Wave resource characterization at the Atlantic Marine Energy Test Site AMETS A

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Contents

1. Introduction

The Atlantic Marine Energy Test Site (AMETS) is located west of Belmullet on the west coast of Ireland. This site is being developed by the Sustainable Energy Authority of Ireland (SEAI) to facilitate testing of full scale wave energy converters in an open ocean environment [1].

This report presents the results of an analysis of the characterization of the wave climate at AMETS Test Area A (AMETS A) using data measured at a location within the area since May 2012. The characterization follows the guidelines/recommendations published by the International Electrotechnical Commission (IEC) in the document: *IEC TS 62600-101:Marine energy Wave, tidal and other water current converters-Part 101: Wave energy resource assessment and characterisation* (referred to as IEC-62600-101 throughout the rest of this report) [2].

The purpose of the IEC-62600-101 is, according to its Introduction, to provide *a uniform methodology that will ensure consistency and accuracy in the estimation, measurement, and analysis of the wave energy resource at sites that could be suitable for the installation of Wave Energy Converters (WECs), together with defining a standardised methodology with which this resource can be described*.

The specification divides the resource assessment studies into three different categories: reconnaissance (Class 1), feasibility (Class 2), and design (Class 3). The broad characteristics of each class is shown in Table 1.1.

Class	Description	Uncertainty of wave energy resource parameter estimation	Typical long-shore extent
Class 1	Reconnaissance	High	Greater than 300 km
Class 2	Feasibility	Medium	20 km to 500 km
Class 3	Design	Low	Less than 25 km

Table 1.1: Classes of Resource Assessment (*IEC-62600-101)*

Class 1 studies are typically conducted at low to medium resolution, span a relatively large area, and produce estimates with considerable uncertainty. The other two classes assume that the focus is on particular sites or a single site and require greater certainty of results (and higher resolution in space and time in a modelling context). For Class 2 and Class 3 studies, the IEC-62600-101 assumes that the wave energy resource will be primarily defined using hydrodynamic models which have been successfully validated against measurements.

Given that this study uses measured data only for the classification analysis, the resource assessment of AMETS A should be considered a Class 1 study.

2. Description of study location

The Atlantic Marine Energy Test Site (AMETS) Is located off Belmullet in the west coast of Ireland (Figure 2.1). This is an open-ocean site with large wave energy potential and has been chosen by the SEAI to facilitate testing of full scale wave energy converters in a harsh wave environment.

There are two test areas defined within the site:

Test Area A is at 100m water depth and covers approx. 6.9 km2.
Test Area B is at 50m water depth and covers approx. 1.5 km2.

There have been long-term deployments of wave sensors at two locations (AMETS A and AMETS B) within the AMETS as part of an effort to understand the wave climate in the area. Figure 2.1 shows the location of the two sites relative to the Irish coast. The focus of this study is AMETS A which has a water depth of 100 metres.

Cahill and Lewis (2013) [3] carried out an assessment of the site using data acquired in 2010 only. This assessment did not follow the IEC-62600-101 standards. A number of assessments using modelled data have been undertaken. For example, Atan et al (2016) [4] used twelve years of modelled data to provide an assessment of annual and seasonal wave characteristics. The assessment did not strictly follow the IEC-62600-101 standards, but does provide similar analyses to that expected in an IEC-62600-101 study.

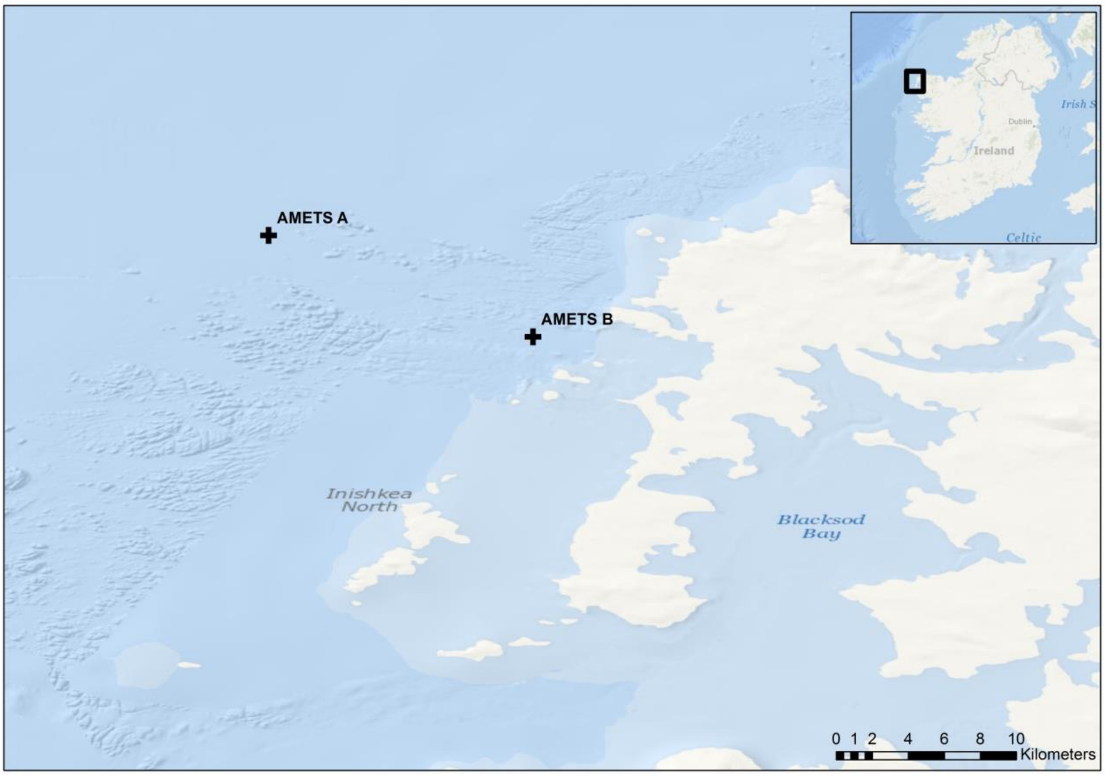

Figure 2.1: Location of Waverider buoys in AMETS

2.1 Wave data Measurement

The Marine Institute uses Datawell Directional Waveriders AMETS A to monitor wave conditions. Apart from a short period in 2019, a Waverider MkIII was deployed at the site The MkIII was replaced with a MkIV for the short period in 2019, but both versions of the Waverider measure waves using the same approach. The Directional Waveriders are spherical, surface-following buoys that measure wave height by means of an accelerometer mounted onto a platform within the buoy that remains horizontal under any movement expected to be experienced at sea. Wave direction is measured by correlating horizontal motion of the buoy with the vertical motions. The Directional Waverider provides average spectra every 30 minutes. They also provide, at the same interval, bulk parameters such as significant height and zero crossing wave period.

AMETS A, the focus of this study, has been occupied by a Directional Waverider near-continuously since May 2012 (Figure 2.2 demonstrates this in graphical form). The years 2012 and 2019 do have significant gaps. In September 2020, the buoy was deployed at a location approx. 1700 metres from the average location of the previous deployments (which were all grouped closely together). As a result, the data recorded since September 2020 was not analysed for this report.

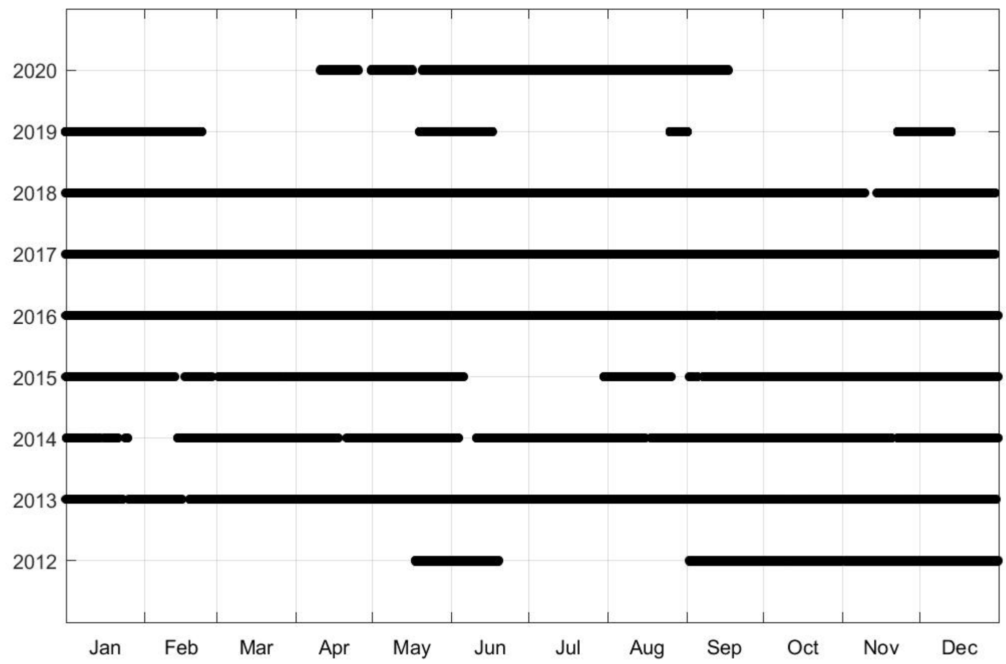

Figure 2.2: Datawell Directional Waverider Service history for AMETS A

3. Characterization Requirements

IEC-62600-101 requires the production of characteristic parameters to facilitate the analysis of the wave energy resource. Assuming directional spectra are available (which they are in this case) then the recommended characteristic parameters are those listed in 3.1 below (note a normal Class 1 study would not be expected to have the necessary raw data to calculate most of the parameters in 3.1).

3.1 Parameters required for characterization

Characteristic Wave Height

A spectrally derived estimate of the significant wave height using the zeroth spectral moment (m_0)

$$H_{\mathrm{m0}} = 4\sqrt{m_0}$$

Characteristic Wave Period

The preferred characteristic wave period is the energy period which is calculated using spectral moments

$$Te = m_{-1}/m_0$$

Spectral Width

The spectral width characterizes the relative spreading of energy along the wave spectrum. There are numerous ways to calculate this, but IEC-62600-101 defines it using spectral moments as the following

$$\epsilon_0 = \sqrt{\frac{m_0 m_{-2}}{m_{-1}^2} - 1}$$

Omni-directional wave power

The omni-directional, or directionally unresolved, wave power is the time averaged energy flux through an envisioned vertical cylinder of unit diameter, integrated from the sea floor to the surface. In essence, this means that we are calculating the total wave power coming from all directions at a site. This can be calculated from the wave spectral data using the formula:

$$J = \rho g \sum_{i,j} c_{g,i} S_{ij} \Delta f_i \Delta\theta_j$$

where

ρ = water density
g = gravitational acceleration constant
$c_{g,i}$ = group velocity at i^{th} frequency
S_{ij} = variance density at i^{th} frequency and at j^{th} discrete direction

Maximum directionally resolved wave power

It may useful to WEC developers to know the power available in the waves from all directions projected on to a given directional alignment rather than just the omni-directional wave power. This is termed directionally resolved wave power. Given a direction, θ, the directionally resolved wave power is the sum of the contributions of each component (e.g. wave power from every 1 degree increment from 0 to 360) with a positive component in that direction, and is calculated according to the equation:

$$J_\theta = \rho g \sum_{i,j} c_{g,i} S_{ij} \Delta f_i \Delta\theta_j \cos(\theta - \theta_j)\delta \qquad \begin{cases} \delta = 1, & \cos(\theta - \theta_j) \geq 0 \\ \delta = 0, & \cos(\theta - \theta_j) < 0 \end{cases}$$

The equation is the same as that for omni-directional wave power except for the extra element of "cos(θ – θj)" which is used to identify the mean directions associated with each frequency that have a positive power contribution for a given direction component (ranging from 0 to 360 degrees).

The maximum value of J_θ is named the maximum directionally resolved wave power and is denoted as $J_{\theta Jmax}$.

Direction of maximum directionally resolved wave power

The direction corresponding to the maximum directionally resolved wave power is named the direction of maximum directionally resolved wave power (denoted as θ_{Jmax}).

IEC-62600-101 notes that this direction is preferable to using peak wave direction (direction associated with spectral peak) because peak direction is highly variable/unstable and does not represent the direction of wave energy propagation.

Directionality Coefficient

The directionality coefficient is the ratio of the maximum directionally resolved wave power to the omnidirectional wave power.

$$d = \frac{J_{\theta_{\mathrm{Jmax}}}}{J}$$

This can be seen as representing the degree to which the wave power of a sea state follows a common direction (increasing values indicate narrowing directional spread).

3.2 Data preparation and analysis

The Datawell Directional Waveriders output spectral data every 30 minutes. In that 30-minute period, 8 consecutive spectra are calculated by the MkIII (this is 17 in the MkIV) and then averaged to produce the half-hourly spectrum. Bulk spectral parameters like H_{m0} and T_{m02} are calculated from the half-hourly spectra and are included in each spectrum data file.

All spectral data logged between May 2012 and Sep 2020 were assembled into one dataset. The bulk parameters were subjected to quality control and the spectra associated with erroneous bulk parameters were excluded from the analysis.

Most of the characteristic parameters that IEC-62600-101 requires are not available within the Directional Waverider spectra files and so need to be calculated. The calculations were performed in Matlab using the raw spectral data and following the formulae provided by IEC-62600-101 as detailed above in 3.1.

4. Wave Resource Characterization Results

If we are to strictly adhere to the resource assessment classes described in Section 5 of IEC-62600-101, then this resource assessment of AMETS A falls into Class 1 because neither a numerical wave model nor measure-correlate-predict (MCP) methods were used to generate the data on which the characteristic parameters are based.

IEC-62600-101 recommends that a minimum of 10 years of data be used for resource assessment, but accepts that this may not always be the case. AMETS A has measured data for the period May 2012 to Sep 2020 which is approx. 8 years of data. However, 2019 has a very limited data record and 2012 and 2020 are only partial years. So in practical terms, there are 6 years' worth of data on which to base long-term statistics.

4.1 Statistical Summary

Annual and monthly statistics for the wave energy resource parameters were calculated and are presented in Tables 4.1 to 4.7.

Table 4.1: Annual and monthly statistics for significant wave height (H_{m0})

Hm0 (m)	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	3.15	4.63	4.44	3.56	2.75	2.38	2.04	1.84	2.19	2.78	3.02	3.74	4.62
Standard Deviation	1.76	2.08	2.04	1.64	1.26	1.20	1.06	0.86	0.92	1.24	1.41	1.46	1.97
50th percentile	2.77	4.17	4.12	3.21	2.45	2.14	1.79	1.66	2.03	2.63	2.84	3.65	4.39
10th percentile	1.29	2.42	2.15	1.72	1.41	1.12	0.93	0.92	1.13	1.36	1.33	1.89	2.29
90th percentile	5.51	7.65	6.94	5.90	4.52	4.00	3.38	3.00	3.46	4.36	4.89	5.73	7.35
Max	15.03	14.15	14.38	11.25	8.35	10.59	7.00	6.82	6.80	9.53	9.81	10.49	15.03
Min	0.32	1.15	1.25	0.77	0.67	0.55	0.49	0.32	0.66	0.56	0.65	0.97	0.99
Monthly Variability	2.79	---	---	---	---	---	---	---	---	---	---	---	---

Table 4.2: Annual and monthly statistics for energy period (Te)

Te (s)	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	8.98	10.37	10.36	9.72	9.07	8.26	7.72	7.32	7.56	8.61	9.03	9.70	10.22
Standard Deviation	1.81	1.61	1.67	1.61	1.69	1.36	1.29	1.17	1.23	1.38	1.57	1.44	1.65
50th percentile	8.88	10.20	10.28	9.71	8.92	8.24	7.64	7.19	7.46	8.57	8.91	9.68	10.23
10th percentile	6.73	8.45	8.32	7.79	7.09	6.53	6.09	5.91	6.10	6.92	7.12	7.82	8.04
90th percentile	11.40	12.46	12.61	11.82	11.37	9.95	9.43	8.90	9.16	10.33	11.08	11.53	12.35
Max	16.79	16.49	16.23	15.90	16.42	15.92	12.56	11.83	14.40	14.60	15.38	15.19	16.79
Min	4.07	6.29	5.50	4.70	4.73	4.83	4.48	4.07	4.67	4.89	4.90	5.70	5.70
Monthly Variability	3.05	---	---	---	---	---	---	---	---	---	---	---	---

Table 4.3: Annual and monthly statistics for omni-directional wave power (J)

J (kW/m)	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	70.78	155.03	144.01	83.96	46.90	33.02	22.57	16.87	23.48	44.01	56.44	85.76	149.04
Standard Deviation	110.13	183.39	178.45	93.22	55.71	49.19	30.24	21.44	26.01	51.68	66.09	79.66	161.36
50th percentile	33.64	90.18	87.42	49.28	26.90	18.55	12.05	9.52	14.99	29.22	36.07	64.08	99.79
10th percentile	5.90	25.88	21.24	12.30	7.86	4.50	2.91	2.76	4.14	6.75	6.48	16.01	21.36
90th percentile	170.73	377.35	310.33	201.73	108.28	75.27	50.86	39.39	51.66	95.16	125.43	186.12	343.28
Max	2082.93	1747.65	1665.25	960.12	510.89	981.62	256.02	272.93	301.09	619.77	720.37	906.20	2082.93
Min	0.00	4.54	6.93	2.56	1.89	0.91	0.72	0.37	0.00	1.10	1.62	2.95	3.67
Monthly Variability	138.16	---	---	---	---	---	---	---	---	---	---	---	---

Table 4.4: Annual and monthly statistics for maximum directionally resolved wave power ($J_{\theta Jmax}$)

$J_{\theta Jmax}$ (kW/m)	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	67.99	150.19	138.89	80.21	44.67	31.64	21.46	16.14	22.45	42.22	53.48	82.34	143.55
Standard Deviation	108.38	181.41	176.72	91.57	54.94	48.66	29.69	21.09	25.78	51.10	64.84	78.95	159.29
50th percentile	31.53	85.85	82.79	46.16	25.41	17.35	10.98	8.87	14.00	27.60	33.35	60.58	94.14
10th percentile	5.03	23.01	18.62	10.51	6.19	3.72	2.45	2.41	3.48	6.06	5.58	13.39	19.28
90th percentile	165.09	366.44	304.49	194.71	105.03	73.06	49.50	38.21	50.04	92.73	120.46	182.68	334.79
Max	2067.18	1724.64	1655.75	932.74	497.47	936.96	254.61	266.74	298.13	618.53	712.73	893.72	2067.18
Min	0.00	3.25	4.36	1.38	1.38	0.48	0.52	0.34	0.00	0.84	1.03	1.89	2.46
Monthly Variability	134.05	---	---	---	---	---	---	---	---	---	---	---	---

Table 4.5: Annual and monthly statistics for direction of maximum directionally resolved wave power (θ_{Jmax})

θ_{Jmax} (deg)	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	286.94	283.22	281.47	291.10	297.23	293.03	292.53	279.64	281.84	287.00	286.11	293.38	278.80
Standard Deviation	35.27	28.38	31.40	38.81	38.63	40.87	40.34	27.56	35.64	33.16	35.61	32.84	30.61
50th percentile	280.00	281.00	278.00	278.00	282.00	275.00	276.00	278.00	276.00	285.00	282.00	289.00	276.00
10th percentile	234.00	249.00	242.00	74.00	54.00	20.00	23.00	245.00	231.00	233.00	230.00	244.00	235.00
90th percentile	325.00	320.00	315.00	321.00	336.00	325.00	333.00	315.00	325.00	321.00	322.00	337.00	318.00
Max	359.00	359.00	359.00	359.00	359.00	359.00	359.00	359.00	359.00	359.00	359.00	359.00	359.00
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	0.00
Monthly Variability	18.42	---	---	---	---	---	---	---	---	---	---	---	---

Table 4.6: Annual and monthly statistics for directionality coefficient (d)

d	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.92	0.95	0.94	0.92	0.91	0.92	0.91	0.93	0.93	0.93	0.91	0.93	0.94
Standard Deviation	0.09	0.06	0.08	0.09	0.10	0.09	0.10	0.08	0.09	0.08	0.10	0.09	0.07
50th percentile	0.96	0.97	0.96	0.95	0.95	0.95	0.95	0.96	0.96	0.96	0.95	0.97	0.97
10th percentile	0.81	0.87	0.85	0.80	0.78	0.79	0.74	0.82	0.82	0.84	0.78	0.81	0.86
90th percentile	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Max	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Min	0.38	0.47	0.42	0.42	0.42	0.42	0.47	0.46	0.38	0.41	0.39	0.43	0.47
Monthly Variability	0.04	---	---	---	---	---	---	---	---	---	---	---	---

Table 4.7: Annual and monthly statistics for spectral width (E_0)

E_0	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.32	0.31	0.31	0.32	0.32	0.32	0.33	0.33	0.32	0.32	0.33	0.31	0.31
Standard Deviation	0.06	0.04	0.05	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.05	0.04
50th percentile	0.31	0.30	0.30	0.30	0.31	0.31	0.32	0.32	0.31	0.31	0.31	0.30	0.30
10th percentile	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.27	0.27	0.26	0.26	0.26	0.26
90th percentile	0.39	0.37	0.37	0.39	0.41	0.40	0.42	0.42	0.39	0.39	0.41	0.38	0.37
Max	0.73	0.63	0.58	0.63	0.64	0.73	0.68	0.71	0.65	0.67	0.68	0.61	0.62
Min	0.17	0.21	0.19	0.20	0.18	0.17	0.18	0.20	0.20	0.18	0.20	0.19	0.21
Monthly Variability	0.02	---	---	---	---	---	---	---	---	---	---	---	---

4.2 Characterization plots

This section (and Appendices referenced in the sub-sections) presents Hs-Te joint distribution plots, rose plots, and cumulative distribution plots for the wave energy resource parameters.

