NAUTICAL AND RISK STUDIES FOR THE DELIMARA LNG TERMINAL IN MARSAXLOKK PORT, MALTA

Item 1: Wave climate study

Final report

Report No. : 27689-1-MSCN-rev.3
Date : December 18, 2015

Signature management :

MARIN
P.O. Box 28
6700 AA Wageningen
The Netherlands
T +31 317 47 99 11
F +31 317 49 32 45
E mscn@marin.nl
I www.marin.nl

NAUTICAL AND RISK STUDIES FOR THE DELIMARA LNG TERMINAL IN MARSAXLOKK PORT, MALTA

Item 1: Wave climate study

Final report

Ordered by : Enemalta
Church Wharf
MRS 1000 Marsa
Malta

Document History

Revision	Status	Date	Reported by	Reviewed by
0	Draft	17 October 2014	ARCADIS	Jaap de Groot (ARCADIS) Johan Dekker (MARIN)
1	Draft Final	9 January 2015	ARCADIS	Jaap de Groot (ARCADIS) Johan Dekker (MARIN)
2	Final	10 March 2015	ARCADIS	Jaap de Groot (ARCADIS) Johan Dekker (MARIN)
3	Updated Final	18 December 2015	ARCADIS	Jaap de Groot (ARCADIS) Johan Dekker (MARIN)

NAUTICAL AND RISK STUDIES FOR THE DELIMARA LNG TERMINAL IN MARSAXLOKK PORT, MALTA

ITEM 1: WAVE CLIMATE STUDY

MARIN

December 15, 2015
078336622:C- Final report
C03051.000014.0100R1r2

ARCADIS

Contents

List of Tables

List of Figures

1 Introduction

1.1 PROJECT BACKGROUND

Enemalta is developing a new gas-fired power station near the existing Delimara Power Station on the north-eastern shore of Marsaxlokk Bay. The gas for the power plant will be imported through a new to build LNG terminal in Marsaxlokk Bay. Figure 1-1 shows the approximate position of the new terminal.

Figure 1-1: Marsaxlokk Port and approximate position of LNG terminal (source: Google Earth)

Enemalta has awarded the contract for design, construction and operation of the new power plant and LNG terminal to Electrogas Malta. The LNG terminal proposed by Electrogas consists of a jetty from the shore south of the power plant to a berth that is positioned where the bay is deeper, so that no or only limited dredging is required. On the jetty a converted LNG carrier will be permanently moored as Floating Storage Unit (FSU), delivering LNG through a cryogenic line over the jetty to the regasification unit onshore. The FSU berth has a conventional layout consisting of a platform, breasting dolphins and mooring dolphins (Figure 1-2). LNG will be imported by LNG carriers (further shortened to LNGCs) that will moor alongside the FSU.

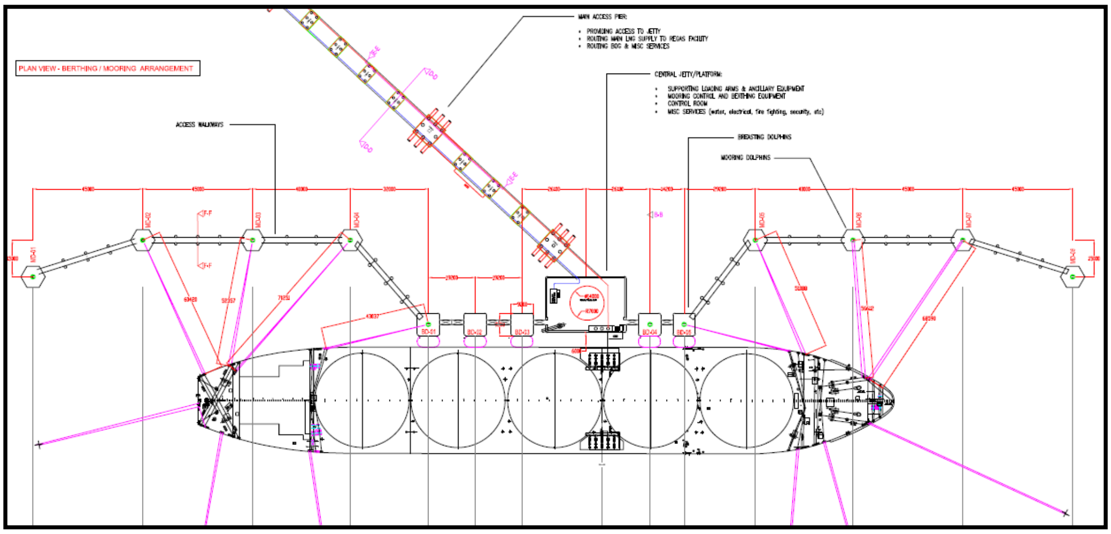


Figure 1-2: Proposed jetty configuration

To verify the design and evaluate safety aspects related to the permanent presence of the FSU in the port and to the regular call of LNGCs to the new LNG terminal, Enemalta has commissioned MARIN to carry out nautical and safety studies for the new LNG terminal. The study addresses a number of items raised by Transport Malta, the authority responsible for the port, who required:

1. Validation of proposed jetty/berth layout
2. Nautical and safety study
    a. Determine the required minimum navigation channel/fairway
    b. Determine the risk involved in the handling of an FSU and LNG carriers when navigating to the terminal
    c. Determine the nautical procedures for the handling of the FSU and LNGC during routine procedures and emergency situations
3. Site specific risk (safety) assessment including
    a. Cargo release
    b. Collision
    c. Fire and explosion
    d. Grounding

The contract for the study (Ref: DPS-GEN-1190) was signed on 25 August 2014 and is based on MARIN's proposal of 24 March 2014.

1.2 OBJECTIVE, APPROACH AND SCOPE OF WORK

Objective

The objectives of the present nautical and risk study for the Delimara LNG terminal are:

- To evaluate the dimensions of the manoeuvring area and port approach
- To determine the operational envelope for ship manoeuvres (input for nautical procedures);
- To evaluate the proposed jetty layout and to determine the limiting operational conditions for safe offloading and for staying safely at the berth (input for nautical procedures);
- To determine the risk involved in the LNG operations in the port regarding grounding of LNGCs and collisions involving FSU or LNGC,
- To determine the consequences (cargo release, fire and explosion) of incidents involving the FSU or an LNGC.

Approach

The above mentioned items are evaluated in this dedicated nautical and safety study for the Delimara LNG terminal. The study consists of the following items:

1. Wave climate study to determine the normal and extreme wave climate outside Marsaxlokk port (frequency of occurrence of directions and wave heights)
2. Wave penetration calculations to determine the wave conditions at the terminal
3. Numerical moored ship response simulations to validate the jetty/berth layout and determine operational limits for the moored FSU;
4. Real-time manoeuvring simulations to verify dimensions of the fairway and determine operational limits for sailing with LNG carriers;
5. Nautical risk study to determine the risks of grounding and collisions involving the FSU or LNG carrier
6. Quantitative Risk Assessment to determine the consequences of collisions in terms of cargo release and risk of fire and explosion

The wave studies (items 1 and 2), which serve as input for the nautical studies (items 3 and 4) were carried out by ARCADIS. Items 3 and 5 were carried out by MARIN. Item 4 was carried out by MARIN in cooperation with MMP (Malta Maritime Pilots) and MMRTC (Malta Maritime Research and Training Centre). SGS Tecnos SA carried out the QRA in item 6.

1.3 REPORTS

The total study is presented in a series of reports, each one treating one of the above mentioned study items. Table 1-1 gives an overview of the reports presenting the results of the study.

Volume	Title	Main author
27689-1-MSCN	**Item 1: Wave climate study**	**ARCADIS**
27689-2-MSCN	Item 2: Wave penetration study	ARCADIS
27689-3-MSCN	Item 3: Moored ship response study	MARIN
27689-4-MSCN	Item 4: Real-time manoeuvring simulations	MARIN
27689-5-MSCN	Item 5: Nautical risk study	MARIN
27689-6-MSCN	Item 6: Nautical Quantitative Risk Assessment	SGS Tecnos

Table 1-1: Overview of reports

To support the design of the modifications to the FSU and the storm mooring for the FSU, some additional analysis was carried out for ElectroGas Malta on the data from the wave climate and wave penetration studies. This has been reported directly to EGM.

1.4 THIS REPORT

This report (marked in bold in Table 1-1) describes the approach and the results of the wave climate study. It presents:

- the wind and wave analysis for the offshore location;
- propagation of the offshore climate (normal and extremes) to nearshore locations.

The results of this study will be used as input conditions for the Wave penetration analysis, item 2 in Table 1-1.

This report is an updated final report to include references to the additional metocean analysis carried out for ElectroGas Malta. The contents of the report is further unchanged.

1.4.1 CONVENTIONS AND DEFINITIONS

Units
All parameters and variables have units according to the international SI conventions except where explicitly stated.

Directions
Unless otherwise stated, wind and wave directions are given according to the nautical convention. For winds and waves, they refer to the direction from which they are coming in degrees, measured clockwise with respect to the North. For example, a wave direction of 90 degrees means the waves are coming from the East.

Coordinate Systems
All the coordinates given in this report are provided in Universal Transverse Mercator zone 33N (WGS 84) unless otherwise stated. The vertical datum used for the bathymetry and different levels is Chart Datum unless otherwise stated.

Notations
The following notations are used in this report:

.	decimal point. Thus 1.5 means one and half.
,	digit grouping symbol. Thus 12,000,000 means 12 million.
E	for the scientific notation with the exponent of 10. Thus 1.2E-3 means 1.2 x 10^{-3} = 0.0012

1.4.2 INTERPRETATION OF WIND AND WAVE ROSES

Roses provide a compact graphical summary directional wind and wave condition statistics. The number in the centre of the rose represents the percentage of the time that calm conditions occur (height, period or speed in the lowest class). The direction that the arm points to (from the centre) represents the direction that winds or waves come from. The length of an arm represents the percentage of the time that winds or waves (other than those in the lowest class) occur in the corresponding direction sector. The colour of a section indicates the corresponding height or speed class. The length of each section represents the percentage of the time that conditions in the given direction sector occur in a given speed, period or height class.

1.4.3 DEFINITION OF WAVE PARAMETERS

The definition of wave parameters is according to the description in SWAN manual [1].

Significant wave height

$$H_s = m_0 = \sqrt{\iint E(\omega,\theta)d\omega d\theta}$$

Peak wave period

$$T_p = \frac{1}{f_p}$$

Mean wave period

$$T_{m-1,0} = 2\pi\frac{m_{-1}}{m_0} = 2\pi\frac{\iint \omega^{-1}E(\omega,\theta)d\omega d\theta}{\iint E(\omega,\theta)d\omega d\theta}$$

Mean wave direction

$$dir = \arctan\left[\frac{\int \sin\theta\, E(\omega,\theta)d\omega d\theta}{\int \cos\theta\, E(\omega,\theta)d\omega d\theta}\right]$$

Directional spreading

The directional spreading is the one-sided width, or standard deviation, of the spectrum.

$$dspr = \frac{\pi}{180}\sqrt{2\left(1-\sqrt{\left[\left(\int \sin\theta\frac{\int E(\omega,\theta)d\omega}{\int E(\omega)d\omega}d\theta\right)^2+\left(\int \cos\theta\frac{\int E(\omega,\theta)d\omega}{\int E(\omega)d\omega}d\theta\right)^2\right]}\right)}$$

Deep water wave steepness

The wave steepness is defined as wave height divided by wave length. In deep water, the wave length is equal to:

$$L_{deep} = \frac{gT^2}{2\pi}$$

The deep water steepness then expressed as:

$$s_{deep} = \frac{H_s}{L_{deep}} = \frac{2\pi H_s}{gT_p^2} \approx \frac{H_s}{1.56T_p^2}$$

With:

E	variance density spectrum
θ	wave direction
ω	radian frequency
f_p	peak frequency, the frequency of the maximum variance density
m_n	n-th order moment of the spectrum, defined as $\iint \omega^n E(\omega,\theta)d\omega d\theta$

2 Offshore wind and wave climate

2.1 INTRODUCTION

This chapter covers the wind and wave conditions offshore Malta. This offshore climate is the basis of the nautical study and has been used in further sections for the derivation of the nearshore wave climate.

In total 33 years of offshore wind- and wave data (1/1/1979 00:00 to 12/31/2011 23:00) were obtained from the OCEANWEATHER Global Reanalysis of Ocean Waves Fine Mediterranean (GROW-FINE MED) hindcast at offshore location (35°45'N, 14°37'30''E), at a depth of 141 m, see Figure 2-1. The time resolution of the time series is 1hr.

The GROW-FINE MED model runs on a grid with 0.125 degree resolution. A location close, but not too close, to the harbour of Marsaxlokk has been selected, that is representative for the offshore wave climate. The island of Malta is well resolved in the OCEANWEATHER models and the sheltering effect of the island is included in the time series at the selected location.

Figure 2-1: OCEANWEATER offshore data point location

The wind and wave data have been analysed to obtain the normal and extreme offshore climate. The normal climate is presented in joint occurrence tables of relevant parameters. The extreme climate is presented in tables presenting values for selected return periods. The presented extreme values are the best estimates for the independent extreme values. For the design of the FSU mooring an additional analysis has been carried out to obtain the confidence intervals of the parameters and the expected joint occurrence of extreme values (e.g. extreme sea and swell wave height associated with 100 year wind). These are presented in a separate report (see [5]).

2.2 WIND CLIMATE

2.2.1 NORMAL WIND CLIMATE

The wind velocity at 10m height in [m/s] as well as the directions in [°N] were delivered by OCEANWEATHER. In total 33 years of offshore wind data (1/1/1979 00:00 to 12/31/2011 23:00) with a time resolution of the time series is 1hr were used. The data was analysed with ARCADIS' in-house statistical analysis tool HYDROBASE (see Appendix A). The wind rose is presented in Figure 2-2 and in Table 2-1, the corresponding probability of exceedance of wind speed for various directional sectors is presented. Calm conditions are those with a wind speed lower than 2 m/s . Most winds come from directions between 255 and 345°N and also most of the stronger winds are coming from these directions. A wind speed of 12 m/s is exceeded less than 7% of the time.

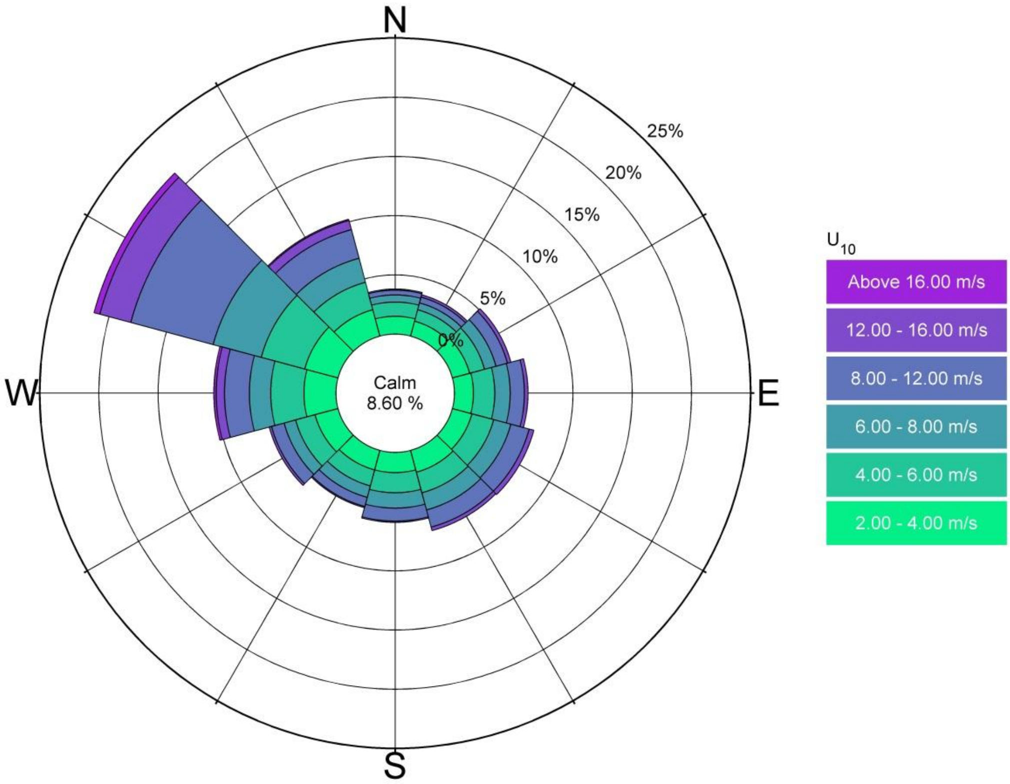


Figure 2-2: Offshore wind rose

U10	wind direction degrees											
per secon	-15 to 15	15 to 45	45 to 75	75 to 105	105 to 135	135 to 165	165 to 195	195 to 225	225 to 255	255 to 285	285 to 315	315 to 345	Total
<	4.47	4.20	5.65	6.87	7.80	7.68	6.64	5.77	6.82	11.09	22.11	10.90	100.00
2.0	3.81	3.58	5.06	6.24	7.13	6.95	5.86	4.99	6.01	10.25	21.26	10.16	91.30
4.0	2.27	2.28	3.60	4.59	5.41	5.14	4.15	3.27	4.01	7.63	18.38	7.86	68.58
6.0	1.09	1.32	2.28	2.83	3.52	3.25	2.50	1.87	2.33	4.84	14.55	5.46	45.83
8.0	.51	.74	1.28	1.51	2.02	1.81	1.24	.90	1.32	2.98	10.41	3.37	28.08
10.0	.22	.41	.61	.71	.95	.86	.47	.30	.65	1.73	6.36	1.89	15.15
12.0	.08	.20	.28	.29	.37	.31	.14	.08	.23	.90	3.19	.88	6.94
14.0	.03	.09	.10	.09	.08	.10	.04	.02	.08	.41	1.28	.33	2.66
16.0	.01	.04	.03	.03	.02	.03	.01	.01	.02	.15	.45	.11	.91
18.0	.01	.01	.01	.01	.00	.01	.00	.00	.00	.05	.12	.04	.26
20.0	.00	.00	.00	.	.00	.00	.	.	.	.02	.03	.01	.07

Table 2-1: Probability of exceedance of offshore wind speed [m/s] for all directional sectors

2.2.2 EXTREME WIND CONDITIONS

The offshore extreme wind conditions are derived based on a statistical extrapolation of the OCEANWEATHER time series. This was done by fitting a Weibull probability distribution function to the data for various classes of wind speed. From our previous studies, the Weibull distribution has been proven to be a robust model for fitting the extreme event distributions. The Weibull distribution has the following formulation:

$$p(\bar{x} > x|\theta) = p_0 e^{-\left(\frac{x-a}{b}\right)^c}$$

With:

x = parameter to be extrapolated, such as wind speed or significant wave height
θ = wave direction
p_0 = normalisation parameter
a = location parameter
b = scaling parameter
c = shape parameter

The Weibull distribution fit was optimized for three parameters: b, c and p_0. The location parameter a is considered fixed and is assigned a value 0.

The Weibull probability distribution function has been fitted to two representations of the data. It has been applied to the cumulative frequency distribution (CFD) of all available data and to the peak-over-threshold (POT) filtered data. The analysis has been carried for directional sectors with a width of 30°.

All available offshore data is lumped into various classes of wind speed and through the lumped data, a Weibull function is fitted. For the CFD method, the probability of exceedance corresponding to a return period is calculated by dividing the duration of the complete time series (33 years) by the duration of a storm event. A storm duration of 3hrs was selected. The time resolution of the input data was 1hr. An example of a Weibull fit for directional sector 120°N is presented in Figure 2-3. The resulting extreme wind conditions are presented in Table 2-2.

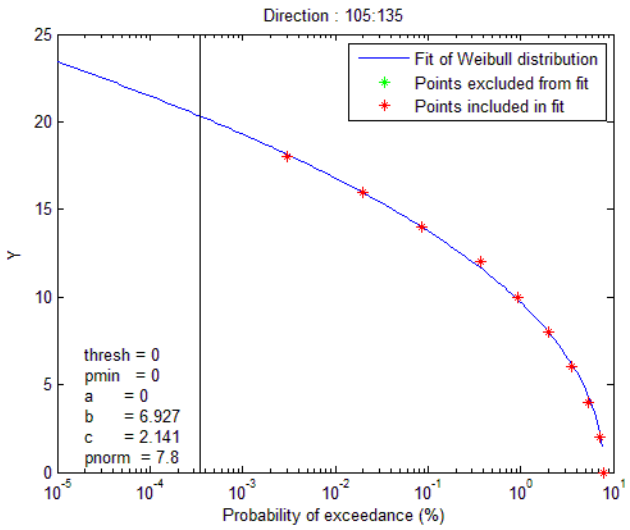


Figure 2-3: Weibull fit extrapolation of offshore extreme wind speed for directional sector 120°N

For the POT method, the maximum wind speed peaks within a time window of 96hr (48hr before and after the peak) and above a threshold value of 10 m/s were selected. The threshold is included to avoid including multiple peaks from one storm and to ensure independence of storm peaks. The threshold value was chosen such that the only the most severe storm conditions were included in the data selection, while sufficient data is included to establish a reliable fitting of the probability of exceedance. An example of the selected peaks above the threshold level of 10 m/s is presented in Figure 2-4.

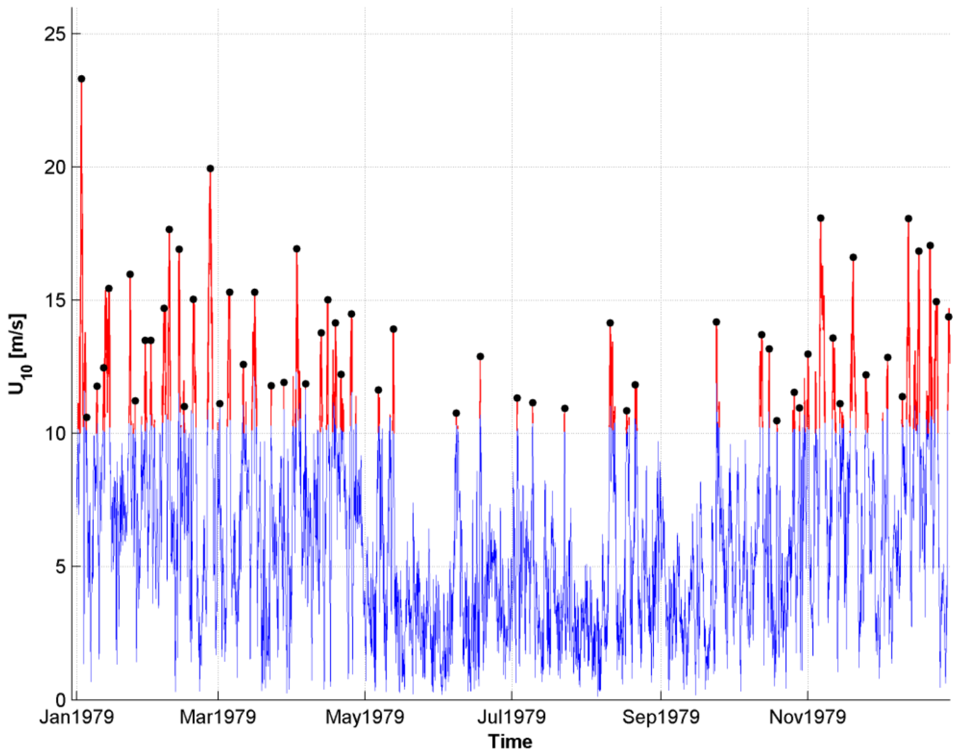


Figure 2-4: Example of peak-over-threshold filtering of offshore wind speed data

The time window of 96 hr was based on an evaluation of a series of storms. In Figure 2-5, the build-up of the ten storms with the highest wind speeds in the offshore OCEANWEATHER time series are presented. The wind speed during a period of 96hr around the maximum is divided by the maximum value. In this manner, the build-up of large storms can be easily compared. The figure shows that the selected time window is appropriate for storms in the project area, as the storm evolution from build up to subsequent decay is observed within this time frame.

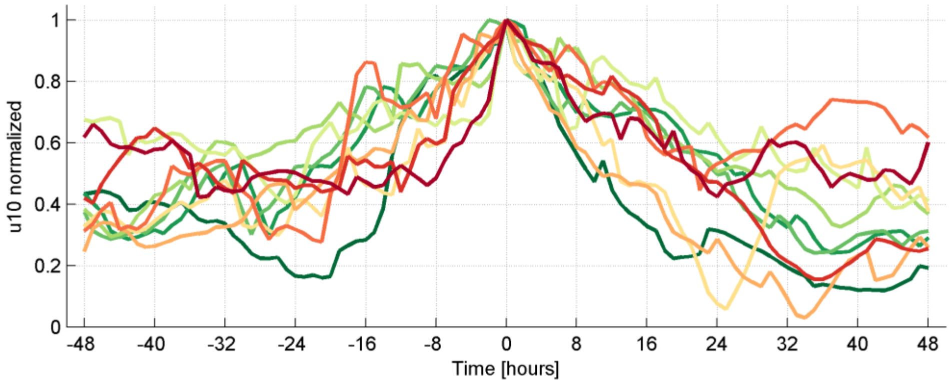


Figure 2-5: Build-up of the ten offshore storm conditions with the highest wind speeds in the offshore time series

The resulting extreme wind conditions are presented in Table 2-2. Comparing the results of the CFD with the POT analysis it can be seen that the results are generally relatively small (<5%). For this study the POT method is believed to be the most suitable method, see also Section 2.3.3, and the POT results will be further used in this study. The most severe extreme conditions are expected from directions 270°N.

Cumulative frequency distribution												
Return period [yr]	0 [°N]	30 [°N]	60 [°N]	90 [°N]	120 [°N]	150 [°N]	180 [°N]	210 [°N]	240 [°N]	270 [°N]	300 [°N]	330 [°N]
1	14.3	15.7	16.1	15.7	15.3	15.7	14.1	13.6	15.2	19.1	19.7	18.0
5	17.5	18.8	18.8	18.1	17.2	17.9	16.1	15.9	17.6	21.9	21.6	20.4
10	18.9	20.0	19.9	19.1	18.0	18.8	16.9	16.8	18.5	23.1	22.4	21.4
25	20.6	21.6	21.3	20.3	19.0	19.9	17.9	17.9	19.7	24.5	23.3	22.6
50	21.8	22.8	22.3	21.1	19.7	20.7	18.6	18.8	20.5	25.6	24.0	23.5
100	23.1	23.9	23.3	22.0	20.3	21.5	19.3	19.6	21.4	26.6	24.6	24.3
Peak over threshold												
Return period [yr]	0 [°N]	30 [°N]	60 [°N]	90 [°N]	120 [°N]	150 [°N]	180 [°N]	210 [°N]	240 [°N]	270 [°N]	300 [°N]	330 [°N]
1	13.6	14.9	15.0	14.8	15.1	15.4	14.1	13.3	15.3	18.5	19.4	17.7
5	17.6	18.8	18.3	17.5	17.3	18.0	16.4	16.0	17.8	21.3	21.7	20.3
10	19.3	20.4	19.5	18.4	18.1	19.0	17.3	17.1	18.8	22.4	22.5	21.4
25	21.6	22.4	21.0	19.6	19.1	20.2	18.4	18.5	19.9	23.6	23.6	22.6
50	23.3	23.8	22.1	20.4	19.8	21.1	19.2	19.6	20.7	24.5	24.3	23.6
100	25.0	25.2	23.1	21.1	20.4	21.9	20.0	20.7	21.4	25.4	25.0	24.4

Table 2-2: Offshore extreme wind speeds in m/s for selected return periods and all directional sectors

2.3 OFFSHORE WAVE CLIMATE

2.3.1 NORMAL WAVE CLIMATE

The time series obtained from OCEANWEATHER contained the significant wave height in [m], peak wave period in [s] and mean wave direction in [°N] for wind sea, swell and wind sea and swell combined (total) conditions. The wind sea and swell conditions are based on a partitioning technique of the total wave conditions that was employed by OCEANWEATHER. The OCEANWATHER data was analysed with ARCADIS' in-house statistical analysis tool HYDROBASE.

The wave roses for the significant wave height are presented in Figure 2-6 for wind sea, swell and total conditions. The corresponding probability of exceedance of significant wave height for the wind sea, swell and total significant wave height are presented in Table 2-3 through Table 2-5.

From the tables and figures it can be seen that most waves are coming from NW directions. Also the higher waves are coming from these directions. Calm conditions are those with a significant wav height lower than 0.5 m. A significant wave height of 2.0m is exceeded less than 12% of the time. The swell waves are generally lower than the wind sea waves. While for wind sea a significant wave height of 2m is exceeded 8.7% of the time, for swell this height is exceeded only 1.4% of the time.

As expected the wave rose for wind sea waves shows a similar directional distribution as the wind rose (Figure 2-2). Most of the wind sea waves come from NW directions and also most of the higher waves are coming from these directions. The directional distribution of swell waves is completely different. The largest contribution of swell waves comes from directions between 45°N and 165°N. This difference can partly be explained by the sheltering effect of the island of Malta which is stronger for long period swell waves than for (partly locally generated) wind seas.

The swell wave rose shows a significant amount of swell waves from 300°N. This might raise questions since the offshore locations at which OCEANWEATHER data has been obtained, is sheltered by land for this direction. In Table 2-4, the joint probability of occurrence of the significant wave height of swell waves for various swell wave directions is presented. This table shows that most of the swell waves from 300°N have very low significant wave heights. A closer inspection of the corresponding periods (Table 2-7) for this direction, shows that these waves have long periods. It is concluded that quite some swell waves pass through the gap between Sicily and Libya. Numerical experiments confirm that swell waves from these directions may diffract around the island and reach the offshore data location.

The wave roses for the peak wave period are presented in Figure 2-7 for wind sea, swell and total conditions. The corresponding probability of exceedance of peak wave period for the wind sea, swell and total significant wave height are presented in Table 2-3 through Table 2-10. Most waves come from NW directions. The longest waves are coming from 90°N. A peak wave period of 8.0s is exceeded less than 11.7% of the time.

