

CAN WORKABILITY BE  
ENHANCED BY OPERATIONAL

# WAVE MODELLING?

Various regions all over the world are known for their problematic wave climate; the African west coast, the French and Spanish Atlantic coast, the Indian coastal waters, and so on are known for their long swell coming with long wave periods. But also less swell-dominated seas such as the North Sea may have severe wind sea systems with typical wave peak periods around 6 to 7 seconds. In extreme cases, even for large cutters, workabilities of less than 50% are not exceptional. Given the large stand-by costs of such specialised vessels, this can have a huge impact on the cost of a dredging project.



There is not only a considerable cost impact. The safety of the crew working on board of a vessel in harsh conditions is also at stake. Usually it is the responsibility of the captain to decide when the works need to be ceased in case of upcoming bad weather conditions. Therefore, the captain needs to have a thorough knowledge of the limits of the vessel in terms of metocean conditions, and he/she should also have good insight in the current and upcoming weather conditions. When there is uncertainty in one of those elements, the captain's decision might be subjective and lead to unsafe situations or inefficiency:

- Unsafe working conditions follow from the fact that the equipment is being exposed to conditions beyond its workable limits. This could lead to damage to the equipment, for example damage to the spud, and uncontrollable motions of the vessel. In

such case there is a risk for unsafe situations for the crew.

- Loss of efficiency is caused by a captain's decision not to work, while in reality the weather conditions are below the critical limits. This often happens after a period of bad weather, and conditions start to improve again, but the decision to resume the works is dominated by over-conservatism. The quality of the consulted weather forecasts also plays an important role in this process.

In order to improve this situation, DEME has developed an operational tool in cooperation with BMT Argoss which aims to provide the on-board crew and site staff with information on the present and near-future sea states and whether operational thresholds are expected to be exceeded. The sea state is broken down in systems of common meteorological genesis which are considered

to be statistically uncorrelated. With the use of response amplitude operators, key operators are determined and presented via a web application. Whenever the actual wave conditions are getting too rough the system will indicate that the workability limits are being reached and work should be ceased. Real time sea state data can be acquired from buoys that are deployed near the works. Future sea states are provided by a combination of operational atmospheric and wave models that typically deliver a forecast window of five to eight days. To be able to further increase the accuracy and skill of these forecasts, the models are calibrated on the measured waves. The wave forecasts make it possible to plan the works more efficiently and to optimally use available workable windows. It generally results in less downtime, less damage and a safer working environment.



The tool has initially been applied for the Wheatstone downstream project, Australia, where a large access channel for a new port had to be dredged. This article discusses a project case where the tool has been applied in the dredging works for a new highway at La Réunion island (Indian Ocean). The focus will be on the quality of the wave forecasts by operational wave models and the continuous calibration efforts which are increasing their reliability during the project.

### Introduction

The Workability Tool (WoTo) has been developed to objectify the decision-making process regarding the weather conditions when active in harsh weather conditions. Combining measured and forecasted metocean parameters with the workable limits of vessels, the crew is able to evaluate the workability at any time. The comparison

between the measured and forecasted wave parameters gives an appreciation of the confidence one can have in the forecasts.

The deployment of this tool has significantly increased the safety, the awareness, the efficiency and the planning on the different projects where it has been deployed. The reliability of the tool is highly dependent on the quality of the weather forecasts and, depending on the location of a project, the wave modelling can be more or less accurate. The development and improvement of wave models are therefore generally necessary to increase the reliability in the forecasts. These step by step improvements are then validated and/or calibrated using measured metocean data.

After a short introduction of the different hardware and software components, a case study will be presented and discussed.

### Description of the WoTo

The workability tool needs different entries to compute different outputs. Some inputs and outputs of the tool will be briefly explained below.

#### Measured wave parameters

To evaluate the current wave conditions, statistical parameters have to be derived from wave energy spectra. These can be obtained from different instruments (radar, buoy, ADCP, etc.). The focus here will be on directional wave rider buoys.

Most wave rider buoys are generally delivering a wave spectrum every 30 minutes. To get closer to a real-time monitoring of the waves, specific software has been developed to reprocess the buoy raw displacements data and obtain new wave spectra containing the buoy displacements of the past 30

