



BETTER SHIPS, BLUE OCEANS



Offshore Operational Advice System (OOAS JIP)

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DOCUMENTATION SHEET: MARIN Simulators

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OFFSHORE OPERATIONAL ADVICE FOR OFFSHORE WIND INSTALLATION AND MAINTENANCE - PUBLIC SUMMARY

For many offshore operators it is a challenge to plan and operate their vessel to its maximum capabilities. For the Dutch energy transition a significant impact is expected from Offshore wind. Innovations, research and development is being supported by a grant of the Topsector Energy of the Dutch Ministry of Economic Affairs (RVO). It has the specific objective to support the joint development of new products, processes or services or the knowledge required for this, which contribute to scaling up the offshore wind energy to about 60 GW (250 TWh) in 2050 at the lowest possible societal costs.

A good example of a joint development for Offshore wind is the Offshore Operational Advisory System (OOAS) joint industry project. A consortium including Acta Marine, MO4, Next Ocean, Radac and SMST was formed and is led by MARIN. We are aiming to improve the efficiency of offshore wind farm installation and maintenance vessels, by using better data for and giving upfront advice on the planning and execution of the operation. The OOAS project started end of 2020 and concluded summer 2023.

Operational complexity

The use case in the developments is the Walk to Work Construction Support Vessel (CSV) Acta Auriga from Acta Marine. The ship is equipped with an SMST walk to work system to transfer technicians from the vessel to the offshore wind turbine. For each approach, the crew decides the heading to approach the turbine. The best heading is depending on many factors. Practical things like the location of landing platform and the wind turbine nacelle heading but also less transparent things like the wind, current and waves and their influence on the vessel response. Especially in a complex wave environment, consisting of a sea and swell(s) from different directions, it can be challenging to find the optimal heading. Contractually the operating limit of the vessel is often related to one single parameter like the significant wave height. In reality the workability limits are much more complex. Insight in how all parameters influence the vessel motion response enables the crew to make a better decision and stretch the operating limits.

Technology under the hood

An onboard forecasting app is developed to give insight in the vessel response by MO4. It represents the vessel response based on weather and wave forecasts to support the crew in selecting the best heading and optimise the planning.

As part of the scope the vessel was equipped with specialised wave radars working on different principles. NextOcean uses the X-Band wave radar and Radac used multiple down looking radars and outlooking radar. The challenge was to record the two-dimensional spectrum which describes how the waves are distributed as a function of frequency and propagation direction. Knowing this accurate wave information has two main benefits: the actual wave information improves the confidence in the wave forecasts and the distributed wave energy improves the prediction of the vessel response significantly. Furthermore it provides very important and complete wave information to validate the ship response model.

The reliability, robustness, and accuracy of the numerical ship response model under the hood of the tool is of vital importance. The Acta Auriga has a unique hull shape and is equipped with a Dynamic Positioning system, an anti-roll tank and a gangway system. This implies nice challenges in creating a numerical model that accurately represents the motion response of the real ship. The monitoring system installed onboard of the Acta Auriga, including the newly included wave radar information, provides an extensive source of information and was used for validation of the numerical modelling. As an example, we used the latest unified flow model in XMF to deliver a validated anti-roll tank numerical model. The non-linear transfer functions based on this model are used in the MO4 application.

Crew centred design

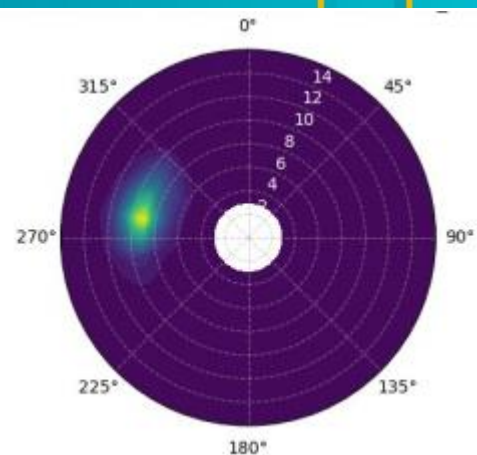
Development of high-tech decision support systems has the risk of running into technical problems resulting in delay. A pitfall often seen in these kinds of projects is that the focus remains on the technical development of the system. Cutting corners in creating a user interface without operator involvement saves time but results in a less optimal user interface. N. Not defining the rules of the game involving both onboard crew and office staff saves time but creates risks in the form of low crew acceptance, poor use or neglect of the system and failure to meet customer expectations investment. Skipping training also saves time, of course, but achieving the goals of the decision support system with an untrained crew is difficult.

In this project we have therefore had multiple visits onboard of the Acta Auriga to have a good understanding of the daily operation. Next a workshop with the crew on shore, captain and DP operator of the Acta Auriga and the app developer was organised making use of the MARIN simulator. During the workshop the technical system, the rules of the game and the required support were evaluated in depth during various scenarios. It resulted in actions for required steps to take for a successful introduction in the daily operation.

This project is made possible by the grant of the Topsector Energy of the Dutch Ministry of Economic Affairs.

For more information watch the OOAS video: [MARIN | OOAS on Vimeo](#)

Or OOAS web page www.marin.nl/jips/ooas



1 PROJECT DATA

RVO reference number	TEHE 119042
<i>Kenmerk besluit tot subsidieverlening</i>	<i>TEHE120FW5GU</i>
<i>Kenmerk wijzigingsbeschikking</i>	<i>TEHE122GVWDU</i>
Project Title	Offshore Operational Advice System (OOAS)
Project partners	Acta Marine, MARIN, MO4, Next Ocean, Radac, SMST
Secretary Applicant (Penvoerder)	Stichting Maritiem Research Instituut Nederland (MARIN)
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2 INTRODUCTION

2.1 Background

During offshore wind farm construction, installation and maintenance the planning and execution of cable laying, wind turbine installation, personnel access or jack-up operations heavily depends on the weather conditions at site. During these operations the vessel needs to keep position in which the wave induced motions and the DP footprint affect the operation. Traditionally wave height was used to determine the operability windows, which result in many unnecessary downtime. By using more complete information and providing this to the onboard crew, it is possible to stretch the operational window.

The operability of offshore wind farm installation and maintenance vessels strongly depends on weather conditions. For example, walk-to-work vessels need to operate closely to wind turbines and connect with a gangway for personnel to access the turbine. Winds, waves and currents impact the ability of a vessel to keep station. High motions in waves can lead up to dangerous situations for the crew or jeopardising integrity of equipment. Operational limits are used to guarantee that operations are executed under safe conditions.

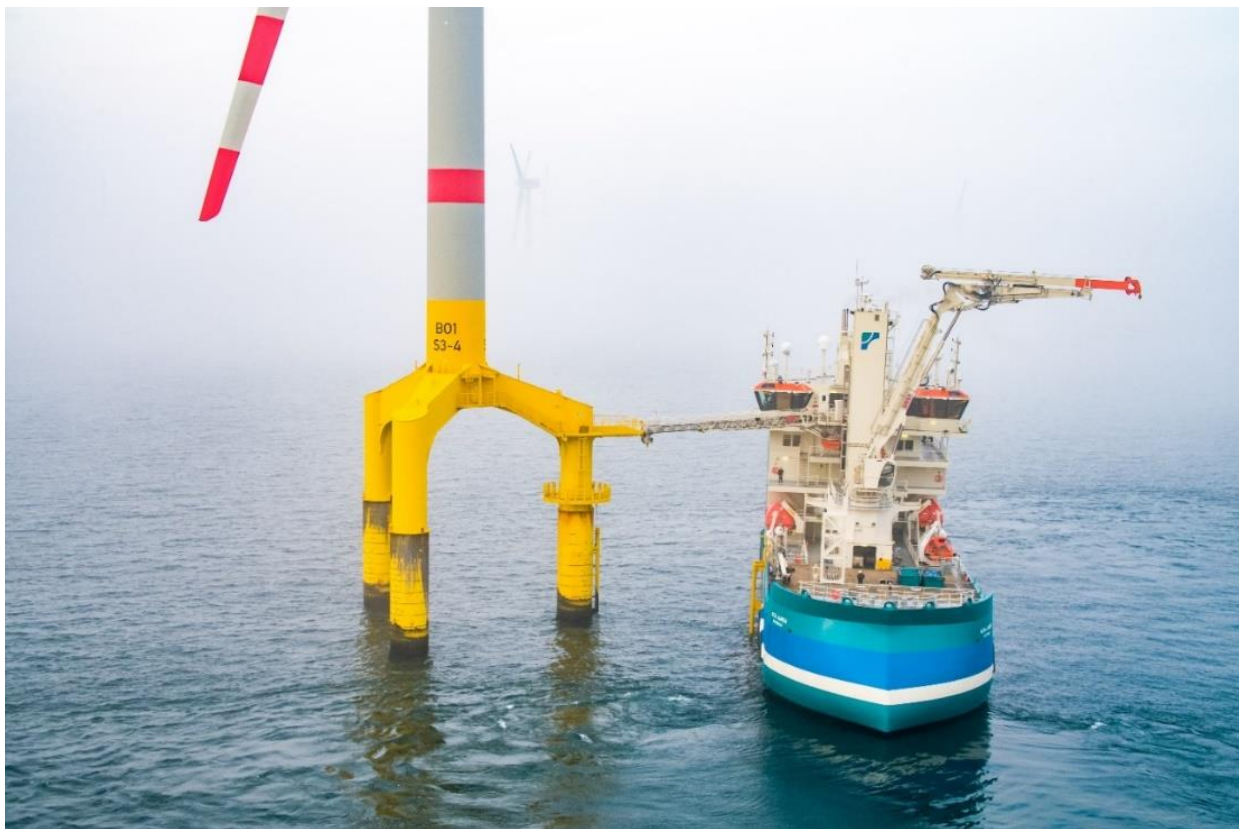


Figure 2-1: Acta Auriga

In the [‘Do-IT’](#) and [‘Access System Utilisation Tool’](#) project, methods were developed to determine wave characteristics and weather windows up to 30 seconds in advance. This allowed critical phases of operations to be executed safer and with a higher workability. However, the tools only measured motions and waves; no mitigation advice could be given in case motion limits were exceeded. Therefore they cannot be used for planning or enhance the workability. In 2019 a feasibility study ([‘Onboard Decision Support’](#)) was performed on the OSV ‘Acta Auriga’ to evaluate the method and add advice and planning functionality to MO4’s decision support tool. In this basic version ship motions and workability were predicted based on basic wave characteristics. This showed the need for more complex sea state characterisation and inclusion of nonlinear responses of the vessel. This preliminary study initiated the

