Hywind Buchan Deep
Metocean Design Basis
RE2014-002

Statoil

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Revisions

Revision 2

Chapter 2.2
Wind data at 87 m above sea level are replaced by wind data at 100 m above sea level.

Chapter 2.5
A chapter on turbulence intensity is inserted.

Chapter 4
Hindcast current data are replaced by current data from measurements at Buchan Deep.

Chapter 10
A chapter describing the relationship (correlation) between significant wave height and wind speed is inserted.

Wind wave direction joint probability tables for use in computations of wind wave direction misalignment effects are included.

1 Introduction

1.1 Hywind Buchan Deep

The Hywind wind power site is centred at about 57.45° N, 01.31° W at Buchan Deep on the east coast of Scotland, see Figure 1.1. The water depth is for computation of some metocean parameters assumed to be in the range 100 – 140 m. For planning of marine operations and structural analysis the exact depth should be verified.

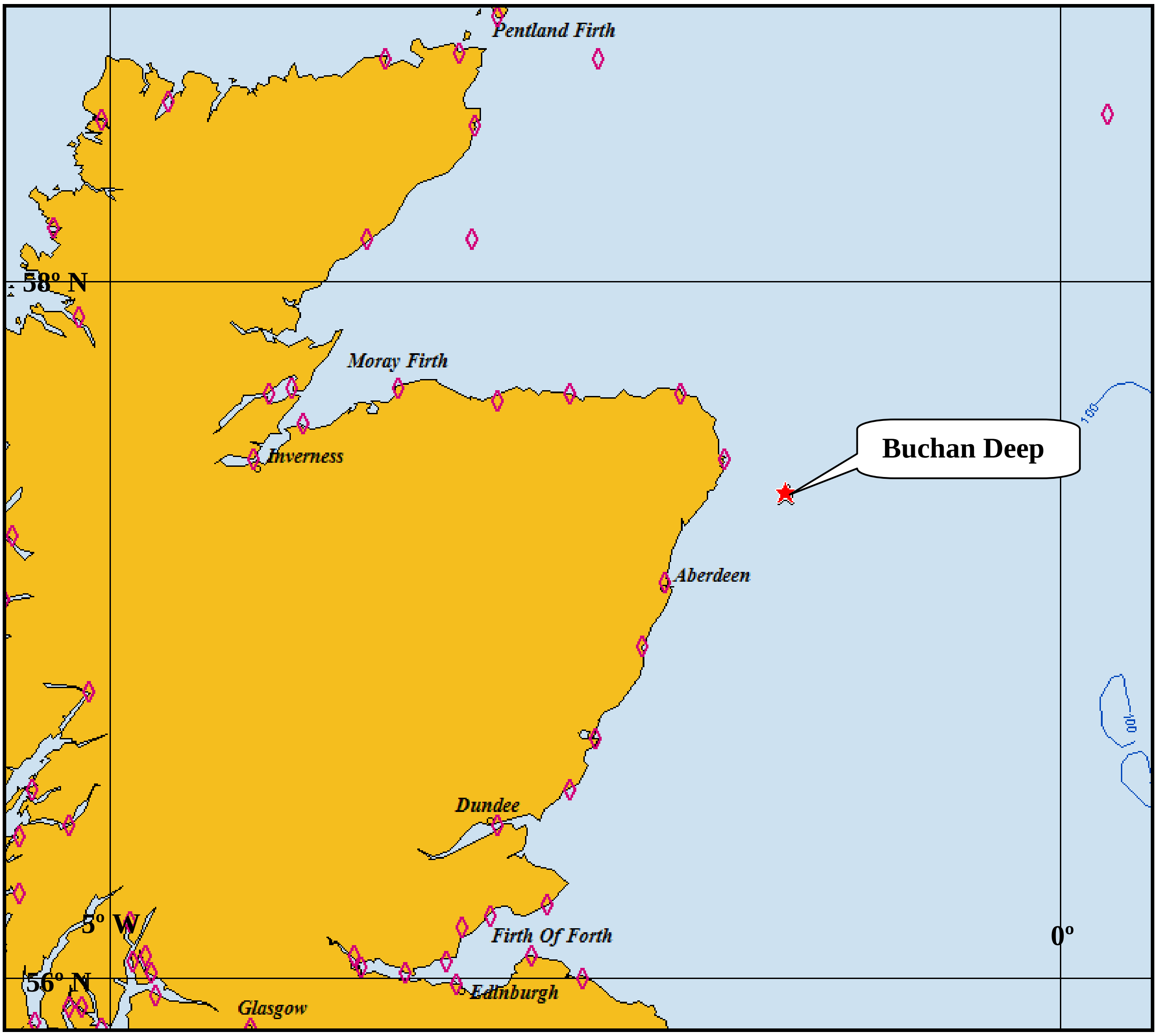


Figure 1.1 Map showing position of Hywind site at Buchan Deep.

1.2 Codes, regulations and design premises

International Electrotechnical Commission (IEC) Standard 61400-3 [1] outlines minimum design requirements for offshore wind turbines.

DNV Offshore Standard DNV-OS-J101 Design of offshore wind turbine structures [3] provides principles, technical requirements and guidance for design, construction and in-service inspection of offshore wind turbine structures

British Standard BS 6349-1:2000 [5] gives guidance and recommendations on general criteria relevant to the planning, design, construction and maintenance of structures set in the maritime environment.

Offshore Technology Report 2001/010, Environmental considerations [6], issued by the UK Health & Safety Executive (HSE), provides technical information on metocean parameters for Offshore Installations in UK waters.

Chapter 2 of Scotland's Marine Atlas [27] gives a general description of the metocean conditions in Scottish waters.

1.3 Conventions and definitions

1.3.1 Units

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

1.3.2 Directions

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

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

1.3.3 Seasons

Seasonal variations are given by month.

1.3.4 Extremes

Extreme values are, in NORSOK Standard N-003 [7], defined through their annual probabilities of exceedance here referred to as q - probability values. A q - probability value is the value corresponding to an annual probability of exceedance of q. The relationship between annual probability of exceedance, q, and return period, R, is given by:

$$q = 1 - \exp\left(-\frac{T}{R}\right) \qquad T = 1 \text{ year} \tag{1.1}$$

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.

1.3.5 Use of extreme values

When using monthly or directional extremes, robustness against uncertainties in the predicted extremes for the target month or direction sector shall be ensured by consider the estimated extremes for the two neighbouring months or direction sectors as **accidental** weather estimates. (This means that for the target sector operations and design are controlled against environmental loads using standard safety factors, while when using environmental loads obtained using environmental conditions for neighbouring sectors safety factors are set equal to 1.0.) Exceptions to this can be cases where there are topographical reasons for not considering a neighbouring sector representative for the target sector.

When predicting extreme structural response for design control purposes (design of structures or design of operations) using directional weather extremes, it shall be verified that the obtained extreme response is in agreement with overall requirements regarding annual exceedance probabilities, see e.g. NORSOK Standard N-006 [8]. For design of mooring lines utilizing directional wave extremes, the designer shall ensure that effects on the expected line tension from neighboring sectors are properly accounted for. The directional extreme values (for wind and waves) corresponding to an exceedance probability of q given the sector will generally not result in an extreme response corresponding to an annual exceedance probability of q even if the sector considered is the worst sector for the response under consideration. The marginal exceedance probability may well exceed q.

The correct approach would be to calculate the marginal exceedance probability of a given response level as a weighted sum of the exceedance probabilities for the various direction sectors. The weights are the probabilities for the various directions. If a long term analysis is not done, corrected directional environmental extremes (individual wave height or significant wave height) shall be established in agreement with the recommendation given in NORSOK Standard N-006 Chapter 6.6 [8]. This procedure will basically result in increasing directional weather extremes, individual wave heights and significant wave height by about 10 % for 10^{-2} – annual probability (100-year values). The percentage correction yields reasonable values for 10^{-2} annual probability. Using the same approach for q = 0.63 per year (annual extreme values) will most probably give un-conservative results, while it is expected to give conservative results for $q = 10^{-4}$. **The corrected values shall not be taken larger than the omni-directional extreme values**. Background information for the recommended corrections can be found in NORSOK Standard N-006 [8].

1.4 Climate change

Sea level rise due to climatic effects, e.g. thermal expansion of the oceans and melting of glaciers, is estimated to be in the range 0.2 – 0.6 m by the year 2100; IPCC Table SPM.1 [22].

1.5 Methods of analysis

The Statoil recommended practice for the analysis of extreme environmental conditions affecting marine structures is given in the report "Extreme environmental conditions, Recommended practice" [10].

2 Wind

2.1 Winds10 m above sea level

Wind data are available from the Nora10 hindcast model operated by the Norwegian Meteorological Institute [26]. The data are from the grid point at 57.40º N, 01.28º W. The wind data cover the period 1958 – 2010 (53 years). The sample interval is 3 hours.

The Nora10 model has a spatial resolution of 10 km. The computed wind speed is considered to represent the 1-hour mean wind speed.

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 underestimated [16]. Consequently, wind speeds higher than 15 m/s have been adjusted (corrected) prior to analysis. The corrected wind speed, U_{Cor}, is computed from [23]:

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

where U is the (Nora10) wind speed, p = 0.20 and U_{Min} = 15.0 m/s.

Figure 2.1 shows the (all-year) wind rose at Buchan Deep. Table 2.1 shows the corresponding annual sample distribution of non-exceedance of 1-hour average wind speed

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

Figure 2.3 - Figure 2.8 show wind roses for each month separately.

Table 2.3 - Table 2.8 show monthly sample distributions of non-exceedance of wind speed.

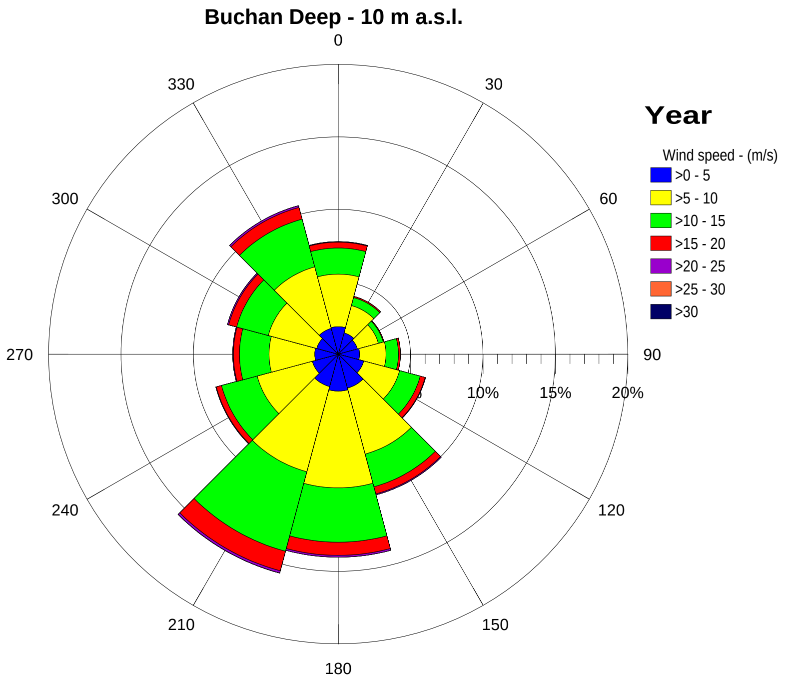


Figure 2.1 **Wind rose for 1-hour average wind speed 10 m above sea level for the period 1958 – 2010 at Buchan Deep.**

Table 2.1 **Annual direction sample distribution of non-exceedance (%) of 1-hour average wind speed 10 m above sea level for the period 1958 – 2010 at Buchan Deep.**

Wind (m/s)	**0°**	**30°**	**60°**	**90°**	**120°**	**150°**	**180°**	**210°**	**240°**	**270°**	**300°**	**330°**	**Omni**
< 2	0.31	0.32	0.30	0.35	0.35	0.37	0.40	0.36	0.35	0.31	0.31	0.34	**4.08**
< 4	1.24	1.05	1.01	1.06	1.24	1.53	1.56	1.48	1.23	1.11	1.04	1.19	**14.74**
< 6	2.61	1.99	1.70	1.86	2.40	3.45	3.73	3.28	2.53	2.20	2.12	2.56	**30.43**
< 8	4.12	2.88	2.41	2.67	3.45	5.42	6.49	5.57	4.09	3.48	3.53	4.34	**48.44**
< 10	5.53	3.47	2.87	3.30	4.38	7.13	9.22	8.40	5.80	4.78	5.00	6.24	**66.11**
< 12	6.55	3.82	3.07	3.77	5.14	8.35	11.18	11.18	7.24	5.92	6.21	7.97	**80.42**
< 14	7.14	4.00	3.18	4.06	5.66	9.19	12.50	13.32	8.10	6.60	6.98	9.20	**89.95**
< 16	7.46	4.08	3.23	4.20	5.96	9.65	13.25	14.55	8.47	6.95	7.45	9.89	**95.14**
< 18	7.65	4.12	3.26	4.26	6.13	9.88	13.68	15.20	8.65	7.15	7.71	10.29	**97.97**
< 20	7.73	4.13	3.26	4.29	6.21	9.98	13.88	15.48	8.71	7.23	7.83	10.49	**99.23**
< 22	7.77	4.14	3.27	4.29	6.24	10.04	13.97	15.59	8.74	7.27	7.88	10.58	**99.77**
< 24	7.77	4.14	3.27	4.29	6.24	10.05	14.00	15.62	8.75	7.28	7.90	10.61	**99.94**
< 26	7.77					10.05	14.01	15.63	8.75	7.29	7.92	10.61	**99.98**
< 28	7.78						14.01	15.64		7.29	7.92	10.62	**100.00**
< 30	7.78							15.64			7.92	10.62	**100.00**
< 32								15.64			7.92		**100.00**
Total	**7.78**	**4.14**	**3.27**	**4.29**	**6.24**	**10.05**	**14.01**	**15.64**	**8.75**	**7.29**	**7.92**	**10.62**	**100.00**
Mean	**8.1**	**6.6**	**6.2**	**7.2**	**8.0**	**8.1**	**8.8**	**9.7**	**8.5**	**8.5**	**8.9**	**9.3**	**8.5**
Maximum	**28.2**	**23.3**	**22.4**	**22.8**	**23.6**	**25.6**	**26.9**	**30.6**	**25.3**	**27.7**	**31.4**	**28.4**	**31.4**

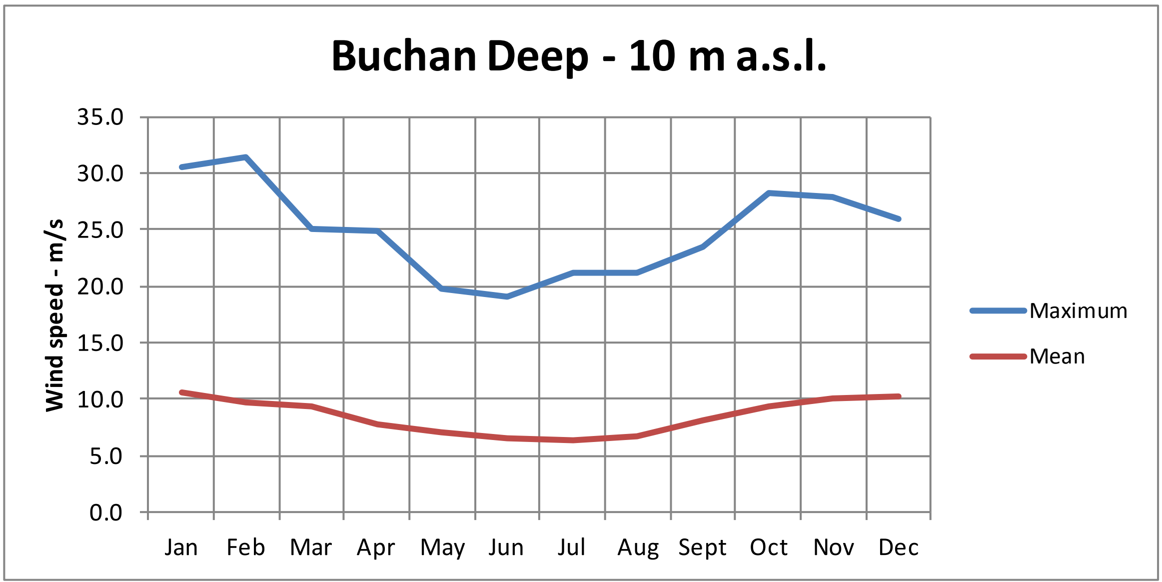


Figure 2.2 Monthly mean and maximum 1-hour average wind speed 10 m above sea level for the period 1958 – 2010 at Buchan Deep.