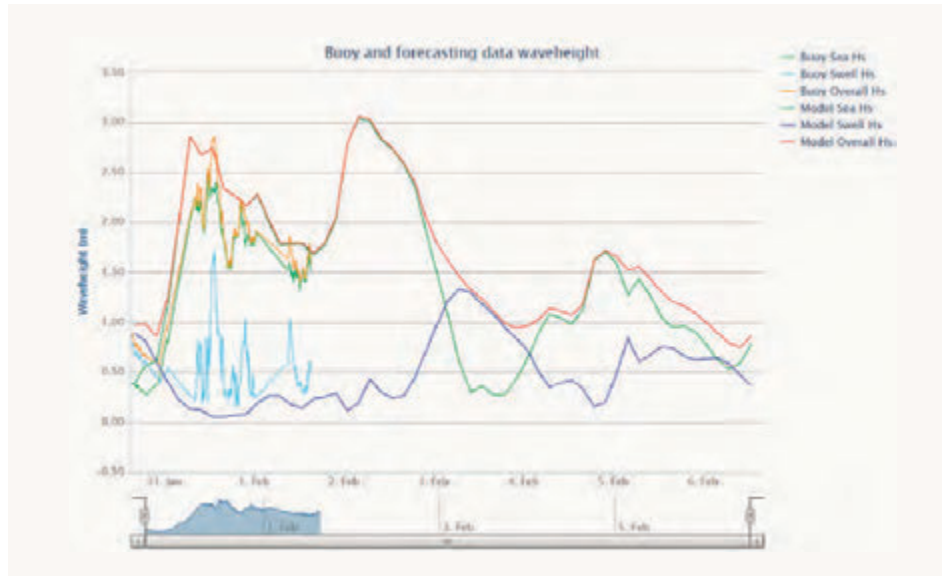


FIGURE 1

Visualisation of the measured and forecasted statistical wave parameters.

minutes every 3.75 minutes using a rolling buffer.

To obtain the wave statistical parameters from the spectra, a splitter has been developed by BMT Argoss and integrated in the WoTo. The splitter uses a wind component (from the forecast or measured) to allocate the spectral energy to a swell or a wind system.

A significant wave height (Hs), a mean period (Tm) and a direction (Dm) will thus be obtained for both the sea/wind and swell components. The system will then look at which system is the most impacting the workability of the vessel.

**Forecasted wave parameters**

The forecasting models are run several times a day by BMT Argoss and the output (Hs, Tm and Dm for both sea/wind and swell components) is imported in the WoTo. Depending on the operations, the frequency of the forecasts is adapted. In the WoTo, the forecast is shown next to the measured data (see Figure 1) in order to get a feeling on the quality of the forecast.

The model setup will be discussed in more detail in the case of La Reunion.

**Workable limits of the operation**

Depending on the operation of interest, different workable limits are considered.

Stationary vessels will generally be modelled in a diffraction model to determine the forces/movements generated under specific wave conditions. Each vessel and activity has its limits and on their basis, workability tables are generated. The WoTo shows the actual wave conditions in a workability plot from which it becomes clear if the conditions are workable or not (see Figure 2).

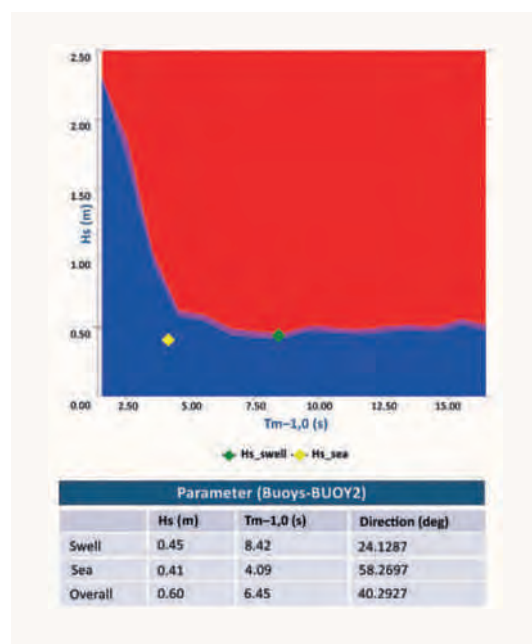


FIGURE 2

Visualisation of the comparison between the measured waves and the workable limits of an activity.

**Project case**

**La Réunion**

**Project description**

La Réunion is a French island and department in the Indian Ocean situated 700 kilometres east of Madagascar. On this island, a new highway is planned from the capital Saint Denis to La Possession. This nine-kilometre-long highway will replace the existing cliff road. This road, constructed in 1976, has two lanes in both directions and was designed for 10,000 vehicles per day. Nowadays, about 60,000 vehicles make use of the road every day. Further, the existing road is subject to rock-falls from the steep cliffs adjacent to it and flooding during tropical storms resulting in unacceptable traffic jams. During heavy rain storms, the road is closed for any traffic. The road is the only link between the port area and the capital city.

The new highway is being constructed partly as a viaduct and partly as a causeway (see Figure 3) and it is designed to be operational during wind speeds up to 150 km/h and waves up to significant heights of 10 meters. The project is financed partly with European funds. The main contractor for this project is a joint venture between French companies. SDI (DEME group) is working on both parts of this project (viaduct and causeway) as a subcontractor.



**FIGURE 3**

The new highway is being constructed partly as a viaduct and partly as a causeway.