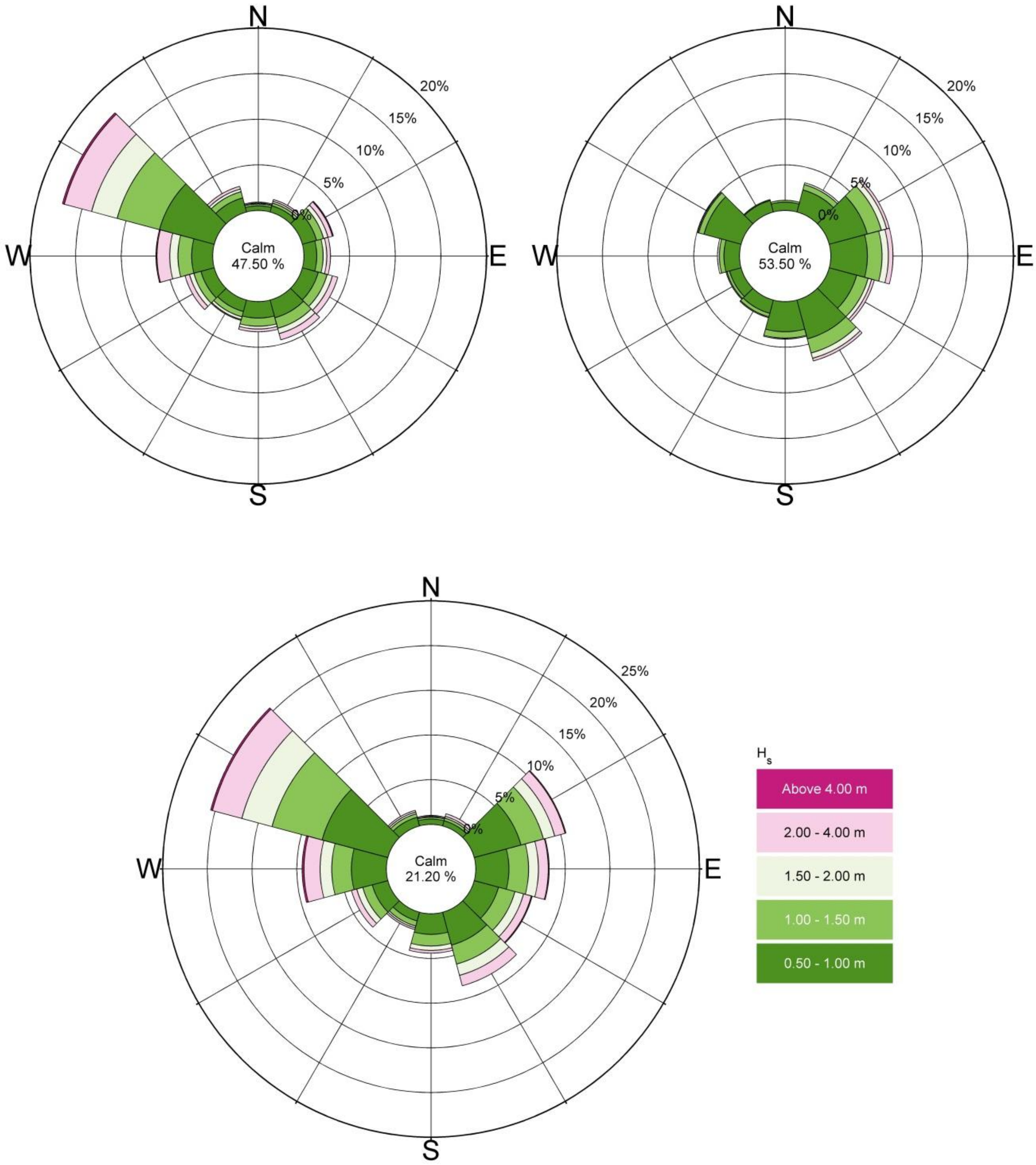


Figure 2-6: Significant wave height roses for offshore wind sea (top left), swell (top right) and total sea states (below)

Hs	wave direction degrees												
meters	-15 to 15	15 to 45	45 to 75	75 to 105	105 to 135	135 to 165	165 to 195	195 to 225	225 to 255	255 to 285	285 to 315	315 to 345	Total
<	3.33	7.81	6.60	5.98	7.00	7.86	6.58	5.35	6.90	12.03	23.95	6.61	100.00
.50	.93	1.40	3.51	2.95	3.96	4.47	3.27	2.25	3.26	6.24	17.23	2.90	52.39
1.00	.39	.73	1.95	1.50	2.21	2.46	1.55	1.01	1.80	3.92	11.01	1.29	29.82
1.50	.19	.39	1.08	.75	1.19	1.35	.64	.36	.99	2.45	6.24	.61	16.24
2.00	.09	.22	.59	.41	.63	.70	.26	.12	.50	1.54	3.31	.30	8.67
2.50	.04	.12	.37	.22	.33	.34	.10	.05	.23	.95	1.71	.13	4.58
3.00	.02	.07	.22	.13	.16	.16	.04	.02	.11	.56	.89	.06	2.45
3.50	.01	.03	.12	.07	.07	.07	.02	.01	.05	.30	.46	.03	1.24
4.00	.00	.02	.07	.04	.04	.03	.00	.00	.02	.15	.23	.01	.61
4.50	.00	.01	.04	.02	.01	.01	.00	.00	.01	.07	.10	.01	.29
5.00	.00	.01	.02	.02	.01	.01	.00	.00	.00	.04	.04	.00	.15
5.50	.	.00	.01	.01	.00	.00	.	.	.00	.02	.02	.	.07
6.00	.	.00	.00	.00	.00	.	.	.	.	.01	.01	.	.03
6.50	.	.00	.00	.	.	.	.	.	.	.01	.00	.	.01
7.00	.	.00	.	.	.	.	.	.	.	.00	.	.	.00
7.50	.	.00	.	.	.	.	.	.	.	.	.	.	.00
8.00	.	.	.	.	.	.	.	.	.	.	.	.	.

Table 2-3: Probability of exceedance of offshore wind sea significant wave height [m] for all directional sectors

Hs	wave direction degrees												
meters	-15 to 15	15 to 45	45 to 75	75 to 105	105 to 135	135 to 165	165 to 195	195 to 225	225 to 255	255 to 285	285 to 315	315 to 345	Total
<	3.78	9.07	13.75	11.27	9.03	12.37	10.28	6.39	3.83	5.14	10.31	4.78	100.00
.50	1.08	3.29	6.84	6.77	5.07	6.95	4.09	1.98	1.66	2.41	4.87	1.42	46.44
1.00	.17	.80	2.53	2.84	2.04	2.52	.80	.45	.40	.67	.75	.14	14.11
1.50	.03	.20	.91	1.18	.72	.85	.15	.09	.09	.15	.05	.01	4.44
2.00	.00	.03	.28	.47	.25	.26	.02	.02	.02	.03	.01	.00	1.42
2.50	.	.00	.10	.17	.10	.06	.01	.01	.00	.01	.00	.00	.47
3.00	.	.	.04	.04	.04	.02	.00	.	.00	.00	.00	.00	.15
3.50	.	.	.01	.01	.01	.01	.00	.	.00	.00	.00	.	.05
4.00	.	.	.00	.00	.00	.00	.	.	.00	.	.	.	.01
4.50	.	.	.00	.	.00	.	.	.	.	.	.	.	.00
5.00	.	.	.	.	.	.	.	.	.	.	.	.	.
5.50	.	.	.	.	.	.	.	.	.	.	.	.	.
6.00	.	.	.	.	.	.	.	.	.	.	.	.	.
6.50	.	.	.	.	.	.	.	.	.	.	.	.	.
7.00	.	.	.	.	.	.	.	.	.	.	.	.	.
7.50	.	.	.	.	.	.	.	.	.	.	.	.	.
8.00	.	.	.	.	.	.	.	.	.	.	.	.	.

Table 2-4: Probability of exceedance of offshore swell significant wave height [m] for all directional sectors

Hs	wave direction degrees												
meters	-15 to 15	15 to 45	45 to 75	75 to 105	105 to 135	135 to 165	165 to 195	195 to 225	225 to 255	255 to 285	285 to 315	315 to 345	Total
<	1.79	2.24	14.88	9.92	7.79	10.12	5.74	2.87	5.36	12.64	23.94	2.71	100.00
.50	1.03	1.37	10.61	8.21	6.74	8.52	4.38	2.02	4.25	9.43	20.55	1.79	78.90
1.00	.42	.84	5.17	4.51	3.85	4.70	2.08	1.02	2.45	5.45	12.90	.81	44.20
1.50	.18	.51	2.57	2.35	1.98	2.47	.80	.41	1.31	3.31	7.08	.37	23.34
2.00	.09	.31	1.27	1.17	1.00	1.22	.32	.16	.64	1.97	3.59	.18	11.90
2.50	.04	.16	.67	.58	.52	.53	.12	.06	.31	1.16	1.85	.08	6.07
3.00	.02	.07	.36	.27	.25	.23	.05	.03	.15	.68	.93	.04	3.06
3.50	.01	.04	.20	.13	.11	.10	.02	.01	.06	.35	.49	.01	1.53
4.00	.00	.02	.12	.06	.05	.04	.00	.00	.03	.17	.24	.00	.76
4.50	.00	.01	.06	.04	.02	.02	.00	.00	.02	.09	.11	.00	.37
5.00	.	.01	.03	.02	.01	.01	.00	.00	.01	.05	.05	.00	.19
5.50	.	.00	.02	.02	.01	.00	.	.00	.00	.02	.02	.	.10
6.00	.	.00	.00	.00	.00	.	.	.	.	.01	.01	.	.04
6.50	.	.00	.	.	.	.	.	.	.	.01	.00	.	.01
7.00	.	.00	.	.	.	.	.	.	.	.00	.	.	.00
7.50	.	.00	.	.	.	.	.	.	.	.	.	.	.00
8.00	.	.	.	.	.	.	.	.	.	.	.	.	.

Table 2-5: Probability of exceedance of offshore total significant wave height [m] for all directional sectors

Hs meters Lower	Upper	wave direction degrees -15 to 15	15 to 45	45 to 75	75 to 105	105 to 135	135 to 165	165 to 195	195 to 225	225 to 255	255 to 285	285 to 315	315 to 345	Total
<	.50	2.70	5.78	6.90	4.50	3.96	5.42	6.19	4.42	2.17	2.73	5.44	3.36	53.56
.50	1.00	.91	2.49	4.32	3.93	3.03	4.43	3.29	1.52	1.26	1.75	4.12	1.28	32.33
1.00	1.50	.15	.61	1.61	1.67	1.32	1.66	.65	.37	.30	.51	.70	.12	9.67
1.50	2.00	.02	.16	.63	.70	.47	.59	.12	.06	.07	.12	.04	.01	3.02
2.00	2.50	.00	.03	.18	.30	.16	.20	.02	.02	.02	.02	.01	.00	.95
2.50	3.00	.	.00	.07	.13	.06	.04	.00	.01	.00	.01	.00	.00	.32
3.00	3.50	.	.	.02	.04	.02	.01	.00	.	.00	.00	.00	.00	.10
3.50	4.00	.	.	.01	.01	.01	.01	.00	.	.00	.00	.00	.	.03
4.00	4.50	.	.	.00	.00	.00	.00	.	.	.00	.	.	.	.01
4.50	5.00	.	.	.00	.	.00	.	.	.	.	.	.	.	.00
5.00	5.50	.	.	.	.	.	.	.	.	.	.	.	.	.
5.50	6.00	.	.	.	.	.	.	.	.	.	.	.	.	.
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.	.
Total		3.78	9.07	13.75	11.27	9.03	12.37	10.28	6.39	3.83	5.14	10.31	4.78	100.00

Table 2-6: Joint probability of occurrence of offshore swell significant wave height [m] and all directional sectors [°N]

Tp seconds Lower	Upper	wave direction degrees -15 to 15	15 to 45	45 to 75	75 to 105	105 to 135	135 to 165	165 to 195	195 to 225	225 to 255	255 to 285	285 to 315	315 to 345	Total
<	4.0	.45	.51	.57	.44	.55	.90	1.57	1.02	.67	.90	.97	.56	9.12
4.0	5.0	.87	1.85	2.03	.98	.95	2.02	2.52	1.45	.63	.63	1.29	.93	16.17
5.0	6.0	1.12	2.40	3.14	1.85	1.97	3.27	2.94	1.63	1.00	1.01	2.49	1.44	24.25
6.0	7.0	.65	1.84	3.01	2.15	2.23	3.12	1.96	1.17	.75	1.03	2.33	.86	21.08
7.0	8.0	.36	1.25	2.31	2.17	1.86	1.89	.79	.54	.39	.70	1.78	.48	14.51
8.0	9.0	.17	.75	1.56	1.82	1.03	.93	.37	.37	.22	.49	.86	.27	8.84
9.0	10.0	.07	.34	.76	1.17	.30	.18	.08	.13	.10	.24	.37	.13	3.85
10.0	11.0	.04	.08	.29	.49	.10	.03	.02	.04	.04	.10	.14	.06	1.44
11.0	12.0	.02	.03	.07	.18	.03	.01	.01	.02	.02	.03	.05	.03	.50
12.0	14.0	.03	.02	.02	.03	.01	.01	.01	.02	.02	.01	.03	.01	.22
14.0	>	.00	.00	.00	.00	.00	.00	.00	.01	.00	.00	.00	.00	.03
Total		3.78	9.07	13.75	11.27	9.03	12.37	10.28	6.39	3.83	5.14	10.31	4.78	100.00

Table 2-7: Joint probability of occurrence of offshore swell peak wave period [s] and all directional sectors [°N]

Figure 2-7: Peak period roses for offshore wind sea (top left), swell (top right) and total sea states (below)

Tp	wave direction degrees												
seconds	-15 to 15	15 to 45	45 to 75	75 to 105	105 to 135	135 to 165	165 to 195	195 to 225	225 to 255	255 to 285	285 to 315	315 to 345	Total
<	3.33	7.81	6.60	5.98	7.00	7.86	6.58	5.35	6.90	12.03	23.95	6.61	100.00
4.0	.73	1.16	3.04	2.43	3.35	3.78	2.66	1.79	2.80	5.40	15.38	2.30	44.80
5.0	.37	.69	1.94	1.42	2.12	2.38	1.44	.93	1.83	3.91	11.39	1.25	29.66
6.0	.16	.39	1.10	.68	1.10	1.25	.54	.30	.95	2.54	7.19	.60	16.80
7.0	.05	.19	.56	.30	.45	.48	.14	.07	.36	1.45	4.14	.23	8.43
8.0	.02	.09	.27	.14	.16	.13	.03	.02	.11	.73	1.78	.07	3.55
9.0	.01	.02	.09	.06	.03	.02	.00	.00	.02	.24	.68	.03	1.20
10.0	.00	.01	.03	.02	.01	.00	.	.00	.00	.06	.22	.01	.36
11.0	.	.00	.00	.01	.00	.	.	.	.	.01	.04	.00	.06
12.0	.	.	.	.	.	.	.	.	.	.	.00	.	.00
14.0	.	.	.	.	.	.	.	.	.	.	.	.	.

Table 2-8: Probability of exceedance of offshore wind sea peak wave period [s] for all directional sectors

Tp	wave direction degrees												
seconds	-15 to 15	15 to 45	45 to 75	75 to 105	105 to 135	135 to 165	165 to 195	195 to 225	225 to 255	255 to 285	285 to 315	315 to 345	Total
<	3.78	9.07	13.75	11.27	9.03	12.37	10.28	6.39	3.83	5.14	10.31	4.78	100.00
4.0	3.33	8.56	13.17	10.84	8.48	11.46	8.71	5.37	3.16	4.24	9.34	4.21	90.88
5.0	2.46	6.71	11.14	9.85	7.53	9.44	6.18	3.92	2.52	3.61	8.05	3.28	74.71
6.0	1.34	4.31	8.01	8.00	5.56	6.17	3.25	2.29	1.53	2.60	5.56	1.84	50.45
7.0	.69	2.47	5.00	5.85	3.33	3.05	1.29	1.12	.78	1.57	3.23	.98	29.38
8.0	.33	1.23	2.69	3.68	1.47	1.17	.50	.58	.39	.87	1.45	.50	14.87
9.0	.16	.48	1.14	1.87	.44	.23	.13	.21	.18	.38	.59	.24	6.03
10.0	.09	.14	.38	.70	.14	.05	.05	.08	.08	.14	.22	.10	2.18
11.0	.05	.06	.09	.21	.04	.02	.02	.04	.04	.05	.08	.04	.74
12.0	.03	.03	.02	.03	.01	.01	.01	.03	.02	.01	.03	.01	.25
14.0	.00	.00	.00	.00	.00	.00	.00	.01	.00	.00	.00	.00	.03

Table 2-9: Probability of exceedance of offshore swell peak wave period [s] for all directional sectors

Tp	wave direction degrees												
seconds	-15 to 15	15 to 45	45 to 75	75 to 105	105 to 135	135 to 165	165 to 195	195 to 225	225 to 255	255 to 285	285 to 315	315 to 345	Total
<	1.79	2.24	14.88	9.92	7.79	10.12	5.74	2.87	5.36	12.64	23.94	2.71	100.00
4.0	1.10	1.73	13.93	9.22	7.16	9.07	4.59	1.92	4.27	10.14	21.49	2.01	86.63
5.0	.60	1.34	11.44	8.07	5.97	6.83	2.91	1.20	3.25	8.24	18.06	1.30	69.21
6.0	.26	.88	7.98	6.23	4.03	3.99	1.16	.48	1.79	5.41	12.11	.60	44.92
7.0	.07	.59	4.89	4.53	2.21	1.84	.30	.13	.79	3.05	6.86	.19	25.47
8.0	.02	.35	2.42	2.92	.82	.58	.05	.04	.25	1.42	2.79	.05	11.71
9.0	.00	.16	.91	1.48	.17	.08	.01	.01	.05	.45	.95	.01	4.28
10.0	.00	.04	.27	.55	.03	.01	.	.00	.01	.12	.29	.00	1.32
11.0	.	.01	.06	.16	.01	.	.	.	.	.01	.05	.	.30
12.0	.	.00	.01	.02	.00	.	.	.	.	.00	.01	.	.04
14.0	.	.	.	.	.	.	.	.	.	.	.	.	.

Table 2-10: Probability of exceedance of offshore total peak wave period [s] for all directional sectors

2.3.2 ANALYSIS OF MIXED SEA STATE CONDITIONS

To investigate the need for a separate evaluation of swell and wind sea conditions, an analysis is made of the joint probability of occurrence of swell and wind wave conditions. From the joint probability of the simultaneous occurrence of wind sea and swell mean wave direction (Table 2-11), it is seen that little to no correlation exists between the directions. This implies that sea and swell conditions should be treated separately.

dir Swell [degrees]		dir Sea [degrees]												
Lower	Upper	-15 to 15	15 to 45	45 to 75	75 to 105	105 to 135	135 to 165	165 to 195	195 to 225	225 to 255	255 to 285	285 to 315	315 to 345	Total
-15	15	.22	.17	.27	.22	.16	.15	.12	.37	.28	.76	.72	.33	3.78
15	45	.44	.41	.81	.79	.59	.46	.29	.66	.46	1.20	2.26	.70	9.07
45	75	.69	.90	1.44	1.05	.81	.86	.62	.90	.48	1.27	3.67	1.05	13.75
75	105	.32	.55	1.16	.90	.89	.86	.79	.91	.58	1.18	2.54	.58	11.27
105	135	.21	.37	.72	.82	.78	.77	.66	.85	.54	.80	2.09	.43	9.03
135	165	.16	.25	.68	1.13	1.63	1.38	1.15	1.28	.77	1.03	2.44	.46	12.37
165	195	.08	.08	.20	.38	1.28	1.73	1.19	1.27	.76	1.08	1.96	.27	10.28
195	225	.06	.04	.10	.10	.30	.62	.50	.56	.66	1.06	2.21	.18	6.39
225	255	.06	.06	.09	.06	.12	.32	.37	.55	.62	.52	.80	.26	3.83
255	285	.23	.22	.18	.07	.10	.24	.38	.57	.45	.66	1.34	.70	5.14
285	315	.61	.52	.63	.26	.21	.33	.36	1.00	.85	1.48	2.80	1.25	10.31
315	345	.25	.19	.32	.19	.13	.15	.13	.47	.44	.99	1.11	.41	4.77
Total		3.33	3.76	6.60	5.98	7.00	7.86	6.58	9.40	6.90	12.03	23.95	6.61	100.00

Table 2-11: Joint probability of occurrence of offshore wind sea and swell direction [°N]

Table 2-12 presents the joint probability of wind sea and swell significant wave heights. From this table it is apparent that there is a rather poor correlation between wind sea and swell wave heights, which is in line with the results shown in Table 2-11. Therefore, they need to be assessed separately.

Hs Swell meters		Hs Sea [m]											
Lower	Upper	< to .25	.25 to .50	.50 to .75	.75 to 1.00	1.00 to 1.25	1.25 to 1.50	1.50 to 2.00	2.00 to 2.50	2.50 to 3.00	3.00 to 5.00	5.00 to >	Total
<	.25	2.92	2.16	2.31	2.18	1.97	1.53	2.23	1.16	.41	.13	.	16.99
.25	.50	13.73	7.15	3.85	2.83	2.15	1.53	2.04	1.24	.86	1.15	.03	36.57
.50	.75	6.40	4.90	2.69	1.93	1.39	1.00	1.18	.57	.33	.41	.04	20.85
.75	1.00	2.79	2.61	1.70	1.26	.91	.65	.76	.38	.18	.21	.03	11.49
1.00	1.25	1.18	1.32	.93	.78	.59	.42	.51	.28	.12	.13	.02	6.28
1.25	1.50	.57	.61	.49	.44	.35	.26	.32	.17	.08	.08	.01	3.39
1.50	2.00	.44	.49	.42	.39	.31	.26	.35	.18	.08	.09	.01	3.02
2.00	2.50	.11	.13	.14	.12	.10	.08	.11	.07	.04	.06	.01	.95
2.50	3.00	.03	.04	.04	.03	.03	.03	.04	.03	.02	.03	.00	.32
3.00	5.00	.01	.01	.01	.02	.01	.01	.02	.01	.01	.02	.00	.15
5.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		28.17	19.44	12.59	9.98	7.81	5.77	7.57	4.09	2.13	2.30	.15	100.00

Table 2-12: Joint probability of occurrence of offshore wind sea and swell significant wave height [m]

From the joint probability of occurrence of wind and wind sea directions (Table 2-13), it can be seen that a strong correlation exists. Their directions can be safely assumed to be equal in the subsequent analysis of wind sea wave conditions.

dir Swell [degrees]		dir Wind [degrees]												
		-15 to 15	15 to 45	45 to 75	75 to 105	105 to 135	135 to 165	165 to 195	195 to 225	225 to 255	255 to 285	285 to 315	315 to 345	Total
Lower	Upper													
-15	15	2.39	.29	.03	.00	.	.	.	.	.	.00	.04	.57	3.33
15	45	.89	2.41	.32	.04	.00	.	.	.	.	.	.00	.10	3.76
45	75	.07	1.16	4.17	1.13	.06	.00	.	.	.	.	.	.01	6.60
75	105	.00	.05	.79	4.14	.94	.06	.00	.	.	.	.	.	5.98
105	135	.	.00	.06	1.22	5.00	.71	.02	.	.	.	.	.	7.00
135	165	.	.	.00	.04	1.46	5.55	.80	.02	.00	.	.	.	7.86
165	195	.	.	.	.00	.03	.97	4.69	.84	.05	.00	.	.	6.58
195	225	.30	.28	.29	.30	.32	.39	1.09	4.04	1.20	.47	.39	.34	9.40
225	255	.	.	.	.	.	.00	.03	.85	4.55	1.30	.16	.01	6.90
255	285	.00	.	.	.	.	.	.00	.02	1.00	7.88	3.00	.12	12.03
285	315	.05	.	.	.	.	.	.	.00	.01	1.43	18.01	4.45	23.95
315	345	.77	.02	.00	.	.	.	.	.	.	.01	.52	5.30	6.61
Total		4.47	4.20	5.65	6.87	7.80	7.68	6.63	5.77	6.81	11.09	22.11	10.90	100.00

Table 2-13: Joint probability of occurrence of offshore wind direction and wind sea direction [°N]

2.3.3 EXTREME WAVE CONDITIONS

The offshore extreme wave conditions are derived based on a statistical extrapolation of the OCEANWEATHER time series. This was done by fitting a Weibull probability distribution function to the data for various classes of (total) significant wave height. From our previous studies, the Weibull distribution has been proven to be a robust model for fitting the extreme event distributions. The same methodology and settings as for the extrapolation of wind speeds were applied, including the analysis per direction sector.

The Weibull probability distribution function has been fitted to two representations of the data. It has been applied to the cumulative frequency distribution (CFD) of all available data and to the peak-over-threshold (POT) filtered data.

All available offshore data is lumped into various classes of wind speed and through the lumped data, a Weibull function is fitted. For the CFD method, the probability of exceedance corresponding to a return period is calculated by dividing the duration of the complete time series (33 years) by the duration of a storm event. A storm duration of 3hrs was selected. The time resolution of the input data was 1hr. An example of a Weibull fit is presented in Figure 2-8. The resulting extreme significant wave heights are presented in Table 2-14.

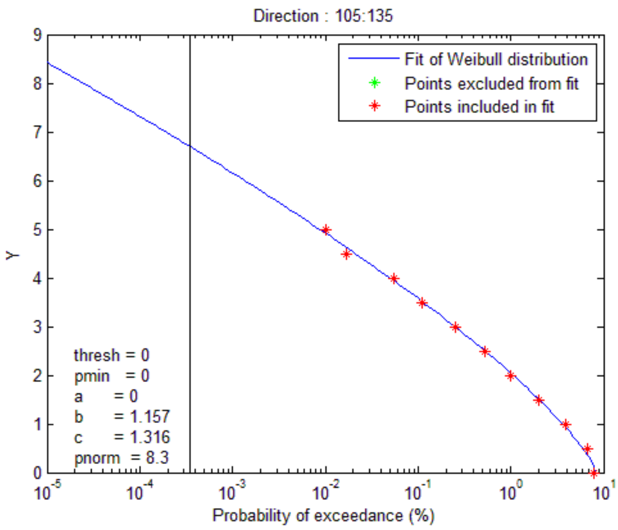


Figure 2-8: Weibull fit extrapolation of offshore significant wave height for directional sector 120°N

For the POT method, the maximum significant wave height peaks within a time window of 96hr (48hr before and after the peak) and above a threshold value of 2 m were selected was selected. The threshold is included to avoid including multiple peaks from one storm and to ensure independence of storm peaks. The threshold value was chosen such that the only the most severe storm conditions were included in the data selection, while sufficient data is included to establish a reliable fitting of the probability of exceedance. The extreme significant wave heights obtained with the POT analysis are presented in Table 2-14.

The time window was based on an evaluation of a series of storms. In Figure 2-9, the build-up of the ten storms with the highest significant wave heights in the offshore OCEANWEATHER time series are presented. The significant wave height during a period of 96hr around the maximum is divided by the maximum value. In this manner, the build-up of large storms can be easily compared. The figure shows that the selected time window is appropriate for storms in the project area, as the storm evolution from build up to subsequent decay is observed within this time frame.

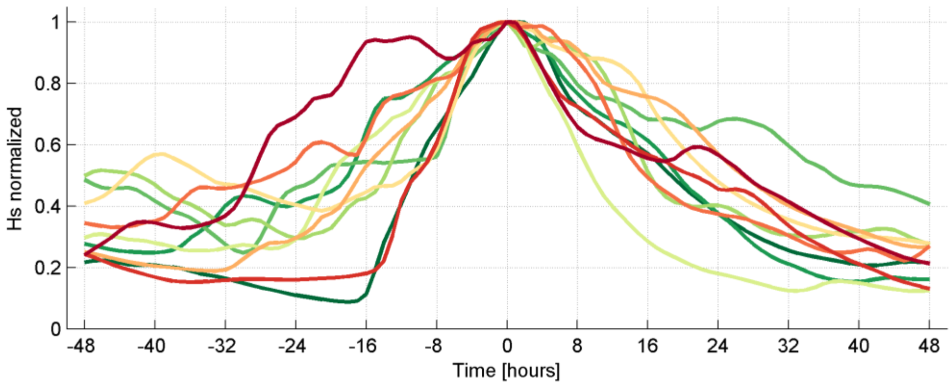


Figure 2-9: Build-up of the ten offshore storm conditions with the highest significant wave height in the offshore time series

From comparison between the CFD method and the POT method (both are presented in Table 2-14) it can be seen that the largest differences in extreme significant wave heights are found for the 60°N and 90°N directional bins (up to 1m difference in Hs). Based on the maximum significant wave heights observed in the OCEANWEATHER time series, which cover 33 years of hindcast data, the values obtained using the POT method are believed to produce more realistic estimates (in the time series the maximum Hs in the 45°N-75°N direction sector is 6.4m, which corresponds quite well with the POT values for the 60°N bin for a 25 year return period).Therefore, the POT results are used further in the present study.

Cumulative frequency distribution												
Return period [yr]	0 [°N]	30 [°N]	60 [°N]	90 [°N]	120 [°N]	150 [°N]	180 [°N]	210 [°N]	240 [°N]	270 [°N]	300 [°N]	330 [°N]
1	2.6	3.7	4.9	4.6	4.2	4.2	3.2	2.9	4.0	5.3	5.2	3.0
5	3.5	5.0	6.2	5.7	5.1	5.0	3.9	3.8	5.0	6.4	6.1	3.9
10	3.8	5.6	6.8	6.2	5.5	5.4	4.3	4.2	5.4	6.9	6.5	4.2
25	4.3	6.3	7.5	6.8	6.0	5.9	4.7	4.7	5.9	7.6	7.0	4.7
50	4.7	6.8	8.1	7.3	6.4	6.2	5.0	5.1	6.3	8.0	7.4	5.1
100	5.1	7.3	8.6	7.8	6.7	6.6	5.3	5.5	6.7	8.5	7.8	5.5
Peak over threshold												
Return period [yr]	0 [°N]	30 [°N]	60 [°N]	90 [°N]	120 [°N]	150 [°N]	180 [°N]	210 [°N]	240 [°N]	270 [°N]	300 [°N]	330 [°N]
1	2.8	3.3	3.9	3.5	3.5	3.6	3.1	2.9	3.5	4.6	4.7	3.2
5	3.9	4.8	5.3	4.8	4.7	4.7	4.0	4.0	4.6	5.9	5.8	4.2
10	4.3	5.5	5.9	5.4	5.1	5.1	4.3	4.5	5.1	6.3	6.2	4.6
25	5.0	6.3	6.6	6.2	5.8	5.6	4.8	5.2	5.7	6.9	6.8	5.1
50	5.4	7.0	7.1	6.8	6.2	5.9	5.1	5.7	6.2	7.4	7.2	5.4
100	5.9	7.6	7.6	7.4	6.7	6.3	5.4	6.2	6.6	7.8	7.6	5.8

Table 2-14: Offshore extreme (total) significant wave height in m for selected return periods and all directional sectors

The most appropriate peak wave periods corresponding to the derived offshore extreme wave height conditions were determined by fitting a square root function to the data in the OCEANWEATHER time series ensuring a relation with constant deep water wave steepness. The applied function was defined as:

$$T_p \leq \beta\sqrt{H_{m0}}$$

With:

H_{m0}	=	Significant wave height [m]
T_p	=	Peak wave period [s]

Because extreme wave conditions are dominated by wind seas, the wind sea data was used for the fitting. Only data with significant wave heights larger than 1.0m was included in the fitting. The fitting procedure was applied for each directional sector. The optimal values for β and the resulting peak wave periods are presented in Table 2-15.

In Appendix 1, the tables with the joint probability of offshore significant wave height and peak wave period for each directional sector are presented for wind sea, swell and total waves. In Appendix 2, the scatter plots of significant wave height and peak wave period, with the corresponding fitted square root function are presented for the wind sea waves. As an example, Figure 2-10 presents the scatter plot and the fitted relationship for directional sector 120°N, together with curves for various constant wave steepnesses.