Table 2.2 Monthly and annual sample distribution of non-exceedance (%) of 1-hour average wind speed 10 m above sea level for the period 1958 – 2010 at Buchan Deep.

Wind (m/s)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Year**
< 2	1.53	2.36	2.28	4.65	5.42	7.22	8.51	6.89	3.72	2.65	1.89	1.68	**4.08**
< 4	6.41	9.34	9.77	16.85	20.31	24.27	26.42	24.22	15.07	9.17	8.07	6.65	**14.74**
< 6	15.95	21.08	22.78	34.78	40.98	46.56	49.37	45.44	32.59	20.49	18.00	16.60	**30.43**
< 8	29.43	36.60	38.39	56.07	63.31	67.34	69.80	66.46	52.48	37.49	32.19	31.08	**48.44**
< 10	46.10	54.23	56.58	73.47	80.90	84.57	85.62	83.13	71.37	57.71	50.35	48.73	**66.11**
< 12	63.25	70.81	73.93	86.45	92.26	94.57	95.02	93.34	84.84	75.37	68.01	66.68	**80.42**
< 14	78.20	83.43	86.08	94.30	97.57	98.34	98.46	98.20	93.61	87.56	82.14	81.23	**89.95**
< 16	88.25	91.29	93.49	97.73	99.50	99.51	99.54	99.59	97.44	93.82	91.08	90.22	**95.14**
< 18	94.44	96.40	97.53	99.21	99.91	99.91	99.89	99.92	99.06	97.41	96.19	95.68	**97.97**
< 20	97.63	98.61	99.20	99.71	100.00	100.00	99.98	99.99	99.69	99.03	98.52	98.37	**99.23**
< 22	99.16	99.58	99.77	99.96			100.00	100.00	99.93	99.69	99.51	99.59	**99.77**
< 24	99.70	99.92	99.97	99.98					100.00	99.92	99.84	99.95	**99.94**
< 26	99.91	99.96	100.00	100.00						99.96	99.97	100.00	**99.98**
< 28	99.98	99.98								99.98	100.00		**100.00**
< 30	99.99	99.99								100.00			**100.00**
< 32	100.00	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	**10.7**	**9.8**	**9.5**	**7.8**	**7.1**	**6.6**	**6.4**	**6.7**	**8.1**	**9.5**	**10.1**	**10.3**	**8.5**
Maximum	**30.6**	**31.4**	**25.1**	**25.0**	**19.8**	**19.1**	**21.2**	**21.2**	**23.5**	**28.2**	**27.8**	**25.9**	**31.4**

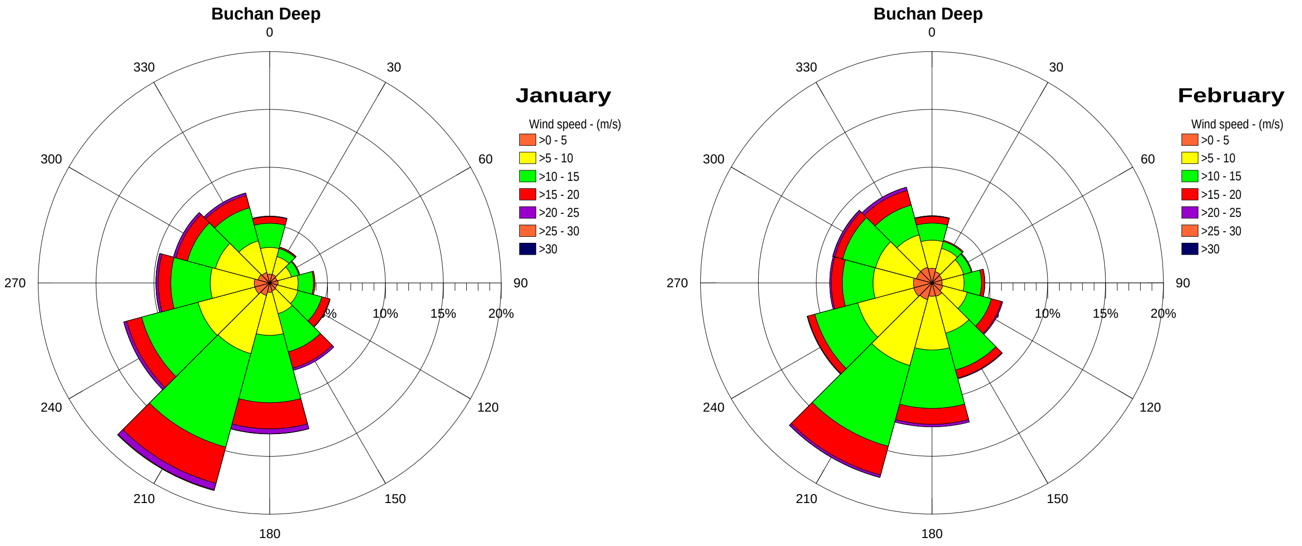


Figure 2.3 **Wind roses for January and February at Buchan Deep.**

Table 2.3 **Directional sample distribution of non-exceedance (%) of 1-hour mean wind speed 10 m above sea level for the months January and February at Buchan Deep.**

Wind (m/s)	Wind direction											
	0°	**30°**	**60°**	**90°**	**120°**	**150°**	**180°**	**210°**	**240°**	**270°**	**300°**	**330°**	**Omni**
January													
< 5	0.75	0.76	0.65	0.72	0.64	0.70	0.81	1.11	1.32	1.32	1.03	0.94	**10.75**
< 10	3.10	2.37	1.94	2.45	2.53	2.74	4.53	6.31	6.41	5.13	4.85	3.77	**46.10**
< 15	5.18	3.09	2.60	3.77	4.65	6.16	10.34	14.68	11.44	8.54	7.35	6.72	**84.52**
< 20	5.75	3.20	2.69	3.90	5.36	7.61	12.60	17.92	12.77	9.62	8.38	7.83	**97.63**
< 25	5.80	3.23			5.40	7.82	13.02	18.50	13.03	9.81	8.60	8.04	**99.87**
< 30							13.05	18.56	13.05	9.83	8.60	8.05	**99.99**
< 35								18.56					**100.00**
Total	**5.80**	**3.23**	**2.69**	**3.90**	**5.40**	**7.82**	**13.05**	**18.56**	**13.05**	**9.83**	**8.60**	**8.05**	**100.00**
Mean	**9.8**	**8.1**	**7.8**	**8.7**	**10.4**	**11.5**	**11.8**	**11.8**	**10.4**	**10.1**	**10.0**	**10.7**	**10.7**
Maximum	**22.0**	**23.0**	**19.8**	**18.6**	**21.8**	**24.6**	**26.9**	**30.6**	**25.3**	**27.7**	**26.6**	**26.5**	**30.6**
February													
< 5	1.25	1.00	0.89	0.87	0.96	1.20	1.15	1.49	1.63	1.60	1.39	1.39	**14.83**
< 10	3.68	3.09	2.82	2.76	3.15	4.49	5.79	7.38	6.64	5.09	5.05	4.28	**54.23**
< 15	5.16	3.71	3.51	4.26	5.29	7.79	10.84	14.62	10.48	7.74	7.99	6.95	**88.34**
< 20	5.74	3.82	3.57	4.56	6.20	8.51	12.22	17.23	11.11	8.69	8.68	8.27	**98.61**
< 25	5.79		3.59	4.57	6.31	8.58	12.44	17.43	11.17	8.83	8.87	8.54	**99.95**
< 30	5.79							17.45			8.88	8.55	**99.99**
< 35											8.88		**100.00**
Total	**5.79**	**3.82**	**3.59**	**4.57**	**6.31**	**8.58**	**12.44**	**17.45**	**11.17**	**8.83**	**8.88**	**8.55**	**100.00**
Mean	**8.9**	**7.4**	**7.5**	**8.9**	**10.2**	**9.8**	**10.6**	**10.9**	**9.2**	**9.5**	**9.5**	**10.4**	**9.8**
Maximum	**26.0**	**19.4**	**22.4**	**20.4**	**23.6**	**23.8**	**24.1**	**26.9**	**22.1**	**24.6**	**31.4**	**28.4**	**31.4**

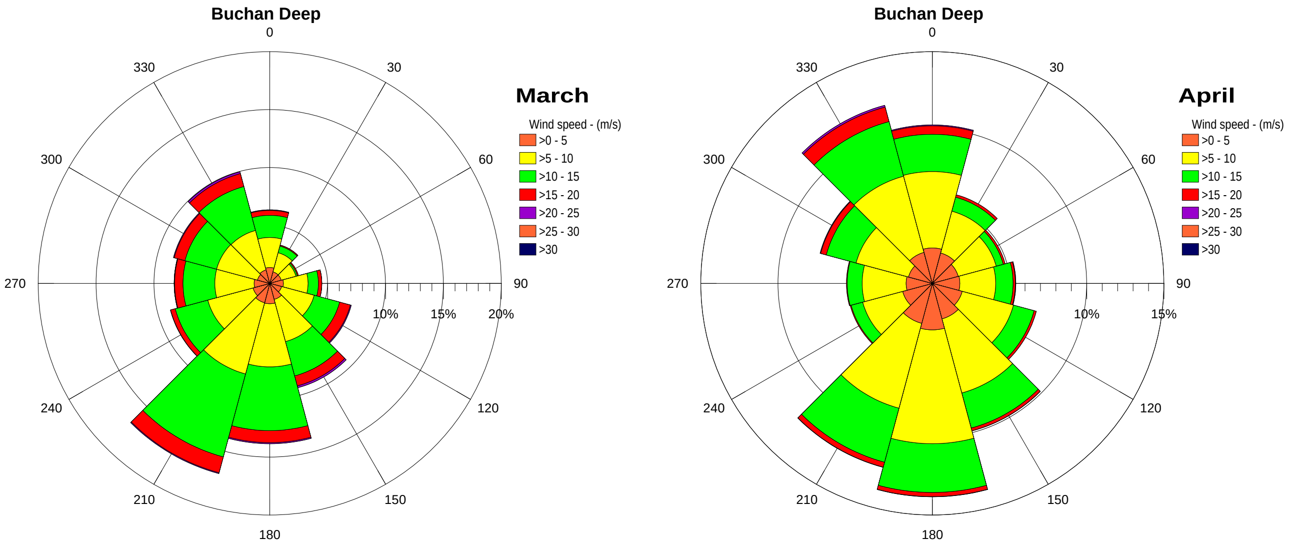


Figure 2.4 Wind roses for March and April at Buchan Deep.

Table 2.4 Directional sample distribution of non-exceedance (%) of 1-hour mean wind speed 10 m above sea level for the months March and April at Buchan Deep.

Wind (m/s)	Wind direction												
	0°	**30°**	**60°**	**90°**	**120°**	**150°**	**180°**	**210°**	**240°**	**270°**	**300°**	**330°**	**Omni**
March													
< 5	1.36	1.03	1.02	1.17	1.05	1.43	1.75	1.73	1.50	1.35	1.10	1.20	**15.70**
< 10	3.96	2.74	2.34	3.30	3.96	5.20	7.20	8.11	5.55	4.74	4.76	4.73	**56.58**
< 15	5.87	3.33	2.47	4.19	6.24	8.26	12.71	15.51	8.45	7.49	7.59	8.65	**90.75**
< 20	6.29	3.42	2.56	4.49	7.20	9.15	13.74	16.93	8.86	8.21	8.54	9.81	**99.20**
< 25	6.35	3.42		4.50	7.28	9.32	13.84	17.00	8.89	8.25	8.61	9.97	**99.99**
< 30										8.25			**100.00**
< 35													**100.00**
Total	**6.35**	**3.42**	**2.56**	**4.50**	**7.28**	**9.32**	**13.84**	**17.00**	**8.89**	**8.25**	**8.61**	**9.97**	**100.00**
Mean	**8.7**	**7.2**	**6.3**	**8.0**	**9.8**	**9.6**	**9.9**	**10.2**	**8.9**	**9.3**	**9.8**	**10.4**	**9.5**
Maximum	**22.8**	**21.0**	**19.7**	**22.8**	**23.4**	**23.6**	**23.4**	**24.1**	**22.3**	**25.1**	**24.4**	**22.3**	**25.1**
April													
< 5	2.29	2.04	1.73	1.78	2.00	2.37	3.00	2.67	1.99	1.70	1.60	2.08	**25.24**
< 10	7.23	4.83	4.28	4.10	5.43	7.36	10.38	8.36	4.67	4.54	5.11	7.18	**73.47**
< 15	9.65	5.77	4.75	5.22	6.82	9.73	13.53	11.97	5.44	5.51	7.11	10.83	**96.33**
< 20	10.19	5.94	4.87	5.37	6.97	9.92	13.80	12.30	5.50	5.56	7.48	11.81	**99.71**
< 25	10.25			5.40		9.93	13.81	12.32			7.52	11.93	**100.00**
< 30													**100.00**
< 35													**100.00**
Total	**10.25**	**5.94**	**4.87**	**5.40**	**6.97**	**9.93**	**13.81**	**12.32**	**5.50**	**5.56**	**7.52**	**11.93**	**100.00**
Mean	**8.3**	**6.8**	**6.5**	**7.3**	**7.4**	**7.6**	**7.8**	**8.2**	**6.5**	**7.0**	**8.4**	**9.2**	**7.8**
Maximum	**22.8**	**17.6**	**18.7**	**22.1**	**19.4**	**20.3**	**20.0**	**25.0**	**18.8**	**17.2**	**23.4**	**24.1**	**25.0**

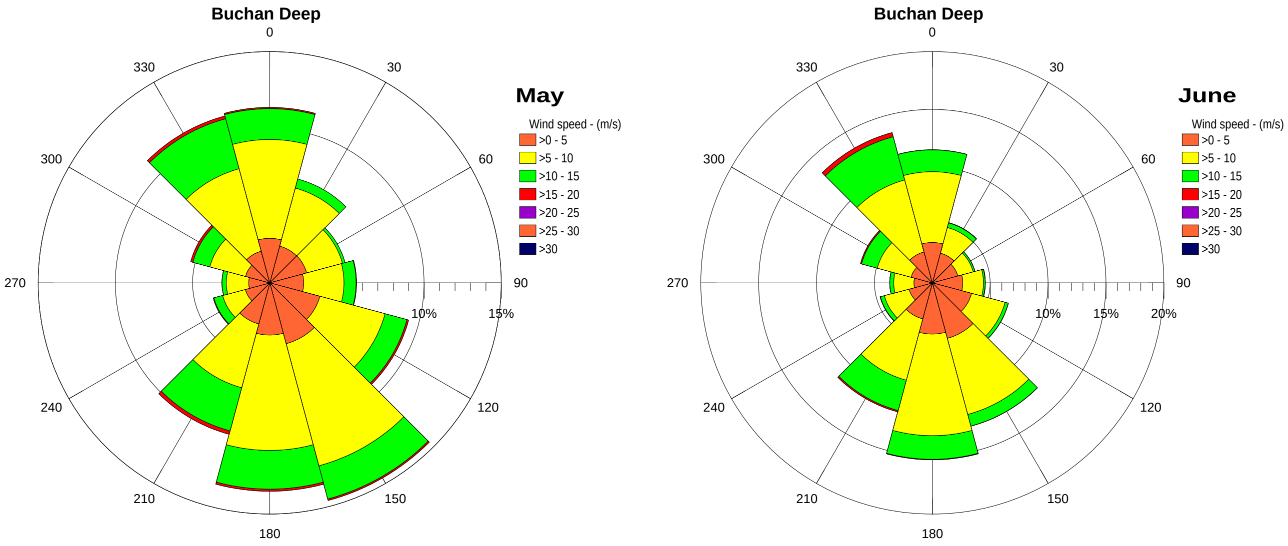


Figure 2.5 Wind roses for May and June at Buchan Deep.