**For the causeway, the work consists of dredging a trench and making the foundation of the revetment of the highway.**

For the causeway, the work consists of dredging a trench and making the foundation of the revetment of the highway. Three sections of the highway are being constructed as a causeway. The total length of the first dredged trench is about 3,070 meters. The trench has a width of 25 meters at the base and a depth of about five meters below existing seabed. The total dredging volume amounts about 250,000 m<sup>3</sup>. The dredger material is partly reused in the body of the revetment.

Apart from the dredging works, the work consisted of the placing of two layers of rock. The first layer is a 2-150 millimetres rock filter of which a total of 170,000 tonnes must be placed. The second rock layer consists of 0.2-1 tonne rock with a total weight of 340,000 tonnes.

For the viaduct, the work consists of dredging 48 pits and laying filter material (by dumping with barges and levelling with a backhoe) as support for the 48 GBF (Gravity based foundations). The backfilling of the pits is also part of SDI's scope. The total dredging volume amounts about 650,000 m<sup>3</sup>. The dredged material is partly reused to backfill the pits. Filter material dumped as bed layers under the pits is totalling 50,000 m<sup>3</sup> of 2/30 mm and 40/80 mm.

The dredging works are carried out by the backhoe dredger Pinocchio. The dimensions of this dredger are 60 x 19 m<sup>2</sup>. It has three spuds with a length of 40 meters and the total installed power is 2,416 kW.

Two methods of disposal of the dredged material are used. The first method is to sidecast the material using a pontoon which is moored alongside of the Pinocchio (causeway). A second method (viaduct) is used with two split hopper barges (1,000 m<sup>3</sup> of capacity each) to dispose the material.