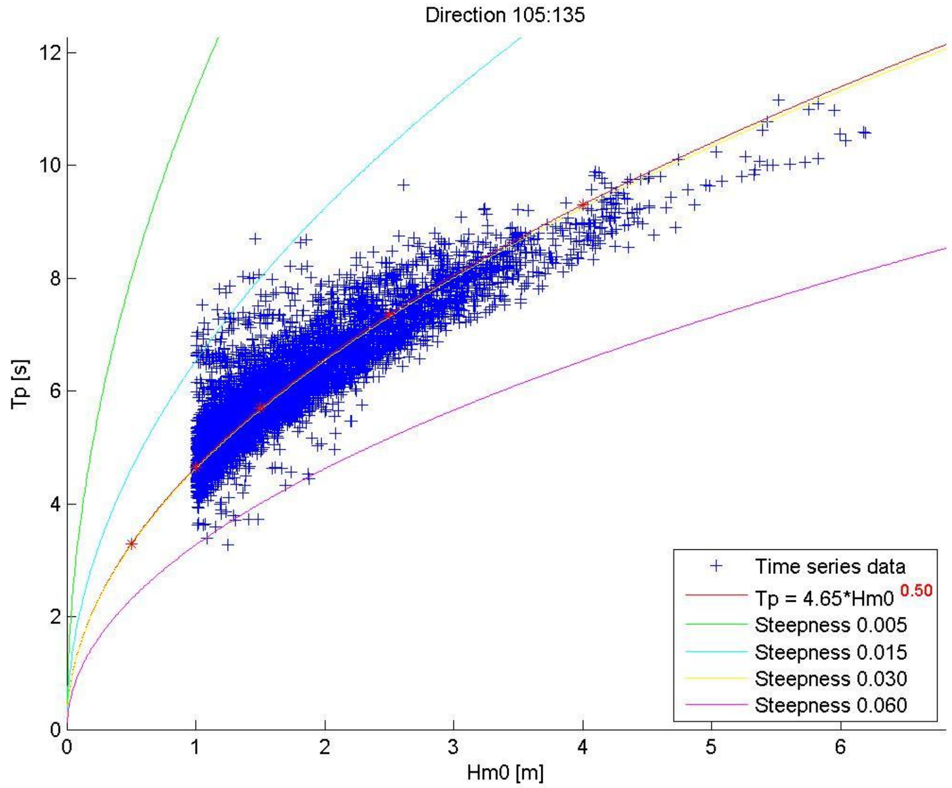


Figure 2-10: Square root relation fitted to the offshore wind sea significant wave height and peak wave period for directional sector 120°N. The curves of four wave steepnesses are included for reference.

Return period [yr]	Square root fitting to offshore time series data 0 [°N]	30 [°N]	60 [°N]	90 [°N]	120 [°N]	150 [°N]	180 [°N]	210 [°N]	240 [°N]	270 [°N]	300 [°N]	330 [°N]
β [-]	4.6	4.7	4.8	4.7	4.7	4.7	4.7	4.7	4.7	4.8	5.0	4.7
1	7.8	9.4	10.3	10.0	9.3	9.2	8.4	8.3	9.0	10.3	10.8	8.5
5	9.0	10.4	11.1	10.7	10.3	10.0	9.3	9.5	10.2	11.6	12.1	9.7
10	9.5	11.0	11.5	10.9	10.7	10.5	9.7	9.9	10.7	12.1	12.5	10.1
25	10.2	11.9	12.2	11.6	11.2	11.0	10.2	10.6	11.3	12.6	13.1	10.6
50	10.7	12.4	12.7	12.1	11.6	11.3	10.6	11.1	11.7	13.0	13.4	11.0
100	11.1	13.0	13.2	12.6	12.0	11.7	10.9	11.6	12.2	13.4	13.8	11.3

Table 2-15: Offshore extreme peak wave periods in s for various return periods and directions

2.4 WATER LEVELS

Given the large water depths in front of the harbour, where the nearshore wave conditions are evaluated, the effect of water level variations on the wave conditions is deemed negligible. In Table 2-16, the tidal levels at Valetta are presented (source: Admiralty Tide Tables of 2006). For the evaluation of the normal climate, the water levels are therefore taken constant at MSL.

Tidal level	Level [m +MSL]
MHWS	0.17
MHWN	0.07
MSL	0.00
MLWN	-0.03
MLWS	-0.23

Table 2-16: Tidal levels at Valetta (source: Admiralty Tide Tables)

Detailed information about air-pressure induced water level variation and storm set-up is not available. Lacking quantitative information on the overall increase of the sea level due to wind speed and air pressure effects, it is estimated that the maximum non-tidal water level variations at the output points is 0.30m. Taking into consideration the tidal effects (HAT is taken as 0.17m +MSL), overall extreme water levels are estimated to be in the order of about 0.47m +MSL. It is noted that at the output points of SWAN, the water depths are relatively large (in the order of 30m) and that the water level variation is small compared to the water depth. The effect of the water level variation on the wave conditions will consequently be small.

It is noted that a detailed evaluation of extreme water levels, storm surge etc. is beyond the scope of this study.

2.5 CLIMATE CHANGE

Potential impacts of climate change over the life time (18 years) of the project are changes in the mean water level, in the normal yearly averaged wind and wave conditions and storm intensities affecting the extreme wind and wave conditions (both offshore and nearshore).

The projections for future sea level rise as predicted by IPCC are (www.realclimate.org):

- For high emissions a global rise by 52-98 cm by the year 2100,
- For the scenario with aggressive emissions reductions, a rise by 28-61 cm by the year 2100.

The likely range of sea level rise for the 21st century is presented in Figure 2-11 (source IPCC AR5).

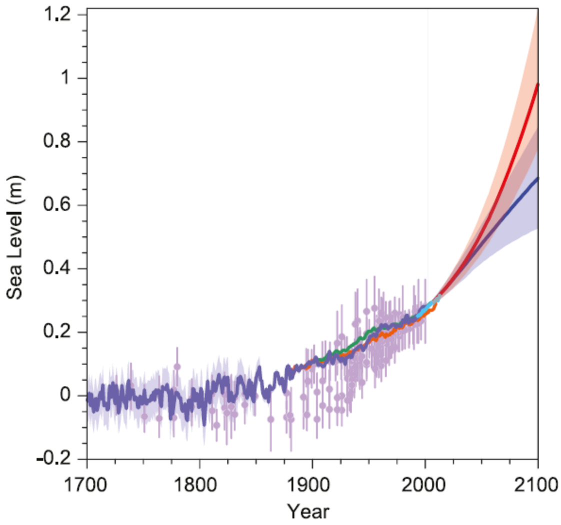


Figure 2-11: Past and future sea-level rise. For the past, proxy data are shown in light purple and tide gauge data in blue. For the future, the IPCC projections for very high emissions (red, RCP8.5 scenario) and very low emissions (blue, RCP2.6 scenario) are shown. Source: IPCC AR5 Fig. 13.27 (www.realclimate.org)

The global projections for sea level rise differ from local effects in the Mediterranean area. Detailed information about the local effects is not readily available.

Considering the relatively large depth at the project site (approximately 15m) and the lifetime of the structure (18 years), the impact of changes in the mean water level on the wave conditions is expected to be small. Intensity of storms might change, but this is has not been considered in the present study.

3 Nearshore wave climate

3.1 INTRODUCTION

This chapter describes the propagation of the offshore OCEANWEATHER wave conditions towards nearshore locations of interest just outside Marsaxlokk Bay. The results of the transformed wave conditions are used to determine the yearly average and design nearshore wave conditions. In turn these nearshore conditions will be propagated to the sites of interest in the Bay of Marsaxlokk (see report 27689-2-MSCN; Wave penetration study).

The wave propagation is carried out using the wave model SWAN (Simulating WAves Nearshore) version 40.91. SWAN is a fully spectral third generation wave model that is developed at the Delft University of Technology (Booij et al., 1999, SWAN team 2014). SWAN represents the wave field on a regular grid using the spectral energy density at discrete frequencies and directions. It solves the wave action balance with sources and sinks. For the transformation of offshore wave conditions to nearshore conditions, relevant physical effects of local wave growth, depth induced dissipation, shoaling and refraction are accounted for in the SWAN model. More information about SWAN is found in Appendix B and the SWAN manual [1].

3.2 SCHEMATIZATION

3.2.1 COMPUTATIONAL GRIDS

SWAN represents the wave field on a two dimensional horizontal rectangular grid. The following information has to be specified:

- The area covered by the grids.
- The spatial grid resolution.
- The use of nested grids. The models on the nested grids receive their boundary conditions from the outer grids.

Furthermore, the spatial grid should meet the following requirements:

- It should be possible to define the wave conditions at the boundary of the outer computational grid. In practice, this means that they can be considered uniform or that their variation must be known.
- Boundaries where the wave conditions cannot properly be defined should not have any influence in the area of interest.
- The computational times should be acceptable.
- The grid resolution should be fine enough to reproduce the spatial depth variations that influence the wave conditions in the area of interest.
- The overall area should be kept sufficiently small to allow the computations to be carried out in stationary mode.

Two different grids were developed to meet the above mentioned criteria. Grid A00 will cover the an area from the offshore data point to 2.5 km offshore the port, where a higher resolution grid (grid B00) is placed to describe the wave transformations in more detail. The main characteristics of the grids are presented in Table 3-1 and Figure 3-1. The grid origin in UTM33 coordinates is given by x0, y0 and alpha is the grid rotation with respect to the x-axis (Cartesian definition). Lx, ly are the lengths of the grid in both directions and dx, dy are the spatial grid resolution in two directions.

Grid name	x0 [m UTM33]	y0 [m UTM33]	Alpha [^{0}]	lx [m]	ly [m]	dx [m]	dy [m]
A00	456800	3946500	44	30000	14000	100	100
B00	459300	3960500	44	6000	5000	20	20

Table 3-1: Main characteristics of the SWAN computational grids

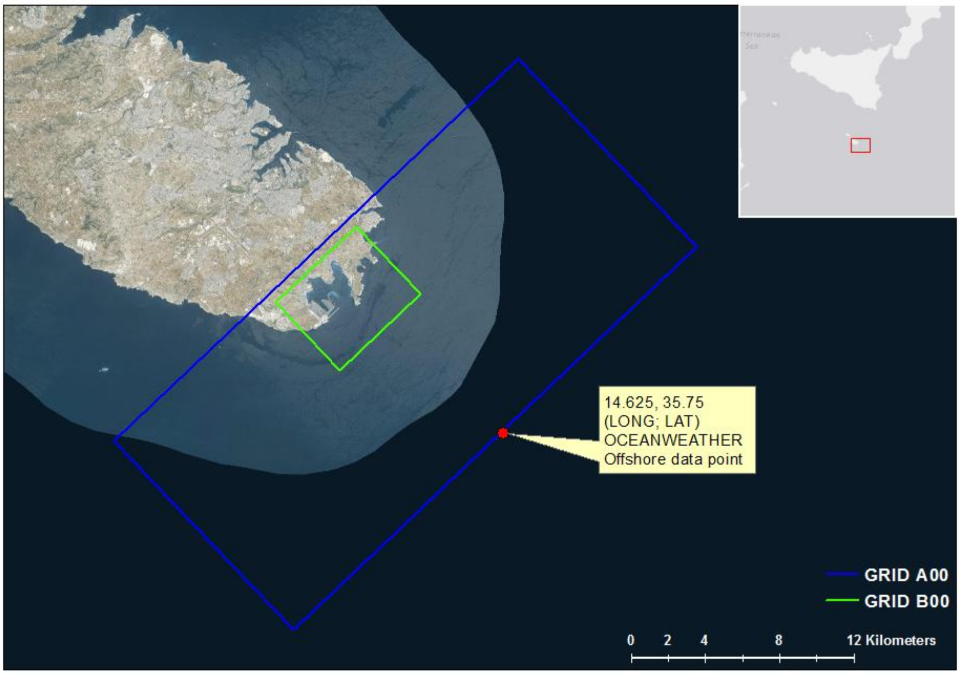


Figure 3-1: SWAN grids and offshore OCEANWEATHER data location

3.2.2 DEPTH SCHEMATIZATION

Bathymetric data of the offshore areas was obtained by geo-referencing and digitising the following Admiralty Charts:

- 2538 – Malta;
- 194 - Approaches to Malta and Ghawdex (Gozo);
- 36 – Marsaxlokk;

This digitised data was then interpolated onto the computational grid using a triangulation technique. The information provided on the Chart is with respect to the Lowest Astronomical Tide or Chart Datum.

The resulting bathymetry for grid A00 is presented in Figure 3-2 and for grid B00 in Figure 3-3. At the bay entrance, the depth is approximately 30m. South of the bay entrance, a shoal is present with water depths around 5m.

The breakwater at the south-western entrance of the bay area is included in the schematisation as an obstacle with zero transmission and 90% reflection. The normal climate presented in this report does include the reflective wave. It is noted that the reflection of the breakwater was not included in the extreme wave computations.

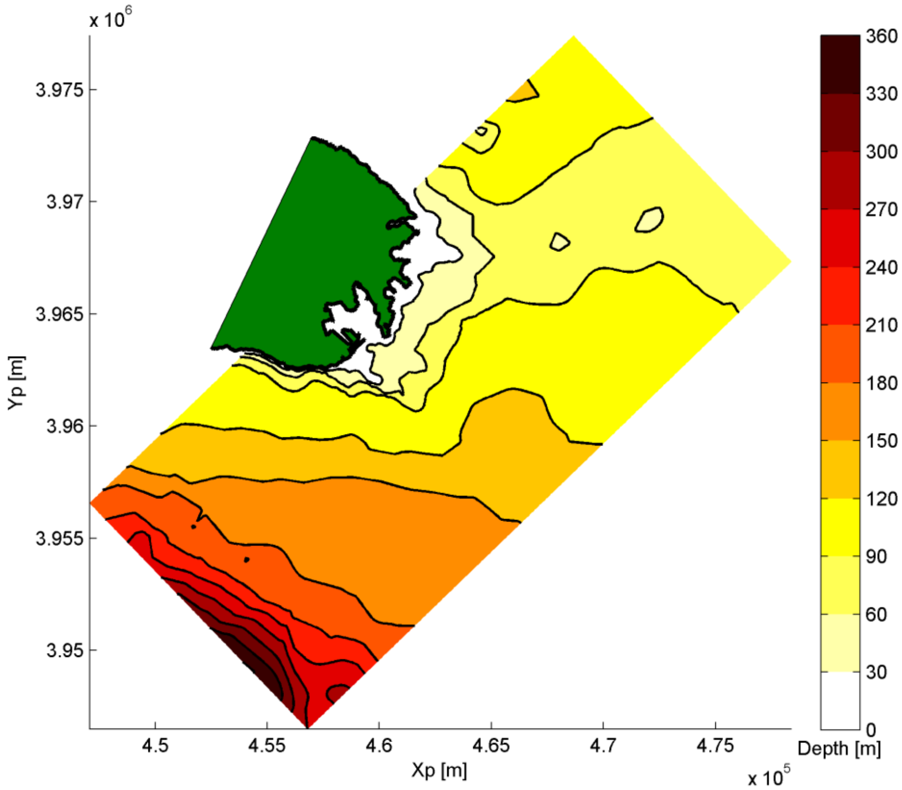


Figure 3-2: Bathymetry SWAN A00 grid

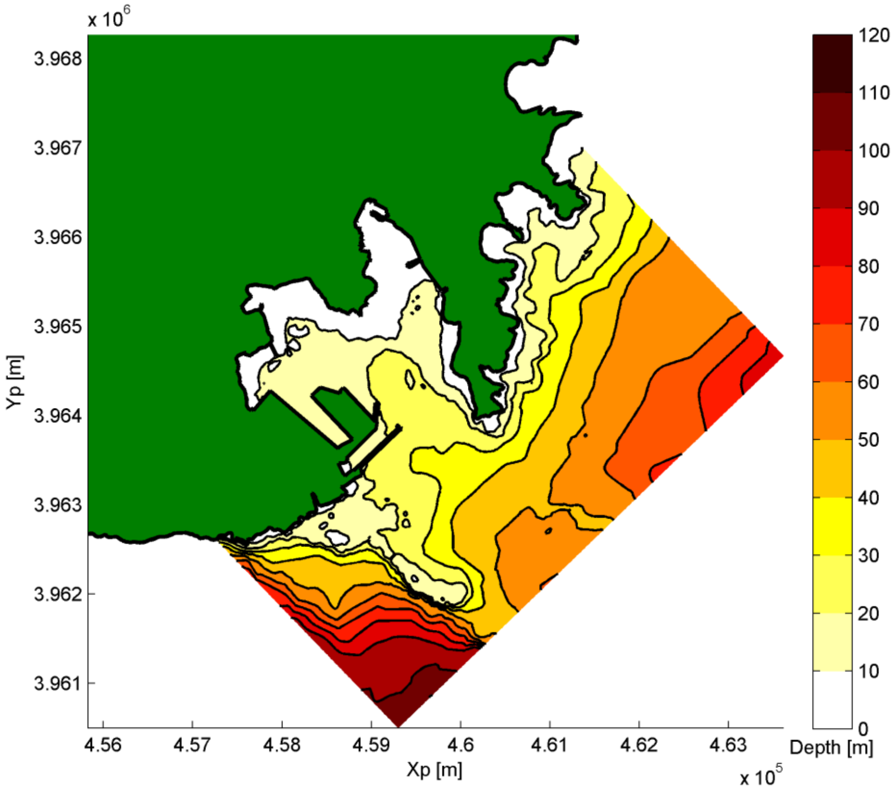


Figure 3-3: Bathymetry SWAN B00 grid

3.2.3 NUMERICAL SETTINGS

The spectral directions cover the full circle and are subdivided into 72 bins, yielding a directional resolution of 5°. The lowest discrete frequency applied is 0.03 Hz and the highest 1.5 Hz. This range is sufficient to include all relevant wave components during storm conditions. The number of frequency bins is 37 and the frequencies of each bin increase in a geometric progression (fixed ratio between subsequent frequencies).

The following numerical settings were applied in SWAN:

```
MODE STATIONARY
CGRID REGULAR   456800.  3946500.   44.00    30000.    14000.     300   140  &
             CIRCLE     72   0.030    1.500    37
NUM ACCUR      0.010     0.010     0.010    99.500  STAT  mxitst= 50  alfa=0.01  limiter=0.1
LIM URSELL=10.0  qb=1.0

GEN3 KOMEN AGROW
WCAP KOMEN delta=1.0
FRIC  JONSWAP 0.038
BREAK CON      1.00     0.73
```

Although SWAN has an option to crudely estimate effects of diffraction, this option has not been activated as its added value is very limited, especially in situations with a large amount of directional spreading.

Effects of diffraction, however, are accounted for in the wave penetration study using the Mike 21- model (see report see report 27689-2-MSCN; Wave penetration study).

3.2.4 OUTPUT LOCATIONS

Since the purpose of this study is to provide input to the harbour propagation model, MIKE21BW in this case, several output points were selected along the boundary of the propagation model (Figure 3-4 and Table 3-2). In this report the results are presented for output location P7 which is location directly in front of the harbour. The results at the other output locations are used for verification of the results and the applied methodology in the MIKE21BW wave penetration study.

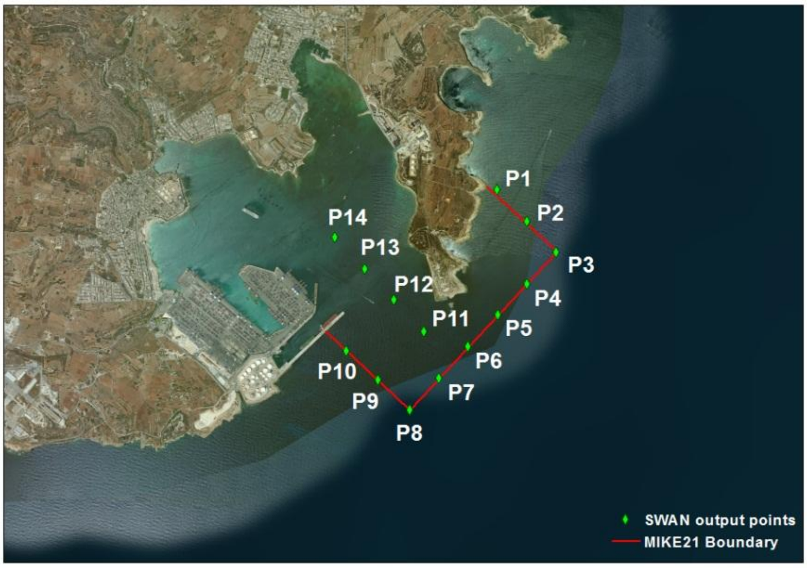


Figure 3-4: SWAN output locations

Output point	x [m UTM33]	y [m UTM33]	Output point	x [m UTM33]	y [m UTM33]
P1	460741	3965005	P8	459928	3962962
P2	461016	3964714	P9	459635	3963234
P3	461292	3964424	P10	459343	3963507
P4	461019	3964132	P11	460061	3963691
P5	460746	3963839	P12	459785	3963982
P6	460473	3963547	P13	459509	3964272
P7	460201	3963254	P14	459234	3964563

Table 3-2: Coordinates of SWAN output locations

3.3 NEARSHORE YEARLY AVERAGE WAVE CLIMATE

3.3.1 INTRODUCTION

The offshore wave conditions were transformed to nearshore locations using the SWAN model in stationary mode. The method to transform the wave conditions is based on a transformation matrix. A transformation matrix is a set of look-up tables giving the nearshore wave parameters (such as significant wave height, wave period and wave direction) for combinations of values of offshore wave conditions (such as significant wave height, wave period, wave direction). These transformation matrices are used to transform the offshore time series to a time series at a nearshore location. One set of tables is generated for each specified nearshore location.

This method was selected since it is capable of efficiently transforming all sea states without loss of available data. At the same time, the computational effort is limited since identical sea states are not modelled repeatedly.

As discussed in Section 2.3.2 many mixed sea states occur . SWAN can handle multi-peaked spectra as input, but then the number of possible combinations becomes unfeasibly large. Therefore, the swell and wind sea conditions were propagated separately, resulting in two transformation matrices for each output location, one for wind sea and one for swell. Using these transformation matrices, two time series were created. This division into separate transformation matrices is allowed as swell waves hardly affect the propagation of the wind seas and vice versa (cf. Ardhuin et al., 2007).

Instead of selecting combinations of offshore significant wave heights and peak wave periods, combinations of significant wave height and deep water wave steepnesses are selected. This was done because the range of occurring offshore conditions is better described by the latter (see for instance Figure 3-5). For each steepness, the peak wave periods corresponding to the selected significant wave heights are calculated and applied in SWAN.

The offshore (wind sea or swell) conditions, consisting of combinations of significant wave height, wave steepness and mean wave direction were transformed as follows:

- The nearest nodes (wave height, wave steepness, wave direction) are found in the look-up tables and the corresponding values for the nearshore wave conditions established;
- Multi-linear interpolation is carried out to establish the corresponding nearshore wave condition;
- Where interpolation is not possible, extrapolation is performed based on the ratio of nearshore and offshore conditions of the nearest wave conditions in the transformation matrix;
- The results are stored in a time series at the evaluated location.

The time series of wind sea and swell conditions were combined afterwards. For the combination of time series, it is assumed that a linear superposition of wind sea and swell conditions is allowed. This assumption is valid for relatively short distances (such that the effect nonlinear quadruplet interactions is limited) where limited depth induced wave breaking occurs (the rate of dissipation depends on the total energy. The effect of white-capping is calculated more accurately by propagating wind sea and swell separately, since the total wave steepness is better represented [2]. Numerical experiments have confirmed that for simulations with a bi-model sea state (representing joint wind sea and swell conditions) with low wind speeds, SWAN yields unrealistic results due to limitations in the white-capping formulation. This is due to known (in literature) limitations in the source term formulation for whitecapping. By treating swell and wind seas separately, the consequences of this numerical artefact are avoided.

The combination of wind sea and swell conditions is done according to the following relations:

$$H_{m0}^{tot} = 4\sqrt{m_0^{tot}} = 4\sqrt{m_0^{sea} + m_0^{swell}}$$

$$T_{m-1,0}^{tot} = \frac{m_{-1}^{tot}}{m_0^{tot}} = \frac{m_{-1}^{sea} + m_{-1}^{swell}}{m_0^{sea} + m_0^{swell}}$$

$$\theta^{tot} = \text{atan}\left(\frac{b}{a}\right)$$

$$a = m_0^{sea} cos(\theta^{sea}) + m_0^{swell} cos(\theta^{swell})$$
$$b = m_0^{sea} sin(\theta^{sea}) + m_0^{swell} sin(\theta^{swell})$$

The superscripts *tot*, *sea* and *swell* refer to total, wind sea and swell conditions. The spectral moments m_n are defined as:

$$m_n = \iint \omega^n E(\omega, \theta) d\omega d\theta$$

The mean wave period $T_{m-1,0}$ is used instead of the peak wave period T_p because the SWAN results for the mean wave period are generally more accurate and robust than the peak wave period results. To avoid using the peak wave period results from SWAN direction, it is calculated from the known ratio between $T_{m-1,0}$ and T_p for JONSWAP spectra (which is approximately 1.11, see Goda [3]).

3.3.2 WIND SEA CONDITIONS

Based on statistical analysis of the offshore conditions supported with numerical experiments, the following conditions were applied at the offshore boundary of grid A00 for wind sea conditions:

- Significant wave height: 0.5, 1.0, 1.5, 2.5, 4.0, 5.0 and 8.0m;
- Deep water wave steepness: 0.005, 0.015, 0.030, 0.060;
- Mean wave direction: 0°N, 30°N, 60°N, 90°N, 120°N, 150°N, 180°N, 210°N, 240°N, 270°N, 300°N and 330°N.

The significant wave heights and peak wave periods were selected to cover more than 99% of the full range of occurring in the offshore time series. Figure 3-5 shows a scatterplot of the significant wave heights and peak wave periods of offshore wind sea conditions and shows the locations of the boundary conditions that were evaluated with SWAN.

The water level was set to 0.63m +CD, which is approximately MSL and the wave steepness formulation is used to determine the wave period to be applied in the computations. The wave steepness is defined as the significant wave height divided by the deep-water wavelength based on the peak wave period. The steepness is thus given by:

$$s = \frac{H_s}{1.56T_p^2}$$

The wind speed and significant wave height of wind sea waves correlate strongly with each other (see also Table 2.13. A relation between wind speed and wave height was derived by fitting a relation to the data

(Figure 3-6). This relation was then used to determine the wind speed for each applied wind sea significant wave height (Table 3-3).

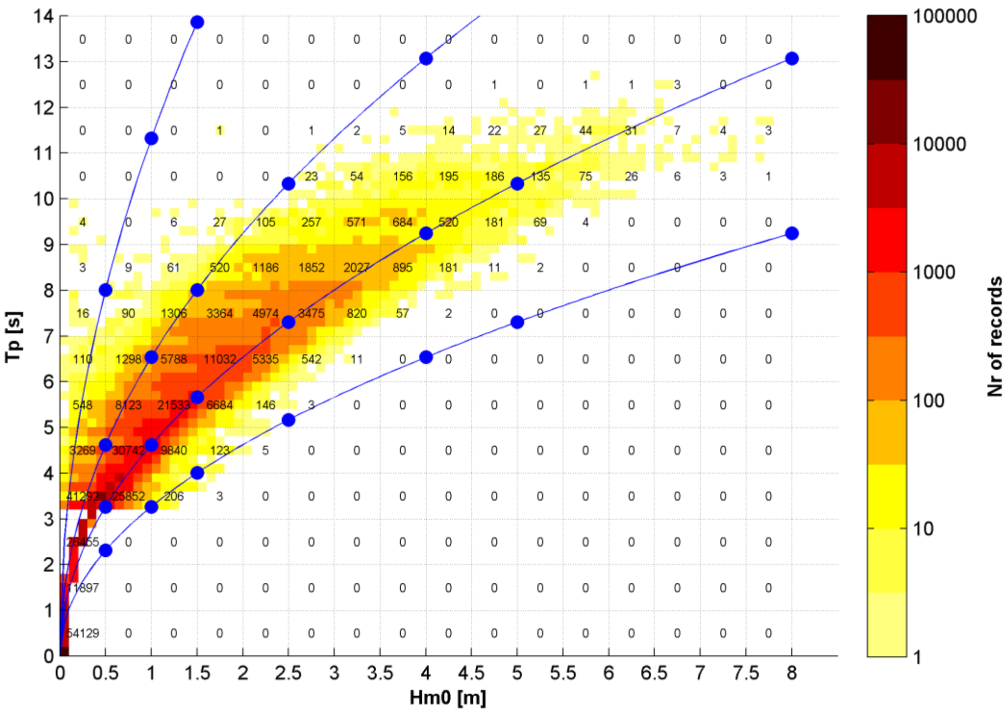


Figure 3-5: Offshore peak wave period [s] against significant wave height [m] for wind sea conditions, and applied SWAN boundary conditions represented by the blue dots

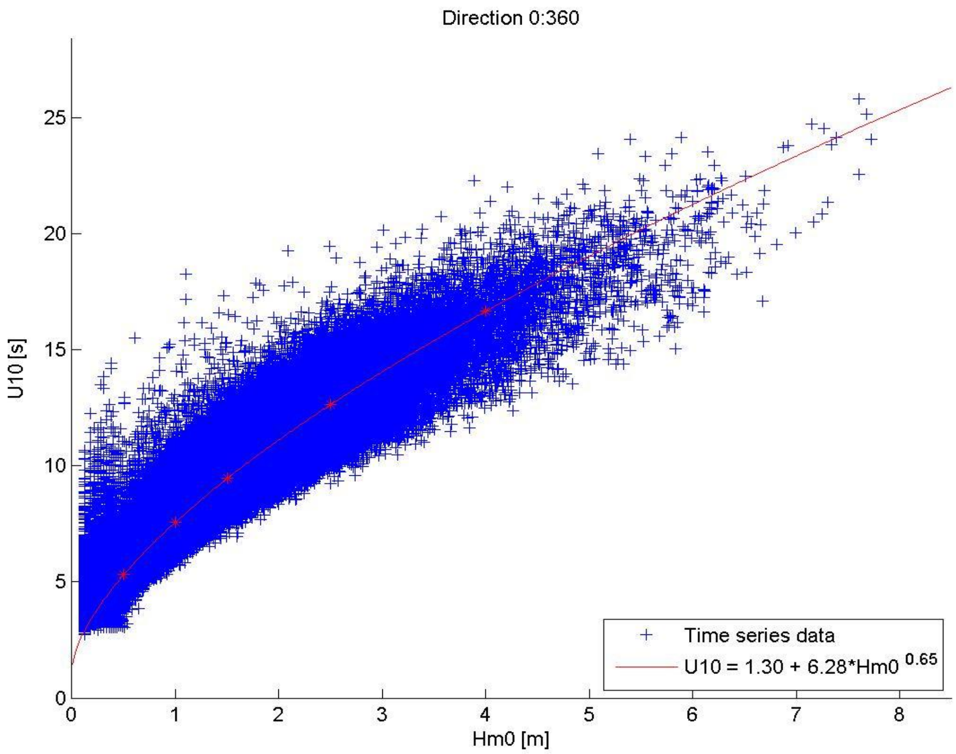


Figure 3-6: Wind speed [m/s] against significant wave height [m] of offshore wind sea waves

Significant wave height [m]	Wind speed [m/s]
0.5	5.3
1.0	7.6
1.5	9.5
2.5	12.7
4.0	16.8
5.0	19.2
8.0	25.6

Table 3-3: Calculated offshore wind speeds for each significant wave height of wind sea

A JONSWAP spectrum with a spectral peakedness parameter (γ) of 3.3 was selected, based on recommendations in Goda [3]. An inspection of the directional spreading in the offshore OCEANWEATHER time series, shows that the correlation between directional spreading $\cos^m$ power values and significant wave height is quite poor for wind sea (Figure 3-7). As a result, typical values, based on experience and literature have been discussed with expert and selected. As a power for the $\cos^m$ directional distribution a value of 3.0 is selected, which corresponds to a one-sided directional spreading of 27.6°. This value is recommended by Goda [3] as representative of relatively young and steep spectra.