Table 2.5 Directional sample distribution of non-exceedance (%) of 1-hour mean wind speed 10 m above sea level for the months May and June at Buchan Deep.

Wind (m/s)	Wind direction											
	0°	**30°**	**60°**	**90°**	**120°**	**150°**	**180°**	**210°**	**240°**	**270°**	**300°**	**330°**	**Omni**
May													
< 5	2.88	2.47	2.47	2.19	3.36	4.08	3.40	2.75	1.64	1.37	1.62	2.13	**30.36**
< 10	9.29	6.36	4.87	4.80	7.72	12.27	10.88	7.04	3.16	2.82	4.02	7.66	**80.90**
< 15	11.29	6.97	5.04	5.58	9.19	14.50	13.39	9.94	3.75	3.10	5.15	11.02	**98.92**
< 20	11.37			5.61	9.30	14.60	13.53	10.16	3.80	3.10	5.30	11.21	**100.00**
< 25													**100.00**
< 30													**100.00**
< 35													**100.00**
Total	**11.37**	**6.97**	**5.04**	**5.61**	**9.30**	**14.60**	**13.53**	**10.16**	**3.80**	**3.10**	**5.30**	**11.21**	**100.00**
Mean	**7.2**	**6.2**	**5.3**	**6.2**	**6.8**	**7.0**	**7.4**	**7.8**	**6.3**	**5.8**	**7.3**	**8.2**	**7.1**
Maximum	**18.4**	**14.7**	**13.8**	**18.7**	**19.6**	**17.9**	**18.6**	**18.5**	**17.0**	**17.8**	**19.8**	**19.1**	**19.8**
June													
< 5	3.48	2.66	2.27	2.62	3.51	4.98	4.42	3.22	2.08	1.59	1.89	2.77	**35.50**
< 10	9.60	4.95	3.65	4.40	6.52	11.80	13.20	8.70	4.28	3.33	4.92	9.21	**84.57**
< 15	11.49	5.36	3.80	4.55	6.80	12.84	15.24	11.42	4.64	3.67	6.32	13.07	**99.19**
< 20	11.50	5.39	3.81	4.58	6.82	12.85	15.29	11.54	4.67	3.69	6.42	13.44	**100.00**
< 25													**100.00**
< 30													**100.00**
< 35													**100.00**
Total	**11.50**	**5.39**	**3.81**	**4.58**	**6.82**	**12.85**	**15.29**	**11.54**	**4.67**	**3.69**	**6.42**	**13.44**	**100.00**
Mean	**6.9**	**5.6**	**4.9**	**4.9**	**5.2**	**6.1**	**6.9**	**7.5**	**5.7**	**5.9**	**7.2**	**8.2**	**6.6**
Maximum	**15.7**	**16.9**	**16.8**	**16.2**	**16.4**	**15.2**	**17.4**	**17.4**	**16.7**	**19.1**	**16.8**	**18.7**	**19.1**

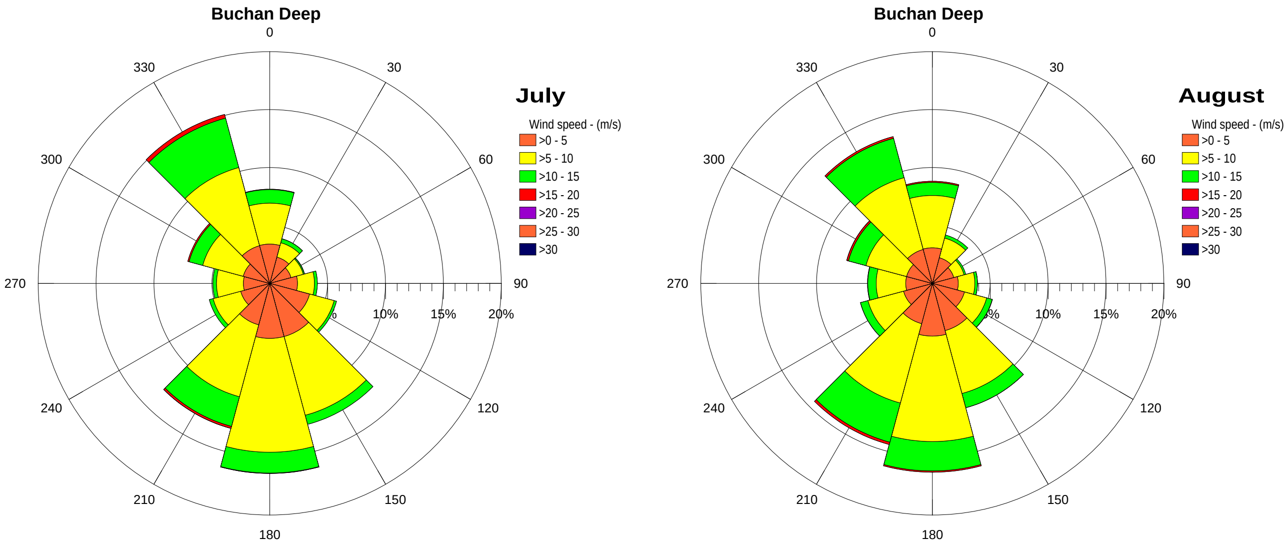


Figure 2.6 Wind roses for July and August at Buchan Deep.

Table 2.6 Directional sample distribution of non-exceedance (%) of 1-hour mean wind speed 10 m above sea level for the months July and August at Buchan Deep.

Wind (m/s)	Wind direction											
	0°	**30°**	**60°**	**90°**	**120°**	**150°**	**180°**	**210°**	**240°**	**270°**	**300°**	**330°**	**Omni**
July													
< 5	3.39	2.34	1.89	2.40	3.58	4.74	4.74	3.70	2.59	2.27	2.37	3.36	**37.39**
< 10	6.92	3.63	2.99	3.87	5.77	11.78	14.56	10.12	5.06	4.60	5.99	10.34	**85.62**
< 15	8.09	3.98	3.09	4.13	5.99	12.59	16.36	12.77	5.40	4.91	7.20	14.75	**99.25**
< 20	8.13	3.99	3.11				16.38	12.94			7.33	15.09	**99.98**
< 25							16.40	12.95					**100.00**
< 30													**100.00**
< 35													**100.00**
Total	**8.13**	**3.99**	**3.11**	**4.13**	**5.99**	**12.59**	**16.40**	**12.95**	**5.40**	**4.91**	**7.33**	**15.09**	**100.00**
Mean	**6.2**	**5.1**	**4.6**	**5.0**	**4.7**	**5.9**	**6.7**	**7.3**	**5.4**	**5.5**	**6.9**	**8.1**	**6.4**
Maximum	**18.2**	**18.0**	**18.4**	**13.5**	**14.3**	**14.4**	**21.1**	**21.2**	**14.4**	**14.9**	**19.4**	**19.1**	**21.2**
August													
< 5	3.07	2.29	1.91	2.23	2.86	4.21	4.54	3.59	2.57	2.30	2.30	3.03	**34.90**
< 10	7.58	4.05	2.83	3.66	4.86	9.86	13.65	10.68	5.75	4.85	5.93	9.43	**83.13**
< 15	8.70	4.32	2.98	3.89	5.36	11.13	16.18	14.17	6.42	5.57	7.49	12.95	**99.17**
< 20	8.81			3.90	5.38	11.14	16.30	14.39	6.43	5.60	7.65	13.11	**99.99**
< 25											7.65		**100.00**
< 30													**100.00**
< 35													**100.00**
Total	**8.81**	**4.32**	**2.98**	**3.90**	**5.38**	**11.14**	**16.30**	**14.39**	**6.43**	**5.60**	**7.65**	**13.11**	**100.00**
Mean	**6.5**	**5.2**	**4.7**	**4.9**	**5.5**	**6.3**	**7.0**	**7.7**	**6.2**	**6.2**	**7.2**	**7.9**	**6.7**
Maximum	**17.0**	**15.0**	**12.9**	**18.0**	**16.9**	**15.1**	**19.2**	**19.8**	**16.1**	**17.2**	**21.2**	**18.2**	**21.2**

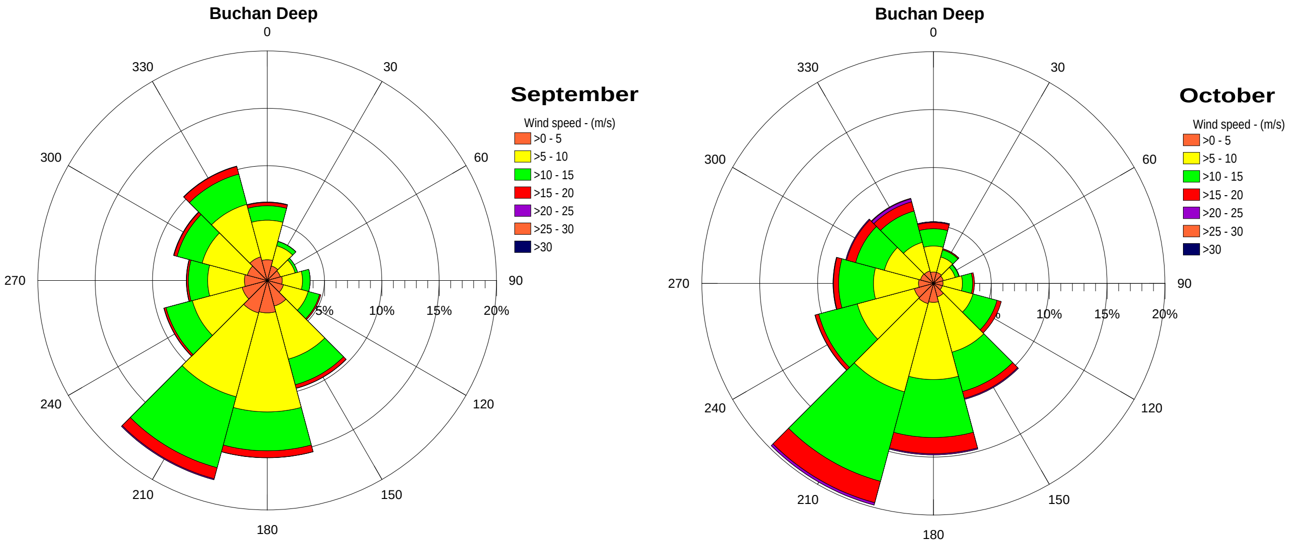


Figure 2.7 Wind roses for September and October at Buchan Deep.

Table 2.7 Directional sample distribution of non-exceedance (%) of 1-hour mean wind speed 10 m above sea level for the months September and October at Buchan Deep.

Wind (m/s)	Wind direction												
	0°	**30°**	**60°**	**90°**	**120°**	**150°**	**180°**	**210°**	**240°**	**270°**	**300°**	**330°**	**Omni**
September													
< 5	1.80	1.31	1.18	1.31	1.49	2.31	2.81	2.92	2.26	1.98	1.78	2.13	**23.29**
< 10	5.24	3.13	2.52	3.07	3.73	7.09	11.44	10.48	6.75	5.19	5.86	6.86	**71.37**
< 15	6.50	3.51	2.73	3.73	4.76	9.40	14.83	16.87	9.13	6.87	8.13	9.58	**96.05**
< 20	6.78	3.54	2.74	3.74	4.88	9.72	15.42	17.87	9.30	7.02	8.41	10.27	**99.69**
< 25	6.83					9.73	15.44	17.96	9.32	7.05	8.45	10.31	**100.00**
< 30													**100.00**
< 35													**100.00**
Total	**6.83**	**3.54**	**2.74**	**3.74**	**4.88**	**9.73**	**15.44**	**17.96**	**9.32**	**7.05**	**8.45**	**10.31**	**100.00**
Mean	**7.8**	**6.2**	**5.8**	**6.6**	**7.4**	**8.0**	**8.1**	**9.2**	**7.9**	**7.6**	**8.3**	**8.6**	**8.1**
Maximum	**23.5**	**16.3**	**18.6**	**16.4**	**19.9**	**22.2**	**22.2**	**23.0**	**22.9**	**22.4**	**23.2**	**21.7**	**23.5**
October													
< 5	0.97	0.98	0.88	0.82	0.78	1.20	1.64	1.80	1.71	1.29	1.16	1.11	**14.35**
< 10	3.22	2.36	1.94	2.50	3.55	6.15	8.29	9.68	6.80	5.17	4.38	3.66	**57.71**
< 15	4.71	2.99	2.27	3.39	5.71	9.67	13.29	17.67	10.25	8.18	6.95	6.45	**91.52**
< 20	5.24	3.08	2.30	3.55	6.09	10.29	14.69	19.58	10.57	8.62	7.75	7.27	**99.03**
< 25	5.31	3.10	2.31			10.38	14.79	19.80	10.59	8.67	7.84	7.54	**99.94**
< 30	5.32											7.59	**100.00**
< 35													**100.00**
Total	**5.32**	**3.10**	**2.31**	**3.55**	**6.09**	**10.38**	**14.79**	**19.80**	**10.59**	**8.67**	**7.84**	**7.59**	**100.00**
Mean	**9.3**	**7.3**	**6.6**	**8.1**	**9.3**	**9.4**	**9.8**	**10.3**	**8.7**	**9.1**	**9.6**	**10.4**	**9.5**
Maximum	**28.2**	**23.3**	**20.4**	**19.9**	**18.7**	**22.1**	**22.7**	**24.0**	**22.3**	**21.2**	**22.7**	**28.1**	**28.2**

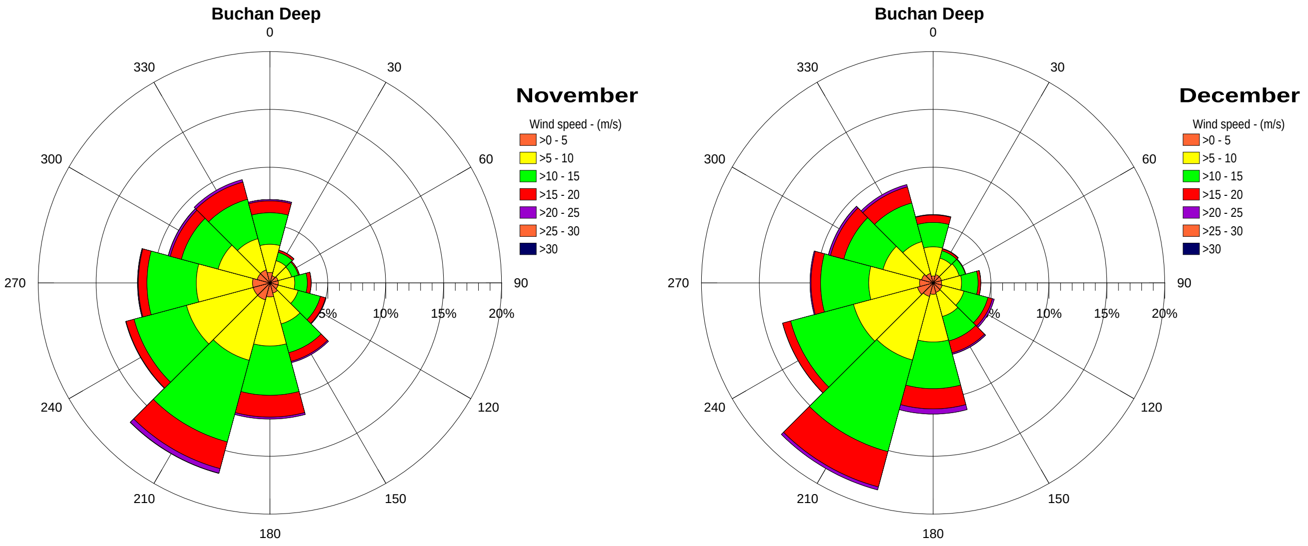


Figure 2.8 Wind roses for November and December at Buchan Deep.