follow-up development of the OOAS project described in this report. The purpose of the joint industry project OOAS is to improve the accuracy of the weather related part of the planning of offshore operations involved in Offshore Wind installation and maintenance. These operations concern mainly crew transfers.

2.2 Objective

The Offshore Operational Advice System (OOAS) joint industry project (JIP) is aiming to improve the efficiency of offshore wind farm installation and maintenance vessels, by giving upfront advice for the planning and execution.

To reach this objective the following sub-objectives are defined:

- Improve accuracy of onboard monitoring of the 2D wave spectra.
- Include non-linear effects of the vessel motion response in the numerical model to accurately represent the response of the ship.
- Install, test and evaluate the system onboard.

In addition to this we agreed that the tool should be used onboard at the end of the project and that it should be possible to include the information about the actual wave measured by the wave radar.

The use case in the developments is the Walk to Work Construction Support Vessel (CSV) Acta Auriga from Acta Marine (<https://www.actamarine.com/vessels/61/Acta-Auriga>). The developments are directly applicable for other types of offshore vessels.

2.3 Approach and schedule

The project was set-up as a Joint Industry Project (JIP) which has the following advances:

- Strong cooperation between the different partners (industry and research) and the sponsors to solve an industry wide problem.
- It offers a route to carry out expensive research and development but spread the costs over a number of interested parties.
- A good spreading of the development knowledge between the participating companies with their own expertise.

The project duration was 2½ years. The OOAS project started Q4 2020. After extension with 6 months the project is finalised in June 2023. During this period a progress meeting was organised every 3 months with all the project partners to exchange the gained knowledge and experience, inform each other about the progress and planned activities and elaborate on the way forward.

2.4 Project partners

A consortium including Acta Marine, MO4, Next Ocean, Radac and SMST was formed and is led by MARIN. An overview of the partners, type of organisation and role in the project is given in Table 2-1.



Figure 2-2: Overview of project partners

Table 2-1: List of project partners

Project partner:	Internet Address	Type	Role in project
MARIN	www.marin.nl	Research institute	Project coordinator MARIN will deliver the hydrodynamic core (WP1) and the dedicated tests and validation of the model (WP3). Furthermore we will take part in the joint evaluation of the tool (WP5).
Acta Marine Offshore Services B.V.	www.actamarine.com	MKB	Ship operator and responsible for providing the test platform (<i>Acta Auriga</i> and/or <i>Acta Centaurus</i>). More in detail: they will facilitate the dedicated tests (WP3), provide the full scale measurement data for the evaluation phase (WP5) and give feedback on the developed approach by their operational experience.
MO4	https://MO4.online	MKB	Delivers the platform that handles the incoming data, the algorithms as developed in the method and the presentation of clear and concise data to the relevant decision making people on board in WP1, 3 and 4 and evaluate the tool (WP5).
NextOcean	www.nextocean.nl	MKB	Next Ocean will further develop their wave radar system in WP2 that is capable of measuring directional wave spectra and surface current, using sensor fusing of the ship's navigation radar and a motion sensor. This will be input to the planning tool in order to quantify wave forecast errors in WP3 and to enhance the accuracy of the real time heading advice.
Radac	https://radac.nl	MKB	Wave radar Manufacturer and developer of Wave Radars. For this project the new 3D wave radar will be improved so it delivers accurately the wave and current condition the vessel is operating in (WP 2). The radar will be improved and validated as part of WP 5.
SMST	www.smstequipment.com	Medium company	SMST delivers the gangway system, which is also installed on the <i>Acta Auriga</i> . In WP 1 and WP 3 and 4 the control system of the gangway system will be improved by using real time weather conditions.

3 PROJECT RESULTS AND DISCUSSION

3.1 General

This section provides an overview of the activities, results and a discussion of the results. It starts with a description of the scope of work and the division and contributing partners of the work packages. This is followed by an overview of project internal reports that were used as a basis to write this technical summary report. The used case for this development is the Offshore Construction Support Vessel Acta Auriga. The vessel, the schedule of the vessel during the project and the support from Acta Marine is described in Section 3.4. These introductory paragraphs are followed by a technical summary of each work package.

3.2 Scope of work

The project partners developed and evaluated a planning system that makes use of a numerical model of the walk-to-work vessel Acta Auriga of Acta Marine and the gangway of SMST. The numerical model considers the hydrodynamic characteristics, the DP system and gangway and an anti-roll tank and is developed by MARIN and MO4. This accurate model is combined with a weather forecast and used to predict the operability. The model is validated with detailed environmental and response data gathered on board by project partners Next Ocean and Radac. An overview of the work package and contributing partners is given in the table below.

Table 3-1: Overview of the Work Packages

WP	Name	Partners
1	Motion simulation model	MARIN, MO4, Acta, SMST
2	Wave finecast	NextOcean, Radac, MARIN
3	Validation simulation model	All
4	Advice & planning tool	MO4, Acta, MARIN
5	Implementation and evaluation	MO4, Acta
6	Project management	MARIN, all partners

3.3 Overview of project reports

An overview of internal project reports is given in the table below:

Table 3-2: Overview of the project reports

Name	Content	Author
SeaStateFromMultipleVesselMountedRadars	Comparison of wave measurements	Radac
20230626_2023-06-006-01_0_OOAS_final_report	Final report OOAS, describing the system improvements, fixes, analysis, results and conclusions	NextOcean
2D_spectra_St_Nazaire	Memo on the comparison of waves	MO4
MEM-20066-001-01	Memo on the comparison of motions	MO4
Eindrapport SMST_v012.docx		SMST
OOAS Rapportage – AM.docx		Acta Marine
Report 32468-1-MO_OOAS_VisitActaAuriga_V1.1		MARIN
Report 32468-1-MO/HF_OOAS_SimulatorWorkshop_V1.0		MARIN

These reports are used as a basis to write this technical summary report.

3.4 Construction Support Vessel Acta Auriga

Acta Auriga is an Offshore Construction Support Vessels (CSV) owned and operated by Acta Marine. Main dimensions are given in the table below. The vessel provides accommodation for 120 persons. The vessel is equipped with five thrusters:

- 2 x Rolls-Royce Azimuth Thruster US 205P20 FP 1500 kW @ 1200 rpm;
- 2 x swing up bow thruster Rolls-Royce TCNS 75/M-170 880 Kw @ 1800 rpm;
- 1 x tunnel bow thruster Rolls-Royce TT2200 DPN FP 1040 Kw @ 1200 rpm.

To keep the Acta Auriga on position the vessel is equipped with a Rolls-Royce Icon DP system. Furthermore the vessel is equipped with a controlled SMST gangway for transfer of technicians to the wind turbine.

Table 3-3: Main dimensions of the Acta Auriga

Dimension	Unit	Acta Auriga
Length overall	[m]	93,4
Length between perpendiculars	[m]	89,6
Beam (waterline)	[m]	18,0
Draught	[m]	5,6
Displacement	[m ³]	6.440
Service speed (harbour full)	[kn]	9,6
Engine power (manoeuvring mode)	[mW]	5,8
Bow thruster	[mW]	1,04
Frontal wind area (A_x)	[m ²]	132
Lateral wind area (A_y)	[m ²]	702



Figure 3-1: Picture of the SMST gangway to transfer from the Acta Auriga to the wind turbine

During the period of the OOAS project the Acta Auriga operated in four wind farms. This is summarised in the table below.

Table 3-4: Vessel schedule and wind farm locations

time	Wind farm location
... - April 2021	Bard
May 2021-March 2022	Hornsea 2
April 2022-November 2023	Saint Nazaire
November 2023-April 2024	Hollandse Kust Noord

During this project, Acta Marine provided support to all stakeholders by offering operational feedback. This feedback consists of measured data obtained from several years of offshore operations on various wind farms, as well as feedback from seafarers. The involvement of Acta Marine was beneficial because their primary focus was on assisting with the installation of offshore wind farms. Consequently, a significant amount of environmental data and vessel motion data was gathered from diverse offshore locations during both summer and winter periods. The experiences and on-site visual observations of the main offshore stakeholders aboard the vessel, specifically the Deck Equipment Operator (DEO) and Dynamic Positioning Operator (DPO), played a crucial role in validating the mathematical and theoretical models. Furthermore Acta Marine share with the project partners the activity code from the daily progress reports (DPR) such that relevant and interesting moments could be selected for the analysis and validation.