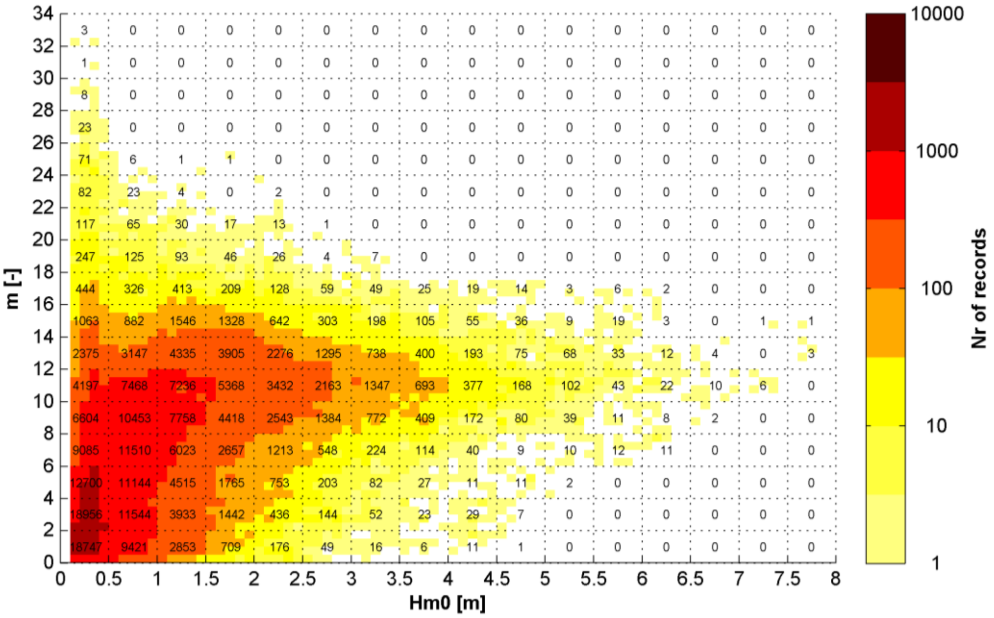


Figure 3-7: Values of cos^m power [-] against significant wave height [m] for offshore wind sea conditions

By running simulations for all directions including wind, the effect of locally generated wind waves is accounted for.

The 7 significant wave heights, 4 wave steepnesses and 12 directions yield a total of 336 conditions that were run for the construction of wind sea transformation matrices.

3.3.3 SWELL CONDITIONS

A similar statistical analysis of the offshore conditions as for wind sea was performed for swell wave conditions. The following conditions were applied at the offshore boundary of grid A00 for the propagation of swell conditions to nearshore locations:

- Significant wave height: 0.25, 0.50, 0.75, 1.0, 2.0, 3.0 and 5.0m;
- Deepwater wave steepness: 0.001, 0.004, 0.008, 0.015, 0.030;
- Mean wave direction: 30°N, 60°N, 90°N, 120°N, 150°N, 180°N, 210°N, 240°N, 270°N and 300°N.

The water level was set to 0.63m +CD, which is approximately MSL and the wave steepness formulation is used to determine the wave period to be applied in the computations.

Figure 3-8 shows a scatterplot of the significant wave heights and peak wave periods of offshore swell conditions and shows the locations of the boundary conditions that were evaluated with SWAN.

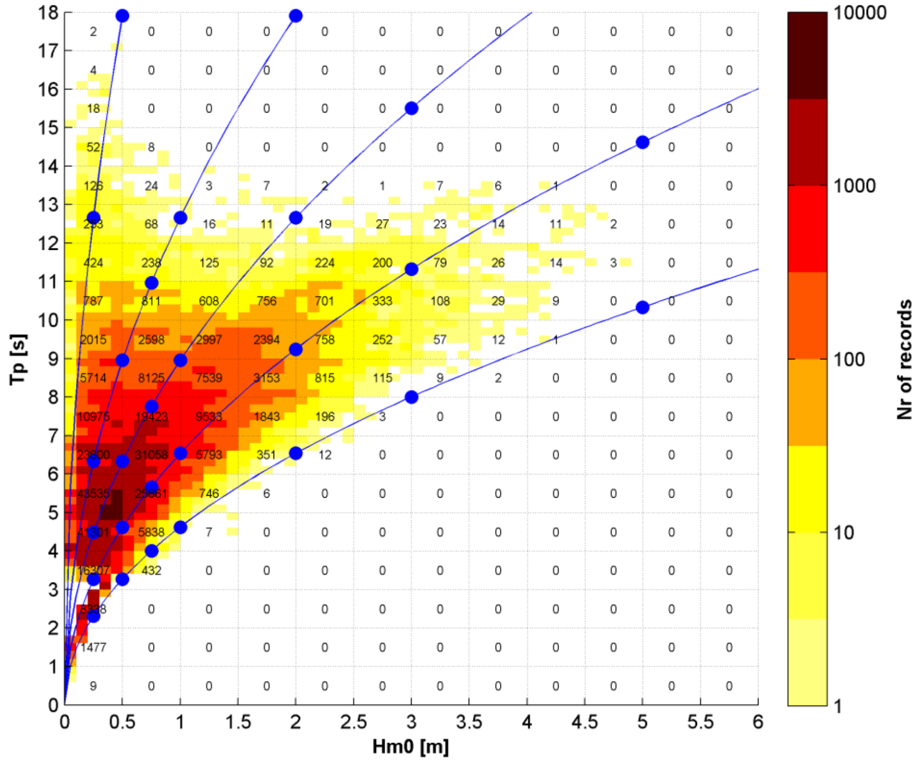


Figure 3-8: Offshore peak wave period [s] against significant wave height [m] for swell conditions, and applied SWAN boundary conditions represented by the blue dots

A JONSWAP spectrum with a spectral peakedness parameter (γ) of 3.3 was selected, based on recommendations in Goda [3]. As was the case for wind sea, the directional spreading in the offshore OCEANWEATHER time series, shows that the correlation between directional spreading $\cos^m$ power values and significant wave height is quite poor for swell (Figure 3-9). As a result, typical values, based on experience and literature have been discussed with expert and selected. As a power for the $\cos^m$ directional distribution a value of 8.0 is selected, which corresponds to a one-sided directional spreading of 18.8°. This value is stated by Goda (2003) as representative of relatively young swell conditions.

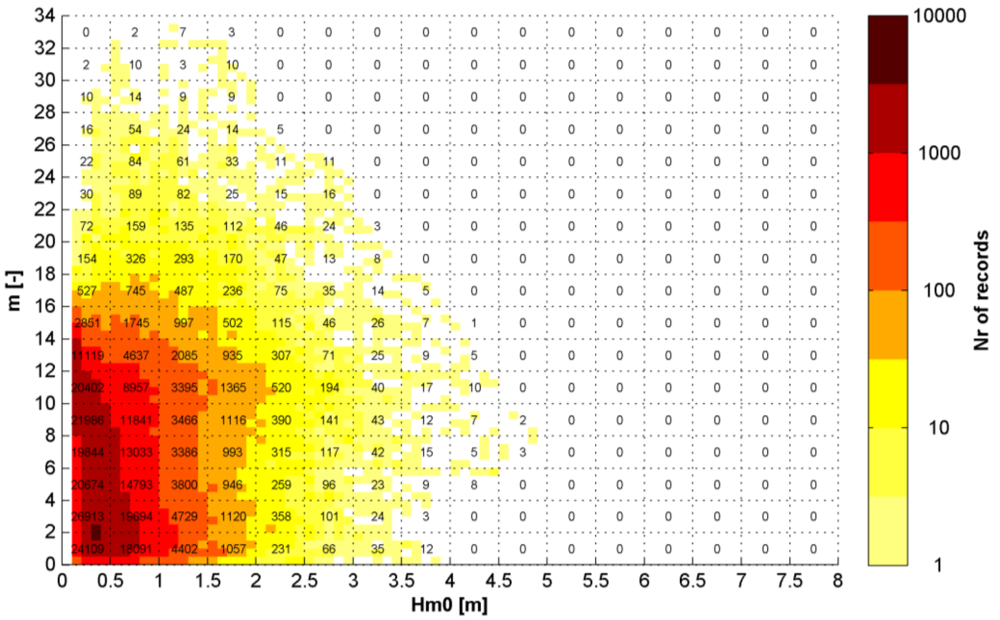


Figure 3-9: Values of $\cos^m$ power [-] against significant wave height [m] for offshore swell conditions

The 7 significant wave heights, 5 wave steepnesses and 10 directions yield a total of 350 conditions to be run for the construction of swell transformation matrices.

3.3.4 RESULTS

Examples of the computational results for a few conditions are presented in Figure 3-10 to Figure 3-12 (wind sea) and Figure 3-13 to Figure 3-15 (swell).

The applied boundary conditions were:

Offshore significant wave height H_{m0}:	1.0 m;
Offshore peak wave period T_p:	6.5 s (steepness = 0.015).
Offshore wave directions θ:	90°N, 120°N and 150°N

For wind sea, the wave conditions at the boundary of the B00 grid are generally a bit higher than what was imposed at the boundary of the larger A00 grid. This is due to the wind that was included, which enhances the waves a bit from offshore to nearshore for some directions. For swell waves, this effect is absent.

The figures clearly show the effect of refraction close to the shore, where the main wave direction turns to become more perpendicular to the depth contours, and the wave height reduces due to bottom dissipation and wave breaking.

Close to the harbour entrance, the shoal increases refraction. For wave directions smaller than approximately 120°N this causes waves to divert away from the harbour entrance and for waves from the south and southwest this turns the wave direction towards the bay entrance. Also visible is the effect of reflection against the breakwater, southwest of the bay entrance which was included in the schematisation as a reflecting obstacle. The refraction of swell waves is stronger than for wind sea because swell wave generally have larger periods and “feel” the bottom more.

The wave conditions inside the bay are strongly affected by the effect of directional spreading which cause part of the waves to enter and others not. The wave penetration of wind sea waves is larger than swell waves because of the larger directional spreading of wind waves.

For output location P7, the wind sea, swell and combined conditions are presented here. In Table 3-4 to Table 3-6, the probability of exceedance of significant wave height for those conditions is presented. The corresponding wave roses are presented in Figure 3-16 and Figure 3-17.

The wave rose for wind sea conditions shows that most of the wind sea waves at location P7 come from around 240°N. In the offshore data, most waves come from 300°N. Due to the combined effect of refraction and directional spreading, these waves have decreased in height and their mean directions have rotated. A wind sea significant wave height of 2.0m is exceeded around 4.1% of the time, while offshore this height was exceeded 8.7% of the time.

The wave rose for swell waves shows a stronger contribution of waves from 60°N and 180°N. A swell significant wave height of 1.0m is exceeded around 11.5% of the time, while offshore this height was exceeded 14.1% of the time. It is concluded that for swell waves, the reducing effect of dissipation and refraction is not strong from offshore to nearshore . As can be seen in Figure 3-13 and Figure 3-15, the spatial variation in wave directions is large near the harbour entrance. Especially for swell waves from 150°N their mean directions are noticeably rotated towards 180°N.

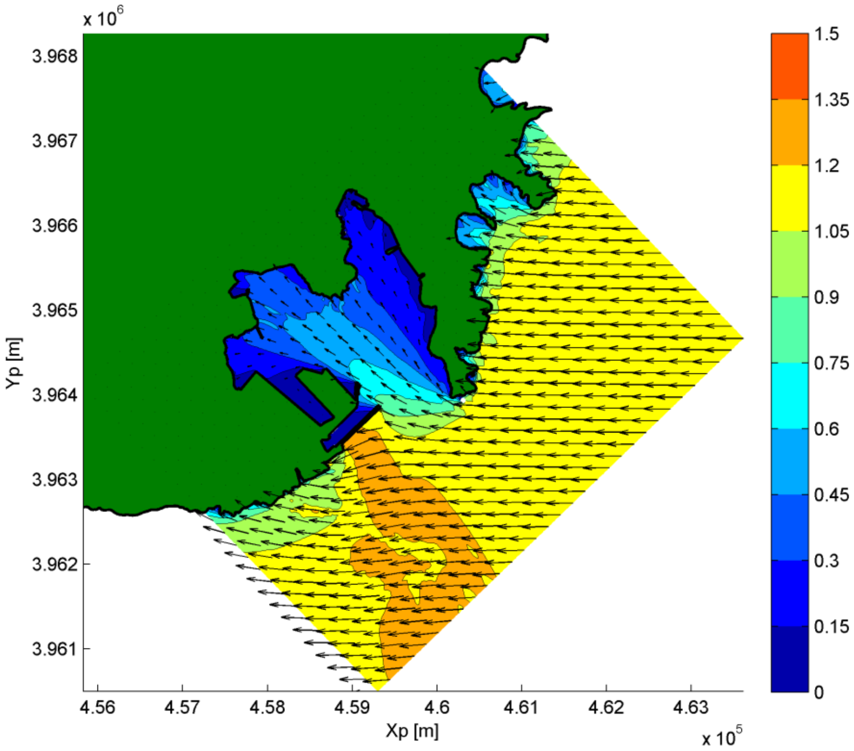


Figure 3-10: Spatial distribution of significant wave height [m] in grid B00 for offshore wind sea conditions with Hm0 = 1.0m, Tp = 6.5s and direction 90°N

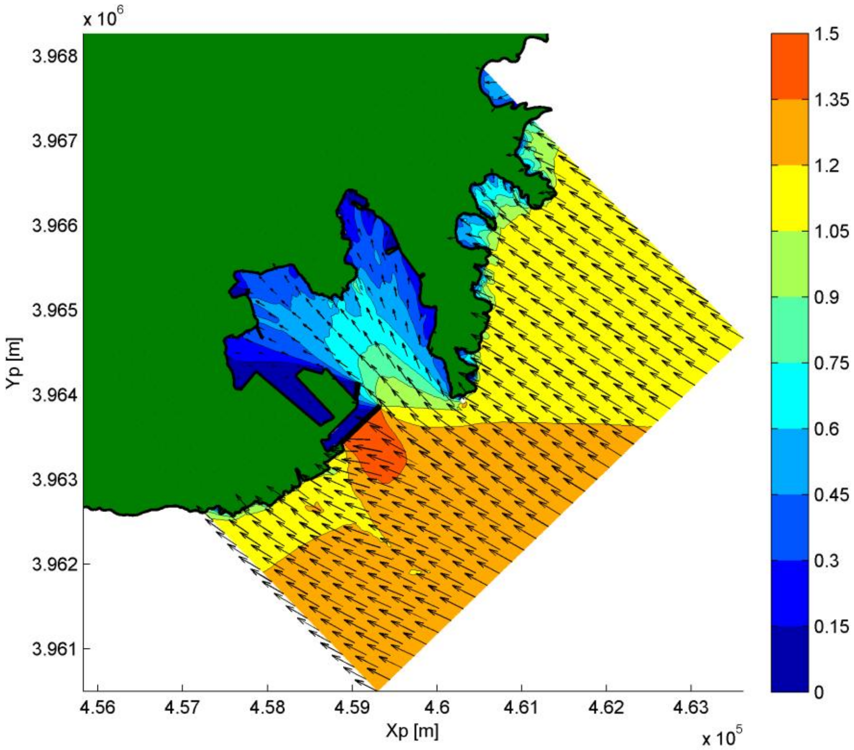


Figure 3-11: Spatial distribution of significant wave height [m] in grid B00 for offshore wind sea conditions with Hm0 = 1.0m, Tp = 6.5s and direction 120°N

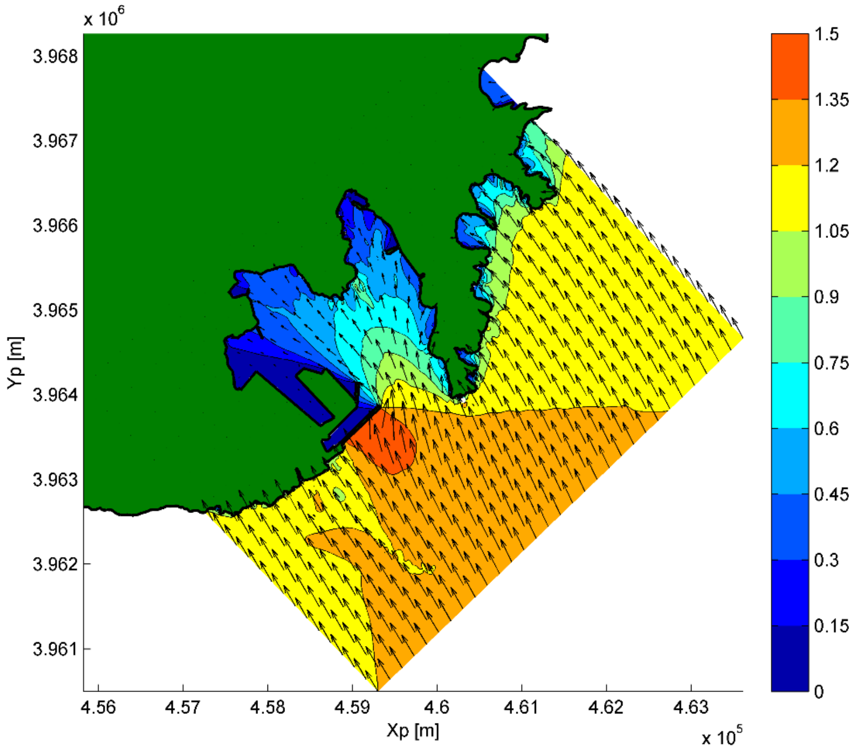


Figure 3-12: Spatial distribution of significant wave height [m] in grid B00 for offshore wind sea conditions with Hm0 = 1.0m, Tp = 6.5s and direction 150°N

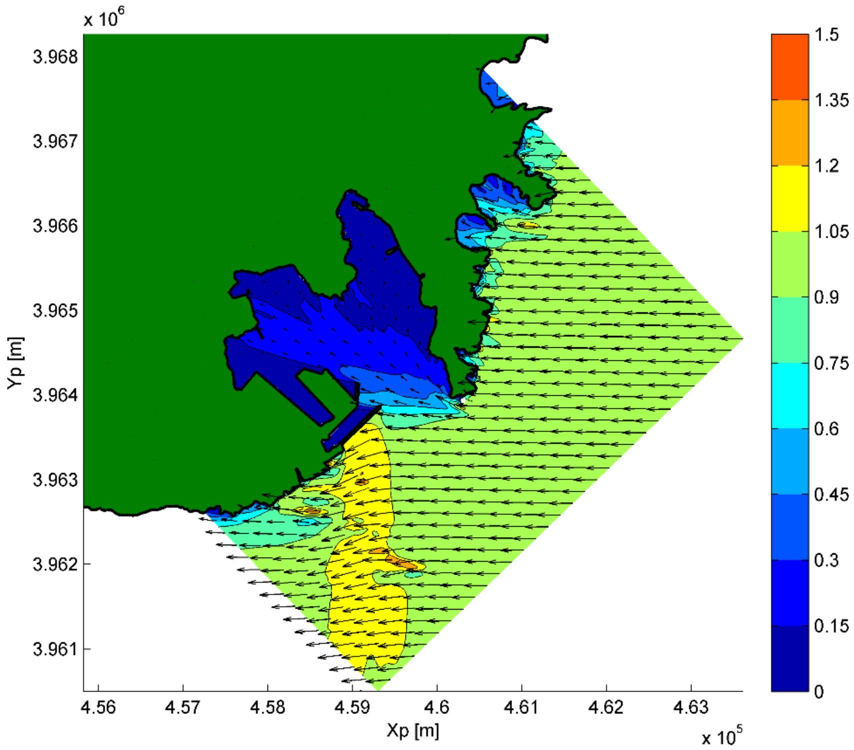


Figure 3-13: Spatial distribution of significant wave height [m] in grid B00 for offshore swell conditions with Hm0 = 1.0m, Tp = 6.5s and direction 90°N

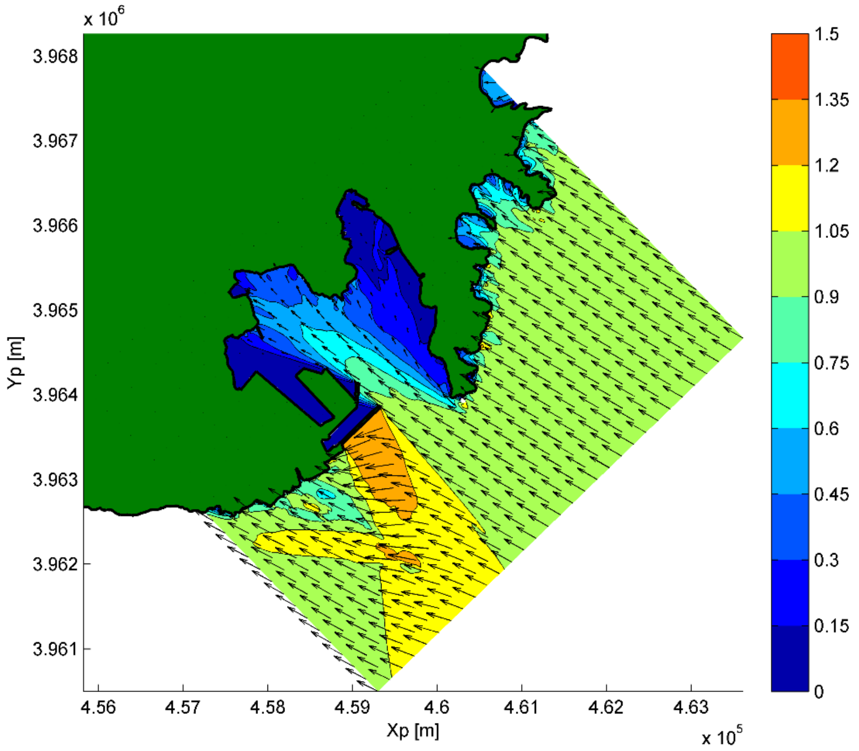


Figure 3-14: Spatial distribution of significant wave height [m] in grid B00 for offshore swell conditions with Hm0 = 1.0m, Tp = 6.5s and direction 120°N

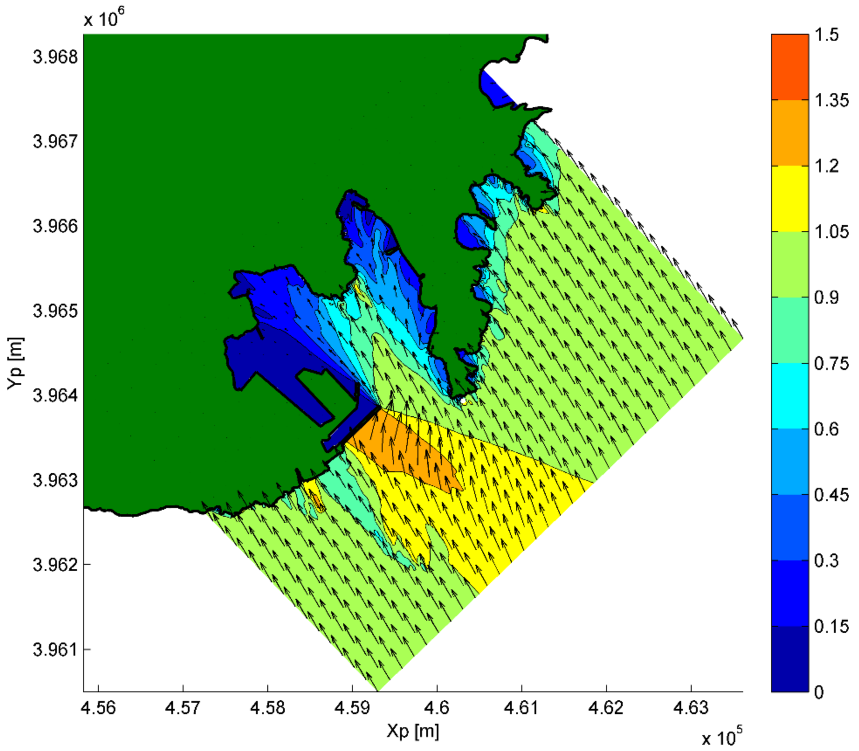


Figure 3-15: Spatial distribution of significant wave height [m] in grid B00 for offshore swell conditions with Hm0 = 1.0m, Tp = 6.5s and direction 150°N

Hs	wave direction degrees												
meters	-15	15	45	75	105	135	165	195	225	255	285	315	
	to	to	to	to	to	to	to	to	to	to	to	to	Total
	15	45	75	105	135	165	195	225	255	285	315	345	
<	3.02	3.95	8.65	7.27	6.05	6.33	7.28	17.02	18.46	13.82	5.18	2.96	100.00
.50	.24	.55	3.58	3.65	3.55	3.93	4.24	5.80	8.21	4.95	1.27	.37	40.35
1.00	.01	.09	1.84	1.92	2.07	2.31	2.43	2.93	3.53	.27	.09	.03	17.52
1.50	.00	.01	.96	.98	1.22	1.41	1.33	1.33	1.11	.02	.01	.00	8.38
2.00	.	.	.49	.51	.72	.87	.71	.57	.27	.00	.00	.	4.15
2.50	.	.	.26	.27	.44	.49	.33	.23	.04	.	.	.	2.06
3.00	.	.	.12	.15	.24	.26	.15	.10	.00	.	.	.	1.02
3.50	.	.	.05	.08	.12	.13	.07	.04	.	.	.	.	.48
4.00	.	.	.02	.05	.06	.06	.03	.01	.	.	.	.	.22
4.50	.	.	.01	.02	.03	.03	.01	.00	.	.	.	.	.11
5.00	.	.	.00	.01	.01	.01	.00	.	.	.	.	.	.05
5.50	.	.	.	.01	.01	.01	.00	.	.	.	.	.	.02
6.00	.	.	.	.00	.00	.	.	.	.	.	.	.	.01
6.50	.	.	.	.	.00	.	.	.	.	.	.	.	.00
7.00	.	.	.	.	.	.	.	.	.	.	.	.	.
7.50	.	.	.	.	.	.	.	.	.	.	.	.	.
8.00	.	.	.	.	.	.	.	.	.	.	.	.	.

Table 3-4: Nearshore (P7) probability of exceedance of wind sea significant wave height [m] for various directions

Hs	wave direction degrees												
meters	-15	15	45	75	105	135	165	195	225	255	285	315	
	to	to	to	to	to	to	to	to	to	to	to	to	Total
	15	45	75	105	135	165	195	225	255	285	315	345	
<	3.01	3.47	18.91	12.04	7.64	8.18	11.35	13.40	13.35	3.41	2.40	2.85	100.00
.50	.	.11	6.94	7.01	4.44	5.17	6.34	4.58	.85	.	.	.	35.44
1.00	.	.00	1.63	2.78	1.87	2.28	1.91	.95	.04	.	.	.	11.46
1.50	.	.	.32	1.07	.72	.91	.47	.15	.	.	.	.	3.64
2.00	.	.	.07	.39	.28	.29	.12	.03	.	.	.	.	1.19
2.50	.	.	.02	.11	.11	.08	.03	.01	.	.	.	.	.34
3.00	.	.	.00	.02	.04	.02	.00	.00	.	.	.	.	.09
3.50	.	.	.00	.00	.01	.01	.00	.00	.	.	.	.	.03
4.00	.	.	.	.00	.01	.00	.00	.	.	.	.	.	.01
4.50	.	.	.	.	.00	.	.	.	.	.	.	.	.00
5.00	.	.	.	.	.	.	.	.	.	.	.	.	.
5.50	.	.	.	.	.	.	.	.	.	.	.	.	.
6.00	.	.	.	.	.	.	.	.	.	.	.	.	.
6.50	.	.	.	.	.	.	.	.	.	.	.	.	.
7.00	.	.	.	.	.	.	.	.	.	.	.	.	.
7.50	.	.	.	.	.	.	.	.	.	.	.	.	.
8.00	.	.	.	.	.	.	.	.	.	.	.	.	.

Table 3-5: Nearshore (P7) probability of exceedance of swell significant wave height [m] for various directions

Hs	wave direction degrees												
meters	-15	15	45	75	105	135	165	195	225	255	285	315	
	to	to	to	to	to	to	to	to	to	to	to	to	Total
	15	45	75	105	135	165	195	225	255	285	315	345	
<	1.72	3.33	12.85	10.48	8.03	8.94	11.16	11.79	15.89	9.22	4.98	1.62	100.00
.50	.35	.90	7.82	8.53	6.84	7.82	9.24	8.52	8.34	4.01	1.12	.40	63.90
1.00	.04	.16	3.33	4.48	4.01	4.60	4.92	4.13	3.55	.35	.11	.04	29.73
1.50	.00	.02	1.43	2.22	2.18	2.57	2.36	1.76	1.12	.03	.01	.00	13.69
2.00	.	.00	.61	1.11	1.16	1.41	1.13	.77	.27	.01	.00	.	6.47
2.50	.	.	.30	.52	.68	.70	.51	.30	.05	.	.	.	3.06
3.00	.	.	.13	.26	.37	.36	.22	.12	.01	.	.	.	1.47
3.50	.	.	.05	.14	.18	.17	.09	.04	.	.	.	.	.67
4.00	.	.	.02	.07	.09	.08	.04	.01	.	.	.	.	.30
4.50	.	.	.01	.04	.04	.03	.01	.01	.	.	.	.	.14
5.00	.	.	.00	.02	.02	.02	.00	.00	.	.	.	.	.06
5.50	.	.	.00	.01	.01	.01	.00	.	.	.	.	.	.03
6.00	.	.	.	.00	.01	.00	.	.	.	.	.	.	.01
6.50	.	.	.	.	.00	.	.	.	.	.	.	.	.00
7.00	.	.	.	.	.	.	.	.	.	.	.	.	.
7.50	.	.	.	.	.	.	.	.	.	.	.	.	.
8.00	.	.	.	.	.	.	.	.	.	.	.	.	.