Table 2.8 Directional sample distribution of non-exceedance (%) of 1-hour mean wind speed 10 m above sea level for the months November and December at Buchan Deep.

Wind (m/s)	Wind direction												
	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°	Omni
November													
< 5	0.90	0.64	0.72	0.72	0.72	0.91	1.20	1.51	1.49	1.51	1.13	1.16	**12.62**
< 10	3.33	1.98	1.93	2.14	2.52	3.66	5.45	6.93	7.45	6.36	4.64	3.95	**50.35**
< 15	6.06	2.73	2.53	3.22	4.50	6.24	9.72	14.24	12.13	10.61	7.92	7.47	**87.37**
< 20	7.08	2.92	2.63	3.55	4.96	7.02	11.61	16.63	12.85	11.35	8.91	9.02	**98.52**
< 25	7.20	2.93	2.64	3.56	5.02	7.14	11.78	17.04	12.89	11.42	9.09	9.24	**99.94**
< 30	7.21							17.06		11.43	9.10		**100.00**
< 35													**100.00**
Total	**7.21**	**2.93**	**2.64**	**3.56**	**5.02**	**7.14**	**11.78**	**17.06**	**12.89**	**11.43**	**9.10**	**9.24**	**100.00**
Mean	**10.5**	**8.3**	**7.9**	**9.0**	**10.0**	**10.1**	**10.7**	**11.1**	**9.4**	**9.5**	**10.1**	**10.8**	**10.1**
Maximum	**25.1**	**20.9**	**20.2**	**20.4**	**21.6**	**24.5**	**24.0**	**27.8**	**22.6**	**26.8**	**26.0**	**24.1**	**27.8**
December													
< 5	0.59	0.75	0.75	0.72	0.80	0.84	0.98	1.21	1.39	1.17	1.03	0.84	**11.08**
< 10	3.13	2.21	2.32	2.45	2.75	3.01	5.11	6.89	7.11	5.56	4.49	3.71	**48.73**
< 15	5.23	2.87	2.87	3.87	4.89	5.20	9.14	15.10	12.73	9.72	7.99	7.16	**86.76**
< 20	5.87	3.04	2.92	4.10	5.29	6.26	10.89	18.25	13.44	10.54	9.18	8.60	**98.37**
< 25	5.92	3.07	2.92	4.12	5.46	6.38	11.34	18.52	13.45	10.63	9.37	8.81	**99.98**
< 30						6.39					9.37		**100.00**
< 35													**100.00**
Total	**5.92**	**3.07**	**2.92**	**4.12**	**5.46**	**6.39**	**11.34**	**18.52**	**13.45**	**10.63**	**9.37**	**8.81**	**100.00**
Mean	**10.1**	**8.2**	**7.5**	**9.1**	**10.0**	**10.7**	**11.1**	**11.3**	**9.7**	**9.8**	**10.5**	**11.1**	**10.3**
Maximum	**21.1**	**22.3**	**17.0**	**21.2**	**23.2**	**25.6**	**24.5**	**24.4**	**20.3**	**23.6**	**25.9**	**23.8**	**25.9**

2.2 Winds 100 m above sea level

Wind data are available from the Nora10 hindcast model operated by the Norwegian Meteorological Institute [26]. The wind data are from the grid point at 57.40º N, 01.28º W. The wind data cover the period 1958 – 2010 (53 years), but only data from the period 1980 – 2010 (31 years) are used here. The reason is that there is a slight trend-shift in the data and that the data from 1980 onwards are deemed to better represent present wind conditions [24]. The sample interval is 3 hours.

The Nora10 wind data are given at a height of 100 m above sea level. No correction is done to the wind speed data at 100 m.

Figure 2.9 shows the (all-year) wind rose at Buchan Deep. Table 2.9 shows the corresponding annual sample distribution of non-exceedance of 1-hour average wind speed

Figure 2.10 shows the mean and maximum monthly 1-hour average wind speed. Table 2.10 shows the monthly sample distribution of non-exceedance-

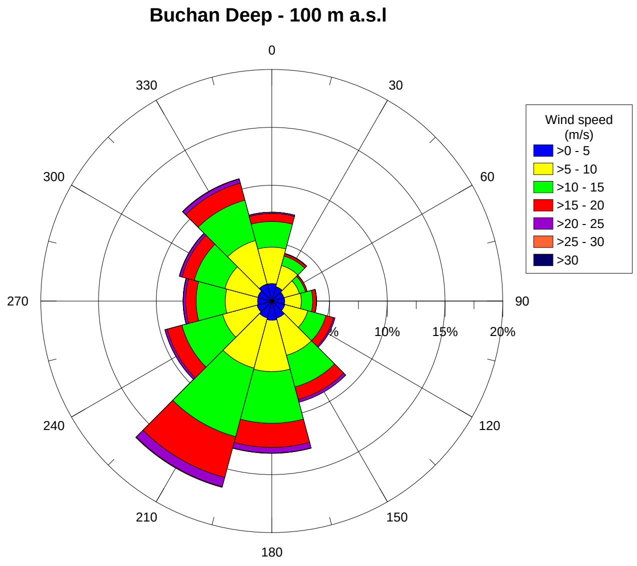


Figure 2.9 **Wind rose for 1-hour average wind speed 100 m above sea level for the period 1980 – 2010 at Buchan Deep.**

Table 2.9 **Annual direction sample distribution of non-exceedance (%) of 1-hour average wind speed 100 m above sea level for the period 1980 – 2010 at Buchan Deep.**

Wind (m/s)	**Wind direction**											
	0°	**30°**	**60°**	**90°**	**120°**	**150°**	**180°**	**210°**	**240°**	**270°**	**300°**	**330°**	**Omni**
< 2	0.23	0.22	0.22	0.25	0.22	0.22	0.26	0.24	0.24	0.22	0.22	0.24	**2.78**
< 4	0.95	0.84	0.79	0.77	0.81	0.94	1.02	0.94	0.82	0.78	0.80	0.95	**10.41**
< 6	2.03	1.68	1.34	1.38	1.50	2.01	2.23	2.12	1.73	1.61	1.65	2.09	**21.38**
< 8	3.34	2.48	1.92	1.95	2.38	3.36	3.95	3.77	2.91	2.73	2.83	3.55	**35.17**
< 10	4.59	3.16	2.44	2.52	3.18	4.77	5.97	5.87	4.31	3.97	4.12	5.32	**50.22**
< 12	5.70	3.63	2.78	3.05	3.90	6.14	7.99	8.25	5.88	5.15	5.50	6.98	**64.94**
< 14	6.53	3.92	2.96	3.40	4.54	7.21	9.74	10.77	7.45	6.18	6.55	8.39	**77.64**
< 16	7.06	4.08	3.06	3.64	5.05	7.99	11.12	13.11	8.45	6.82	7.25	9.44	**87.07**
< 18	7.35	4.18	3.12	3.77	5.35	8.48	12.00	14.69	9.03	7.20	7.73	10.12	**93.02**
< 20	7.56	4.22	3.15	3.84	5.51	8.78	12.60	15.72	9.35	7.45	8.03	10.53	**96.76**
< 22	7.64	4.24	3.17	3.87	5.61	8.93	12.93	16.27	9.49	7.58	8.18	10.77	**98.69**
< 24	7.67	4.26	3.18	3.88	5.65	9.01	13.07	16.53	9.55	7.65	8.24	10.87	**99.55**
< 26	7.68	4.26		3.88	5.66	9.04	13.13	16.62	9.57	7.66	8.28	10.92	**99.87**
< 28	7.68				5.66	9.05	13.15	16.64	9.58	7.68	8.29	10.93	**99.97**
< 30	7.68					9.05	13.15	16.65	9.59	7.68	8.29	10.93	**99.99**
< 32								16.65		7.68	8.29	10.93	**100.00**
< 34								16.65			8.29		**100.00**
< 36								16.65			8.29		**100.00**
Total	7.68	4.26	3.18	3.88	5.66	9.05	13.15	16.65	9.59	7.68	8.29	10.93	**100.00**
Mean	**9.2**	**7.6**	**7.3**	**8.3**	**9.5**	**9.9**	**10.8**	**12.0**	**10.5**	**10.0**	**10.2**	**10.5**	**10.2**
Maximum	**28.6**	**25.6**	**23.6**	**25.5**	**26.1**	**28.4**	**29.6**	**33.6**	**28.2**	**30.6**	**34.5**	**31.8**	**34.5**

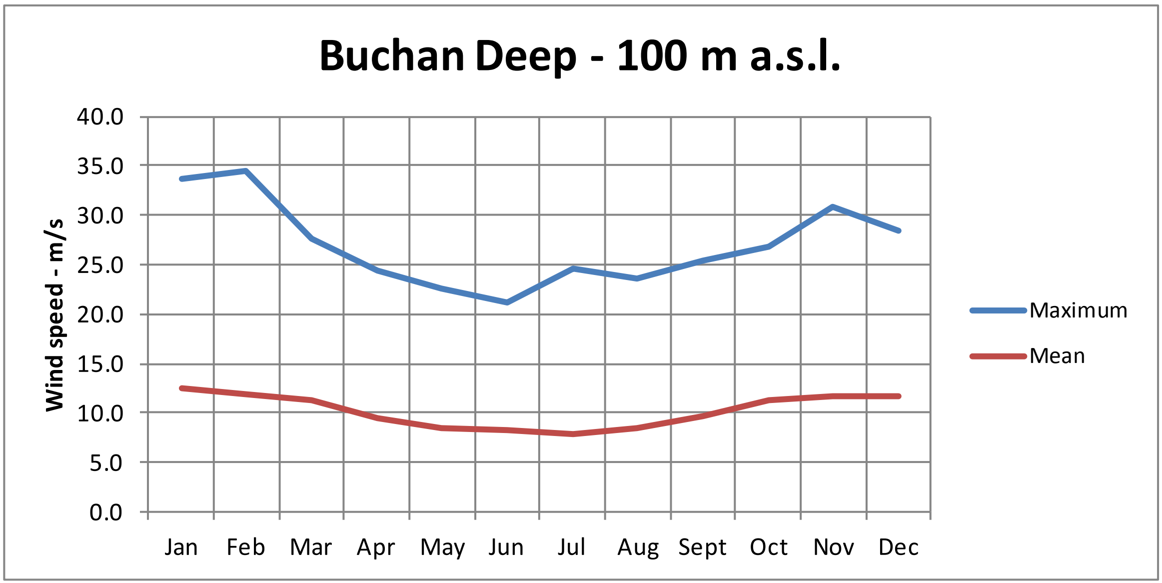


Figure 2.10 **Monthly mean and maximum 1-hour average wind speed 100 m above sea level for the period 1980 – 2010 at Buchan Deep.**

Table 2.10 **Monthly and annual sample distribution of non-exceedance (%) of 1-hour average wind speed 100 m above sea level for the period 1980 – 2010 at Buchan Deep.**

Wind (m/s)	Month												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Year**
< 2	1.11	1.97	1.57	2.78	3.94	4.60	5.12	4.81	2.67	1.76	1.51	1.47	**2.78**
< 4	4.84	7.01	6.71	11.76	14.52	15.82	18.04	16.06	10.54	6.46	7.11	5.89	**10.41**
< 6	11.64	15.05	15.70	24.01	28.41	31.41	33.60	31.36	22.37	13.94	14.54	14.16	**21.38**
< 8	21.14	25.80	27.06	39.95	46.51	47.89	51.74	47.37	37.26	25.99	24.97	25.78	**35.17**
< 10	32.69	37.79	40.60	57.20	64.79	65.28	68.83	64.53	53.25	40.54	37.90	38.54	**50.22**
< 12	46.19	51.98	55.29	71.21	79.45	80.44	83.70	79.06	68.09	56.59	53.44	53.07	**64.94**
< 14	60.43	65.60	70.50	83.05	89.48	91.44	93.02	90.01	80.93	71.45	67.92	67.22	**77.64**
< 16	72.92	77.21	82.43	91.87	95.81	97.14	97.66	96.38	90.12	83.57	79.58	79.59	**87.07**
< 18	83.18	86.12	91.08	96.68	98.57	99.06	99.28	98.89	95.60	91.09	88.16	88.20	**93.02**
< 20	90.73	93.24	96.08	98.95	99.65	99.81	99.71	99.75	98.19	95.81	94.37	94.61	**96.76**
< 22	95.41	97.27	98.53	99.65	99.95	100.00	99.96	99.96	99.46	98.48	97.62	97.89	**98.69**
< 24	98.17	99.12	99.54	99.95	100.00		99.96	100.00	99.91	99.53	99.17	99.27	**99.55**
< 26	99.30	99.79	99.91	100.00			100.00		100.00	99.93	99.73	99.80	**99.87**
< 28	99.80	99.93	100.00							100.00	99.91	99.99	**99.97**
< 30	99.93	99.97									99.99	100.00	**99.99**
< 32	99.96	99.99									100.00		**100.00**
< 34	100.00	99.99											**100.00**
< 36		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	**12.6**	**11.8**	**11.3**	**9.4**	**8.5**	**8.3**	**7.9**	**8.4**	**9.8**	**11.2**	**11.6**	**11.6**	**10.2**
Maximum	**33.6**	**34.5**	**27.7**	**24.5**	**22.5**	**21.2**	**24.7**	**23.6**	**25.5**	**26.8**	**30.8**	**28.4**	**34.5**

2.3 Long-term wind statistics – 10 m above sea level

The long-term distribution of wind speed is modelled in terms of a Weibull distribution:

$$F(u) = 1 - \exp\left\{ -\left[\frac{u-\varepsilon}{\theta} \right]^{\gamma} \right\} \qquad \text{where} \qquad u \geq \max(0;\varepsilon) \tag{2.1}$$

where:

u	Wind speed, 1-hour mean
ε	Location parameter
θ	Scale parameter
γ	Shape parameter

When $\varepsilon < 0$, then $F(0) > 0$ means that a (significant) fraction of the data has the value $u = 0$.

