



Reference site technical report A: Reference site 1 preliminary metocean site conditions assessment

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Final Report

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Executive Summary

This report presents a preliminary Front-End Engineering Design (FEED) Metocean Study for the Integrated Design of Floating Wind Arrays - Ireland's (IDEA-IRL) reference site 1. The results presented herein can only be considered as a pre-FEED study and are aimed to serve as input for preliminary design. This report will primarily serve as Work Package 1 (WP1) Deliverable 1A (D1A), a technical report designed to feed directly into WP1 of the IEA TCP Wind Task 49 of the same name.

Reference site 1 is aligned with Ireland's DRAFT Offshore Renewable Energy Development Plan II's broad area of interest 'Mid-West Broad Area Floating Wind' and utilises 'Moneypoint Offshore One' as a reference point for data collection. Moneypoint Offshore One, represents phase 1 of the proposed floating offshore wind farm development Moneypoint Offshore Wind Farm. It is located 16 km off the Clare/Kerry Coast in the Atlantic Ocean and is expected to reach a capacity of 400 MW. It will likely cover 70 km². The proposed development owned by ESB, Ireland's foremost energy company and the largest supplier of renewable energy in Ireland, with Ørsted a 50/50 partner in the project.

To conduct a preliminary site characterisation study in the proximity of this site, a 43-year timeseries was utilised from the ERA5 reanalysis dataset for both wind and wave conditions, whereas a 10-year modelled timeseries was extracted for water levels and currents from the three-dimensional North East Atlantic Model (NEATL), an implementation of the Regional Ocean Modelling System (ROMS) model.

Normal, extreme and severe metocean statistics and parameters were generated from these datasets. Operability statistics such as wind-wave persistence were also generated. A summary of parameters most relevant to design are presented in Table 1-1.

Table 1-1 Summary of metocean conditions at Moneypoint Offshore One

Variable	Value
High Still Water Level (50-year) (mMSL)	4.06
High Still Water Level (1-year) (mMSL)	2.76
Highest Astronomical Tide (HAT) (mMSL)	2.14
Lowest Astronomical Tide (LAT) (mMSL)	-2.25
Low Still Water Level (1-year) (mMSL)	-2.73
Low Still Water Level (50-year) (mMSL)	-2.94
Bottom current speed (m/s) (Normal Conditions)	Mean: 0.09 Max: 0.32 P25: 0.06 P50: 0.08 P75: 0.11
Bottom current speed (m/s) (1-year)	0.23

Bottom current speed (m/s) (50-year)	0.36
Mid current speed (m/s) (Normal Conditions)	Mean: 0.14 Max: 0.54 P25: 0.07 P50: 0.13 P75: 0.19
Mid current speed (m/s) (1-year)	0.44
Mid current speed (m/s) (50-year)	0.58
Surface current speed (m/s) (Normal Conditions)	Mean: 0.20 Max: 1.08 P25: 0.11 P50: 0.18 P75: 0.27
Surface current speed (m/s) (1-year)	0.67
Surface current speed (m/s) (50-year)	1.10
Wind speed (150 m above sea level) (m/s) mean	10.1
Wind speed (150 m above sea level) (m/s) max	41.3
Wind speed (150 m above sea level) (m/s) P95	18.9
Wind direction (150 m above sea level) (°) mean	245.4
Wind speed (10 m above sea level) – Weibull parameters	A = 8.7; k = 2.28
Wind speed (150 m above sea level) – Weibull parameters	A = 11.4; k = 2.19
Extreme 10-min wind speed (150 m above sea level) (m/s) (1-year)	27.4
Extreme 10-min wind speed (150 m above sea level) (m/s) (50-year)	44.2
Extreme 10-min wind speed (150 m above sea level) (m/s) (100-year)	46.7
Normal Sea State (NSS)	See relevant report section
Extreme Sea State (ESS) – Significant wave height (1-year) (m)	6.0

ESS – Peak wave period (1-year) (s)	$9.7 \leq 12.4$
ESS – Individual maximum wave height (1-year) (m)	11.2
ESS – Period of maximum wave height (1-year) (s)	$8.7 \leq 11.2$
ESS – Significant wave height (50-year) (m)	14.0
ESS – Peak wave period (50-year) (s)	$14.7 \leq 19.0$
ESS – Individual maximum wave height (50-year) (m)	26.0
ESS – Period of maximum wave height (50-year) (s)	$13.3 \leq 17.1$
Severe Sea State	See relevant report section

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1 Introduction

This report has been prepared by the IDEA-IRL project as the first of three deliverables for WP1 of the project. The IDEA-IRL project commenced in February 2023 and is being undertaken by the partnership of University College Cork (UCC), Wind Energy Ireland (WEI), and Gavin and Doherty Geosolutions (GDG). Its goal is to accelerate the sustainable development of Floating Offshore Wind Arrays (FOWA) both domestically and internationally. This will be achieved by building upon key background knowledge and by coordinating and leveraging the international FOWA research effort under the framework of the supported IEA TCP Wind Task 49. Specific objectives across all work packages include:

1. Deliver a set of fully defined reference sites characteristic of the international global floating wind deployment pipeline including all relevant technical, social, environmental and economic parameters.
2. Deliver a set of fully open source and customisable floating wind array reference designs including key engineering tool input files, cost and environmental impact models.
3. Deliver a Failure Mode, Effects & Criticality Analysis framework for floating wind arrays including for coupled / cascading failures.
4. Engage with the international groups developing innovations for the floating wind energy industry, categorise in terms of multidisciplinary impact and ensure that functionality for their development is included in the reference sites and/or reference farm definitions.
5. Engage with the international agencies responsible for Marine Spatial Planning (MSP) to collect open research questions and concerns. Provide responses directly where possible and otherwise ensure that the reference sites and reference farms are defined in such a manner that they enable the required research.
6. Apply the work of Task 49 in an Irish context and engage with the local supply chain to provide specific policy recommendations and development pathways.
7. Raise the profile of floating wind energy technology, related research and expertise in Ireland through the delivery of a multifaceted communications strategy.

This WP1 focusses on defining the metocean, geotechnical, socio-ecological factors and other site-specific conditions for a range of hypothetical reference sites that are representative of the types of conditions in which the initial phase of commercial scale floating wind may be deployed. In essence, these are the type of site parameters that a developer would collect and use to inform the project design phase. Sites will be used to inform the design of the reference floating wind arrays in WP 2 and will be made open-source and available to the wider research community to facilitate future multidisciplinary FOWA research. WP1 deliverables are broken down into the following:

- WP1 D1A: Reference site technical report A. Technical report containing preliminary metocean site condition assessment for reference site 1 only. This technical report is designed to feed directly into WP1 of the IEA TCP Wind Task 49 of the same name.
- WP1 D1B: Reference site technical report B. All defined reference sites, along with all relevant data, will be published as a technical report.
- WP1 D2: Reference site dataset. Available data and descriptions of the reference sites will be made publicly available in an online repository.

This report will primarily serve as WP1 D1A. Specifically, this technical report delivers a preliminary metocean site characterisation study of reference site 1, selected based on a review of Ireland's Offshore Wind Policy and Marine Spatial Planning documents provided by WP4 [1].

As outlined in [1], the Irish Government has created a distinct programme of work to provide systems to enable 2 GW of offshore wind for additional non-grid use to be in development by 2030. It was initially stated by Government in the Phase 2 Policy Statement that this 2 GW would be exclusively floating wind, but it is currently uncertain if this is still the case, and some fixed-bottom projects may be included. Regardless, the 2 GW is expected to include floating wind projects.

These floating offshore windfarm (FLOW) developments are referred to as Phase 3 developments. Phase 3 will be informed by the in-development Offshore Renewable Energy Development Plan II (OREDPPII). This was consulted on from February to April 2023. OREDPPII will be Ireland's new national spatial strategy for our offshore renewable energy future. The OREDPPII draft report focusses on the spatial strategy, proposing how the State will identify the area's best suited for ORE, in line with the principles of good Marine Spatial Planning. The draft OREDPPII document presents three potential broad areas of interest based on the proposed criteria (Figure 1-1):

1. Celtic Sea East Broad Area Floating Wind
2. Mid-West Broad Area Floating Wind
3. North-West Broad Area Floating Wind.

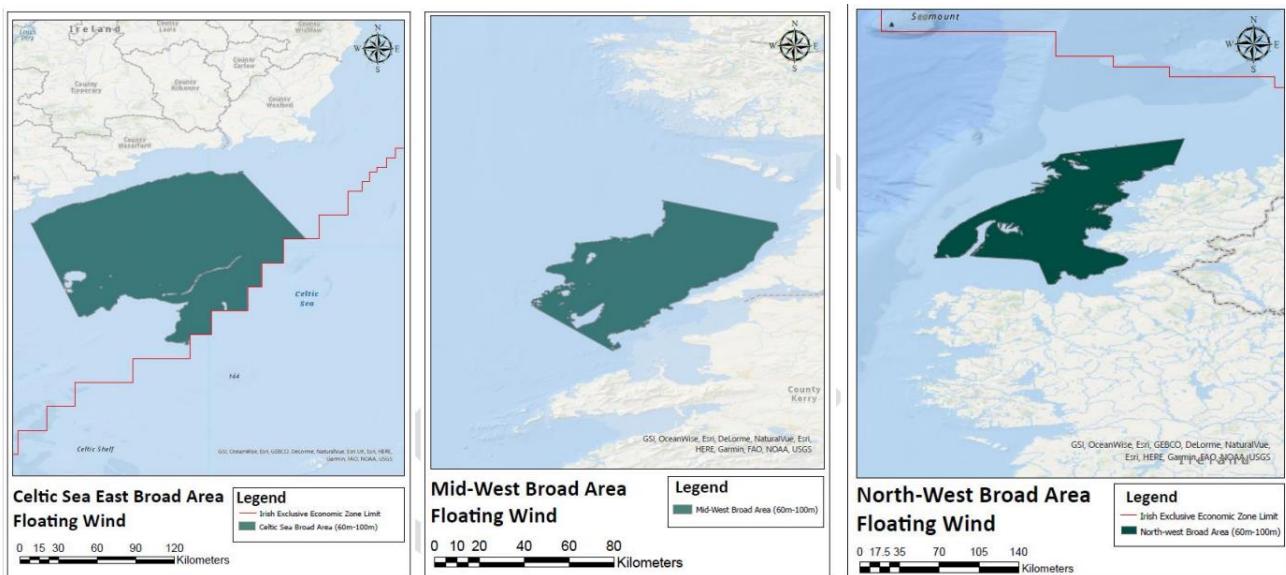


Figure 1-1 Example Broad Areas of Interest as shown in the Draft OREDPPII [2]

IDEA-IRL's defined reference site 1 is designed to align with the approximate location of the 'Mid-West Broad Area Floating Wind'. Many proposed Floating Offshore Windfarm developments overlap with this proposed development zone (Figure 1-2) therefore IDEA-IRL utilises the coordinates of the proposed floating offshore wind farm development, Moneypoint Offshore One, provided by 4C Offshore Wind database (52.519° , -10.276°), as a reference point for data collation for reference site 1.

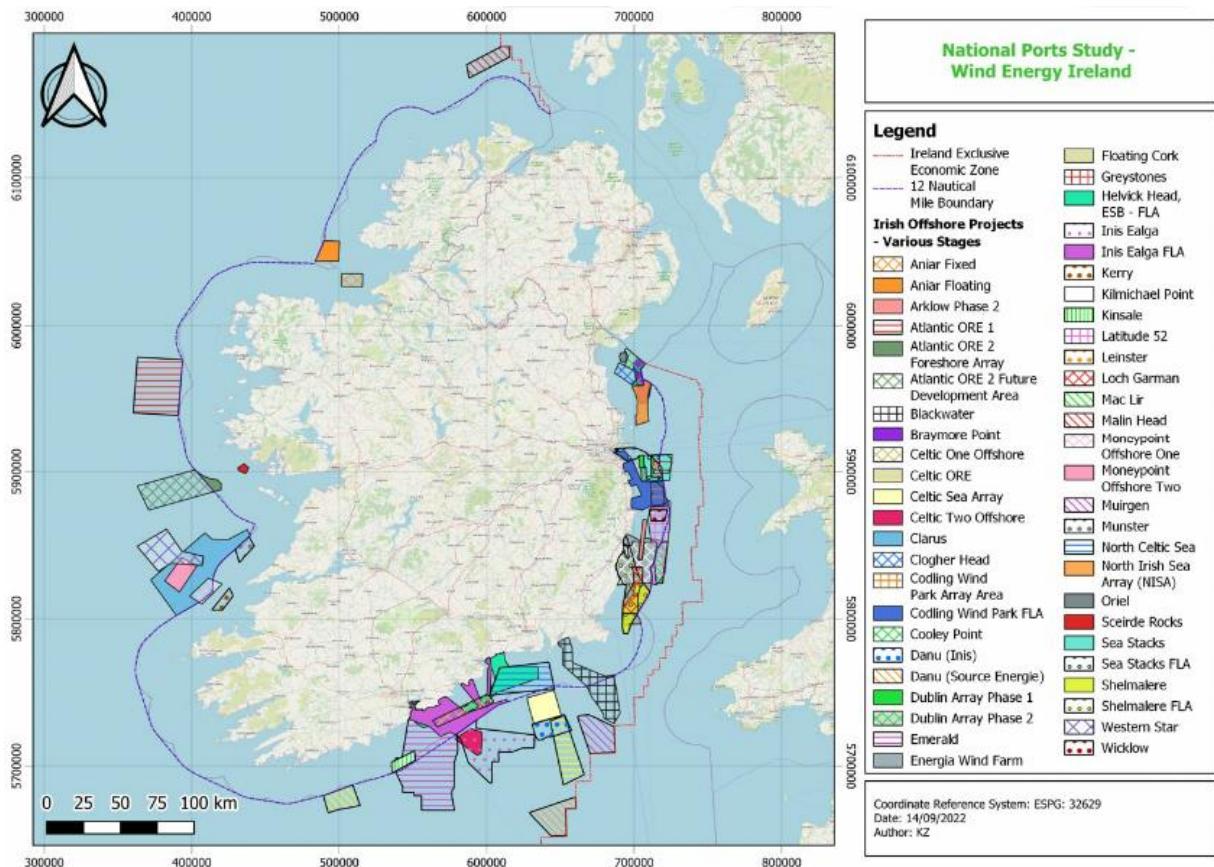


Figure 1-2 Proposed projects in Irish Waters [3]

Moneypoint Offshore Wind Farm is a proposed floating offshore wind farm development located in Ireland, owned by the ESB (with Danish offshore wind developer Ørsted as a 50/50 partner). The ESB is Ireland's foremost energy company and the largest supplier of renewable energy in Ireland. If this project is developed, it will be delivered in two phases. The first phase, Moneypoint Offshore One, is located 16 km off the Clare/Kerry Coast. The expected capacity from the first phase is estimated to be 400 MW and will likely cover 70 km². The second phase is proposed to be located a further 20 km west of the first phase, taking the total project capacity to between 1 GW – 1.5 GW. The second phase will likely cover 180 km².

1.1 Scope of the report

The scope of this report is to conduct a preliminary FEED Metocean Study for IDEA-IRL reference site 1. The results presented herein can only be considered as a pre-FEED study and are aimed to serve as input for preliminary design. Section 2 gives an overview of the data sources utilised; Section 3 provides the results of a preliminary metocean site characterisation. This includes the production of normal and extreme conditions of water levels, currents, wind and wave conditions, alongside operability statistics. Section 4 provides conclusions and recommendations.

2 Data Sources

The coordinates of the Moneypoint Offshore One wind farm available on the 4C Offshore Database is used as a reference point for metocean data compilation. The European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 climate reanalysis model was identified as the best model to provide numerical datasets for wind and wave variables for this study. ERA5 is the fifth-generation atmospheric reanalysis model produced by Copernicus Climate Change Service (C3S) at the ECMWF and is based on the 2016 version of the integrated forecasting system (C3S, 2017). It produces data from 1950 to present. Its outputs include atmospheric, ocean wave and land surface data. The reanalysis combines model data with observations from across the world into a globally complete and consistent dataset. The horizontal resolution of the model is $0.25^\circ \times 0.25^\circ$ (atmosphere variables) and $0.5^\circ \times 0.5^\circ$ (ocean waves variables). Parameters of interest for this study are displayed in Table 2-1. Data from the closest grid point to the site were downloaded and analysed. A detailed description of the model and each parameter can be found on the ECMWF website [4].

Table 2-1 Wind and wave variables obtained from the ERA5 model

ERA5 code	Parameter	Metocean discipline	Units	Time frame	Temporal resolution (hours)	Data point
hmax	Maximum individual wave height	Wave	m	1979 – 2022	1	-10.5°, 52.5°
pp1d	Peak wave period	Wave	s	1979 – 2022	1	-10.5°, 52.5°
swh	Significant wave height of combined wind waves and swell	Wave	m	1979 – 2022	1	-10.5°, 52.5°
mwd	Mean wave direction	Wave	degrees	1979 – 2022	1	-10.5°, 52.5°
u10	10 m u-component of wind	Wind	m/s	1979 – 2022	1	-10.25°, 52.5°
v10	10 m v-component of wind	Wind	m/s	1979 – 2022	1	-10.25°, 52.5°
u100	10 m u-component of wind	Wind	m/s	1979 – 2022	1	-10.25°, 52.5°
v100	10 m v-component of wind	Wind	m/s	1979 – 2022	1	-10.25°, 52.5°

Due to the lack of availability of measured water level and tidal current data for the site of interest, modelled data from the Marine Institute's North East Atlantic (NEATL) model was acquired and analysed. This model is an implementation of ROMS for a domain covering the Irish coastal and oceanic waters held by the Marine Institute [5]. It is a hindcast and forecast 3D physics model with a curvilinear grid. Grid size is $1200 \times 750 \times 40$ km with a variable data resolution from 1.2 to 2km. It should be noted that the NEATL model is not specifically validated using in situ datasets for this site therefore currents should be interpreted with caution until in situ measured data is collected. Data

from the model grid point closest to the centre of the site was downloaded and utilised (-10.2625°, 52.5125°).

