



Naval Point Metocean Study

Wind and wave ambient and extreme statistics

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1. Introduction

Christchurch City Council has commissioned MetOcean Solutions (MOS, subsidiary of Meteorological Service of New Zealand Ltd) to provide a summary of metocean conditions at Naval Point, Lyttelton Harbour, New Zealand (Figure 1.1, Table 1.1). An overview of the metocean conditions along the proposed outer and inner breakwaters is required to provide an initial characterisation of the environment, plus identify potential hazards and document environmental conditions that may require further attention. Sites P1-P4 are located along the outer breakwater, while sites P5-P6 are situated along the inner breakwater.

Numerical hindcasting techniques are the primary source of oceanographic and meteorological data used in preparing this report. A brief summary of the data sources is provided in Section 2. Results for the site specific wind conditions are provided in Section 3. The wave climate is detailed in Section 4. Extreme statistics are reported in Section 5. Analytical methods are described in Section 6 and the references cited are listed in the final Section 7.

Note that the standard oceanographic directional conventions are applied in this report, with waves and winds reported in the 'coming from' directional reference.



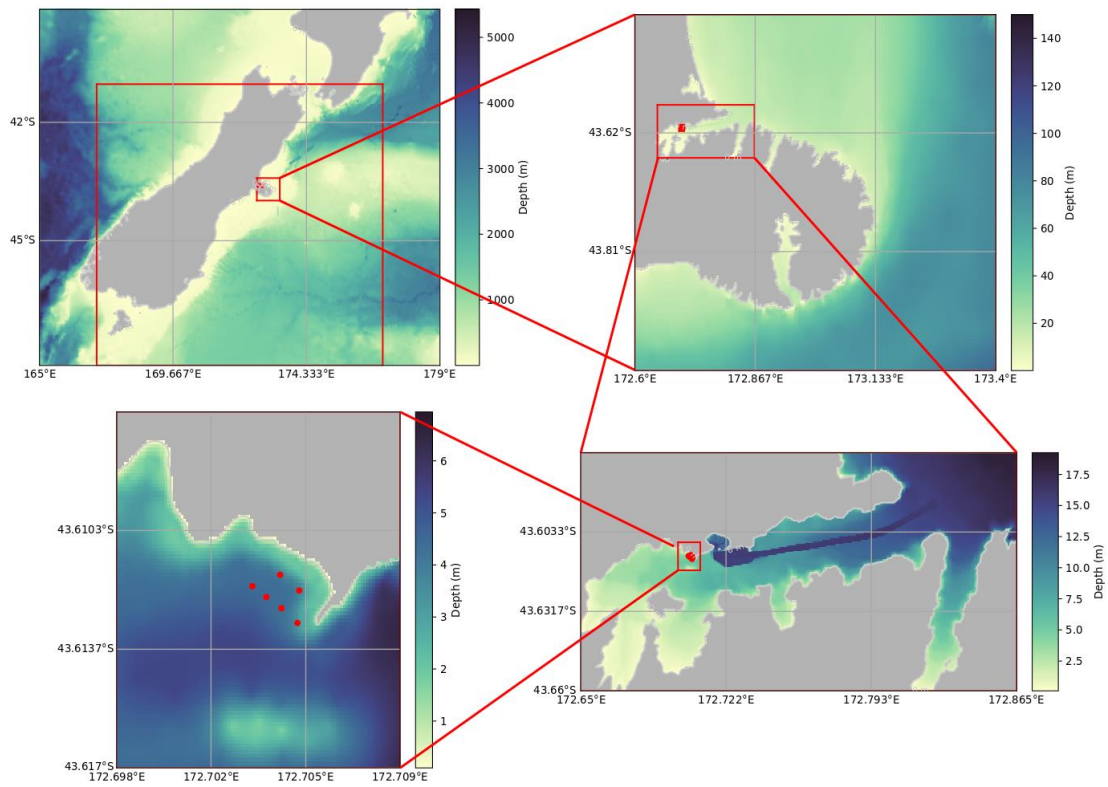


Figure 1.1 Bathymetry maps showing the successive model nests and the representative sites at Naval Point, Lyttelton Harbour, New Zealand.

Table 1.1 Coordinates and approximate water depths at the representative data reporting sites.

Site	World Geodetic System 1984 (WGS84)		Water depth (m, MSL)
	Longitude	Latitude	
P1	172° 42' 18.05" E	43°36'46.54" S	3.2
P2	172° 42' 15.84" E	43°36'45.05" S	4.3
P3	172° 42' 13.71" E	43°36'43.92" S	4.4
P4	172° 42' 11.77" E	43°36'42.83" S	4.4
P5	172° 42' 15.64" E	43°36'41.68" S	3.8
P6	172° 42' 18.31" E	43°36'43.26" S	3.8

2. Metocean datasources

2.1. Wind data

The 10-min averaged wind data at 10-m elevation were prescribed by a regional atmospheric hindcast carried out by MOS between 2009-2018 (inclusive). The WRF (Weather Research and Forecasting) model domain covers the whole of New Zealand with a spatial resolution of approximately 12 km, outputs are provided at hourly intervals to a nested domain over central regions with a 4 km resolution. The hindcast was specifically tuned to provide highly accurate marine wind fields for metocean studies around New Zealand.

The WRF model boundaries were sourced from the CFSR (Climate Forecast System Reanalysis) dataset distributed by NOAA (Saha et al., 2010).

Validation of the WRF reanalysis has been undertaken at various locations around New Zealand.

2.2. Wave data

The wave modelling was performed using a modified version of SWAN¹. This section describes details of the wave model and the technique employed in the simulations.

Model description

SWAN is a third generation ocean wave propagation model which solves the spectral action density balance equation (Booij et al., 1999). The model simulates the growth, refraction and decay of each frequency-direction component of the complete sea state, providing a realistic description of the wave field as it changes in time and space. Physical processes that can be modelled include the generation of waves by surface wind, dissipation by white-capping, resonant nonlinear interaction between the wave components, bottom friction and depth-induced wave-breaking dissipation. A detailed description of the model equations, parametrisations and numerical schemes can be found in Holthuijsen et al. (2007) and in the SWAN documentation².

Model setup

The wave hindcast was set and run for a 10-year period, from 2009 to 2018. The model was configured in non-stationary mode including all third generation physics. The source term parameterisations of Van der Westhuysen et al. (2007) and the bottom friction scheme of Collins (1972) with coefficient of 0.015 were applied. Depth-induced

¹ Modified from SWAN version of the 40.91 release

² <http://swanmodel.sourceforge.net/>



wave breaking dissipation was modelled according to Battjes and Janssen (1978). The wave spectra were discretised with 36 directional bins (10 deg directional resolution) and up to 44 frequencies logarithmically spaced between 0.0412 and 3.002 Hz at 10% increments.

A dynamical downscaling nesting approach was applied to resolve the nearshore region around the sites of interest. To fully capture the details of the coastal line and bathymetry in the area, 4 regular SWAN nests were defined with resolutions of ~4 km, ~400m, ~50m, and a fine grid of ~10m, to resolve the small scale bathymetric features between each output location (see Figure 1.1).

Full spectral boundaries for the parent SWAN hindcast domain were prescribed from a global implementation of the WAVEWATCHIII (WW3) spectral wave model (Tolman, 1991), run at 0.5 degrees resolution with the source terms of Ardhuin et al. (2010). Bathymetry to setup the SWAN domains was derived by processing and combining data from the General Bathymetric Charts of the Oceans (GEBCO) global database Weatherall et al. (2015), Electronic Nautical Charts (ENCs) and survey data. The model was forced with surface winds from the WRF model configuration described in the previous subsection. The wave model also included tidal elevation derived from the constituents obtained from the POM (Princeton Ocean Model) model.

Examples of significant wave height (H_s) wave fields for the three last SWAN nests are given in Figure 2.1 and Figure 2.2 for scenarios where waves entered the Canterbury Basin from the NE and S sectors, respectively.

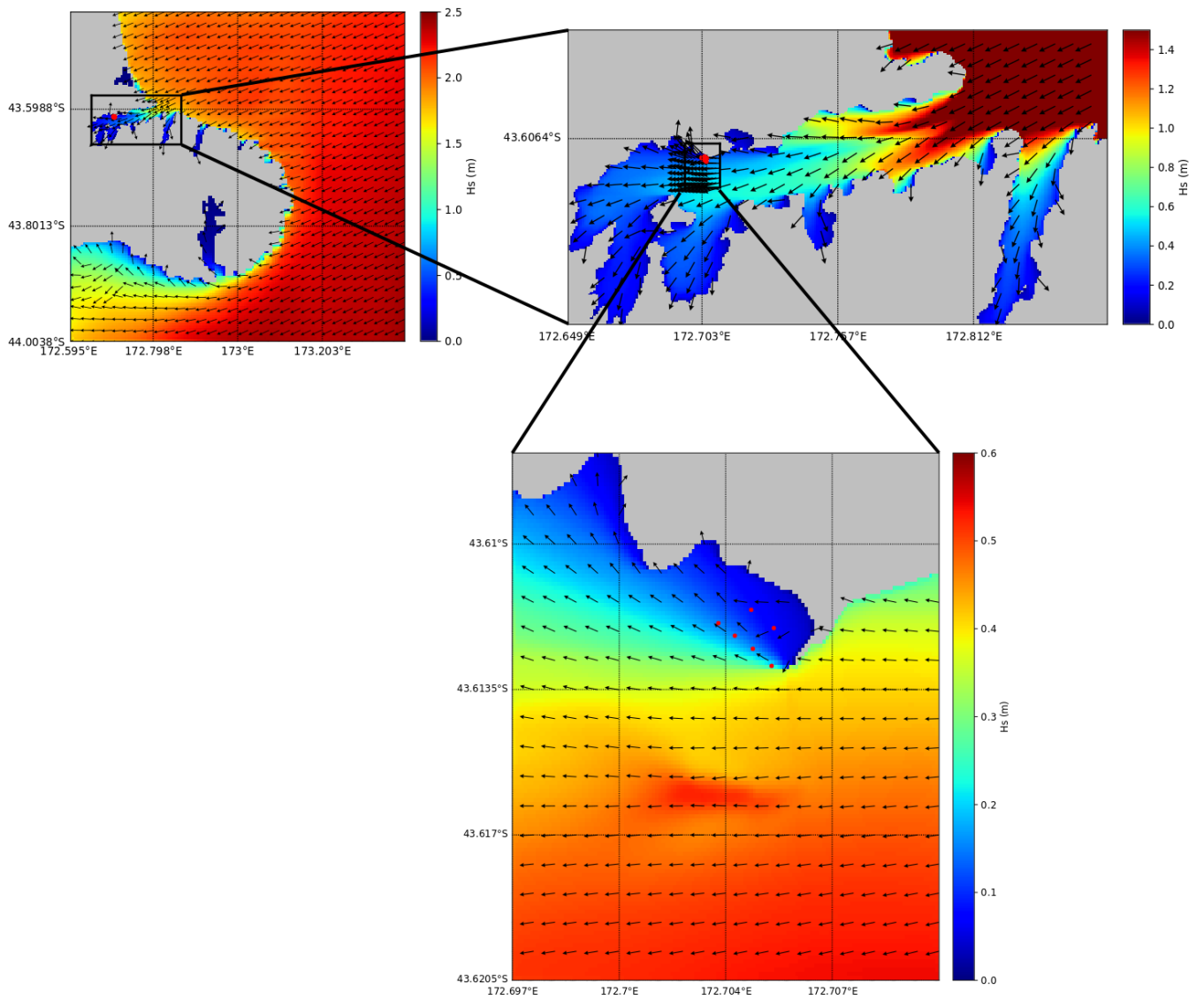


Figure 2.1 Example of modelled H_s field output for waves incoming from the NE sector for the 3 last SWAN nests. Vectors represent modelled wave direction. Red dots show sites for output results.

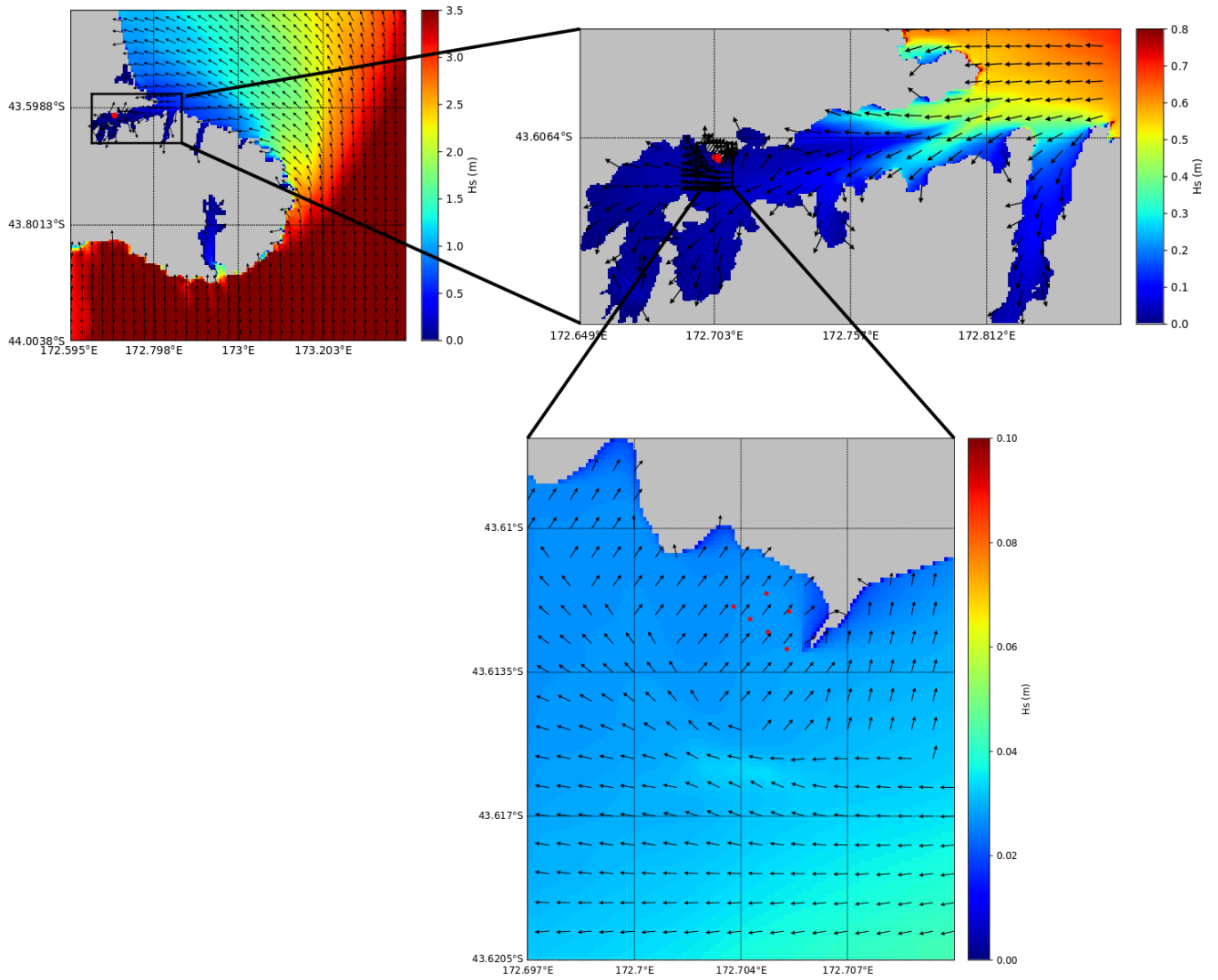


Figure 2.2 Example of modelled Hs field output for waves incoming from the S sector for the 3 last SWAN nests. Vectors represent modelled wave direction. Red dots show sites for output results.

3. Wind climate

The modelled wind data are nearly identical at all sites. Therefore, wind statistics are only reported for one representative site (P3).

A summary of the wind speed statistics for the 10-minute mean at 10 m elevation above mean sea level (AMSL) at P3 is provided in Table 3.1.

The annual joint probability distribution of the wind speed and direction is presented in Table 3.2.

The monthly and annual 10-min wind roses are illustrated in Figure 3.1, showing the annual predominance of winds coming mainly from the E quadrants.

Table 3.1 Annual and monthly 10-min wind speed statistics at P3.

