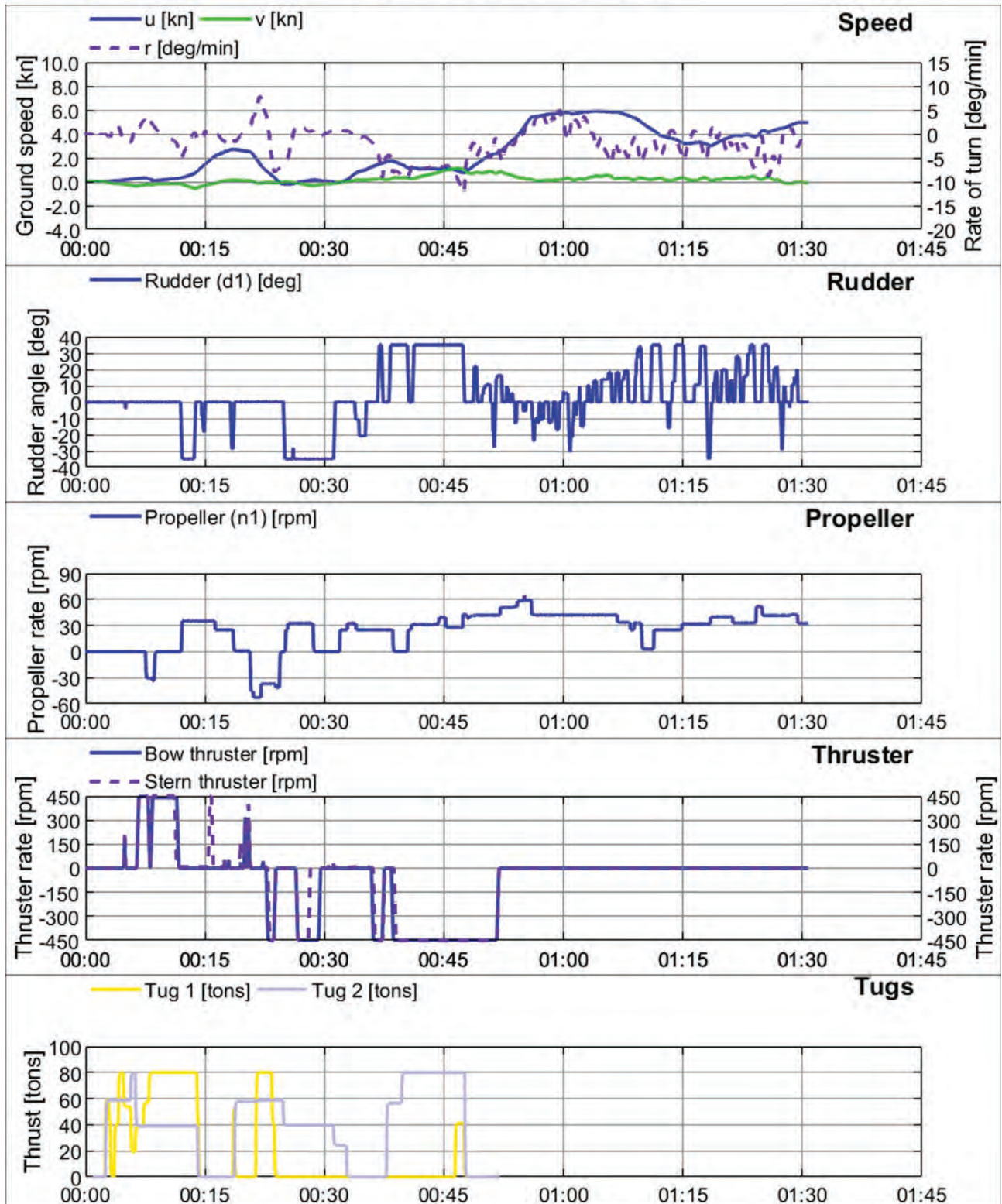
Simulation: U1 P3

Time: 09:02:41

Player: 3/4

Simulator: Sim Lara

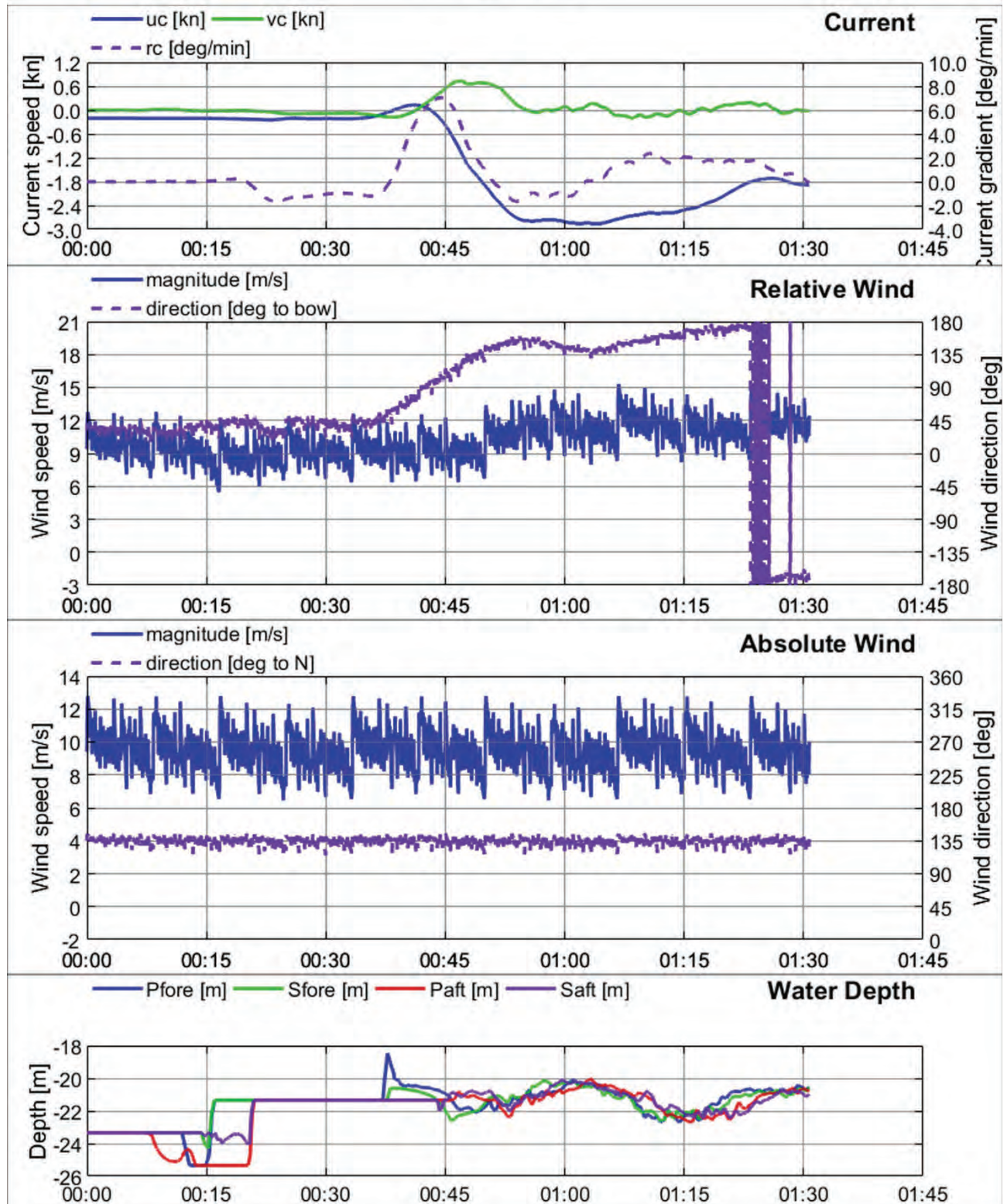
Tugs: 80 80 80 80 tons



[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 07/03/2022
Current: -1hHW stat
Wind: NW5



Container vessel: $L_{OA} = 400$ m; $B = 61.5$ m; $T = 14.0$ m

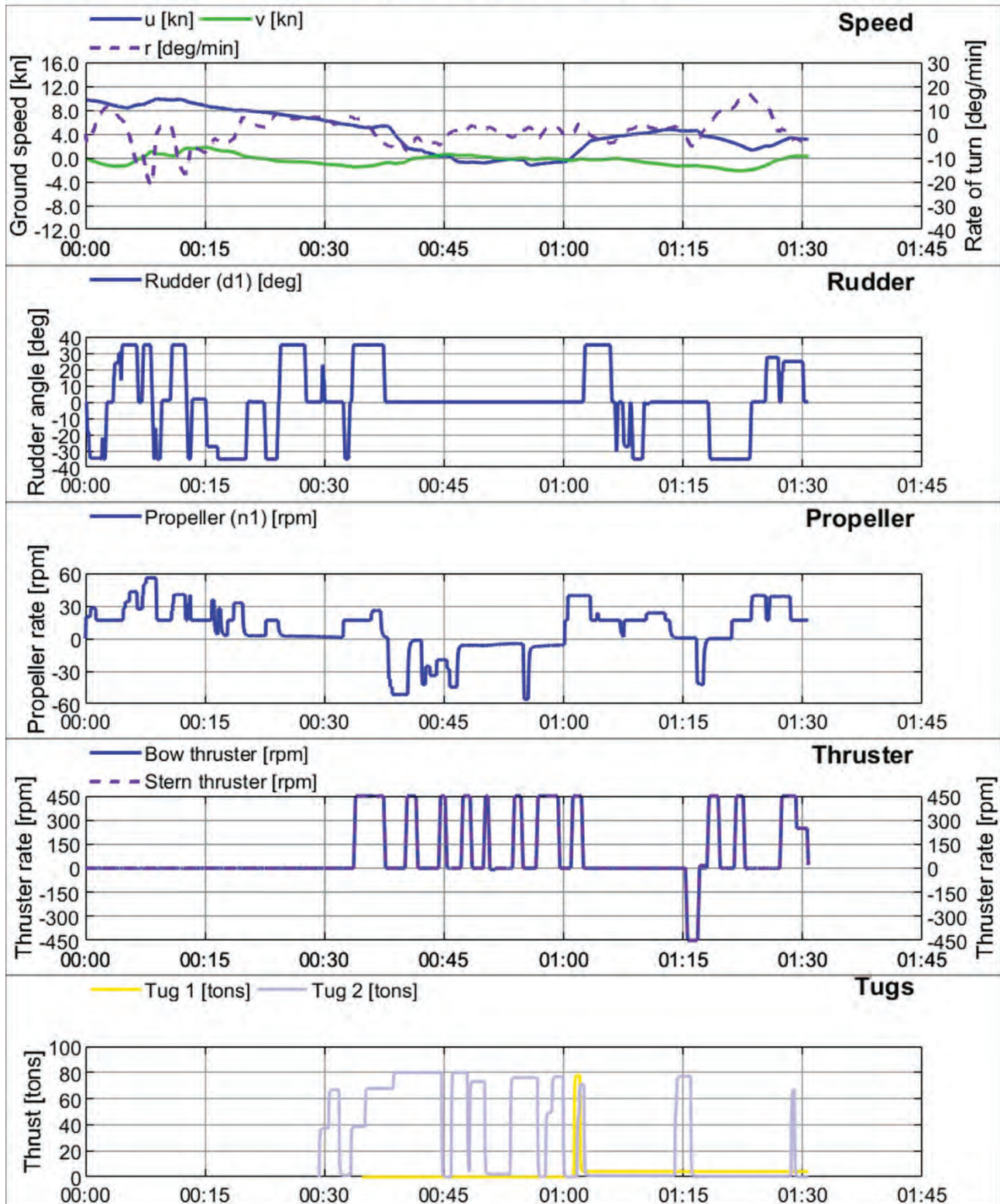
Simulation: U1 P4

Time: 08:55:49

Player: 4/4

Simulator: Sim 5

Tugs: 80 80 80 80 tons



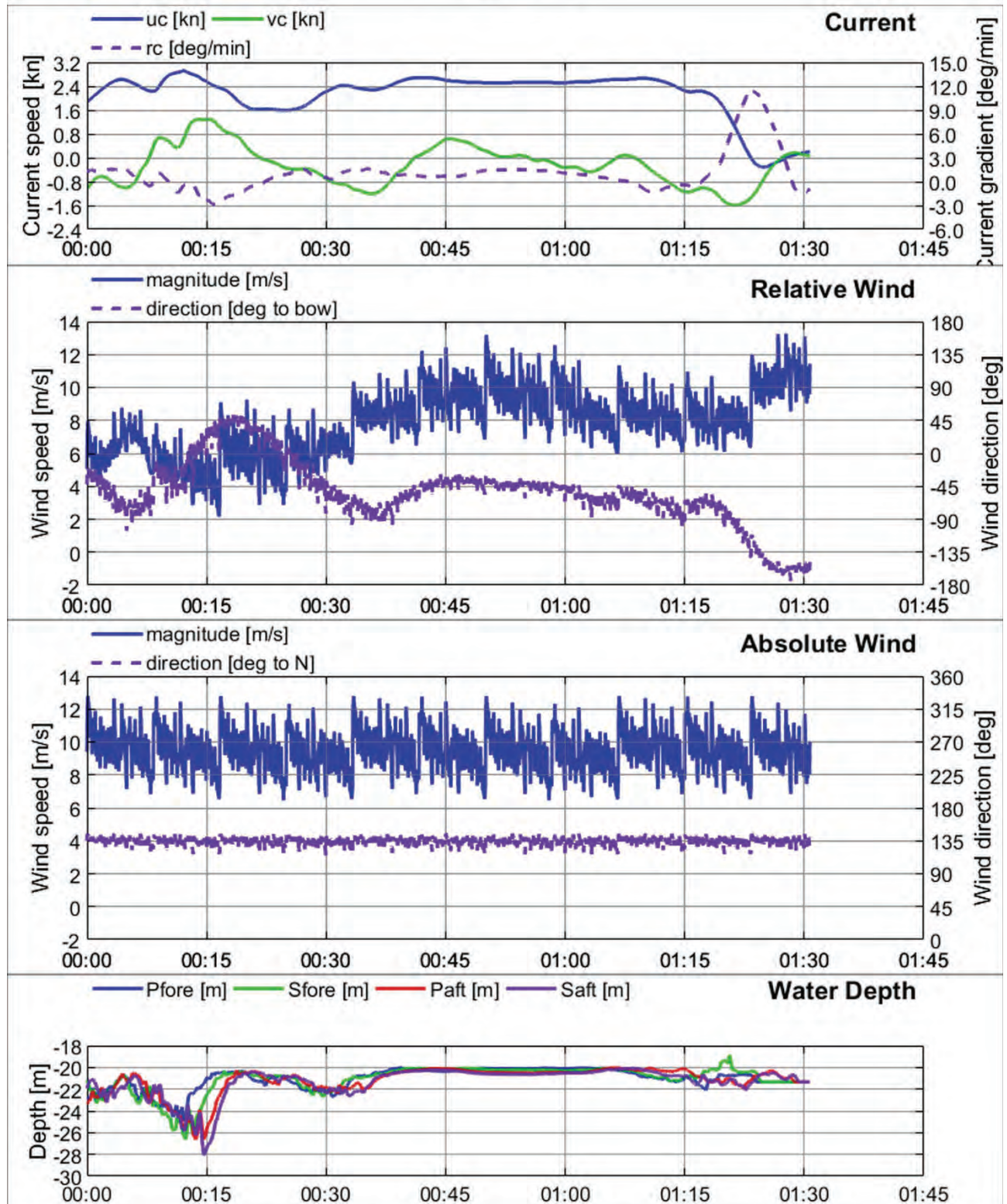
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 07/03/2022

Current: -1hHW stat

Wind: NW5



Container vessel: $L_{OA} = 430$ m; $B = 62.0$ m; $T = 15.0$ m

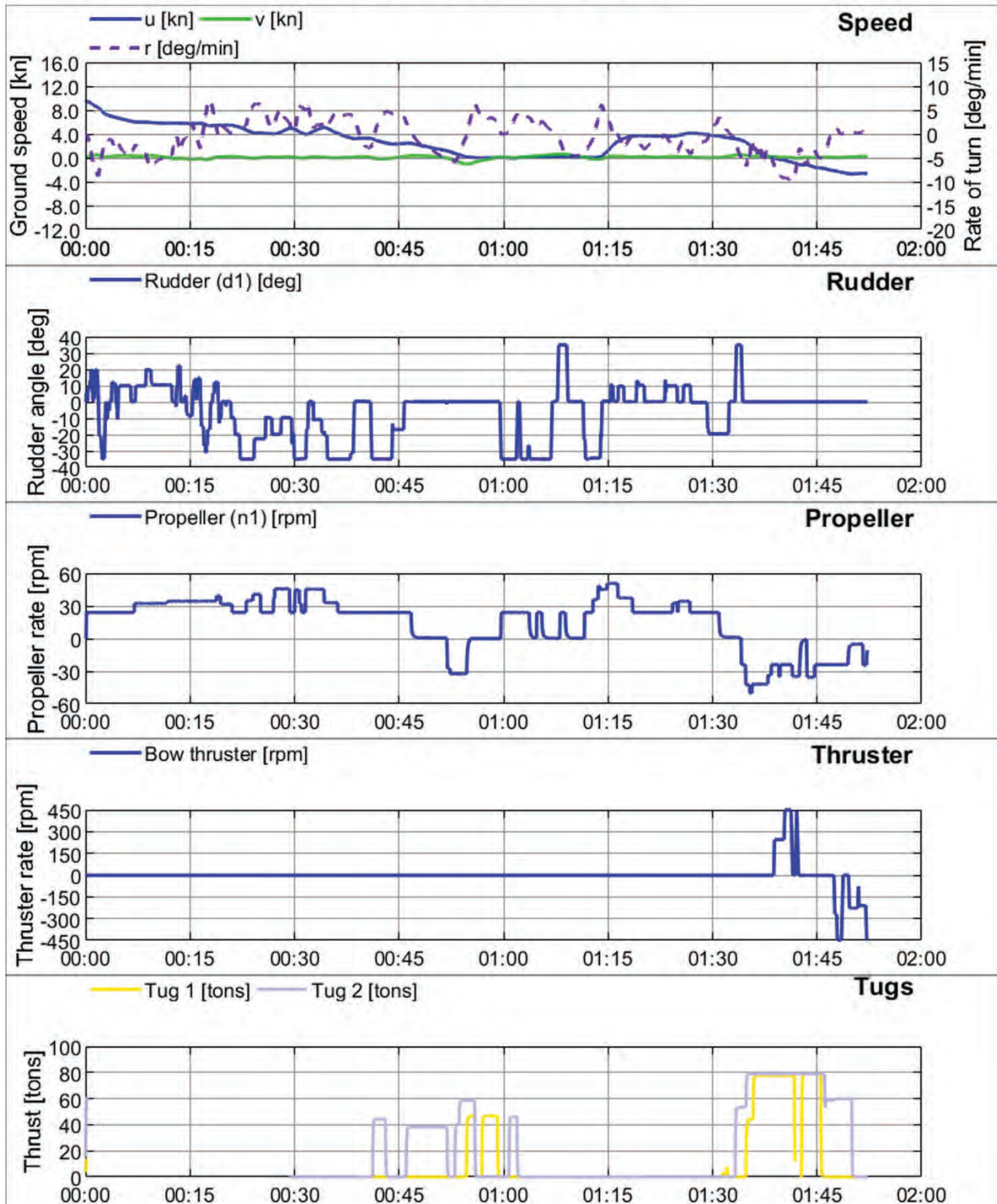
Simulation: U2 P1

Time: 11:18:23

Player: 1/4

Simulator: Sim 360+

Tugs: 80 80 80 80 tons



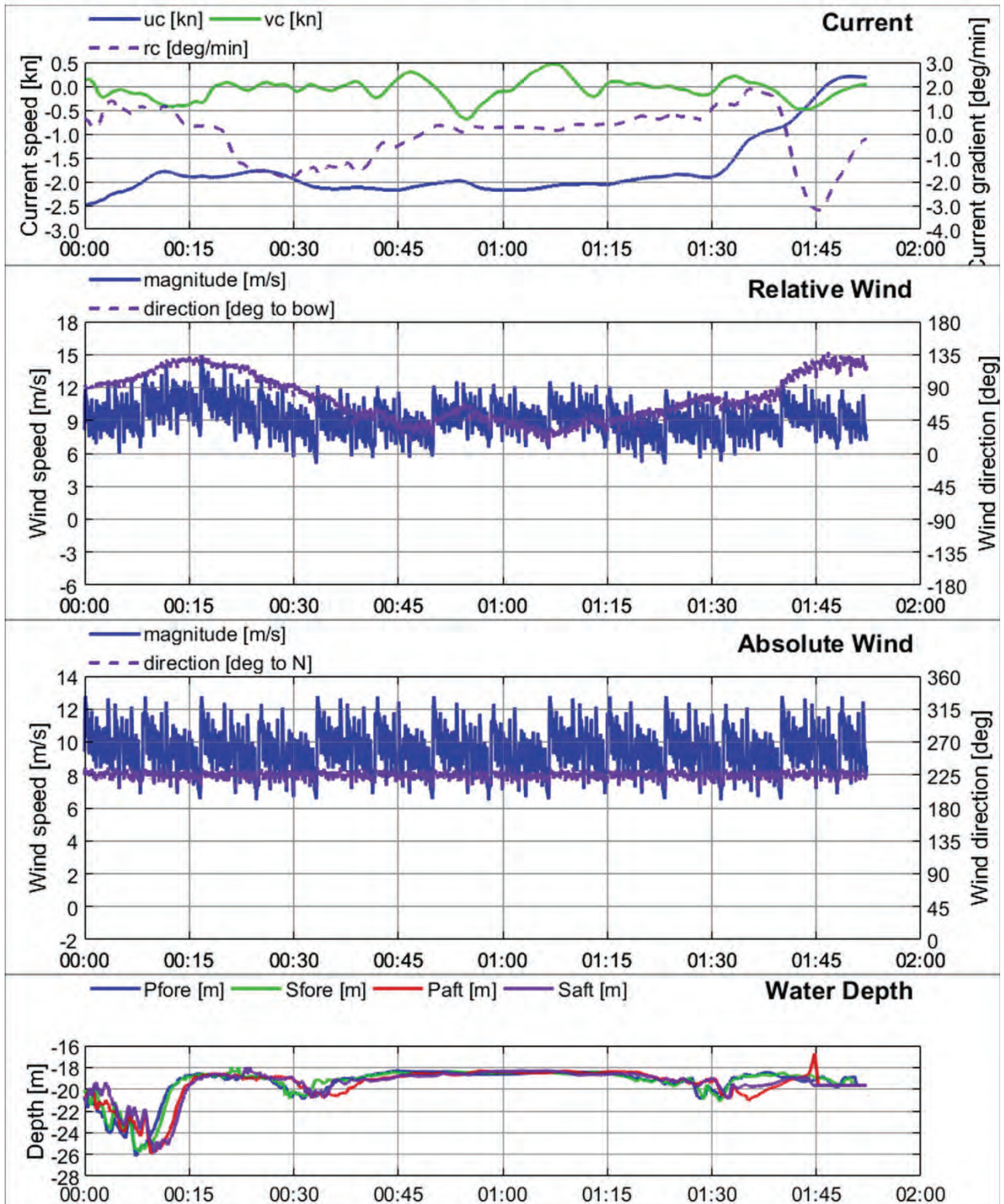
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 07/03/2022

Current: 3.33hHW stat

Wind: NE5



Container vessel: $L_{OA} = 430$ m; $B = 62.0$ m; $T = 15.0$ m

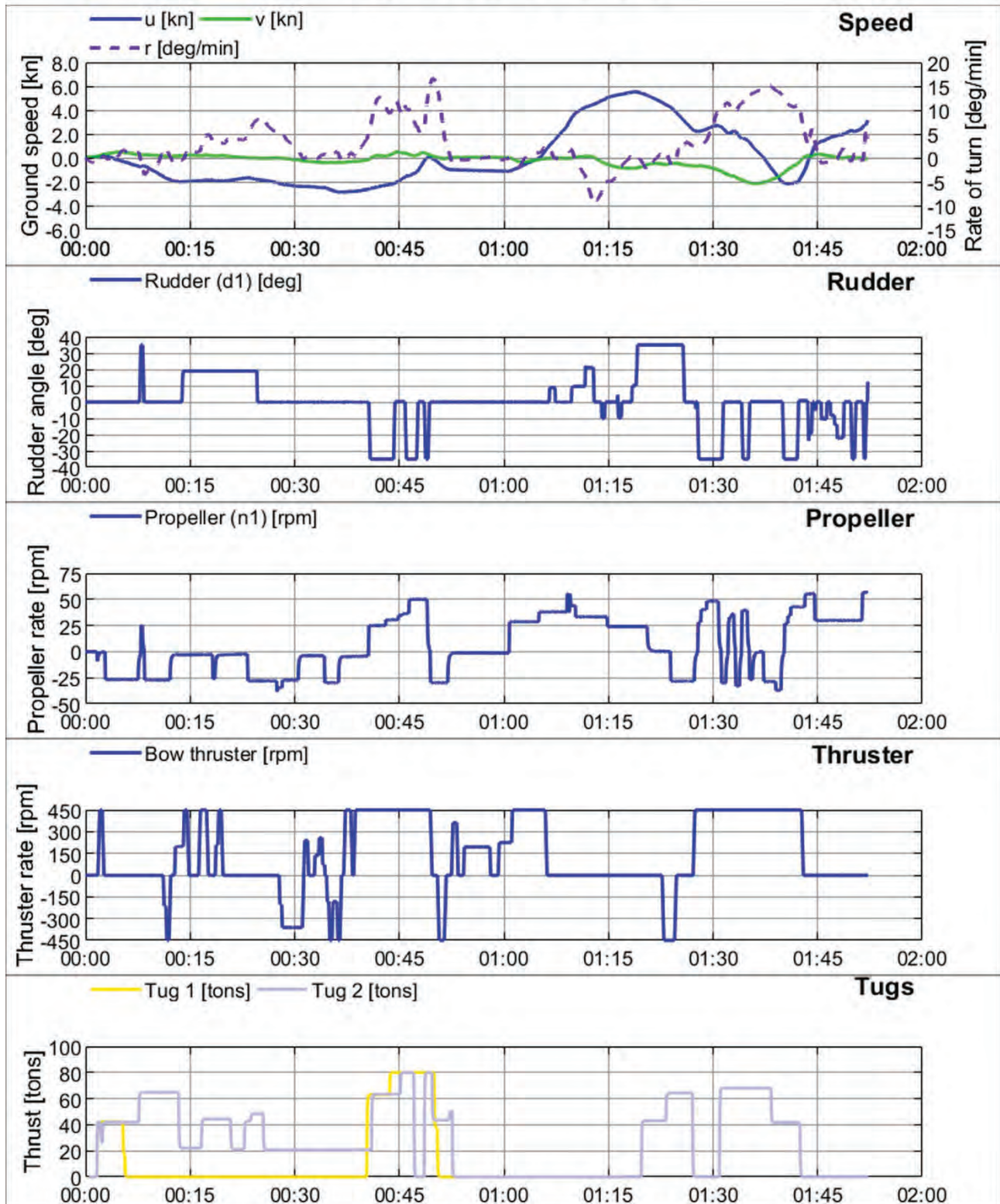
Simulation: U2 P2

Time: 11:22:19

Player: 2/4

Simulator: Sim 225

Tugs: 80 80 80 80 tons



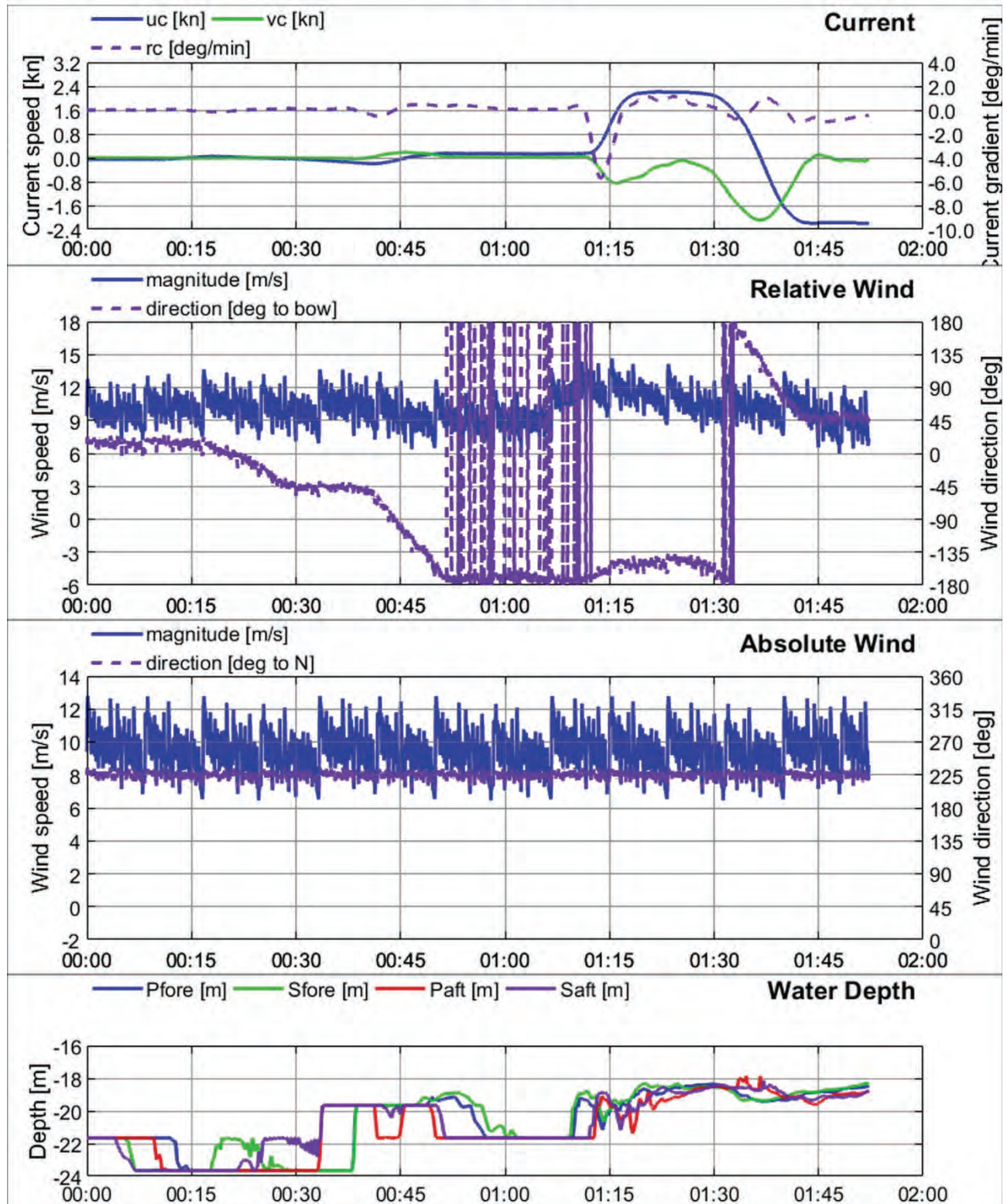
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 07/03/2022

Current: 3.33hHW stat

Wind: NE5



Container vessel: $L_{OA} = 400$ m; $B = 61.5$ m; $T = 14.0$ m

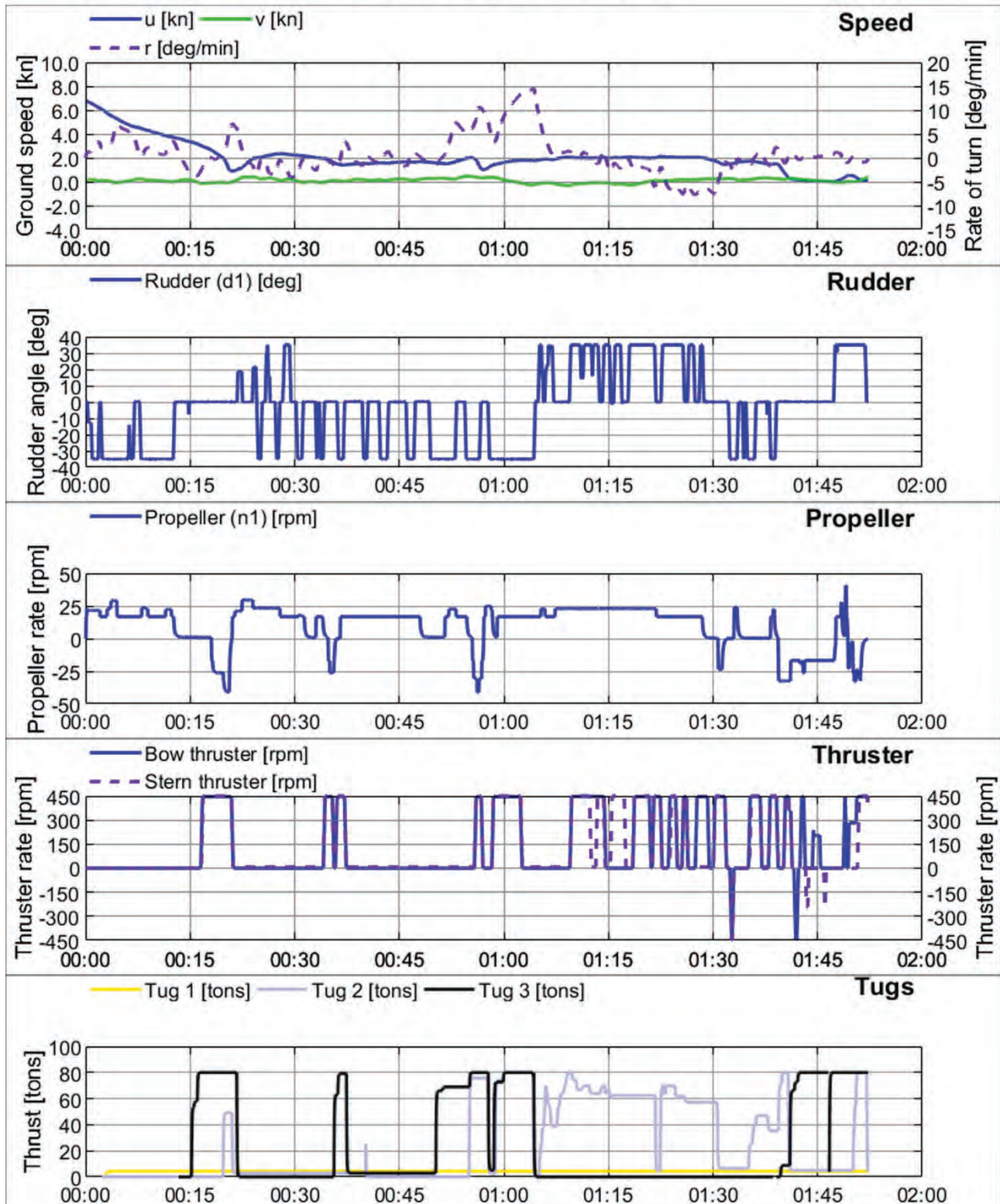
Simulation: U2 P3

Time: 11:23:56

Player: 3/4

Simulator: Sim Lara

Tugs: 80 80 80 80 tons



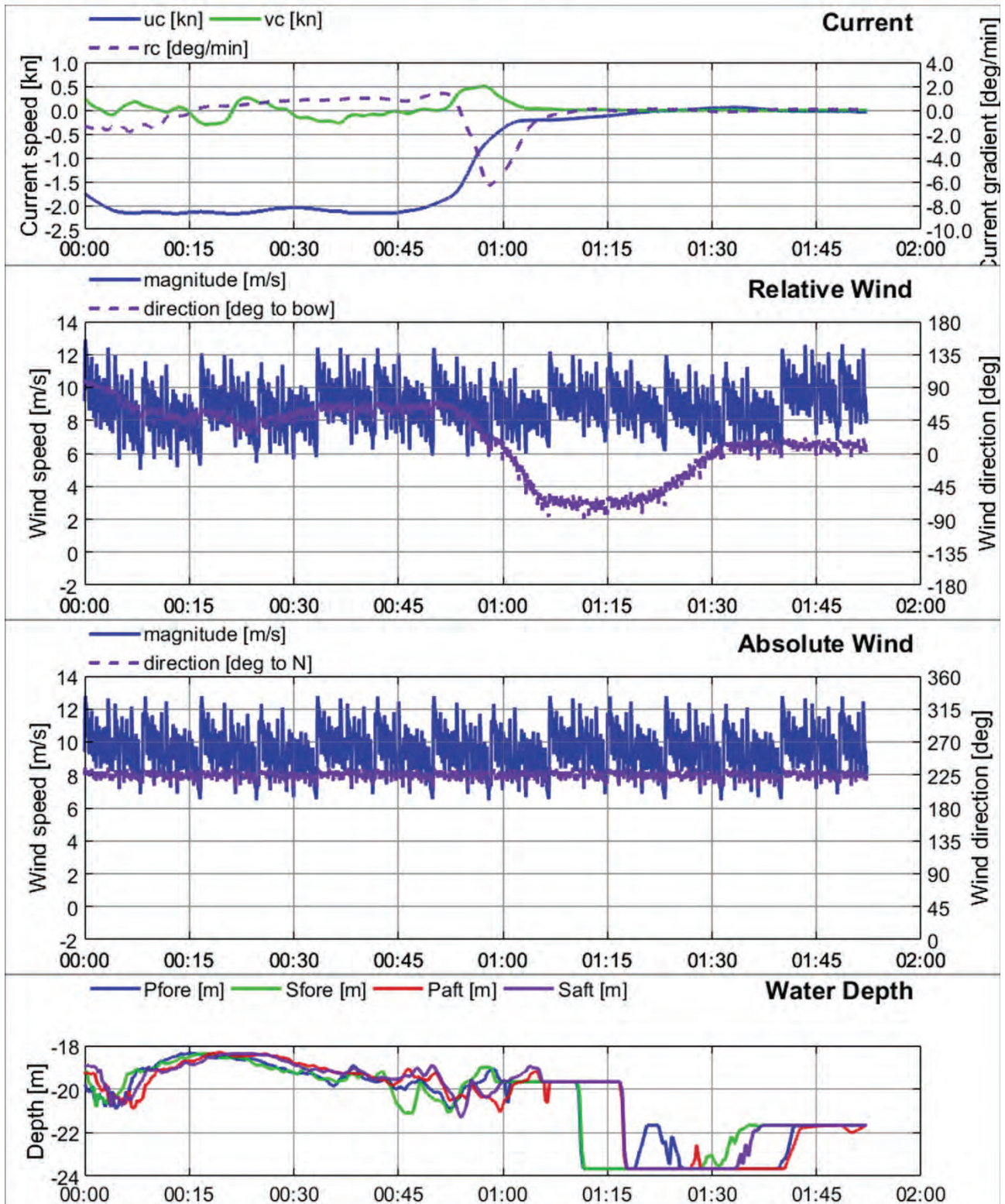
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 07/03/2022

Current: 3.33hHW stat

Wind: NE5



Container vessel: $L_{OA} = 400$ m; $B = 61.5$ m; $T = 12.0$ m

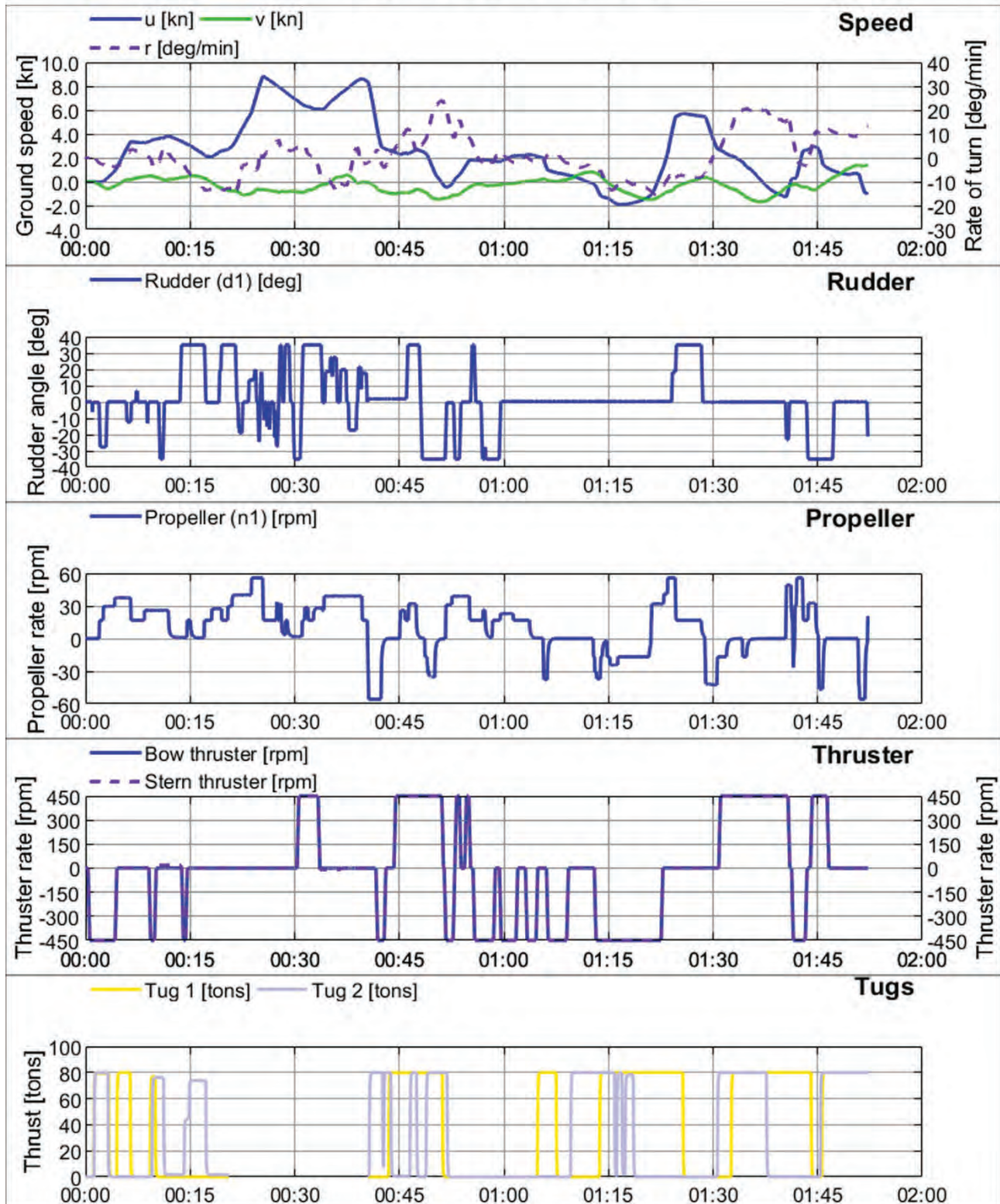
Simulation: U2 P4

Time: 11:17:05

Player: 4/4

Simulator: Sim 5

Tugs: 80 80 80 80 tons



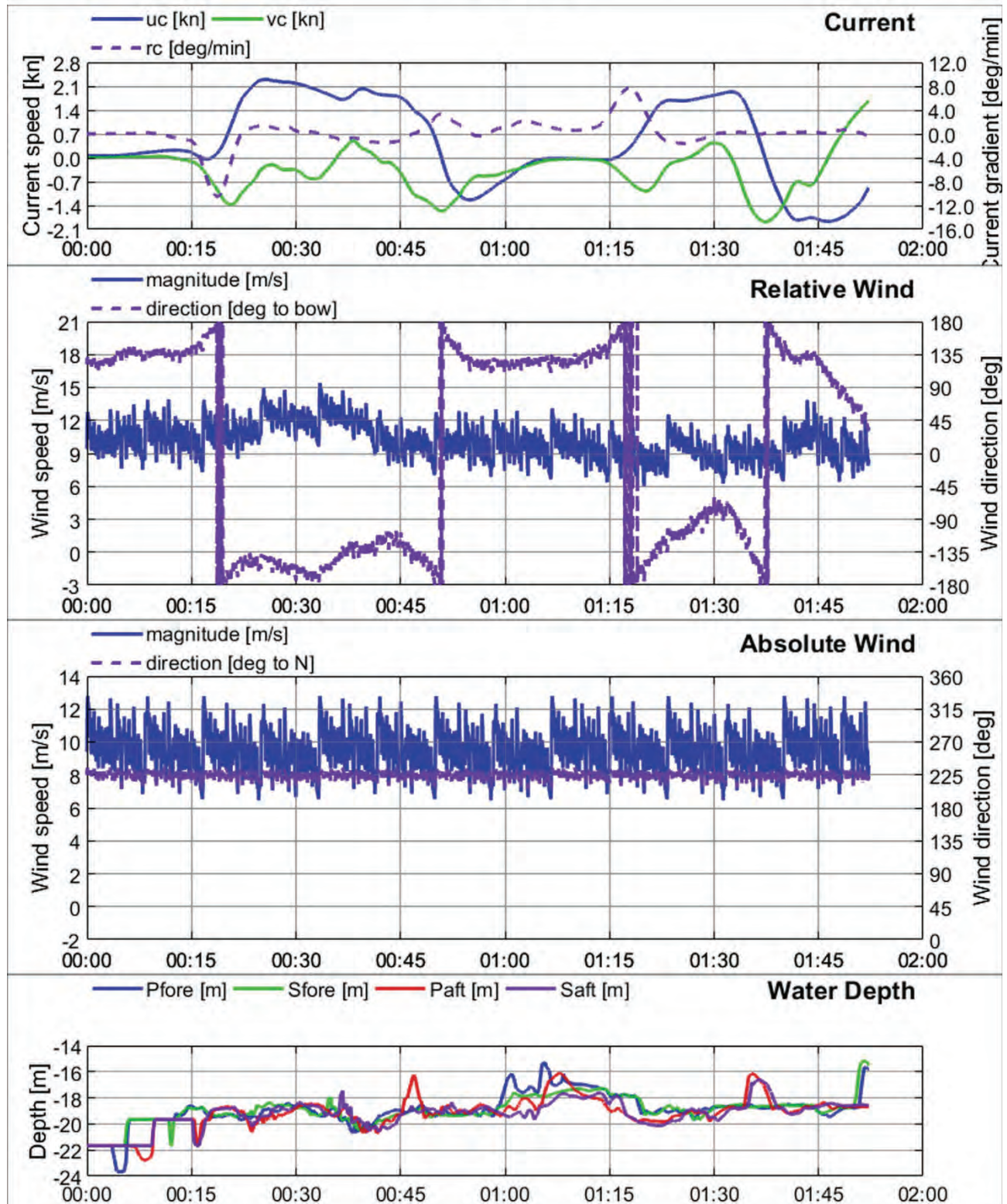
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 07/03/2022