4.2.1 H_{m0}-Te joint distribution

Figure 4.1 shows the joint distribution of H_{m0} and Te based on all data collected at AMETS A.

Appendix 1 (Figures A1 to A12) show the joint distribution of H_{m0} and Te based on all data collected at AMETS A divided into months.

The joint distribution plots show the proportional frequency of occurrence of sea states, parameterized in terms of the significant wave height, H_{m0}, and energy period, Te. The dimensions of each bin in the plots are 0.5m for H_{m0} and 1s for Te. As required by IEC-62600-101, bins with frequency of occurrence of less than 0.01% are represented by an asterix followed by the actual number of occurrences in that bin.

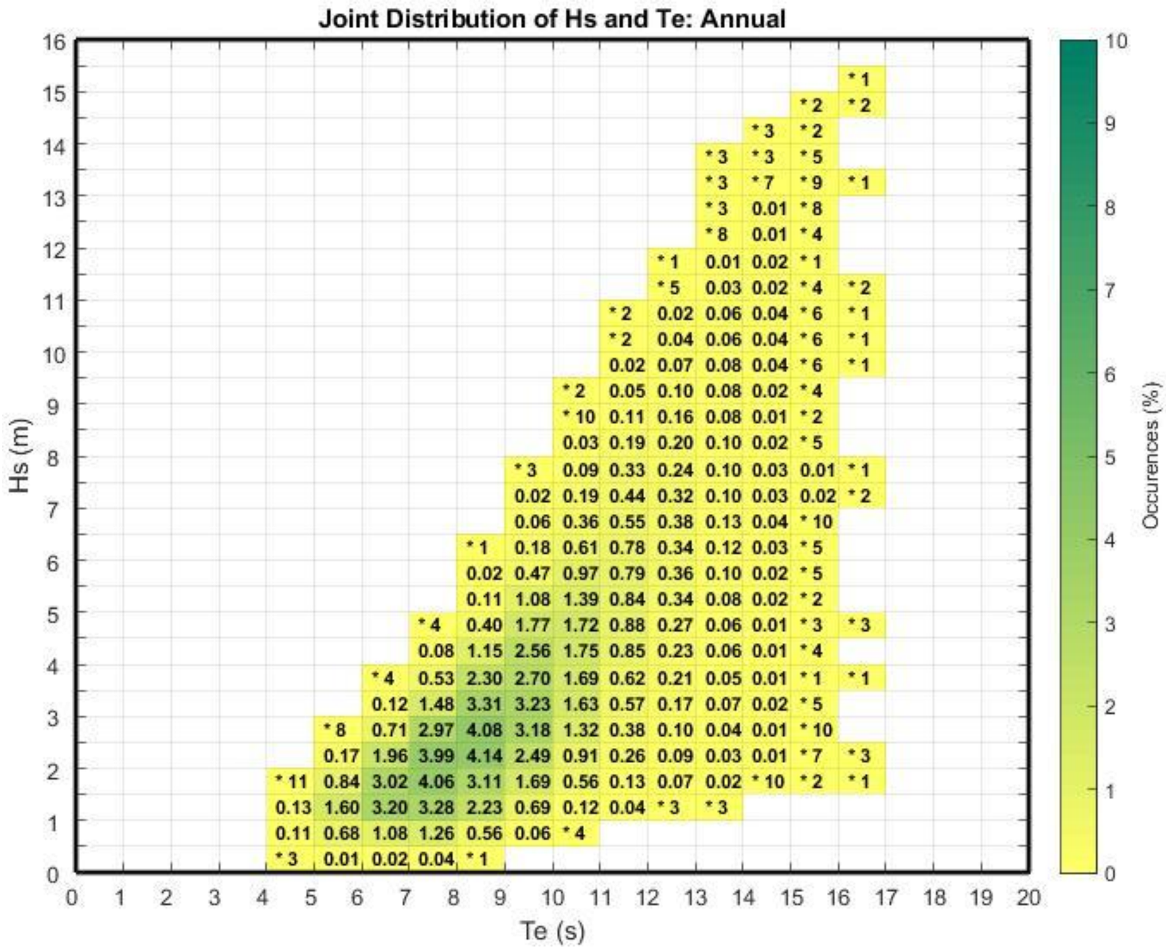

Figure 4.1: Joint distribution of H_{m0} and Te based on all data collected at AMETS A.

4.2.2 Wave power rose

Figure 4.2 shows a wave rose depicting the joint distribution of maximum directionally resolved wave power ($J_{\theta Jmax}$) and the direction of maximum directionally resolved power (θ_{Jmax}) based on all data collected at AMETS A.

Appendix 2 (Figures B1 to B12) show wave roses based on all data collected at AMETS A divided into months.

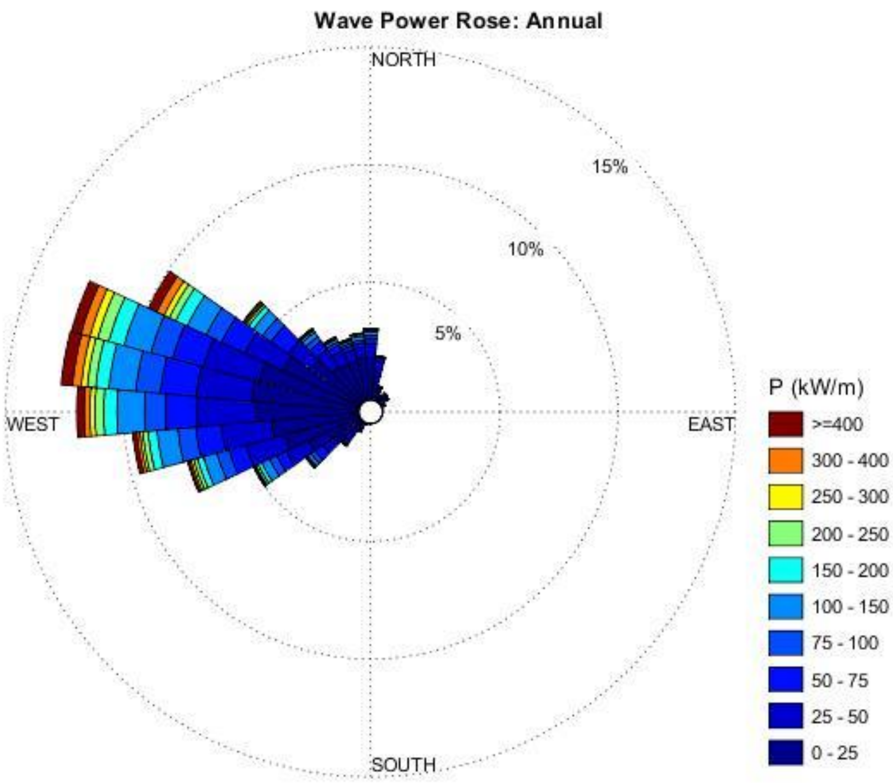

Figure 4.2: Wave power rose depicting joint distribution of $J_{\theta Jmax}$ and θ_{Jmax} based on all data collected at AMETS A.

4.2.3 Directionally resolved joint distributions of H_{m0} and Te

Figures 4.3 to 4.9 show directionally resolved joint distributions of H_{m0} and Te based on all data collected at AMETS A. The data is partitioned into 30-degree directional windows based on the direction of maximum directionally resolved power (θ_{Jmax}). As can be seen from the rose plot in Figure 4.2, some directional windows contain very few data points so they have not been included here. The 7 sectors included here account for 99.5% of all data recorded. Like Figure 4.1, bins with frequency of occurrence of less than 0.01% are represented by an asterix followed by the actual number of occurrences in that bin.

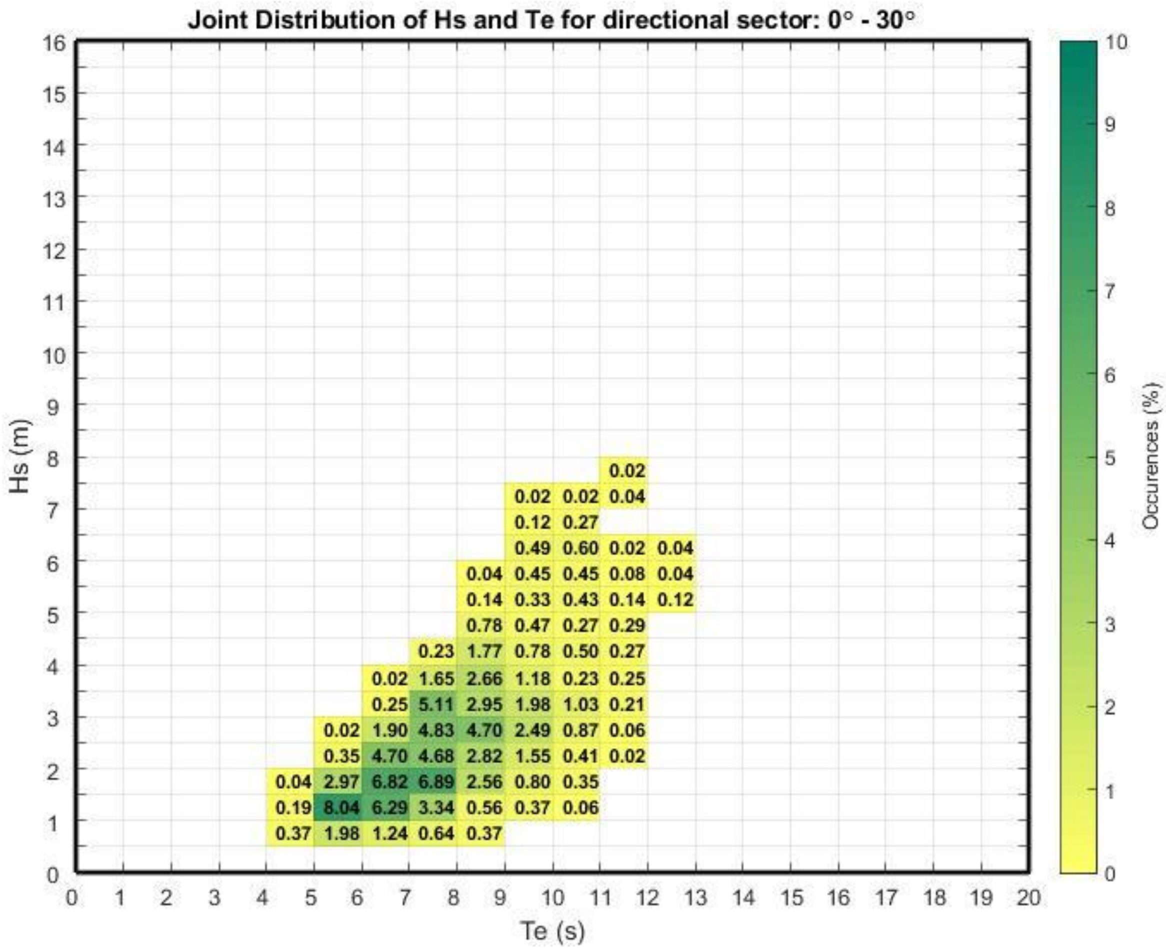

Figure 4.3: Joint distribution of H_{m0} and Te based on all data collected at AMETS A from directional sector 0° - 30°

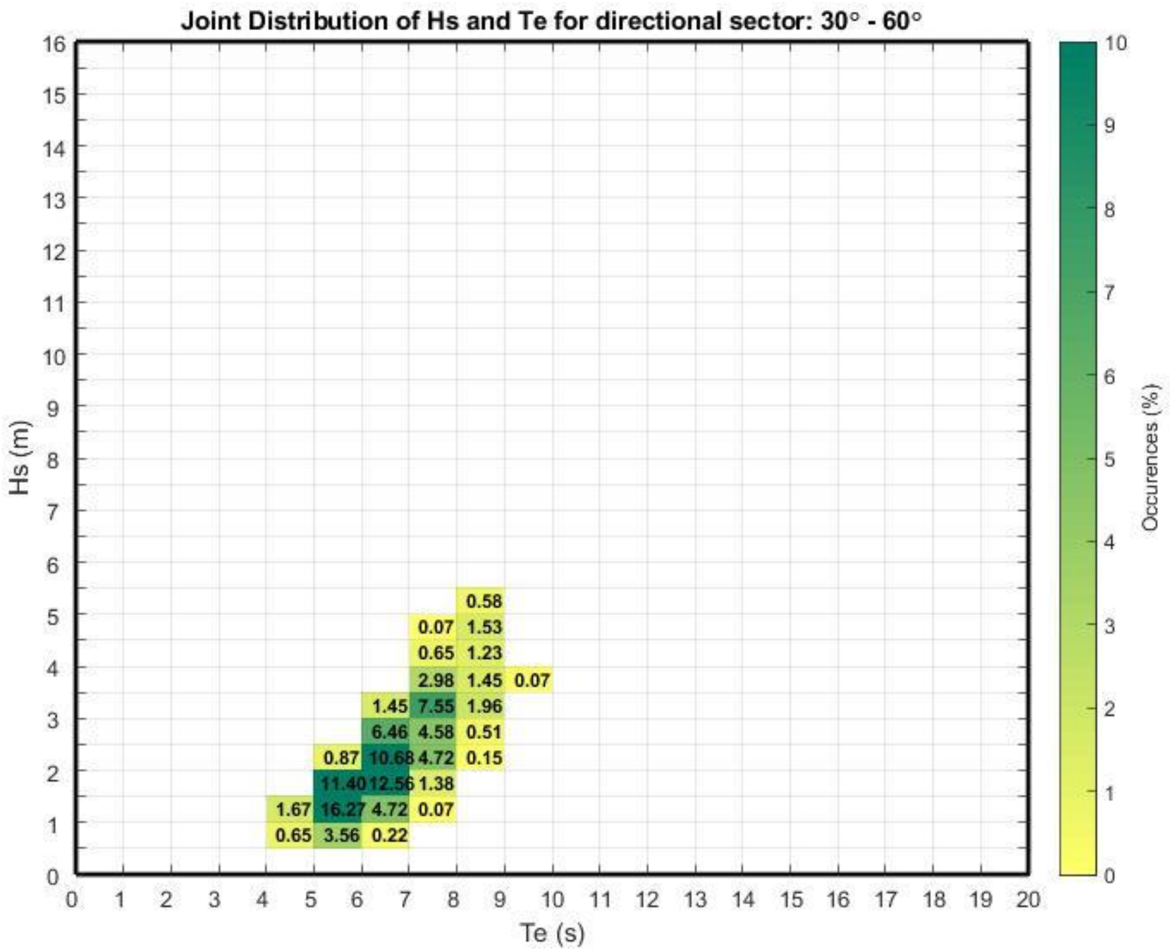

Figure 4.4: Joint distribution of H_{m0} and Te based on all data collected at AMETS A from directional sector 30° - 60°

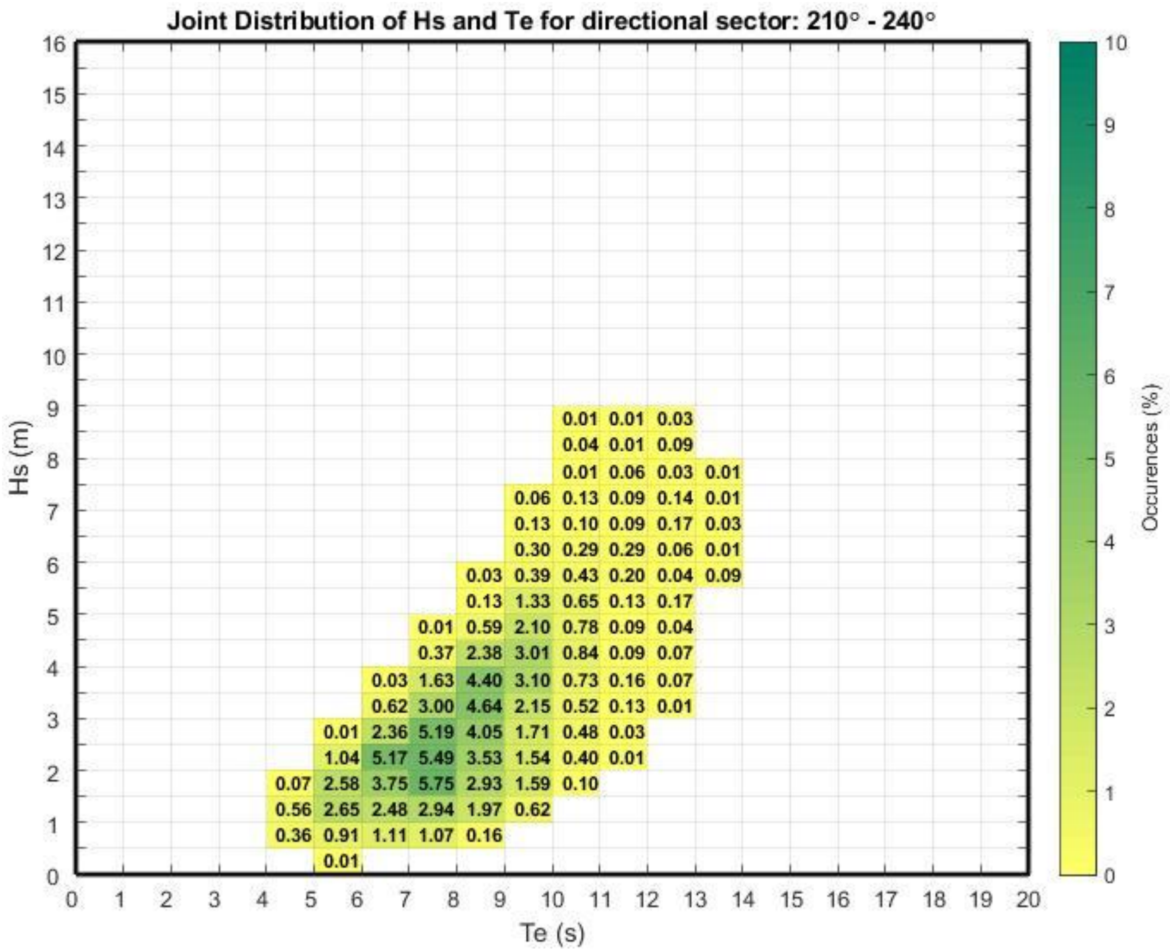

Figure 4.5: Joint distribution of H_{m0} and Te based on all data collected at AMETS A from directional sector 210° - 240°

