NeuWave

Portwind Offshore Wind Farm

Hindcast Weather Window and Extreme Value Analysis

Customer Sample Report

Manchester, UK
August 13, 2025

Contents

1 | Disclaimer

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2 | Executive Summary

The following data sources were utilised:

- NeuWave-generated data at 500 metre (m) resolution for significant wave height, 10 m wind, swell wave height, peak wave period, mean wave direction, and current velocity.

- NeuWave-generated tidal current amplitude model based on tidal constituents modelling (uncorrected to buoy measured data).

- Industry-standard ERA5 wave parameters have also been used for comparison of accuracy with NeuWave-generated data:

  - significant wave height combining wind and swell waves,
  - mean wave direction,
  - peak wave period.

NeuWave wave and tidal hindast data is based on a 32 year time period over the client-selected simulation area with corner points (50.2, -5.7) NW and (49.2, -3.6) SE. This area corresponds to the proposed Portwind offshore wind farm [3].

3 | Normal Sea-State Conditions

NeuWave-generated data is used to calculate relevant statistics for the wave parameters, namely the mean, standard deviation, minimum, maximum, and 25th, 50th, 75th, 90th, and 95th percentiles. The statistics are calculated at each grid point and averaged over the area and for each month over the years 1990–2021. Table 3.1 shows the corresponding monthly statistics for significant wave height H_s, peak wave period T_p, and maximum wave height H_{max}, along with the monthly mean wave direction θ_{wave} (°).

Variable	Stat	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
H_s (m)	Mean	2.85	2.75	2.22	1.78	1.51	1.37	1.30	1.35	1.59	2.08	2.39	2.73
	Std	1.33	1.27	1.11	0.92	0.77	0.68	0.64	0.66	0.79	1.05	1.11	1.31
	Min	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	Max	8.37	8.23	7.07	6.15	5.21	4.41	4.24	4.54	5.23	7.01	7.18	8.27
	P_{25}	1.87	1.82	1.41	1.12	0.96	0.87	0.85	0.88	1.02	1.31	1.57	1.75
	P_{50}	2.65	2.55	2.03	1.61	1.37	1.24	1.18	1.22	1.45	1.89	2.24	2.54
	P_{75}	3.64	3.48	2.84	2.24	1.91	1.73	1.63	1.67	2.01	2.66	3.06	3.51
	P_{90}	4.70	4.46	3.72	2.99	2.52	2.29	2.16	2.22	2.65	3.47	3.91	4.53
	P_{95}	5.37	5.12	4.30	3.55	2.98	2.69	2.54	2.62	3.10	4.04	4.44	5.16
T_p (s)	Mean	11.27	11.30	10.64	9.65	8.88	8.55	8.12	8.12	9.00	9.54	10.10	10.74
	Std	2.97	3.00	2.86	2.77	2.48	2.31	2.09	2.16	2.80	2.74	2.87	2.92
	Min	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83
	Max	18.34	18.43	17.72	16.51	16.13	15.32	15.81	16.10	17.22	16.99	17.24	18.21
	P_{25}	9.30	9.31	8.83	7.67	7.11	6.90	6.73	6.66	6.83	7.60	8.04	8.78
	P_{50}	11.87	11.77	11.21	10.06	9.17	8.91	8.33	8.31	9.17	9.76	10.45	11.10
	P_{75}	13.39	13.40	12.65	11.63	10.66	10.19	9.49	9.59	10.95	11.46	12.20	12.87
	P_{90}	14.59	14.77	13.80	12.90	11.82	11.28	10.55	10.66	12.48	12.92	13.52	14.18
	P_{95}	15.34	15.63	14.53	13.66	12.54	11.93	11.34	11.37	13.43	13.73	14.36	14.95
H_{max} (m)	Mean	5.31	5.11	4.13	3.30	2.81	2.54	2.42	2.50	2.95	3.86	4.45	5.09
	Std	2.48	2.37	2.06	1.70	1.42	1.27	1.18	1.23	1.47	1.96	2.06	2.44
	Min	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	Max	15.57	15.31	13.15	11.44	9.69	8.21	7.89	8.45	9.73	13.05	13.36	15.38
	P_{25}	3.48	3.39	2.62	2.09	1.79	1.62	1.58	1.64	1.90	2.44	2.93	3.25
	P_{50}	4.93	4.75	3.77	2.99	2.55	2.30	2.20	2.27	2.69	3.52	4.17	4.72
	P_{75}	6.77	6.47	5.29	4.16	3.55	3.22	3.03	3.11	3.74	4.96	5.69	6.53
	P_{90}	8.74	8.29	6.92	5.56	4.70	4.25	4.02	4.14	4.93	6.46	7.27	8.42
	P_{95}	9.98	9.52	8.00	6.61	5.54	5.00	4.73	4.88	5.77	7.51	8.26	9.59
θ_{wave} (°)	Mean	236.48	241.26	238.31	234.36	231.81	244.13	253.19	252.14	239.15	231.75	244.33	236.04