Table 2-2 Parameters utilised from the NEATL model

Parameter	Units	Time frame	Temporal resolution (hours)
Surface elevation	m	2012 – 2017	3
		2017 – 2022	1
Bottom-water u component	m/s	2012 – 2017	3
		2017 – 2022	1
Bottom-water v component	m/s	2012 – 2017	3
		2017 – 2022	1
Mid-water u component	m/s	2012 – 2017	3
		2017 – 2022	1
Mid-water v component	m/s	2012 – 2017	3
		2017 – 2022	1
Surface-water u component	m/s	2012 – 2017	3
		2017 – 2022	1
Surface-water v component	m/s	2012 – 2017	3
		2017 – 2022	1

3 Preliminary Metocean Site Conditions Assessment

3.1 Water Levels

A 10-year timeseries of water levels was extracted from the three-dimensional North East Atlantic Model, an implementation of the ROMS model for Irish Waters [5]. The full dataset was interpolated to a 1-hour timeseries. This timeseries underwent tidal harmonic analysis to separate the tidal and non-tidal (residual) components. A representative spring-neap cycle of this water level timeseries is presented in Figure 3-1, while the statistics of the full dataset are presented in Table 3-1.

Extreme positive and negative surge values were calculated from this 10-year modelled dataset. A generalised extreme value (GEV) methodology was chosen as the best-fitting analysis to calculate the extreme surge values for this location. A peaks-over-threshold approach was chosen to extract discrete extreme events over the 10-year time period as input into the general extreme value analysis. Long-term global sea level rise is given by the Intergovernmental Panel on Climate Change (IPCC) Synthesis Report 2014 [6]. A 20-year dataset was predicted using the tidal harmonic results, from which long-term water level parameters ranging from Highest Astronomical Tide (HAT) to Lowest Astronomical Tide (LAT) were produced. Design water level parameters, ranging from High Still Water Level (HSWL) to Low Still Water Level (LSWL) are presented in Table 3-1.

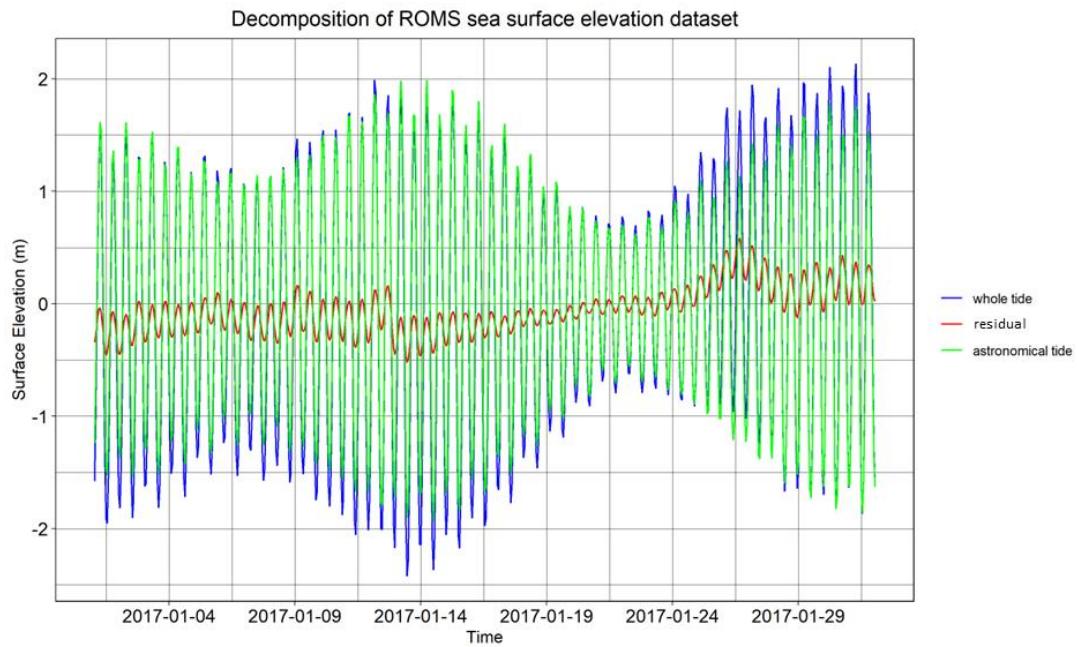


Figure 3-1 Separation of astronomical and residual components of the tide from NEATL modelled sea surface elevation from 2012 to 2021. Figure displays 2017 snapshot.

Table 3-1 Statistics of water levels

Component	Statistic	Water Level (mMSL)
Total	max	2.58
	min	-2.60
	mean	0.00
	standard deviation	1.00
Tide	max	2.16
	min	-2.24
	mean	0.00
	standard deviation	0.98
Residual	max	1.03
	min	-0.67
	mean	0.00
	standard deviation	0.19

Table 3-2 Design Water Level

Parameter	Water Levels (mMSL)
High Still Water Level (50-year)	4.06
High Still Water Level (1-year)	2.76
Long term Sea Level Rise	0.63
Positive storm surge (50-year)	1.29
Positive storm surge (1-year)	0.62
Highest Astronomical Tide (HAT)	2.14
Mean High Water Spring (MHWS)	1.69
Mean High Water Neap (MHWN)	0.78
Mean Sea Level (MSL)	0
Mean Low Water Neap (MLWN)	-0.78

Mean Low Water Spring (MLWS)	-1.69
Lowest Astronomical Tide (LAT)	-2.25
Negative storm surge (1-year)	-0.48
Negative storm surge (50-year)	-0.69
Low Still Water Level (1-year)	-2.73
Low Still Water Level (50-year)	-2.94

3.2 Normal Wind Conditions

The ERA5 provides wind speed and direction values at heights of 10 m and 100 m above sea level. The spatial resolution is $0.25^\circ \times 0.25^\circ$ and temporal resolution is 1 hour. 10 m and 100 m timeseries was downloaded at -10.25° , 52.5° for a 43-year period (1979 to 2022).

A 15 MW reference turbine is assumed. Based on the technical report produced by IEA Wind TCP Task 39 [7], hub height is therefore assumed to be 150 m. The ERA5 1-hour wind speeds at 100 m above sea level were extrapolated to hub height (150 m) using the power law with the shear exponent value 0.14 as recommended by IEC 61400-3-1: 2019 [8] for normal wind conditions:

$$V_{\text{power law}} = V_{\text{ref}} * \left(\frac{z}{z_{\text{ref}}} \right)^\alpha$$

Where $V_{\text{power law}}$ and V_{ref} are the wind speeds at z and z_{ref} respectively, and α is the shear exponent.

A 10 m and 150 m wind rose are displayed in Figure 3-2 and Figure 3-3 respectively. Monthly, annual and overall statistics of 10 m and 150 m wind speeds are presented in Table 3-3 to Table 3-6.

Wind rose based on 1979 to 2022 dataset

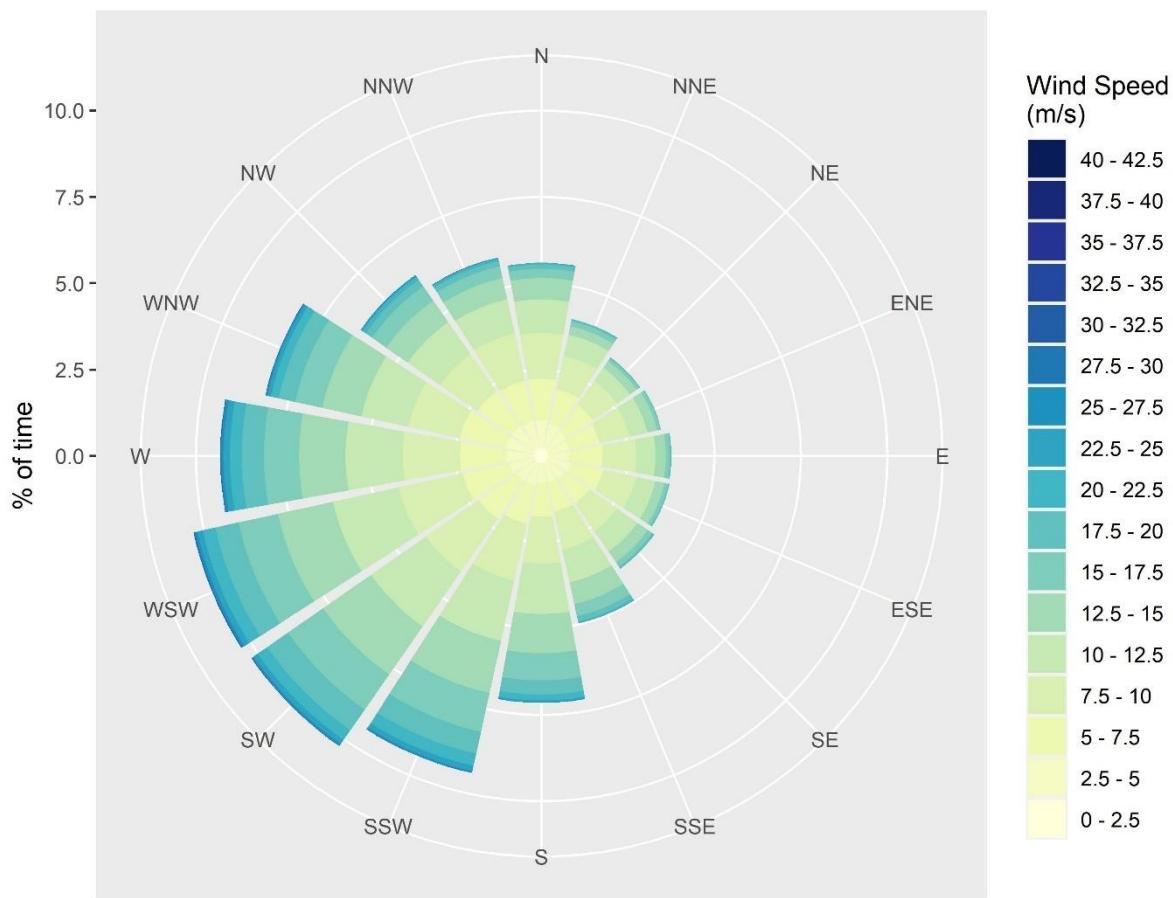


Figure 3-2 Rose plot of 1-hour averaged wind speed and direction at hub height (150 m) from 1979 to 2022 dataset

Table 3-3 Monthly wind statistics from ERA5 at 150 m hub height (1979 – 2022)

Data type	Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
wind speed at hub height (m/s)	mean	12.2	11.8	10.8	9.1	8.9	8.4	8.3	8.6	9.4	10.6	11.2	12.2
	median	12.0	11.4	10.4	8.7	8.6	8.2	8.1	8.5	9.0	10.2	10.9	11.7
	standard deviation	5.5	5.4	5.2	4.4	4.2	3.9	3.7	4.0	4.3	4.8	5.0	5.3
	max	35.0	37.0	30.7	32.4	29.6	26.0	25.9	27.8	30.0	36.1	31.7	41.3
	min	0.2	0.2	0.1	0.0	0.1	0.1	0.0	0.0	0.1	0.1	0.0	0.1
	P25	8.0	7.9	6.8	6.0	5.8	5.5	5.6	5.7	6.2	7.0	7.6	8.2
	P50	12.0	11.4	10.4	8.7	8.6	8.2	8.1	8.5	9.0	10.2	10.9	11.7
	P75	16.0	15.4	14.4	11.8	11.5	11.0	10.7	11.2	12.3	13.9	14.6	15.7
	P90	19.6	19.1	17.8	15.1	14.4	13.6	13.3	13.9	15.4	17.0	18.0	19.3
	P95	21.8	21.5	19.7	17.1	16.2	15.2	14.9	15.5	17.0	18.8	19.8	21.6
wind direction (°)	mean	234.9	230.1	247.1	278.9	264.2	270.1	263.1	254.5	241.9	232.7	244.4	233.3

Table 3-4 Annual and overall wind statistics from ERA5 at 150 m hub height (1979 – 2022)

Year	wind speed at hub height (m/s)										wind direction (°)
	mean	median	standard deviation	max	min	P25	P50	P75	P90	P95	
1979	10.3	10.1	4.6	26.7	0.1	7.1	10.1	13.2	16.6	18.5	255.6
1980	10.1	9.8	4.6	29.6	0.1	6.7	9.8	13.6	16.2	17.9	252.3
1981	10.0	9.3	4.6	31.6	0.2	6.6	9.3	13.1	16.2	18.1	253.2
1982	10.4	10.0	5.0	29.6	0.1	6.7	10.0	13.6	17.1	19.1	239.5
1983	10.3	9.6	5.1	30.7	0.2	6.6	9.6	13.6	17.2	19.6	254.5
1984	9.5	8.6	5.2	36.1	0.1	5.8	8.6	12.6	16.9	19.3	261.1
1985	10.0	9.6	4.4	28.3	0.1	6.7	9.6	12.9	15.9	17.7	229.8
1986	11.0	10.3	5.2	29.6	0.1	7.0	10.3	14.6	18.2	20.2	244.6
1987	9.7	9.3	4.3	26.6	0.2	6.5	9.3	12.5	15.5	17.5	243.0
1988	10.2	9.9	4.9	33.6	0.1	6.7	9.9	13.2	16.4	19.0	249.1
1989	10.3	9.6	4.9	33.8	0.1	6.7	9.6	13.5	17.1	19.4	242.5
1990	11.0	10.3	5.5	33.1	0.2	6.9	10.3	14.9	18.5	20.6	249.4
1991	10.2	9.4	5.2	34.0	0.2	6.4	9.4	13.4	17.4	19.9	246.0
1992	10.6	10.3	4.8	31.4	0.3	7.0	10.3	14.0	17.0	18.9	247.1
1993	10.3	9.9	5.0	36.0	0.3	6.7	9.9	13.1	17.0	19.7	252.0
1994	10.7	10.2	5.1	28.1	0.2	6.9	10.2	13.9	17.6	20.1	238.1
1995	10.1	9.7	4.7	32.7	0.1	6.7	9.7	13.1	16.4	18.6	246.6
1996	9.9	9.3	4.5	30.0	0.1	6.8	9.3	12.5	15.6	18.1	231.4
1997	9.8	9.3	5.0	41.3	0.1	6.2	9.3	12.7	16.6	18.8	226.5
1998	10.7	10.3	4.9	34.6	0.1	7.2	10.3	13.8	17.3	19.2	249.7
1999	10.6	10.1	4.9	28.6	0.1	7.2	10.1	13.8	17.1	19.4	252.4
2000	10.3	9.9	5.2	28.6	0.1	6.1	9.9	13.8	17.4	19.3	257.7
2001	9.1	8.7	4.5	32.4	0.0	5.7	8.7	12.1	15.3	17.1	247.2
2002	10.3	9.7	4.9	31.5	0.3	6.6	9.7	13.2	16.9	19.5	231.1
2003	9.7	9.3	4.3	28.2	0.2	6.7	9.3	12.4	15.6	17.5	222.3
2004	10.1	9.5	4.8	29.1	0.2	6.5	9.5	13.3	16.7	18.7	257.0
2005	9.9	9.6	4.9	29.8	0.1	6.3	9.6	12.9	16.6	18.9	252.5
2006	9.8	9.4	4.8	34.1	0.2	6.4	9.4	12.5	16.3	18.4	230.0
2007	9.7	8.8	5.2	31.0	0.2	5.8	8.8	12.8	17.0	19.6	252.6
2008	10.5	10.1	4.9	30.7	0.1	6.8	10.1	13.6	17.2	19.0	255.4
2009	10.0	9.5	4.6	35.0	0.2	6.6	9.5	12.8	16.4	18.5	233.3
2010	8.9	8.4	4.1	29.5	0.2	6.0	8.4	11.2	14.3	16.4	252.9
2011	10.4	10.0	5.1	26.6	0.1	6.3	10.0	13.9	17.3	19.3	237.2
2012	9.9	9.8	4.4	29.7	0.1	6.8	9.8	12.8	15.7	17.4	256.9
2013	10.2	9.7	4.9	35.6	0.1	6.6	9.7	13.1	16.5	18.8	241.2
2014	9.9	9.1	5.1	37.0	0.0	6.3	9.1	13.0	17.1	19.6	246.3
2015	10.7	10.0	5.5	31.6	0.2	6.6	10.0	14.2	18.3	20.9	241.2
2016	9.9	9.3	4.7	31.2	0.2	6.5	9.3	12.8	16.3	18.5	245.9
2017	10.0	9.8	4.7	28.6	0.2	6.6	9.8	13.1	16.4	18.3	248.0
2018	10.0	9.5	4.9	30.9	0.1	6.4	9.5	13.0	16.6	18.7	234.9
2019	10.3	9.9	4.9	32.4	0.2	6.5	9.9	13.6	16.7	18.8	245.1
2020	10.8	10.2	5.4	31.0	0.0	6.6	10.2	14.4	18.2	20.6	250.4
2021	9.4	8.8	4.7	32.9	0.1	5.9	8.8	12.2	15.9	18.3	245.4
Overall	10.1	9.6	4.9	41.3	0.0	6.5	9.6	13.2	16.8	18.9	245.4

