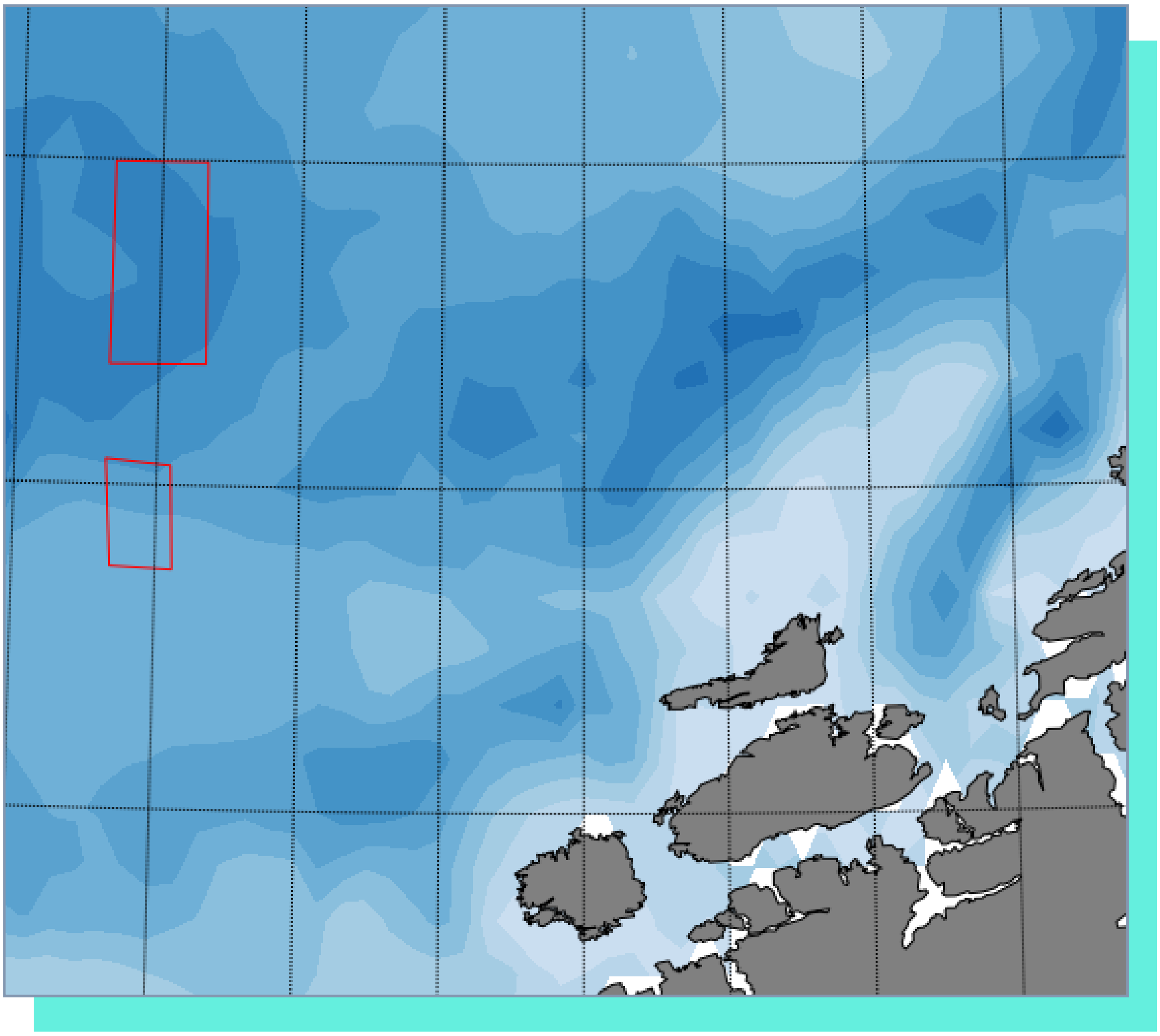
MariCulture Smart Fishfarm

Metocean Design Basis, Haltenbanken II

Øistein Johnsen



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Summary

Background and objectives

This report presents meteorological and oceanographic (metocean) data for two areas at Haltenbanken in the Norwegian Sea. These data are to be used as a basis for design and planning of operations.

Scope of work

NORA10 (Norwegian ReAnalysis 10 km grid) hindcast wind data for a period of 61 years are analysed to obtain wind roses, tables of non-exceedance of wind speed, and estimates of extreme winds representative of the two areas.

NORA10 hindcast wave data for a period of 61 years are analysed to obtain wave roses, tables of non-exceedance of significant wave height and estimates of extreme waves, Hs-Tp relation and wave induced bottom currents are obtained for the two areas.

Current data from buoy measurements (Station I1, 1981 – 1983) are analysed to obtain current roses, tables of non-exceedance of current speed and estimates of directional extreme currents.

Conclusions

Table 0.1 gives a summary of the estimated extreme winds, waves and current at the areas, denoted A (south) and B (north).

Table 0.1: Summary of estimated extreme wind, wave and current for Haltenbanken Area A and B.

Area	Parameter	Unit	Return period [years]					
			1	**10**	**50**	**100**	**1 000**	**10 000**
A	Wind speed, 1 hour,10 m	[m/s]	28.4	31.7	33.9	34.8	37.6	40.2
	Wind speed, 10 min, 10 m	[m/s]	32.3	36.5	39.2	40.3	43.8	47.2
	Wind speed, 1 min, 10 m	[m/s]	37.5	42.6	45.9	47.3	51.8	56.1
	Significant wave height	[m]	11.6	13.9	15.5	16.2	18.4	20.5
	Mean spectral peak period	[s]	13.7	15.0	15.87	16.2	17.2	18.5
	Individual wave height	[m]	22.3	26.2	28.9	30.1	34.2	38.4
	Crest height	[m]	13.4	15.9	17.6	18.4	21.1	23.8
B	Wind speed, 1 hour,10 m	[m/s]	28.4	31.7	33.9	34.8	37.5	40.1
	Wind speed, 10 min, 10 m	[m/s]	32.4	36.5	39.1	40.2	43.7	47.0
	Wind speed, 1 min, 10 m	[m/s]	37.5	42.6	45.9	47.3	51.7	55.8
	Significant wave height	[m]	11.6	14.0	15.6	16.2	18.4	20.5
	Mean spectral peak period	[s]	15.9	17.2	18	18.4	19.5	20.6
	Individual wave height	[m]	22.4	26.2	29	30.2	34.3	38.5
	Crest height	[m]	13.4	15.9	17.7	18.5	21.1	23.8
A+B	Current speed, 3 m depth	[cm/s]	97	112	122	126	-	-

Contents

List of figures

List of tables

Definitions

Statistics

- **Conditional distribution:** Statistical distribution of a variable x given another variable y.
- **Percentile:** The value below which a given percentage of observation fall. E.g. the 90th percentile is the value below which 90% of the data fall.
- **Return period:** The average time interval between two consecutive exceedances of some value of a statistical variable.
- **Scatter plot:** A type of plot used to display variables from two sets of data. E.g. plot of simultaneous hindcast and measured wind speed data.
- **Weibull distribution:** Probability distribution function.

Wind

- **Offshore wind:** A wind blowing seaward from land.
- **Onshore wind:** A wind blowing landward from the sea.
- **Sustained wind:** Time averaged wind speed with an averaging duration of 10 minutes or longer.
- **Wind direction:** The direction from which the wind is blowing.
- **Wind gust:** Temporary change in the wind speed.
- **Wind profile:** Variation of wind speed with height above sea level.
- **Wind rose:** A figure that shows the percent distribution of wind speed within each 30º sector.
- **Wind speed:** The average speed of wind over a given averaging period.

Waves

- **Crest height:** The height of a wave above still water level.
- **Design wave height:** Significant wave height with a return period of 50 (or 100) years used in design.
- **Directional spread:** Standard deviation of directional distribution of wave energy.
- **Directional wave spectrum:** A function that describes how the energy in a wave field is distributed with respect to wave frequency and wave direction.
- **Fetch length:** The length of the area in the direction of the wind over which waves are generated.
- **Frequency spectrum:** A function that describes how the energy in a wave field is distributed with respect to wave frequency.
- **Hindcast wave data:** Wave data computed from wind data determined from analyses of historical air pressure fields.
- **Maximum wave height:** The highest of the wave heights in a record.
- **Sea state**: Condition of the sea in which its statistics remain nearly constant.
- **Shallow water:** Water depth where the waves are noticeably affected by water depth.
- **Shoaling:** The increase in height of waves travelling into shallow water.
- **Significant wave height:** Wave height computed as 4 times the standard deviation of the surface elevation. (The average of the highest one-third of the waves in a record, also called significant wave height, is 5% lower.)

- **Swell:** Sea state in which the waves have been generated by winds remote from the site rather than being generated locally.
- **Significant wave period:** The average period of the highest third of the waves in a record.
- **Wave direction:** The direction from which the waves are coming.
- **Wave frequency:** 1) The inverse of wave period. 2) Number of waves passing a given point per unit time.
- **Wave height:** The vertical distance between wave crest and the following wave through.
- **Wave period:** 1) The time it takes for a wave to move a distance of one wavelength. 2) The time between passage of two wave crests past a fixed point.
- **Wave rose:** A figure that shows the percent distribution of significant wave height within each 30º sector.
- **Wave steepness:** The ratio of wave height to wavelength.

Tide and Current

- **Coriolis force:** A fictional force in the hydrodynamic equations of motion that takes into account the effect of the earth's rotation on moving objects.
- **Current direction:** The direction towards which the current is flowing.
- **Diurnal tide:** Characterized by having one high and one low tide each day.
- **Lunar month (Synodical month):** The average period for the revolution of the moon around the earth with respect to the sun. The lunar month is approximately 29.531 days in length.
- **Mixed tide:** Characterize by having two high tides (and two low tides) of different height each day.
- **Residual current:** The observed current minus the astronomical tidal current.
- **Semi-diurnal tide**: Characterized by having two nearly equal high and low tides each day.
- **Storm surge:** The total change in water elevation due to a storm measured by subtracting the astronomical tidal elevation from the total elevation.
- **Tide:** The periodic rise and fall of the water level resulting from gravitational interactions between sun, moon and earth.

1 Introduction

This report presents meteorological and oceanographic (metocean) data for the Haltenbanken area in the Norwegian Sea. MariCulture will use the data as a basis in the planning of a fish farm. Wave, wind and current conditions are investigated for the planned locations A and B (Figure 1.1)

NORA10 wind and wave hindcast data (1958 – 2019) from the Norwegian Meteorological Institute is used in the analysis. The hindcast wave data are compared with measurements for performance rating and adjustment.

Current analysis is based on measured data near Haltenbanken (1981 – 1983).

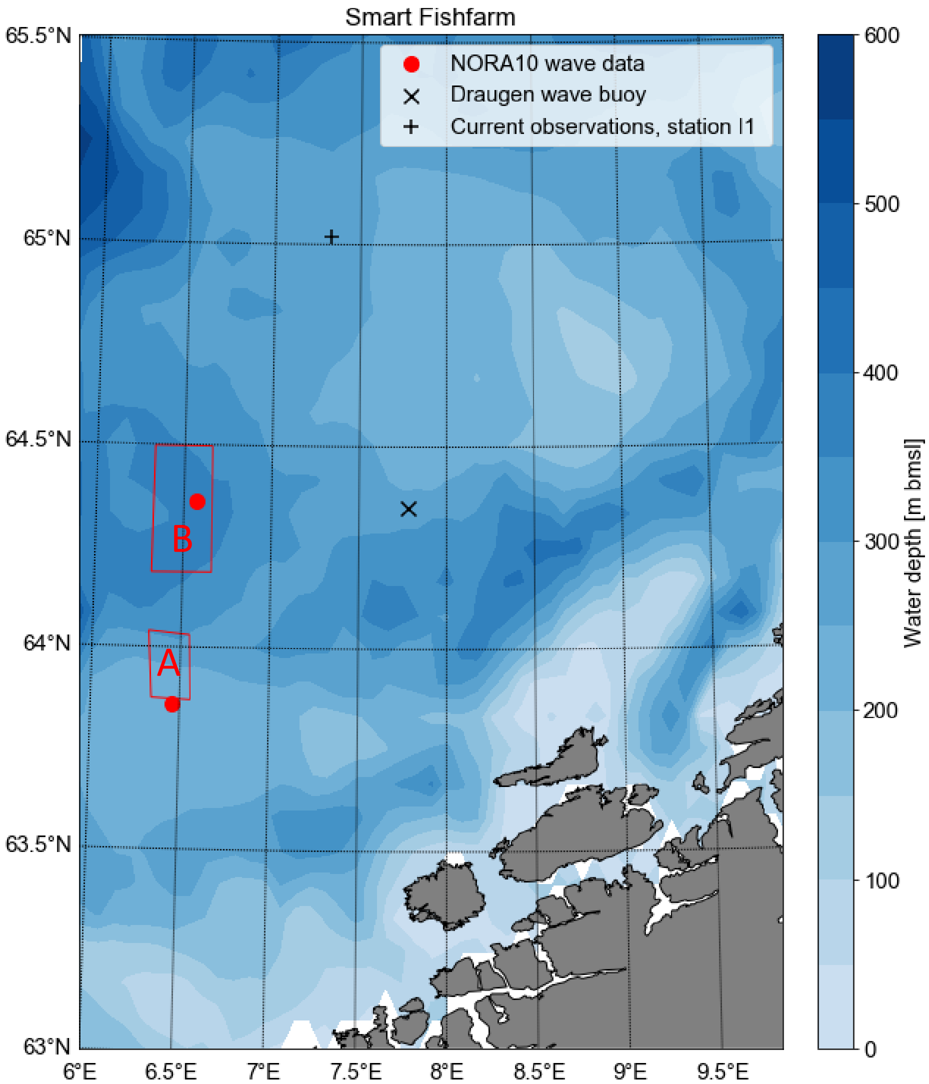


Figure 1.1: Map showing the area (red polygon) and position (●) of the location under consideration for MariCulture's Smart Fishfarm concept at Haltenbanken and positions of wind, wave and current data used for analysis. The bathymetry [3] in the area is given as water depth [m] below mean sea level.

1.1 Conventions

1.1.1 Units

Parameters and data values are given in the International System of Units (SI). Current, wind and wave directions are given in degrees [°] measured clockwise from north.

1.1.2 Directions

Wind

The wind direction, measured in degrees clockwise from north, is the direction from which the wind is blowing. Winds of direction 90° are coming from the east.

Waves

The wave direction, measured in degrees clockwise from north, is the direction from which the waves are coming. Waves of direction 90° are coming from the east.

Current

The current direction, measured in degrees clockwise from north, is the direction towards which the current is flowing. Currents of direction 90° are towards the east.

1.1.3 Seasons

Seasonal variations are given by month.

1.2 Climate change

Climate changes may lead to change in metocean conditions compared to present basis for structural design and assessment, NORSOK Standard N-003:2017 [1, Section 6.1.2]. For permanent structures with a life time of more than 50 years climate changes must be accounted for:

In lack of more detailed information the following increase in metocean values 50 years ahead may be used; NORSOK Standard N-003:2017, [1, Chapter A2]:

Extreme significant wave height	4 % on q-probability values
Extreme wind speeds	4 % on q-probability values
Sea level	0.25 m

1.3 Direction extremes

The direction extremes (of wind, waves and currents) are adjusted in agreement with NORSOK Standard N-003:2017 [1, Section 6.1.4] stating that the characteristic directional value of a statistical variable U can be calculated from the exceedance probability q/(0.5 $N_{sectors}$), where q is the annual exceedance probability and $N_{sectors}$ is the number of sectors.

When $N_{sectors}$ = 12, the extreme values with return period R for each sector corresponds to the minimum of the 6, 60, 300, 600, 6 000 and 60 000 year return period extremes and the 1, 10, 50, 10, 1 000 and 10 000 year return period omni-direction extremes:

$$U_{Sector,Adjusted}(R) = minimum[U_{Sector}(6R), U_{Omni-directional}(R)]$$

2 Meteorological data

2.1 Wind

2.1.1 Wind Data

Wind data are available from the NORA10 hindcast model operated by the Norwegian Meteorological Institute [8]. The data chosen for analysis are from the grid point A = 63.86 °N, 6.46 °E and B = 64.36 °N, 6.57 °E (Figure 1.1). The model grid spatial resolution is approximately 10 km x 10 km. The NORA10 data covers the period 1958 to 2019 (61 years) with a sample interval of 3 hours. The computed wind speed represents the 1-hour mean wind speed 10 m above sea level (amsl).

The NORA10 wind data are found to be of good quality for wind speeds up to about 15 m/s. Wind speeds higher than this are suspected to be underestimated. Consequently, wind speeds higher than 15 m/s have been adjusted (corrected) prior to analysis according to recommendations [1, 12]. The corrected wind speed, U_{Cor}, is computed from:

$$U_{Cor} = U + p(U - U_{Min}) \quad \text{for} \quad U \geq U_{Min} \tag{2.1}$$

where U is (the NORA10) wind speed, p = 0.10 and U_{Min} = 15.0 m/s.

Climate models predict little or no change in mean wind speed [9]. The frequency of higher wind speeds (storms) is expected to increase, but this is uncertain.

2.1.2 Wind analysis, Haltenbanken Area A

2.1.2.1 Wind data statistics

Figure 2.1 shows the (all-year) wind rose from the Haltenbanken Area A for the period 1959 – 2019. The wind rose shows the percentage of observations within each 30° sector.

Table 2.1 shows the annual directional sample distribution of non-exceedance of 1-hour mean wind speed.

Figure 2.2 shows the directional data scatter density and mean, P99 and maximum of 1-hour mean wind speed.

Table 2.2 shows the monthly sample distribution of non-exceedance of 1-hour mean wind speed.

Figure 2.3 shows the monthly data scatter density and mean, P99 and maximum of 1-hour mean wind speed.

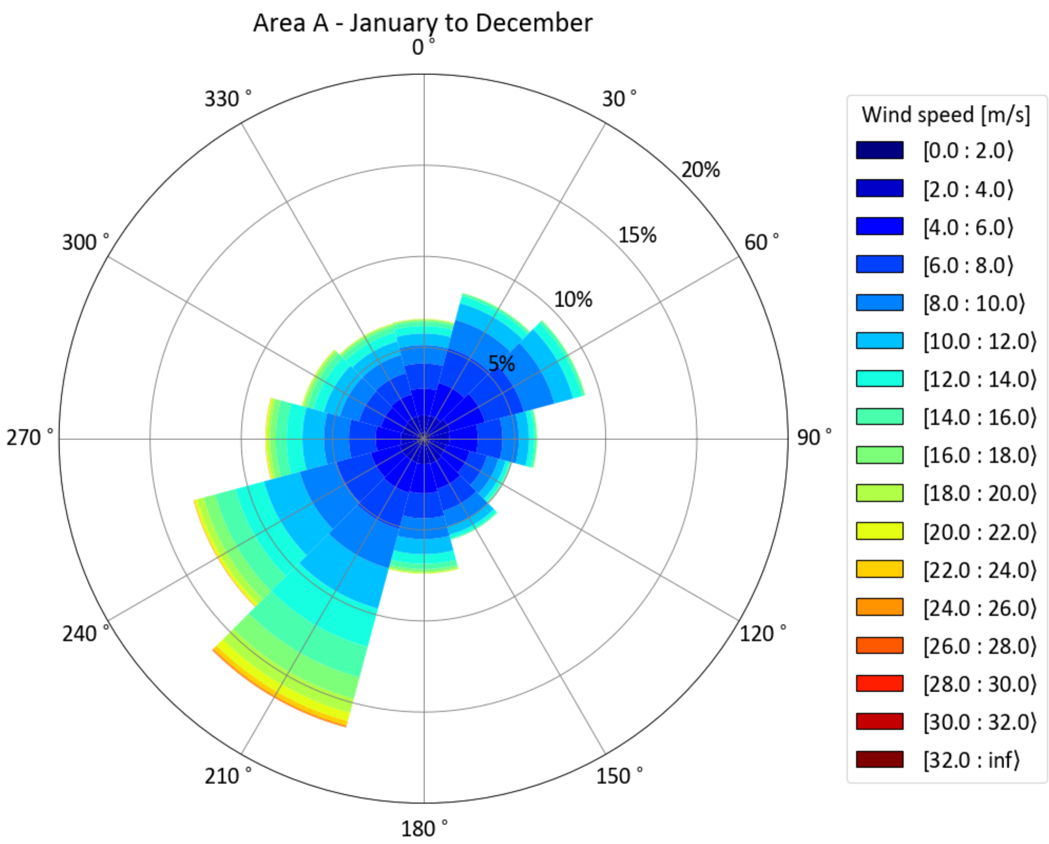


Figure 2.1: All year wind rose; 1-hour mean wind speed at 10 m elevation above mean sea level for the Haltenbanken Area A.

Table 2.1: Directional sample distribution of non-exceedance [%] of 1-hour mean wind speed 10 m above sea level.

Wind speed	Wind direction												Omni
[m/s]	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°	
< 2	0.30	0.29	0.37	0.35	0.31	0.37	0.35	0.32	0.33	0.32	0.30	0.35	**3.95**
< 4	1.21	1.24	1.44	1.37	1.25	1.37	1.33	1.29	1.30	1.21	1.16	1.21	**15.37**
< 6	2.62	2.99	3.31	2.89	2.54	2.76	2.90	2.95	2.86	2.54	2.36	2.42	**33.14**
< 8	3.95	4.85	5.42	4.20	3.49	4.02	4.26	4.95	4.77	3.98	3.62	3.64	**51.15**
< 10	4.95	6.38	7.10	5.11	4.14	4.97	5.44	7.16	6.83	5.38	4.74	4.69	**66.88**
< 12	5.61	7.29	8.14	5.68	4.59	5.49	6.30	9.43	8.87	6.61	5.71	5.50	**79.21**
< 14	6.05	7.69	8.64	6.00	4.84	5.72	6.88	11.62	10.53	7.52	6.36	6.05	**87.90**
< 16	6.29	7.83	8.80	6.15	4.93	5.81	7.21	13.43	11.76	8.17	6.74	6.37	**93.49**
< 18	6.40	7.87	8.83	6.19	4.96	5.83	7.39	14.73	12.48	8.52	6.94	6.52	**96.67**
< 20	6.45	7.88	8.84	6.20	4.96		7.47	15.62	12.91	8.70	7.05	6.58	**98.50**
< 22	6.47	7.88	8.85	6.21	4.96		7.51	16.15	13.09	8.78	7.08	6.60	**99.42**
< 24	6.48	7.88		6.21			7.51	16.43	13.15	8.82	7.09	6.61	**99.82**
< 26	6.48	7.88					7.52	16.53	13.17	8.82	7.09	6.61	**99.95**
< 28								16.57	13.18	8.82	7.09	6.61	**99.99**
< 30								16.57	13.18	8.82		6.61	**100.00**
< 32								16.57		8.82			**100.00**
< 34								16.57					**100.00**
Total	**6.48**	**7.88**	**8.85**	**6.21**	**4.96**	**5.83**	**7.52**	**16.57**	**13.18**	**8.82**	**7.09**	**6.61**	**100.00**
Mean	7.4	7.2	7.2	6.7	6.4	6.5	7.8	11.2	10.0	9.0	8.3	7.8	8.4
P99	18.4	15.4	15.1	15.8	15.4	14.8	18.9	23.7	21.4	20.6	19.3	18.7	20.8
Maximum	24.0	25.6	21.2	22.1	21.1	18.0	25.4	32.4	29.5	31.2	26.2	29.0	32.4

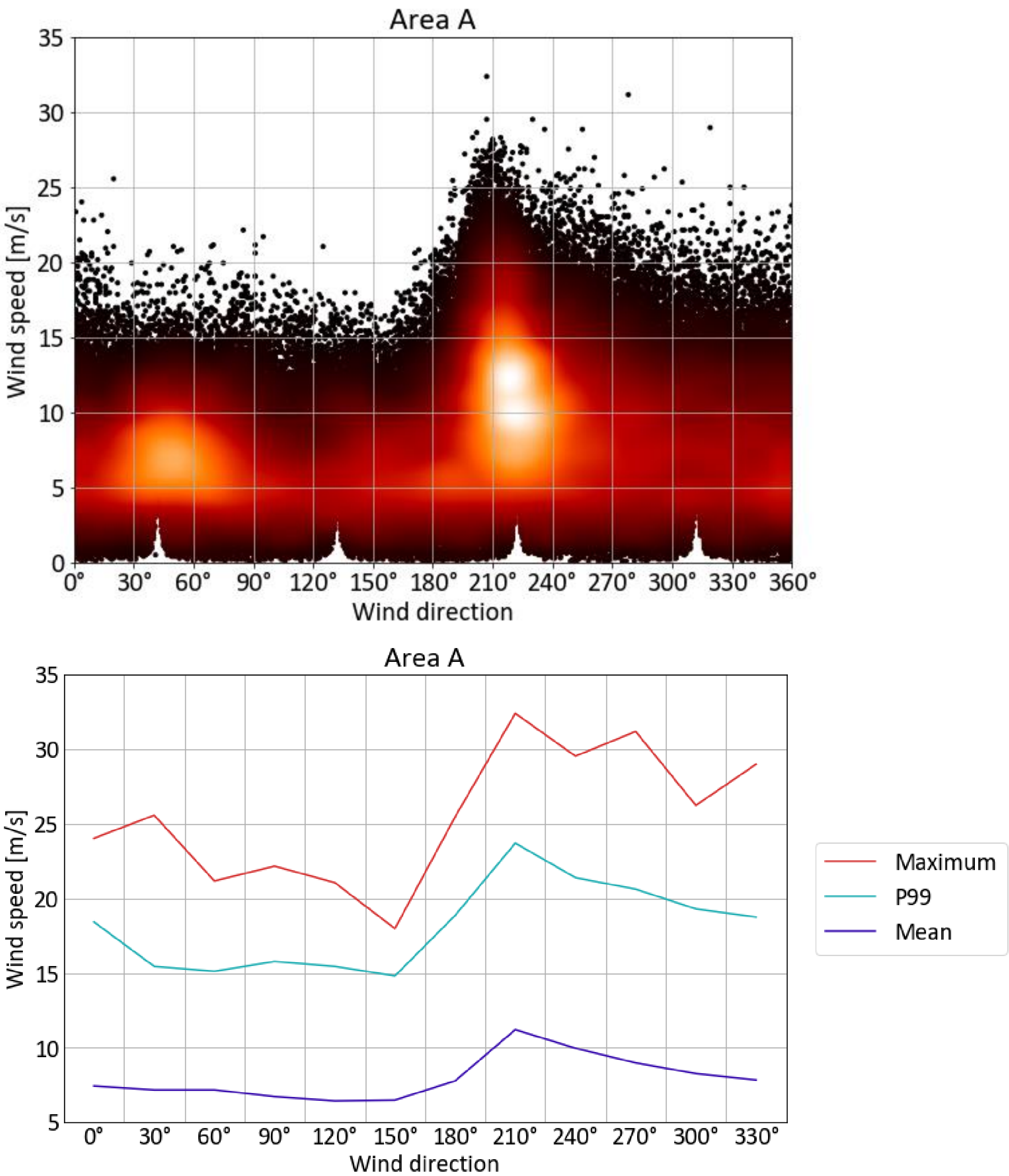


Figure 2.2: Directional mean, P99 and maximum wind speed 10 m above mean sea level.

Table 2.2: Monthly and annual sample distribution of non-exceedance [%] of 1-hour mean wind speed 10 m above sea level.

Wind speed [m/s]	Month												Year
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
< 2	2.28	2.12	2.82	4.69	6.02	5.98	5.99	6.09	4.20	2.72	2.48	1.94	**3.95**
< 4	8.74	9.11	12.00	17.35	21.77	22.10	23.45	22.71	16.44	11.55	10.64	8.21	**15.37**
< 6	20.35	21.37	26.76	35.16	44.65	46.08	49.13	47.32	35.37	27.63	24.26	18.81	**33.14**
< 8	34.87	36.44	42.49	54.39	66.47	68.07	71.29	68.66	53.29	44.24	40.48	32.21	**51.15**
< 10	50.69	52.55	57.53	70.70	82.58	82.99	86.58	83.79	69.56	60.34	56.32	48.05	**66.88**
< 12	65.61	66.92	71.31	83.35	92.03	92.86	94.82	92.74	82.20	74.13	70.87	63.02	**79.21**
< 14	78.16	78.48	82.58	91.64	96.53	97.35	98.43	97.40	90.77	84.92	82.28	75.71	**87.90**
< 16	86.83	87.38	90.73	96.28	98.86	99.10	99.56	99.08	95.51	92.29	90.33	85.64	**93.49**
< 18	92.29	93.06	95.29	98.59	99.55	99.72	99.92	99.68	98.14	96.58	95.06	92.05	**96.67**
< 20	96.01	96.60	97.80	99.64	99.85	99.90	99.99	99.93	99.27	98.78	97.85	96.27	**98.50**
< 22	98.22	98.64	99.07	99.94	99.97	99.97	100.00	99.99	99.78	99.56	99.34	98.49	**99.42**
< 24	99.24	99.60	99.75	99.99	100.00	100.00		99.99	99.95	99.87	99.83	99.56	**99.82**
< 26	99.74	99.91	99.95	100.00				99.99	99.99	99.97	99.96	99.88	**99.95**
< 28	99.96	99.99	100.00					100.00	99.99	99.99	99.99	99.99	**99.99**
< 30	99.99	100.00							100.00	100.00	100.00	100.00	**100.00**
< 32	99.99												**100.00**
< 34	100.00												**100.00**
Total	**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**
Mean	10.3	10.1	9.4	7.9	6.8	6.7	6.4	6.6	8.1	9.1	9.6	10.6	8.4
P99	23.4	22.6	21.8	18.5	16.5	15.9	14.5	15.9	19.2	20.3	21.4	22.6	20.8
Maximum	32.4	28.6	27.9	25.1	22.4	23.1	20.8	26.4	28.3	28.3	28.9	29.0	32.4

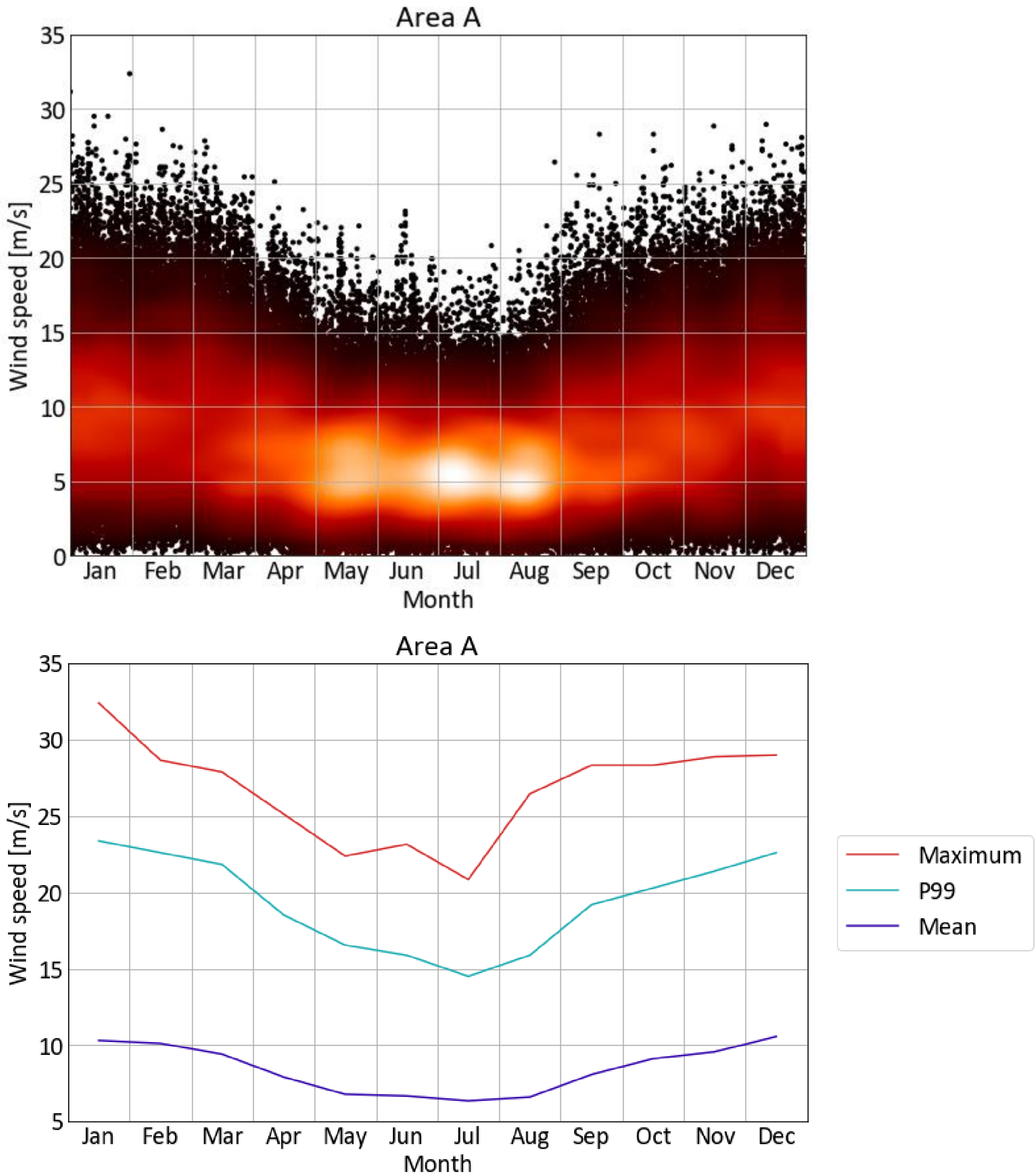


Figure 2.3: Monthly mean, P99 and maximum wind speed 10 m above mean sea level.

2.1.2.2 Long-term wind statistics

The long-term distribution of wind speed is modelled in terms of a 3-parameter Weibull distribution as described in Chapter 3.6.1. Figure 2.4 shows the hindcast and fitted distributions of wind speed at the Haltenbanken Area A.

Figure 2.4: Hindcast (red dots) and fitted (black line) distributions of 1-hour mean wind speed 10 m above sea level.

Figure 2.5 and Table 2.3 show directional Weibull parameters and corresponding extremes of 1-hour mean wind speed at the Haltenbanken Area A. The direction extremes are adjusted in agreement with NORSOK Standard N-003:2017 [1, Section 6.1.4].

Figure 2.6 and Table 2.4 show monthly Weibull parameters and corresponding extremes.

Table 2.3: Weibull parameters and corresponding directional extremes values for 1-hour mean wind speed 10 m above sea level. The direction extremes are adjusted in agreement with NORSOK Standard N-003:2017 [1, Section 6.1.4]. Duration of event is 1 hour.

Direction	Sector prob.	Weibull parameters			Return period [years]					
		Shape	Scale	Location	1	10	50	100	1 000	10 000
-	[%]	-	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]
0°	6.48	1.900	7.903	0.46	24.3	27.6	29.7	30.6	33.4	35.9
30°	7.88	2.100	8.001	0.13	22.1	24.8	26.5	27.2	29.4	31.4
60°	8.85	2.350	8.635	-0.44	21.0	23.3	24.7	25.3	27.2	28.9
90°	6.21	2.030	7.529	0.10	21.2	24.0	25.7	26.4	28.7	30.8
120°	4.96	2.050	7.275	0.04	19.9	22.6	24.3	25.0	27.1	29.1
150°	5.83	2.400	7.833	-0.40	18.3	20.3	21.6	22.1	23.8	25.3
180°	7.52	2.030	8.736	0.08	24.8	28.0	30.0	30.9	33.4	35.9
210°	16.57	2.710	14.586	-1.73	28.4	31.7	33.9	34.8	37.6	40.2
240°	13.18	2.550	12.651	-1.24	28.4	31.3	33.1	33.8	36.1	38.1
270°	8.82	2.200	10.969	-0.69	28.2	31.6	33.7	34.6	37.3	39.8
300°	7.09	2.213	9.996	-0.54	25.4	28.4	30.3	31.1	33.6	35.8
330°	6.61	2.100	9.410	-0.44	25.1	28.3	30.4	31.2	33.8	36.2
0° - 360°	**100.00**	**1.990**	**9.275**	**0.26**	**28.4**	**31.7**	**33.9**	**34.8**	**37.6**	**40.2**

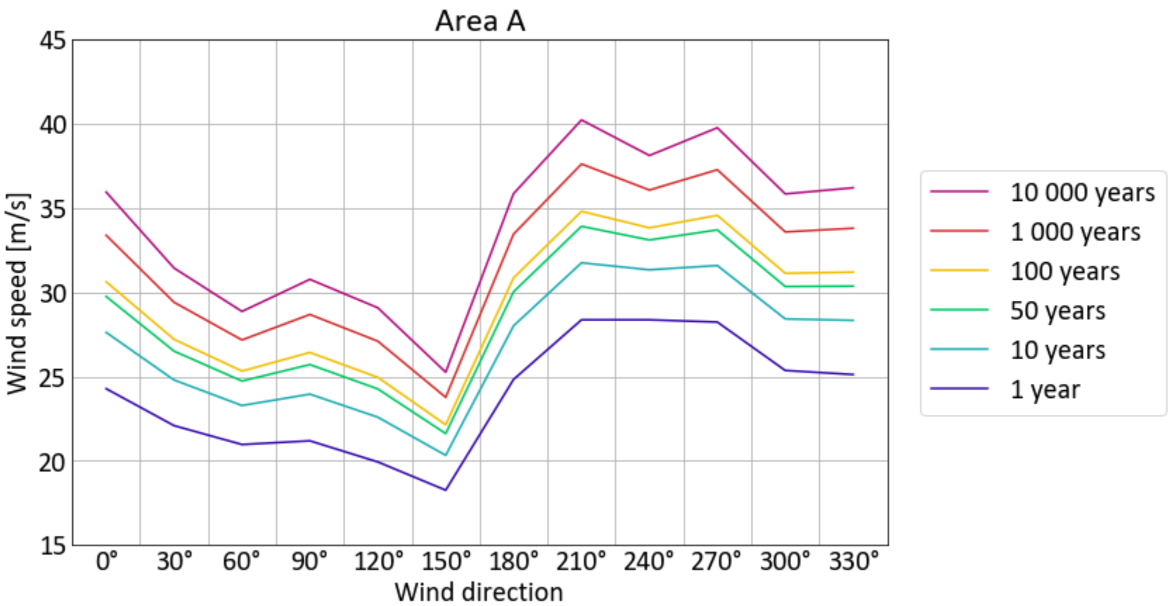


Figure 2.5: Directional extreme values of 1-hour mean wind speed with return period of 1, 10, 50, 100, 1 000 and 10 000 years, 10 m above sea level. The direction extremes are adjusted in agreement with NORSOK Standard N-003:2017 [1, Section 6.1.4].

Table 2.4: Monthly and annual Weibull parameters and corresponding extreme values for 1-hour mean wind speed 10 m above sea level. Duration of event is 1 hour.

Month	Annual prob.	Weibull parameters			Return period [years]					
		Shape	Scale	Location	1	10	50	100	1 000	10 000
-	[%]	-	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]
Jan	8.33	2.222	11.737	-0.05	27.4	31.3	33.8	34.8	37.8	40.6
Feb	8.33	2.350	11.740	-0.25	25.9	29.5	31.7	32.6	35.3	37.8
Mar	8.33	2.330	11.216	-0.48	24.7	28.2	30.3	31.1	33.8	36.2
Apr	8.33	2.250	9.504	-0.46	21.5	24.6	26.6	27.4	29.8	32.0
May	8.33	1.930	7.418	0.26	20.0	23.3	25.3	26.2	28.8	31.3
Jun	8.33	1.920	7.281	0.27	19.7	23.0	25.1	25.9	28.5	30.9
Jul	8.33	2.123	7.134	0.09	17.4	20.1	21.7	22.4	24.4	26.3
Aug	8.33	1.930	7.183	0.28	19.4	22.6	24.6	25.4	28.0	30.3
Sep	8.33	2.070	9.212	-0.04	22.9	26.4	28.7	29.6	32.3	34.9
Oct	8.33	2.300	10.747	-0.37	24.0	27.4	29.5	30.4	33.0	35.3
Nov	8.33	2.360	11.344	-0.44	24.8	28.2	30.3	31.1	33.7	36.1
Dec	8.33	2.590	12.841	-0.80	25.8	29.1	31.0	31.8	34.3	36.5
Year	**100.00**	**1.990**	**9.275**	**0.26**	**28.4**	**31.7**	**33.9**	**34.8**	**37.6**	**40.2**

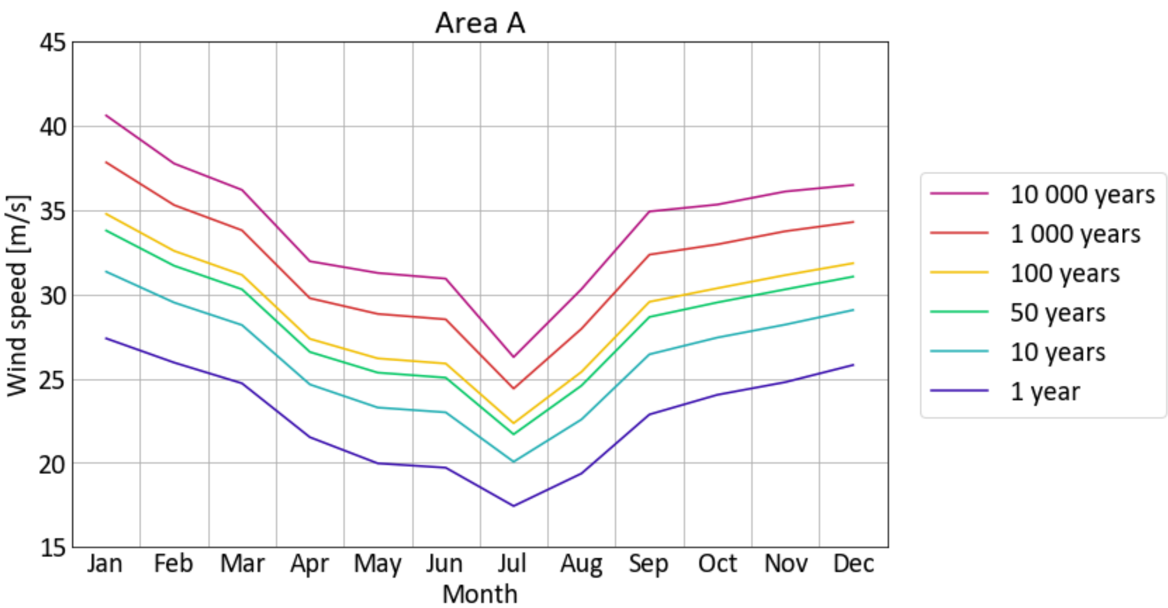


Figure 2.6: Monthly extreme values of 1-hour mean wind speed with return period of 1, 10, 50, 100, 1 000 and 10 000 years 10 m above sea level.

2.1.2.3 Wind gust

The computation of wind gust is performed as described in Appendix 1.2.

Table 2.5 shows directional and omni-directional extreme 10-minute average wind speed 10 m amsl at Haltenbanken Area A. Table 2.6 shows monthly and annual extreme 10-minute average wind speed 10 m amsl.

Table 2.5: Omni-directional and adjusted directional extreme values for 10-minute average wind speed 10 m above sea level, Area A. The direction extremes are adjusted in agreement with NORSOK Standard N-003:2017 [1, Section 6.1.4].

Direction	Return period [years]					
	1	10	50	100	1 000	10 000
-	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]
0°	27.4	31.4	34.0	35.1	38.5	41.7
30°	24.8	28.0	30.1	30.9	33.6	36.1
60°	23.5	26.2	28.0	28.7	30.9	32.9
90°	23.7	27.0	29.1	30.0	32.7	35.3
120°	22.3	25.4	27.4	28.2	30.8	33.2
150°	20.3	22.7	24.2	24.9	26.8	28.6
180°	28.1	31.9	34.4	35.4	38.6	41.6
210°	32.3	36.5	39.2	40.3	43.8	47.2
240°	32.3	36.0	38.2	39.1	41.9	44.5
270°	32.2	36.3	38.9	40.0	43.4	46.6
300°	28.7	32.4	34.8	35.7	38.8	41.6
330°	28.4	32.3	34.8	35.8	39.0	42.0
0° - 360°	**32.3**	**36.5**	**39.2**	**40.3**	**43.8**	**47.2**

Table 2.6: Monthly and annual extreme values for 10-minute average wind speed 10 m above sea level, Area A.

Month	Return period [years]					
	1	10	50	100	1 000	10 000
-	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]
Jan	31.1	36.0	39.0	40.2	44.1	47.6
Feb	29.4	33.7	36.4	37.5	40.9	44.0
Mar	27.9	32.1	34.7	35.7	39.0	42.0
Apr	24.1	27.9	30.2	31.1	34.0	36.7
May	22.3	26.2	28.7	29.7	32.9	35.9
Jun	22.0	25.9	28.3	29.3	32.5	35.5
Jul	19.4	22.4	24.3	25.1	27.6	29.8
Aug	21.6	25.4	27.8	28.8	31.8	34.7
Sep	25.7	30.0	32.7	33.8	37.2	40.4
Oct	27.1	31.2	33.7	34.8	38.0	40.9
Nov	28.0	32.1	34.7	35.7	39.0	41.9
Dec	29.2	33.2	35.6	36.6	39.6	42.4
Year	**32.3**	**36.5**	**39.2**	**40.3**	**43.8**	**47.2**

Table 2.7 shows directional and omni-directional extreme 1-minute average wind speed 10 m amsl at Haltenbanken Area A. Table 2.8 shows monthly and annual extreme 1-minute average wind speed 10 m amsl.

Table 2.7: Omni-directional and adjusted directional extreme values for 1-minute average wind speed 10 m above sea level, Area A. The direction extremes are adjusted in agreement with NORSOK Standard N-003:2017 [1, Section 6.1.4].

Direction	Return period [years]					
	1	10	50	100	1 000	10 000
-	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]
0°	31.4	36.3	39.5	40.9	45.1	49.1
30°	28.3	32.2	34.7	35.7	39.0	42.1
60°	26.7	30.0	32.1	33.0	35.7	38.2
90°	27.0	31.0	33.5	34.6	37.9	41.1
120°	25.3	29.0	31.4	32.4	35.6	38.5
150°	23.0	25.8	27.6	28.4	30.7	32.9
180°	32.2	36.9	40.0	41.2	45.2	49.0
210°	37.5	42.6	45.9	47.3	51.8	56.1
240°	37.5	41.9	44.7	45.8	49.3	52.6
270°	37.3	42.3	45.6	47.0	51.3	55.3
300°	33.0	37.5	40.4	41.6	45.4	49.0
330°	32.7	37.4	40.5	41.7	45.8	49.5
0° - 360°	**37.5**	**42.6**	**45.9**	**47.3**	**51.8**	**56.1**

Table 2.8: Monthly and annual extreme values for 1-minute average wind speed 10 m above sea level, Area A.

Month	Return period [years]					
	1	10	50	100	1 000	10 000
-	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]
Jan	36.0	42.0	45.7	47.3	52.2	56.7
Feb	33.9	39.2	42.5	43.9	48.1	52.0
Mar	32.1	37.2	40.4	41.7	45.8	49.5
Apr	27.5	32.0	34.8	35.9	39.6	42.9
May	25.3	30.0	33.0	34.2	38.2	41.8
Jun	25.0	29.6	32.6	33.8	37.7	41.3
Jul	21.8	25.5	27.7	28.7	31.6	34.3
Aug	24.5	29.0	31.9	33.1	36.8	40.4
Sep	29.4	34.6	37.9	39.2	43.5	47.5
Oct	31.1	36.1	39.2	40.5	44.5	48.2
Nov	32.2	37.2	40.4	41.6	45.7	49.4
Dec	33.7	38.5	41.5	42.7	46.5	50.0
Year	**37.5**	**42.6**	**45.9**	**47.3**	**51.8**	**56.1**

2.1.2.4 Wind profile

Offshore wind profiles are described in Appendix 1.1.

Table 2.9 shows the omni-directional extreme values for 1-hour mean wind speed as function of height above mean sea level (amsl) at Haltenbanken Area A.