Extreme values, u_R, corresponding to a return period, R, are obtained by inverting Equation (2.1) for a cumulative probability $F = 1 - \tau/pR$, i.e.:

$$u_R = \varepsilon + \theta \cdot \left[-\ln\left(\frac{\tau}{pR} \right) \right]^{1/\gamma} \tag{2.2}$$

where

τ	Duration of event (= 1 hour for mean wind speed)
p	Sector or monthly probability (=1/12 for monthly omni-directional distributions)
R	Return period

The annual probability of exceedance, q, is given by:

$$q = 1 - \exp\left(-\frac{T}{R} \right) \qquad T = 1 \text{ year} \tag{2.3}$$

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.

Figure 2.11 shows the observed and fitted distributions of wind speed.

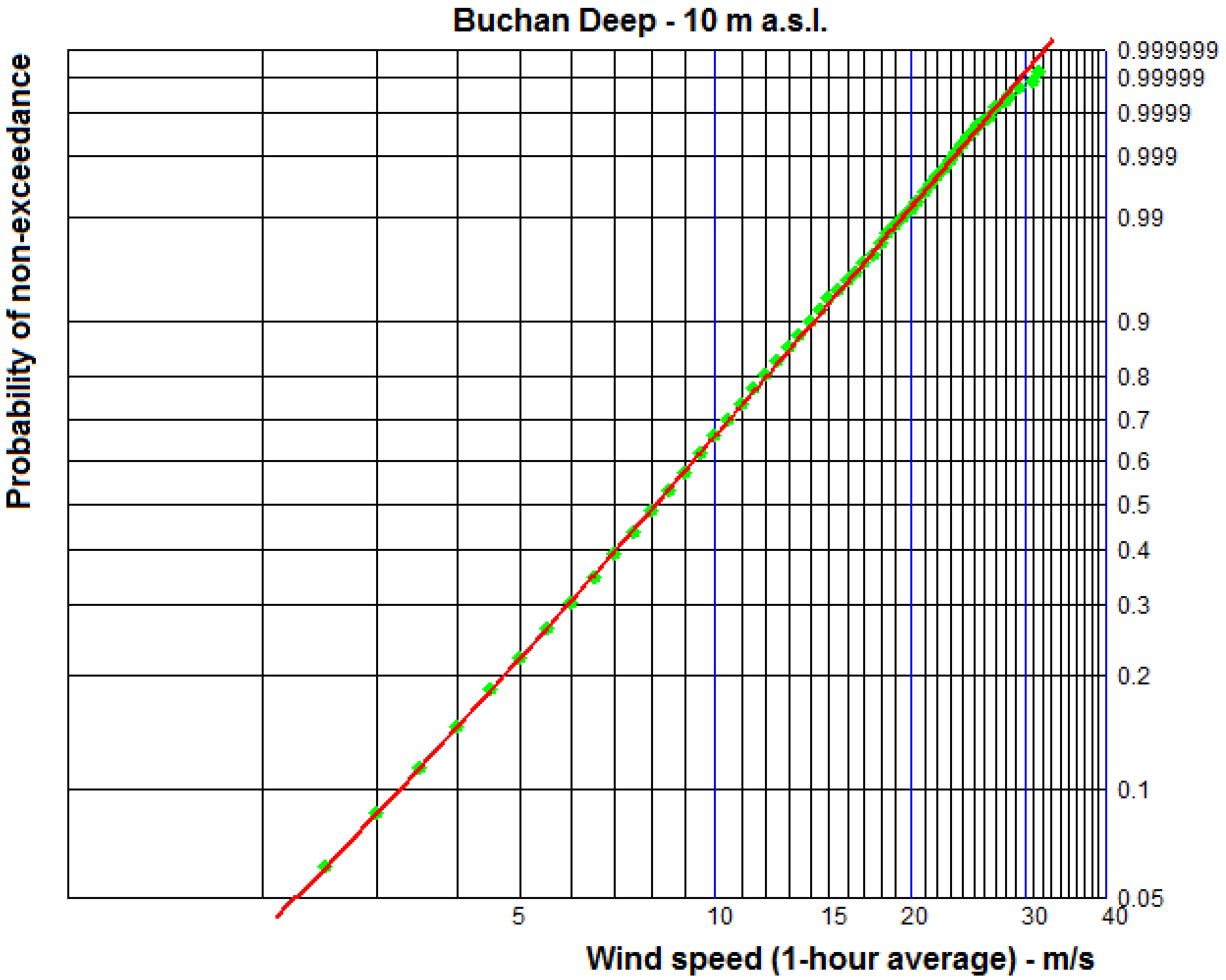


Figure 2.11 **Observed (green dots) and fitted (red line) distributions of 1-hour average wind speed 10 m above sea level at Buchan Deep.**

Figure 2.12 and Table 2.11 show directional Weibull parameters and corresponding extremes of 1-hour average wind speed 10 m above sea level. Figure 2.13 and Table 2.12 show monthly Weibull parameters and corresponding extremes. The extreme values are rounded off to the nearest 0.5 m/s.

Table 2.13 shows directional and monthly extreme values for 10-minute average wind speed. The extreme values are rounded off to the nearest 0.5 m/s.

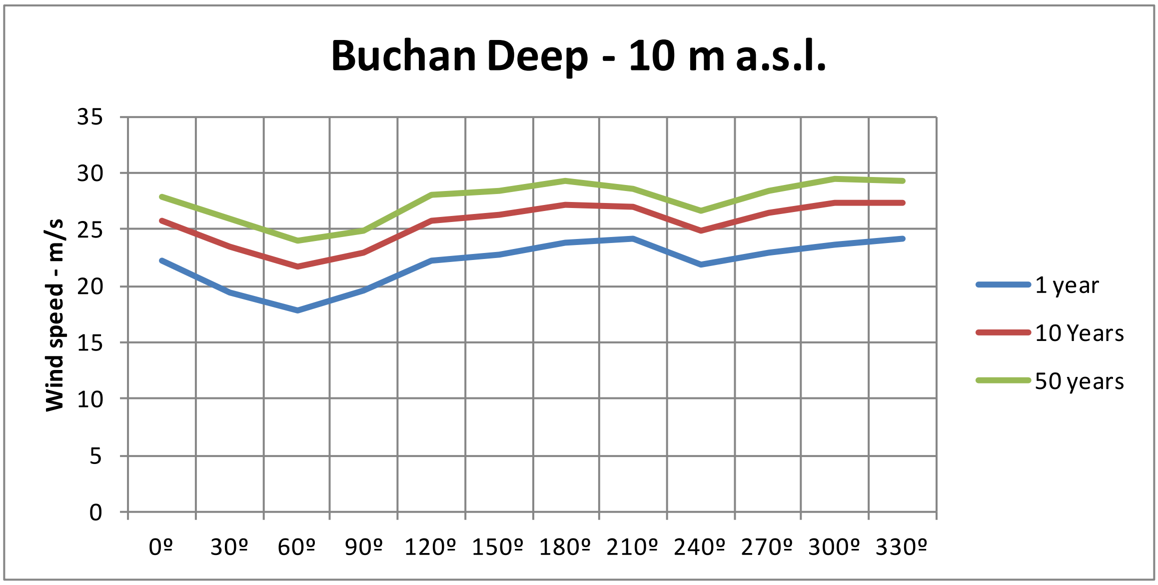


Figure 2.12 **Direction variation of 1-hour average wind speed of return periods 1, 10 and 50 years 10 m above sea level at Buchan Deep.**

Table 2.11 **Directional Weibull parameters and corresponding extreme values for 1-hour average wind speed 10 m above sea level at Buchan Deep. Duration of event is 1 hour.**

Direction	Sector prob.	Weibull parameters			Return period		
		Shape	Scale	Location	1 year	10 years	50 years
	%	-	m/s	m/s	m/s	m/s	m/s
0º	7.78	2.067	8.94	0.14	22.5	26.0	28.0
30º	4.14	1.757	6.96	0.40	19.5	23.5	26.0
60º	3.27	1.772	6.67	0.20	18.0	21.5	24.0
90º	4.29	2.189	9.08	-0.93	19.5	23.0	25.0
120º	6.24	2.134	9.63	-0.63	22.0	26.0	28.0
150º	10.05	2.033	8.76	0.32	23.0	26.5	28.5
180º	14.01	2.125	9.30	0.51	24.0	27.0	29.5
210º	15.64	2.666	12.03	-1.05	24.0	27.0	28.5
240º	8.75	2.453	10.57	-0.99	22.0	25.0	26.5
270º	7.29	2.234	10.20	-0.58	23.0	26.5	28.5
300º	7.92	2.202	10.20	-0.20	23.5	27.5	29.5
330º	10.62	2.406	11.13	-0.64	24.0	27.5	29.0
0º - 360º	**100.00**	**2.235**	**10.03**	**-0.41**	**26.5**	**29.5**	**31.0**

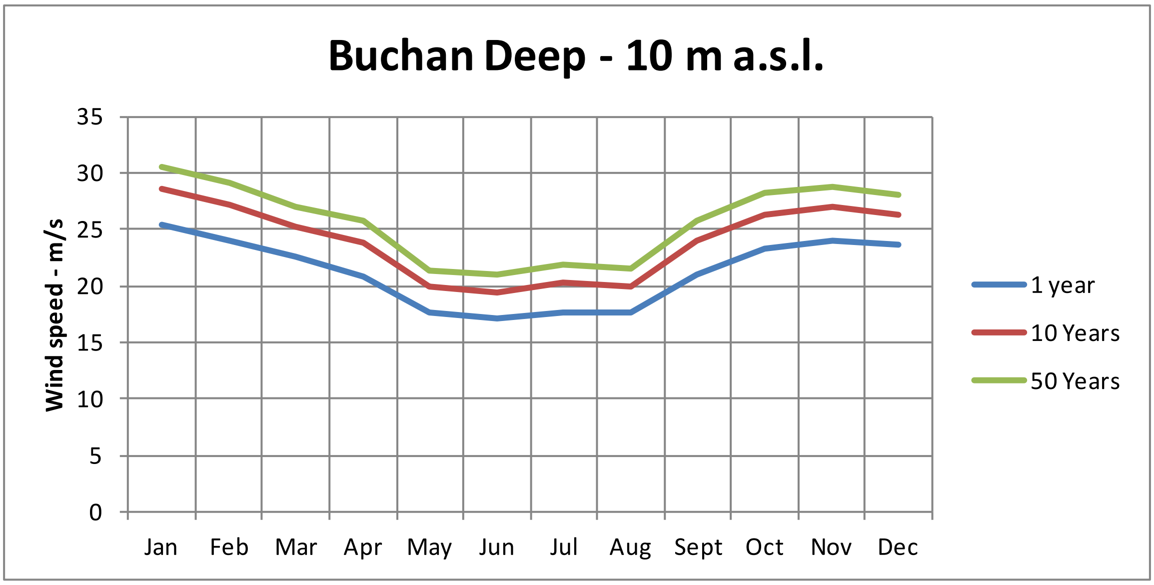


Figure 2.13 **Monthly variation of 1-hour average wind speed of return periods 1, 10 and 50 years 10 m above sea level at Buchan Deep.**

Table 2.12 **Monthly and annual Weibull parameters and corresponding extreme values for 1-hour average wind speed 10 m above sea level at Buchan Deep. Duration of event is 1 hour.**

Month	Annual prob.	Weibull parameters			Return period		
		Shape	Scale	Location	1 year	10 years	50 years
	%	-	m/s	m/s	m/s	m/s	m/s
Jan	8.33	2.560	12.36	-0.38	25.5	28.5	30.5
Feb	8.33	2.540	11.80	-0.75	24.0	27.0	29.0
Mar	8.33	2.690	11.64	-0.95	22.5	25.5	27.0
Apr	8.33	2.246	9.17	-0.39	21.0	24.0	25.5
May	8.33	2.556	8.87	-0.87	17.5	20.0	21.5
Jun	8.33	2.474	8.45	-0.94	17.0	19.5	21.0
Jul	8.33	2.263	8.04	-0.77	17.5	20.5	22.0
Aug	8.33	2.444	8.56	-0.93	17.5	20.0	21.5
Sept	8.33	2.288	9.32	-0.26	21.0	24.0	26.0
Oct	8.33	2.442	10.86	-0.24	23.5	26.5	28.0
Nov	8.33	2.688	12.38	-0.94	24.0	27.0	29.0
Dec	8.33	2.791	12.36	-0.73	23.5	26.5	28.0
Year	**100.00**	**2.235**	**10.03**	**-0.41**	**26.5**	**29.5**	**31.0**

Table 2.13 **Directional and monthly extreme values for 10-minute average wind speed 10 m above sea level at Buchan Deep. Duration of event is 1 hour.**

	Return period					Return period		
Direction	**1 year**	**10 yrs**	**50 yrs**		**Month**	**1 year**	**10 yrs**	**50 yrs**
	m/s	**m/s**	**m/s**			**m/s**	**m/s**	**m/s**
0°	24.0	28.0	30.5		**Jan**	27.5	31.5	33.5
30°	21.0	25.5	28.5		**Feb**	26.0	29.5	32.0
60°	19.5	23.5	26.0		**Mar**	24.5	27.5	29.5
90°	21.0	25.0	27.0		**Apr**	22.5	26.0	28.0
120°	24.0	28.0	30.5		**May**	19.0	21.5	23.0
150°	25.0	29.0	31.0		**Jun**	18.5	21.0	22.5
180°	26.0	30.0	32.0		**Jul**	19.0	22.0	24.0
210°	26.5	29.5	31.5		**Aug**	19.0	21.5	23.5
240°	24.0	27.0	29.0		**Sept**	23.0	26.0	28.0
270°	25.0	29.0	31.0		**Oct**	25.5	29.0	31.0
300°	26.0	30.0	32.5		**Nov**	26.0	29.5	31.5
330°	26.5	30.0	32.0		**Dec**	25.5	29.0	30.5
0° - 360°	**29.0**	**32.5**	**34.5**		**Year**	**29.0**	**32.5**	**34.5**

2.4 Wind profile and gust

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; NS-EN ISO 19901-1:2005 Section A.7.3 [2]:

$$U(z) = U_0 \cdot \left[1 + C \cdot \ln\left(\frac{z}{z_r}\right)\right] \tag{2.4}$$

where

$$C = 5.73 \cdot 10^{-2} \cdot \left[1 + 1.5 \cdot \frac{U_0}{U_{ref}}\right]^{\frac{1}{2}} \tag{2.5}$$

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

$$U(z,t)=U(z)\cdot\left[1-0.41\cdot I_u(z)\cdot\ln\left(\frac{t}{t_0}\right)\right] \qquad (2.6)$$

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

$$I_u=0.06\cdot\left[1+0.43\cdot\frac{U_0}{U_{ref}}\right]\cdot\left(\frac{z}{z_r}\right)^{-0.22} \qquad \text{for} \qquad U_0>12.0m/s \qquad (2.7)$$

The conversion to shorter averaging times does not conserve return period.