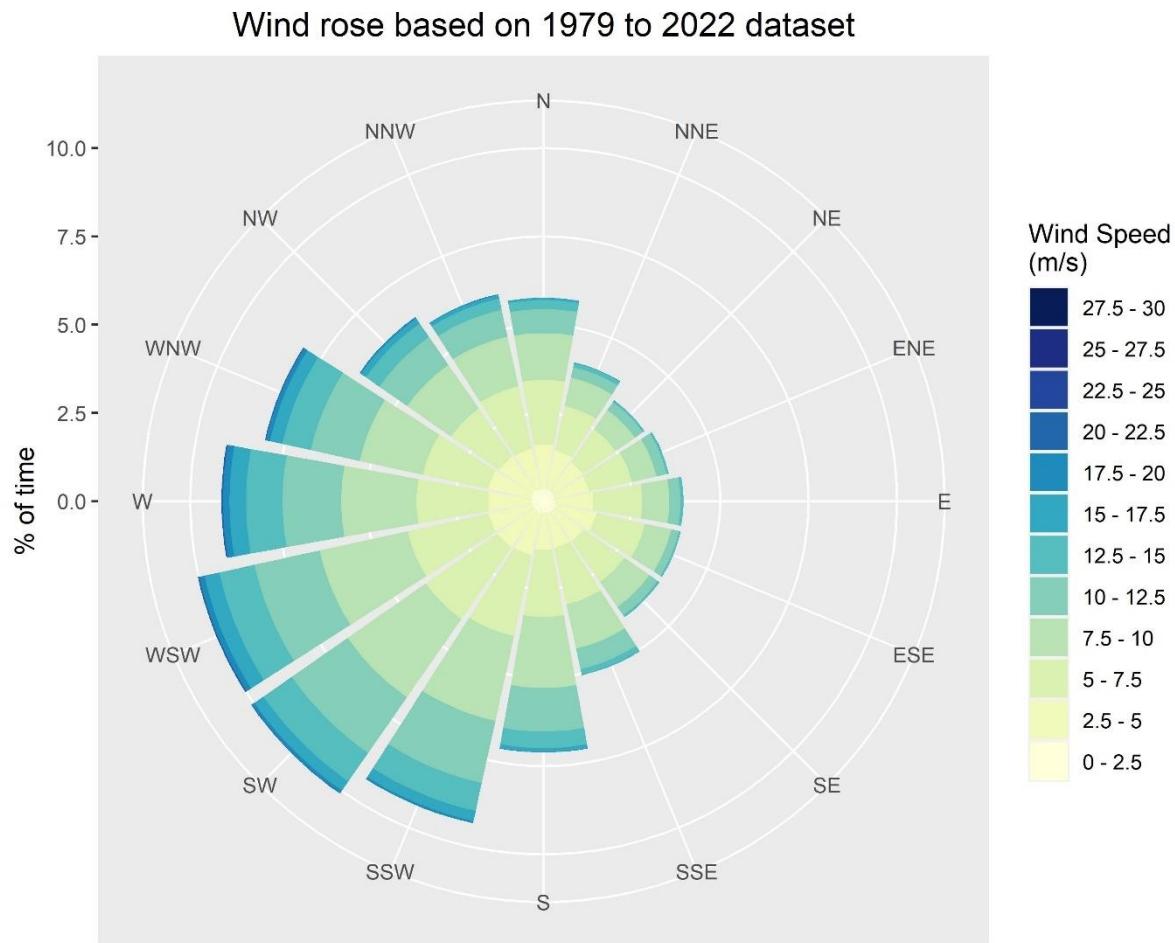


Figure 3-3 Rose plot of 1-hour averaged wind speed and direction at hub height (10 m) from 1979 to 2022 dataset

Table 3-5 Monthly wind statistics from ERA5 at 10 m above sea level (1979 – 2022)

Data type	Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
wind speed at 10 m above sea level (m/s)	mean	9.2	8.9	8.1	6.9	6.7	6.5	6.4	6.6	7.1	8.1	8.6	9.2
	median	9.0	8.6	7.8	6.6	6.5	6.3	6.3	6.6	6.9	7.8	8.3	8.8
	standard deviation	4.0	3.9	3.8	3.2	3.1	2.9	2.7	2.9	3.2	3.5	3.6	3.8
	max	25.2	26.4	22.8	23.6	21.0	18.1	17.9	20.2	21.2	25.9	22.2	29.2
	min	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.0	0.1
	P25	6.2	6.0	5.2	4.6	4.5	4.3	4.5	4.6	4.8	5.5	6.0	6.4
	P50	9.0	8.6	7.8	6.6	6.5	6.3	6.3	6.6	6.9	7.8	8.3	8.8
	P75	11.9	11.4	10.8	8.9	8.7	8.4	8.2	8.6	9.3	10.4	11.1	11.8
	P90	14.6	14.2	13.2	11.3	10.8	10.3	10.0	10.4	11.4	12.7	13.4	14.3
	P95	16.1	15.9	14.6	12.7	12.1	11.4	11.1	11.6	12.7	14.0	14.8	16.0
wind direction (°)	mean	235.4	230.7	250.0	292.3	275.6	276.1	266.6	258.0	246.1	236.1	247.5	234.3

Table 3-6 Annual and overall wind statistics from ERA5 at 10 m above sea level (1979 – 2022)

Year	wind speed at 10 m above sea level (m/s)										wind direction (°) mean
	mean	median	standard deviation	max	min	P25	P50	P75	P90	P95	
1979	7.9	7.8	3.4	19.3	0.2	5.5	7.8	10.0	12.3	13.9	260.0
1980	7.7	7.5	3.4	20.6	0.1	5.2	7.5	10.1	12.2	13.2	257.0
1981	7.6	7.2	3.3	22.8	0.1	5.1	7.2	9.8	12.1	13.4	257.5
1982	7.9	7.6	3.7	21.7	0.1	5.2	7.6	10.3	12.8	14.2	242.7
1983	7.8	7.3	3.7	22.2	0.2	5.1	7.3	10.2	13.0	14.5	260.0
1984	7.3	6.6	3.8	25.9	0.1	4.5	6.6	9.4	12.9	14.6	265.9
1985	7.6	7.4	3.2	19.7	0.2	5.2	7.4	9.7	11.8	13.0	232.8
1986	8.3	8.0	3.8	21.3	0.1	5.5	8.0	11.0	13.5	14.9	247.6
1987	7.4	7.2	3.2	20.1	0.0	5.1	7.2	9.4	11.5	13.1	250.3
1988	7.7	7.5	3.6	24.7	0.1	5.1	7.5	9.9	12.4	14.1	251.9
1989	7.9	7.5	3.5	24.1	0.1	5.4	7.5	10.1	12.7	14.3	246.9
1990	8.4	7.9	4.0	24.8	0.1	5.4	7.9	11.2	13.8	15.4	252.6
1991	7.7	7.2	3.8	25.2	0.0	4.9	7.2	10.2	13.0	14.8	249.4
1992	8.1	7.9	3.4	22.6	0.2	5.5	7.9	10.5	12.7	14.0	250.1
1993	7.8	7.5	3.6	25.4	0.3	5.3	7.5	9.9	12.6	14.5	257.2
1994	8.1	7.7	3.7	20.7	0.2	5.4	7.7	10.4	13.0	14.8	240.9
1995	7.7	7.4	3.4	23.4	0.2	5.3	7.4	9.9	12.3	13.9	253.5
1996	7.6	7.3	3.3	21.4	0.1	5.4	7.3	9.5	11.7	13.3	238.9
1997	7.4	7.0	3.6	29.2	0.1	4.8	7.0	9.6	12.3	13.8	231.1
1998	8.1	7.9	3.5	24.8	0.2	5.6	7.9	10.4	12.7	14.2	253.0
1999	8.1	7.7	3.6	21.3	0.1	5.5	7.7	10.4	12.9	14.4	255.6
2000	7.8	7.6	3.8	21.5	0.1	4.9	7.6	10.5	13.0	14.4	261.3
2001	7.0	6.7	3.3	23.0	0.0	4.6	6.7	9.2	11.3	12.7	252.4
2002	7.7	7.3	3.6	23.5	0.1	5.1	7.3	9.8	12.5	14.5	233.2
2003	7.3	7.1	3.2	20.9	0.2	5.2	7.1	9.3	11.6	13.0	225.6
2004	7.7	7.3	3.5	20.6	0.2	5.0	7.3	10.0	12.5	13.9	260.2
2005	7.5	7.3	3.5	21.5	0.0	4.9	7.3	9.7	12.3	13.9	258.5
2006	7.4	7.2	3.5	24.1	0.1	5.0	7.2	9.4	12.1	13.7	232.0
2007	7.4	6.8	3.8	22.9	0.2	4.5	6.8	9.7	12.6	14.6	255.9
2008	8.0	7.7	3.6	22.8	0.2	5.3	7.7	10.4	12.9	14.3	258.4
2009	7.6	7.3	3.4	24.2	0.1	5.1	7.3	9.7	12.2	13.9	235.6
2010	6.8	6.6	3.0	21.7	0.1	4.8	6.6	8.7	10.8	12.2	265.7
2011	7.8	7.6	3.7	19.9	0.1	5.0	7.6	10.3	12.8	14.2	239.4
2012	7.6	7.5	3.3	20.7	0.1	5.2	7.5	9.6	11.8	13.1	262.4
2013	7.7	7.4	3.5	24.9	0.1	5.2	7.4	9.8	12.4	14.1	245.3
2014	7.6	7.0	3.7	26.4	0.0	5.0	7.0	10.0	12.6	14.4	249.6
2015	8.1	7.7	3.9	22.2	0.0	5.1	7.7	10.7	13.7	15.3	244.3
2016	7.5	7.2	3.4	23.0	0.0	5.1	7.2	9.6	12.2	13.8	250.4
2017	7.6	7.3	3.4	20.8	0.1	5.1	7.3	9.8	12.3	13.5	251.1
2018	7.6	7.2	3.5	21.7	0.0	5.1	7.2	9.8	12.4	13.7	238.5
2019	7.8	7.5	3.6	23.6	0.1	5.0	7.5	10.1	12.4	14.0	249.7
2020	8.1	7.7	4.0	22.8	0.1	5.1	7.7	10.8	13.7	15.2	254.5
2021	7.1	6.7	3.4	24.1	0.0	4.6	6.7	9.2	11.8	13.6	251.5
Overall	7.7	7.4	3.6	29.2	0.0	5.1	7.4	9.9	12.5	14.1	249.4

3.3 Weibull Parameters

Weibull parameters for normal wind speeds have been calculated for the omni-directional conditions for both wind speeds at 10 m and 150 m above sea level. The Weibull scale (A) and shape (k) parameters fitted to the omni-directional wind data are given in Table 3-7, Figure 3-4 and Figure 3-5.

Table 3-7 Weibull fit parameters for wind speed 10mMSL and 150mMSL

Wind speed height above sea level (m)	Weibull parameters	
	Scale (A)	Shape (k)
10	8.72	2.29
150	11.46	2.19

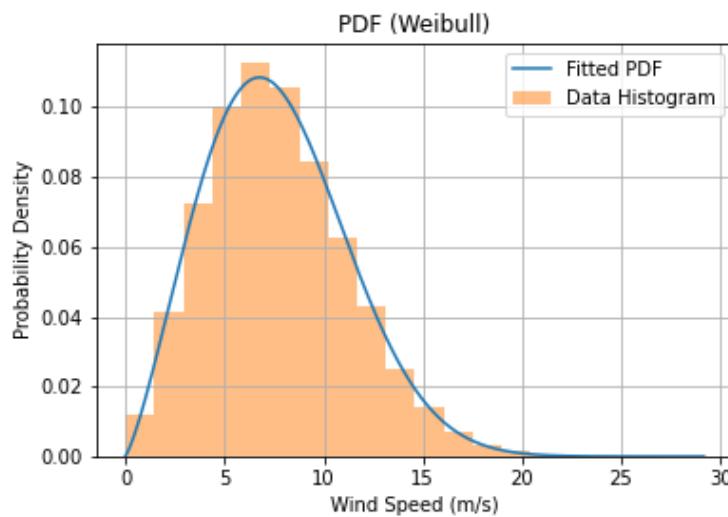


Figure 3-4 Histogram and Weibull fit parameters for wind speed 10 mMSL

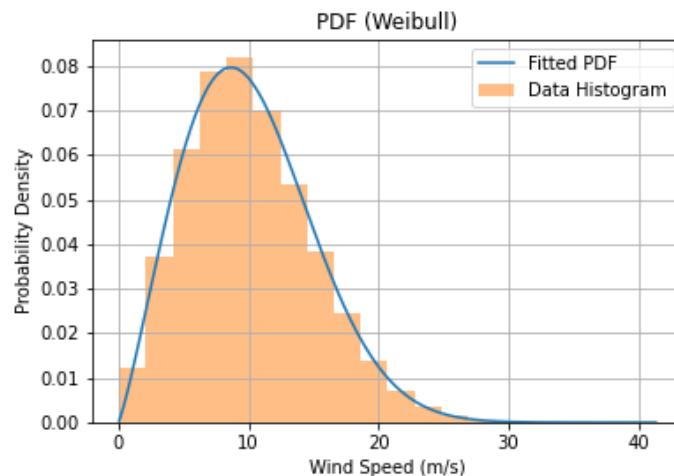


Figure 3-5 Histogram and Weibull fit parameters for wind speed 150 mMSL

3.4 Extreme Wind Conditions

The ERA5 dataset was used to calculate 10-minute extreme wind speeds at hub height. A GEV methodology was chosen as the best-fitting analysis to calculate the extreme values for wind speed at this location. Due to the adequate length of the wave dataset, the block maxima (annual maxima) approach was chosen to extract extreme events over the 43-year time period as input into the general extreme value analysis. The 1-hour averaged wind speed dataset at 100 m above sea level was used as an input to predict 1-, 50- and 100-year return values.

The predicted 1-hour extreme wind speeds at 100 m above sea level were converted to 10-minute extreme wind speeds using the Frøya wind speed profile which is documented in DNVGL-RP-C205: 2021 [9]:

$$U(T, z) = U_0 \cdot \left\{ 1 + C \cdot \ln \frac{z}{H} \right\} \cdot \left\{ 1 - 0.41 \cdot I_U(z) \cdot \ln \frac{T}{T_0} \right\}$$

Where U_0 represents the 1-hr mean wind speed at height H above the sea level (100 m) to the mean wind speed U with averaging period T at height z above the sea level. T_0 is fixed at 3600 s. The expression for C is given as:

$$C = 5.73 \times 10^{-2} \sqrt{1 + 0.148U_0}$$

and

$$I_U = 0.06 \cdot (1 + 0.043U_0) \cdot \left(\frac{z}{H} \right)^{-0.22}$$

These 10-minute extreme wind speeds at 100 m above sea level were extrapolated to hub height (150 m) using the power law (IEC 61400-3-1: 2019) with the shear exponent value 0.11 as recommended by IEC 61400-3-1: 2019 [8] for extreme conditions:

$$V_{power\ law} = V_{ref} * \left(\frac{z}{z_{ref}} \right)^\alpha$$

Where $V_{power\ law}$ and V_{ref} are the wind speeds at z and z_{ref} respectively, and α is the shear exponent.

The final 1-year, 50-year, and 100-year return values are presented in Table 3-8.

Table 3-8 Extreme wind speeds

Height above sea level (m)	Averaging period	Extreme wind speed (m/s)		
		1-Year	50-Year	100-Year
100	1-hour	24.0	37.9	39.9
100	10-min	26.2	42.3	44.6
150	10-min	27.4	44.2	46.7

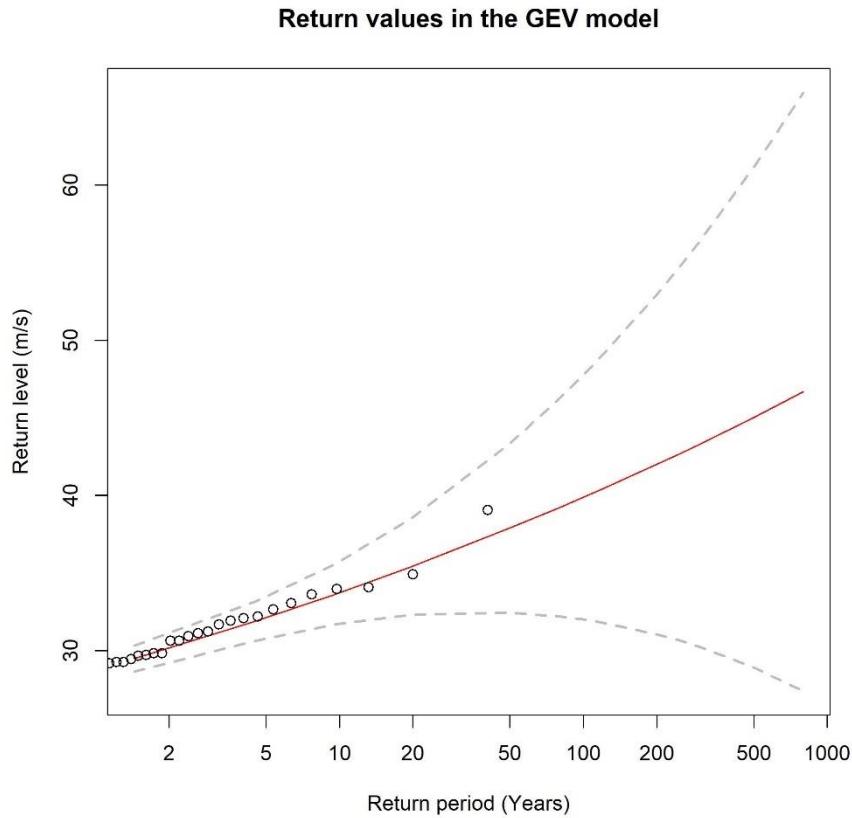


Figure 3-6 Return values of wind speed (m/s) at 100 m above sea level in the GEV model. Red curve represents the best fit with the data and aligns with the input data. Dashed lines represent the 95 % confidence intervals. Distribution parameters: location = 28.800; scale = 2.097; shape = 0.0305.