Table 3.1: Summary of monthly statistics for the significant wave height H_s (m), peak wave period T_p (s), and maximum wave height H_{max} (m), for the years 1990–2021, along with the monthly mean wave direction θ_{wave} (°).

4 | Weather-Window Estimation

A weather-window analysis is carried out using our 32-year NeuWave-generated data for the client-selected 6-hour window duration and variable threshold combination of 10 m wind speed $U_{10} = 7.5 \text{ ms}^{-1}$ and significant wave height $H_s = 2.5$ m. We calculate two weather window tables: the first is a percentage-based weather window shown in Table 4.1a, and the second is a coverage-based weather window shown in Table 4.1b.

The percentage-based table (4.1a) shows the availabile percentage of time each month that you could start a 6-hour job under the conditional limits across the site, i.e., "During March, a 6-hour window with $H_s \leq 2.5m$ and $U_{10} \leq 7.5\text{ms}^{-1}$ was available 36 % of the time on average across the site."

The coverage-based table (4.1b) shows the integer count of distinct 6-hour windows for various percentage area coverages across the site, i.e., "During March, there were 23 distinct 6-hour windows where the condition $H_s \leq 2.5$ m and $U_{10} \leq 7.5\text{ms}^{-1}$ was true for at least 95 % of the site area (95 % coverage across the site)."

(a) Percentage-based

Combination	Window (h)	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
$H_s \leq 2.5$ (m), $U_{10} \leq 7.5$ (ms^{-1})	6	23	27	36	48	55	61	61	62	54	37	29	24

(b) Coverage-based

Combination	Window (h)	Coverage (%)	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
$H_s \leq 2.5$ (m), $U_{10} \leq 7.5$ (ms^{-1})	6	25	33	33	52	64	78	76	85	80	64	48	38	31
		50	24	24	40	53	65	66	74	70	55	40	28	23
		75	17	19	31	44	56	58	64	63	48	33	22	18
		90	14	16	26	39	51	53	59	58	43	29	18	15
		95	13	14	23	37	48	50	56	56	40	27	16	14

Table 4.1: Weather-window tables showing (a) the percentage of time each month for which a 6-hour weather window can be started, on average across the site, with significant wave height $H_s \leq 2.5$ m and 10 m wind speed $U_{10} \leq 7.5$ms^{-1}, and (b) the integer count of distinct 6-hour weather windows for which $H_s \leq 2.5$ m and $U_{10} \leq 7.5$ms^{-1} across at least 25, 50, 75, 90, and 95 % of the site area. Each table is calculated using 32 years of NeuWave-generated data.

5 | Extreme Sea-State Conditions

5.1 | Extreme Sea States

A generalised extreme value (GEV) analysis gives return values for 2-year, 50-year and 100-year extreme wave events. It is estimated with 100% chance that the 1-year return-period value will be exceeded at least once in a year, the 2-year return period will be exceeded at least once over a 2-year period, etc. It follows that, for a 50-year period, there is a 2% chance that the largest wave height will exceed the 50-year return value on any given year.