Table 3-6: Nearshore (P7) probability of exceedance of total significant wave height [m] for various directions

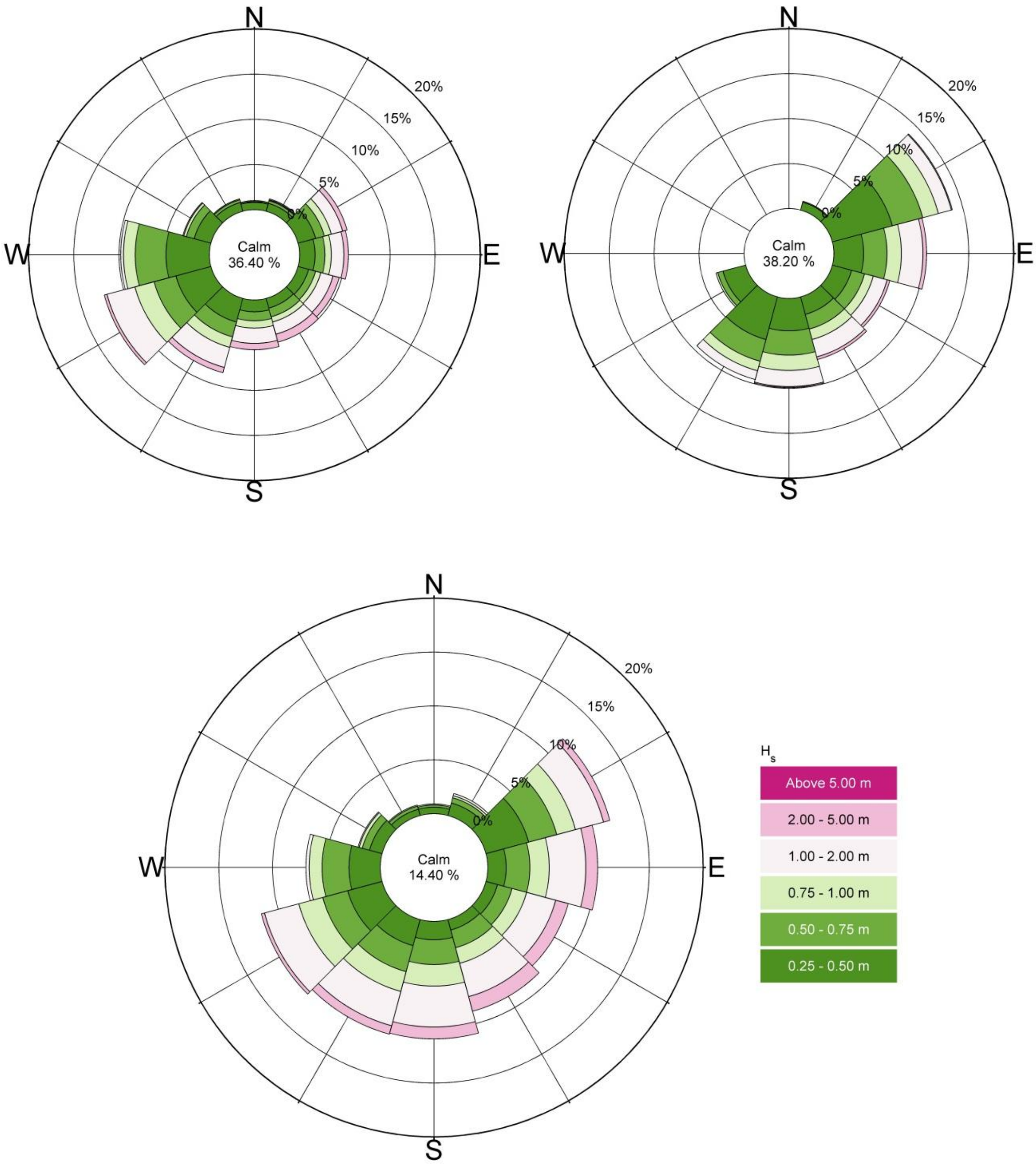


Figure 3-16: Nearshore (P7) significant wave height roses for wind sea (top left), swell (top right) and total sea states (below)

Figure 3-17: Nearshore (P7) peak period roses for wind sea (top left), swell (top right) and total sea states (below)

3.4 NEARSHORE EXTREME WAVE CLIMATE

3.4.1 APPROACH

The derived extreme conditions at the offshore location have been transformed to nearshore locations with SWAN. Computations were carried out for directions between 60°N and 240°N with 30°N intervals. The significant wave height and peak wave period were taken from Table 2-14 and Table 2-15 and the wind with equal return period (Table 2-2) was applied. The extreme water levels, described in Section 2.4, were taken.

A JONSWAP spectrum with a spectral peakedness parameter (γ) of 3.3 was selected. As a power for the $\cos^m$ directional distribution a value of 8.0 is selected, which corresponds to a one-sided directional spreading of 18.8°.

Note that the presented values are the best estimates for the independent extreme values. Confidence intervals and the joint occurrence of extreme values are presented in [5].

3.4.2 RESULTS

The nearshore extreme wave conditions at location P7 are presented in Table 3-7. For directions 90°N, 120°N, 150°N and 180°N, the significant wave height at location P7 is higher than offshore. For other directions the significant wave height is lower. For extreme wave conditions, with very large periods , the effect of refraction is strong. This causes the wave to turn towards the bay entrance.

The most severe extreme wave conditions at location P7 (in front of the harbour entrance) are for offshore direction 90°N. The mean wave direction for this conditions however is such (around 100°N) that this condition does not yield the severest condition inside the bay. Waves from offshore directions 120°N, 150°N and 180°N are lower, but they can freely propagate into the harbour.

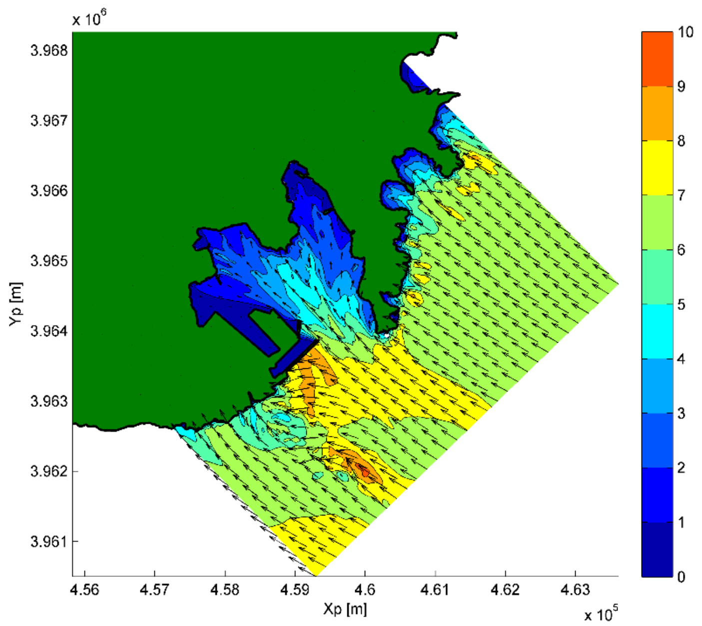


Figure 3-18: Spatial distribution of significant wave height [m] in grid B00 for extreme conditions with offshore direction 120°N and return period 1:100 years

Return period [yr]	Offshore direction [°N]	Offshore U10 [m/s]	Offshore Hm0 [m]	Offshore Tp [s]	Nearshore Hm0 [m]	Nearshore Tm-1,0 [s]	Nearshore Tp [s]	Nearshore Dir [°N]	Nearshore Dspr [°]
1	60	15.0	3.9	10.3	3.5	8.5	9.3	71	18
1	90	14.8	3.5	10.0	3.5	8.3	9.1	93	22
1	120	15.1	3.5	9.3	3.7	8.0	8.8	121	24
1	150	15.4	3.6	9.2	3.8	8.0	8.8	151	24
1	180	14.1	3.1	8.5	3.2	7.4	8.2	181	24
1	210	13.3	2.9	8.3	3	7.3	8.0	204	21
1	240	15.3	3.5	9.0	2.9	7.5	8.2	218	20
5	60	18.3	5.3	11.1	4.6	9.4	10.3	73	18
5	90	17.5	4.8	10.7	4.7	9.2	10.1	95	22
5	120	17.3	4.7	10.4	4.9	9.1	10	121	23
5	150	18.0	4.7	10.1	4.8	8.8	9.7	151	24
5	180	16.4	4.0	9.4	4.1	8.2	9.0	181	24
5	210	16.0	4.0	9.5	3.9	8.3	9.1	202	20
5	240	17.8	4.6	10.1	3.6	8.4	9.3	214	20
10	60	19.5	5.9	11.6	5	9.8	10.8	74	17
10	90	18.4	5.4	10.9	5.2	9.5	10.4	95	22
10	120	18.1	5.1	10.7	5.3	9.4	10.3	121	23
10	150	19.0	5.1	10.5	5.2	9.2	10.1	151	24
10	180	17.3	4.3	9.7	4.4	8.5	9.3	180	24
10	210	17.1	4.5	9.9	4.2	8.6	9.5	201	20
10	240	18.8	5.1	10.7	3.9	8.9	9.7	213	20
25	60	21.0	6.6	12.3	5.6	10.5	11.5	75	17
25	90	19.6	6.2	11.6	5.9	10.1	11.1	97	21
25	120	19.1	5.8	11.2	5.9	9.9	10.9	121	23
25	150	20.2	5.6	11.0	5.7	9.6	10.5	151	24
25	180	18.4	4.8	10.3	4.8	8.9	9.8	179	24
25	210	18.5	5.2	10.7	4.7	9.2	10.2	199	20
25	240	19.9	5.7	11.3	4.2	9.4	10.3	210	20
50	60	22.1	7.1	12.7	6.1	10.9	12.0	76	17
50	90	20.4	6.8	12.1	6.4	10.6	11.6	98	21
50	120	19.8	6.2	11.6	6.4	10.3	11.3	121	22
50	150	21.1	5.9	11.3	6	9.9	10.9	150	24
50	180	19.2	5.1	10.6	5.1	9.2	10.1	179	23
50	210	19.6	5.7	11.2	5	9.7	10.6	198	20
50	240	20.7	6.2	11.8	4.4	9.7	10.7	210	20
100	60	23.1	7.6	13.1	6.5	11.2	12.4	77	17
100	90	21.1	7.4	12.6	7	11.1	12.2	99	21
100	120	20.4	6.7	12.0	6.8	10.6	11.7	121	22
100	150	21.9	6.3	11.7	6.4	10.2	11.2	150	23
100	180	20.0	5.4	10.9	5.3	9.5	10.4	178	23
100	210	20.7	6.2	11.7	5.3	10.0	11.0	197	20
100	240	21.4	6.6	12.2	4.5	10.1	11.1	209	20

Table 3-7: Offshore and nearshore (P7) extreme conditions. The presented results do not include the waves reflected by the breakwater.

4 Conclusions

4.1 WIND CLIMATE

The offshore OCEANWEATHER wind data was analysed and the resulting wind rose is presented in Figure 4-1. Most winds come from directions between 255 and 345°N and also most of the stronger winds are coming from these directions. A wind speed of 12 m/s is exceeded less than 7% of the time.

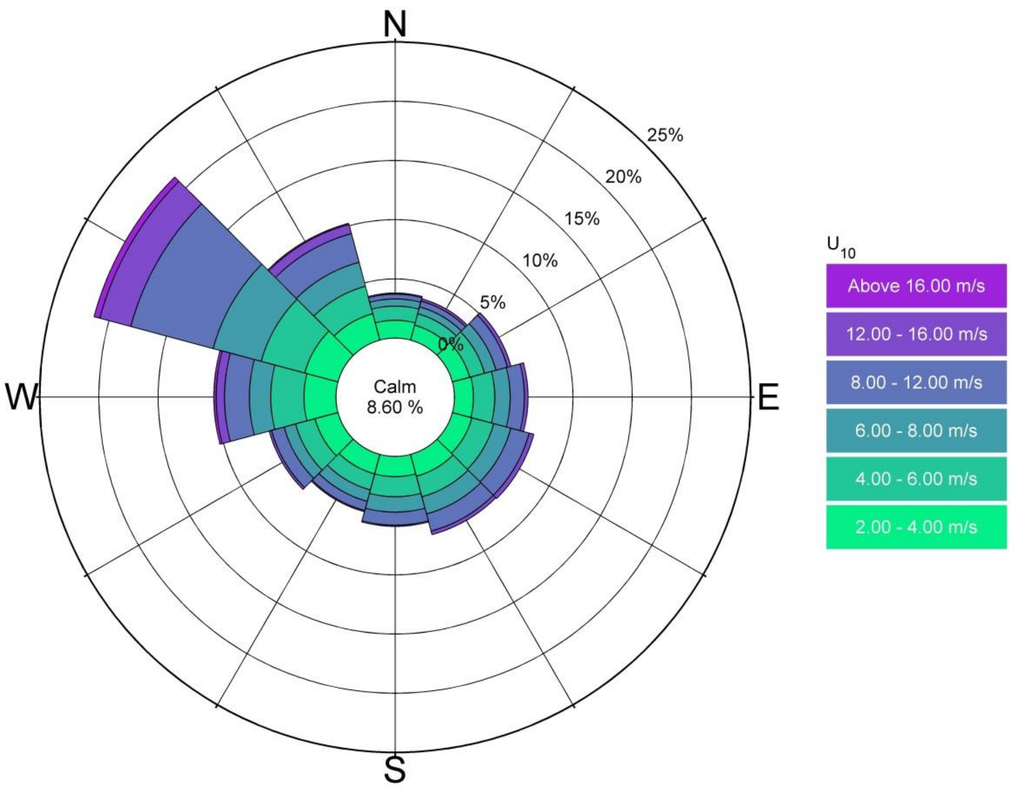


Figure 4-1: Offshore wind rose

The offshore extreme wind conditions are derived based on extrapolation by fitting a Weibull to the peak-over-threshold (POT) filtered OCEANWEATHER data. The resulting extreme wind speeds are presented in Table 4-1.

Return period [yr]	0 [°N]	30 [°N]	60 [°N]	90 [°N]	120 [°N]	150 [°N]	180 [°N]	210 [°N]	240 [°N]	270 [°N]	300 [°N]	330 [°N]
1	13.6	14.9	15.0	14.8	15.1	15.4	14.1	13.3	15.3	18.5	19.4	17.7
5	17.6	18.8	18.3	17.5	17.3	18.0	16.4	16.0	17.8	21.3	21.7	20.3
10	19.3	20.4	19.5	18.4	18.1	19.0	17.3	17.1	18.8	22.4	22.5	21.4
25	21.6	22.4	21.0	19.6	19.1	20.2	18.4	18.5	19.9	23.6	23.6	22.6
50	23.3	23.8	22.1	20.4	19.8	21.1	19.2	19.6	20.7	24.5	24.3	23.6
100	25.0	25.2	23.1	21.1	20.4	21.9	20.0	20.7	21.4	25.4	25.0	24.4

Table 4-1: Offshore extreme wind speeds in m/s for various return periods and directions

4.2 OFFSHORE WAVE CLIMATE

The time series obtained from OCEANWEATHER contained wave conditions for wind sea, swell and total conditions. The wind sea and swell conditions are based on a partitioning technique of the total wave conditions.

The wave roses for the significant wave height are presented in Figure 4-2 for wind sea, swell and total conditions. It can be seen that most waves are coming from NW directions. Also the higher waves are coming from these directions. A significant wave height of 2.0m is exceeded less than 12% of the time. The swell waves are generally lower than the wind sea waves. While for wind sea a significant wave height of 2m is exceeded 8.7% of the time, for swell this height is exceeded only 1.4% of the time.

As expected the wave rose for wind sea waves shows a similar directional distribution as the wind rose (Figure 4-1). Most of the wind sea waves come from NW directions and also most of the higher waves are coming from these directions. The directional distribution of swell waves is completely different. The largest contribution of swell waves comes from directions between 45°N and 165°N.

To investigate the need for a separate evaluation of swell and wind sea conditions, an analysis was made of the joint probability of occurrence of swell and wind wave conditions. Analysis of the occurrence of mixed sea states of wind sea and swell conditions indicated that the correlation of wind sea and swell conditions is poor and therefore a separate treatment was applied in this study.

Figure 4-2: Significant wave height roses for offshore wind waves (top left), swell (top right) and total sea states (below)

The offshore extreme significant wave heights were derived based on extrapolation by fitting a Weibull to the peak-over-threshold (POT) filtered OCEANWEATHER data. The corresponding peak wave periods were derived from fitting a square root relationship to the scattered significant wave height versus peak wave period data. The resulting extreme wave conditions are presented in Table 4-2.

4.3 NEARSHORE WAVE CLIMATE

The offshore wave climate is transformed to nearshore locations using the SWAN model. Transformation matrices were used to transform the offshore time series to time series at nearshore locations assuming stationary condition.

The swell and wind sea conditions were propagated separately. The results are two transformation matrices for each output location, one for wind sea and one for swell, with which two time series were created. The time series of wind sea and swell conditions were combined afterwards.

The wave roses at output location P7 are presented in Figure 4-3. The wave rose for wind sea conditions shows that most of the wind sea waves at location P7 come from around 240°N. A wind sea significant wave height of 2.0m is exceeded around 4.1% of the time, while offshore this height was exceeded 8.7% of the time.

The wave rose for swell waves shows a stronger contribution of waves from 60°N and 180°N. A swell significant wave height of 1.0m is exceeded around 11.5% of the time, while offshore this height was exceeded 14.1% of the time. Near the harbour entrance large difference exist between the offshore and near mean wave directions Especially swell waves from 150°N are noticeably rotated towards 180°N.

The nearshore extreme wave conditions at location P7 are presented in Table 4-2. The most severe extreme wave conditions at location are for offshore direction 90°N. The mean wave direction for this conditions however is such (around 100°N) that this condition does not yield the severest condition inside the bay. Waves from offshore directions 120°N, 150°N and 180°N are lower, but they can freely propagate into the harbour.

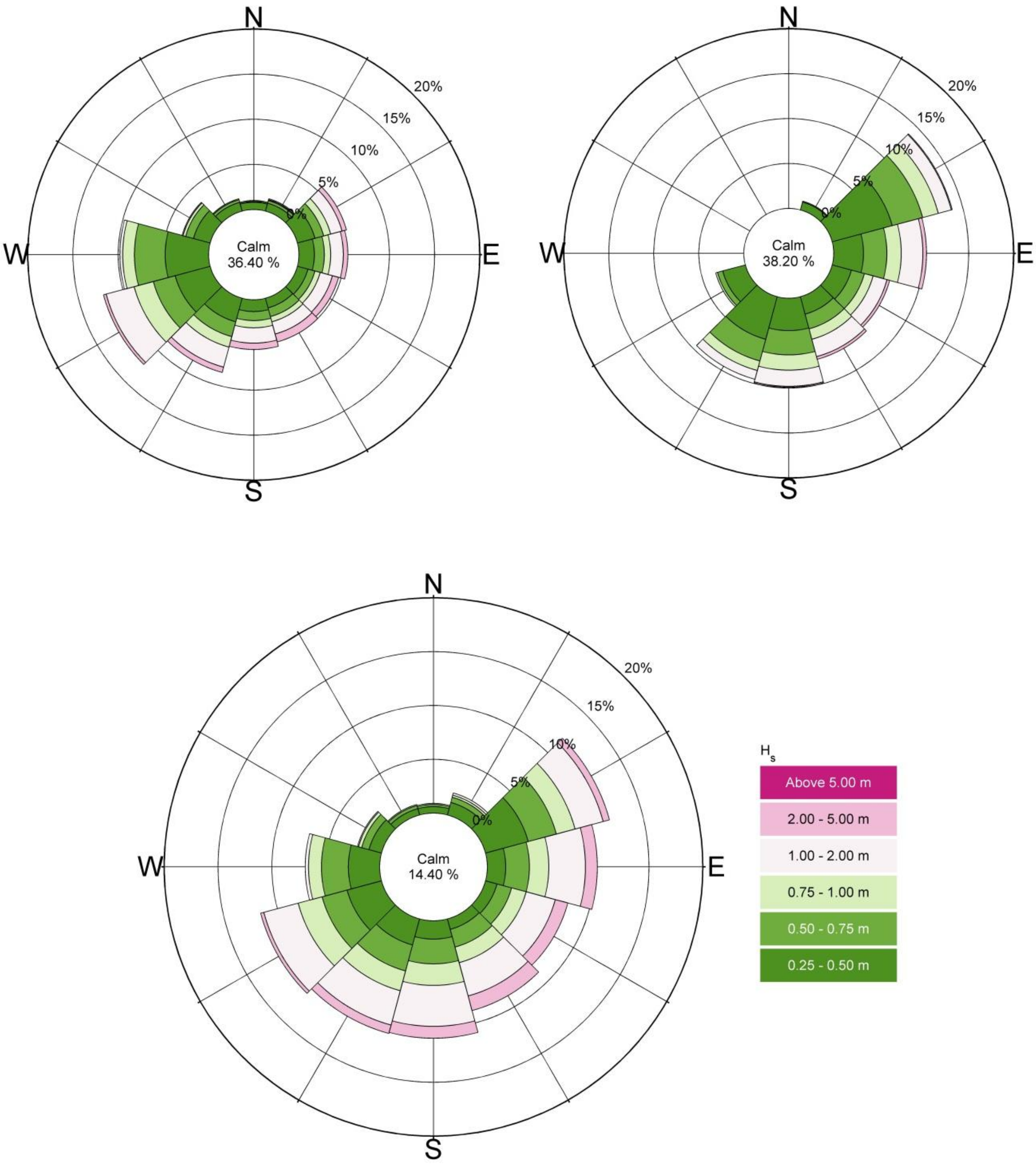


Figure 4-3: Nearshore (P7) significant wave height roses of wind waves (top left), swell (top right) and total sea states (below)

Return period [yr]	Offshore direction [°N]	Offshore U10 [m/s]	Hm0 [m]	Tp [s]	Nearshore Hm0 [m]	Tm-1,0 [s]	Tp [s]	Dir [°N]	Dspr [°]
1	60	15.0	3.9	10.3	3.5	8.5	9.3	71	18
1	90	14.8	3.5	10.0	3.5	8.3	9.1	93	22
1	120	15.1	3.5	9.3	3.7	8	8.8	121	24
1	150	15.4	3.6	9.2	3.8	8	8.8	151	24
1	180	14.1	3.1	8.5	3.2	7.4	8.2	181	24
1	210	13.3	2.9	8.3	3	7.3	8	204	21
1	240	15.3	3.5	9.0	2.9	7.5	8.2	218	20
5	60	18.3	5.3	11.1	4.6	9.4	10.3	73	18
5	90	17.5	4.8	10.7	4.7	9.2	10.1	95	22
5	120	17.3	4.7	10.4	4.9	9.1	10	121	23
5	150	18.0	4.7	10.1	4.8	8.8	9.7	151	24
5	180	16.4	4.0	9.4	4.1	8.2	9	181	24
5	210	16.0	4.0	9.5	3.9	8.3	9.1	202	20
5	240	17.8	4.6	10.1	3.6	8.4	9.3	214	20
10	60	19.5	5.9	11.6	5	9.8	10.8	74	17
10	90	18.4	5.4	10.9	5.2	9.5	10.4	95	22
10	120	18.1	5.1	10.7	5.3	9.4	10.3	121	23
10	150	19.0	5.1	10.5	5.2	9.2	10.1	151	24
10	180	17.3	4.3	9.7	4.4	8.5	9.3	180	24
10	210	17.1	4.5	9.9	4.2	8.6	9.5	201	20
10	240	18.8	5.1	10.7	3.9	8.9	9.7	213	20
25	60	21.0	6.6	12.3	5.6	10.5	11.5	75	17
25	90	19.6	6.2	11.6	5.9	10.1	11.1	97	21
25	120	19.1	5.8	11.2	5.9	9.9	10.9	121	23
25	150	20.2	5.6	11.0	5.7	9.6	10.5	151	24
25	180	18.4	4.8	10.3	4.8	8.9	9.8	179	24
25	210	18.5	5.2	10.7	4.7	9.2	10.2	199	20
25	240	19.9	5.7	11.3	4.2	9.4	10.3	210	20
50	60	22.1	7.1	12.7	6.1	10.9	12	76	17
50	90	20.4	6.8	12.1	6.4	10.6	11.6	98	21
50	120	19.8	6.2	11.6	6.4	10.3	11.3	121	22
50	150	21.1	5.9	11.3	6	9.9	10.9	150	24
50	180	19.2	5.1	10.6	5.1	9.2	10.1	179	23
50	210	19.6	5.7	11.2	5	9.7	10.6	198	20
50	240	20.7	6.2	11.8	4.4	9.7	10.7	210	20
100	60	23.1	7.6	13.1	6.5	11.2	12.4	77	17
100	90	21.1	7.4	12.6	7	11.1	12.2	99	21
100	120	20.4	6.7	12.0	6.8	10.6	11.7	121	22
100	150	21.9	6.3	11.7	6.4	10.2	11.2	150	23
100	180	20.0	5.4	10.9	5.3	9.5	10.4	178	23
100	210	20.7	6.2	11.7	5.3	10	11	197	20
100	240	21.4	6.6	12.2	4.5	10.1	11.1	209	20

Table 4-2: Offshore and nearshore (location P7) extreme conditions

Note that the presented values are the best estimates for the independent extreme values. Confidence intervals and the joint occurrence of extreme values are presented in [5].

5 References

[1] SWAN development team 2014, "SWAN User Manual". Definitions of variables: http://swanmodel.sourceforge.net/

[2] Ardhuin, F., T.H.C. Herbers, G.Ph. van Vledder, K.P. Watts, R. Jensen and H.C. Graber., 2007: Swell and slanting fetch effects on wind wave growth. J. Phys. Oceanogr. 37, 908–931

[3] Goda, Y., 2000: "Random Seas and Design of Maritime Structures". Advanced Series on Ocean Engineering **15** (2 ed.).

[4] DNV, 2000: "Environmental conditions and environmental loads, Classification Notes, No 30.5". Issue March 2000.

[5] MARIN/ARCADIS, 2015: Nautical and risk studies for the Delimara LNG terminal in Marsaxlokk Port, Malta; Additional metocean analysis. Report 27689-7-MSCN.rev.1, 17 December 2015 (Arcadis report C03051_000014_0200R3_(078630641-D), 21 September 2015). Prepared for Electrogas Malta.

Appendix 1 Offshore joint probability of significant wave height and peak wave period

Wind sea

Hs meters		spectral peak wave period seconds											
		< to 4.0	4.0 to 5.0	5.0 to 6.0	6.0 to 7.0	7.0 to 8.0	8.0 to 9.0	9.0 to 10.0	10.0 to 11.0	11.0 to 12.0	12.0 to 14.0	14.0 to >	Total
Lower	Upper												
<	.50	46.24	1.13	.19	.04	.01	.00	.00	.	.	.	.	47.61
.50	1.00	8.89	10.45	2.77	.44	.03	.00	.	.	.	.	.	22.57
1.00	1.50	.08	3.51	7.51	2.01	.45	.02	.00	.	.	.	.	13.58
1.50	2.00	.00	.04	2.34	3.83	1.16	.18	.01	.	.00	.	.	7.57
2.00	2.50	.	.00	.05	1.87	1.73	.41	.04	.	.	.	.	4.09
2.50	3.00	.	.	.00	.19	1.21	.64	.09	.01	.00	.	.	2.13
3.00	3.50	.	.	.	.00	.28	.71	.20	.02	.00	.	.	1.21
3.50	4.00	.	.	.	.	.02	.31	.24	.05	.00	.	.	.63
4.00	4.50	.	.	.	.	.00	.06	.18	.07	.00	.	.	.32
4.50	5.00	.	.	.	.	.	.00	.06	.06	.01	.00	.	.14
5.00	5.50	.	.	.	.	.	.00	.02	.05	.01	.	.	.08
5.50	6.00	.	.	.	.	.	.	.00	.03	.01	.00	.	.04
6.00	6.50	.	.	.	.	.	.	.	.01	.01	.00	.	.02
6.50	7.00	.	.	.	.	.	.	.	.00	.00	.00	.	.01
7.00	7.50	.	.	.	.	.	.	.	.00	.00	.	.	.00
7.50	8.00	.	.	.	.	.	.	.	.00	.00	.	.	.00
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		55.20	15.14	12.87	8.37	4.88	2.35	.84	.30	.06	.00	.	100.00

Table A1-5-1: Joint probability of occurrence of offshore wind sea significant wave height [m] and peak wave period [s] for all directions

Hs meters		spectral peak wave period seconds											
		< to 4.0	4.0 to 5.0	5.0 to 6.0	6.0 to 7.0	7.0 to 8.0	8.0 to 9.0	9.0 to 10.0	10.0 to 11.0	11.0 to 12.0	12.0 to 14.0	14.0 to >	Total
Lower	Upper												
<	.50	2.34	.05	.01	.00	.	.	.	.	.	.	.	2.40
.50	1.00	.26	.24	.04	.00	.00	.	.	.	.	.	.	.54
1.00	1.50	.00	.06	.10	.02	.00	.	.	.	.	.	.	.19
1.50	2.00	.	.00	.06	.03	.01	.00	.	.	.	.	.	.11
2.00	2.50	.	.	.00	.03	.01	.00	.	.	.	.	.	.05
2.50	3.00	.	.	.00	.01	.00	.00	.00	.	.	.	.	.02
3.00	3.50	.	.	.	.00	.01	.00	.00	.	.	.	.	.01
3.50	4.00	.	.	.	.	.00	.00	.00	.	.	.	.	.01
4.00	4.50	.	.	.	.	.	.00	.00	.00	.	.	.	.00
4.50	5.00	.	.	.	.	.	.00	.00	.	.	.	.	.00
5.00	5.50	.	.	.	.	.	.00	.	.	.	.	.	.00
5.50	6.00	.	.	.	.	.	.	.	.	.	.	.	.
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		2.60	.36	.21	.11	.03	.01	.00	.00	.	.	.	3.33

Table A1-5-2: Joint probability of occurrence of offshore wind sea significant wave height [m] and peak wave period [s] for directional sector 345°N-15°N

Hs meters		spectral peak wave period seconds											
Lower	Upper	< to 4.0	4.0 to 5.0	5.0 to 6.0	6.0 to 7.0	7.0 to 8.0	8.0 to 9.0	9.0 to 10.0	10.0 to 11.0	11.0 to 12.0	12.0 to 14.0	14.0 to >	Total
<	.50	6.34	.05	.01	.00	.	.	.	.	.	.	.	6.40
.50	1.00	.31	.31	.05	.01	.00	.00	.	.	.	.	.	.68
1.00	1.50	.00	.11	.18	.04	.00	.00	.	.	.	.	.	.33
1.50	2.00	.00	.00	.06	.10	.01	.00	.	.	.	.	.	.17
2.00	2.50	.	.	.00	.05	.04	.01	.	.	.	.	.	.10
2.50	3.00	.	.	.	.00	.03	.02	.	.	.	.	.	.05
3.00	3.50	.	.	.	.	.01	.03	.00	.	.00	.	.	.04
3.50	4.00	.	.	.	.	.00	.01	.00	.00	.	.	.	.01
4.00	4.50	.	.	.	.	.	.00	.01	.00	.	.	.	.01
4.50	5.00	.	.	.	.	.	.	.00	.00	.	.	.	.01
5.00	5.50	.	.	.	.	.	.	.00	.00	.00	.	.	.00
5.50	6.00	.	.	.	.	.	.	.	.	.	.	.	.
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.00	.00	.	.	.00
7.00	7.50	.	.	.	.	.	.	.	.	.00	.	.	.00
7.50	8.00	.	.	.	.	.	.	.	.00	.00	.	.	.00
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		6.65	.47	.30	.20	.10	.07	.01	.00	.00	.	.	7.81

Table A1-5-3: Joint probability of occurrence of offshore wind sea significant wave height [m] and peak wave period [s] for directional sector 15°N-45°N

Hs meters		spectral peak wave period seconds											
Lower	Upper	< to 4.0	4.0 to 5.0	5.0 to 6.0	6.0 to 7.0	7.0 to 8.0	8.0 to 9.0	9.0 to 10.0	10.0 to 11.0	11.0 to 12.0	12.0 to 14.0	14.0 to >	Total
<	.50	2.97	.10	.02	.00	.	.	.00	.	.	.	.	3.09
.50	1.00	.59	.78	.17	.02	.00	.00	.	.	.	.	.	1.56
1.00	1.50	.00	.21	.54	.10	.01	.00	.00	.	.	.	.	.87
1.50	2.00	.	.00	.11	.30	.07	.01	.00	.	.	.	.	.49
2.00	2.50	.	.00	.00	.11	.10	.01	.00	.	.	.	.	.22
2.50	3.00	.	.	.00	.01	.09	.05	.00	.00	.	.	.	.15
3.00	3.50	.	.	.	.	.02	.07	.01	.00	.	.	.	.10
3.50	4.00	.	.	.	.	.00	.03	.02	.00	.	.	.	.05
4.00	4.50	.	.	.	.	.	.01	.02	.00	.00	.	.	.03
4.50	5.00	.	.	.	.	.	.00	.01	.01	.00	.	.	.02
5.00	5.50	.	.	.	.	.	.00	.01	.00	.00	.	.	.01
5.50	6.00	.	.	.	.	.	.	.00	.00	.00	.	.	.01
6.00	6.50	.	.	.	.	.	.	.	.00	.00	.	.	.00
6.50	7.00	.	.	.	.	.	.	.	.00	.	.	.	.00
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		3.56	1.09	.85	.54	.29	.18	.06	.02	.00	.	.	6.60