Table 2.9: Omni-directional extreme values for 1-hour mean wind speed as function of height above mean sea level at Haltenbanken Area A.

Height	Return period [years]					
amsl	1	10	50	100	1000	10 000
[m]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]
10	28.4	31.7	33.9	34.8	37.6	40.2
20	30.9	34.8	37.2	38.2	41.5	44.5
30	32.5	36.5	39.2	40.3	43.7	46.9
40	33.5	37.8	40.6	41.7	45.3	48.7
50	34.4	38.8	41.6	42.8	46.5	50.1
60	35.0	39.6	42.5	43.7	47.6	51.2
70	35.6	40.2	43.2	44.5	48.4	52.1
80	36.1	40.8	43.9	45.1	49.2	52.9
90	36.6	41.3	44.4	45.7	49.8	53.6
100	36.9	41.8	44.9	46.2	50.4	54.3
125	37.8	42.8	46.0	47.4	51.6	55.7
150	38.5	43.6	46.9	48.3	52.6	56.8
200	39.5	44.8	48.3	49.7	54.2	58.5

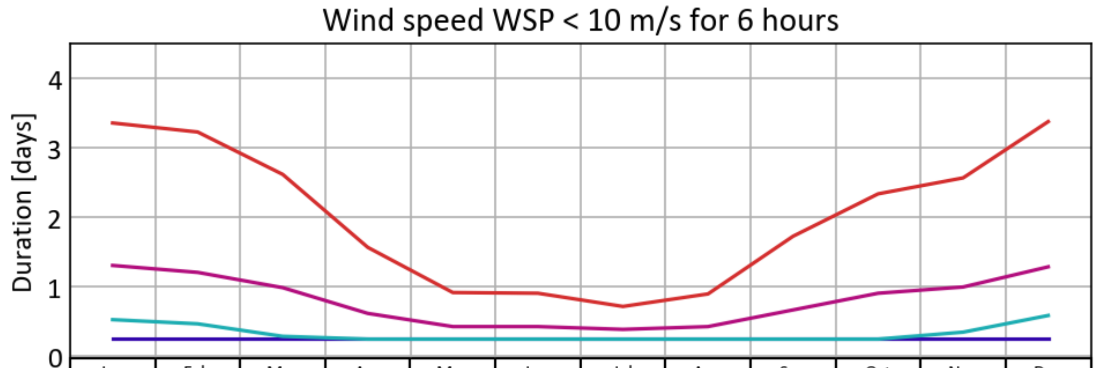
2.1.2.5 Operational wind data

Marine operations may be delayed due to wind speeds exceeding prescribed operational levels (limits) leading to a possible increase in the duration of the operations. Marine operations which must be completed without break are called critical. Otherwise they are termed non-critical.

The duration statistics presented in this report is restricted to critical operations, only.

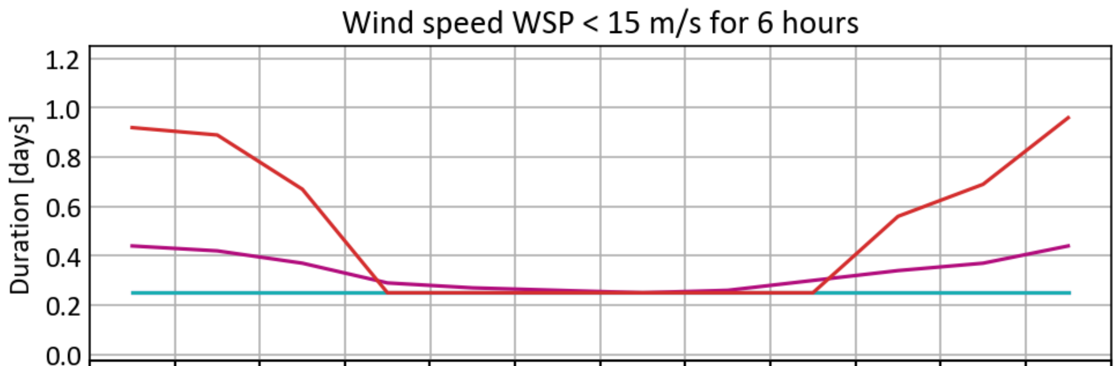
Figure 2.7- Figure 2.18 show characteristic durations of operations limited by wind speeds of 10, 15 and 20 m/s for 6, 12, 24 and 48 hours. The figures show the expected mean duration and 10, 50 and 90 percentiles.

The figures show duration characteristics for completing a critical operation including waiting time. Duration is measured from the day the operation is ready for launching. The day of launching is assumed to be an arbitrary day within the relevant month.



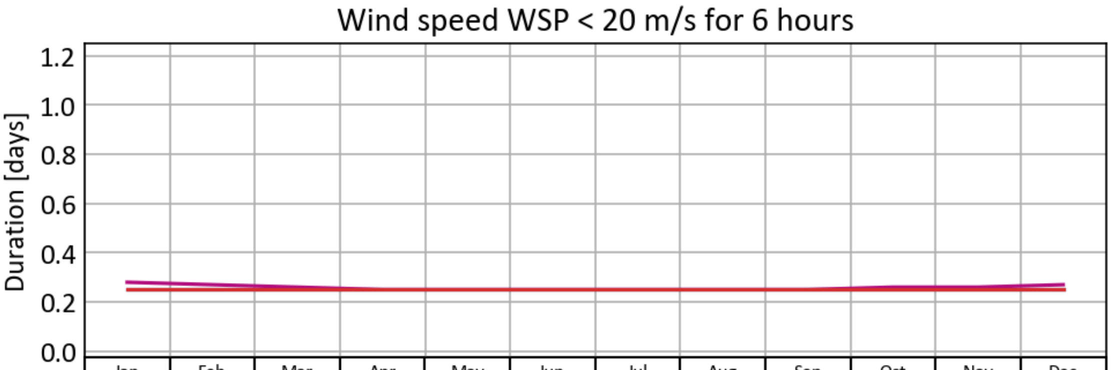
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
P50	0.53	0.47	0.29	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.35	0.59
Mean	1.31	1.21	0.99	0.62	0.43	0.43	0.39	0.43	0.67	0.91	1.00	1.29
P90	3.36	3.23	2.62	1.57	0.92	0.91	0.72	0.90	1.73	2.34	2.57	3.38

Figure 2.7: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 10 m/s for 6 hours.



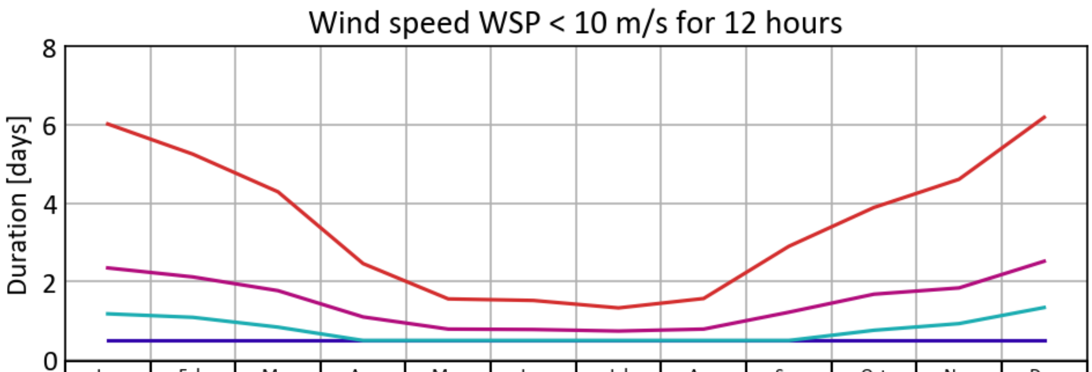
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
P50	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Mean	0.44	0.42	0.37	0.29	0.27	0.26	0.25	0.26	0.30	0.34	0.37	0.44
P90	0.92	0.89	0.67	0.25	0.25	0.25	0.25	0.25	0.25	0.56	0.69	0.96

Figure 2.8: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 15 m/s for 6 hours.



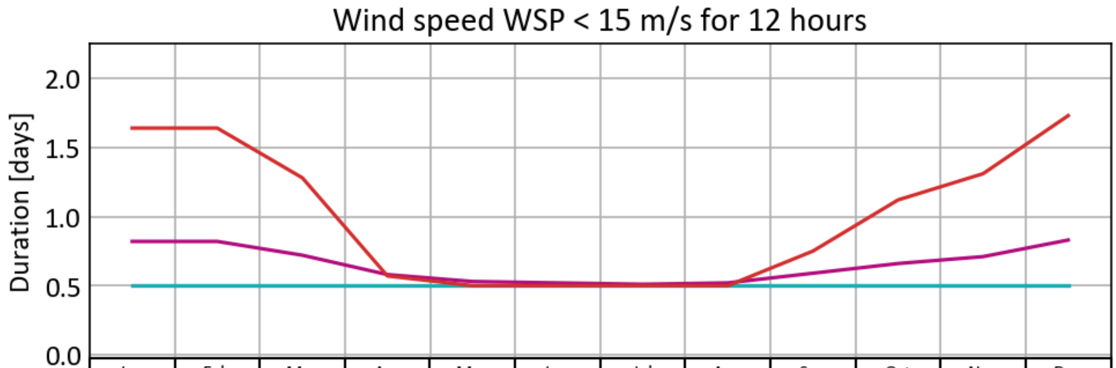
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
P50	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Mean	0.28	0.27	0.26	0.25	0.25	0.25	0.25	0.25	0.25	0.26	0.26	0.27
P90	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25

Figure 2.9: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 20 m/s for 6 hours.



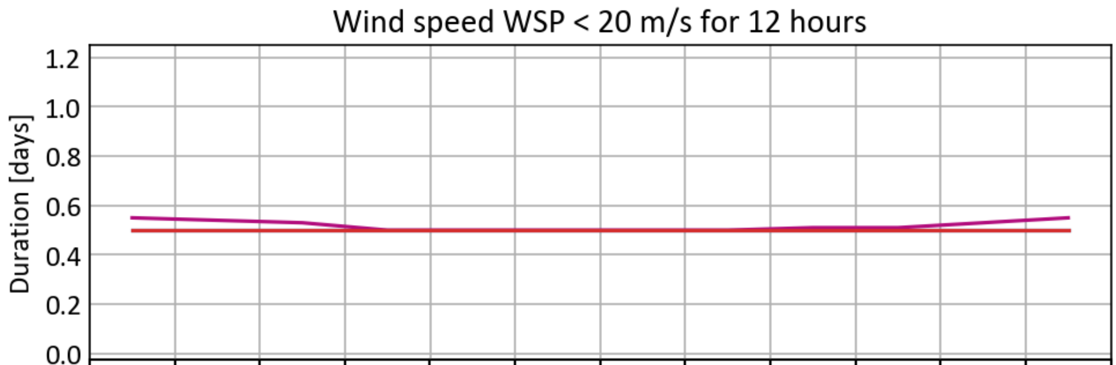
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
P50	1.18	1.09	0.84	0.50	0.50	0.50	0.50	0.50	0.50	0.76	0.93	1.34
Mean	2.35	2.12	1.77	1.10	0.79	0.78	0.74	0.79	1.22	1.68	1.84	2.52
P90	6.02	5.25	4.29	2.46	1.56	1.52	1.33	1.57	2.90	3.89	4.61	6.19

Figure 2.10: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 10 m/s for 12 hours.



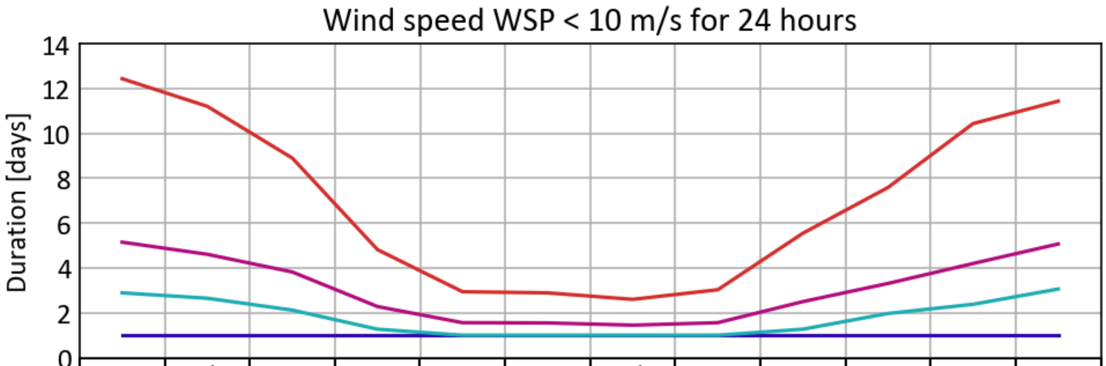
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
P50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Mean	0.82	0.82	0.72	0.58	0.53	0.52	0.51	0.52	0.59	0.66	0.71	0.83
P90	1.64	1.64	1.28	0.57	0.50	0.50	0.50	0.50	0.75	1.12	1.31	1.73

Figure 2.11: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 15 m/s for 12 hours.



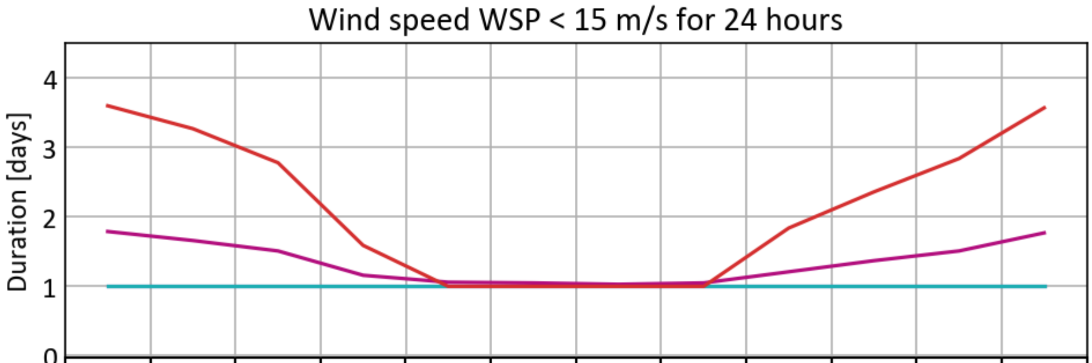
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
P50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Mean	0.55	0.54	0.53	0.50	0.50	0.50	0.50	0.50	0.51	0.51	0.53	0.55
P90	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50

Figure 2.12: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 20 m/s for 12 hours.



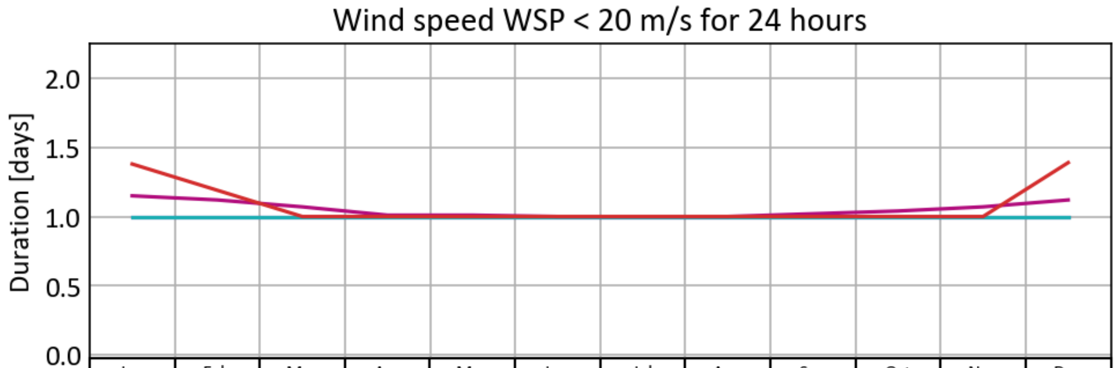
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P50	2.89	2.65	2.12	1.27	1.00	1.00	1.00	1.00	1.27	1.97	2.38	3.06
Mean	5.15	4.61	3.82	2.28	1.56	1.55	1.45	1.56	2.50	3.31	4.20	5.07
P90	12.44	11.21	8.90	4.82	2.94	2.89	2.60	3.03	5.55	7.59	10.44	11.44

Figure 2.13: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 10 m/s for 24 hours.



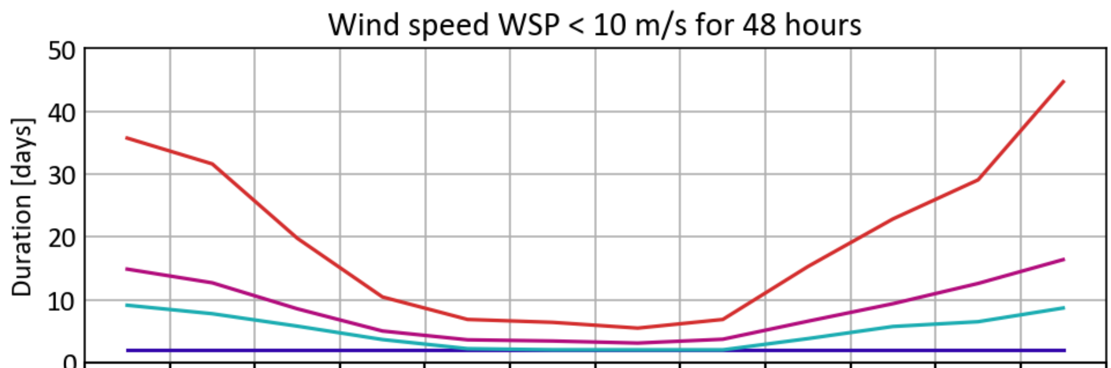
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Mean	1.79	1.66	1.51	1.16	1.06	1.05	1.03	1.05	1.21	1.37	1.51	1.77
P90	3.60	3.27	2.78	1.59	1.00	1.00	1.00	1.00	1.84	2.36	2.84	3.57

Figure 2.14: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 15 m/s for 24 hours.



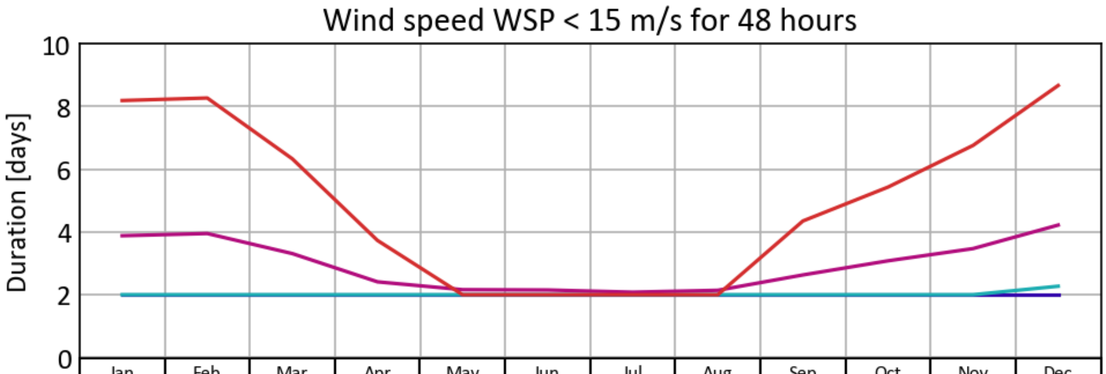
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Mean	1.15	1.12	1.07	1.01	1.01	1.00	1.00	1.00	1.02	1.04	1.07	1.12
P90	1.38	1.19	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.39

Figure 2.15: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 20 m/s for 24 hours.



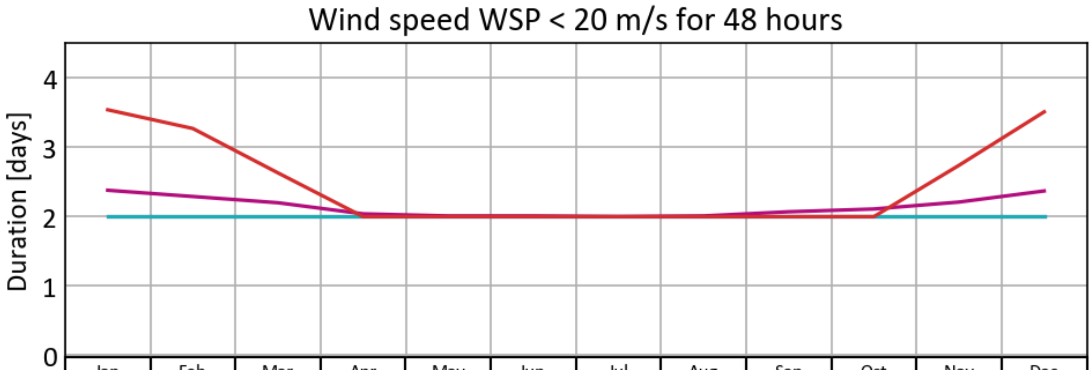
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
P50	9.10	7.75	5.77	3.64	2.19	2.01	2.00	2.00	3.79	5.72	6.48	8.66
Mean	14.85	12.67	8.53	5.00	3.60	3.41	3.08	3.69	6.56	9.35	12.57	16.36
P90	35.70	31.59	19.75	10.42	6.84	6.38	5.46	6.84	15.26	22.84	29.05	44.66

Figure 2.16: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 10 m/s for 48 hours.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
P50	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.27
Mean	3.88	3.95	3.31	2.41	2.16	2.15	2.08	2.14	2.63	3.08	3.47	4.22
P90	8.19	8.27	6.33	3.73	2.00	2.00	2.00	2.00	4.35	5.43	6.76	8.67

Figure 2.17: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 15 m/s for 48 hours.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
P50	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Mean	2.38	2.29	2.20	2.04	2.01	2.01	2.00	2.01	2.07	2.11	2.21	2.37
P90	3.54	3.27	2.63	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.74	3.51

Figure 2.18: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 20 m/s for 48 hours.

2.1.3 Wind Analysis, Haltenbanken Area B

2.1.3.1 Wind data statistics

Figure 2.19 shows the (all-year) wind rose from the Haltenbanken Area B for the period 1958 – 2019. The wind rose shows the percentage of observations within each 30° sector.

Table 2.10 shows the annual directional sample distribution of non-exceedance of 1-hour mean wind speed.

Figure 2.20 shows the directional data scatter density and mean, P99 and maximum of 1-hour mean wind speed.

Table 2.11 shows the monthly sample distribution of non-exceedance of 1-hour mean wind speed.

Figure 2.21 shows the monthly data scatter density and mean, P99 and maximum of 1-hour mean wind speed.

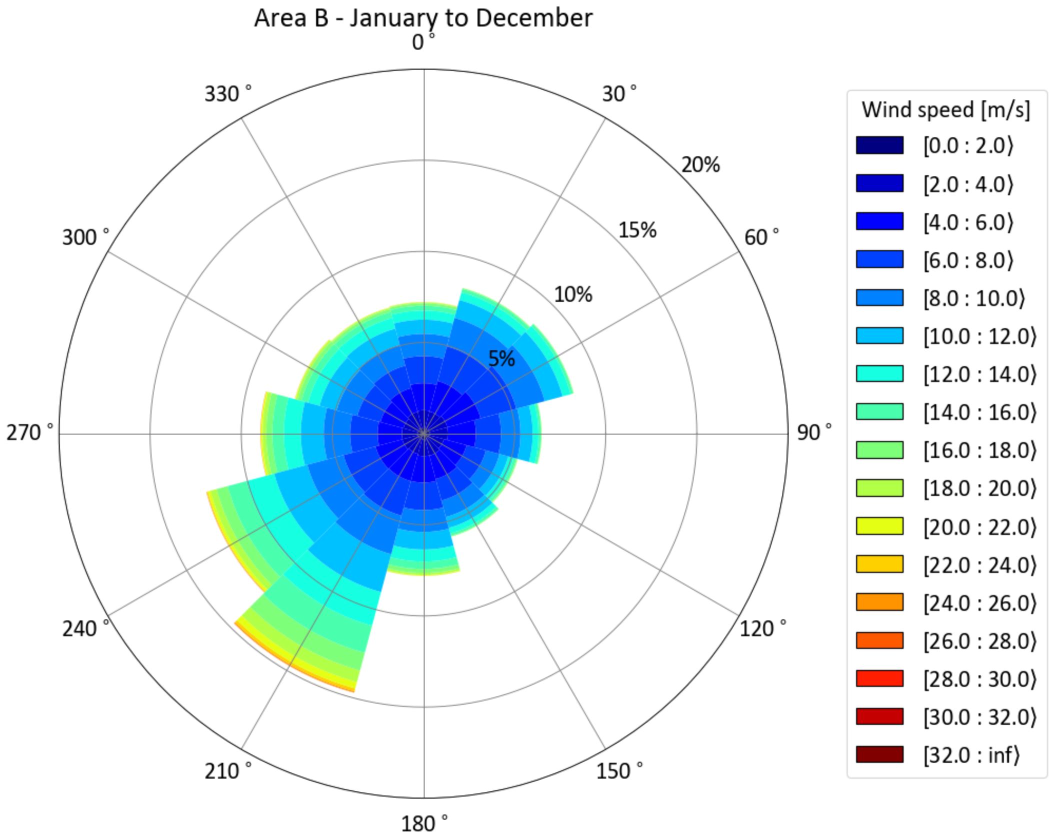


Figure 2.19: All year wind rose; 1-hour mean wind speed at 10 m elevation above mean sea level for the Haltenbanken Area B.

Table 2.10: Directional sample distribution of non-exceedance [%] of 1-hour mean wind speed 10 m above sea level.

Wind speed	Wind direction												Omni
[m/s]	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°	
< 2	0.28	0.25	0.32	0.30	0.26	0.30	0.31	0.25	0.31	0.28	0.29	0.30	**3.44**
< 4	1.24	1.20	1.30	1.29	1.12	1.21	1.17	1.10	1.17	1.14	1.10	1.19	**14.21**
< 6	2.66	2.84	3.08	2.77	2.37	2.50	2.57	2.57	2.62	2.43	2.38	2.50	**31.30**
< 8	4.09	4.70	5.01	4.11	3.46	3.74	4.05	4.47	4.41	3.92	3.70	3.78	**49.45**
< 10	5.29	6.25	6.57	5.18	4.24	4.71	5.26	6.60	6.44	5.40	4.91	4.97	**65.82**
< 12	6.09	7.22	7.57	5.87	4.75	5.37	6.26	8.74	8.33	6.69	5.95	5.93	**78.76**
< 14	6.61	7.65	8.03	6.23	5.09	5.72	6.95	10.68	9.94	7.69	6.65	6.59	**87.83**
< 16	6.90	7.84	8.18	6.38	5.27	5.91	7.39	12.30	11.09	8.37	7.07	6.96	**93.66**
< 18	7.04	7.90	8.22	6.43	5.34	5.96	7.65	13.37	11.78	8.75	7.30	7.13	**96.86**
< 20	7.10	7.91	8.23	6.43	5.37	5.97	7.78	14.11	12.18	8.97	7.42	7.21	**98.68**
< 22	7.13	7.91	8.23	6.44	5.37	5.98	7.82	14.53	12.36	9.07	7.47	7.24	**99.53**
< 24	7.13	7.91					7.84	14.71	12.42	9.10	7.48	7.25	**99.85**
< 26	7.14						7.84	14.78	12.44	9.11	7.48	7.25	**99.97**
< 28								14.80	12.45	9.11	7.48	7.25	**100.00**
< 30								14.80	12.45	9.11		7.25	**100.00**
< 32								14.80	12.45	9.11			**100.00**
< 34										9.11			**100.00**
Total	**7.14**	**7.91**	**8.23**	**6.44**	**5.37**	**5.98**	**7.84**	**14.80**	**12.45**	**9.11**	**7.48**	**7.25**	**100.00**
Mean	7.7	7.4	7.2	7.0	7.1	7.1	8.4	11.0	10.0	9.2	8.5	8.1	8.6
P99	18.7	15.8	15.2	15.8	17.0	16.3	19.6	23.1	21.5	20.7	19.7	19.2	20.6
Maximum	24.7	23.7	20.9	21.7	21.3	20.7	25.9	30.9	30.8	32.3	26.9	28.4	32.3

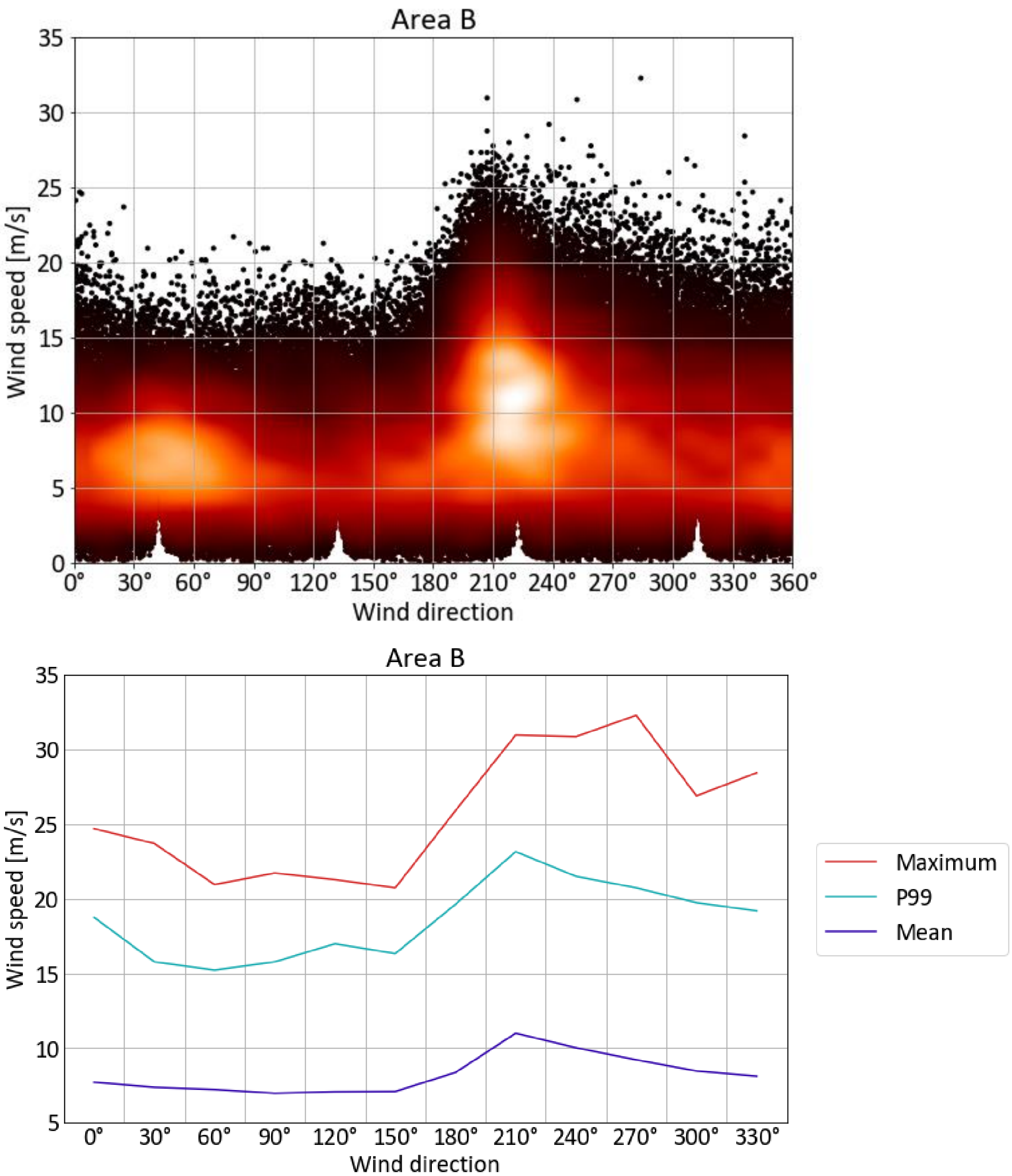


Figure 2.20: Directional scatter density plot (top) and mean, P99 and maximum (bottom) of wind speed 10 m above mean sea level.

Table 2.11: Monthly and annual sample distribution of non-exceedance [%] of 1-hour mean wind speed 10 m above sea level.

Wind speed	Month												Year
[m/s]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
< 2	2.07	1.84	2.47	3.82	5.10	5.01	5.24	5.29	3.84	2.37	2.31	1.79	**3.44**
< 4	8.59	8.29	11.24	16.02	20.00	20.74	21.74	20.86	14.58	10.62	9.67	7.76	**14.21**
< 6	19.24	19.75	24.91	33.18	42.19	44.91	47.19	44.92	33.16	25.13	22.52	17.77	**31.30**
< 8	33.51	34.93	40.22	51.30	64.71	67.17	70.02	67.38	51.64	41.92	38.33	31.27	**49.45**
< 10	48.92	51.37	55.94	69.01	81.76	83.10	86.38	83.43	68.60	58.67	54.88	46.91	**65.82**
< 12	64.30	65.86	70.52	83.20	92.05	93.31	94.94	92.85	81.94	73.27	70.06	62.07	**78.76**
< 14	77.32	78.02	82.57	91.88	96.99	97.53	98.57	97.44	90.81	84.68	81.99	75.62	**87.83**
< 16	87.00	87.47	90.94	96.45	98.96	99.24	99.64	99.20	95.85	92.36	90.32	86.18	**93.66**
< 18	92.64	93.04	95.69	98.70	99.60	99.74	99.97	99.72	98.31	96.81	95.36	92.52	**96.86**
< 20	96.53	96.89	98.13	99.65	99.90	99.92	99.99	99.97	99.38	98.93	98.07	96.76	**98.68**
< 22	98.55	98.86	99.27	99.95	100.00	99.98	100.00	99.99	99.82	99.62	99.50	98.81	**99.53**
< 24	99.37	99.64	99.81	99.99		100.00		99.99	99.97	99.89	99.84	99.70	**99.85**
< 26	99.82	99.96	99.95	99.99				100.00	100.00	99.99	99.97	99.92	**99.97**
< 28	99.97	100.00	100.00	100.00						100.00	99.98	99.99	**100.00**
< 30	99.99										99.99	100.00	**100.00**
< 32	99.99										100.00		**100.00**
< 34	100.00												**100.00**
Total	**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**
Mean	10.4	10.2	9.5	8.1	6.9	6.7	6.5	6.7	8.2	9.3	9.7	10.6	8.6
P99	22.9	22.1	21.5	18.4	16.1	15.8	14.4	15.7	19.0	20.2	20.9	22.4	20.6
Maximum	32.3	27.1	27.3	26.4	21.9	22.7	20.5	24.6	25.7	27.3	30.8	28.4	32.3

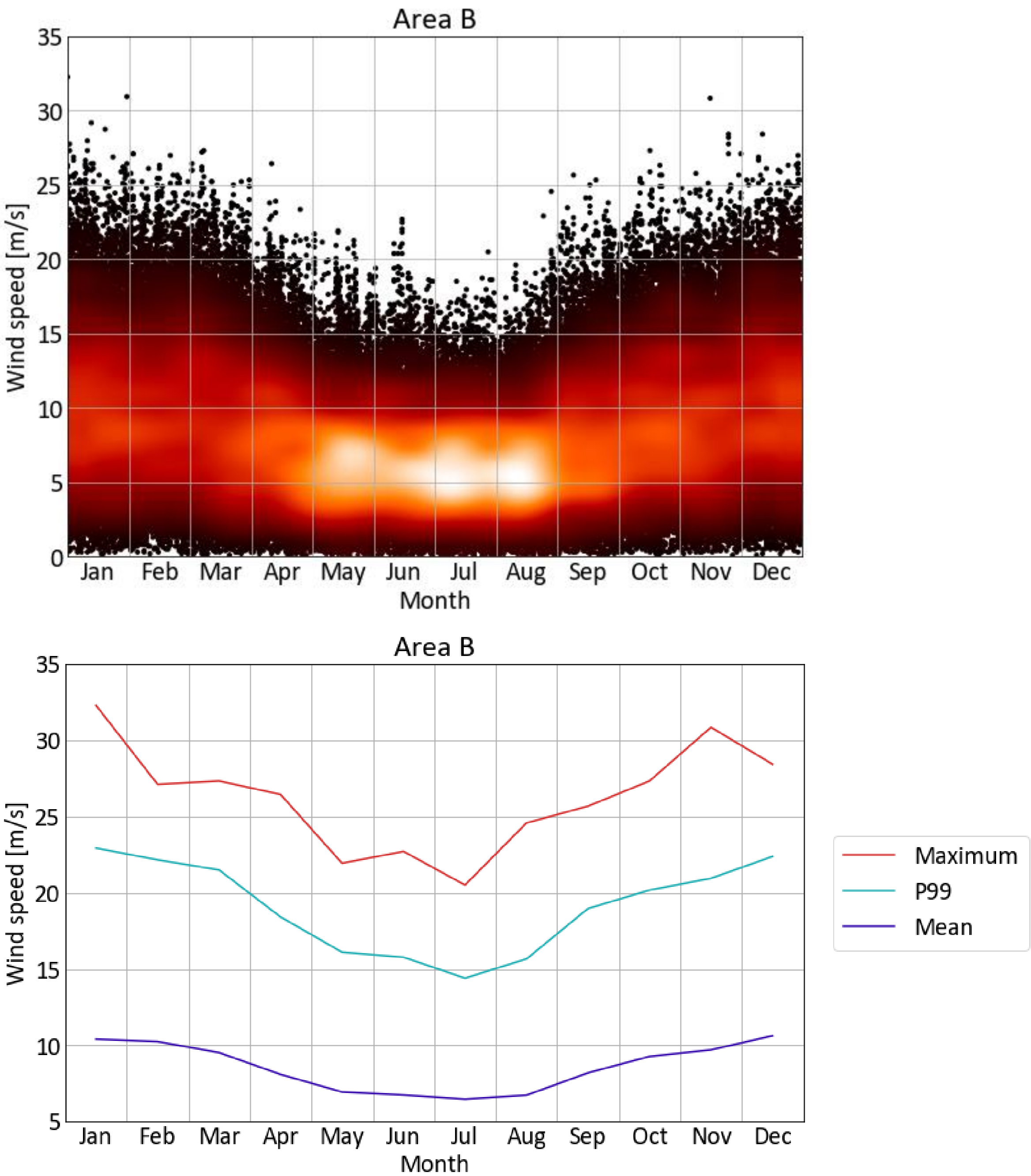


Figure 2.21: Monthly scatter density plot (top) and mean, P99 and maximum (bottom) of wind speed 10 m above mean sea level.

2.1.3.2 Long-term wind statistics

The long-term distribution of wind speed is modelled in terms of a 3-parameter Weibull distribution as described in Chapter 3.6.1. Figure 2.22 shows the hindcast and fitted distributions of wind speed at the Haltenbanken Area B.

Figure 2.22: Hindcast (red dots) and fitted (black line) distributions of 1-hour mean wind speed 10 m above sea level.

Figure 2.23 and Table 2.12 show directional Weibull parameters and corresponding extremes of 1-hour mean wind speed at the Haltenbanken Area B. The direction extremes are adjusted in agreement with NORSOK Standard N-003:2017 [1, Section 6.1.4].

Figure 2.24 and Table 2.13 show monthly Weibull parameters and corresponding extremes.

Table 2.12: Weibull parameters and corresponding directional extremes values for 1-hour mean wind speed 10 m above sea level. The direction extremes are adjusted in agreement with NORSOK Standard N-003:2017 [1, Section 6.1.4]. Duration of event is 1 hour.

Direction	Sector prob.	Weibull parameters			Return period [years]					
		Shape	Scale	Location	1	10	50	100	1 000	10 000
-	[%]	-	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]
0°	7.14	1.940	8.197	0.49	24.8	28.1	30.2	31.0	33.8	36.3
30°	7.91	2.140	8.188	0.16	22.2	24.9	26.6	27.2	29.4	31.4
60°	8.23	2.350	8.498	-0.27	20.7	23.0	24.4	25.0	26.8	28.5
90°	6.44	2.195	8.050	-0.11	20.8	23.3	24.9	25.5	27.6	29.4
120°	5.37	2.000	7.784	0.22	22.2	25.1	27.0	27.8	30.2	32.5
150°	5.98	2.230	8.304	-0.22	20.9	23.5	25.1	25.7	27.7	29.6
180°	7.84	2.150	9.612	-0.11	25.6	28.7	30.7	31.5	34.0	36.3
210°	14.80	2.680	13.870	-1.29	28.4	31.7	33.9	34.8	37.5	39.6
240°	12.45	2.460	12.519	-1.05	28.4	31.7	33.9	34.8	37.3	39.5
270°	9.12	2.240	11.128	-0.61	28.3	31.6	33.6	34.5	37.1	39.5
300°	7.48	2.185	9.946	-0.30	25.9	29.0	30.9	31.7	34.2	36.5
330°	7.25	2.150	9.597	-0.34	25.3	28.4	30.3	31.1	33.6	36.0
0° - 360°	**100.00**	**2.020**	**9.452**	**0.24**	**28.4**	**31.7**	**33.9**	**34.8**	**37.5**	**40.1**

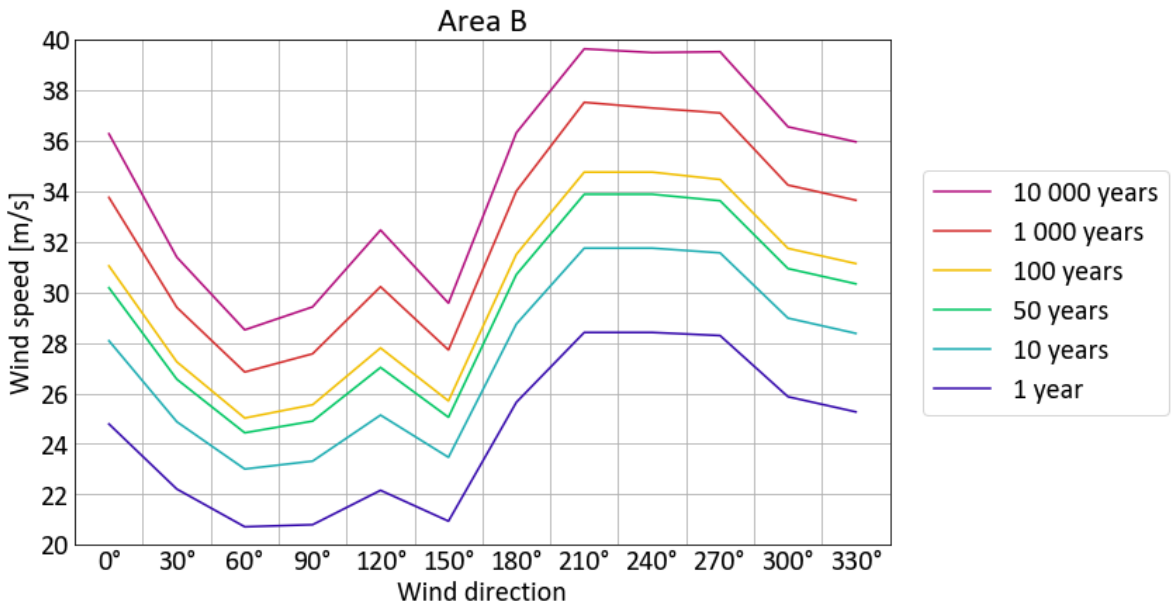


Figure 2.23: Directional extreme values of 1-hour mean wind speed with return period of 1, 10, 50, 100, 1 000 and 10 000 years, 10 m above sea level. The direction extremes are adjusted in agreement with NORSOK Standard N-003:2017 [1, Section 6.1.4].

Table 2.13: Monthly and annual Weibull parameters and corresponding extreme values for 1-hour mean wind speed 10 m above sea level. Duration of event is 1 hour.

Month	Annual prob.	Weibull parameters			Return period [years]					
		Shape	Scale	Location	1	10	50	100	1 000	10 000
-	[%]	-	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]
Jan	8.33	2.320	12.281	-0.44	27.2	31.1	33.4	34.4	37.3	39.9
Feb	8.33	2.370	11.944	-0.31	26.2	29.7	31.9	32.8	35.5	38.0
Mar	8.33	2.372	11.578	-0.69	24.9	28.4	30.5	31.4	34.0	36.4
Apr	8.33	2.302	9.742	-0.50	21.6	24.7	26.6	27.3	29.7	31.8
May	8.33	2.040	7.691	0.17	19.6	22.6	24.5	25.3	27.7	29.9
Jun	8.33	1.950	7.338	0.29	19.6	22.8	24.8	25.6	28.2	30.5
Jul	8.33	2.254	7.381	-0.01	17.0	19.4	20.9	21.5	23.4	25.1
Aug	8.33	2.000	7.365	0.25	19.2	22.2	24.1	24.9	27.3	29.5
Sep	8.33	2.148	9.386	-0.07	22.5	25.9	28.0	28.8	31.5	33.9
Oct	8.33	2.387	11.067	-0.50	23.9	27.2	29.1	30.0	32.4	34.7
Nov	8.33	2.410	11.607	-0.54	24.8	28.2	30.3	31.1	33.6	35.9
Dec	8.33	2.632	13.140	-1.00	25.9	29.1	31.1	31.9	34.3	36.5
Year	**100.00**	**2.020**	**9.452**	**0.24**	**28.4**	**31.7**	**33.9**	**34.8**	**37.5**	**40.1**

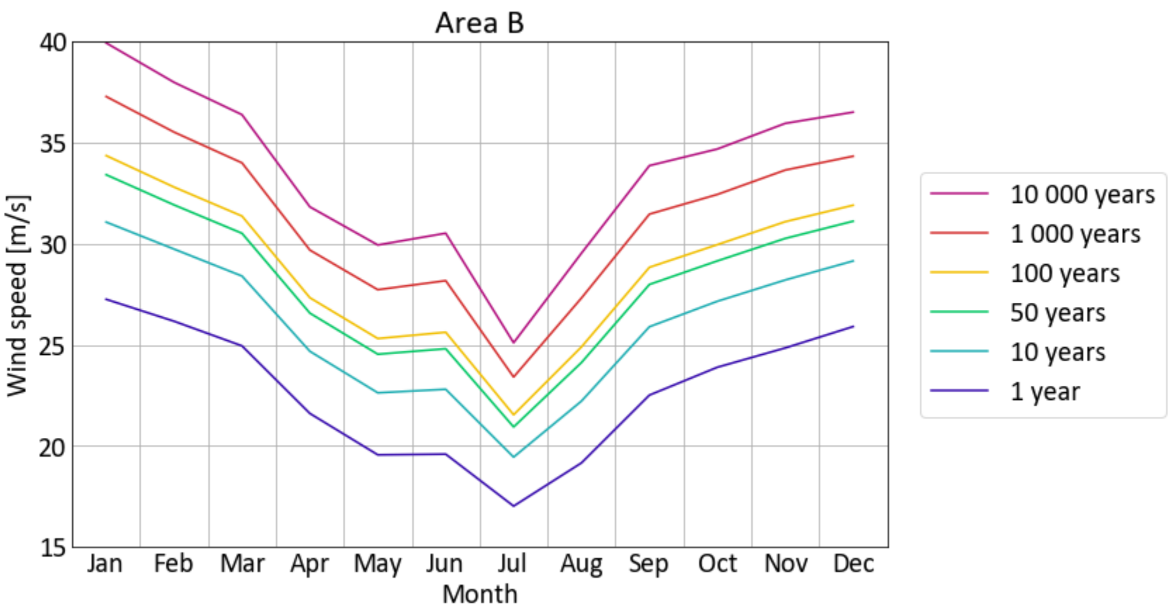


Figure 2.24: Monthly extreme values of 1-hour mean wind speed with return period of 1, 10, 50, 100, 1 000 and 10 000 years 10 m above sea level.

2.1.3.3 Wind gust

The computation of wind gust is performed as described in Appendix 1.2.

Table 2.14 shows directional and omni-directional extreme 10-minute average wind speed 10 m amsl at Haltenbanken Area B. Table 2.15 shows monthly and annual extreme 10-minute average wind speed 10 m amsl.

Table 2.14: Omni-directional and adjusted directional extreme values for 10-minute average wind speed 10 m above sea level, Area B. The direction extremes are adjusted in agreement with NORSOK Standard N-003:2017 [1, Section 6.1.4].