Current: 3.33hHW stat

Wind: NE5



Container vessel: $L_{OA} = 430$ m; $B = 62.0$ m; $T = 15.0$ m

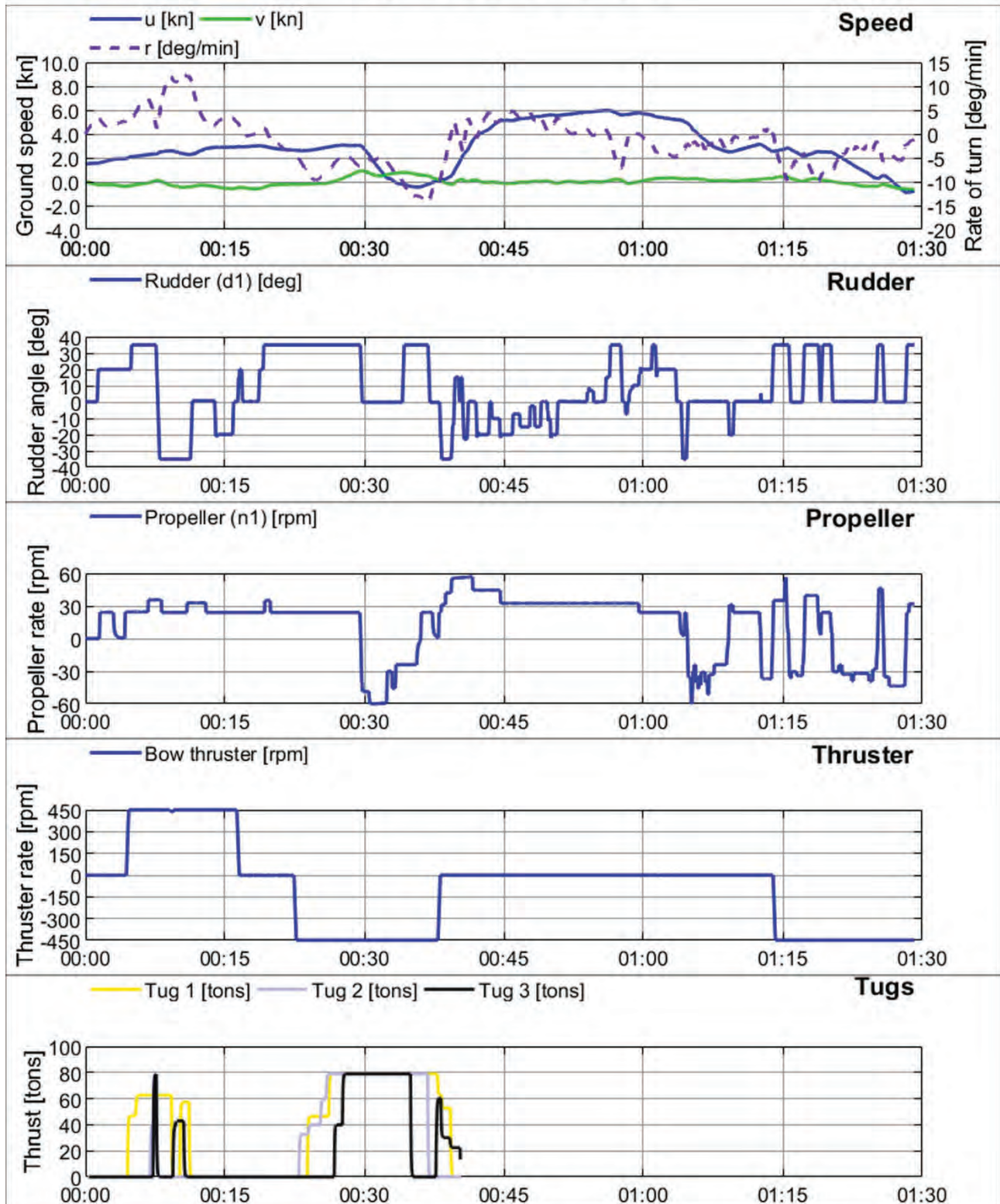
Simulation: M1 P1

Time: 14:08:44

Player: 1/4

Simulator: Sim 360+

Tugs: 80 80 80 80 tons



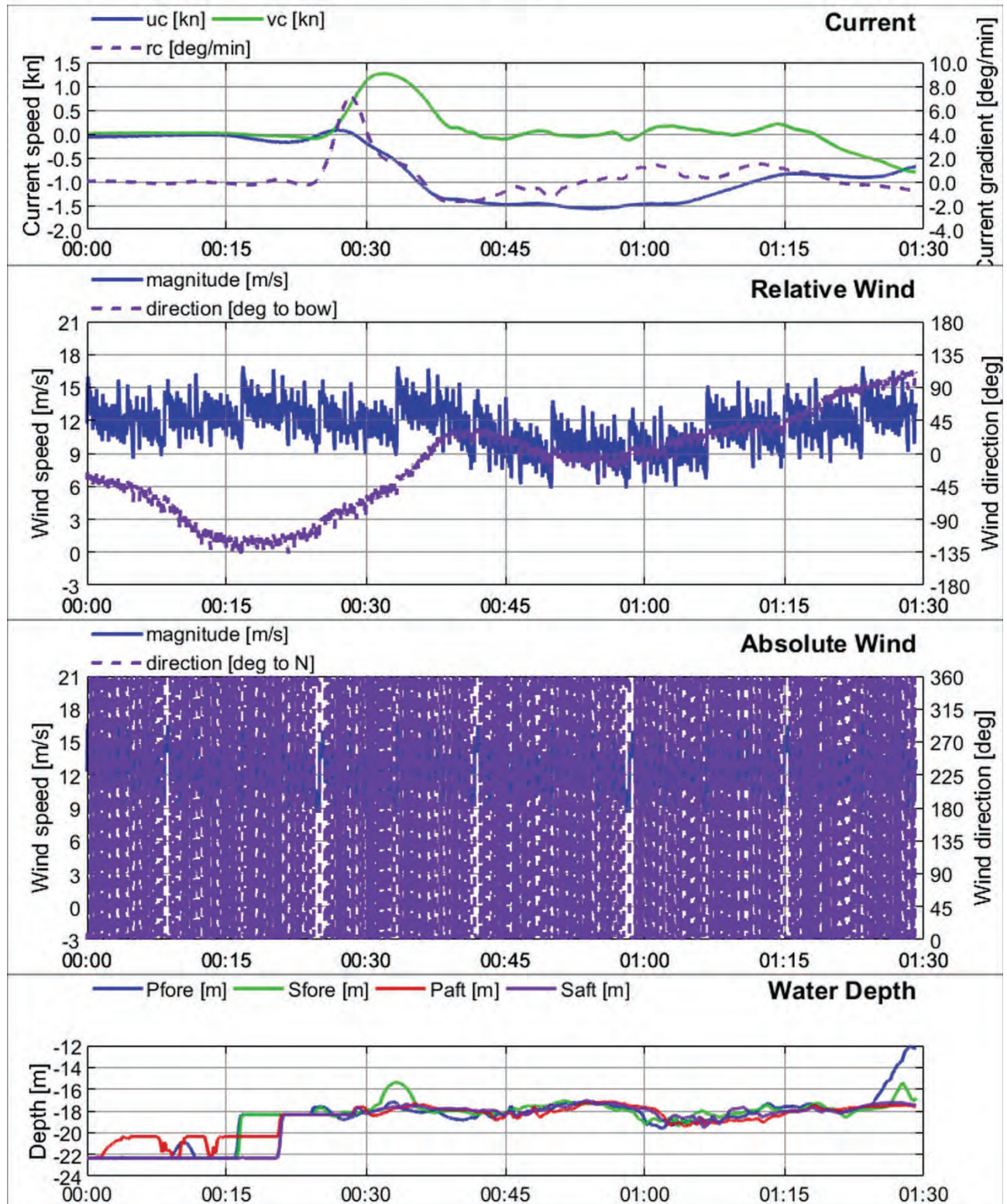
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 07/03/2022

Current: -3.5hHW stat

Wind: S6



Container vessel: $L_{OA} = 400$ m; $B = 61.5$ m; $T = 14.0$ m

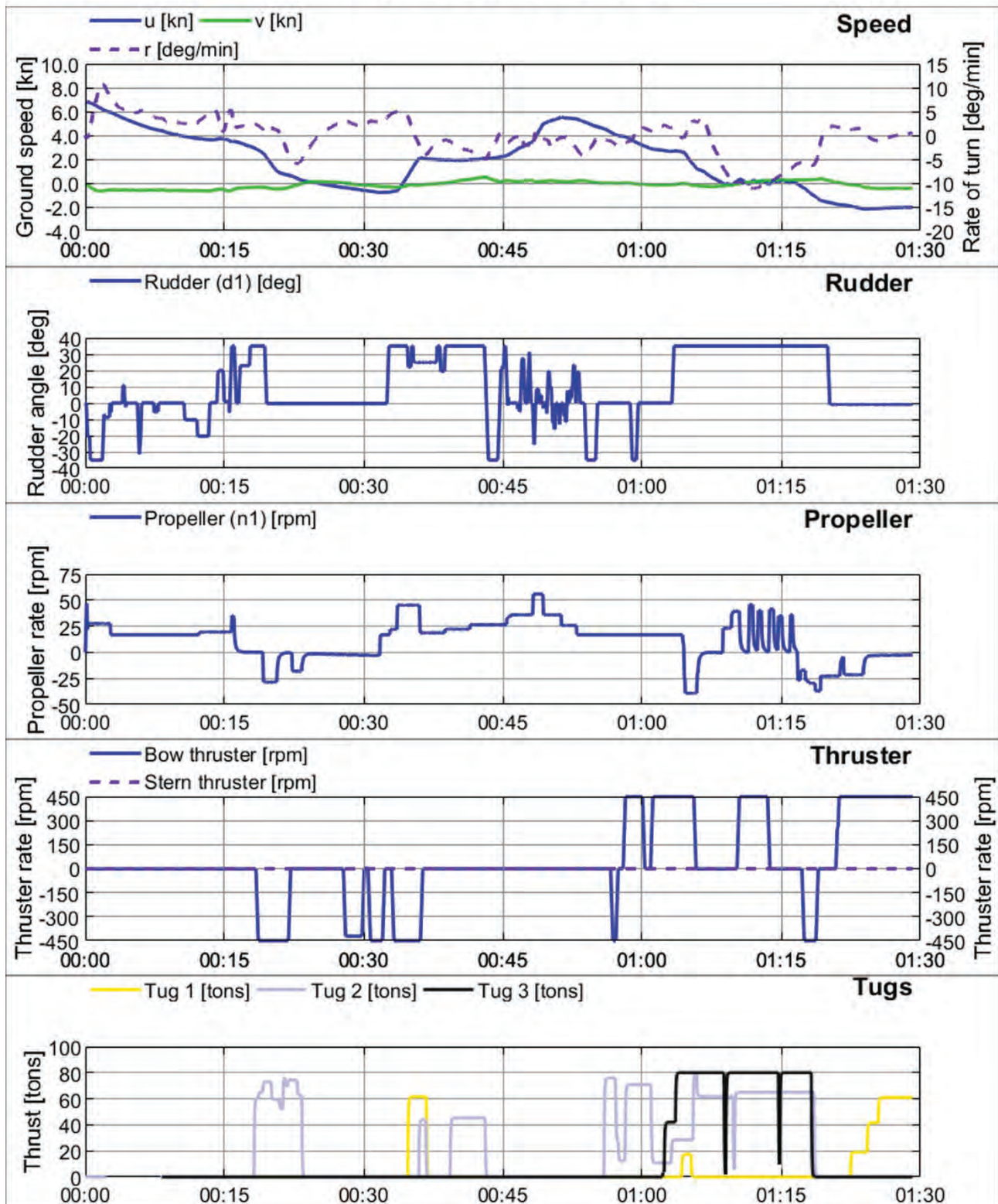
Simulation: M1 P2

Time: 14:12:40

Player: 2/4

Simulator: Sim 225

Tugs: 80 80 80 80 tons



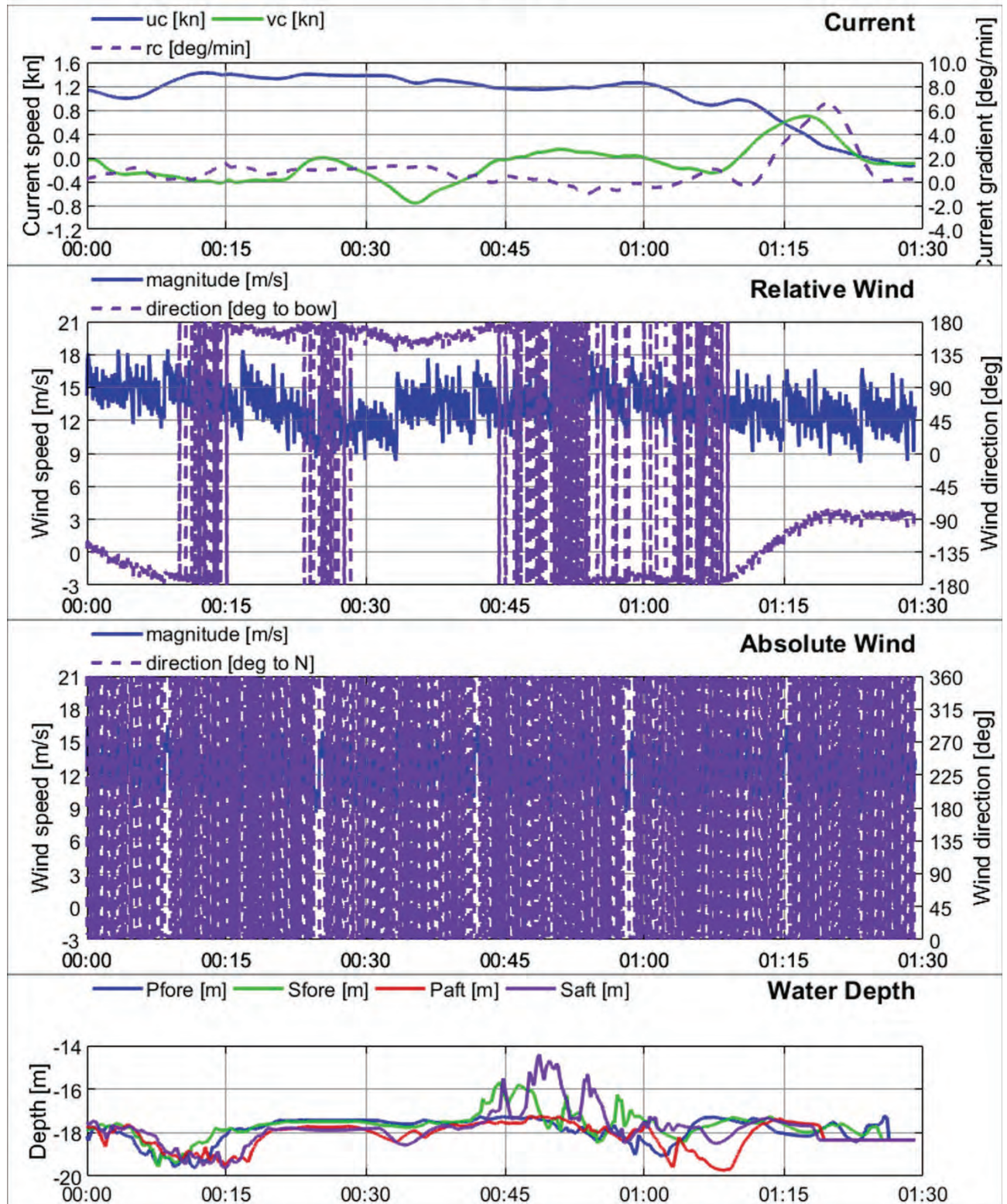
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 07/03/2022

Current: -3.5hHW stat

Wind: S6



Container vessel: $L_{OA} = 210$ m; $B = 32.2$ m; $T = 11.0$ m

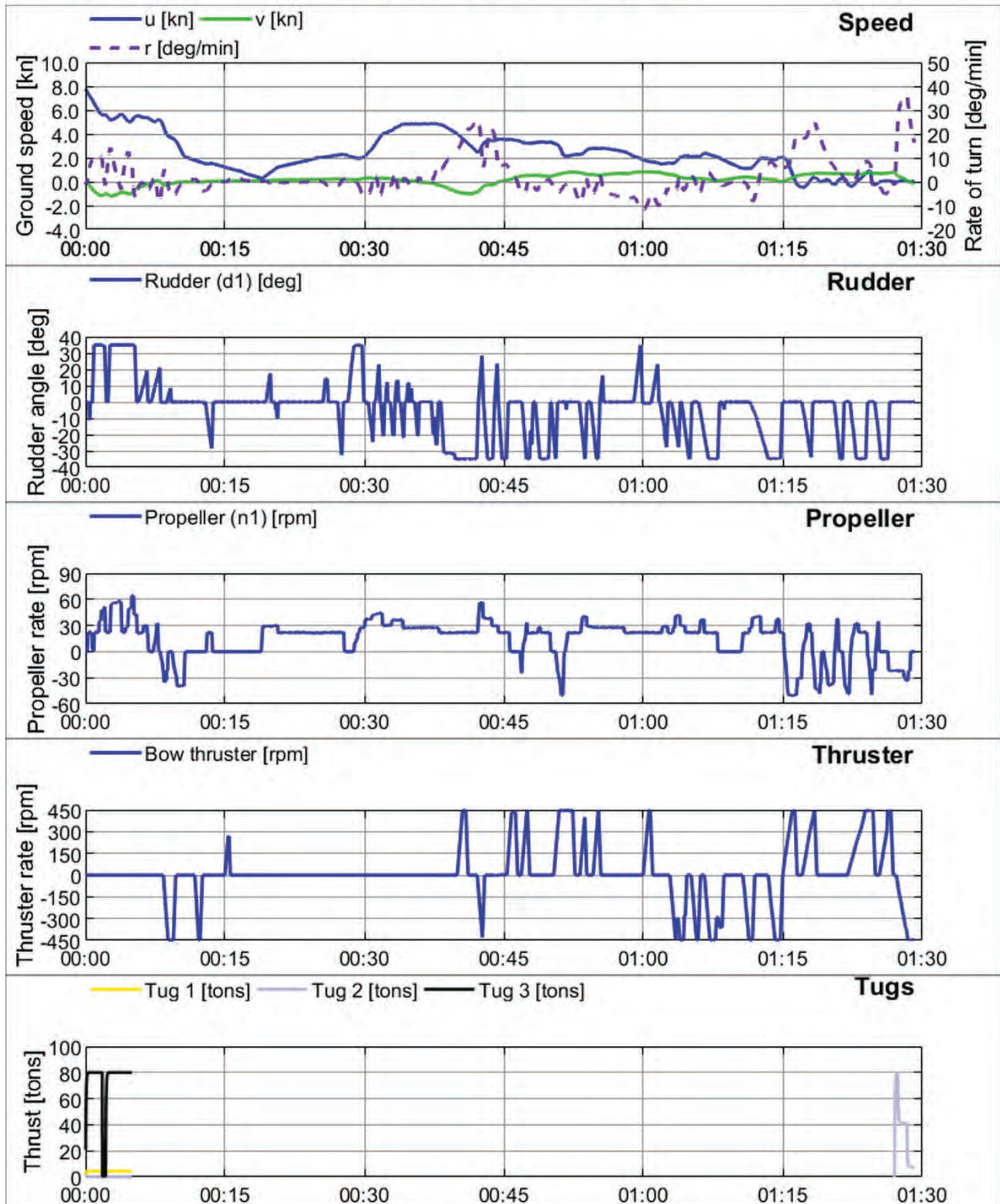
Simulation: M1 P3

Time: 14:14:17

Player: 3/4

Simulator: Sim Lara

Tugs: 80 80 80 80 tons



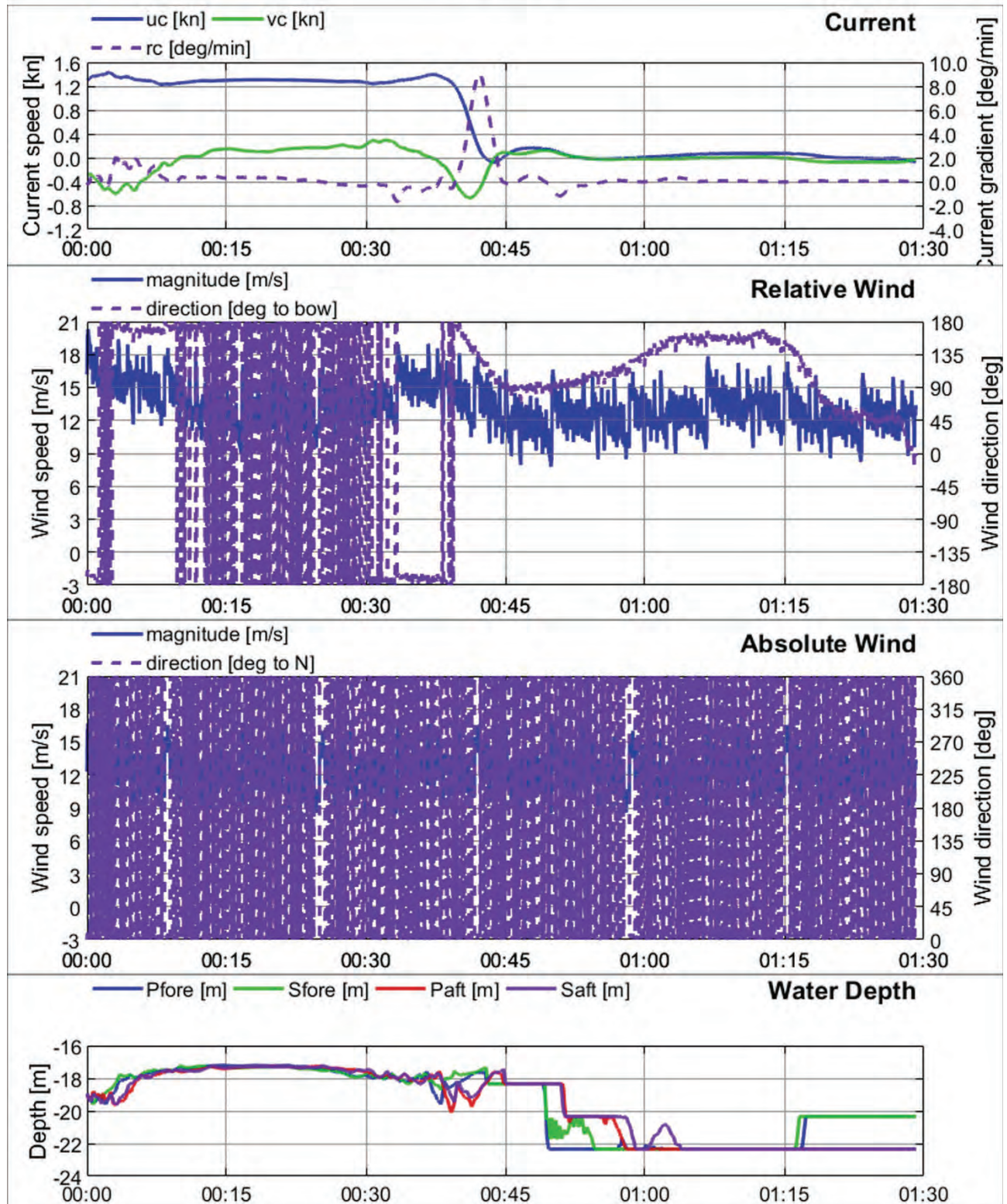
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 07/03/2022

Current: -3.5hHW stat

Wind: S6



Container vessel: $L_{OA} = 255$ m; $B = 32.3$ m; $T = 12.0$ m

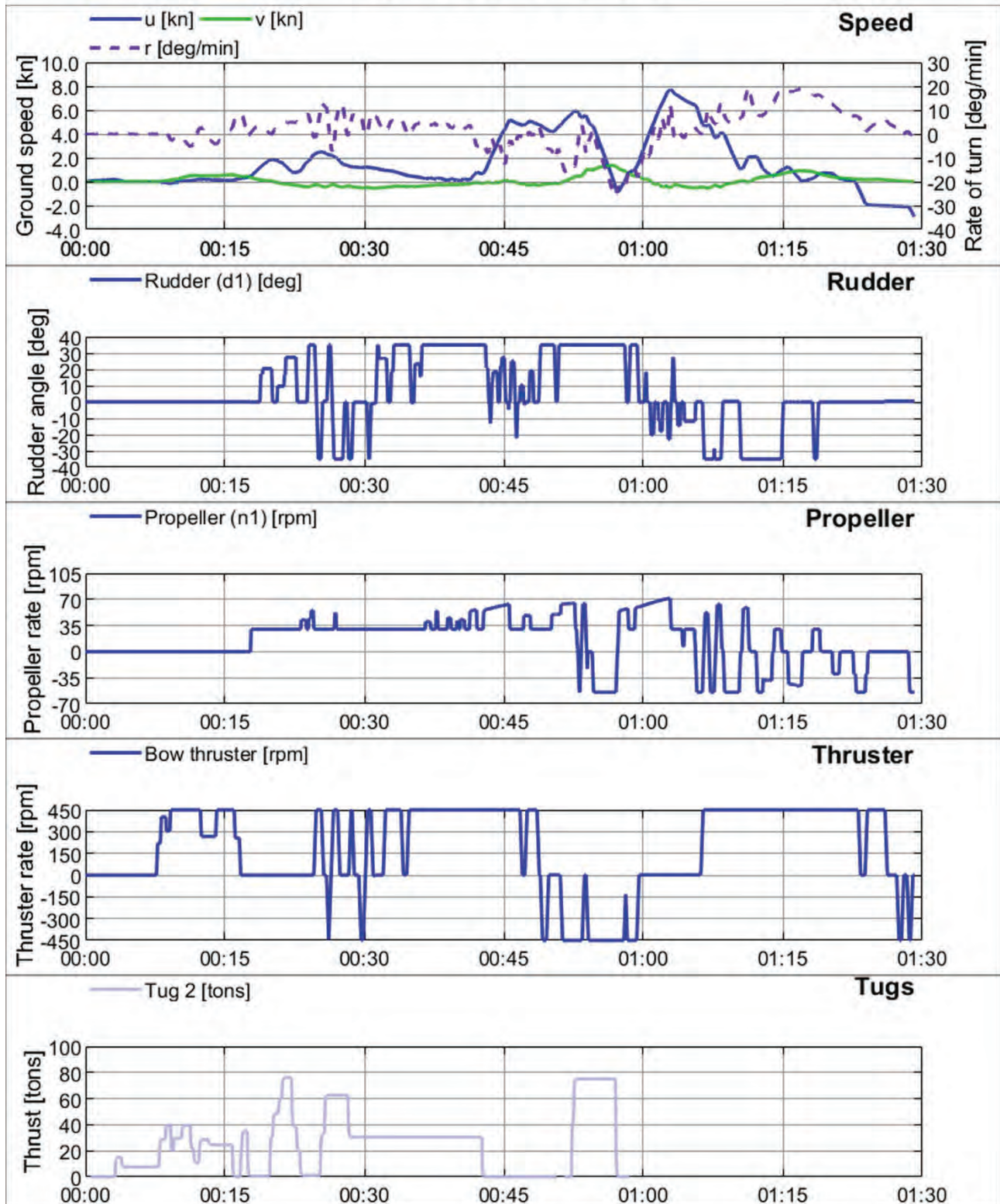
Simulation: M1 P4

Time: 14:07:25

Player: 4/4

Simulator: Sim 5

Tugs: 80 80 80 80 tons



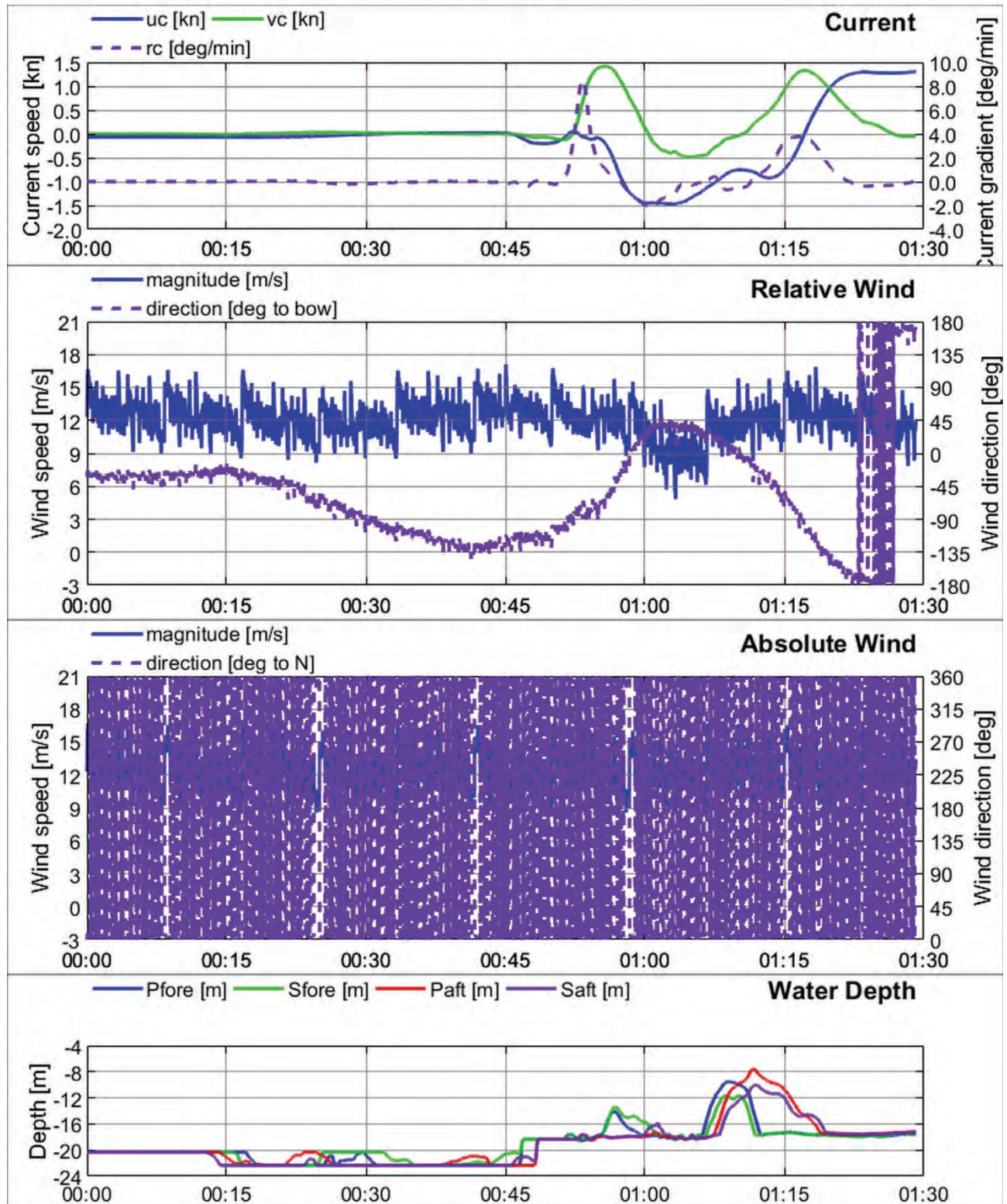
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 07/03/2022

Current: -3.5hHW stat

Wind: S6



Container vessel: $L_{OA} = 430$ m; $B = 62.0$ m; $T = 15.0$ m

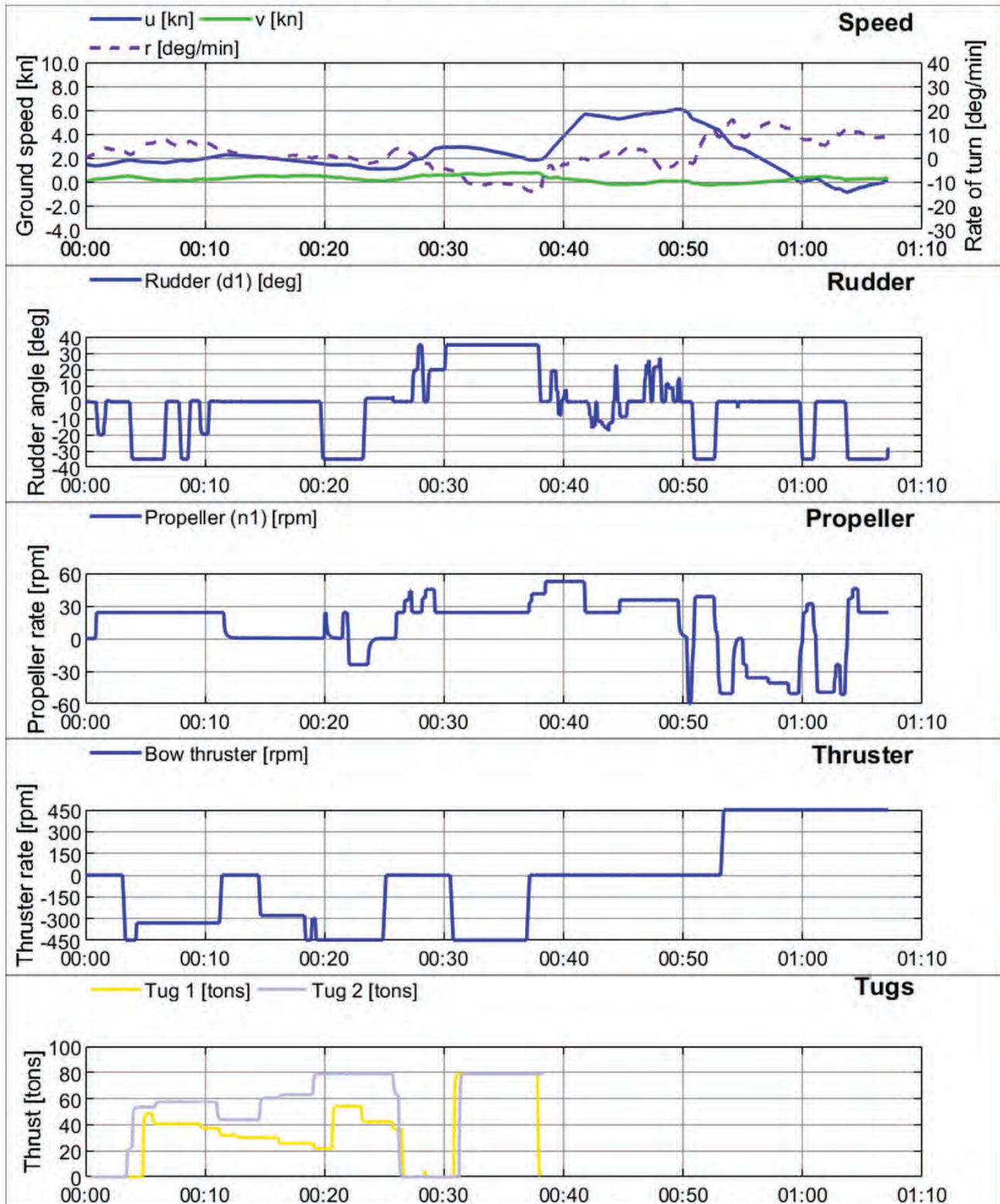
Simulation: M2 P1

Time: 16:04:30

Player: 1/4

Simulator: Sim 360+

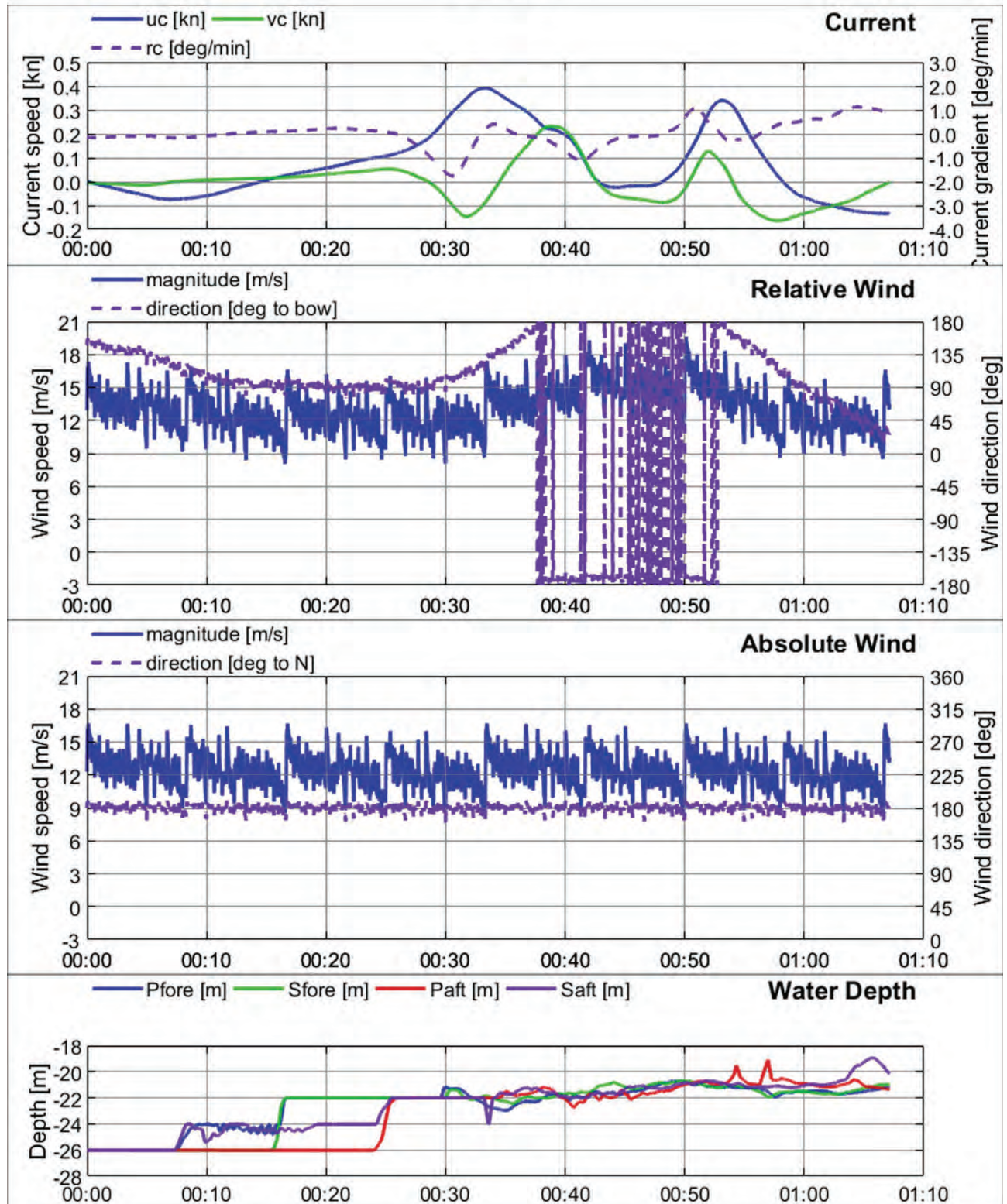
Tugs: 80 80 80 80 tons



[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 07/03/2022
Current: 1hHW stat
Wind: N6



Container vessel: $L_{OA} = 400$ m; $B = 61.5$ m; $T = 15.0$ m

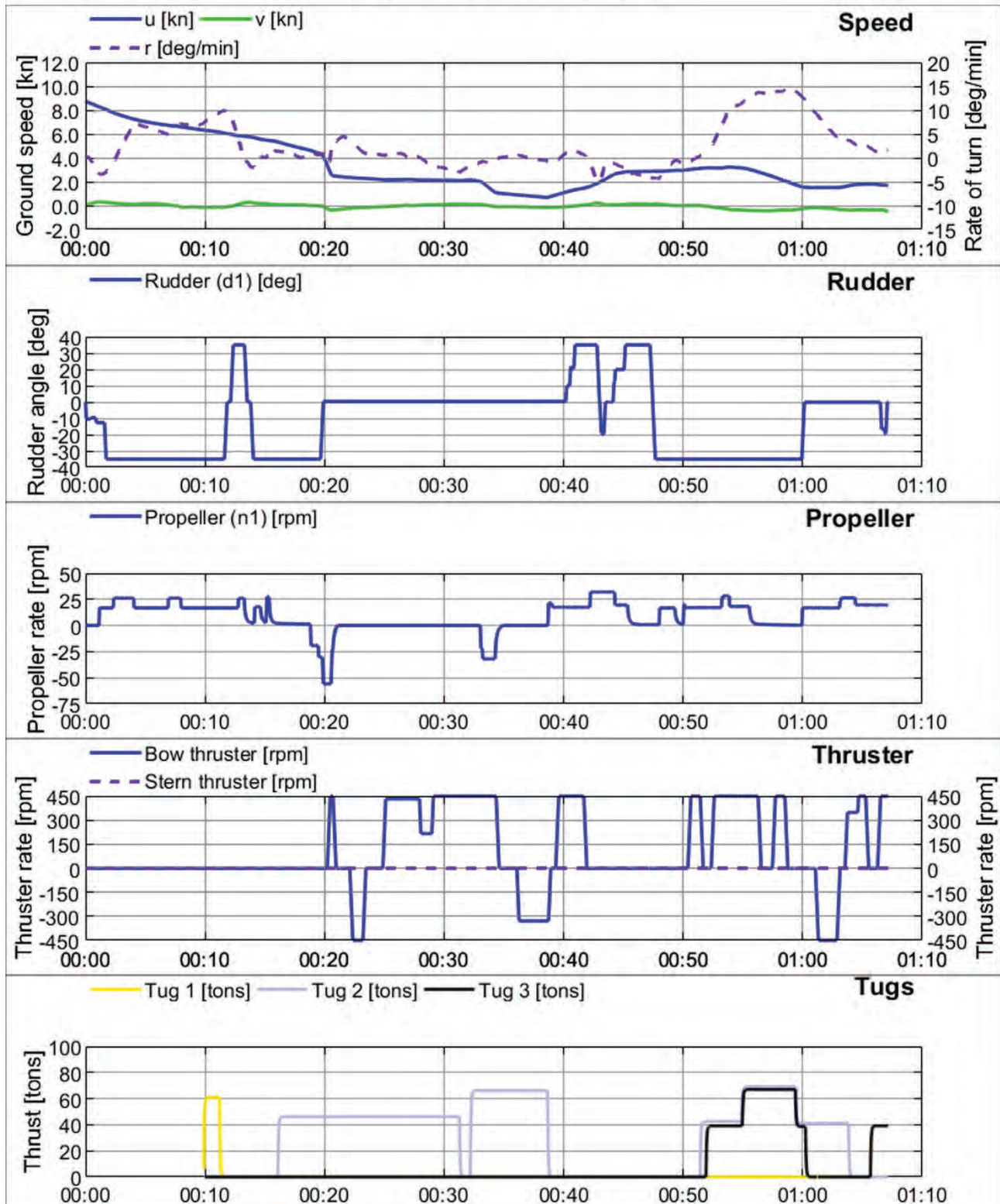
Simulation: M2 P2

Time: 16:08:26

Player: 2/4

Simulator: Sim 225

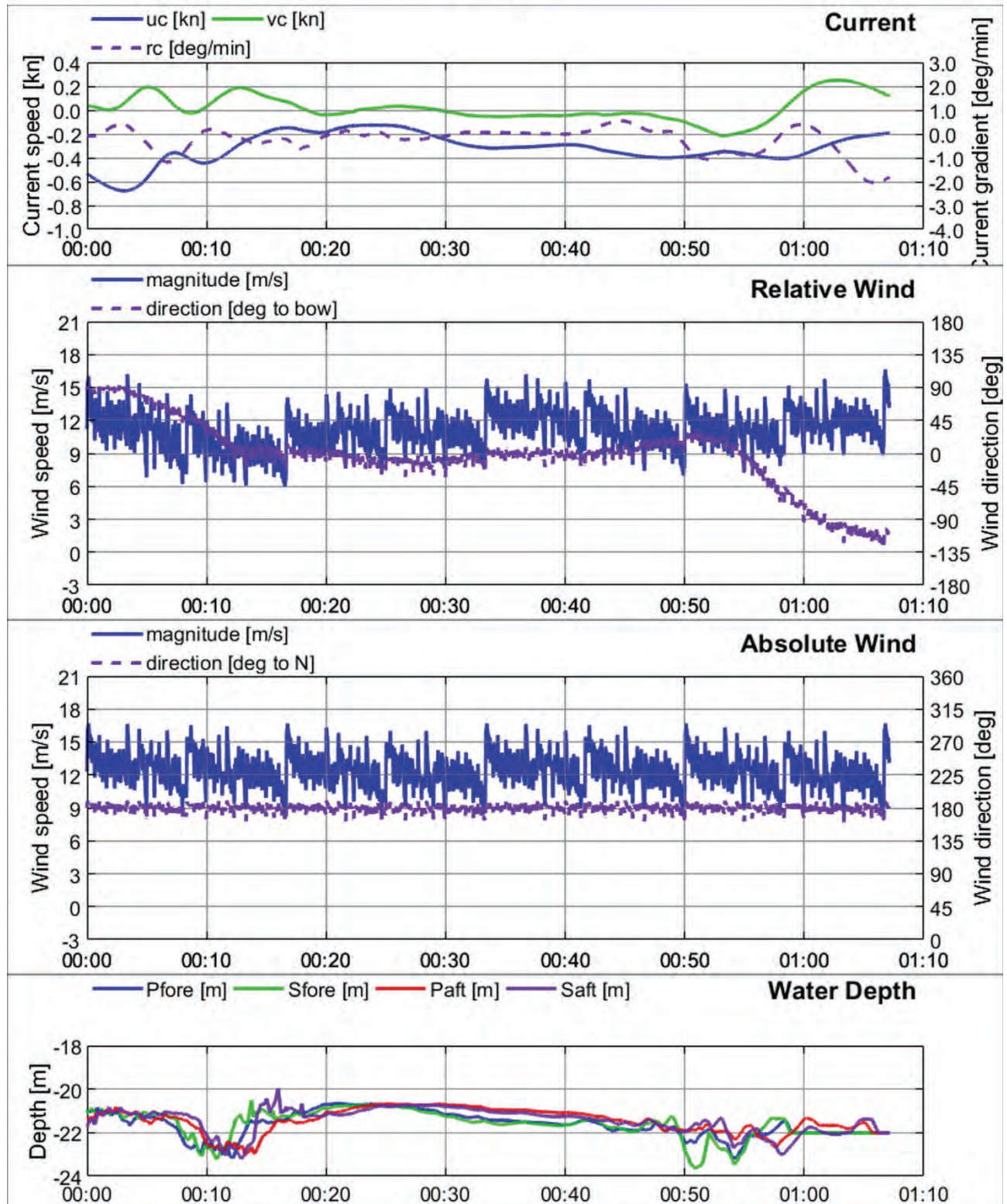
Tugs: 80 80 80 80 tons



[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 07/03/2022
Current: 1hHW stat
Wind: N6