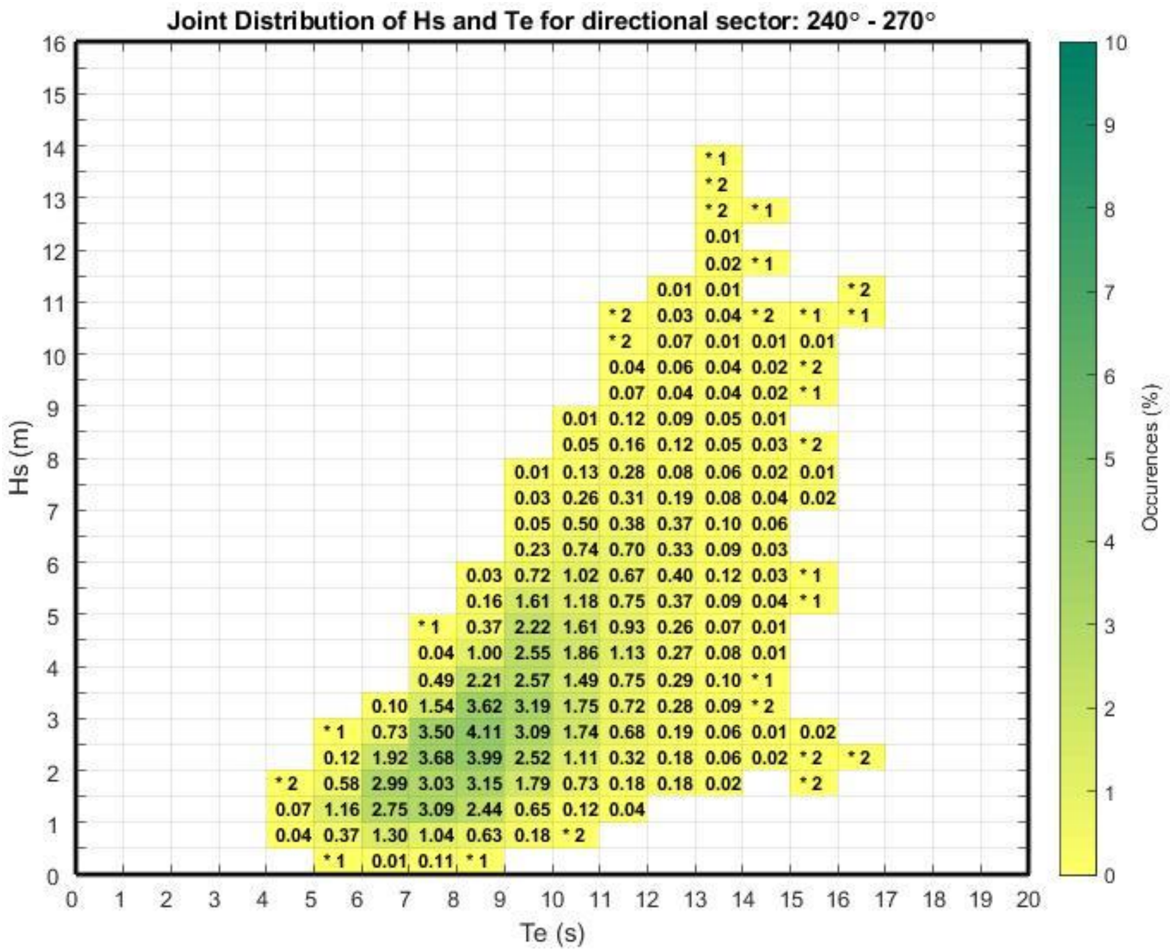

Figure 4.6: Joint distribution of H_{m0} and Te based on all data collected at AMETS A from directional sector 240° - 270°

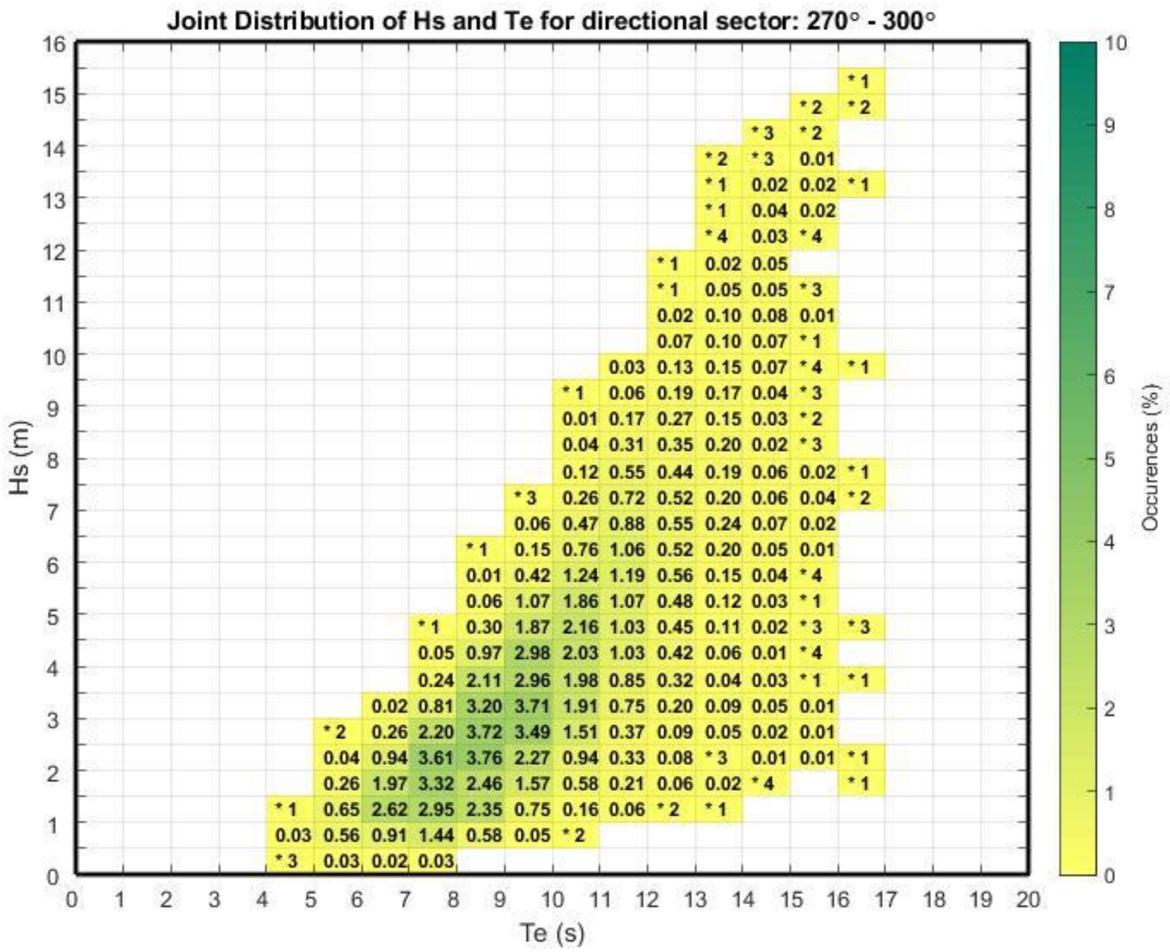

Figure 4.7: Joint distribution of H_{m0} and Te based on all data collected at AMETS A from directional sector 270° - 300°

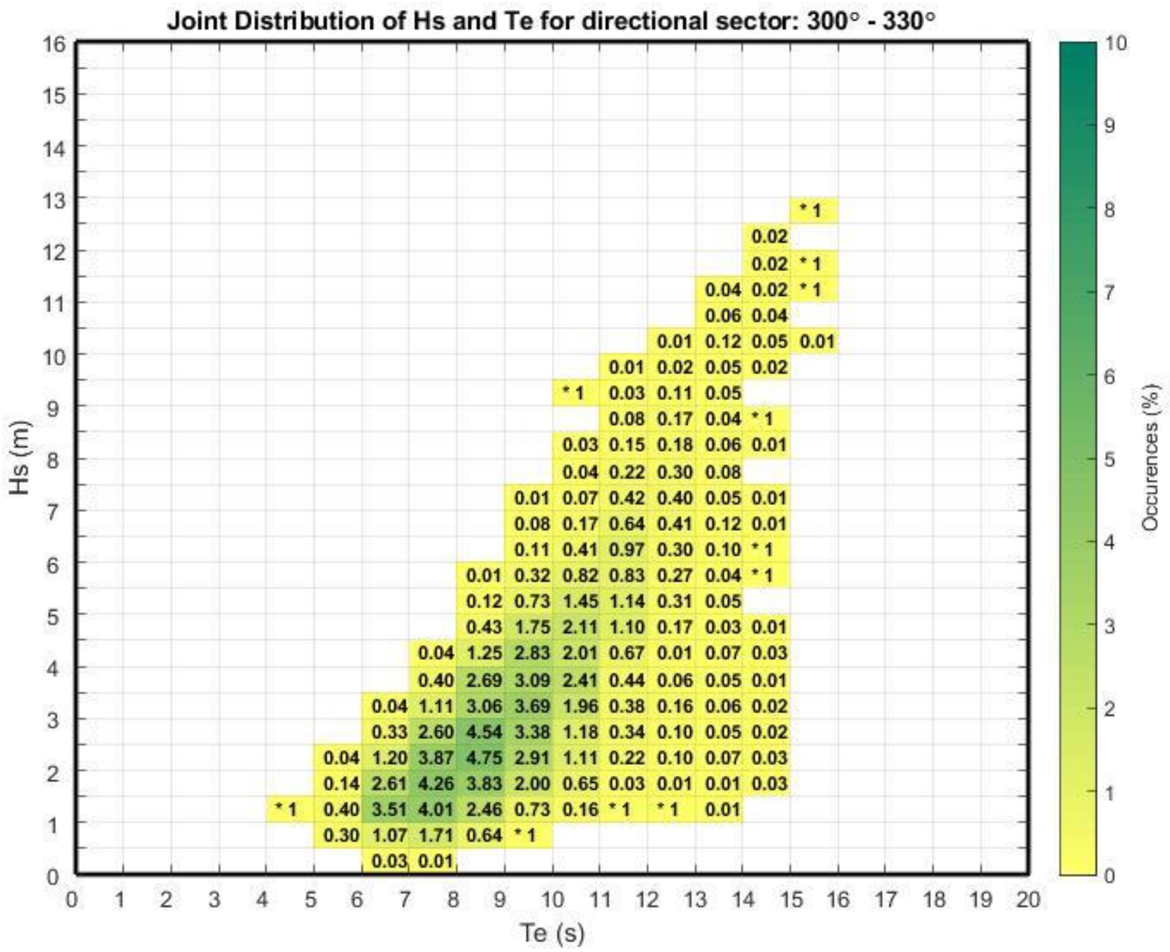

Figure 4.8: Joint distribution of H_{m0} and Te based on all data collected at AMETS A from directional sector 300° - 330°

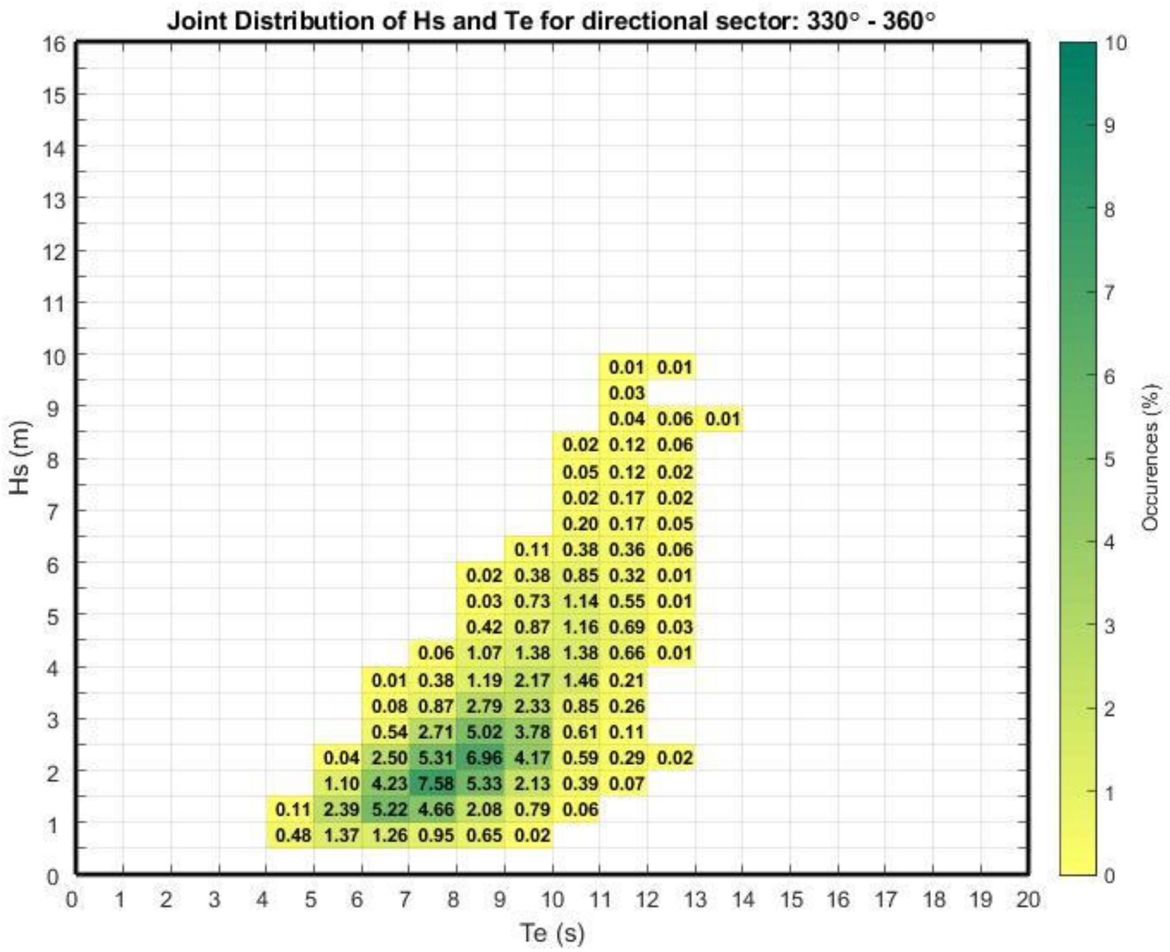

Figure 4.9: Joint distribution of H_{m0} and Te based on all data collected at AMETS A from directional sector 330° - 360°

4.2.4 Cumulative distribution plots

Figures 4.10 to 4.16 show whole series and monthly cumulative distributions of the wave energy resource parameters based on all data collected at AMETS A.

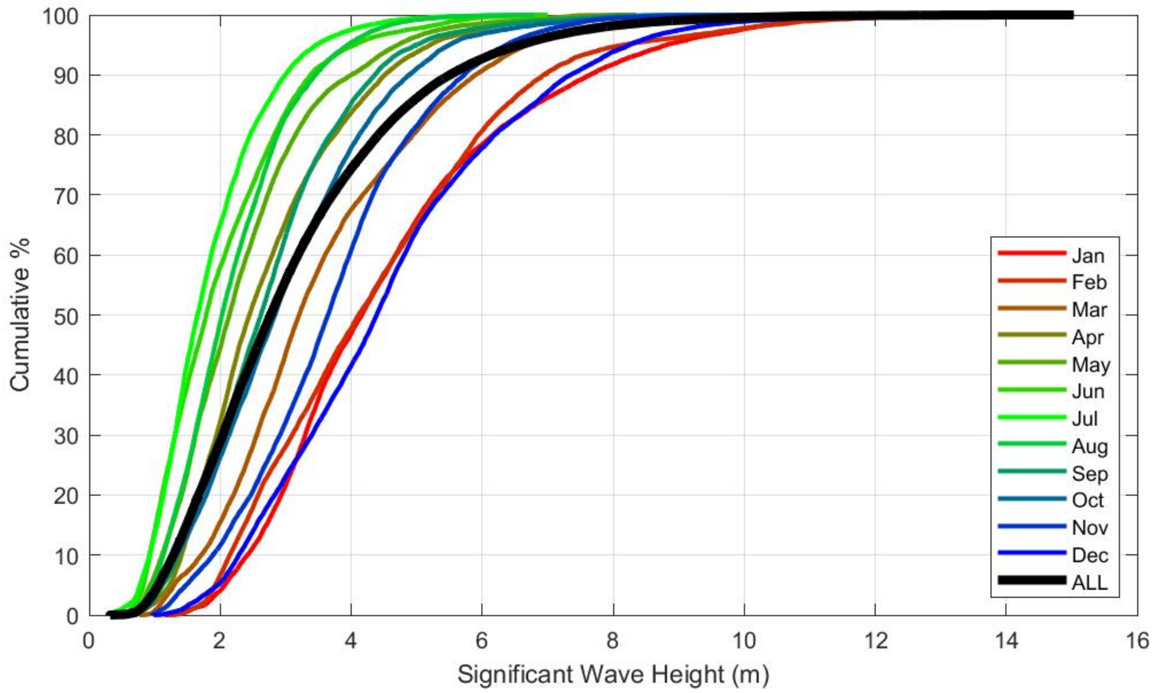

Figure 4.10: Cumulative distribution of significant wave height (H_{m0}) by month and whole series (ALL)