Direction	Return period [years]					
	1	10	50	100	1 000	10 000
-	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]
0°	28.0	32.0	34.6	35.6	39.0	42.1
30°	25.0	28.1	30.1	31.0	33.6	36.0
60°	23.2	25.9	27.6	28.3	30.5	32.5
90°	23.3	26.3	28.2	28.9	31.4	33.6
120°	24.9	28.4	30.7	31.6	34.6	37.4
150°	23.5	26.4	28.3	29.1	31.6	33.8
180°	29.1	32.8	35.2	36.2	39.3	42.2
210°	32.4	36.5	39.1	40.2	43.7	46.4
240°	32.4	36.5	39.1	40.2	43.4	46.2
270°	32.2	36.3	38.8	39.9	43.2	46.3
300°	29.3	33.1	35.5	36.5	39.6	42.5
330°	28.6	32.3	34.7	35.7	38.8	41.7
0° - 360°	**32.4**	**36.5**	**39.1**	**40.2**	**43.7**	**47.0**

Table 2.15: Monthly and annual extreme values for 10-minute average wind speed 10 m above sea level, Area B.

Month	Return period [years]					
	1	10	50	100	1 000	10 000
-	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]
Jan	31.0	35.6	38.5	39.7	43.4	46.8
Feb	29.7	34.0	36.7	37.8	41.2	44.3
Mar	28.2	32.4	35.0	36.0	39.3	42.3
Apr	24.2	27.9	30.2	31.1	33.9	36.6
May	21.8	25.4	27.7	28.6	31.6	34.3
Jun	21.9	25.7	28.0	29.0	32.1	35.0
Jul	18.9	21.7	23.5	24.2	26.4	28.4
Aug	21.4	25.0	27.2	28.2	31.1	33.8
Sep	25.3	29.3	31.9	32.9	36.1	39.1
Oct	26.9	30.9	33.3	34.3	37.3	40.1
Nov	28.1	32.1	34.7	35.7	38.8	41.7
Dec	29.4	33.3	35.7	36.7	39.7	42.4
Year	**32.4**	**36.5**	**39.1**	**40.2**	**43.7**	**47.0**

Table 2.16 shows directional and omni-directional extreme 1-minute average wind speed 10 m amsl at Haltenbanken Area B. Table 2.17 shows monthly and annual extreme 1-minute average wind speed 10 m amsl.

Table 2.16: Omni-directional and adjusted directional extreme values for 1-minute average wind speed 10 m above sea level, Area B. The direction extremes are adjusted in agreement with NORSOK Standard N-003:2017 [1, Section 6.1.4].

Direction	Return period [years]					
	1	10	50	100	1 000	10 000
-	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]
0°	32.2	37.0	40.2	41.5	45.7	49.7
30°	28.5	32.3	34.8	35.8	39.0	42.0
60°	26.4	29.6	31.7	32.5	35.2	37.7
90°	26.5	30.1	32.3	33.3	36.3	39.0
120°	28.4	32.7	35.5	36.6	40.2	43.7
150°	26.7	30.3	32.6	33.5	36.5	39.3
180°	33.4	38.0	41.0	42.2	46.1	49.7
210°	37.5	42.6	45.9	47.3	51.7	55.1
240°	37.5	42.6	45.9	47.3	51.3	54.9
270°	37.3	42.3	45.5	46.8	51.0	54.9
300°	33.7	38.4	41.3	42.6	46.5	50.1
330°	32.9	37.5	40.4	41.6	45.5	49.2
0° - 360°	**37.5**	**42.6**	**45.9**	**47.3**	**51.7**	**55.8**

Table 2.17: Monthly and annual extreme values for 1-minute average wind speed 10 m above sea level, Area B.

Month	Return period [years]					
	1	10	50	100	1 000	10 000
-	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]
Jan	35.8	41.5	45.2	46.6	51.3	55.6
Feb	34.2	39.5	42.8	44.2	48.5	52.4
Mar	32.4	37.5	40.7	42.0	46.1	49.8
Apr	27.6	32.0	34.8	35.9	39.4	42.7
May	24.8	29.1	31.8	32.9	36.5	39.8
Jun	24.8	29.3	32.2	33.4	37.2	40.7
Jul	21.3	24.6	26.7	27.5	30.2	32.6
Aug	24.2	28.5	31.2	32.3	35.9	39.2
Sep	28.9	33.8	36.9	38.1	42.1	45.9
Oct	30.9	35.6	38.6	39.8	43.6	47.1
Nov	32.3	37.2	40.3	41.6	45.5	49.1
Dec	33.8	38.6	41.6	42.8	46.6	50.0
Year	**37.5**	**42.6**	**45.9**	**47.3**	**51.7**	**55.8**

2.1.3.4 Wind profile

Offshore wind profiles are described in Appendix 1.1.

Table 2.18 shows the omni-directional extreme values for 1-hour mean wind speed as function of height above mean sea level (amsl) at Haltenbanken Area B.

Table 2.18: Omni-directional extreme values for 1-hour mean wind speed as function of height above mean sea level at Haltenbanken Area B.

Height	Return period [years]					
amsl	1	10	50	100	1000	10 000
[m]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]
10	28.4	31.7	33.9	34.8	37.5	40.1
20	31.0	34.8	37.2	38.2	41.4	44.3
30	32.5	36.5	39.1	40.2	43.6	46.8
40	33.6	37.8	40.5	41.6	45.2	48.5
50	34.4	38.8	41.6	42.7	46.4	49.9
60	35.1	39.6	42.5	43.6	47.4	51.0
70	35.7	40.2	43.2	44.4	48.3	51.9
80	36.2	40.8	43.8	45.1	49.0	52.7
90	36.6	41.3	44.4	45.7	49.7	53.4
100	37.0	41.8	44.9	46.2	50.3	54.1
125	37.8	42.8	46.0	47.3	51.5	55.4
150	38.5	43.6	46.8	48.2	52.5	56.6
200	39.6	44.8	48.2	49.6	54.1	58.3

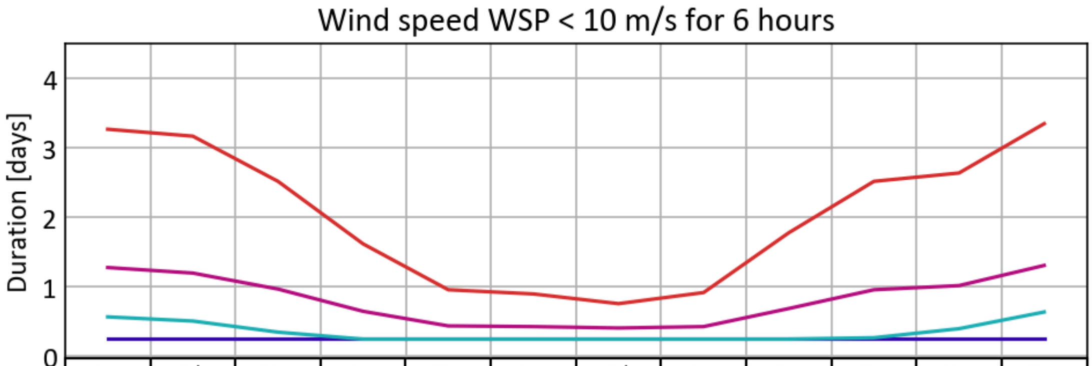
2.1.3.5 Operational wind data

Marine operations may be delayed due to wind speeds exceeding prescribed operational levels (limits) leading to a possible increase in the duration of the operations. Marine operations which must be completed without break are called critical. Otherwise they are termed non-critical.

The duration statistics presented in this report is restricted to critical operations, only.

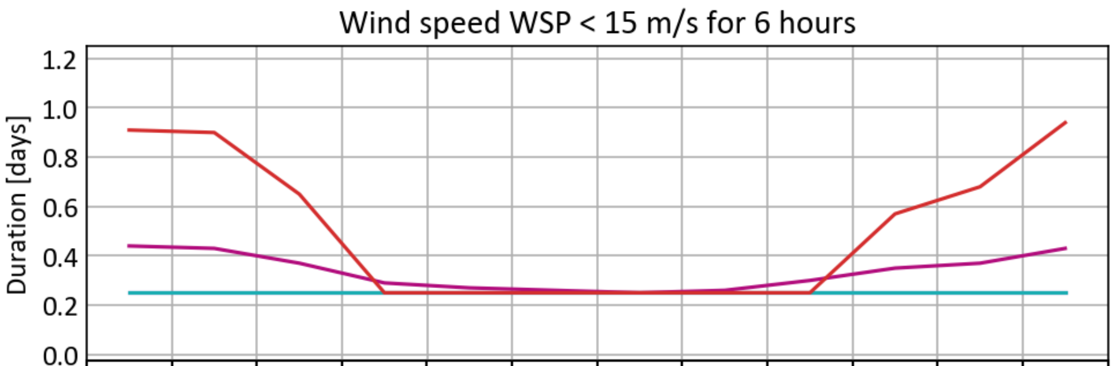
Figure 2.25 - Figure 2.36 show characteristic durations of operations limited by wind speeds of 10, 15 and 20 m/s for 6, 12, 24 and 48 hours. The figures show the expected mean duration and 10, 50 and 90 percentiles.

The figures show duration characteristics for completing a critical operation including waiting time. Duration is measured from the day the operation is ready for launching. The day of launching is assumed to be an arbitrary day within the relevant month.



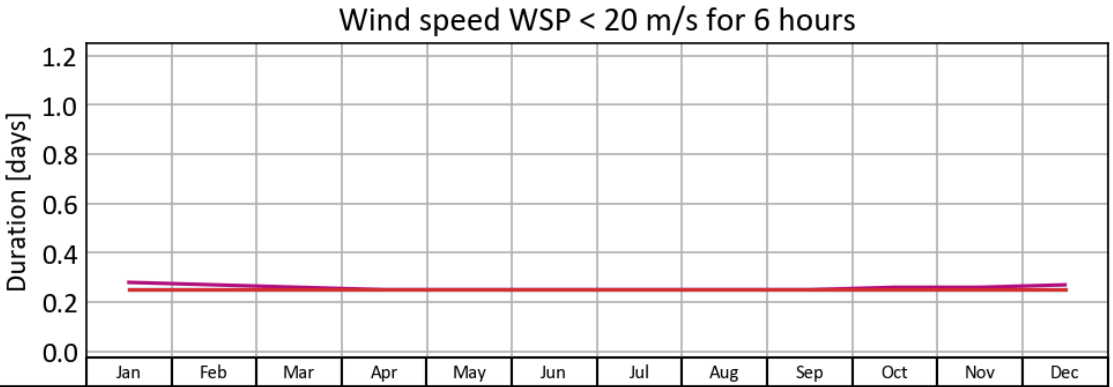
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
P50	0.57	0.51	0.35	0.25	0.25	0.25	0.25	0.25	0.25	0.27	0.40	0.64
Mean	1.28	1.20	0.97	0.65	0.44	0.43	0.41	0.43	0.69	0.96	1.02	1.31
P90	3.27	3.17	2.52	1.62	0.96	0.90	0.76	0.92	1.78	2.52	2.64	3.35

Figure 2.25: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 10 m/s for 6 hours.



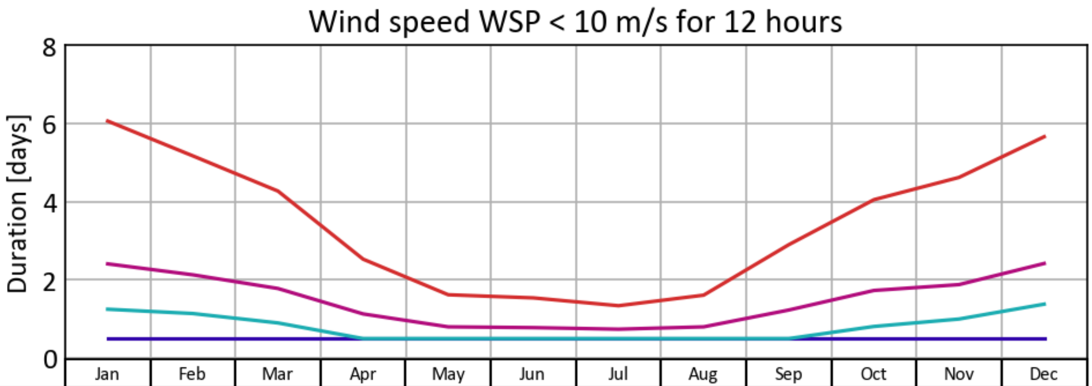
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
P50	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Mean	0.44	0.43	0.37	0.29	0.27	0.26	0.25	0.26	0.30	0.35	0.37	0.43
P90	0.91	0.90	0.65	0.25	0.25	0.25	0.25	0.25	0.25	0.57	0.68	0.94

Figure 2.26: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 15 m/s for 6 hours.



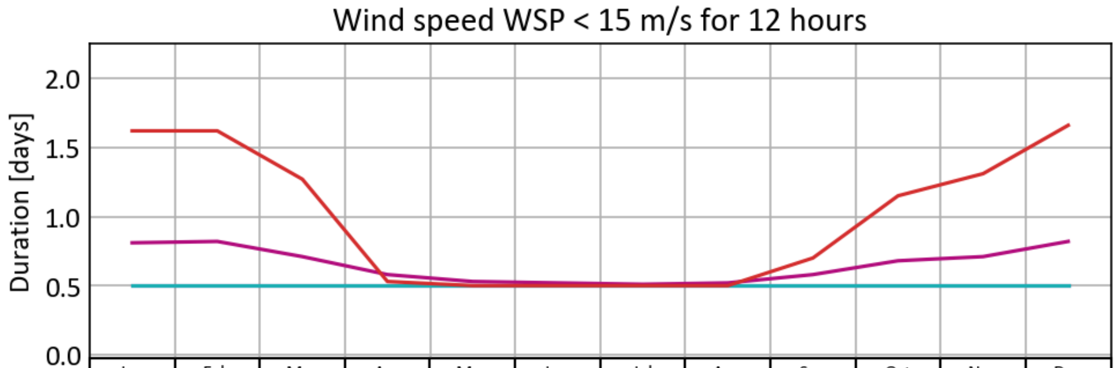
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
P50	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Mean	0.28	0.27	0.26	0.25	0.25	0.25	0.25	0.25	0.25	0.26	0.26	0.27
P90	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25

Figure 2.27: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 20 m/s for 6 hours.



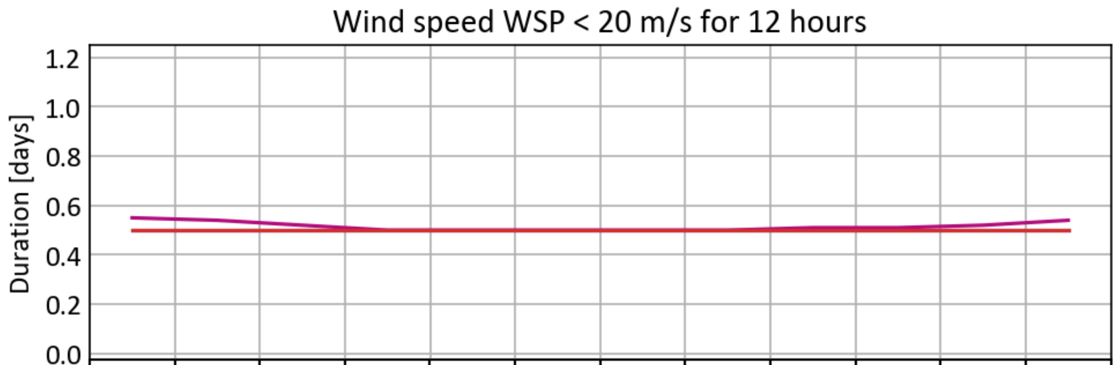
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
P50	1.25	1.14	0.90	0.50	0.50	0.50	0.50	0.50	0.50	0.81	1.00	1.38
Mean	2.41	2.13	1.78	1.13	0.80	0.78	0.74	0.80	1.23	1.73	1.88	2.42
P90	6.06	5.17	4.27	2.53	1.62	1.54	1.34	1.61	2.90	4.05	4.62	5.66

Figure 2.28: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 10 m/s for 12 hours.



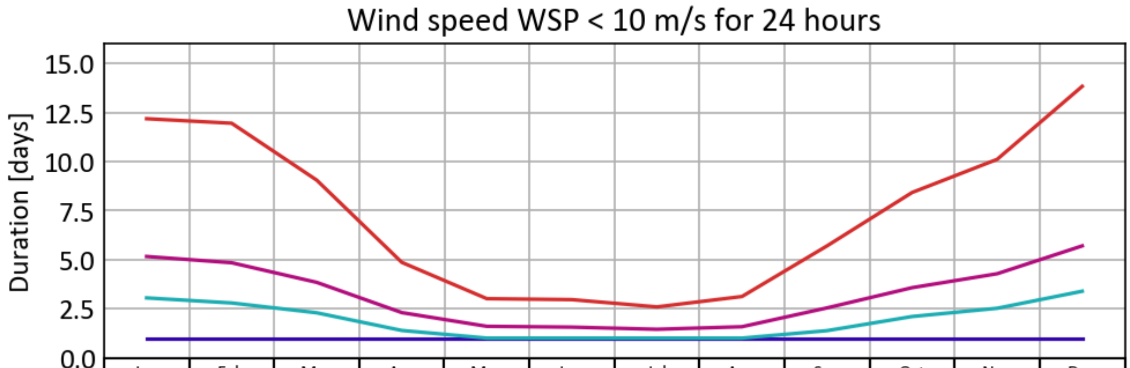
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
P50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Mean	0.81	0.82	0.71	0.58	0.53	0.52	0.51	0.52	0.58	0.68	0.71	0.82
P90	1.62	1.62	1.27	0.53	0.50	0.50	0.50	0.50	0.70	1.15	1.31	1.66

Figure 2.29: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 15 m/s for 12 hours.



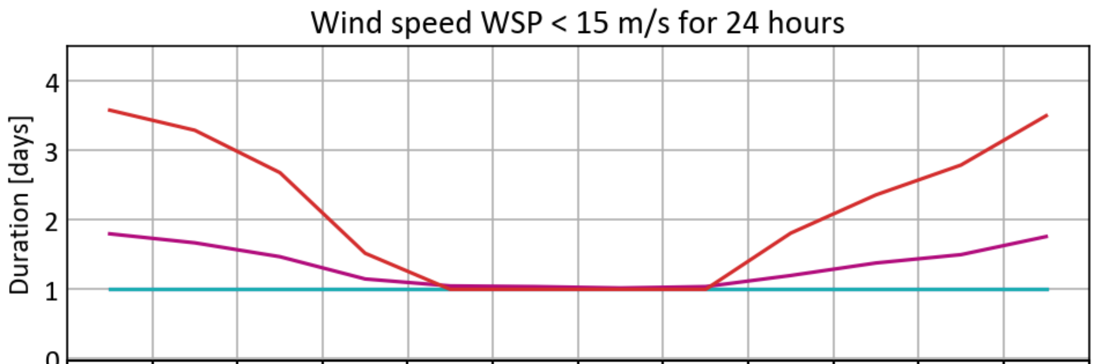
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
P50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Mean	0.55	0.54	0.52	0.50	0.50	0.50	0.50	0.50	0.51	0.51	0.52	0.54
P90	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50

Figure 2.30: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 20 m/s for 12 hours.



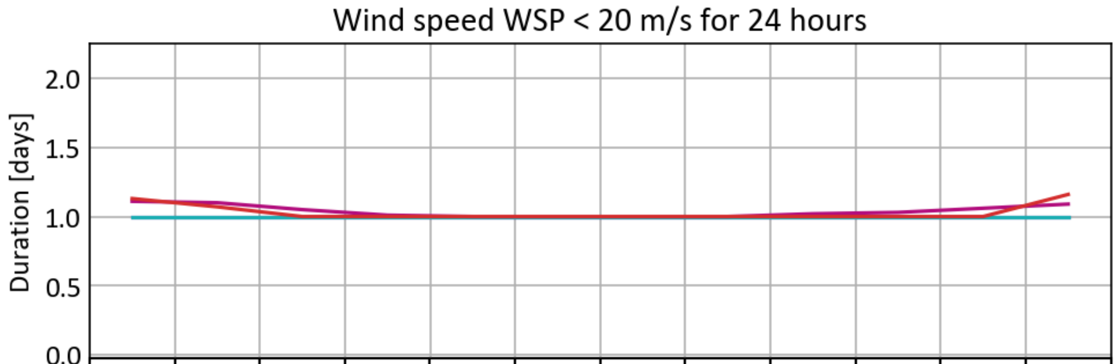
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P50	3.05	2.79	2.29	1.39	1.00	1.00	1.00	1.00	1.38	2.10	2.52	3.39
Mean	5.16	4.84	3.84	2.30	1.60	1.56	1.45	1.58	2.54	3.57	4.28	5.70
P90	12.18	11.95	9.05	4.86	3.01	2.96	2.59	3.12	5.70	8.42	10.11	13.83

Figure 2.31: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 10 m/s for 24 hours.



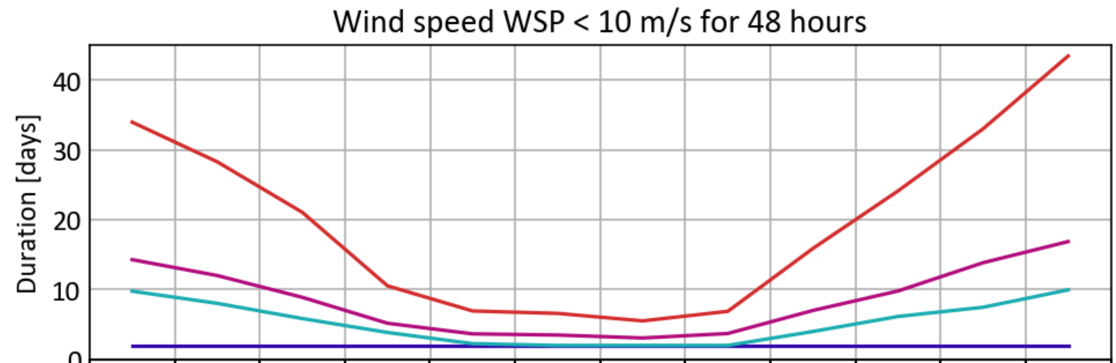
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Mean	1.80	1.67	1.47	1.15	1.05	1.04	1.02	1.04	1.20	1.38	1.50	1.76
P90	3.58	3.29	2.68	1.52	1.00	1.00	1.00	1.00	1.81	2.36	2.79	3.50

Figure 2.32: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 15 m/s for 24 hours.



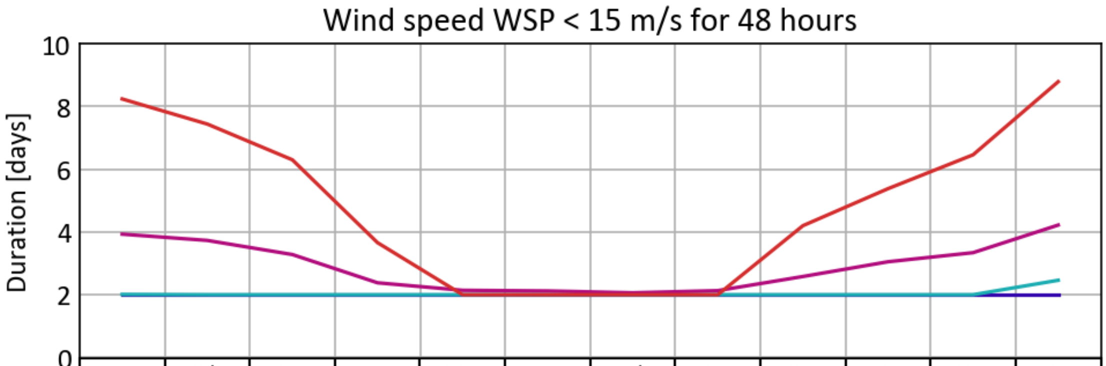
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Mean	1.11	1.10	1.05	1.01	1.00	1.00	1.00	1.00	1.02	1.03	1.06	1.09
P90	1.13	1.07	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.16

Figure 2.33: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 20 m/s for 24 hours.



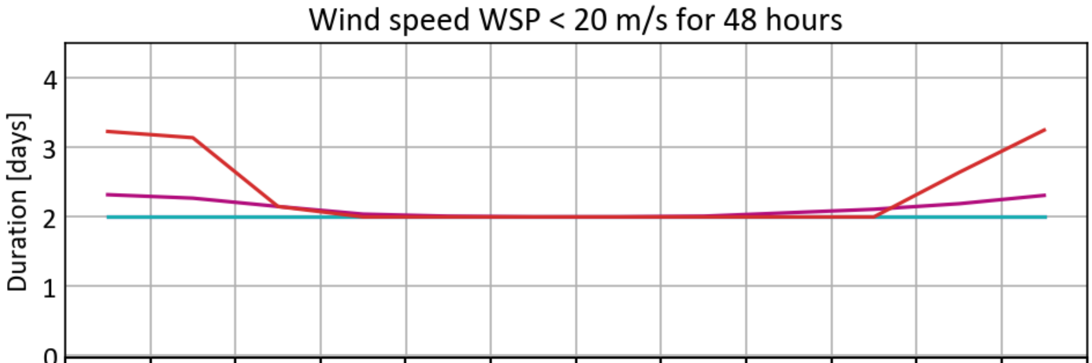
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
P50	9.77	8.03	5.85	3.86	2.26	2.00	2.00	2.00	4.00	6.15	7.47	9.96
Mean	14.29	12.01	8.89	5.18	3.66	3.49	3.07	3.71	7.01	9.80	13.85	16.88
P90	33.98	28.30	21.06	10.54	6.94	6.59	5.52	6.89	15.89	24.13	33.03	43.46

Figure 2.34: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 10 m/s for 48 hours.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
P50	2.01	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.46
Mean	3.93	3.73	3.28	2.38	2.14	2.12	2.06	2.13	2.58	3.05	3.34	4.22
P90	8.24	7.44	6.30	3.66	2.00	2.00	2.00	2.00	4.20	5.38	6.46	8.79

Figure 2.35: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 15 m/s for 48 hours.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
P50	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Mean	2.32	2.27	2.15	2.04	2.01	2.00	2.00	2.01	2.06	2.11	2.19	2.31
P90	3.23	3.14	2.15	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.64	3.25

Figure 2.36: Characteristic durations, including waiting time, to perform operations limited by a wind speed of 20 m/s for 48 hours.

2.1.4 Wind spectra

Wind spectra are described in Chapter 1.3

2.2 Air temperature

Information on air temperature is obtained from measurements 55 m above sea level at Draugen at 64.35° N, 7.78° E during the period 2001 – 2018.

Figure 2.37 shows the monthly minimum, mean, P99 and maximum air temperatures measured at the Draugen field during the period 2001– 2018.

Table 2.19 shows monthly and annual frequency of non-exceedance of air temperature at the Draugen Field.

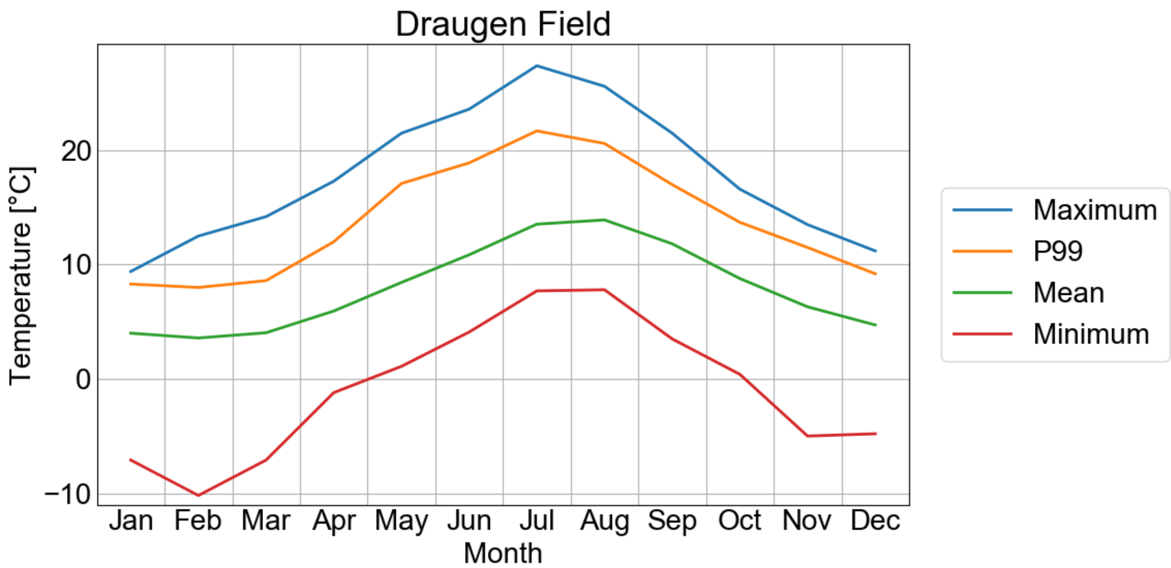


Figure 2.37: Monthly minimum, mean, P99 and maximum air temperature measured at Draugen during the period 2001 – 2018.

Table 2.19: Monthly and annual sample frequency of non-exceedance [%] of air temperature at Draugen during the period 2001 – 2018.

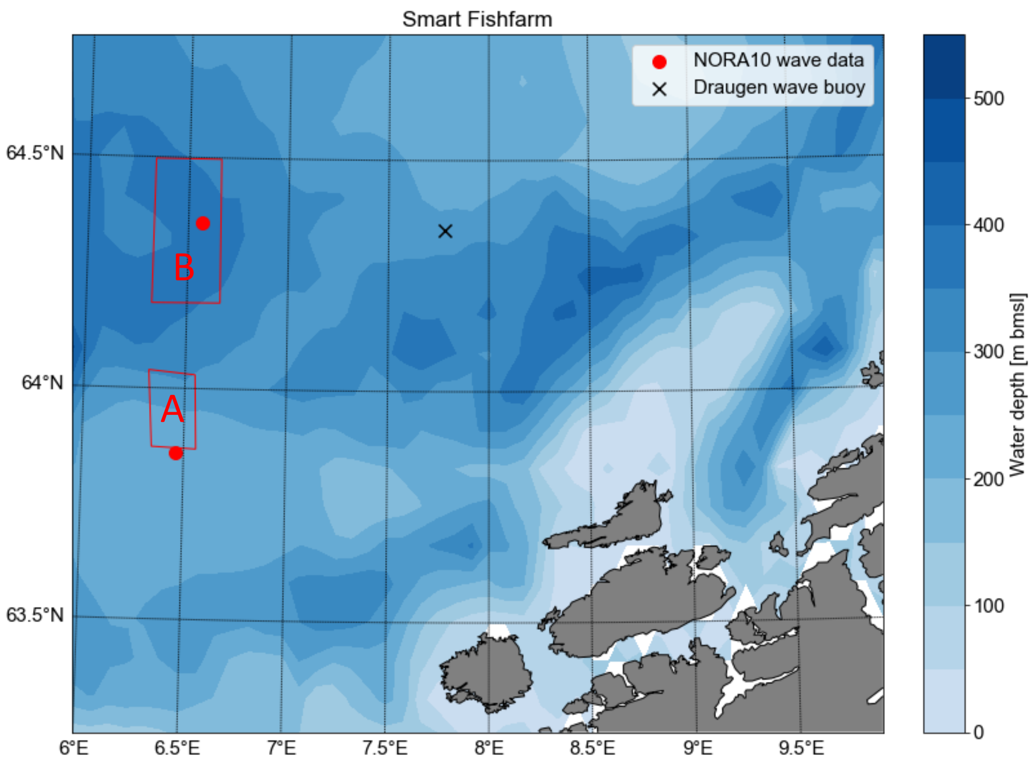
Air temp.	Month												Year
[°C]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	
< -10		0.05											
< -9		0.38											0.03
< -8		0.60											0.05
< -7	0.03	1.02	0.02										0.08
< -6	0.08	1.37	0.10										0.12
< -5	0.13	1.90	0.17										0.17
< -4	0.55	2.53	0.32								0.34	0.62	0.35
< -3	1.43	3.71	0.66								0.59	1.46	0.63
< -2	2.76	4.70	1.67								0.91	2.15	0.99
< -1	4.19	6.21	3.90	0.05							1.30	3.61	1.57
< 0	7.05	9.51	6.69	0.34							2.40	6.16	2.63
< 1	11.39	15.58	12.19	1.64						0.09	3.75	9.65	4.44
< 2	19.51	25.25	21.26	3.99	0.07					0.32	6.38	14.83	7.50
< 3	30.62	36.22	31.90	8.74	0.75					1.32	11.09	23.58	11.84
< 4	44.80	48.04	44.68	17.62	2.77				0.02	3.38	17.69	34.11	17.55
< 5	60.90	61.53	58.14	29.64	6.19	0.13			0.07	6.95	27.56	47.67	24.66
< 6	74.79	77.60	73.44	48.07	14.55	0.46			0.32	12.07	40.76	62.88	33.49
< 7	88.16	92.00	88.97	70.34	28.94	2.46			1.22	21.50	54.92	77.27	43.56
< 8	97.47	98.96	97.74	86.12	48.38	9.10	0.02	0.02	3.20	32.83	69.67	90.63	52.64
< 9	99.85	99.86	99.34	92.54	66.37	21.81	0.29	0.22	9.71	48.47	84.15	98.19	59.94
< 10	100.00	99.92	99.73	95.86	77.69	40.42	2.31	1.45	20.21	67.70	93.99	99.86	66.52
< 11		99.95	99.88	97.92	85.13	58.74	11.92	5.74	33.37	82.72	98.26	99.98	72.76
< 12		99.97	99.95	98.92	89.90	72.86	31.49	17.11	51.90	92.98	99.48	100.00	79.54
< 13		100.00	99.98	99.49	92.71	82.75	49.74	36.39	69.88	97.34	99.90		85.68
< 14			99.98	99.78	94.64	89.08	65.26	57.10	85.15	99.24	100.00		90.85
< 15			100.00	99.90	96.81	92.64	76.66	73.21	93.05	99.81			94.34
< 16				99.95	98.00	95.26	83.37	83.49	97.29	99.93			96.43
< 17				99.95	98.83	97.18	88.75	90.72	98.98	100.00			97.86
< 18				100.00	99.55	98.39	92.55	94.79	99.75				98.75
< 19					99.70	99.00	95.58	97.41	99.90				99.29
< 20					99.88	99.46	97.24	98.50	99.93				99.58
< 21					99.98	99.69	98.49	99.30	99.98				99.78
< 22					100.00	99.87	99.09	99.63	100.00				99.88
< 23						99.95	99.50	99.90					99.94
< 24						100.00	99.78	99.95					99.98
< 25							99.90	99.95					99.99
< 26							99.95	100.00					100.00
< 27							99.98						100.00
< 28							100.00						100.00
Total	**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**
Minimum	-7.10	-10.20	-7.10	-1.20	1.10	4.10	7.70	7.80	3.50	0.40	-5.00	-4.80	-10.20
Mean	4.00	3.58	4.04	5.94	8.44	10.86	13.54	13.91	11.82	8.78	6.31	4.72	8.02
Maximum	9.40	12.50	14.20	17.30	21.50	23.60	27.40	25.60	21.50	16.60	13.50	11.20	27.40

3 Oceanograpic data

3.1 Waves

3.1.1 Wave Data

Wave data are available from the NORA10 hindcast model operated by the Norwegian Meteorological Institute [5]. The model grid spatial resolution is approximately 10 km x 10 km. The wave parameters are; significant wave height Hs [m], peak wave period Tp [s], and mean wave direction Mdir [°] for the NORA10 grid positions closest to the locations (Figure 3.1). The NORA10 data covers the period 1958 to 2019 (61 years) with a sample interval of 3 hours. The significant wave height represents the 1-hour sea state.



Location	Position	Water depth [m] bmsl
NORA10 Haltenbanken A	63.86 °N, 6.46 °E	221
NORA10 Haltenbanken B	64.36 °N, 6.57 °E	334
Draugen buoy [4]	64.35° N 7.78° E	260

Figure 3.1: Map showing the fishfarm area (red polygon) and physical position (●) under consideration for MariCulture's Smart Fishfarm concept at Haltenbanken. The NORA10 wave hindcast coordinates and the Draugen Platform wave buoy is mapped. The bathymetry [3] in the area is given as water depth [m] below mean sea level.

NORA10 spectral peak periods are represented by discrete frequencies, f_i, given by:

$$f_i = 0.042 \cdot (1.1)^{i-1} s^{-1} \quad \text{for} \quad i = 1, \ldots, 25 \tag{3.1}$$

I.e. there are no spectral peak periods in the intervals $[15, 15.9\rangle$, $[17, 17.9\rangle$ and $[20, 20.9\rangle$. The spectral peak periods are thus adjusted (non-discretized) prior to analysis. The adjustment is performed by recalculating the spectral peak frequencies with i' for i:

$$i' = i - 0.5 + x \tag{3.2}$$

in the preceding formula for f_i. The number x is drawn randomly from the uniform distribution on the interval [0, 1].

The NORA10 wave height data are found to be conservative, i.e. Hs is generally overpredicted during storm events [9, 11, 12, 18, 21]. NORA10 hindcast wave data have been compared with wave measurements in the vicinity (Draugen field) and a calibration factor recommended based on regression analysis [21]. Significant wave height and peak period are intrinsically correlated and calibration of wave height implies calibration of wave period accordingly [1]. Wave data are subjected to the following calibration:

- $H_S = H_S^{NORA10\ orig.} - \left(H_S^{NORA10\ orig.} - 6\ m \right) \cdot 0.14$ for $H_S > 6$ m
- $H_S = H_S^{NORA10\ orig.}$ for $H_S < 6$ m
- $T_P = T_P^{NORA10\ orig.} - (T_P^{NORA10\ orig.} - 10\ s) \cdot 0.05$ for $T_p > 10$ s
- $T_P = T_P^{NORA10\ orig.}$ for $T_p < 10$ s

where $H_S^{NORA10\ orig.}$ and $T_P^{NORA10\ orig.}$ refers to H_S and T_p of the original unadjusted NORA10 data.

3.1.2 Wave analysis, Haltenbanken Area A

3.1.2.1 Wave data statistics

Figure 3.2 shows the all-year wave rose, i.e. the sample direction distribution of significant wave height, at the Haltenbanken Area A.

Table 3.1 shows the direction sample distribution of non-exceedance of significant wave height.

Figure 3.3 shows the directional scatter density and mean, P99 and maximum of significant wave height.

Table 3.2 shows the monthly sample distribution of non-exceedance of significant wave height.

Figure 3.4 shows the monthly scatter density and mean, P99 and maximum of significant wave height.

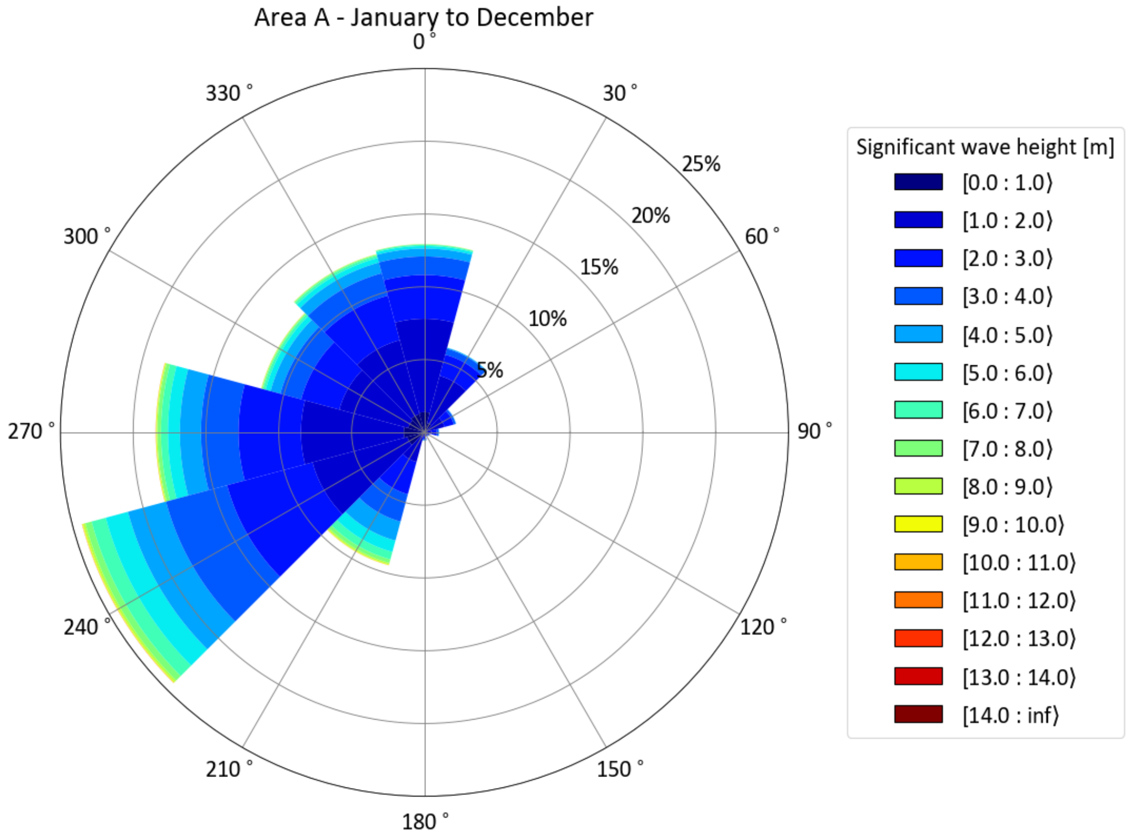


Figure 3.2: All year wave rose of significant wave height [m] for the Haltenbanken Area A.

Table 3.1: Directional sample distribution of non-exceedance [%] of significant wave height.

Hs [m]	Wave direction												Omni
	0°	**30°**	**60°**	**90°**	**120°**	**150°**	**180°**	**210°**	**240°**	**270°**	**300°**	**330°**	
< 0.5	0.02	0.01	0.01						0.04	0.05	0.02	0.02	**0.18**
< 1.0	1.28	0.60	0.19	0.07	0.03	0.02	0.04	0.26	1.11	1.31	1.06	1.19	**7.15**
< 1.5	4.49	2.23	0.69	0.25	0.11	0.08	0.15	0.94	3.91	4.78	3.57	3.92	**25.12**
< 2.0	7.32	3.72	1.34	0.49	0.18	0.15	0.25	2.00	7.42	7.96	5.70	6.20	**42.73**
< 2.5	9.12	4.64	1.79	0.71	0.27	0.21	0.35	3.11	10.65	10.41	7.29	8.04	**56.60**
< 3.0	10.33	5.18	2.02	0.87	0.33	0.27	0.44	4.25	13.42	12.31	8.47	9.47	**67.36**
< 3.5	11.13	5.47	2.13	0.98	0.37	0.29	0.50	5.32	15.89	13.84	9.42	10.53	**75.86**
< 4.0	11.69	5.59	2.18	1.02	0.38	0.30	0.54	6.27	17.91	15.06	10.08	11.22	**82.24**
< 4.5	12.06	5.64	2.21	1.04	0.39	0.31	0.57	7.07	19.53	15.98	10.56	11.77	**87.11**
< 5.0	12.29	5.66	2.21	1.04	0.40	0.31	0.57	7.70	20.82	16.67	10.86	12.07	**90.61**
< 5.5	12.41	5.67	2.21	1.05	0.40	0.31	0.58	8.20	21.81	17.20	11.10	12.30	**93.24**
< 6.0	12.48	5.67		1.05	0.40		0.58	8.60	22.55	17.60	11.26	12.45	**95.17**
< 6.5	12.55	5.67		1.05			0.58	8.96	23.22	17.91	11.38	12.57	**96.80**
< 7.0	12.58							9.21	23.68	18.13	11.46	12.64	**97.93**
< 7.5	12.61							9.39	24.01	18.28	11.52	12.69	**98.73**
< 8.0	12.62							9.51	24.19	18.39	11.55	12.73	**99.22**
< 8.5	12.62							9.57	24.32	18.45	11.57	12.75	**99.52**
< 9.0	12.63							9.62	24.38	18.49	11.59	12.76	**99.70**
< 9.5	12.63							9.65	24.44	18.53	11.60	12.77	**99.84**
< 10.0	12.63							9.67	24.46	18.54	11.60	12.77	**99.90**
< 10.5	12.63							9.68	24.48	18.55	11.61	12.78	**99.95**
< 11.0	12.63							9.69	24.49	18.56	11.61		**99.97**
< 11.5								9.69	24.49	18.56	11.61		**99.98**
< 12.0								9.69	24.50	18.56	11.61		**99.99**
< 12.5								9.69	24.50	18.56			**99.99**
< 13.0									24.50	18.56			**100.00**
< 13.5									24.50				**100.00**
< 14.0									24.50				**100.00**
< 14.5									24.50				**100.00**
< 15.0									24.50				**100.00**
Sum	**12.63**	**5.67**	**2.21**	**1.05**	**0.40**	**0.31**	**0.58**	**9.69**	**24.50**	**18.56**	**11.61**	**12.78**	**100.00**
Mean	2.1	1.8	1.9	2.1	2.1	2.1	2.3	3.5	3.1	2.7	2.4	2.3	2.6
P99	6.2	4.1	4.0	4.3	4.4	4.3	5.1	8.7	8.2	8.0	7.3	7.0	7.8
Maximum	10.7	6.3	5.4	6.0	5.6	5.4	6.1	12.4	14.5	12.7	11.8	10.4	14.5

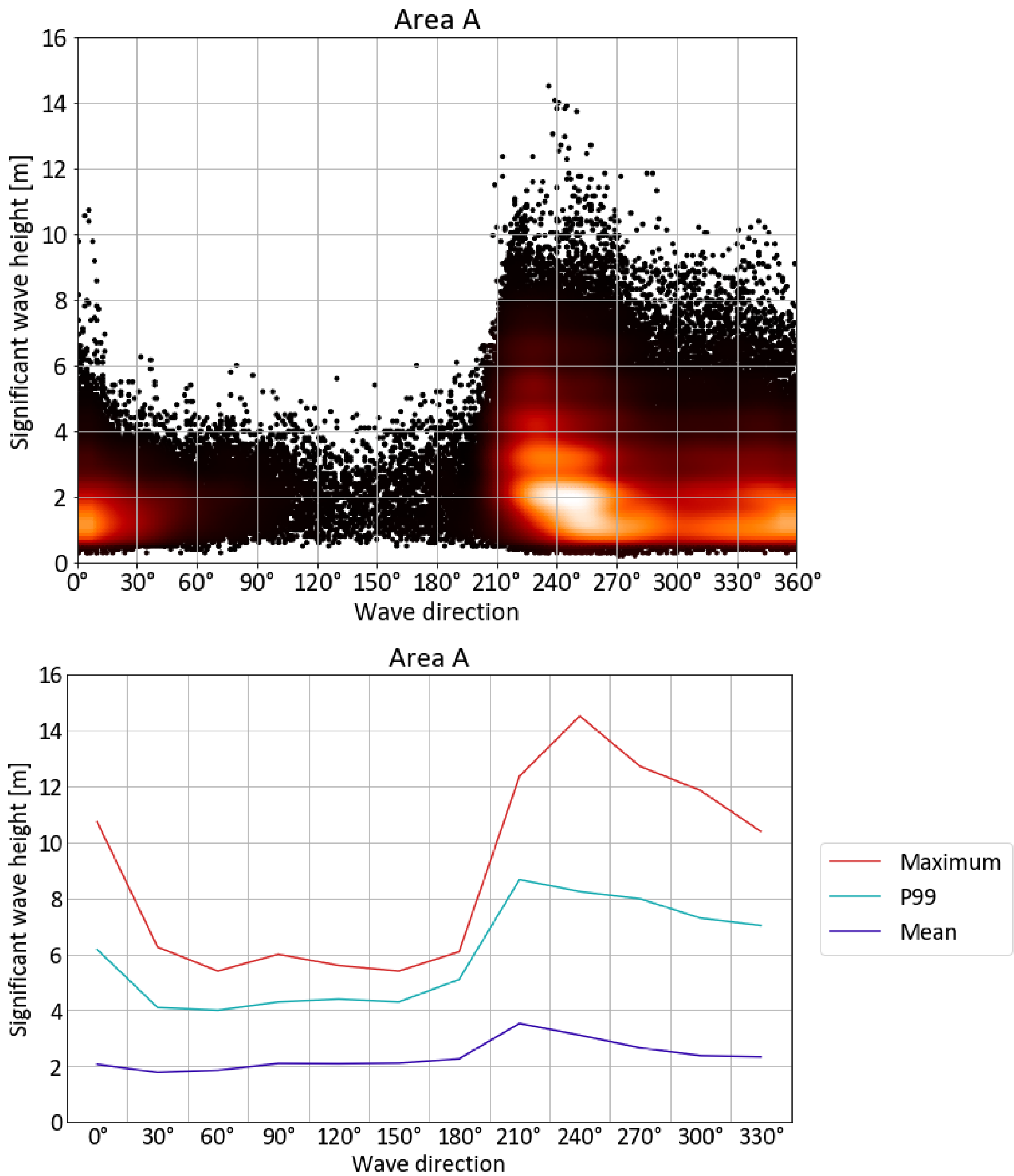


Figure 3.3: Directional scatter density plot (top) and mean, P99 and maximum (bottom) of significant wave height.