The neutral stability assumption is reasonable when the 1-hour mean wind speed at 10 m exceeds 10 – 15 m/s. For light to moderate wind speeds thermal effects may introduce significant deviations from the logarithmic dependency on z and t.

Figure 2.14 and Table 2.14 show (scaled) wind profiles for wind speeds from 10 to 35 m/s at z = 10 m.

Figure 2.15 and Table 2.15 show (scaled) expected maximum wind speed for various averaging times when U_0 = 32.0 m/s which corresponds to an annual probability of exceedance of 10^{-2}.

Structures or structural components that are not sensitive to wind gusts may be calculated by considering the wind action as static. In the case of structures or structural parts where the maximum dimension is less than approximately 50 m, 3 s wind gusts shall be used when calculating static wind actions. In the case of structures or structural parts where the maximum length is greater than 50 m, the length of averaging for wind may be increased to 15 s. When design actions due to wind need to be combined with extreme actions due to waves and current and actions due to waves and/or currents are governing, wind speed averaged over a 1-minute period can be used. A longer averaging period may be used if properly documented; NORSOK Standard N-003 Section 6.3.3 [7].

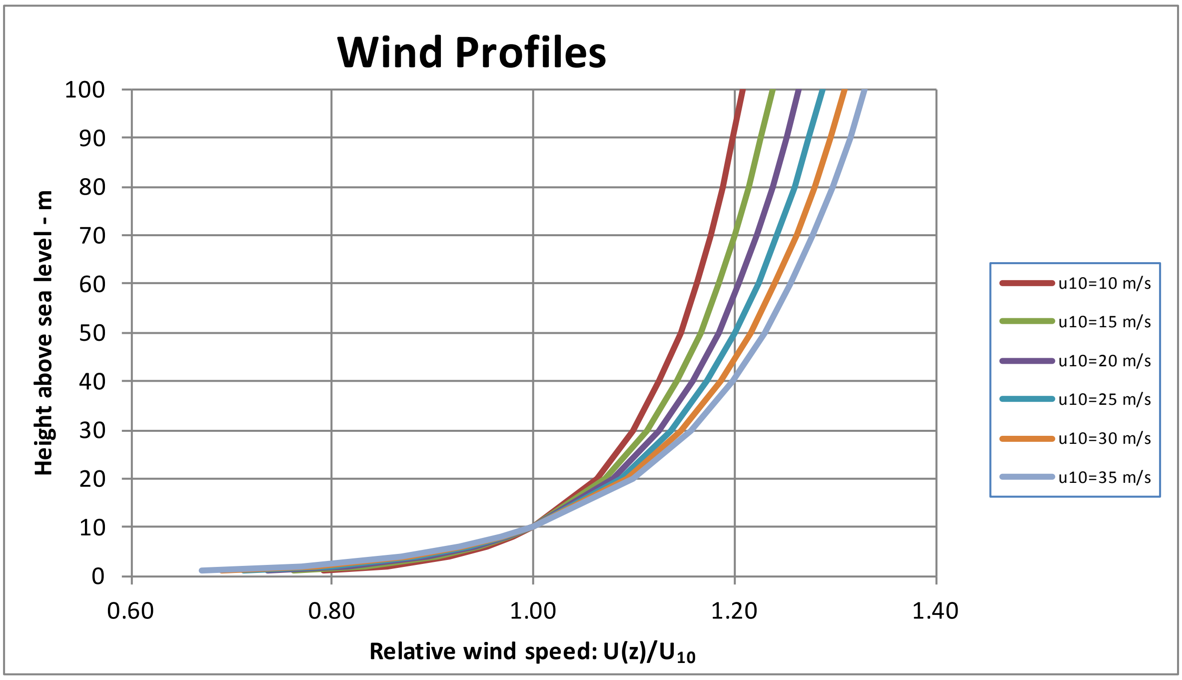


Figure 2.14 Wind profiles for various values of wind speed, U_{10}, 10 m above sea level.

Table 2.14 Wind speed at height z relative to wind speed at z = 10 m.

Height above sea level (m)	Wind speed (m/s) at z = 10 m above sea level					
	10	**15**	**20**	**25**	**30**	**35**
100	1.21	1.24	1.26	1.29	1.31	1.33
90	1.20	1.23	1.25	1.27	1.30	1.31
80	1.19	1.21	1.24	1.26	1.28	1.30
70	1.18	1.20	1.22	1.24	1.26	1.28
60	1.16	1.19	1.21	1.22	1.24	1.26
50	1.15	1.17	1.18	1.20	1.22	1.23
40	1.13	1.14	1.16	1.17	1.19	1.20
30	1.10	1.11	1.13	1.14	1.15	1.16
20	1.06	1.07	1.08	1.09	1.09	1.10
10	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
8	0.98	0.98	0.97	0.97	0.97	0.97
6	0.95	0.95	0.94	0.94	0.93	0.93
4	0.92	0.91	0.89	0.89	0.88	0.87
2	0.85	0.83	0.82	0.80	0.78	0.77
1	0.79	0.76	0.74	0.71	0.69	0.67

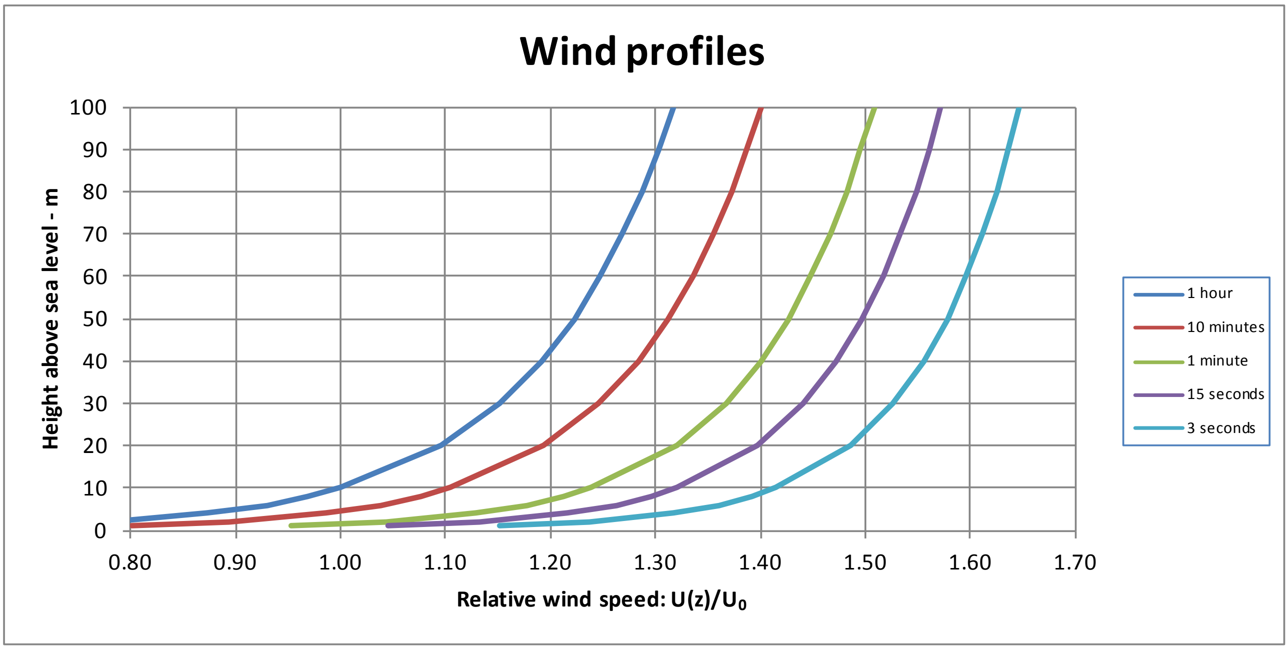


Figure 2.15 **Expected maximum wind speed for averaging time t during 1 hour at height z relative to wind speed U_0 when U_0 = 32.0 m/s.**

Table 2.15 **Expected maximum wind speed for averaging time t during 1 hour at height z relative to wind speed U_0 when U_0 = 32.0 m/s.**

Height above sea level (m)	**Averaging time: t**				
	1 hour	**10 minutes**	**1 minute**	**15 seconds**	**3 seconds**
100	1.32	1.40	1.51	1.57	1.65
90	1.30	1.39	1.50	1.56	1.64
80	1.29	1.37	1.48	1.55	1.62
70	1.27	1.36	1.47	1.53	1.61
60	1.25	1.34	1.45	1.52	1.60
50	1.22	1.31	1.43	1.50	1.58
40	1.19	1.28	1.40	1.47	1.56
30	1.15	1.25	1.37	1.44	1.53
20	1.10	1.19	1.32	1.40	1.49
10	**1.00**	1.10	1.24	1.32	1.41
8	0.97	1.08	1.21	1.30	1.39
6	0.93	1.04	1.18	1.26	1.36
4	0.87	0.99	1.13	1.22	1.32
2	0.78	0.89	1.04	1.13	1.24
1	0.68	0.80	0.95	1.04	1.15

2.5 Turbulence intensity

The turbulence intensity given by Equation (2.7) is found to agree well with observed data for wind speeds U_0 greater than about 12 m/s. For lower wind speeds the mean turbulence intensity is computed by:

$$I_U = \frac{a \exp[0.09 \cdot U(z)]}{U(z)} \qquad \text{for} \quad U_0 < 12.0 m/s \tag{2.8}$$

where a is determined from:

$$a = I_U \exp[-0.09 \cdot U(z)] \cdot U(z) \qquad \text{for} \quad U_0 = 12.0 m/s \tag{2.9}$$

where U(z) is computed from Equation (2.4) and I_U from Equation (2.7) for U_0 = 12.0 m/s.

Figure 2.16 shows the computed turbulence intensity compared to the turbulence intensity determined from measurements at 100 m above mean sea level at Station FINO 3 in the German Bight.

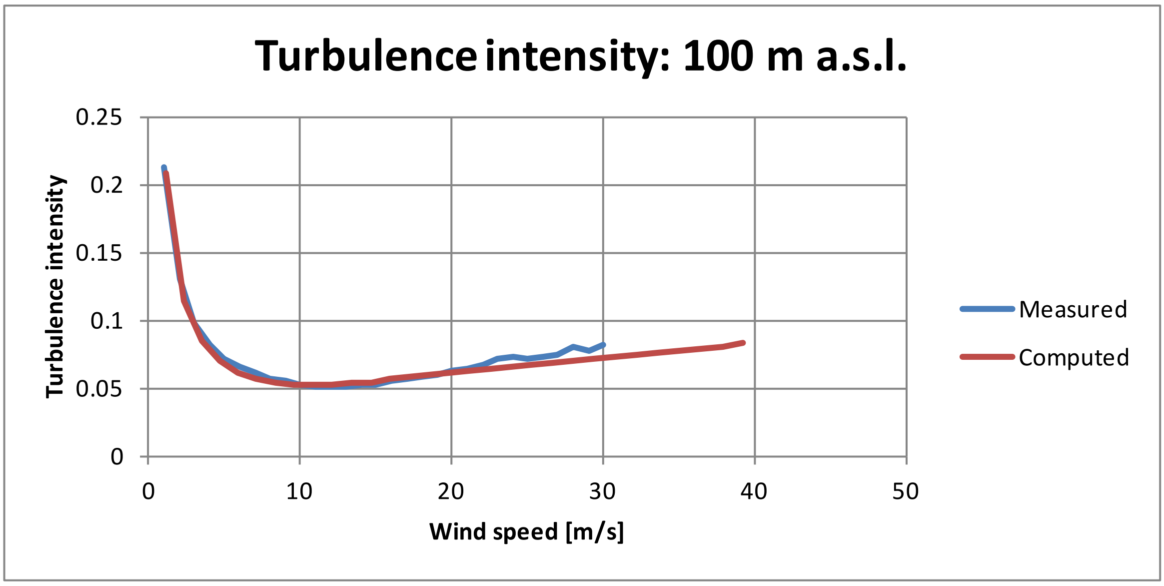


Figure 2.16 Computed turbulence intensity compared to turbulence intensity determined from measurement at 100 m above sea level at FINO 3 (German Bight).

2.6 Wind spectra

For structures and structural elements for which the dynamic wind behaviour is of importance, the following 1-point wind spectrum shall be used for the spectral density of the longitudinal wind speed fluctuations; NS-EN ISO 19901-1:2005 Section A.7.4 [2], Andersen and Løvseth [14]:

$$S(f) = \frac{320 \cdot \left(\frac{U_0}{U_{ref}}\right)^2 \cdot \left(\frac{z}{z_r}\right)^{0.45}}{\left(1+\tilde{f}^{\,n}\right)^{\frac{5}{3n}}} \left[m^2 / s\right] \tag{2.10}$$

where n = 0.468, and

$$\tilde{f} = 172 \cdot f \cdot \left(\frac{z}{z_r}\right)^{\frac{2}{3}} \cdot \left(\frac{U_0}{U_{ref}}\right)^{-0.75} \left[s\right] \tag{2.11}$$

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

The wind profile description Equations (2.6) - (2.7) and the spectral description Equations (2.10) - (2.11) are valid both for moderate and strong (extreme) wind speed conditions. However, for moderate conditions (U_0 < 15 – 20 m/s) and non-neutral stability conditions both the wind profile and the wind spectrum may deviate significantly from the above neutral descriptions. For the non-neutral wind profile reference is made to Plate [25] and for the wind spectrum to Andersen and Løvseth [15].

The squared correlation between the spectral densities, Equation (2.10), of the longitudinal wind speed fluctuations of frequency f between two points is described in terms of the two-point coherence spectrum.

The recommended coherence spectrum between two points $P_1(x_1,y_1,z_1)$ and $P_2(x_2,y_2,z_2)$ with:

x_1 and x_2	Along-wind positions
y_1 and y_2	Across-wind positions
z_1 and z_2	Elevations

is given by:

$$Coh(f) = \exp\left[-\frac{1}{U_0} \cdot \left(\sum_{i=1}^{3} A_i^2 \right)^{\frac{1}{2}} \right] \tag{2.12}$$

where

$$A_i = \alpha_i \cdot f^{r_i} \cdot \Delta_i^{q_i} \cdot \left(\frac{z_g}{z_r} \right)^{-p_i} \tag{2.13}$$

$$z_g = (z_1 \cdot z_2)^{\frac{1}{2}} \tag{2.14}$$

where the coefficients α_i, p_i, q_i, r_i and the separations Δ_i are given in Table 2.16.

Table 2.16 Coefficients and separation for the 3-D (i = 1, 2, 3) coherence spectrum. Separations are given by absolute values.

i	**Δ_i**	**q_i**	**p_i**	**r_i**	**α_i**
1	$\lvert x_2 - x_1 \rvert$	1.00	0.4	0.92	2.9
2	$\lvert y_2 - y_1 \rvert$	1.00	0.4	0.92	45.0
3	$\lvert z_2 - z_1 \rvert$	1.25	0.5	0.85	13.0

Equations (2.12) - (2.14) require that f is in Hertz (Hz), A_i in metres per second (m/s) and Δ_i in metres (m).