Given that the NeuWave dataset spans 32 years, a block-maxima approach is adopted here in the GEV analysis for significant wave height H_s (m). This is whereby the annual maximum value of H_s is chosen as the input into the GEV distribution model. Following this, the maximum wave height H_{max} (m) is calculated using the equation provided in IEC 61400-3-1: (2019) [2] and which is detailed in the Appendix, Section 8.1.1. The limits of wave period associated with maximum wave height, T_{ass} (s), as well as the corresponding limits of peak wave period T_p (s), can also be caluclated using equations detailed in the Appendix, Section 8.1.1. Note that a 1-hour sea state is used here.

Table 5.1 then shows the calculated extreme wave data values for 2, 50, and 100-year return periods. In addition, Figure 5.1 shows the return values of H_s calculated from the GEV model (using a block-maxima approach) with fitted distribution parameters: location = 8.002, shape = 0.081, and scale = 1.059. The return period is extrapolated to 1000 years with a line a best fit and 95% confidence intervals plotted. Note that the x-axis is a log axis.

Return Period (years)	H_s (m)	T_p (s) lower	T_p (s) upper	H_{max} (m)	T_{ass} (s) lower	T_{ass} (s) upper
2	8.38	11.40	14.69	15.59	10.26	13.22
50	11.55	13.38	17.24	21.48	12.04	15.51
100	12.07	13.68	17.63	22.45	12.31	15.86

Table 5.1.: Extreme wave data values for significant wave height H_s (m); upper and lower limits of T_p (s); maximum wave height H_{max} (m); and upper and lower limits of the wave period associated with maximum wave height, T_{ass} (s). Return periods are 2, 50, and 100 years.
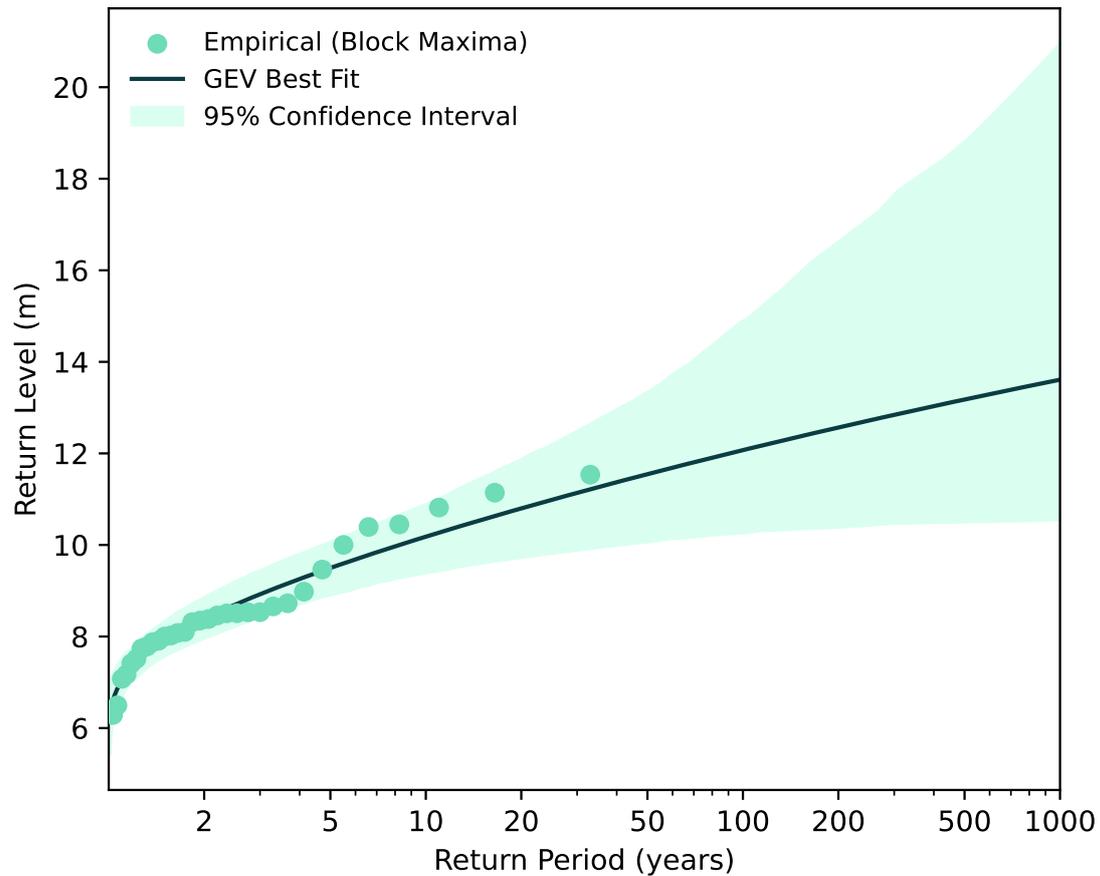
Figure 5.1: Return value plot for significant wave height H_s (m) calculated from the GEV model (using a block maxima approach) with fitted distribution parameters: location = 8.002, shape = 0.081, and scale = 1.059. The return period is extrapolated to 1000 years with a line a best fit and 95% confidence intervals plotted. Note that the x-axis is a log axis and has a left limit of 1 year (as standard).