Period (01 Jan 2009 – 31 Dec 2018)	10-min wind speed statistics ⁽¹⁾												
	10-min wind speed (m/s)			Exceedance percentile for 10-min wind speed (m/s)									Main ⁽²⁾ Direction(s)
	max	mean	std	p1	p5	p10	p50	p80	p90	p95	p98	p99	
January	16.26	5.75	2.94	0.43	1.04	1.75	5.78	8.21	9.48	10.63	12.14	13.40	E SW
February	18.00	5.36	2.73	0.34	0.95	1.54	5.33	7.63	8.55	9.54	11.50	12.27	E SW
March	19.61	5.17	2.90	0.34	0.79	1.29	5.14	7.52	8.67	9.91	11.74	12.81	E SW
April	18.85	4.94	3.13	0.24	0.66	1.15	4.61	7.21	9.03	11.18	13.16	14.49	E SW
May	17.73	5.16	3.38	0.27	0.66	1.10	4.65	7.66	9.93	11.86	14.24	15.09	E SW W
June	19.18	5.05	3.18	0.28	0.60	1.02	4.70	7.69	9.47	10.78	12.43	13.84	E SW W
July	15.10	4.91	3.04	0.28	0.66	1.13	4.59	7.53	9.20	10.63	12.19	13.30	E SW W
August	16.44	4.81	2.89	0.20	0.64	1.03	4.67	7.06	8.46	9.92	11.69	13.51	E SW
September	21.66	5.20	3.03	0.25	0.78	1.27	4.97	7.58	9.14	10.72	12.50	13.57	E SW W
October	17.93	5.34	2.94	0.36	0.87	1.53	5.20	7.72	9.07	10.37	12.23	13.77	E SW
November	16.42	5.58	2.84	0.34	0.94	1.69	5.56	8.07	9.15	10.17	11.38	12.28	E SW
December	18.19	5.67	2.81	0.39	1.01	1.72	5.71	8.09	9.22	10.19	11.38	12.33	E SW
Winter (Jun-Aug)	19.18	4.92	3.04	0.26	0.63	1.05	4.65	7.37	9.06	10.46	12.13	13.64	E SW W
Spring (Sep-Nov)	21.66	5.37	2.94	0.31	0.85	1.49	5.23	7.80	9.12	10.42	12.04	13.19	E SW
Summer (Dec-Feb)	18.19	5.60	2.83	0.38	1.01	1.67	5.59	7.97	9.13	10.20	11.67	12.81	E SW
Autumn (Mar-May)	19.61	5.09	3.14	0.28	0.68	1.17	4.80	7.46	9.12	11.00	13.07	14.52	E SW
All	21.66	5.24	3.00	0.31	0.76	1.32	5.07	7.70	9.11	10.48	12.25	13.60	E SW

Notes: (1) All statistics derived from hindcast wind data (10-min mean at 10m AMSL) for the period 01 January 2009 to 31 December 2018.
 (2) Main directions are those with greater than 15% occurrence and represent directions from which the winds approach.

Table 3.2 Annual joint probability distribution (%) of the wind speed and wind direction at P3.

U10min (m/s)	Wind direction (degT)									Total	Exceed%
	337.5-22.5	22.5-67.5	67.5-112.5	112.5-157.5	157.5-202.5	202.5-247.5	247.5-292.5	292.5-337.5			
>0<=2	0.96	1.60	2.77	1.24	1.42	2.81	3.09	1.85	15.74	100.00	
>2<=4	1.20	2.66	5.41	0.61	1.72	5.71	2.60	0.91	20.82	84.27	
>4<=6	1.15	3.79	9.17	0.24	0.97	6.57	2.35	1.10	25.34	63.45	
>6<=8	0.50	1.83	9.73	0.13	0.43	5.03	2.16	1.09	20.90	38.11	
>8<=10	0.14	0.74	4.13	0.03	0.18	2.96	1.83	0.81	10.82	17.21	
>10<=12	0.02	0.23	0.62	0.01	0.09	1.77	0.93	0.47	4.14	6.39	
>12<=14	0.01	0.05	0.08	0.01	0.04	0.92	0.25	0.13	1.49	2.26	
>14<=16	-	0.01	0.03	-	0.02	0.44	0.09	0.02	0.61	0.77	
>16<=18	-	-	-	-	-	0.10	0.01	0.01	0.12	0.16	
>18<=20	-	-	-	-	-	0.03	-	*	0.03	0.04	
>20<=22	-	-	-	-	-	*	-	-			
Total	3.98	10.91	31.94	2.27	4.87	26.34	13.31	6.39	100.00		

Notes: * represents less than 0.005%.



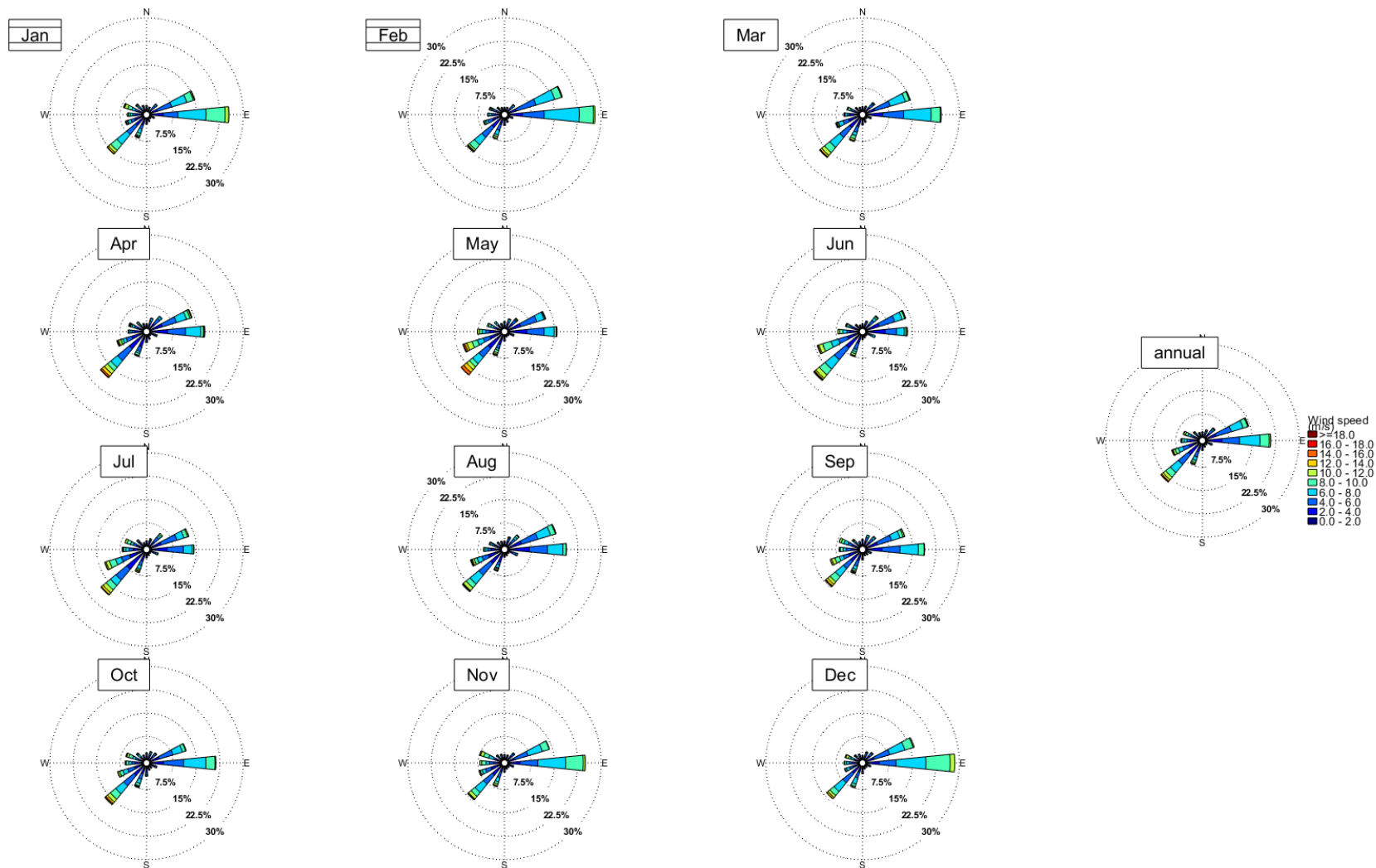


Figure 3.1 Monthly and annual wind rose plot (10-minute mean at 10m AMSL) at P3. Sectors indicate the direction from which the winds blow.

4. Wave climate

The mean H_s map (averaged over the 10-year hindcast) of the highest resolution domain is provide in Figure 4.1. Detailed site-specific wave statistics are given in the following subsections 4.1-4.6.

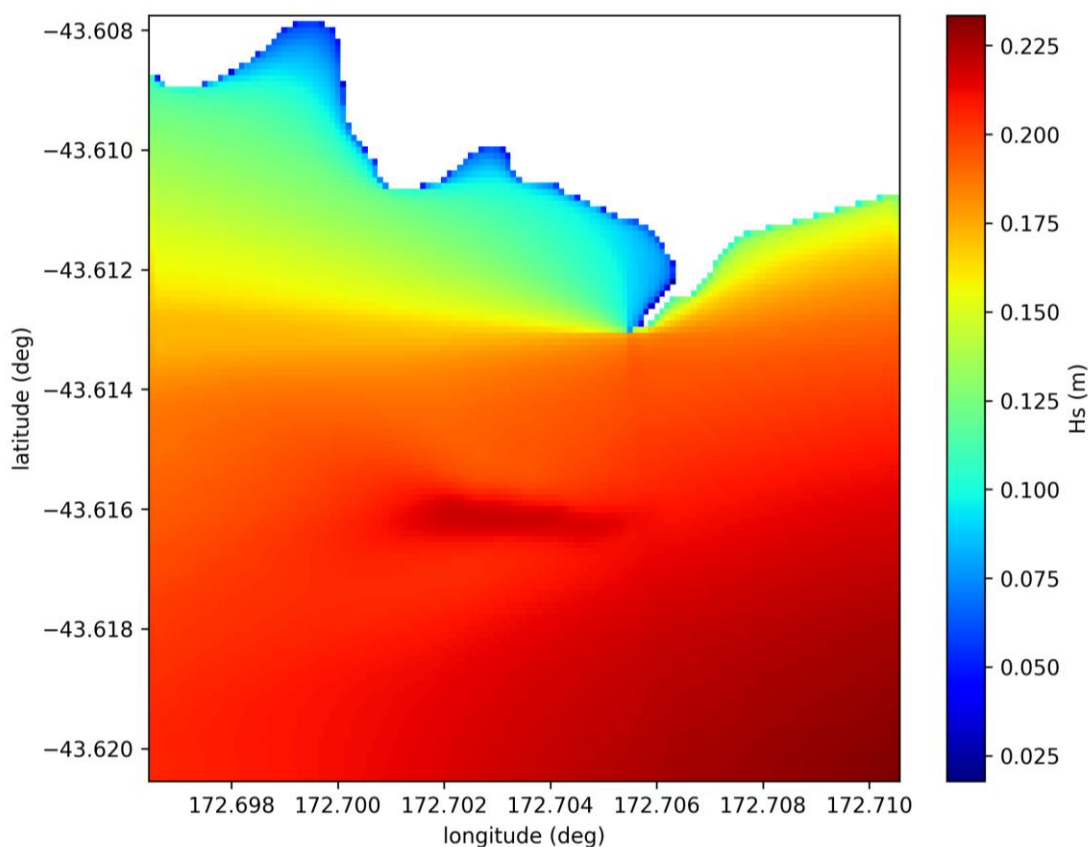


Figure 4.1 Map showing the mean H_s from the highest resolution SWAN domain over the 10-year (2019-2018) hindcast period.

4.1. P1

A summary of the total significant wave height statistics (H_s) at P1 is provided in Table 4.1.

The monthly and annual significant wave height exceedance probabilities are presented in Table 4.2.

The annual joint probability distribution of the total significant wave height and peak period is presented in Table 4.3.

The annual joint probability distribution of the total significant wave height and mean wave direction at peak energy is presented in Table 4.4.

Wave roses for the monthly and annual total significant wave height are presented in Figure 4.2, showing the predominance of waves incoming from the ESE sector.

Table 4.1 Annual and monthly total significant wave height statistics at P1.

Period (01 Jan 2009 – 31 Dec 2018)	Total significant wave height statistics ⁽¹⁾													
	Total significant wave height (m)				Exceedance percentile for total significant wave height (m)									Main ⁽²⁾ Direction(s)
	min	max	mean	std	p1	p5	p10	p50	p80	p90	p95	p98	p99	
January	0.01	0.60	0.14	0.09	0.02	0.04	0.05	0.13	0.20	0.26	0.30	0.37	0.42	E SE SW
February	0.01	0.53	0.13	0.08	0.02	0.03	0.04	0.12	0.19	0.23	0.28	0.35	0.38	E SE SW
March	0.01	0.79	0.14	0.10	0.02	0.03	0.04	0.12	0.19	0.26	0.32	0.42	0.46	E SE SW
April	0.01	0.64	0.13	0.10	0.02	0.03	0.04	0.10	0.19	0.26	0.36	0.46	0.50	E SE SW
May	0.01	0.71	0.14	0.12	0.01	0.02	0.03	0.10	0.21	0.33	0.43	0.52	0.57	E SE SW
June	0.00	0.66	0.15	0.11	0.01	0.02	0.03	0.12	0.23	0.31	0.37	0.44	0.50	SE SW
July	0.01	0.60	0.14	0.11	0.01	0.02	0.03	0.11	0.21	0.29	0.36	0.44	0.47	SE SW
August	0.01	0.61	0.13	0.10	0.01	0.02	0.03	0.10	0.19	0.25	0.33	0.43	0.50	E SE SW
September	0.01	0.67	0.14	0.10	0.02	0.03	0.04	0.11	0.20	0.28	0.35	0.45	0.50	SE SW
October	0.01	0.57	0.14	0.09	0.02	0.03	0.04	0.12	0.20	0.25	0.32	0.39	0.45	SE SW
November	0.01	0.54	0.14	0.08	0.02	0.03	0.04	0.12	0.20	0.24	0.28	0.35	0.39	SE SW W
December	0.01	0.57	0.14	0.08	0.02	0.03	0.05	0.13	0.20	0.24	0.28	0.32	0.38	E SE SW
Winter (Jun-Aug)	0.00	0.66	0.14	0.11	0.01	0.02	0.03	0.11	0.21	0.28	0.36	0.44	0.49	SE SW
Spring (Sep-Nov)	0.01	0.67	0.14	0.09	0.02	0.03	0.04	0.12	0.20	0.26	0.32	0.40	0.45	SE SW
Summer (Dec-Feb)	0.01	0.60	0.14	0.08	0.02	0.03	0.05	0.13	0.20	0.25	0.29	0.35	0.40	E SE SW
Autumn (Mar-May)	0.01	0.79	0.14	0.11	0.01	0.03	0.04	0.11	0.20	0.28	0.37	0.47	0.53	E SE SW
All	0.00	0.79	0.14	0.10	0.01	0.03	0.04	0.12	0.20	0.26	0.33	0.42	0.48	SE SW

Notes: (1) All statistics derived from hindcast wave data for the period 01 January 2009 to 31 December 2018.

(2) Main directions are those with greater than 15% occurrence and represent directions from which the waves approach.

Table 4.2 Monthly and annual total significant wave height exceedance probabilities (%) at P1.



H _s (m)	Exceedance (%)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	annual
>0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
>0.1	65.28	63.30	58.51	51.54	53.35	56.63	53.39	52.46	56.04	59.23	63.96	63.75	58.09
>0.2	21.45	15.69	18.75	17.29	21.21	25.21	21.37	17.38	20.25	19.52	19.63	20.60	19.89
>0.3	4.96	4.17	6.13	7.54	11.61	10.67	9.11	6.09	8.21	6.17	3.83	3.31	6.83
>0.4	1.25	0.71	2.62	3.33	6.09	3.58	3.10	2.62	3.25	1.90	0.83	0.81	2.52
>0.5	0.28	0.09	0.73	1.00	2.66	1.00	0.52	0.93	0.96	0.40	0.08	0.08	0.73
>0.6	0.04	0.00	0.36	0.21	0.52	0.25	0.00	0.04	0.08	0.00	0.00	0.00	0.13
>0.7	0.00	0.00	0.24	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02



Table 4.3 Annual joint probability distribution (in %) of the total significant wave height and peak period at P1.