Table A1-5-4: Joint probability of occurrence of offshore wind sea significant wave height [m] and peak wave period [s] for directional sector 45°N-75°N

Hs meters		spectral peak wave period seconds											
		< to 4.0	4.0 to 5.0	5.0 to 6.0	6.0 to 7.0	7.0 to 8.0	8.0 to 9.0	9.0 to 10.0	10.0 to 11.0	11.0 to 12.0	12.0 to 14.0	14.0 to >	Total
Lower	Upper												
<	.50	2.91	.10	.02	.01	.	.	.	.	.	.	.	3.04
.50	1.00	.64	.66	.12	.02	.00	.	.	.	.	.	.	1.44
1.00	1.50	.00	.25	.43	.05	.01	.00	.00	.	.	.	.	.75
1.50	2.00	.	.00	.17	.14	.02	.01	.00	.	.	.	.	.34
2.00	2.50	.	.00	.00	.13	.05	.00	.00	.	.	.	.	.20
2.50	3.00	.	.	.	.02	.05	.02	.00	.	.00	.	.	.08
3.00	3.50	.	.	.	.00	.02	.03	.01	.00	.	.	.	.06
3.50	4.00	.	.	.	.	.00	.02	.01	.00	.00	.	.	.03
4.00	4.50	.	.	.	.	.00	.01	.01	.00	.	.	.	.01
4.50	5.00	.	.	.	.	.	.	.01	.00	.00	.	.	.01
5.00	5.50	.	.	.	.	.	.	.00	.00	.00	.	.	.00
5.50	6.00	.	.	.	.	.	.	.	.01	.00	.	.	.01
6.00	6.50	.	.	.	.	.	.	.	.00	.00	.	.	.00
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		3.55	1.01	.74	.37	.17	.08	.04	.01	.01	.	.	5.98

Table A1-5-5: Joint probability of occurrence of offshore wind sea significant wave height [m] and peak wave period [s] for directional sector 75°N-105°N

Hs meters		spectral peak wave period seconds											
		< to 4.0	4.0 to 5.0	5.0 to 6.0	6.0 to 7.0	7.0 to 8.0	8.0 to 9.0	9.0 to 10.0	10.0 to 11.0	11.0 to 12.0	12.0 to 14.0	14.0 to >	Total
Lower	Upper												
<	.50	2.91	.10	.03	.01	.00	.	.	.	.	.	.	3.04
.50	1.00	.74	.83	.15	.03	.00	.	.	.	.	.	.	1.75
1.00	1.50	.01	.30	.61	.09	.01	.00	.	.	.	.	.	1.02
1.50	2.00	.	.00	.22	.30	.03	.00	.	.	.	.	.	.56
2.00	2.50	.	.00	.01	.20	.10	.01	.	.	.	.	.	.31
2.50	3.00	.	.	.	.02	.12	.03	.00	.	.	.	.	.17
3.00	3.50	.	.	.	.	.04	.05	.00	.	.	.	.	.09
3.50	4.00	.	.	.	.	.00	.02	.00	.	.	.	.	.03
4.00	4.50	.	.	.	.	.	.01	.01	.	.	.	.	.03
4.50	5.00	.	.	.	.	.	.00	.00	.00	.	.	.	.00
5.00	5.50	.	.	.	.	.	.	.00	.00	.	.	.	.00
5.50	6.00	.	.	.	.	.	.	.	.00	.00	.	.	.00
6.00	6.50	.	.	.	.	.	.	.	.00	.	.	.	.00
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		3.66	1.23	1.01	.65	.30	.13	.02	.01	.00	.	.	7.00

Table A1-5-6: Joint probability of occurrence of offshore wind sea significant wave height [m] and peak wave period [s] for directional sector 105°N-135°N

Hs meters		spectral peak wave period seconds											
		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	3.30	.08	.01	.00	.	.	.	.	.	.	.	3.39
.50	1.00	.78	1.01	.21	.01	.00	.00	.	.	.	.	.	2.01
1.00	1.50	.01	.31	.71	.09	.00	.00	.	.	.	.	.	1.11
1.50	2.00	.	.00	.20	.41	.03	.00	.	.	.	.	.	.64
2.00	2.50	.	.00	.00	.23	.13	.00	.	.	.	.	.	.37
2.50	3.00	.	.	.	.02	.15	.01	.	.	.	.	.	.18
3.00	3.50	.	.	.	.00	.04	.05	.00	.	.	.	.	.09
3.50	4.00	.	.	.	.	.00	.03	.00	.	.	.	.	.04
4.00	4.50	.	.	.	.	.00	.01	.01	.	.	.	.	.02
4.50	5.00	.	.	.	.	.	.	.01	.00	.	.	.	.01
5.00	5.50	.	.	.	.	.	.	.00	.00	.	.	.	.01
5.50	6.00	.	.	.	.	.	.	.	.00	.	.	.	.00
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		4.09	1.40	1.13	.77	.35	.11	.02	.00	.	.	.	7.86

Table A1-5-7: Joint probability of occurrence of offshore wind sea significant wave height [m] and peak wave period [s] for directional sector 135°N-165°N

Hs meters		spectral peak wave period seconds											
		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	3.23	.06	.01	.00	.	.	.	.	.	.	.	3.31
.50	1.00	.68	.90	.13	.00	.00	.	.	.	.	.	.	1.73
1.00	1.50	.01	.24	.61	.05	.	.	.	.	.	.	.	.91
1.50	2.00	.00	.00	.14	.23	.01	.	.	.	.	.	.	.38
2.00	2.50	.	.00	.00	.11	.04	.00	.	.	.	.	.	.16
2.50	3.00	.	.	.	.01	.05	.00	.	.	.	.	.	.06
3.00	3.50	.	.	.	.	.01	.01	.	.	.	.	.	.02
3.50	4.00	.	.	.	.	.00	.01	.00	.	.	.	.	.01
4.00	4.50	.	.	.	.	.	.00	.00	.	.	.	.	.00
4.50	5.00	.	.	.	.	.	.	.00	.	.	.	.	.00
5.00	5.50	.	.	.	.	.	.	.00	.	.	.	.	.00
5.50	6.00	.	.	.	.	.	.	.	.	.	.	.	.
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		3.92	1.21	.90	.40	.11	.03	.00	.	.	.	.	6.58

Table A1-5-8: Joint probability of occurrence of offshore wind sea significant wave height [m] and peak wave period [s] for directional sector 165°N -195°N

Hs		spectral peak wave period seconds											
meters		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	3.05	.05	.00	.	.	.	.	.	.	.	.	3.10
.50	1.00	.51	.63	.10	.00	.	.	.	.	.	.	.	1.25
1.00	1.50	.00	.17	.44	.03	.00	.00	.	.	.	.	.	.65
1.50	2.00	.	.00	.10	.13	.00	.00	.	.	.	.	.	.23
2.00	2.50	.	.	.00	.06	.02	.	.	.	.	.	.	.08
2.50	3.00	.	.	.	.00	.02	.00	.	.	.	.	.	.03
3.00	3.50	.	.	.	.	.00	.01	.	.	.	.	.	.01
3.50	4.00	.	.	.	.	.00	.01	.	.	.	.	.	.01
4.00	4.50	.	.	.	.	.	.00	.00	.	.	.	.	.00
4.50	5.00	.	.	.	.	.	.	.00	.	.	.	.	.00
5.00	5.50	.	.	.	.	.	.	.00	.00	.	.	.	.00
5.50	6.00	.	.	.	.	.	.	.	.	.	.	.	.
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		3.56	.86	.64	.23	.05	.02	.00	.00	.	.	.	5.35

Table A1-5-9: Joint probability of occurrence of offshore wind sea significant wave height [m] and peak wave period [s] for directional sector 195°N -225°N

Hs		spectral peak wave period seconds											
meters		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	3.57	.06	.01	.00	.	.	.	.	.	.	.	3.64
.50	1.00	.53	.74	.18	.01	.00	.	.	.	.	.	.	1.46
1.00	1.50	.00	.17	.55	.09	.00	.	.	.	.	.	.	.82
1.50	2.00	.00	.00	.13	.34	.02	.00	.	.	.	.	.	.49
2.00	2.50	.	.	.00	.14	.13	.00	.	.	.	.	.	.27
2.50	3.00	.	.	.	.02	.09	.02	.	.	.	.	.	.12
3.00	3.50	.	.	.	.	.02	.04	.00	.	.	.	.	.06
3.50	4.00	.	.	.	.	.00	.02	.00	.	.	.	.	.03
4.00	4.50	.	.	.	.	.	.00	.01	.00	.	.	.	.01
4.50	5.00	.	.	.	.	.	.	.00	.00	.	.	.	.00
5.00	5.50	.	.	.	.	.	.	.00	.00	.	.	.	.00
5.50	6.00	.	.	.	.	.	.	.	.00	.	.	.	.00
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		4.10	.98	.87	.59	.25	.09	.02	.00	.	.	.	6.90

Table A1-5-10: Joint probability of occurrence of offshore wind sea significant wave height [m] and peak wave period [s] for directional sector 225°N -255°N

Hs meters Lower	Upper	spectral peak wave period seconds < to 4.0	4.0 to 5.0	5.0 to 6.0	6.0 to 7.0	7.0 to 8.0	8.0 to 9.0	9.0 to 10.0	10.0 to 11.0	11.0 to 12.0	12.0 to 14.0	14.0 to >	Total
<	.50	5.62	.13	.02	.01	.00	.	.00	.	.	.	.	5.79
.50	1.00	1.00	1.03	.26	.03	.00	.00	.	.	.	.	.	2.32
1.00	1.50	.01	.33	.82	.28	.03	.00	.00	.	.	.	.	1.47
1.50	2.00	.	.00	.26	.51	.13	.01	.	.	.	.	.	.91
2.00	2.50	.	.	.00	.25	.28	.06	.00	.	.	.	.	.59
2.50	3.00	.	.	.00	.03	.22	.13	.01	.00	.	.	.	.38
3.00	3.50	.	.	.	.	.05	.18	.03	.	.	.	.	.26
3.50	4.00	.	.	.	.	.00	.09	.06	.00	.	.	.	.15
4.00	4.50	.	.	.	.	.	.01	.05	.01	.	.	.	.07
4.50	5.00	.	.	.	.	.	.00	.02	.01	.	.	.	.03
5.00	5.50	.	.	.	.	.	.	.01	.02	.	.	.	.02
5.50	6.00	.	.	.	.	.	.	.00	.01	.00	.	.	.01
6.00	6.50	.	.	.	.	.	.	.	.00	.00	.	.	.01
6.50	7.00	.	.	.	.	.	.	.	.00	.00	.	.	.00
7.00	7.50	.	.	.	.	.	.	.	.00	.00	.	.	.00
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		6.63	1.49	1.37	1.09	.72	.48	.18	.05	.01	.	.	12.03

Table A1-5-11: Joint probability of occurrence of offshore wind sea significant wave height [m] and peak wave period [s] for directional sector 255°N -285°N

Hs meters Lower	Upper	spectral peak wave period seconds < to 4.0	4.0 to 5.0	5.0 to 6.0	6.0 to 7.0	7.0 to 8.0	8.0 to 9.0	9.0 to 10.0	10.0 to 11.0	11.0 to 12.0	12.0 to 14.0	14.0 to >	Total
<	.50	6.41	.24	.05	.01	.00	.00	.00	.	.	.	.	6.71
.50	1.00	2.13	2.62	1.17	.28	.01	.00	.	.	.	.	.	6.22
1.00	1.50	.02	1.11	2.22	1.06	.35	.01	.00	.	.	.	.	4.77
1.50	2.00	.	.01	.76	1.23	.78	.14	.01	.	.	.	.	2.93
2.00	2.50	.	.	.01	.45	.80	.31	.03	.	.	.	.	1.60
2.50	3.00	.	.	.	.02	.37	.34	.07	.01	.	.	.	.82
3.00	3.50	.	.	.	.00	.04	.23	.14	.02	.00	.	.	.43
3.50	4.00	.	.	.	.	.00	.06	.13	.05	.00	.	.	.24
4.00	4.50	.	.	.	.	.	.01	.06	.05	.00	.	.	.13
4.50	5.00	.	.	.	.	.	.	.01	.04	.01	.00	.	.05
5.00	5.50	.	.	.	.	.	.	.00	.01	.01	.	.	.02
5.50	6.00	.	.	.	.	.	.	.	.00	.01	.00	.	.01
6.00	6.50	.	.	.	.	.	.	.	.00	.01	.00	.	.01
6.50	7.00	.	.	.	.	.	.	.	.	.	.00	.	.00
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		8.57	3.98	4.20	3.05	2.36	1.10	.46	.18	.04	.00	.	23.95

Table A1-5-12: Joint probability of occurrence of offshore wind sea significant wave height [m] and peak wave period [s] for directional sector 285°N -315°N

Hs		spectral peak wave period seconds											
meters		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	3.59	.10	.02	.00	.00	.00	.	.	.	.	.	3.70
.50	1.00	.72	.70	.17	.02	.00	.	.	.	.	.	.	1.61
1.00	1.50	.01	.24	.30	.11	.02	.00	.00	.	.	.	.	.68
1.50	2.00	.00	.00	.15	.11	.05	.01	.00	.	.00	.	.	.31
2.00	2.50	.	.	.01	.11	.03	.01	.00	.	.	.	.	.17
2.50	3.00	.	.	.	.02	.03	.01	.00	.	.	.	.	.07
3.00	3.50	.	.	.	.00	.02	.01	.00	.00	.	.	.	.04
3.50	4.00	.	.	.	.	.00	.01	.00	.00	.	.	.	.02
4.00	4.50	.	.	.	.	.	.00	.00	.00	.	.	.	.01
4.50	5.00	.	.	.	.	.	.00	.00	.00	.00	.	.	.00
5.00	5.50	.	.	.	.	.	.	.00	.00	.00	.	.	.00
5.50	6.00	.	.	.	.	.	.	.	.	.	.	.	.
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		4.31	1.05	.65	.37	.15	.05	.02	.01	.00	.	.	6.61

Table A1-5-13: Joint probability of occurrence of offshore wind sea significant wave height [m] and peak wave period [s] for directional sector 315°N -345°N

Swell

Hs		spectral peak wave period seconds											
meters		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	8.97	14.19	15.14	8.20	3.80	1.98	.70	.27	.15	.13	.03	53.56
.50	1.00	.15	1.98	8.84	10.68	6.63	2.77	.89	.28	.08	.03	.00	32.33
1.00	1.50	.	.00	.27	2.08	3.36	2.65	1.05	.21	.04	.01	.	9.67
1.50	2.00	.	.00	.00	.12	.65	1.10	.84	.26	.03	.01	.	3.02
2.00	2.50	.	.	.	.00	.07	.28	.26	.25	.08	.01	.	.95
2.50	3.00	.	.	.	.	.00	.04	.09	.12	.07	.01	.	.32
3.00	3.50	.	.	.	.	.	.00	.02	.04	.03	.01	.	.10
3.50	4.00	.	.	.	.	.	.00	.00	.01	.01	.01	.	.03
4.00	4.50	.	.	.	.	.	.	.00	.00	.00	.00	.	.01
4.50	5.00	.	.	.	.	.	.	.	.	.00	.00	.	.00
5.00	5.50	.	.	.	.	.	.	.	.	.	.	.	.
5.50	6.00	.	.	.	.	.	.	.	.	.	.	.	.
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		9.12	16.17	24.25	21.08	14.51	8.84	3.85	1.44	.50	.22	.03	100.00

Table A1-5-14: Joint probability of occurrence of offshore swell significant wave height [m] and peak wave period [s] for all directions

Hs		spectral peak wave period seconds											
meters		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	.44	.83	.82	.29	.14	.07	.03	.03	.02	.02	.00	2.70
.50	1.00	.01	.04	.30	.33	.14	.05	.02	.01	.00	.00	.	.91
1.00	1.50	.	.	.00	.02	.07	.03	.01	.00	.00	.	.	.15
1.50	2.00	.	.	.	.	.00	.01	.01	.00	.00	.	.	.02
2.00	2.50	.	.	.	.	.	.00	.00	.00	.00	.	.	.00
2.50	3.00	.	.	.	.	.	.	.	.	.	.	.	.
3.00	3.50	.	.	.	.	.	.	.	.	.	.	.	.
3.50	4.00	.	.	.	.	.	.	.	.	.	.	.	.
4.00	4.50	.	.	.	.	.	.	.	.	.	.	.	.
4.50	5.00	.	.	.	.	.	.	.	.	.	.	.	.
5.00	5.50	.	.	.	.	.	.	.	.	.	.	.	.
5.50	6.00	.	.	.	.	.	.	.	.	.	.	.	.
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		.45	.87	1.12	.65	.36	.17	.07	.04	.02	.03	.00	3.78

Table A1-5-15: Joint probability of occurrence of offshore swell significant wave height [m] and peak wave period [s] for directional sector 345°N -15°N

Hs		spectral peak wave period seconds											
meters		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	.50	1.77	1.96	.95	.33	.14	.06	.02	.02	.02	.00	5.78
.50	1.00	.01	.08	.44	.84	.74	.29	.08	.01	.01	.00	.	2.49
1.00	1.50	.	.	.00	.04	.17	.24	.12	.02	.00	.	.	.61
1.50	2.00	.	.	.00	.00	.01	.07	.06	.01	.00	.	.	.16
2.00	2.50	.	.	.	.	.	.00	.02	.01	.00	.	.	.03
2.50	3.00	.	.	.	.	.	.00	.00	.00	.00	.	.	.00
3.00	3.50	.	.	.	.	.	.	.	.	.	.	.	.
3.50	4.00	.	.	.	.	.	.	.	.	.	.	.	.
4.00	4.50	.	.	.	.	.	.	.	.	.	.	.	.
4.50	5.00	.	.	.	.	.	.	.	.	.	.	.	.
5.00	5.50	.	.	.	.	.	.	.	.	.	.	.	.
5.50	6.00	.	.	.	.	.	.	.	.	.	.	.	.
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		.51	1.85	2.40	1.84	1.25	.75	.34	.08	.03	.02	.00	9.07

Table A1-5-16: Joint probability of occurrence of offshore swell significant wave height [m] and peak wave period [s] for directional sector 15°N -45°N

Hs		spectral peak wave period seconds											
meters		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	.56	1.92	2.37	1.24	.47	.23	.08	.02	.01	.01	.00	6.90
.50	1.00	.01	.11	.76	1.65	1.23	.41	.11	.03	.01	.	.00	4.32
1.00	1.50	.	.00	.01	.11	.57	.64	.23	.04	.00	.	.	1.61
1.50	2.00	.	.	.	.00	.04	.25	.25	.07	.01	.	.	.63
2.00	2.50	.	.	.	.	.00	.03	.07	.06	.01	.	.	.18
2.50	3.00	.	.	.	.	.	.	.01	.04	.01	.00	.	.07
3.00	3.50	.	.	.	.	.	.	.00	.01	.01	.00	.	.02
3.50	4.00	.	.	.	.	.	.	.	.00	.00	.00	.	.01
4.00	4.50	.	.	.	.	.	.	.	.	.00	.00	.	.00
4.50	5.00	.	.	.	.	.	.	.	.	.	.00	.	.00
5.00	5.50	.	.	.	.	.	.	.	.	.	.	.	.
5.50	6.00	.	.	.	.	.	.	.	.	.	.	.	.
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		.57	2.03	3.14	3.01	2.31	1.56	.76	.29	.07	.02	.00	13.75

Table A1-5-17: Joint probability of occurrence of offshore swell significant wave height [m] and peak wave period [s] for directional sector 45°N -75°N

Hs		spectral peak wave period seconds											
meters		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	.42	.84	1.23	1.05	.59	.26	.07	.02	.01	.00	.	4.50
.50	1.00	.01	.15	.61	.98	1.22	.65	.21	.07	.02	.00	.00	3.93
1.00	1.50	.	.	.01	.12	.31	.73	.43	.06	.01	.00	.	1.67
1.50	2.00	.	.	.	.01	.03	.16	.36	.14	.01	.00	.	.70
2.00	2.50	.	.	.	.00	.00	.01	.08	.14	.06	.00	.	.30
2.50	3.00	.	.	.	.	.	.00	.02	.05	.05	.01	.	.13
3.00	3.50	.	.	.	.	.	.	.00	.01	.01	.01	.	.04
3.50	4.00	.	.	.	.	.	.	.	.00	.00	.00	.	.01
4.00	4.50	.	.	.	.	.	.	.	.	.00	.	.	.00
4.50	5.00	.	.	.	.	.	.	.	.	.	.	.	.
5.00	5.50	.	.	.	.	.	.	.	.	.	.	.	.
5.50	6.00	.	.	.	.	.	.	.	.	.	.	.	.
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		.44	.98	1.85	2.15	2.17	1.82	1.17	.49	.18	.03	.00	11.27

Table A1-5-18: Joint probability of occurrence of offshore swell significant wave height [m] and peak wave period [s] for directional sector 75°N -105°N

Hs		spectral peak wave period seconds											
meters		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	.54	.79	1.18	.78	.43	.17	.05	.01	.01	.01	.00	3.96
.50	1.00	.01	.16	.76	1.12	.67	.25	.05	.01	.00	.00	.	3.03
1.00	1.50	.	.00	.03	.31	.64	.28	.05	.01	.00	.	.	1.32
1.50	2.00	.	.	.	.02	.12	.24	.07	.02	.00	.	.	.47
2.00	2.50	.	.	.	.00	.01	.07	.05	.02	.00	.00	.	.16
2.50	3.00	.	.	.	.	.	.01	.03	.01	.00	.	.	.06
3.00	3.50	.	.	.	.	.	.00	.01	.01	.00	.	.	.02
3.50	4.00	.	.	.	.	.	.00	.00	.00	.00	.00	.	.01
4.00	4.50	.	.	.	.	.	.	.	.00	.00	.	.	.00
4.50	5.00	.	.	.	.	.	.	.	.	.00	.	.	.00
5.00	5.50	.	.	.	.	.	.	.	.	.	.	.	.
5.50	6.00	.	.	.	.	.	.	.	.	.	.	.	.
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		.55	.95	1.97	2.23	1.86	1.03	.30	.10	.03	.01	.00	9.03

Table A1-5-19: Joint probability of occurrence of offshore swell significant wave height [m] and peak wave period [s] for directional sector 105°N -135°N

Hs		spectral peak wave period seconds											
meters		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	.88	1.65	1.49	.85	.32	.16	.03	.01	.01	.01	.00	5.42
.50	1.00	.02	.38	1.69	1.55	.56	.19	.03	.01	.00	.00	.00	4.43
1.00	1.50	.	.	.08	.66	.66	.22	.04	.01	.00	.	.	1.66
1.50	2.00	.	.	.00	.05	.29	.22	.03	.00	.00	.00	.	.59
2.00	2.50	.	.	.	.00	.05	.13	.02	.00	.00	.	.	.20
2.50	3.00	.	.	.	.	.00	.02	.02	.00	.	.	.	.04
3.00	3.50	.	.	.	.	.	.00	.01	.00	.	.	.	.01
3.50	4.00	.	.	.	.	.	.	.00	.00	.	.	.	.01
4.00	4.50	.	.	.	.	.	.	.00	.00	.	.	.	.00
4.50	5.00	.	.	.	.	.	.	.	.	.	.	.	.
5.00	5.50	.	.	.	.	.	.	.	.	.	.	.	.
5.50	6.00	.	.	.	.	.	.	.	.	.	.	.	.
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		.90	2.02	3.27	3.12	1.89	.93	.18	.03	.01	.01	.00	12.37

Table A1-5-20: Joint probability of occurrence of offshore swell significant wave height [m] and peak wave period [s] for directional sector 135°N -165°N

Hs		spectral peak wave period seconds											
meters		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	1.55	2.02	1.40	.71	.27	.17	.04	.01	.01	.01	.00	6.19
.50	1.00	.03	.50	1.47	.86	.28	.12	.03	.01	.00	.00	.00	3.29
1.00	1.50	.	.	.07	.36	.17	.04	.01	.00	.00	.	.	.65
1.50	2.00	.	.	.00	.03	.06	.02	.00	.00	.	.00	.	.12
2.00	2.50	.	.	.	.00	.00	.01	.00	.00	.	.	.	.02
2.50	3.00	.	.	.	.	.	.00	.00	.	.	.	.	.00
3.00	3.50	.	.	.	.	.	.00	.00	.00	.	.	.	.00
3.50	4.00	.	.	.	.	.	.	.	.00	.	.	.	.00
4.00	4.50	.	.	.	.	.	.	.	.	.	.	.	.
4.50	5.00	.	.	.	.	.	.	.	.	.	.	.	.
5.00	5.50	.	.	.	.	.	.	.	.	.	.	.	.
5.50	6.00	.	.	.	.	.	.	.	.	.	.	.	.
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		1.57	2.52	2.94	1.96	.79	.37	.08	.02	.01	.01	.00	10.28

Table A1-5-21: Joint probability of occurrence of offshore swell significant wave height [m] and peak wave period [s] for directional sector 165-195°N

Hs meters		spectral peak wave period seconds											
		< to 4.0	4.0 to 5.0	5.0 to 6.0	6.0 to 7.0	7.0 to 8.0	8.0 to 9.0	9.0 to 10.0	10.0 to 11.0	11.0 to 12.0	12.0 to 14.0	14.0 to >	Total
Lower	Upper												
<	.50	1.00	1.23	1.08	.57	.24	.19	.05	.01	.01	.02	.01	4.42
.50	1.00	.02	.22	.53	.42	.17	.10	.04	.02	.00	.00	.00	1.52
1.00	1.50	.	.00	.02	.17	.10	.05	.02	.00	.00	.	.	.37
1.50	2.00	.	.00	.	.00	.02	.02	.01	.00	.00	.	.	.06
2.00	2.50	.	.	.	.	.00	.01	.01	.00	.	.	.	.02
2.50	3.00	.	.	.	.	.	.00	.00	.00	.00	.	.	.01
3.00	3.50	.	.	.	.	.	.	.	.	.	.	.	.
3.50	4.00	.	.	.	.	.	.	.	.	.	.	.	.
4.00	4.50	.	.	.	.	.	.	.	.	.	.	.	.
4.50	5.00	.	.	.	.	.	.	.	.	.	.	.	.
5.00	5.50	.	.	.	.	.	.	.	.	.	.	.	.
5.50	6.00	.	.	.	.	.	.	.	.	.	.	.	.
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		1.02	1.45	1.63	1.17	.54	.37	.13	.04	.02	.02	.01	6.39

Table A1-5-22: Joint probability of occurrence of offshore swell significant wave height [m] and peak wave period [s] for directional sector 195°N -225°N

Hs meters		spectral peak wave period seconds											
		< to 4.0	4.0 to 5.0	5.0 to 6.0	6.0 to 7.0	7.0 to 8.0	8.0 to 9.0	9.0 to 10.0	10.0 to 11.0	11.0 to 12.0	12.0 to 14.0	14.0 to >	Total
Lower	Upper												
<	.50	.66	.51	.47	.26	.10	.08	.03	.01	.02	.01	.00	2.17
.50	1.00	.01	.12	.51	.37	.13	.07	.04	.01	.01	.00	.00	1.26
1.00	1.50	.	.	.01	.12	.12	.03	.01	.01	.00	.00	.	.30
1.50	2.00	.	.	.	.00	.03	.02	.01	.00	.00	.00	.	.07
2.00	2.50	.	.	.	.	.	.01	.01	.00	.	.	.	.02
2.50	3.00	.	.	.	.	.	.00	.00	.	.	.	.	.00
3.00	3.50	.	.	.	.	.	.	.	.	.	.00	.	.00
3.50	4.00	.	.	.	.	.	.	.	.	.	.00	.	.00
4.00	4.50	.	.	.	.	.	.	.	.	.	.00	.	.00
4.50	5.00	.	.	.	.	.	.	.	.	.	.	.	.
5.00	5.50	.	.	.	.	.	.	.	.	.	.	.	.
5.50	6.00	.	.	.	.	.	.	.	.	.	.	.	.
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		.67	.63	1.00	.75	.39	.22	.10	.04	.02	.02	.00	3.83

Table A1-5-23: Joint probability of occurrence of offshore swell significant wave height [m] and peak wave period [s] for directional sector 225°N -255°N

Hs		spectral peak wave period seconds											
meters		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	.89	.53	.56	.36	.18	.10	.06	.03	.01	.01	.00	2.73
.50	1.00	.01	.10	.44	.58	.33	.17	.08	.02	.01	.00	.	1.75
1.00	1.50	.	.	.01	.08	.17	.15	.07	.02	.00	.00	.	.51
1.50	2.00	.	.	.00	.00	.02	.06	.03	.01	.00	.00	.	.12
2.00	2.50	.	.	.	.00	.	.00	.01	.00	.00	.	.	.02
2.50	3.00	.	.	.	.	.	.	.00	.00	.00	.	.	.01
3.00	3.50	.	.	.	.	.	.	.00	.00	.00	.	.	.00
3.50	4.00	.	.	.	.	.	.	.	.00	.	.	.	.00
4.00	4.50	.	.	.	.	.	.	.	.	.	.	.	.
4.50	5.00	.	.	.	.	.	.	.	.	.	.	.	.
5.00	5.50	.	.	.	.	.	.	.	.	.	.	.	.
5.50	6.00	.	.	.	.	.	.	.	.	.	.	.	.
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		.90	.63	1.01	1.03	.70	.49	.24	.10	.03	.01	.00	5.14

Table A1-5-24: Joint probability of occurrence of offshore swell significant wave height [m] and peak wave period [s] for directional sector 255°N -285°N

Hs		spectral peak wave period seconds											
meters		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	.96	1.21	1.59	.75	.46	.26	.13	.05	.02	.01	.00	5.44
.50	1.00	.01	.08	.90	1.52	.99	.38	.16	.05	.02	.01	.00	4.12
1.00	1.50	.	.	.00	.06	.33	.20	.06	.03	.01	.00	.	.70
1.50	2.00	.	.	.	.	.00	.02	.01	.00	.00	.00	.	.04
2.00	2.50	.	.	.	.	.	.00	.	.00	.00	.	.	.01
2.50	3.00	.	.	.	.	.	.	.00	.	.	.	.	.00
3.00	3.50	.	.	.	.	.	.	.00	.00	.	.	.	.00
3.50	4.00	.	.	.	.	.	.	.	.00	.	.	.	.00
4.00	4.50	.	.	.	.	.	.	.	.	.	.	.	.
4.50	5.00	.	.	.	.	.	.	.	.	.	.	.	.
5.00	5.50	.	.	.	.	.	.	.	.	.	.	.	.
5.50	6.00	.	.	.	.	.	.	.	.	.	.	.	.
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		.97	1.29	2.49	2.33	1.78	.86	.37	.14	.05	.03	.00	10.31