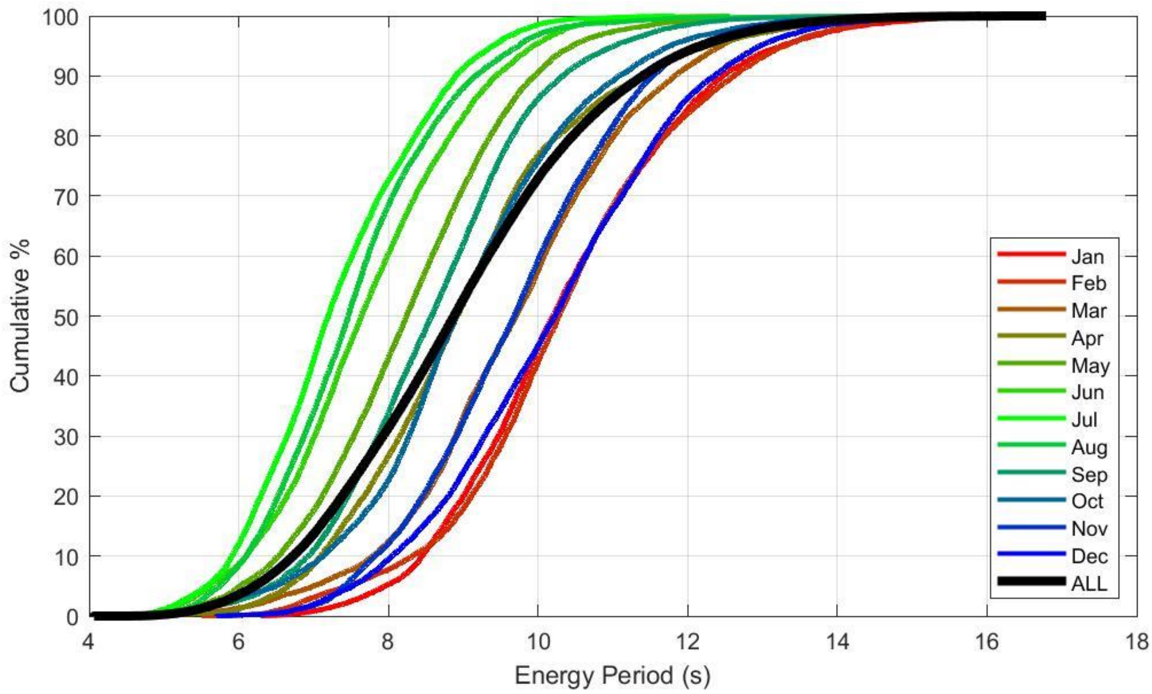

Figure 4.11: Cumulative distribution of energy period (Te) by month and whole series (ALL)

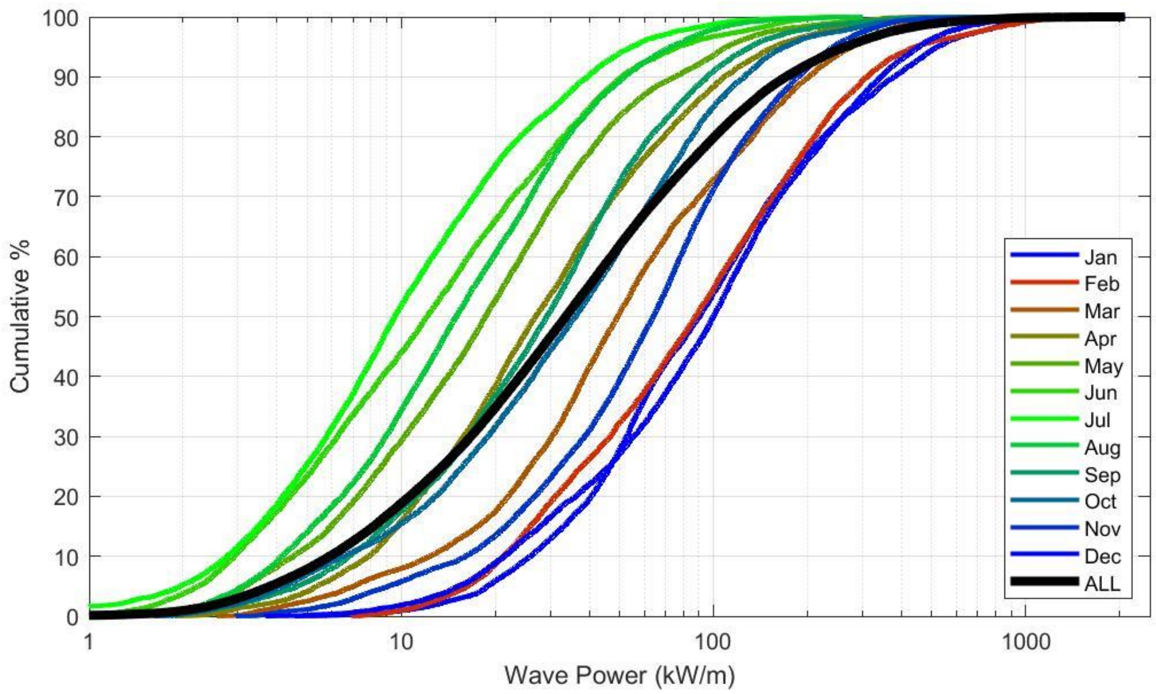

Figure 4.12: Cumulative distribution of omni-directional wave power (J) by month and whole series (ALL)

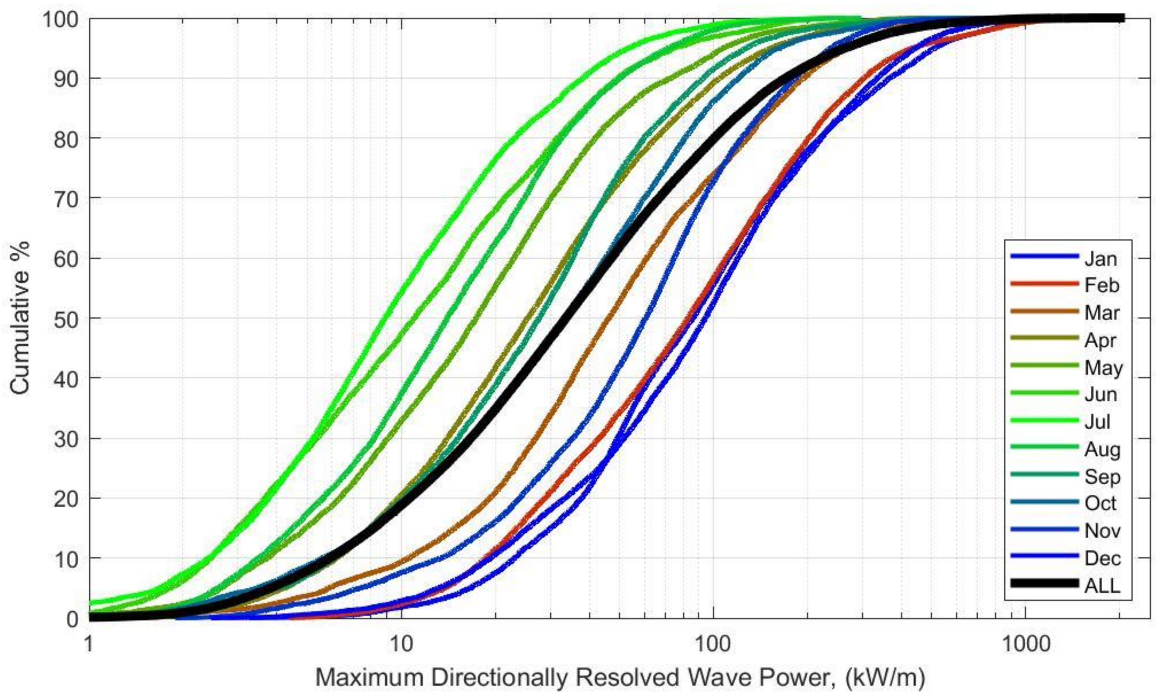

Figure 4.13: Cumulative distribution of maximum directionally resolved wave power ($J_{\theta Jmax}$) by month and whole series (ALL)

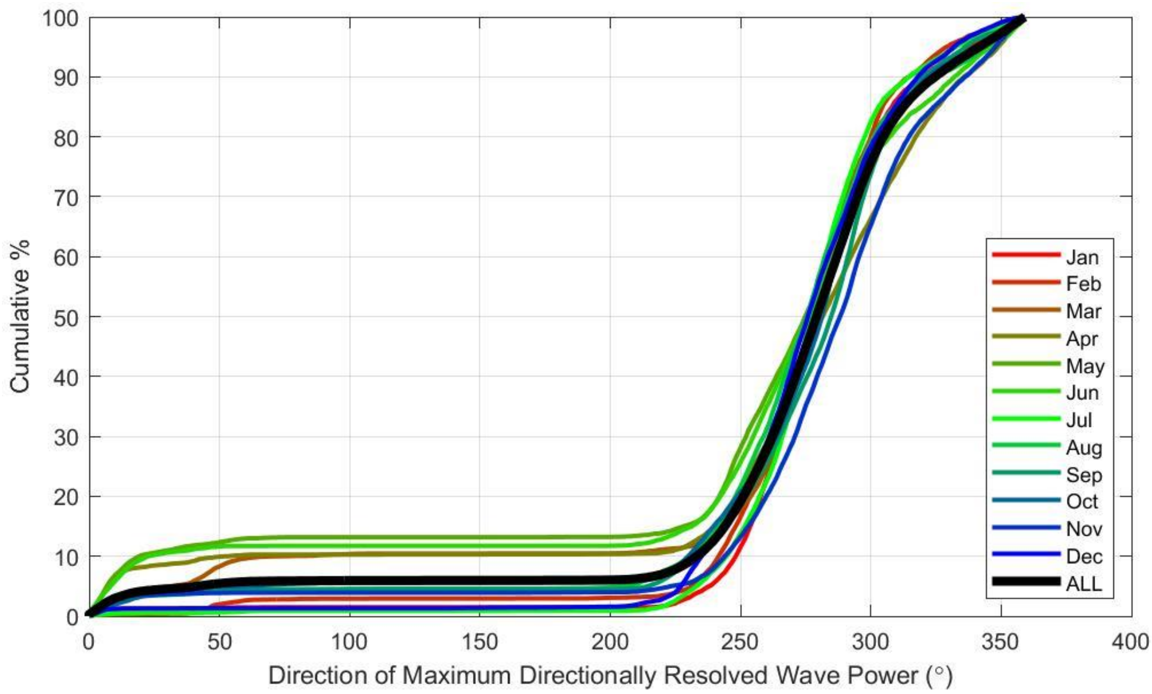

Figure 4.14: Cumulative distribution of the direction of maximum directionally resolved power (θ_{Jmax}) by month and whole series (ALL)

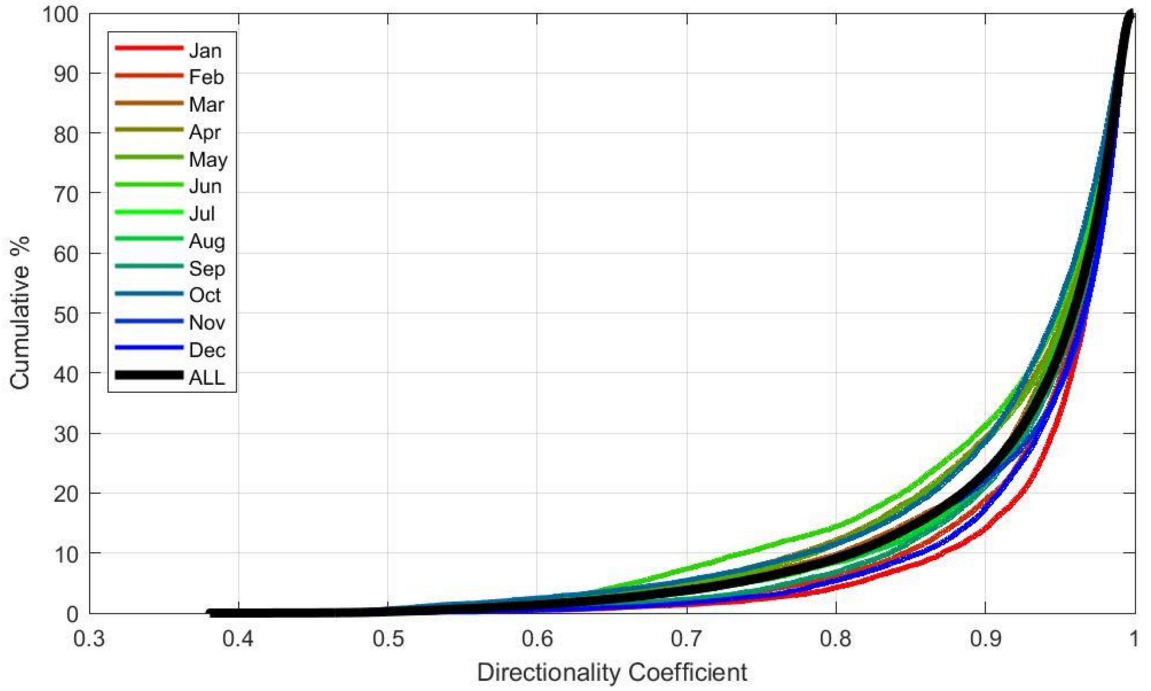

Figure 4.15: Cumulative distribution of directionality coefficient (d) by month and whole series (ALL)

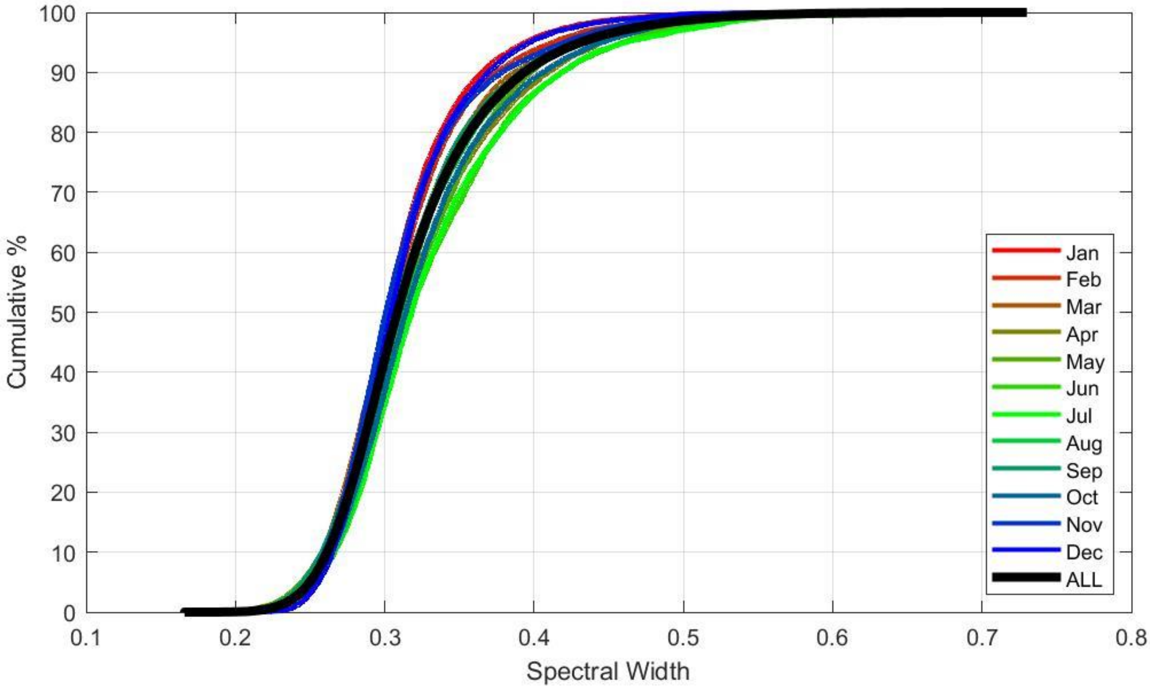

Figure 4.16: Cumulative distribution of spectral width (E_0) by month and whole series (ALL)

4.2.5 Long-term uncertainty – interannual variability

The wave climate at a site will vary year on year. This is a source of uncertainty in the characterization of the wave resource at a site because the period used for the characterization analysis may not fully represent long-term wave climate (i.e. over many decades). Ideally data (measured and/or modelled) covering a period many decades long is used to describe the interannual variability, but in practice this may not be possible.

Figures 4.17 and 4.18 show the interannual variability of monthly mean significant wave height (H_{m0}) and wave power respectively based on the measured AMETS A data. The most obvious observation is that the variability is much larger in winter months compared to summer. January 2015 (a much windier January than normal according to Met Eireann [5]) has the highest monthly mean wave power over the series.

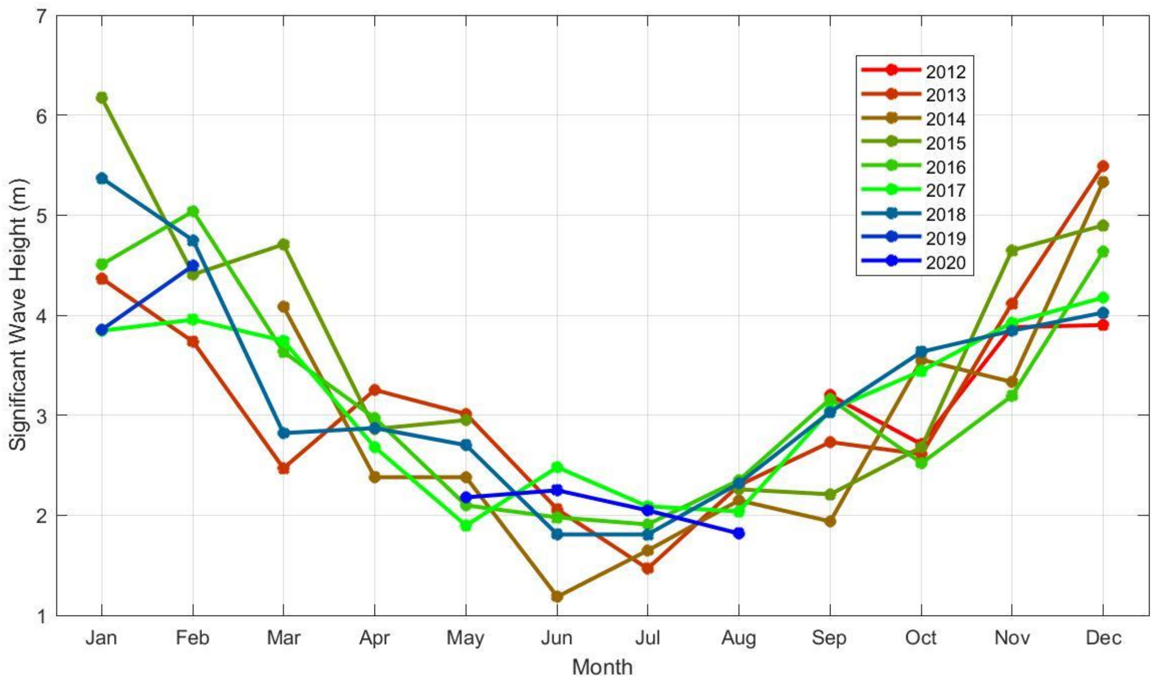

Figure 4.17: Interannual variability of monthly mean significant wave height (H_{m0})

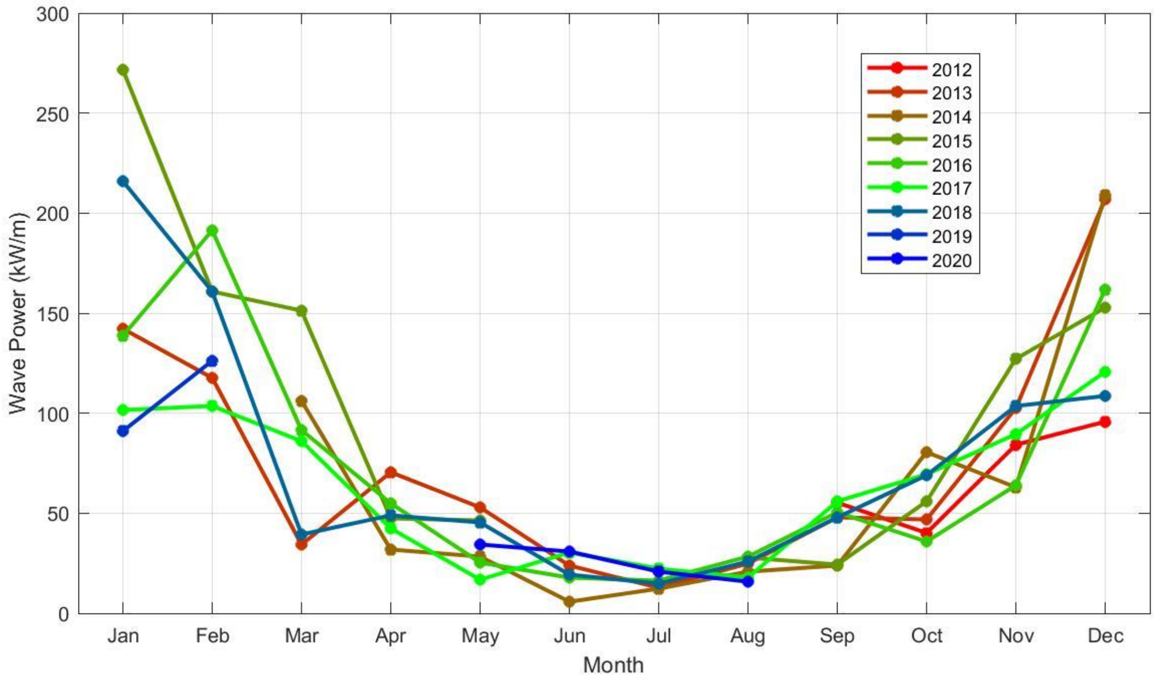

Figure 4.18: Interannual variability of monthly mean of omni-directional wave power (J)

Conclusion

A resource assessment of the AMETS A site was conducted using the IEC-62600-101 standard for wave resource characterization. The analysis was based on spectral wave data measured at the site between May 2012 and September 2020 which means this is considered a Class 1 resource assessment by the IEC-62600-101 standard.