Container vessel: $L_{OA} = 367$ m; $B = 48.4$ m; $T = 13.1$ m

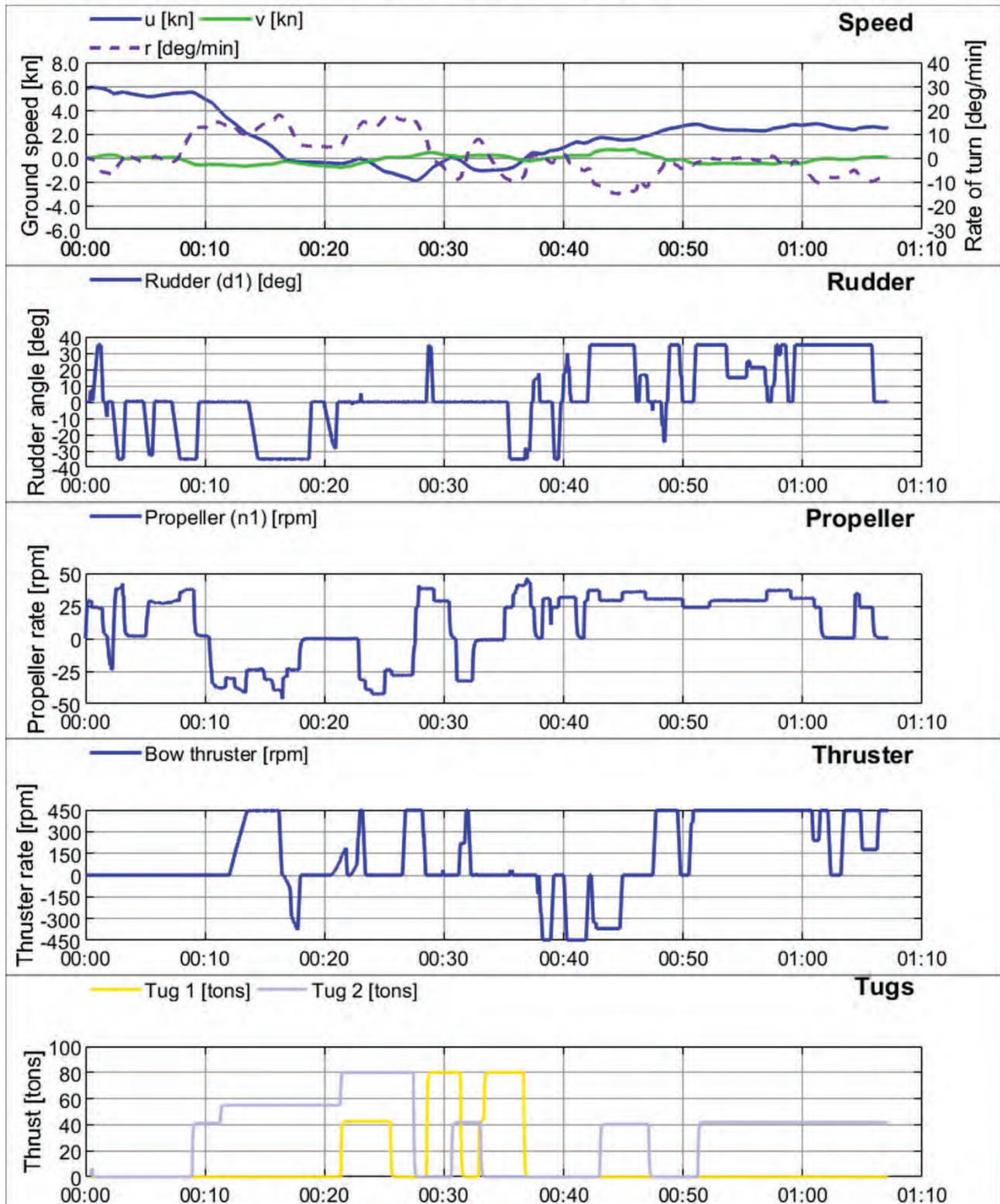
Simulation: M2 P3

Time: 16:10:03

Player: 3/4

Simulator: Sim Lara

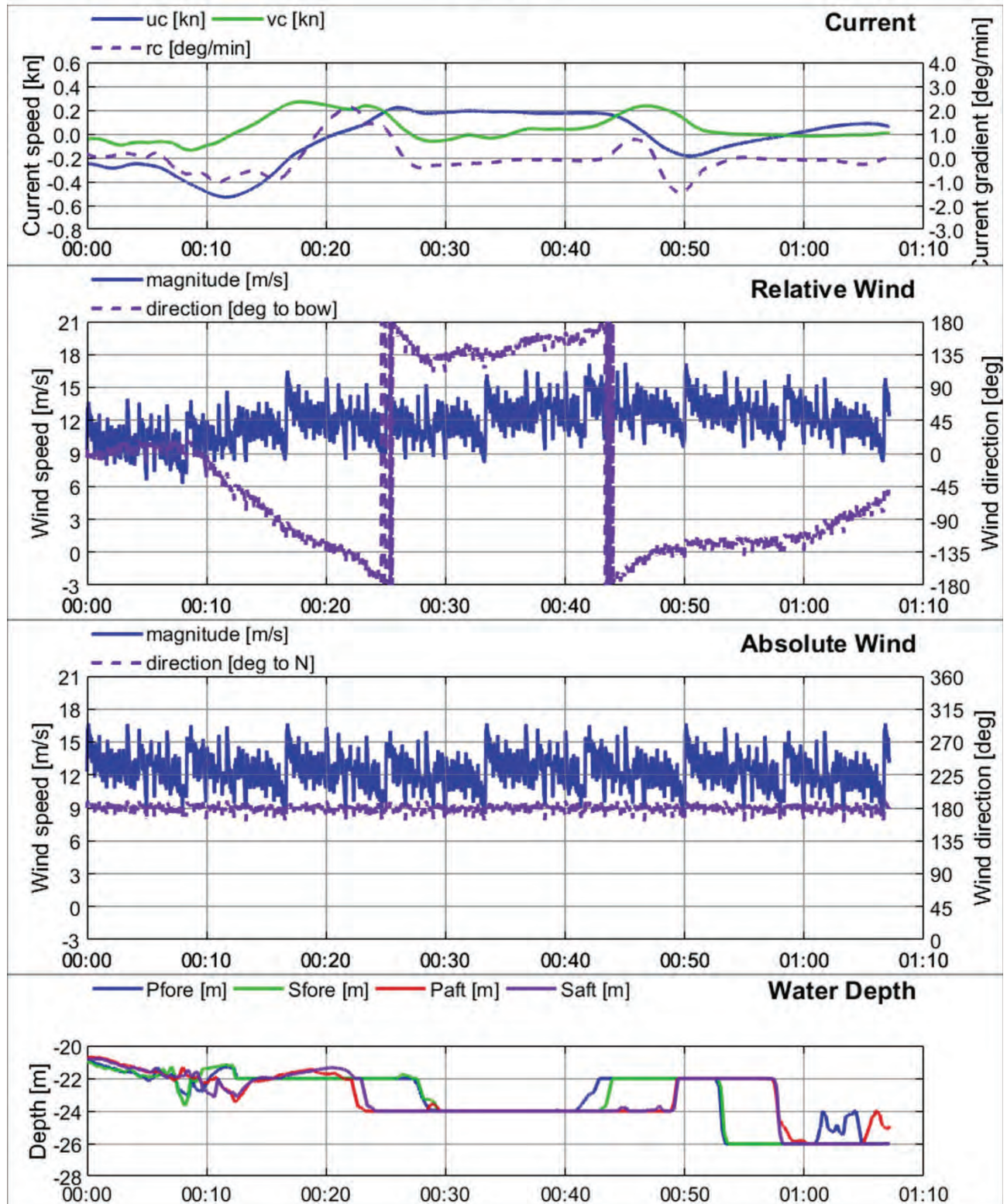
Tugs: 80 80 80 80 tons



[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 07/03/2022
Current: 1hHW stat
Wind: N6



Container vessel: $L_{OA} = 255$ m; $B = 32.3$ m; $T = 12.0$ m

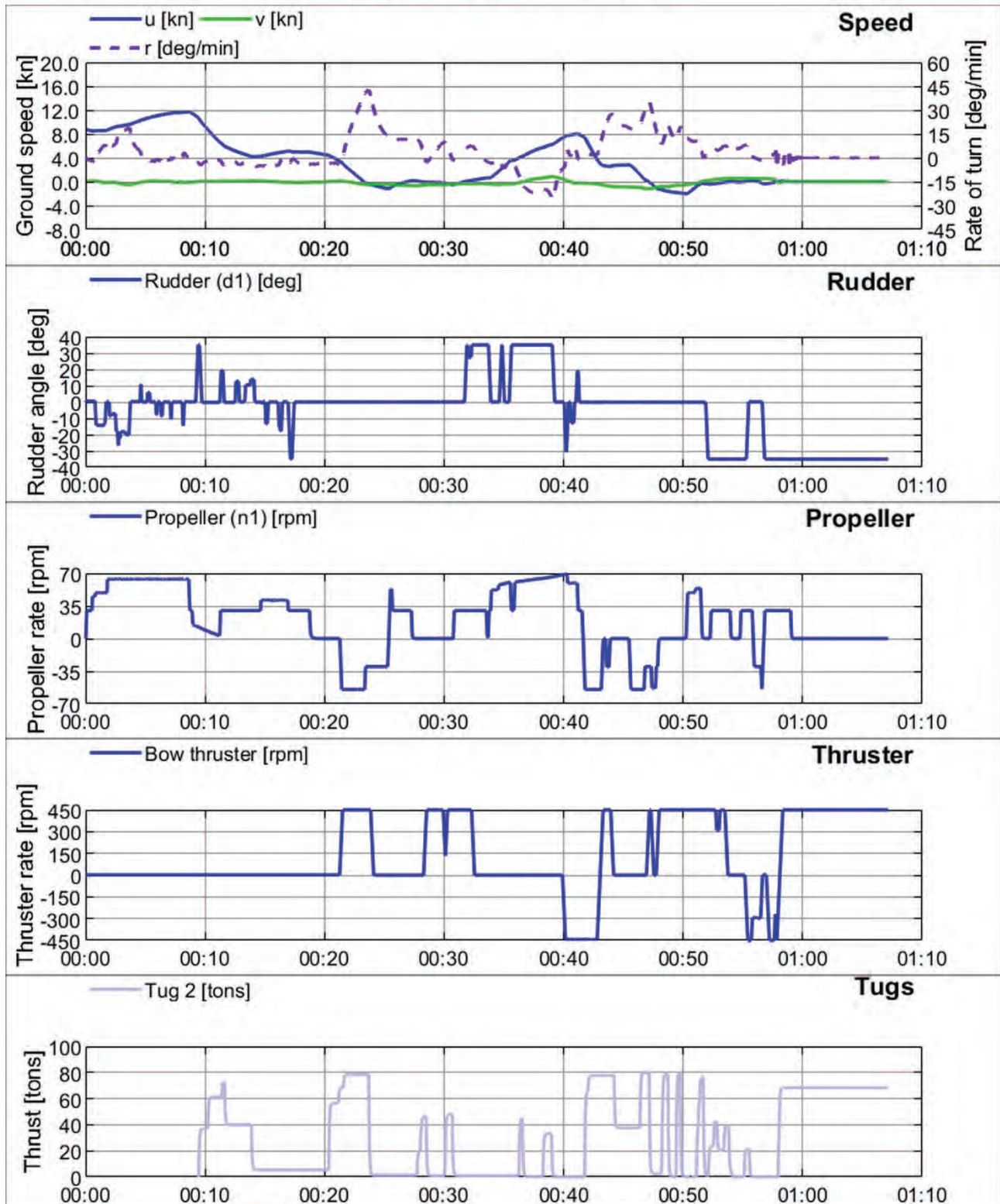
Simulation: M2 P4

Time: 16:03:12

Player: 4/4

Simulator: Sim 5

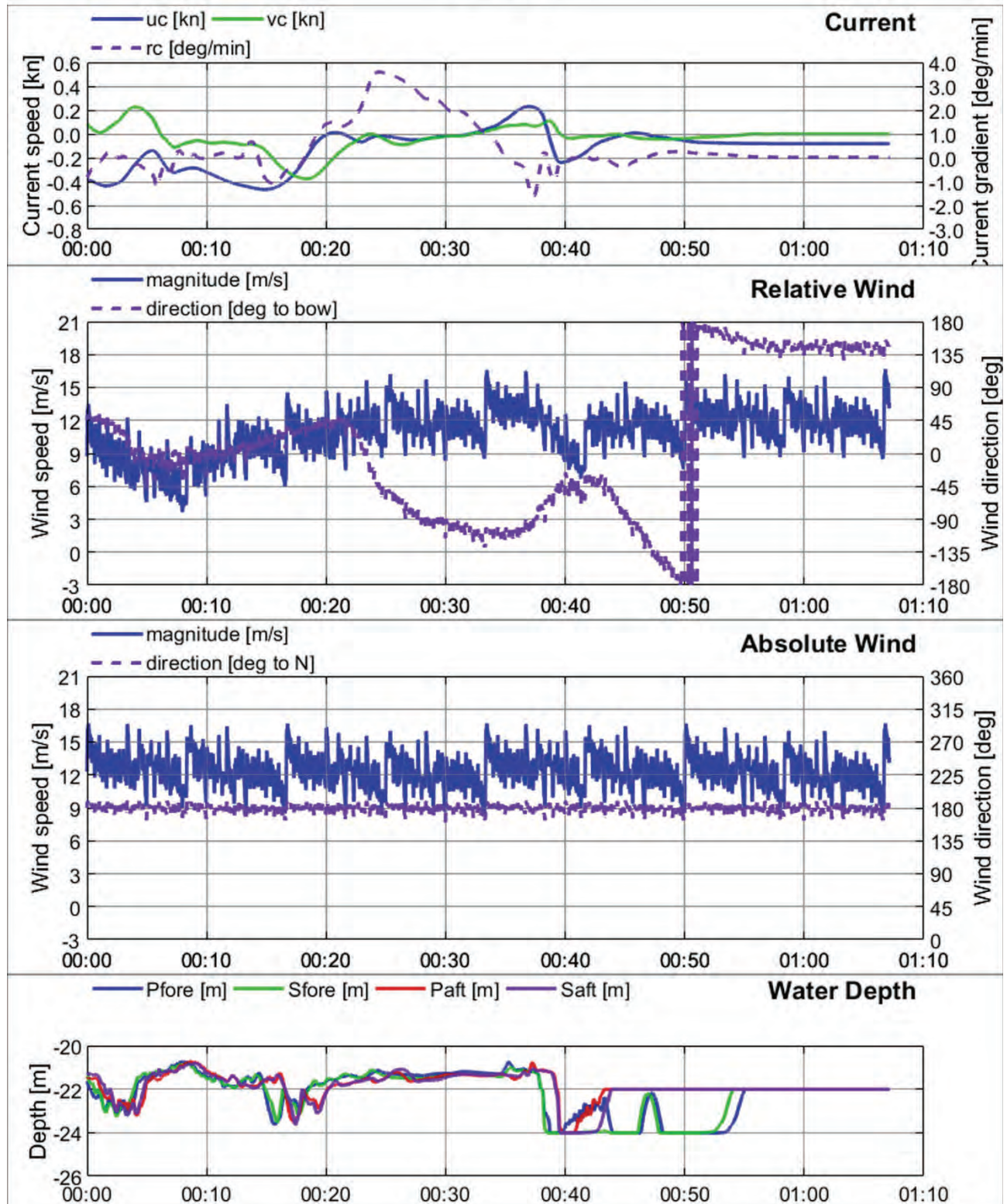
Tugs: 80 80 80 80 tons



[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 07/03/2022
Current: 1hHW stat
Wind: N6



Container vessel: $L_{OA} = 430$ m; $B = 62.0$ m; $T = 15.0$ m

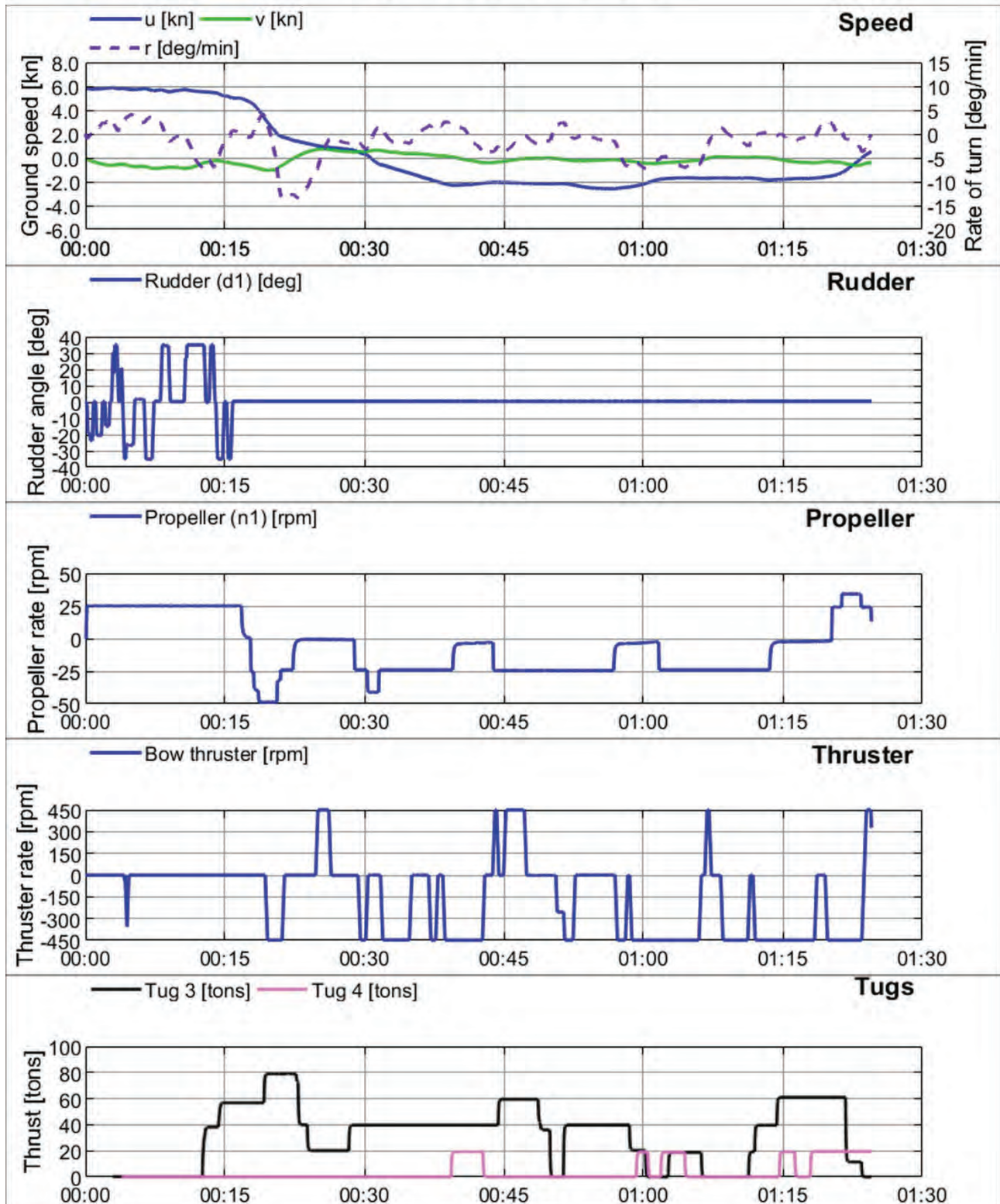
Simulation: U3 P1

Time: 09:14:23

Player: 1/4

Simulator: Sim 360+

Tugs: 80 80 80 80 tons



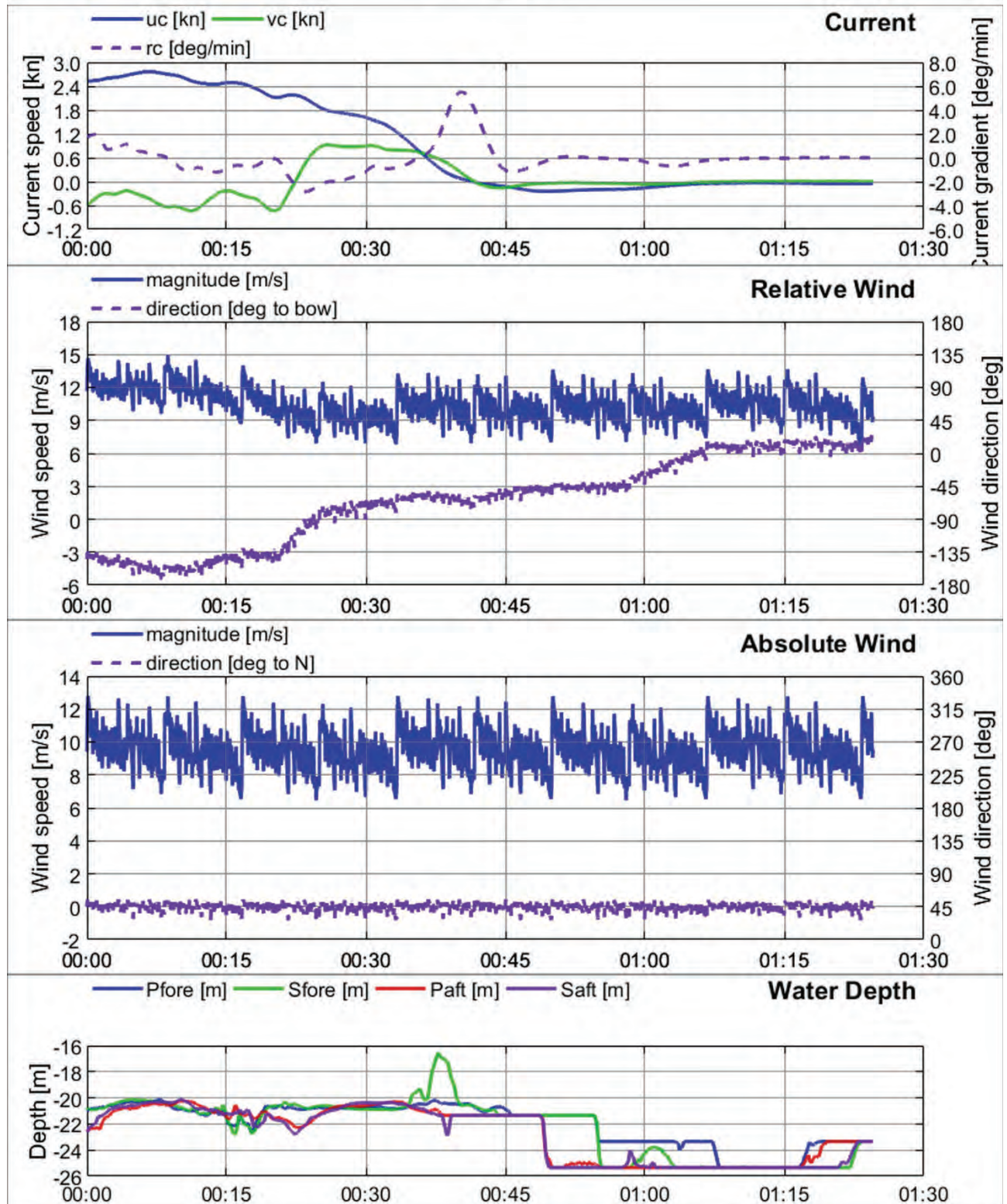
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 14/03/2022

Current: -1hHW stat

Wind: SW5



Container vessel: $L_{OA} = 400$ m; $B = 61.5$ m; $T = 12.0$ m

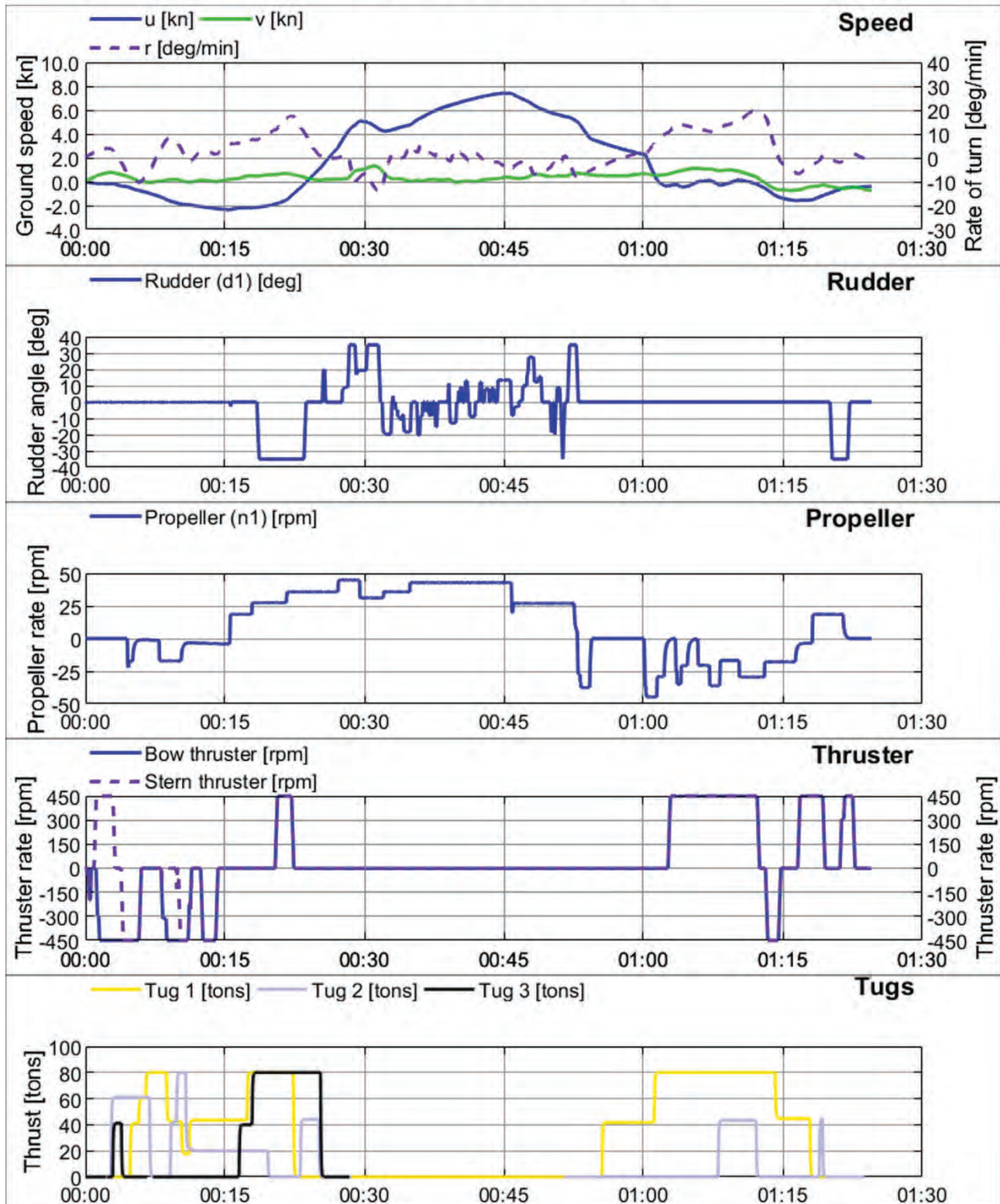
Simulation: U3 P2

Time: 09:18:21

Player: 2/4

Simulator: Sim 225

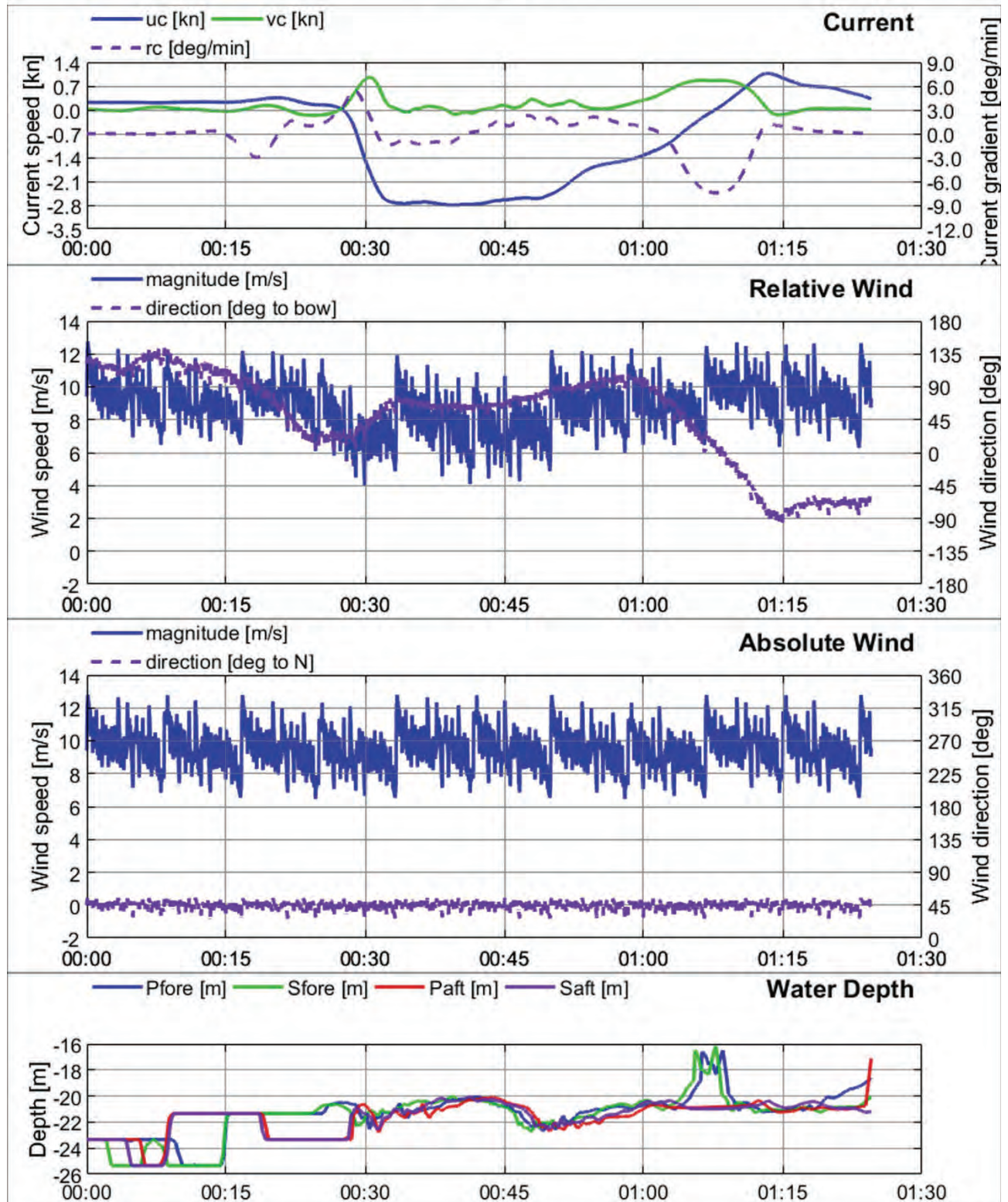
Tugs: 80 80 80 80 tons



[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 14/03/2022
Current: -1hHW stat
Wind: SW5



Container vessel: $L_{OA} = 135$ m; $B = 11.4$ m; $T = 3.5$ m

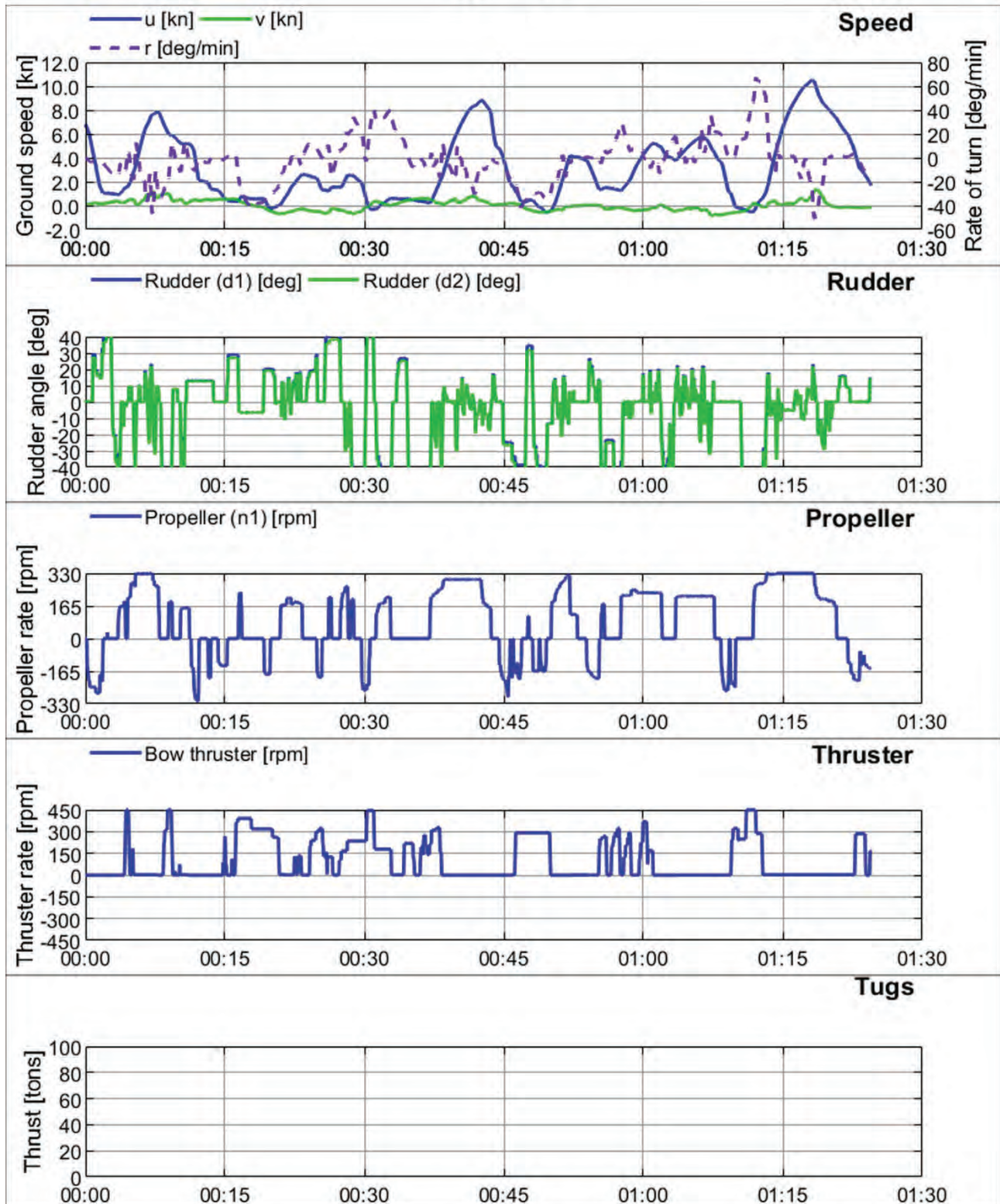
Simulation: U3 P3

Time: 09:19:56

Player: 3/4

Simulator: Sim Lara

Tugs: none



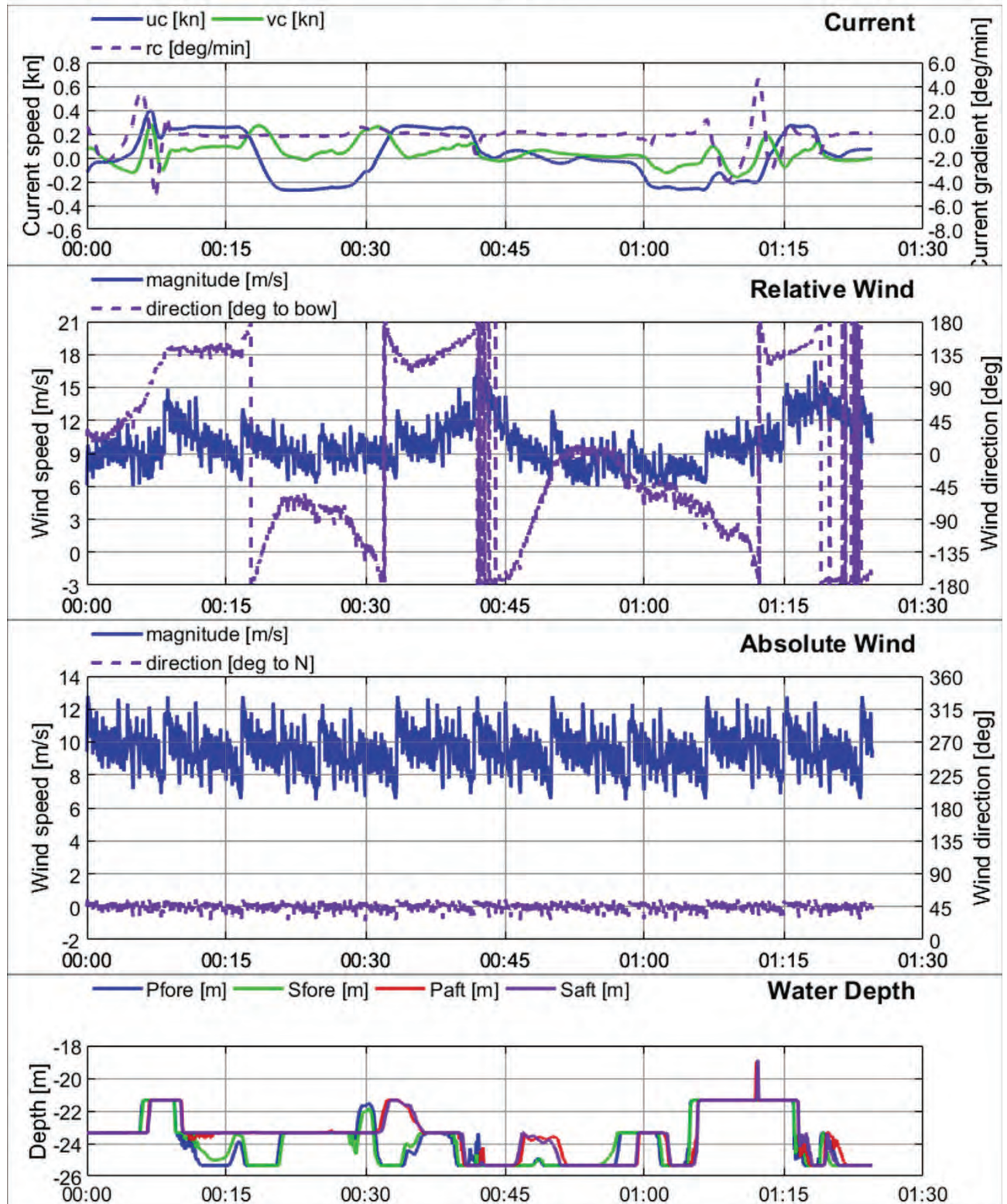
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 14/03/2022