Table A1-5-25: Joint probability of occurrence of offshore swell significant wave height [m] and peak wave period [s] for directional sector 285°N -315°N

Hs		spectral peak wave period seconds											
meters		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	.56	.88	1.00	.39	.26	.14	.07	.04	.02	.01	.00	3.36
.50	1.00	.00	.05	.44	.44	.16	.10	.05	.02	.01	.00	.00	1.28
1.00	1.50	.	.	.00	.02	.06	.02	.01	.00	.00	.00	.	.12
1.50	2.00	.	.	.	.00	.00	.01	.00	.00	.	.	.	.01
2.00	2.50	.	.	.	.	.	.00	.00	.	.	.	.	.00
2.50	3.00	.	.	.	.	.	.	.00	.00	.	.	.	.00
3.00	3.50	.	.	.	.	.	.	.	.00	.	.	.	.00
3.50	4.00	.	.	.	.	.	.	.	.	.	.	.	.
4.00	4.50	.	.	.	.	.	.	.	.	.	.	.	.
4.50	5.00	.	.	.	.	.	.	.	.	.	.	.	.
5.00	5.50	.	.	.	.	.	.	.	.	.	.	.	.
5.50	6.00	.	.	.	.	.	.	.	.	.	.	.	.
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		.56	.93	1.44	.86	.48	.27	.13	.06	.03	.01	.00	4.78

Table A1-5-26: Joint probability of occurrence of offshore swell significant wave height [m] and peak wave period [s] for directional sector 315°N -345°N

Total

Hs		spectral peak wave period seconds											
meters		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	9.28	6.47	4.11	.95	.22	.05	.01	.00	.00	.00	.	21.10
.50	1.00	4.00	8.43	11.53	7.15	2.84	.61	.11	.03	.01	.00	.	34.70
1.00	1.50	.08	2.45	6.55	5.61	4.08	1.68	.35	.04	.00	.	.	20.86
1.50	2.00	.00	.06	2.03	3.89	2.96	1.71	.68	.08	.01	.00	.	11.43
2.00	2.50	.	.01	.06	1.66	2.10	1.21	.56	.20	.03	.00	.	5.84
2.50	3.00	.	.	.00	.18	1.26	.97	.35	.18	.05	.00	.	3.00
3.00	3.50	.	.	.00	.01	.27	.79	.32	.11	.03	.01	.	1.53
3.50	4.00	.	.	.	.00	.02	.33	.29	.11	.02	.01	.	.78
4.00	4.50	.	.	.	.	.00	.07	.19	.10	.02	.00	.	.39
4.50	5.00	.	.	.	.	.	.01	.07	.07	.03	.00	.	.18
5.00	5.50	.	.	.	.	.	.00	.03	.05	.02	.00	.	.09
5.50	6.00	.	.	.	.	.	.	.00	.03	.02	.00	.	.06
6.00	6.50	.	.	.	.	.	.	.	.01	.01	.00	.	.03
6.50	7.00	.	.	.	.	.	.	.	.00	.00	.00	.	.01
7.00	7.50	.	.	.	.	.	.	.	.00	.00	.00	.	.00
7.50	8.00	.	.	.	.	.	.	.	.	.00	.00	.	.00
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		13.37	17.42	24.29	19.45	13.75	7.43	2.96	1.02	.26	.04	.	100.00

Table A1-5-27: Joint probability of occurrence of offshore total significant wave height [m] and peak wave period [s] for all directions

Hs		spectral peak wave period seconds											
meters		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	.57	.18	.01	.00	.00	.	.	.	.	.	.	.76
.50	1.00	.11	.26	.21	.02	.00	.00	.00	.	.	.	.	.61
1.00	1.50	.01	.05	.11	.07	.01	.	.	.	.	.	.	.24
1.50	2.00	.00	.00	.03	.04	.02	.00	.	.	.	.	.	.09
2.00	2.50	.	.	.00	.03	.00	.01	.00	.	.	.	.	.05
2.50	3.00	.	.	.	.01	.00	.00	.00	.	.	.	.	.02
3.00	3.50	.	.	.	.00	.01	.00	.	.	.	.	.	.01
3.50	4.00	.	.	.	.	.00	.00	.	.	.	.	.	.01
4.00	4.50	.	.	.	.	.	.00	.	.	.	.	.	.00
4.50	5.00	.	.	.	.	.	.	.	.00	.	.	.	.00
5.00	5.50	.	.	.	.	.	.	.	.	.	.	.	.
5.50	6.00	.	.	.	.	.	.	.	.	.	.	.	.
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		.69	.50	.35	.19	.05	.02	.00	.00	.	.	.	1.79

Table A1-5-28: Joint probability of occurrence of offshore total significant wave height [m] and peak wave period [s] for directional sector 345°N -15°N

Hs		spectral peak wave period seconds											
meters		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	.43	.23	.16	.05	.00	.00	.	.	.	.	.	.87
.50	1.00	.08	.11	.16	.10	.05	.01	.00	.00	.	.	.	.53
1.00	1.50	.01	.04	.09	.06	.08	.04	.01	.00	.00	.	.	.33
1.50	2.00	.	.00	.04	.04	.04	.05	.03	.00	.	.	.	.20
2.00	2.50	.	.00	.00	.03	.03	.03	.04	.01	.	.	.	.15
2.50	3.00	.	.	.00	.01	.03	.02	.01	.01	.	.	.	.08
3.00	3.50	.	.	.00	.00	.00	.02	.00	.00	.	.	.	.03
3.50	4.00	.	.	.	.00	.00	.01	.00	.00	.	.	.	.01
4.00	4.50	.	.	.	.	.	.00	.01	.00	.	.	.	.01
4.50	5.00	.	.	.	.	.	.00	.00	.00	.00	.	.	.01
5.00	5.50	.	.	.	.	.	.	.00	.00	.	.	.	.00
5.50	6.00	.	.	.	.	.	.	.	.	.	.	.	.
6.00	6.50	.	.	.	.	.	.	.	.	.	.00	.	.00
6.50	7.00	.	.	.	.	.	.	.	.00	.	.00	.	.00
7.00	7.50	.	.	.	.	.	.	.	.	.00	.00	.	.00
7.50	8.00	.	.	.	.	.	.	.	.	.00	.00	.	.00
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		.52	.39	.45	.30	.24	.19	.12	.03	.00	.00	.	2.24

Table A1-5-29: Joint probability of occurrence of offshore total significant wave height [m] and peak wave period [s] for directional sector 15°N -45°N

Hs		spectral peak wave period seconds											
meters		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	.71	1.71	1.43	.33	.07	.01	.00	.	.	.	.	4.27
.50	1.00	.23	.64	1.52	1.93	.95	.14	.02	.01	.00	.	.	5.44
1.00	1.50	.01	.13	.39	.50	.96	.53	.08	.01	.00	.	.	2.61
1.50	2.00	.00	.01	.10	.25	.28	.45	.20	.01	.00	.	.	1.30
2.00	2.50	.	.00	.00	.07	.13	.19	.16	.05	.00	.	.	.60
2.50	3.00	.	.	.00	.01	.07	.09	.08	.05	.01	.	.	.31
3.00	3.50	.	.	.	.00	.01	.06	.04	.03	.01	.00	.	.15
3.50	4.00	.	.	.	.	.00	.02	.03	.02	.01	.00	.	.08
4.00	4.50	.	.	.	.	.	.01	.02	.01	.01	.00	.	.05
4.50	5.00	.	.	.	.	.	.00	.01	.01	.01	.00	.	.03
5.00	5.50	.	.	.	.	.	.00	.00	.01	.00	.00	.	.01
5.50	6.00	.	.	.	.	.	.	.00	.01	.00	.00	.	.01
6.00	6.50	.	.	.	.	.	.	.	.00	.00	.	.	.00
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		.95	2.49	3.46	3.09	2.47	1.51	.64	.22	.05	.01	.	14.88

Table A1-5-30: Joint probability of occurrence of offshore total significant wave height [m] and peak wave period [s] for directional sector 45°N -75°N

Hs meters		spectral peak wave period seconds											
		< to 4.0	4.0 to 5.0	5.0 to 6.0	6.0 to 7.0	7.0 to 8.0	8.0 to 9.0	9.0 to 10.0	10.0 to 11.0	11.0 to 12.0	12.0 to 14.0	14.0 to >	Total
Lower	Upper												
<	.50	.43	.48	.53	.20	.05	.02	.01	.00	.00	.00	.	1.71
.50	1.00	.27	.50	.88	.98	.79	.21	.05	.02	.01	.00	.	3.70
1.00	1.50	.01	.17	.29	.28	.53	.67	.19	.02	.00	.	.	2.16
1.50	2.00	.00	.01	.14	.14	.12	.36	.36	.06	.00	.	.	1.18
2.00	2.50	.	.	.00	.09	.06	.09	.18	.14	.02	.	.	.59
2.50	3.00	.	.	.	.01	.04	.04	.07	.09	.05	.00	.	.30
3.00	3.50	.	.	.	.00	.01	.03	.04	.03	.02	.00	.	.14
3.50	4.00	.	.	.	.	.00	.01	.02	.02	.01	.01	.	.07
4.00	4.50	.	.	.	.	.00	.00	.01	.01	.00	.00	.	.03
4.50	5.00	.	.	.	.	.	.00	.00	.00	.01	.	.	.01
5.00	5.50	.	.	.	.	.	.	.00	.00	.00	.	.	.01
5.50	6.00	.	.	.	.	.	.	.00	.00	.01	.00	.	.01
6.00	6.50	.	.	.	.	.	.	.	.00	.00	.	.	.00
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		.70	1.15	1.84	1.70	1.61	1.44	.94	.38	.14	.02	.	9.92

Table A1-5-31: Joint probability of occurrence of offshore total significant wave height [m] and peak wave period [s] for directional sector 75°N -105°N

Hs meters		spectral peak wave period seconds											
		< to 4.0	4.0 to 5.0	5.0 to 6.0	6.0 to 7.0	7.0 to 8.0	8.0 to 9.0	9.0 to 10.0	10.0 to 11.0	11.0 to 12.0	12.0 to 14.0	14.0 to >	Total
Lower	Upper												
<	.50	.34	.32	.29	.06	.03	.01	.00	.	.	.	.	1.04
.50	1.00	.28	.66	.97	.73	.21	.04	.01	.	.	.	.	2.89
1.00	1.50	.01	.20	.51	.55	.53	.07	.00	.	.	.	.	1.88
1.50	2.00	.00	.00	.17	.31	.30	.19	.01	.	.	.	.	.98
2.00	2.50	.	.00	.01	.15	.16	.13	.03	.00	.	.	.	.48
2.50	3.00	.	.	.	.02	.12	.09	.03	.00	.	.	.	.27
3.00	3.50	.	.	.	.	.04	.08	.02	.00	.	.	.	.14
3.50	4.00	.	.	.	.	.00	.03	.01	.01	.	.	.	.05
4.00	4.50	.	.	.	.	.	.01	.02	.00	.00	.	.	.04
4.50	5.00	.	.	.	.	.	.00	.00	.00	.00	.	.	.01
5.00	5.50	.	.	.	.	.	.	.00	.00	.00	.	.	.00
5.50	6.00	.	.	.	.	.	.	.	.00	.00	.00	.	.00
6.00	6.50	.	.	.	.	.	.	.	.00	.00	.	.	.00
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		.63	1.19	1.94	1.82	1.39	.65	.14	.03	.00	.00	.	7.79

Table A1-5-32: Joint probability of occurrence of offshore total significant wave height [m] and peak wave period [s] for directional sector 105°N -135°N

Hs		spectral peak wave period seconds											
meters		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	.70	.73	.16	.00	.00	.00	.	.	.	.	.	1.60
.50	1.00	.34	1.29	1.69	.46	.04	.00	.00	.	.	.	.	3.83
1.00	1.50	.01	.21	.81	.88	.29	.02	.	.	.	.	.	2.23
1.50	2.00	.	.01	.18	.55	.42	.09	.	.	.	.	.	1.25
2.00	2.50	.	.00	.00	.22	.31	.15	.01	.	.	.	.	.69
2.50	3.00	.	.	.00	.02	.16	.10	.02	.	.	.	.	.30
3.00	3.50	.	.	.	.00	.04	.07	.01	.00	.	.	.	.13
3.50	4.00	.	.	.	.	.00	.04	.01	.00	.	.	.	.06
4.00	4.50	.	.	.	.	.00	.01	.01	.00	.	.	.	.02
4.50	5.00	.	.	.	.	.	.00	.01	.00	.	.	.	.01
5.00	5.50	.	.	.	.	.	.	.00	.00	.	.	.	.01
5.50	6.00	.	.	.	.	.	.	.00	.00	.	.	.	.00
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		1.05	2.24	2.84	2.14	1.27	.49	.07	.01	.	.	.	10.12

Table A1-5-33: Joint probability of occurrence of offshore total significant wave height [m] and peak wave period [s] for directional sector 135-165°N

Hs		spectral peak wave period seconds											
meters		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	.89	.44	.02	.00	.00	.	.	.	.	.	.	1.36
.50	1.00	.25	1.09	.90	.06	.00	.00	.	.	.	.	.	2.30
1.00	1.50	.01	.14	.73	.39	.01	.	.	.	.	.	.	1.28
1.50	2.00	.00	.00	.10	.31	.07	.00	.	.	.	.	.	.48
2.00	2.50	.	.00	.00	.09	.10	.01	.	.	.	.	.	.20
2.50	3.00	.	.	.	.01	.06	.01	.	.	.	.	.	.07
3.00	3.50	.	.	.	.	.01	.02	.00	.	.	.	.	.03
3.50	4.00	.	.	.	.	.00	.01	.00	.	.	.	.	.01
4.00	4.50	.	.	.	.	.	.00	.00	.	.	.	.	.00
4.50	5.00	.	.	.	.	.	.	.00	.	.	.	.	.00
5.00	5.50	.	.	.	.	.	.	.00	.	.	.	.	.00
5.50	6.00	.	.	.	.	.	.	.	.	.	.	.	.
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		1.15	1.68	1.75	.86	.25	.05	.01	.	.	.	.	5.74

Table A1-5-34: Joint probability of occurrence of offshore total significant wave height [m] and peak wave period [s] for directional sector 165°N-195°N

Hs meters Lower	Upper	< to 4.0	4.0 to 5.0	5.0 to 6.0	6.0 to 7.0	7.0 to 8.0	8.0 to 9.0	9.0 to 10.0	10.0 to 11.0	11.0 to 12.0	12.0 to 14.0	14.0 to >	Total
		spectral peak wave period seconds											
<	.50	.74	.10	.00	.	.	.	.	.	.	.	.	.85
.50	1.00	.21	.51	.27	.01	.00	.00	.	.	.	.	.	1.00
1.00	1.50	.00	.10	.37	.13	.01	.	.	.	.	.	.	.61
1.50	2.00	.00	.00	.07	.15	.03	.00	.	.	.	.	.	.25
2.00	2.50	.	.00	.00	.05	.04	.00	.00	.	.	.	.	.10
2.50	3.00	.	.	.	.00	.02	.01	.00	.	.	.	.	.03
3.00	3.50	.	.	.	.	.00	.01	.00	.	.	.	.	.01
3.50	4.00	.	.	.	.	.00	.01	.00	.00	.	.	.	.01
4.00	4.50	.	.	.	.	.	.00	.00	.	.	.	.	.00
4.50	5.00	.	.	.	.	.	.	.00	.	.	.	.	.00
5.00	5.50	.	.	.	.	.	.	.00	.00	.	.	.	.00
5.50	6.00	.	.	.	.	.	.	.00	.	.	.	.	.00
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		.95	.72	.72	.34	.10	.03	.01	.00	.	.	.	2.87

Table A1-5-35: Joint probability of occurrence of offshore total significant wave height [m] and peak wave period [s] for directional sector 195°N -225°N

Hs meters Lower	Upper	< to 4.0	4.0 to 5.0	5.0 to 6.0	6.0 to 7.0	7.0 to 8.0	8.0 to 9.0	9.0 to 10.0	10.0 to 11.0	11.0 to 12.0	12.0 to 14.0	14.0 to >	Total
		spectral peak wave period seconds											
<	.50	.81	.23	.07	.01	.00	.00	.	.	.	.	.	1.11
.50	1.00	.28	.65	.69	.14	.03	.01	.	.	.	.	.	1.80
1.00	1.50	.01	.14	.56	.37	.06	.01	.00	.00	.	.	.	1.14
1.50	2.00	.00	.00	.13	.35	.17	.02	.	.	.	.	.	.67
2.00	2.50	.	.00	.00	.12	.16	.03	.00	.00	.	.	.	.32
2.50	3.00	.	.	.	.01	.09	.05	.00	.00	.	.	.	.17
3.00	3.50	.	.	.	.00	.02	.05	.01	.	.	.	.	.09
3.50	4.00	.	.	.	.	.00	.03	.01	.00	.	.	.	.04
4.00	4.50	.	.	.	.	.	.00	.01	.00	.	.	.	.01
4.50	5.00	.	.	.	.	.	.00	.01	.00	.	.	.	.01
5.00	5.50	.	.	.	.	.	.	.00	.00	.	.	.	.00
5.50	6.00	.	.	.	.	.	.	.	.00	.	.	.	.00
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		1.10	1.02	1.46	1.00	.54	.20	.04	.01	.	.	.	5.36

Table A1-5-36: Joint probability of occurrence of offshore total significant wave height [m] and peak wave period [s] for directional sector 225°N -255°N

Hs		spectral peak wave period seconds											
meters		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	1.74	.88	.51	.06	.01	.00	.00	.00	.00	.	.	3.21
.50	1.00	.75	.72	1.38	.85	.20	.06	.01	.00	.00	.	.	3.98
1.00	1.50	.00	.29	.67	.64	.41	.09	.02	.01	.00	.	.	2.14
1.50	2.00	.00	.01	.26	.52	.39	.14	.02	.01	.	.	.	1.34
2.00	2.50	.	.00	.01	.26	.31	.19	.03	.00	.	.	.	.82
2.50	3.00	.	.	.	.03	.24	.17	.04	.01	.	.	.	.48
3.00	3.50	.	.	.	.	.06	.21	.05	.01	.	.	.	.33
3.50	4.00	.	.	.	.	.00	.09	.07	.01	.00	.	.	.18
4.00	4.50	.	.	.	.	.	.02	.05	.01	.00	.	.	.08
4.50	5.00	.	.	.	.	.	.00	.02	.01	.00	.	.	.04
5.00	5.50	.	.	.	.	.	.	.01	.02	.00	.	.	.03
5.50	6.00	.	.	.	.	.	.	.00	.01	.00	.	.	.01
6.00	6.50	.	.	.	.	.	.	.	.00	.00	.00	.	.01
6.50	7.00	.	.	.	.	.	.	.	.00	.00	.00	.	.00
7.00	7.50	.	.	.	.	.	.	.	.00	.00	.	.	.00
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		2.49	1.90	2.83	2.35	1.63	.97	.33	.10	.01	.00	.	12.64

Table A1-5-37: Joint probability of occurrence of offshore total significant wave height [m] and peak wave period [s] for directional sector 255°N -285°N

Hs		spectral peak wave period seconds											
meters		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	1.40	.86	.86	.23	.05	.00	.	.	.	.	.	3.40
.50	1.00	1.03	1.66	2.47	1.76	.57	.13	.02	.00	.00	.	.	7.65
1.00	1.50	.02	.90	1.88	1.58	1.15	.25	.04	.01	.00	.	.	5.82
1.50	2.00	.00	.01	.73	1.17	1.09	.41	.06	.01	.00	.00	.	3.49
2.00	2.50	.	.00	.02	.47	.77	.38	.09	.01	.00	.00	.	1.75
2.50	3.00	.	.	.	.03	.39	.37	.10	.02	.00	.00	.	.91
3.00	3.50	.	.	.	.00	.04	.23	.14	.03	.00	.	.	.45
3.50	4.00	.	.	.	.	.00	.06	.13	.05	.00	.	.	.24
4.00	4.50	.	.	.	.	.	.01	.06	.06	.00	.	.	.13
4.50	5.00	.	.	.	.	.	.	.02	.04	.01	.00	.	.06
5.00	5.50	.	.	.	.	.	.	.00	.02	.01	.00	.	.02
5.50	6.00	.	.	.	.	.	.	.	.00	.01	.	.	.01
6.00	6.50	.	.	.	.	.	.	.	.00	.01	.00	.	.01
6.50	7.00	.	.	.	.	.	.	.	.	.	.00	.	.00
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		2.45	3.44	5.95	5.25	4.07	1.85	.66	.23	.05	.01	.	23.94

Table A1-5-38: Joint probability of occurrence of offshore total significant wave height [m] and peak wave period [s] for directional sector 285°N –315°N

Hs meters		spectral peak wave period seconds											
		<	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	
		to	to	to	to	to	to	to	to	to	to	to	Total
Lower	Upper	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	>	
<	.50	.53	.30	.07	.01	.00	.00	.	.	.	.	.	.92
.50	1.00	.16	.32	.39	.10	.01	.00	.00	.	.	.	.	.98
1.00	1.50	.01	.08	.16	.16	.03	.00	.00	.	.	.	.	.44
1.50	2.00	.	.01	.08	.06	.04	.01	.	.	.	.	.	.20
2.00	2.50	.	.00	.01	.06	.01	.01	.00	.00	.	.	.	.09
2.50	3.00	.	.	.	.02	.02	.00	.00	.	.	.	.	.05
3.00	3.50	.	.	.00	.	.02	.00	.00	.00	.	.	.	.02
3.50	4.00	.	.	.	.	.00	.01	.00	.00	.	.	.	.01
4.00	4.50	.	.	.	.	.	.00	.00	.00	.	.	.	.00
4.50	5.00	.	.	.	.	.	.	.	.00	.	.	.	.00
5.00	5.50	.	.	.	.	.	.00	.00	.	.	.	.	.00
5.50	6.00	.	.	.	.	.	.	.	.	.	.	.	.
6.00	6.50	.	.	.	.	.	.	.	.	.	.	.	.
6.50	7.00	.	.	.	.	.	.	.	.	.	.	.	.
7.00	7.50	.	.	.	.	.	.	.	.	.	.	.	.
7.50	8.00	.	.	.	.	.	.	.	.	.	.	.	.
8.00	>	.	.	.	.	.	.	.	.	.	.	.	.
Total		.70	.71	.70	.41	.14	.04	.01	.00	.	.	.	2.71

Table A1-5-39: Joint probability of occurrence of offshore total significant wave height [m] and peak wave period [s] for directional sector 315°N -345°N

Appendix 2 Offshore scatter plots of significant wave height and peak wave period

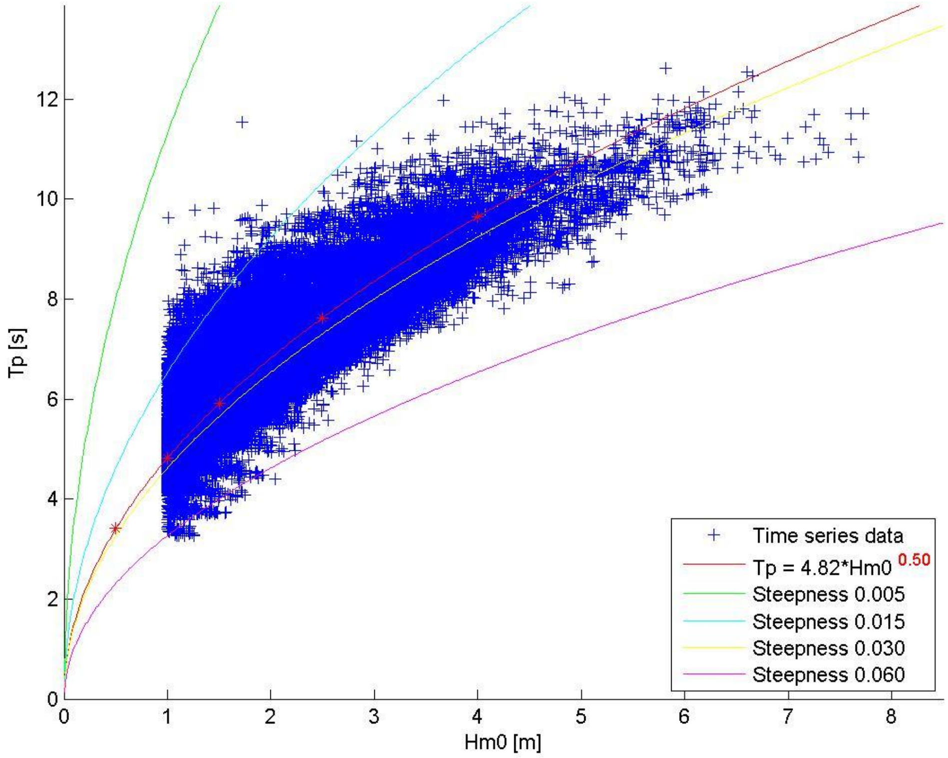


Figure A2-5-1: Square root relation fitted to the offshore wind sea significant wave height and peak wave period for all directions

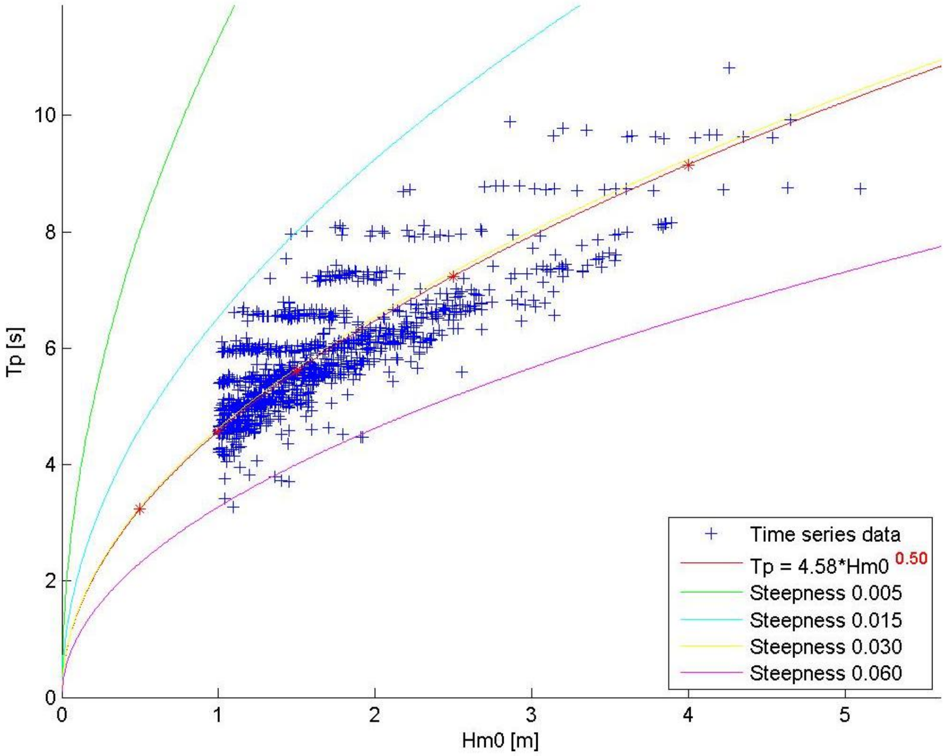


Figure A2-5-2: Square root relation fitted to the offshore wind sea significant wave height and peak wave period for directional sector 0°N

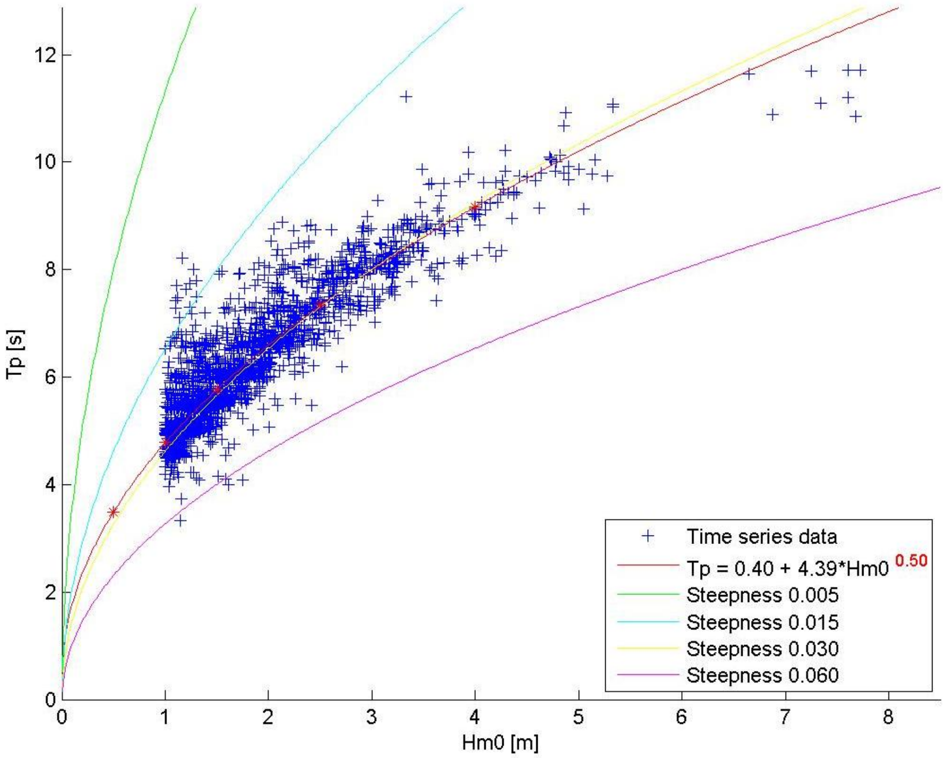


Figure A2-5-3: Square root relation fitted to the offshore wind sea significant wave height and peak wave period for directional sector 30°N

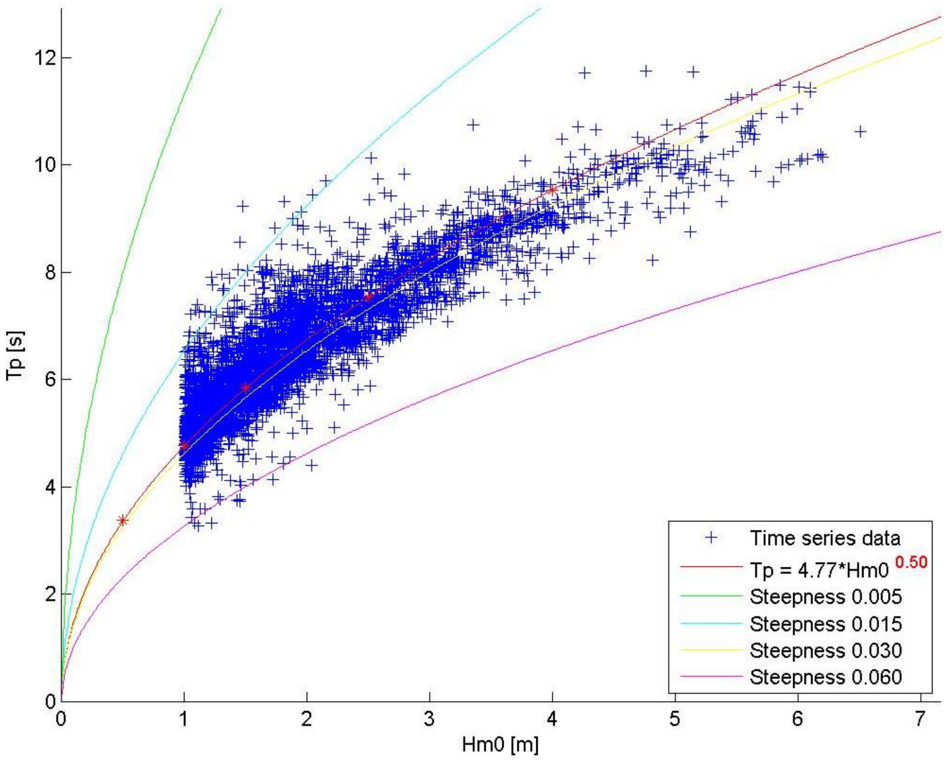


Figure A2-5-4: Square root relation fitted to the offshore wind sea significant wave height and peak wave period for directional sector 60°N