As might be expected there is a strong seasonal variation in significant wave height (H_{m0}), energy period (Te) and wave power at the AMETS A site. For example, the monthly mean omni-directional wave power (J) ranges from 155.03 kW/m in January to 16.87 kW/m in July. The variability can also be seen in a narrower spectral width and increased directionality coefficient in the winter months. This narrowing of the directional spread in winter may, at least in part, be due to powerful swell arriving from Atlantic winter storms [6]. The mean direction of maximum directionally resolved wave power (θ_{Jmax}) is 286.94 degrees (i.e. roughly WNW) and this is, as would be expected, quite consistent throughout the year. Even though the time series for the analysis is relatively short, the inter-annual variability of significant wave height and omni-directional wave power for winter months is notable.

References

[1] Ocean Energy Ireland [Internet]. [cited 1 Sept 2021] http://www.oceanenergyireland.com/TestFacility/AMETS.

[2] IEC-TS 62600:101. Marine energy wave, tidal and other water current converters, Part 101: Wave energy resource assessment and characterization, Ed. 1, 2015.

[3] Cahill B, Lewis T. Wave energy resource characterisation of the atlantic marine energy test site. Int J Mar Energy 2013;1:3e15. http://dx.doi.org/10.1016/j.ijome.2013.05.001.

[4] Atan, R.; Goggins, J.; Nash, S. A Detailed Assessment of the Wave Energy Resource at the Atlantic Marine Energy Test Site. Energies 2016, 9, 967. https://doi.org/10.3390/en9110967

[5] Met Eireann Weather Statement No. 344. [Internet] https://www.met.ie/climate/past-weather-statements

[6] Lenee-Bluhm, P., Paasch, R. , Özkan-Haller, H. Characterizing the wave energy resource of the US Pacific Northwest, Renewable Energy, Volume 36, Issue 8, 2011, Pages 2106-2119, https://doi.org/10.1016/j.renene.2011.01.016.

Appendix 1: Monthly joint distribution plots

Figures A1 to A12 show monthly joint distribution plots of H_{m0} and Te based on all data collected at AMETS A

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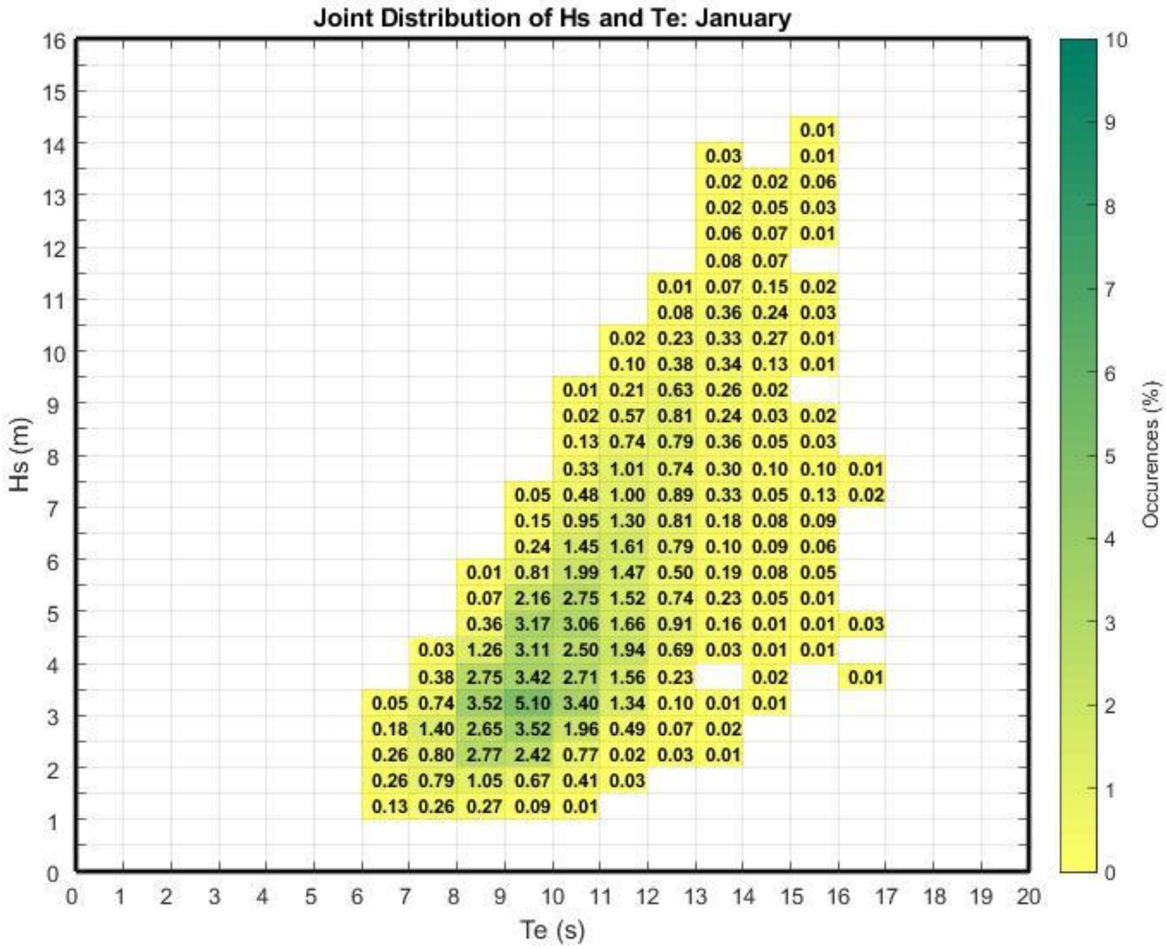


Figure A1

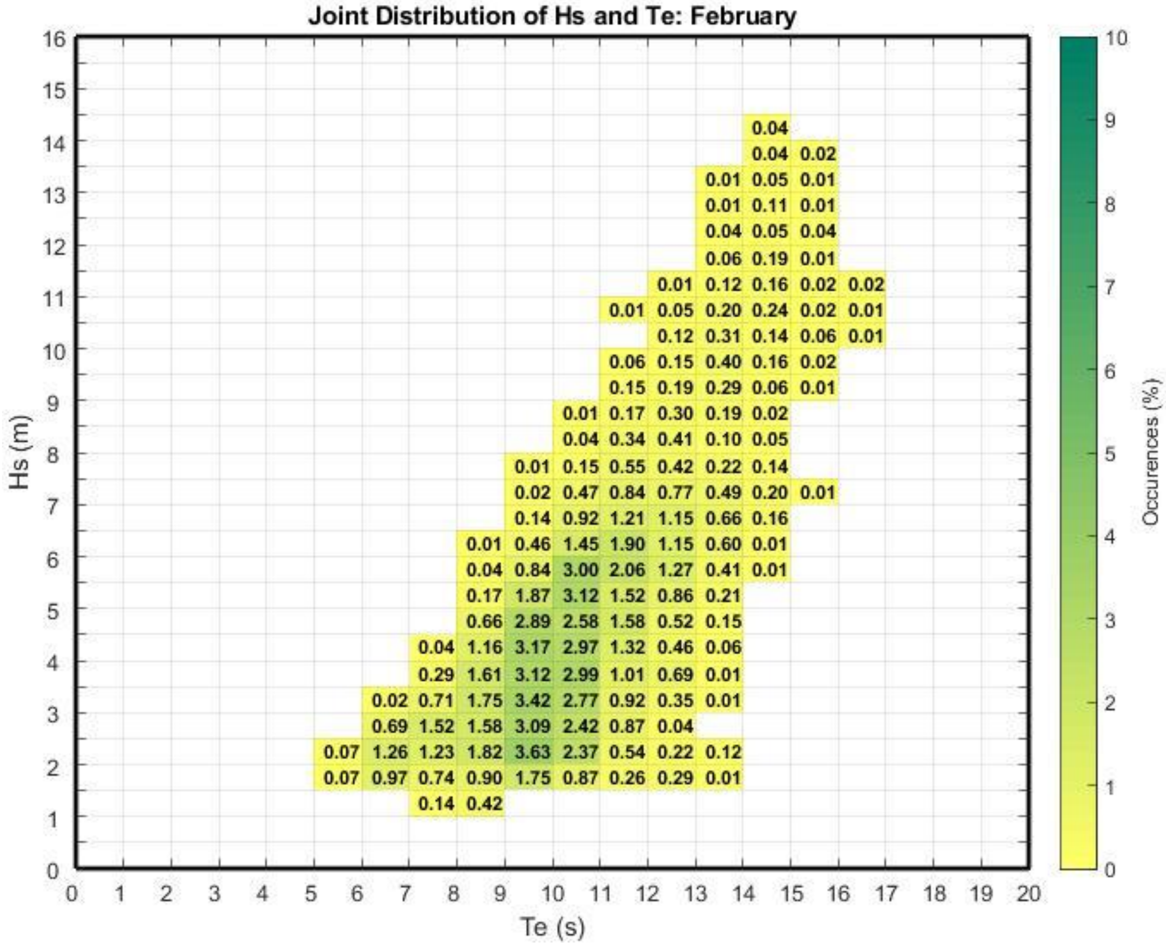

Joint Distribution of Hs and Te: February
Hs (m)
Te (s)
Occurences (%)

Figure A2

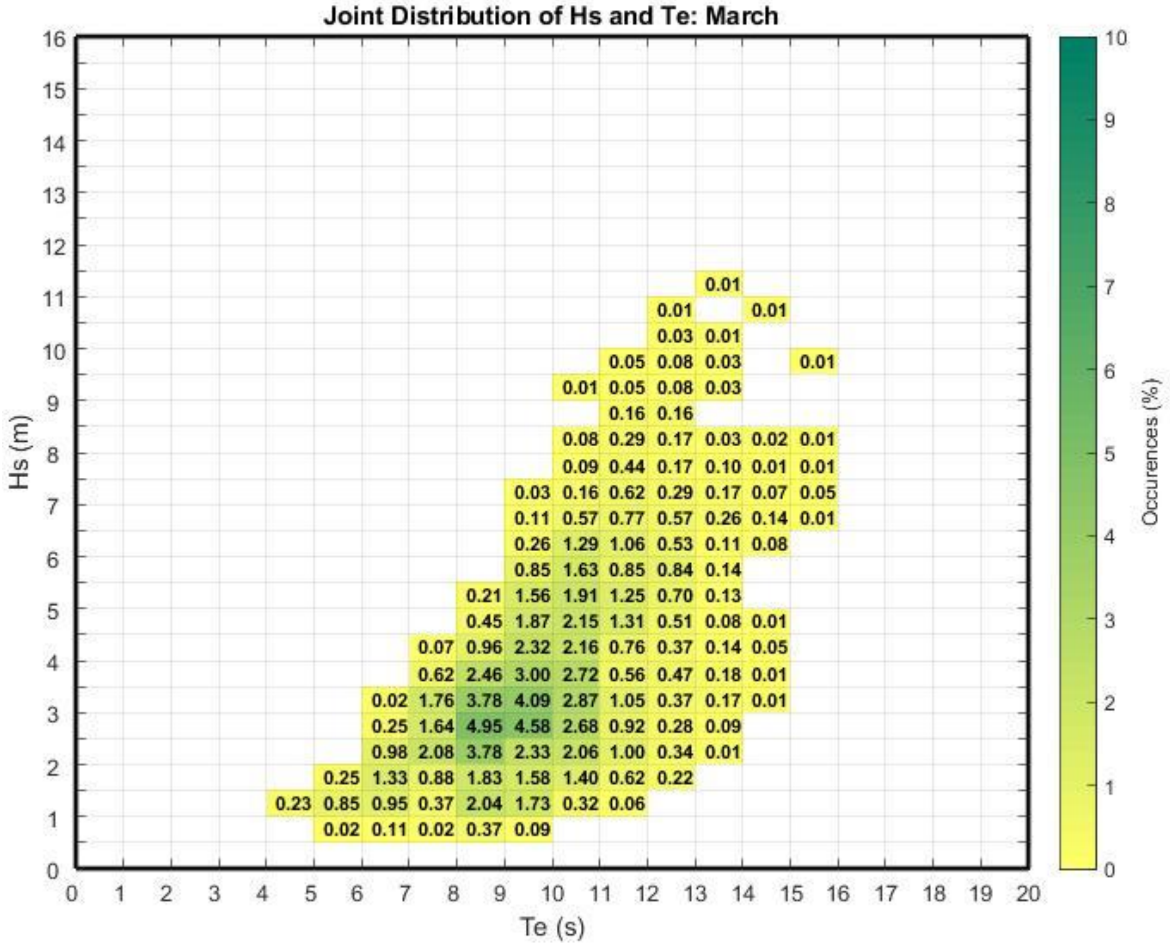


Figure A3

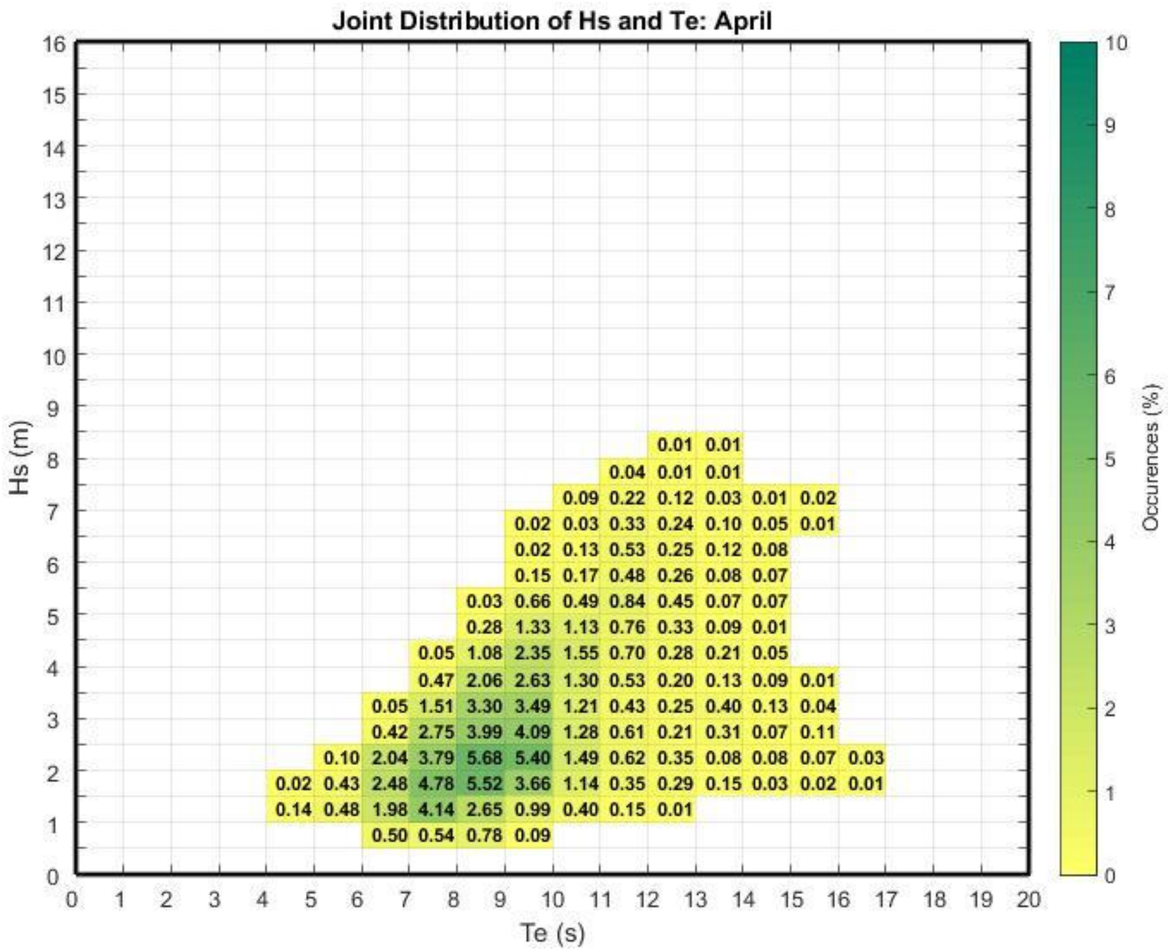

Joint Distribution of Hs and Te: April
Hs (m)
Te (s)
Occurences (%)
0.01 0.01
0.04 0.01 0.01
0.09 0.22 0.12 0.03 0.01 0.02
0.02 0.03 0.33 0.24 0.10 0.05 0.01
0.02 0.13 0.53 0.25 0.12 0.08
0.15 0.17 0.48 0.26 0.08 0.07
0.03 0.66 0.49 0.84 0.45 0.07 0.07
0.28 1.33 1.13 0.76 0.33 0.09 0.01
0.05 1.08 2.35 1.55 0.70 0.28 0.21 0.05
0.47 2.06 2.63 1.30 0.53 0.20 0.13 0.09 0.01
0.05 1.51 3.30 3.49 1.21 0.43 0.25 0.40 0.13 0.04
0.42 2.75 3.99 4.09 1.28 0.61 0.21 0.31 0.07 0.11
0.10 2.04 3.79 5.68 5.40 1.49 0.62 0.35 0.08 0.08 0.07 0.03
0.02 0.43 2.48 4.78 5.52 3.66 1.14 0.35 0.29 0.15 0.03 0.02 0.01
0.14 0.48 1.98 4.14 2.65 0.99 0.40 0.15 0.01
0.50 0.54 0.78 0.09