Current: -1hHW stat

Wind: SW5



Container vessel: $L_{OA} = 400$ m; $B = 61.5$ m; $T = 15.0$ m

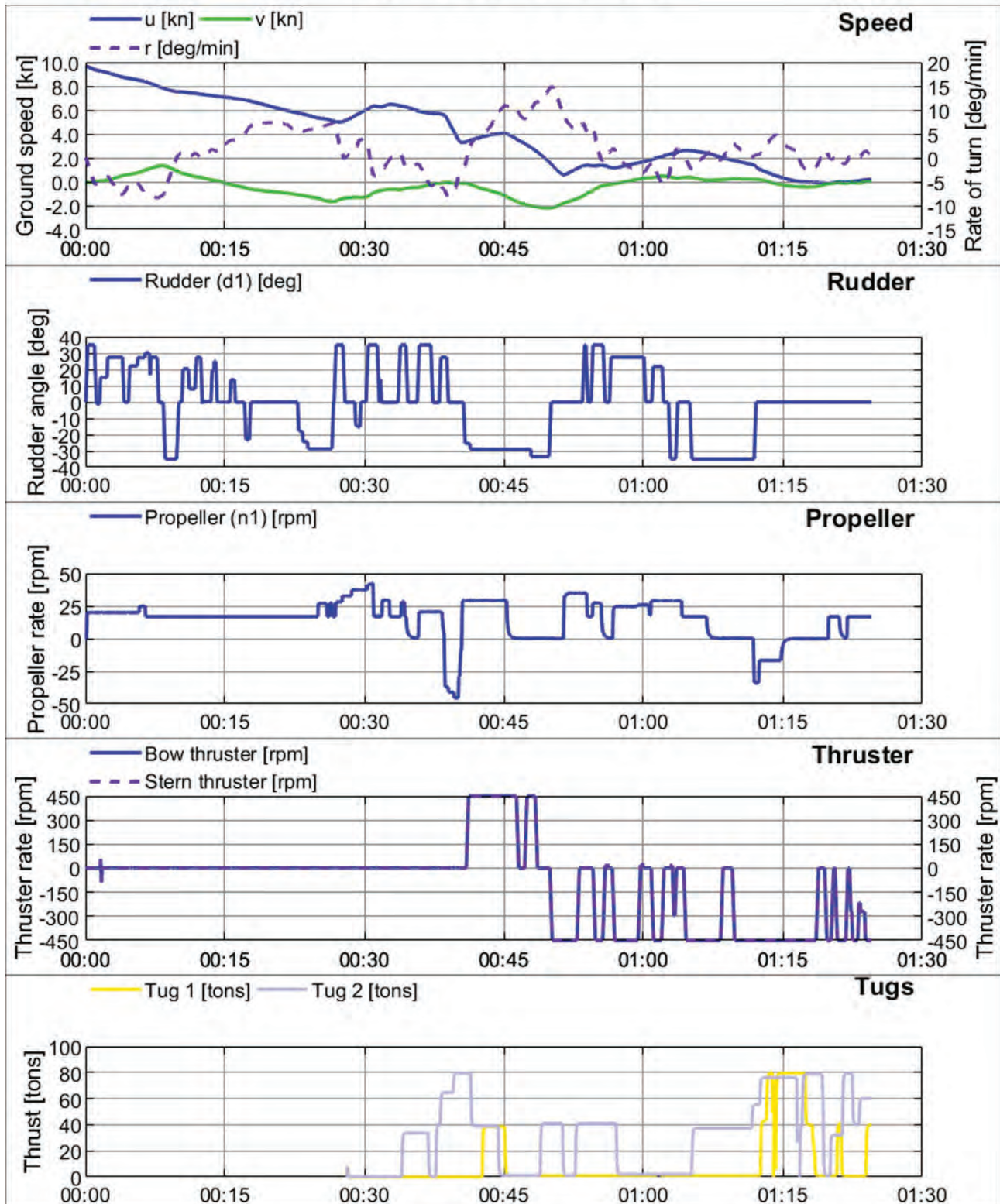
Simulation: U3 P4

Time: 09:12:56

Player: 4/4

Simulator: Sim 5

Tugs: 80 80 80 80 tons



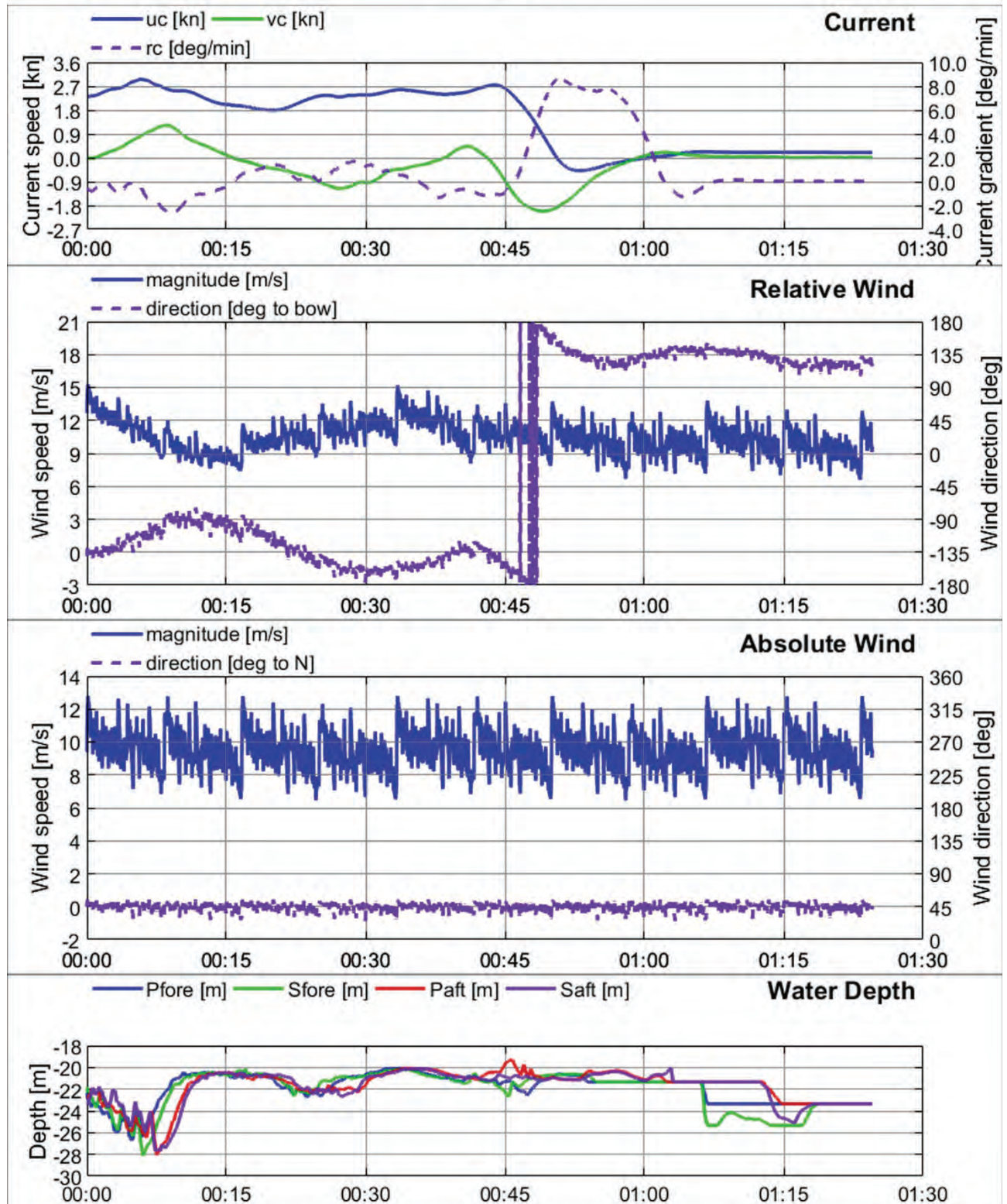
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 14/03/2022

Current: -1hHW stat

Wind: SW5



Container vessel: $L_{OA} = 400$ m; $B = 61.5$ m; $T = 13.1$ m

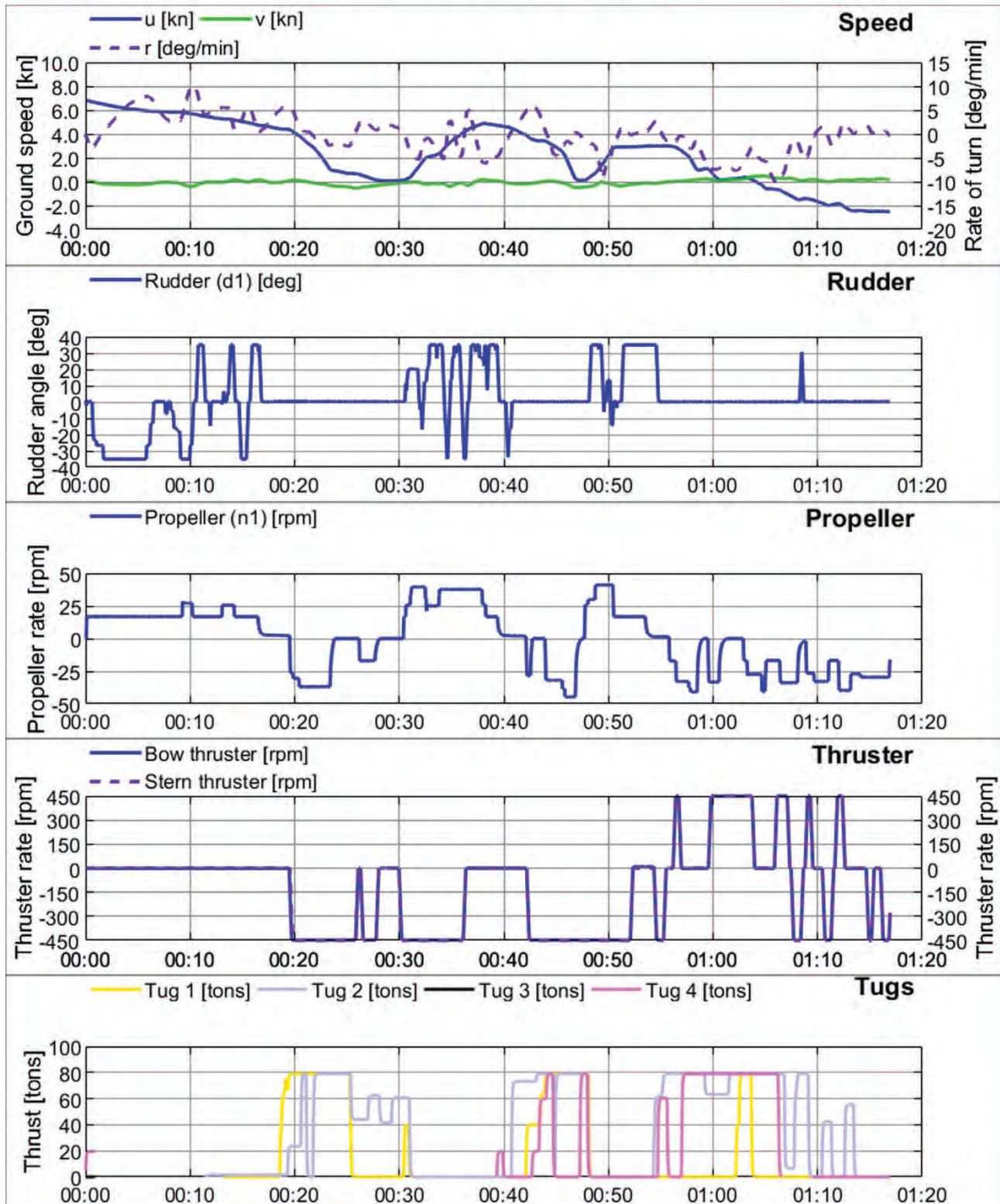
Simulation: U4 P1

Time: 11:14:54

Player: 1/4

Simulator: Sim 360+

Tugs: 80 80 80 80 tons



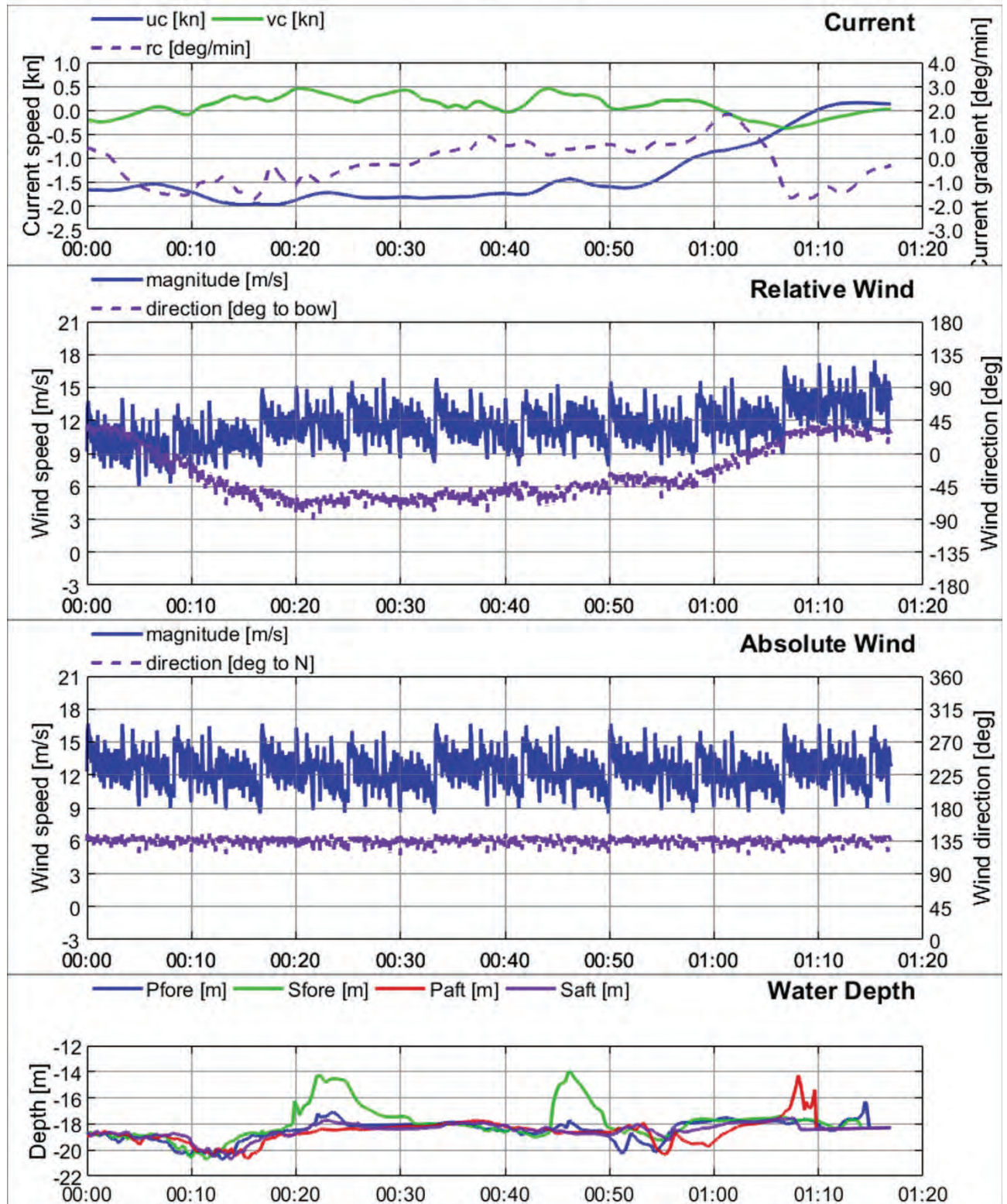
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 14/03/2022

Current: 3.33hHW stat

Wind: NW6



Container vessel: $L_{OA} = 430$ m; $B = 62.0$ m; $T = 15.0$ m

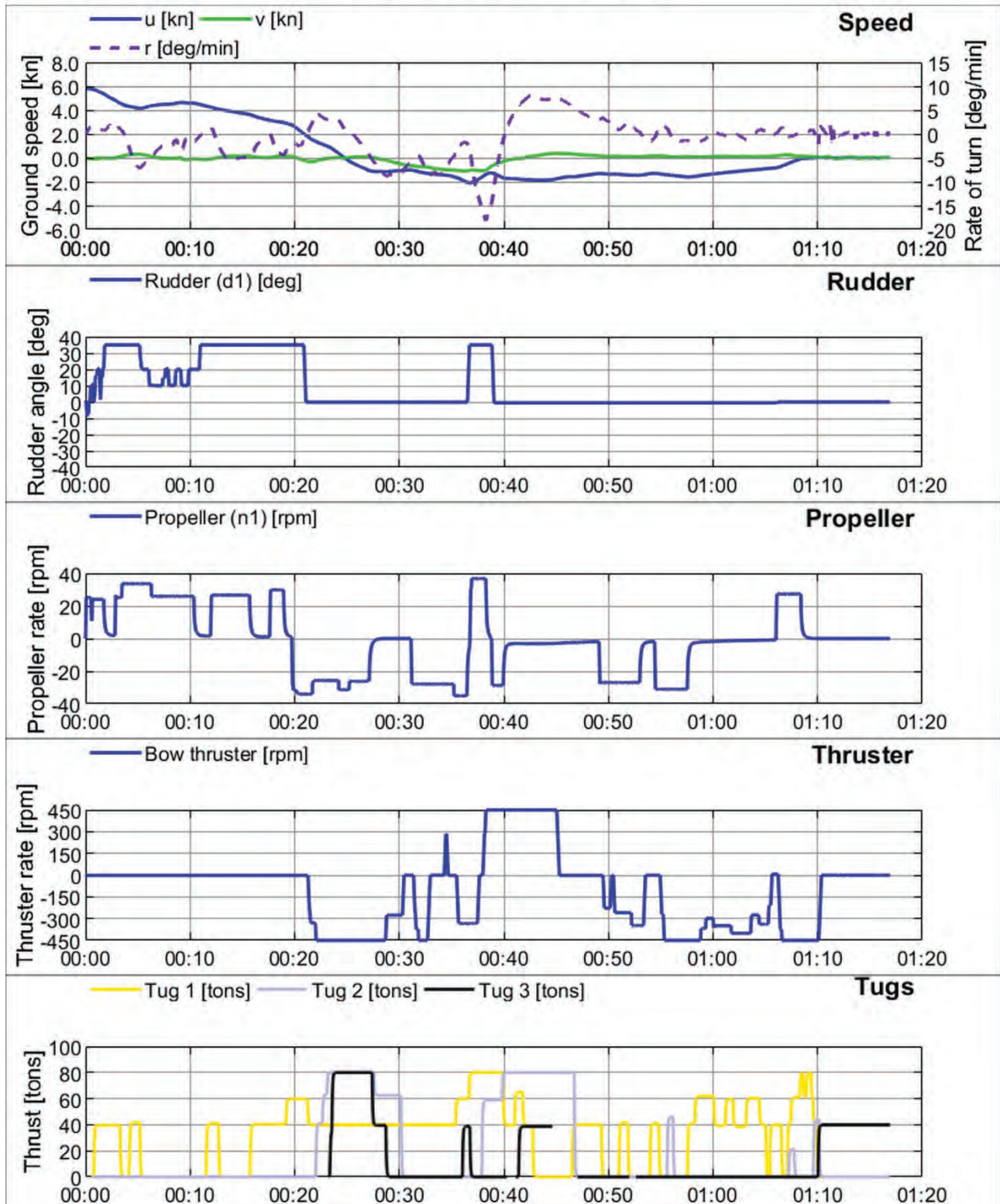
Simulation: U4 P2

Time: 11:18:52

Player: 2/4

Simulator: Sim 225

Tugs: 80 80 80 80 tons



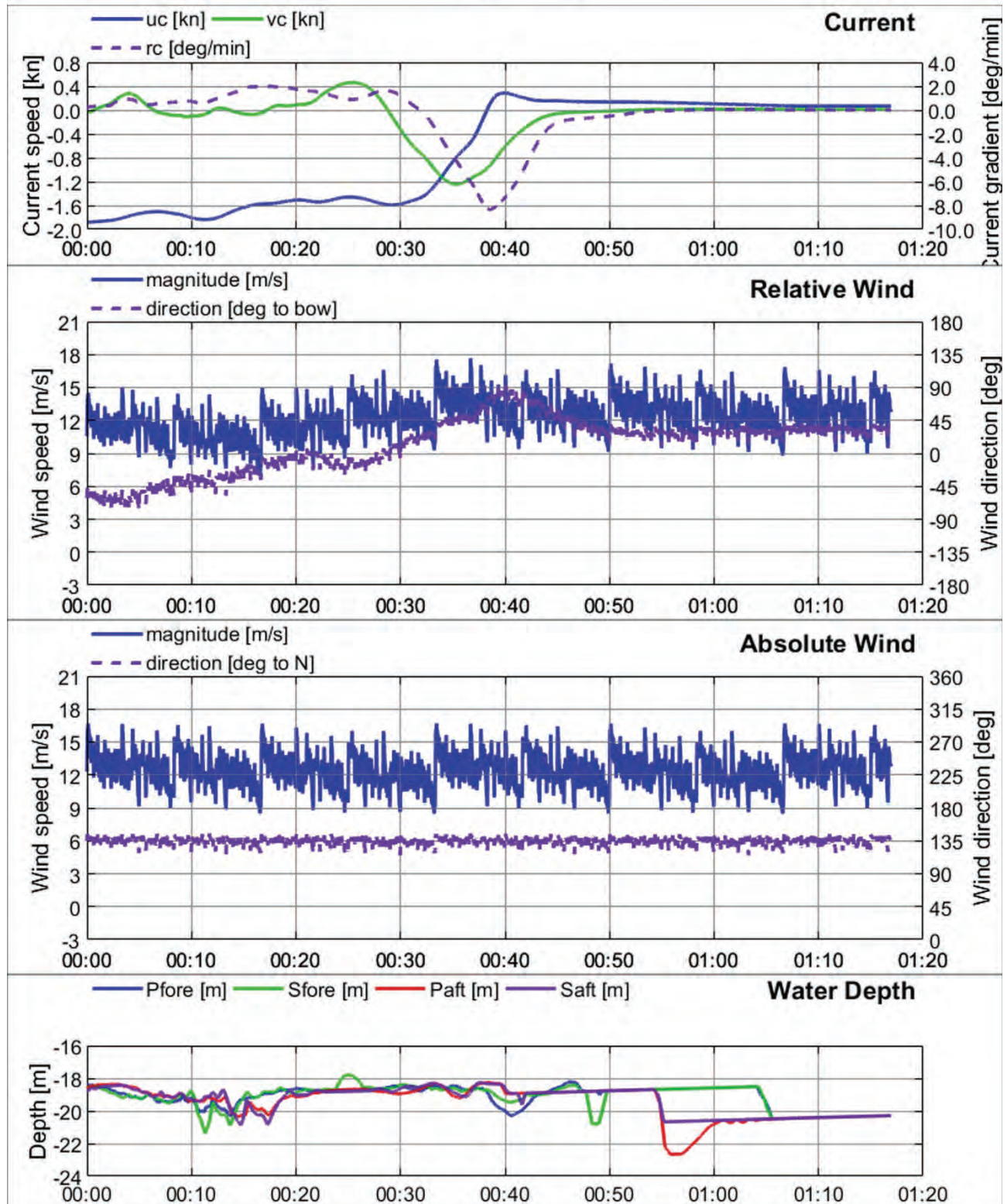
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 14/03/2022

Current: 3.33hHW stat

Wind: NW6



Container vessel: $L_{OA} = 110$ m; $B = 22.8$ m; $T = 4.0$ m

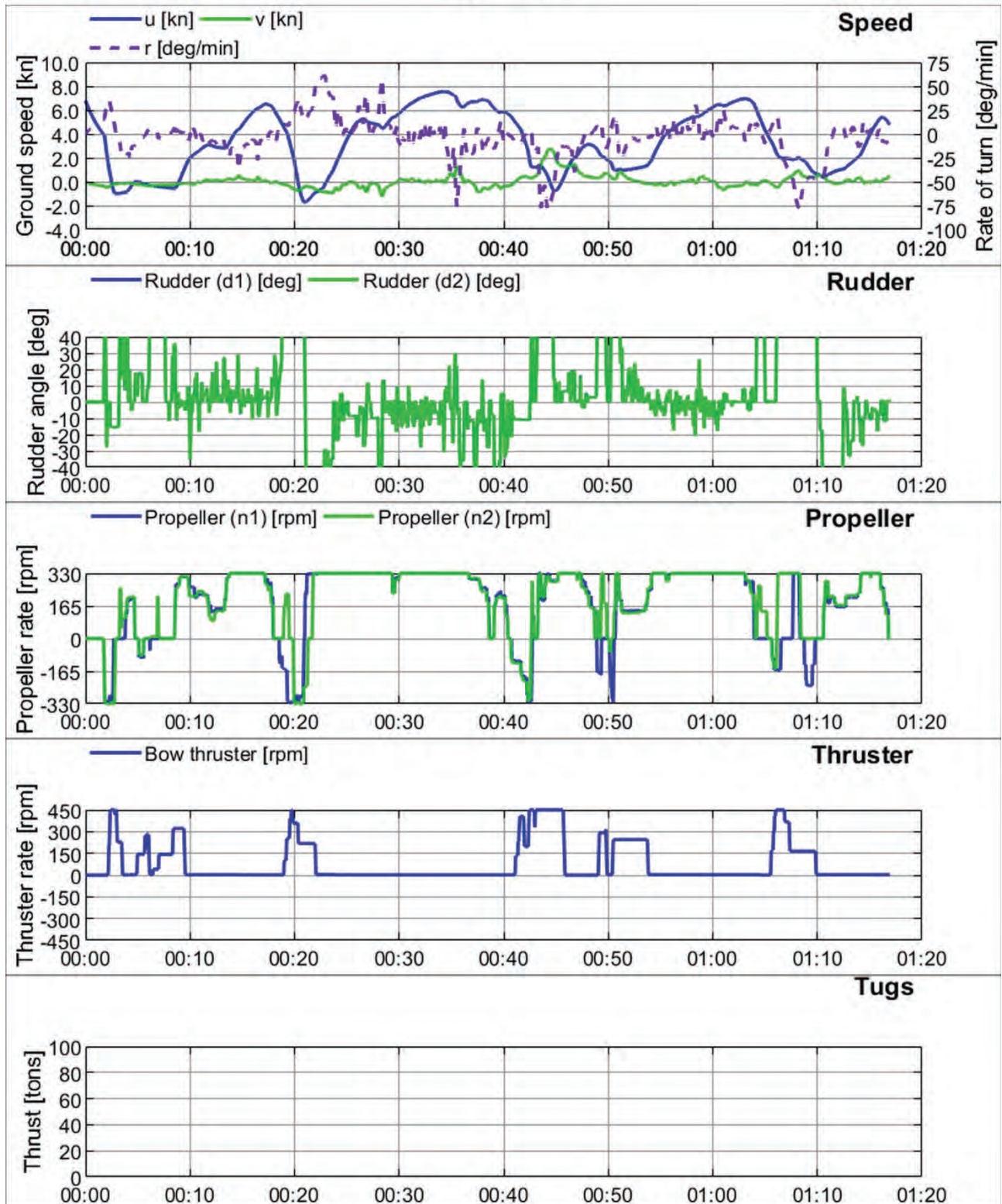
Simulation: U4 P3

Time: 11:20:27

Player: 3/4

Simulator: Sim Lara

Tugs: none



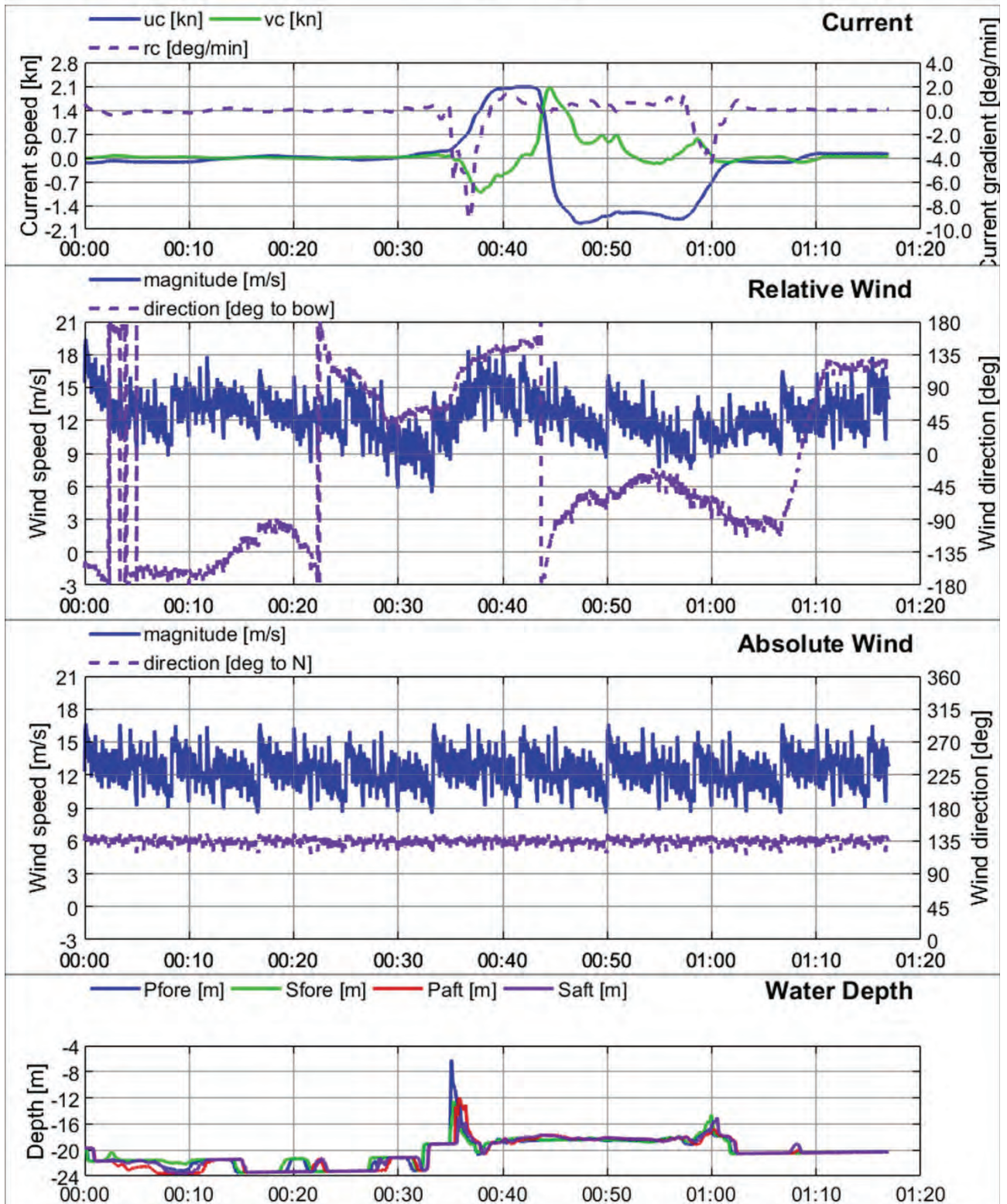
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 14/03/2022

Current: 3.33hHW stat

Wind: NW6



Container vessel: $L_{OA} = 430$ m; $B = 62.0$ m; $T = 15.0$ m

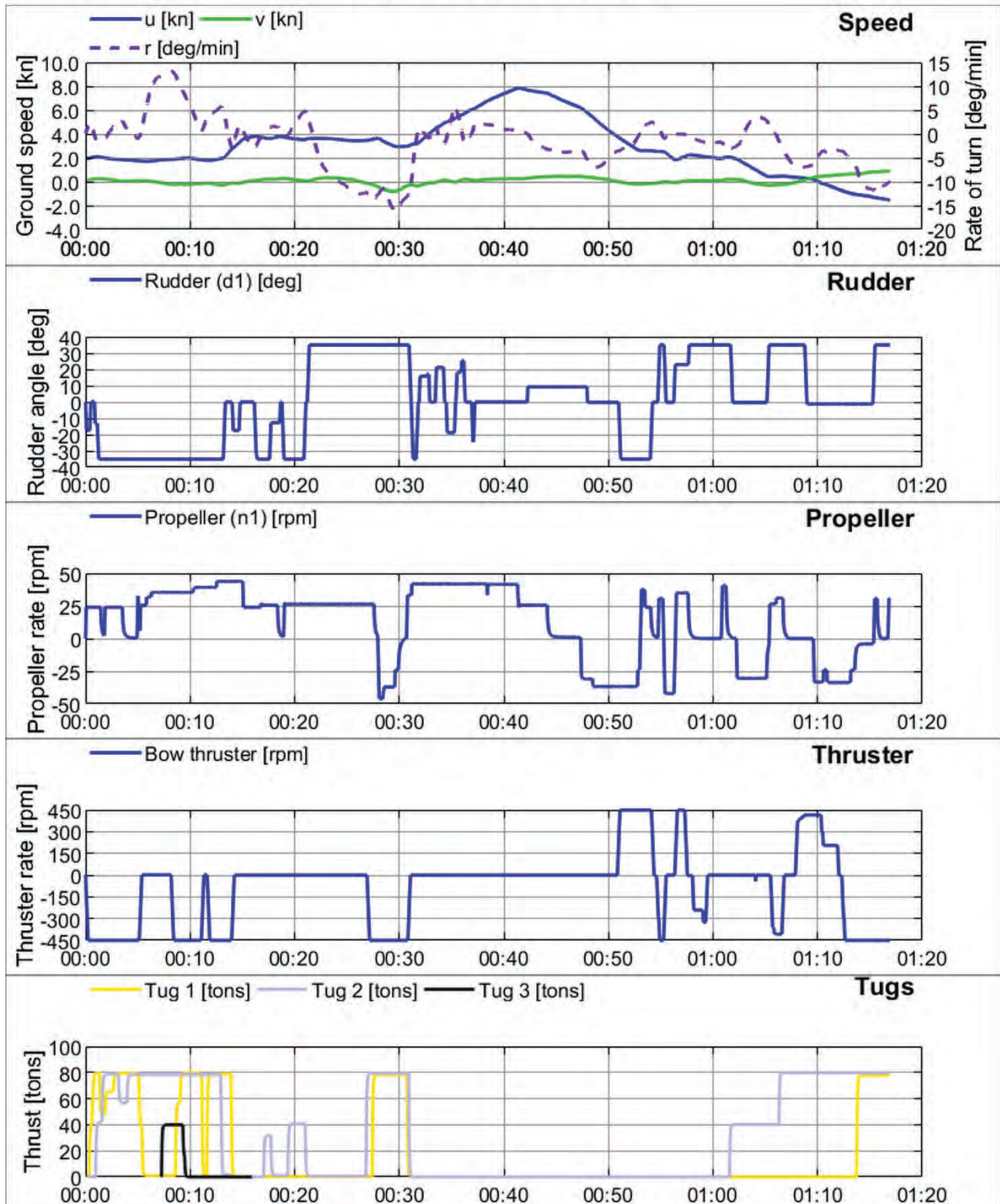
Simulation: U4 P4

Time: 11:13:29

Player: 4/4

Simulator: Sim 5

Tugs: 80 80 80 80 tons



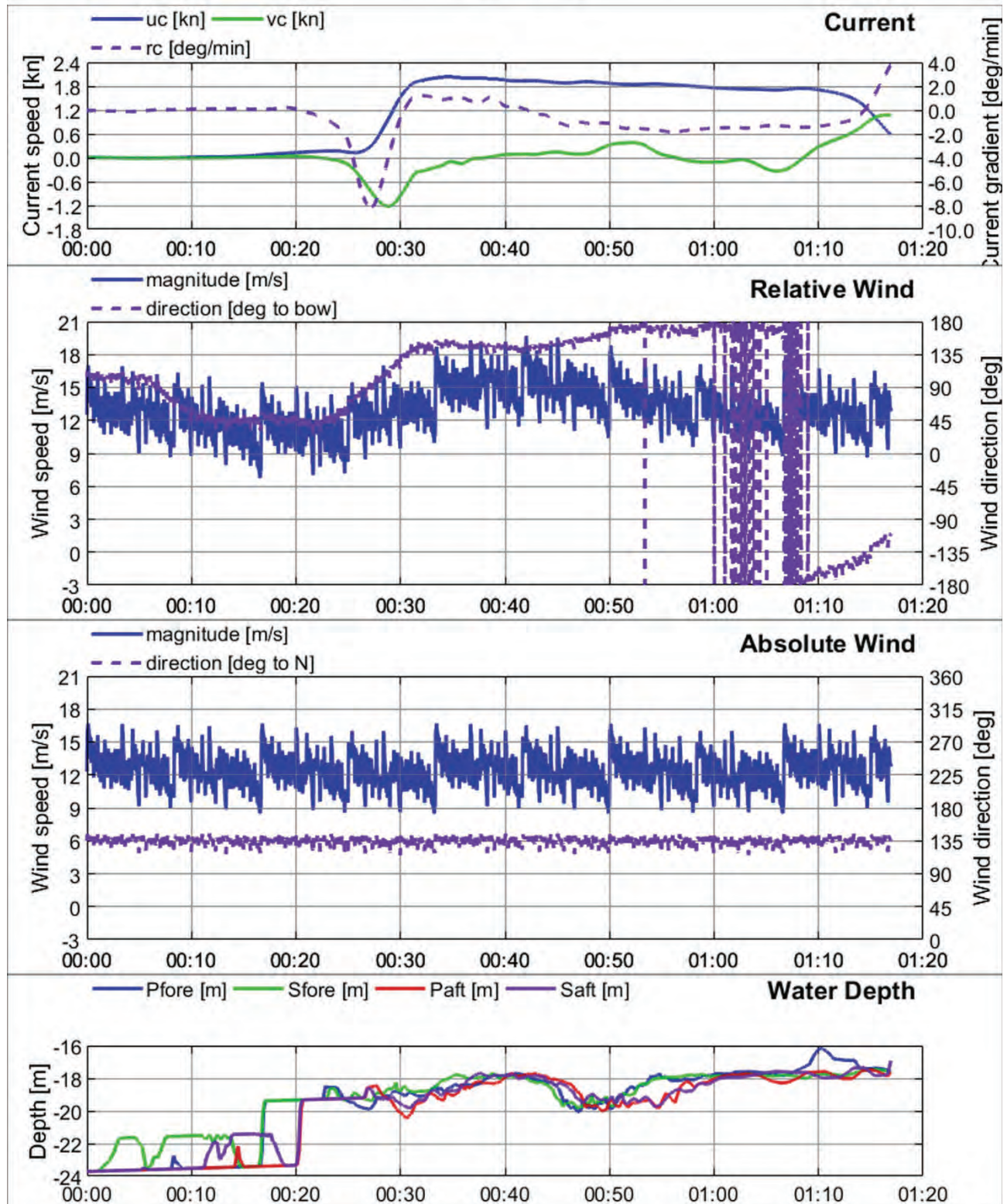
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 14/03/2022

Current: 3.33hHW stat

Wind: NW6



Container vessel: $L_{OA} = 400$ m; $B = 61.5$ m; $T = 13.1$ m

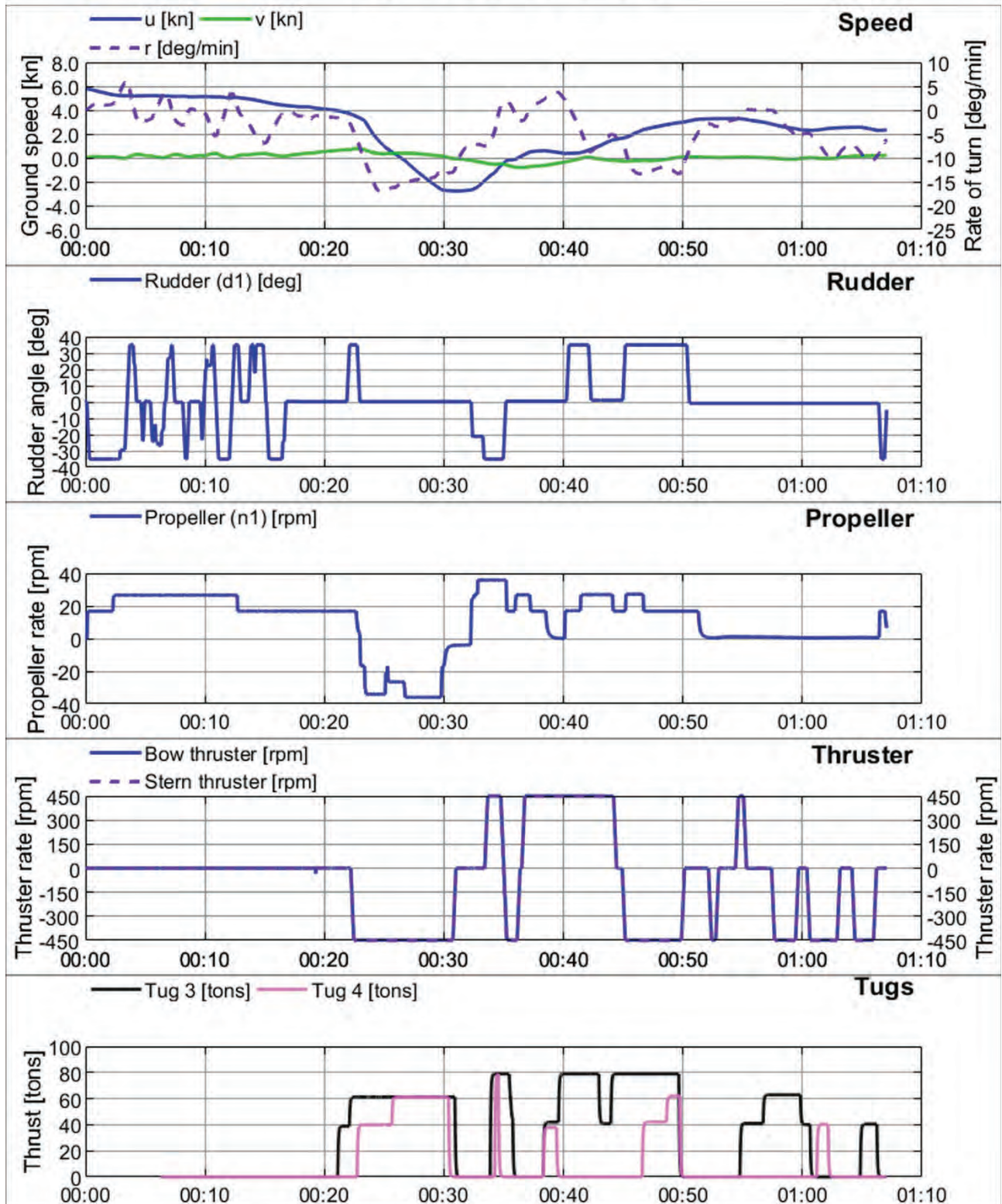
Simulation: M3 P1

Time: 13:57:51

Player: 1/4

Simulator: Sim 360+

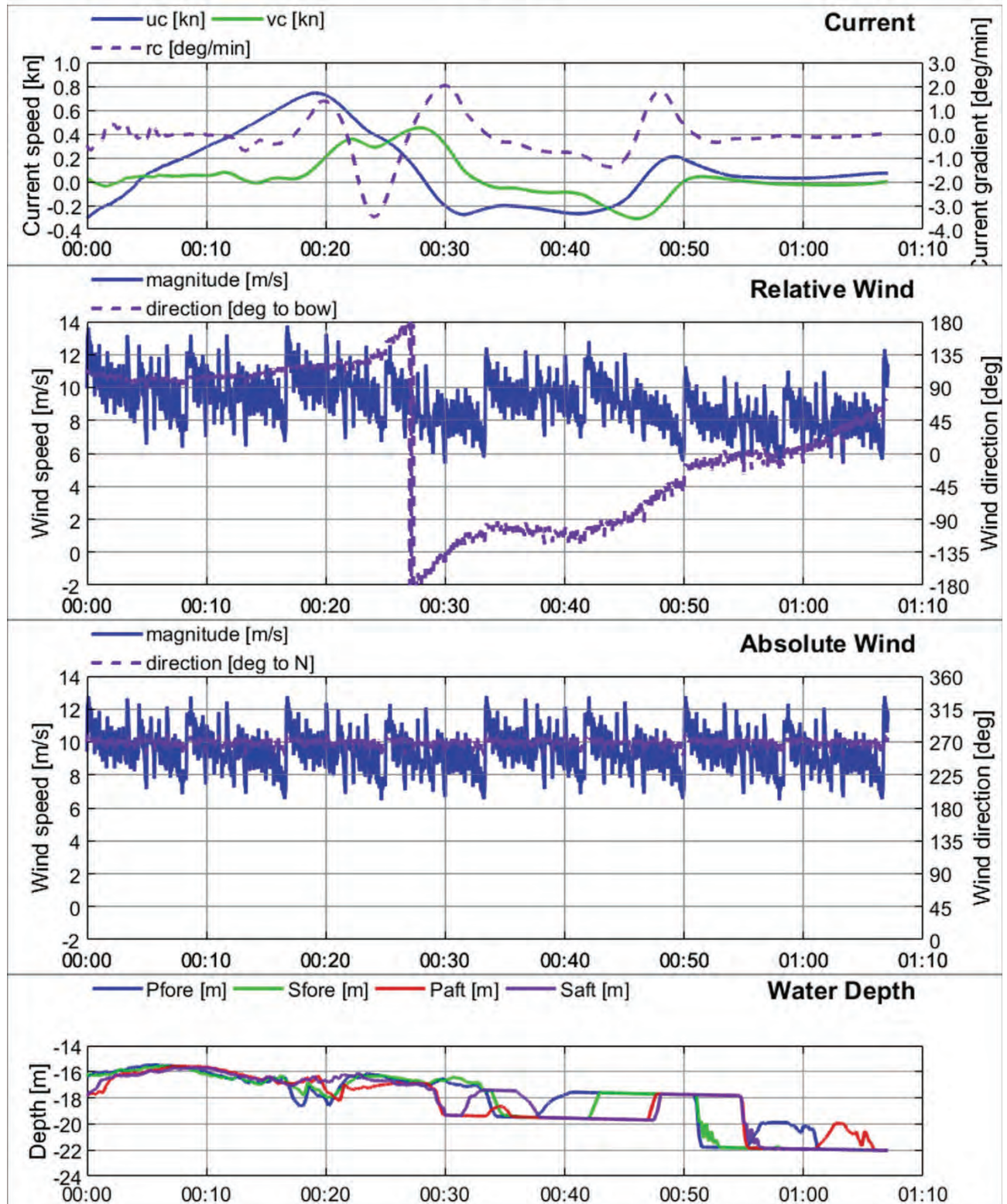
Tugs: 80 80 80 80 tons



[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 14/03/2022
Current: -5hHW dyn
Wind: E5