3.5 Normal Sea States

For normal sea states, the metocean database is analysed in order to establish the long-term joint probability distribution of the following parameters:

- Mean wind speed at hub height, V_{hub}
- Significant wave height, H_s
- Peak wave period, T_p

According to IEC 61400-3-1: 2019 [8], a 1-hour averaging period is required for the establishment of the long-term joint probability distribution of V_{hub} , H_s and T_p under NSS. The wind and wave data are subsequently gathered in bins. The V_{hub} bins cover 2 m/s, the H_s bins cover 0.5 m and the T_p bins span 0.5 s (IEC 61400-3-1: 2019). The binning of the V_{hub} data is done in such a way that the wind speed bin corresponding to for example $V_{hub} = 2$ m/s contains all wind speed observations ranging from ≥ 1 m/s to < 3 m/s. The bin $H_s = 2$ m contains all wave height observations between ≥ 1.75 m and < 2.25 m, while the bin $T_p = 2$ s includes all wave period observations from ≥ 1.75 s to < 2.25 s. Subsequently, the occurrence of all combinations of V_{hub} , H_s and T_p is counted. The data is gathered per wind speed bin and entered in a scatter diagram giving the frequency of occurrences of each combination of H_s and T_p for that wind speed bin as a percentage value. The full set of scatter diagrams make up the 3-D scatter diagram. The H_s/T_p scatter diagram for all wind speeds (Figure 0-1) and the full set of 3D scatter diagrams are available in the Appendix.

The data is gathered per wind speed bin and entered in a scatter diagram giving the frequency of occurrences of each combination of H_s and T_p for that wind speed bin as a percentage value. The full set of scatter diagrams make up the 3-D scatter diagram. From each scatter plot, the most probable H_s/T_p bin was identified. The average H_s and T_p bin was then calculated and assigned to each V_{hub} . The reduced (lumped) scatter is shown in Table 3-9.

Table 3-9 Lumped scatter diagram of the given offshore site

V_{hub} (m/s)	H_s (m)	T_p (s)	Wave direction (°)	Wind direction (°)	Frequency of Occurrence (%)
2	1.01	9.00	281.25	303.75	0.25
4	1.03	8.47	281.25	303.75	0.46
6	1.50	9.99	281.25	292.50	0.64
8	1.50	9.02	281.25	225.00	0.67
10	2.00	9.99	270.00	247.50	0.58
12	2.50	10.00	270.00	236.25	0.33
14	2.01	6.46	270.00	236.25	0.26
16	3.00	8.49	270.00	213.75	0.19
18	4.02	11.99	270.00	213.75	0.11
20	4.98	11.02	258.75	236.25	0.08
22	5.00	11.02	270.00	202.50	0.04
24	6.50	12.04	270.00	270.00	0.02
26	8.03	13.53	258.75	270.00	0.01
28	9.45	14.52	258.75	247.50	0.01
30	8.04	12.14	270.00	247.50	0.00
32	9.76	13.69	270.00	258.75	0.01
34	11.03	14.38	247.50	258.75	0.00
36	10.18	13.46	270.00	281.25	0.00
42	6.41	11.82	247.50	270.00	0.00

A rose plot displaying wave direction and significant wave height is presented in Figure 3-7, whereby monthly, annual and overall wave summary statistics are given in Table 3-10 to Table 3-13. Kernel density and contour plots of significant wave height and peak wave period are presented in Figure 3-8 and Figure 3-9.

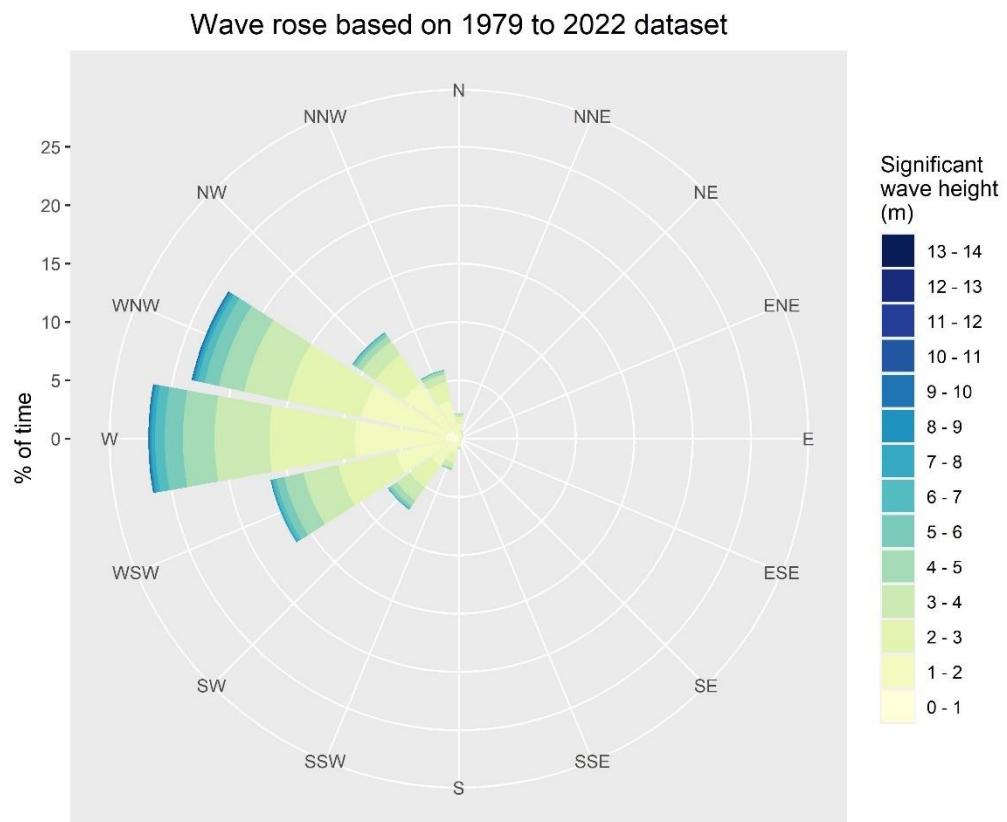


Figure 3-7 Rose plot of significant wave height and wave direction from 1979 to 2022 dataset

Table 3-10 Monthly wave statistics from ERA5 dataset (1979 – 2022)

Variable	Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hs (m)	mean	3.8	3.6	3.2	2.3	2.0	1.7	1.7	1.8	2.3	2.8	3.2	3.6
	median	3.5	3.3	2.9	2.1	1.7	1.6	1.5	1.7	2.1	2.6	3.0	3.3
	standard deviation	1.7	1.6	1.4	1.1	0.9	0.8	0.7	0.7	1.0	1.3	1.4	1.6
	max	13.3	13.6	11.8	10.3	8.1	6.5	6.3	6.4	9.5	9.7	12.0	12.7
	min	0.8	0.7	0.5	0.6	0.5	0.4	0.4	0.5	0.4	0.6	0.6	0.7
	P25	2.5	2.4	2.1	1.6	1.3	1.2	1.2	1.3	1.5	1.9	2.2	2.4
	P50	3.5	3.3	2.9	2.1	1.7	1.6	1.5	1.7	2.1	2.6	3.0	3.3
	P75	4.7	4.5	4.0	2.8	2.4	2.2	2.0	2.2	2.8	3.4	3.9	4.5
	P90	6.1	5.8	5.2	3.7	3.2	2.7	2.5	2.8	3.6	4.4	5.0	5.8
	P95	6.9	6.8	5.9	4.3	3.8	3.1	3.0	3.3	4.1	5.2	5.6	6.6
Hmax (m)	mean	7.0	6.7	5.9	4.4	3.7	3.3	3.1	3.4	4.2	5.2	5.9	6.6
	median	6.5	6.1	5.3	4.0	3.3	3.0	2.9	3.2	3.9	4.8	5.5	6.1
	standard deviation	3.1	3.0	2.6	2.0	1.8	1.4	1.3	1.4	1.9	2.3	2.5	3.0
	max	24.0	24.5	20.9	18.7	14.9	12.2	11.9	11.9	17.6	17.7	21.3	23.1
	min	1.5	1.4	0.9	1.1	0.9	0.7	0.8	1.0	0.8	1.1	1.2	1.3
	P25	4.6	4.5	3.9	3.0	2.5	2.2	2.2	2.4	2.9	3.5	4.1	4.4
	P50	6.5	6.1	5.3	4.0	3.3	3.0	2.9	3.2	3.9	4.8	5.5	6.1
	P75	8.8	8.3	7.4	5.3	4.5	4.1	3.7	4.1	5.3	6.4	7.3	8.3

	P90	11.2	10.7	9.6	6.9	6.0	5.1	4.7	5.3	6.6	8.3	9.2	10.6
	P95	12.7	12.4	10.9	8.0	7.1	5.9	5.6	6.2	7.6	9.6	10.4	12.2
Tp (s)	mean	12.4	12.4	11.8	10.8	9.8	9.1	8.7	8.9	10.2	10.9	11.5	12.2
	median	12.4	12.4	11.9	10.9	9.8	9.1	8.6	8.9	10.1	10.9	11.5	12.1
	standard deviation	2.1	2.3	2.1	1.9	1.9	1.8	1.6	1.7	2.0	2.0	2.0	2.2
	max	20.9	21.5	18.8	19.2	18.3	17.1	16.6	17.8	20.9	19.4	19.5	20.4
	min	4.5	4.4	3.6	4.3	3.3	3.3	3.6	3.6	3.2	3.8	4.3	4.4
	P25	11.2	11.2	10.7	9.8	8.6	8.1	7.7	7.9	9.0	9.7	10.3	10.9
	P50	12.4	12.4	11.9	10.9	9.8	9.1	8.6	8.9	10.1	10.9	11.5	12.1
	P75	13.7	13.8	13.1	12.1	11.0	10.2	9.6	9.9	11.3	12.1	12.7	13.5
	P90	15.0	15.1	14.4	13.3	12.1	11.2	10.7	10.9	12.6	13.4	14.0	14.9
	P95	15.7	16.1	15.0	14.0	12.8	12.0	11.3	11.7	13.5	14.3	14.7	15.8
Wave direction (°)	mean	262.5	260.3	268.1	275.4	267.2	271.6	275.1	272.6	272.3	266.9	269.6	261.1

Table 3-11 Annual and overall significant wave height (Hs) from ERA5 dataset (1979 – 2022)

Year	Hs (m)									
	mean	median	standard deviation	max	min	P25	P50	P75	P90	P95
1979	2.6	2.4	1.3	9.4	0.5	1.7	2.4	3.2	4.5	5.2
1980	2.5	2.3	1.3	10.2	0.6	1.6	2.3	3.2	4.1	4.8
1981	2.5	2.3	1.2	9.9	0.4	1.6	2.3	3.1	4.0	4.6
1982	2.8	2.5	1.6	11.7	0.5	1.7	2.5	3.6	5.0	6.1
1983	2.6	2.1	1.6	9.6	0.5	1.4	2.1	3.4	4.9	5.6
1984	2.5	2.1	1.6	10.4	0.5	1.4	2.1	3.2	4.7	6.0
1985	2.4	2.1	1.1	9.1	0.6	1.5	2.1	2.9	3.8	4.4
1986	2.9	2.5	1.7	12.0	0.5	1.5	2.5	3.9	5.2	6.0
1987	2.3	2.0	1.1	7.9	0.6	1.4	2.0	2.8	3.8	4.6
1988	2.6	2.2	1.4	13.6	0.6	1.6	2.2	3.2	4.4	5.2
1989	2.7	2.3	1.5	8.2	0.6	1.5	2.3	3.6	5.0	5.8
1990	2.9	2.5	1.8	10.7	0.5	1.5	2.5	3.9	5.5	6.4
1991	2.6	2.2	1.6	13.3	0.5	1.6	2.2	3.3	4.7	5.8
1992	2.8	2.6	1.3	9.0	0.7	1.8	2.6	3.6	4.6	5.3
1993	2.7	2.3	1.6	12.7	0.5	1.6	2.3	3.5	4.8	5.8
1994	2.9	2.5	1.7	11.8	0.6	1.7	2.5	3.9	5.2	6.1
1995	2.6	2.3	1.4	9.7	0.6	1.7	2.3	3.3	4.7	5.5
1996	2.5	2.1	1.3	10.3	0.7	1.5	2.1	3.1	4.2	5.0
1997	2.5	2.2	1.4	9.1	0.6	1.5	2.2	3.2	4.3	5.3
1998	2.8	2.5	1.5	11.8	0.7	1.6	2.5	3.4	4.7	5.6
1999	2.8	2.5	1.5	9.5	0.6	1.6	2.5	3.5	4.6	5.8
2000	2.8	2.5	1.5	9.7	0.6	1.6	2.5	3.8	5.0	5.8
2001	2.4	2.1	1.1	7.7	0.7	1.6	2.1	2.9	3.9	4.6
2002	2.8	2.5	1.5	12.0	0.6	1.7	2.5	3.5	4.8	5.9
2003	2.5	2.2	1.3	8.7	0.5	1.6	2.2	3.1	4.2	4.9

2004	2.6	2.4	1.3	8.1	0.6	1.6	2.4	3.3	4.5	5.2
2005	2.5	2.1	1.4	11.1	0.7	1.5	2.1	3.0	4.3	5.4
2006	2.5	2.2	1.4	9.9	0.6	1.6	2.2	3.1	4.4	5.3
2007	2.7	2.2	1.6	11.3	0.6	1.5	2.2	3.4	4.9	5.9
2008	2.8	2.5	1.5	10.4	0.7	1.7	2.5	3.6	5.0	5.6
2009	2.7	2.4	1.4	9.8	0.5	1.7	2.4	3.3	4.6	5.6
2010	2.2	1.9	1.0	9.7	0.6	1.5	1.9	2.6	3.5	4.1
2011	2.9	2.6	1.4	9.1	0.7	1.8	2.6	3.7	4.8	5.5
2012	2.5	2.2	1.2	8.9	0.6	1.6	2.2	3.1	4.0	4.8
2013	2.7	2.3	1.5	10.9	0.4	1.6	2.3	3.3	4.8	5.8
2014	2.8	2.4	1.7	13.6	0.5	1.6	2.4	3.7	4.9	5.8
2015	3.0	2.5	1.6	11.8	0.6	1.7	2.5	3.9	5.4	6.2
2016	2.7	2.3	1.4	11.9	0.7	1.6	2.3	3.3	4.7	5.6
2017	2.6	2.3	1.3	9.2	0.6	1.7	2.3	3.3	4.2	5.1
2018	2.8	2.5	1.4	10.7	0.7	1.8	2.5	3.4	4.6	5.6
2019	2.7	2.4	1.4	10.0	0.7	1.7	2.4	3.4	4.7	5.5
2020	2.9	2.4	1.7	10.2	0.6	1.6	2.4	3.8	5.2	6.4
2021	2.4	2.1	1.3	8.9	0.4	1.4	2.1	3.1	4.1	4.9
Overall	2.6	2.3	1.4	13.6	0.4	1.6	2.3	3.3	4.6	5.5

Table 3-12 Annual and overall individual maximum wave height (Hmax) from ERA5 dataset (1979 – 2022)

Year	Hmax (m)									
	mean	median	standard deviation	max	min	P25	P50	P75	P90	P95
1979	4.9	4.4	2.4	17.2	0.9	3.2	4.4	5.9	8.3	9.7
1980	4.7	4.2	2.3	18.8	1.1	3.0	4.2	6.0	7.6	8.9
1981	4.6	4.3	2.2	18.4	0.7	3.0	4.3	5.7	7.4	8.7
1982	5.3	4.7	2.9	21.1	0.9	3.2	4.7	6.7	9.3	11.1
1983	4.8	3.9	2.9	17.6	1.0	2.6	3.9	6.3	9.0	10.3
1984	4.7	4.0	3.0	19.1	0.9	2.7	4.0	5.9	8.7	11.0
1985	4.4	4.0	2.1	16.6	1.1	2.8	4.0	5.5	7.1	8.2
1986	5.3	4.6	3.1	21.3	0.9	2.9	4.6	7.3	9.6	11.0
1987	4.3	3.7	2.1	14.7	1.1	2.7	3.7	5.3	7.1	8.6
1988	4.8	4.1	2.7	24.5	1.1	3.0	4.1	5.9	8.1	9.7
1989	5.1	4.4	2.8	15.8	1.2	2.9	4.4	6.7	9.2	10.6
1990	5.4	4.6	3.2	19.5	0.9	2.9	4.6	7.3	10.1	11.8
1991	4.9	4.1	2.8	24.0	0.9	3.0	4.1	6.2	8.8	10.6
1992	5.2	4.9	2.4	16.9	1.3	3.4	4.9	6.7	8.5	9.8
1993	5.1	4.3	2.8	23.1	1.0	3.1	4.3	6.5	8.9	10.7
1994	5.4	4.7	3.0	20.9	1.2	3.1	4.7	7.1	9.6	11.3
1995	4.9	4.3	2.6	17.4	1.2	3.1	4.3	6.1	8.6	10.2
1996	4.6	4.0	2.4	18.4	1.2	2.9	4.0	5.8	7.8	9.2
1997	4.7	4.1	2.6	16.8	1.1	2.9	4.1	6.0	8.0	9.8
1998	5.1	4.6	2.7	21.7	1.3	3.1	4.6	6.4	8.7	10.3
1999	5.2	4.6	2.7	17.4	1.2	3.1	4.6	6.6	8.6	10.8