Figure A4

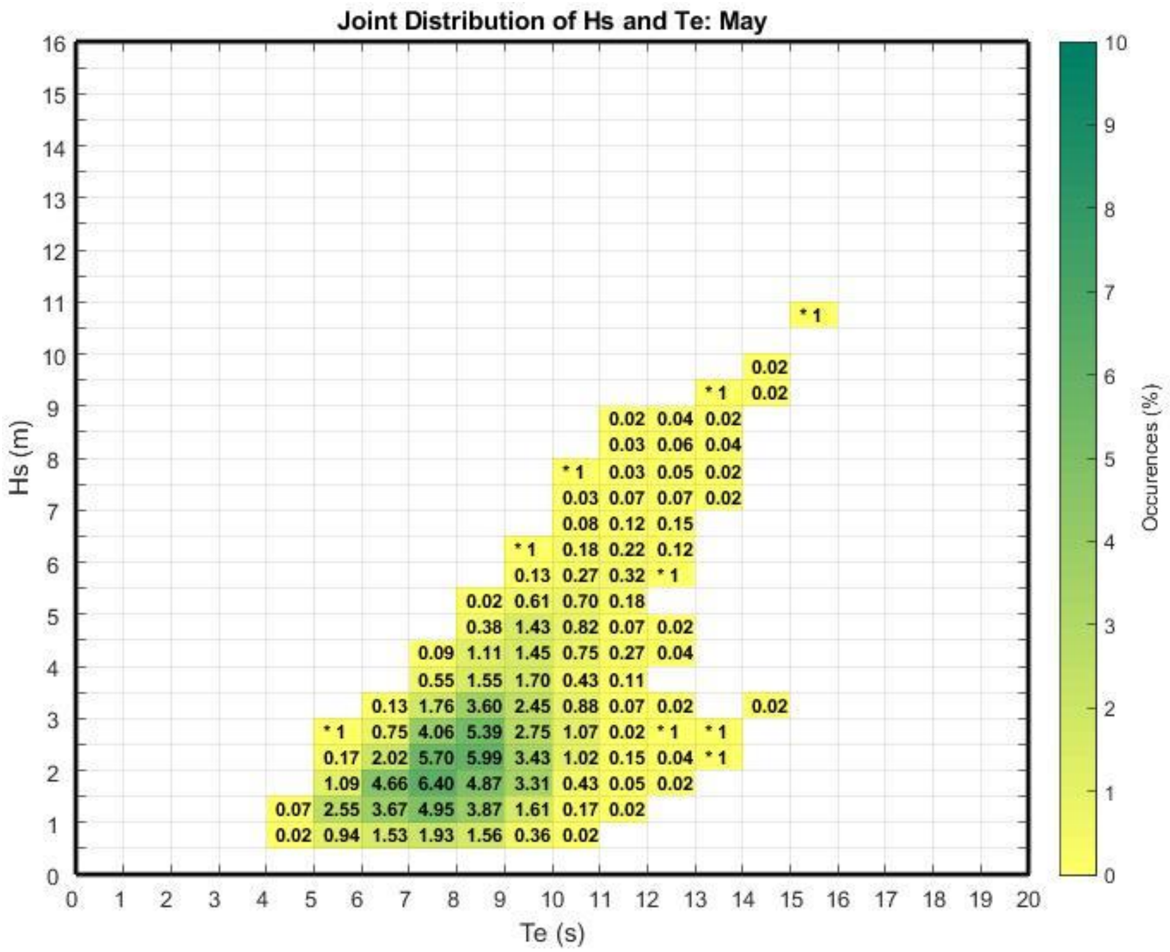


Figure A5

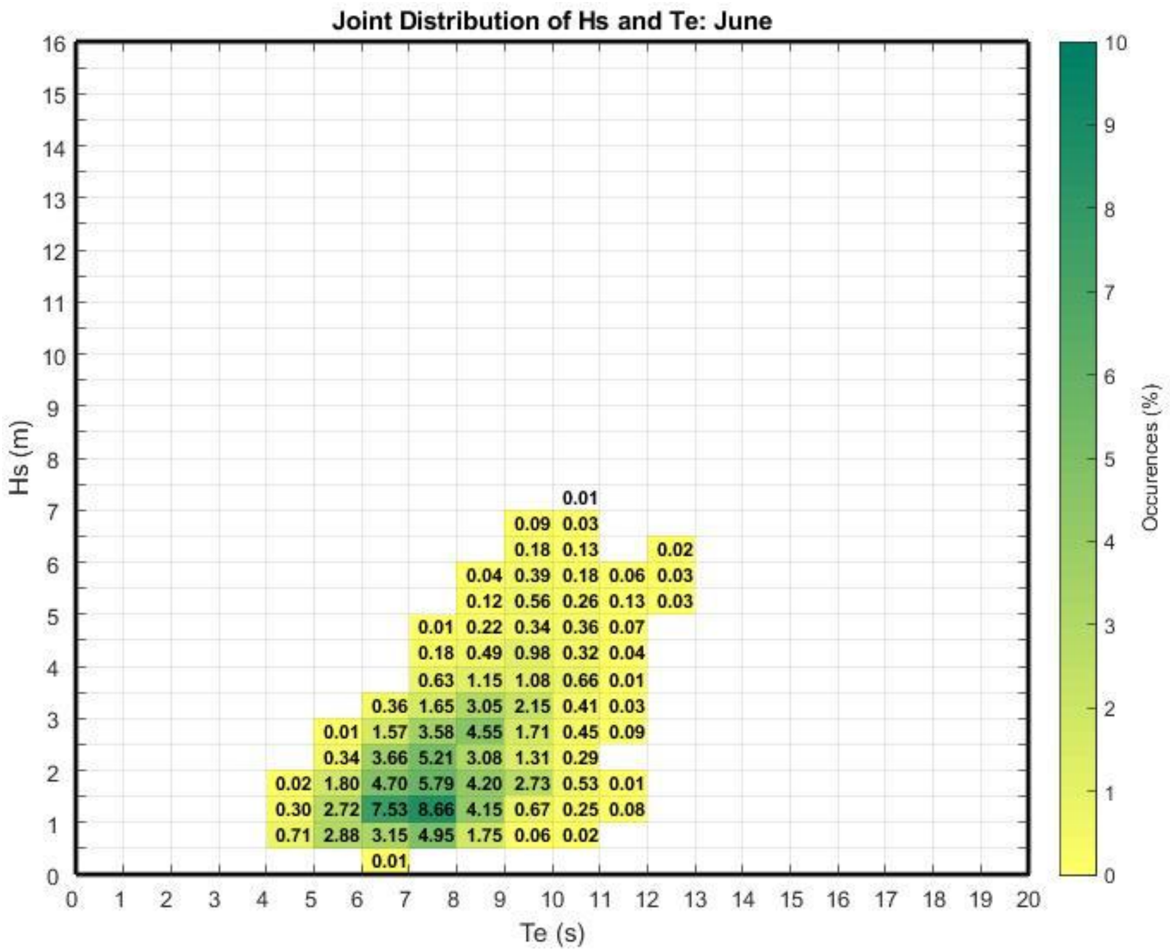


Figure A6

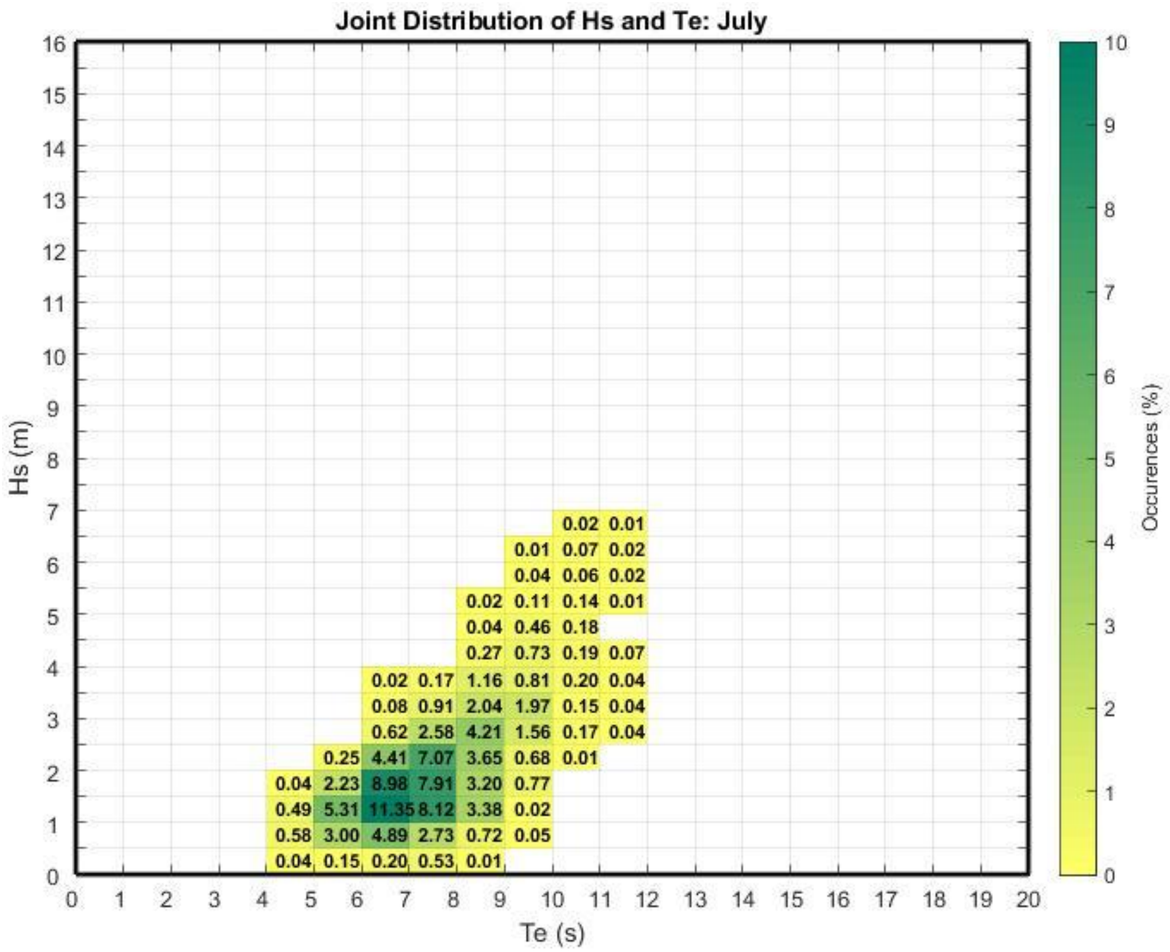
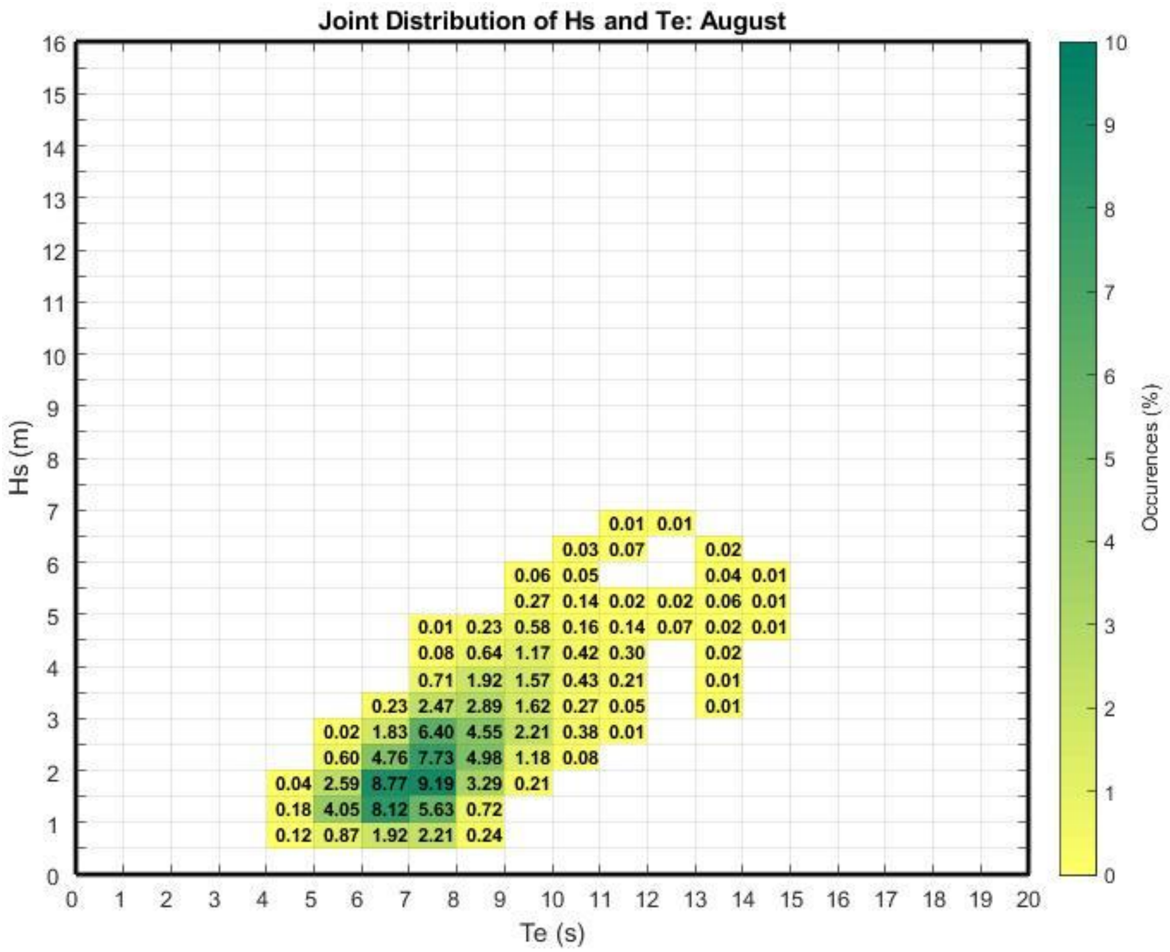

Joint Distribution of Hs and Te: July
Hs (m)
Te (s)
Occurences (%)
0.02 0.01
0.01 0.07 0.02
0.04 0.06 0.02
0.02 0.11 0.14 0.01
0.04 0.46 0.18
0.27 0.73 0.19 0.07
0.02 0.17 1.16 0.81 0.20 0.04
0.08 0.91 2.04 1.97 0.15 0.04
0.62 2.58 4.21 1.56 0.17 0.04
0.25 4.41 7.07 3.65 0.68 0.01
0.04 2.23 8.98 7.91 3.20 0.77
0.49 5.31 11.35 8.12 3.38 0.02
0.58 3.00 4.89 2.73 0.72 0.05
0.04 0.15 0.20 0.53 0.01

Figure A7



Joint Distribution of Hs and Te: August
Hs (m)
Te (s)
Occurences (%)
0.01 0.01
0.03 0.07 0.02
0.06 0.05 0.04 0.01
0.27 0.14 0.02 0.02 0.06 0.01
0.01 0.23 0.58 0.16 0.14 0.07 0.02 0.01
0.08 0.64 1.17 0.42 0.30 0.02
0.71 1.92 1.57 0.43 0.21 0.01
0.23 2.47 2.89 1.62 0.27 0.05 0.01
0.02 1.83 6.40 4.55 2.21 0.38 0.01
0.60 4.76 7.73 4.98 1.18 0.08
0.04 2.59 8.77 9.19 3.29 0.21
0.18 4.05 8.12 5.63 0.72
0.12 0.87 1.92 2.21 0.24

Figure A8

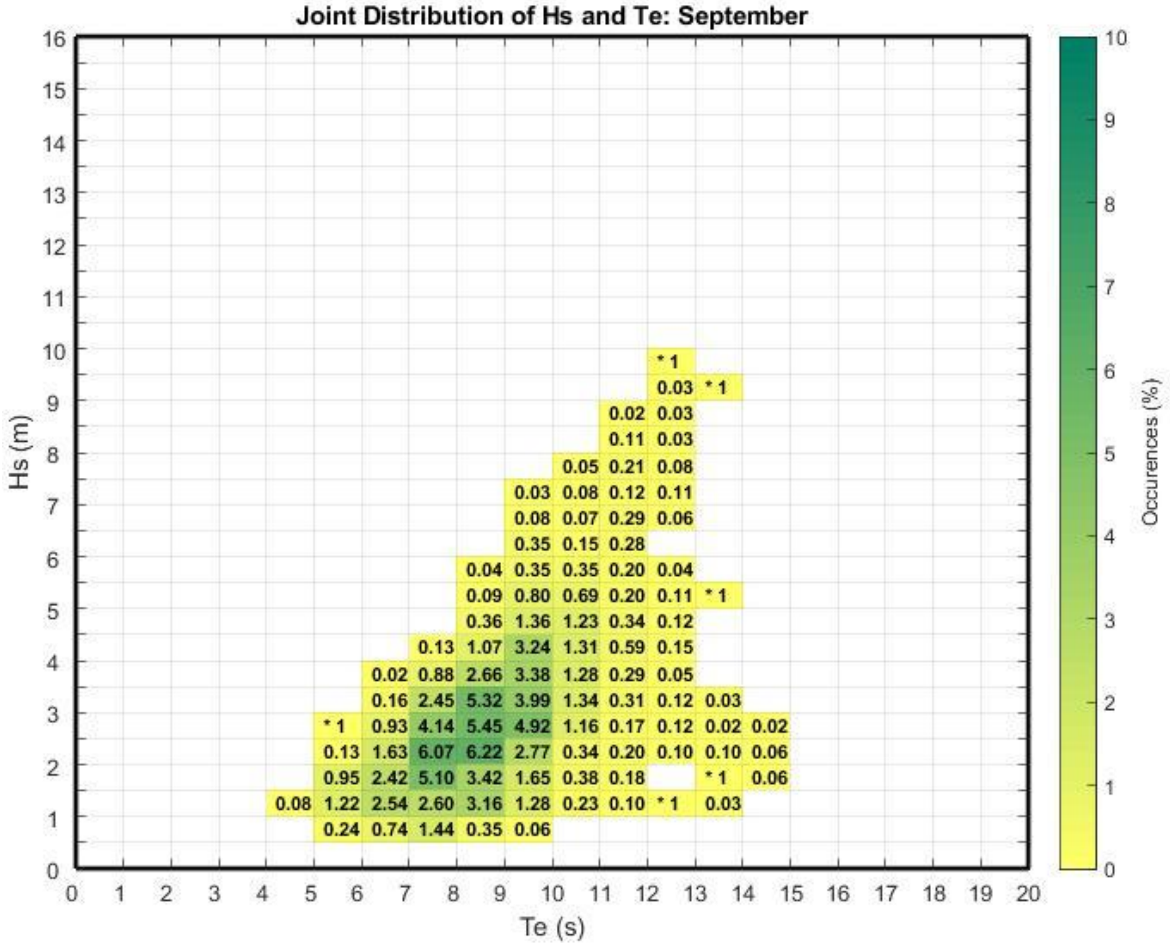

Joint Distribution of Hs and Te: September
Hs (m)
Te (s)
Occurences (%)