6 | Data Sources Used

6.1 | MetOcean Conditions

Sea-surface data was generated by the NeuWave in-house model. The NeuWave model is based on the SWAN 3rd-generation spectral wave model [7, 6] but has been adapted for scalability and efficiency. The NeuWave model has a resolution of 500 m and generates data for the years 1990–2021. The model has been validated against third-party wave buoy sources available from CEFAS WaveNet [8] to produce a regional model that is consistent with locally measured sources. Bathymetry data from GEBCO [5] was used at a resolution of 250 m.

6.2 | Atmospheric Conditions

The ERA5 [4] climate reanalysis data set is used for oceanographic and atmospheric input variables in the NeuWave model; namely, 2-D wave spectra and 10 m surface winds. ERA5 is the fifth-generation atmospheric reanalysis model produced by Copernicus Climate Change Service (C3S) at the European Centre for Medium-Range Weather Forecasts (ECMWF); it produces data from 1950 to present and 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° x 0.25° (atmosphere variables) and 0.5° x 0.5° (ocean waves variables).

6.3 | Tidal Data

Tidal data is generated from the NeuWave tidal model which is a constituent based model used to calculate astronomical tidal elevation amplitude and tidal currents in the Northerly and Easterly directions. As tidal surges are not considered in this report, the estimations for tidal amplitude have not been verified against time-dependent locally measured sources and instead serve as an estimate in the region of choice to aid timeline planning. Currents should therefore be interpreted with caution until in-situ measured data is collected. Astronomical tidal current direction and speed were used as input in the NeuWave spectral wave model to produce the downscaled output used in the report analysis.

7 | Surface-Wave Model Validation

The NeuWave surface-wave model is used to simulate over the proposed Portwind wind farm [3] area (50.2, -5.7) NW and (49.2, -3.6) SE for the years 1990–2021 and is validated at the Penzance Waverider, point (50.144, -5.504), for the year 2010. To gauge the predictive accuracy of the model in the region, statistical measures are gathered for the significant wave height H_s (m). The first is a simple time-series comparison of simulated data and measured buoy data: Figure 7.1 shows this for H_s from April to July 2010. In addition, Figure 7.3 shows a Quantile-Quantile (Q-Q) plot; Q-Q plots gives a simple yet powerful assessment of whether the simulated data conforms to the measured buoy data.