2000	5.2	4.6	2.8	17.7	1.1	3.0	4.6	7.1	9.1	10.7
2001	4.4	4.0	2.0	14.3	1.3	2.9	4.0	5.4	7.2	8.5
2002	5.2	4.6	2.8	21.8	1.2	3.2	4.6	6.5	8.9	10.8
2003	4.6	4.1	2.3	15.9	0.9	3.0	4.1	5.8	7.8	9.1
2004	4.9	4.4	2.4	14.9	1.2	3.1	4.4	6.1	8.3	9.6
2005	4.6	4.0	2.5	19.8	1.3	2.8	4.0	5.6	8.0	9.9
2006	4.7	4.2	2.5	18.2	1.1	2.9	4.2	5.8	8.2	9.7
2007	4.9	4.1	2.9	20.6	1.2	2.8	4.1	6.4	9.0	10.9
2008	5.2	4.6	2.7	18.9	1.4	3.1	4.6	6.7	9.2	10.4
2009	5.0	4.4	2.6	17.8	0.9	3.3	4.4	6.2	8.5	10.3
2010	4.1	3.6	1.9	17.9	1.2	2.8	3.6	5.0	6.4	7.6
2011	5.3	4.9	2.5	16.6	1.4	3.4	4.9	6.8	8.9	10.2
2012	4.7	4.2	2.2	16.2	1.1	3.0	4.2	5.9	7.5	8.9
2013	5.0	4.3	2.8	20.2	0.8	3.0	4.3	6.1	8.9	10.6
2014	5.2	4.6	3.1	24.1	0.9	2.9	4.6	6.9	9.0	10.6
2015	5.5	4.6	3.0	21.3	1.2	3.2	4.6	7.3	9.9	11.5
2016	5.0	4.4	2.6	21.5	1.3	3.1	4.4	6.2	8.6	10.3
2017	4.8	4.4	2.3	16.7	1.1	3.1	4.4	6.2	7.9	9.4
2018	5.2	4.6	2.6	19.3	1.3	3.3	4.6	6.4	8.5	10.3
2019	5.0	4.5	2.6	18.4	1.3	3.1	4.5	6.3	8.7	10.1
2020	5.4	4.4	3.1	18.5	1.2	3.0	4.4	7.0	9.7	11.7
2021	4.4	4.0	2.4	16.7	0.8	2.6	4.0	5.7	7.6	9.0
Overall	4.9	4.3	2.7	24.5	0.7	3.0	4.3	6.2	8.5	10.1

Table 3-13 Annual and overall peak wave period (T_p) and wave direction from ERA5 dataset (1979 – 2022)

Year	Tp (s)										Wave direction (°)
	mean	median	standard deviation	max	min	P25	P50	P75	P90	P95	
1979	10.5	10.4	2.3	21.5	4.1	8.7	10.4	12.1	13.4	14.5	267.8
1980	10.4	10.2	2.5	19.2	4.0	8.6	10.2	12.2	13.4	14.5	263.9
1981	10.2	10.4	2.1	18.2	4.3	8.8	10.4	11.6	12.5	13.3	273.3
1982	10.9	10.8	2.5	20.9	3.9	9.1	10.8	12.5	14.2	15.2	266.3
1983	10.5	10.4	2.4	19.7	3.8	8.8	10.4	12.1	13.4	14.5	268.2
1984	10.6	10.4	2.4	19.1	3.6	8.8	10.4	12.2	13.8	14.7	274.2
1985	10.4	10.4	2.2	17.5	4.1	8.8	10.4	11.9	13.3	14.1	262.5
1986	10.6	10.7	2.7	18.6	3.6	8.6	10.7	12.5	14.0	15.0	258.3
1987	10.2	10.2	2.3	17.9	4.1	8.7	10.2	11.9	13.2	13.9	261.2
1988	10.5	10.3	2.2	17.6	4.2	9.0	10.3	11.9	13.4	14.4	268.3
1989	10.9	10.9	2.5	19.2	3.9	9.2	10.9	12.6	14.3	14.9	270.8
1990	10.7	10.7	2.4	18.5	3.9	9.1	10.7	12.2	13.9	14.9	273.4
1991	10.8	10.7	2.3	19.8	3.3	9.2	10.7	12.3	13.6	14.7	272.9
1992	11.0	10.9	2.2	17.7	3.9	9.5	10.9	12.4	14.0	14.9	273.3
1993	11.0	11.0	2.4	18.8	4.3	9.3	11.0	12.6	14.2	14.9	271.3
1994	10.9	10.8	2.4	18.8	3.7	9.3	10.8	12.6	14.2	14.9	264.1

1995	10.9	10.8	2.5	19.8	3.3	9.3	10.8	12.5	14.3	14.9	267.6
1996	10.6	10.7	2.4	18.8	4.0	9.1	10.7	12.2	13.6	14.6	259.7
1997	10.9	10.8	2.4	19.5	4.1	9.3	10.8	12.4	13.9	14.8	261.7
1998	10.7	10.7	2.4	19.0	4.0	9.1	10.7	12.2	13.9	14.9	274.0
1999	10.8	10.8	2.2	19.4	3.8	9.3	10.8	12.2	13.4	14.5	269.1
2000	11.0	11.0	2.4	20.4	3.6	9.3	11.0	12.5	14.1	15.1	273.1
2001	10.7	10.7	2.2	17.9	4.2	9.3	10.7	12.1	13.5	14.4	267.4
2002	11.1	11.1	2.4	20.8	4.1	9.4	11.1	12.8	14.2	14.9	267.6
2003	10.7	10.6	2.5	20.8	3.6	8.9	10.6	12.3	13.9	14.8	264.5
2004	10.7	10.8	2.2	19.6	3.9	9.1	10.8	12.2	13.4	14.2	274.5
2005	10.5	10.4	2.3	18.2	4.2	9.0	10.4	12.0	13.5	14.4	271.7
2006	10.6	10.5	2.4	19.7	3.9	9.0	10.5	12.2	13.5	14.4	263.1
2007	10.8	10.9	2.4	18.6	4.0	9.2	10.9	12.5	13.6	14.6	274.4
2008	10.8	10.8	2.3	19.0	3.6	9.3	10.8	12.3	13.8	14.7	272.9
2009	10.8	10.8	2.3	17.8	4.2	9.3	10.8	12.2	13.7	14.9	261.9
2010	10.4	10.4	2.3	20.9	3.6	9.0	10.4	11.9	13.1	14.3	270.4
2011	11.1	11.1	2.3	18.7	4.0	9.4	11.1	12.7	14.1	15.0	271.0
2012	10.3	10.3	2.4	18.1	3.7	8.7	10.3	12.0	13.5	14.2	266.4
2013	10.8	10.8	2.3	17.4	4.4	9.3	10.8	12.3	13.7	14.7	264.2
2014	11.0	10.9	2.5	19.1	3.8	9.2	10.9	12.5	14.3	15.0	271.5
2015	10.9	11.0	2.3	19.1	4.3	9.4	11.0	12.5	14.1	14.8	271.3
2016	10.9	10.9	2.3	17.6	4.3	9.2	10.9	12.5	14.0	14.8	271.4
2017	10.6	10.5	2.2	18.6	4.3	9.1	10.5	12.0	13.6	14.6	271.8
2018	11.1	11.0	2.3	18.7	4.2	9.6	11.0	12.5	14.0	15.0	265.1
2019	10.8	10.8	2.3	18.2	4.2	9.1	10.8	12.3	13.6	14.6	268.9
2020	10.9	10.8	2.4	19.2	4.0	9.1	10.8	12.6	14.0	14.9	273.3
2021	10.5	10.3	2.5	19.3	3.2	8.9	10.3	12.1	13.8	14.8	270.2
Overall	10.7	10.7	2.4	21.5	3.2	9.1	10.7	12.3	13.7	14.7	268.6

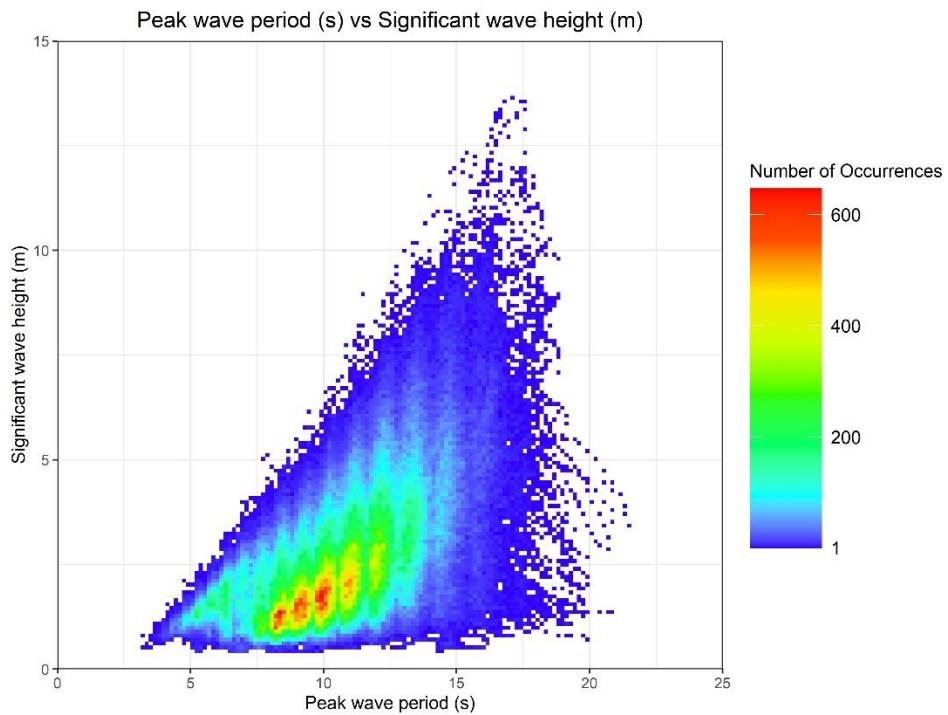


Figure 3-8 Kernel density plot of significant wave height and peak wave period

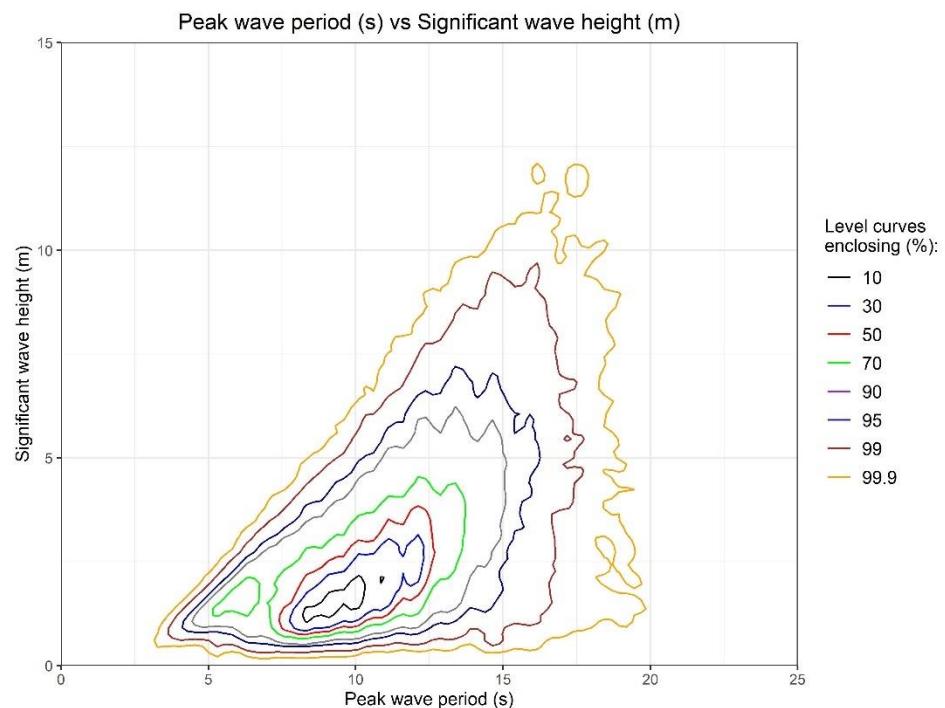


Figure 3-9 Contour plot of significant wave height and peak wave period

A weather window analysis was carried out using various limits of significant wave height and wind speed at 10 m above sea level. Table 3-14 shows the percentage of time for each month, for which weather window limits with specific H_s and wind speed specifications, along with durations ranging from 3 hours and 72 hours, occur.

Table 3-14 Wind-wave persistence – Weather Windows (10 m wind speeds)

	Time duration threshold (hours)	Month												Overall dataset
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
<i>Hs < 1.5 m, Uw < 5m/s</i>	3	2.2	1.9	5.4	11.4	18.8	23.5	23.8	20.9	13.4	7.1	4.1	1.4	11.2
	6	2.0	1.8	5.1	10.5	17.8	22.3	22.4	19.9	12.8	6.8	3.9	1.2	10.6
	12	1.6	1.2	4.4	8.7	15.2	19.2	19.0	17.3	11.1	5.9	3.3	0.8	9.1
	24	1.0	0.6	3.5	5.3	10.0	12.4	12.0	11.7	8.1	4.3	2.3	0.2	6.0
	48	0.2	NA	1.6	2.1	4.3	7.0	5.2	5.7	4.7	1.8	0.5	NA	2.8
	72	NA	NA	0.5	0.6	1.1	3.0	2.5	3.0	1.2	0.9	NA	NA	1.2
<i>Hs < 2.0 m, Uw < 5m/s</i>	3	5.3	5.1	11.1	19.6	26.2	29.9	29.6	27.0	19.9	12.0	7.4	4.1	16.5
	6	4.8	4.8	10.6	18.2	24.9	28.4	28.0	25.6	18.8	11.2	7.0	3.7	15.6
	12	4.1	3.7	9.0	15.7	21.7	24.2	23.9	22.4	16.1	9.4	5.9	2.9	13.4
	24	2.8	1.9	7.1	10.4	14.7	15.9	14.6	14.5	11.1	6.9	3.8	1.3	8.9
	48	0.9	0.5	3.6	5.2	6.3	8.5	6.6	6.6	6.0	3.3	1.5	NA	4.2
	72	0.6	NA	1.8	1.7	2.3	3.8	2.9	3.3	2.5	1.7	0.3	NA	1.9
<i>Hs < 2.5 m, Uw < 5m/s</i>	3	8.0	8.6	15.8	24.8	29.2	31.6	30.9	28.8	23.6	15.6	10.8	7.1	19.6
	6	7.3	7.9	14.9	23.0	27.6	30.1	29.2	27.4	22.3	14.5	10.0	6.6	18.5
	12	6.2	6.6	12.9	19.5	24.0	25.9	25.0	23.9	19.0	12.2	8.2	5.1	15.9
	24	4.2	4.2	9.9	13.0	15.9	17.0	15.7	15.7	12.3	8.5	5.6	2.6	10.6
	48	1.2	1.5	5.8	6.8	7.2	9.1	7.3	7.6	6.5	4.1	2.5	0.4	5.1
	72	0.6	NA	2.2	3.0	3.0	4.1	3.7	3.6	3.0	2.1	0.3	0.2	2.3
<i>Hs < 3.5 m, Uw < 5m/s</i>	3	12.7	13.4	20.6	28.7	30.1	32.1	31.1	29.3	25.9	18.6	14.8	11.3	22.4
	6	11.5	12.5	19.3	26.7	28.6	30.5	29.4	27.8	24.6	17.1	13.6	10.3	21.1
	12	9.2	9.8	16.6	23.2	25.1	26.3	25.3	24.3	20.9	14.4	10.8	7.8	18.0
	24	6.1	6.4	12.4	15.2	16.3	17.5	15.9	15.8	13.6	9.8	6.9	3.5	11.8
	48	2.0	2.7	7.2	7.5	7.4	9.1	7.3	7.7	6.7	4.4	2.9	1.0	5.6
	72	0.8	0.7	3.9	3.5	3.0	4.1	3.7	3.9	3.3	2.1	0.6	0.5	2.7
<i>Hs < 1.5 m, Uw < 7.5 m/s</i>	3	4.2	4.2	8.1	19.0	33.2	41.3	43.7	36.4	22.8	12.3	8.2	3.9	19.9
	6	4.1	4.0	7.9	18.6	32.7	40.5	43.0	35.9	22.5	12.1	7.9	3.8	19.5
	12	3.8	3.7	7.3	17.8	31.3	38.8	41.3	33.9	21.5	11.5	7.5	3.4	18.6
	24	2.8	2.8	6.3	14.6	26.8	34.1	36.5	29.3	18.4	9.6	5.8	2.5	16.0
	48	1.7	1.8	3.4	9.7	19.1	25.1	26.4	20.8	14.2	6.1	3.4	0.6	11.4
	72	0.9	0.6	2.2	4.4	12.0	17.8	19.4	13.9	9.4	3.9	1.6	0.3	7.7
<i>Hs < 2.0 m, Uw < 7.5 m/s</i>	3	11.0	10.7	19.2	37.2	50.2	56.8	60.3	53.0	38.1	24.2	15.9	11.4	32.4
	6	10.6	10.5	18.8	36.4	49.2	56.0	59.1	52.0	37.5	23.5	15.4	11.0	31.8
	12	9.9	9.7	17.5	34.5	46.7	54.0	56.7	49.5	35.4	21.7	14.1	10.0	30.2
	24	8.2	7.6	14.6	29.1	41.2	47.2	50.4	43.0	30.9	18.6	11.8	7.5	26.2
	48	5.8	4.5	10.2	21.0	32.3	37.6	38.1	30.8	21.9	11.5	7.0	3.5	19.3
	72	3.8	2.7	7.7	15.3	22.4	26.6	28.1	19.5	16.8	8.9	4.7	1.5	14.1
<i>Hs < 2.5 m, Uw < 7.5 m/s</i>	3	17.7	18.5	29.1	49.5	58.3	62.2	65.0	58.8	48.4	33.9	24.3	19.0	40.5
	6	17.2	17.8	28.6	48.3	57.1	61.1	63.7	57.6	47.3	32.7	23.5	18.5	39.6
	12	16.0	16.5	26.7	46.0	54.5	58.5	61.0	55.0	44.1	30.3	21.0	16.6	37.4
	24	13.6	13.0	23.1	39.8	47.7	51.6	54.6	48.0	38.0	24.9	16.6	13.3	32.5
	48	10.3	8.7	17.0	29.6	37.3	40.9	42.6	34.4	25.9	16.1	10.4	7.2	24.1