3.5 Motion simulation model (WP1)

A stand-alone simulation model is developed based on MARINs in-house developed in aNySIM XMF. This high fidelity time domain simulation software is used to include non-linear responses such as:

- DP station keeping accuracy.
- Non-linear damping: linear and quadratic damping, anti-roll tank damping.
- Low frequent wave drift forces.
- Response in crossed environmental conditions.

The MO4 hydrodynamic model is based on a frequency domain approach. A frequency domain approach is generally more robust and fast then a time domain approach. The onboard app needs to be able to do onboard calculations and do this for a large number of data points. Calculation speed and robustness are therefore required. The disadvantage of the frequency domain approach is however that it is more challenging to include the non-linear and low frequency effects correctly. Therefore MO4 and MARIN worked together to substantiate the choices made in the frequency domain approach based on the numerical models from the time domain approach.

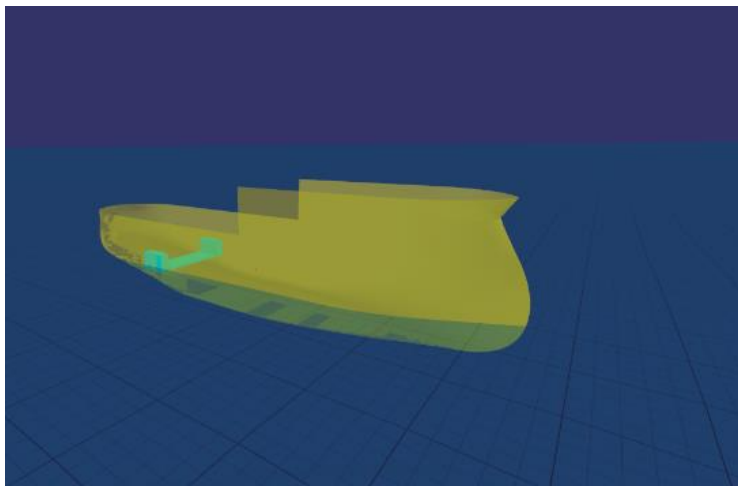


Figure 3-2: Numerical model of the Acta Auriga with the Anti-Roll tank (MARIN)

In short this included the following activities:

- ART modelling and conversion to a database for further use in the frequency domain core.
- Investigation in the statistics of the response of the vessel to substantiate the linear approach.
- Assessment on combining wave frequency and low frequency response.
- Attempt on reverse engineering of the settings of the DP system.
- Alignment on data storage and use of measured data.

Detailed information about the gangway is provided by SMST. This includes physical, performance and system limitations and knowledge and experience to the project about gangway operations. Minimum motions generally mean minimum power consumption, as well as increased comfort level for personnel. Furthermore the gangway market is evolving rapidly and by SMST involvement we could anticipate with the numerical model on future operations. The frequency domain core developed by MO4 is used in the tool developed under WP3.

The time domain simulation model of the Acta Auriga developed under WP1 was later in the project also used for the workshop on the MARIN Bridge simulator as described in paragraph 3.9.1.

3.6 Wave Finecast (WP2)

The wave measurement techniques, implemented as part of the OOAS project, aim to provide validated sea state information to support efficient planning in offshore wind farms. Accurate, measured 2D wave spectra are determined and this has two purposes: Accurate on board wave observations will improve the accuracy of operational now-cast and provide information to validate and detect trends/bias in weather forecasts that can be taken into account.

In WP2 a wave and current observation system is developed that is able to determine the 2D wave characteristics (height, period, direction spectra for both waves and swell). The following methodologies are used:

1. Fused navigation X-band radar with motion sensor (suitable, fair to good agreement).
2. FMCW radar (suitable, only 90 deg azimuth).

The development of the two developed methodologies are described in more detail in below paragraphs. This is followed by a description of the reference wave data and the validation of the results.

3.6.1 Fused navigation X-band radar with motion sensor

Main task of Next Ocean within the project is to provide and validate the 2D wave spectra observations obtained from Next Ocean's Wave Analyzer, based on X band radar data.

As part of the work done to improve the directional wave spectrum and current detection, improvement have been pursued on both hardware, software algorithmic and robustness / bug fixing. These are reported extensively in the NextOcean report referenced in Table 3-2. In this paragraph a short summary is given. Of the set-up and developments, followed by a selection of results from the validation in paragraph 3.6.4.

The working principle of using a radar from wave measurements is that the radar backscatter data from incoherent pulse radar can be modelled as being proportional to the *angle of incidence* between the EM waves and the normal to the sea surface. In order to obtain a wave spectrum associated to the *wave elevation*, a modulation transfer function (MTF) is required. The mentioned MTF has been implemented in the operational software and used for all (re)generated results presented in this report. Improvements were made during this project. Some examples are the MRU processing (aliasing), recorded motion buffer robustness and synchronisation, radar antenna orientation and MRU orientation.

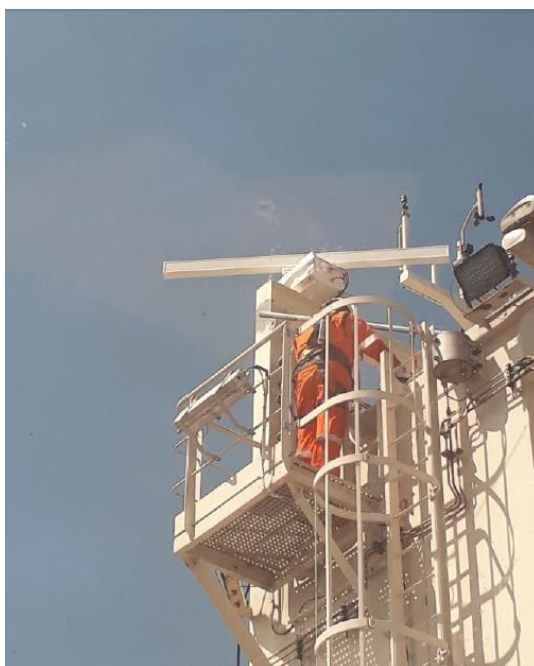


Figure 3-3: Transceiver and antenna mounted at the top of the gangway tower (NextOcean)

In order to provide insight in wave spectrum and the surface current (output from the NextOcean Wave Analyser) the effect of these conditions on the vessel operations is visualised in an animation. This animation is coupled to the so-called activity code from the daily progress reports (DPR) of the Acta Auriga as provided by Acta Marine. A snapshot from this animation is shown in Figure 3-4.

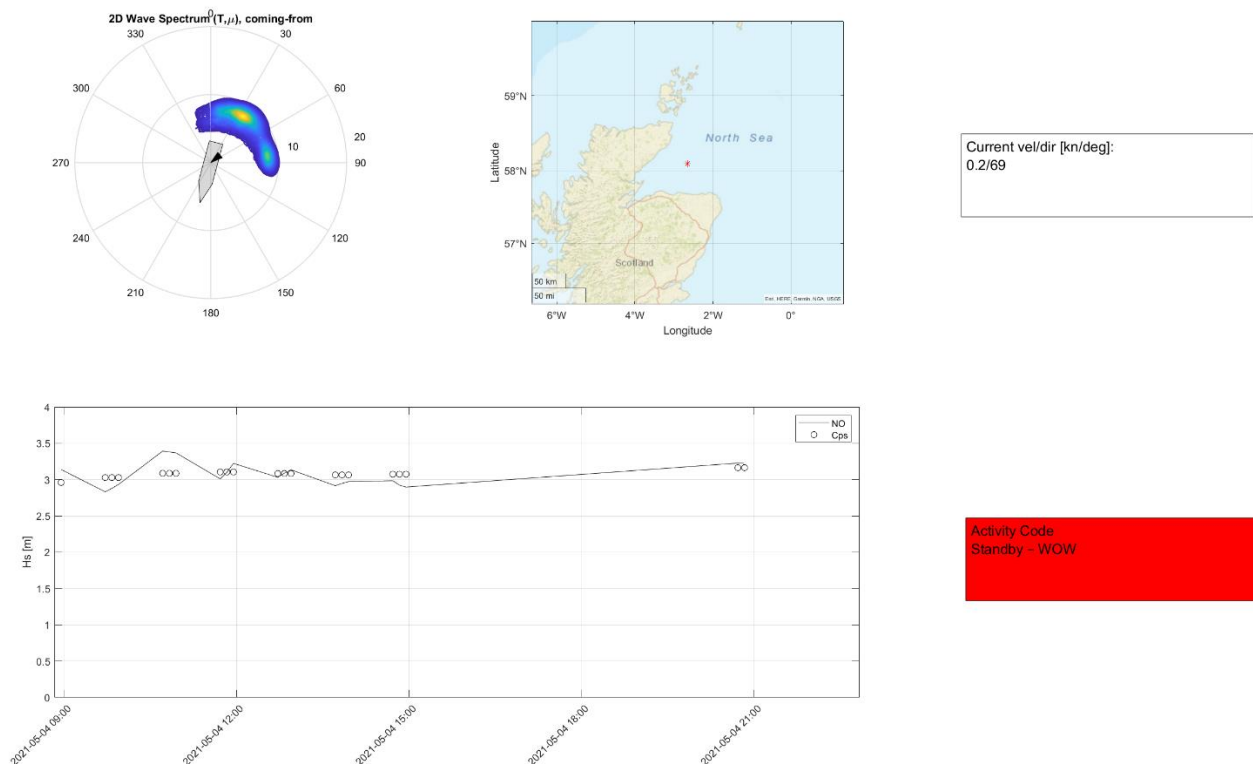


Figure 3-4: Combined visualisation of the Wave Analyzer output and DPR (NextOcean)

Data has been recorded throughout the project, starting from the moment the dedicated radar was commissioned (May 2021) until the end of the project (June 2023). In this period also the raw data was stored to allow for re-analysis after updates in the system. Of all available hours of collected data, a selection was made for re-analysis with the purpose of limiting the analysis to the most relevant circumstances, both in terms of purpose and expected capabilities of the system. From the total available 10476 hours of collected data, 4510 have been selected for further (re-)analysis. Significant progress was made on system improvements and concerning the surface current detection and spectral shape.