An ordinary least squares (OLS) estimates the relationship between a dependent variable and one or more independent variables by minimizing the sum of squared differences between observed and predicted values. The regression line represents the change in response between the measured and modelled data, with a regression slope close to 1 indicating that the wave model creates wave states that are similar to the measured data. Figure 7.2 shows OLS regression plots for H_s when considering simulated NeuWave data and measured buoy data.
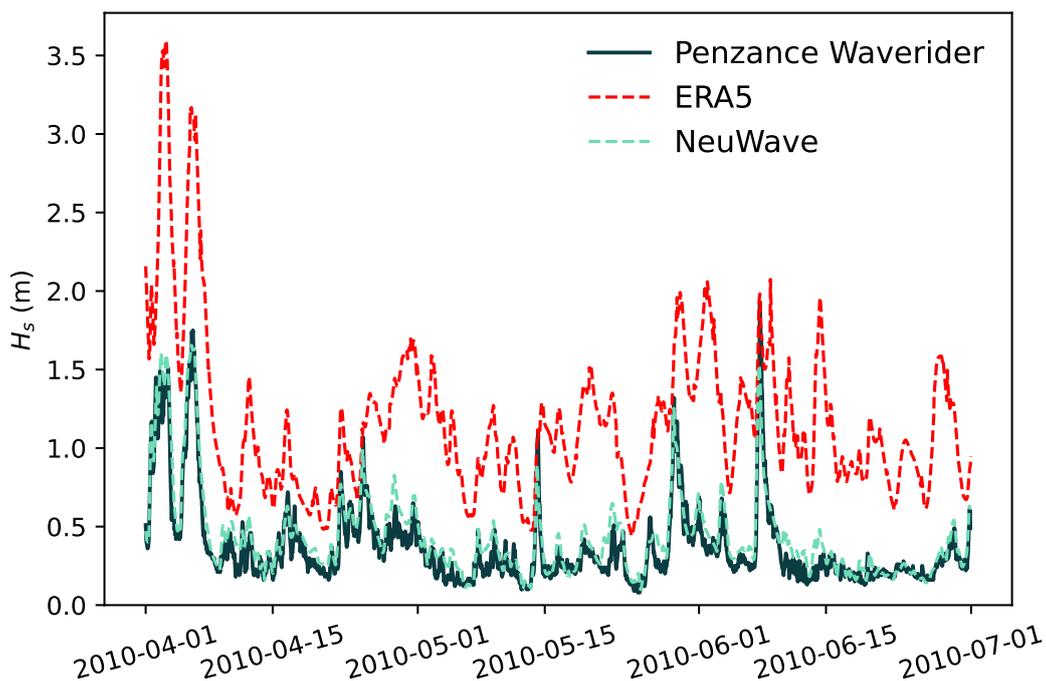