Figure A9

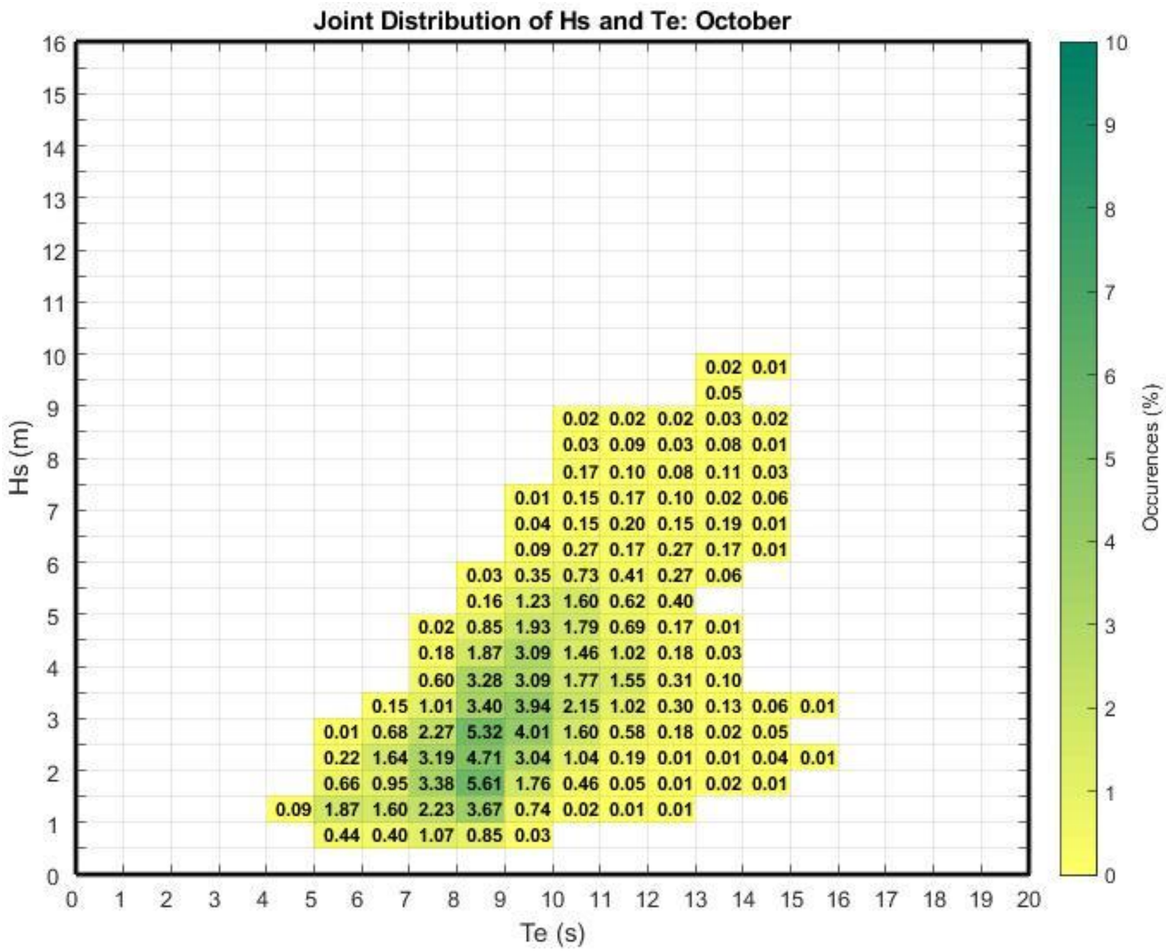


Figure A10

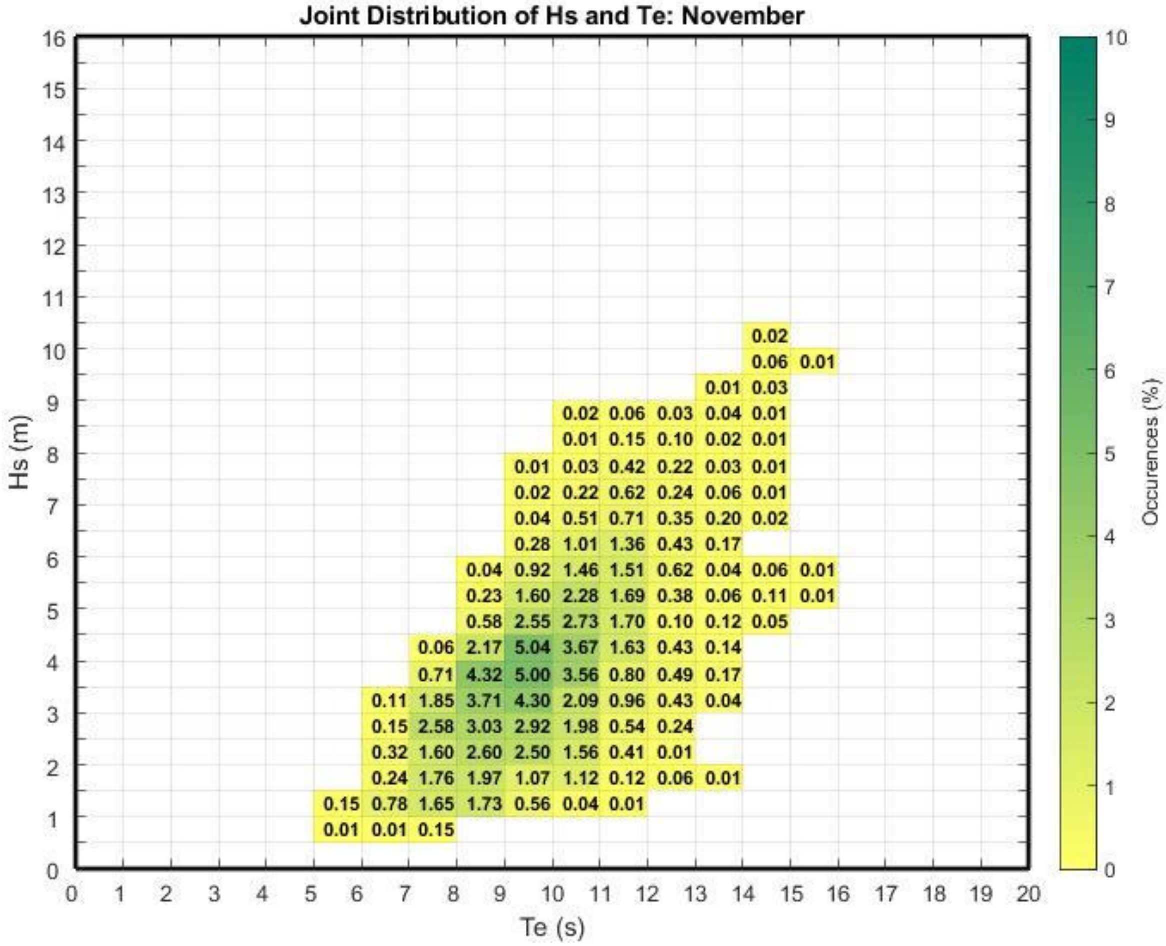

Joint Distribution of Hs and Te: November
Hs (m)
Te (s)
Occurences (%)

Figure A11

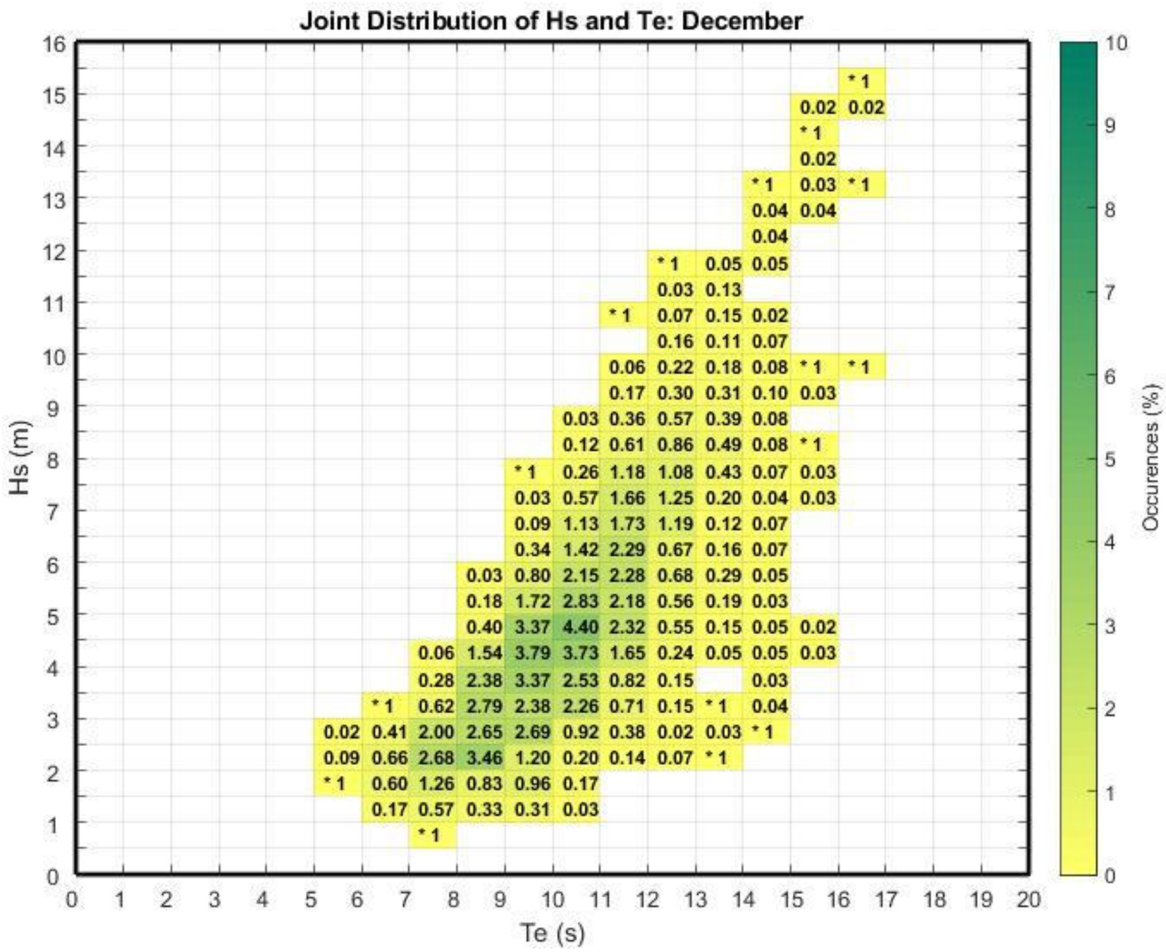

Joint Distribution of Hs and Te: December
Hs (m)
Te (s)
Occurences (%)

Figure A12

Appendix 2: Monthly wave power rose plots

Figures B1 to B12 show wave roses depicting the monthly joint distribution of maximum directionally resolved wave power ($J_{\theta Jmax}$) and the direction of maximum directionally resolved power (θ_{Jmax}) based on all data collected at AMETS A.

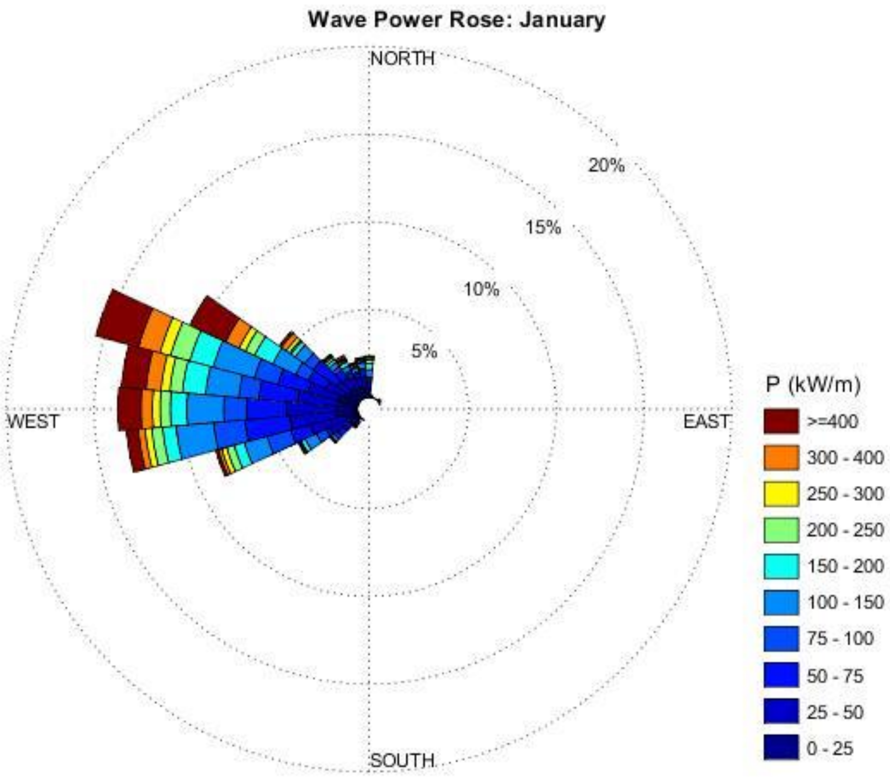
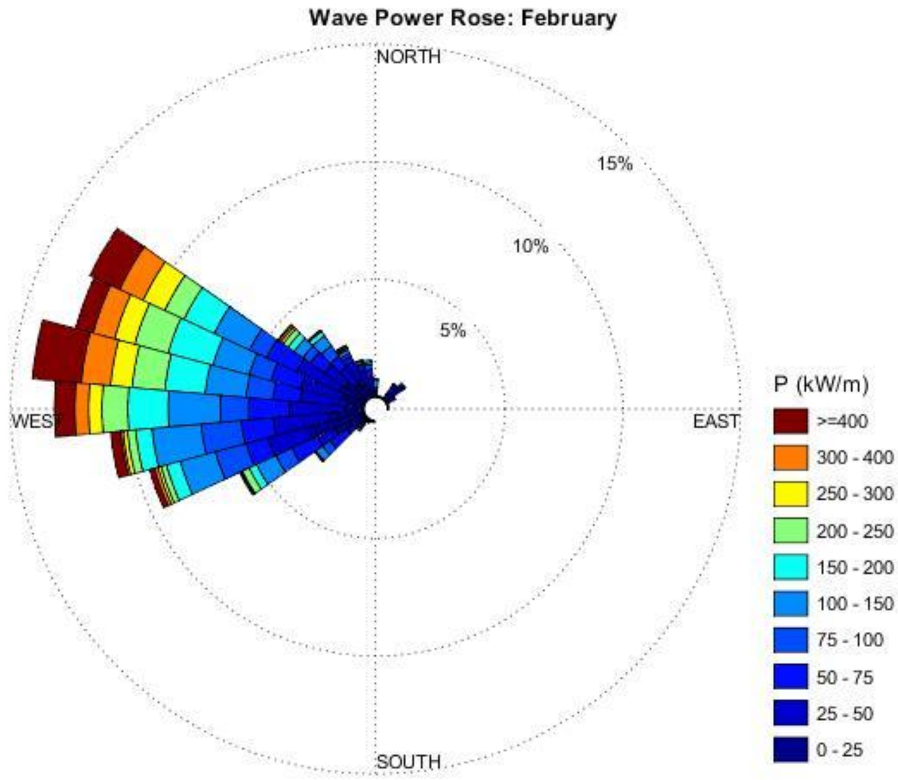


Figure B1



Wave Power Rose: February
NORTH
15%
10%
5%
WEST
EAST
SOUTH
P (kW/m)
>=400
300 - 400
250 - 300
200 - 250
150 - 200
100 - 150
75 - 100
50 - 75
25 - 50
0 - 25

Figure B2

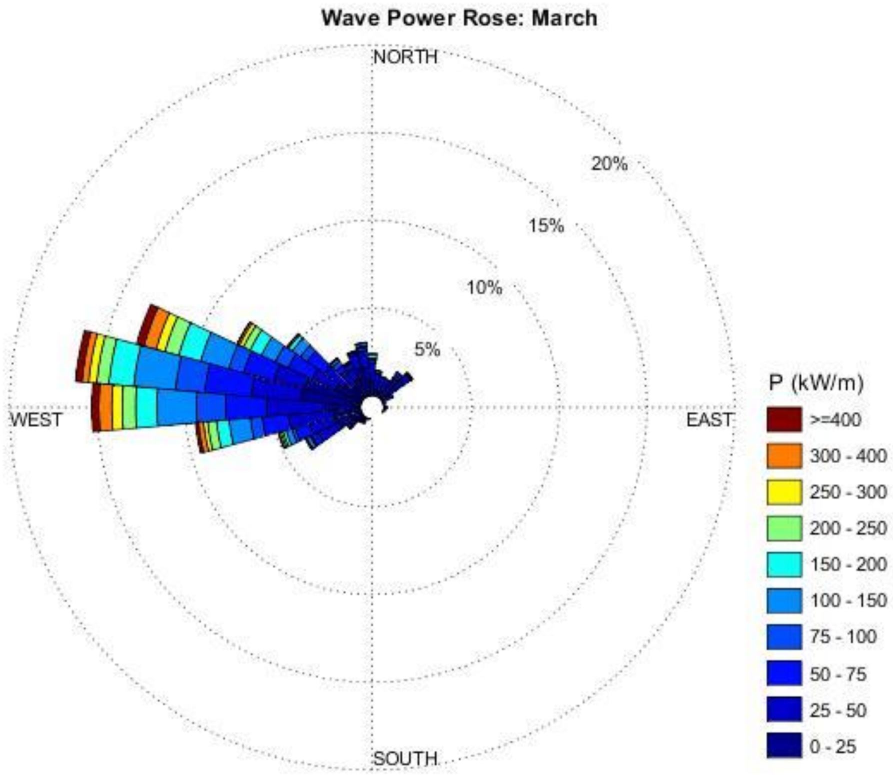
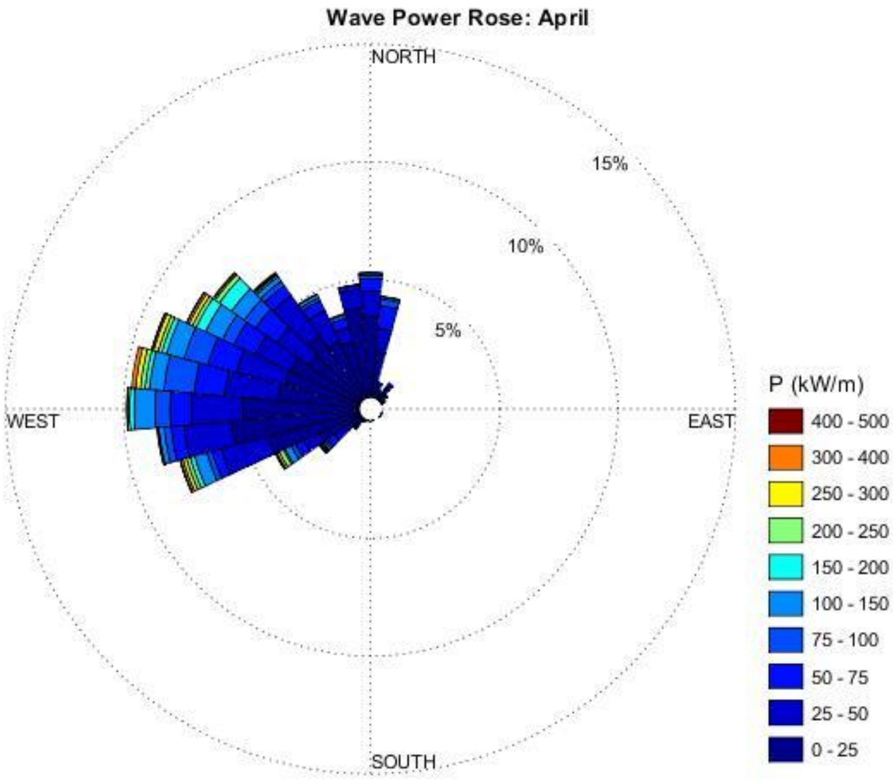
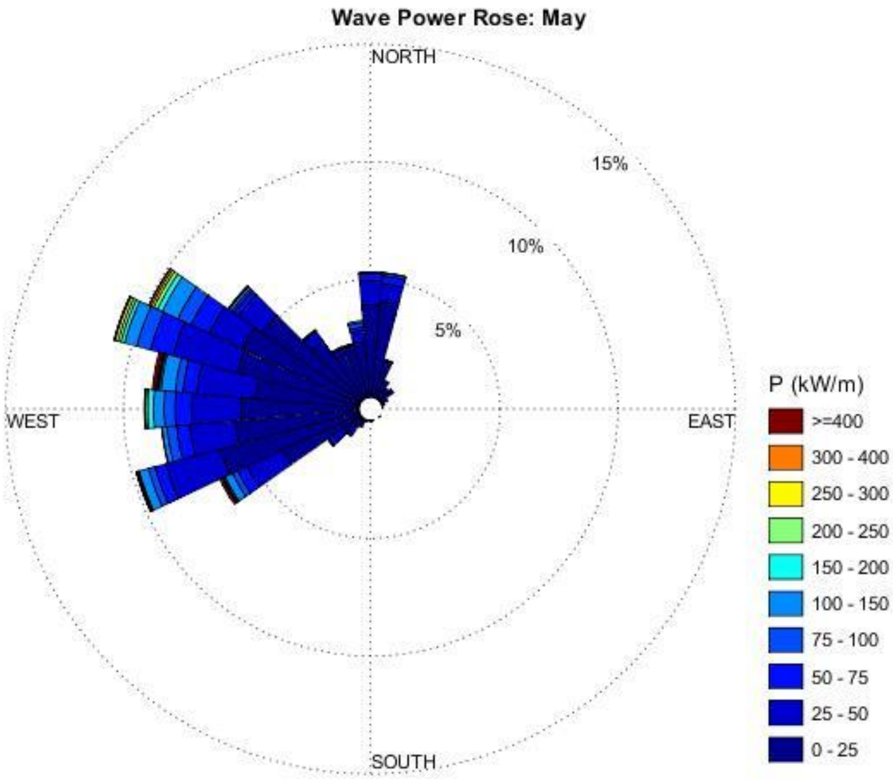