	72	7.0	6.0	13.5	21.8	26.0	29.7	33.9	22.9	20.2	11.2	7.3	3.8	17.9
$H_s < 3.5 \text{ m}, U_w < 7.5 \text{ m/s}$	3	29.0	30.3	40.9	58.4	61.5	64.0	66.0	60.7	55.8	43.4	35.6	29.7	48.0
	6	28.1	29.1	39.7	57.1	60.2	62.9	64.7	59.4	54.4	41.8	34.5	28.7	46.8
	12	25.9	26.8	36.7	54.5	57.4	60.2	62.1	56.7	51.0	38.3	30.6	26.2	44.1
	24	21.0	21.1	30.5	47.9	50.8	52.9	55.4	49.3	44.5	31.5	24.0	20.5	37.9
	48	13.5	13.6	23.1	36.1	39.4	42.1	43.1	35.9	30.4	19.5	14.3	12.3	27.8
	72	10.0	10.2	18.6	28.2	28.2	31.2	34.2	24.0	23.6	12.4	9.8	6.9	20.9
$H_s < 1.5 \text{ m}, U_w < 10 \text{ m/s}$	3	4.6	4.8	8.7	20.3	36.6	45.2	47.9	39.7	24.1	13.3	8.8	4.5	21.6
	6	4.5	4.7	8.5	20.1	36.3	44.9	47.5	39.5	23.8	13.1	8.6	4.4	21.5
	12	4.3	4.4	8.0	19.4	35.4	44.0	46.6	38.3	23.2	12.8	8.3	4.1	20.9
	24	3.2	3.5	6.9	16.6	32.3	41.5	43.8	35.5	20.8	11.2	6.9	3.4	19.0
	48	1.9	2.1	3.7	12.1	26.1	34.7	36.0	27.6	16.3	7.7	4.8	1.5	15.1
	72	1.1	1.1	2.2	7.5	20.0	26.8	27.8	20.7	11.6	4.9	2.5	0.8	11.3
$H_s < 2.0 \text{ m}, U_w < 10 \text{ m/s}$	3	13.8	13.5	22.2	43.7	61.0	68.7	74.6	66.0	45.3	29.5	19.6	15.2	39.6
	6	13.7	13.3	22.0	43.5	60.7	68.5	74.4	65.6	45.0	29.2	19.5	15.0	39.4
	12	13.1	12.6	21.1	42.2	59.5	67.7	73.5	64.4	44.0	28.3	18.9	14.5	38.6
	24	11.6	10.8	18.5	38.9	56.7	65.6	70.6	61.1	40.3	25.2	16.8	12.3	36.2
	48	8.6	6.8	14.2	32.5	51.3	60.3	64.2	54.1	33.6	19.9	12.6	8.5	31.3
	72	6.1	5.1	10.2	25.9	44.0	51.6	58.0	46.2	28.0	15.1	9.5	6.6	26.7
$H_s < 2.5 \text{ m}, U_w < 10 \text{ m/s}$	3	23.8	25.1	36.7	62.3	75.2	80.8	86.0	79.8	62.9	45.0	33.6	27.0	53.3
	6	23.6	24.7	36.4	61.9	74.9	80.3	85.7	79.4	62.5	44.5	33.1	26.7	53.0
	12	22.6	23.8	35.5	60.6	73.8	79.3	84.9	78.4	61.0	42.9	31.5	25.8	52.0
	24	20.5	20.4	32.5	57.6	70.5	76.2	82.3	75.1	57.0	38.6	28.8	22.9	49.1
	48	15.8	14.7	26.1	50.5	65.6	70.7	76.1	67.7	48.8	31.1	22.5	16.7	43.2
	72	12.7	11.2	20.4	43.6	58.5	63.6	71.9	60.2	43.5	24.9	16.8	12.2	38.1

3.6 Wind-wave misalignment

The wind-wave misalignment was defined as the wind direction minus the mean wave direction for each model time step and was analysed with respect to the wind speed at hub height (150 mMSL). Scatter diagram of the misalignment of the full datasets against wind speed at hub height is presented in Figure 3-10. Wind speed was binned into 2 m/s bins and the mean misalignment for that bin was calculated. A scatter plot displaying the results of this analysis for omni-directional and 22.5 ° sectors is given in Figure 3-11.

As expected, wind-wave misalignment values are relatively higher at lower wind speeds and reduces as wind speed increases. Misalignment is also lowest in the prevailing south-western to western directional sectors.

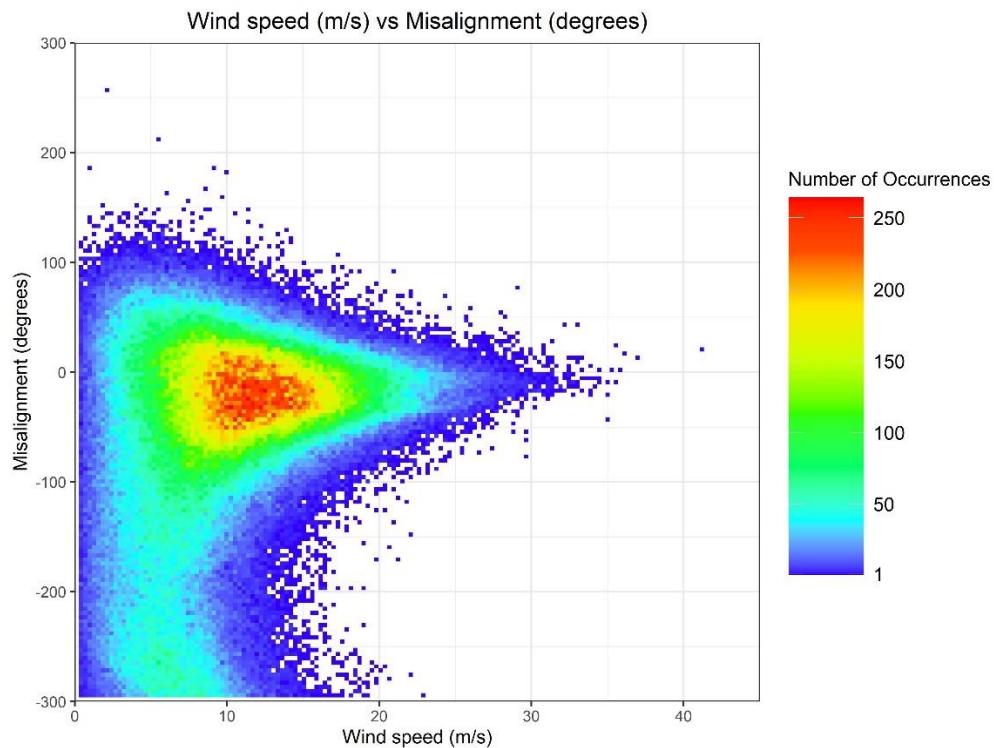


Figure 3-10 Wind-wave misalignment – full dataset (wind speed at hub height)

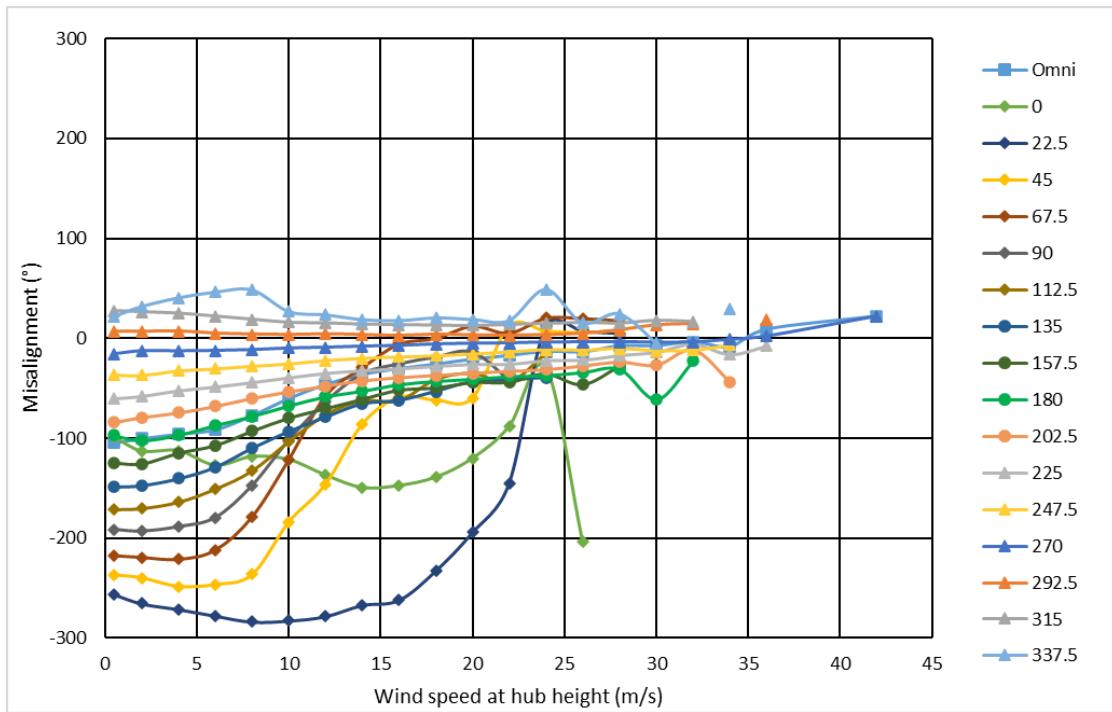


Figure 3-11 Wind-wave misalignment. Mean misalignment per 2 m/s wind speed bins are given for each wind speed directional sector

Kernel density and contour plots for significant wave height and wind speed at hub height (150 m) are presented in Figure 3-12 and Figure 3-13.

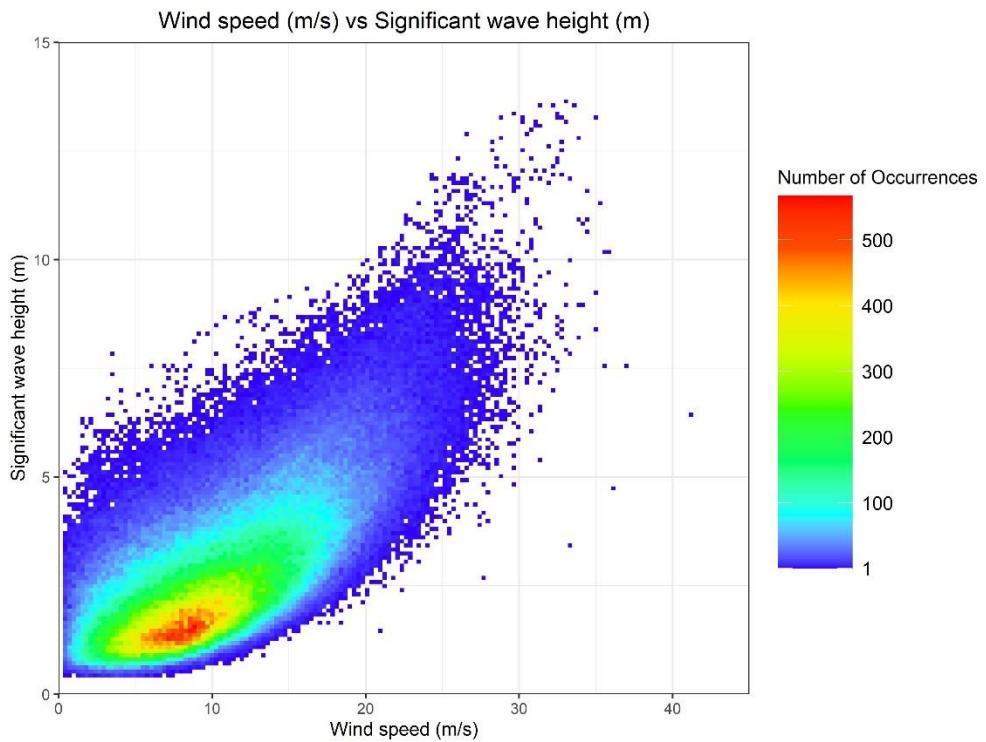


Figure 3-12 Kernel density plot of significant wave height and wind speed at 150 m above sea level

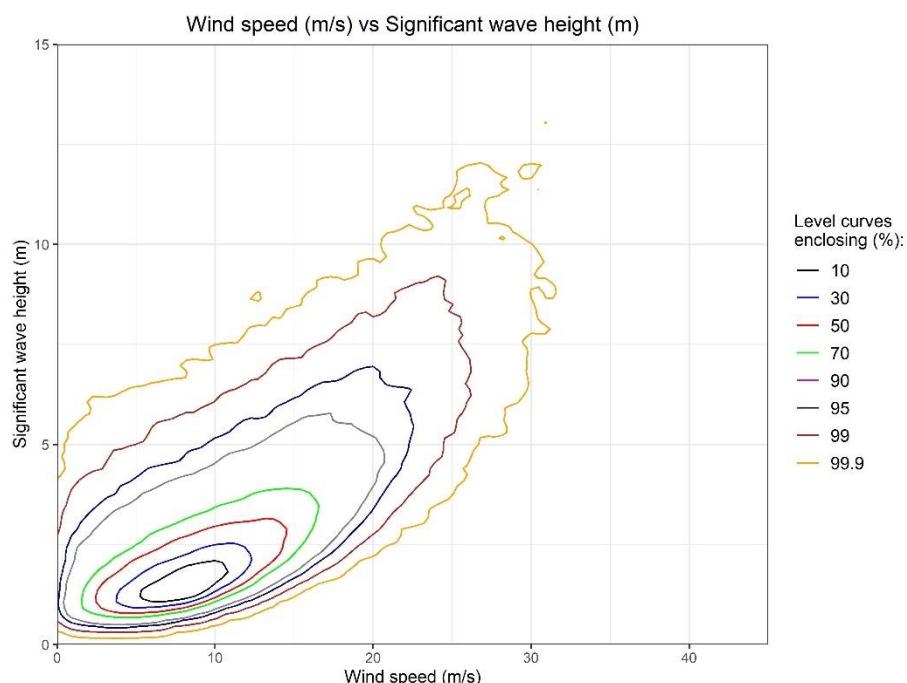


Figure 3-13 Contour plot of significant wave height and wind speed at 150 m above sea level

Wind-wave coincidence and exceedance tables for wind speeds at 10 m above sea level are provided in Figure 0-2.

3.7 Extreme Sea States

The ERA5 dataset [4] was used to calculate extreme wave variables. For this study, a generalised extreme value (GEV) methodology was chosen as the best-fitting analysis to calculate the extreme values for wave height at this location. Due to the adequate length of the wave dataset, the block maxima (annual maxima) approach was chosen to extract extreme events over the 43-year time period as input into the general extreme value analysis.

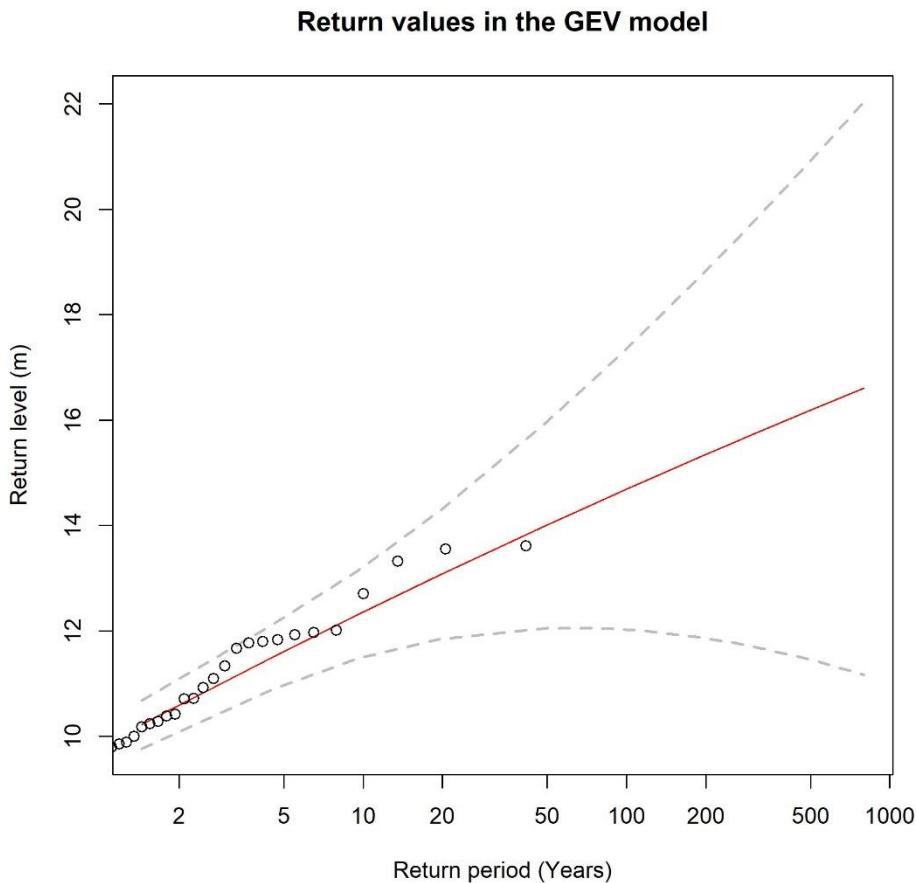


Figure 3-14 Return values of significant wave height (H_s) in the GEV model. Red curve represents the best fit with the data and aligns with the input data. Dashed lines represent the 95 % confidence intervals. Distribution parameters: location = 9.774; scale = 1.213; shape = -0.035.