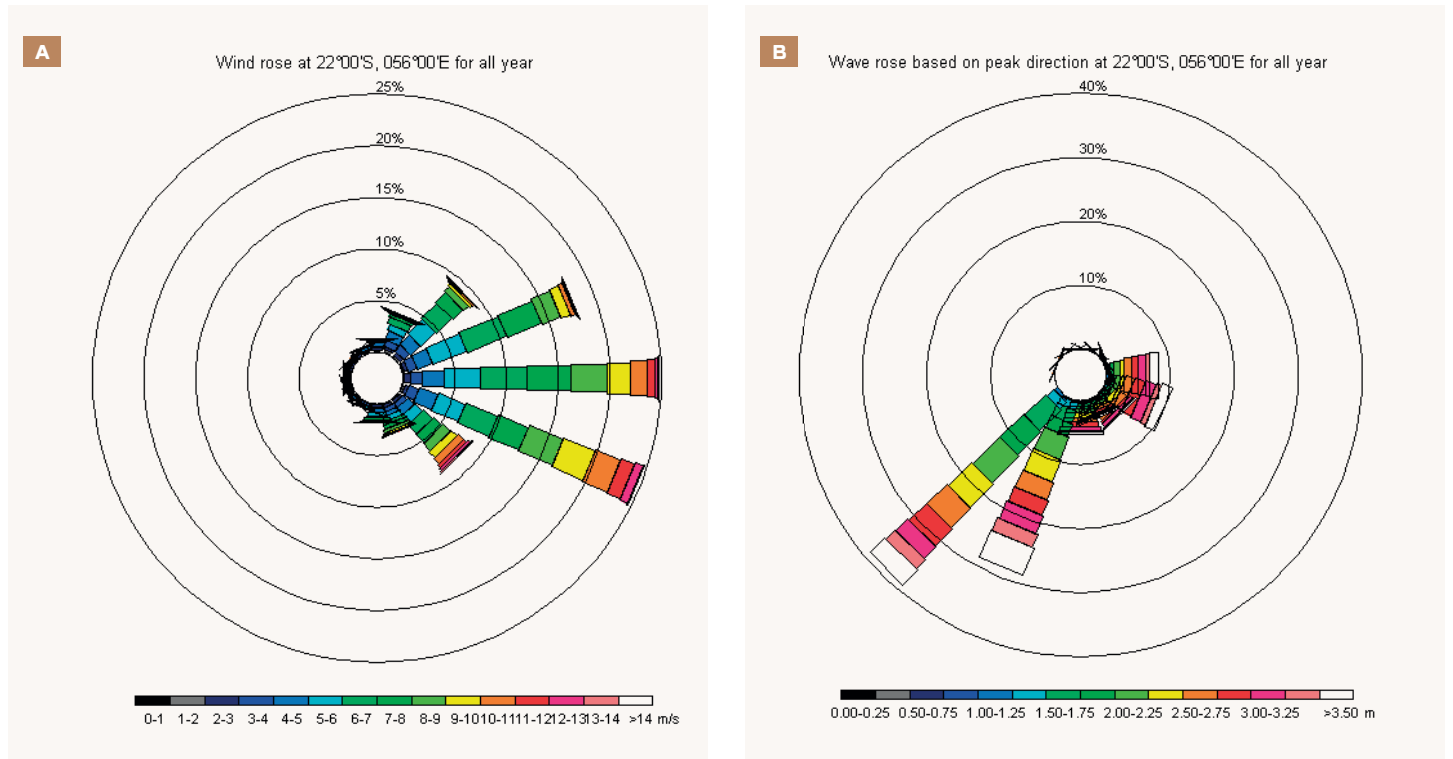
#### Climate

The volcanic island of La Réunion is characterised by a complex orography. High peaks and deep valleys have a strong effect on the atmosphere over and around the island. In winter and spring, the trade winds blow over the region. Strong lee effects can be observed on the west side of the island which are highly correlated to the background wind conditions over the region; small differences in the background wind direction cause significant changes in wind conditions at La Possession. For example: with winds blowing from the E or ENE, the north-easterly wind velocity is higher, up to 20-25 knots, and blows throughout most of the day. Under conditions with a slightly veered background wind (ESE) the enhanced north-easterlies are sparser and weaker. They are then alternated by weak sea breezes. Sea breezes play a very important role

in the wind climate on and around La Réunion. A background sea breeze is caused by the difference of surface temperature between land and sea.

Diurnal heating of the island surface by the sun causes, in combination with the high mountains on the island, a strong convection over the island in general and particularly over the mountain tops. This phenomenon occurs virtually every afternoon, especially in summer. The opposite takes place in the evening and early nights. As the convection, triggered by the heating of the sun, stops at the end of the day, the air in the mountains starts to cool. The colder air flows downhill and reaches the coastal areas as a weak to moderate land breeze. When the temperature drop in the mountains is relatively strong in comparison to the one over the coastal areas, the air in the mountains will start to descend rapidly. Like any fluid it will follow the easiest path which is through valleys towards the coast. These so called katabatic winds can reach high speeds and occur very locally. Occasionally, these gusty winds can last for approximately (half) an hour.

Waves do not grow significantly due to the diurnal wind effects at the site of interest as the forcing surface winds are so short lived. During the stronger trade winds in winter waves from the ENE can refract around

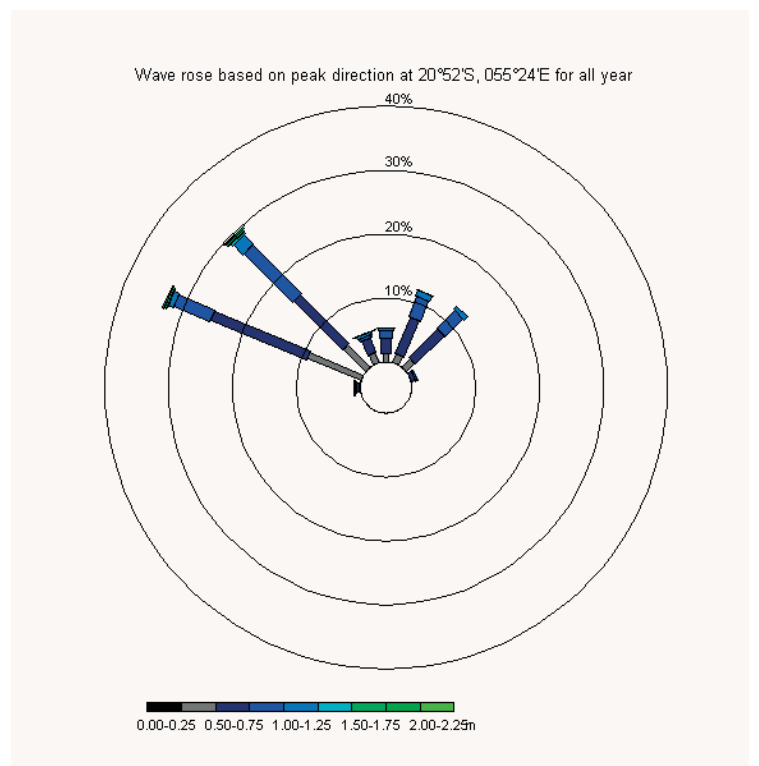


**FIGURE 4** Directional roses of  $u_{10}$  (A) and  $H_s$  (B). Data was taken from grid point 22°00'S, 56°00'E from WW3-global model. Years used: 2016-2017.

Saint Denis which results in waves travelling along the shore and reach La Possession. Cross seas can be found with an additional wave system, generated by southern ocean depressions, which refracts around La Reunion and approaches La Possession from the northwest. During summer low, variable winds are, as an exception, alternated with severe storms (Ceulemans & Hulst, 2016).

Figure 4 shows directional roses of 10 metre wind speed (one-hour sustained) and significant wave height from WaveWatch III Global offshore grid point 22°00'S, 56°00'E. The wave rose (Figure 4) shows the two majors wave systems from the east and from the southwest. Both wave systems curve around the Island of La Réunion and merge on the northern side of the island. This results in a sea state in which dominant peak switches between both wave systems. This is illustrated by a directional rose of significant wave height and peak direction in Figure 5. The data was taken from the swan reunionD grid using model grid point at the project site 20°52'21.1S, 55°24'31.0E. A spatial impression of this process is shown in Figure 6. This shows

**FIGURE 5** Directional rose  $H_s$ . Data was taken from grid point 20°52'21.1S, 55°24'31.0E from swan reunion model. Years used: 2015.