Container vessel: $L_{OA} = 255$ m; $B = 32.3$ m; $T = 12.0$ m

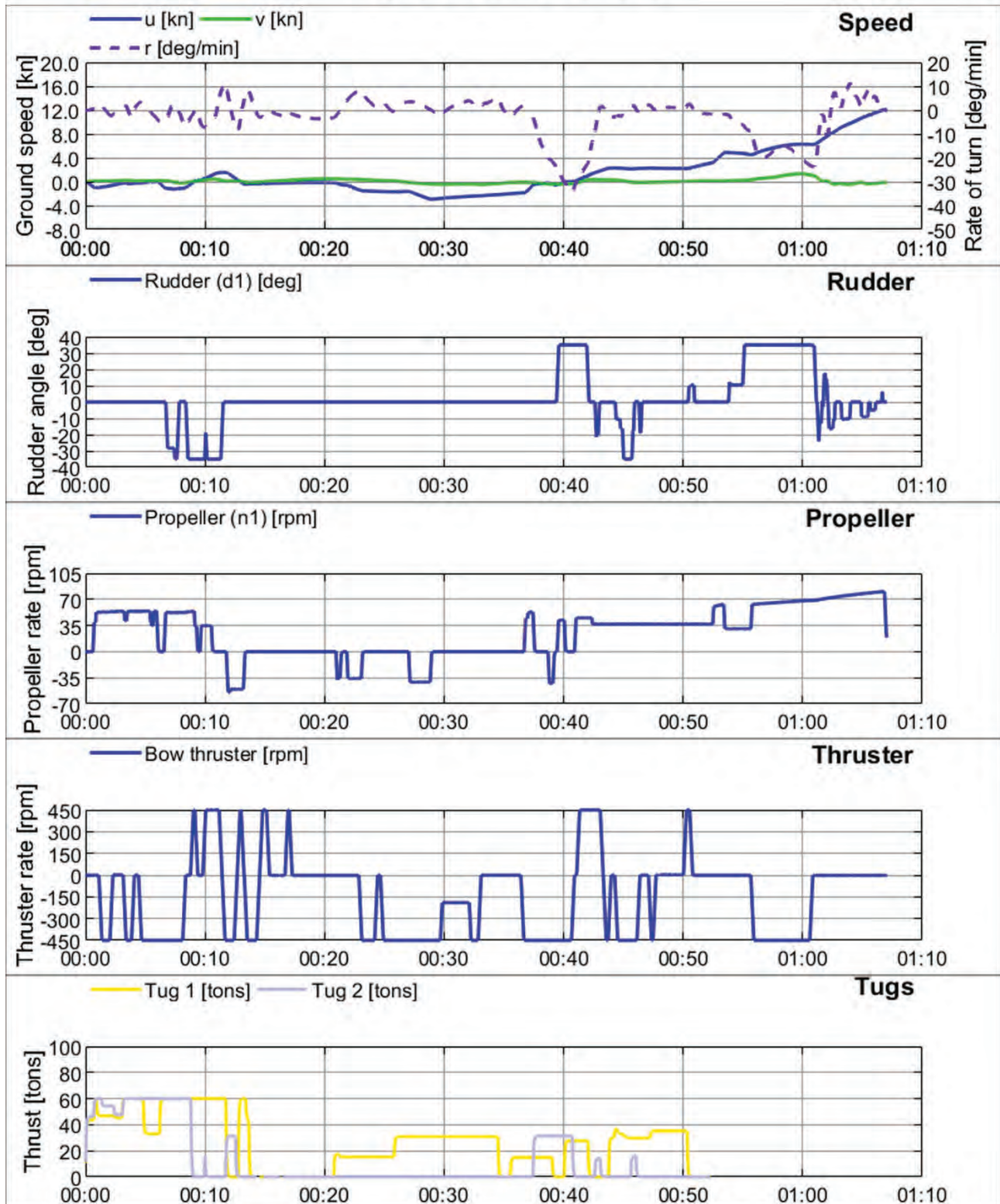
Simulation: M3 P2

Time: 14:01:48

Player: 2/4

Simulator: Sim 225

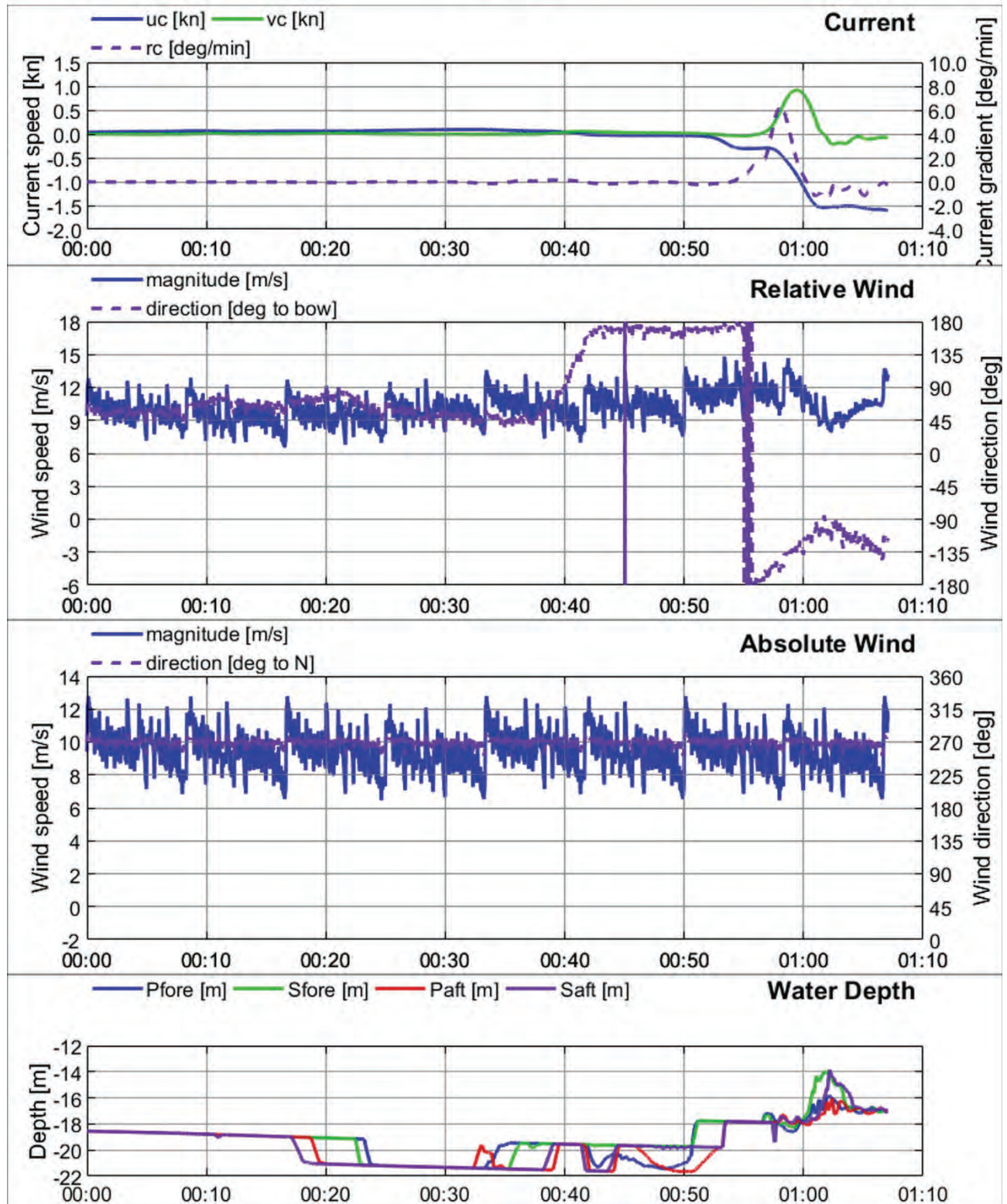
Tugs: 60 60 60 60 tons



[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 14/03/2022
Current: -5hHW dyn
Wind: E5



Container vessel: $L_{OA} = 135$ m; $B = 11.4$ m; $T = 3.5$ m

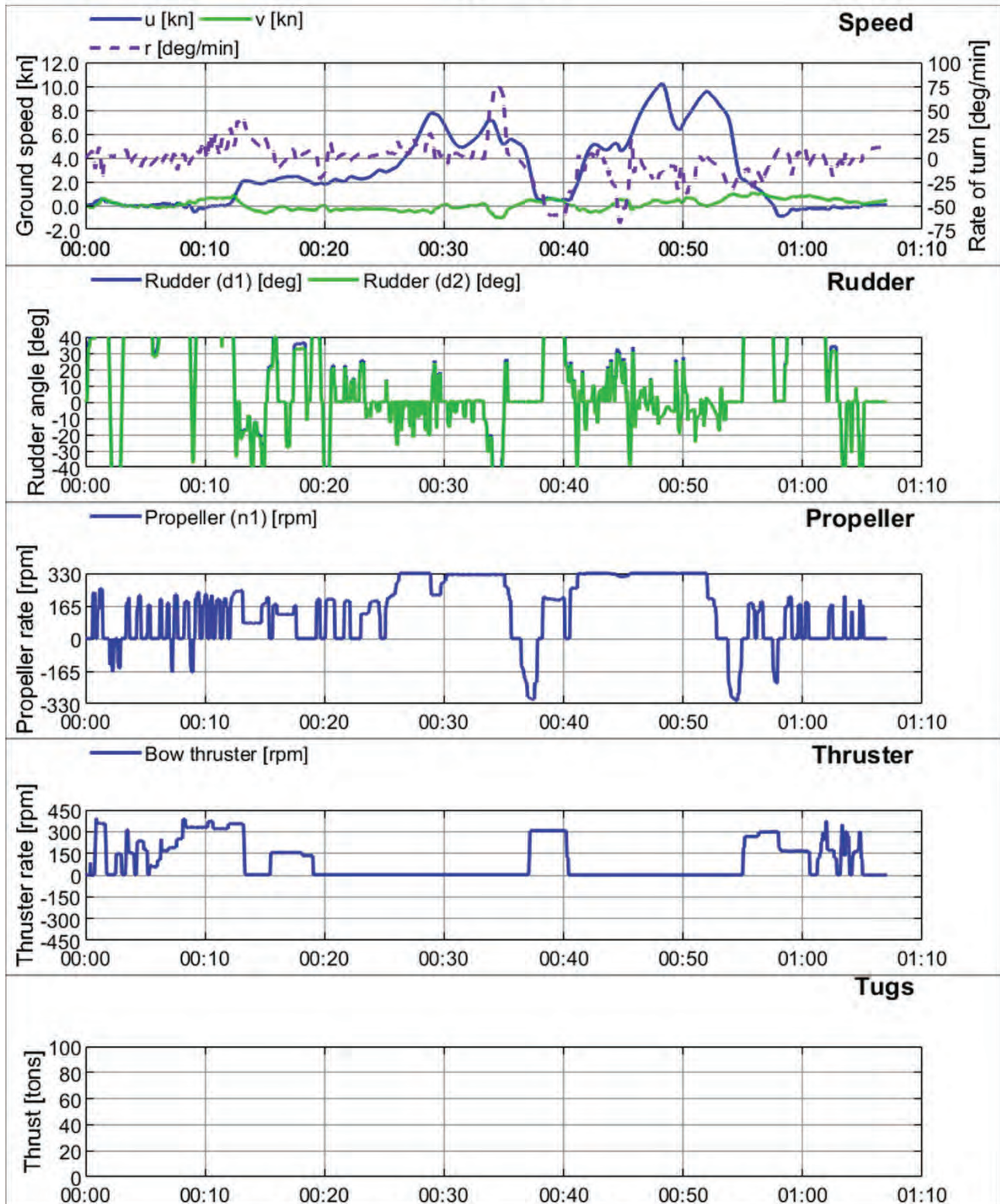
Simulation: M3 P3

Time: 14:03:24

Player: 3/4

Simulator: Sim Lara

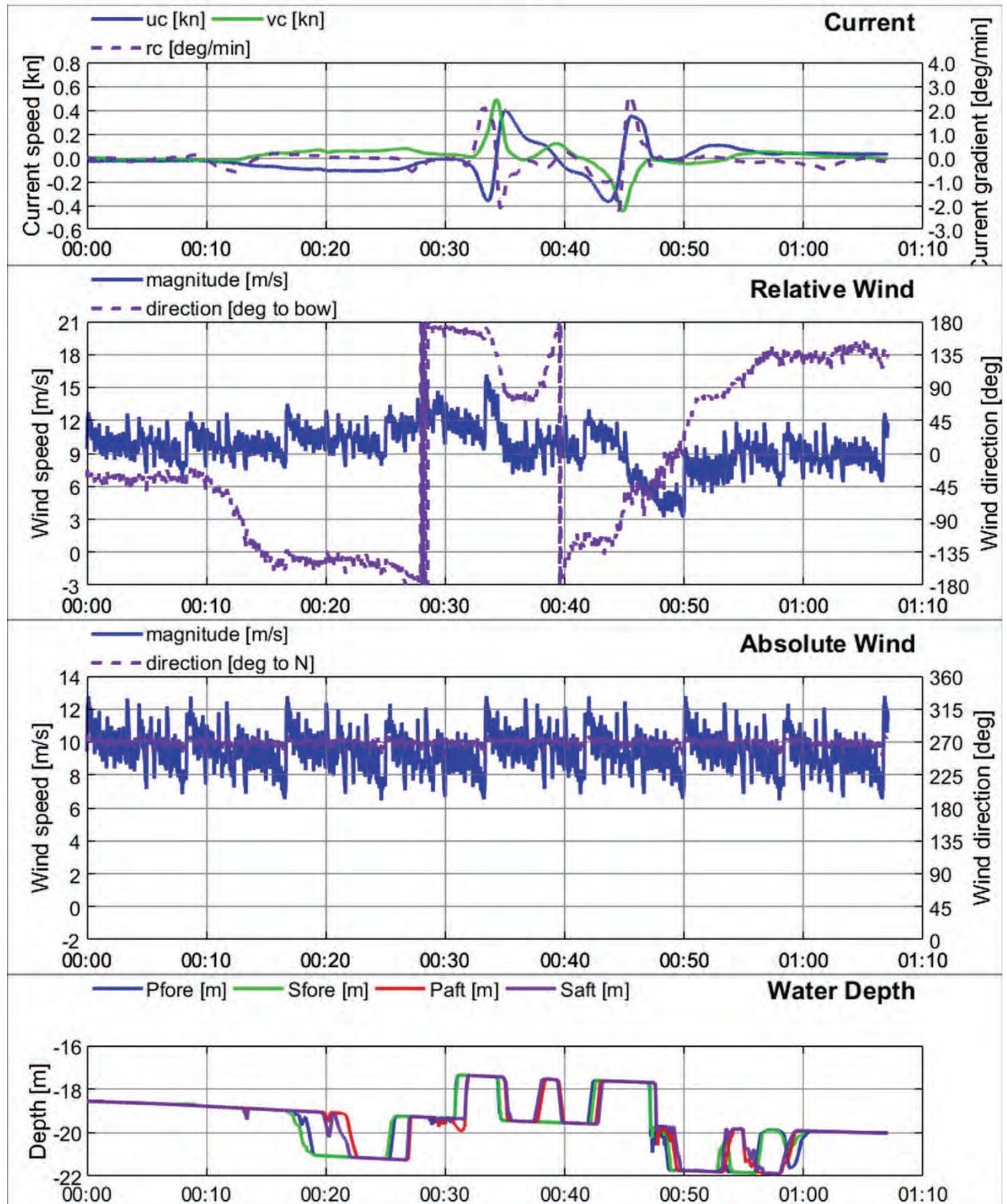
Tugs: none



[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 14/03/2022
Current: -5hHW dyn
Wind: E5



Container vessel: $L_{OA} = 400$ m; $B = 61.5$ m; $T = 13.1$ m

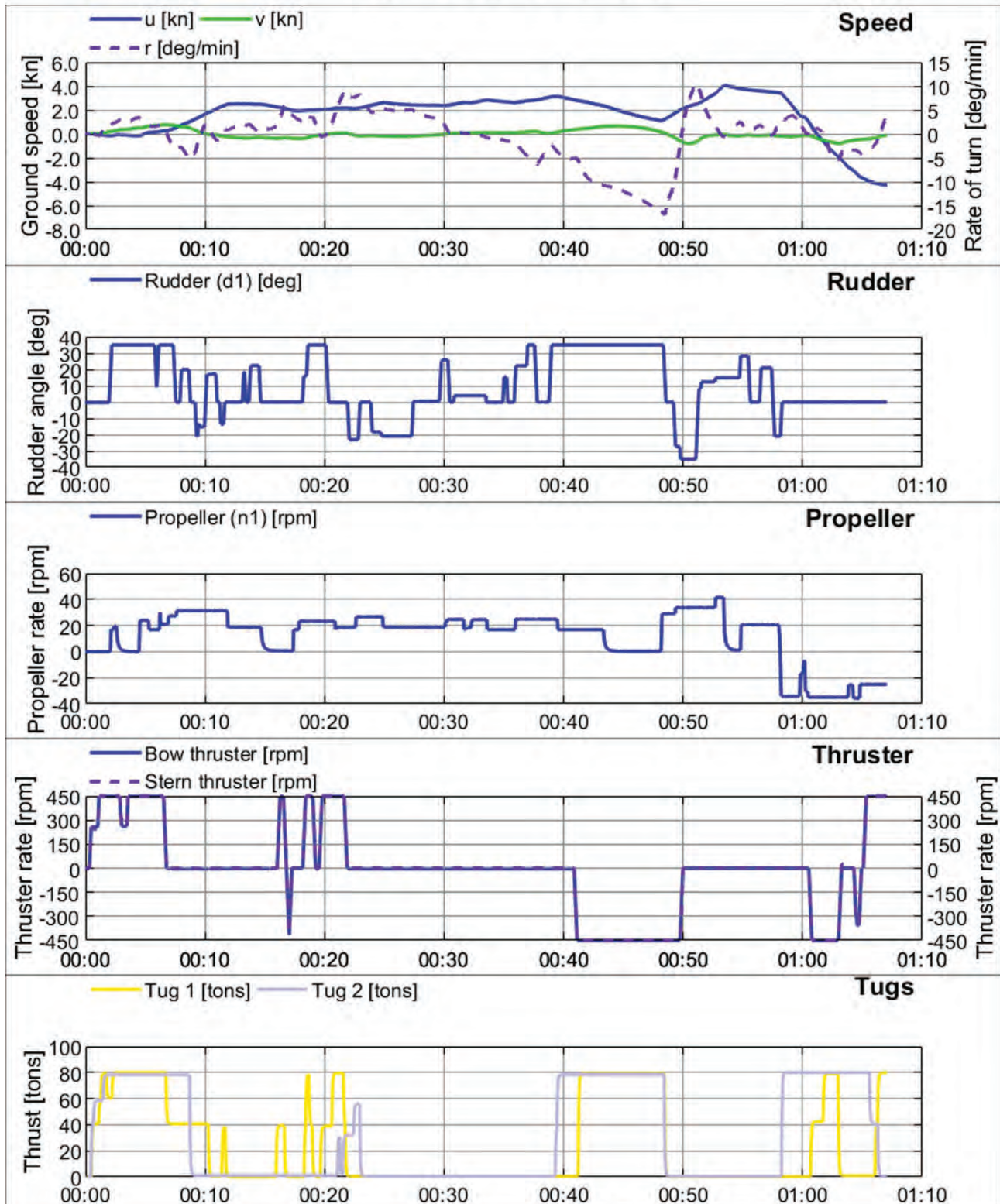
Simulation: M3 P4

Time: 13:56:26

Player: 4/4

Simulator: Sim 5

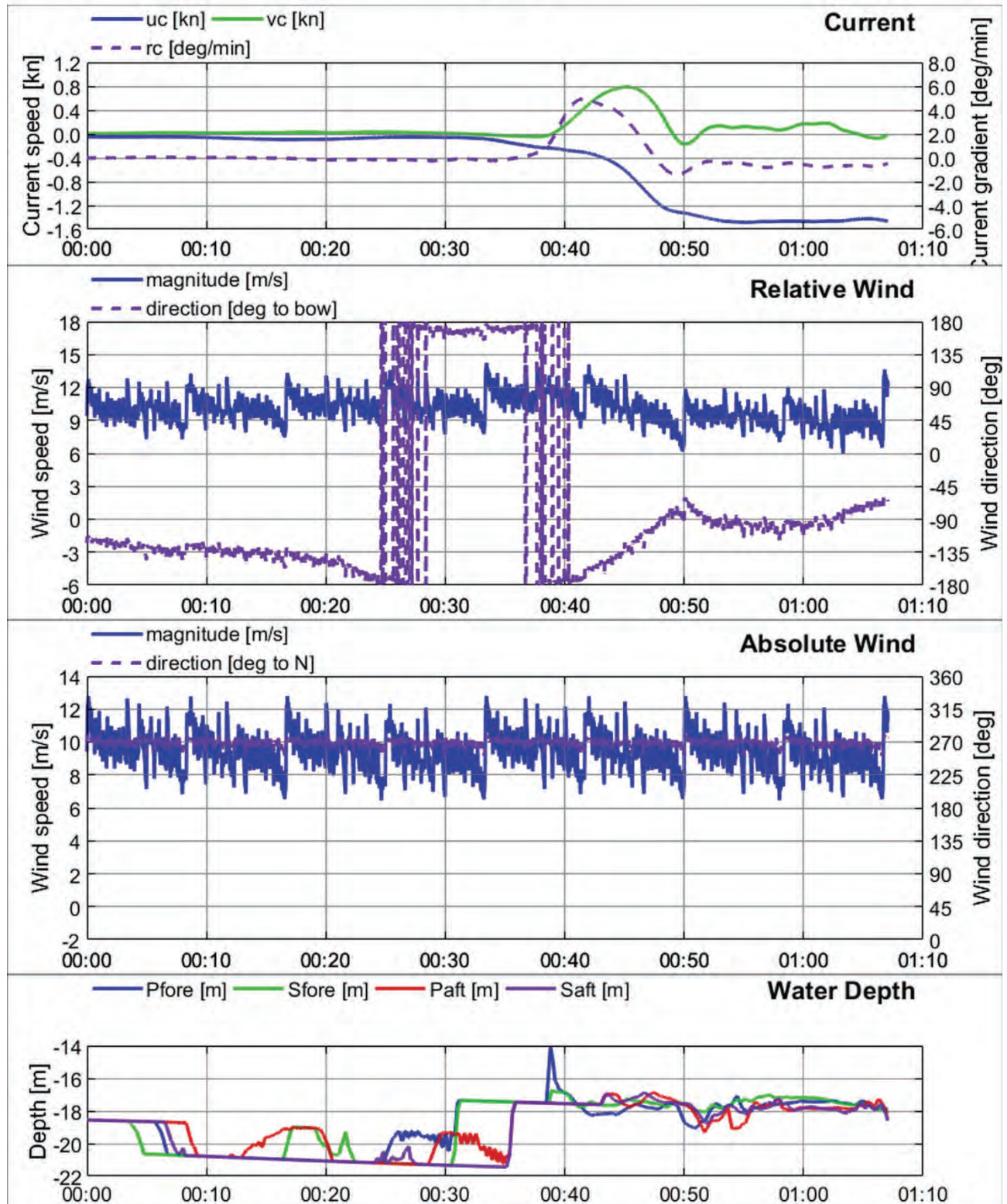
Tugs: 80 80 80 80 tons



[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 14/03/2022
Current: -5hHW dyn
Wind: E5



Container vessel: $L_{OA} = 430$ m; $B = 62.0$ m; $T = 15.0$ m

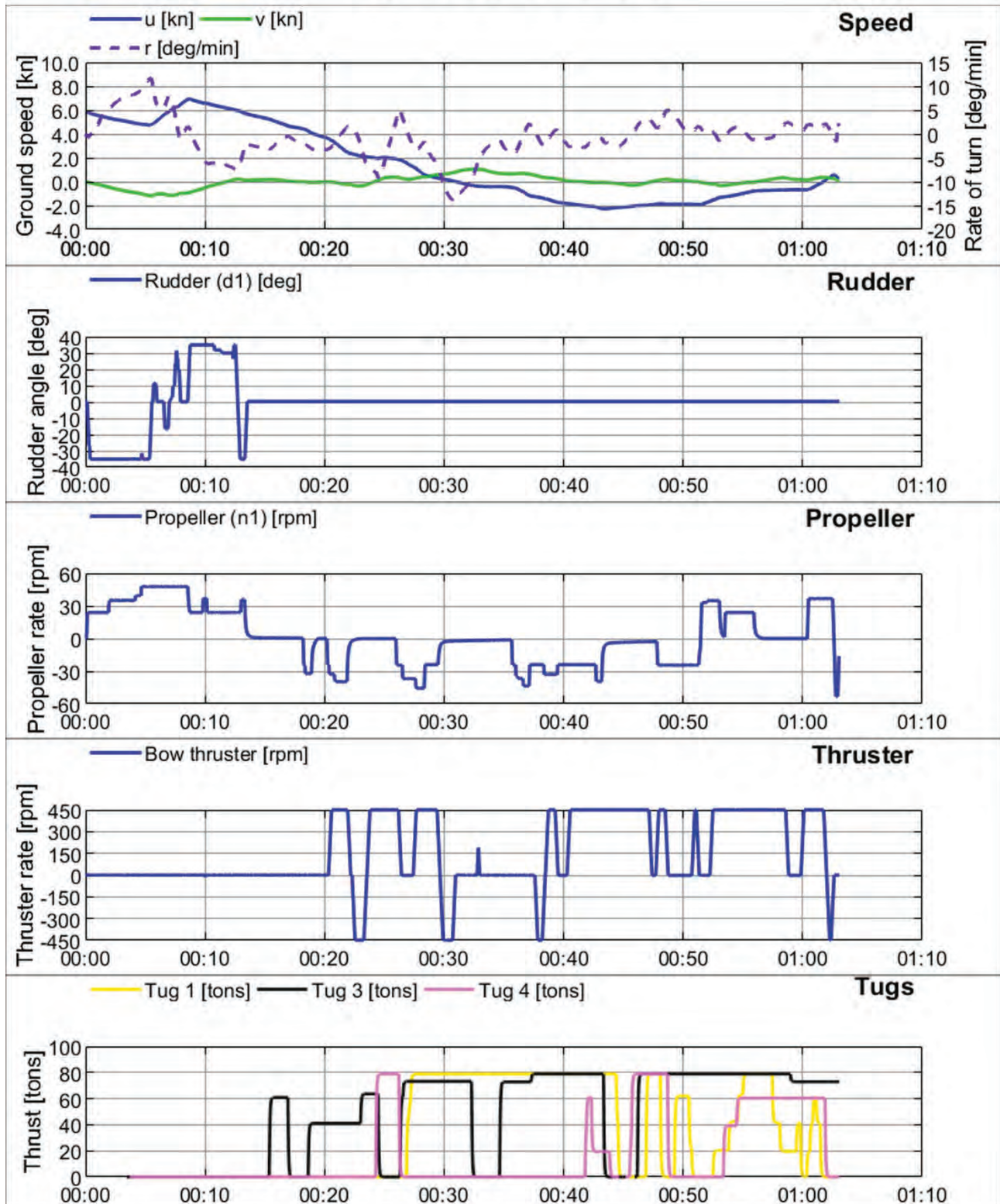
Simulation: M4 P1

Time: 15:39:21

Player: 1/4

Simulator: Sim 360+

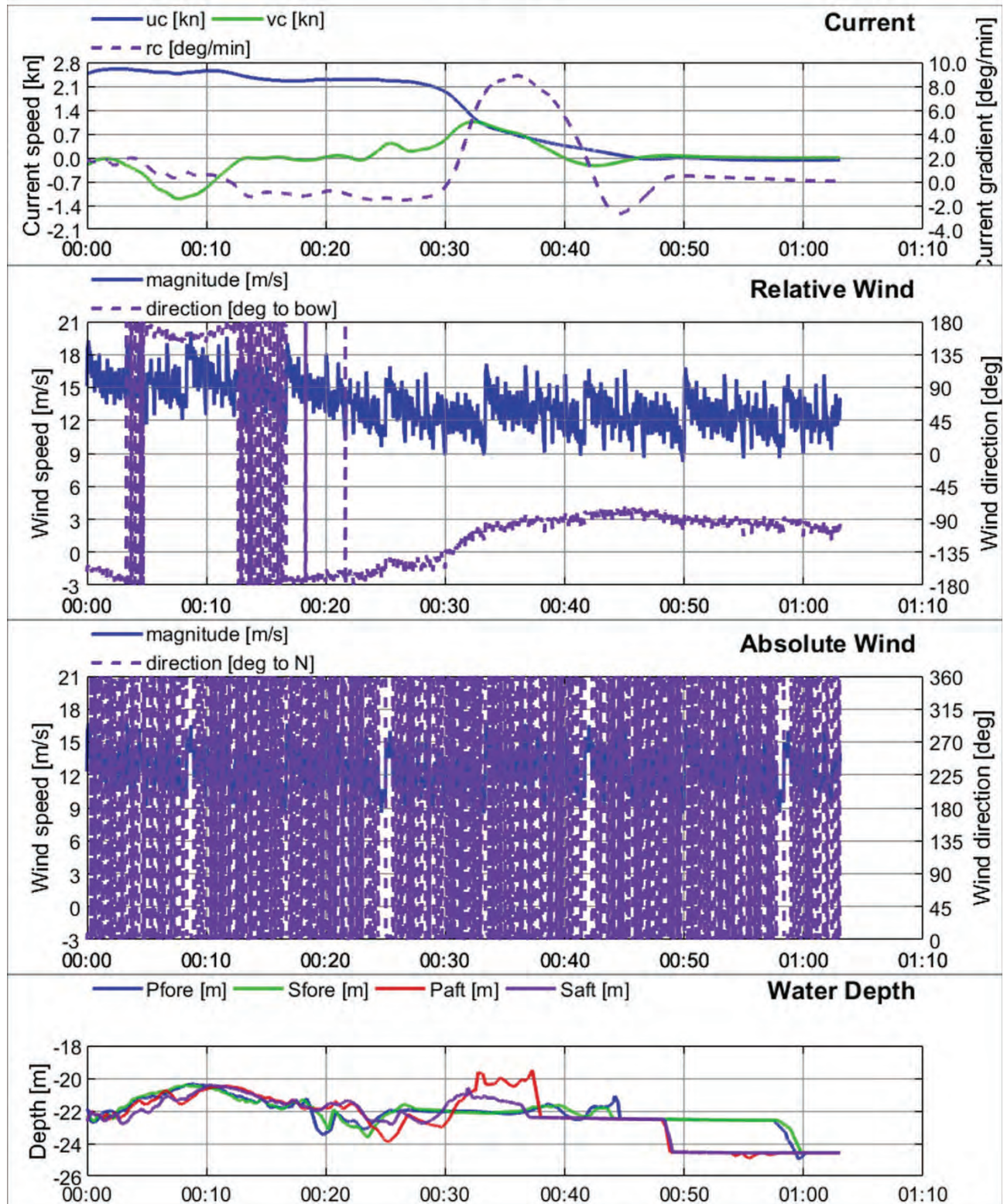
Tugs: 80 80 80 80 tons



[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 14/03/2022
Current: -1hHW dyn
Wind: S6



Container vessel: $L_{OA} = 367$ m; $B = 48.4$ m; $T = 14.5$ m

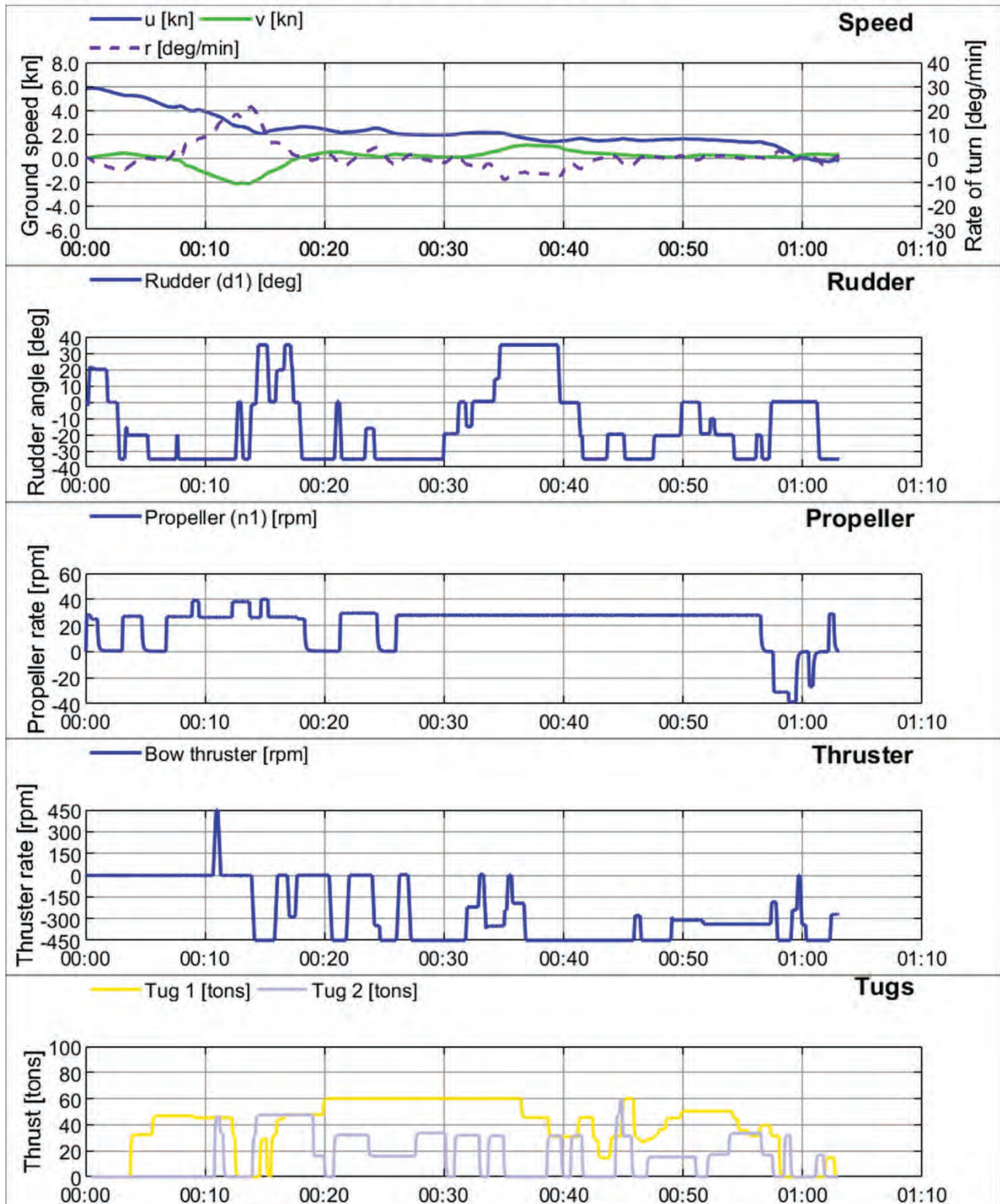
Simulation: M4 P2

Time: 15:43:19

Player: 2/4

Simulator: Sim 225

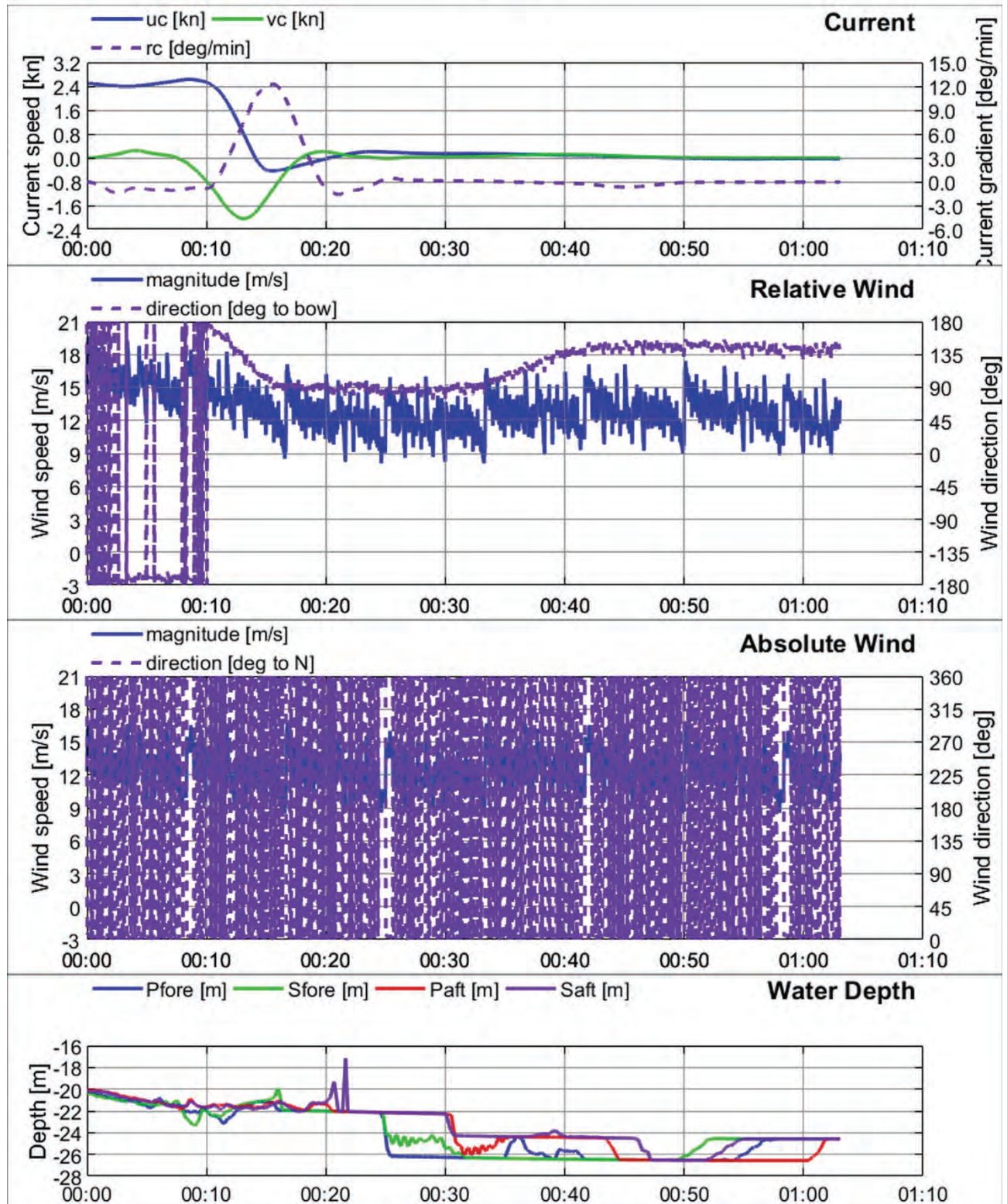
Tugs: 60 60 60 60 tons



[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 14/03/2022
Current: -1hHW dyn
Wind: S6



Container vessel: $L_{OA} = 191$ m; $B = 22.8$ m; $T = 4.0$ m

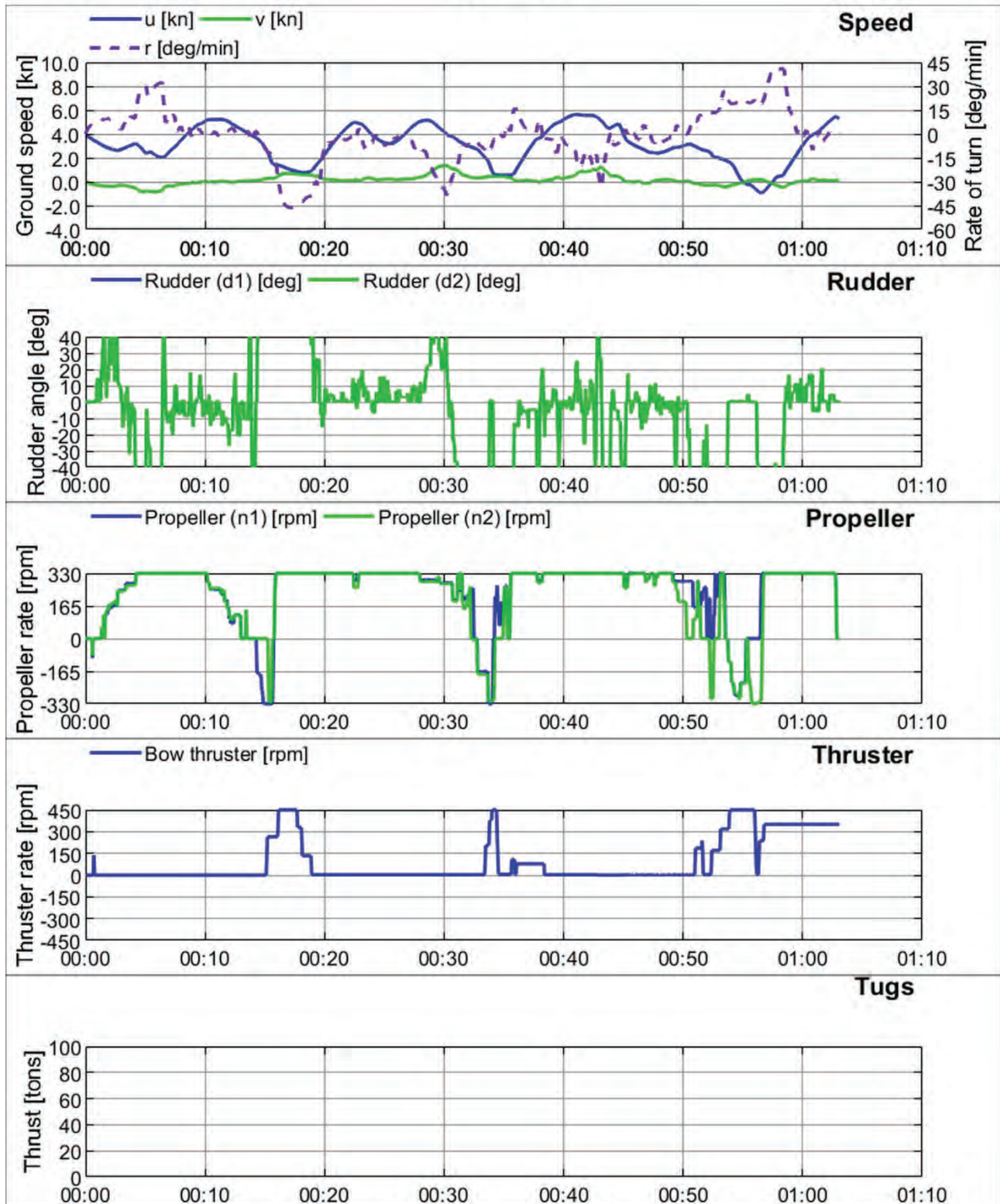
Simulation: M4 P3

Time: 15:44:54

Player: 3/4

Simulator: Sim Lara

Tugs: none



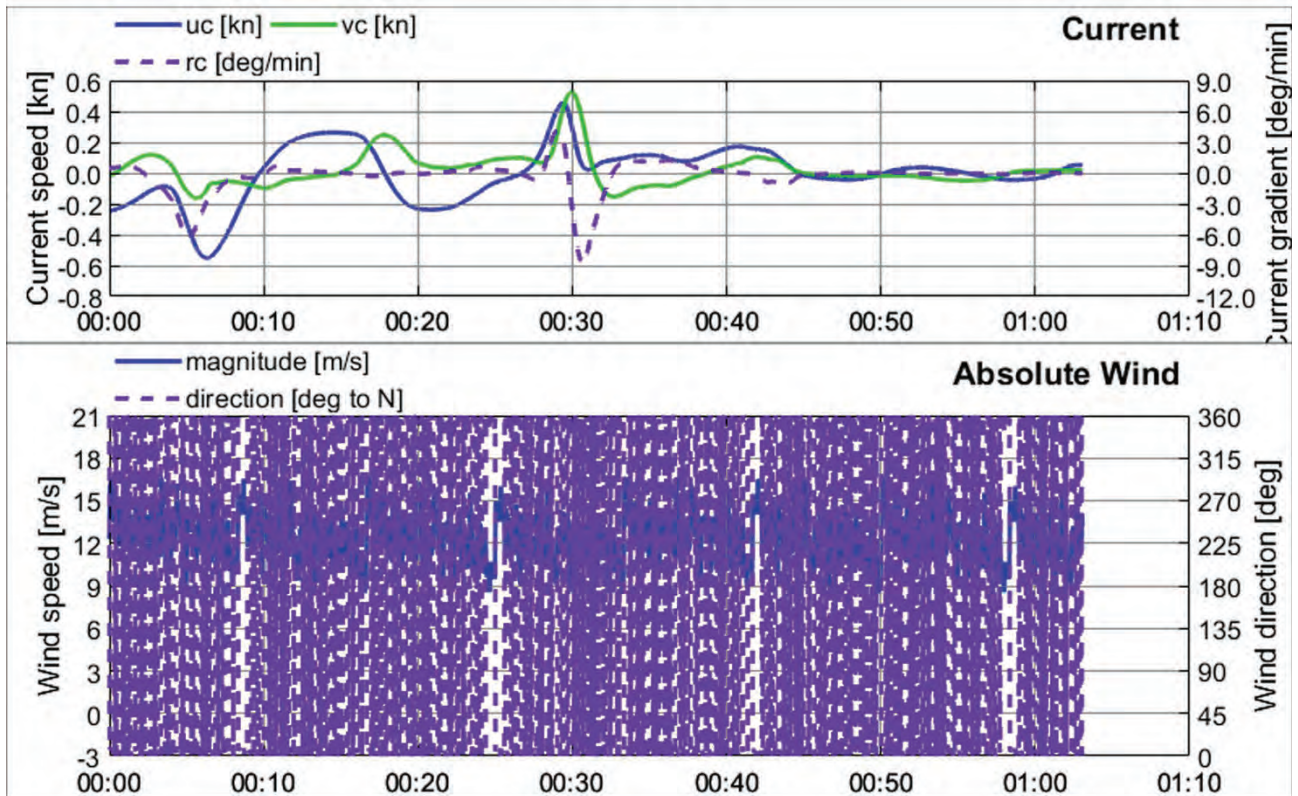
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 14/03/2022