The predicted 1-, 50- and 100-year return values of significant wave height H_s is presented in Table 3-5. The maximum wave height is determined according to the equation provided in IEC 61400-3-1: 2019 [8].

$$H_{max} = 1.86H_s$$

The wave period associated with maximum wave height, T_{Hmax} or T_{ass} , is calculated based on the relationship between H_s and T_{ass} (IEC 61400-3-1: 2019)

$$11.1 \sqrt{\frac{H_s}{g}} \leq T_{ass} \leq 14.3 \sqrt{\frac{H_s}{g}}$$

Where g is the acceleration due to gravity. The following equation provided in DNV-RP-C205: 2021 [9] is used to estimate the upper and lower limits of peak wave period T_p .

$$T_{ass} = 0.9T_p$$

It is noted that, IEC 61400-3-1: 2019 [8] recommend a 3-hour sea state as input into extreme value analysis. In this study, a 1-hour sea state is utilised and therefore the calculated extreme values are considered conservative.

Table 3-15 Omni-directional Extreme Wave Data

Return Period (Years)	Significant Wave Height, H_s (m)	Peak Period, T_p (s) (Lower Limit)	Peak Period, T_p (s) (Upper Limit)	Maximum Wave Height, H_{max} (m)	Period of Max Wave, T_{Hmax} (s) (Lower Limit)	Period of Max Wave, T_{Hmax} (s) (Upper Limit)
1	6.0	9.7	12.4	11.2	8.7	11.2
2	10.2	12.6	16.2	19.0	11.3	14.6
50	14.0	14.7	19.0	26.0	13.3	17.1
100	14.7	15.1	19.4	27.3	13.6	17.5

3.8 Severe Sea States

The severe sea states (SSS) conditions are found using Inverse First-Order Reliability Method (IFORM) as recommended by IEC 61400-3-1; 2019 [8]. The methodology described in Papi et al [10] was followed. The 50-year and 1-year environmental contours of V_{hub} - H_s are shown as solid lines in Figure 3-15. The SSS values, defined by the points along the 50-year contours between the cut-in and cut-out wind speeds are provided in Figure 3-18.

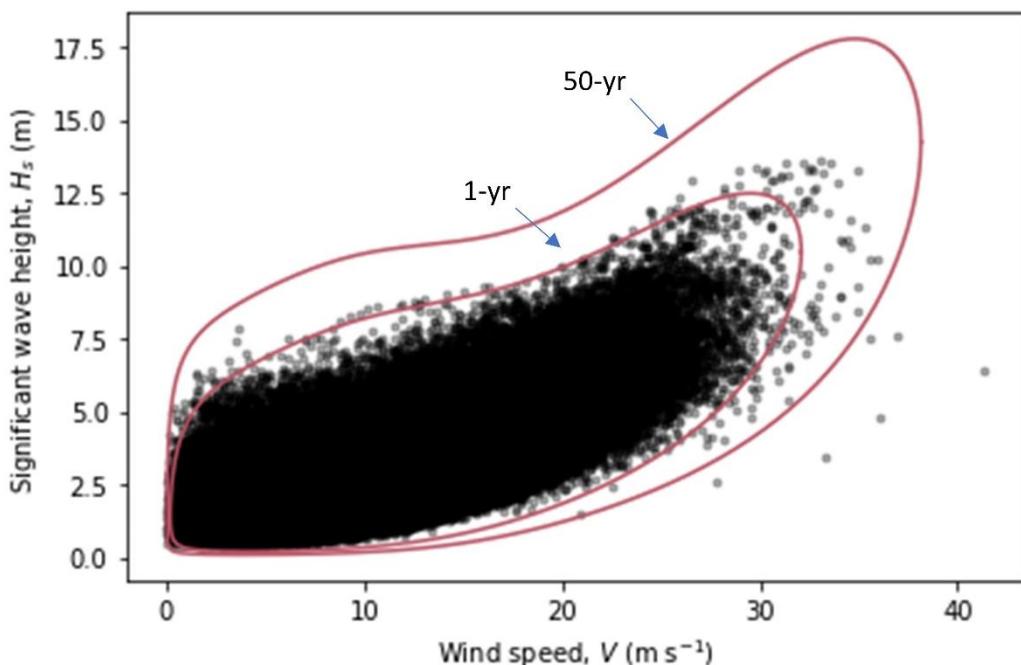


Figure 3-15 Wind speed (150 m) – significant wave height environmental contours compute with IFORM method

Table 3-16 Severe sea states within cut-in and cut-out wind speeds, computed from IFORM Method

ID	Vhub (150 m)	Hs	Tp	Tp min	Tp max
0	1	6.99	14.23	11.54	17.36
1	2	7.88	14.73	12.22	17.61
2	3	8.41	15.02	12.62	17.76
3	4	8.82	15.25	12.92	17.87
4	5	9.18	15.43	13.17	17.97
5	6	9.51	15.60	13.40	18.06
6	7	9.79	15.74	13.60	18.13
7	8	10.04	15.87	13.77	18.20
8	9	10.25	15.97	13.90	18.25
9	10	10.41	16.05	14.01	18.29
10	11	10.53	16.11	14.09	18.33
11	12	10.63	16.15	14.16	18.35
12	13	10.70	16.19	14.21	18.37
13	14	10.77	16.22	14.25	18.39
14	15	10.86	16.26	14.31	18.41
15	16	10.97	16.32	14.38	18.44
16	17	11.12	16.39	14.47	18.48
17	18	11.31	16.48	14.60	18.53
18	19	11.55	16.59	14.75	18.59
19	20	11.84	16.72	14.93	18.67
20	21	12.18	16.87	15.14	18.76
21	22	12.56	17.05	15.37	18.86
22	23	12.98	17.23	15.62	18.97
23	24	13.43	17.43	15.88	19.09
24	25	13.92	17.63	16.16	19.21
25	26	14.41	17.84	16.43	19.34
26	27	14.92	18.05	16.71	19.48
27	28	15.43	18.26	16.98	19.61
28	29	15.92	18.46	17.24	19.74
29	30	16.39	18.64	17.48	19.87

3.9 Currents – Normal Conditions

A 10-year hourly timeseries of bottom, mid and surface current speeds and directions were extracted from the three-dimensional North East Atlantic Model, an implementation of the ROMS model for Irish Waters [5] at 52.519, -10.276. Current roses of this dataset are presented in Figure

3-16 to Figure 3-18. Monthly, annual and overall statistics are presented in Table 3-17 to Table 3-20.

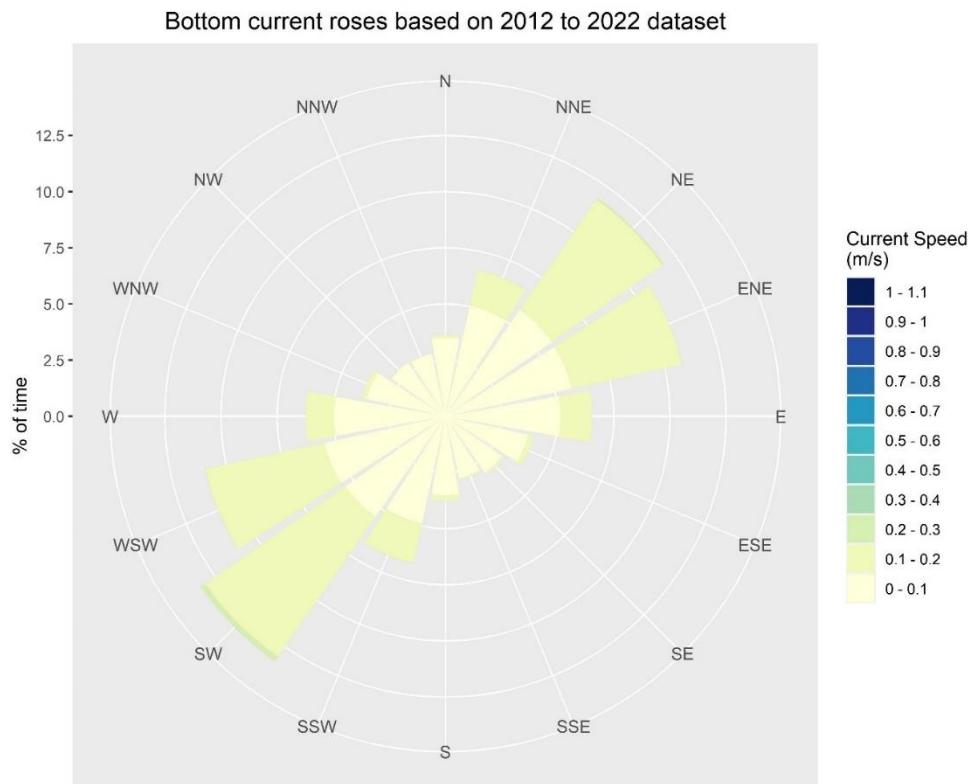


Figure 3-16 Current rose (10-year modelled bottom current)

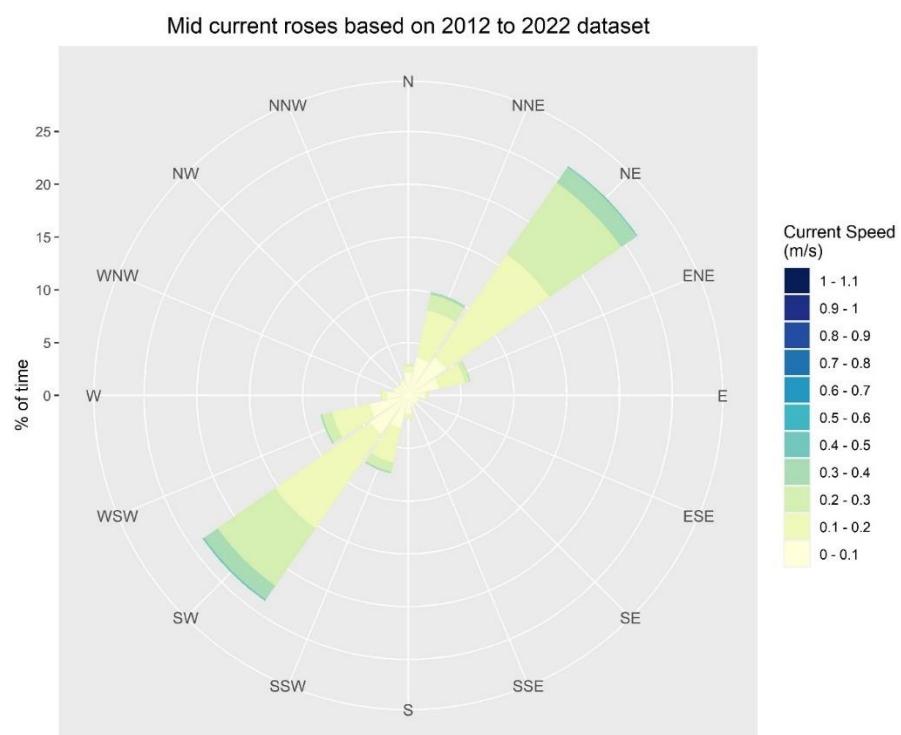


Figure 3-17 Current rose (10-year modelled mid current)

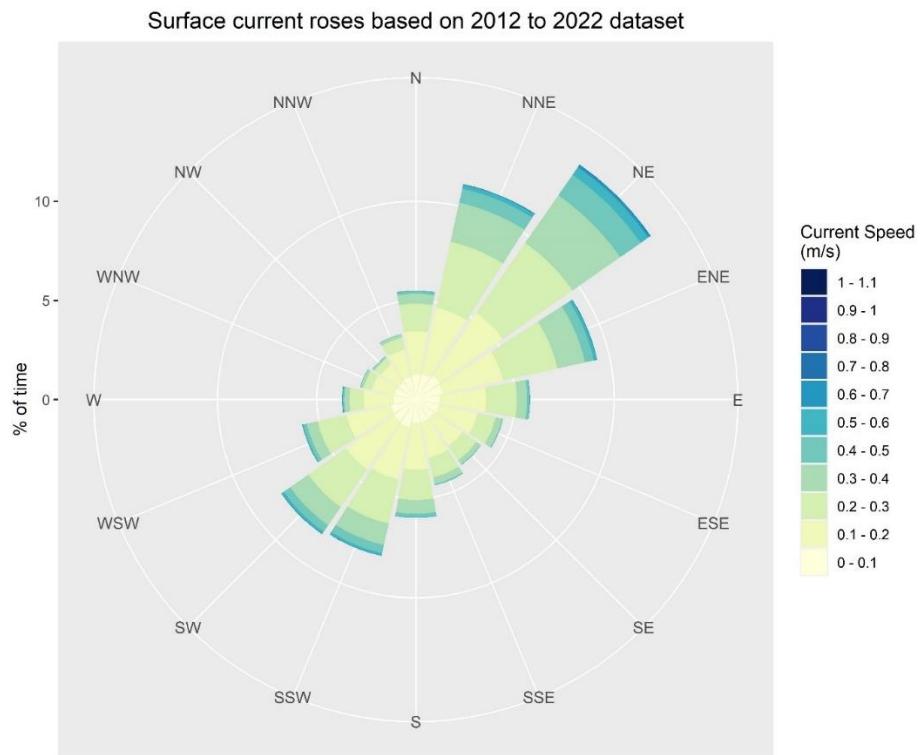


Figure 3-18 Current rose (10-year modelled surface current)

Table 3-17 Percent exceedance of bottom, mid and surface current speeds (derived from 10-year modelled dataset)

Exceedance threshold (m/s)	Bottom current speed exceedance (%)	Mid current speed exceedance (%)	Surface current speed (%)
0.1	31.45	62.72	79.92
0.2	0.36	23.15	44.02
0.3	0.00	4.20	18.10
0.4		0.27	5.73
0.5		0.01	1.58
0.6			0.36
0.7			0.07
0.8			0.01
0.9			0.01
1			0.00

Table 3-18 Monthly bottom, mid and surface current statistics (derived from 10-year modelled dataset)

	Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
bottom current speed (m/s)	mean	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09
	max	0.32	0.30	0.25	0.22	0.20	0.22	0.20	0.22	0.22	0.22	0.23	0.26
	min	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
	P25	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	P50	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
	P75	0.12	0.11	0.11	0.11	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11
	P90	0.14	0.15	0.14	0.14	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.14

	P95	0.16	0.17	0.16	0.15	0.14	0.14	0.14	0.15	0.16	0.15	0.15	0.16
mid current speed (m/s)	mean	0.14	0.14	0.14	0.14	0.13	0.14	0.14	0.14	0.15	0.15	0.14	0.14
	max	0.54	0.51	0.51	0.43	0.41	0.51	0.42	0.48	0.48	0.51	0.52	0.52
	min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	P25	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.07	0.07
	P50	0.13	0.12	0.12	0.13	0.12	0.13	0.13	0.13	0.14	0.14	0.13	0.13
	P75	0.19	0.19	0.20	0.19	0.19	0.19	0.20	0.20	0.21	0.21	0.19	0.19
	P90	0.25	0.26	0.26	0.26	0.24	0.24	0.25	0.26	0.27	0.28	0.25	0.25
	P95	0.28	0.29	0.30	0.29	0.28	0.28	0.28	0.30	0.31	0.32	0.29	0.28
surface current speed(m/s)	mean	0.20	0.22	0.21	0.19	0.19	0.19	0.20	0.21	0.20	0.20	0.20	0.20
	max	0.74	0.82	0.74	0.74	0.70	0.70	0.72	1.08	0.77	0.79	0.83	0.85
	min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	P25	0.12	0.13	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.11	0.12
	P50	0.19	0.20	0.19	0.18	0.17	0.18	0.17	0.18	0.18	0.19	0.18	0.19
	P75	0.27	0.29	0.28	0.26	0.25	0.25	0.25	0.27	0.28	0.27	0.27	0.27
	P90	0.36	0.38	0.37	0.34	0.33	0.33	0.34	0.36	0.37	0.36	0.36	0.36
	P95	0.41	0.44	0.42	0.40	0.37	0.39	0.39	0.42	0.43	0.42	0.42	0.42
bottom current direction (°)	mean	235.7	235.8	238.8	242.5	241.2	243.5	242.3	242.2	243.5	244.1	239.5	236.9
	mean	78.8	77.3	82.7	83.8	88.1	86.6	85.7	89.0	87.8	90.4	84.1	80.7
mid current direction (°)	mean	229.4	229.0	229.4	229.5	227.8	231.5	238.2	234.3	232.7	235.1	228.0	229.9
	mean	56.8	56.3	55.1	53.7	55.9	58.9	63.9	66.2	64.7	66.9	61.0	58.2
surface current direction (°)	mean	227.2	232.9	240.9	244.1	230.6	231.9	230.3	225.9	229.1	235.9	228.4	231.3
	mean	81.5	84.1	83.7	84.9	81.2	88.1	84.3	86.4	80.7	81.6	83.7	79.3