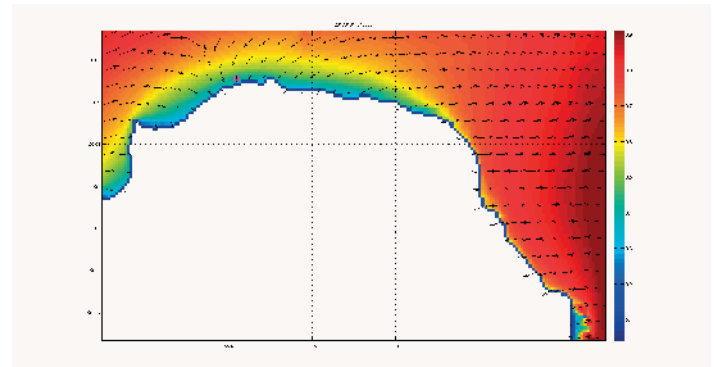
significant wave height and direction from the reunionC grid. The project site (20°52'21.1S, 55°24'31.0E) is shown by the pink square.

**Model description**

The SWAN model is a third generation spectral model developed at Delft University of Technology that computes random, short-crested wind-generated waves in coastal regions and inland waters. The model is based on the wave action balance equation with sources and sinks. SWAN accounts for the following processes:

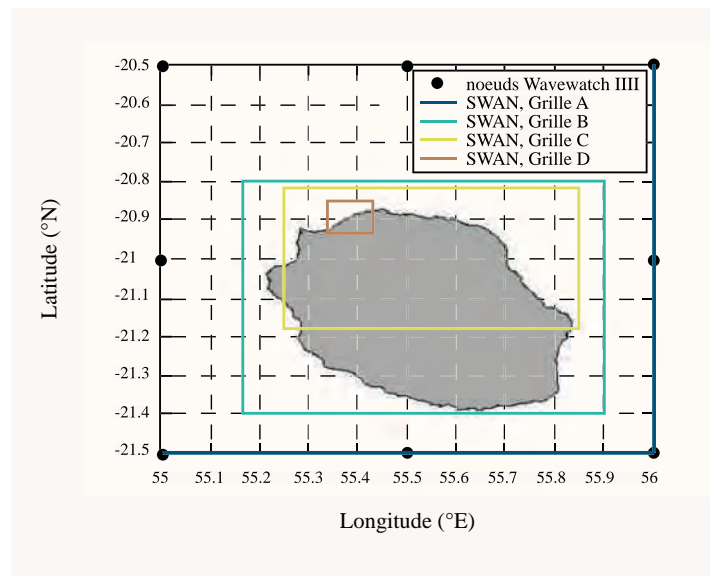
- Wave propagation in time and space, shoaling, refraction due to current and depth,
- Frequency shifting due to currents and non-stationary depth.
- Wave generation by wind.
- Three- and four-wave interactions.
- White-capping, bottom friction and depth-induced breaking.
- Dissipation due to aquatic vegetation, turbulent flow and viscous fluid mud.
- Wave-induced set-up (not applied in this project).
- Transmission through and reflection (specular and diffuse) against obstacles

The BMT Argoss model suite for La Réunion comprises of four nested SWAN grids. Specifications of these grids are shown in Table 1 and outline is shown in Figure 7. The large SWAN domain (reunionA) receives its boundary conditions from the WaveWatchIII Global wave model.



**FIGURE 6**

Significant wave height and direction from wave grid reunionC on 01-jan-2017 at 04:00 UTC. The project site is shown by the pink square.



**FIGURE 7**

Extents of the swan grids for La Réunion.

**TABLE 1**

Model specifications for La Réunion model suite.

Grid	Engine	Forcing (resolution)	Boundary	Outline ([lon],[lat])	Resolution
reunionA	SWAN	WRF-DO1 (27 km)	WW3-Global	[55,56],[-21.5,-20.5]	10 km
reunionB	SWAN	WRF-DO1 (27 km)	reunionA	[55.17,55.9],[-21.18,-20.8]	2 km
reunionC	SWAN	WRF-DO2 (9 km)	reunionB	[55.25,55.85],[-21.18,-20.82]	300 m
reunionD	SWAN	WRF-DO2 (9 km)	reunionC	[55.34,55.43],[-20.93,-20.85]	90 m

## TECHNICAL

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During the project, several model developments were tested. The developments that lead to improvement of model results are shown in Table 2.

In August 2017, we switched nesting the outer grid (reunionA) from 1D spectra (spectral wave information per frequency) to 2D spectra (spectral information per frequency and per direction). The assumption was that this would improve the wave direction since directional information is better represented in 2D spectra as compared to 1D spectra.