Hs (m)	Peak period (s)																	Total	Exceed%
	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18		
>0<=0.1	28.12	4.54	1.01	2.89	0.15	0.01	0.08	0.18	0.27	0.34	0.26	0.18	0.10	0.01	*	-	-	38.14	100.00
>0.1<=0.2	20.12	17.69	0.11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	37.92	58.09
>0.2<=0.3	8.12	4.15	0.58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12.85	19.89
>0.3<=0.4	0.40	3.69	0.22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.31	6.83
>0.4<=0.5	-	1.74	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.79	2.52
>0.5<=0.6	-	0.60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.60	0.73
>0.6<=0.7	-	0.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.10	0.13
>0.7<=0.8	-	0.02	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03	0.02
Total	56.76	32.53	1.98	2.89	0.15	0.01	0.08	0.18	0.27	0.34	0.26	0.18	0.10	0.01	-	-	-	100.00	
>Exceed%	95.74	39.03	6.47	4.47	1.59	1.43	1.43	1.35	1.16	0.89	0.55	0.29	0.11	0.01	0.01	*	*		

Notes: * represents less than 0.005%.



Table 4.4 Annual joint probability distribution (in %) of the total significant wave height and mean wave direction at peak energy at P1.

Hs (m)	Mean wave direction at peak energy (degT)								Total	Exceed%
	337.5-22.5	22.5-67.5	67.5-112.5	112.5-157.5	157.5-202.5	202.5-247.5	247.5-292.5	292.5-337.5		
>0<=0.1	0.16	0.23	9.98	14.93	4.64	7.54	4.35	0.57	42.40	100.00
>0.1<=0.2	-	*	4.90	15.49	1.66	10.94	4.88	0.04	37.91	58.09
>0.2<=0.3	-	-	-	3.46	0.34	7.07	1.98	-	12.85	19.89
>0.3<=0.4	-	-	-	0.24	0.12	3.33	0.63	-	4.32	6.83
>0.4<=0.5	-	-	-	0.05	0.04	1.61	0.09	-	1.79	2.52
>0.5<=0.6	-	-	-	-	*	0.59	*	-	0.59	0.73
>0.6<=0.7	-	-	-	-	0.01	0.09	*	-	0.10	0.13
>0.7<=0.8	-	-	-	-	-	0.02	-	-	0.02	0.02
Total	0.16	0.23	14.88	34.17	6.81	31.19	11.93	0.61	100.00	

Notes: * represents less than 0.005%.



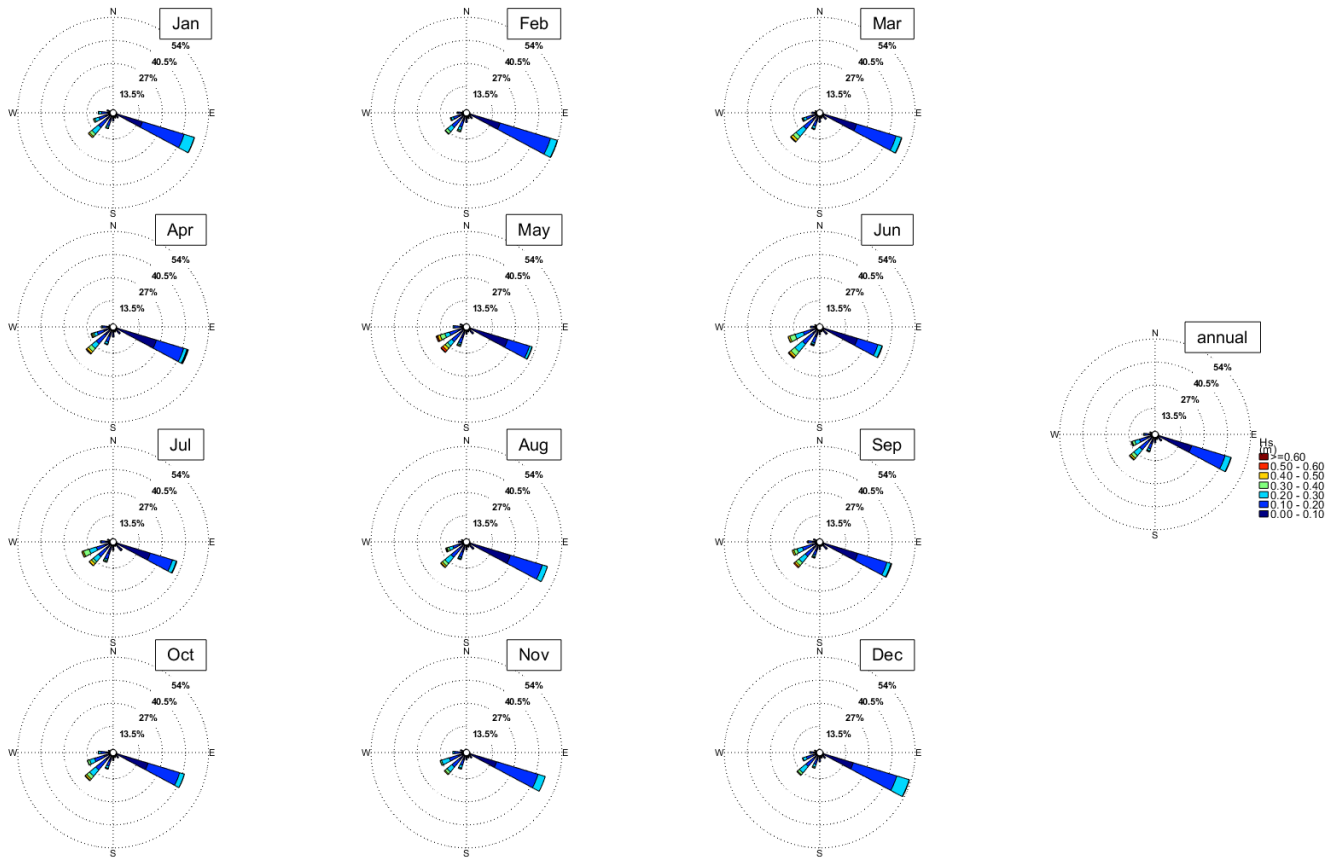


Figure 4.2 Monthly and annual wave rose plot for the total significant wave height at P1. Sectors indicate the direction from which waves approach.

4.2. P2

A summary of the total significant wave height statistics (H_s) at P2 is provided in Table 4.5.

The monthly and annual significant wave height exceedance probabilities are presented in Table 4.6.

The annual joint probability distribution of the total significant wave height and peak period is presented in Table 4.7.

The annual joint probability distribution of the total significant wave height and mean wave direction at peak energy is presented in Table 4.8.

Wave roses for the monthly and annual total significant wave height are presented in Figure 4.3, showing the predominance of waves incoming from the ESE sector.



Table 4.5 Annual and monthly total significant wave height statistics at P2.

Period (01 Jan 2009 – 31 Dec 2018)	Total significant wave height statistics ⁽¹⁾													Main ⁽²⁾ Direction(s)
	Total significant wave height (m)				Exceedance percentile for total significant wave height (m)									
	min	max	mean	std	p1	p5	p10	p50	p80	p90	p95	p98	p99	
January	0.01	0.61	0.13	0.09	0.02	0.03	0.04	0.11	0.18	0.25	0.30	0.37	0.41	SE SW
February	0.01	0.54	0.12	0.08	0.01	0.03	0.04	0.10	0.16	0.22	0.28	0.35	0.39	SE SW
March	0.01	0.80	0.12	0.10	0.01	0.02	0.03	0.10	0.17	0.25	0.32	0.43	0.46	SE SW
April	0.01	0.65	0.12	0.10	0.01	0.02	0.03	0.09	0.17	0.26	0.35	0.45	0.51	SE SW
May	0.01	0.73	0.14	0.13	0.01	0.02	0.03	0.09	0.20	0.33	0.44	0.52	0.58	SE SW
June	0.00	0.68	0.14	0.12	0.01	0.02	0.03	0.10	0.22	0.31	0.38	0.45	0.51	SE SW
July	0.00	0.61	0.13	0.11	0.01	0.02	0.03	0.09	0.20	0.29	0.36	0.45	0.47	SE SW
August	0.00	0.62	0.12	0.10	0.01	0.02	0.03	0.09	0.17	0.24	0.34	0.44	0.50	SE SW
September	0.01	0.68	0.13	0.11	0.01	0.02	0.03	0.10	0.19	0.27	0.35	0.46	0.51	SE SW
October	0.01	0.58	0.13	0.09	0.02	0.03	0.04	0.10	0.19	0.25	0.32	0.40	0.45	SE SW
November	0.01	0.55	0.12	0.08	0.02	0.03	0.04	0.11	0.18	0.23	0.28	0.35	0.40	SE SW W
December	0.01	0.58	0.12	0.08	0.02	0.03	0.04	0.11	0.18	0.22	0.27	0.32	0.39	SE SW
Winter (Jun-Aug)	0.00	0.68	0.13	0.11	0.01	0.02	0.03	0.10	0.19	0.28	0.36	0.45	0.50	SE SW
Spring (Sep-Nov)	0.01	0.68	0.13	0.09	0.01	0.03	0.04	0.10	0.18	0.25	0.32	0.40	0.46	SE SW
Summer (Dec-Feb)	0.01	0.61	0.12	0.08	0.02	0.03	0.04	0.11	0.17	0.23	0.28	0.35	0.40	SE SW
Autumn (Mar-May)	0.01	0.80	0.13	0.11	0.01	0.02	0.03	0.09	0.18	0.27	0.37	0.48	0.54	SE SW
All	0.00	0.80	0.13	0.10	0.01	0.02	0.03	0.10	0.18	0.26	0.33	0.43	0.48	SE SW

Notes: (1) All statistics derived from hindcast wave data for the period 01 January 2009 to 31 December 2018.
(2) Main directions are those with greater than 15% occurrence and represent directions from which the waves approach.

Table 4.6 Monthly and annual total significant wave height exceedance probabilities (%) at P2.



H _s (m)	Exceedance (%)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	annual
>0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
>0.1	56.73	52.30	48.95	43.92	45.65	51.42	47.14	44.80	47.75	50.52	55.00	55.97	50.00
>0.2	16.13	11.88	15.73	15.67	19.88	23.38	19.07	14.64	18.08	16.65	15.46	14.60	16.79
>0.3	4.96	3.90	5.97	7.25	11.61	10.42	8.95	6.05	7.96	6.21	3.83	3.19	6.71
>0.4	1.25	0.71	2.62	3.04	6.17	4.00	3.35	2.66	3.21	1.94	0.92	0.89	2.57
>0.5	0.36	0.13	0.81	1.21	2.86	1.13	0.65	1.09	1.08	0.52	0.17	0.08	0.85
>0.6	0.04	0.00	0.36	0.25	0.65	0.29	0.04	0.04	0.13	0.00	0.00	0.00	0.15
>0.7	0.00	0.00	0.28	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
>0.8	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



Table 4.7 Annual joint probability distribution (in %) of the total significant wave height and peak period at P2.

Hs (m)	Peak period (s)																	Total	Exceed%
	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18		
>0<=0.1	27.63	9.93	0.41	2.52	0.15	0.01	0.05	0.11	0.29	0.33	0.32	0.20	0.11	0.01	0.01	*	*	42.08	100.00
>0.1<=0.2	18.24	13.70	0.87	-	-	-	-	-	-	-	-	-	-	-	-	-	-	32.81	50.00
>0.2<=0.3	7.92	1.42	0.62	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.96	16.79
>0.3<=0.4	0.39	3.70	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.16	6.71
>0.4<=0.5	-	1.72	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.72	2.57
>0.5<=0.6	-	0.68	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.68	0.85
>0.6<=0.7	-	0.12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.12	0.15
>0.7<=0.8	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	0.03
>0.8<=0.9	-	*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
Total	54.18	31.29	1.97	2.52	0.15	0.01	0.05	0.11	0.29	0.33	0.32	0.20	0.11	0.01	0.01	-	-	100.00	
>Exceed%	91.57	37.45	6.09	4.12	1.61	1.45	1.44	1.39	1.29	0.99	0.66	0.34	0.14	0.03	0.02	0.01	0.01		

Notes: * represents less than 0.005%.



Table 4.8 Annual joint probability distribution (in %) of the total significant wave height and mean wave direction at peak energy at P2.

Hs (m)	Mean wave direction at peak energy (degT)								Total	Exceed%
	337.5-22.5	22.5-67.5	67.5-112.5	112.5-157.5	157.5-202.5	202.5-247.5	247.5-292.5	292.5-337.5		
>0<=0.1	0.82	1.03	0.88	28.64	5.46	8.20	4.61	0.87	50.51	100.00
>0.1<=0.2	0.02	-	-	15.34	1.59	11.19	4.63	0.04	32.81	50.00
>0.2<=0.3	-	-	-	0.79	0.33	7.23	1.61	-	9.96	16.79
>0.3<=0.4	-	-	-	0.07	0.12	3.57	0.40	-	4.16	6.71
>0.4<=0.5	-	-	-	-	0.05	1.62	0.05	-	1.72	2.57
>0.5<=0.6	-	-	-	-	*	0.68	-	-	0.68	0.85
>0.6<=0.7	-	-	-	-	0.01	0.12	-	-	0.13	0.15
>0.7<=0.8	-	-	-	-	-	0.02	-	-	0.02	0.03
>0.8<=0.9	-	-	-	-	-	*	-	-		
Total	0.84	1.03	0.88	44.84	7.56	32.63	11.30	0.91	100.00	

Notes: * represents less than 0.005%.



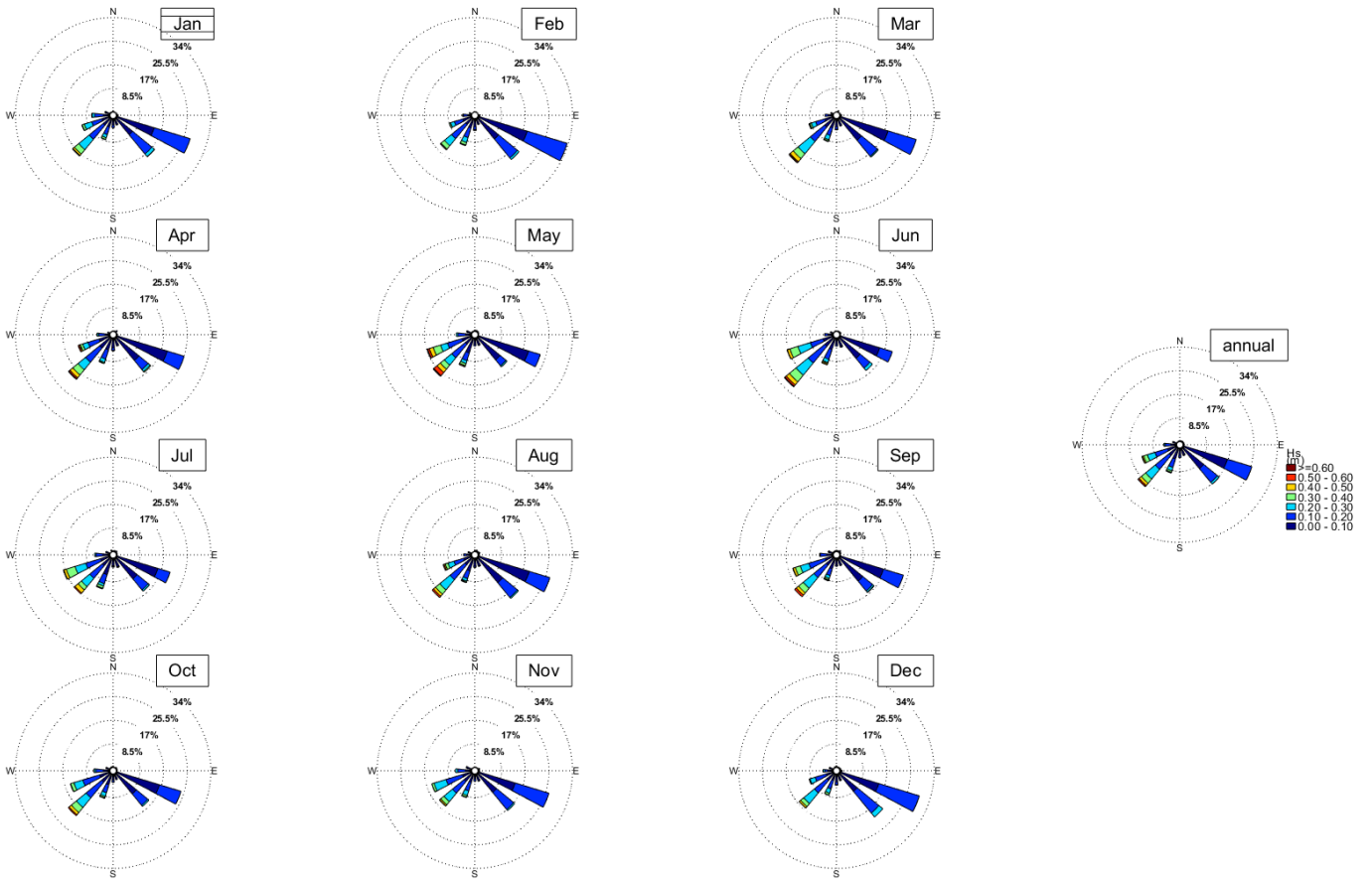


Figure 4.3 Monthly and annual wave rose plot for the total significant wave height at P2. Sectors indicate the direction from which waves approach.