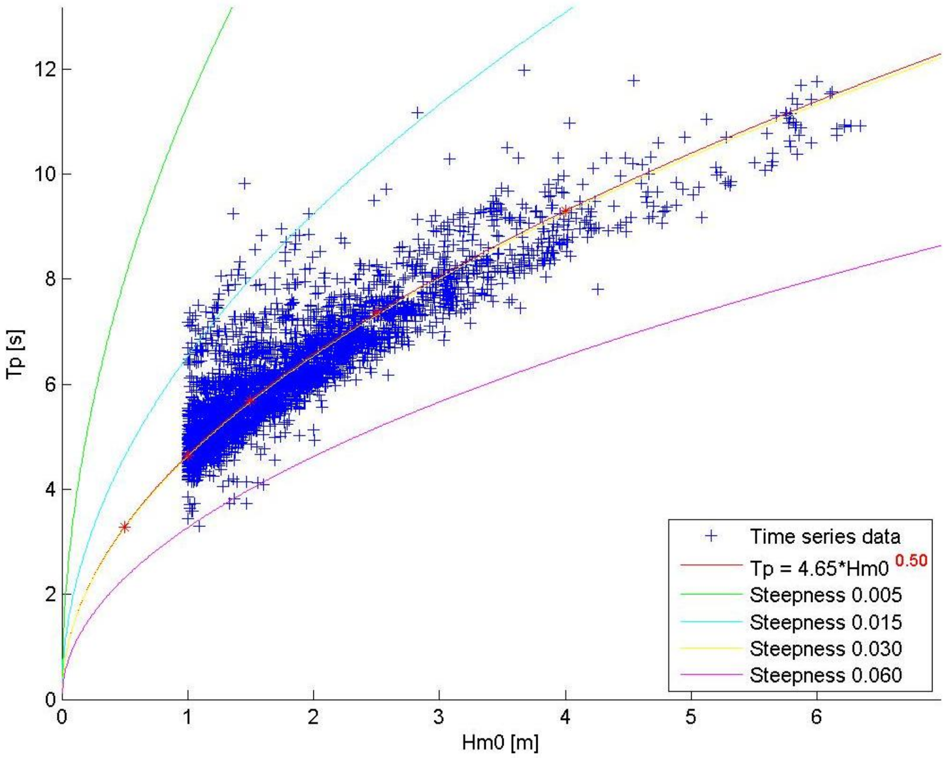


Figure A2-5-5: Square root relation fitted to the offshore wind sea significant wave height and peak wave period for directional sector 90°N

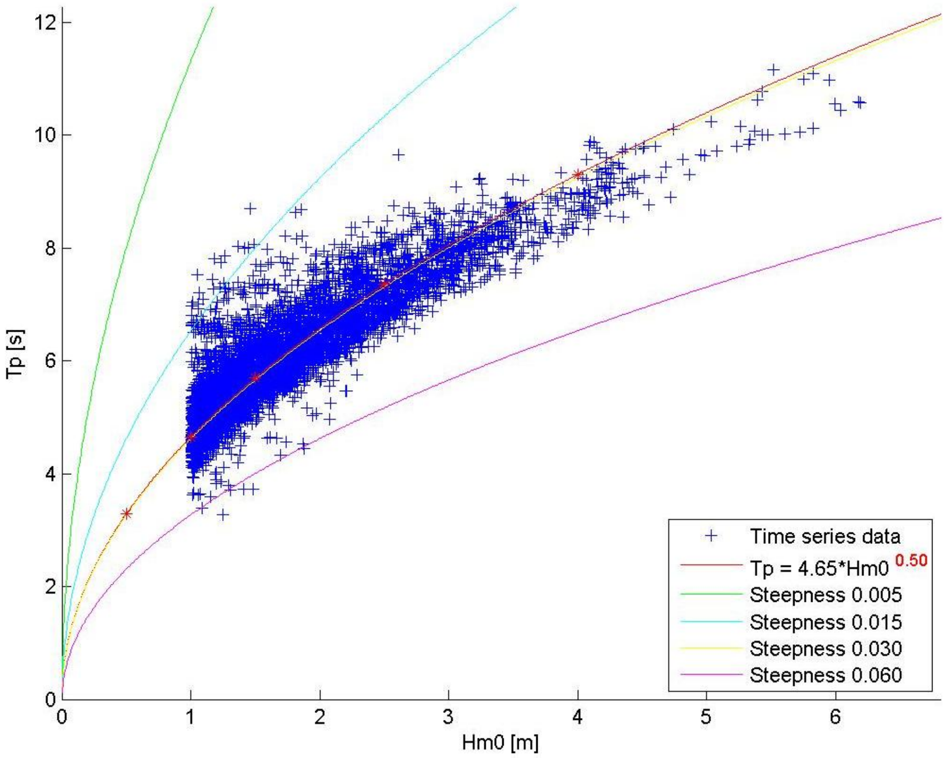


Figure A2-5-6: Square root relation fitted to the offshore wind sea significant wave height and peak wave period for directional sector 120°N

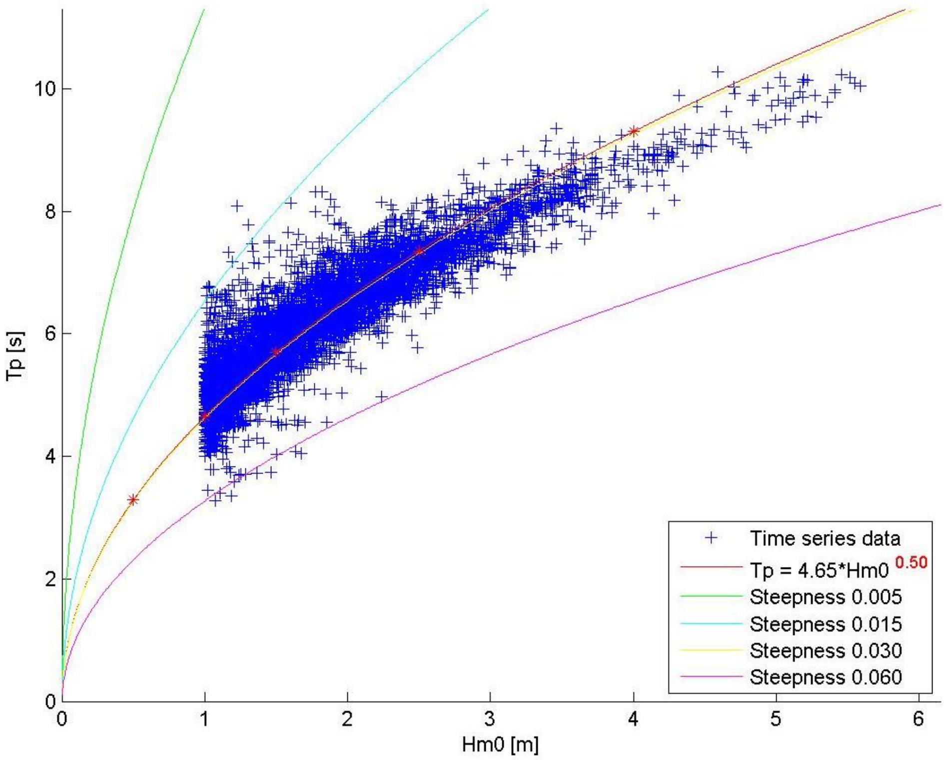


Figure A2-5-7: Square root relation fitted to the offshore wind sea significant wave height and peak wave period for directional sector 150°N

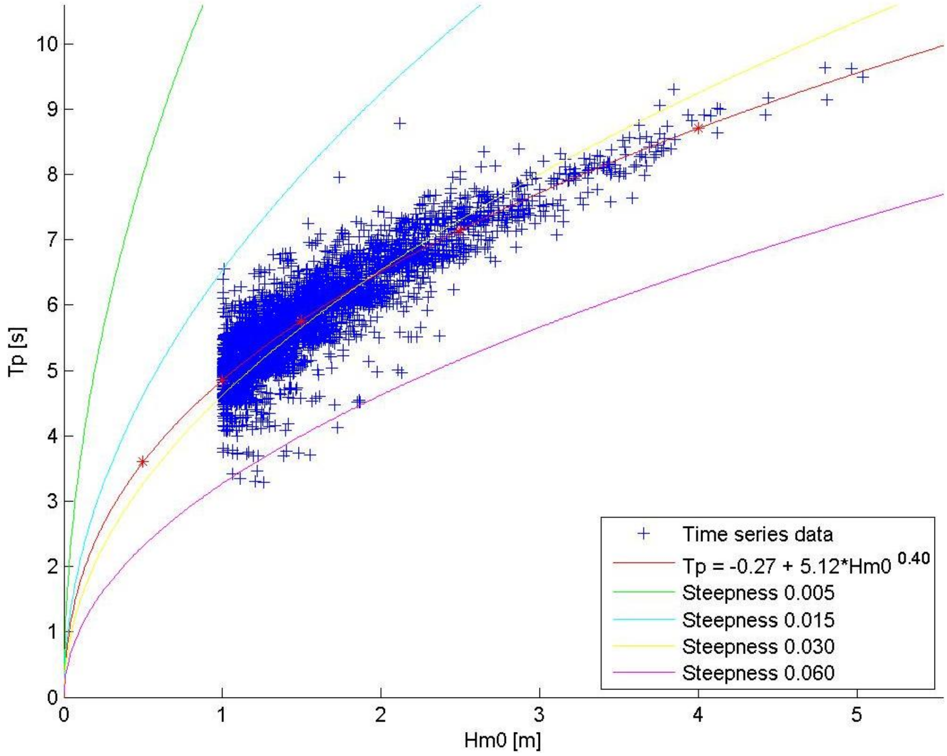


Figure A2-5-8: Square root relation fitted to the offshore wind sea significant wave height and peak wave period for directional sector 180°N

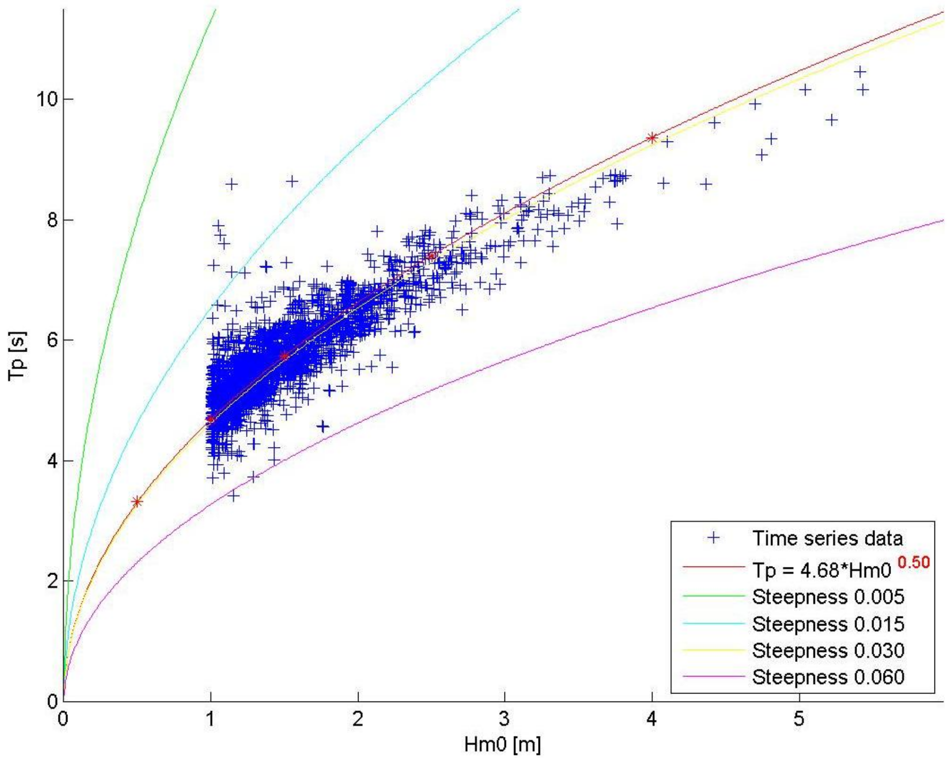


Figure A2-5-9: Square root relation fitted to the offshore wind sea significant wave height and peak wave period for directional sector 210°N

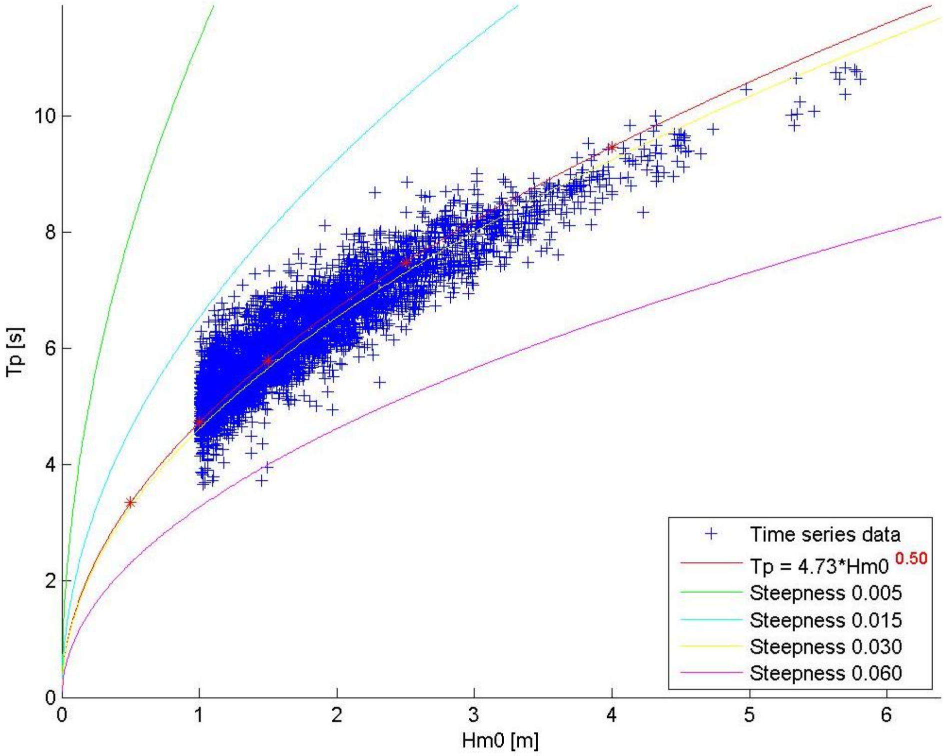


Figure A2-5-10: Square root relation fitted to the offshore wind sea significant wave height and peak wave period for directional sector 240°N

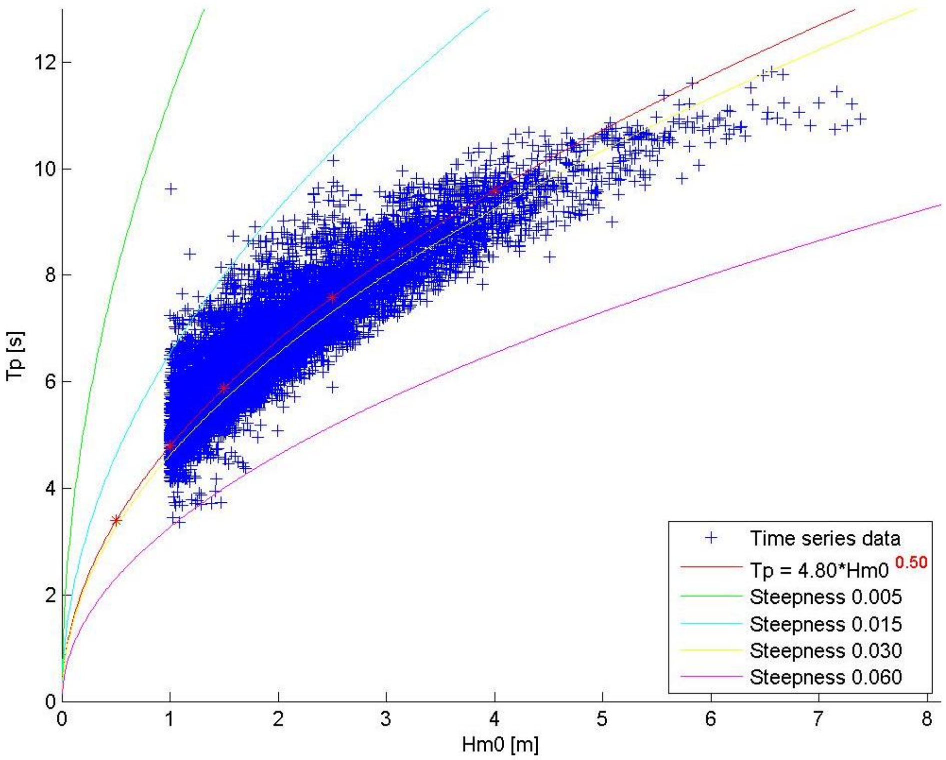


Figure A2-5-11: Square root relation fitted to the offshore wind sea significant wave height and peak wave period for directional sector 270°N

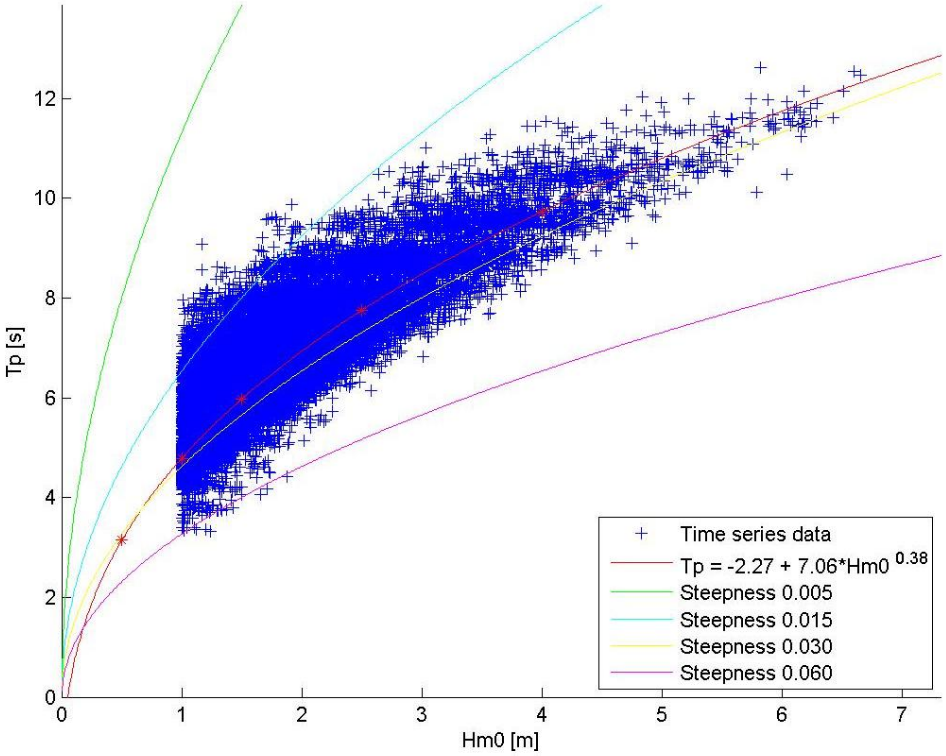


Figure A2-5-12: Square root relation fitted to the offshore wind sea significant wave height and peak wave period for directional sector 300°N

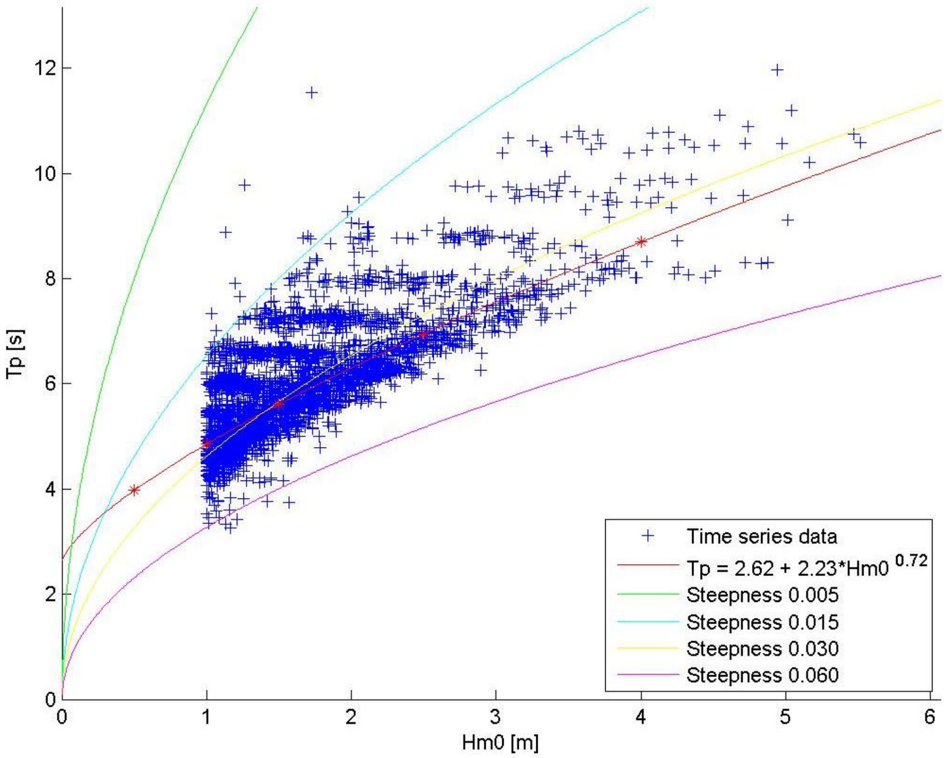


Figure A2-5-13: Square root relation fitted to the offshore wind sea significant wave height and peak wave period for directional sector 330°N

Appendix 3 HYDROBASE

ARCADIS
Infrastructure · Water · Environment · Buildings

Imagine the result

HYDROBASE — PRESENT

Analysis and presentation of hydraulic design conditions

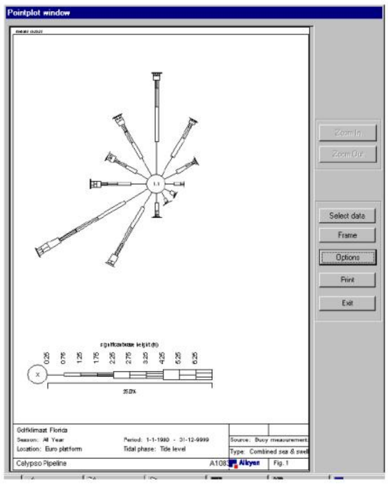
Background

The HYDROBASE program carries out the following activities:

- consistency checks on the data;
- classification of wave observations or measurements according to height, period and direction;
- classification of wind data according to wind speed and direction;
- classification of current data according to water level, current speeds and direction;
- analysis of combinations of up to three of the above variables;
- presentation of classified data in the form of joint occurrence tables, wind, current and wave roses and exceedance curves;
- transformation of series of data or classified data according to a user defined matrix;
- Selection of individual events from a series on the basis of date, record number or height, speed or direction criterion and a facility to code the reliability of an individual record.

HYDROBASE can read data in standard format from the following sources:

- wave hindcast results from the global hindcast model of the Met Office (UK);
- Series of individual ships observations of sea and swell wave height, period and direction and wind speed and direction stored in databases at The Met Office (UK) and at the KNMI (Royal Dutch Meteorological Institute);
- Classified ships observations from The Met Office and condensed format ship observations from the KNMI (this data is cheaper but more restricted);
- User input tables giving the joint probability of occurrence of various conditions;
- Series of values in a number of other standard formats;
- Data can be selected according to month or season, location, year and time of day. Further, classes are included for undetermined or variable values.



For the purposes of the presentation of the exceedance curves, a Weibull fit is made to the wave height or wind speeds data in each direction sector. This can be used to obtain the extreme wave conditions (e.g. those conditions occurring for 6 hours in 50 years) for design purposes (e.g. breakwater design).

ARCADIS
Infrastructure · Water · Environment · Buildings

Imagine the result

Applications

- wave, wind and water level conditions
- coastal evolution
- harbour design

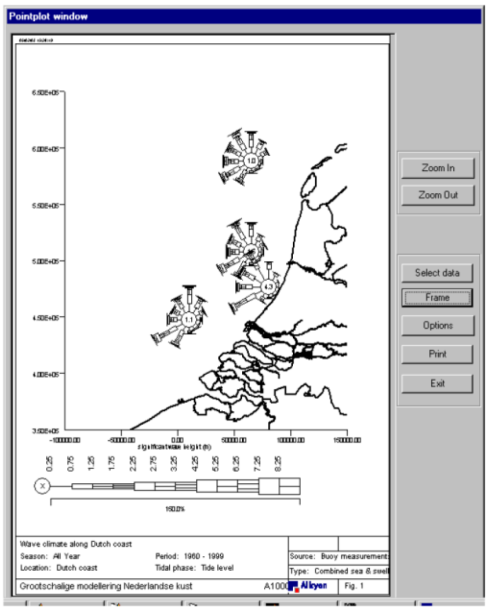
Processes

- classification of data
- transformation of statistics
- quality control

References

CERC, 1984. "Shore protection Manual". Dept. Of the Army, Waterways Experiment Station, Corps of Engineers, Coastal Engineering Research Station, USA

Hurdle, D.P. and Stive, R.J.H., 1989. "Revision of SPM 1984 wave hindcast model to avoid inconsistencies in engineering applications", Coastal Engineering, 12 (1989), pp 339-351.



More information

Please contact our office:

Zwolle
Hanzelaan 286
8017 JJ Zwolle, the Netherlands
P.O. Box 137, 8000 AC Zwolle
T 038 777 7701
E info@arcadis.nl
I www.arcadis.com

About ARCADIS

ARCADIS is an international company providing consultancy, design, engineering and management services in infrastructure, water, environment and buildings. We enhance mobility, sustainability and quality of life by creating balance in the built and natural environment. ARCADIS develops, designs, implements, maintains and operates projects for companies and governments. With 21,000 people and € 2.4 billion in revenues, the company has an extensive international network supported by strong local market positions. ARCADIS supports UNHABITAT with knowledge and expertise to improve the quality of life in rapidly growing cities around the world. Please visit: www.arcadis.com

Appendix 4 SWAN

ARCADIS
Infrastructure · Water · Environment · Buildings

Imagine the result

SWAN

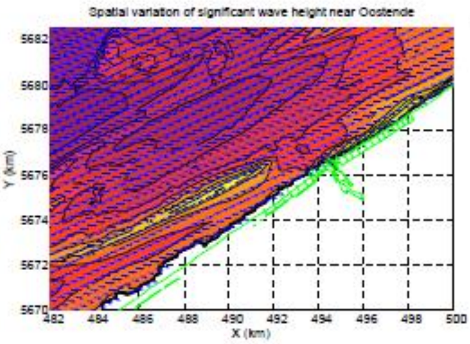
Simulation of wave generation, propagation and dissipation in coastal areas

General
Swan is a third-generation wave model for application in coastal regions. The SWAN model is being developed by Delft University of Technology and has been verified using laboratory and field data.

Applications
Knowledge of the wave conditions is required for the design of offshore installations, breakwaters or harbours and the study of morphological and coastal development.

In many seas, little information is available on the operational and extreme wave climate in shallow water or at locations where the fetch length is restricted. However, data on wind and wave conditions is often available offshore. In such situations, the swan model can be applied to transform the offshore wave climate to nearshore. swan is a wave generation and propagation model suitable for use in water of intermediate and shallow depth. Typical areas for the application of swan range between 10 X 5 km2 and 30 X 100 km2 (e.g. along a coastal strip).

The swan model can be run in stationary and non-stationary mode and can be nested in the wam and wavewatch model to enable an easy transition from ocean scale models to coastal scale applications.

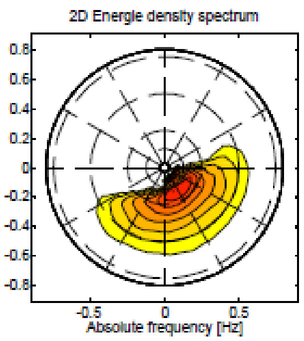


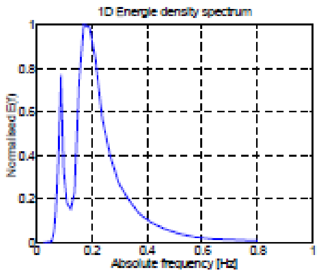
Typical applications:

- determination of wave boundary conditions for coastal protection measures
- transformation of wave climate from deep to shallow water
- wave penetration studies for harbour development
- coastal management
- wave forecasting and hindcasting
- design of offshore and nearshore structures

ARCADIS
Infrastructure · Water · Environment · Buildings

Imagine the result





Processes

The following processes are modelled by Swan:

- wave generation by the action of the wind
- refraction over a bottom of variable depth
- refraction over a spatially varying ambient current
- wave blocking by currents
- dissipation by whitecapping
- dissipation by wave breaking
- dissipation by bottom friction
- non-linear wave interactions
- partial wave transmission
- partial wave reflection
- diffraction behind breakwaters

Representation

Swan represents the wave field on a two-dimensional horizontal rectangular grid covering the computational area. At each grid point, the wave field is represented by a discrete two-dimensional energy density spectrum using a number of frequencies and directions. The evolution of the wave field in space and time is described by the wave action balance equation. The action balance equation is solved by means of an iterative procedure. This equation includes propagation of wave energy and source terms describing the growth, decay and redistribution of wave energy for all spectral components. The swan model has source terms for wave growth by wind action, dissipation by white-capping, bottom friction or wave breaking, and non-linear triad and quadruplet wave-wave interactions. A nested grid may be used as well as a curvi-linear grid to enable easy interactive coupling with other models, which use the same grid.

References

Booij, N., L.H. Holthuijsen and R.C. Ris and: 1999, A third-generation wave model for coastal regions. 1. Model description and validation. J. Geophys. Res., Vol 10, No. C, 7649-7666

More information

Please contact our office:

Zwolle
Hanzelaan 286
8017 JJ Zwolle, the Netherlands
P.O. Box 137, 8000 AC Zwolle
T 038 777 7701
E info@arcadis.nl
I www.arcadis.com

About ARCADIS

ARCADIS is an international company providing consultancy, design, engineering and management services in infrastructure, water, environment and buildings. We enhance mobility, sustainability and quality of life by creating balance in the built and natural environment. ARCADIS develops, designs, implements, maintains and operates projects for companies and governments. With 21,000 people and € 2.4 billion in revenues, the company has an extensive international network supported by strong local market positions. ARCADIS supports UNHABITAT with knowledge and expertise to improve the quality of life in rapidly growing cities around the world. Please visit: www.arcadis.com