In October 2017, the wave growth due to local wind was switched off. The local wind growth over grids reunionC and reunionD is assumed to be marginal, and it showed to affect the wave direction in a negative way.

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**Continuous monitoring of the waves combined with the know-how of BMT Argoss has led to a significant improvement in the accuracy of the forecasting.**

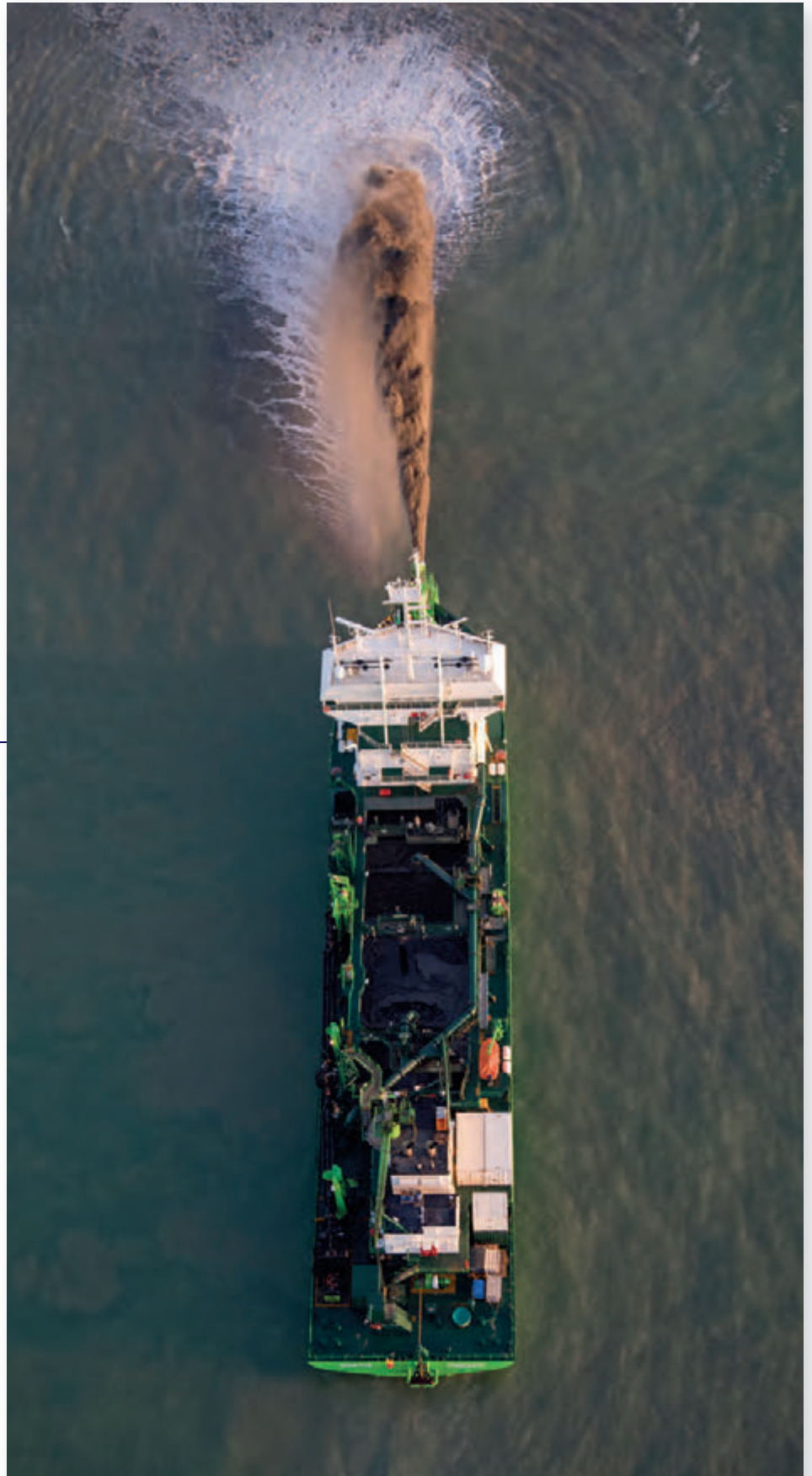




TABLE 2

Main model developments.

Development	Description	Used in grid	Date in effect	Effects
Nest in 2D spectra	Nesting of reunionA grid in WW3-Global 2D spectra instead of 1D spectra to allow for better representation of directional information.	A	August 2017	Wave direction
Switch off windgrowth	Local windgrowth results in unrealistic mean wave directions from the north. Windgrowth switched off for grids C and D.	C and D	October 2017	Wave direction, wave height

**Results**

The region of La Réunion is a very particular environment where a lot of local phenomena influence the wave climate. The continuous monitoring of the waves combined with the know-how of BMT Argoss has led to a significant improvement in the accuracy of the forecasting. Being in the middle of the Indian Ocean, the project is greatly benefiting from this increased reliability.