Current: -1hHW dyn

Wind: S6



Container vessel: $L_{OA} = 210$ m; $B = 32.2$ m; $T = 11.0$ m

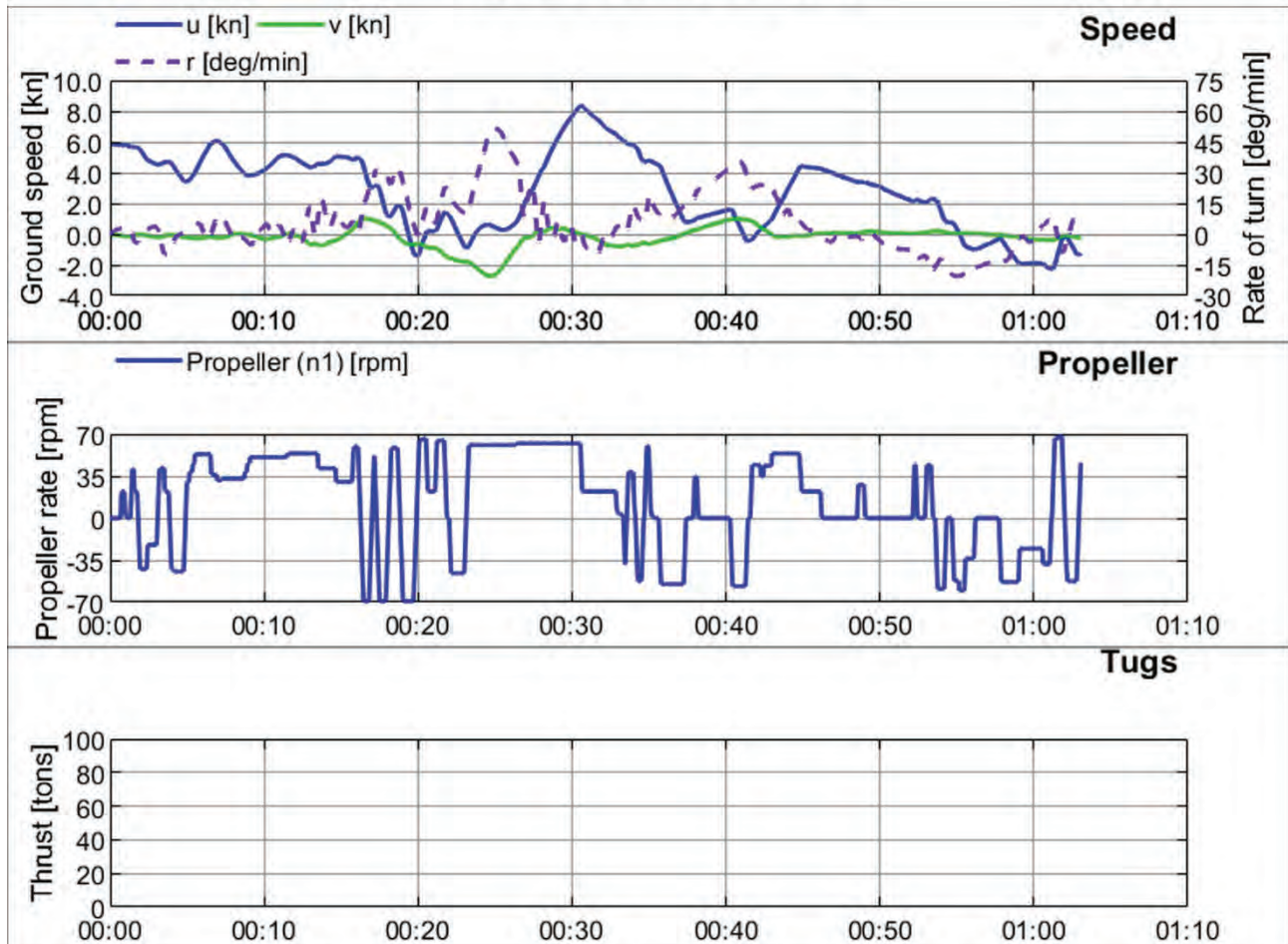
Simulation: M4 P4

Time: 15:37:56

Player: 4/4

Simulator: Sim 5

Tugs: 60 60 60 60 tons



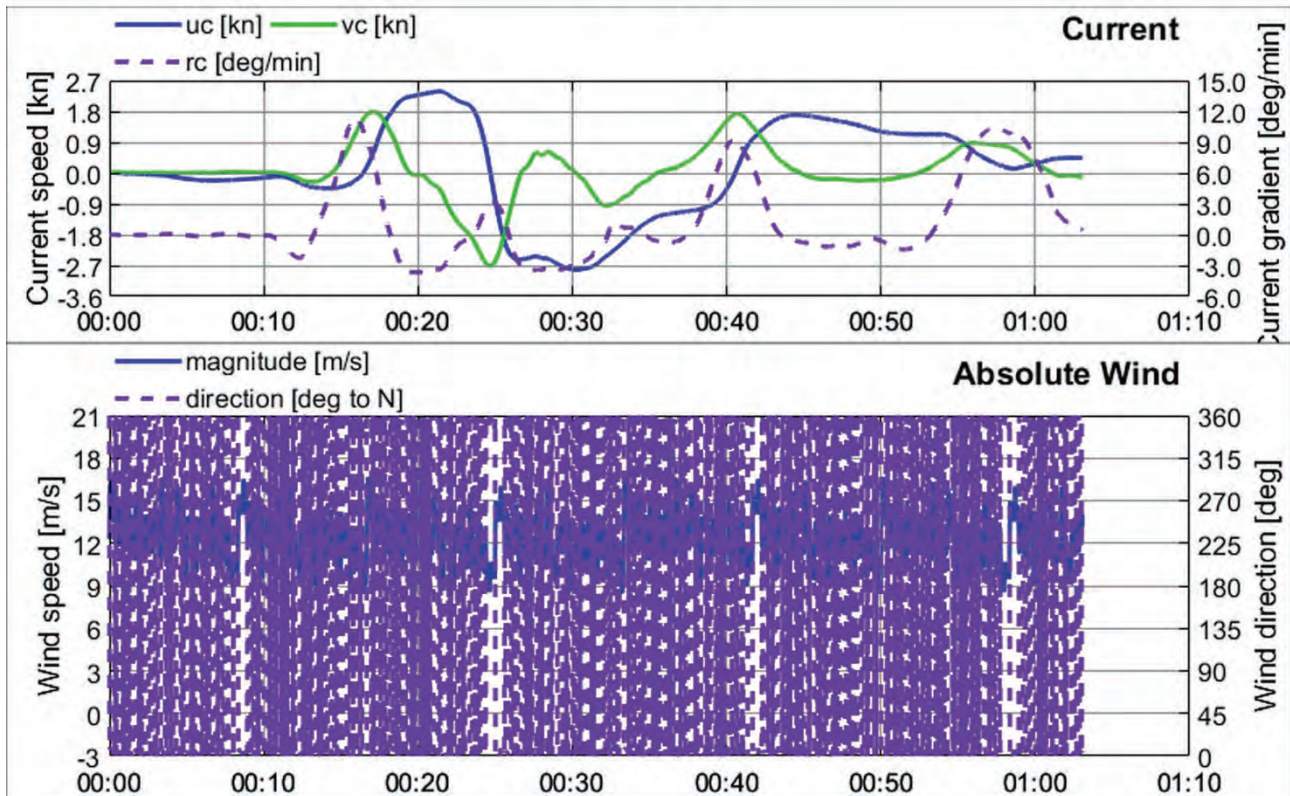
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 14/03/2022

Current: -1hHW dyn

Wind: S6



Container vessel: $L_{OA} = 430$ m; $B = 62.0$ m; $T = 15.0$ m

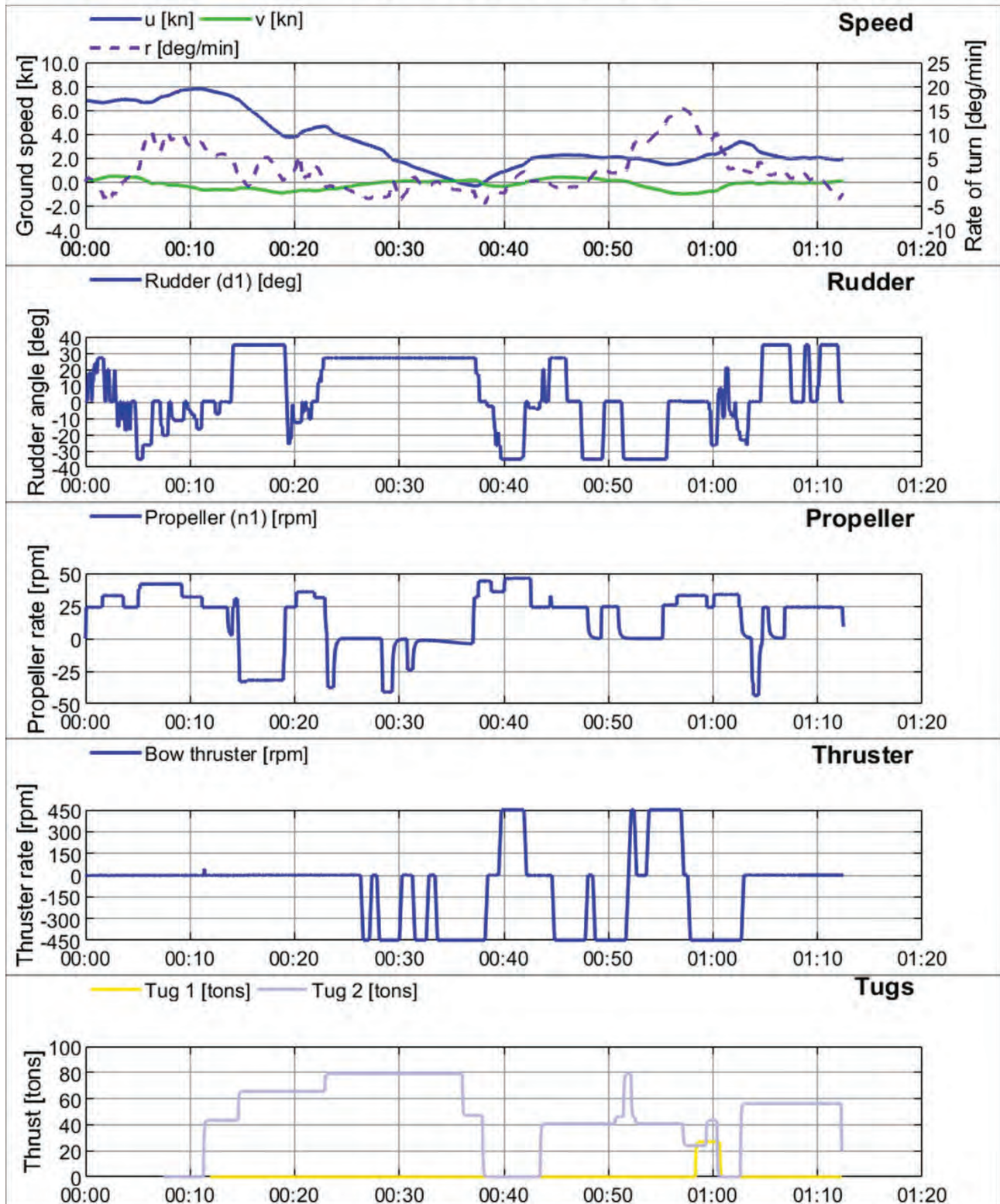
Simulation: U5 P1

Time: 09:00:32

Player: 1/4

Simulator: Sim 360+

Tugs: 80 80 80 80 tons



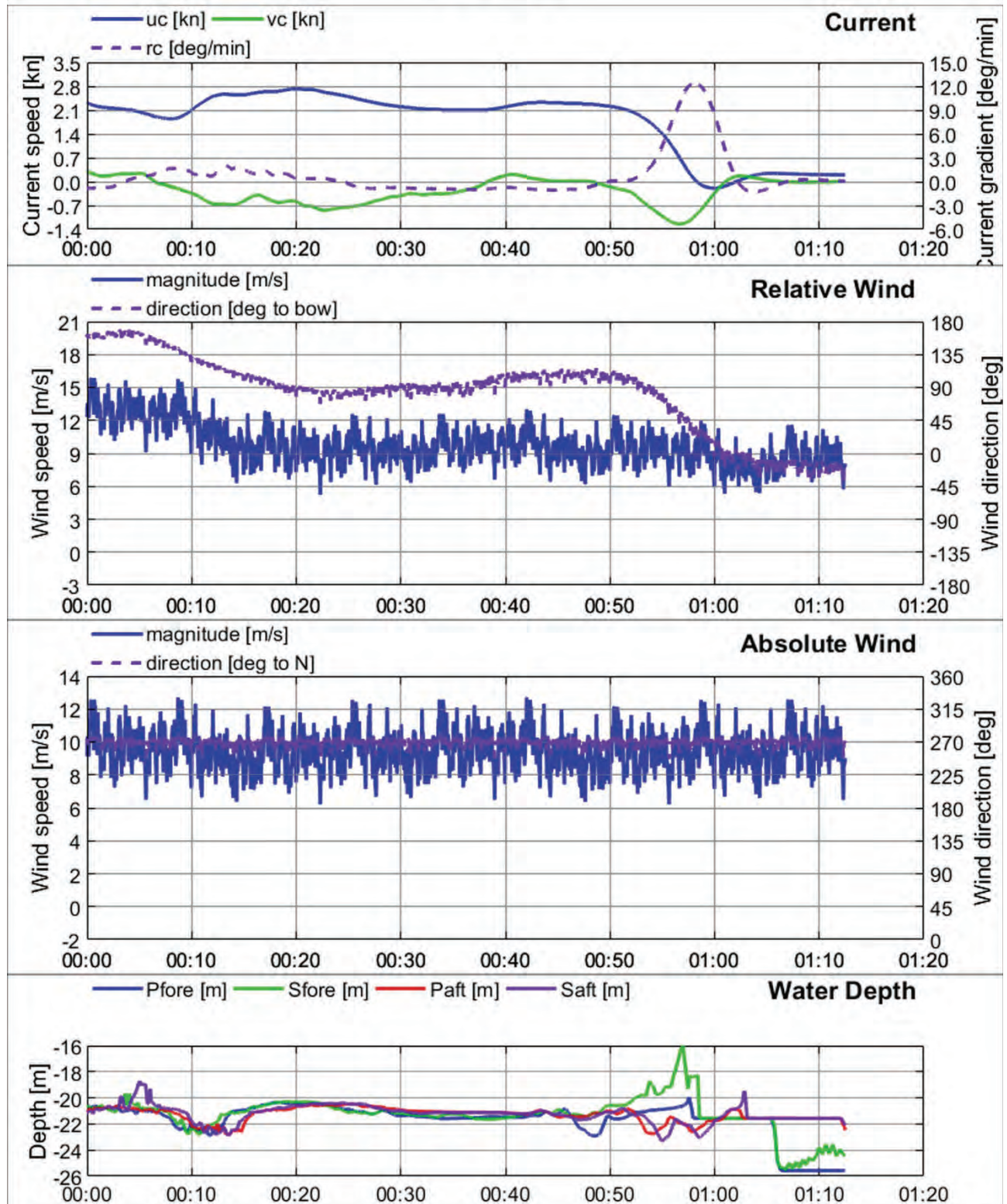
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 21/03/2022

Current: -0.9hHW stat

Wind: E5



Container vessel: $L_{OA} = 430$ m; $B = 62.0$ m; $T = 15.0$ m

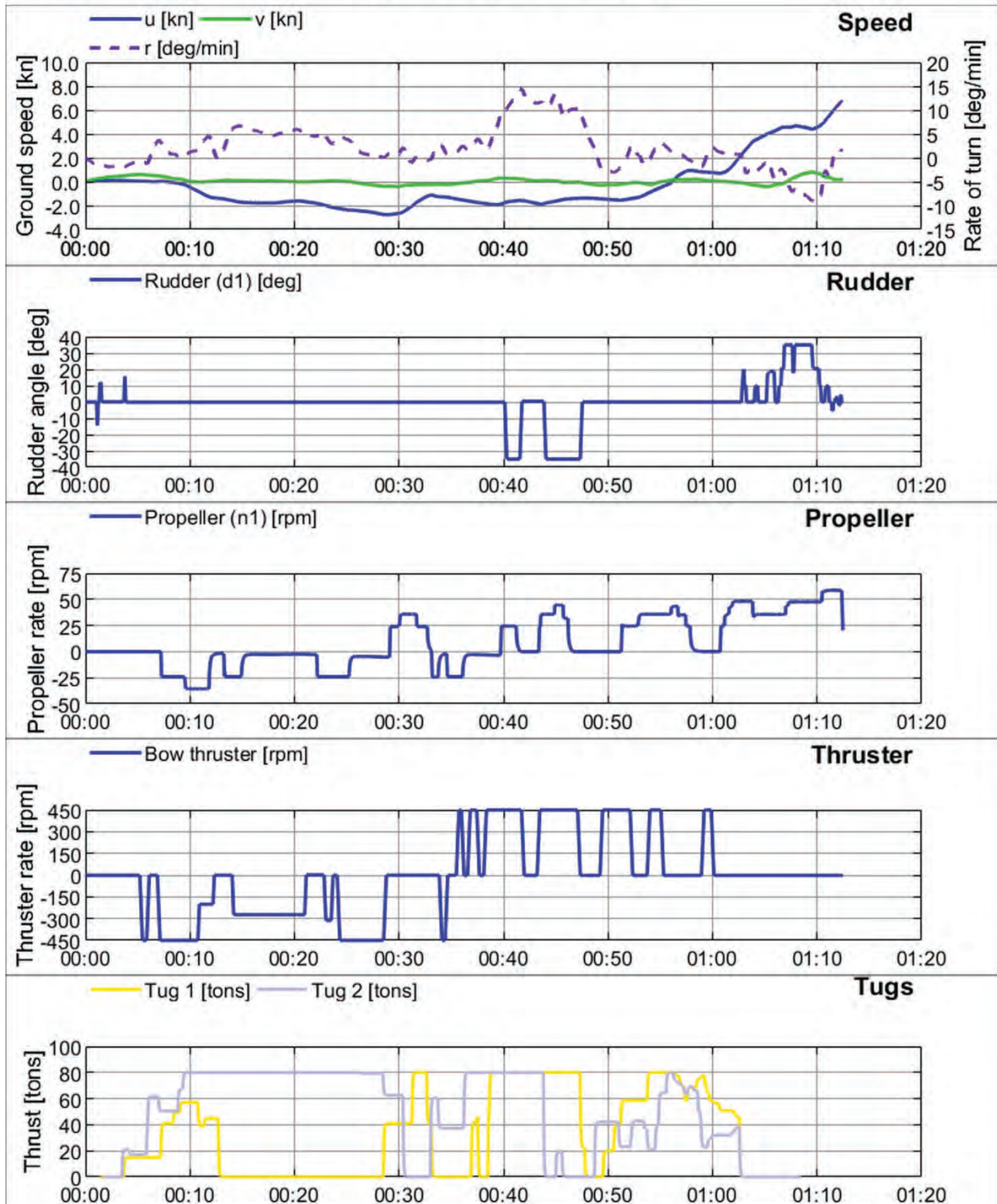
Simulation: U5 P2

Time: 09:04:30

Player: 2/4

Simulator: Sim 225

Tugs: 80 80 80 80 tons



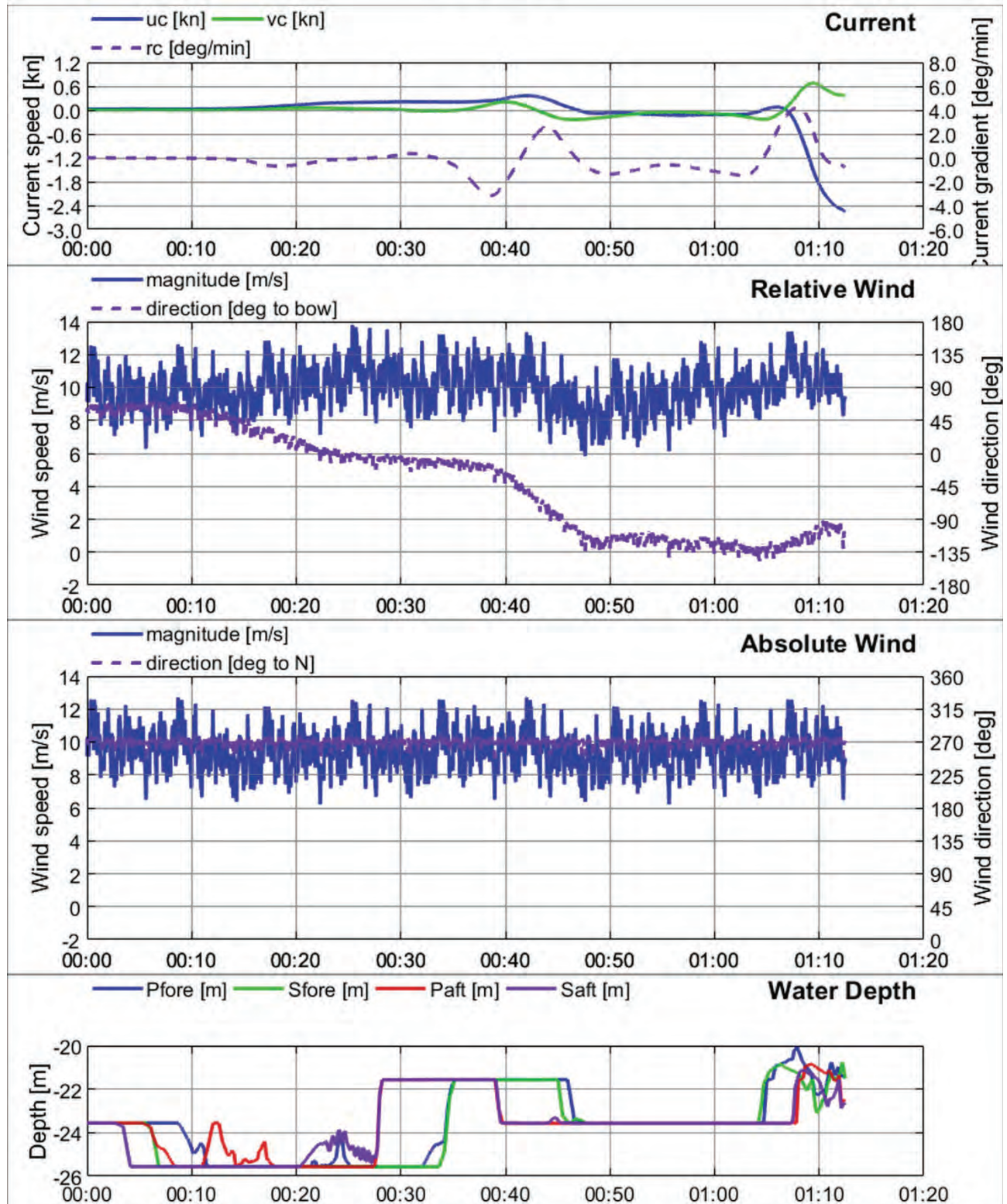
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 21/03/2022

Current: -0.9hHW stat

Wind: E5



Container vessel: $L_{OA} = 430$ m; $B = 62.0$ m; $T = 15.0$ m

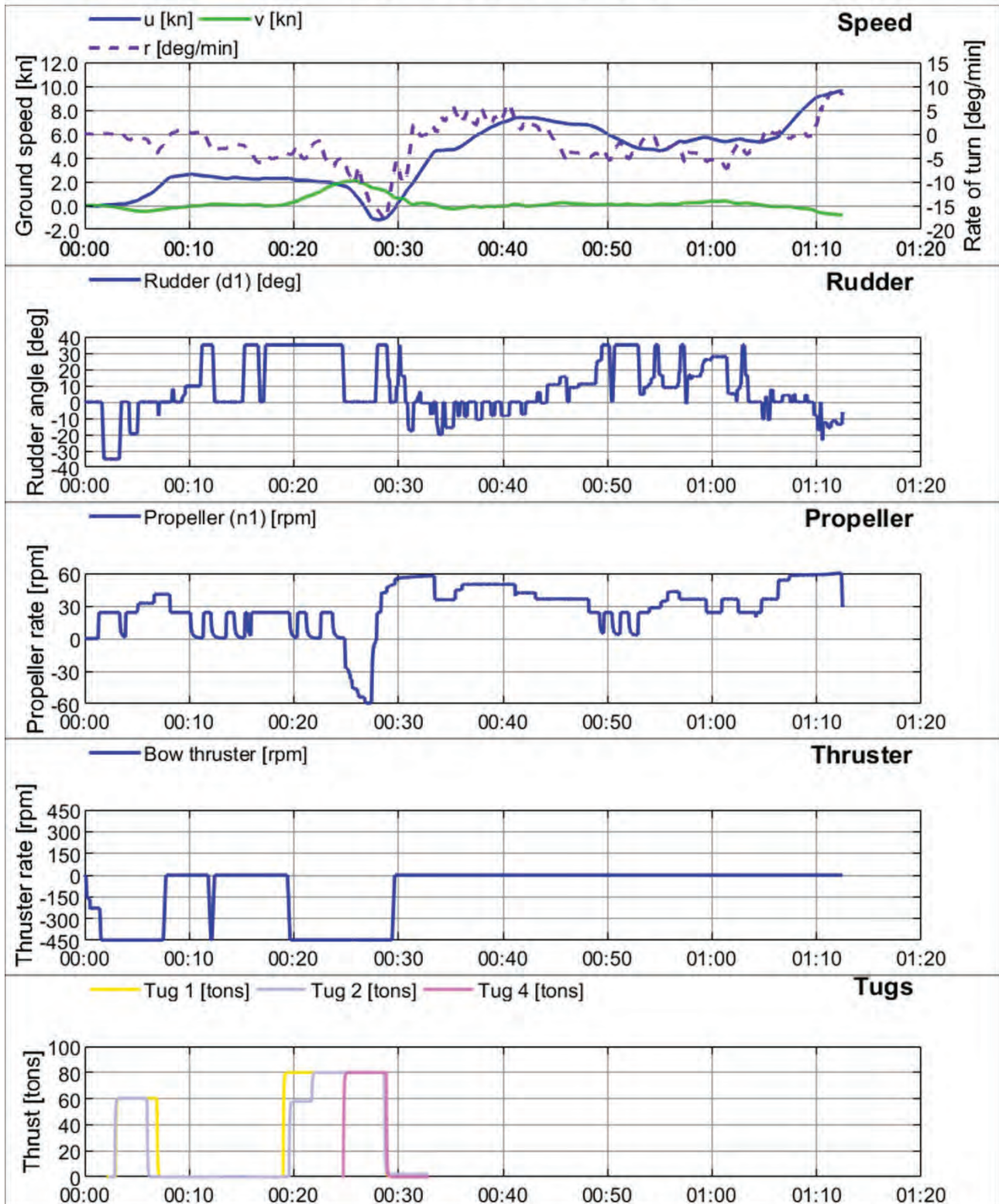
Simulation: U5 P3

Time: 09:05:32

Player: 3/4

Simulator: Sim Lara

Tugs: 80 80 80 80 tons



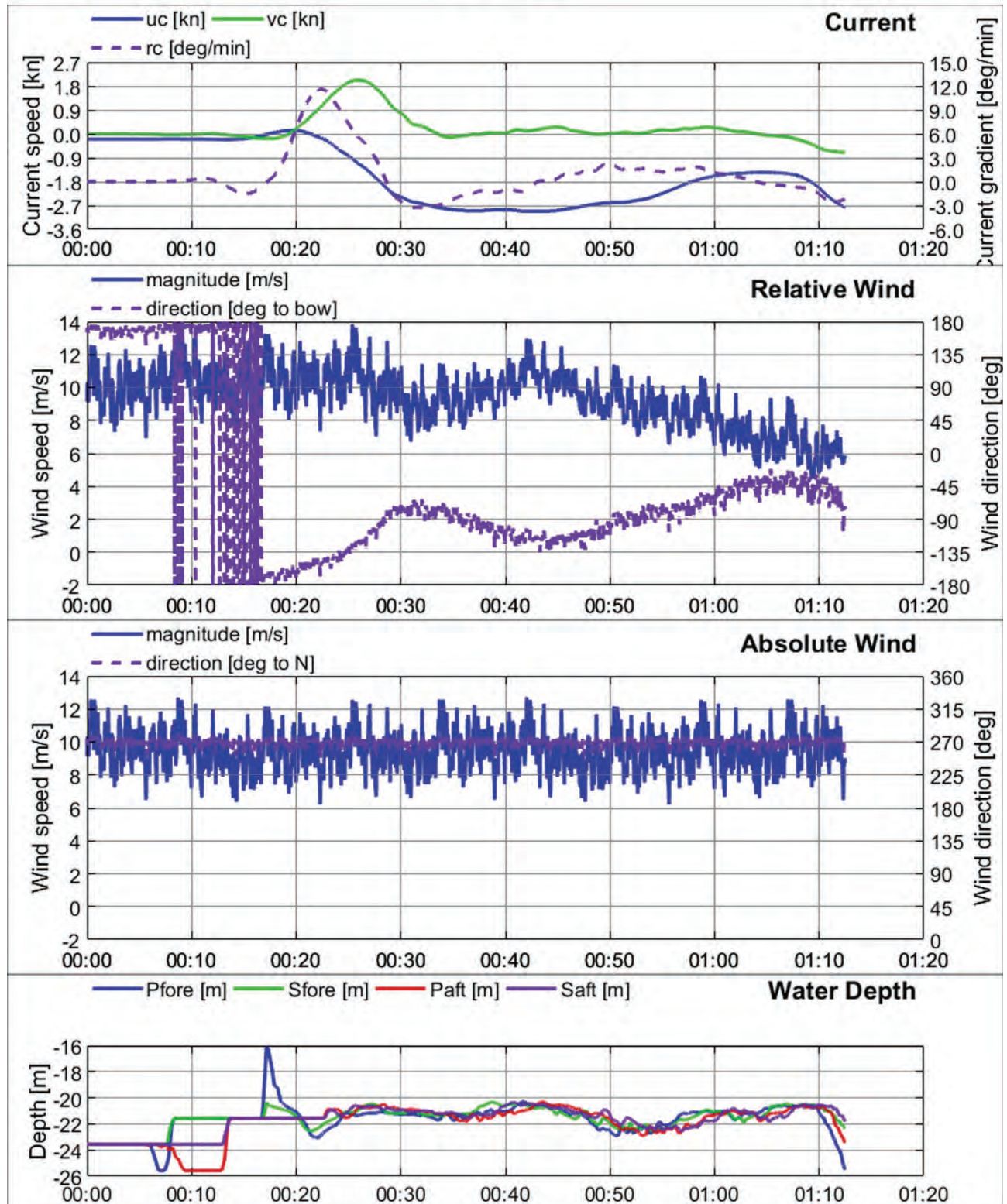
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 21/03/2022

Current: -0.9hHW stat

Wind: E5



Container vessel: $L_{OA} = 400$ m; $B = 61.5$ m; $T = 13.1$ m

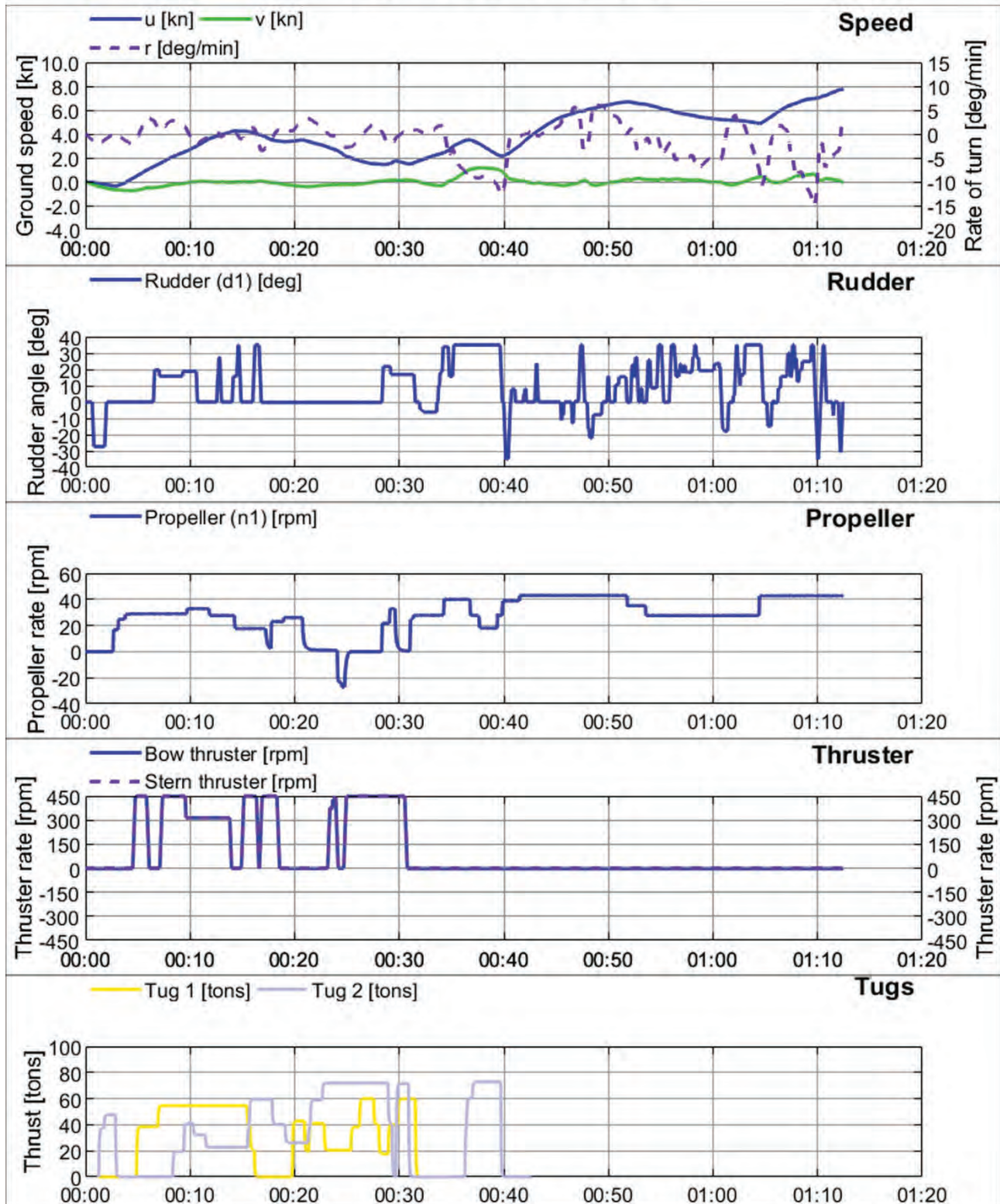
Simulation: U5 P4

Time: 08:58:57

Player: 4/4

Simulator: Sim 5

Tugs: 80 80 80 80 tons



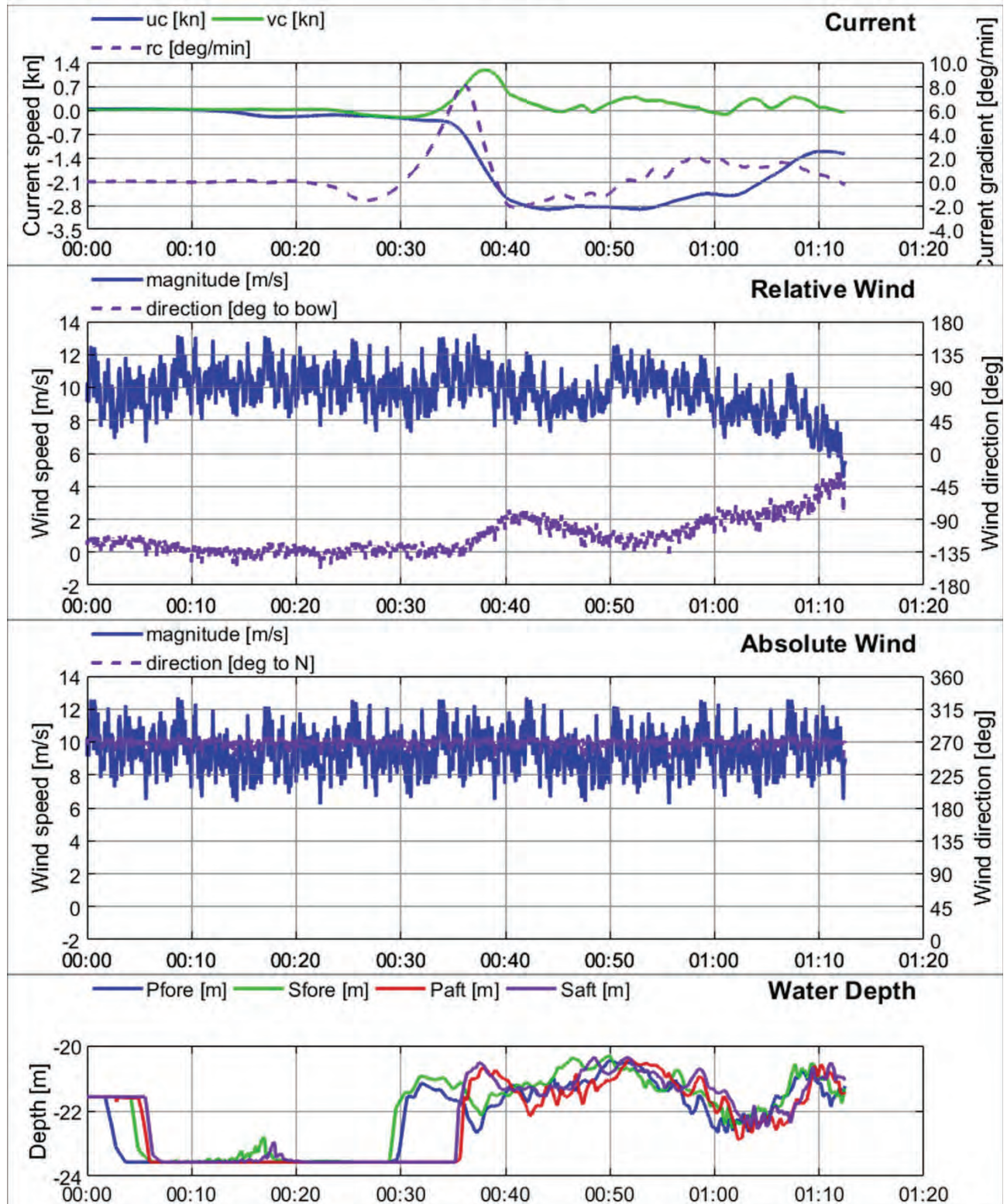
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 21/03/2022

Current: -0.9hHW stat

Wind: E5



Container vessel: $L_{OA} = 400$ m; $B = 61.5$ m; $T = 13.1$ m

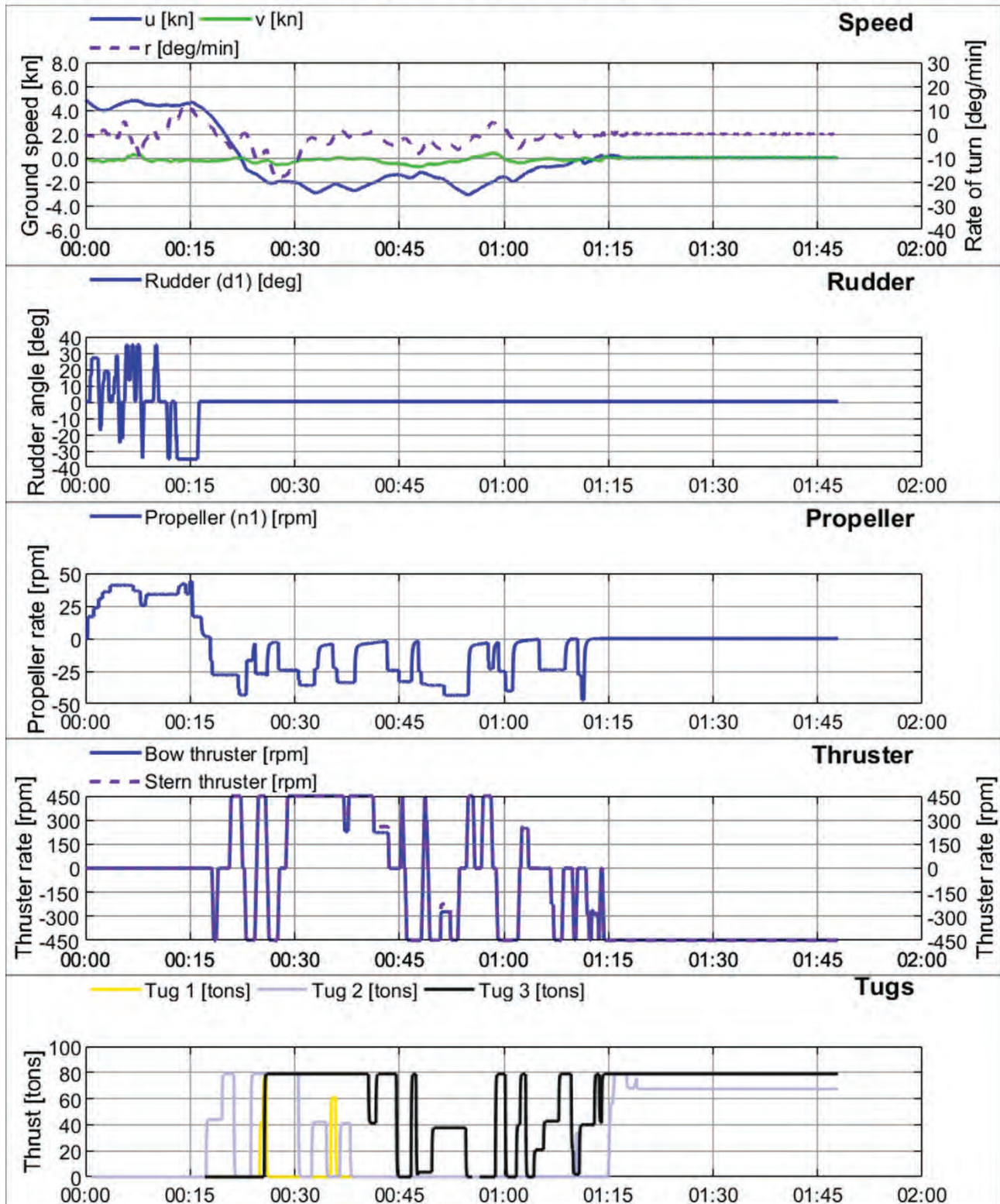
Simulation: U6 P1

Time: 10:52:17

Player: 1/4

Simulator: Sim 360+

Tugs: 80 80 80 80 tons



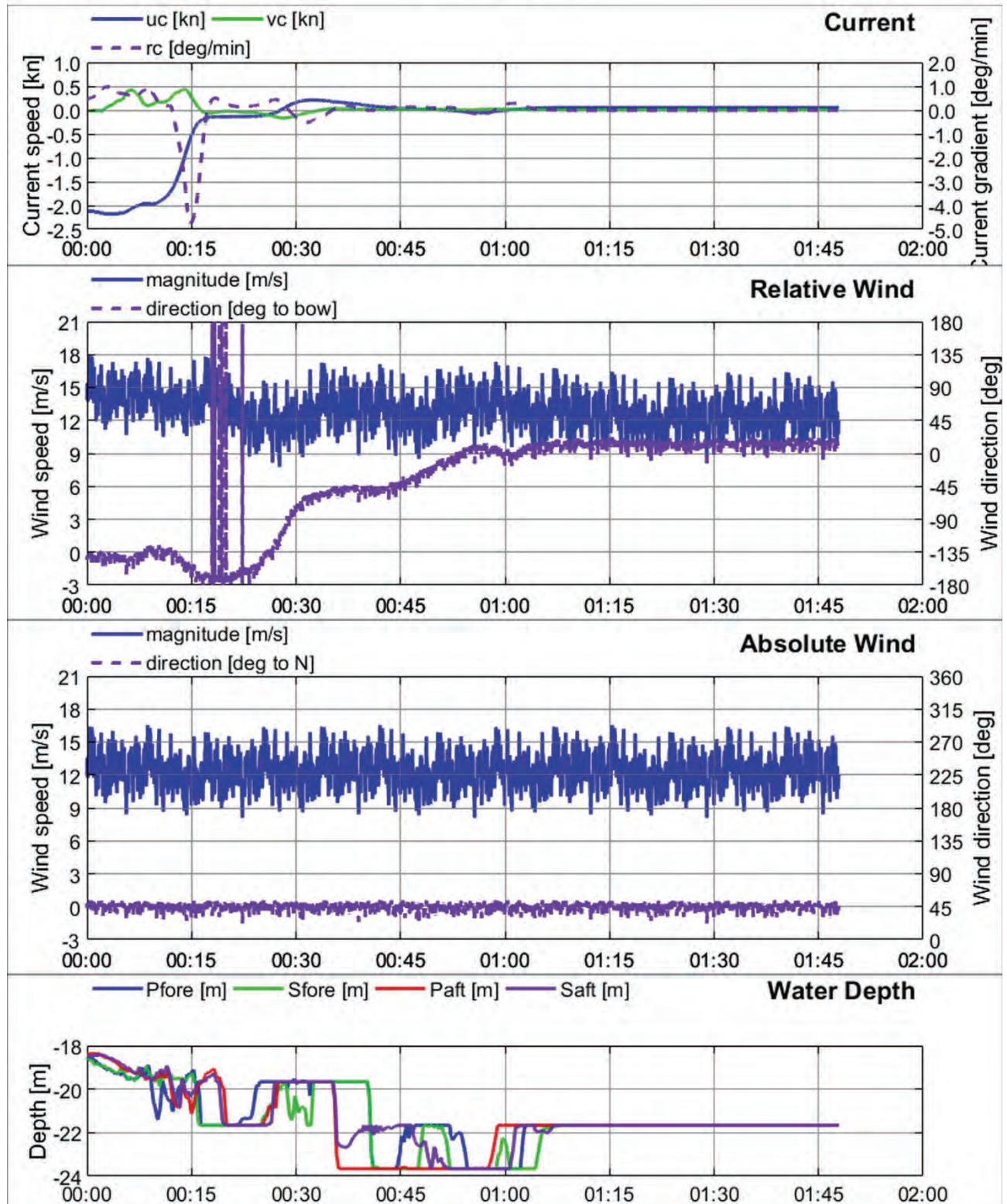
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 21/03/2022