2.7 Operational data – 10 m above sea level

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 the present report is restricted to critical operations, only. Figure 2.17 illustrates how the duration of a critical operation is defined.

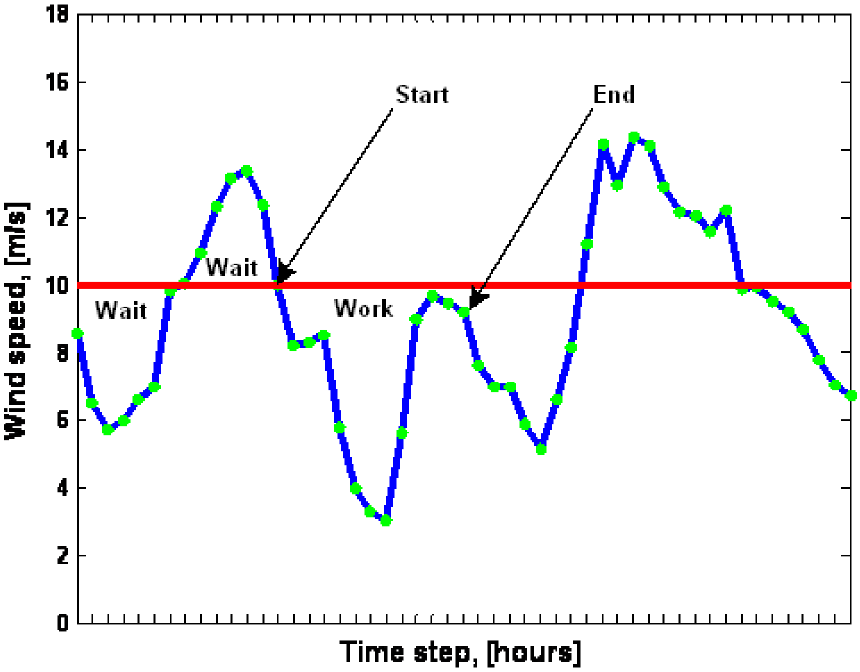
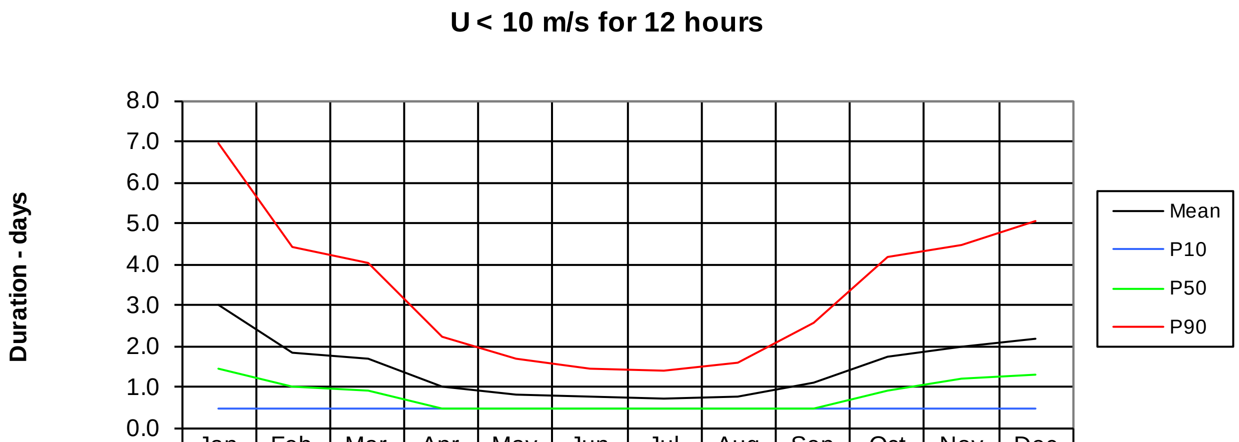


Figure 2.17 Example of a critical operation limited by wind speed 10 m/s and needing 12 hours of work to be completed. Work starts as wind speed becomes lower than 10 m/s and is completed before the wind speed exceeds 10 m/s. The duration of the operation is the time from arrival at time t = 0 to completion. The initial window is too short to be used.

Figure 2.18 - Figure 2.23 show characteristic durations of operations limited by wind speeds of 10 and 15 m/s for 12, 24 and 48 hours. The figures show the expected mean duration and 10, 50 and 90 percentiles.

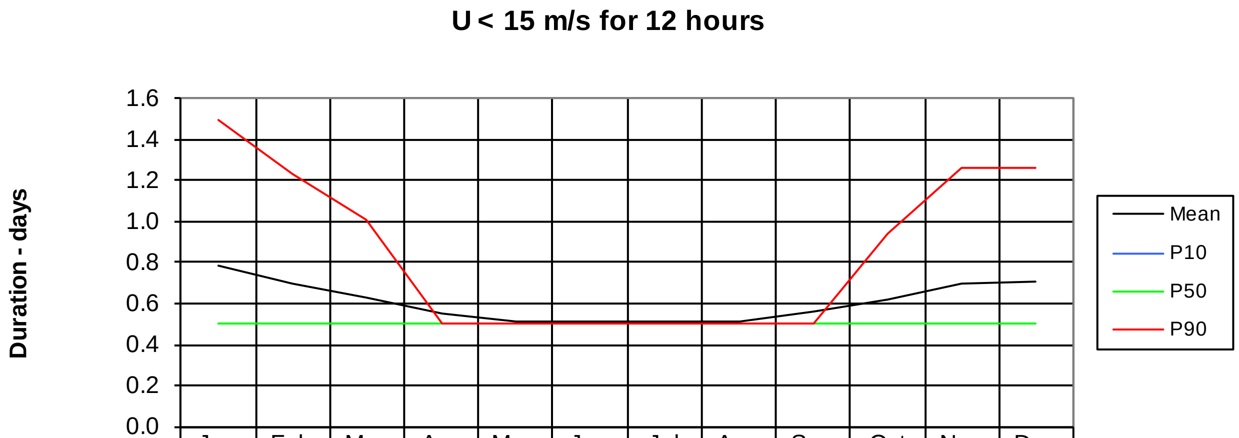
The figures show duration characteristics for completing a critical operation including waiting time. Duration is measured from the day the operation is ready for launching. The day of launching is assumed to be an arbitrary day within the relevant month.

Duration statistics for non-critical operations may be established upon request.



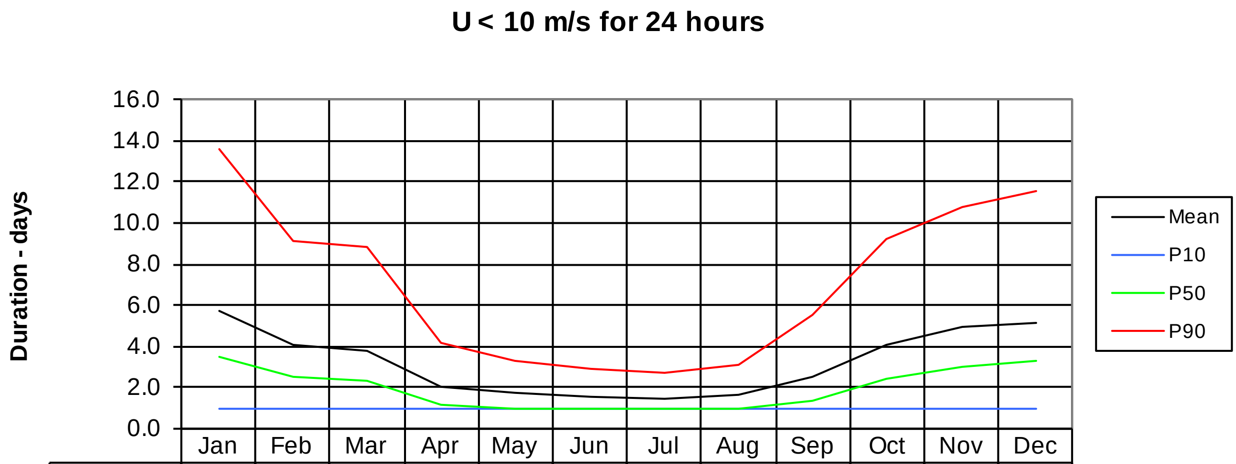
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	3.0	1.9	1.7	1.0	0.8	0.8	0.7	0.8	1.1	1.7	2.0	2.2
P10	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
P50	1.5	1.0	0.9	0.5	0.5	0.5	0.5	0.5	0.5	0.9	1.2	1.3
P90	7.0	4.4	4.0	2.2	1.7	1.5	1.4	1.6	2.6	4.2	4.5	5.0

Figure 2.18 **Characteristic durations, including waiting time, in order to perform operations limited by a wind speed (U) of 10 m/s for 12 hours.**



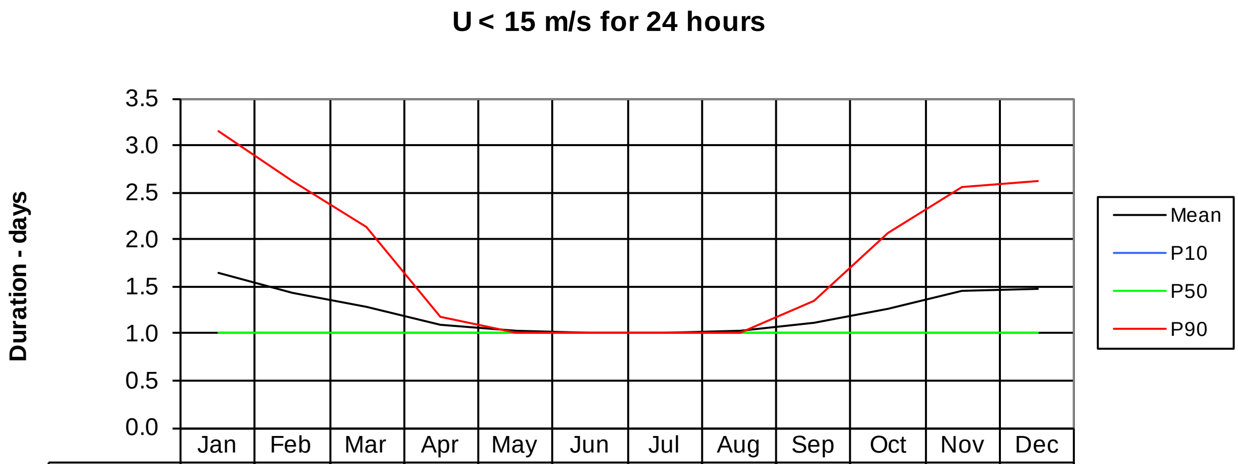
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.8	0.7	0.6	0.6	0.5	0.5	0.5	0.5	0.6	0.6	0.7	0.7
P10	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
P50	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
P90	1.5	1.2	1.0	0.5	0.5	0.5	0.5	0.5	0.5	0.9	1.3	1.3

Figure 2.19 **Characteristic durations, including waiting time, in order to perform operations limited by a wind speed (U) of 15 m/s for 12 hours.**



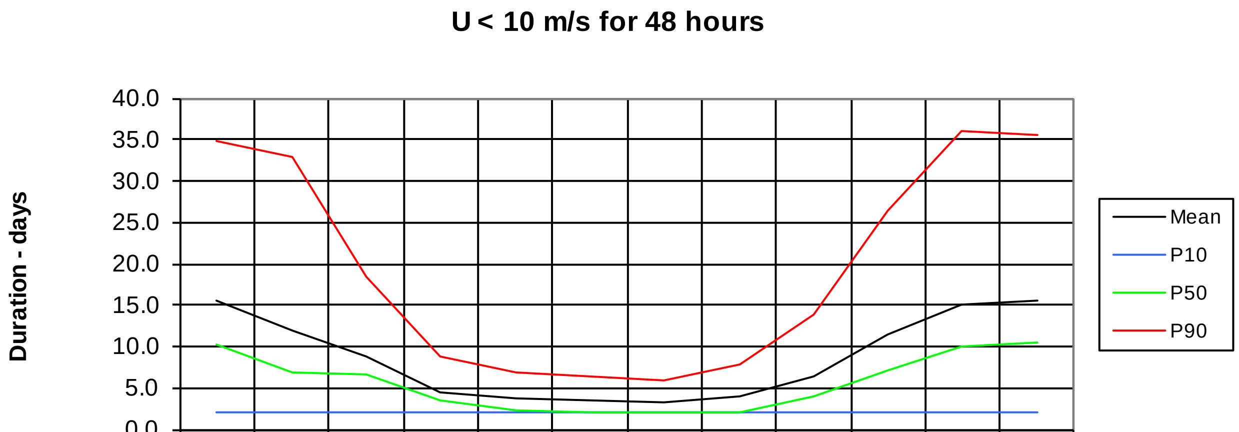
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	5.8	4.1	3.7	2.0	1.7	1.5	1.5	1.6	2.5	4.1	4.9	5.1
P10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
P50	3.5	2.5	2.4	1.1	1.0	1.0	1.0	1.0	1.3	2.4	3.0	3.3
P90	13.5	9.1	8.8	4.2	3.3	2.9	2.7	3.1	5.5	9.2	10.8	11.6

Figure 2.20 Characteristic durations, including waiting time, in order to perform operations limited by a wind speed (U) of 10 m/s for 24 hours.



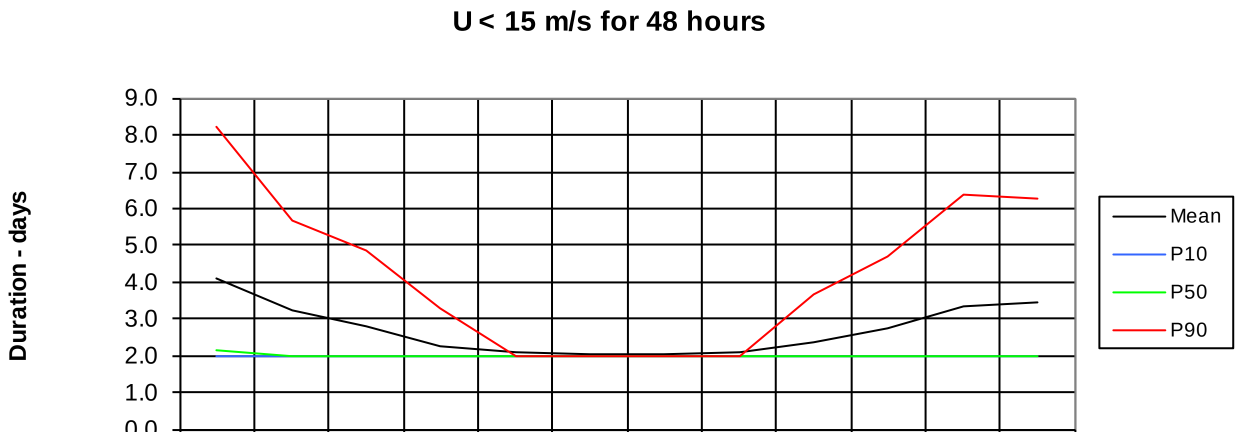
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	1.7	1.4	1.3	1.1	1.0	1.0	1.0	1.0	1.1	1.3	1.5	1.5
P10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
P50	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
P90	3.2	2.6	2.1	1.2	1.0	1.0	1.0	1.0	1.4	2.1	2.6	2.6

Figure 2.21 Characteristic durations, including waiting time, in order to perform operations limited by a wind speed (U) of 15 m/s for 24 hours.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	15.7	12.1	8.8	4.5	3.6	3.4	3.2	4.0	6.3	11.5	15.1	15.7
P10	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
P50	10.2	6.9	6.7	3.4	2.3	2.0	2.0	2.2	3.9	7.0	10.1	10.6
P90	34.9	32.9	18.6	8.9	6.8	6.3	6.0	7.8	14.0	26.5	36.0	35.6

Figure 2.22 Characteristic durations, including waiting time, in order to perform operations limited by a wind speed (U) of 10 m/s for 48 hours.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	4.1	3.3	2.8	2.3	2.1	2.1	2.1	2.1	2.4	2.7	3.4	3.5
P10	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
P50	2.2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
P90	8.2	5.7	4.9	3.3	2.0	2.0	2.0	2.0	3.7	4.7	6.4	6.3

Figure 2.23 Characteristic durations, including waiting time, in order to perform operations limited by a wind speed (U) of 15 m/s for 48 hours.