Table 3.2: Monthly and annual sample distribution of non-exceedance [%] of significant wave height.

Hs [m]	Month												Year
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
< 0.5			0.09	0.01	0.67	0.13	0.56	0.46	0.10	0.06	0.05		**0.18**
< 1.0	0.44	1.09	1.93	5.02	12.60	13.87	19.76	17.75	7.49	2.93	1.96	0.40	**7.15**
< 1.5	4.67	6.00	9.58	22.60	42.12	49.01	58.33	52.44	27.03	14.65	9.63	3.91	**25.12**
< 2.0	14.26	16.95	23.02	44.28	67.21	74.26	79.83	74.87	47.84	31.79	23.84	12.95	**42.73**
< 2.5	26.75	30.38	37.88	61.76	82.21	87.17	89.67	87.00	63.77	46.85	38.49	25.77	**56.60**
< 3.0	39.54	43.57	51.86	74.40	90.00	93.07	95.02	92.53	75.19	60.28	52.49	39.04	**67.36**
< 3.5	52.65	56.02	62.92	83.09	94.00	96.05	97.75	95.93	83.17	71.46	64.19	52.05	**75.86**
< 4.0	63.33	65.75	72.53	88.68	96.27	97.49	98.92	97.85	88.82	79.78	73.84	62.85	**82.24**
< 4.5	72.36	73.82	79.81	92.47	97.77	98.51	99.41	98.89	92.25	86.14	81.38	71.83	**87.11**
< 5.0	78.69	80.18	85.10	95.13	98.66	99.19	99.78	99.42	94.68	90.51	86.53	78.93	**90.61**
< 5.5	83.75	85.31	89.26	96.97	99.28	99.62	99.91	99.70	96.48	93.38	90.40	84.45	**93.24**
< 6.0	87.63	89.03	92.81	98.15	99.60	99.77	99.97	99.87	97.73	95.52	93.19	88.46	**95.17**
< 6.5	91.35	92.37	95.56	99.08	99.81	99.87	100.00	99.95	98.63	97.03	95.65	92.11	**96.80**
< 7.0	93.91	95.01	97.27	99.53	99.93	99.92		99.97	99.28	98.27	97.22	94.74	**97.93**
< 7.5	95.97	96.90	98.33	99.73	99.99	99.95		99.98	99.53	99.06	98.46	96.73	**98.73**
< 8.0	97.33	98.10	99.07	99.85	100.00	99.95		99.99	99.79	99.50	99.14	97.86	**99.22**
< 8.5	98.24	98.88	99.49	99.93		99.99		100.00	99.89	99.71	99.49	98.61	**99.52**
< 9.0	98.85	99.35	99.71	99.95		100.00			99.95	99.81	99.67	99.07	**99.70**
< 9.5	99.29	99.77	99.85	99.99					99.97	99.89	99.84	99.50	**99.84**
< 10.0	99.53	99.85	99.93	99.99					100.00	99.94	99.86	99.72	**99.90**
< 10.5	99.74	99.93	99.98	100.00						99.98	99.92	99.90	**99.95**
< 11.0	99.87	99.93	100.00							99.99	99.94	99.93	**99.97**
< 11.5	99.93	99.96								99.99	99.95	99.96	**99.98**
< 12.0	99.96	99.98								100.00	99.97	99.97	**99.99**
< 12.5	99.97	99.99									99.97	99.98	**99.99**
< 13.0	99.99	99.99									99.99	99.98	**100.00**
< 13.5	99.99	100.00									99.99	99.98	**100.00**
< 14.0	99.99										100.00	99.99	**100.00**
< 14.5	99.99											100.00	**100.00**
< 15.0	100.00												**100.00**
Total	**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**
Mean	3.7	3.6	3.2	2.4	1.8	1.7	1.5	1.6	2.3	2.9	3.2	3.7	2.6
P99	9.1	8.7	8.0	6.3	5.2	4.8	4.0	4.5	6.7	7.5	7.9	8.8	7.8
Maximum	14.5	13.1	10.9	10.3	7.6	8.8	6.3	8.4	9.9	11.5	13.9	14.1	14.5

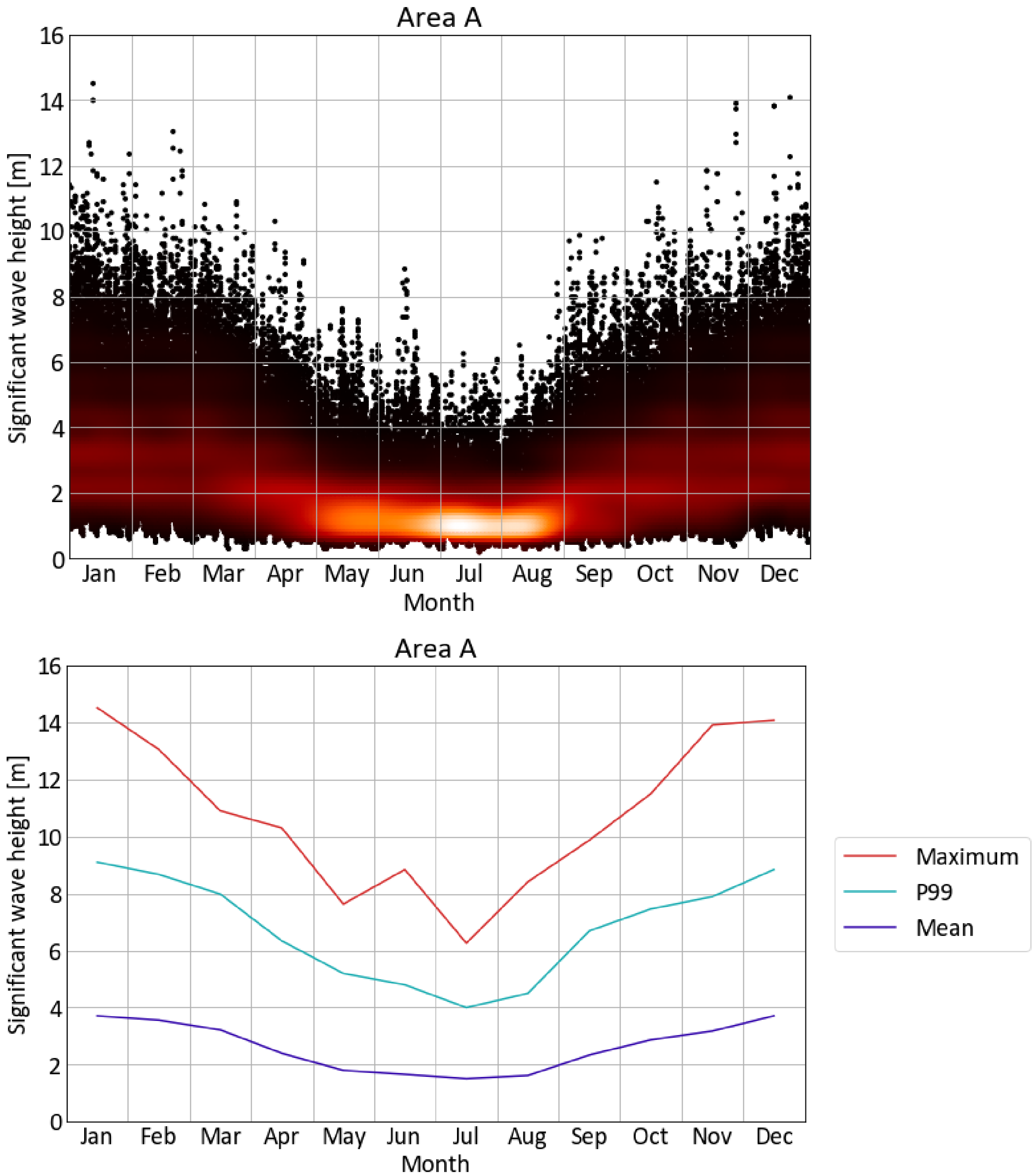


Figure 3.4: Monthly scatter density plot (top) and mean, P99 and maximum (bottom) of significant wave height.

3.1.2.2 Long-term wave statistics

The long-term distribution of significant wave height is modelled in terms of a 3-parameter Weibull distribution as described in Chapter 3.6.1. Figure 3.5 shows the hindcast and fitted distributions of significant wave height at the Haltenbanken Area A.

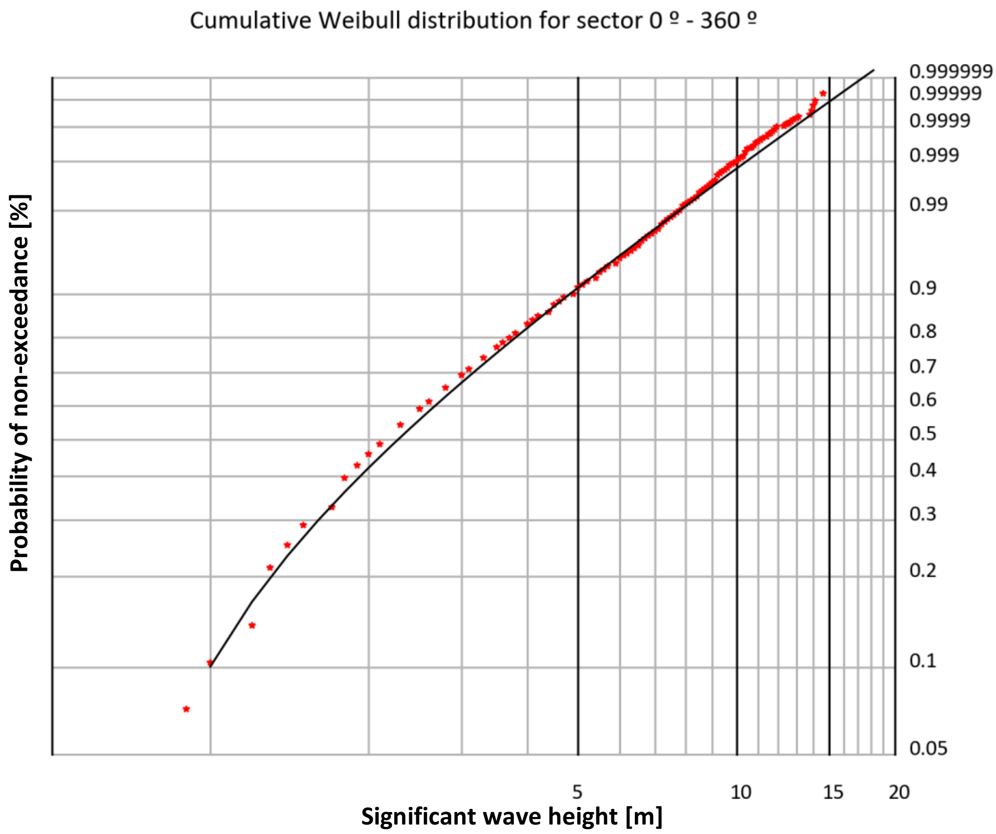


Figure 3.5: Hindcast (red dots) and fitted (black line) distributions of significant wave height at the Haltenbanken Area A.

Figure 3.6 and Table 3.3 show directional Weibull parameters and corresponding extremes of significant wave height at the Haltenbanken Area A. The direction extremes are adjusted in agreement with NORSOK Standard N-003:2017 [1, Section 6.1.4].

Figure 3.7 and Table 3.4 shows the monthly and annual Weibull parameters and corresponding extremes.

Table 3.3: Weibull parameters and corresponding directional extremes for significant wave height. The direction extremes are adjusted in agreement with NORSOK Standard N-003:2017 [1, Section 6.1.4]. Duration of event is 3 hours.

Direction	Sector prob.	Weibull parameters			Return period [years]					
		Shape	Scale	Location	1	10	50	100	1 000	10 000
-	[%]	-	[m]	[m]	[m]	[m]	[m]	[m]	[m]	[m]
0°	12.63	1.118	1.382	0.73	9.3	11.6	13.1	13.8	15.9	18.1
30°	5.67	1.461	1.285	0.61	5.4	6.5	7.2	7.5	8.4	9.2
60°	2.21	1.670	1.401	0.60	4.7	5.6	6.1	6.4	7.1	7.7
90°	1.05	2.020	1.848	0.45	4.6	5.5	6.0	6.2	6.8	7.4
120°	0.40	2.037	1.917	0.39	4.3	5.2	5.8	6.0	6.6	7.3
150°	0.31	2.074	1.935	0.38	4.2	5.1	5.6	5.8	6.5	7.1
180°	0.58	1.986	2.232	0.27	5.1	6.2	6.8	7.1	7.9	8.7
210°	9.69	1.760	3.428	0.46	11.2	13.0	14.1	14.6	16.0	17.4
240°	24.50	1.450	2.885	0.49	11.6	13.9	15.5	16.2	18.4	20.5
270°	18.56	1.290	2.281	0.54	11.6	13.9	15.5	16.2	18.4	20.5
300°	11.61	1.215	1.859	0.62	10.5	12.9	14.5	15.2	17.4	19.6
330°	12.78	1.241	1.822	0.63	10.1	12.3	13.8	14.4	16.5	18.4
0° - 360°	**100.00**	**1.290**	**2.192**	**0.58**	**11.6**	**13.9**	**15.5**	**16.2**	**18.4**	**20.5**

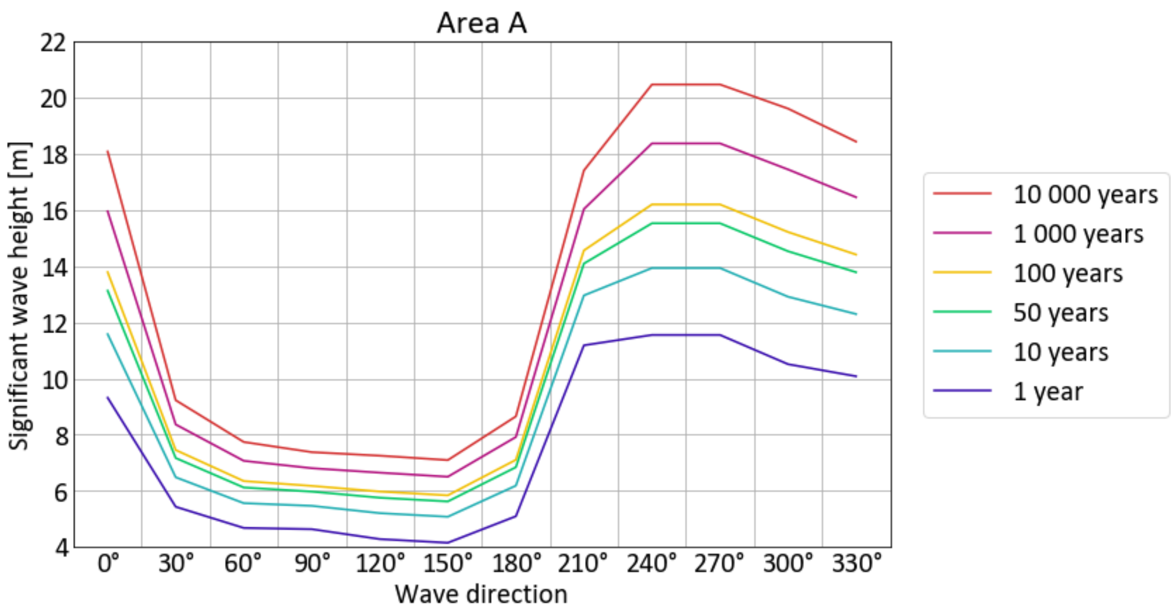


Figure 3.6: Directional extreme values of significant wave height with return period of 1, 10, 50, 100, 1000 and 10 000 years. The direction extremes are adjusted in agreement with NORSOK Standard N-003:2017 [1, Section 6.1.4].

Table 3.4: Monthly and annual Weibull parameters and corresponding extremes for significant wave height. Duration of event is 3 hours.

Month	Annual prob.	Weibull parameters			Return period [years]					
		Shape	Scale	Location	1	10	50	100	1 000	10 000
-	[%]	-	[m]	[m]	[m]	[m]	[m]	[m]	[m]	[m]
Jan	8.33	1.490	2.949	1.04	10.3	12.7	14.3	15.0	17.0	19.0
Feb	8.33	1.580	3.049	0.82	9.8	12.0	13.4	14.0	15.8	17.5
Mar	8.33	1.610	2.773	0.72	8.7	10.7	11.9	12.4	14.0	15.4
Apr	8.33	1.300	1.733	0.78	7.2	9.2	10.5	11.0	12.8	14.5
May	8.33	1.080	1.073	0.76	6.0	7.9	9.3	9.9	11.8	13.7
Jun	8.33	0.950	0.805	0.84	5.7	7.8	9.4	10.0	12.2	14.5
Jul	8.33	1.138	0.856	0.68	4.5	5.9	6.8	7.2	8.5	9.8
Aug	8.33	1.060	0.940	0.70	5.4	7.2	8.5	9.0	10.8	12.6
Sep	8.33	1.250	1.733	0.71	7.5	9.7	11.1	11.7	13.7	15.6
Oct	8.33	1.425	2.310	0.76	8.4	10.5	11.9	12.5	14.3	16.0
Nov	8.33	1.340	2.541	0.86	9.9	12.6	14.4	15.1	17.5	19.8
Dec	8.33	1.499	2.953	1.05	10.2	12.7	14.2	14.9	16.9	18.8
Year	**100.00**	**1.290**	**2.192**	**0.58**	**11.6**	**13.9**	**15.5**	**16.2**	**18.4**	**20.5**

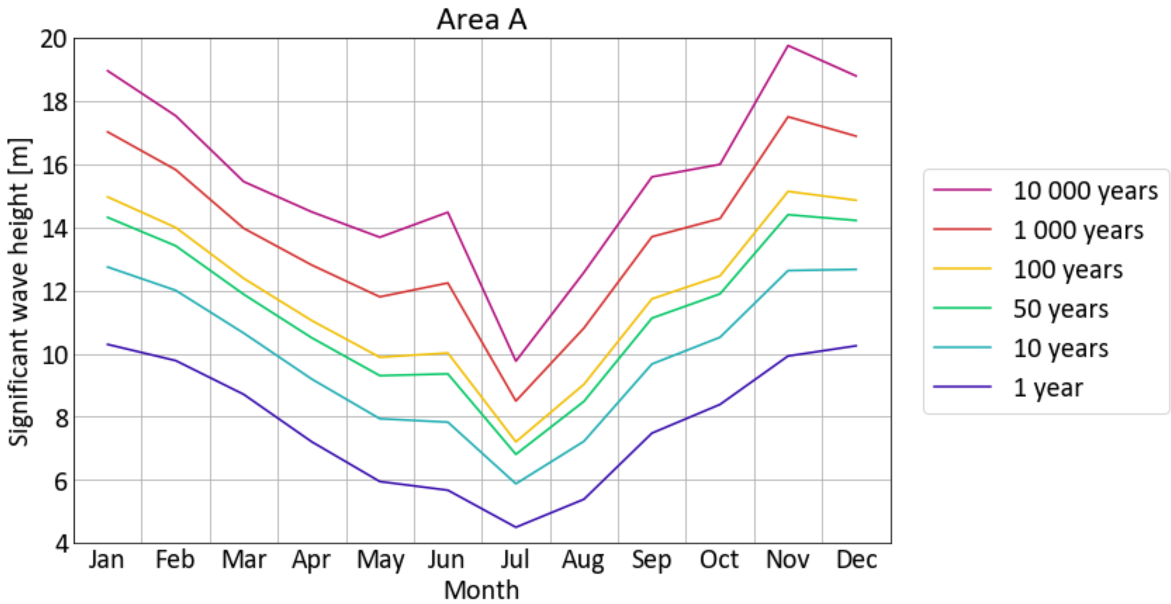


Figure 3.7: Monthly extreme values of significant wave height with return period of 1, 10, 50, 100, 1000 and 10 000 years.

3.1.2.3 H_S-T_p relation

A short-term sea state is for most practical purposes reasonably well characterized by the significant wave height, H_s, and the spectral peak period, T_p.

Table 3.5 shows a scatter table of H_S and T_p for a period of 100 years. The scatter table is obtained from the 61-year NORA10 hindcast data, and table entries are consequently scaled by 100/61. No smoothing is performed.

The conditional distribution of spectral peak period (T_p) given significant wave height (H_S) is modelled by a log-normal distribution, as described in Chapter 2.2.

Table 3.6 shows the parameters in the log-normal distribution of T_p given H_S. Divergent solutions are returned when attempting log-normal distribution fit to data for sectors 150° and 180°, and these sectors are assigned the omni directional log-normal parameters.

Figure 3.8 and Figure 3.8 show spectral peak period as a function of significant wave height.

Table 3.8 shows omni-directional extreme significant wave heights and associated spectral peak periods.

Table 3.9 and Table 3.10 show directional and monthly extreme significant wave heights and associated spectral peak periods.

Figure 3.9 and Table 3.11 show q – probability contour lines of H_s – T_p for q = 0.63, 10^{-1}, $2\cdot10^{-2}$, 10^{-2}, 10^{-3} and 10^{-4}, corresponding to return periods of 1, 10, 50, 100, 1 000 and 10 000 years, for omni-directional waves.

Table 3.5: Scatter table of significant wave height (HS) and spectral peak period (Tp) at the Haltenbanken Area A for a period of 100 years. Duration of sea state is 3 hours.

H_S [m]	Spectral peak period (T_p) - [s]																					Sum
	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**	**18-19**	**19-20**	**20-21**	**21-22**	**22-23**	
0.0-0.5		7	52	64	51	93	123	70	44	10	7	3										**525**
0.5-1.0	3	272	1275	2664	3943	3689	3282	2384	1352	657	426	210	90	51	31	20	5	11				**20366**
1.0-1.5		75	1995	4252	6434	9541	10343	7843	5239	3156	1720	934	393	257	133	98	52	20	8	10		**52505**
1.5-2.0			539	3421	5123	6270	8949	8748	6775	4869	3336	1669	775	413	310	133	80	21	11	11	3	**51459**
2.0-2.5			51	948	3885	4705	5616	6497	6252	4752	3516	2289	1026	485	289	103	52	43	13	13		**40536**
2.5-3.0				159	1557	3605	4195	4469	5284	4595	3184	2156	1130	566	279	148	54	28	8	5		**31420**
3.0-3.5				13	470	2084	3436	3492	3969	3936	3036	1979	1252	610	362	108	59	26	7	7		**24846**
3.5-4.0					79	669	2513	3051	2954	2946	2516	1721	1111	546	334	136	56	15	3	5		**18656**
4.0-4.5					13	187	1315	2559	2526	2244	1957	1500	910	521	285	116	69	11		2		**14216**
4.5-5.0						34	526	1643	2141	1802	1438	1123	716	415	243	107	30	10	2			**10228**
5.0-5.5						7	138	923	1775	1634	1213	856	531	293	193	89	28	3				**7684**
5.5-6.0							25	449	1213	1364	1020	649	428	238	138	84	33	2				**5641**
6.0-6.5							16	157	723	1385	1108	582	387	207	125	54	23	3				**4770**
6.5-7.0							3	33	356	852	875	566	302	133	108	56	16	2				**3302**
7.0-7.5								5	128	477	690	559	230	116	56	49	10	2				**2321**
7.5-8.0								3	33	189	420	444	198	62	44	30	16					**1439**
8.0-8.5									7	61	216	266	182	66	43	30	15					**884**
8.5-9.0										30	75	179	123	46	38	20	3		2			**515**
9.0-9.5										11	64	131	118	36	28	18	13					**420**
9.5-10.0										5	18	54	48	21	16	8	10					**180**
10.0-10.5											8	31	49	26	28	7						**149**
10.5-11.0											3	7	13	15	10	5						**52**
11.0-11.5												3	7	8	11	3						**33**
11.5-12.0												2	3	8	7	3						**23**
12.0-12.5													2	2	2		2					**7**
12.5-13.0														2		5	2					**8**
13.0-13.5																2						**2**
13.5-14.0															3	3						**7**
14.0-14.5																2	2					**3**
14.5-15.0																	2					**2**
SUM	**3**	**354**	**3913**	**11521**	**21556**	**30884**	**40480**	**42325**	**40772**	**34975**	**26848**	**17911**	**10025**	**5143**	**3115**	**1434**	**631**	**197**	**54**	**52**	**3**	**292197**

Table 3.6: Parameters in the log-normal distribution of T_p given H_S. Divergent solutions are returned when attempting log-normal distribution fit to data for sectors 150° and 180°, and these sectors are assigned the omni directional log-normal parameters.

Direction	Parameters					
	a_1	a_2	a_3	b_1	b_2	b_3
0°	1.455	0.568	0.350	0.005	0.100	0.400
30°	1.169	0.655	0.350	0.005	0.092	0.373
60°	1.309	0.492	0.350	0.005	0.089	0.242
90°	1.240	0.579	0.350	0.005	0.121	0.318
120°	1.252	0.634	0.350	0.005	0.131	0.215
150°	1.597	0.494	0.350	0.005	0.098	0.308
180°	1.597	0.494	0.350	0.005	0.098	0.308
210°	1.726	0.393	0.350	0.005	0.111	0.413
240°	1.686	0.455	0.350	0.005	0.096	0.253
270°	1.840	0.391	0.350	0.005	0.068	0.257
300°	1.701	0.449	0.350	0.005	0.074	0.356
330°	1.617	0.488	0.350	0.005	0.055	0.394
0° - 360°	**1.597**	**0.494**	**0.350**	**0.005**	**0.098**	**0.308**

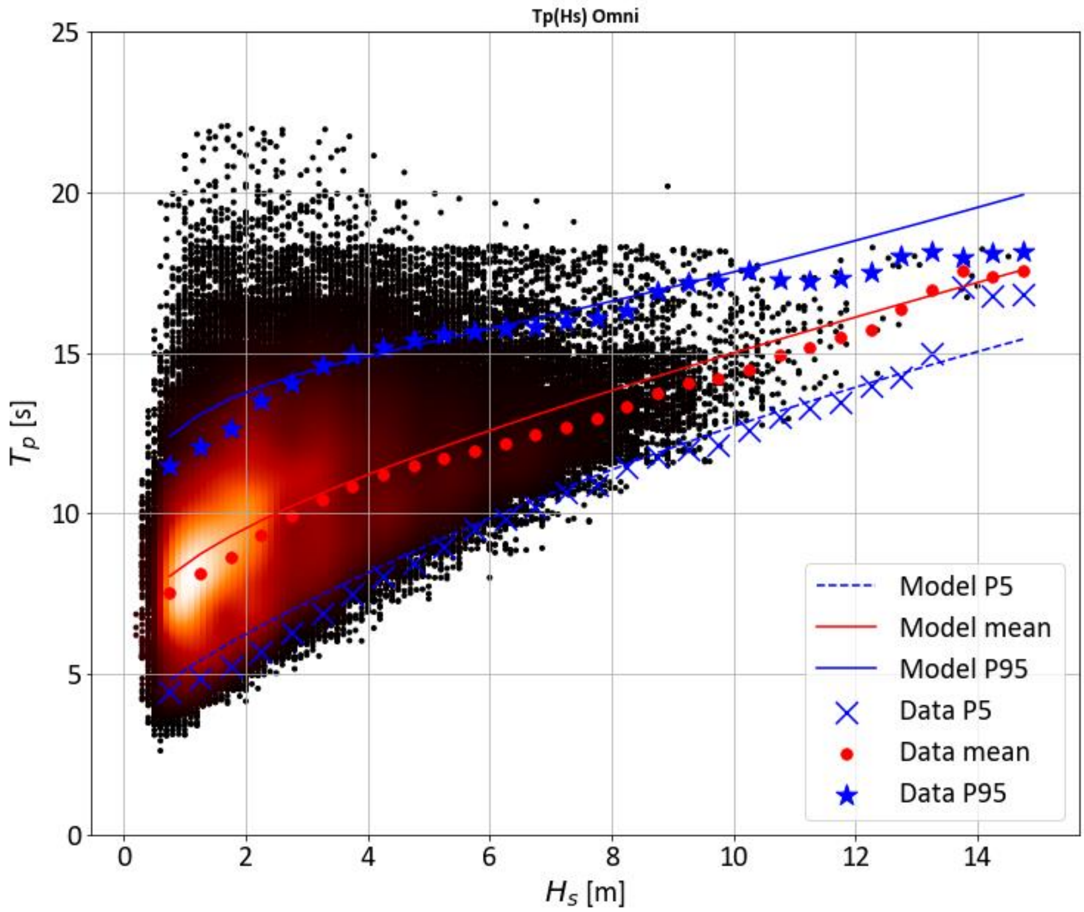


Figure 3.8: Spectral peak period for given significant wave height at the Haltenbanken Area A. Heat colormap gives the density of observations.

Table 3.7: Spectral peak period Tp as a function of significant wave height Hs; mean values and 90 % confidence band.

Significant wave height H_S [m]	Spectral peak period T_p [s]		
	P5	Mean	P95
1.0	5.1	8.4	12.8
2.0	6.2	9.5	13.8
3.0	7.2	10.4	14.4
4.0	8.2	11.2	14.9
5.0	9.0	11.9	15.3
6.0	9.8	12.6	15.8
7.0	10.6	13.2	16.2
8.0	11.4	13.8	16.6
9.0	12.1	14.4	17.1
10.0	12.7	15.0	17.5
11.0	13.3	15.6	18.0
12.0	13.9	16.1	18.5
13.0	14.5	16.7	19.0
14.0	15.0	17.2	19.5
15.0	15.6	17.7	20.1
16.0	16.1	18.2	20.6
17.0	16.6	18.8	21.1
18.0	17.0	19.3	21.7
19.0	17.5	19.8	22.2
20.0	18.0	20.3	22.8

Table 3.8: Omni-directional extreme significant wave heights and corresponding spectral peak periods; mean values and 90 % confidence band.

Return period [years]	Significant wave height H_S [m]	Spectral peak period T_p [s]		
		P5	Mean	P95
1	11.6	11.6	13.7	15.9
10	13.9	13.9	15.0	17.2
50	15.5	15.5	15.8	18.0
100	16.2	16.2	16.2	18.3
1 000	18.4	18.4	17.2	19.5
10 000	20.5	20.5	18.2	20.5

Table 3.9: Omni-directional and adjusted directional extreme significant wave height (H_S) and spectral peak period (T_p). The direction extremes are adjusted in agreement with NORSOK Standard N-003:2017 [1, Section 6.1.4].

Sector	Sector prob.	Return period [years]											
		1		10		50		100		1 000		10 000	
		Hs [m]	Tp [s]	Hs [m]	Tp [s]	Hs [m]	Tp [s]	Hs [m]	Tp [s]	Hs [m]	Tp [s]	Hs [m]	Tp [s]
0°	12.63	9.3	14.9	11.6	16.4	13.1	17.4	13.8	17.8	15.9	19.2	18.1	20.5
30°	5.67	5.4	10.6	6.5	11.4	7.2	11.9	7.5	12.2	8.4	12.8	9.2	13.4
60°	2.21	4.7	8.8	5.6	9.2	6.1	9.5	6.4	9.6	7.1	9.9	7.7	10.2
90°	1.05	4.6	9.5	5.5	10.0	6.0	10.3	6.2	10.4	6.8	10.8	7.4	11.2
120°	0.40	4.3	10.3	5.2	11.1	5.8	11.5	6.0	11.7	6.6	12.2	7.3	12.6
150° *	0.31	4.2	11.3	5.1	12.0	5.6	12.3	5.8	12.5	6.5	12.9	7.1	13.3
180° *	0.58	5.1	12.0	6.2	12.7	6.8	13.1	7.1	13.3	7.9	13.8	8.7	14.2
210°	9.69	11.2	14.1	13.0	14.8	14.1	15.2	14.6	15.4	16.0	15.9	17.4	16.4
240°	24.50	11.6	15.8	13.9	17.0	15.5	17.8	16.2	18.1	18.4	19.1	20.5	20.0
270°	18.56	11.6	15.9	13.9	16.9	15.5	17.5	16.2	17.8	18.4	18.6	20.5	19.4
300°	11.61	10.5	15.3	12.9	16.5	14.5	17.3	15.2	17.6	17.4	18.6	19.6	19.6
330°	12.78	10.1	15.1	12.3	16.3	13.8	17.1	14.4	17.5	16.5	18.5	18.4	19.5
0°-360°	**100.00**	**11.6**	**15.9**	**13.9**	**17.2**	**15.5**	**18.0**	**16.2**	**18.3**	**18.4**	**19.5**	**20.5**	**20.5**

* Directions without a satisfactory solution of log-normal parameters a and b. Omni directional parameters are used.

Table 3.10: Monthly and annual extreme significant wave height (H_S) and spectral peak period (T_p).

Month	Annual prob.	Return period [years]											
		1		10		50		100		1 000		10 000	
		Hs [m]	Tp [s]	Hs [m]	Tp [s]	Hs [m]	Tp [s]	Hs [m]	Tp [s]	Hs [m]	Tp [s]	Hs [m]	Tp [s]
Jan	8.33	10.3	14.9	12.7	15.9	14.3	16.5	15.0	16.7	17.0	17.5	19.0	18.2
Feb	8.33	9.8	14.7	12.0	15.6	13.4	16.2	14.0	16.4	15.8	17.1	17.5	17.8
Mar	8.33	8.7	13.9	10.7	14.7	11.9	15.2	12.4	15.4	14.0	16.1	15.4	16.6
Apr	8.33	7.2	13.1	9.2	14.1	10.5	14.8	11.0	15.1	12.8	16.0	14.5	16.8
May	8.33	6.0	11.7	7.9	12.8	9.3	13.4	9.9	13.7	11.8	14.6	13.7	15.4
Jun	8.33	5.7	11.3	7.8	12.5	9.4	13.3	10.0	13.7	12.2	14.8	14.5	15.9
Jul	8.33	4.5	10.6	5.9	11.5	6.8	12.0	7.2	12.3	8.5	13.0	9.8	13.7
Aug	8.33	5.4	10.9	7.2	11.8	8.5	12.3	9.0	12.6	10.8	13.3	12.6	14.0
Sept	8.33	7.5	12.8	9.7	13.9	11.1	14.6	11.7	14.9	13.7	15.7	15.6	16.6
Oct	8.33	8.4	13.5	10.5	14.5	11.9	15.1	12.5	15.3	14.3	16.1	16.0	16.8
Nov	8.33	9.9	14.6	12.6	15.7	14.4	16.4	15.1	16.7	17.5	17.5	19.8	18.3
Dec	8.33	10.2	15.3	12.7	16.5	14.2	17.2	14.9	17.6	16.9	18.5	18.8	19.4
0°-360°	**100.00**	**11.6**	**15.9**	**13.9**	**17.2**	**15.5**	**18.0**	**16.2**	**18.3**	**18.4**	**19.5**	**20.5**	**20.5**

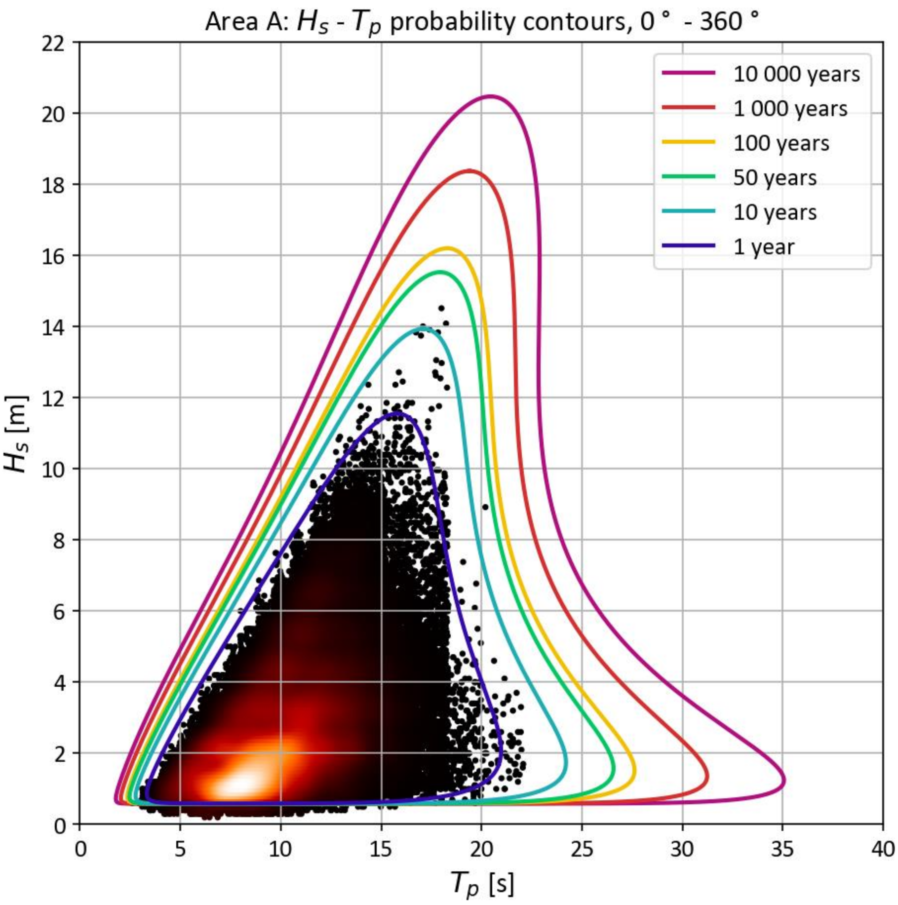


Figure 3.9: Contour lines of H_S – T_p with return period 1, 10, 50, 100, 1 000 and 10 000 years for omni-directional waves. Duration of sea state is 3 hours.

Table 3.11:Contour values of H_S – T_p for return period 1, 10, 50, 100, 1 000 and 10 000 years for omni-directional waves. Duration of sea state is 3 hours. T_{pL} and T_{pH} are lower and higher limits of T_p, respectively.

Return period [years]																	
1			10			50			100			1 000			10 000		
H_S [m]	T_{pL} [s]	T_{pH} [s]	H_S [m]	T_{pL} [s]	T_{pH} [s]	H_S [m]	T_{pL} [s]	T_{pH} [s]	H_S [m]	T_{pL} [s]	T_{pH} [s]	H_S [m]	T_{pL} [s]	T_{pH} [s]	H_S [m]	T_{pL} [s]	T_{pH} [s]
11.6	15.9	15.9	13.9	17.1	17.1	15.5	18.0	18.0	16.2	18.3	18.3	18.4	19.4	19.4	20.5	20.5	20.5
11.0	14.1	17.0	13.0	14.8	18.5	15.0	16.3	19.1	16.0	17.2	19.1	18.0	17.9	20.5	20.0	18.7	21.8
10.0	12.7	17.5	12.0	13.6	18.9	14.0	14.9	19.6	15.0	15.6	19.9	17.0	16.5	21.2	19.0	17.3	22.4
9.0	11.5	17.8	11.0	12.5	19.1	13.0	13.8	19.9	14.0	14.5	20.2	16.0	15.4	21.5	18.0	16.2	22.7
8.0	10.4	18.1	10.0	11.5	19.3	12.0	12.8	20.0	13.0	13.5	20.4	15.0	14.4	21.6	17.0	15.3	22.9
7.0	9.2	18.5	9.0	10.5	19.5	11.0	11.9	20.2	12.0	12.6	20.5	14.0	13.5	21.7	16.0	14.4	22.9
6.0	8.2	18.9	8.0	9.5	19.8	10.0	10.9	20.3	11.0	11.6	20.6	13.0	12.7	21.7	15.0	13.6	22.9
5.0	7.1	19.4	7.0	8.4	20.2	9.0	10.0	20.6	10.0	10.7	20.7	12.0	11.8	21.7	14.0	12.8	22.9
4.0	6.0	20.1	6.0	7.4	20.8	8.0	9.0	20.9	9.0	9.8	21.0	11.0	11.0	21.8	13.0	12.0	22.8
3.0	5.0	20.7	5.0	6.4	21.5	7.0	8.0	21.4	8.0	8.8	21.3	10.0	10.1	22.0	12.0	11.2	22.9
2.0	4.0	21.0	4.0	5.4	22.4	6.0	7.0	22.0	7.0	7.8	21.8	9.0	9.2	22.3	11.0	10.4	22.9
1.0	3.3	19.7	3.0	4.4	23.4	5.0	6.0	22.9	6.0	6.8	22.6	8.0	8.3	22.7	10.0	9.6	23.1
0.7	3.9	13.3	2.0	3.6	21.2	4.0	5.6	20.5	4.0	5.5	21.0	6.0	7.3	20.8	9.0	10.0	21.2

3.1.2.4 Individual wave heights and crest heights

Table 3.12 shows the estimated design wave heights. Extreme value estimates for individual wave heights and wave crests are computed according to Equations (2.17) and (2.32). The wave periods, T_{Hmax}, are computed from $T_{Hmax} = 0.90\ T_p$ [19], were T_p is given in Table 3.8.

Extreme individual wave heights versus direction sectors are given in Table 3.13. These wave heights are determined from the significant wave heights given in Table 3.9 by assuming that H_{max}/H_S for each sector is equal to H_{max}/H_S for omni-directional seas and reflect the same relative severity as shown by that table.

Table 3.12: Extreme individual wave heights for selected annual exceedance probabilities.

Return period [years]	Wave height	Crest height	Wave period T_{Hmax}		
			P5	Mean	P95
-	[m]	[m]	[s]	[s]	[s]
1	22.3	13.4	12.3	14.3	16.4
10	26.2	15.9	13.5	15.4	17.5
50	28.9	17.6	14.2	16.2	18.3
100	30.1	18.4	14.5	16.5	18.6
1 000	34.2	21.1	15.5	17.5	19.7
10 000	38.4	23.8	16.3	18.5	20.7

Table 3.13: Adjusted extreme individual wave height versus direction. Return periods are 100 and 10 000 years.

Direction	Return period 100 years				Return period 10 000 years			
	Wave height	Wave period			Wave height	Wave period		
		P5	Mean	P95		P5	Mean	P95
[°]	[m]	[s]	[s]	[s]	[m]	[s]	[s]	[s]
345 - 15	25.6	14.2	16.0	18.1	33.9	16.4	18.5	20.7
15 - 45	13.9	9.2	10.9	12.9	17.3	10.4	12.1	14.0
45 – 75	11.8	6.6	8.6	11.0	14.5	7.3	9.2	11.4
75 – 105	11.5	7.3	9.4	11.9	13.8	8.1	10.1	12.3
105 - 135	11.1	7.4	10.5	14.4	13.6	8.3	11.4	15.1
135 - 165 *	10.9	8.7	11.2	14.1	13.3	9.6	11.9	14.6
165 - 195 *	13.2	9.6	12.0	14.6	16.2	10.6	12.8	15.2
195 - 225	27.1	12.2	13.8	15.5	32.7	13.1	14.8	16.5
225 - 255	30.1	14.2	16.3	18.5	38.4	15.9	18.0	20.3
255 - 285	30.1	14.1	16.0	18.2	38.4	15.5	17.5	19.7
285 - 315	28.3	14.0	15.8	17.8	36.8	15.7	17.6	19.8
315 - 345	26.8	13.9	15.7	17.7	34.6	15.6	17.6	19.7
0 - 360	**30.1**	**14.5**	**16.5**	**18.6**	**38.4**	**16.3**	**18.5**	**20.7**

* Directions without a satisfactory solution of log-normal parameters a and b. Omni directional parameters are used.

3.1.2.5 Wave induced bottom currents

Table 3.14 and Table 3.15 show wave-induced significant orbital velocity U_S and corresponding zero-crossing period T_u, based on JONSWAP and Torsethaugen spectra. The significant wave height and spectral peak data are as given in Table 3.7.

When the associated spectral peak period is larger than the mean period given in Table 3.13, the most unfavourable orbital velocity from the JONSWAP or Torsethaugen spectrum should be applied.

Table 3.14: Wave induced significant orbital velocity (U_S) and corresponding zero crossing period (T_u) at sea bottom at 221 m depth. Computations are based on JONSWAP spectra.

	Low T_p-value (P5)			Mean T_p-value			High T_p-value (P95)		
H_S	T_p	U_S	T_u	T_p	U_S	T_u	T_p	U_S	T_u
[m]	[s]	[cm/s]	[s]	[s]	[cm/s]	[s]	[s]	[cm/s]	[s]
1.0	5.1	0.0	8.9	8.4	0.0	12.3	12.8	0.5	16.3
2.0	6.2	0.0	10.1	9.5	0.1	13.4	13.8	1.5	17.1
3.0	7.2	0.0	11.1	10.4	0.4	14.2	14.4	2.7	17.6
4.0	8.2	0.0	12.1	11.2	0.8	14.9	14.9	4.2	18.0
5.0	9.0	0.2	12.9	11.9	1.5	15.4	15.3	5.9	18.3
6.0	9.8	0.4	13.6	12.6	2.6	16.0	15.8	8.0	18.6
7.0	10.6	0.9	14.3	13.2	3.9	16.4	16.2	10.2	18.8
8.0	11.4	1.7	14.9	13.8	5.6	16.8	16.6	12.7	19.1
9.0	12.1	2.8	15.5	14.4	7.8	17.3	17.1	15.9	19.4
10.0	12.7	4.3	15.9	15.0	10.5	17.7	17.5	19.0	19.6
11.0	13.3	6.1	16.3	15.6	13.6	18.1	18.0	22.8	19.8
12.0	13.9	8.5	16.7	16.1	16.9	18.5	18.5	26.9	20.1
13.0	14.5	11.4	17.2	16.7	21.1	18.9	19.0	31.2	20.4
14.0	15.0	14.4	17.5	17.2	25.2	19.2	19.5	35.8	20.6
15.0	15.6	18.4	17.9	17.7	29.7	19.5	20.1	41.0	20.9
16.0	16.1	22.4	18.3	18.2	34.5	19.8	20.6	46.0	21.1
17.0	16.6	26.9	18.6	18.8	40.2	20.1	21.1	51.1	21.3
18.0	17.0	31.1	18.9	19.3	45.5	20.4	21.7	56.7	21.6
19.0	17.5	36.4	19.2	19.8	51.1	20.7	22.2	62.1	21.8
20.0	18.0	41.9	19.5	20.3	56.8	20.9	22.8	67.7	22.0

Table 3.15: Wave induced significant orbital velocity (U_S) and corresponding zero crossing period (T_u) at sea bottom at 221 m depth. Computations are based on Torsethaugen spectra.