4.3. P3

A summary of the total significant wave height statistics (H_s) at P3 is provided in Table 4.9.

The monthly and annual significant wave height exceedance probabilities are presented in Table 4.10.

The annual joint probability distribution of the total significant wave height and peak period is presented in Table 4.11.

The annual joint probability distribution of the total significant wave height and mean wave direction at peak energy is presented in Table 4.12.

Wave roses for the monthly and annual total significant wave height are presented in Figure 4.4, showing the predominance of waves incoming from the SE sector.



Table 4.9 Annual and monthly total significant wave height statistics at P3.

Period (01 Jan 2009 – 31 Dec 2018)	Total significant wave height statistics ⁽¹⁾														
	Total significant wave height (m)				Exceedance percentile for total significant wave height (m)										Main ⁽²⁾ Direction(s)
	min	max	mean	std	p1	p5	p10	p50	p80	p90	p95	p98	p99		
January	0.01	0.61	0.13	0.09	0.02	0.03	0.04	0.11	0.18	0.25	0.30	0.37	0.41	SE SW	
February	0.01	0.54	0.12	0.08	0.01	0.03	0.04	0.10	0.16	0.21	0.28	0.35	0.39	SE SW	
March	0.01	0.81	0.12	0.10	0.01	0.02	0.03	0.10	0.17	0.25	0.32	0.43	0.47	SE SW	
April	0.01	0.66	0.12	0.10	0.01	0.02	0.03	0.09	0.17	0.26	0.35	0.46	0.51	SE SW	
May	0.01	0.74	0.13	0.13	0.01	0.02	0.03	0.09	0.20	0.33	0.44	0.53	0.58	SE SW	
June	0.00	0.68	0.14	0.12	0.01	0.02	0.03	0.10	0.22	0.30	0.38	0.45	0.51	SE SW	
July	0.00	0.61	0.13	0.11	0.01	0.02	0.03	0.09	0.19	0.28	0.36	0.45	0.48	SE SW	
August	0.00	0.63	0.12	0.10	0.01	0.02	0.03	0.09	0.17	0.24	0.34	0.44	0.50	SE SW	
September	0.01	0.68	0.13	0.11	0.01	0.02	0.03	0.09	0.18	0.27	0.35	0.46	0.51	SE SW	
October	0.01	0.59	0.12	0.09	0.02	0.03	0.04	0.10	0.18	0.25	0.32	0.40	0.45	SE SW	
November	0.01	0.56	0.12	0.08	0.02	0.03	0.04	0.11	0.18	0.23	0.28	0.35	0.40	SE SW	
December	0.01	0.58	0.12	0.08	0.02	0.03	0.04	0.11	0.17	0.22	0.27	0.32	0.38	SE SW	
Winter (Jun-Aug)	0.00	0.68	0.13	0.11	0.01	0.02	0.03	0.09	0.19	0.28	0.36	0.45	0.50	SE SW	
Spring (Sep-Nov)	0.01	0.68	0.12	0.09	0.01	0.03	0.04	0.10	0.18	0.25	0.32	0.40	0.46	SE SW	
Summer (Dec-Feb)	0.01	0.61	0.12	0.08	0.01	0.03	0.04	0.11	0.17	0.23	0.28	0.35	0.40	SE SW	
Autumn (Mar-May)	0.01	0.81	0.13	0.11	0.01	0.02	0.03	0.09	0.18	0.27	0.37	0.48	0.54	SE SW	
All	0.00	0.81	0.12	0.10	0.01	0.02	0.03	0.10	0.18	0.26	0.33	0.43	0.48	SE SW	

Notes: (1) All statistics derived from hindcast wave data for the period 01 January 2009 to 31 December 2018.
(2) Main directions are those with greater than 15% occurrence and represent directions from which the waves approach.

Table 4.10 Monthly and annual total significant wave height exceedance probabilities (%) at P3.



H _s (m)	Exceedance (%)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	annual
>0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
>0.1	55.24	50.89	48.19	43.17	44.76	50.88	46.25	43.71	46.96	49.84	54.42	55.20	49.11
>0.2	15.77	11.70	15.44	15.46	19.72	23.13	18.79	14.44	18.04	16.53	15.38	14.23	16.57
>0.3	4.92	3.95	6.05	7.12	11.45	10.42	8.91	6.05	7.92	6.17	3.79	3.06	6.66
>0.4	1.33	0.75	2.66	3.08	6.25	4.00	3.39	2.66	3.25	2.06	1.04	0.89	2.63
>0.5	0.36	0.13	0.81	1.21	2.86	1.17	0.73	1.09	1.17	0.52	0.21	0.08	0.87
>0.6	0.04	0.00	0.36	0.29	0.65	0.29	0.04	0.04	0.13	0.00	0.00	0.00	0.15
>0.7	0.00	0.00	0.28	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
>0.8	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



Table 4.11 Annual joint probability distribution (in %) of the total significant wave height and peak period at P3.

Hs (m)	Peak period (s)																	Total	Exceed%
	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18		
>0<=0.1	26.08	9.53	0.38	2.27	0.17	0.01	0.05	0.10	0.30	0.36	0.36	0.22	0.12	0.03	0.01	*	*	39.99	100.00
>0.1<=0.2	18.47	12.40	1.37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	32.24	49.11
>0.2<=0.3	7.84	1.39	0.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.76	16.57
>0.3<=0.4	0.39	3.65	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.09	6.66
>0.4<=0.5	-	1.74	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.74	2.63
>0.5<=0.6	-	0.68	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.68	0.87
>0.6<=0.7	-	0.13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.13	0.16
>0.7<=0.8	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	0.03
>0.8<=0.9	-	*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
Total	52.78	29.54	2.33	2.27	0.17	0.01	0.05	0.10	0.30	0.36	0.36	0.22	0.12	0.03	0.01	-	-	100.00	
>Exceed%	88.66	35.94	6.35	4.00	1.73	1.56	1.56	1.51	1.41	1.11	0.75	0.39	0.17	0.05	0.02	0.01	0.01		

Notes: * represents less than 0.005%.



Table 4.12 Annual joint probability distribution (in %) of the total significant wave height and mean wave direction at peak energy at P3.

Hs (m)	Mean wave direction at peak energy (degT)								Total	Exceed%
	337.5-22.5	22.5-67.5	67.5-112.5	112.5-157.5	157.5-202.5	202.5-247.5	247.5-292.5	292.5-337.5		
>0<=0.1	1.02	1.23	1.83	27.64	5.72	8.53	4.51	0.83	51.31	100.00
>0.1<=0.2	0.02	-	0.01	14.83	1.57	11.38	4.41	0.03	32.25	49.11
>0.2<=0.3	-	-	-	0.63	0.36	7.37	1.41	-	9.77	16.57
>0.3<=0.4	-	-	-	0.05	0.11	3.64	0.28	-	4.08	6.66
>0.4<=0.5	-	-	-	-	0.06	1.66	0.01	-	1.73	2.63
>0.5<=0.6	-	-	-	-	0.01	0.68	-	-	0.69	0.87
>0.6<=0.7	-	-	-	-	0.01	0.12	-	-	0.13	0.16
>0.7<=0.8	-	-	-	-	-	0.02	-	-	0.02	0.03
>0.8<=0.9	-	-	-	-	-	*	-	-		
Total	1.04	1.23	1.84	43.15	7.84	33.40	10.62	0.86	100.00	

Notes: * represents less than 0.005%.



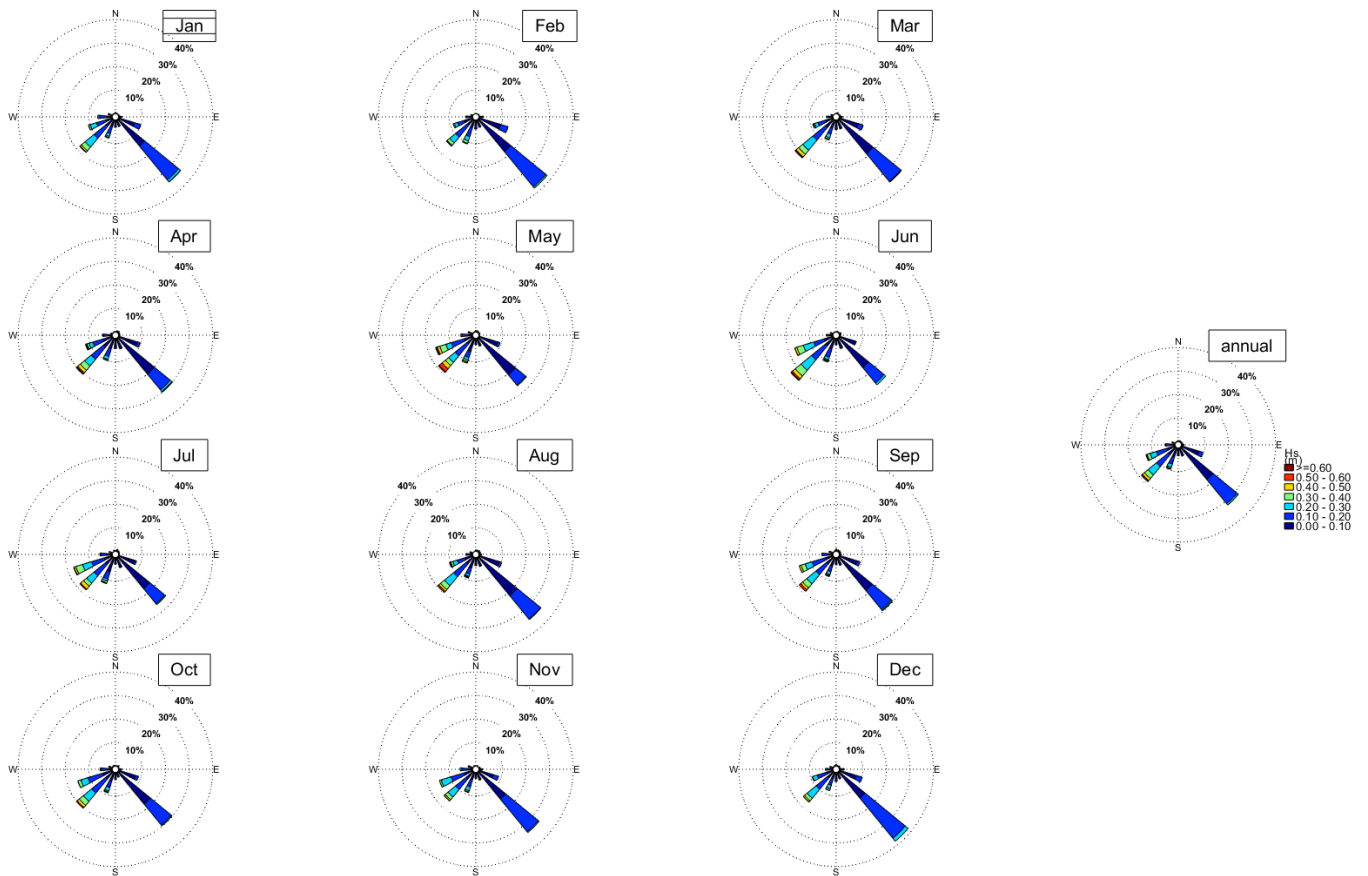


Figure 4.4 Monthly and annual wave rose plot for the total significant wave height at P3. Sectors indicate the direction from which waves approach.

4.4. P4

A summary of the total significant wave height statistics (H_s) at P4 is provided in Table 4.13.

The monthly and annual significant wave height exceedance probabilities are presented in Table 4.14.

The annual joint probability distribution of the total significant wave height and peak period is presented in Table 4.15.

The annual joint probability distribution of the total significant wave height and mean wave direction at peak energy is presented in Table 4.16.

Wave roses for the monthly and annual total significant wave height are presented in Figure 4.5, showing the predominance of waves incoming from the SE sector.



Table 4.13 Annual and monthly total significant wave height statistics at P4.

Period (01 Jan 2009 – 31 Dec 2018)	Total significant wave height statistics ⁽¹⁾														
	Total significant wave height (m)				Exceedance percentile for total significant wave height (m)										Main ⁽²⁾ Direction(s)
	min	max	mean	std	p1	p5	p10	p50	p80	p90	p95	p98	p99		
January	0.01	0.62	0.13	0.09	0.02	0.03	0.04	0.11	0.18	0.25	0.29	0.37	0.41	SE SW	
February	0.01	0.55	0.12	0.08	0.01	0.03	0.04	0.10	0.16	0.21	0.27	0.35	0.39	SE SW	
March	0.01	0.81	0.12	0.10	0.01	0.02	0.03	0.10	0.17	0.25	0.32	0.43	0.47	SE SW	
April	0.01	0.65	0.12	0.10	0.01	0.02	0.03	0.09	0.17	0.25	0.35	0.46	0.51	SE SW	
May	0.01	0.74	0.13	0.13	0.01	0.02	0.03	0.09	0.20	0.32	0.44	0.53	0.58	SE SW	
June	0.00	0.67	0.14	0.12	0.01	0.02	0.03	0.10	0.22	0.30	0.38	0.45	0.51	SE SW	
July	0.00	0.61	0.13	0.11	0.01	0.02	0.03	0.09	0.19	0.28	0.36	0.45	0.47	SE SW	
August	0.00	0.63	0.12	0.10	0.01	0.02	0.03	0.09	0.17	0.24	0.33	0.44	0.50	SE SW	
September	0.01	0.68	0.13	0.11	0.01	0.02	0.03	0.09	0.18	0.27	0.34	0.46	0.51	SE SW	
October	0.01	0.59	0.12	0.09	0.02	0.03	0.04	0.10	0.18	0.25	0.32	0.40	0.45	SE SW	
November	0.01	0.56	0.12	0.08	0.02	0.03	0.04	0.11	0.18	0.23	0.28	0.35	0.40	SE SW	
December	0.01	0.58	0.12	0.08	0.02	0.03	0.04	0.11	0.17	0.22	0.27	0.32	0.38	SE SW	
Winter (Jun-Aug)	0.00	0.67	0.13	0.11	0.01	0.02	0.03	0.09	0.19	0.28	0.36	0.45	0.50	SE SW	
Spring (Sep-Nov)	0.01	0.68	0.12	0.09	0.01	0.03	0.04	0.10	0.18	0.25	0.32	0.40	0.46	SE SW	
Summer (Dec-Feb)	0.01	0.62	0.12	0.08	0.01	0.03	0.04	0.11	0.17	0.23	0.28	0.35	0.40	SE SW	
Autumn (Mar-May)	0.01	0.81	0.12	0.11	0.01	0.02	0.03	0.09	0.18	0.27	0.37	0.48	0.54	SE SW	
All	0.00	0.81	0.12	0.10	0.01	0.02	0.03	0.10	0.18	0.26	0.33	0.43	0.48	SE SW	

Notes: (1) All statistics derived from hindcast wave data for the period 01 January 2009 to 31 December 2018.
 (2) Main directions are those with greater than 15% occurrence and represent directions from which the waves approach.