3.6.2 FMCW radar

The Radac system utilises four independent wave radar systems on the Acta Auriga vessel, each equipped with its own motion sensor. Two Waveguide Direction Onboard 2 (WDO2) systems, consisting of three X-band FMCW radars each, were installed on the portside and starboard bridge wing (reference as *downlooking radars*). Additionally a new type of sensor known as the Outlooking Radar, employing a Phased array FMCW radar operating in the X-band, was positioned on both bridge wings, capable of performing detailed scans of the sea surface up to a distance of 384 meters.

During a 25-month operational period, the Acta Auriga operated in four wind farms, with detailed analysis conducted in the Hornsea 2 and St. Nazaire periods. Sea state measurements were carefully analysed and compared to available buoy references.

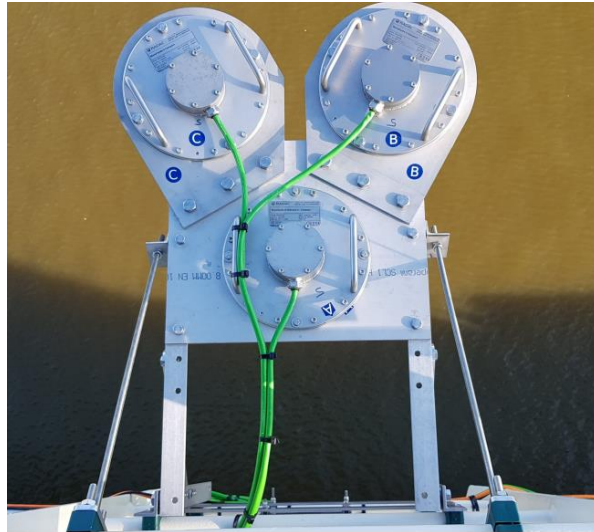


Figure 3-5: Downlooking radar installed onboard Acta Auriga (Radac)

Downlooking radars

The results obtained from the down looking radars indicate that each individual WDO2 agrees well with the buoy references when the vessel is heading into or away from the waves. However, in beam seas, a significant difference between the port and starboard sensors was observed due to the vessel's impact on the measured wave field. To address this, a reprocessing technique was employed to combine the results from both sides of the vessel, resulting in an excellent agreement between the corrected significant wave height and buoy references, with a correlation of 0.997. Based on these findings, it is concluded that the WDO2 systems provide reliable sea state information for the project.

Outlooking radars

Significant development efforts were dedicated to processing the outlooking radar data, which involved raw data analysis and two processing categories: statistical and deterministic processing. Improvements were made to the stability of the raw data stream and the accuracy of the velocity estimator, enhancing the quality of the raw data. Both statistical and deterministic processing approaches demonstrated good agreement with the reference data, although the accuracy was affected by the aforementioned challenges with raw data.

For Radac's Outlooking Radar the surface current measurements are based on a doppler shifting of the radar signal as it reflects from the surface of the water. As such it can be seen as a direct measurement of the surface velocity. Observations are made into different viewing directions. After which a linear fitting technique is applied to conclude the actual current vector. Combining results from both port and starboard radars (Figure 3-8) shows that the results are consistent over a full 180 degree observation.

3.6.3 Reference wave data

For validations purposes this WP initially involved reference in field measurement. Ideally this reference data contains the information of the wave spectrum including the full directional spreading. Despite the proven perseverance it proved impossible to obtain this complete measured data for locations close to the operating area of the Acta Auriga. In the validation use was made of measured parameterised data and hindcast data.

It was intended to use a MARIN wave buoy in the field for a couple of months. Instead of renting a buoy for a relatively long period it was decided to purchase a Spotter wave buoy. Due to wind park restrictions it was impossible to get permission to deploy the buoy. Also the MARIN in house developed autonomous self-sailing wave buoy, the C-drone, has been tested but was not deployed in the field.



Figure 3-6: picture of the Spotter and the C-drone (MARIN)

The Radac downlooking radars are proven technology on fixed structures and could have been valuable as reference data, however this does however include the effect presence of the ship. Correction methods are applied as described in the previous paragraph but not yet validated and therefore this is also not an ideal source as pure reference.

For St Nazaire, a limited set of wave parameters (H_s , T_P and wave direction) from a local buoy ('Nortek:Saint-Nazaire:EAST_BUOY') was made available by MO4. The latter was not useful for full validation of the directional wave spectrum. Therefore the most useful reference data set was considered to be available from Copernicus, the earth observation component of the European Union's Space programme. From the data available through the Copernicus database, specifically the so-called ERA5 re-analysis data produced by the ECMWF has been used. (See <https://climate.copernicus.eu/climate-reanalysis>).

Ship as a Wave Buoy (SaWB)

Wave determination based on vessel motion measurement (Ship As a Wave Buoy), based on Machine Learning, was considered to be applied under this WP. The intention was to reconstruct directional spectra based on the recorded ship motions. However this was cancelled because of the lack of reference data with information about directional spreading of the waves to train the model. Using the motion response of the ship in the wave prediction is part of the NextOcean methodology though.

3.6.4 Validation

Current

An important output parameter of the system is the estimation of the surface current. Estimation of the current by wave radar is based on use of the dispersion relation to fit the current direction and velocity to the phase speed of the waves. This means waves have to be observable in order to estimate the current.

The process of fitting the current to the observed propagation behaviour of the waves uses a selection of wave components that represents sufficient energy. Important improvements in the algorithm that selects the wave components used for current fitting have been achieved leading to more accurate current estimates. The correlation between the deterministic computed and recorded vessel response can be compared between the initial and updated current estimation. An example of a time trace of these correlations for heave roll and pitch response is given by in the figure below. This shows the old and new current estimates.

Multiple hours of data have been investigated in this way, all showing either similar or improved correlations, from which it was concluded that the updated current estimation algorithm indeed is an improvement.

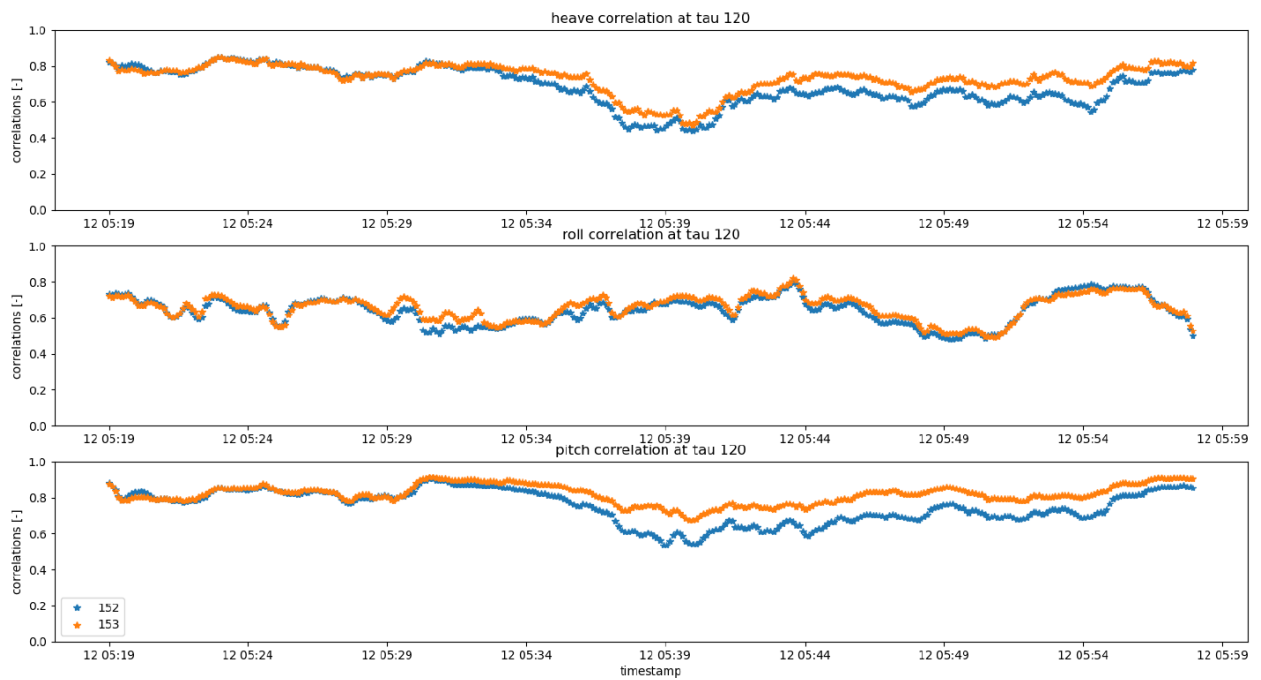


Figure 3-7: Heave, roll and pitch correlation for old and new current estimation (NextOcean)

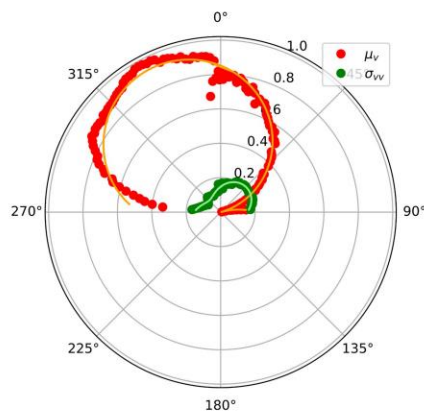


Figure 3-8: Outlooking radar showing consistent average current and velocity (Radac)

Waves

As described in the previous paragraph it has been challenging to obtain reference wave data to the level of detail that it enables validation of the directional wave spectrum. The lack of accurate reference data including the effect of the directional spreading of the waves has effected the validation. However with parameterised data, combining different sources of measured data and combining this with hindcast data was did gain significant insight in the performance of the wave radar techniques.