	Low T_p-value (P5)			Mean T_p-value			High T_p-value (P95)		
H_S	T_p	U_S	T_u	T_p	U_S	T_u	T_p	U_S	T_u
[m]	[s]	[cm/s]	[s]	[s]	[cm/s]	[s]	[s]	[cm/s]	[s]
1.0	5.1	0.0	12.9	8.4	0.0	12.7	12.8	0.3	16.4
2.0	6.2	0.1	14.5	9.5	0.1	13.8	13.8	1.0	16.9
3.0	7.2	0.4	15.6	10.4	0.4	14.6	14.4	1.9	17.2
4.0	8.2	0.9	16.4	11.2	0.9	15.3	14.9	3.0	17.5
5.0	9.0	1.4	17.0	11.9	1.6	15.8	15.3	4.2	17.7
6.0	9.8	2.1	17.4	12.6	2.7	16.3	15.8	5.8	18.0
7.0	10.6	2.8	17.6	13.2	4.0	16.8	16.2	7.6	18.2
8.0	11.4	3.6	17.6	13.8	5.7	17.2	16.6	9.6	18.4
9.0	12.1	4.7	17.5	14.4	7.7	17.5	17.1	11.9	18.6
10.0	12.7	6.1	17.5	15.0	10.2	17.9	17.5	14.4	18.8
11.0	13.3	7.7	17.6	15.6	13.1	18.2	18.0	17.2	19.1
12.0	13.9	9.8	17.7	16.1	16.0	18.5	18.5	20.2	19.3
13.0	14.5	12.4	17.9	16.7	19.5	18.7	19.0	23.4	19.6
14.0	15.0	15.2	18.2	17.2	22.9	19.0	19.5	26.8	19.8
15.0	15.6	18.8	18.5	17.7	26.5	19.2	20.1	30.7	20.1
16.0	16.1	22.5	18.7	18.2	30.2	19.4	20.6	34.7	20.4
17.0	16.6	26.6	19.0	18.8	34.2	19.7	21.1	38.9	20.7
18.0	17.0	30.5	19.2	19.3	38.1	19.9	21.7	43.7	21.1
19.0	17.5	35.3	19.5	19.8	42.2	20.1	22.2	48.4	21.4
20.0	18.0	40.5	19.7	20.3	46.5	20.4	22.8	53.7	21.7

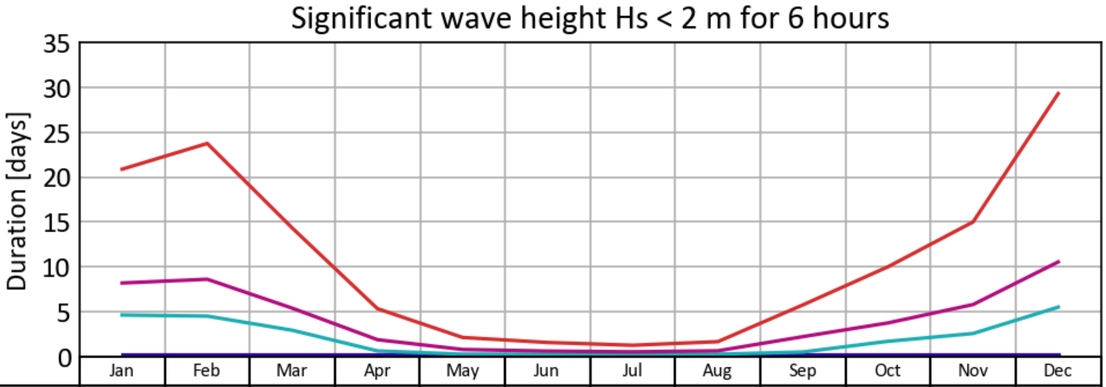
3.1.2.6 Operational wave data

Marine operations may be delayed due to waves exceeding prescribed operational levels (limits) leading to a possible increase in the duration of the operations. Marine operations which must be completed without break are called critical. Otherwise they are termed non-critical.

The duration statistics presented in this report is restricted to critical operations, only.

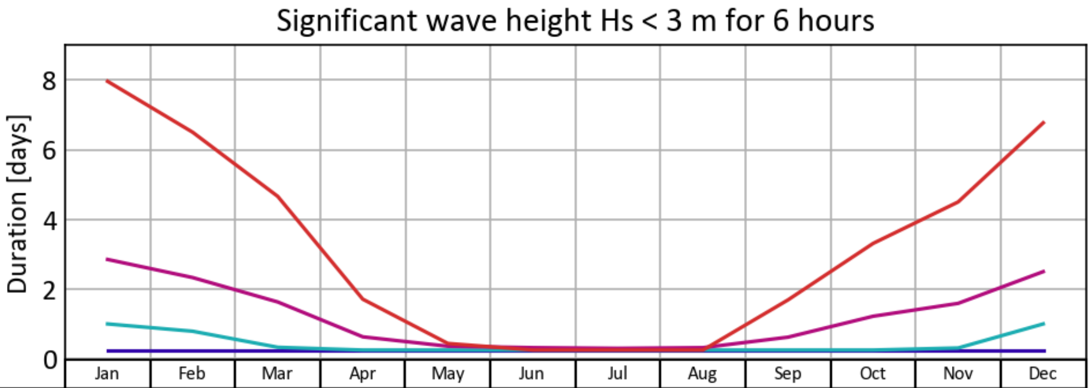
Figure 3.10 – Figure 3.21 show characteristic durations of operations limited by significant wave heights of 2.0 and 3.0 m for 6, 12, 24 and 48 hours. The figures show the expected mean duration and 10, 50 and 90 percentiles.

The figures show duration characteristics for completing a critical operation including waiting time. Duration is measured from the day the operation is ready for launching. The day of launching is assumed to be an arbitrary day within the relevant month.



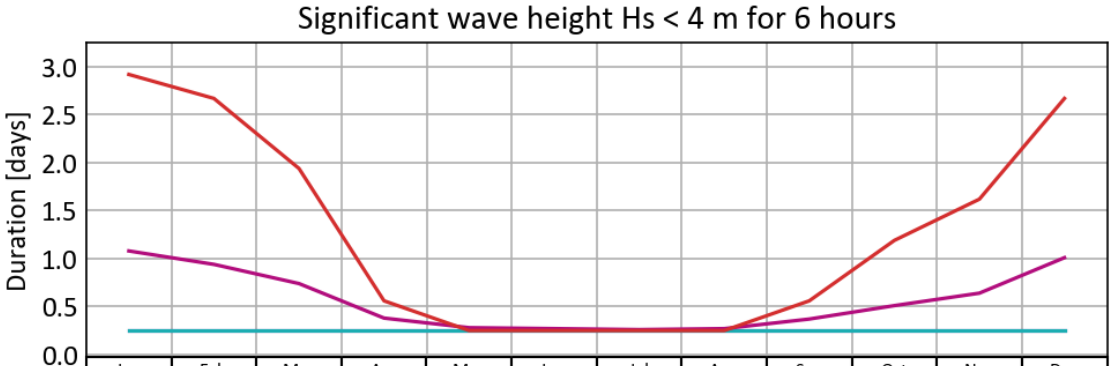
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
P50	4.62	4.50	2.92	0.62	0.25	0.25	0.25	0.25	0.50	1.69	2.56	5.50
Mean	8.19	8.61	5.38	1.87	0.78	0.60	0.52	0.63	2.21	3.74	5.79	10.54
P90	20.88	23.75	14.31	5.33	2.12	1.56	1.25	1.65	5.75	10.00	15.00	29.31

Figure 3.10: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 2.0 m for 6 hours.



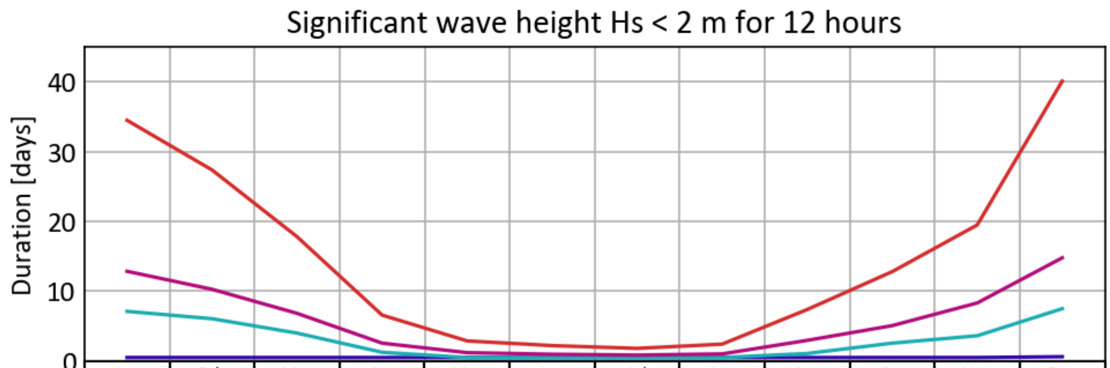
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
P50	1.00	0.79	0.33	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.31	1.00
Mean	2.85	2.33	1.63	0.63	0.36	0.32	0.30	0.32	0.62	1.22	1.59	2.50
P90	7.96	6.50	4.66	1.71	0.44	0.25	0.25	0.25	1.69	3.31	4.50	6.77

Figure 3.11: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 3.0 m for 6 hours.



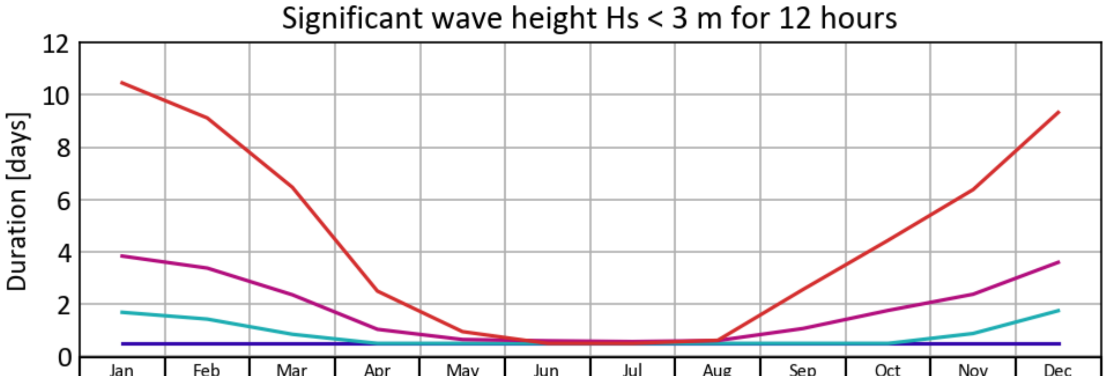
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
P50	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Mean	1.08	0.94	0.74	0.38	0.28	0.27	0.26	0.27	0.37	0.51	0.64	1.01
P90	2.92	2.67	1.94	0.56	0.25	0.25	0.25	0.25	0.56	1.19	1.62	2.67

Figure 3.12: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 4.0 m for 6 hours.



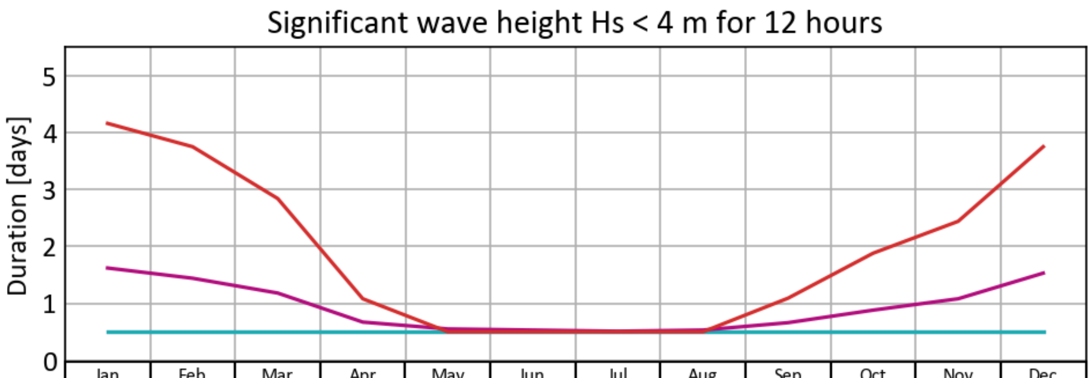
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.62
P50	7.12	6.06	4.00	1.25	0.50	0.50	0.50	0.50	1.08	2.56	3.62	7.50
Mean	12.86	10.28	6.83	2.56	1.20	0.97	0.85	1.02	2.96	5.07	8.32	14.79
P90	34.50	27.38	17.81	6.58	2.88	2.21	1.81	2.42	7.38	12.81	19.50	40.12

Figure 3.13: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 2.0 m for 12 hours.



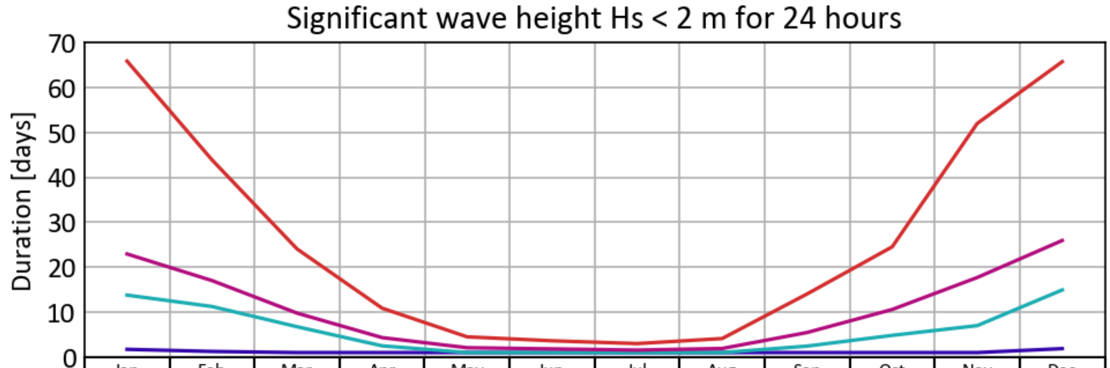
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
P50	1.69	1.43	0.85	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.88	1.75
Mean	3.84	3.38	2.36	1.04	0.65	0.60	0.57	0.61	1.07	1.76	2.38	3.60
P90	10.46	9.12	6.47	2.50	0.95	0.50	0.50	0.62	2.56	4.44	6.38	9.33

Figure 3.14: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 3.0 m for 12 hours.



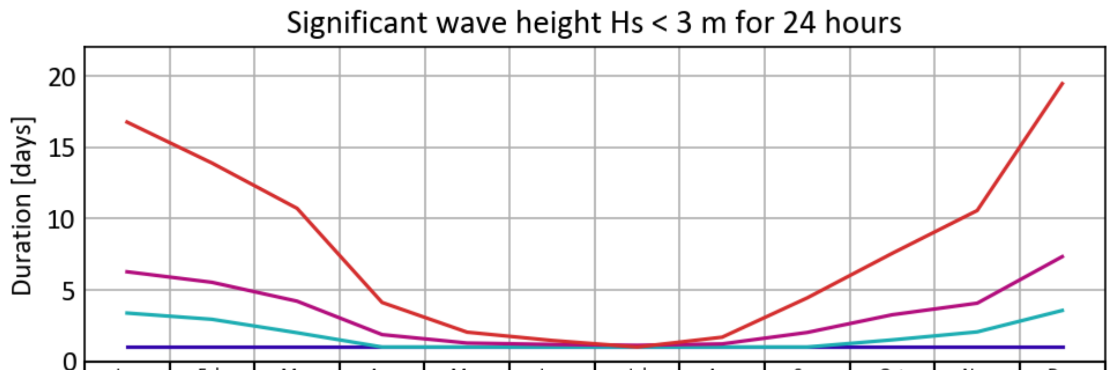
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
P50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Mean	1.62	1.44	1.18	0.67	0.55	0.53	0.51	0.53	0.66	0.88	1.08	1.53
P90	4.16	3.75	2.84	1.08	0.50	0.50	0.50	0.50	1.09	1.88	2.44	3.75

Figure 3.15: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 4.0 m for 12 hours.



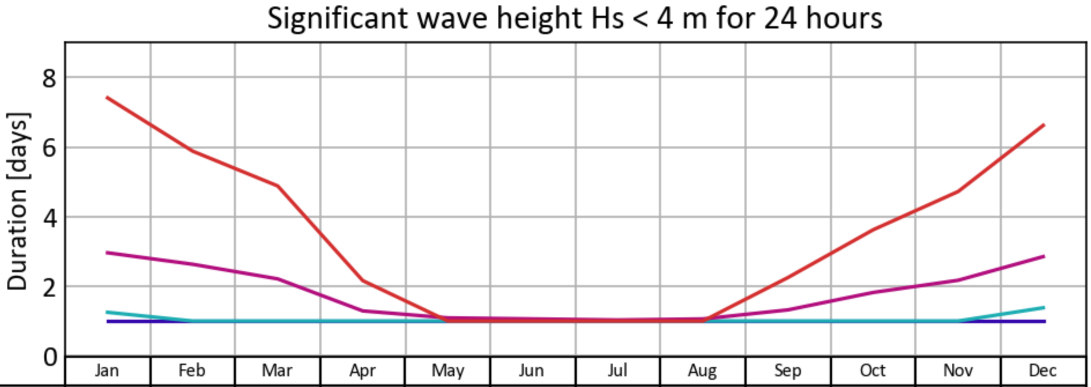
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	1.72	1.25	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.88
P50	13.79	11.25	6.75	2.50	1.00	1.00	1.00	1.00	2.44	4.83	7.00	14.94
Mean	22.95	17.02	9.78	4.33	2.08	1.82	1.55	1.91	5.47	10.59	17.71	25.95
P90	65.88	43.88	24.06	10.88	4.50	3.62	3.00	4.12	14.06	24.54	52.00	65.75

Figure 3.16: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 2.0 m for 24 hours.



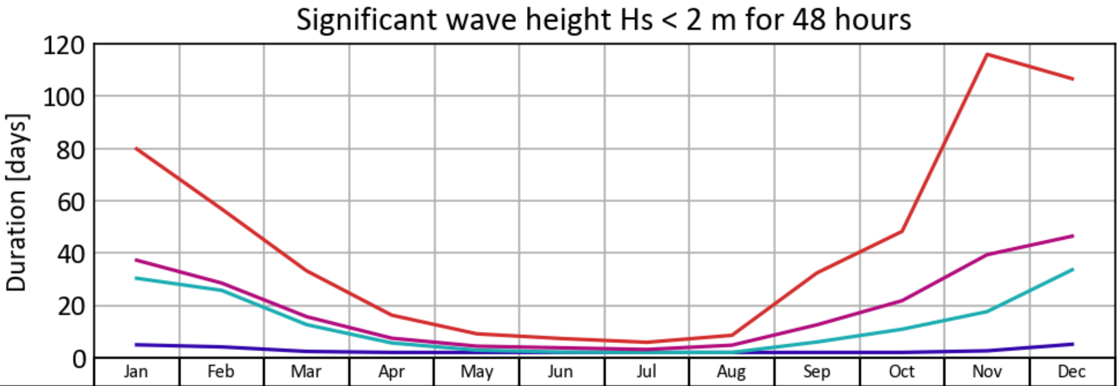
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P50	3.38	2.94	2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.50	2.06	3.56
Mean	6.27	5.53	4.21	1.87	1.28	1.18	1.12	1.22	2.02	3.26	4.07	7.33
P90	16.75	13.88	10.71	4.12	2.04	1.46	1.00	1.69	4.44	7.56	10.56	19.44

Figure 3.17: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 3.0 m for 24 hours.



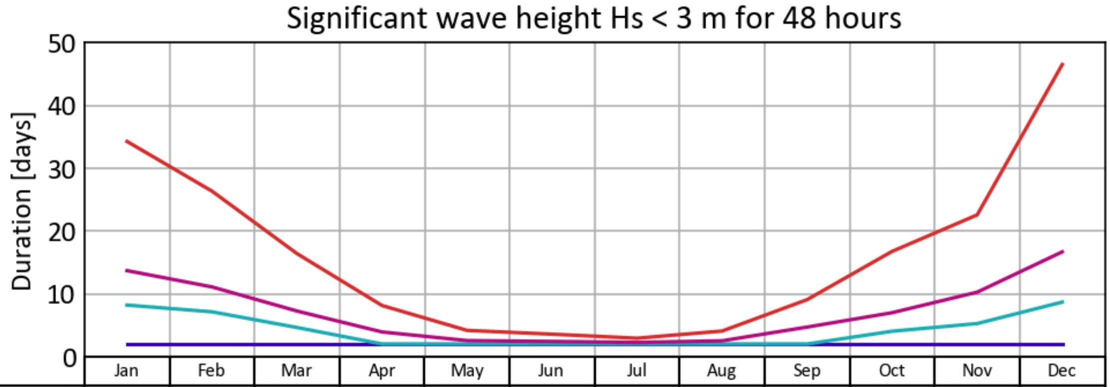
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P50	1.25	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.38
Mean	2.96	2.63	2.21	1.29	1.09	1.06	1.03	1.06	1.32	1.82	2.17	2.85
P90	7.41	5.88	4.88	2.16	1.00	1.00	1.00	1.00	2.25	3.62	4.72	6.62

Figure 3.18: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 4.0 m for 24 hours.



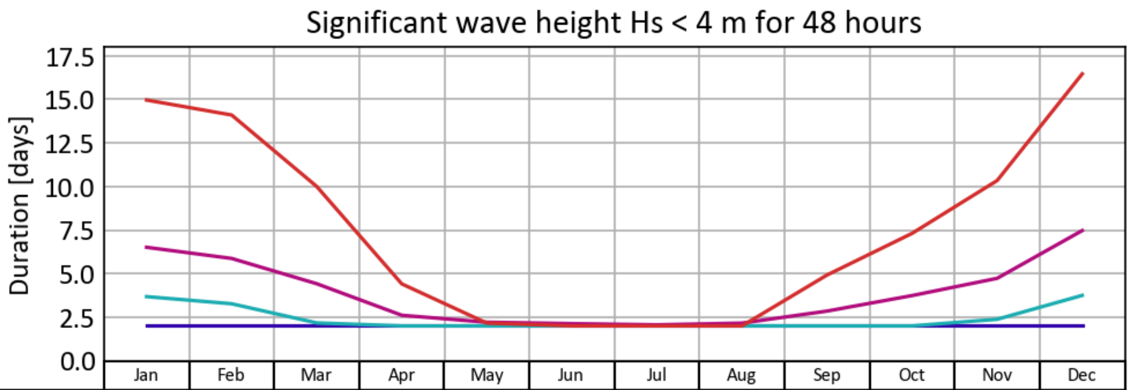
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	4.92	4.12	2.38	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.62	5.12
P50	30.38	25.75	12.62	5.62	2.88	2.12	2.00	2.00	6.00	10.88	17.62	33.62
Mean	37.29	28.54	15.67	7.45	4.40	3.76	3.14	4.78	12.58	21.80	39.40	46.48
P90	79.88	56.88	33.19	16.25	9.12	7.31	5.88	8.56	32.45	48.31	116.06	106.71

Figure 3.19: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 2.0 m for 48 hours.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
P50	8.19	7.12	4.62	2.00	2.00	2.00	2.00	2.00	2.00	4.03	5.25	8.67
Mean	13.68	11.08	7.24	3.91	2.54	2.41	2.25	2.51	4.69	6.98	10.25	16.67
P90	34.25	26.33	16.38	8.12	4.16	3.56	2.92	4.06	9.06	16.75	22.56	46.50

Figure 3.20: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 3.0 m for 48 hours.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
P50	3.68	3.27	2.17	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.38	3.75
Mean	6.51	5.87	4.42	2.61	2.21	2.13	2.06	2.16	2.85	3.74	4.73	7.47
P90	14.96	14.10	10.00	4.41	2.16	2.00	2.00	2.00	4.92	7.31	10.34	16.46

Figure 3.21: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 4.0 m for 48 hours.

3.1.3 Wave analysis, Haltenbanken Area B

3.1.3.1 Wave data statistics

Figure 3.22 shows the all-year wave rose, i.e. the sample direction distribution of significant wave height, at the Haltenbanken Area B.

Table 3.16 shows the direction sample distribution of non-exceedance of significant wave height.

Figure 3.23 shows the directional data scatter density and mean, P99 and maximum of significant wave height.

Table 3.17 shows the monthly sample distribution of non-exceedance of significant wave height.

Figure 3.24 shows the monthly data scatter density and mean, P99 and maximum of significant wave height.

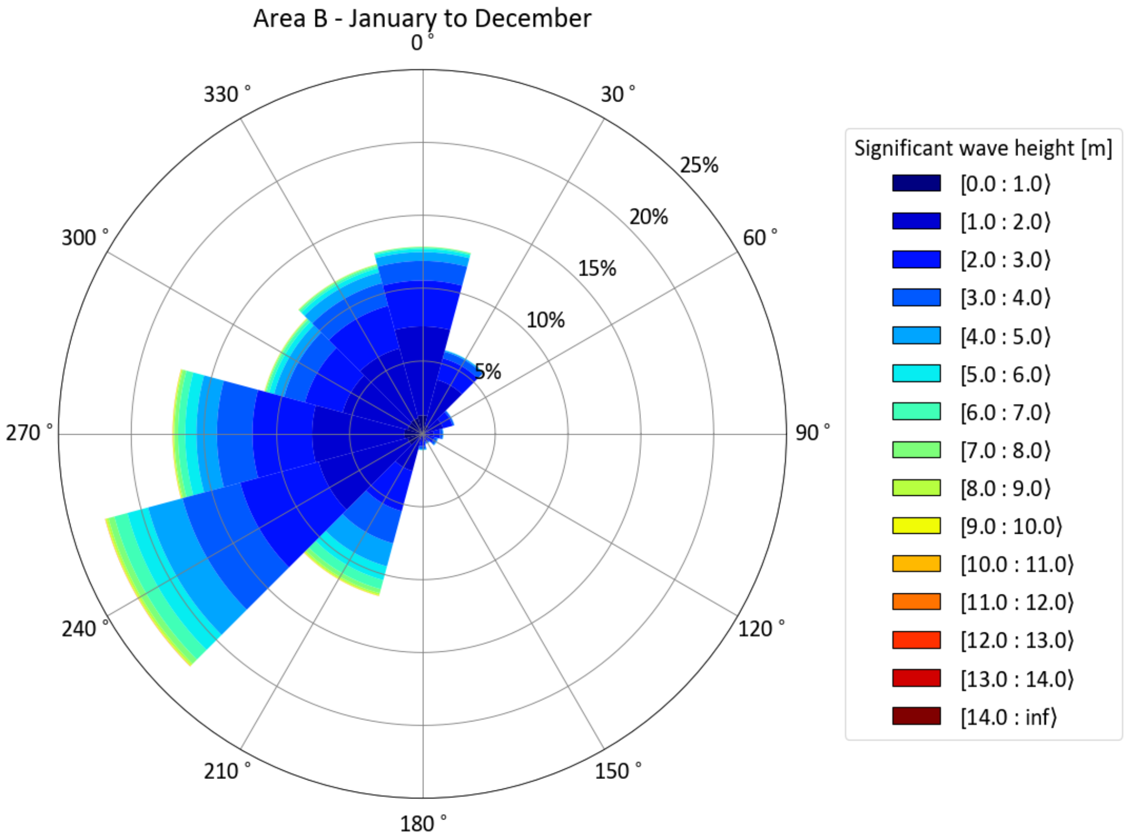


Figure 3.22: All year wave rose of significant wave height [m] for the Haltenbanken Area B.

Table 3.16: Directional sample distribution of non-exceedance [%] of significant wave height.

Hs [m]	Wave direction												Omni
	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°	
< 0.5	0.02	0.01							0.02	0.04	0.02	0.02	**0.14**
< 1.0	1.17	0.55	0.19	0.09	0.05	0.05	0.08	0.30	0.96	1.13	0.96	1.02	**6.56**
< 1.5	4.15	2.12	0.74	0.39	0.23	0.19	0.26	1.15	3.52	4.21	3.31	3.53	**23.79**
< 2.0	6.93	3.56	1.37	0.73	0.46	0.33	0.48	2.48	6.86	7.09	5.33	5.73	**41.35**
< 2.5	8.78	4.49	1.80	1.03	0.69	0.46	0.66	3.88	9.78	9.37	6.89	7.47	**55.30**
< 3.0	10.07	5.04	2.04	1.23	0.87	0.57	0.81	5.29	12.35	11.21	8.09	8.85	**66.42**
< 3.5	10.91	5.34	2.13	1.37	1.01	0.65	0.93	6.50	14.67	12.65	9.05	9.88	**75.09**
< 4.0	11.51	5.51	2.16	1.45	1.10	0.69	1.02	7.64	16.58	13.79	9.71	10.58	**81.74**
< 4.5	11.91	5.57	2.19	1.48	1.14	0.72	1.08	8.62	18.07	14.69	10.19	11.12	**86.77**
< 5.0	12.16	5.59	2.20	1.49	1.16	0.74	1.11	9.36	19.24	15.36	10.51	11.45	**90.38**
< 5.5	12.33	5.61	2.20	1.49	1.17	0.75	1.13	9.97	20.17	15.85	10.72	11.66	**93.03**
< 6.0	12.40	5.61	2.20	1.49	1.17	0.75	1.13	10.44	20.85	16.23	10.89	11.81	**95.00**
< 6.5	12.49	5.61			1.17	0.76	1.14	10.88	21.44	16.55	11.02	11.94	**96.69**
< 7.0	12.53	5.61					1.14	11.18	21.88	16.77	11.11	12.00	**97.85**
< 7.5	12.55	5.62					1.14	11.40	22.18	16.92	11.16	12.05	**98.65**
< 8.0	12.56	5.62						11.53	22.37	17.04	11.20	12.09	**99.17**
< 8.5	12.57							11.60	22.48	17.11	11.22	12.12	**99.48**
< 9.0	12.57							11.66	22.55	17.14	11.24	12.12	**99.67**
< 9.5	12.58							11.70	22.60	17.17	11.25	12.13	**99.82**
< 10.0	12.58							11.72	22.62	17.19	11.26	12.14	**99.89**
< 10.5	12.58							11.73	22.64	17.21	11.26	12.14	**99.95**
< 11.0	12.58							11.74	22.65	17.21	11.26		**99.97**
< 11.5								11.74	22.66	17.22	11.26		**99.98**
< 12.0								11.74	22.66	17.22	11.26		**99.99**
< 12.5								11.74	22.66	17.22	11.26		**99.99**
< 13.0									22.66				**99.99**
< 13.5									22.67				**100.00**
< 14.0									22.67				**100.00**
< 14.5									22.67				**100.00**
< 15.0									22.67				**100.00**
Sum	**12.58**	**5.62**	**2.20**	**1.49**	**1.17**	**0.76**	**1.14**	**11.74**	**22.67**	**17.22**	**11.26**	**12.14**	**100.00**
Mean	2.1	1.8	1.8	2.1	2.4	2.3	2.4	3.5	3.1	2.7	2.4	2.4	2.7
P99	6.3	4.3	4.1	4.5	5.0	5.1	5.7	8.7	8.3	8.1	7.4	7.1	7.8
Maximum	10.7	7.5	5.5	5.9	6.4	6.3	7.1	12.0	14.7	12.4	12.4	10.5	14.7

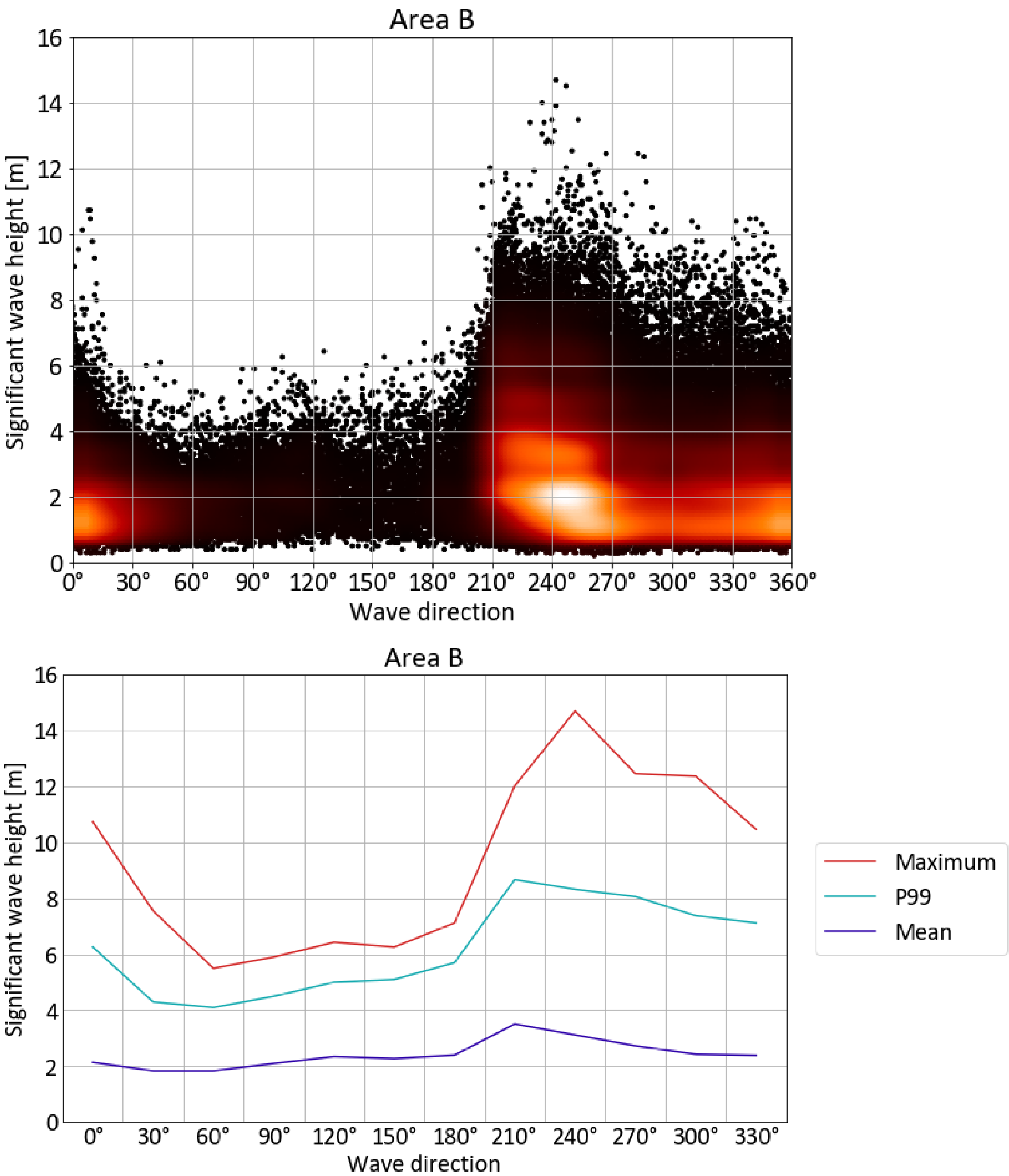


Figure 3.23: Directional scatter density plot (top) and mean, P99 and maximum (bottom) of significant wave height.

Table 3.17: Monthly and annual sample distribution of non-exceedance [%] of significant wave height.

Hs [m]	Month												Year
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
< 0.5			0.07	0.04	0.44	0.12	0.50	0.34	0.10	0.04			**0.14**
< 1.0	0.30	0.69	1.50	4.29	11.73	13.38	19.04	16.93	6.26	2.29	1.56	0.20	**6.56**
< 1.5	3.89	5.08	8.24	20.93	40.46	48.07	56.83	50.53	25.43	12.92	8.35	3.34	**23.79**
< 2.0	12.53	15.33	21.33	42.66	65.77	73.50	79.32	74.14	46.37	29.88	21.95	11.67	**41.35**
< 2.5	24.90	28.34	36.20	60.42	81.44	86.77	89.48	86.38	62.77	44.82	36.40	24.02	**55.29**
< 3.0	37.79	41.74	50.58	73.65	89.75	92.86	94.91	92.34	74.64	58.91	50.94	37.50	**66.41**
< 3.5	50.85	54.35	61.92	82.49	93.83	96.00	97.75	95.74	83.05	70.37	63.05	50.51	**75.08**
< 4.0	62.01	64.65	71.74	88.30	96.30	97.48	98.95	97.81	88.68	79.25	73.24	61.54	**81.73**
< 4.5	71.09	73.06	79.34	92.42	97.81	98.50	99.42	98.88	92.36	85.62	80.98	71.04	**86.77**
< 5.0	77.85	79.59	84.99	94.95	98.64	99.25	99.77	99.40	94.71	90.04	86.26	78.46	**90.37**
< 5.5	83.17	84.66	89.03	96.87	99.22	99.63	99.92	99.66	96.45	93.14	89.89	84.29	**93.03**
< 6.0	87.37	88.49	92.54	97.98	99.59	99.77	99.97	99.86	97.72	95.34	92.70	88.23	**94.99**
< 6.5	91.10	92.01	95.55	98.96	99.81	99.84	100.00	99.95	98.61	97.03	95.29	91.84	**96.69**
< 7.0	93.80	94.75	97.16	99.42	99.93	99.92		99.98	99.18	98.23	97.05	94.59	**97.85**
< 7.5	95.76	96.60	98.25	99.70	99.99	99.95		99.99	99.58	98.92	98.33	96.61	**98.65**
< 8.0	97.23	97.88	99.02	99.82	100.00	99.97		99.99	99.73	99.44	99.10	97.85	**99.17**
< 8.5	98.21	98.67	99.45	99.92		99.98		100.00	99.88	99.67	99.44	98.56	**99.48**
< 9.0	98.75	99.23	99.65	99.96		100.00			99.95	99.80	99.67	99.02	**99.67**
< 9.5	99.27	99.68	99.85	99.97					99.97	99.86	99.80	99.48	**99.82**
< 10.0	99.48	99.85	99.91	99.99					100.00	99.93	99.86	99.70	**99.89**
< 10.5	99.76	99.91	99.95	99.99						99.96	99.92	99.86	**99.95**
< 11.0	99.85	99.92	99.99	100.00						99.99	99.92	99.95	**99.97**
< 11.5	99.91	99.94	99.99							99.99	99.93	99.96	**99.98**
< 12.0	99.95	99.98	100.00							100.00	99.95	99.98	**99.99**
< 12.5	99.97	99.98									99.97	99.99	**99.99**
< 13.0	99.97	99.99									99.97	99.99	**99.99**
< 13.5	99.99	100.00									99.99	100.00	**100.00**
< 14.0	99.99										99.99		**100.00**
< 14.5	100.00										99.99		**100.00**
< 15.0											100.00		**100.00**
Total	**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**
Mean	3.8	3.6	3.3	2.4	1.8	1.7	1.5	1.6	2.4	2.9	3.2	3.8	2.7
P99	9.2	8.8	8.0	6.5	5.3	4.8	4.0	4.6	6.8	7.6	7.9	8.9	7.8
Maximum	14.0	13.1	11.6	10.9	7.9	8.8	6.3	8.1	9.8	11.5	14.7	13.1	14.7

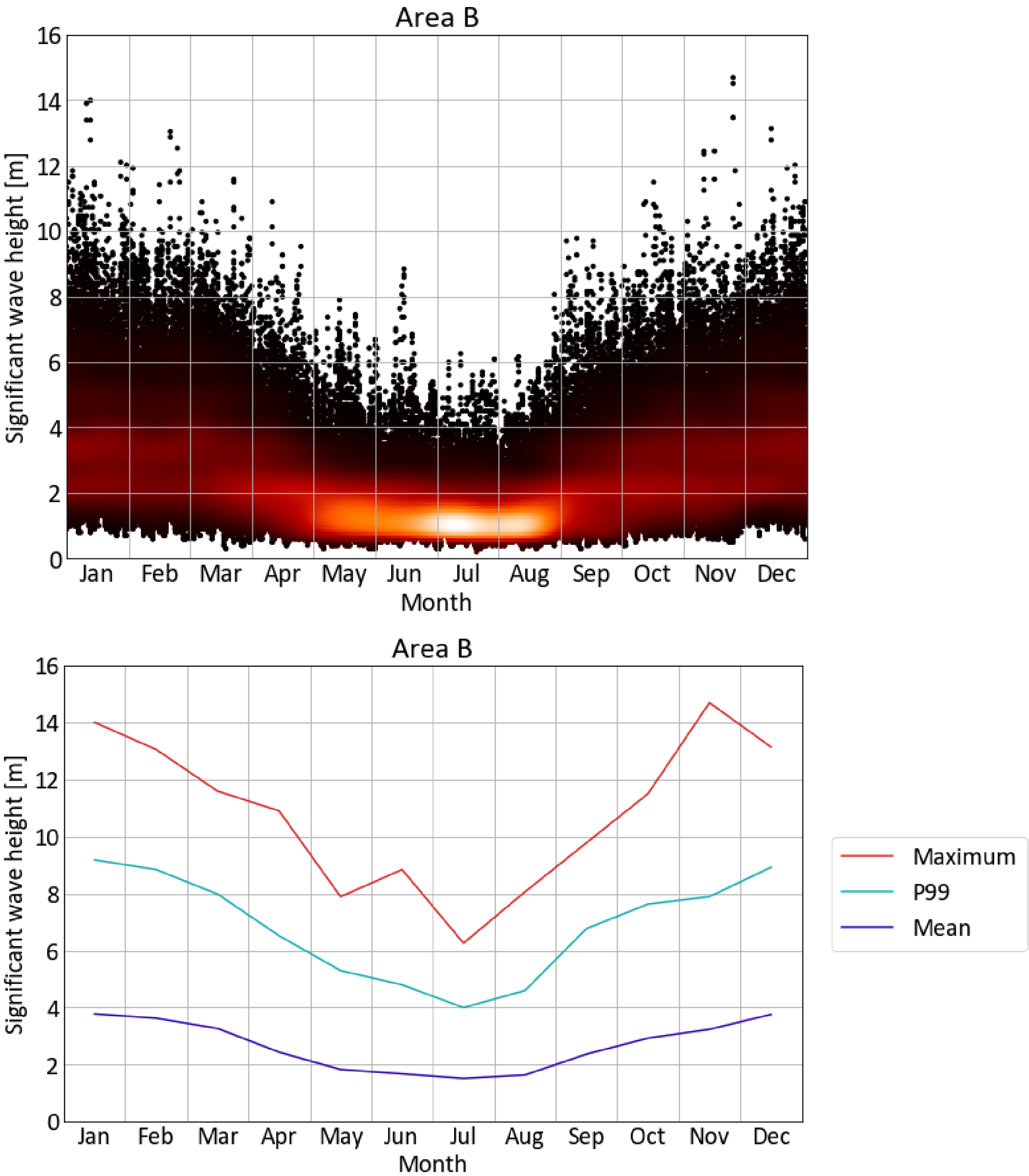


Figure 3.24: Monthly scatter density plot (top) and mean, P99 and maximum (bottom) of significant wave height.

3.1.3.2 Long-term wave statistics

The long-term distribution of significant wave height is modelled in terms of a 3-parameter Weibull distribution as described in Chapter 3.6.1. Figure 3.25 shows the hindcast and fitted distributions of significant wave height at the Haltenbanken Area B.

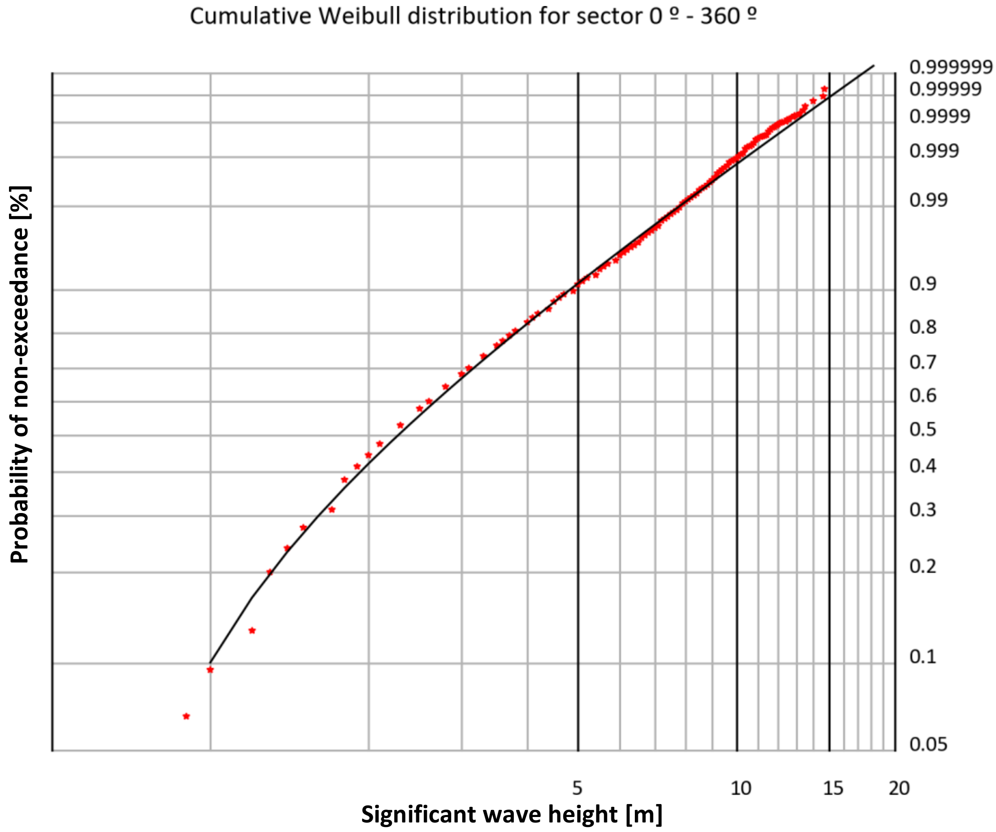


Figure 3.25: Hindcast (red dots) and fitted (black line) distributions of significant wave height at the Haltenbanken Area B.

Figure 3.26 and Table 3.18 show directional Weibull parameters and corresponding extremes of significant wave height at the Haltenbanken Area B. The direction extremes are adjusted in agreement with NORSOK Standard N-003:2017 [1, Section 6.1.4].

Figure 3.27 and Table 3.19 shows the monthly and annual Weibull parameters and corresponding extremes.

Table 3.18: Weibull parameters and corresponding directional extremes for significant wave height. The direction extremes are adjusted in agreement with NORSOK Standard N-003:2017 [1, Section 6.1.4]. Duration of event is 3 hours.

Direction	Sector prob.	Weibull parameters			Return period [years]					
		Shape	Scale	Location	1	10	50	100	1 000	10 000
-	[%]	-	[m]	[m]	[m]	[m]	[m]	[m]	[m]	[m]
0°	12.58	1.139	1.475	0.73	9.6	11.9	13.4	14.1	16.3	18.4
30°	5.62	1.360	1.261	0.68	5.9	7.1	7.9	8.3	9.4	10.4
60°	2.20	1.530	1.295	0.66	4.8	5.8	6.4	6.7	7.5	8.3
90°	1.49	1.840	1.777	0.51	5.0	6.0	6.5	6.8	7.5	8.2
120°	1.17	1.950	2.122	0.46	5.5	6.5	7.1	7.3	8.1	8.8
150°	0.76	1.880	2.131	0.37	5.3	6.5	7.1	7.4	8.3	9.1
180°	1.14	1.771	2.220	0.41	6.1	7.4	8.2	8.5	9.5	10.5
210°	11.74	1.755	3.378	0.48	11.2	13.0	14.1	14.6	16.0	17.4
240°	22.67	1.440	2.846	0.54	11.6	14.0	15.6	16.2	18.4	20.5
270°	17.22	1.301	2.342	0.55	11.6	14.0	15.6	16.2	18.4	20.5
300°	11.26	1.222	1.902	0.63	10.6	13.0	14.7	15.4	17.6	19.8
330°	12.14	1.249	1.853	0.65	10.1	12.3	13.8	14.4	16.5	18.4
0° - 360°	**100.00**	**1.295**	**2.211**	**0.61**	**11.6**	**14.0**	**15.6**	**16.2**	**18.4**	**20.5**

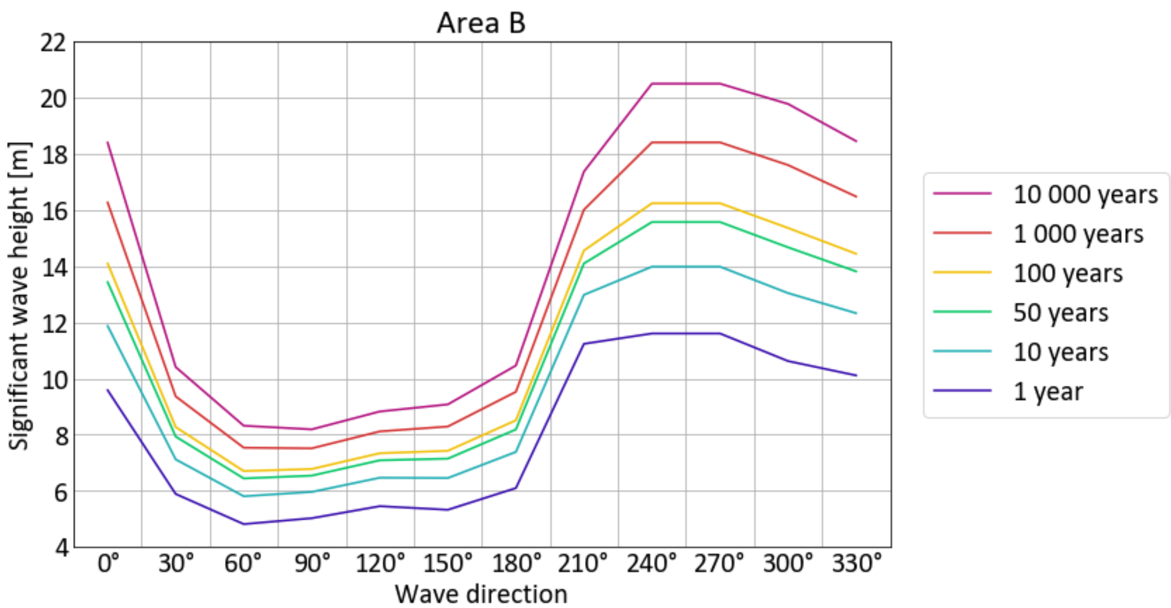


Figure 3.26: Directional extreme values of significant wave height with return period of 1, 10, 50, 100, 1000 and 10 000 years. The direction extremes are adjusted in agreement with NORSOK Standard N-003:2017 [1, Section 6.1.4].