Table 4.14 Monthly and annual total significant wave height exceedance probabilities (%) at P4.

H _s (m)	Exceedance (%)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	annual
>0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
>0.1	54.84	51.06	48.19	43.13	44.40	50.71	45.89	43.35	46.46	49.64	54.29	54.76	48.88
>0.2	15.48	11.61	15.44	15.33	19.35	22.67	18.67	14.35	17.88	16.33	15.04	13.95	16.36
>0.3	4.76	4.03	5.93	7.04	11.33	10.29	8.71	6.01	7.88	6.09	3.79	3.06	6.59
>0.4	1.29	0.80	2.66	3.08	6.21	3.88	3.27	2.66	3.21	2.10	1.00	0.85	2.59
>0.5	0.32	0.13	0.81	1.21	2.82	1.17	0.69	1.09	1.04	0.52	0.25	0.08	0.85
>0.6	0.04	0.00	0.36	0.29	0.69	0.29	0.04	0.04	0.13	0.00	0.00	0.00	0.16
>0.7	0.00	0.00	0.28	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
>0.8	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



Table 4.15 Annual joint probability distribution (in %) of the total significant wave height and peak period at P4.

Hs (m)	Peak period (s)																	Total	Exceed%
	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18		
>0<=0.1	25.90	8.14	0.36	2.17	0.19	0.01	0.05	0.12	0.32	0.37	0.41	0.25	0.13	0.03	0.01	0.01	*	38.47	100.00
>0.1<=0.2	19.20	11.30	1.75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	32.25	48.88
>0.2<=0.3	7.71	1.42	0.52	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.65	16.36
>0.3<=0.4	0.38	3.62	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.04	6.59
>0.4<=0.5	-	1.73	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.73	2.59
>0.5<=0.6	-	0.67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.67	0.85
>0.6<=0.7	-	0.13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.13	0.16
>0.7<=0.8	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	0.03
>0.8<=0.9	-	*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
Total	53.19	27.03	2.67	2.17	0.19	0.01	0.05	0.12	0.32	0.37	0.41	0.25	0.13	0.03	0.01	0.01	-	100.00	
>Exceed%	86.96	33.82	6.76	4.08	1.90	1.71	1.70	1.65	1.54	1.22	0.85	0.44	0.18	0.06	0.03	0.02	0.01		

Notes: * represents less than 0.005%.



Table 4.16 Annual joint probability distribution (in %) of the total significant wave height and mean wave direction at peak energy at P4.

Hs (m)	Mean wave direction at peak energy (degT)								Total	Exceed%
	337.5-22.5	22.5-67.5	67.5-112.5	112.5-157.5	157.5-202.5	202.5-247.5	247.5-292.5	292.5-337.5		
>0<=0.1	1.03	1.31	2.47	26.66	5.98	8.81	4.50	0.73	51.49	100.00
>0.1<=0.2	0.02	0.01	0.02	14.87	1.52	11.72	4.10	0.02	32.28	48.88
>0.2<=0.3	-	-	-	0.61	0.35	7.52	1.18	-	9.66	16.36
>0.3<=0.4	-	-	-	0.04	0.11	3.71	0.17	-	4.03	6.59
>0.4<=0.5	-	-	-	-	0.07	1.65	0.01	-	1.73	2.59
>0.5<=0.6	-	-	-	-	*	0.66	-	-	0.66	0.85
>0.6<=0.7	-	-	-	-	0.01	0.12	-	-	0.13	0.16
>0.7<=0.8	-	-	-	-	-	0.02	-	-	0.02	0.03
>0.8<=0.9	-	-	-	-	-	*	-	-		
Total	1.05	1.32	2.49	42.18	8.04	34.21	9.96	0.75	100.00	

Notes: * represents less than 0.005%.



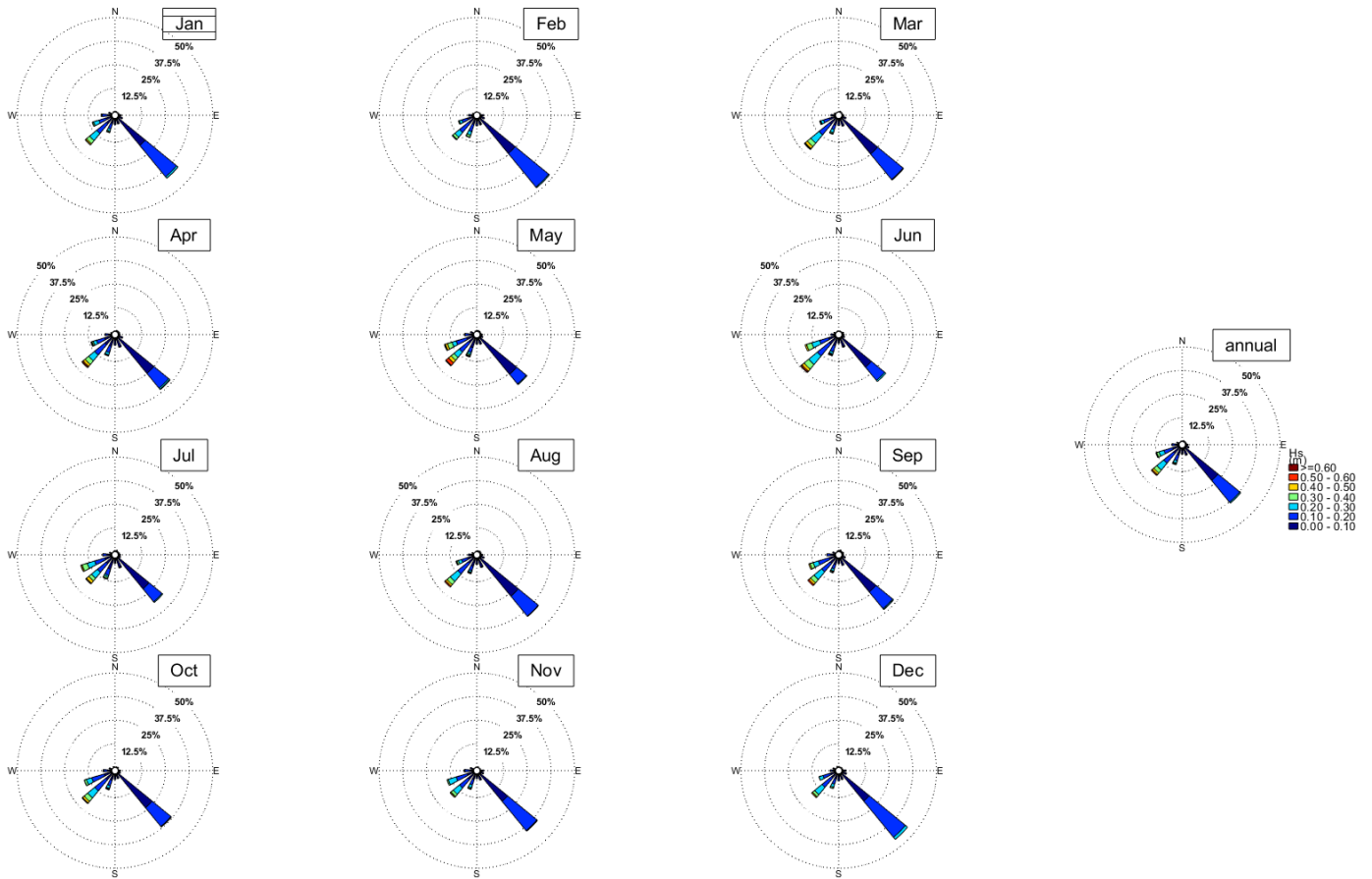


Figure 4.5 Monthly and annual wave rose plot for the total significant wave height at P4. Sectors indicate the direction from which waves approach.

4.5. P5

A summary of the total significant wave height statistics (H_s) at P5 is provided in Table 4.17.

The monthly and annual significant wave height exceedance probabilities are presented in Table 4.18.

The annual joint probability distribution of the total significant wave height and peak period is presented in Table 4.19.

The annual joint probability distribution of the total significant wave height and mean wave direction at peak energy is presented in Table 4.20.

Wave roses for the monthly and annual total significant wave height are presented in Figure 4.6, showing the predominance of waves incoming from the SW sector.

Table 4.17 Annual and monthly total significant wave height statistics at P5.

Period (01 Jan 2009 – 31 Dec 2018)	Total significant wave height statistics ⁽¹⁾														
	Total significant wave height (m)				Exceedance percentile for total significant wave height (m)										Main ⁽²⁾ Direction(s)
	min	max	mean	std	p1	p5	p10	p50	p80	p90	p95	p98	p99		
January	0.01	0.60	0.11	0.09	0.01	0.02	0.03	0.07	0.16	0.24	0.29	0.37	0.41	E SE SW	
February	0.00	0.53	0.09	0.08	0.01	0.02	0.03	0.07	0.13	0.21	0.27	0.35	0.38	E SE SW	
March	0.00	0.79	0.10	0.10	0.01	0.02	0.02	0.07	0.16	0.25	0.32	0.43	0.46	E SE SW	
April	0.00	0.64	0.10	0.11	0.01	0.01	0.02	0.06	0.16	0.24	0.34	0.45	0.50	E SE SW	
May	0.00	0.71	0.12	0.13	0.01	0.01	0.02	0.06	0.19	0.32	0.43	0.52	0.57	E SW	
June	0.00	0.66	0.12	0.12	0.01	0.01	0.02	0.08	0.21	0.30	0.37	0.44	0.50	E SW	
July	0.00	0.60	0.11	0.11	0.01	0.01	0.02	0.07	0.19	0.28	0.36	0.44	0.47	E S SW	
August	0.00	0.61	0.10	0.10	0.01	0.01	0.02	0.06	0.16	0.24	0.33	0.44	0.50	E SE SW	
September	0.01	0.65	0.11	0.11	0.01	0.02	0.02	0.07	0.18	0.27	0.34	0.45	0.50	E SE SW	
October	0.01	0.57	0.11	0.10	0.01	0.02	0.03	0.07	0.18	0.25	0.32	0.39	0.45	E SE SW	
November	0.00	0.54	0.10	0.09	0.01	0.02	0.03	0.07	0.16	0.23	0.28	0.35	0.39	E SE SW	
December	0.00	0.57	0.10	0.08	0.01	0.02	0.03	0.07	0.15	0.22	0.27	0.32	0.38	E SE SW	
Winter (Jun-Aug)	0.00	0.66	0.11	0.11	0.01	0.01	0.02	0.07	0.19	0.28	0.36	0.44	0.49	E SW	
Spring (Sep-Nov)	0.00	0.65	0.11	0.10	0.01	0.02	0.03	0.07	0.17	0.25	0.31	0.40	0.46	E SE SW	
Summer (Dec-Feb)	0.00	0.60	0.10	0.08	0.01	0.02	0.03	0.07	0.15	0.22	0.28	0.35	0.39	E SE SW	
Autumn (Mar-May)	0.00	0.79	0.11	0.11	0.01	0.01	0.02	0.06	0.17	0.27	0.36	0.47	0.53	E SE SW	
All	0.00	0.79	0.11	0.10	0.01	0.02	0.02	0.07	0.17	0.25	0.33	0.42	0.48	E SE SW	

Notes: (1) All statistics derived from hindcast wave data for the period 01 January 2009 to 31 December 2018.
(2) Main directions are those with greater than 15% occurrence and represent directions from which the waves approach.

Table 4.18 Monthly and annual total significant wave height exceedance probabilities (%) at P5.



H _s (m)	Exceedance (%)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	annual
>0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
>0.1	34.40	28.37	31.01	32.83	37.70	41.54	37.18	30.00	35.50	37.26	34.75	31.37	34.35
>0.2	14.23	10.90	14.96	14.25	18.83	21.67	18.06	14.11	17.13	15.85	14.37	12.38	15.58
>0.3	4.60	3.81	5.85	6.71	11.37	10.21	8.55	5.97	7.63	5.93	3.71	3.06	6.46
>0.4	1.09	0.71	2.62	3.04	6.05	3.42	3.15	2.62	3.13	1.85	0.88	0.85	2.46
>0.5	0.32	0.09	0.73	1.04	2.62	1.04	0.52	0.93	1.04	0.40	0.13	0.08	0.75
>0.6	0.00	0.00	0.36	0.21	0.52	0.25	0.00	0.04	0.08	0.00	0.00	0.00	0.12
>0.7	0.00	0.00	0.24	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02



Table 4.19 Annual joint probability distribution (in %) of the total significant wave height and peak period at P5.

Hs (m)	Peak period (s)																	Total	Exceed%
	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18		
>0<=0.1	18.36	0.59	0.76	0.50	0.11	0.05	0.09	0.12	0.17	0.26	0.34	0.24	0.13	0.03	0.02	0.01	-	21.78	100.00
>0.1<=0.2	17.61	0.22	0.34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18.17	34.35
>0.2<=0.3	7.55	1.44	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.00	15.58
>0.3<=0.4	0.30	3.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.01	6.46
>0.4<=0.5	-	1.70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.70	2.46
>0.5<=0.6	-	0.62	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.62	0.75
>0.6<=0.7	-	0.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.10	0.12
>0.7<=0.8	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	0.02
Total	43.82	8.40	1.11	0.50	0.11	0.05	0.09	0.12	0.17	0.26	0.34	0.24	0.13	0.03	0.02	0.01	-	100.00	
>Exceed%	55.41	11.60	3.18	2.07	1.57	1.46	1.41	1.32	1.20	1.03	0.77	0.42	0.19	0.06	0.03	0.02	*		

Notes: * represents less than 0.005%.



Table 4.20 Annual joint probability distribution (in %) of the total significant wave height and mean wave direction at peak energy at P5.

Hs (m)	Mean wave direction at peak energy (degT)								Total	Exceed%
	337.5-22.5	22.5-67.5	67.5-112.5	112.5-157.5	157.5-202.5	202.5-247.5	247.5-292.5	292.5-337.5		
>0<=0.1	1.07	2.46	18.69	16.80	10.73	10.35	5.10	0.73	65.93	100.00
>0.1<=0.2	-	0.01	0.50	0.93	1.42	11.98	3.77	-	18.61	34.35
>0.2<=0.3	-	-	-	0.01	0.25	7.77	0.96	-	8.99	15.58
>0.3<=0.4	-	-	-	-	0.09	3.82	0.11	-	4.02	6.46
>0.4<=0.5	-	-	-	-	0.03	1.66	0.01	-	1.70	2.46
>0.5<=0.6	-	-	-	-	-	0.62	-	-	0.62	0.75
>0.6<=0.7	-	-	-	-	*	0.10	-	-	0.10	0.12
>0.7<=0.8	-	-	-	-	-	0.02	-	-	0.02	0.02
Total	1.07	2.47	19.19	17.74	12.52	36.32	9.95	0.73	100.00	

Notes: * represents less than 0.005%.