Therefore, the same type of figure is repeatedly used to indicate the performance of the model against the observations. These figures consist of an upper plot showing both the 0 to 24 hours, 24 to 48 hours and 48 to 72 hours forecasted (blue) and observed parameters (orange). The lower plot shows the bias where pink indicates forecasts higher

than the observed data and blue indicates forecasts lower than observed.

**La Réunion**

As explained in the section on the climate of La Réunion, the island is prone to very complex refraction as well as local phenomena. The model has thus needed some fine-tuning to accurately predict the wave height and direction.

Due to these refraction and local effects, the forecast and measurement locations are of crucial importance. The results presented here will focus on one location to keep it short and clear for the reader. To follow the evolution of the works, the wave rider buoy and forecast locations are modified on a regular basis.

In order to demonstrate the impact of the model performances that have been implemented in August-October 2017 (see Table 2), results from a period before the improvements (June 2017) have been compared to a period after the improvements (February 2018).

Note that the mean wave period is not further discussed here to keep it clear and concise for the reader. The significant height parameter is generally more relevant as limit for marine equipment.

Below, Figures 8 and 9 show comparisons of predicted and observed significant wave height and wave direction for the period of June 2017 (before model improvements).

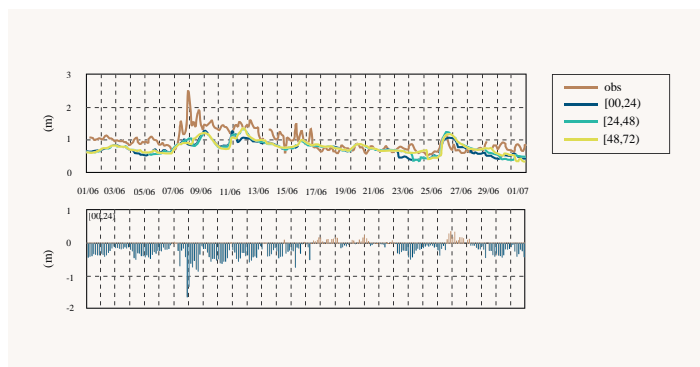


FIGURE 8

Wave height forecast for June 2017 (upper plot) and the bias (lower plot).



FIGURE 9

Wave direction forecast for June 2017 (upper plot) and the bias (lower plot).

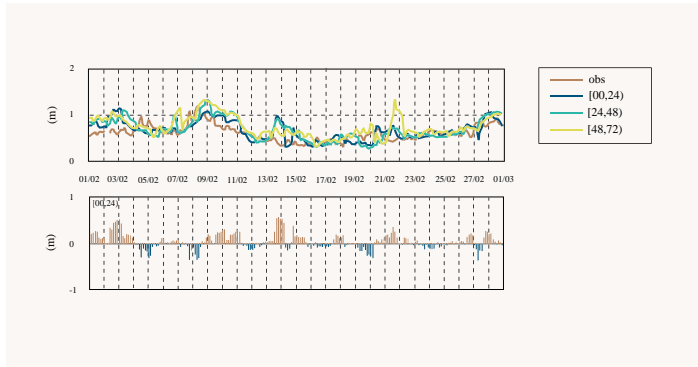


FIGURE 10

Wave height forecast for February 2018 (upper plot) and the bias (lower plot).



FIGURE 11

Wave direction forecast for February 2018 (upper plot) and the bias (lower plot).

Figures 10 and 11 show the same figures for February 2018 (improved model).

TABLE 3

Main model developments.

ME [00.24]	Before model improvements April-June 2017	With improved model January-February 2018
Sig. wave height [m]	-0.24	0.08
Wave direction [deg]	37	-5

Table 3 presents the bias of the model performance for a period before model improvements (based on April to June 2017) and after the model improvements (January-February 2018). These numbers and Figures 8 through 11 show that in the old situation, the forecast on average significantly underestimated the wave height at the project location and that the wave direction



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was systematically off by about 40 degrees (observations: northeast, model: north), while after improvements the wave height on average was only slightly overestimated while the wave direction is pretty much spot on.

### Discussion

The case study shows the efforts being done to improve the predicted metocean conditions

on site by using feedback (observations) from the site. There are some restrictions however that have demonstrated it is impossible to let the forecasts exactly match the observations:

- It is hard to find a consistent data set from buoy measurements on a project due to the fact that sometimes the buoy is displaced by the project crew, the buoys

are taken out of the water (protection during storms), gaps in the data due to bad signal (remote sites), problems with acquisition software etc.

- It is not always straightforward to compare mean wave periods from models to mean wave periods from buoys. This is caused by the fact that the wave model and buoy may use



different techniques to compute the mean wave period.