Table 3.19: Monthly and annual Weibull parameters and corresponding extremes for significant wave height. Duration of event is 3 hours.

Month	Annual prob.	Weibull parameters			Return period [years]					
		Shape	Scale	Location	1	10	50	100	1 000	10 000
-	[%]	-	[m]	[m]	[m]	[m]	[m]	[m]	[m]	[m]
Jan	8.33	1.490	2.944	1.11	10.3	12.8	14.4	15.0	17.1	19.0
Feb	8.33	1.580	3.013	0.91	9.8	12.0	13.4	13.9	15.7	17.4
Mar	8.33	1.580	2.737	0.80	8.8	10.8	12.1	12.6	14.3	15.8
Apr	8.33	1.275	1.704	0.84	7.3	9.4	10.7	11.3	13.1	14.9
May	8.33	1.080	1.078	0.78	6.0	8.0	9.4	10.0	11.9	13.8
Jun	8.33	0.950	0.813	0.85	5.7	7.9	9.5	10.1	12.4	14.6
Jul	8.33	1.130	0.870	0.69	4.6	6.0	7.0	7.4	8.8	10.1
Aug	8.33	1.098	0.953	0.71	5.2	6.9	8.1	8.5	10.2	11.7
Sep	8.33	1.245	1.716	0.76	7.5	9.7	11.1	11.8	13.7	15.6
Oct	8.33	1.405	2.291	0.83	8.5	10.7	12.1	12.7	14.6	16.4
Nov	8.33	1.320	2.496	0.96	10.0	12.8	14.6	15.3	17.8	20.1
Dec	8.33	1.574	2.940	1.11	9.8	11.9	13.3	13.9	15.7	17.3
Year	100.00	1.295	2.211	0.61	11.6	14.0	15.6	16.2	18.4	20.5

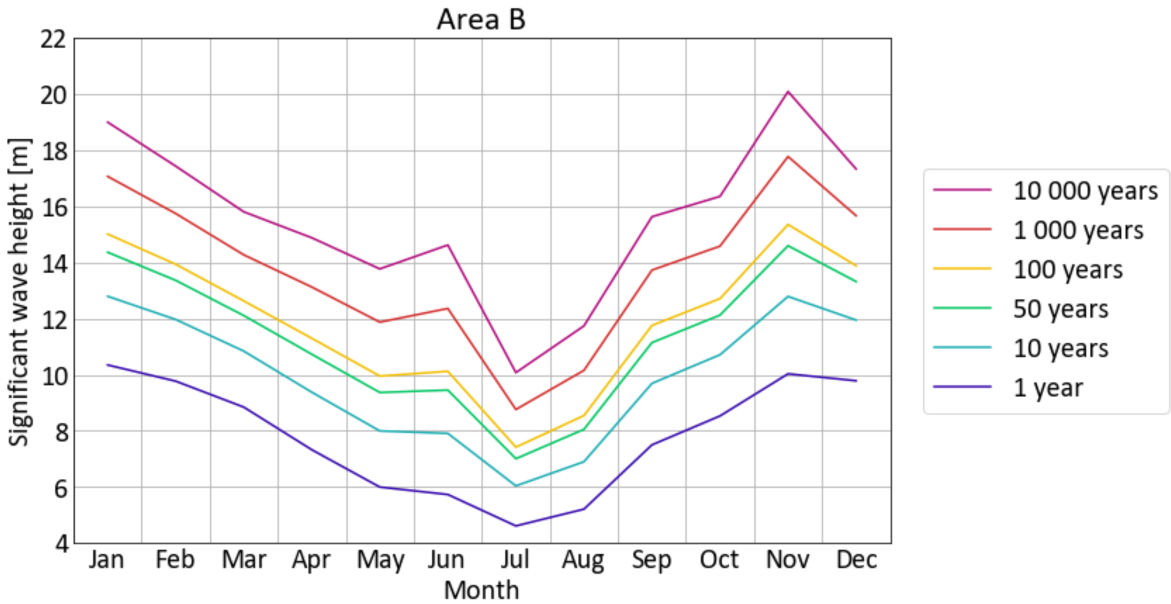


Figure 3.27: Monthly extreme values of significant wave height with return period of 1, 10, 50, 100, 1000 and 10 000 years.

3.1.3.3 H_S-T_p relation

A short-term sea state is for most practical purposes reasonably well characterized by the significant wave height, H_s, and the spectral peak period, T_p.

Table 3.20 shows a scatter table of H_S and T_p for a period of 100 years. The scatter table is obtained from the 61-year NORA10 hindcast data, and table entries are consequently scaled by 100/61. No smoothing is performed.

The conditional distribution of spectral peak period (T_p) given significant wave height (H_S) is modelled by a log-normal distribution, as described in Chapter 2.2.

Table 3.21 shows the parameters in the log-normal distribution of T_p given H_S. Divergent solutions are returned when attempting log-normal distribution fit to data for sectors 150° and 180°, and these sectors are assigned the omni directional log-normal parameters..

Table 3.22 and Figure 3.28 show spectral peak period as a function of significant wave height.

Table 3.23 shows omni-directional extreme significant wave heights and associated spectral peak periods.

Table 3.24 and Table 3.25 show directional and monthly extreme significant wave heights and associated spectral peak periods.

Figure 3.29 and Table 3.26 show q – probability contour lines of H_s – T_p for q = 0.63, 10^{-1}, $2{\cdot}10^{-2}$, 10^{-2}, 10^{-3} and 10^{-4}, corresponding to return periods of 1, 10, 50, 100, 1 000 and 10 000 years, for omni-directional waves.

Table 3.20: Scatter table of significant wave height (HS) and spectral peak period (Tp) at the Haltenbanken Area B for a period of 100 years. Duration of sea state is 3 hours.

H_S [m]	Spectral peak period (T_p) - [s]																					Sum
	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	18-19	19-20	20-21	21-22	22-23	
0.0-0.5		13	43	51	38	80	102	43	30	8	2	2										**410**
0.5-1.0	2	257	1261	2590	3848	3370	2920	2154	1166	539	348	148	51	44	21	21	5	11	3			**18759**
1.0-1.5		82	2161	4475	6502	9344	10092	7125	4675	2826	1467	777	338	216	125	79	34	23	2	5		**50348**
1.5-2.0			503	3649	5534	6631	9187	8685	6492	4549	2985	1538	674	366	257	128	74	16	15	10	3	**51297**
2.0-2.5			48	974	4325	4913	5954	6600	6170	4525	3330	2064	926	439	256	110	57	30	11	18		**40749**
2.5-3.0				193	1744	3780	4625	4844	5310	4638	3169	2061	1010	566	308	138	51	39	11	7		**32493**
3.0-3.5				21	508	2202	3674	3749	4077	4031	2933	1895	1169	551	315	113	57	21	10	5		**25331**
3.5-4.0				2	79	767	2672	3302	3179	3074	2492	1762	1067	531	311	110	62	18	2	7		**19436**
4.0-4.5					13	185	1316	2579	2710	2433	1982	1502	911	507	331	141	61	23	7	2		**14702**
4.5-5.0						34	472	1611	2325	1933	1503	1087	752	425	234	111	34	5	2			**10530**
5.0-5.5						5	138	831	1792	1798	1205	859	549	290	182	90	30	2	2			**7772**
5.5-6.0							39	366	1169	1475	1092	661	413	246	151	84	31	5	3			**5734**
6.0-6.5							13	118	670	1444	1192	638	415	220	144	66	28	2		2		**4951**
6.5-7.0							2	20	325	841	993	543	313	170	103	66	16	2				**3393**
7.0-7.5								5	93	433	757	580	213	116	74	49	11	2				**2334**
7.5-8.0									21	192	416	531	198	74	51	46	13					**1543**
8.0-8.5									3	56	211	338	170	59	31	26	13					**908**
8.5-9.0										16	90	187	136	49	34	16	11					**541**
9.0-9.5										7	56	156	130	38	38	18	8					**449**
9.5-10.0										2	16	49	69	31	18	8	11					**205**
10.0-10.5												33	57	26	23	10	3					**152**
10.5-11.0											3	2	25	16	13	8	2					**69**
11.0-11.5												2	5	11	3	2						**23**
11.5-12.0												2	7	10	11	3	2					**34**
12.0-12.5													2	2	5	2						**10**
12.5-13.0														2	2	3						**7**
13.0-13.5															2	5	3					**10**
13.5-14.0																2						**2**
14.0-14.5																2						**2**
14.5-15.0															2	2						**3**
SUM	**2**	**352**	**4015**	**11956**	**22590**	**31313**	**41205**	**42031**	**40207**	**34820**	**26243**	**17413**	**9600**	**5005**	**3046**	**1457**	**620**	**198**	**67**	**54**	**3**	**292197**

Table 3.21: Parameters in the log-normal distribution of T_p given H_S. Divergent solutions are returned when attempting log-normal distribution fit to data for sectors 150° and 180°, and these sectors are assigned the omni directional log-normal parameters.

Direction	Parameters					
	a_1	a_2	a_3	b_1	b_2	b_3
0°	1.446	0.567	0.350	0.005	0.100	0.832
30°	1.129	0.705	0.350	0.005	0.079	0.327
60°	1.127	0.626	0.350	0.005	0.089	0.230
90°	1.233	0.550	0.350	0.005	0.129	0.438
120°	1.584	0.332	0.350	0.005	0.189	0.504
150°	1.578	0.502	0.350	0.005	0.100	0.318
180°	1.578	0.502	0.350	0.005	0.100	0.318
210°	1.617	0.457	0.350	0.005	0.100	0.408
240°	1.704	0.450	0.350	0.005	0.091	0.246
270°	1.804	0.409	0.350	0.005	0.069	0.260
300°	1.676	0.458	0.350	0.005	0.074	0.346
330°	1.589	0.499	0.350	0.005	0.062	0.418
0° - 360°	**1.578**	**0.502**	**0.350**	**0.005**	**0.100**	**0.318**

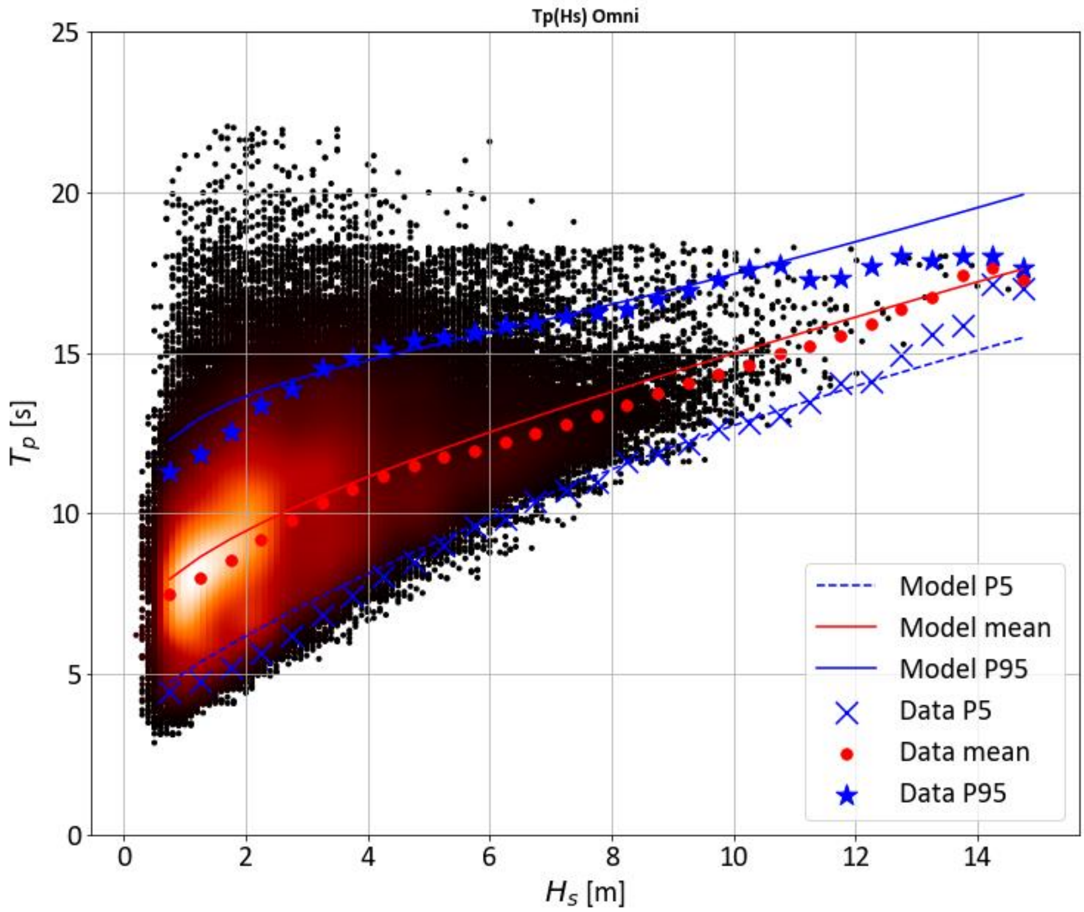


Figure 3.28: Spectral peak period for given significant wave height at the Haltenbanken Area B. Heat colormap gives the density of observations.

Table 3.22: Spectral peak period Tp as a function of significant wave height Hs; mean values and 90 % confidence band.

Significant wave height H_S [m]	Spectral peak period T_p [s]		
	P5	Mean	P95
1.0	5.1	8.3	12.6
2.0	6.2	9.5	13.6
3.0	7.2	10.3	14.3
4.0	8.1	11.1	14.7
5.0	9.0	11.9	15.2
6.0	9.8	12.5	15.6
7.0	10.6	13.2	16.1
8.0	11.4	13.8	16.5
9.0	12.1	14.4	17.0
10.0	12.7	15.0	17.4
11.0	13.4	15.5	17.9
12.0	14.0	16.1	18.5
13.0	14.5	16.7	19.0
14.0	15.1	17.2	19.5
15.0	15.6	17.7	20.1
16.0	16.1	18.3	20.6
17.0	16.6	18.8	21.2
18.0	17.1	19.3	21.7
19.0	17.6	19.8	22.3
20.0	18.0	20.3	22.8

Table 3.23: Omni-directional extreme significant wave heights and corresponding spectral peak periods; mean values and 90 % confidence band.

Return period [years]	Significant wave height H_S [m]	Spectral peak period T_p [s]		
		P5	Mean	P95
1	11.6	13.7	15.9	18.2
10	14.0	15.1	17.2	19.5
50	15.6	15.9	18.0	20.4
100	16.2	16.2	18.4	20.7
1 000	18.4	17.3	19.5	22.0
10 000	20.5	18.3	20.6	23.1

Table 3.24: Omni-directional and adjusted directional extreme significant wave height (H_S) and spectral peak period (T_p). The direction extremes are adjusted in agreement with NORSOK Standard N-003:2017 [1, Section 6.1.4].

Sector	Sector prob.	Return period [years]											
		1		10		50		100		1 000		10 000	
		H_S [m]	T_p [s]	H_S [m]	T_p [s]	H_S [m]	T_p [s]	H_S [m]	T_p [s]	H_S [m]	T_p [s]	H_S [m]	T_p [s]
0°	12.58	9.6	14.9	11.9	16.4	13.4	17.4	14.1	17.8	16.3	19.2	18.4	20.5
30°	5.62	5.9	11.6	7.1	12.6	7.9	13.3	8.3	13.6	9.4	14.5	10.4	15.4
60°	2.20	4.8	9.3	5.8	10.0	6.4	10.4	6.7	10.6	7.5	11.1	8.3	11.6
90°	1.49	5.0	9.1	6.0	9.7	6.5	10.0	6.8	10.1	7.5	10.5	8.2	10.9
120°	1.17	5.5	9.0	6.5	9.3	7.1	9.5	7.3	9.5	8.1	9.8	8.8	10.0
150°	0.76	5.3	12.1	6.5	12.8	7.1	13.3	7.4	13.4	8.3	14.0	9.1	14.4
180°	1.14	6.1	12.6	7.4	13.4	8.2	13.9	8.5	14.1	9.5	14.7	10.5	15.2
210°	11.74	11.2	14.7	13.0	15.5	14.1	16.0	14.6	16.2	16.0	16.9	17.4	17.5
240°	22.67	11.6	16.0	14.0	17.1	15.6	17.9	16.2	18.2	18.4	19.2	20.5	20.1
270°	17.22	11.6	16.0	14.0	17.1	15.6	17.7	16.2	18.0	18.4	18.9	20.5	19.8
300°	11.26	10.6	15.3	13.0	16.5	14.7	17.3	15.4	17.6	17.6	18.7	19.8	19.7
330°	12.14	10.1	15.1	12.3	16.3	13.8	17.2	14.4	17.5	16.5	18.6	18.4	19.6
0^o-360^o	**100.00**	**11.6**	**15.9**	**14.0**	**17.2**	**15.6**	**18.0**	**16.2**	**18.4**	**18.4**	**19.5**	**20.5**	**20.6**

* Directions without a satisfactory solution of log-normal parameters a and b. Omni directional parameters are used.

Table 3.25: Monthly and annual extreme significant wave height (H_S) and spectral peak period (T_p).

Month	Annual prob.	Return period [years]											
		1		10		50		100		1 000		10 000	
		H_S [m]	T_p [s]	H_S [m]	T_p [s]	H_S [m]	T_p [s]	H_S [m]	T_p [s]	H_S [m]	T_p [s]	H_S [m]	T_p [s]
Jan	8.33	10.3	15.1	12.8	16.2	14.4	16.8	15.0	17.1	17.1	18.0	19.0	18.7
Feb	8.33	9.8	14.7	12.0	15.8	13.4	16.4	13.9	16.6	15.7	17.4	17.4	18.1
Mar	8.33	8.8	14.0	10.8	14.8	12.1	15.4	12.6	15.6	14.3	16.3	15.8	16.9
Apr	8.33	7.3	13.0	9.4	14.1	10.7	14.8	11.3	15.1	13.1	16.0	14.9	16.8
May	8.33	6.0	11.8	8.0	12.9	9.4	13.6	10.0	13.9	11.9	14.8	13.8	15.7
Jun	8.33	5.7	11.5	7.9	12.9	9.5	13.8	10.1	14.2	12.4	15.5	14.6	16.7
Jul	8.33	4.6	10.9	6.0	12.0	7.0	12.6	7.4	12.9	8.8	13.8	10.1	14.6
Aug	8.33	5.2	10.9	6.9	11.8	8.1	12.4	8.5	12.6	10.2	13.4	11.7	14.1
Sept	8.33	7.5	12.9	9.7	14.0	11.1	14.8	11.8	15.1	13.7	16.0	15.6	16.9
Oct	8.33	8.5	13.6	10.7	14.6	12.1	15.2	12.7	15.5	14.6	16.3	16.4	17.0
Nov	8.33	10.0	14.7	12.8	15.9	14.6	16.7	15.3	17.0	17.8	18.0	20.1	18.9
Dec	8.33	9.8	15.2	11.9	16.4	13.3	17.2	13.9	17.5	15.7	18.4	17.3	19.3
0^o-360^o	**100.00**	**11.6**	**15.9**	**14.0**	**17.2**	**15.6**	**18.0**	**16.2**	**18.4**	**18.4**	**19.5**	**20.5**	**20.6**

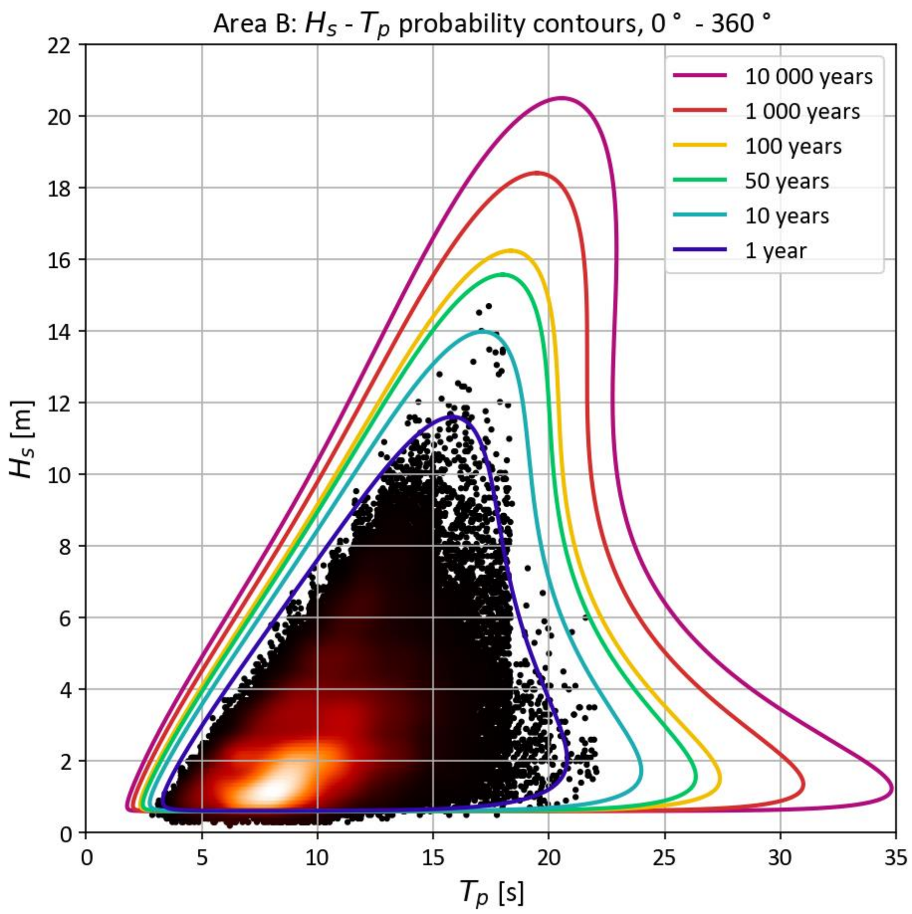


Figure 3.29: Contour lines of H_S – T_p with return period 1, 10, 50, 100, 1 000 and 10 000 years for omni-directional waves. Duration of sea state is 3 hours.

Table 3.26:Contour values of H_S – T_p for return period 1, 10, 50, 100, 1 000 and 10 000 years for omni-directional waves. Duration of sea state is 3 hours. T_{pL} and T_{pH} are lower and higher limits of T_p, respectively.

Return period [years]																	
1			10			50			100			1 000			10 000		
H_S [m]	T_{pL} [s]	T_{pH} [s]	H_S [m]	T_{pL} [s]	T_{pH} [s]	H_S [m]	T_{pL} [s]	T_{pH} [s]	H_S [m]	T_{pL} [s]	T_{pH} [s]	H_S [m]	T_{pL} [s]	T_{pH} [s]	H_S [m]	T_{pL} [s]	T_{pH} [s]
11.6	15.9	15.9	14.0	17.2	17.2	15.6	18.1	18.1	16.2	18.4	18.4	18.4	19.5	19.5	20.5	20.6	20.6
11.0	14.1	17.0	13.0	14.8	18.6	15.0	16.2	19.2	16.0	17.2	19.3	18.0	17.9	20.6	20.0	18.8	21.9
10.0	12.7	17.5	12.0	13.6	18.9	14.0	14.9	19.7	15.0	15.6	19.9	17.0	16.5	21.3	19.0	17.3	22.5
9.0	11.5	17.8	11.0	12.5	19.1	13.0	13.8	19.9	14.0	14.5	20.2	16.0	15.4	21.5	18.0	16.2	22.8
8.0	10.4	18.0	10.0	11.5	19.2	12.0	12.8	20.0	13.0	13.5	20.3	15.0	14.4	21.6	17.0	15.3	22.9
7.0	9.3	18.3	9.0	10.5	19.4	11.0	11.9	20.1	12.0	12.6	20.4	14.0	13.6	21.6	16.0	14.5	22.9
6.0	8.2	18.7	8.0	9.5	19.7	10.0	11.0	20.2	11.0	11.7	20.5	13.0	12.7	21.6	15.0	13.6	22.9
5.0	7.1	19.2	7.0	8.5	20.1	9.0	10.0	20.4	10.0	10.7	20.6	12.0	11.9	21.6	14.0	12.9	22.8
4.0	6.0	19.9	6.0	7.4	20.6	8.0	9.0	20.7	9.0	9.8	20.8	11.0	11.0	21.7	13.0	12.1	22.8
3.0	5.0	20.5	5.0	6.4	21.3	7.0	8.0	21.1	8.0	8.8	21.1	10.0	10.1	21.8	12.0	11.3	22.8
2.0	4.0	20.8	4.0	5.4	22.2	6.0	7.0	21.8	7.0	7.9	21.6	9.0	9.2	22.1	11.0	10.5	22.8
1.0	3.3	19.5	3.0	4.4	23.2	5.0	6.0	22.6	6.0	6.9	22.3	8.0	8.3	22.5	10.0	9.7	22.9
0.6	3.9	14.5	2.0	3.5	23.9	4.0	5.0	23.8	5.0	5.9	23.2	7.0	7.4	23.1	9.0	8.8	23.2

3.1.3.4 Individual wave heights and crest heights

Table 3.27 shows the estimated design wave heights. Extreme value estimates for individual wave heights and wave crests are computed according to Equations (2.17) and (2.32). The wave periods, T_{Hmax}, are computed from $T_{Hmax} = 0.90\ T_p$ [19], were T_p is given in Table 3.23.

Extreme individual wave heights versus direction sectors are given in Table 3.28. These wave heights are determined from the significant wave heights given in Table 3.9 by assuming that H_{max}/H_S for each sector is equal to H_{max}/H_S for omni-directional seas and reflect the same relative severity as shown by that table.

Table 3.27: Extreme individual wave heights for selected annual exceedance probabilities.

Return period [years]	Wave height	Crest height	Wave period T_{Hmax}		
			P5	Mean	P95
-	[m]	[m]	[s]	[s]	[s]
1	22.4	13.4	12.4	14.3	16.4
10	26.2	15.9	13.6	15.5	17.6
50	29.0	17.7	14.3	16.2	18.3
100	30.2	18.5	14.6	16.6	18.7
1 000	34.3	21.1	15.6	17.6	19.8
10 000	38.5	23.8	16.4	18.5	20.8

Table 3.28: Adjusted extreme individual wave height versus direction. Return periods are 100 and 10 000 years.

Direction	Return period 100 years				Return period 10 000 years			
	Wave height	Wave period			Wave height	Wave period		
		P5	Mean	P95		P5	Mean	P95
[°]	[m]	[s]	[s]	[s]	[m]	[s]	[s]	[s]
345 - 15	26.2	14.2	16.0	18.0	34.6	16.4	18.4	20.7
15 - 45	15.4	10.3	12.3	14.4	19.6	11.9	13.8	15.9
45 – 75	12.5	7.3	9.5	12.1	15.6	8.3	10.4	12.9
75 – 105	12.6	7.6	9.1	10.8	15.4	8.4	9.8	11.3
105 - 135	13.7	7.3	8.6	10.0	16.6	7.8	9.0	10.3
135 - 165 *	13.8	9.9	12.1	14.6	17.1	10.9	13.0	15.3
165 - 195 *	15.8	10.6	12.7	15.1	19.7	11.7	13.7	15.9
195 - 225	27.1	12.9	14.6	16.4	32.6	13.9	15.7	17.6
225 - 255	30.2	14.3	16.4	18.7	38.5	16.0	18.1	20.4
255 - 285	30.2	14.2	16.2	18.4	38.5	15.7	17.8	20.0
285 - 315	28.6	14.0	15.9	17.9	37.1	15.7	17.7	19.9
315 - 345	26.9	14.0	15.7	17.7	34.7	15.7	17.6	19.8
0 - 360	**30.2**	**14.6**	**16.6**	**18.7**	**38.5**	**16.4**	**18.5**	**20.8**

* Directions without a satisfactory solution of log-normal parameters a and b. Omni directional parameters are used.

3.1.3.5 Wave induced bottom currents

Table 3.29 and Table 3.30 show wave-induced significant orbital velocity U_S and corresponding zero-crossing period T_u, based on JONSWAP and Torsethaugen spectra. The significant wave height and spectral peak data are as given in Table 3.22.

When the associated spectral peak period is larger than the mean period given in Table 3.13, the most unfavourable orbital velocity from the JONSWAP or Torsethaugen spectrum should be applied.

Table 3.29: Wave induced significant orbital velocity (U_S) and corresponding zero crossing period (T_u) at sea bottom at 334 m depth. Computations are based on JONSWAP spectra.

	Low T_p-value (P5)			Mean T_p-value			High T_p-value (P95)		
H_S	T_p	U_S	T_u	T_p	U_S	T_u	T_p	U_S	T_u
[m]	[s]	[cm/s]	[s]	[s]	[cm/s]	[s]	[s]	[cm/s]	[s]
1.0	5.1	0.0	9.5	8.3	0.0	13.1	12.6	0.1	17.3
2.0	6.2	0.0	10.8	9.5	0.0	14.4	13.6	0.3	18.2
3.0	7.2	0.0	11.9	10.3	0.0	15.2	14.3	0.7	18.8
4.0	8.1	0.0	12.9	11.1	0.1	15.9	14.7	1.1	19.2
5.0	9.0	0.0	13.8	11.9	0.3	16.7	15.2	1.6	19.6
6.0	9.8	0.0	14.7	12.5	0.5	17.2	15.6	2.3	19.8
7.0	10.6	0.1	15.4	13.2	0.8	17.8	16.1	3.1	20.2
8.0	11.4	0.3	16.2	13.8	1.3	18.3	16.5	4.0	20.4
9.0	12.1	0.5	16.8	14.4	2.0	18.8	17.0	5.1	20.7
10.0	12.7	0.8	17.3	15.0	2.8	19.2	17.4	6.3	20.8
11.0	13.4	1.4	17.9	15.5	3.8	19.5	17.9	7.8	21.1
12.0	14.0	2.1	18.4	16.1	5.1	19.9	18.5	9.6	21.3
13.0	14.5	2.8	18.7	16.7	6.6	20.3	19.0	11.5	21.5
14.0	15.1	4.0	19.2	17.2	8.2	20.6	19.5	13.4	21.7
15.0	15.6	5.1	19.5	17.7	10.0	20.8	20.1	15.8	21.9
16.0	16.1	6.6	19.8	18.3	12.2	21.1	20.6	18.0	22.0
17.0	16.6	8.2	20.1	18.8	14.4	21.3	21.2	20.6	22.2
18.0	17.1	10.1	20.3	19.3	16.7	21.4	21.7	23.1	22.4
19.0	17.6	12.2	20.6	19.8	19.2	21.6	22.3	25.9	22.6
20.0	18.0	14.1	20.8	20.3	21.8	21.8	22.8	28.5	22.7

Table 3.30: Wave induced significant orbital velocity (U_S) and corresponding zero crossing period (T_u) at sea bottom at 334 m depth. Computations are based on Torsethaugen spectra.

	Low T_p-value (P5)			Mean T_p-value			High T_p-value (P95)		
H_S	T_p	U_S	T_u	T_p	U_S	T_u	T_p	U_S	T_u
[m]	[s]	[cm/s]	[s]	[s]	[cm/s]	[s]	[s]	[cm/s]	[s]
1.0	5.1	0.0	13.9	8.3	0.0	13.5	12.6	0.1	17.7
2.0	6.2	0.0	15.6	9.5	0.0	14.8	13.6	0.2	18.5
3.0	7.2	0.1	16.8	10.3	0.1	15.6	14.3	0.5	19.0
4.0	8.1	0.2	17.7	11.1	0.1	16.4	14.7	0.7	19.2
5.0	9.0	0.3	18.4	11.9	0.3	17.1	15.2	1.1	19.5
6.0	9.8	0.5	19.0	12.5	0.5	17.7	15.6	1.6	19.7
7.0	10.6	0.8	19.4	13.2	0.9	18.3	16.1	2.2	19.9
8.0	11.4	1.0	19.6	13.8	1.4	18.7	16.5	2.8	20.0
9.0	12.1	1.3	19.6	14.4	2.1	19.2	17.0	3.6	20.1
10.0	12.7	1.7	19.6	15.0	2.9	19.6	17.4	4.4	20.2
11.0	13.4	2.1	19.4	15.5	3.7	19.9	17.9	5.4	20.3
12.0	14.0	2.8	19.5	16.1	4.8	20.1	18.5	6.6	20.5
13.0	14.5	3.5	19.7	16.7	6.1	20.3	19.0	7.8	20.6
14.0	15.1	4.6	19.9	17.2	7.3	20.4	19.5	9.2	20.8
15.0	15.6	5.7	20.1	17.7	8.6	20.5	20.1	10.9	21.0
16.0	16.1	7.1	20.3	18.3	10.1	20.6	20.6	12.6	21.3
17.0	16.6	8.6	20.6	18.8	11.6	20.7	21.2	14.8	21.6
18.0	17.1	10.4	20.8	19.3	13.2	20.9	21.7	17.0	21.9
19.0	17.6	12.3	21.0	19.8	14.9	21.0	22.3	19.6	22.2
20.0	18.0	14.0	21.1	20.3	16.9	21.2	22.8	22.2	22.5

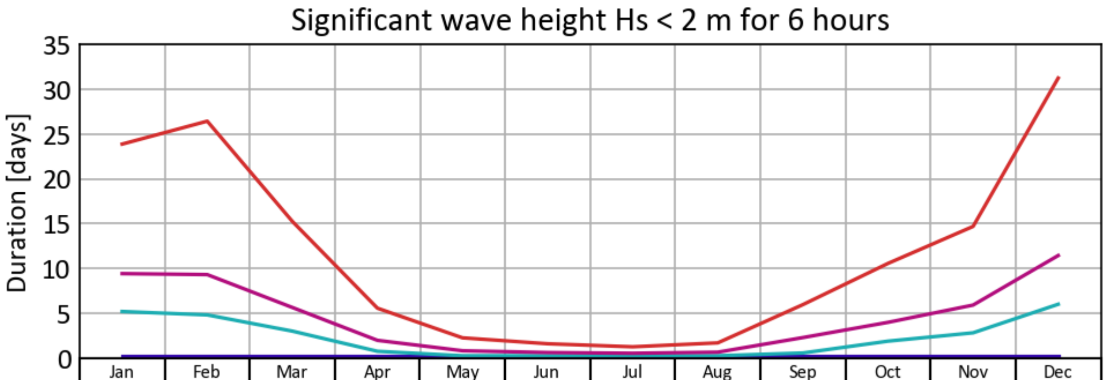
3.1.3.6 Operational wave data

Marine operations may be delayed due to waves exceeding prescribed operational levels (limits) leading to a possible increase in the duration of the operations. Marine operations which must be completed without break are called critical. Otherwise they are termed non-critical.

The duration statistics presented in this report is restricted to critical operations, only.

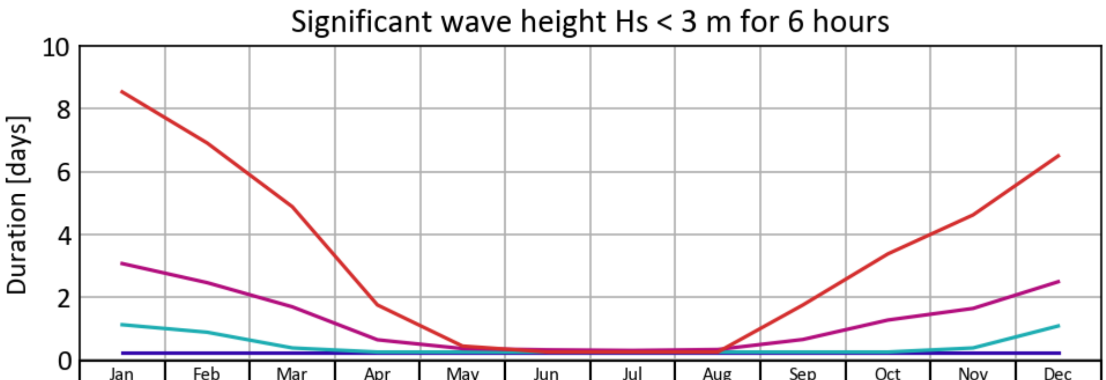
Figure 3.30 – Figure 3.41 show characteristic durations of operations limited by significant wave heights of 2.0 and 3.0 m for 6, 12, 24 and 48 hours. The figures show the expected mean duration and 10, 50 and 90 percentiles.

The figures show duration characteristics for completing a critical operation including waiting time. Duration is measured from the day the operation is ready for launching. The day of launching is assumed to be an arbitrary day within the relevant month.



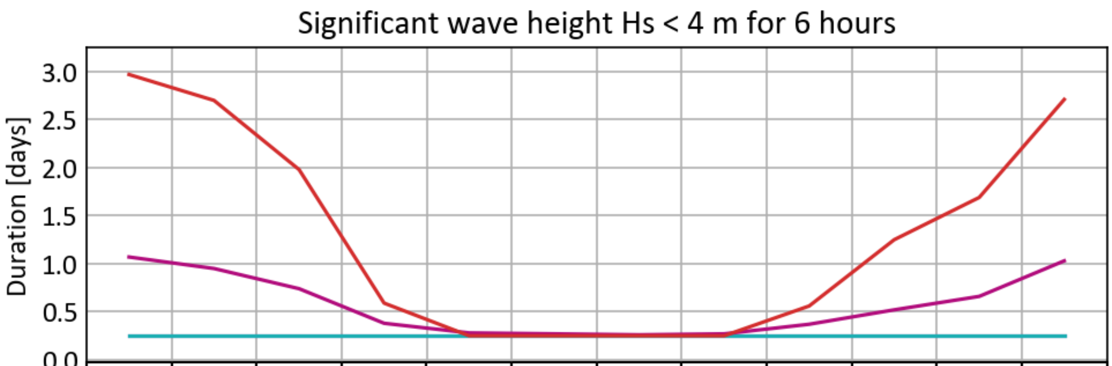
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
P50	5.19	4.81	3.00	0.75	0.25	0.25	0.25	0.25	0.56	1.88	2.81	6.00
Mean	9.42	9.31	5.64	1.97	0.81	0.61	0.53	0.65	2.28	3.98	5.91	11.44
P90	23.88	26.44	15.25	5.56	2.25	1.59	1.25	1.69	5.96	10.56	14.69	31.25

Figure 3.30: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 2.0 m for 6 hours.



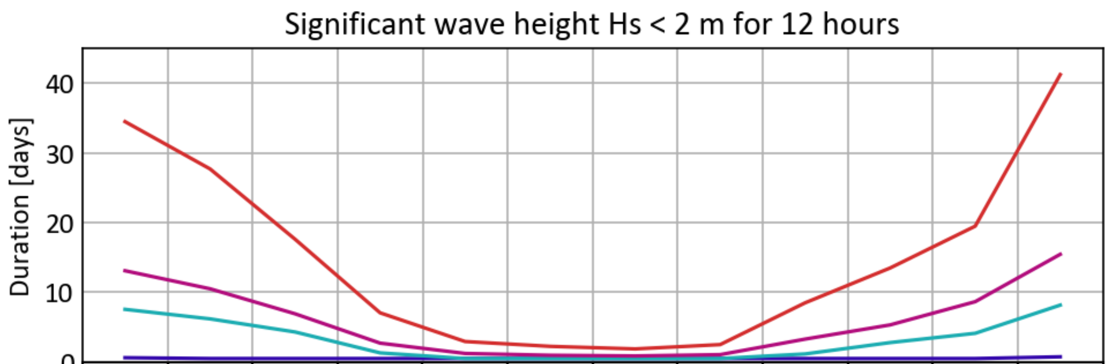
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
P50	1.12	0.88	0.38	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.38	1.08
Mean	3.07	2.46	1.69	0.64	0.36	0.32	0.30	0.33	0.65	1.27	1.64	2.49
P90	8.54	6.91	4.88	1.75	0.44	0.25	0.25	0.25	1.75	3.38	4.62	6.50

Figure 3.31: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 3.0 m for 6 hours.



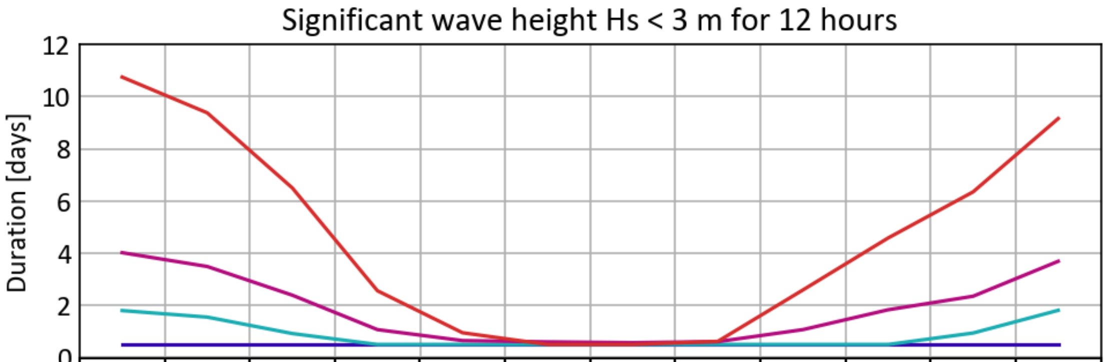
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
P50	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Mean	1.07	0.95	0.74	0.38	0.28	0.27	0.26	0.27	0.37	0.52	0.66	1.03
P90	2.97	2.70	1.98	0.59	0.25	0.25	0.25	0.25	0.56	1.25	1.69	2.71

Figure 3.32: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 4.0 m for 6 hours.



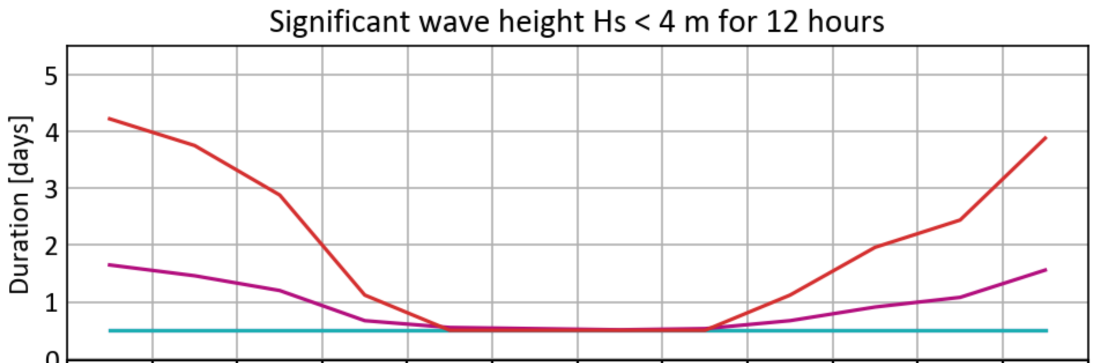
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.62	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.75
P50	7.56	6.19	4.31	1.31	0.50	0.50	0.50	0.50	1.16	2.79	4.12	8.17
Mean	13.10	10.51	6.92	2.71	1.23	0.97	0.87	1.06	3.29	5.33	8.66	15.46
P90	34.50	27.71	17.62	7.06	2.94	2.25	1.88	2.50	8.50	13.50	19.50	41.25

Figure 3.33: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 2.0 m for 12 hours.



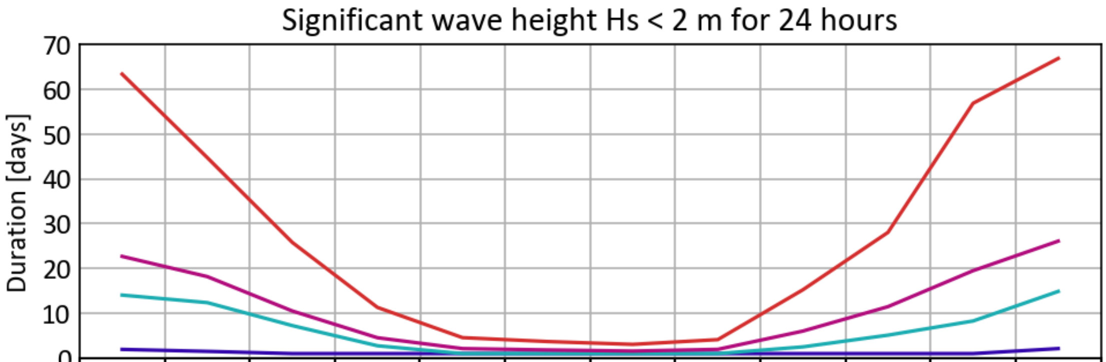
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
P50	1.80	1.55	0.92	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.94	1.81
Mean	4.02	3.49	2.39	1.07	0.65	0.60	0.57	0.61	1.07	1.83	2.35	3.69
P90	10.75	9.38	6.50	2.56	0.95	0.50	0.50	0.62	2.59	4.58	6.35	9.16

Figure 3.34: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 3.0 m for 12 hours.



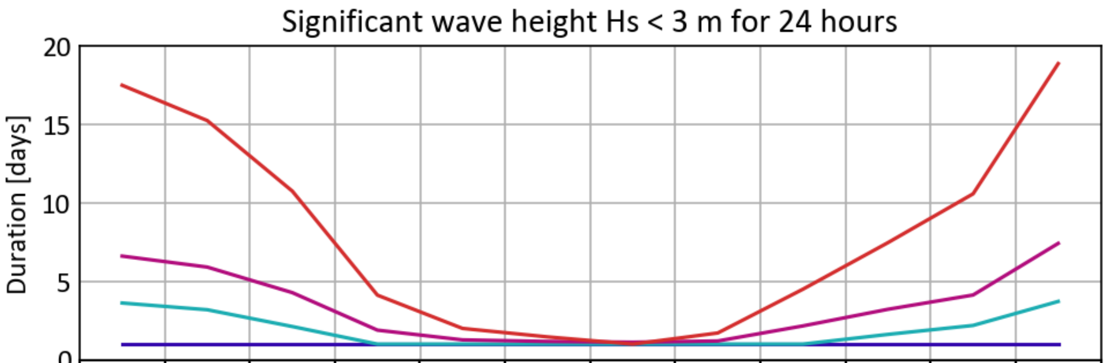
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
P50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Mean	1.65	1.46	1.20	0.67	0.55	0.53	0.51	0.53	0.67	0.91	1.08	1.56
P90	4.22	3.75	2.88	1.12	0.50	0.50	0.50	0.50	1.12	1.96	2.44	3.88

Figure 3.35: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 4.0 m for 12 hours.



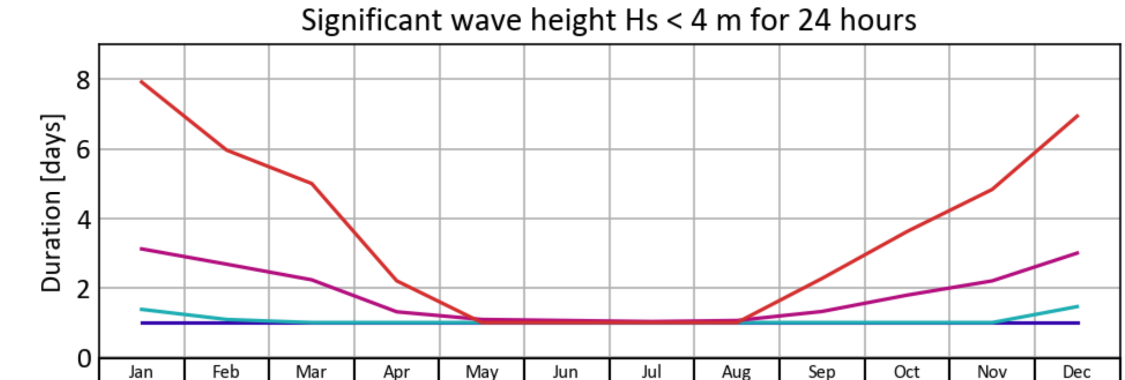
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	1.94	1.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.12
P50	14.06	12.38	7.25	2.75	1.00	1.00	1.00	1.00	2.50	5.12	8.28	14.88
Mean	22.70	18.19	10.51	4.54	2.12	1.82	1.57	1.95	6.03	11.48	19.51	26.11
P90	63.38	44.75	25.81	11.31	4.56	3.69	3.06	4.12	15.25	28.06	56.88	66.88

Figure 3.36: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 2.0 m for 24 hours.