Table 3-19 Annual bottom, mid and surface current statistics (derived from 10-year modelled dataset)

	Statistic	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
bottom current speed (m/s)	mean	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09
	max	0.23	0.26	0.29	0.23	0.24	0.24	0.32	0.25	0.30	0.26	0.27
	min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	P25	0.05	0.05	0.05	0.05	0.05	0.07	0.07	0.06	0.06	0.06	0.06
	P50	0.07	0.07	0.07	0.07	0.07	0.09	0.09	0.09	0.09	0.09	0.09
	P75	0.10	0.10	0.10	0.10	0.10	0.12	0.12	0.12	0.12	0.11	0.12
	P90	0.12	0.12	0.12	0.12	0.13	0.15	0.15	0.15	0.15	0.14	0.14
	P95	0.14	0.14	0.14	0.14	0.14	0.16	0.16	0.16	0.16	0.16	0.16
mid current speed (m/s)	mean	0.13	0.13	0.13	0.13	0.13	0.15	0.15	0.15	0.15	0.15	0.15
	max	0.46	0.52	0.46	0.44	0.50	0.45	0.54	0.52	0.51	0.49	0.51
	min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	P25	0.07	0.07	0.06	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08
	P50	0.12	0.12	0.11	0.12	0.12	0.14	0.14	0.14	0.14	0.14	0.14
	P75	0.17	0.17	0.17	0.17	0.18	0.21	0.21	0.21	0.21	0.21	0.20
	P90	0.23	0.23	0.23	0.23	0.24	0.27	0.27	0.28	0.27	0.27	0.27
	P95	0.26	0.26	0.27	0.26	0.27	0.31	0.31	0.31	0.31	0.31	0.31
surface current speed(m/s)	mean	0.18	0.19	0.18	0.20	0.19	0.20	0.22	0.21	0.21	0.21	0.20
	max	0.76	0.70	0.75	0.82	1.07	0.74	0.73	0.75	1.08	0.69	0.79
	min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	P25	0.10	0.11	0.10	0.12	0.11	0.12	0.12	0.12	0.12	0.12	0.11
	P50	0.17	0.17	0.16	0.18	0.18	0.19	0.20	0.19	0.19	0.19	0.18
	P75	0.25	0.25	0.24	0.26	0.26	0.27	0.29	0.28	0.28	0.28	0.27
	P90	0.33	0.33	0.32	0.35	0.34	0.36	0.38	0.36	0.39	0.36	0.36
	P95	0.38	0.38	0.37	0.40	0.39	0.41	0.43	0.43	0.45	0.42	0.43

bottom current direction (°)	mean	241.7	239.5	240.1	240.8	241.7	238.2	241.7	239.6	239.5	242.1	240.3
	mean	85.3	86.9	88.1	86.4	84.4	85.3	85.2	83.0	82.7	83.5	80.9
mid current direction (°)	mean	227.7	231.4	232.6	231.2	229.9	229.8	232.3	229.3	233.7	233.1	232.5
	mean	60.5	61.9	58.9	62.2	59.1	60.2	57.1	59.2	60.8	59.2	59.2
surface current direction (°)	mean	229.9	236.3	232.1	230.2	231.6	226.4	235.7	229.1	236.0	233.1	235.4
	mean	82.6	87.5	82.9	81.3	85.8	84.8	81.4	83.5	82.7	80.9	81.9

Table 3-20 Overall bottom, mid and surface current statistics (derived from 10-year modelled dataset)

Current variable	Statistic	Value
bottom current speed (m/s)	mean	0.09
	max	0.32
	min	0.00
	P25	0.06
	P50	0.08
	P75	0.11
	P90	0.14
	P95	0.15
mid current speed (m/s)	mean	0.14
	max	0.54
	min	0.00
	P25	0.07
	P50	0.13
	P75	0.19
	P90	0.26
	P95	0.29
surface current speed(m/s)	mean	0.20
	max	1.08
	min	0.00
	P25	0.11
	P50	0.18
	P75	0.27
	P90	0.35
	P95	0.41
bottom current direction (°)	mean	240.5
	mean	84.7
mid current direction (°)	mean	231.2
	mean	59.8
surface current direction (°)	mean	232.4
	mean	83.2

3.10 Currents – Extreme Conditions

The 1- and 50-year extreme omni directional bottom, mid and surface current speeds, calculated from a 10-year hourly NEATL timeseries are presented in Table 3-21 and Figure 3-19 to Figure 3-21. The GEV methodology was chosen to calculate the extreme values for current speeds and the peaks-over-threshold method was chosen to extract discrete extreme events over the 10-year time period as input into the general extreme value analysis.

Table 3-21 Omni-directional bottom, mid and surface current extreme return values statistics (derived from 10-year modelled dataset)

	1-Year	50-Year
Bottom current speed (m/s)	0.23	0.36
Mid current speed (m/s)	0.44	0.58
Surface current speed (m/s)	0.67	1.10

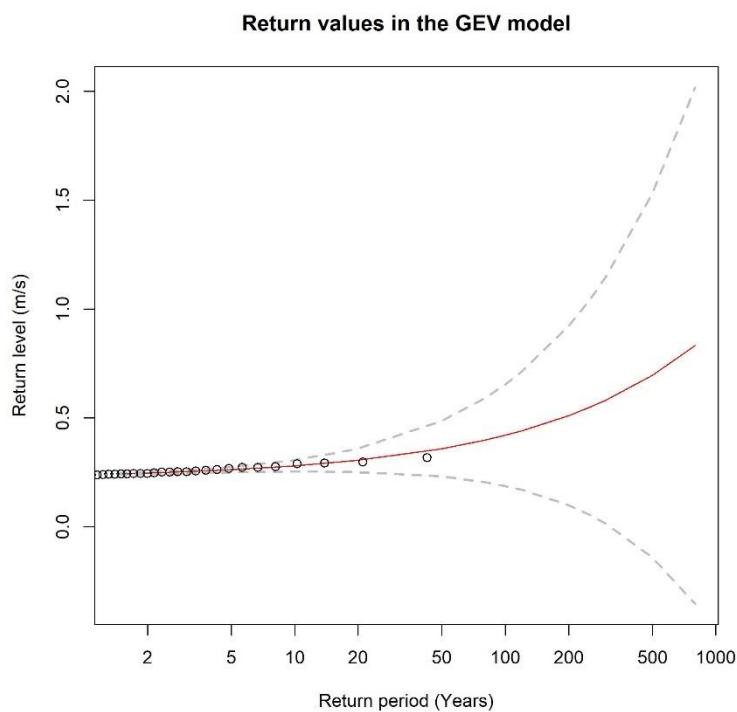


Figure 3-19 Return values of bottom current speed (m/s) in the GEV model. Red curve represents the best fit with the data and aligns with the input data. Dashed lines represent the 95 % confidence intervals. Distribution parameters: location = 0.2395; scale = 0.0107; shape = -0.2974

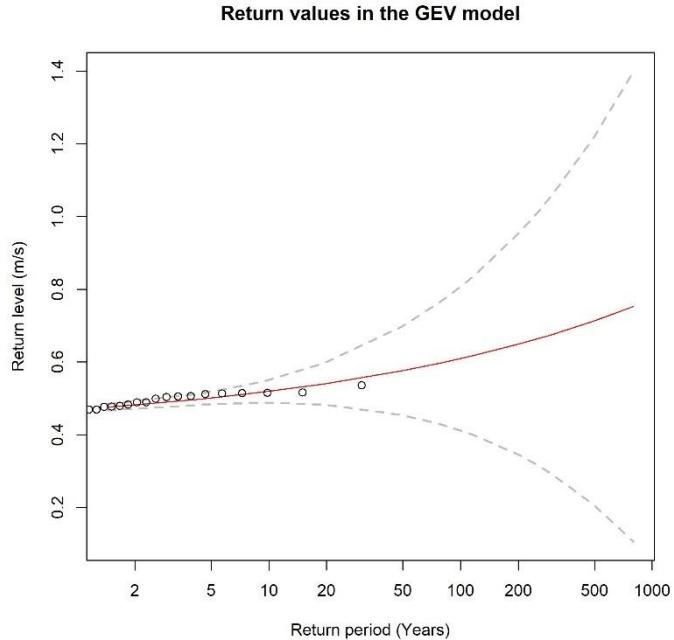


Figure 3-20 Return values of mid current speed (m/s) in the GEV model. Red curve represents the best fit with the data and aligns with the input data. Dashed lines represent the 95 % confidence intervals. Distribution parameters: location = 0.4716; scale = 0.0196; shape = -0.0085

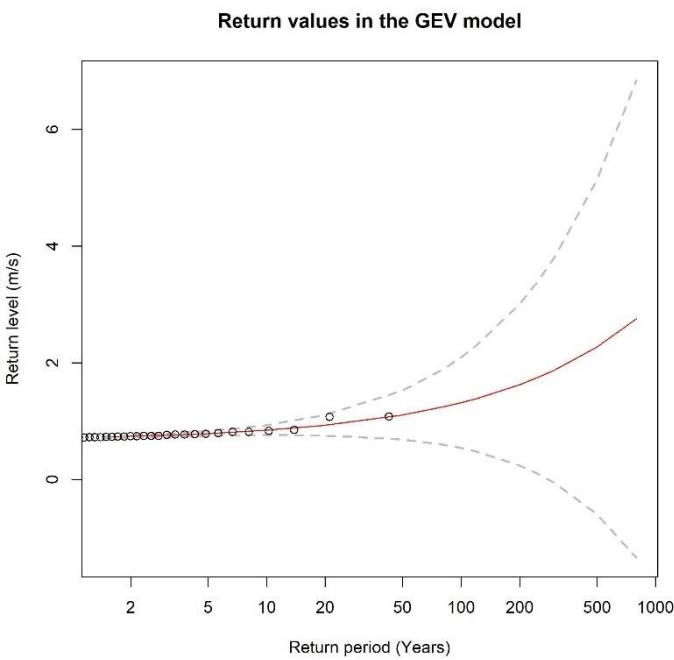


Figure 3-21 Return values of surface current speed (m/s) in the GEV model. Red curve represents the best fit with the data and aligns with the input data. Dashed lines represent the 95 % confidence intervals. Distribution parameters: location = 0.715; scale = 0.031; shape = 0.4082

3.11 Marine Growth

As no confirmed measurements have been carried out, marine growth thicknesses for design for both cases are based on recommended values for UK waters in DNVGL-ST-0437 [11]. These are summarised in Table 3-22. The dry density of marine growth will be taken as 1325 kg/m³ (DNVGL-ST-0437 [11]).

Table 3-22 Marine growth thickness

Depth below MWL (m)	Marine Growth Thickness (mm)
-2 to 40	100
> 40	50

3.12 Other parameters

Other environmental parameters are defined as follows (DNVGL-ST-0437 [11]):

- Sea water density: 1025 kg/m³ (assumed in lieu of site-specific measurement)
- Sea water salinity: 3.5 %

4 Conclusion

A preliminary Front-End Engineering Design Metocean Study has been produced for IDEA-IRL's reference site 1. This reference site represents an area close to Moneypoint Offshore One located off the west coast of Ireland. A robust set of metocean parameters was produced that will be used to inform the design of the reference floating wind arrays in WP2. The results presented herein can only be considered as a pre-FEED study and are aimed to serve as input for preliminary design. This report will primarily serve as WP1 D1A, a technical report designed to feed directly into WP1 of the IEA TCP Wind Task 49 of the same name. This technical report will be integrated into WP1 D1B.

5 References

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Appendix

Scatter plots (all wind speeds)

Figure 0-1 Frequency of occurrence (%) scatter plot of T_p vs H_s (All wind speeds)

Occurrence values as %	Significant wave height (m)																				cumulative sum									
	0 - 0.5	0.5 - 1	1 - 1.5	1.5 - 2	2 - 2.5	2.5 - 3	3 - 3.5	3.5 - 4	4 - 4.5	4.5 - 5	5 - 5.5	5.5 - 6	6 - 6.5	6.5 - 7	7 - 7.5	7.5 - 8	8 - 8.5	8.5 - 9	9 - 9.5	9.5 - 10	10 - 10.5	10.5 - 11	11 - 11.5	11.5 - 12	12 - 12.5	12.5 - 13	13 - 13.5	13.5 - 14	14 - 14.5	14.5 - 15
0 - 0.5	0.00	0.04	0.06	0.04	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
0.5 - 1	0.00	0.12	0.19	0.12	0.07	0.04	0.02	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.78
1 - 1.5	0.01	0.23	0.34	0.21	0.14	0.08	0.04	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.84
1.5 - 2	0.00	0.33	0.50	0.32	0.20	0.11	0.05	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.41
2 - 2.5	0.01	0.39	0.68	0.45	0.26	0.16	0.08	0.05	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.52
2.5 - 3	0.01	0.49	0.84	0.58	0.33	0.19	0.11	0.05	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.16
3 - 3.5	0.01	0.53	1.01	0.67	0.41	0.22	0.15	0.06	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.13
3.5 - 4	0.01	0.59	1.18	0.87	0.48	0.29	0.18	0.09	0.04	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.75
4 - 4.5	0.01	0.56	1.35	1.02	0.60	0.34	0.20	0.10	0.06	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.27
4.5 - 5	0.00	0.52	1.46	1.14	0.71	0.38	0.23	0.15	0.06	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	24.02
5 - 5.5	0.00	0.47	1.64	1.27	0.82	0.46	0.26	0.15	0.08	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	29.22
5.5 - 6	0.00	0.37	1.59	1.42	0.89	0.55	0.30	0.17	0.10	0.04	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	34.69
6 - 6.5	0.00	0.25	1.54	1.51	0.98	0.61	0.32	0.19	0.11	0.05	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	40.30
6.5 - 7	0.00	0.12	1.35	1.57	1.10	0.69	0.41	0.20	0.12	0.05	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	45.96
7 - 7.5	0.00	0.05	1.15	1.57	1.17	0.76	0.43	0.24	0.14	0.07	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	51.61
7.5 - 8	0.00	0.01	0.79	1.52	1.24	0.84	0.46	0.28	0.16	0.09	0.04	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	57.07
8 - 8.5	0.00	0.00	0.48	1.32	1.21	0.88	0.53	0.32	0.19	0.10	0.05	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	62.20
8.5 - 9	0.00	0.00	0.25	1.10	1.17	0.89	0.55	0.35	0.20	0.13	0.06	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	66.96
9 - 9.5	0.00	0.00	0.12	0.78	1.09	0.91	0.61	0.37	0.24	0.14	0.08	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	44.41
9.5 - 10	0.00	0.00	0.04	0.50	0.57	0.97	0.61	0.34	0.21	0.15	0.09	0.05	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	71.37
10 - 10.5	0.00	0.00	0.01	0.30	0.72	0.80	0.62	0.48	0.29	0.18	0.11	0.05	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	75.40
10.5 - 11	0.00	0.00	0.00	0.14	0.54	0.71	0.64	0.51	0.32	0.20	0.11	0.06	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	82.31
11 - 11.5	0.00	0.00	0.00	0.05	0.35	0.56	0.61	0.51	0.34	0.22	0.14	0.08	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	85.23
11.5 - 12	0.00	0.00	0.00	0.02	0.19	0.43	0.52	0.50	0.36	0.23	0.16	0.10	0.05	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	87.81
12 - 12.5	0.00	0.00	0.00	0.00	0.10	0.27	0.41	0.44	0.35	0.25	0.18	0.11	0.06	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	90.03
12.5 - 13	0.00	0.00	0.00	0.00	0.00	0.04	0.16	0.30	0.39	0.33	0.26	0.20	0.12	0.06	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	91.95
13 - 13.5	0.00	0.00	0.00	0.00	0.01	0.09	0.19	0.28	0.29	0.24	0.18	0.13	0.08	0.04	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	93.54
13.5 - 14	0.00	0.00	0.00	0.00	0.00	0.04	0.11	0.20	0.23	0.22	0.17	0.13	0.08	0.05	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	94.82
14 - 14.5	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.12	0.19	0.20	0.17	0.13	0.10	0.06	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	95.91
14.5 - 15	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.06	0.12	0.16	0.15	0.12	0.11	0.06	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	96.78
15 - 15.5	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.08	0.09	0.09	0.09	0.07	0.04	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	97.53
15.5 - 16	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.06	0.08	0.06	0.03	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	98.9
16 - 16.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.06	0.08	0.06	0.03	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	98.53
16.5 - 17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.03	0.05	0.04	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	98.88
17 - 17.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.03	0.05	0.04	0.02	0.02	0.01	0.00	0.00	0											

IDEA-IRL Document WP1_D1A

3D Scatter plots (Vs-Hs-Tp)

IDEA-IRL Document WP1_D1A

IDEA-IRL Document WP1_D1A

IDEA-IRL Document WP1_D1A

IDEA-IRL Document WP1_D1A

IDEA-IRL Document WP1 D1A

IDEA-IRL Document WP1_D1A

IDEA-IRL Document WP1_D1A