For the purpose of quantifying the quality of observations / estimations of the 2D spectra, a limited number of parameters was chosen. Since Copernicus data appeared to provide the most complete reference data set, the selection / definition of these parameters was established based on availability via the Copernicus portal.

For the most important parameters¹ NextOcean made a comparison with the Copernicus information. Based on this comparison the following conclusions are justified:

- Validation of the directional wave spectra has been challenging due to very limited availability of reference data. Mainly Copernicus data has been used for validation. For this reasons, only a limited set of parameters was used for validation.
- Concerning Significant Wave Height estimations, fairly good agreement with Copernicus (and buoy) data was found. However, a bias to underestimation, especially for lower wave heights, will be subject to follow-up research.
- Mean wave directions show a good match too.
- Wave Peak Period show good agreement with Copernicus, obviously with the expected noisiness because of unsynchronised jumps from sea to swell peaks.

Radac concludes that while each system individually can provide sea state information in agreement with the references, further work is necessary to ensure consistent and reliable results. Additionally, the development of a clear quality indicator could enhance the sensor's overall performance and development status.

Direct validation of directional spreading is complicated. A visual comparison is made for a selection of relevant conditions. The spectra from Radac and NextOcean systems are visually compared with the wave spectrum from InfoPlaza. An example of such visual comparison is shown in Figure 3-9.

Furthermore some insight on how good the directionality and spreading in the measured wave spectrum is, is reflected in the comparison of the vessel motions described under Section 3.7.

¹ Significant Wave Height (of all wave systems summed up)
Mean wave period based on first order spectral moment
Mean Wave Direction
Mean Spectral Spread
Goda spectral peakedness factor

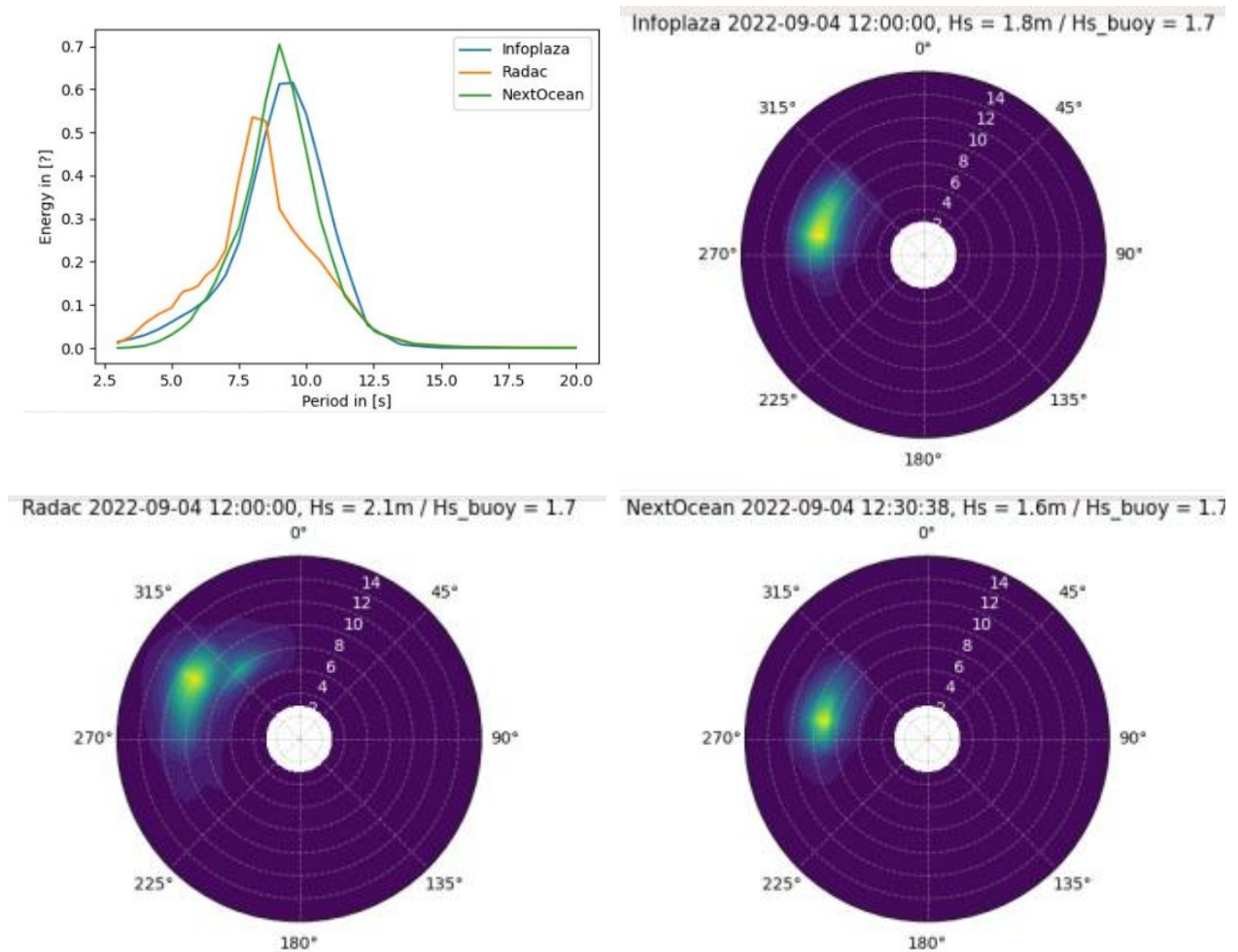


Figure 3-9: Example visual comparison of the wave spreading and hindcast (sept 4) (MO4)

3.7 Validation simulation model (WP3)

The numerical model of the vessel motion response, developed under WP1, includes several “challenging to model” characteristics. The behaviour of the DP system, gangway and anti-roll tank are examples of systems that require dedicated set-up, tuning and validation. To correctly include their behaviour in various conditions the Acta Auriga is monitored over the full duration of the project. Furthermore dedicated trials are carried out.

Data is collected from all relevant systems onboard the Acta Auriga. The output of those reference sensors for wave height, current, wind, ship motion, propulsion power and fuel consumption are used to compare with the numerical model developed under WP1.

As an example the onboard measurement, numerical modelling and validation of the Anti-Roll tank is described in more detail below.

Anti-Roll Tank

For the workability of the ship the roll response is very important. To minimise the roll motions the ship is equipped with an Anti-Roll Tank (ART). It is important that the roll response in the numerical model accurately represents the roll response of the real ship. To do this the numerical is configured with a ART. This modelled ART is tuned to match the reality and this is validated with onboard measurements. The figure below shows a dedicated heeling test of the ship and the effect on the level in the ART tank on the left. On the right the same test is applied to the numerical model using two different approaches (Stichter and Unified Internal Flow (UIF)).