Current: 3.33hHW stat

Wind: SW6



Container vessel: $L_{OA} = 430$ m; $B = 62.0$ m; $T = 15.0$ m

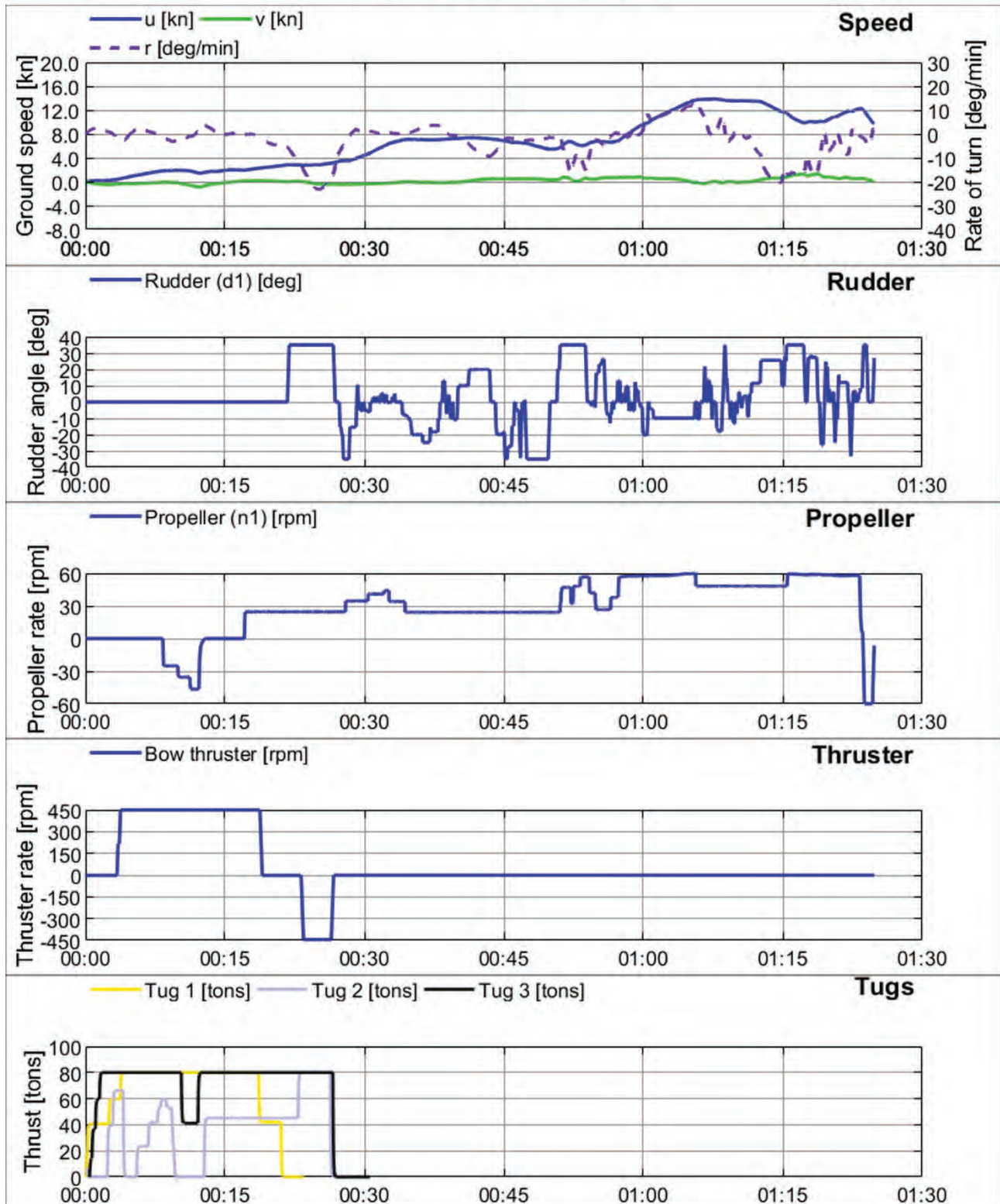
Simulation: U6 P2

Time: 10:56:15

Player: 2/4

Simulator: Sim 225

Tugs: 80 80 80 80 tons



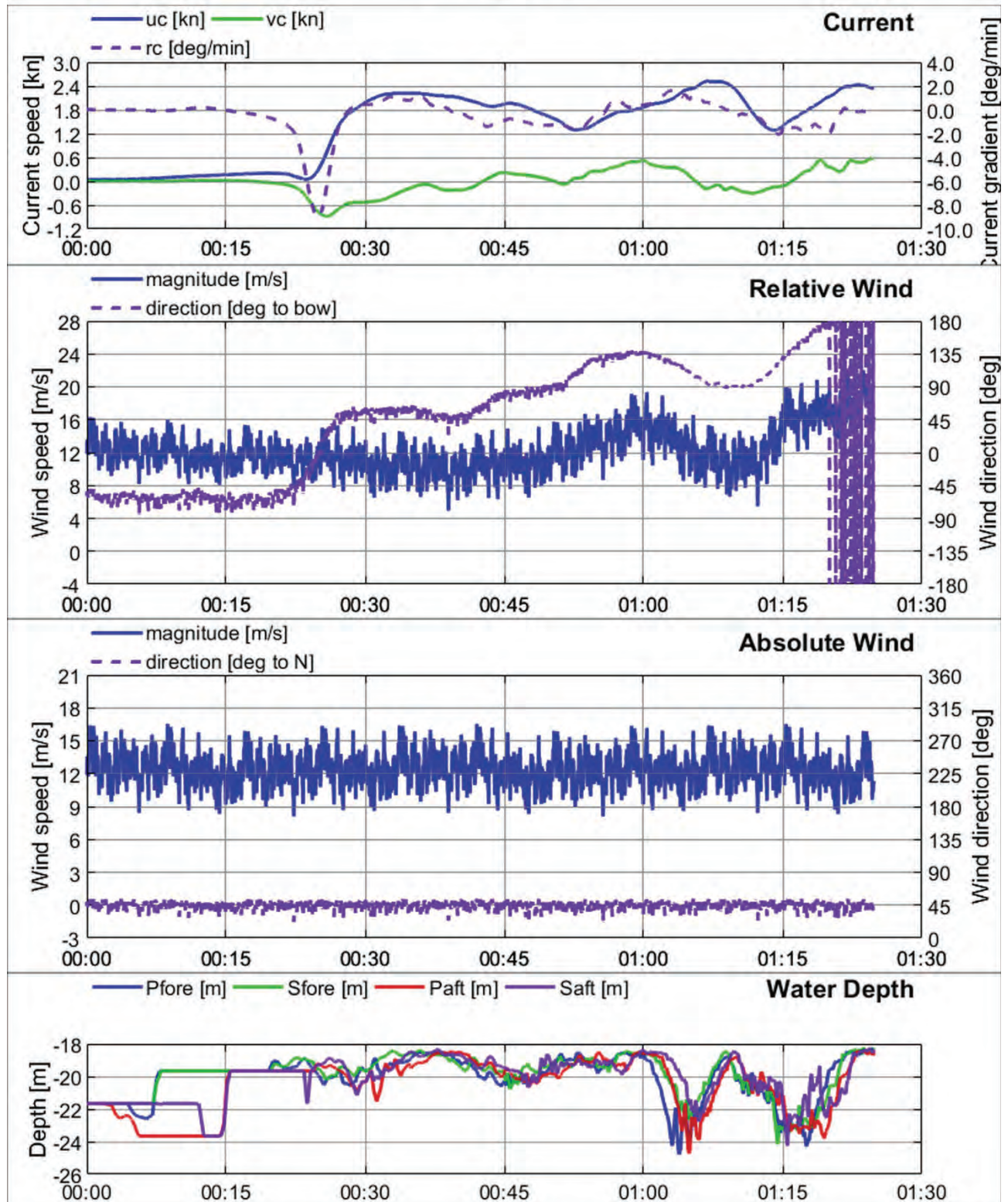
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 21/03/2022

Current: 3.33hHW stat

Wind: SW6



Container vessel: $L_{OA} = 430$ m; $B = 62.0$ m; $T = 15.0$ m

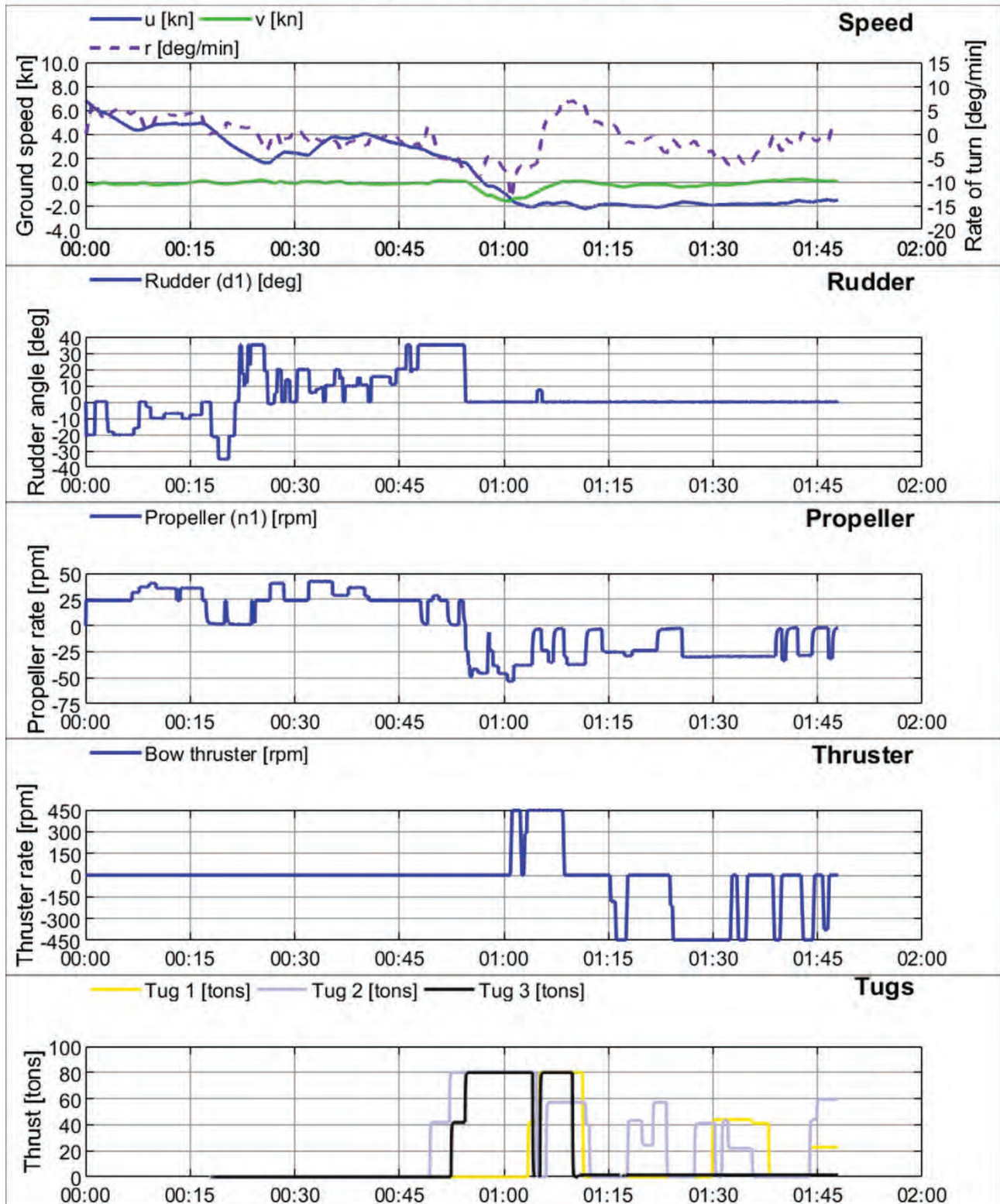
Simulation: U6 P3

Time: 10:57:17

Player: 3/4

Simulator: Sim Lara

Tugs: 80 80 80 80 tons



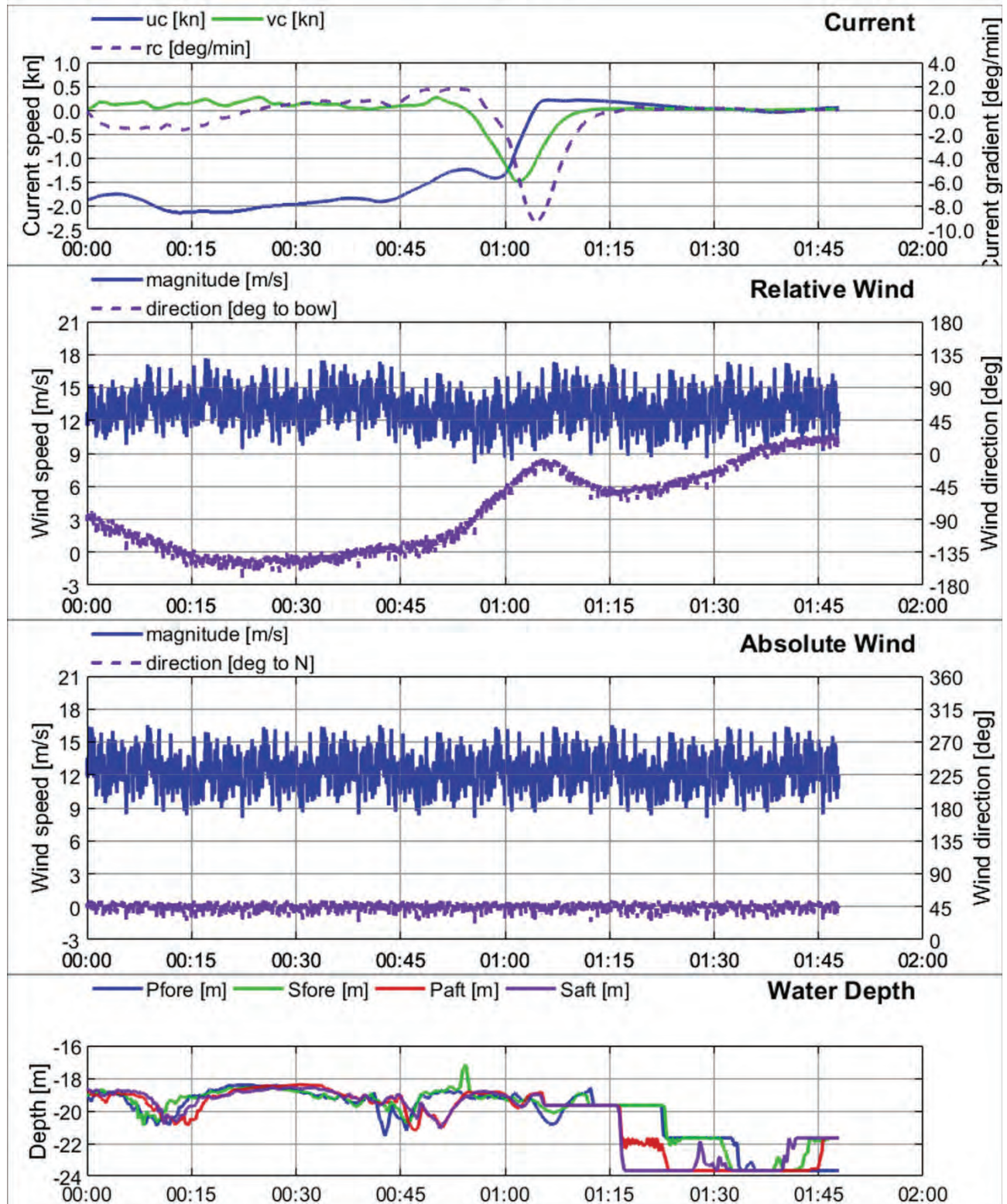
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 21/03/2022

Current: 3.33hHW stat

Wind: SW6



Container vessel: $L_{OA} = 430$ m; $B = 62.0$ m; $T = 15.0$ m

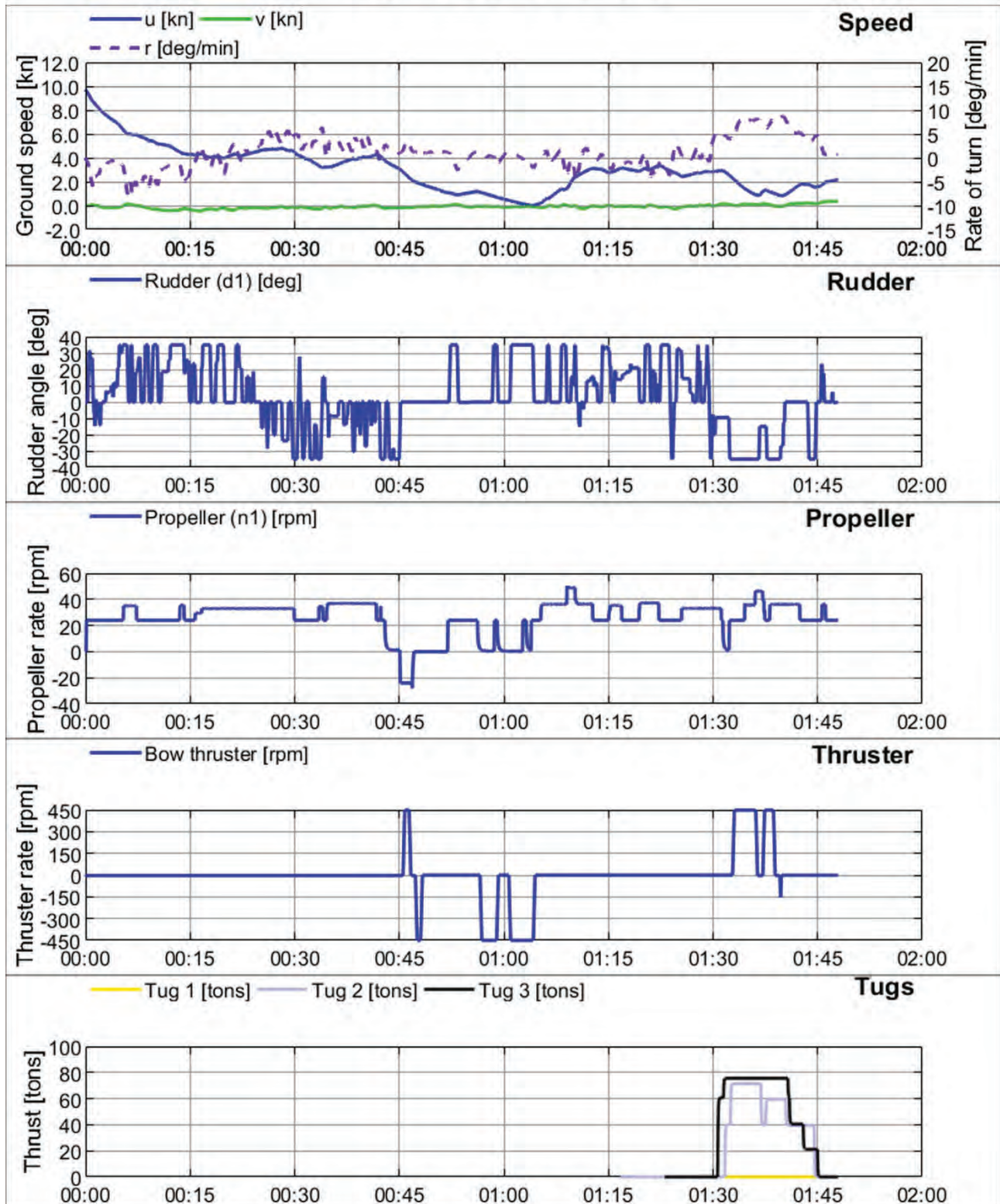
Simulation: U6 P4

Time: 10:50:44

Player: 4/4

Simulator: Sim 5

Tugs: 80 80 80 80 tons



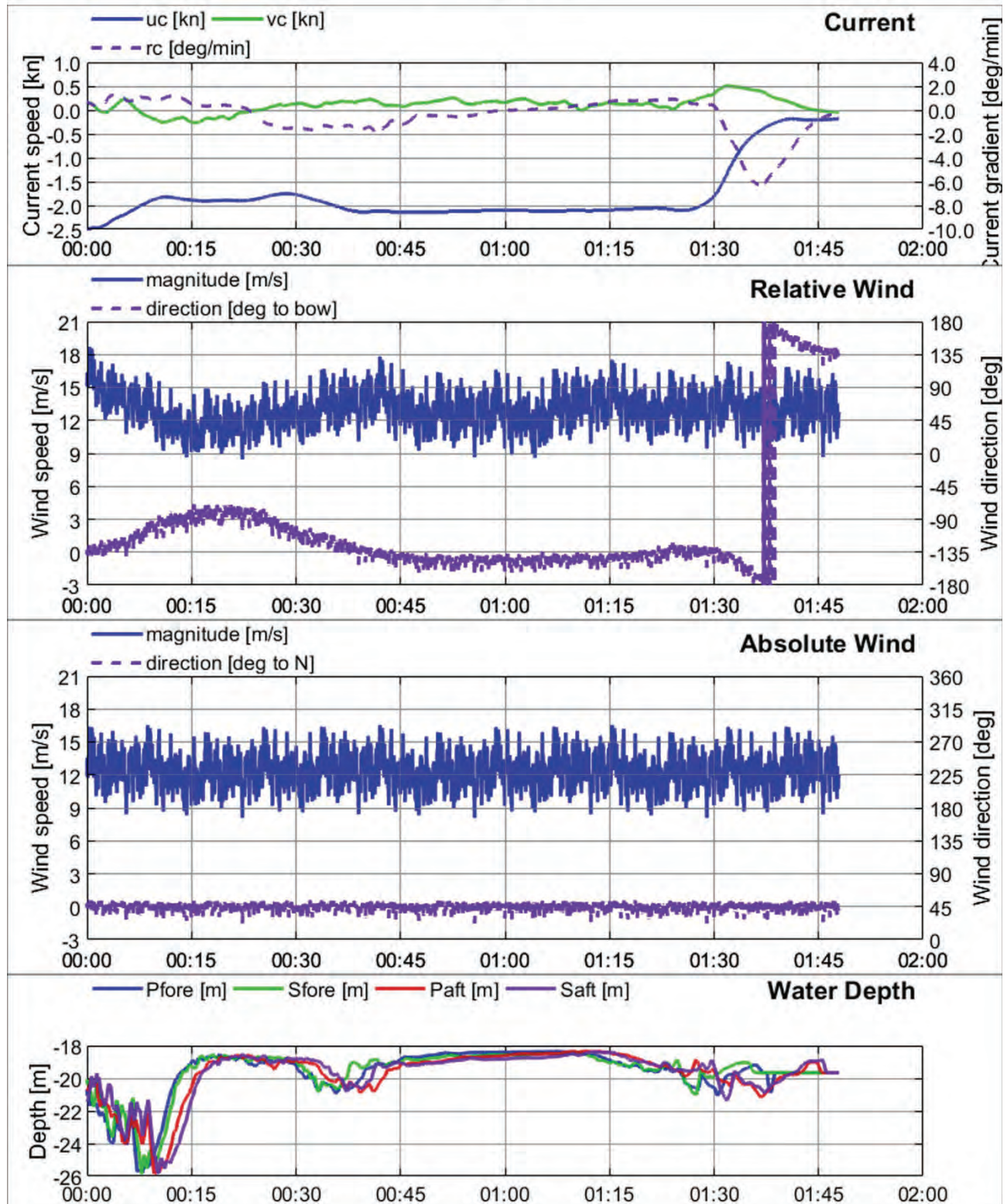
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 21/03/2022

Current: 3.33hHW stat

Wind: SW6



Container vessel: $L_{OA} = 400$ m; $B = 61.5$ m; $T = 12.0$ m

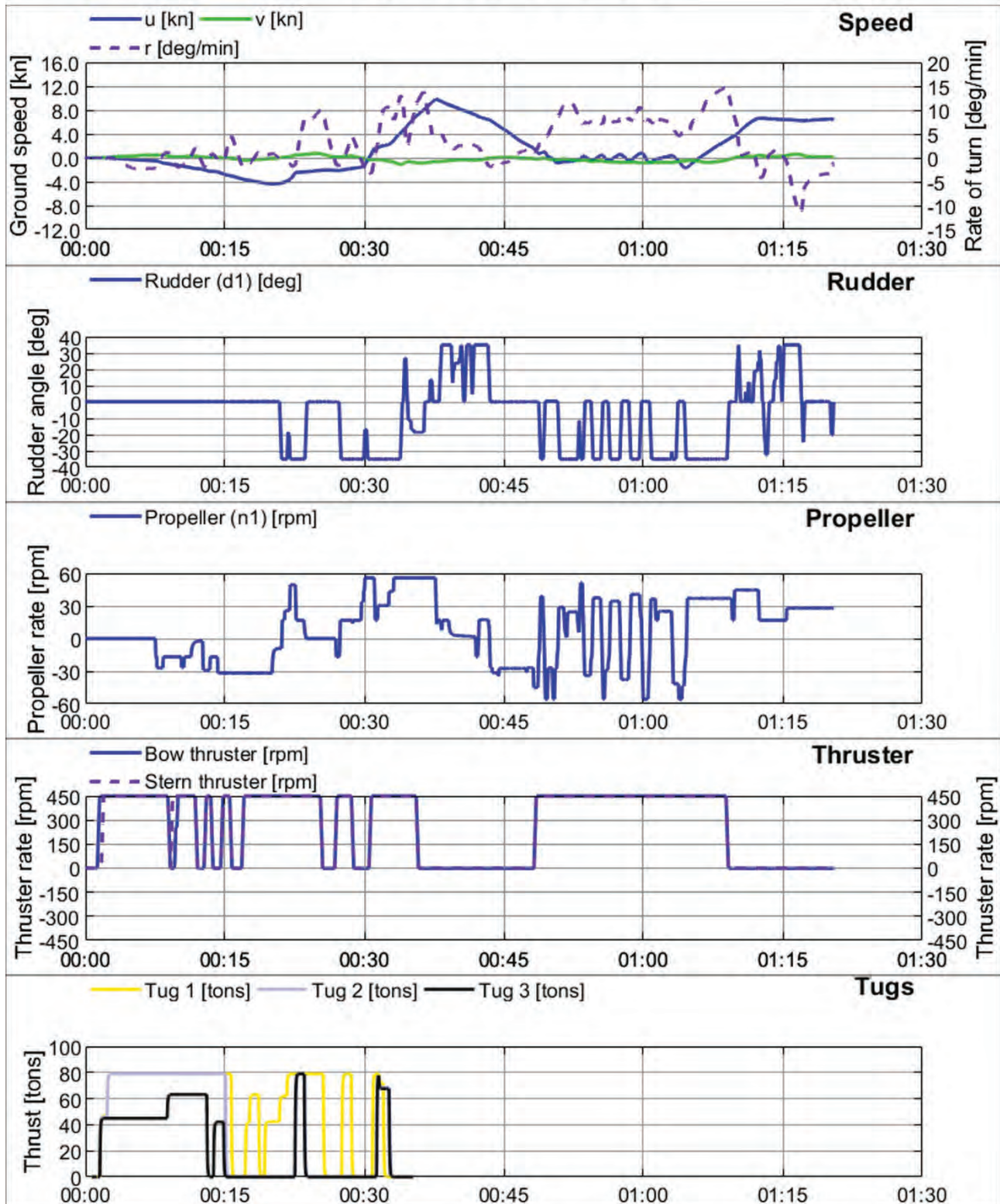
Simulation: M5 P1

Time: 13:55:36

Player: 1/4

Simulator: Sim 360+

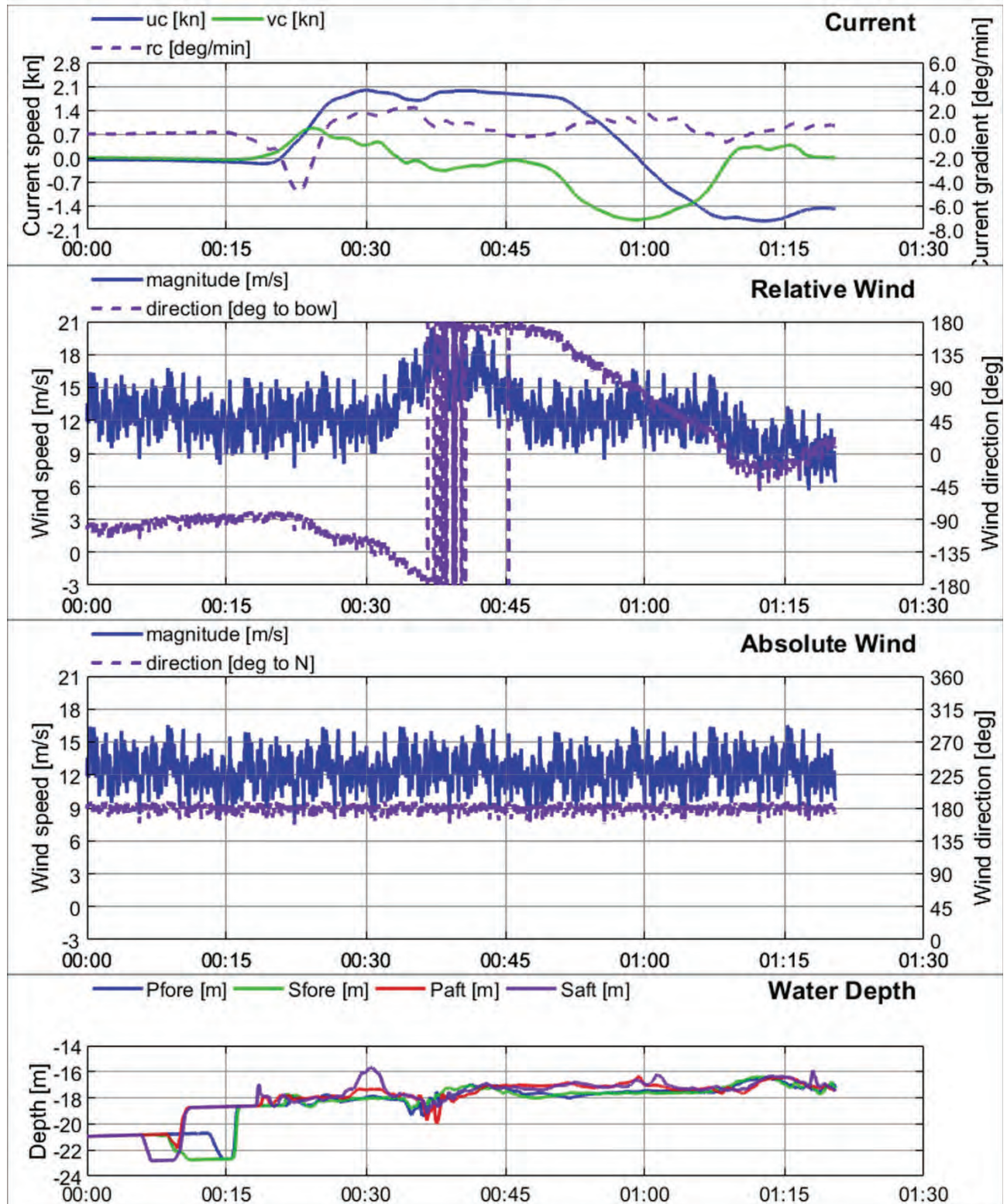
Tugs: 80 80 80 80 tons



[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 21/03/2022
Current: 4hHW dyn
Wind: N6



Container vessel: $L_{OA} = 400$ m; $B = 61.5$ m; $T = 14.0$ m

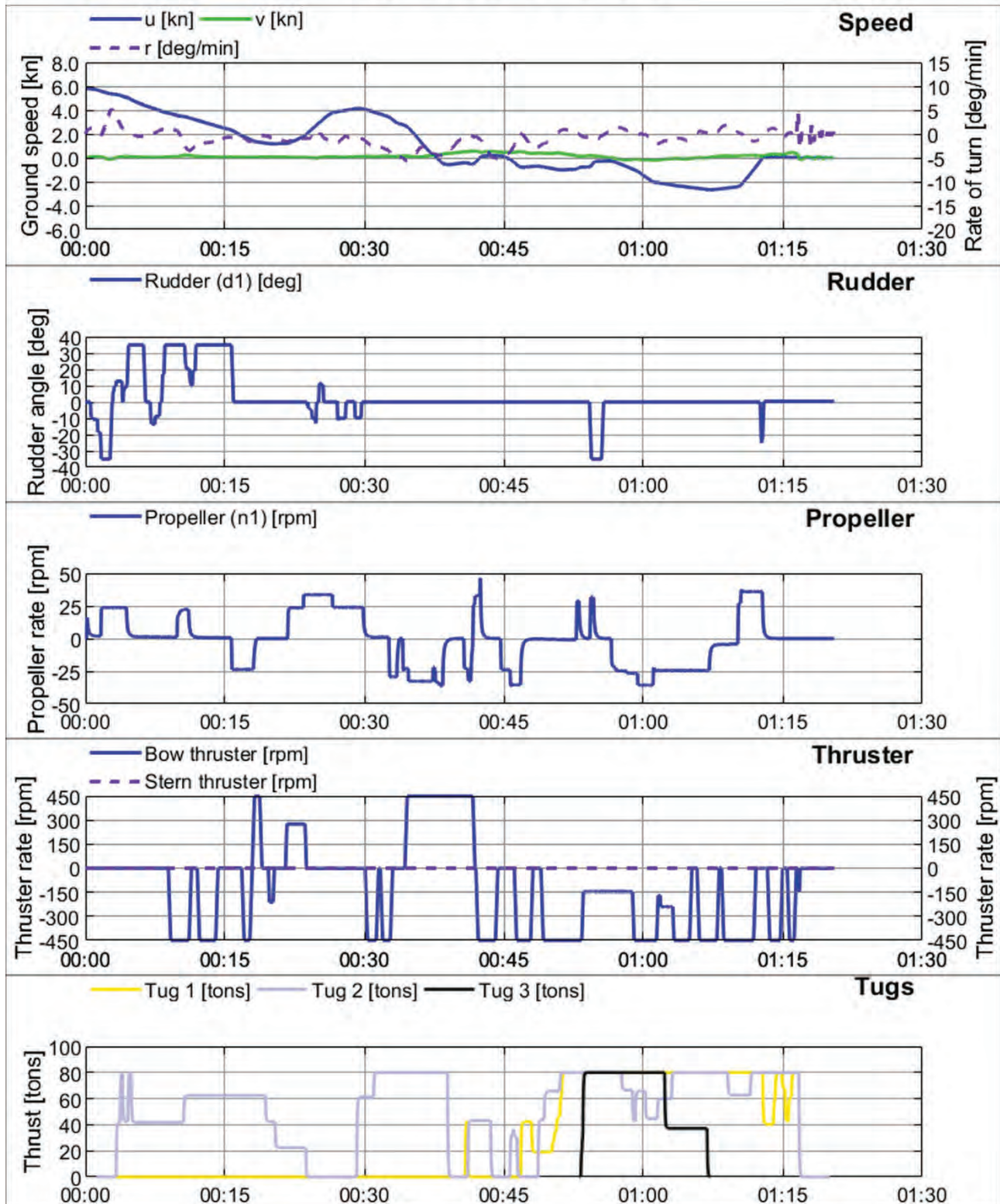
Simulation: M5 P2

Time: 13:59:35

Player: 2/4

Simulator: Sim 225

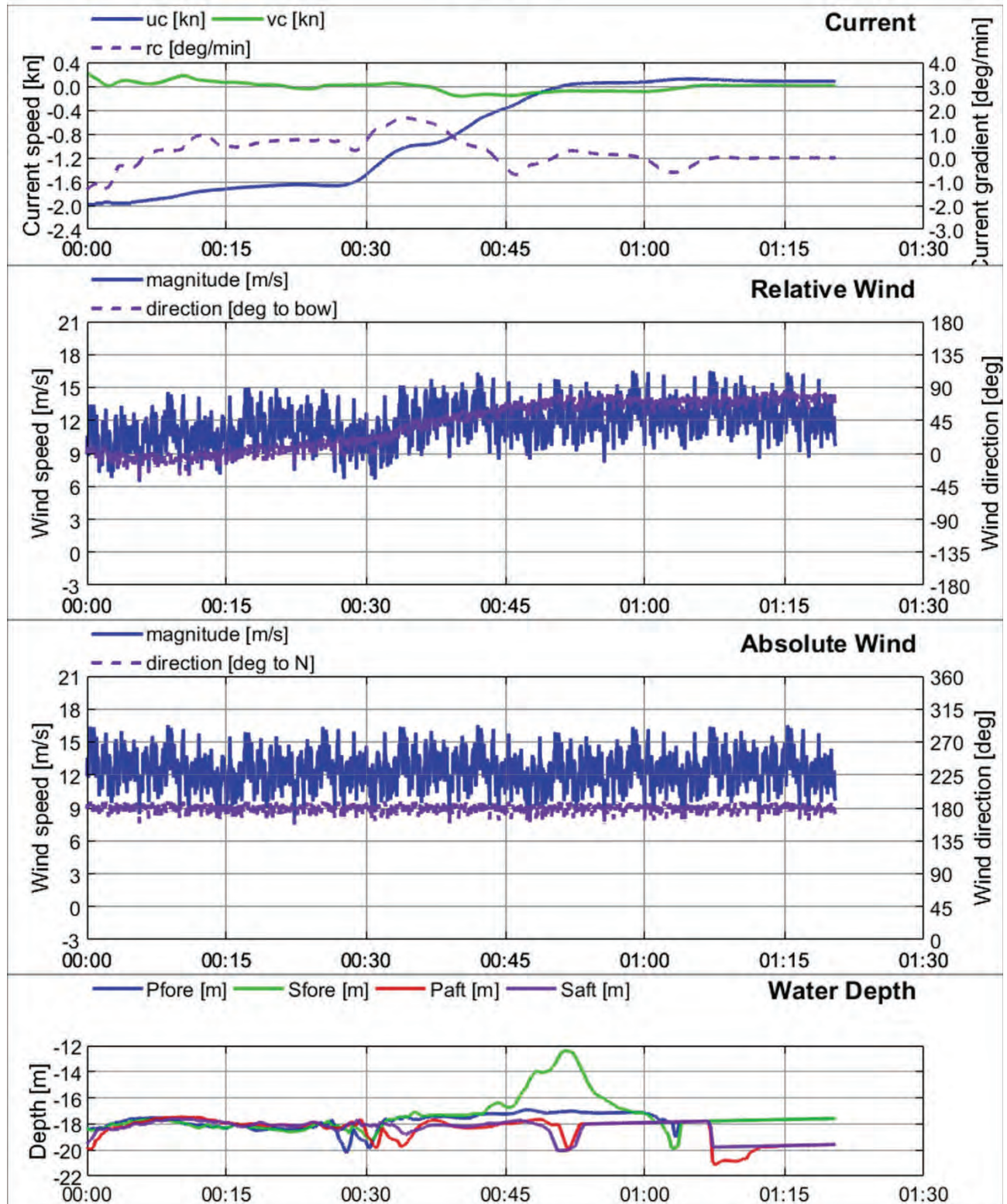
Tugs: 80 80 80 80 tons



[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 21/03/2022
Current: 4hHW dyn
Wind: N6