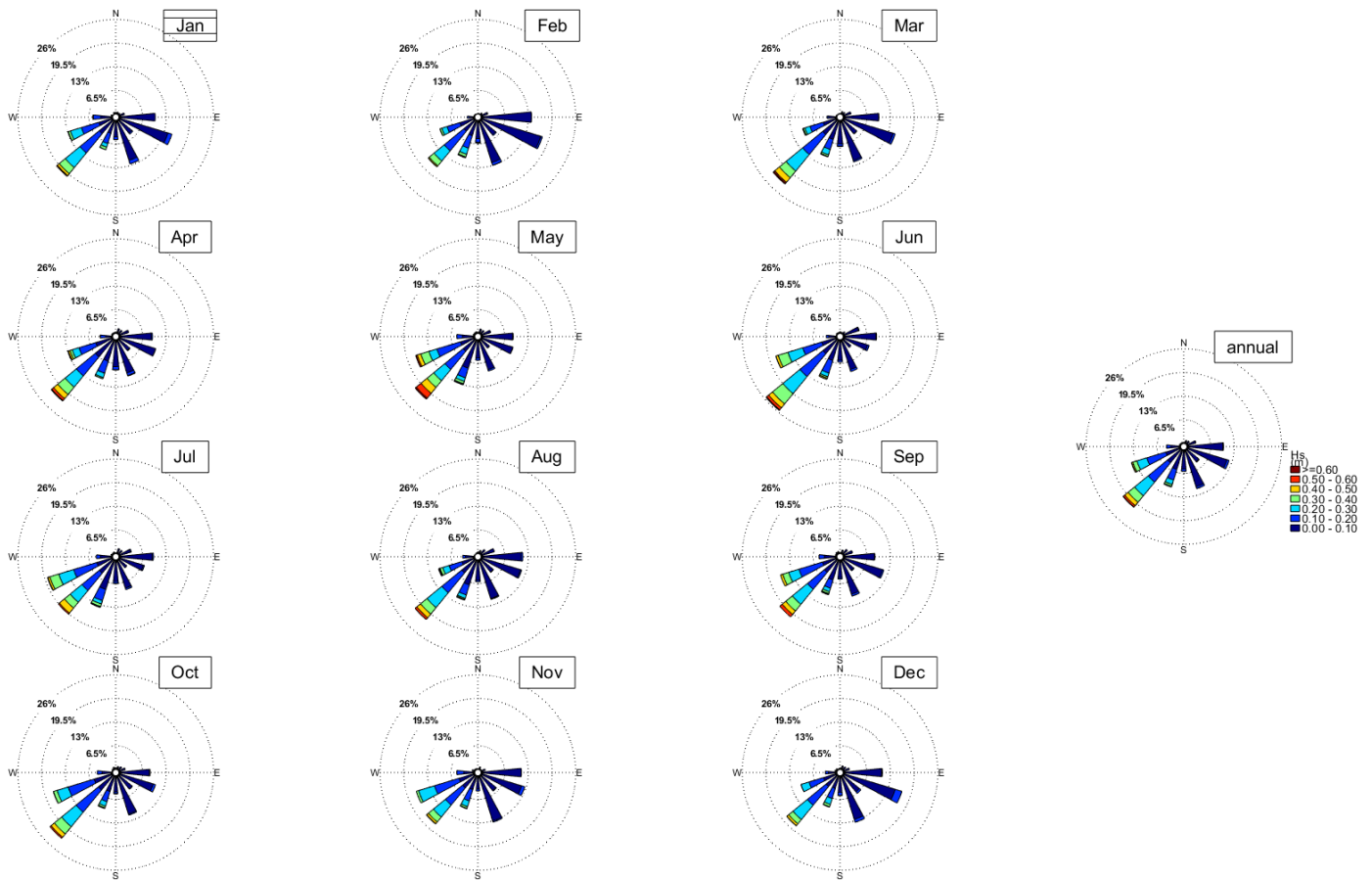


Figure 4.6 Monthly and annual wave rose plot for the total significant wave height at P5. Sectors indicate the direction from which waves approach.

4.6. P6

A summary of the total significant wave height statistics (H_s) at P6 is provided in Table 4.21.

The monthly and annual significant wave height exceedance probabilities are presented in Table 4.22.

The annual joint probability distribution of the total significant wave height and peak period is presented in Table 4.23.

The annual joint probability distribution of the total significant wave height and mean wave direction at peak energy is presented in Table 4.24.

Wave roses for the monthly and annual total significant wave height are presented in Figure 4.7, showing the predominance of waves incoming from the SW sector.



Table 4.21 Annual and monthly total significant wave height statistics at P6.

Period (01 Jan 2009 – 31 Dec 2018)	Total significant wave height statistics ⁽¹⁾														
	Total significant wave height (m)				Exceedance percentile for total significant wave height (m)										Main ⁽²⁾ Direction(s)
	min	max	mean	std	p1	p5	p10	p50	p80	p90	p95	p98	p99		
January	0.00	0.58	0.10	0.09	0.01	0.02	0.03	0.06	0.16	0.24	0.29	0.36	0.41	E SW	
February	0.00	0.52	0.09	0.08	0.01	0.02	0.02	0.05	0.13	0.21	0.27	0.34	0.38	E SW	
March	0.00	0.78	0.10	0.10	0.01	0.01	0.02	0.05	0.16	0.25	0.31	0.42	0.45	E SW	
April	0.00	0.63	0.10	0.11	0.01	0.01	0.02	0.05	0.16	0.24	0.33	0.44	0.50	E SW	
May	0.00	0.69	0.12	0.13	0.01	0.01	0.02	0.06	0.19	0.32	0.43	0.51	0.56	E SW	
June	0.00	0.66	0.12	0.12	0.01	0.01	0.01	0.07	0.21	0.30	0.37	0.44	0.49	E SW	
July	0.00	0.60	0.11	0.11	0.01	0.01	0.02	0.06	0.18	0.28	0.35	0.43	0.46	E SW	
August	0.00	0.60	0.09	0.10	0.01	0.01	0.01	0.05	0.16	0.24	0.33	0.43	0.49	E SW	
September	0.00	0.62	0.11	0.11	0.01	0.01	0.02	0.06	0.17	0.27	0.34	0.45	0.50	E SW	
October	0.00	0.55	0.10	0.10	0.01	0.02	0.02	0.06	0.17	0.24	0.31	0.39	0.44	E SW	
November	0.00	0.53	0.10	0.09	0.01	0.02	0.02	0.06	0.17	0.23	0.28	0.34	0.39	E SW W	
December	0.00	0.57	0.09	0.08	0.01	0.02	0.02	0.06	0.15	0.21	0.26	0.31	0.38	E SW	
Winter (Jun-Aug)	0.00	0.66	0.11	0.11	0.01	0.01	0.01	0.06	0.18	0.28	0.36	0.44	0.48	E SW	
Spring (Sep-Nov)	0.00	0.62	0.10	0.10	0.01	0.02	0.02	0.06	0.17	0.25	0.31	0.39	0.45	E SW	
Summer (Dec-Feb)	0.00	0.58	0.09	0.09	0.01	0.02	0.02	0.06	0.15	0.22	0.27	0.34	0.39	E SW	
Autumn (Mar-May)	0.00	0.78	0.10	0.12	0.01	0.01	0.02	0.05	0.17	0.26	0.36	0.47	0.53	E SW	
All	0.00	0.78	0.10	0.10	0.01	0.01	0.02	0.06	0.17	0.25	0.33	0.42	0.47	E SW	

Notes: (1) All statistics derived from hindcast wave data for the period 01 January 2009 to 31 December 2018.
(2) Main directions are those with greater than 15% occurrence and represent directions from which the waves approach.

Table 4.22 Monthly and annual total significant wave height exceedance probabilities (%) at P6.



H _s (m)	Exceedance (%)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	annual
>0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
>0.1	31.69	26.60	29.84	31.79	36.73	40.21	36.17	28.67	34.46	35.56	32.88	28.02	32.74
>0.2	14.60	10.86	14.76	13.83	18.99	21.83	18.10	13.91	16.96	15.97	14.46	12.30	15.57
>0.3	4.52	3.59	5.48	6.38	11.33	10.08	8.63	5.93	7.58	5.93	3.62	2.74	6.33
>0.4	1.09	0.71	2.58	3.00	5.89	3.33	2.90	2.54	3.08	1.81	0.75	0.73	2.38
>0.5	0.24	0.09	0.69	0.96	2.42	0.88	0.48	0.93	0.96	0.40	0.08	0.08	0.69
>0.6	0.00	0.00	0.36	0.13	0.48	0.17	0.00	0.00	0.04	0.00	0.00	0.00	0.10
>0.7	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02



Table 4.23 Annual joint probability distribution (in %) of the total significant wave height and peak period at P6.

Hs (m)	Peak period (s)																	Total	Exceed%
	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18		
>0<=0.1	16.95	0.03	0.10	0.21	0.06	0.01	0.04	0.08	0.13	0.21	0.30	0.21	0.12	0.02	0.01	0.01	0.01	18.50	100.00
>0.1<=0.2	16.82	0.12	*	*	-	-	-	-	-	-	-	-	-	-	-	-	-	16.94	32.77
>0.2<=0.3	7.64	1.52	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.16	15.59
>0.3<=0.4	0.30	3.67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.97	6.34
>0.4<=0.5	-	1.68	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.68	2.38
>0.5<=0.6	-	0.58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.58	0.69
>0.6<=0.7	-	0.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.08	0.10
>0.7<=0.8	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	0.02
Total	41.71	7.70	0.10	0.21	0.06	0.01	0.04	0.08	0.13	0.21	0.30	0.21	0.12	0.02	0.01	0.01	0.01	100.00	
>Exceed%	50.93	9.26	1.52	1.42	1.21	1.15	1.13	1.10	1.02	0.89	0.68	0.38	0.17	0.05	0.03	0.02	0.01		

Notes: * represents less than 0.005%.



Table 4.24 Annual joint probability distribution (in %) of the total significant wave height and mean wave direction at peak energy at P6.

Hs (m)	Mean wave direction at peak energy (degT)								Total	Exceed%
	337.5-22.5	22.5-67.5	67.5-112.5	112.5-157.5	157.5-202.5	202.5-247.5	247.5-292.5	292.5-337.5		
>0<=0.1	1.52	7.13	25.54	5.82	8.60	12.25	5.87	0.71	67.44	100.00
>0.1<=0.2	-	0.05	0.18	0.01	0.78	11.72	4.34	-	17.08	32.74
>0.2<=0.3	-	-	-	-	0.12	7.61	1.42	-	9.15	15.57
>0.3<=0.4	-	-	-	-	0.04	3.64	0.29	-	3.97	6.33
>0.4<=0.5	-	-	-	-	0.01	1.65	0.03	-	1.69	2.38
>0.5<=0.6	-	-	-	-	-	0.58	-	-	0.58	0.69
>0.6<=0.7	-	-	-	-	-	0.08	-	-	0.08	0.10
>0.7<=0.8	-	-	-	-	-	0.02	-	-	0.02	0.02
Total	1.52	7.18	25.72	5.83	9.55	37.55	11.95	0.71	100.00	

Notes: * represents less than 0.005%.



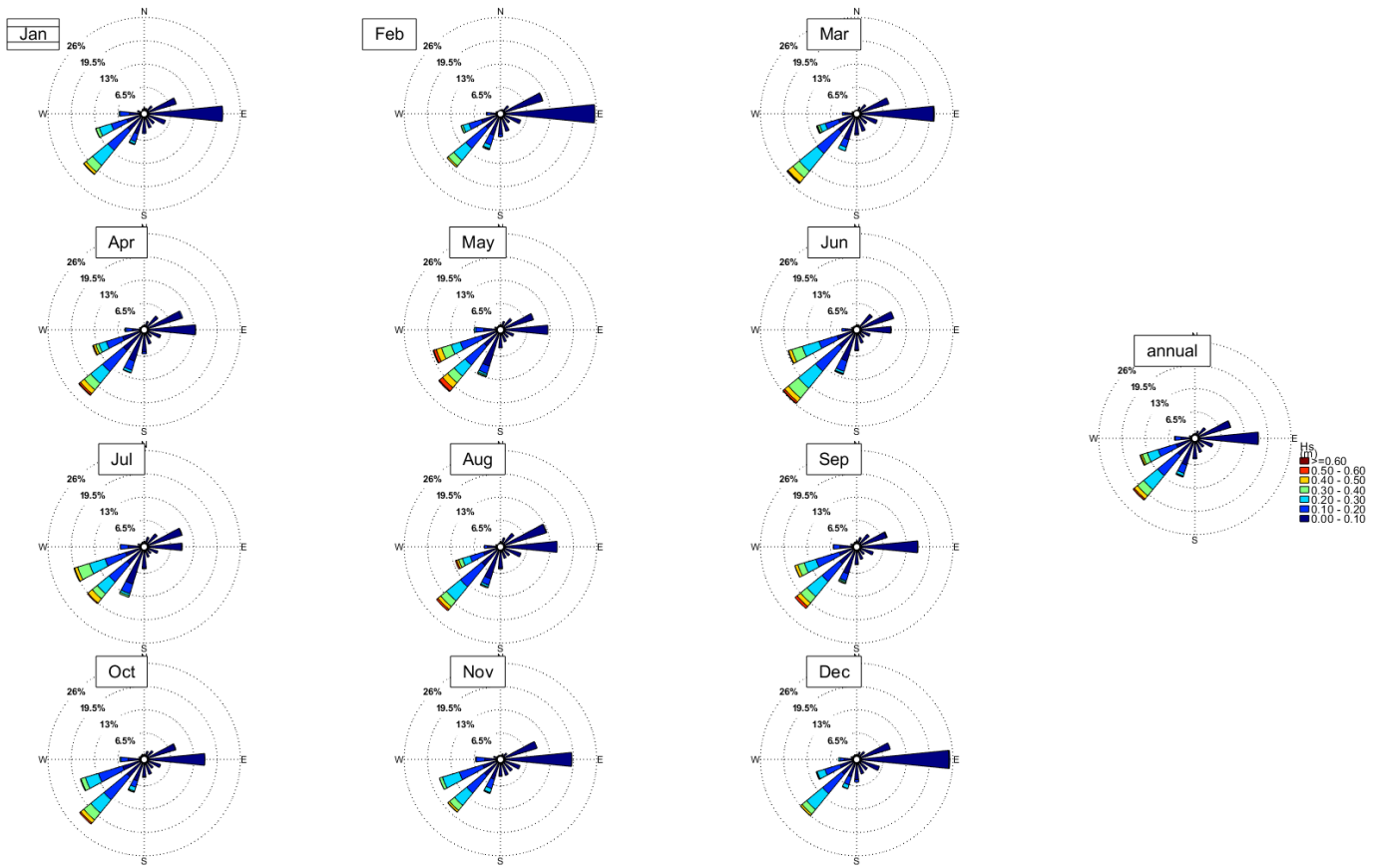


Figure 4.7 Monthly and annual wave rose plot for the total significant wave height at P6. Sectors indicate the direction from which waves approach.

5. Extreme metocean statistics

The wind and wave extremes are provide in this section. Note an arbitrary minimum number of 10 storm peaks was chosen for reliable distribution fitting. This results in specific directional return period values being omitted.

5.1. Wind

The directional return period values for wind at P3 (representative of all sites) are given in Table 5.1.

Table 5.1 Annual independent omni-directional and directional extreme criteria for wind speed at P3.

Wind direction	Units	Return period (year)			
		1	25	50	100
N	m/s	-	-	-	-
NE		10.82	14.81	15.59	16.35
E		12.00	15.04	15.69	16.34
SE		-	-	-	-
S		-	-	-	-
SW		17.34	21.65	22.47	23.26
W		12.44	17.48	18.61	19.77
NW		11.51	17.70	19.37	21.12
Omni-directional		18.16	23.52	24.64	25.74

5.2. P1 extreme wave

The directional return period values for wave extremes at P1 are given in Table 5.2 to for 1, 25, 50 and 100-year return periods.

Contour plot of omni-directional bi-variate return period values for significant wave height and peak wave period are presented in Figure 5.1.

Note the omni-directional results were based on a fixed peak over thresholds of 0.5 m for site P1 due to a few events with a lower H_s and longer T_p than is typically representative of extreme events. These events resulted in instabilities of the Inverse FORM method (see Section 6.2) and were therefore omitted.

Table 5.2 Annual independent omni-directional extreme criteria for waves at P1.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	m	0.62	0.76	0.78	0.80
Peak wave period	T_p	s	2.71	2.93	2.96	2.99
Maximum individual wave height	H_{max}	m	1.17	1.45	1.50	1.55
Maximum individual wave crest	C_{max}	m	0.72	0.92	0.95	0.98



Table 5.3 Annual independent South-East extreme criteria for waves at P1.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	<i>m</i>	0.35	0.49	0.52	0.55
Peak wave period	T_p	<i>s</i>	3.33	3.77	3.85	3.93
Maximum individual wave height	H_{max}	<i>m</i>	0.63	0.90	0.93	0.95
Maximum individual wave crest	C_{max}	<i>m</i>	0.39	0.52	0.55	0.56

Table 5.4 Annual independent South extreme criteria for waves at P1.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	<i>m</i>	0.26	0.48	0.50	0.52
Peak wave period	T_p	<i>s</i>	1.90	2.45	2.49	2.52
Maximum individual wave height*	H_{max}	<i>m</i>	0.48	0.89	0.93	0.97
Maximum individual wave crest	C_{max}	<i>m</i>	0.34	0.54	0.56	0.57

*the method Tromans and Vanderschuren (1995) described in Section 6.2 failed to find associated H_{max} , therefore the standard conventional value of $H_{max} = 1.86 H_s$ was adopted (assuming Rayleigh distribution of individual wave heights).