- Comparing wave model output to buoy data can result in significant improvement of model results. However, there are a few limitations to this. These limitations include
  - Representability of model results for the buoy location
  - Wave model resolution
  - Differences in computation method of integrated parameters (wave height, wave period) between buoy and model
  - The wind data source driving the wave model. Poor quality wind data will in general result in poor quality wave data.
  - Quality of bathymetric data (for nearshore location)

### Conclusions

Working in exposed marine environments may seriously affect the workability of the equipment being used in a project. Given the

large stand-by costs of specialised offshore equipment, this can have a huge impact on the cost of those projects. There is not only a considerable cost impact. Also the safety of the crew working on board of vessels in harsh conditions is at stake.

The Workability Tool has been deployed to inform the crew and site staff with information on actual and upcoming wave conditions linked to the working limits of the equipment. In numerous situations, the tool has proven itself by limiting downtime and letting crew work more safely and better plan the works. Besides, the tool makes the bridge personnel aware of the metocean conditions. With increased confidence upon having comparison between wave forecast and real-time measured waves, the crew can now easily make an objective decision to stop, start or relocate the works.

Input to the WoTo are forecasts coming from models. Wave models are developed to represent sea states on a global, regional and

local scale. Many processes are included in the wave model, which are used all over the globe. Specific locations require specific tuning of the wave model parameters, such as wind drag, coefficients influencing refraction and others, and for this it is vital to have reliable buoy information. This paper has shown that the quality of the weather forecast can significantly improve during the project by making use of the field observations. The expert meteorologists are able to use the observations in the interpretation of the model forecasts to deliver an improved manual forecast. Besides, at set times they will use the observations to adjust and tune the wave models to better represent the observed conditions. When the quality of the forecast is increasing, the crew will also gain more confidence in the forecast which will help them to better plan the works and take objective decisions.



### François De Keuleneer

Following graduation from the University of Neuchâtel (Switzerland) with an MSc in Hydrogeology and Geothermics, François joined DEME group in 2014. After a year as an on-site project engineer, he joined the Research & Development department in DEME's head office. Currently an environment engineer, he is also involved in wave data acquisition systems and operational workability assessments for different projects. With his team and BMT Argoss, François is developing tools to assist the crew and project teams when working in exposed conditions. He is a member of the Ecosystem Restoration Camps Foundation's supervisory board, an organisation applying cooperative efforts for the ecological restoration of degraded lands.



### Joris de Vroom

After graduating with an MSc in Physics from the Vrije Universiteit Amsterdam, Joris joined the Royal Dutch Meteorological Institute and worked in the field of climate and weather research. He joined BMT Argoss in 2010 and worked as an operational forecaster at the BMTA's weather desk. In 2015, he switched to his current role as metocean consultant and modeller at BMTA. He designs wave model grids for projects and operational use, and carries out consultancy projects for customers in the offshore industry.



### Arjan Mol

Upon completion of his Civil Engineering study at the University of Twente (The Netherlands), Arjan began working at WL | Delft Hydraulics (currently Deltares) as an advisor/researcher in the hydraulic engineering department. He gained experience in the field of hydrodynamic and morphological modelling, metocean studies and hydraulic structure design. In 2011, he started working at DEME group in Belgium as a senior coastal engineer. He focuses on the hydraulic design of large projects, is involved in workability studies and has a special interest in the development of operational systems.

## Summary

When dredging in exposed waters, wave conditions may seriously impact the workability of a dredging project. Especially stationary dredging equipment that makes use of spuds in order to remain in position and transfer the dredging forces to the seabed, like a backhoe dredger or a cutter suction dredger, is vulnerable for harsh wave conditions. The workability of such vessels is not only affected by the wave height, but also the wave period. Other types of marine operations, such as the construction of jetties, installation of wind turbines or the placement of scour protections are affected as well in their workability by the ambient conditions at sea.

Various regions all over the world are known for their problematic wave climate. In extreme cases, even for large cutters, workabilities of less than 50% are not exceptional. Given the large stand-by costs of such specialised vessels, this can have a huge impact on the cost of a dredging project.

There is not only a considerable cost impact, but also the safety of the crew working on board of vessels in harsh conditions is at stake. Usually it is the responsibility of the captain to decide when the works need to be ceased in case of upcoming bad weather conditions. Therefore the captain needs to have a thorough knowledge of the limits of the vessel in terms of metocean conditions, and he/she should also have good insight in the current and upcoming weather conditions. When there is uncertainty in one of those elements, the captain's decision might be subjective and lead to unsafe situations or inefficiency.

In order to improve this situation, DEME group has developed an operational tool in cooperation with BMT Argoss which aims to provide the on-board crew and site staff with information on the present and near-future sea states and whether operational thresholds are expected to be exceeded.

First presented as a paper at the 34th PIANC World Congress 2018, this article has been published in a slightly adapted version with permission of the copyright holder, PIANC. At the conclusion of the congress, the Young Author Award was given to François De Keuleneer to recognise his outstanding paper and presentation.

**With increased confidence upon having comparison between wave forecast and real-time measured waves, the crew can now easily make an objective decision to stop, start or relocate the works.**

## REFERENCES

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