Wave Power Rose: March
NORTH
SOUTH
WEST
EAST
5%
10%
15%
20%
P (kW/m)
>=400
300 - 400
250 - 300
200 - 250
150 - 200
100 - 150
75 - 100
50 - 75
25 - 50
0 - 25

Figure B3



Wave Power Rose: April
NORTH
15%
10%
5%
WEST
EAST
SOUTH
P (kW/m)
400 - 500
300 - 400
250 - 300
200 - 250
150 - 200
100 - 150
75 - 100
50 - 75
25 - 50
0 - 25

Figure B4



Wave Power Rose: May
NORTH
15%
10%
5%
WEST
EAST
SOUTH
P (kW/m)
>=400
300 - 400
250 - 300
200 - 250
150 - 200
100 - 150
75 - 100
50 - 75
25 - 50
0 - 25

Figure B5

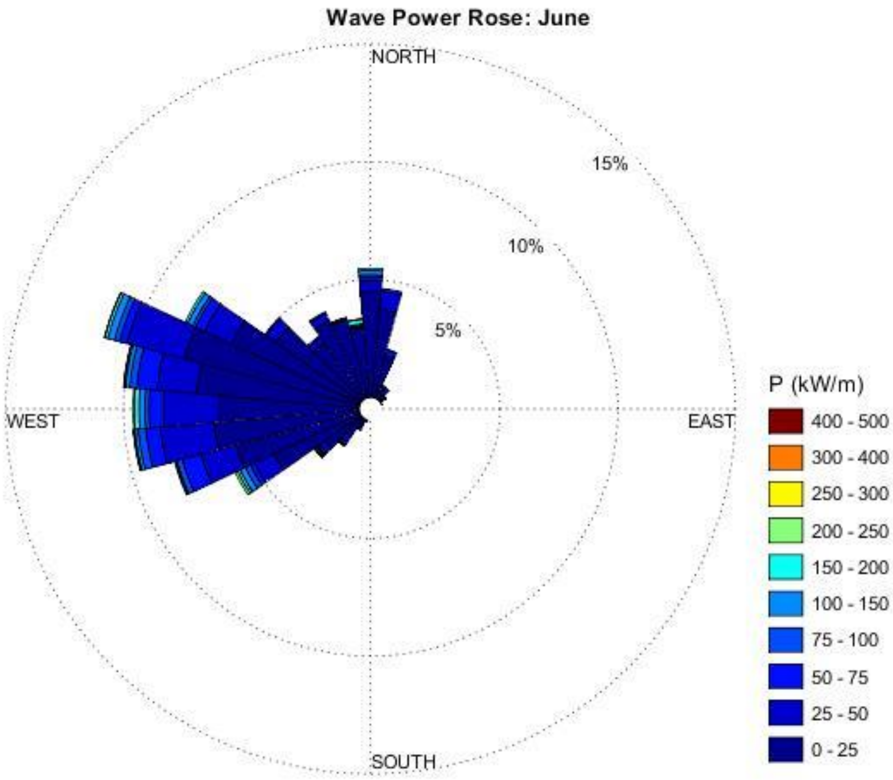

Wave Power Rose: June
NORTH
15%
10%
5%
WEST
EAST
SOUTH
P (kW/m)
400 - 500
300 - 400
250 - 300
200 - 250
150 - 200
100 - 150
75 - 100
50 - 75
25 - 50
0 - 25

Figure B6

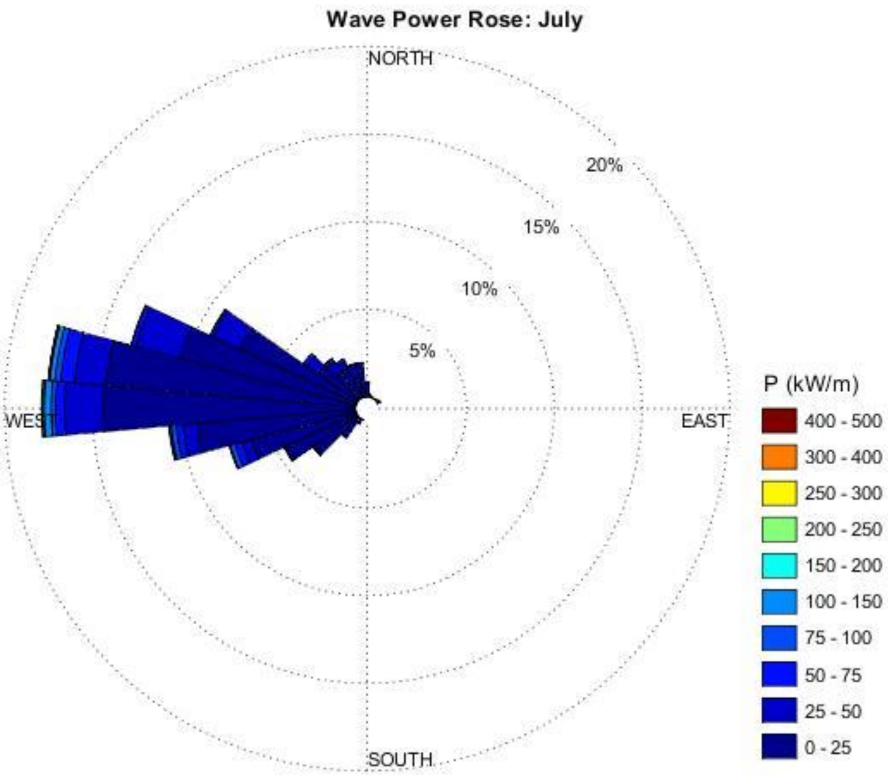

Wave Power Rose: July
NORTH
20%
15%
10%
5%
WEST
EAST
SOUTH
P (kW/m)
400 - 500
300 - 400
250 - 300
200 - 250
150 - 200
100 - 150
75 - 100
50 - 75
25 - 50
0 - 25

Figure B7

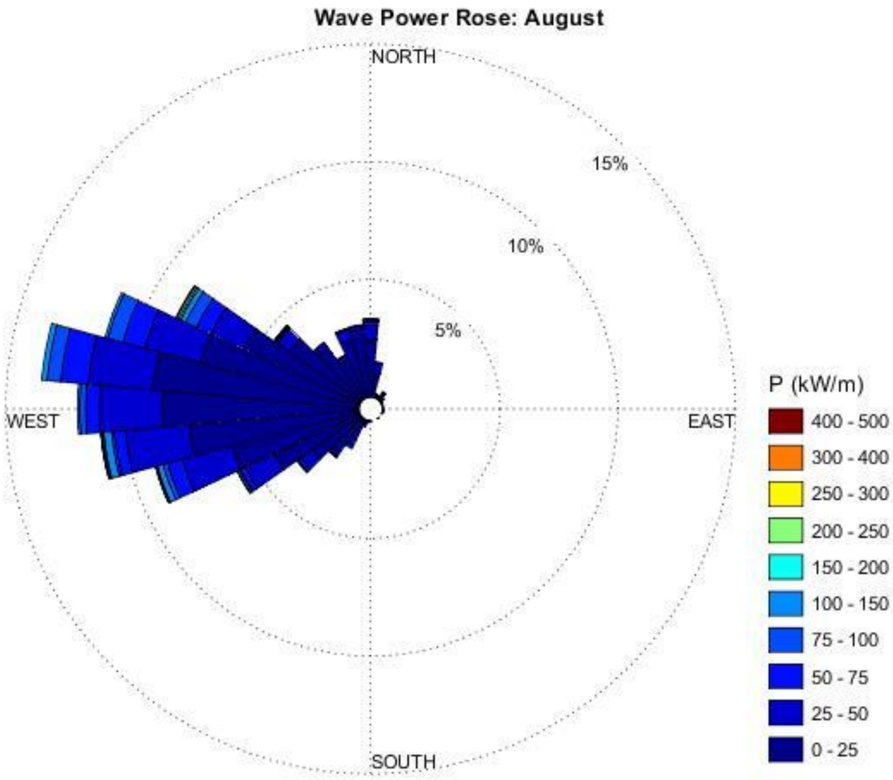
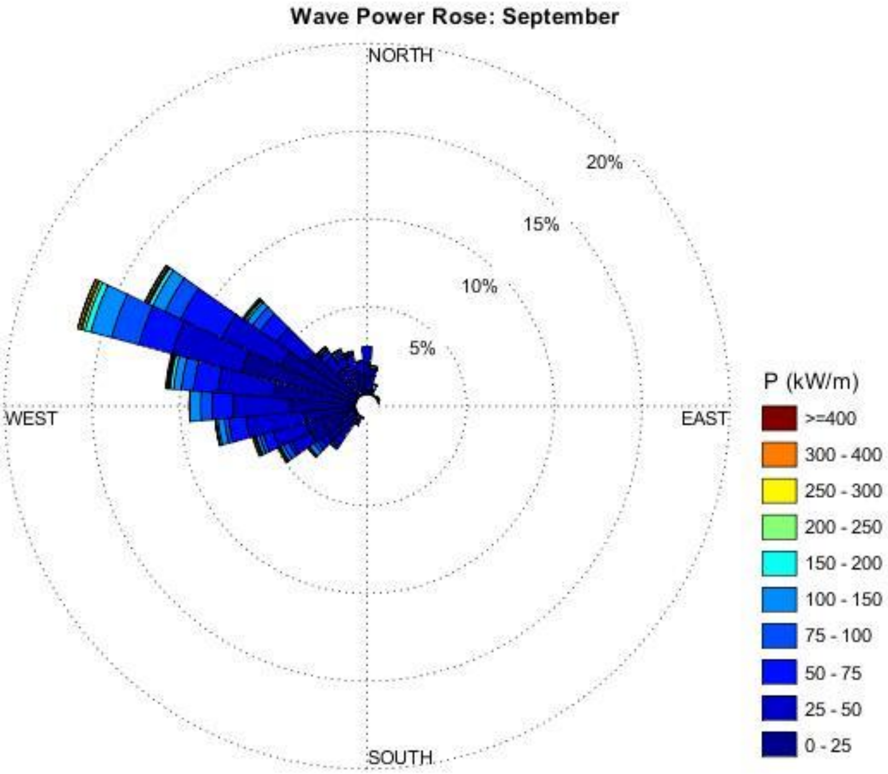

Wave Power Rose: August
NORTH
15%
10%
5%
WEST
EAST
SOUTH
P (kW/m)
400 - 500
300 - 400
250 - 300
200 - 250
150 - 200
100 - 150
75 - 100
50 - 75
25 - 50
0 - 25

Figure B8



Wave Power Rose: September
NORTH
WEST
EAST
SOUTH
5%
10%
15%
20%
P (kW/m)
>=400
300 - 400
250 - 300
200 - 250
150 - 200
100 - 150
75 - 100
50 - 75
25 - 50
0 - 25

Figure B9

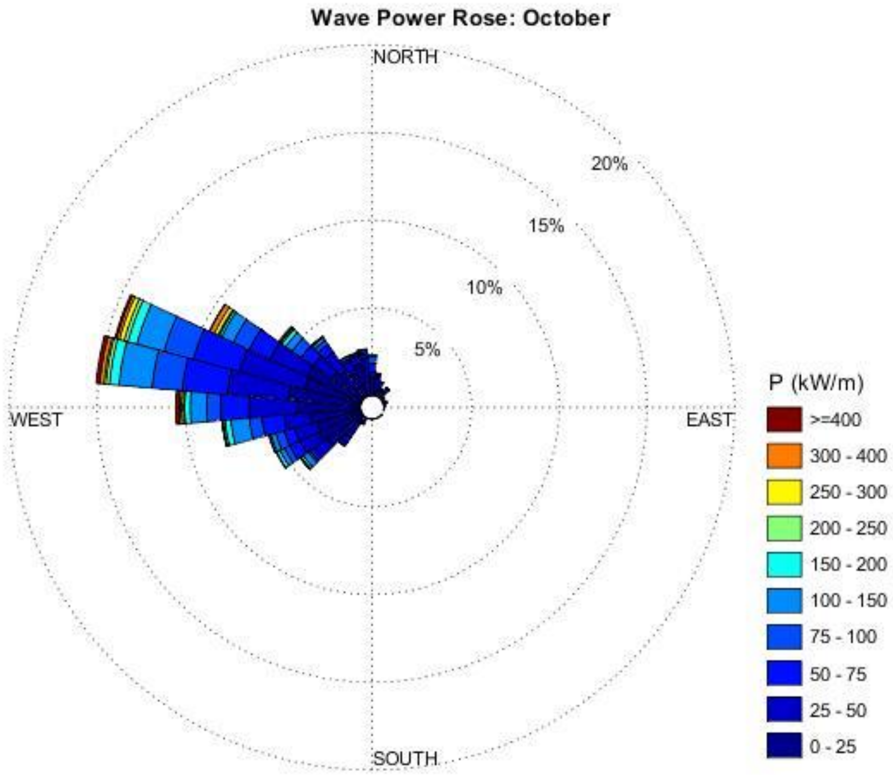
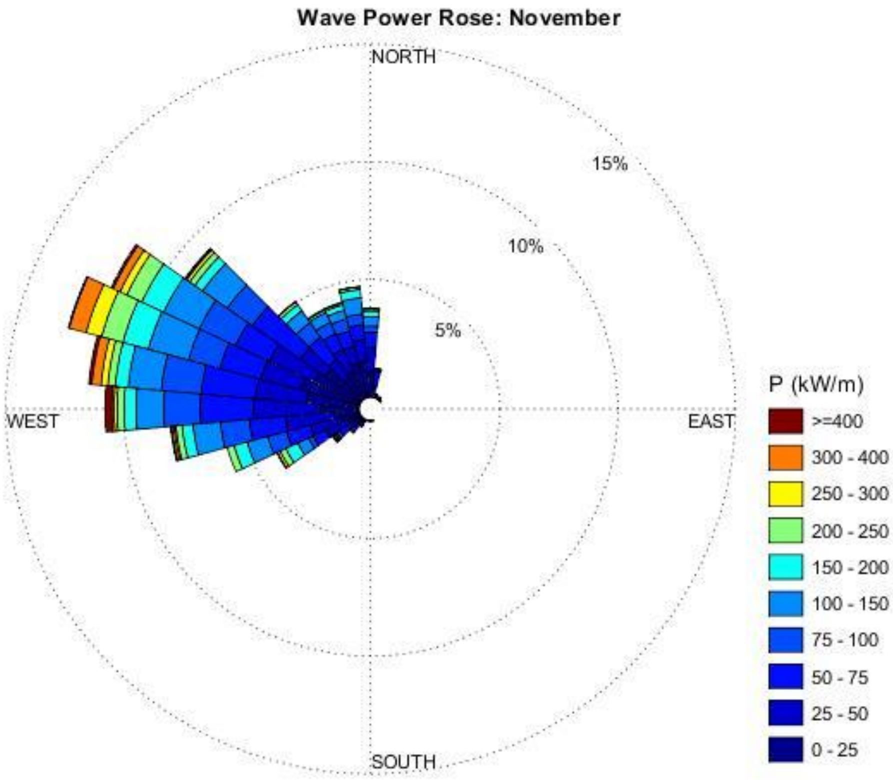

Wave Power Rose: October
NORTH
WEST
EAST
SOUTH
5%
10%
15%
20%
P (kW/m)
>=400
300 - 400
250 - 300
200 - 250
150 - 200
100 - 150
75 - 100
50 - 75
25 - 50
0 - 25

Figure B10



Wave Power Rose: November
NORTH
15%
10%
5%
WEST
EAST
SOUTH
P (kW/m)
>=400
300 - 400
250 - 300
200 - 250
150 - 200
100 - 150
75 - 100
50 - 75
25 - 50
0 - 25

Figure B11

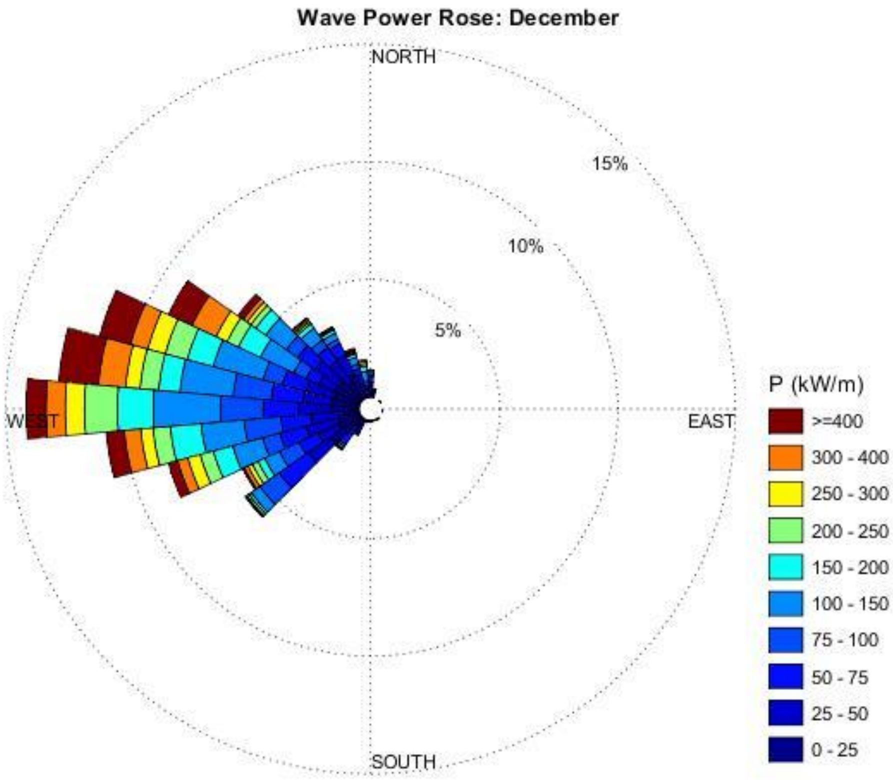

Wave Power Rose: December
NORTH
15%
10%
5%
WEST
EAST
SOUTH
P (kW/m)
>=400
300 - 400
250 - 300
200 - 250
150 - 200
100 - 150
75 - 100
50 - 75
25 - 50
0 - 25

Figure B12