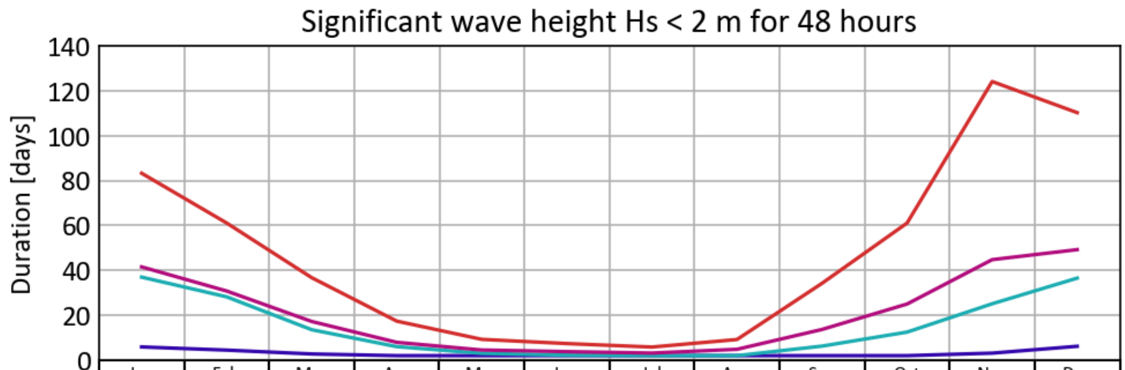
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P50	3.62	3.19	2.12	1.00	1.00	1.00	1.00	1.00	1.00	1.62	2.19	3.72
Mean	6.61	5.91	4.28	1.89	1.27	1.17	1.12	1.20	2.16	3.22	4.13	7.42
P90	17.50	15.25	10.75	4.12	2.00	1.46	1.00	1.71	4.50	7.47	10.58	18.88

Figure 3.37: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 3.0 m for 24 hours.



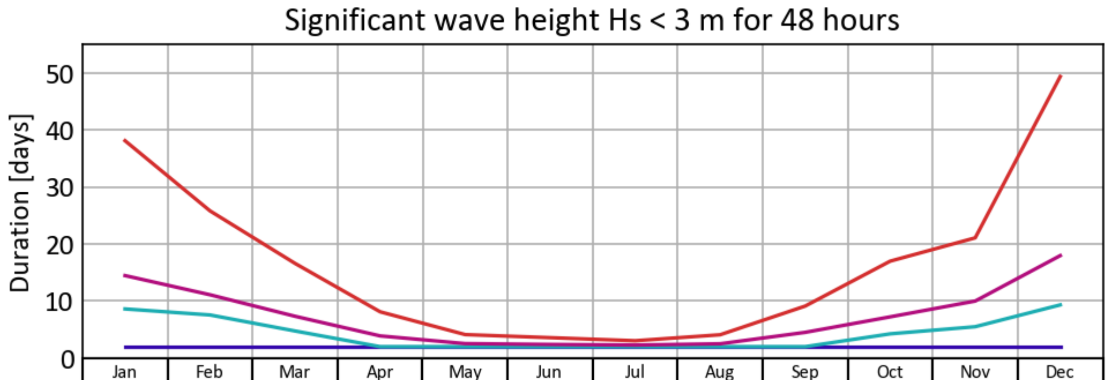
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P50	1.38	1.09	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.46
Mean	3.12	2.68	2.23	1.31	1.09	1.06	1.03	1.06	1.32	1.79	2.20	3.00
P90	7.92	5.96	5.00	2.20	1.00	1.00	1.00	1.00	2.27	3.62	4.83	6.94

Figure 3.38: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 4.0 m for 24 hours.



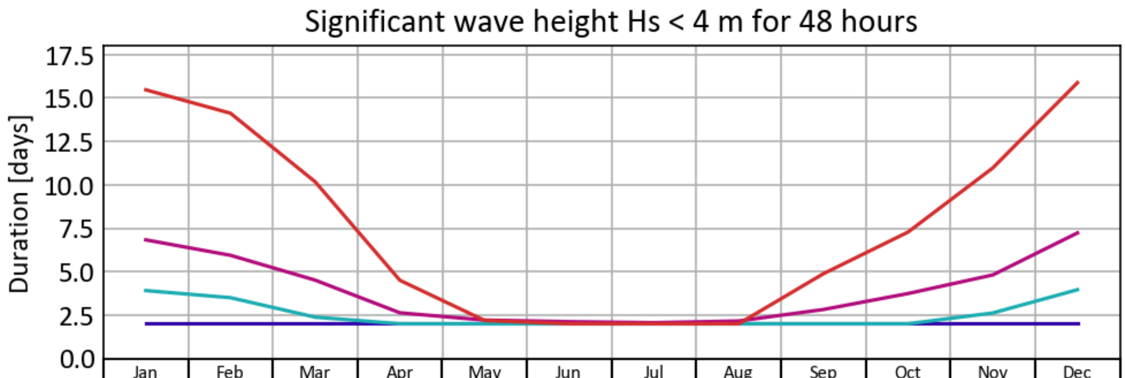
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	5.88	4.46	2.75	2.00	2.00	2.00	2.00	2.00	2.00	2.00	3.12	6.17
P50	37.00	28.21	13.56	6.00	3.04	2.19	2.00	2.00	6.25	12.50	25.12	36.56
Mean	41.57	30.81	17.23	7.93	4.51	3.79	3.15	4.83	13.68	25.02	44.79	49.25
P90	83.31	61.12	36.75	17.38	9.25	7.38	5.83	9.19	34.25	61.12	124.19	110.31

Figure 3.39: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 2.0 m for 48 hours.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
P50	8.62	7.56	4.75	2.00	2.00	2.00	2.00	2.00	2.00	4.25	5.50	9.33
Mean	14.47	11.10	7.33	3.89	2.54	2.39	2.28	2.51	4.51	7.23	10.00	17.97
P90	38.12	25.81	16.60	8.12	4.12	3.58	3.04	4.09	9.12	17.00	21.09	49.38

Figure 3.40: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 3.0 m for 48 hours.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P10	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
P50	3.91	3.50	2.38	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.62	3.96
Mean	6.83	5.94	4.51	2.63	2.21	2.12	2.06	2.16	2.82	3.74	4.81	7.23
P90	15.47	14.12	10.17	4.50	2.19	2.00	2.00	2.00	4.88	7.28	10.97	15.88

Figure 3.41: Characteristic durations, including waiting time, to perform operations limited by a significant wave height (H_S) of 4.0 m for 48 hours.

3.2 Current

3.2.1 Current data

Current data from measurements in the Haltenbanken area are not freely available, except for data from measurements at Station I1 at 65.02° N, 07.33° E (Figure 3.42). These data are measured with RCM current meters at 2 m depth during the period April 1981 to January 1984. There are gaps in the data series so that the effective length of the data series is only 0.79 years. The sample interval is 20 minutes.

Based on experience from other studies of the Norwegian coastal current in the region it is assumed that the currents at the fish-farm area A and B are similar to the currents at Station I1, but that the current speeds are expected to be about 30 % higher than I1 measurements suggests. Consequently; **the current speeds at Station I1 are increased by 30 % prior to computation to represent the currents at the areas A and B.**

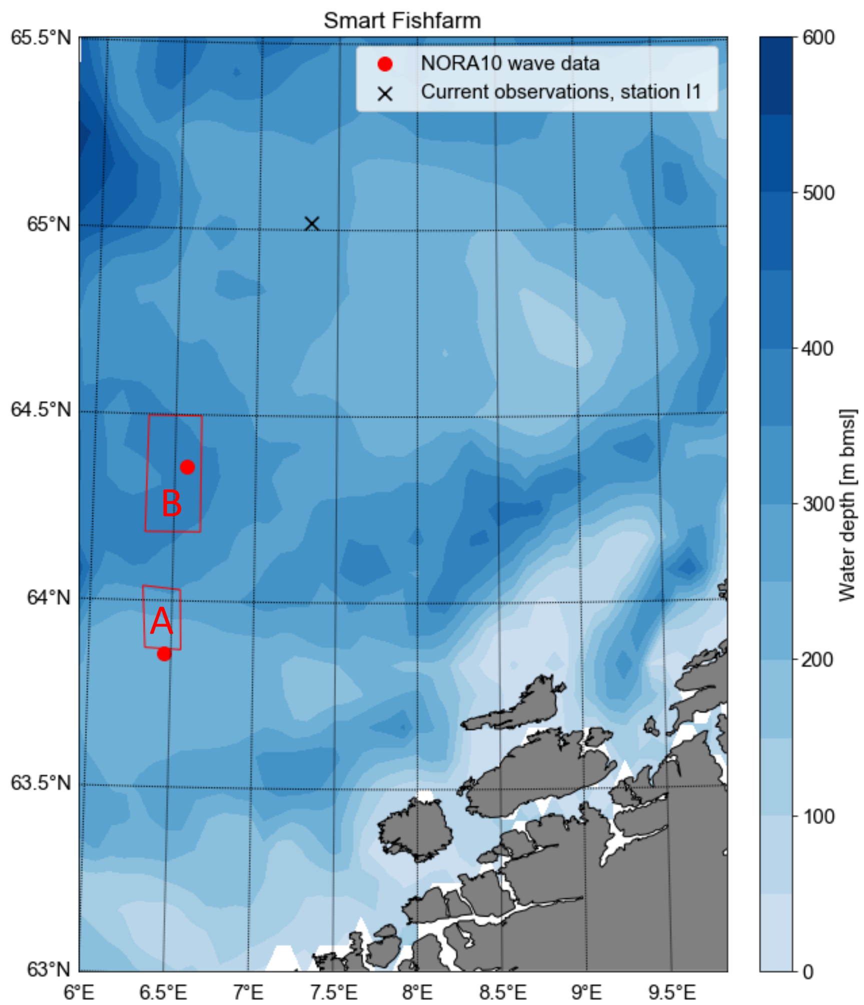


Figure 3.42: Current measurement Station I1 position relative to Haltenbanken Area A and B.

3.2.2 Current data statistics

Figure 3.43 shows the current rose at 2 m depth below mean sea level (bmsl).

Table 3.31 shows the corresponding distribution of non-exceedance. The current data applies for Haltenbanken area A and B.

Figure 3.44 shows the directional scatter density and mean, P99 and maximum current speed.

Monthly scatter density plot of current speed measured (Figure 3.45) demonstrates poor monthly coverage (periods of missing data) rendering monthly distribution and extreme analysis unreliable.

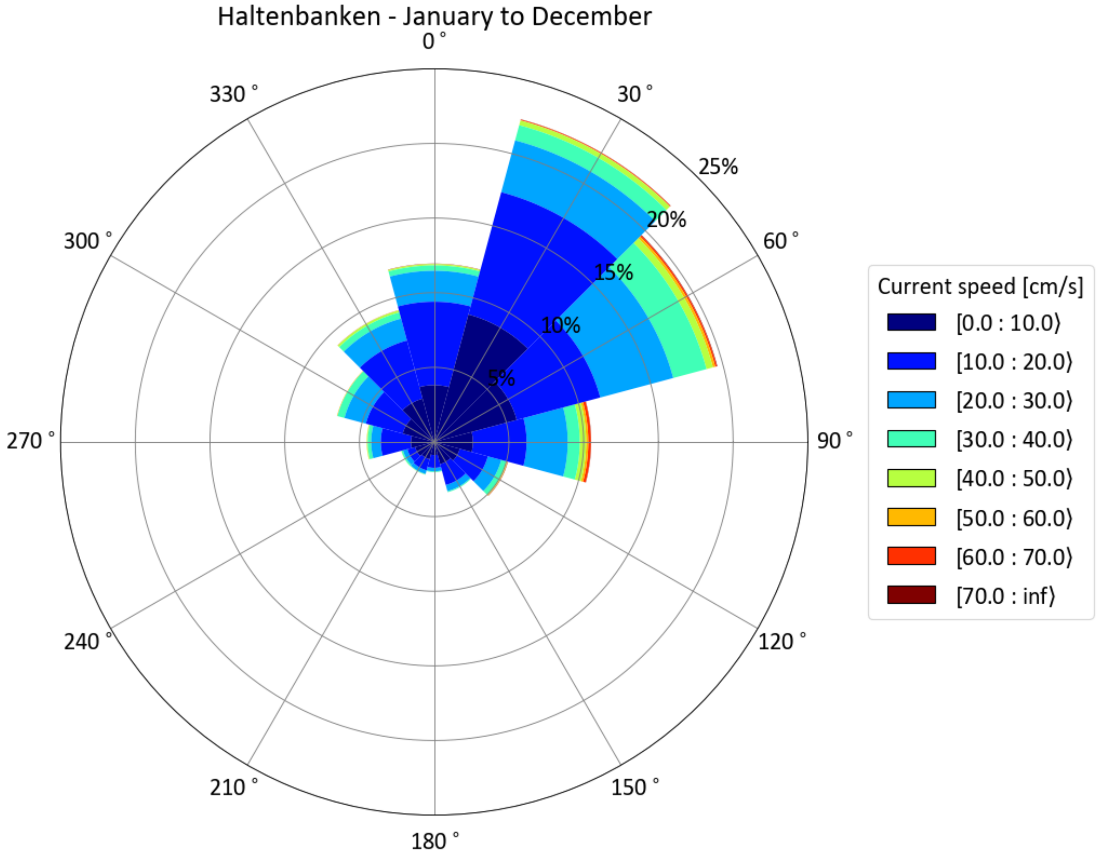


Figure 3.43: All year current rose for current speed [cm/s] at 2 m bmsl Haltenbanken.

Table 3.31: Directional sample distribution of non-exceedance [%] of current speed at 2 m depth.

Current speed [cm/s]	Current direction												Omni
	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°	
< 5	1.15	1.70	1.64	1.13	0.84	0.58	0.36	0.51	0.65	0.55	0.77	1.06	**10.95**
< 10	3.64	8.04	5.69	3.06	1.74	1.50	0.86	1.12	1.23	1.52	2.28	3.05	**33.74**
< 15	6.53	12.75	8.71	4.66	2.89	2.25	1.44	1.64	1.60	2.56	3.82	5.30	**54.15**
< 20	9.02	15.75	11.70	6.59	3.78	2.95	1.84	2.11	1.86	3.47	4.76	6.91	**70.74**
< 25	10.37	17.67	14.61	8.10	4.43	3.31	2.13	2.38	2.12	3.82	5.65	7.97	**82.56**
< 30	11.18	19.33	16.61	9.22	4.70	3.51	2.35	2.54	2.25	4.04	6.10	8.45	**90.29**
< 35	11.65	20.23	18.15	9.64	4.89	3.69	2.48	2.60	2.32	4.17	6.35	8.68	**94.85**
< 40	11.75	20.78	18.95	9.99	5.02	3.73	2.57	2.63	2.42	4.23	6.49	8.80	**97.36**
< 45	11.79	20.97	19.28	10.25	5.07	3.75	2.58	2.63	2.47	4.25	6.49	8.87	**98.40**
< 50	11.83	21.18	19.52	10.41	5.11	3.76		2.64	2.48	4.27	6.49	8.92	**99.20**
< 55	11.83	21.23	19.60	10.47	5.14					4.27	6.52	8.92	**99.45**
< 60	11.85	21.24	19.65	10.53	5.14					4.28		8.92	**99.59**
< 65	11.85	21.30	19.70	10.66	5.14							8.93	**99.85**
< 70	11.85	21.30	19.73	10.67	5.15								**99.91**
< 75	11.86	21.30	19.75	10.69	5.17								**99.97**
< 80		21.32	19.76										**100.00**
Total	**11.86**	**21.32**	**19.76**	**10.69**	**5.17**	**3.76**	**2.58**	**2.64**	**2.48**	**4.28**	**6.52**	**8.93**	**100.00**
Mean	15.1	15.4	18.5	18.6	15.5	14.0	15.3	13.1	13.4	14.1	14.7	14.4	16.0
P99	37.0	47.0	52.9	61.6	46.4	39.0	37.9	35.1	40.8	41.0	38.5	42.1	48.1
Maximum	71.2	77.6	77.0	74.0	72.6	48.4	40.5	45.5	47.9	55.1	54.4	63.5	77.6

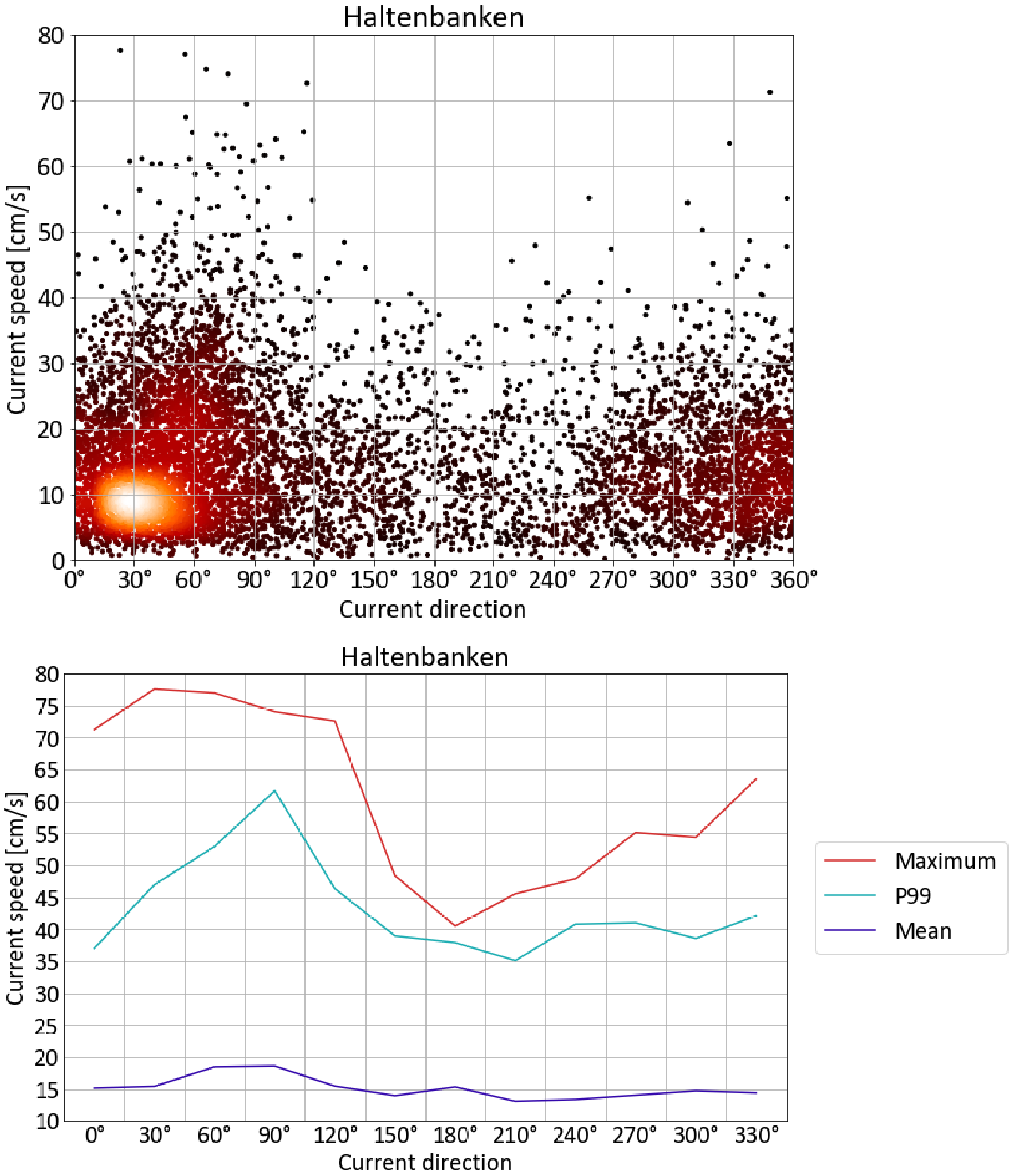


Figure 3.44: Directional scatter density plot (top) and mean, P99 and maximum (bottom) of current speed measured at Haltenbanken, Station I1.

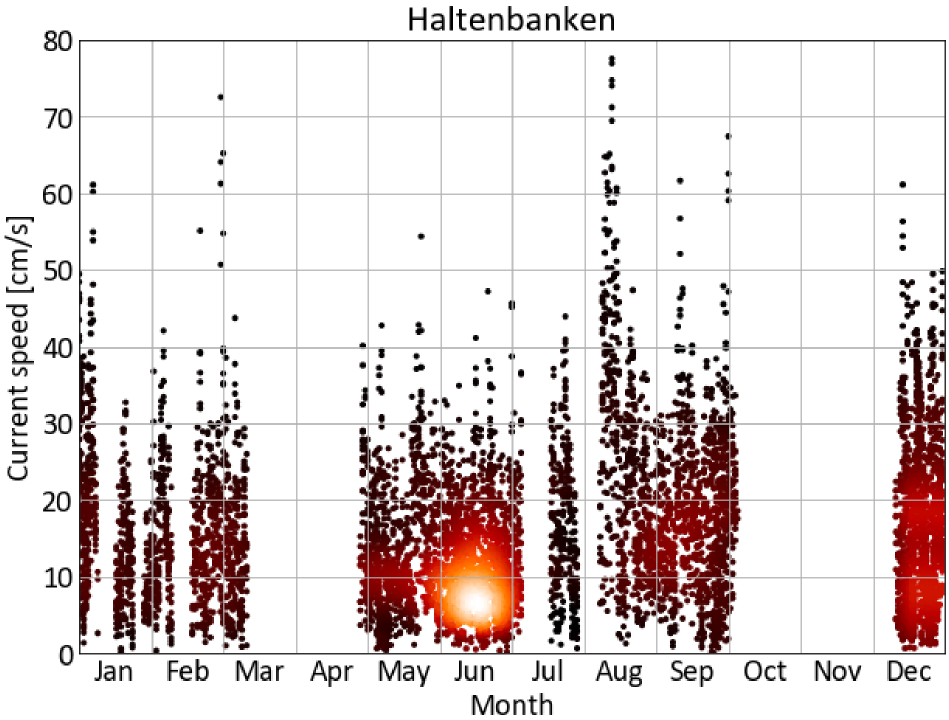


Figure 3.45: Monthly scatter density plot of current speed measured at Haltenbanken, Station I1.

3.2.3 Long-term current statistics

The long-term distribution of current speed is modelled in terms of a three parameter Weibull distribution as described in Section 3.6.1. Table 3.32 shows the Weibull parameters and estimated extremes. Figure 3.46 shows directional extreme values of current speed at 2 m depth.

The current speed may be assumed to reduce linearly by about 35 % from surface to 50 m depth and then constant below 50 m.

Table 3.32: Directional and omni-directional Weibull parameters and corresponding extreme values of current speed at 2 m depth. The direction extremes are adjusted in agreement with NORSOK Standard N-003:2017 [1, Section 6.1.4]. Duration of extreme event is 10 minutes.

Direction sector	Sector prob.	Weibull parameters			Return period [years]			
		Shape	Scale	Location	1	10	50	100
-	[%]	-	[cm/s]	[cm/s]	[cm/s]	[cm/s]	[cm/s]	[cm/s]
0°	11.86	1.46	13.49	2.90	71	81	87	90
30°	21.32	1.28	13.93	2.53	93	108	118	122
60°	19.76	1.50	19.96	0.57	97	112	122	125
90°	10.69	1.37	18.57	1.62	97	112	122	126
120°	5.17	1.24	14.17	2.26	90	107	118	123
150°	3.76	1.63	15.89	-0.22	62	71	77	80
180°	2.58	2.05	20.79	-3.07	58	65	69	71
210°	2.64	1.72	15.88	-1.06	56	64	69	71
240°	2.48	1.55	17.51	-2.39	70	81	89	92
270°	4.28	1.41	13.30	1.91	68	79	86	89
300°	6.52	1.67	16.12	0.32	64	72	78	80
330°	8.93	1.44	13.68	2.01	71	81	88	91
0°-360°	**100.00**	**1.310**	**15.36**	**1.93**	**97**	**112**	**122**	**126**

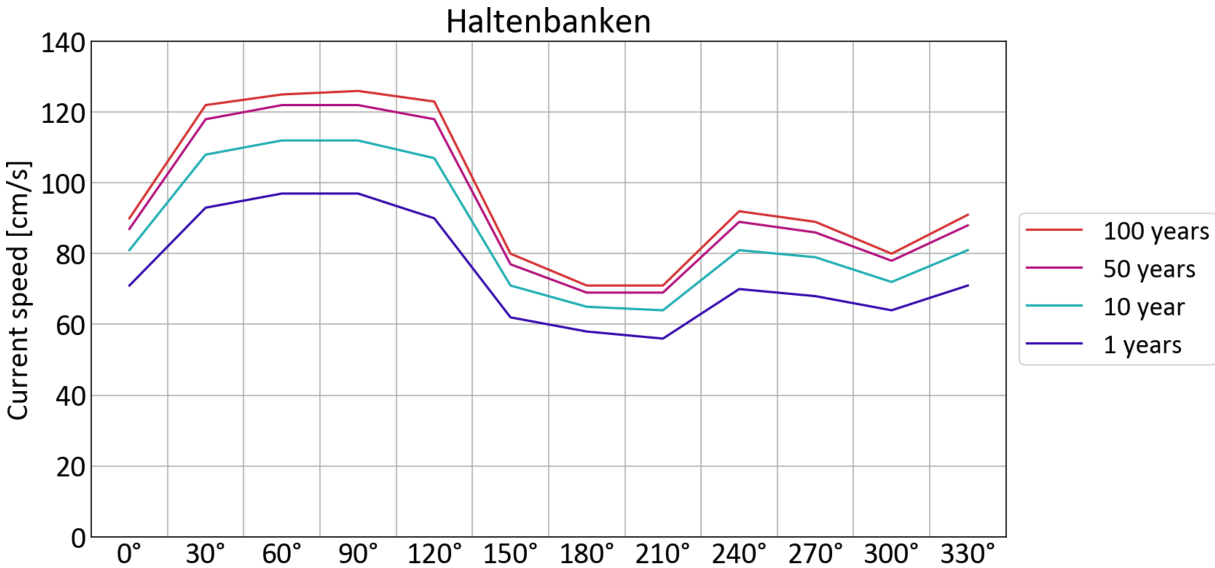


Figure 3.46: Directional extreme values of current speed (increased by 30 %) of annual probability of exceedance of 1, 10, 50 and 100 year return period at 2 m depth. The direction extremes are adjusted in agreement with NORSOK Standard N-003:2017 [1, Section 6.1.4].

3.3 Water Level

3.3.1 Tidal elevations, Haltenbanken Area A

Tidal variations at Haltenbanken Area A have been computed using the NAO99.b tidal prediction system [5]. Figure 3.47 shows the tidal variations during a lunar month at the time of the highest astronomical tide. Table 3.33 shows different tide levels.

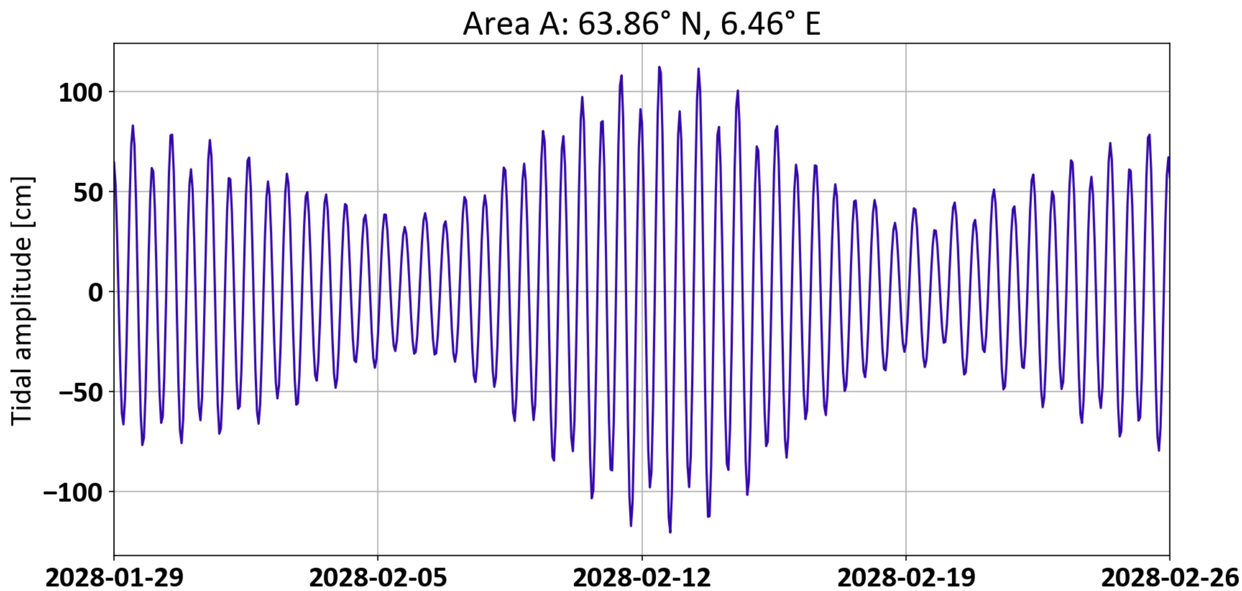


Figure 3.47: Tidal variations during a lunar month (27.55 days) at the time of the highest astronomical tide (HAT).

Table 3.33: Tidal levels at Haltenbanken Area A relative to mean sea level.

Tidal datum		Tide level [cm]
HAT	Highest astronomical tide	113
MHWS	Mean high water springs	86
MHHW	Mean higher high water	69
MHW	Mean high water	64
MHWN	Mean high water neaps	40
MWL	Mean water level	0
MLWN	Mean low water neaps	-41
MLW	Mean low water	-64
MLLW	Mean lower low water	-70
MLWS	Mean low water springs	-87
LAT	Lowest astronomical tides	-122

3.3.2 Tidal elevations, Haltenbanken Area B

Tidal variations at Haltenbanken Area B have been computed using the NAO99.b tidal prediction system [5]. Figure 3.47 shows the tidal variations during a lunar month at the time of the highest astronomical tide. Table 3.33 shows different tide levels.

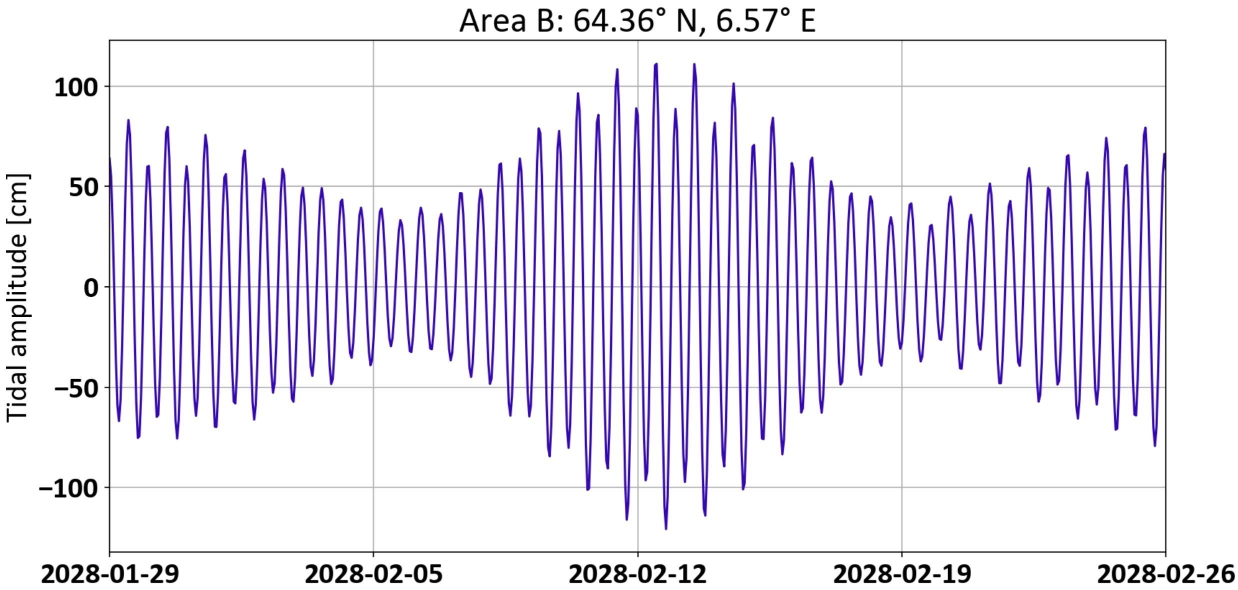


Figure 3.48: Tidal variations during a lunar month (27.55 days) at the time of the highest astronomical tide (HAT).

Table 3.34: Tidal levels at Haltenbanken Area B relative to mean sea level.

Tidal datum		Tide level [cm]
HAT	Highest astronomical tide	113
MHWS	Mean high water springs	86
MHHW	Mean higher high water	69
MHW	Mean high water	64
MHWN	Mean high water neaps	40
MWL	Mean water level	0
MLWN	Mean low water neaps	-41
MLW	Mean low water	-64
MLLW	Mean lower low water	-70
MLWS	Mean low water springs	-87
LAT	Lowest astronomical tides	-121

3.3.3 Storm surge

Storm surges in the open ocean are generally due to increase in water level because of reduced barometric air pressure; called pressure surge. The “rule of thumb” is that a reduction in barometric pressure by 1 hPa increases the water level by 0.01 m (1 cm).

Storm surge data are obtained from the NEXTRA hindcast data base [7]. The storm surge with annual probability of exceedance of 10^{-2} and 10^{-4} are estimated to be about 1.0 m and 1.3 m respectively.

3.3.4 Sea level rise

An additional rise in water level may be due to climatic effects; e.g. thermal expansion of the oceans and melting of glaziers. The likely change in mean sea level over the 50 years is about 0.25 m, NORSOK Standard N-003:2017, [1, Chapter A2].

3.4 Sea water properties

Sea salinity and temperature profiles and their standard deviation σ are available from the World Ocean Atlas 2013 [6].

The minimum and maximum sea temperatures may be approximated by:

$$T_{Minimum} = T_{Mean} - 3.5 \cdot \sigma_T \tag{3.3}$$

$$T_{Maximum} = T_{Mean} + 3.5 \cdot \sigma_T \tag{3.4}$$

where σ_T is the standard deviation in sea temperature.

Cold water events in the northern part of the Norwegian Trench occur, by definition, when the sea water temperature drops below 5 °C. The drop in sea water temperature is due to intrusion of a combination (mixture) of North Icelandic water and Arctic intermediate water with temperatures in the range 2 – 4 °C generally found at depths between 400 and 500 m in the Norwegian Sea.

The intrusion of cold water into the Norwegian Trench is most likely due to a disturbance of the (sea water) density field in the Norwegian Sea causing water at greater depths to be lifted upwards. This may result from internal waves generated by atmospheric forcing; i.e. by atmospheric pressure variations over the North Atlantic. This may, however, not be the only cause.

3.4.1 Sea temperature, Area A

Figure 3.49 and Table 3.35 show monthly mean sea temperature profiles at Haltenbanken Area A.

Table 3.36 shows the corresponding standard deviations and Table 3.37 and Table 3.38 show the monthly minimum and maximum sea temperatures derived from (3.3) and (3.4).

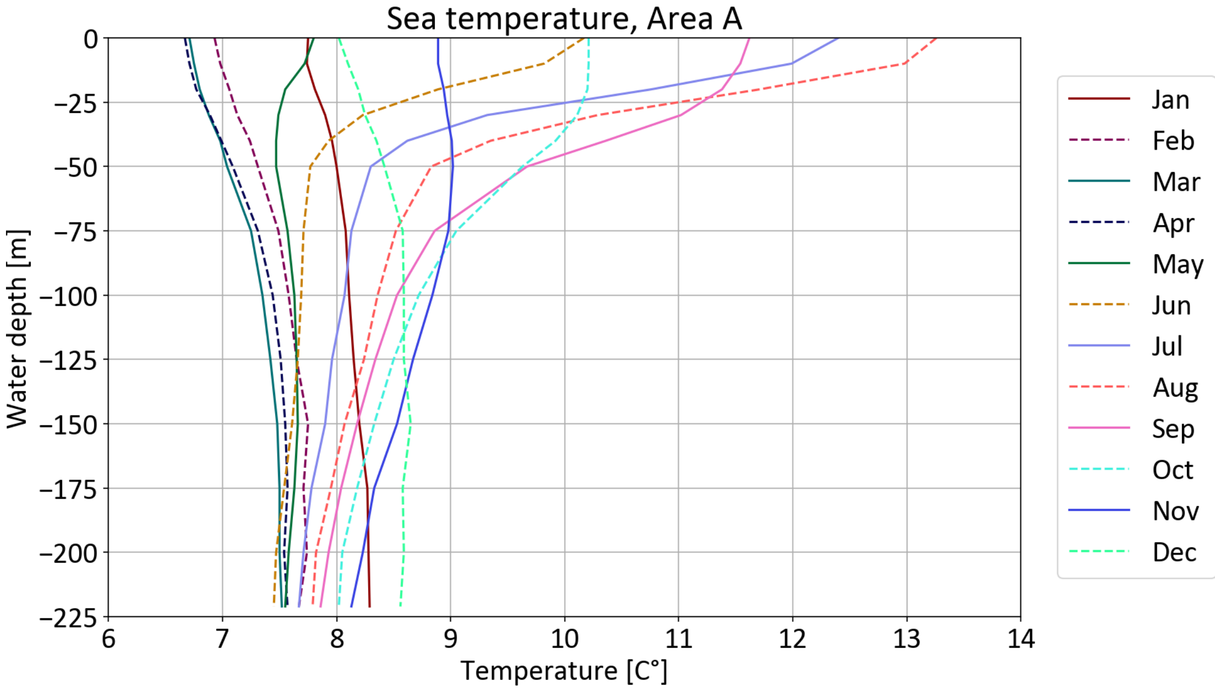


Figure 3.49: Monthly sea temperature profiles for Haltenbanken Area A.

Table 3.35: Monthly mean sea temperature [°C] at selected water depths for Haltenbanken Area A.

Depth [m]	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
0	7.8	6.9	6.7	6.7	7.8	10.2	12.4	13.3	11.6	10.2	8.9	8.0
-10	7.7	7.0	6.8	6.7	7.7	9.8	12.0	13.0	11.5	10.2	8.9	8.1
-20	7.8	7.1	6.8	6.8	7.5	8.9	10.8	11.7	11.4	10.2	8.9	8.2
-30	7.9	7.1	6.9	6.9	7.5	8.2	9.3	10.3	11.0	10.1	9.0	8.2
-40	8.0	7.2	7.0	7.0	7.5	7.9	8.6	9.3	10.4	9.9	9.0	8.3
-50	8.0	7.3	7.0	7.1	7.5	7.8	8.3	8.8	9.7	9.6	9.0	8.4
-75	8.1	7.5	7.2	7.3	7.6	7.7	8.1	8.5	8.9	9.1	9.0	8.6
-100	8.1	7.6	7.3	7.4	7.6	7.7	8.1	8.4	8.5	8.7	8.8	8.6
-125	8.2	7.7	7.4	7.5	7.7	7.7	8.0	8.2	8.3	8.5	8.7	8.6
-150	8.2	7.8	7.5	7.5	7.7	7.6	7.9	8.1	8.2	8.3	8.5	8.7
-175	8.3	7.7	7.5	7.6	7.6	7.5	7.8	8.0	8.0	8.2	8.3	8.6
-200	8.3	7.7	7.5	7.5	7.6	7.5	7.7	7.8	7.9	8.1	8.2	8.6
-221	8.3	7.7	7.5	7.6	7.5	7.5	7.7	7.8	7.9	8.0	8.1	8.6

Table 3.36: Standard deviation of the monthly mean sea temperature [°C] at selected water depths for at Haltenbanken Area A.

Depth [m]	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
0	0.59	0.91	0.93	0.77	0.83	1.38	1.09	1.05	0.86	1.05	0.59	1.11
-10	0.57	0.86	0.90	0.74	0.80	1.54	1.06	1.01	0.80	1.03	0.62	1.01
-20	0.52	0.85	0.86	0.73	0.68	1.07	1.34	1.27	0.76	1.09	0.66	0.89
-30	0.52	0.84	0.86	0.72	0.66	0.95	1.28	1.09	0.95	0.97	0.70	0.71
-40	0.51	0.86	0.83	0.72	0.67	0.89	1.08	0.94	1.10	0.86	0.69	0.43
-50	0.49	0.88	0.82	0.71	0.68	0.87	0.92	0.83	1.26	0.89	0.69	0.35
-75	0.42	0.81	0.74	0.67	0.59	0.66	0.85	0.72	0.98	0.95	0.65	0.37
-100	0.39	0.63	0.59	0.63	0.51	0.52	0.66	0.61	0.72	0.73	0.48	0.37
-125	0.38	0.55	0.58	0.54	0.46	0.46	0.57	0.52	0.61	0.59	0.40	0.37
-150	0.33	0.49	0.51	0.48	0.42	0.37	0.52	0.48	0.51	0.52	0.32	0.40
-175	0.32	0.48	0.46	0.42	0.40	0.36	0.55	0.38	0.50	0.52	0.28	0.38
-200	0.31	0.44	0.42	0.39	0.39	0.33	0.55	0.44	0.49	0.55	0.32	0.37
-221	0.30	0.41	0.43	0.40	0.43	0.36	0.56	0.36	0.49	0.43	0.38	0.34

Table 3.37: Monthly minimum sea temperature [°C] at selected water depths for at Haltenbanken Area A.

Depth [m]	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
0	5.7	3.7	3.5	4.0	4.9	5.3	8.6	9.6	8.6	6.5	6.8	4.1
-10	5.7	4.0	3.6	4.1	4.9	4.4	8.3	9.4	8.7	6.6	6.7	4.6
-20	6.0	4.1	3.8	4.2	5.2	5.1	6.1	7.3	8.7	6.4	6.6	5.1
-30	6.1	4.2	3.9	4.4	5.2	4.9	4.8	6.5	7.7	6.7	6.5	5.8
-40	6.2	4.2	4.1	4.5	5.1	4.8	4.8	6.1	6.5	6.9	6.6	6.8
-50	6.3	4.2	4.2	4.6	5.1	4.7	5.1	5.9	5.3	6.5	6.6	7.2
-75	6.6	4.7	4.7	5.0	5.5	5.4	5.2	6.0	5.4	5.7	6.7	7.3
-100	6.7	5.4	5.3	5.2	5.8	5.9	5.8	6.2	6.0	6.2	7.2	7.3
-125	6.8	5.7	5.4	5.6	6.0	6.0	6.0	6.4	6.2	6.4	7.3	7.3
-150	7.0	6.0	5.7	5.9	6.2	6.3	6.1	6.4	6.4	6.5	7.4	7.2
-175	7.1	6.0	5.9	6.1	6.2	6.3	5.9	6.6	6.3	6.4	7.3	7.2
-200	7.2	6.2	6.0	6.2	6.2	6.3	5.8	6.3	6.2	6.1	7.1	7.3
-221	7.2	6.2	6.0	6.2	6.0	6.2	5.7	6.5	6.1	6.5	6.8	7.4

Table 3.38: Monthly maximum sea temperature [°C] at selected water depths for at Haltenbanken Area A.

Depth [m]	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
0	9.8	10.1	10.0	9.4	10.7	15.0	16.2	16.9	14.6	13.9	11.0	11.9
-10	9.7	10.0	9.9	9.3	10.5	15.2	15.7	16.5	14.3	13.8	11.1	11.6
-20	9.6	10.0	9.8	9.3	9.9	12.6	15.4	16.2	14.0	14.0	11.2	11.3
-30	9.7	10.1	9.9	9.4	9.8	11.6	13.8	14.1	14.3	13.5	11.4	10.7
-40	9.7	10.2	9.9	9.5	9.8	11.0	12.4	12.6	14.2	12.9	11.4	9.9
-50	9.7	10.4	9.9	9.6	9.8	10.8	11.5	11.7	14.1	12.7	11.4	9.6
-75	9.6	10.3	9.8	9.7	9.6	10.0	11.1	11.0	12.3	12.4	11.3	9.9
-100	9.5	9.8	9.4	9.6	9.4	9.5	10.4	10.5	11.0	11.3	10.5	9.9
-125	9.5	9.6	9.4	9.4	9.3	9.3	10.0	10.1	10.5	10.6	10.1	9.9
-150	9.4	9.5	9.3	9.2	9.1	8.9	9.7	9.8	10.0	10.2	9.6	10.1
-175	9.4	9.4	9.1	9.0	9.0	8.8	9.7	9.3	9.8	10.0	9.3	9.9
-200	9.4	9.3	9.0	8.9	8.9	8.6	9.6	9.4	9.6	10.0	9.4	9.9
-221	9.3	9.1	9.0	9.0	9.1	8.7	9.6	9.1	9.6	9.5	9.5	9.8

3.4.2 Sea temperature, Area B

Figure 3.50 and Table 3.39 shows monthly mean sea temperature profiles for Haltenbanken Area B. Table 3.40 shows the corresponding standard deviations and Table 3.41 and Table 3.42 show the monthly minimum and maximum sea temperatures derived from (3.3) and (3.4).

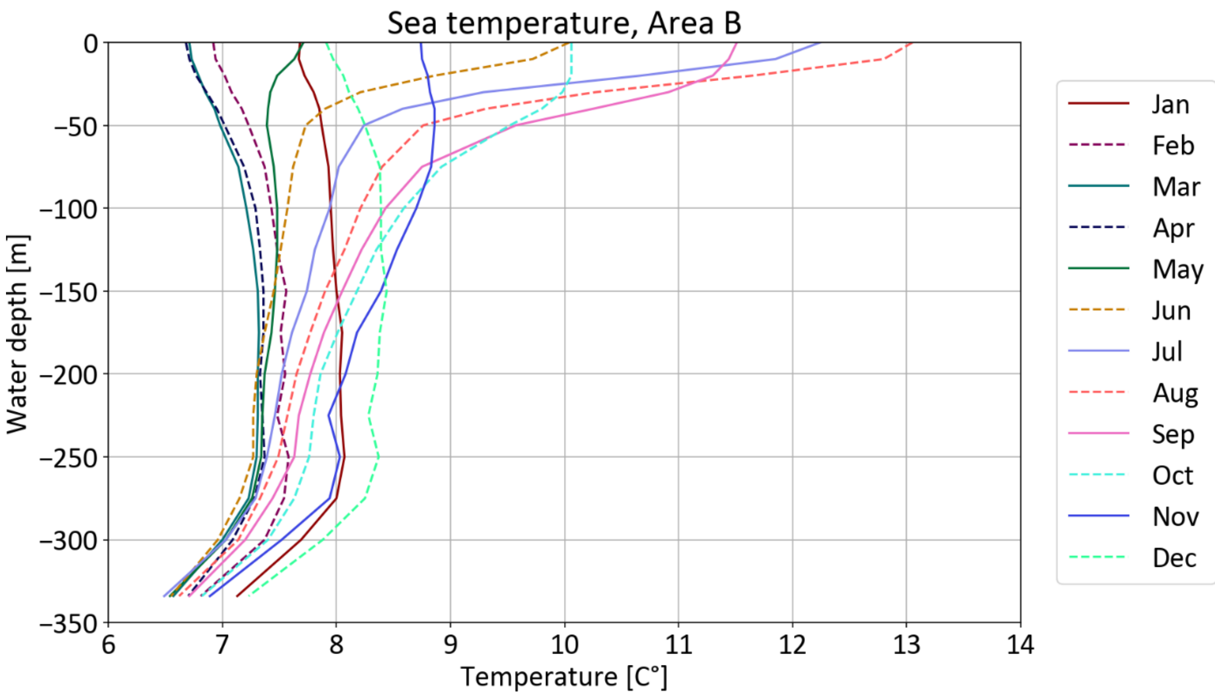


Figure 3.50: Monthly sea temperature profiles for Haltenbanken Area B.