Table 5.5 Annual independent South-West extreme criteria for waves at P1.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	<i>m</i>	0.63	0.76	0.77	0.79
Peak wave period	T_p	<i>s</i>	2.70	2.90	2.92	2.94
Maximum individual wave height	H_{max}	<i>m</i>	1.17	1.46	1.50	1.54
Maximum individual wave crest	C_{max}	<i>m</i>	0.71	0.92	0.94	0.97

Table 5.6 Annual independent West extreme criteria for waves at P1.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	<i>m</i>	0.37	0.45	0.45	0.46
Peak wave period	T_p	<i>s</i>	2.19	2.35	2.37	2.39
Maximum individual wave height	H_{max}	<i>m</i>	0.70	0.85	0.89	0.91
Maximum individual wave crest	C_{max}	<i>m</i>	0.39	0.49	0.51	0.53



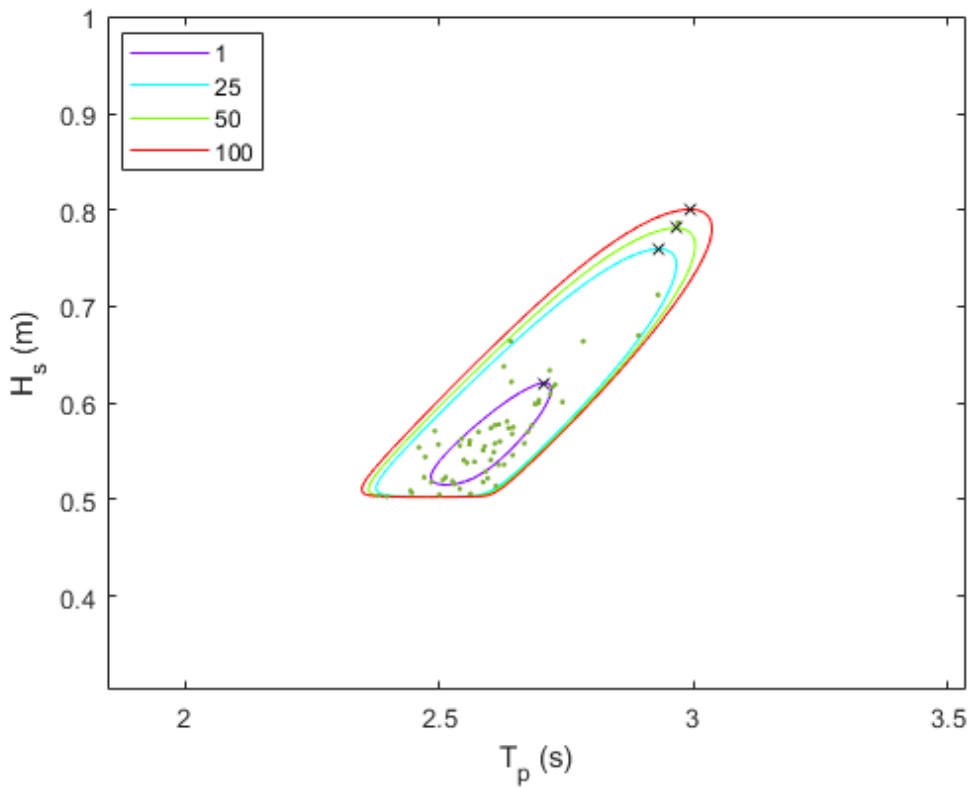


Figure 5.1 Contour plot of omni-directional bi-variate (H_s - T_p) return period values for 1, 25, 50 and 100-year ARIs. The dark crosses correspond to the estimated deterministic H_s and associated T_p return period values for each ARI indicated in the legend at P1.

5.3. P2 extreme wave

The directional return period values for wave extremes at P2 are given in Table 5.7 to Table 5.11 for 1, 25, 50 and 100-year return periods.

Contour plot of omni-directional bi-variate return period values for significant wave height and peak wave period are presented in Figure 5.2.

Table 5.7 Annual independent omni-directional extreme criteria for wave at P2.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	m	0.64	0.78	0.79	0.81
Peak wave period	T_p	s	2.72	2.94	2.96	2.98
Maximum individual wave height	H_{max}	m	1.21	1.50	1.56	1.60
Maximum individual wave crest	C_{max}	m	0.71	0.89	0.92	0.94

Table 5.8 Annual independent South-East extreme criteria for waves at P2.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	m	0.28	0.38	0.40	0.42
Peak wave period	T_p	s	3.28	3.55	3.59	3.63
Maximum individual wave height	H_{max}	m	0.54	0.69	0.72	0.74
Maximum individual wave crest	C_{max}	m	0.29	0.43	0.46	0.46

Table 5.9 Annual independent South extreme criteria for waves at P2.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	m	0.24	0.92	1.61	2.97
Peak wave period	T_p	s	1.85	3.02	3.57	4.14
Maximum individual wave height	H_{max}	m	0.53	0.86	0.91	0.94
Maximum individual wave crest	C_{max}	m	0.29	0.46	0.48	0.51

Table 5.10 Annual independent South-West extreme criteria for waves at P2.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	m	0.64	0.77	0.79	0.80
Peak wave period	T_p	s	2.71	2.90	2.92	2.94
Maximum individual wave height	H_{max}	m	1.21	1.50	1.56	1.60
Maximum individual wave crest	C_{max}	m	0.72	0.90	0.93	0.95

Table 5.11 Annual independent West extreme criteria for waves at P2.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	m	0.35	0.44	0.45	0.46
Peak wave period	T_p	s	2.13	2.37	2.40	2.43
Maximum individual wave height	H_{max}	m	0.67	0.82	0.85	0.89
Maximum individual wave crest	C_{max}	m	0.38	0.46	0.47	0.49



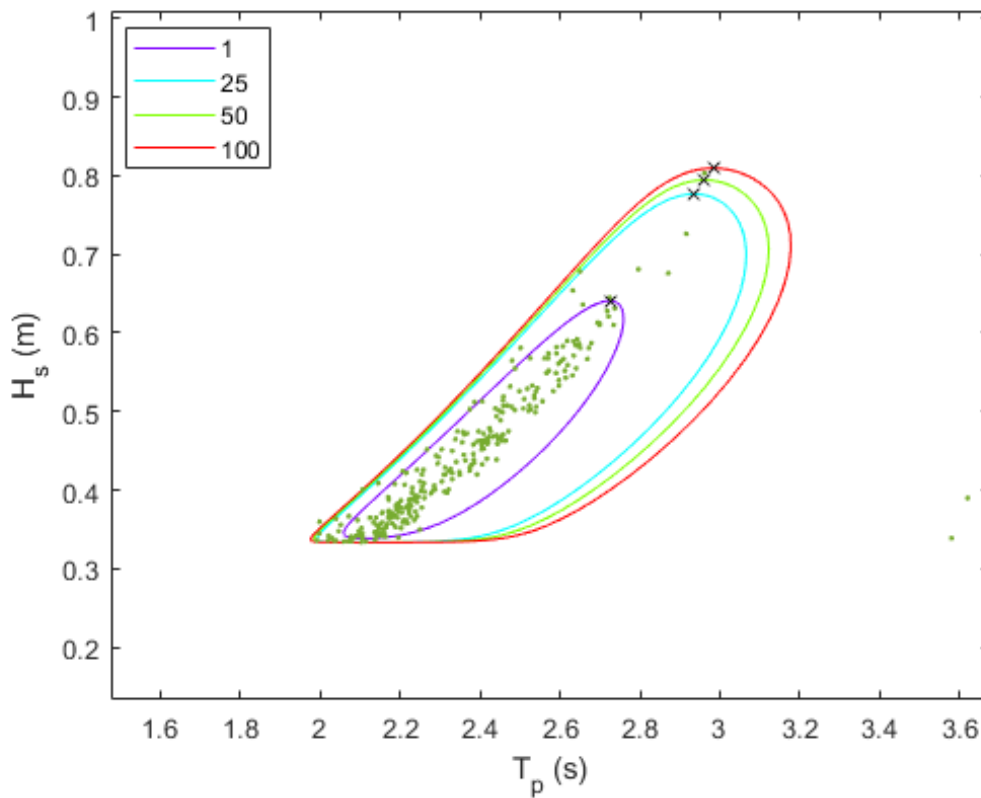


Figure 5.2 Contour plot of omni-directional bi-variate (H_s - T_p) return period values for 1, 25, 50 and 100-year ARIs. The dark crosses correspond to the estimated deterministic H_s and associated T_p return period values for each ARI indicated in the legend at P2.

5.4. P3 extreme wave

The directional return period values for wave extremes at P3 are given in Table 5.12 to Table 5.15 for 1, 25, 50 and 100-year return periods.

Contour plot of omni-directional bi-variate return period values for significant wave height and peak wave period are presented in Figure 5.3.

Table 5.12 Annual independent omni-directional extreme criteria for waves at P3.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	m	0.64	0.78	0.80	0.81
Peak wave period	T_p	s	2.73	2.94	2.96	2.98
Maximum individual wave height	H_{max}	m	1.21	1.52	1.56	1.60
Maximum individual wave crest	C_{max}	m	0.71	0.90	0.93	0.94



Table 5.13 Annual independent South-East extreme criteria for waves at P3.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	<i>m</i>	0.27	0.38	0.40	0.42
Peak wave period	T_p	<i>s</i>	3.32	3.62	3.67	3.71
Maximum individual wave height	H_{max}	<i>m</i>	0.52	0.67	0.69	0.70
Maximum individual wave crest	C_{max}	<i>m</i>	0.27	0.39	0.41	0.41

Table 5.14 Annual independent South-West extreme criteria for waves at P3.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	<i>m</i>	0.64	0.77	0.79	0.81
Peak wave period	T_p	<i>s</i>	2.73	2.93	2.95	2.97
Maximum individual wave height	H_{max}	<i>m</i>	1.21	1.50	1.56	1.60
Maximum individual wave crest	C_{max}	<i>m</i>	0.72	0.91	0.93	0.95

Table 5.15 Annual independent West extreme criteria for waves at P3.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	<i>m</i>	0.35	0.43	0.44	0.44
Peak wave period	T_p	<i>s</i>	2.12	2.33	2.36	2.38
Maximum individual wave height	H_{max}	<i>m</i>	0.64	0.79	0.81	0.83
Maximum individual wave crest	C_{max}	<i>m</i>	0.36	0.46	0.46	0.48



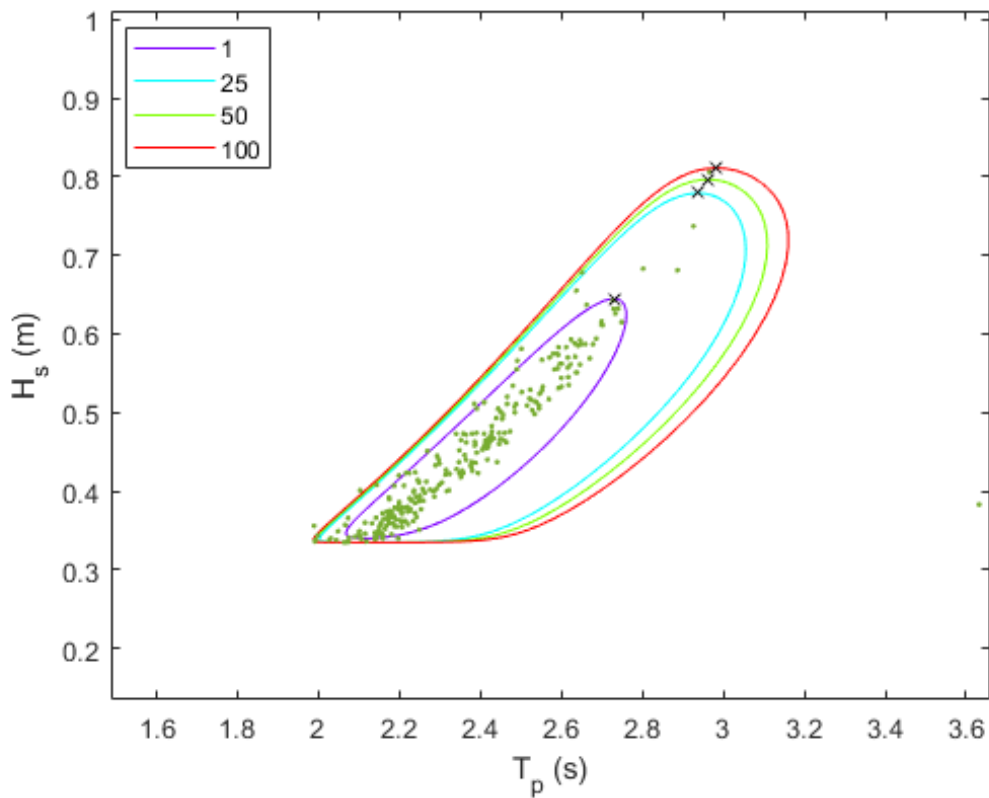


Figure 5.3 Contour plot of omnidirectional bi-variate (H_s - T_p) return period values for 1, 25, 50 and 100-year ARIs. The dark crosses correspond to the estimated deterministic H_s and associated T_p return period values for each ARI indicated in the legend at P3.

5.5. P4 extreme wave

The directional return period values for wave extremes at P4 are given in Table 5.16 to Table 5.20 for 1, 25, 50 and 100-year return periods.

Contour plot of omnidirectional bi-variate return period values for significant wave height and peak wave period are presented in Figure 5.4.

Table 5.16 Annual independent omnidirectional extreme criteria for waves at P4.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	m	0.64	0.78	0.79	0.81
Peak wave period	T_p	s	2.73	2.94	2.96	2.98
Maximum individual wave height	H_{max}	m	1.21	1.52	1.56	1.60
Maximum individual wave crest	C_{max}	m	0.71	0.90	0.93	0.94

Table 5.17 Annual independent South-East extreme criteria for waves at P4.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	m	0.27	0.38	0.41	0.44
Peak wave period	T_p	s	3.32	3.64	3.70	3.75
Maximum individual wave height	H_{max}	m	0.51	0.66	0.69	0.70
Maximum individual wave crest	C_{max}	m	0.26	0.39	0.40	0.41

Table 5.18 Annual independent South extreme criteria for waves at P4.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	m	0.25	0.51	0.54	0.58
Peak wave period	T_p	s	1.87	2.48	2.55	2.60
Maximum individual wave height	H_{max}	m	0.59	0.90	0.94	0.96
Maximum individual wave crest	C_{max}	m	0.26	0.53	0.56	0.60

*the method Tromans and Vanderschuren (1995) described in Section 6.2 failed to find associated C_{max} , therefore the HSE (2002) standard conventional value of $C_{max} = 1.05 H_s$ was adopted.