Figure 7.1: Time-series comparison chart between simulated NeuWave significant wave height H_s (m), measured buoy H_s, and ERA5 H_s, April to July 2010.
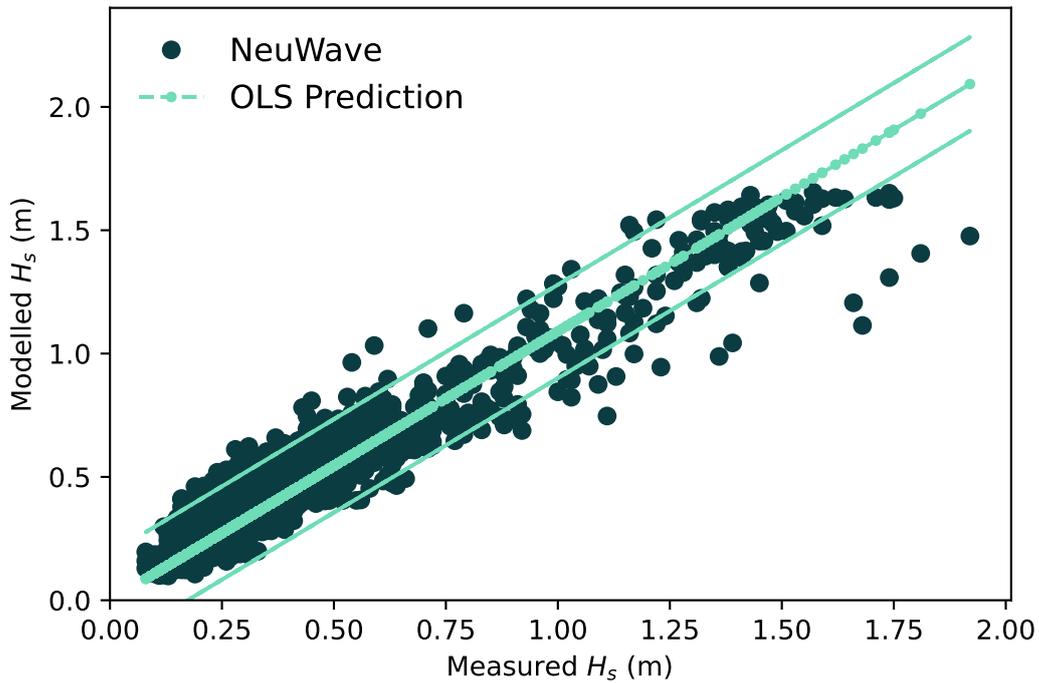
Figure 7.2: Ordinary least squares (OLS) regression plot for significant wave height H_s (m) when considering simulated NeuWave data and measured buoy data.
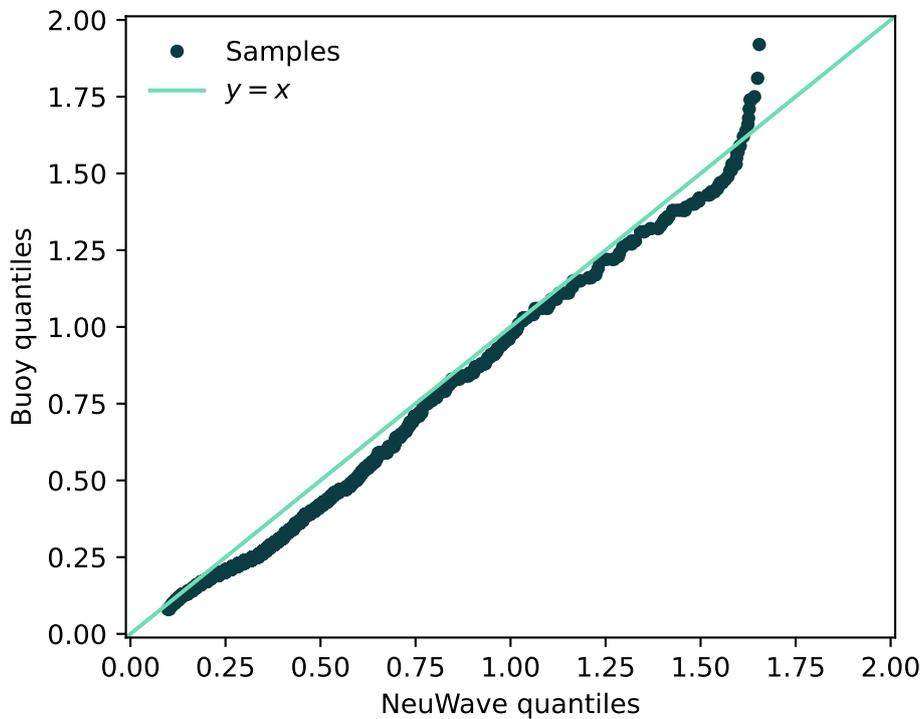

Figure 7.3: Quantile-Quantile (Q-Q) plot for significant wave height H_s (m) when considering simulated NeuWave data and measured buoy data.

References

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8 | Appendix

8.1 | Equation Disclosure

8.1.1 | Estimation of 1, 2, 50, and 100-year return values for extreme sea states

The recommended methodology from the IEC 61400-3-1 (2019) [2] is used to find the predicted 1, 50 and 100-year return values for max wave height and peak wave period. According to IEC methodology, the maximum wave height is determined using

$$H_{max} = 1.86 H_s,$$

where

- H_{max} is the maximum wave height,

- H_s is the significant wave height.

The associated wave period, known as T_{ass} or T_{Hmax}, is calculated based on its relationship with H_s: the upper and lower bounds are calculated using

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

where

- g is the acceleration due to gravity 9.81ms^{-1}.

DNV-RP-C205 (2021) [1] is then used to estimate the upper and lower limits of the peak wave period T_p:

$$T_{ass} = 0.9 T_p.$$