Table 3.39: Monthly mean sea temperature [°C] at selected water depths for Haltenbanken Area B.

Depth [m]	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
0	7.7	6.9	6.7	6.7	7.7	10.0	12.2	13.1	11.5	10.1	8.7	7.9
-10	7.7	6.9	6.7	6.7	7.6	9.7	11.8	12.8	11.4	10.1	8.8	8.0
-20	7.7	7.0	6.8	6.8	7.5	8.9	10.7	11.7	11.3	10.1	8.8	8.1
-30	7.8	7.1	6.8	6.9	7.4	8.2	9.3	10.3	10.9	10.0	8.8	8.1
-40	7.8	7.2	6.9	7.0	7.4	7.9	8.6	9.3	10.2	9.8	8.9	8.2
-50	7.9	7.2	7.0	7.0	7.4	7.7	8.2	8.8	9.6	9.5	8.9	8.2
-75	7.9	7.4	7.1	7.2	7.5	7.6	8.0	8.4	8.8	8.9	8.8	8.4
-100	8.0	7.4	7.2	7.3	7.5	7.6	7.9	8.2	8.4	8.6	8.7	8.4
-125	8.0	7.5	7.3	7.3	7.5	7.5	7.8	8.1	8.2	8.3	8.5	8.4
-150	8.0	7.6	7.3	7.4	7.5	7.5	7.7	7.9	8.1	8.2	8.4	8.4
-175	8.1	7.5	7.3	7.4	7.4	7.4	7.6	7.8	7.9	8.0	8.2	8.4
-200	8.0	7.5	7.3	7.3	7.4	7.3	7.5	7.7	7.8	7.9	8.1	8.4
-225	8.0	7.5	7.3	7.3	7.3	7.3	7.5	7.6	7.7	7.8	7.9	8.3
-250	8.1	7.6	7.3	7.4	7.3	7.3	7.4	7.5	7.6	7.8	8.0	8.4
-275	8.0	7.5	7.2	7.3	7.3	7.2	7.3	7.3	7.4	7.6	7.9	8.2
-300	7.7	7.4	7.0	7.1	7.0	7.0	7.0	7.1	7.2	7.4	7.5	7.9
-334	7.1	6.8	6.6	6.7	6.5	6.5	6.5	6.6	6.7	6.8	6.9	7.2

Table 3.40: Standard deviation of the monthly mean sea temperature [°C] at selected water depths for Haltenbanken Area B.

Depth [m]	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
0	0.39	0.67	0.69	0.69	0.80	1.36	0.96	1.05	0.80	0.88	0.45	1.03
-10	0.39	0.63	0.66	0.67	0.68	1.40	0.93	0.98	0.88	0.83	0.45	0.90
-20	0.38	0.66	0.66	0.62	0.55	1.00	1.03	1.24	0.83	0.86	0.50	0.87
-30	0.38	0.68	0.68	0.60	0.50	0.95	1.22	1.20	0.89	0.68	0.55	0.70
-40	0.37	0.77	0.67	0.61	0.53	0.83	0.96	0.78	0.96	0.58	0.53	0.39
-50	0.37	0.83	0.67	0.59	0.54	0.78	0.75	0.60	1.09	0.70	0.55	0.32
-75	0.38	0.89	0.64	0.56	0.53	0.66	0.63	0.56	0.80	0.80	0.55	0.33
-100	0.39	0.67	0.46	0.53	0.49	0.56	0.54	0.54	0.64	0.67	0.44	0.32
-125	0.39	0.69	0.56	0.51	0.46	0.53	0.45	0.51	0.54	0.54	0.41	0.40
-150	0.39	0.60	0.46	0.48	0.46	0.46	0.36	0.49	0.47	0.49	0.30	0.49
-175	0.39	0.59	0.46	0.47	0.45	0.46	0.34	0.48	0.47	0.46	0.29	0.47
-200	0.38	0.52	0.44	0.46	0.47	0.44	0.32	0.52	0.46	0.49	0.31	0.43
-225	0.34	0.49	0.45	0.47	0.49	0.47	0.27	0.47	0.51	0.50	0.34	0.51
-250	0.20	0.52	0.45	0.48	0.48	0.44	0.28	0.48	0.47	0.28	0.31	0.45
-275	0.00	0.44	0.44	0.51	0.50	0.46	0.25	0.47	0.50	0.32	0.27	0.34
-300	0.00	0.14	0.44	0.52	0.49	0.48	0.26	0.55	0.53	0.21	0.20	0.00
-334	0.42	0.12	0.42	0.42	0.43	0.47	0.24	0.70	0.66	0.21	0.12	0.00

Table 3.41: Monthly minimum sea temperature [°C] at selected water depths for Haltenbanken Area B.

Depth	Month											
[m]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
0	6.3	4.6	4.3	4.3	4.9	5.3	8.9	9.4	8.7	7.0	7.2	4.3
-10	6.3	4.7	4.4	4.4	5.2	4.8	8.6	9.4	8.4	7.2	7.2	4.8
-20	6.4	4.7	4.5	4.6	5.6	5.4	7.1	7.3	8.4	7.1	7.1	5.0
-30	6.5	4.7	4.5	4.8	5.7	4.9	5.0	6.1	7.8	7.6	6.9	5.7
-40	6.6	4.5	4.6	4.8	5.5	5.0	5.2	6.6	6.9	7.8	7.0	6.8
-50	6.6	4.3	4.6	5.0	5.5	5.0	5.6	6.7	5.8	7.1	6.9	7.1
-75	6.6	4.3	4.9	5.2	5.6	5.3	5.8	6.4	5.9	6.1	6.9	7.2
-100	6.6	5.1	5.6	5.4	5.8	5.6	6.1	6.3	6.2	6.2	7.2	7.3
-125	6.6	5.1	5.3	5.5	5.9	5.7	6.2	6.3	6.3	6.5	7.1	7.0
-150	6.6	5.5	5.7	5.7	5.8	5.8	6.5	6.2	6.4	6.5	7.3	6.7
-175	6.7	5.4	5.7	5.7	5.9	5.8	6.4	6.1	6.2	6.4	7.2	6.7
-200	6.7	5.7	5.8	5.7	5.7	5.8	6.4	5.8	6.2	6.1	7.0	6.9
-225	6.8	5.8	5.7	5.7	5.6	5.6	6.5	5.9	5.9	6.0	6.7	6.5
-250	7.4	5.8	5.7	5.7	5.7	5.7	6.4	5.8	6.0	6.8	6.9	6.8
-275	8.0	6.0	5.7	5.5	5.5	5.5	6.4	5.7	5.7	6.5	7.0	7.1
-300	7.7	6.9	5.5	5.3	5.3	5.3	6.1	5.2	5.3	6.7	6.8	7.9
-334	5.7	6.4	5.1	5.2	5.0	4.9	5.7	4.2	4.4	6.1	6.5	7.2

Table 3.42: Monthly maximum sea temperature [°C] at selected water depths for Haltenbanken Area B.

Depth	Month											
[m]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
0	9.0	9.3	9.1	9.1	10.5	14.8	15.6	16.7	14.3	13.1	10.3	11.5
-10	9.0	9.1	9.0	9.1	10.0	14.6	15.1	16.2	14.5	13.0	10.3	11.1
-20	9.1	9.3	9.1	8.9	9.4	12.4	14.3	16.0	14.2	13.1	10.6	11.1
-30	9.1	9.5	9.2	9.0	9.2	11.5	13.6	14.5	14.0	12.4	10.7	10.6
-40	9.1	9.9	9.3	9.1	9.3	10.8	11.9	12.0	13.6	11.8	10.7	9.6
-50	9.2	10.1	9.3	9.1	9.3	10.5	10.9	10.9	13.4	12.0	10.8	9.4
-75	9.3	10.5	9.4	9.2	9.3	9.9	10.2	10.4	11.6	11.7	10.8	9.5
-100	9.3	9.8	8.8	9.1	9.2	9.5	9.8	10.1	10.7	10.9	10.2	9.5
-125	9.3	9.9	9.2	9.1	9.1	9.4	9.4	9.9	10.1	10.2	10.0	9.8
-150	9.4	9.7	8.9	9.0	9.1	9.1	9.0	9.6	9.7	9.9	9.4	10.2
-175	9.4	9.6	8.9	9.0	9.0	9.0	8.8	9.4	9.5	9.6	9.2	10.0
-200	9.4	9.4	8.8	8.9	9.0	8.8	8.6	9.5	9.4	9.6	9.2	9.9
-225	9.2	9.2	8.9	9.0	9.1	8.9	8.4	9.2	9.5	9.6	9.1	10.1
-250	8.8	9.4	8.9	9.1	9.0	8.8	8.4	9.2	9.3	8.7	9.1	9.9
-275	8.0	9.1	8.8	9.1	9.0	8.8	8.2	9.0	9.2	8.8	8.9	9.4
-300	7.7	7.9	8.5	8.9	8.7	8.6	7.9	9.1	9.1	8.1	8.2	7.9
-334	8.6	7.2	8.0	8.2	8.0	8.2	7.3	9.1	9.0	7.6	7.3	7.2

3.4.3 Sea salinity, Area A

Figure 3.51 shows monthly mean salinity profiles for Haltenbanken Area A.

Table 3.43 shows monthly mean salinity at selected depths and Table 3.44 shows the corresponding standard deviations.

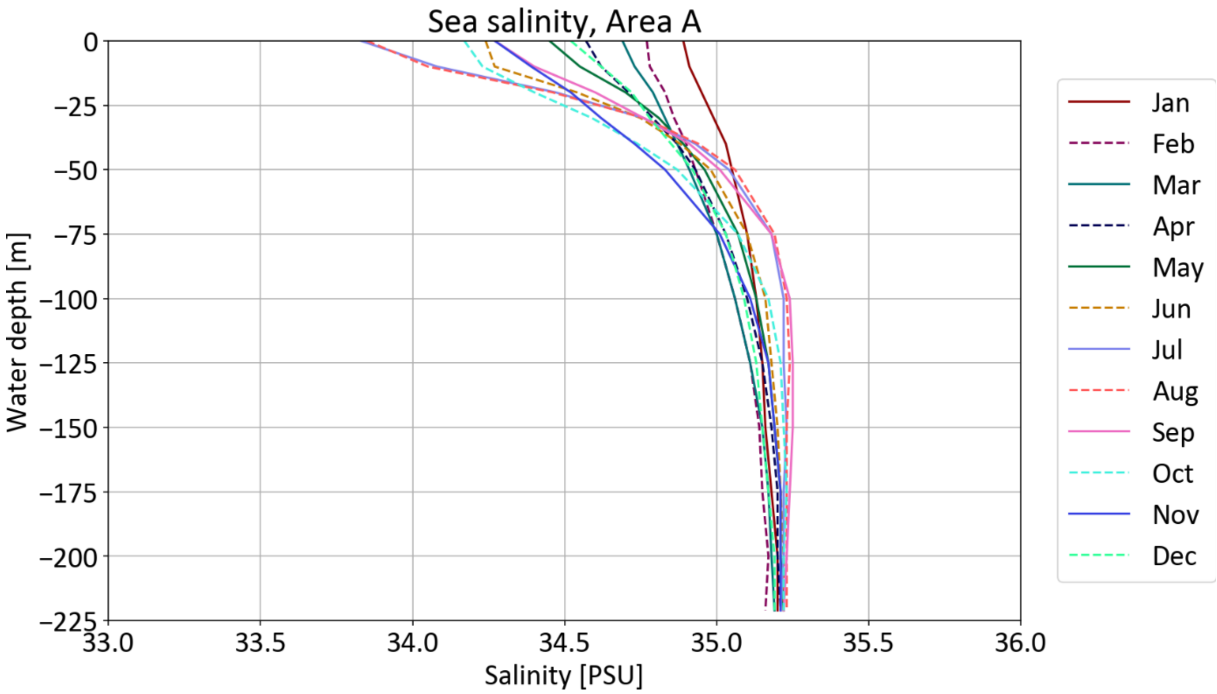


Figure 3.51: Monthly mean sea salinity profiles for Haltenbanken Area A.

Table 3.43: Monthly mean sea salinity at selected water depths for Haltenbanken Area A.

Depth	Month											
[m]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
0	34.89	34.77	34.69	34.57	34.45	34.24	33.83	33.85	34.27	34.17	34.27	34.52
-10	34.91	34.78	34.73	34.62	34.55	34.27	34.08	34.05	34.40	34.23	34.39	34.62
-20	34.95	34.83	34.79	34.71	34.70	34.54	34.47	34.46	34.60	34.40	34.52	34.72
-30	34.99	34.86	34.83	34.79	34.81	34.75	34.76	34.76	34.76	34.59	34.62	34.78
-40	35.03	34.90	34.87	34.87	34.89	34.88	34.93	34.94	34.91	34.74	34.73	34.85
-50	35.05	34.93	34.91	34.93	34.96	34.98	35.04	35.06	35.01	34.87	34.83	34.92
-75	35.10	35.00	35.00	35.03	35.07	35.10	35.18	35.19	35.18	35.07	35.01	35.03
-100	35.13	35.06	35.06	35.10	35.13	35.16	35.22	35.23	35.24	35.17	35.11	35.09
-125	35.15	35.11	35.11	35.15	35.17	35.18	35.22	35.24	35.25	35.21	35.17	35.13
-150	35.16	35.14	35.15	35.18	35.19	35.20	35.23	35.23	35.25	35.22	35.19	35.15
-175	35.18	35.15	35.17	35.20	35.21	35.21	35.22	35.23	35.24	35.23	35.21	35.17
-200	35.20	35.17	35.18	35.20	35.21	35.22	35.22	35.23	35.23	35.22	35.21	35.19
-221	35.20	35.16	35.19	35.21	35.22	35.22	35.21	35.23	35.22	35.22	35.21	35.19

Table 3.44: Standard deviation of the monthly mean sea salinity at selected water depths for Haltenbanken Area A.

Depth [m]	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
0	0.50	0.42	1.21	0.57	0.56	0.58	0.76	0.72	1.29	0.74	0.75	0.54
-10	0.48	0.40	0.48	0.48	0.53	0.58	0.67	0.68	1.17	0.75	0.69	0.53
-20	0.41	0.38	0.43	0.44	0.47	0.55	0.64	0.46	0.64	0.70	0.68	0.49
-30	0.36	0.35	0.40	0.41	0.42	0.50	0.46	0.36	0.31	0.63	0.66	0.42
-40	0.33	0.35	0.37	0.37	0.38	0.36	0.34	0.32	0.26	0.54	0.63	0.30
-50	0.33	0.34	0.36	0.35	0.34	0.32	0.25	0.27	0.24	0.48	0.54	0.24
-75	0.26	0.32	0.30	0.28	0.23	0.24	0.16	0.22	0.13	0.33	0.36	0.14
-100	0.17	0.26	0.25	0.22	0.16	0.16	0.10	0.19	0.09	0.15	0.19	0.07
-125	0.12	0.21	0.20	0.16	0.12	0.13	0.06	0.08	0.07	0.13	0.14	0.07
-150	0.10	0.17	0.14	0.11	0.10	0.10	0.04	0.05	0.07	0.10	0.07	0.08
-175	0.08	0.14	0.10	0.08	0.08	0.05	0.04	0.04	0.06	0.07	0.06	0.07
-200	0.07	0.13	0.09	0.07	0.06	0.04	0.05	0.04	0.05	0.06	0.05	0.06
-221	0.06	0.12	0.06	0.06	0.06	0.04	0.05	0.04	0.06	0.05	0.03	0.03

3.4.4 Sea salinity, Area B

Figure 3.52 shows monthly mean salinity profiles for Haltenbanken Area B.

Table 3.45 shows monthly mean salinity at selected depths and Table 3.46 shows the corresponding standard deviations.

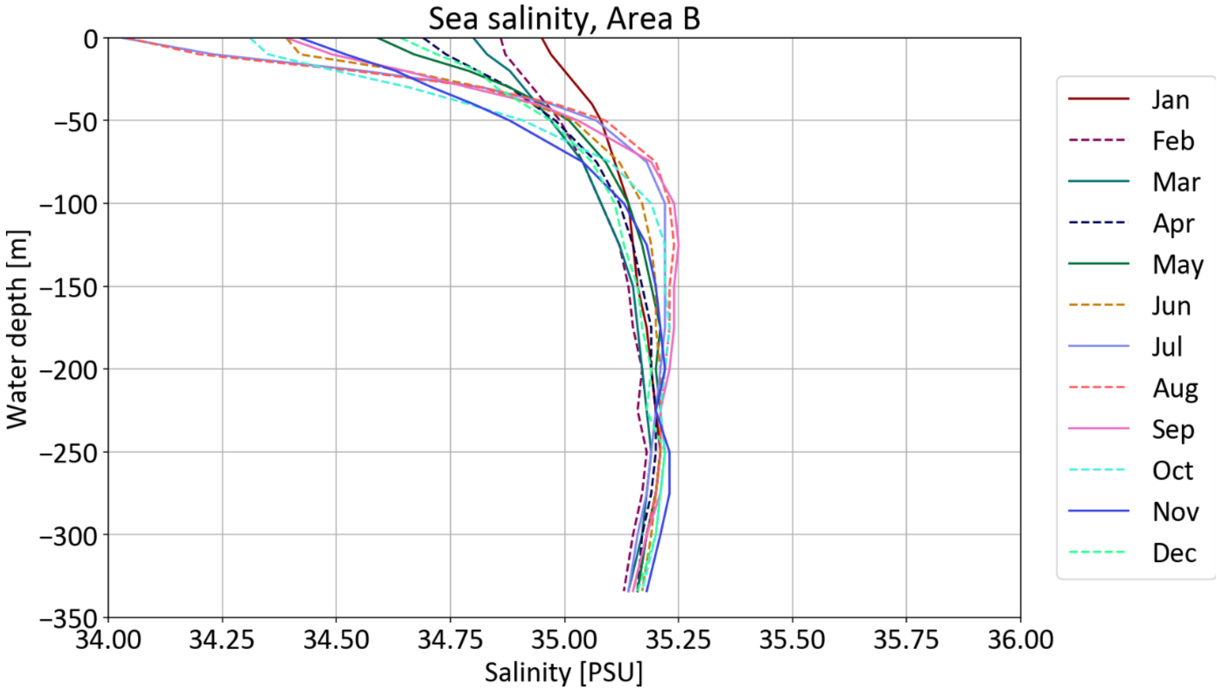


Figure 3.52: Monthly mean sea salinity profiles for Haltenbanken Area B.

Table 3.45: Monthly mean sea salinity at selected water depths for Haltenbanken Area B.

Depth [m]	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
0	34.95	34.86	34.80	34.69	34.59	34.39	34.03	34.04	34.39	34.31	34.42	34.64
-10	34.97	34.87	34.83	34.74	34.67	34.42	34.23	34.20	34.49	34.35	34.52	34.72
-20	35.00	34.90	34.88	34.81	34.79	34.65	34.56	34.54	34.65	34.50	34.63	34.81
-30	35.03	34.93	34.91	34.88	34.88	34.82	34.82	34.82	34.79	34.66	34.71	34.85
-40	35.06	34.96	34.94	34.93	34.95	34.93	34.97	34.98	34.94	34.79	34.80	34.91
-50	35.08	34.99	34.97	34.98	35.01	35.02	35.07	35.09	35.03	34.91	34.88	34.97
-75	35.11	35.04	35.04	35.07	35.09	35.12	35.18	35.20	35.19	35.10	35.04	35.06
-100	35.14	35.08	35.08	35.12	35.14	35.17	35.22	35.23	35.24	35.19	35.13	35.11
-125	35.15	35.12	35.12	35.15	35.17	35.19	35.22	35.24	35.25	35.22	35.18	35.13
-150	35.16	35.14	35.15	35.17	35.19	35.20	35.22	35.23	35.24	35.22	35.20	35.16
-175	35.18	35.15	35.16	35.19	35.21	35.20	35.22	35.23	35.24	35.23	35.21	35.17
-200	35.19	35.17	35.17	35.19	35.20	35.21	35.21	35.22	35.23	35.22	35.22	35.19
-225	35.20	35.16	35.18	35.20	35.21	35.21	35.20	35.21	35.21	35.21	35.20	35.18
-250	35.21	35.18	35.19	35.20	35.21	35.21	35.19	35.21	35.22	35.22	35.23	35.22
-275	35.20	35.17	35.18	35.19	35.20	35.20	35.18	35.20	35.21	35.21	35.23	35.21
-300	35.18	35.15	35.17	35.17	35.18	35.19	35.16	35.18	35.18	35.20	35.21	35.20
-334	35.16	35.13	35.14	35.16	35.16	35.17	35.14	35.15	35.15	35.17	35.18	35.16

Table 3.46: Standard deviation of the monthly mean sea salinity at selected water depths for Haltenbanken Area B.

Depth [m]	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
0	0.14	0.23	1.84	0.53	0.41	0.58	0.54	0.48	0.52	0.33	0.59	0.54
-10	0.12	0.22	0.26	0.37	0.37	0.50	0.52	0.49	0.48	0.34	0.52	0.50
-20	0.11	0.21	0.22	0.33	0.33	0.42	0.54	0.37	0.32	0.33	0.46	0.48
-30	0.10	0.20	0.20	0.29	0.28	0.37	0.39	0.23	0.19	0.35	0.46	0.39
-40	0.09	0.20	0.18	0.26	0.26	0.27	0.28	0.21	0.16	0.35	0.44	0.19
-50	0.09	0.21	0.17	0.24	0.23	0.24	0.21	0.15	0.16	0.25	0.38	0.08
-75	0.09	0.24	0.14	0.19	0.18	0.19	0.14	0.12	0.08	0.21	0.14	0.06
-100	0.08	0.22	0.13	0.15	0.13	0.16	0.10	0.09	0.06	0.12	0.10	0.05
-125	0.07	0.16	0.11	0.12	0.10	0.13	0.06	0.06	0.04	0.10	0.09	0.04
-150	0.07	0.15	0.09	0.09	0.09	0.09	0.04	0.04	0.05	0.09	0.06	0.07
-175	0.06	0.15	0.08	0.07	0.07	0.07	0.04	0.04	0.04	0.07	0.05	0.06
-200	0.06	0.13	0.07	0.07	0.06	0.05	0.05	0.04	0.04	0.07	0.06	0.06
-225	0.06	0.14	0.06	0.06	0.07	0.04	0.04	0.04	0.04	0.06	0.03	0.01
-250	0.06	0.12	0.06	0.06	0.06	0.05	0.04	0.04	0.03	0.03	0.02	0.04
-275	0.00	0.14	0.05	0.06	0.05	0.05	0.04	0.04	0.04	0.04	0.01	0.03
-300	0.08	0.15	0.05	0.05	0.05	0.05	0.02	0.04	0.03	0.00	0.01	0.00
-334	0.09	0.10	0.03	0.05	0.04	0.04	0.01	0.05	0.04	0.00	0.01	0.00

- APPENDIX -

1 Wind theory

1.1 Wind profile

In strong nearly neutrally stable atmospheric wind conditions the 1-hour mean wind speed U(z) at height z above sea level may be described by; ISO 19901-1:2015 Section A.7.3 [2]:

$$U(z) = U_0 \cdot \left[1 + C \cdot \ln\left(\frac{z}{z_r}\right)\right] \tag{1.1}$$

where

$$C = 5.73 \cdot 10^{-2} \cdot \left[1 + 1.5 \cdot \frac{U_0}{U_{ref}}\right]^{\frac{1}{2}} \tag{1.2}$$

and

z_r	Reference elevation above mean sea level, z_r = 10 m
U_o	1-hour mean wind speed at the reference elevation z_r
U_{ref}	Reference wind speed, U_{ref} = 10 m/s

The neutral stability assumption is reasonable when the 1-hour mean wind speed at 10 m exceeds 15 m/s, i.e. higher than over land (since the surface over sea is smoother than over land). For light to moderate wind speeds thermal effects may introduce significant deviations from the logarithmic dependency on z and t.

1.2 Wind gust

The most likely largest wind speed (gust) U(z,t) for averaging times t during t_0 = 1 hour is given by:

$$U(z,t) = U(z) \cdot \left[1 - 0.41 \cdot I_u(z) \cdot \ln\left(\frac{t}{t_0}\right)\right] \tag{1.3}$$

where the turbulence intensity $I_u(z)$ is given by:

$$I_u = 0.06 \cdot \left[1 + 0.43 \cdot \frac{U_0}{U_{ref}}\right] \cdot \left(\frac{z}{z_r}\right)^{-0.22} \tag{1.4}$$

where

z	Height (elevation) above sea level
z_r	Reference elevation above sea level, z_r = 10 m
U_0	1-hour mean wind speed at the reference elevation z_r
U_{ref}	Reference wind speed, U_{ref} = 10 m/s

The conversion to shorter averaging times, as given by Equation (1.3), does not conserve return period. It is assumed (based on results from analysis of wave data) that the return period will be preserved by choosing the P90 gust. Results from analysis of wind data from Race Bank, Docking Shoal and Doggerbank [13] indicate that the P90 gust factor can be computed from:

$$U(z,t,P90) = U(z)\cdot\left[1-0.59\cdot I_u(z)\cdot\ln\left(\frac{t}{t_0}\right)\right] \quad (1.5)$$

1.3 ISO spectrum

For structures and structural elements, but not for wind turbines, for which the dynamic wind behaviour is of importance, the following 1-point wind spectrum is recommended for the spectral density of the longitudinal wind speed fluctuations; ISO 19901-1:2015 Section A.7.4 [2].

$$S(f) = \frac{320\cdot\left(\frac{U_0}{U_{ref}}\right)^2\cdot\left(\frac{z}{z_r}\right)^{0.45}}{\left(1+\tilde{f}^{\,n}\right)^{\frac{5}{3n}}}\left[m^2/s\right] \quad (1.6)$$

where n = 0.468, and

$$\tilde{f} = 172\cdot f\cdot\left(\frac{z}{z_r}\right)^{\frac{2}{3}}\cdot\left(\frac{U_0}{U_{ref}}\right)^{-0.75}\left[s\right] \quad (1.7)$$

where

S(f)	Spectral density
f	Frequency
z	Height above sea level
z_r	Reference elevation above mean sea level, z_r = 10 m.
U_0	1 hour mean wind speed at the reference elevation z_r
U_{ref}	Reference wind speed, U_{ref} = 10 m/s

2 Wave theory

2.1 Wave spectra

2.1.1 Significant wave height

Spectral moments are defined by:

$$m_n = \int_0^\infty f^n \cdot S(f)\, df \qquad (2.1)$$

where f is wave frequency and S(f) the wave spectrum. The significant wave height (as used in this report) is defined by:

$$H_S = H_{m0} = 4 \cdot \sqrt{m_0} \qquad (2.2)$$

The significant wave height computed as the average of the highest waves in a record is 5 % lower; i.e.

$$H_{1/3} = 3.8 \cdot H_{m0} \qquad (2.3)$$

The different definitions of significant wave height may at times be confusing: Significant wave heights from hindcast studies are (always) computed from wave spectra, but significant wave heights from measurements may be computed from individual wave heights or from spectra.

2.1.2 JONSWAP spectrum

The JONSWAP spectrum may be used to describe pure wind seas. This spectrum can be defined in terms of three parameters: the significant wave height, H_S, the spectral peak period, T_p, and the peak enhancement factor, γ:

$$S(f) = \frac{5}{16} H_S{}^2 T_p \left(\frac{f}{f_p}\right)^{-5} exp\left\{-\frac{5}{4}\left(\frac{f}{f_p}\right)^{-4}\right\}(1 - 0.287\, ln(\gamma)) \cdot \gamma^{exp\left\{-0.5\left(\frac{f-f_p}{f_p\sigma}\right)^2\right\}} \qquad (2.4)$$

where $f_p = 1/T_p$ is the spectral peak frequency.

$$\sigma = \begin{cases} 0.07 & \text{for} \quad f \le f_p \\ 0.09 & \text{for} \quad f > f_p \end{cases} \qquad (2.5)$$

The peak-enhancement factor γ can be computed from:

$$\gamma = max\left[1.0, 42.2 \cdot \left(\frac{2\pi H_S}{gT_p^2}\right)^{6/7}\right] \tag{2.6}$$

where g = 9.81 m/s^2 is acceleration due to gravity.

2.1.3 Torsethaugen spectrum

The NORSOK Standard N-003 Section 6.2.2.3 [1] advocates use of the Torsethaugen frequency spectrum [22].

$$S(f) = S_{Swell}(f) + S_{Windsea}(f) \tag{2.7}$$

where $S_{Swell}(f)$ and $S_{Wind\ sea}(f)$ are modified JONSWAP spectra representing swell and wind seas contributions, respectively. The modification is primarily that the Torsethaugen spectrum decays according to f^{-4}, while the JONSWAP model decays according to f^{-5}. The dividing line (in the H_S – T_p plane) between wind seas and swell is the limiting sea defined by:

$$T_f = a_f H_S^{1/3} \qquad a_f = 6.6 \cdot m^{-1/3} s \tag{2.8}$$

where T_f is the spectral peak period of the limiting sea. When $T_p \leq T_f$ wind sea (spectral peak) dominates, whereas swell sea dominates when $T_p > T_f$. In principle a_f will be fetch dependent, but for most offshore sites at the Norwegian Continental Shelf, a_f = 6.6 $m^{-1/3}s$ is a good approximation for storm conditions.

2.1.4 TMA spectrum

The TMA (Texel, MARSEN, ARSLOE) spectrum dedicated to shallow water waves is defined by [10]:

$$S(f) = S_J(f) \cdot \Phi(kh) \tag{2.9}$$

where $S_J(f)$ denotes the JONSWAP spectrum and Φ(kh) is given by:

$$\Phi(kh) = \frac{tanh^2(kh)}{1 + \frac{2kh}{sinh(2kh)}} \tag{2.10}$$

The function Φ(kh) may be approximated (to within ± 4 %) by: [9].

$$\Phi(kh) = \begin{cases} \frac{1}{2}\,\omega_h^2 & for\ \ \omega_h \le 1 \\ 1 - \frac{1}{2}\cdot(2 - \omega_h)^2 & for\ \ 1 < \omega_h \le 2 \\ 1 & for\ \ \omega_h > 2 \end{cases} \tag{2.11}$$

where

$$\omega_h = 2\pi f \cdot \sqrt{\frac{h}{g}} \tag{2.12}$$

Figure 2.1 shows Φ as a function of ω_h.

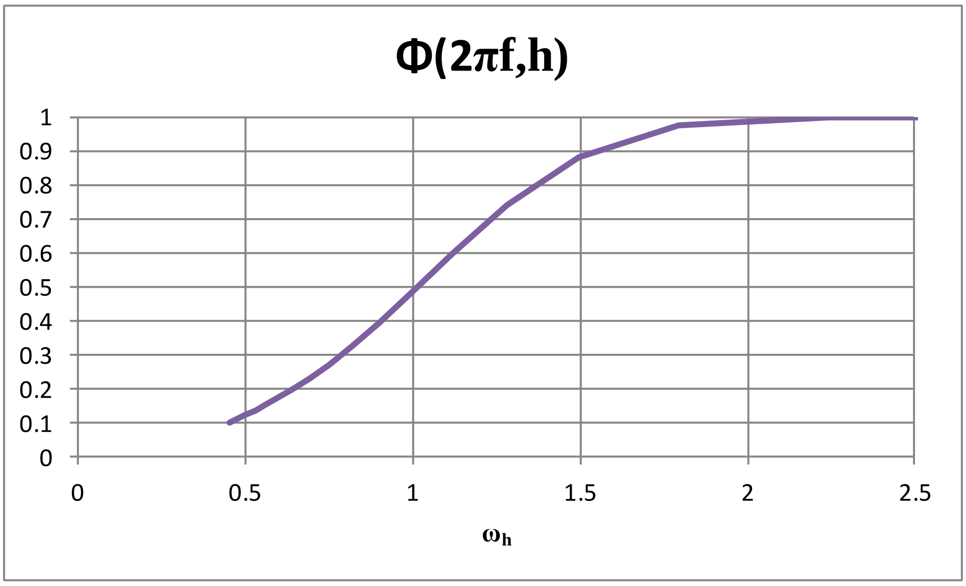


Figure 2.1 Φ as a function of ω_h.

2.2 T_p – H_S relationship

The conditional distribution of spectral peak period (T_p) given significant wave height (H_S) is modelled by a log-normal distribution:

$$f(T_p|H_s) = \frac{1}{T_p \cdot \sigma\sqrt{2\pi}} \cdot exp\left(-\frac{\left(ln(T_p) - \mu\right)^2}{2 \cdot \sigma^2}\right) \quad (2.13)$$

where

$$\begin{aligned} \mu &= a_1 + a_2 \cdot {H_s}^{a_3} \\ \sigma^2 &= b_1 + b_2 \cdot exp(-b_3 \cdot H_s) \end{aligned} \quad (2.14)$$

The mean spectral peak period, $\overline{T_p}$, and corresponding standard deviation, σ_{Tp}, are computed from:

$$\overline{T_p} = exp\left(\mu + \frac{1}{2}\sigma^2\right) \quad (2.15)$$

$$\sigma_{Tp} = \overline{T_p} \cdot \sqrt{exp(\sigma^2) - 1} \quad (2.16)$$

2.3 Individual wave heights

The short term distribution of individual wave heights should be modelled using the two-parameter Weibull distribution proposed by Forristall [2,16]:

$$F(h) = 1 - exp\left[-2.263 \cdot \left(\frac{h}{H_S}\right)^{2.126}\right] \quad (2.17)$$

where h is wave height and H_S is significant wave height.

Extreme individual wave heights should be computed from a long-term distribution of individual wave heights. The long term distribution of individual wave heights is given by:

$$F(h) = \frac{1}{\overline{\nu_0^+}} \int_0^\infty \int_0^\infty \nu_0^+(H_s, T_p) F(h|H_s, T_p) f(H_s, T_p) dH_s dT_p \quad (2.18)$$

where $\nu_0^+(h_s, t_p)$ is the expected zero-up-crossing wave frequency for a given sea state and $\overline{\nu_0^+}$ is the long term average zero-up-crossing wave frequency given by:

$$\overline{\nu_0^+} = \int_0^\infty \int_0^\infty \nu_0^+(H_s, T_p) f(H_s, T_p) dH_s dT_p \quad (2.19)$$

Values corresponding to an annual exceedance probability of q are estimated by:

$$1-F(h_q)=\frac{q}{n_h} \tag{2.20}$$

where n_h is the expected number of waves per year.

If extreme wave heights (for some reason) cannot be computed from the long-term distribution of H; extreme wave heights may alternatively be computed from the distribution of the highest of N waves in an extreme sea state. The distribution (probability of non-exceedance) F_N of the highest of N waves in a sea state is given by:

$$F_N(H_{max}) = [F(H_{max})]^N \tag{2.21}$$

When H_{max} is computed from an extreme short-term (3 hours) sea state it is recommended that H_{max} is chosen such that $F_N(H_{max})$ = 0.85 [14]. This value is chosen such that H_{max} is approximately equal to the value obtained from a long-term distribution analysis.

2.4 Crest heights

The distribution of crest heights is modelled by a two-parameter Weibull distribution proposed by Forristall [17]:

$$F(\eta) \;=\; 1 \;-\; exp\left[- \cdot \left(\frac{\eta}{\alpha H_S}\right)^{\beta}\right] \tag{2.22}$$

where α and β are parameters expressed as functions of wave steepness and Ursell number.

The steepness parameter, s_1, is defined by:

$$s_1 = \frac{2\pi \; H_S}{g T_{m01}^2} \tag{2.23}$$

where the mean period T_{m01} is given by:

$$T_{m01} = \frac{\int_0^\infty S(f)df}{\int_0^\infty f \cdot S(f)df} \tag{2.24}$$

The Ursell number, U_r, is defined by:

$$U_r = \frac{H_S}{k_1^2 h^3} \tag{2.25}$$

where k_1 is the wave number computed from:

$$\sigma_1^2 = gk_1 \cdot tanh(\,k_1 h) \tag{2.26}$$

The angular frequency $\sigma_1 = 2\pi/T_{m01}$ and $g = 9.81$ m/s^2 is acceleration due to gravity. An approximate solution to within 1.5 % is [15]:

$$k_1 \approx \frac{\sigma_1^2}{g}\left\{coth\left[\left(\sigma_1\sqrt{\frac{h}{g}}\right)^{3/2}\right]\right\}^{2/3} \tag{2.27}$$

For long-crested (two-dimensional) seas the parameters α and β are given by [17]:

$$\alpha_2 = 0.3536 + 0.2892 s_1 + 0.1060\ U_r \tag{2.28}$$
$$\beta_2 = 2 - 2.1597 s_1 + 0.0968\ U_r^2 \tag{2.29}$$

and for short-crested (three-dimensional) seas by:

$$\alpha_3 = 0.3536 + 0.2568 s_1 + 0.0800\ U_r \tag{2.30}$$
$$\beta_3 = 2 - 1.7912 s_1 - 0.5302\ U_r + 0.2824\ U_r^2 \tag{2.31}$$

For deep water waves with $U_r \approx 0$, the crests in long-crested seas are slightly bigger, but in shallow waters the crests in short-crested seas are always larger.

The distribution F_N of the highest of N crest heights in a sea state, η_{max}, is given by:

$$F_N(\eta_{max}) = [F(\eta_{max})]^N \tag{2.32}$$

When H_{max} is computed from an extreme short-term (3 hours) sea state it is recommended that η_{max} is chosen such that $F_N(\eta_{max}) = 0.90$ [14]. This value is chosen such that η_{max} is approximately equal to the value obtained from a long-term distribution analysis.

2.5 Breaking waves

The most widely used breaking criteria is that $H_{max} = 0.78$ h derived for solitary waves by McCowan. However, there is some evidence that the limit could be as low as $H_{max} = 0.55$ h. A solution to this problem is that the largest wave forms can be of two fundamental wave event types:

- A focused-type wave event, driven by linear dispersion and similar to those arising in deep water. These occur for $k_p h > 0.5$, in which case $H_{max}/h \le 0.6$ and $\eta_{max}/H \approx 0.7$.
- A solitary-type wave form undergoing only gradual changes in wave shape. These occur in shallow water, $k_p h < 0.5$, involving the traditional solitary wave limit of $H_{max}/h \to 0.8$ with $\eta_{max}/H \approx 0.9$.

where η_{max} is the limiting crest height.

For gradual bed slopes, i.e. bed slopes m ≤ 1/100, breaker height formulas based on the so-called Miche Criterion are advised:

$$\frac{1}{2}H_{S,\max}k_L = 0.10 \cdot \pi \cdot \tanh(k_L h) \quad (2.33)$$

$$\frac{1}{2}H_{\max}k_L = 0.12 \cdot \pi \cdot \tanh(k_L h) \quad (2.34)$$

where k_L is a local wave-number based upon a locally measured wave period.

The maximum crest height is given by:

$$\frac{\eta_{max}}{H} \approx \begin{cases} 0.7 & for \quad k_L h > 0.5 \\ 0.9 & for \quad k_L h < 0.5 \end{cases} \quad (2.35)$$

3 Statistical analysis

3.1 Characteristic largest value

Let the initial distribution of some physical variable (e.g., significant wave height, wind speed, current speed) be given by F(x). The probability of obtaining one observation larger than a value x is given by:

$$P(X \geq x) = 1 - F(x) \quad (3.1)$$

In a sample of size n one would expect, on the average, n (1 – F(x)) observations larger than x. Such observations are called exceedances of x.

The value of x that has, on the average, only one exceedance in a sample of size n is called the characteristic largest value x_n and is defined by:

$$n[1 - F(x_n)] = 1 \quad (3.2)$$

or

$$1 - F(x_n) = \frac{1}{n} \quad (3.3)$$

3.2 Return period

Assume that the average time between storms (rare events) is given by τ. The number of storms during a period R is n = R/τ. The characteristic largest value, x(R), in a sample of size R/τ is obtained by inverting the formula:

$$1 - F(x(R)) = \frac{\tau}{R} \tag{3.4}$$

In this case R is called the return period and x(R) the return value.

3.3 Annual probability of exceedance

Let n_T be the number of storm events per year T and $n_R = (R/T)\, n_T$ the number of storm events during the return period R. The annual probability of exceedance q(x(R)) is given by:

$$q(x(R) = 1 - \left(1 - \frac{T}{R \cdot n_T}\right)^{n_T} \quad \text{T = 1 year} \tag{3.5}$$

that for large values of n_T becomes:

$$q(x(R)) \approx 1 - exp\left(-\frac{T}{R}\right) \quad \text{T = 1 year} \tag{3.6}$$

It is seen that q = 0.63 for R = 1 year and that q is approximately 10^{-1} and 10^{-2} for R = 10 and 100 years, respectively.

3.4 Data selection

Most methods of extreme analysis require a sample to be selected from the full data set. The sample should be representative of the extreme events in the data set. The most common data selection methods are:

- Initial distribution method: Analysis performed using all data values.
- Peaks over threshold method: Analysis performed using peak values above some threshold, where threshold typically is at the 90th percentile of the full data set.
- Annual maxima method: Analysis performed using annual maxima; only.

3.5 Fitting methods

3.5.1 General description

In fitting a model distribution to the observed data, the task is to determine the unknown parameters of the model distribution subject to certain prescribed conditions. It is these prescribed conditions that distinguish the different fitting techniques. Three fitting methods are commonly used, namely the maximum likelihood method, the method of moments and the method of least squares.

3.5.2 Method of moments

The method of moments is probably the most widely used parameter estimation method. The method works by equating the statistical moments (mean value, standard deviation, skewness etc.) of the model distribution to the moments of the distribution of the observed data. The number of statistical moments used is equal to the number of parameters of the model distribution.

The resulting parameter estimators may be biased or unbiased depending on the model distribution considered. The efficiency of the parameter estimators is less than for the maximum likelihood method and depends on the true distribution parameters.

3.6 Model distributions

3.6.1 Weibull distribution

The long-term distribution of wind speed, significant wave height and current speed are modelled in terms of a three-parameter Weibull distribution:

$$F(x) = 1 - exp\left\{-\left[\frac{x-\varepsilon}{\theta}\right]^{\gamma}\right\} \qquad x \geq max(0, \varepsilon) \qquad (3.7)$$

where:

x Statistical variable
ε Location parameter
θ Scale parameter
γ Shape parameter

In the case $\varepsilon < 0$; then $F(0) > 0$ means that a (significant) fraction of the data has the value $x = 0$.

Extreme values, x_R, corresponding to a return period, R, are obtained by inverting Equation (3.7) for a cumulative probability $F = 1 - \tau/pR$, i.e.:

$$x_R = \varepsilon + \theta\left[-ln\left(\frac{\tau}{pR}\right)\right]^{1/\gamma} \qquad (3.8)$$

where

τ Duration of event [1 hour (wind), 3 hours (waves) or 10 minutes (current)]
p Sector or monthly probability (=1/12 for monthly omni-directional distributions)
R Return period

The parameters of the Weibull distribution are estimated using the method of moments.

3.6.2 Truncated Weibull distribution

The distribution obtained by truncated the three-parameter Weibull distribution below x_0 is given by:

$$F_T(x) = 1 - exp\left[-\left(\frac{x - \varepsilon}{\theta}\right)^{\gamma} + \left(\frac{x_0 - \varepsilon}{\theta}\right)^{\gamma}\right]$$

When using the Peaks over threshold method extreme values, X_R, corresponding to a return period, R, are obtained by inverting the cumulative probability $F_T = 1 - 1/(n R)$:

$$x_R = \varepsilon + \theta \cdot \left[\left(\frac{x_0 - \varepsilon}{\theta}\right)^{\gamma} - ln\left(\frac{1}{n \cdot R}\right)\right]^{1/\gamma}$$

where n is the number of events per year.

References

Standards and guidelines

1 NORSOK Standard N-003:2017, Action and action effects. URL: http://www.standard.no/

2 ISO 19901-1:2015, Petroleum and natural gas industries - Specific requirements for offshore structures – Part 1: Metocean design and operating conditions. International Organization for Standardization.
URL http://www.standard.no/

Data sources

3 COPERNICUS GLOBAL_REANALYSIS_PHY_001_030, Copernicus - Marine environment monitoring service). URL: http://marine.copernicus.eu/

4 eKlima open access to weather- and climate data; historical data to real time observations, Norwegian Meteorological Institute.
URL: http://www.eklima.met.no

5 Matsumoto, K, Takanezawa, T and Ooe, M (2004), NAO.99b tidal prediction system.
URL: http://www.miz.nao.ac.jp/staffs/nao99/index_En.html

6 NOAA National Centers for Envronmental Information (2018), World Ocean Atlas 2018 prerelease.
URL: https://www.nodc.noaa.gov/OC5/woa18/

7 Oceanweather inc (2008), NEXTRA hindcast data base.

8 Reistad, M, Breivik, Ø, Haakenstad, H, Aarnes, O J, Furuvik, B R and Bidlot, J-R (2011), A high-resolution hindcast of wind and waves for the North Sea, Norwegian Sea, and the Barents Sea, Journal of Geophysical Research, 116, C05019, doi: 10.1029/2010JC006402. URL: http://onlinelibrary.wiley.com/doi/10.1029/2010JC006402/suppinfo

Reports and journal papers

9 Bonaduce, A., Staneva, J., Beherens, A., Bidlot, J. R., & Wilcke, R. A. I. (2019). Wave Climate Change in the North Sea and Baltic Sea. *Journal of Marine Science and Engineering*, *7*(6), 166.

10 Bouws, E, Günter, H, Rosenthal, W and Vincent C L (1985), Similarity of the wind wave spectrum in finite water depth: 1. Spectral form, Journal of Geophysical Research, Vol. 90 C1 pp 975-986.

11 Bruserud, K. & Haver, S. (2016) Comparison of wave and current measurements to NORA10 and NoNoCur hindcast data in the northern North Sea, Ocean Dynamics, 66: 823.

12 Equinor MetOcean Group, personal communications.

13 Equinor MetOcean Group (2016), series of North Sea Wind Mast Studies (restricted distribution).

14 Equinor MetOcean Group (2017). Metocean Design Basis Analysis of extremes - Recommended practice, revision 2.01.

15 Fenton, J D and McKee, W D (1989), On calculating the lengths of water waves, Coastal Engineering, Vol. 14, pp. 499-513.

16 Forristall, G. Z. (1978), On the statistical distribution of wave heights in a storm, Journal of Geophysical Research, Vol. 83, No. C5, pp. 2353-2358.

17 Forristall, G. Z. (2000), Wave crest distributions: Observations and second-order theory, Journal of physical oceanography, pp. 1931-1943.

18 Furevik, B., Röhrs, J. J., Carrasco, A., Engedahl, H., & Reistad, M. (2015, April). Are certain storms overestimated in the NORA10 wave hindcast?. In EGU General Assembly Conference Abstracts (Vol. 17).

19 Goda, Y (1988), Statistical variability of sea state parameters as a function of wave spectrum. Coastal Engineering in Japan, Vol. 31, No. 1, pp. 39-52.
20 Hanssen-Bauer, I., Førland, E.J, Hadde- Freeland, I., Hisdal, H., Lawrence, D., Mayer, S., Nesje, A., Nilsen, J.E.Ø , Sandven, S., Sandø, A.B., Sorteberg, A., and Ådlandsvik, B. (2017): Climate in Norway 2100 – a knowledge base for climate adaptation. URL: http://www.miljodirektoratet.no/no/Publikasjoner/2017/Mai-2017/Climate-in-Norway-2100--a-knowledge-base-for-climate-adaptation/
21 NORCE (2020) MariCulture Smart Fishfarm - Metocean Design Basis, Haltenbanken, 102183 2020-1
22 Torsethaugen, K. and Haver, S (2004), Simplified double peak spectral model for ocean waves, Proceedings of The Fourteenth (2004) International Offshore and Polar Engineering Conference, pp. 76-84.

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