Table 5.19 Annual independent South-West extreme criteria for wave at P4.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	m	0.64	0.77	0.79	0.81
Peak wave period	T_p	s	2.73	2.93	2.95	2.97
Maximum individual wave height	H_{max}	m	1.21	1.50	1.56	1.60
Maximum individual wave crest	C_{max}	m	0.72	0.90	0.93	0.95

Table 5.20 Annual independent West extreme criteria for wave at P4.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	m	0.34	0.41	0.42	0.43
Peak wave period	T_p	s	2.09	2.28	2.30	2.31
Maximum individual wave height	H_{max}	m	0.61	0.78	0.81	0.82
Maximum individual wave crest	C_{max}	m	0.33	0.43	0.45	0.46



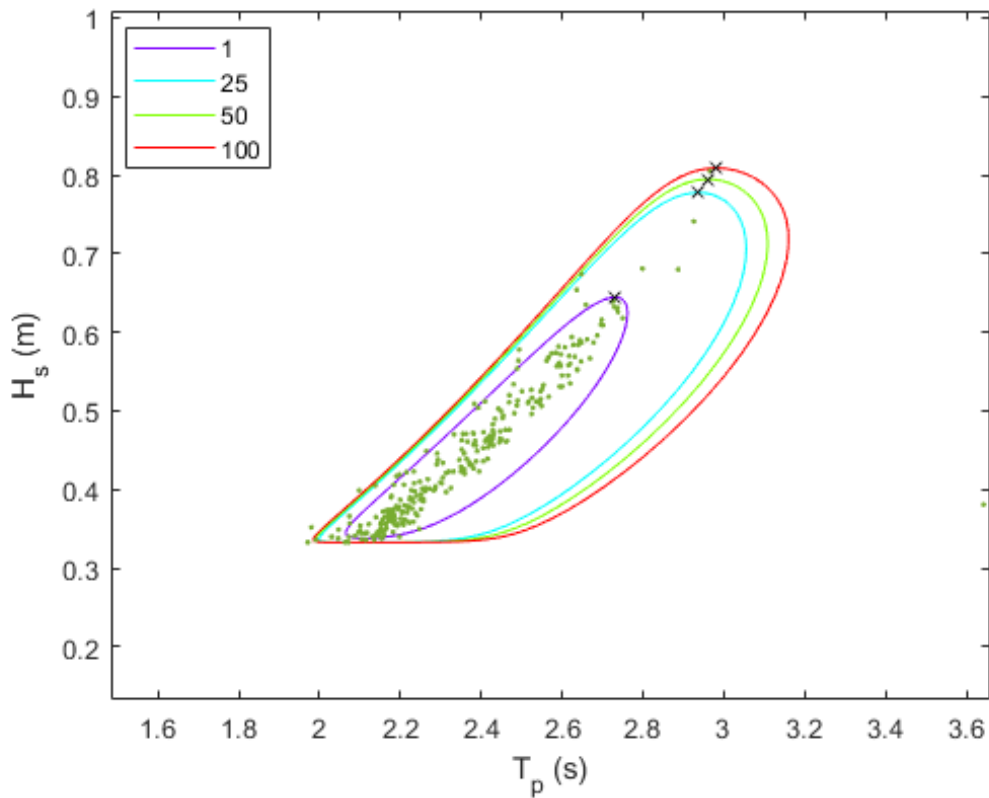


Figure 5.4 Contour plot of omni-directional bi-variate (H_s - T_p) return period values for 1, 25, 50 and 100-year ARIs. The dark crosses correspond to the estimated deterministic H_s and associated T_p return period values for each ARI indicated in the legend at P4.

5.6. P5 extreme wave

The directional return period values for wave extremes at P5 are given in Table 5.21 to Table 5.25 for 1, 25, 50 and 100-year return periods.

Contour plot of omni-directional bi-variate return period values for significant wave height and peak wave period are presented in Figure 5.5.

Table 5.21 Annual independent omni-directional extreme criteria for wave at P5.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	m	0.63	0.76	0.77	0.79
Peak wave period	T_p	s	2.73	2.94	2.96	2.98
Maximum individual wave height	H_{max}	m	1.19	1.46	1.52	1.56
Maximum individual wave crest	C_{max}	m	0.69	0.89	0.92	0.94

Table 5.22 Annual independent South-East extreme criteria for wave at P5.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	<i>m</i>	0.13	0.20	0.22	0.25
Peak wave period	T_p	<i>s</i>	1.59	1.53	1.52	1.51
Maximum individual wave height	H_{max}	<i>m</i>	0.21	0.35	0.38	0.40
Maximum individual wave crest	C_{max}	<i>m</i>	0.17	0.23	0.23	0.24

Table 5.23 Annual independent South extreme criteria for wave at P5.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	<i>m</i>	0.21	0.45	0.50	0.55
Peak wave period	T_p	<i>s</i>	1.78	2.41	2.51	2.60
Maximum individual wave height	H_{max}	<i>m</i>	0.42	0.74	0.79	0.81
Maximum individual wave crest	C_{max}	<i>m</i>	0.21	0.42	0.46	0.47

Table 5.24 Annual independent South-West extreme criteria for wave at P5.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	<i>m</i>	0.63	0.76	0.77	0.78
Peak wave period	T_p	<i>s</i>	2.71	2.89	2.92	2.93
Maximum individual wave height	H_{max}	<i>m</i>	1.21	1.48	1.52	1.58
Maximum individual wave crest	C_{max}	<i>m</i>	0.70	0.89	0.92	0.94

Table 5.25 Annual independent West extreme criteria for wave at P5.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	<i>m</i>	0.32	0.40	0.41	0.42
Peak wave period	T_p	<i>s</i>	2.06	2.27	2.29	2.30
Maximum individual wave height	H_{max}	<i>m</i>	0.58	0.76	0.78	0.81
Maximum individual wave crest	C_{max}	<i>m</i>	0.34	0.45	0.46	0.47



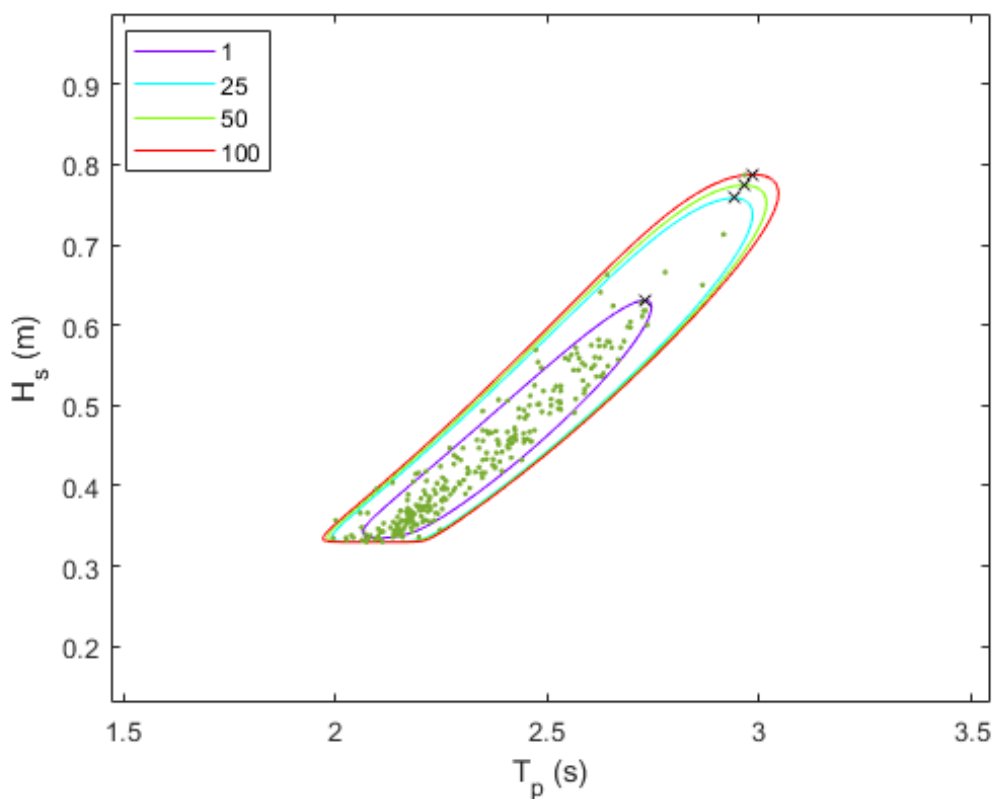


Figure 5.5 Contour plot of omni-directional bi-variate (H_s - T_p) return period values for 1, 25, 50 and 100-year ARIs. The dark crosses correspond to the estimated deterministic H_s and associated T_p return period values for each ARI indicated in the legend at P5.

5.7. P6 extreme wave

The directional return period values for wave extremes at P6 are given in Table 5.26 to Table 5.30 for 1, 25, 50 and 100-year return periods.

Contour plot of omni-directional bi-variate return period values for significant wave height and peak wave period are presented in Figure 5.6.

Table 5.26 Annual independent omni-directional extreme criteria for waves at P6.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	m	0.62	0.75	0.76	0.78
Peak wave period	T_p	s	2.73	2.95	2.97	2.99
Maximum individual wave height	H_{max}	m	1.17	1.46	1.50	1.54
Maximum individual wave crest	C_{max}	m	0.69	0.84	0.88	0.91



Table 5.27 Annual independent North-East extreme criteria for waves at P6.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	m	0.10	0.13	0.13	0.13
Peak wave period	T_p	s	0.91	1.02	1.03	1.04
Maximum individual wave height	H_{max}	m	0.18	0.23	0.24	0.26
Maximum individual wave crest	C_{max}	m	0.08	0.11	0.13	0.13

Table 5.28 Annual independent East extreme criteria for waves at P6.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	m	0.10	0.17	0.20	0.22
Peak wave period	T_p	s	1.31	1.50	1.54	1.57
Maximum individual wave height	H_{max}	m	0.17	0.28	0.29	0.29
Maximum individual wave crest	C_{max}	m	0.08	0.15	0.15	0.17

Table 5.29 Annual independent South-West extreme criteria for waves at P6.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	m	0.62	0.74	0.76	0.77
Peak wave period	T_p	s	2.70	2.89	2.91	2.93
Maximum individual wave height	H_{max}	m	1.17	1.46	1.50	1.56
Maximum individual wave crest	C_{max}	m	0.68	0.84	0.88	0.90

Table 5.30 Annual independent West extreme criteria for waves at P6.

Parameter	Symbol	Units	Return period (year)			
			1	25	50	100
Significant wave height	H_s	m	0.34	0.42	0.43	0.44
Peak wave period	T_p	s	2.11	2.34	2.37	2.40
Maximum individual wave height	H_{max}	m	0.63	0.78	0.81	0.82
Maximum individual wave crest	C_{max}	m	0.34	0.45	0.46	0.47



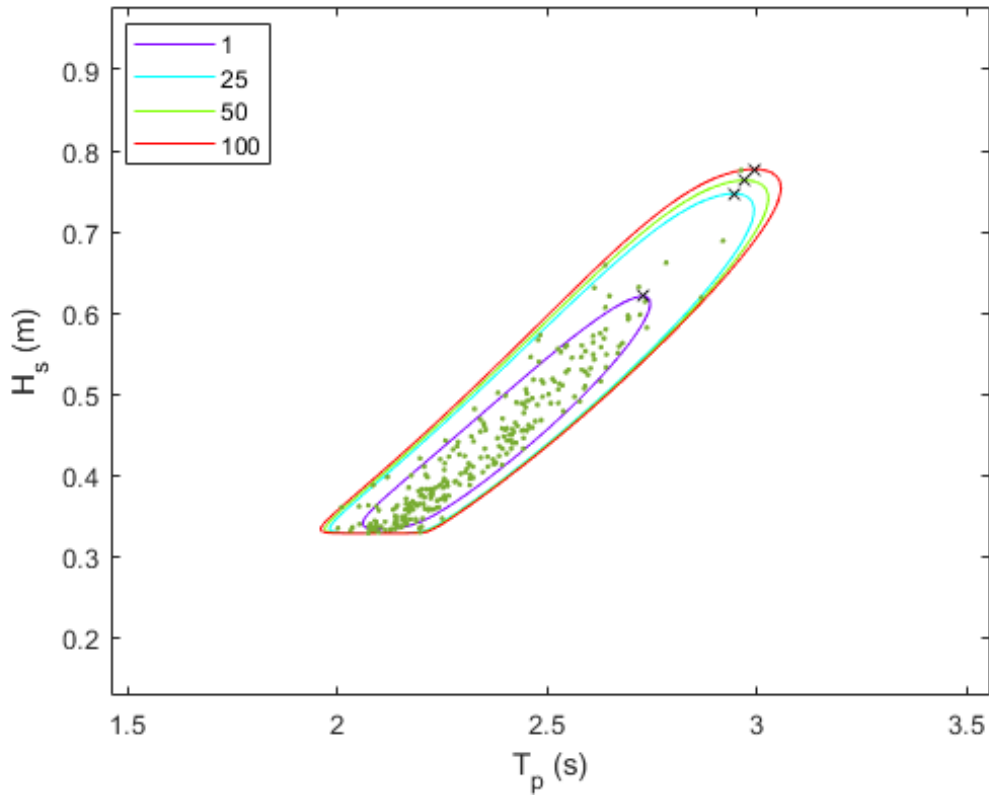


Figure 5.6 Contour plot of omni-directional bi-variate (H_s - T_p) return period values for 1, 25, 50 and 100-year ARIs. The dark crosses correspond to the estimated deterministic H_s and associated T_p return period values for each ARI indicated in the legend at P6.

6. Analytical methods

6.1. Wave

The wave spectra were post-processed to calculate wave statistics for the total wave field, as well as for sea and swell components. The spectral partitioning method consists of a split at the frequency corresponding to 8s period, with sea and swell assigned to the high- and low-frequency parts, respectively. For the total spectra and each partition, one-dimensional frequency spectra were defined by integrating over all directions:

$$E(f) = \int_{-\pi}^{\pi} E(f, \theta) d\theta. \quad (6.1)$$

Spectral moments were calculated as

$$m_x = \iint f^x E(f, \theta) df d\theta, \quad (6.2)$$

The significant wave height, H_s , mean direction at peak energy, θ_p , and peak wave period, T_p , are defined as:

$$H_s = 4\sqrt{m_0}, \quad (6.3)$$

$$D_{pm} = \tan^{-1} \frac{\int_{-\pi}^{\pi} E(f_p, \theta) \sin \theta d\theta}{\int_{-\pi}^{\pi} E(f_p, \theta) \cos \theta d\theta}, \quad (6.4)$$

$$T_p = 1/f_p, \quad (6.5)$$

where f_p is the peak wave frequency of the one-dimensional spectra and $E_n(f_p, \theta)$ is the energy contained in the peak wave frequency band. Note that T_p and θ_p require spectral peaks within a given partition and are not defined when peaks are not identified for that partition.

6.2. Extreme

Directional return period values have been calculated from the hindcast time series of wind speed and significant wave height.

A *Peaks over Threshold* (POT) sampling method is used for event selection, applying the 95th percentile exceedance level as the threshold with a 24 hour window. For wind extreme value analysis (EVA), the 3-parameter Weibull distribution was applied, with the Maximum Likelihood Method (MLM) used to find the best-fit of the sampled events to the model distribution. For wave EVA, the selected events were fitted to a Pareto



distribution, with the location parameter fixed by the threshold and the MLM used to obtain the scale and shape parameters.

Bivariate return period values were calculated for significant wave height and peak period. The method of Repko et al. (2005) was employed, which considers the distribution of H_s and wave steepness, s . A joint probability distribution function (PDF) is calculated by multiplying marginal distributions of H_s and s (thus assuming they are independent), after which the PDF is transformed back into H_s/T_p space. In addition, a minimum wave steepness threshold of 0.005 is applied to exclude events with very long wave periods, which are not believed to be representative of extreme conditions.

The marginal distributions for H_s and s are estimated by fitting the POT values to a Weibull distribution using the maximum likelihood method (as implemented in the WAFO toolbox). Contours of the return period values were constructed from the joint PDF using the Inverse FORM method (Winterstein et al., 1993) at the return year levels.

The methods used to estimate extreme maximum individual wave height (H_{max}) and maximum wave crest (C_{max}) account for the long-term uncertainty in the severity of the environment, and the short-term uncertainty in the severity of the maximum wave of a given sea state, as suggested by Tromans and Vanderschuren (1995) and recommended by ISO (2015). The most probable value of the extreme individual wave height (H_{mp}) of each storm is obtained from the product of the Forristall distributions of individual wave height in each hindcast interval within the storm duration (Forristall, 1978; ISO, 2015). The same technique is used for the most probable value of the extreme individual wave crest (C_{mp}) but using the Weibull distribution with scale and shape parameters dependent on the wave steepness and the Ursell number (ISO, 2015; Forristall, 2000). Note, that the resulting short-term distributions for each storm are dependent on the number of intervals with H_s values near the region of maximum peak H_s . The uncertainty in the height and crest of the maximum wave of any storm is represented as a short-term probability distribution conditional on H_{mp} and C_{mp} , respectively (Tromans and Vanderschuren, 1995). The long-term distributions of H_{mp} and C_{mp} are then fitted to Pareto distributions. Finally, the convolutions of the short- and long-term distributions give the complete long-term distributions of H_{max} and C_{max} (Tromans and Vanderschuren, 1995; ISO 2015).

An arbitrary minimum number of 10 storm peaks was chosen for reliable distribution fitting, resulting in specific directional return period values being omitted.

7. References

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