Container vessel: $L_{OA} = 210$ m; $B = 32.2$ m; $T = 11.0$ m

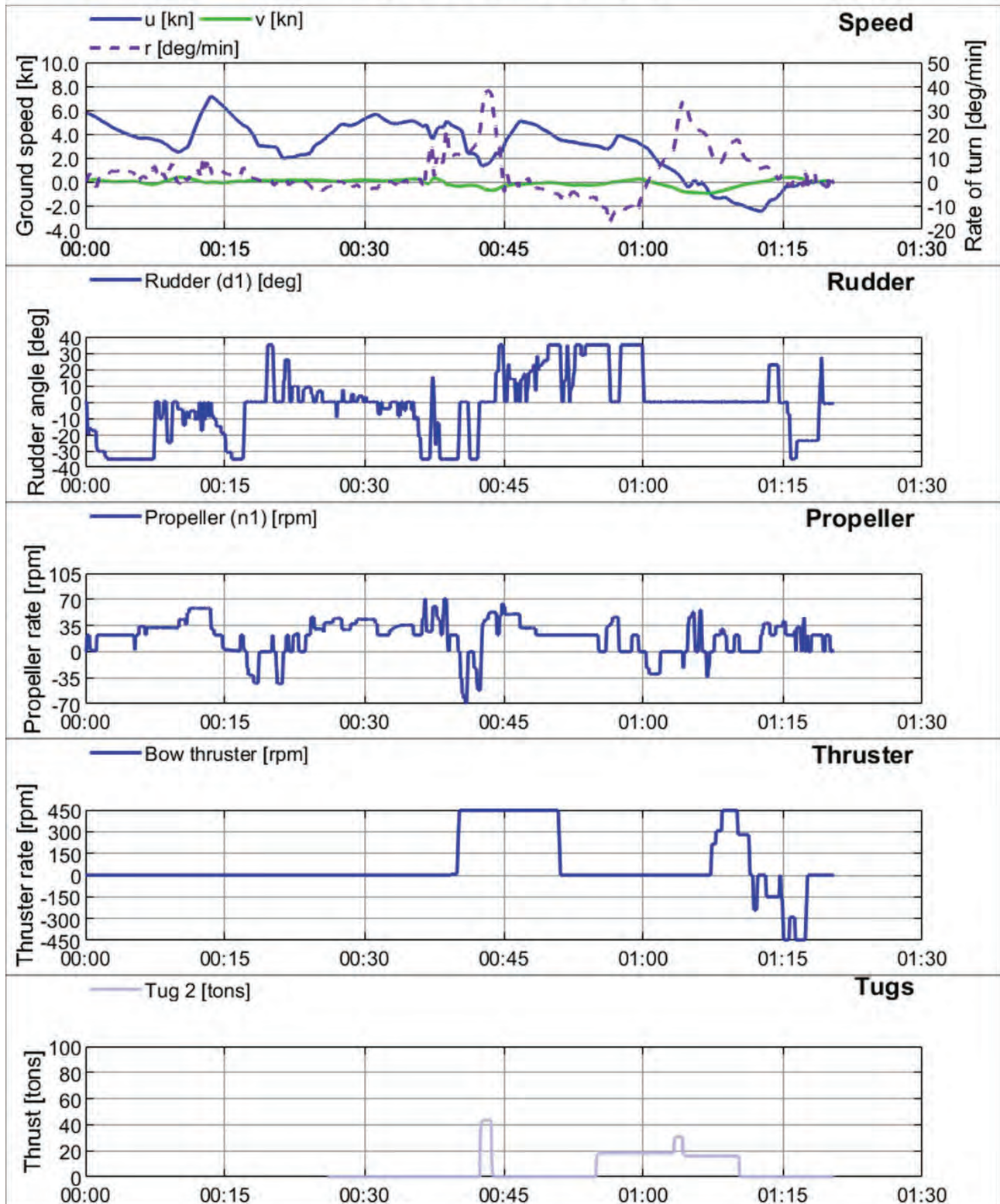
Simulation: M5 P3

Time: 14:00:37

Player: 3/4

Simulator: Sim Lara

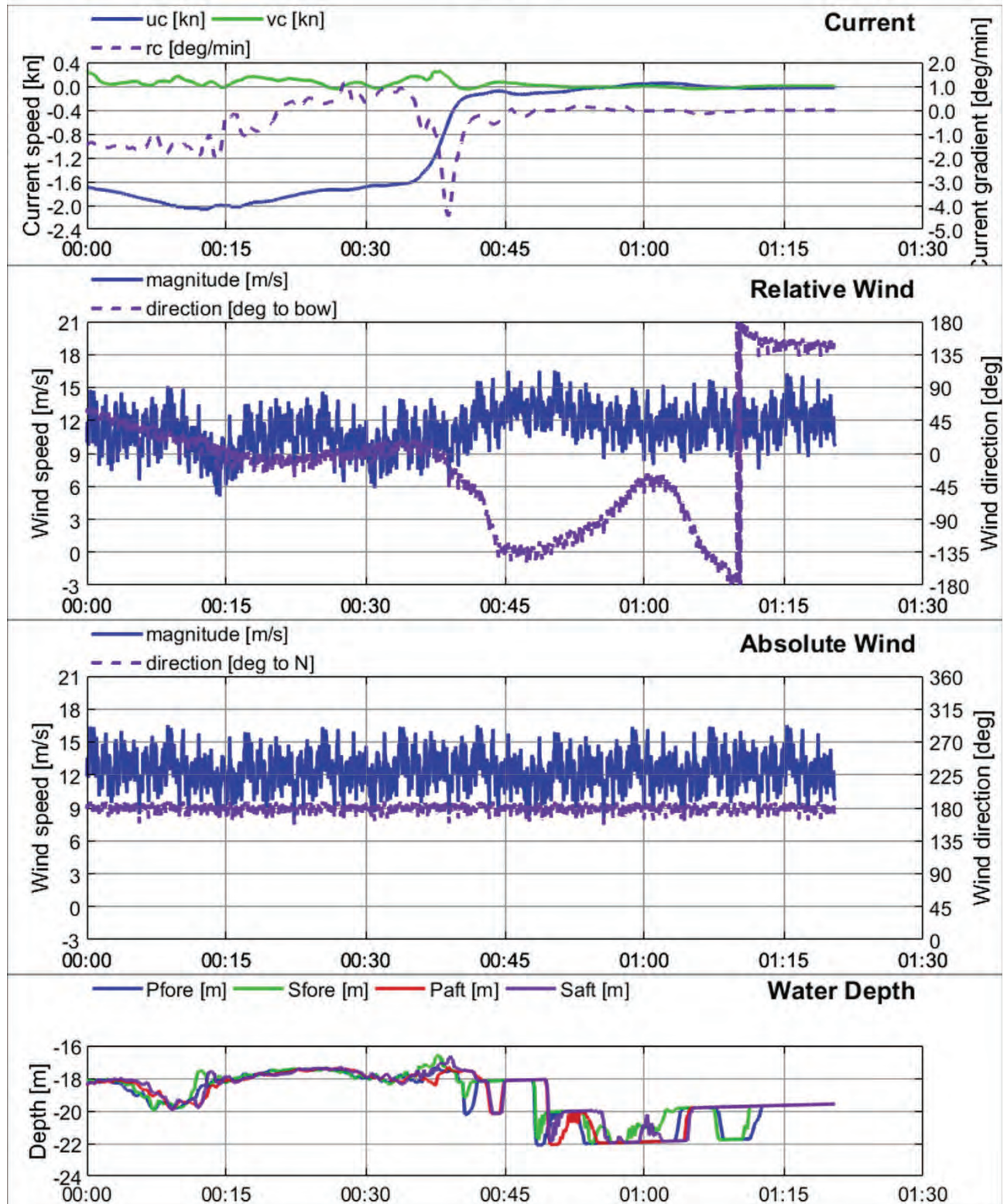
Tugs: 60 60 60 60 tons



[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 21/03/2022
Current: 4hHW dyn
Wind: N6



Container vessel: $L_{OA} = 255$ m; $B = 32.3$ m; $T = 12.0$ m

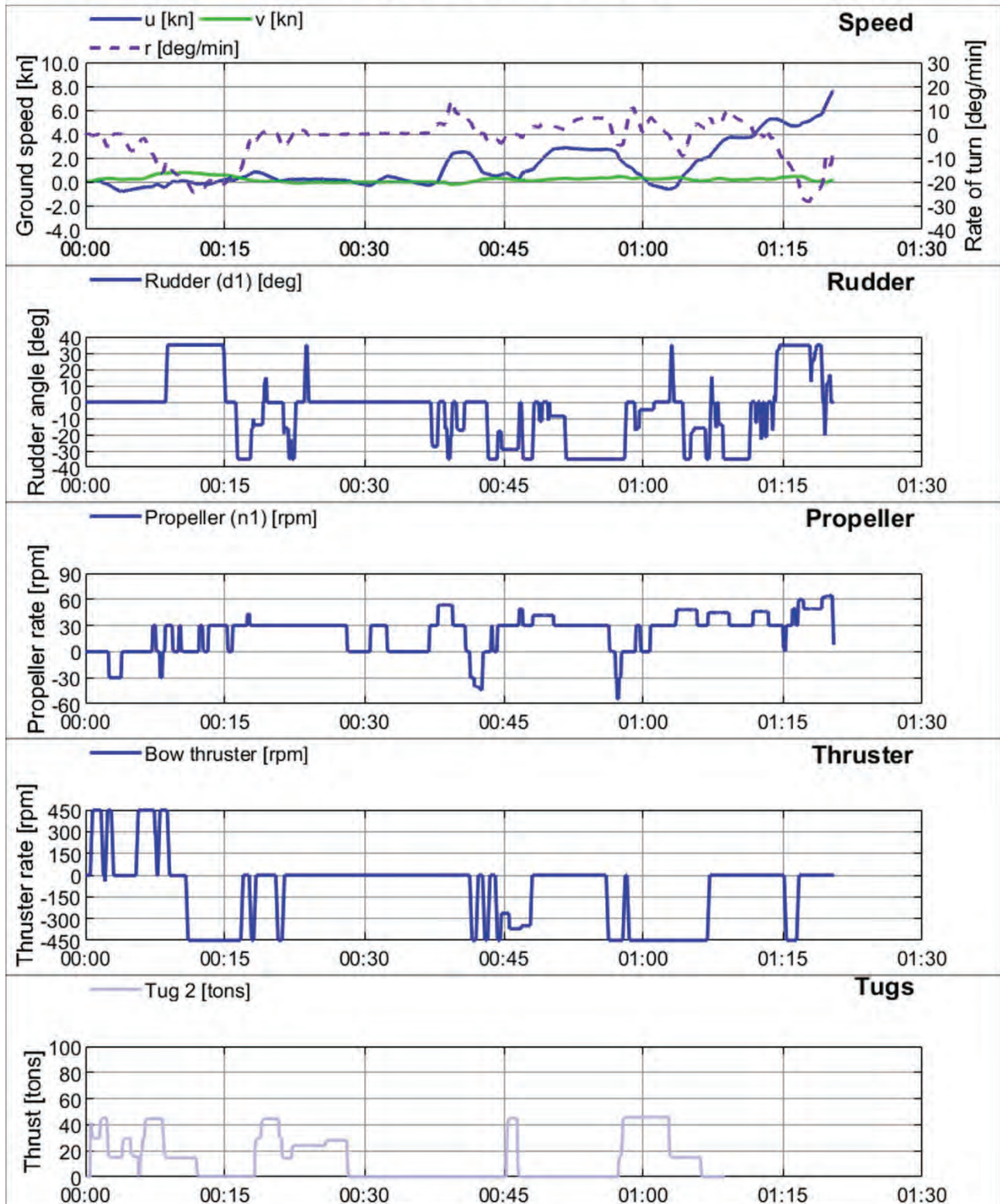
Simulation: M5 P4

Time: 13:54:03

Player: 4/4

Simulator: Sim 5

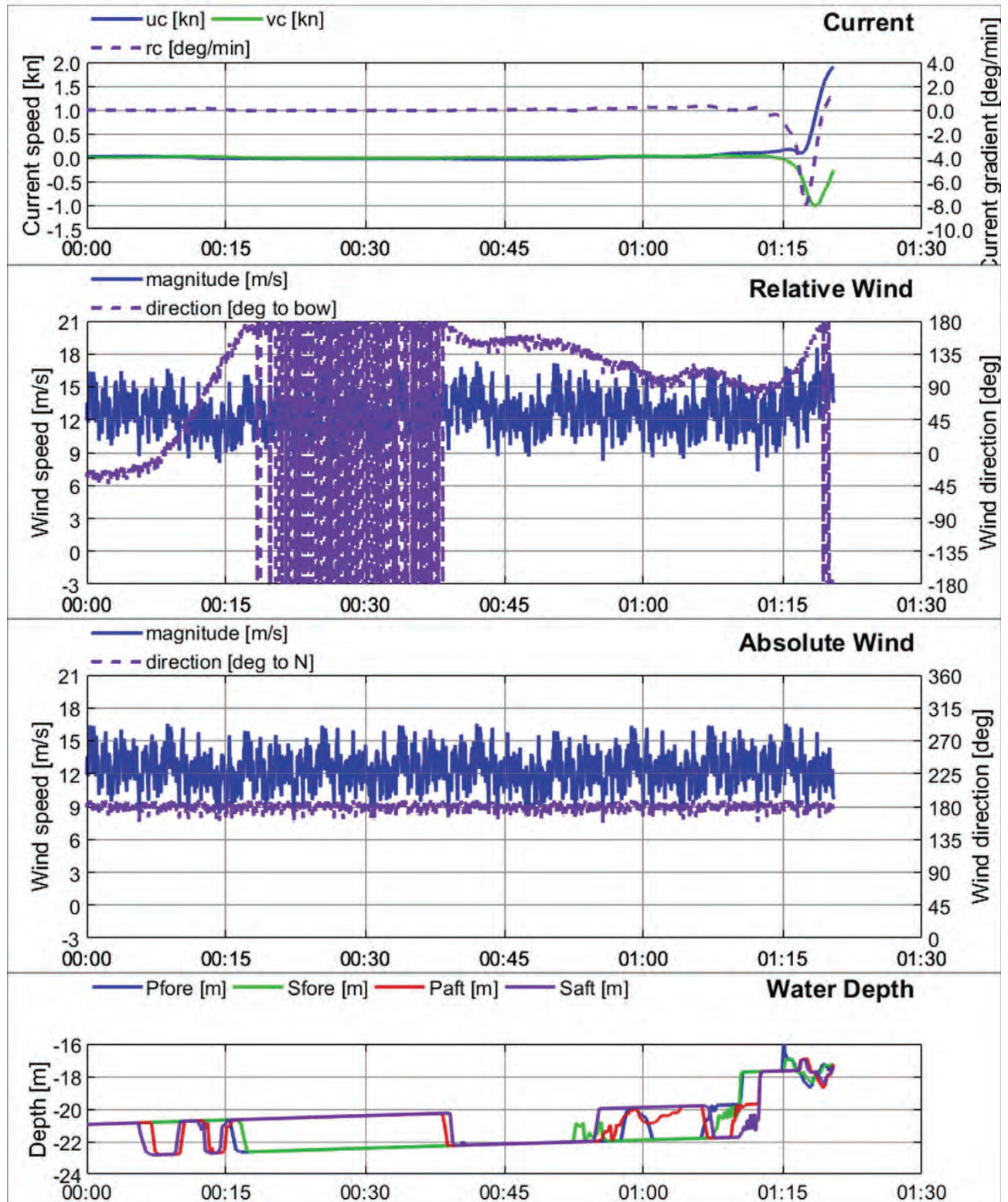
Tugs: 60 60 60 60 tons



[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 21/03/2022
Current: 4hHW dyn
Wind: N6



Container vessel: $L_{OA} = 400$ m; $B = 61.5$ m; $T = 13.1$ m

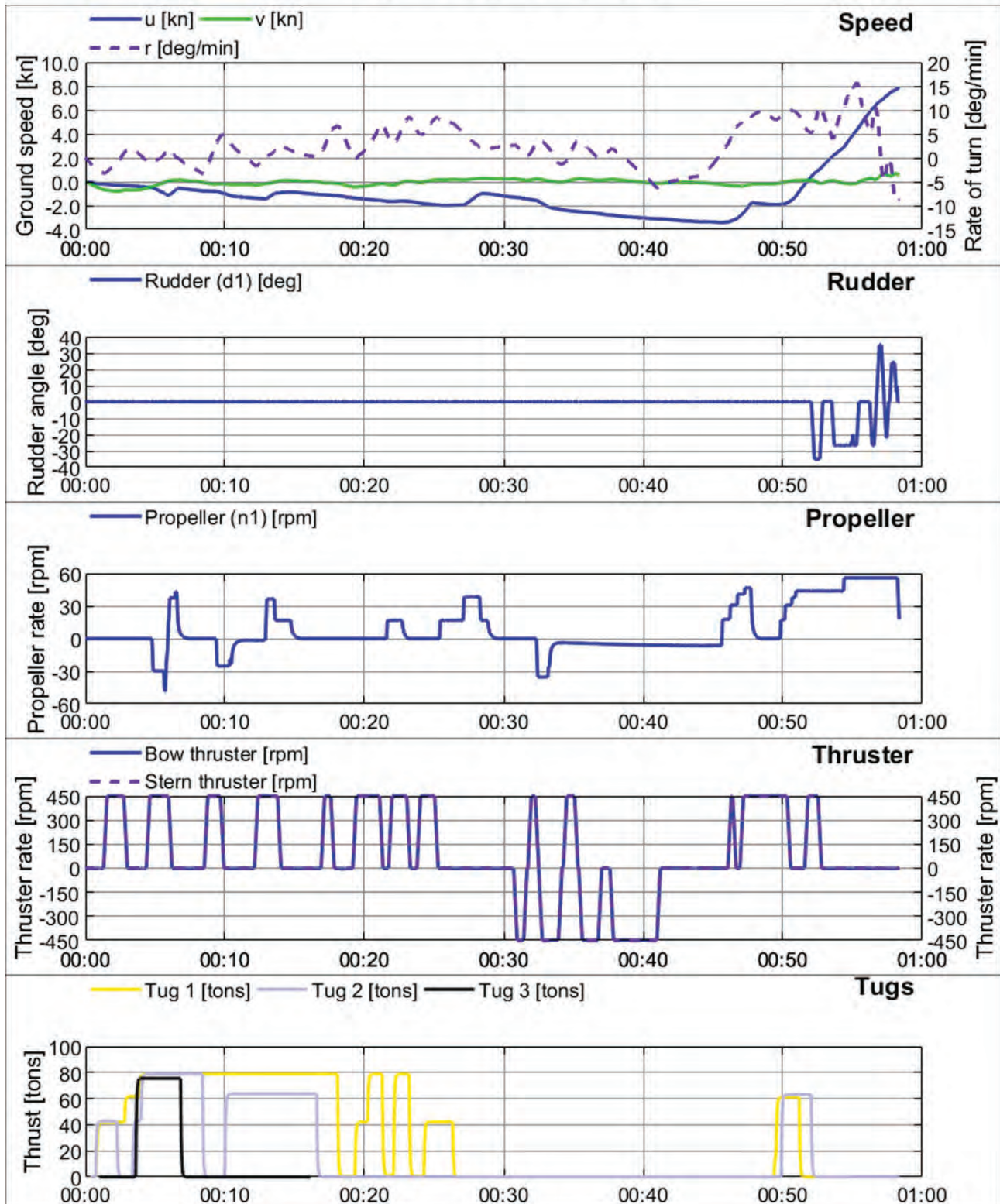
Simulation: M6 P1

Time: 15:52:35

Player: 1/4

Simulator: Sim 360+

Tugs: 80 80 80 80 tons



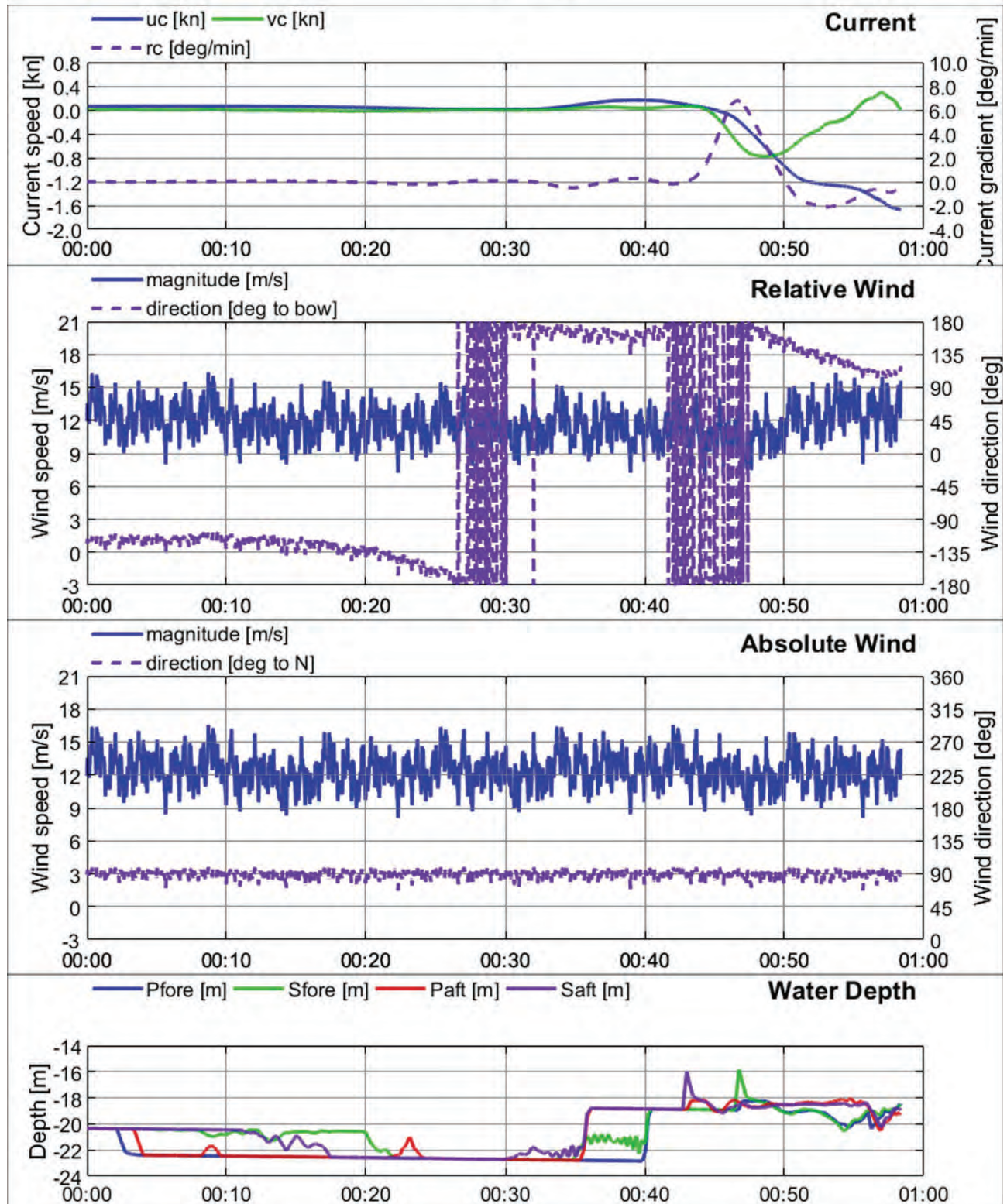
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 21/03/2022

Current: -3.5hHW dyn

Wind: W6



Container vessel: $L_{OA} = 400$ m; $B = 61.5$ m; $T = 13.1$ m

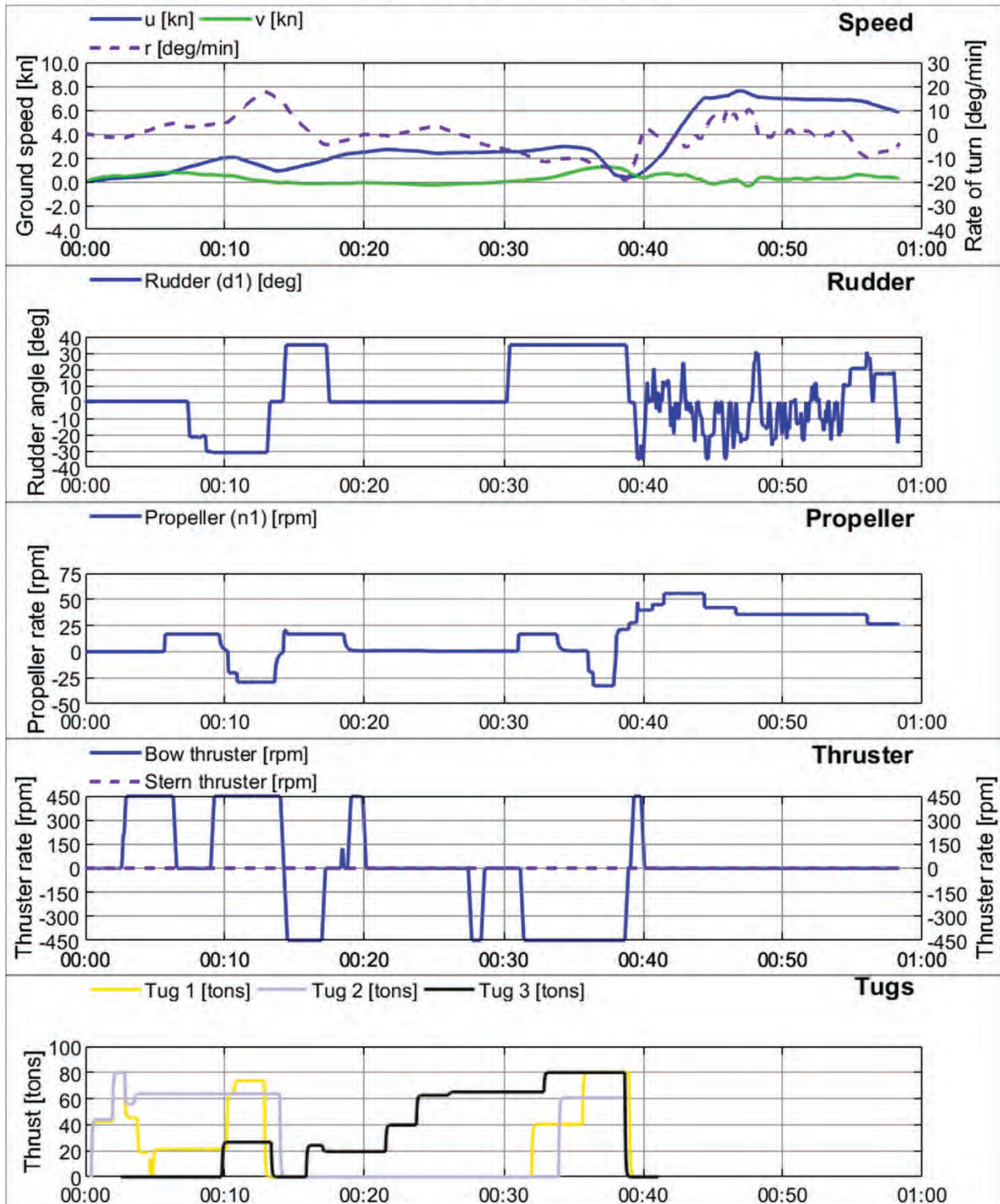
Simulation: M6 P2

Time: 15:56:34

Player: 2/4

Simulator: Sim 225

Tugs: 80 80 80 80 tons



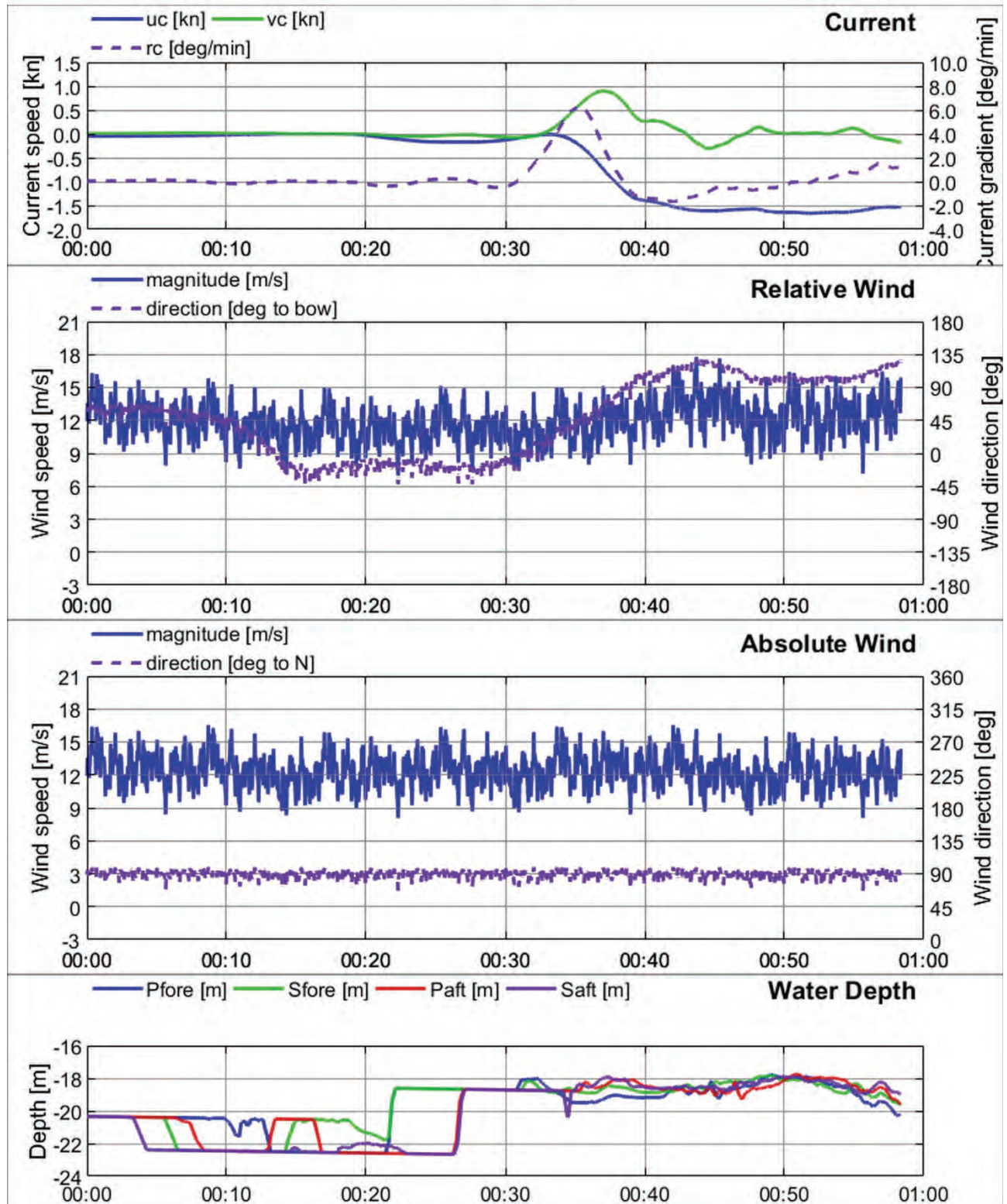
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 21/03/2022

Current: -3.5hHW dyn

Wind: W6



Container vessel: $L_{OA} = 367$ m; $B = 48.4$ m; $T = 14.5$ m

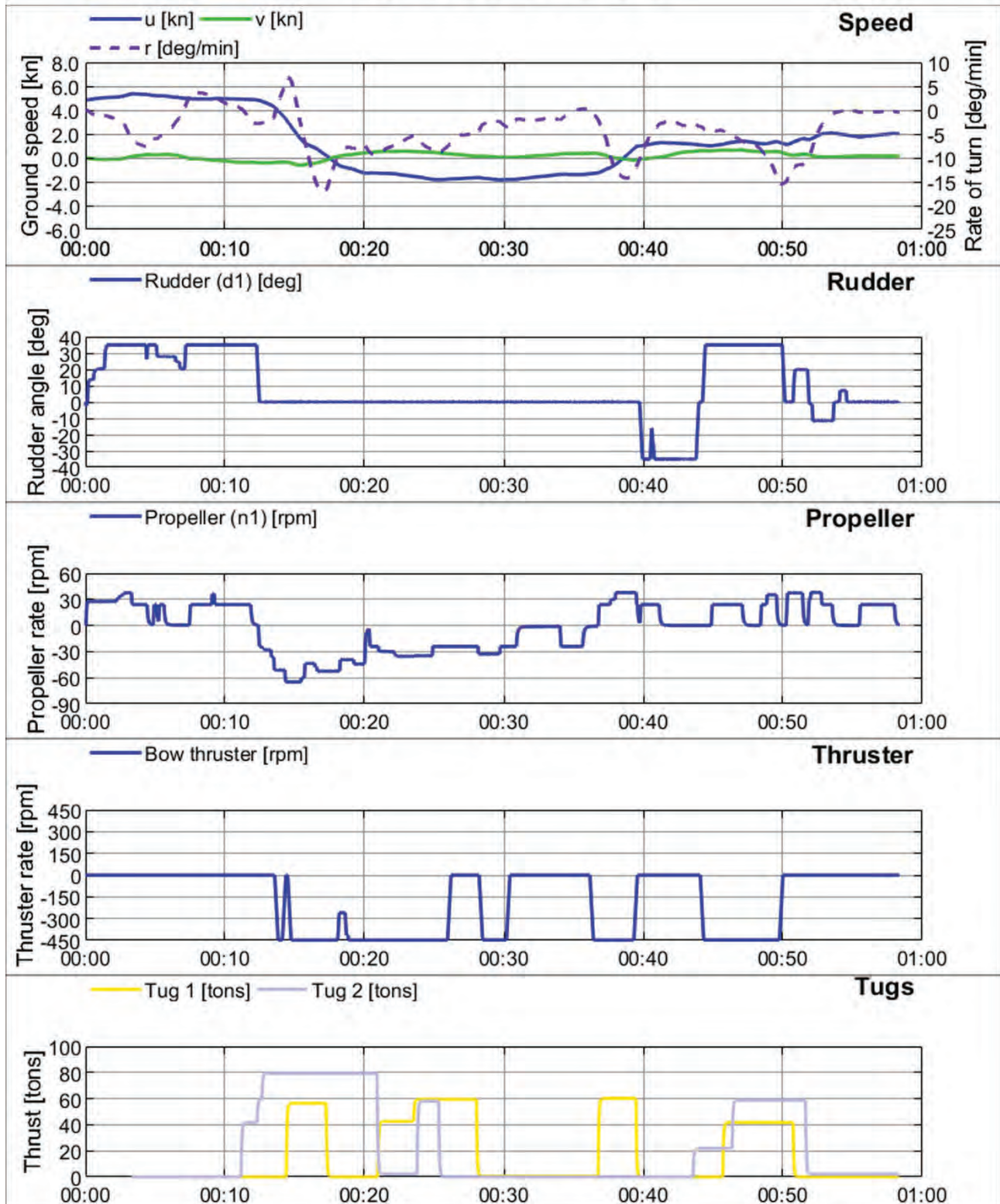
Simulation: M6 P3

Time: 15:57:34

Player: 3/4

Simulator: Sim Lara

Tugs: 80 80 80 80 tons



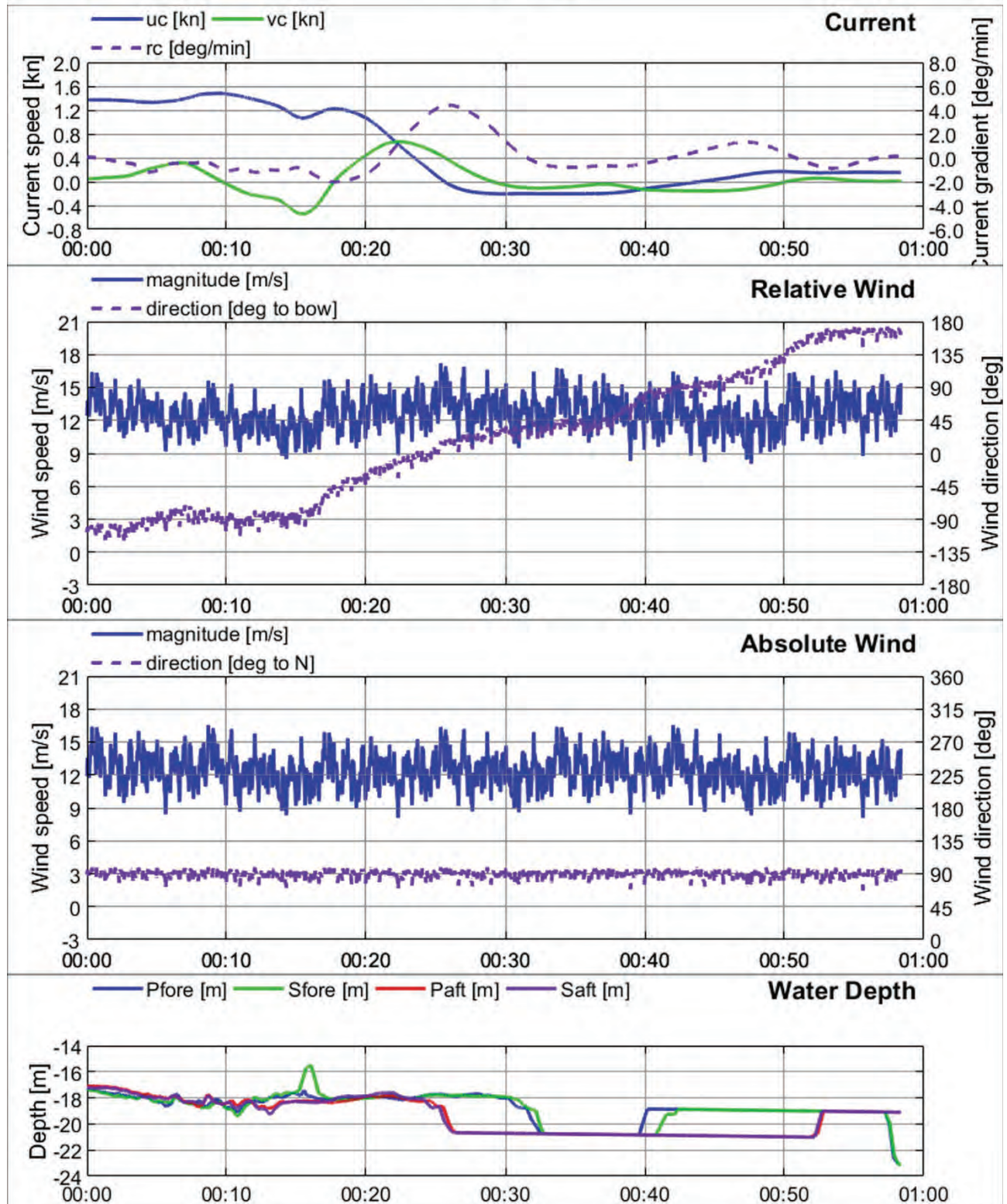
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 21/03/2022

Current: -3.5hHW dyn

Wind: W6



Container vessel: $L_{OA} = 255$ m; $B = 32.3$ m; $T = 12.0$ m

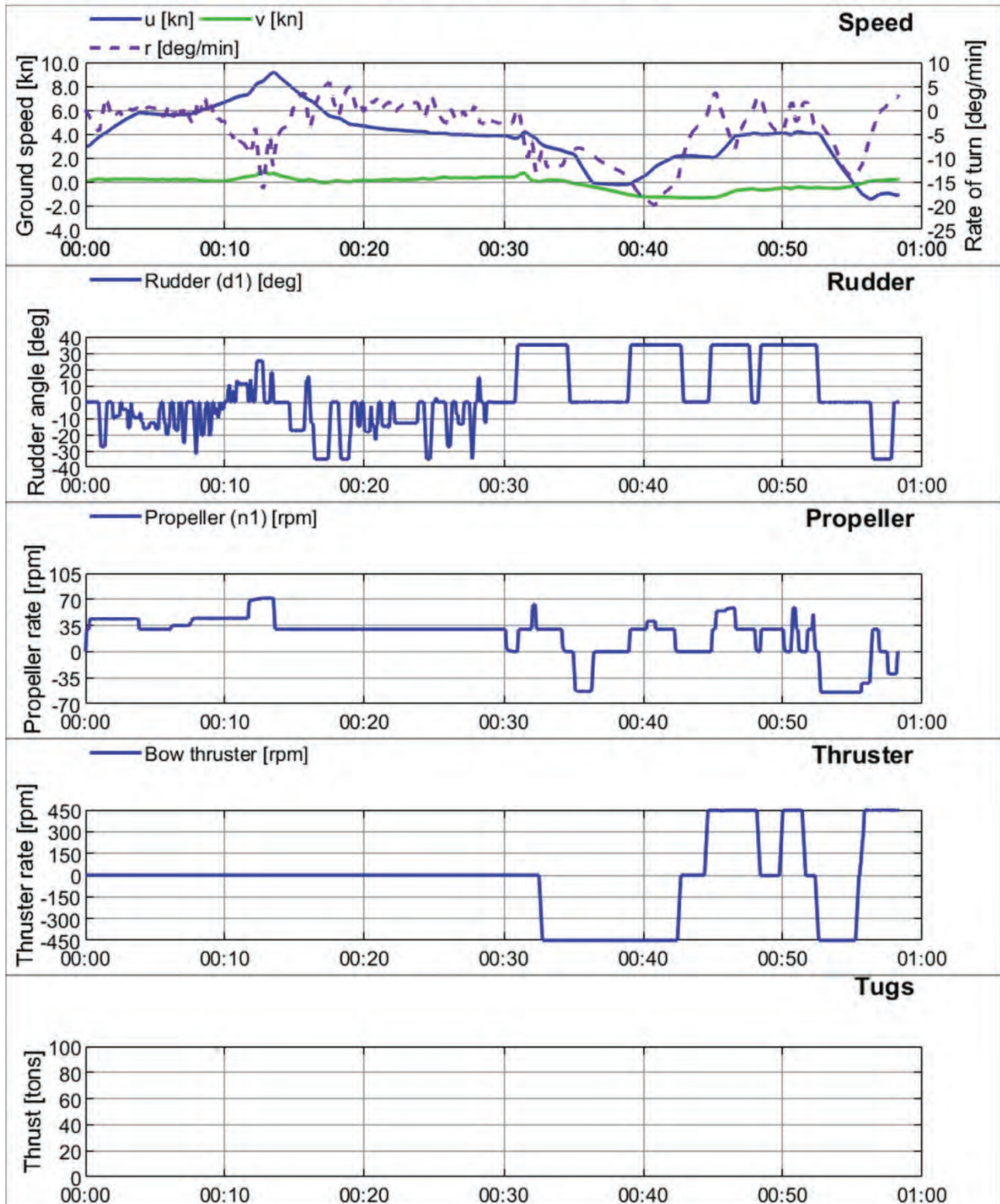
Simulation: M6 P4

Time: 15:51:02

Player: 4/4

Simulator: Sim 5

Tugs: 60 60 60 60 tons



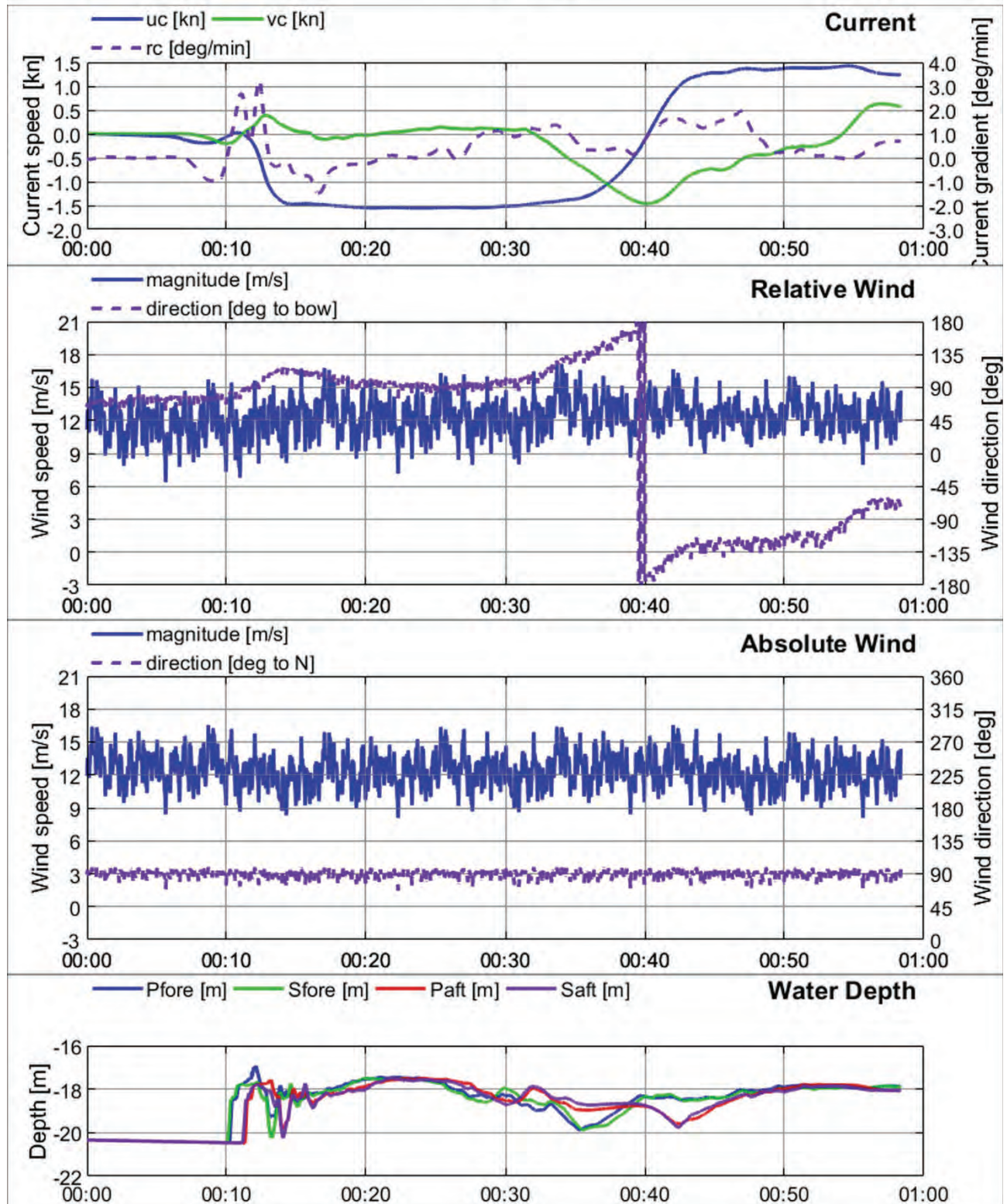
[21 043] Extra Containercapaciteit Antwerpen

Schelde

Date: 21/03/2022

Current: -3.5hHW dyn

Wind: W6



Appendix 5: Crosslines

The crosslines used in the report are based on Verwilligen *et al.* (2021a) and are presented in Figure 70.



Figure 70 – Crosslines and waterway sections from Verwilligen *et al.* (2021a)

The waterway sections chosen and the Lambert coordinates of the crosslines are summarised in Table 34.

Table 34 – Coordinates of crosslines

Waterway section/crossline	Point 1		Point 2	
0290_.kml	223050.0	142074.5	223650.0	142168.1
0330.kml	223300.0	140956.1	223880.7	141550.6
2010_EntranceDGD2GTD01.kml	223163.8	141728.4	223800.0	140903.1
3010_2GTD01_West.kml	222848.5	141210.7	223100.0	141692.9
3010_2GTD01_West_430	222418.5	141210.7	222670.0	141692.9

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