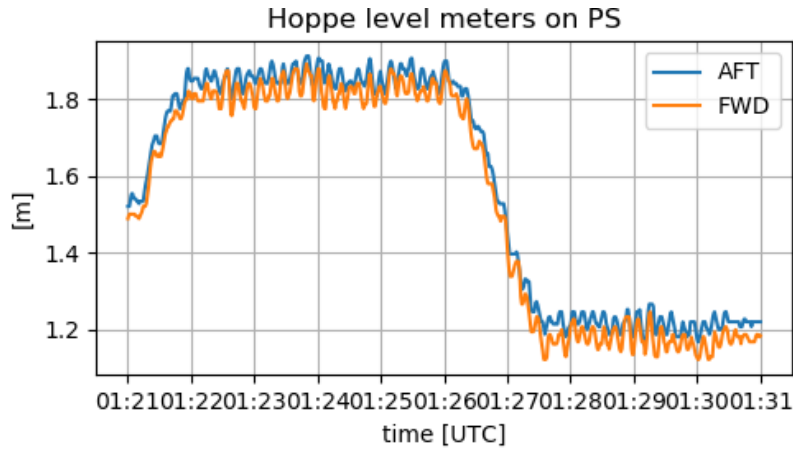


Figure 3-10: Dedicated heeling test required for tuning of the ART numerical model

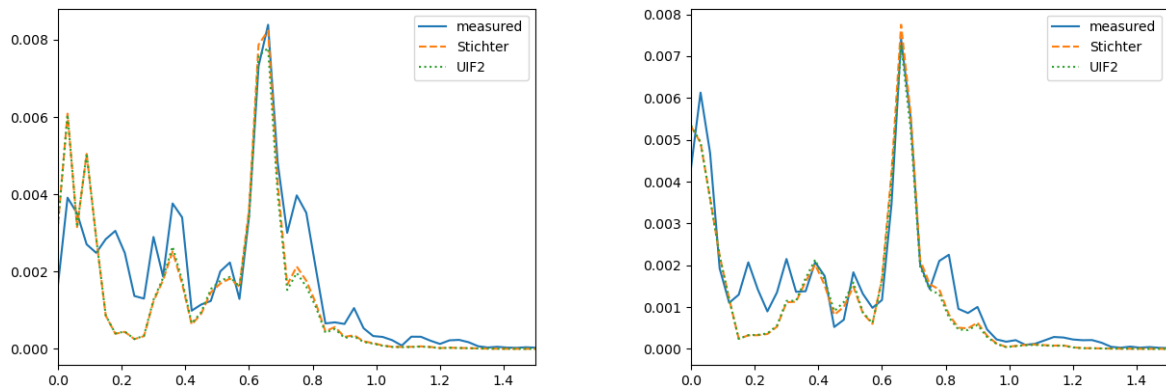


Figure 3-11: Spectrum of ART level (measured, simulated with Stichter, simulated with UIF)

Above spectra show the measured elevation in the ART and compare this with the calculated elevation based on the two ART modelling methodologies. It can be concluded that this tuning is very accurate. Based on the tuned numerical model in time domain A frequency domain database was created by MARIN and provided for use in the frequency domain model of MO4.

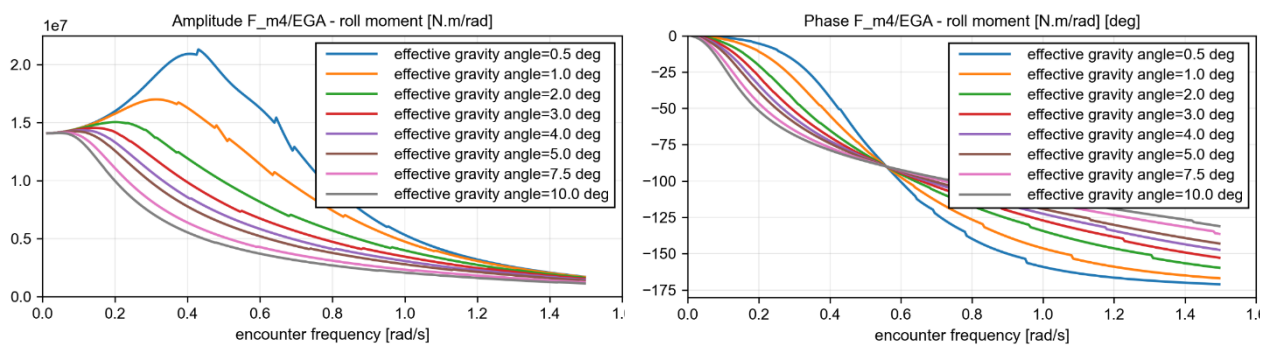


Figure 3-12: Transfer function of the tuned ART

2D wave spectrum

Direct validation of directional spreading of the wave is complicated. This is also described in more detail in paragraph 3.6.4. Instead of comparing the measured 2D wave spectra to each other the measured 2D wave spectra are used to calculate the motion response of the ship. These 'forecasted motions' are compared with the measured motions. Results are presented in a memo from MO4 (see Table 3-2). For reference a selection of figures is shown on the next page.

The performance of each wave measurement compared to the measurements of the vessel. The different wave measurements comprise of four different sources. First, the significant wave height (H_s) of the wave buoy in the St. Nazaire wind park is used to generate a unidirectional wave spectrum. This is the conventional way of how offshore operations are often assessed. The results of the accuracy of the wave buoy versus the measurements form the baseline to compare the other three wave measurements to. Secondly, the nowcast of the 2D spectral weather forecast of InfoPlaza is assessed. This source, technically is not a measurement but rather a forecast of the present. Finally, there are two radar systems on board of the Acta Auriga that capture snapshots of the wave spectrum in 2D; Next Ocean and Radac.

This wave data forms the input for the MO4 software and is used to predict the significant motions of the vessel. Using a Xsens MRU, MO4 is also able to measure the actual motions of the ship. Comparing these values when the vessel is idling at sea for at least 30 minutes, gives a good estimate of how accurate each wave measurement provider is. The correlation coefficient (r) is calculated for each wave measurement provider to see which provider captures the sea best. The results are sub-divided into five degrees of freedom: Surge, Sway and Heave accelerations and Roll and Pitch velocities. These motions have been chosen as they are also directly measured by the Xsens MRU. This lowers the amount of errors by avoiding extra computations on the measured signals.

These plots clearly illustrate the added value of use a 2D spectrum (including directional spreading of the waves) above unidirectional. And also the calculated motions and the measured motions compare much better when the wave, measured from the ship, is used.



Figure 3-13: Measured motion compared to forecasted motion based (4x) (MO4)

3.8 Advice and planning tool (WP4)

The simulation algorithms from WP1 are coupled to weather forecasts and measured environmental data of WP2. This required significant development in the backbone of the MO4 software. Furthermore, these algorithms are implemented in a long-term planning advisory tool that determines the expected workability based on hindcast metocean data. MO4 extended the tool with the motion simulation model from WP1, the dedicated wave finecast from WP2, the advice on the best heading per turbine approach and planning tool for the day at hand.

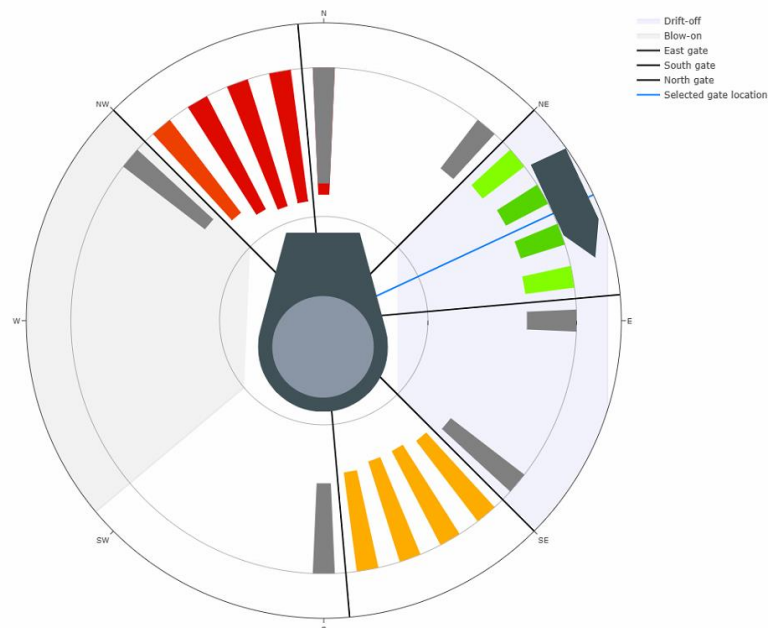


Figure 3-14: Interface with information to support the choice for the best heading



Figure 3-15: Interface with information for the planning of the day

3.9 Implementation and evaluation (WP5)

The onboard planning app provides the results from the simulation model in the expected and measured weather in a clear and concise manner. The algorithms are complex, but the information is presented in a easy to clear and dedicated way. This was not instantly achieved but took considerable effort, cooperation between project partners and engagement of the crew.

Soon after installation onboard it was clear that the follow up on the initial version of the tool onboard was not sufficient. We realised that the involvement of the crew in the development of the tool was more important than initially anticipated in proposal phase.

Task analysis

There have been multiple visits onboard to understand the use of the tool in the operation. And session with the crew onshore. Who is making which decisions and based on which information are those decisions made? This determines the best position for the screen, the main user and the information to be displayed.

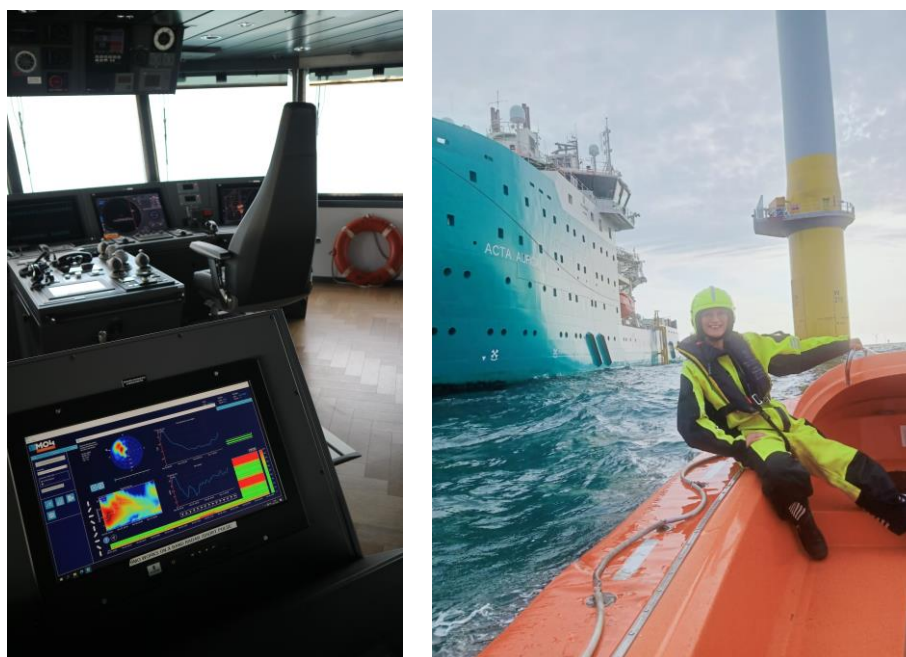


Figure 3-16: MARIN onboard visit to observe the operation with the first version of app

This task analysis is illustrated in the sketch below. Recommendations were made for the tool interface, functionality and support, Implementation in the process on board, Integration with wave measurement and Integration with daily reporting.

One of the unforeseen benefits of the tool is that it is used to strengthen collaboration and communication: encourage effective communication and collaboration between the crew, client and captain (during assessments and operations near wind turbines). The MO4 tool can assist with this when all parties use it for planning functionalities and for assessing situations.

Throughout the project, various test setups were implemented and evaluated. Initially, a static setup was installed on the Acta Auriga, specifically at the centre of the bridge. This location underwent assessment by MARIN and MO4, resulting in the determination that a flexible setup accessible at the workstations of the DEO and DPO would be more beneficial. Additionally, MARIN conducted an extensive analysis of human interaction among the client, Acta Marine crew, and the developed software. As a result of all the tests, a flexible setup was developed, incorporating an interface that enables clients and crew to easily log in and share planning and expectations.

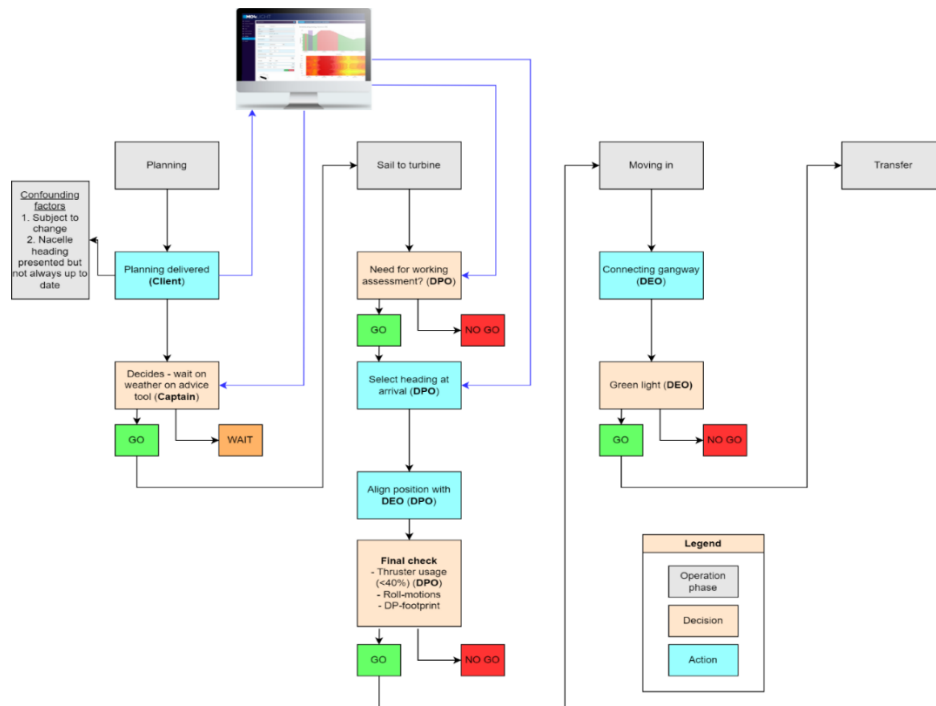


Figure 3-17: Task analysis

3.9.1 Workshop in MARIN simulator

A workshop was organised in the MARIN simulator to evaluate and improve the MO4 advisory tool, get agreement about the role of the MO4 advisory tool on-board and define required support (tech and ops). The advantage of evaluating the use of a tool in the simulator is that conditions can be selected and created. In one day it is possible to perform and train on a variety of challenging conditions. For this workshop MARIN has prepared a 6-degrees of freedom mathematical manoeuvring model of the Acta Auriga including the visual model. The existing model, developed under WP1, was amended for manoeuvring in the real time bridge simulator.

The Acta Auriga was steered from MARIN's Full Mission Bridge 1 (FMB 1), see documentation sheet for more information. This simulator facility provides 360° outside view. The FMB 1 have bridge wing controls for steering the ship manually.

The MO4 advisory tool that was used in the workshop was available on a stand-alone tablet. The environmental conditions used in the tablet corresponded with the environmental conditions in the simulations.

Prior to the simulations a presentation was given by MARIN to all of the companies involved in the Joint Industry Project, which explained the preparations of the database, the configuration on the simulator and the program. Also a test day and a validation day prior to the workshop are conducted to finetune the scenarios, optimise the MARIN DP system and adjust the environmental conditions. During the workshop, five simulation scenarios were conducted.

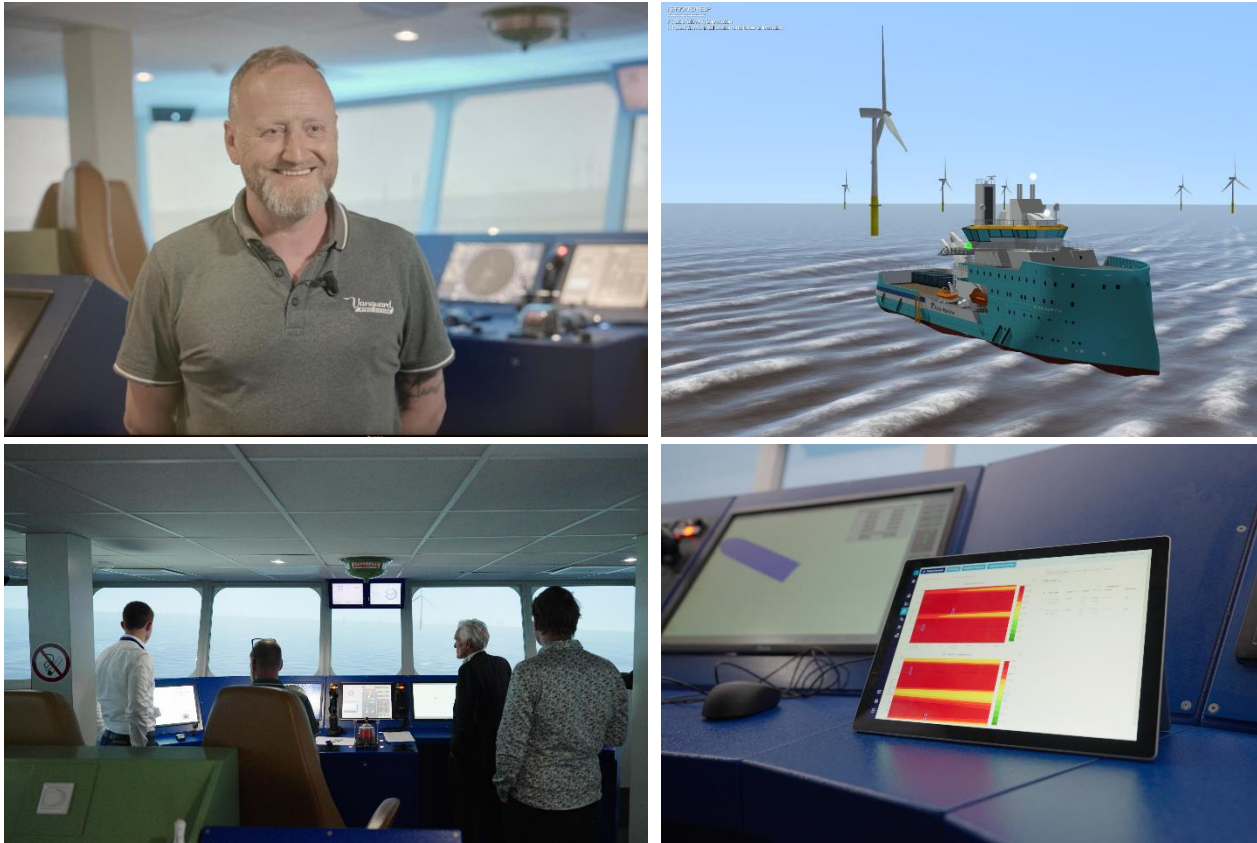


Figure 3-18: Workshop with Acta crew (captain and DP operator) and app in the simulator

3.10 Project Management (WP6)

In WP 6 the project was supervised and the overall progress, deliverables, milestones were monitored. Furthermore the interaction between WPs and the project meetings were organised.

Generally the project was a success. The project started in the middle of the corona pandemic and it took more effort to start-up and get aligned. Also it was more complicated to visit the vessel or invite crew in the office. This resulted in some delays and need for more frequent (online) communications. Related to the original plan some changes took place. Such as the added effort to involvement of the crew in the development and evaluation of the app. And also the timing of execution of different activities somewhat changed from original planning. As some delay during the execution of different activities was encountered, we were able to finish the project within the extended deadline.

In summary the project led to the successful development and implementation of the 2D wave spectra based on onboard wave radar measurement and planning-app development and both can be used in planning and execution in transfers to offshore wind turbines.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The main objective of the OOAS JIP is to improve the operability by giving upfront advice for the planning and execution of critical offshore operations. The following sub objectives were defined and reached as follows:

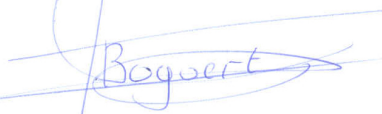
- To improve accuracy of onboard monitoring of the 2D wave spectra. This objective was reached by the development, implementation, testing and validation of the different onboard wave radar measurement technologies. Although it was difficult to obtain accurate reference data about the wave spectrum we were able to compare the different methods to one another, with hindcast wave information and by indirect comparison of calculated and measured vessel motions. These plots clearly illustrate the added value of use a 2D spectrum (including directional spreading of the waves) above unidirectional for example the correspondence for the roll increases from $r = 0.50$ to $r = 0.73$. And also the calculated motions and the measured motions compare much better when the wave, measured from the ship, is used increasing to $r = 0.88$.
- To Include non-linear effects of the vessel motion response in the numerical model to accurately represent the response of the ship. This objective was reached by using a two step approach for model development. A high fidelity time domain numerical model of the Acta Auriga is developed in aNySIM XMF. This model could be directly compared with data from the extensive measurement campaign onboard of the Acta Auriga. The insights and model settings from this are implemented in the frequency domain model used inside the MO4 app. The statistics of the motion response in the app in turn are compared against statistics of the measured motions.
- To install, test and evaluate the system onboard. This objective was reached in an iterative approach, involving the end-users (onboard crew) in the development process. Development of both the front end and back end of the tool was done by MO4. Using the information and support from Acta Marine and cooperating on technical and Human Factor content with MARIN. Although initially the focus was more on the technical development it was soon clear that for the effectiveness of the tool the understanding of the process onboard and how the tool fits in this process is crucial. The captain, client and DPO are the key users of the MO4 tool. Presentation results of the tool must correspond with the decision-making on board (DEO uses telescoping; DPO uses DP footprint and thruster saturation). In addition to testing the system onboard the system was also evaluated on the MARIN bridge simulator. This allowed to evaluate especially the challenging conditions in a very effective manner.
- To have the tool onboard, not only installed, tested and evaluated built also actively used. This sub-goal was added halfway the project. It has been reached but for an optimal gain in planning and execution it also requires involvement of the client on board and change of the process and working procedures. It should be repeated that the tool provides advice and not decision-making. Ultimate tool can contribute to decision-making on board. At the moment the results can partly be used to consider carrying out certain activities in addition to the information available from the customer, weather reports, visual observations, etcetera. The management of this innovation is gradual and ongoing process in which possible update of the tool is just one item.
- To use the information about the actual wave measured by the wave radars in the tool. This objective has been reach by creating an interface between the tool and the actual wave measurement. The actual wave is directly compared to the weather forecast in the tool. This provides information to validate and detect trends/bias in weather forecasts that can be taken into account in the planning process.

4.2 Recommendations

The work that has been performed in the OOAS JIP paved the way to explore relevant topics for future research. The recommended actions are discussed below:

- The considered approach and cooperation will be very useful for other operations. For example the installation of wind turbines. To make such project successful the right partners should work together, the technology should be adapted to the operation and the operational context and end users should be involved from the start of the project.
- Prediction of the footprint of the horizontal motions when using the DP system is complicated. This is a combination of the confidentiality of the control settings used in the system and the uncertainty on the ships excitation of the low frequency motions. In this project we did not get to the full detail of it. For other applications positioning accuracy can be crucial. More work is needed.
- Further improvements of the wave measurement and validation with different techniques and a combination of techniques. And further integration with tool interface. while each system individually can provide sea state information in agreement with the references, further work is necessary to ensure consistent and reliable results. Additionally, the development of a clear quality indicator could enhance the sensor's overall performance and development status.
- An optimal gain in planning and execution requires alignment of processes from the CSV and the wind park operator. Involvement of the client on board and change of the process and working procedures. The management of this innovation is gradual and ongoing process in which a possible update of the tool is just one item. This includes the continuation of making the customers aware of the tool and the use and added value of the tool.
- Improve data completeness: address the missing data (wind and current) and ensure that all relevant information, including blow on/drift on conditions, is included in the MO4 tool. The current information in the MO4 tool is not yet complete enough for a comprehensive assessment (missing data and blow on/drift on conditions). In addition, turbulence or shielding effects in close proximity to the turbine would be a useful addition. Also showing the favourability of landing with the stern of bow in front are considered useful additions to the tool.
- Enhance user guidance and training: provide clear instructions and user guidance within the MO4 advisory tool to assist users in understanding its features and functionalities.
- Foster continuous improvement and feedback: establish a feedback loop with users, including the captain, client and DPO, to gather input and suggestions for improving the MO4 advisory tool on human machine interaction. Regularly evaluate and implement updates to enhance its usability and effectiveness. This can be done with the implementation of a feedback function within the tool, as well as planned meetings with users to assess the MO4 tool.

Wageningen, October 2023
MARITIME RESEARCH INSTITUTE NETHERLANDS



Hannes Bogaert
Manager Performance at Sea

DOCUMENTATION SHEET



MARIN simulators

MARIN (Wageningen) operates three different types of real-time simulators for research, consultancy and training purposes of professional mariners. The simulators can be used separately or combined in the same scenario. The steering controls can be easily adapted to the specifications of the simulated vessel. At MARIN the following 6 real-time simulators are available:

- Full Mission Bridge I (FMBI): Especially suitable to simulate large ocean-going vessels.
- Full Mission Bridge II (FMBII): A flexible facility, capable of simulating a wide range of vessels.
- Four Compact Manoeuvring Simulators (CMS): Smaller simulators that can be used to simulate all kind of tugs and smaller vessels.

MARIN operates full mission ship manoeuvring simulators at three different locations:

- MARIN: Wageningen, The Netherlands;
- MARIN USA: Houston, USA.
- Depending on the wishes of the client research projects, consultancy and maritime training can be done on each of these locations.

Full Mission Bridge I (FMBI)



This is a fully equipped bridge with 360 degrees visual projected scenery. A mock-up of a real ship bridge is located in the centre of a cylindrical projection wall on which the graphics image is projected. The diameter is 20m and the bridge house is approximately 8m by 6m. The bridge is equipped with realistic consoles and instrumentation, including bridge wing consoles. Bridge and console layout can be adapted according to client wishes or research needs.



FMBI, bridge house with cylindrical projection wall

Software

All simulators use MERMAID500 and Dolphin simulation software. This software is DNV approved.



Houston simulators

The simulator facilities in Houston uses the same software as in Wageningen. This facility consists of a primary bridge and has the possibility to include a secondary bridge or Pilot/Captain station. The primary bridge has 360 degrees visuals. The secondary bridge can be used as a second vessel in the simulation or as a tug.



More information

A detailed description of the capabilities of MARIN simulators is given in the 'Capability statement'. This document can be obtained through the website (www.marin.nl) or can be provided upon request.

For more information contact MARIN:

T +31 317 47 99 11

E mo@marin.nl

Full Mission Bridge II (FMBII)

Full Mission Bridge II (FMB II), has a 210 degrees visual projected image. In addition to the projection system, the rear view is presented on three separate displays, thus providing almost 360 degrees view. Additional viewing positions offering a 3D view from any observation point can be installed.

Compact Manoeuvring Simulators (CMS)

The four Compact Manoeuvring Simulators can be divided into:

- Two cubicles with 300 degrees visuals and rear-view monitor
- Two CMS with 180 degrees visuals and rear-view monitor

The four Compact Manoeuvring Simulators are based on exactly the same 'ownship' functionality as the full-mission simulators. The default configuration consists of a U-shape console with steering controls, radar, instruments and bird's eye view showing the area and position of vessels. These facilities are ideal to simulate tugs and smaller vessels, but can also be used for anchor handling or crane operations.

Mathematical modelling

In nautical simulations the mathematical manoeuvring model of the ownship is of major importance. The quality of this model can determine the outcome of a research project and the realism of training to a high degree. Maritime Operation's models are based on extensive research into the field of ship hydrodynamics and port and waterway design. The ownship models have six-degrees-of-freedom (6 DOF) taking into account the influence of all external effects, e.g. wind, waves, tidal currents, bank suction, ship-ship interaction, etc. They are water depth/draft dependent, so the manoeuvring characteristics will vary depending on the actual water depth and the vessel's draught.

Maritime Operations has a large database of mathematical manoeuvring models available. In addition to this, MARIN's experts can prepare a dedicated model based on available model tests or manoeuvring tests.

Tugs and targets

Tugs can be included in MARIN's simulators in three different ways:

- Controlled from a simulator (FMBII or CMS)
- Instructor controlled tug model (C-tug)
- Instructor controlled forces

The most realistic option is a man controlled tug from another simulator. It has the most realistic behaviour, especially when the tug is controlled by an experienced tug master. However, the instructor controlled tug model also results in realistic behaviour of the tugs. For the simulation of other traffic MARIN has a large number of target vessels available. Each target consists of a visual representation as well as a mathematical model for realistic manoeuvring.