3 Waves

3.1 Wave data

Wave data are available from the Nora10 hindcast model operated by the Norwegian Meteorological Institute [26]. The data are from the grid point at 57.40º N, 01.28º W. The wave data cover the period 1958 – 2010 (53 years). The sample interval is 3 hours.

The Nora10 wave height data are found to be of good quality [16].

Nora10 spectral peak periods are represented by discrete frequencies, f_i, given by:

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

The spectral peak periods are adjusted (non-discretized) prior to analysis [23]. Adjustment ("non-discretization") 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].

3.2 Wave data analysis

Figure 3.1 show the all-year wave rose, i.e. the sample direction distribution of significant wave height, at Buchan Deep.

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

Figure 3.2 shows monthly mean and maximum significant wave height.

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

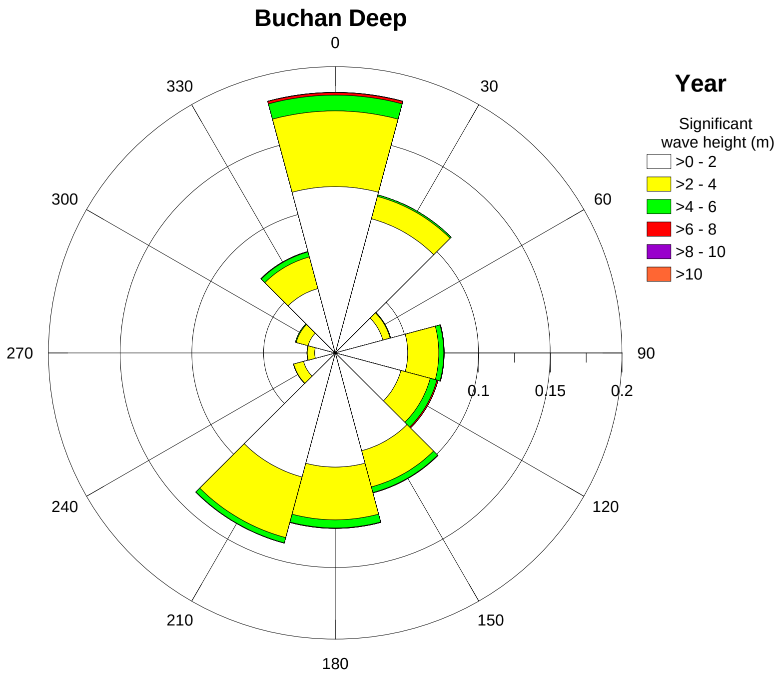


Figure 3.1 All-year wave rose at Buchan Deep for the period 1958 - 2010.

Table 3.1 Annual direction sample distributions of non-exceedance (%) of significant wave height (H_S) at Buchan Deep.

H_S (m)	Wave direction												
	0°	**30°**	**60°**	**90°**	**120°**	**150°**	**180°**	**210°**	**240°**	**270°**	**300°**	**330°**	**Omni**
< 1	4.40	4.73	1.78	2.07	2.07	3.15	3.00	2.86	0.88	0.55	0.73	1.76	**27.98**
< 2	11.62	9.70	3.44	5.05	4.74	7.07	7.97	8.97	2.29	1.43	1.96	4.65	**68.88**
< 3	15.31	10.98	3.86	6.52	6.16	8.81	10.56	12.24	2.88	1.83	2.60	6.26	**88.00**
< 4	16.91	11.32	3.96	7.22	6.85	9.69	11.66	13.36	3.00	1.95	2.82	6.94	**95.66**
< 5	17.66	11.40	3.99	7.47	7.17	10.00	12.09	13.67	3.02	1.97	2.86	7.22	**98.51**
< 6	18.01	11.42	4.00	7.56	7.33	10.10	12.22	13.74	3.02	1.97	2.88	7.30	**99.54**
< 7	18.14	11.43	4.00	7.58	7.40	10.13	12.25	13.75	3.02	1.97	2.88	7.32	**99.87**
< 8	18.18	11.43		7.59	7.42	10.13	12.26	13.76				7.33	**99.97**
< 9	18.20	11.43		7.60	7.42		12.26	13.76				7.34	**100.00**
< 10	18.20												**100.00**
< 11	18.20												**100.00**
Total	**18.20**	**11.43**	**4.00**	**7.60**	**7.42**	**10.13**	**12.26**	**13.76**	**3.02**	**1.97**	**2.88**	**7.34**	**100.00**
Mean	**2.0**	**1.4**	**1.3**	**1.8**	**1.9**	**1.7**	**1.9**	**1.8**	**1.6**	**1.7**	**1.8**	**1.9**	**1.8**
Maximum	**10.2**	**8.1**	**6.7**	**8.6**	**8.4**	**7.7**	**8.4**	**8.9**	**6.3**	**6.2**	**6.6**	**8.4**	**10.2**

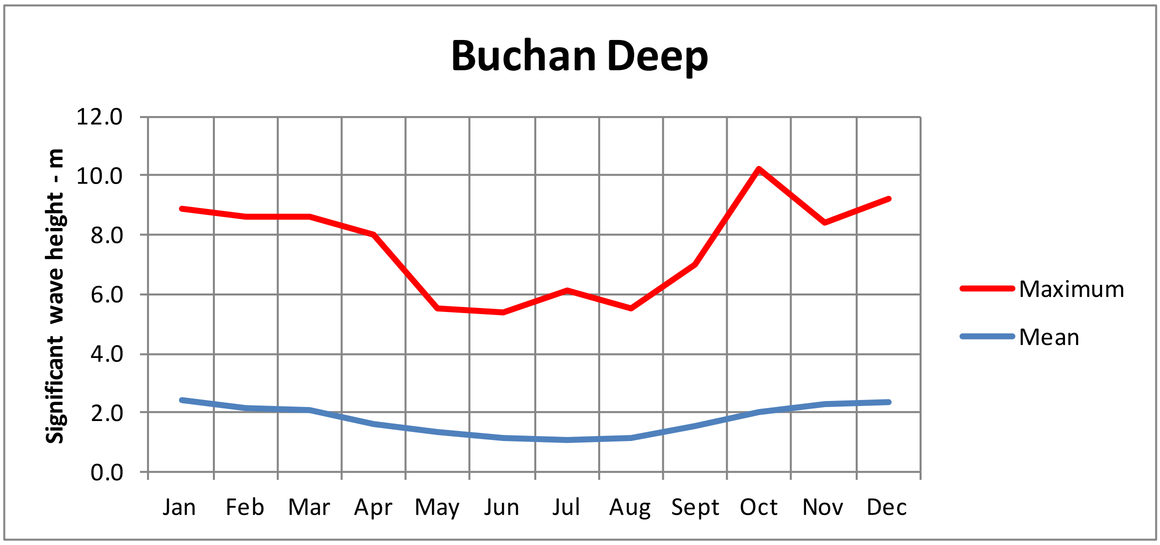


Figure 3.2 **Monthly mean and maximum significant wave height at Buchan Deep.**

Table 3.2 **Monthly and annual sample distributions of non-exceedance (%) of significant wave height (H_S) at Buchan Deep.**

H_S (m)	**Month**												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Year**
< 1	9.47	13.90	14.27	29.40	38.69	50.48	57.98	52.50	31.60	15.50	11.08	9.96	**27.98**
< 2	44.35	53.53	57.81	75.08	83.77	90.69	93.27	90.82	78.51	60.61	50.64	46.72	**68.88**
< 3	73.33	80.58	83.93	91.50	96.28	98.36	98.55	98.80	93.66	85.07	78.62	77.01	**88.00**
< 4	90.00	92.40	94.05	96.91	99.54	99.72	99.73	99.82	98.29	94.65	91.34	91.33	**95.66**
< 5	96.50	97.12	97.77	99.01	99.94	99.94	99.95	99.97	99.56	98.11	97.22	96.90	**98.51**
< 6	98.84	99.11	99.09	99.68	100.00	100.00	99.99	100.00	99.89	99.54	99.27	99.03	**99.54**
< 7	99.75	99.77	99.76	99.90			100.00		100.00	99.75	99.83	99.74	**99.87**
< 8	99.96	99.97	99.95	100.00						99.88	99.99	99.92	**99.97**
< 9	100.00	100.00	100.00							99.98	100.00	99.99	**100.00**
< 10										99.99		100.00	**100.00**
< 11										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	**2.4**	**2.2**	**2.1**	**1.6**	**1.4**	**1.2**	**1.1**	**1.1**	**1.5**	**2.0**	**2.3**	**2.3**	**1.8**
Maximum	**8.9**	**8.6**	**8.6**	**8.0**	**5.5**	**5.4**	**6.1**	**5.5**	**7.0**	**10.2**	**8.4**	**9.2**	**10.2**

3.3 Long-term wave statistics

$$F(h) = 1 - \exp\left\{-\left[\frac{h-\varepsilon}{\theta}\right]^{\gamma}\right\} \tag{3.3}$$

where:

h	Significant wave height
ε	Location parameter
θ	Scale parameter
γ	Shape parameter

Extreme values, h_R, corresponding to a return period, R, are obtained by inverting Equation (3.3) for a cumulative probability F = 1 – τ/pR, i.e.:

$$h_R = \varepsilon + \theta \cdot \left[-\ln\left(\frac{\tau}{pR}\right)\right]^{1/\gamma} \tag{3.4}$$

where

τ	Duration of event (= 3 hours for significant wave height)
p	Sector or monthly probability (=1/12 for monthly omni-directional distributions)
R	Return period

The annual probability of exceedance, q, is given by:

$$q = 1 - \exp\left(-\frac{T}{R}\right) \qquad T = 1 \text{ year} \tag{3.5}$$

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.

Figure 3.3 shows the observed and fitted distributions of significant wave height at Buchan Deep.

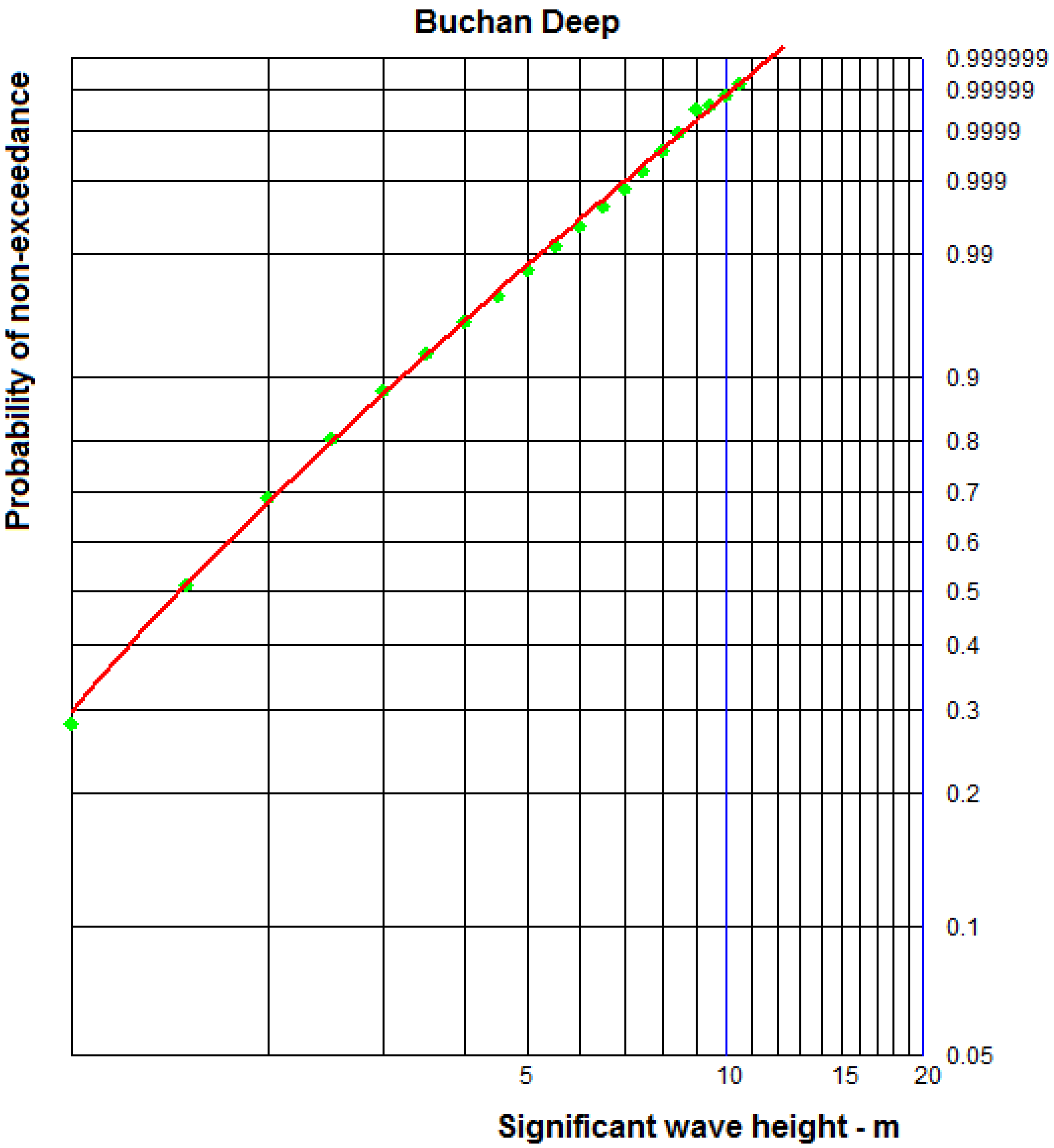


Figure 3.3 Observed (green dots) and fitted (red line) distributions of significant wave height at the Hywind site at Buchan Deep.

Figure 3.4 and Table 3.3 show directional Weibull parameters and corresponding extremes of significant wave height at Buchan Deep. Figure 3.5 and Table 3.4 show monthly Weibull parameters and corresponding extremes.

If directional extremes are to be used for calculating response extremes, one must ensure that the estimated response extremes correspond to an annual marginal exceedance probability in agreement with rule defined requirements, NORSOK Standard N-006 [8].

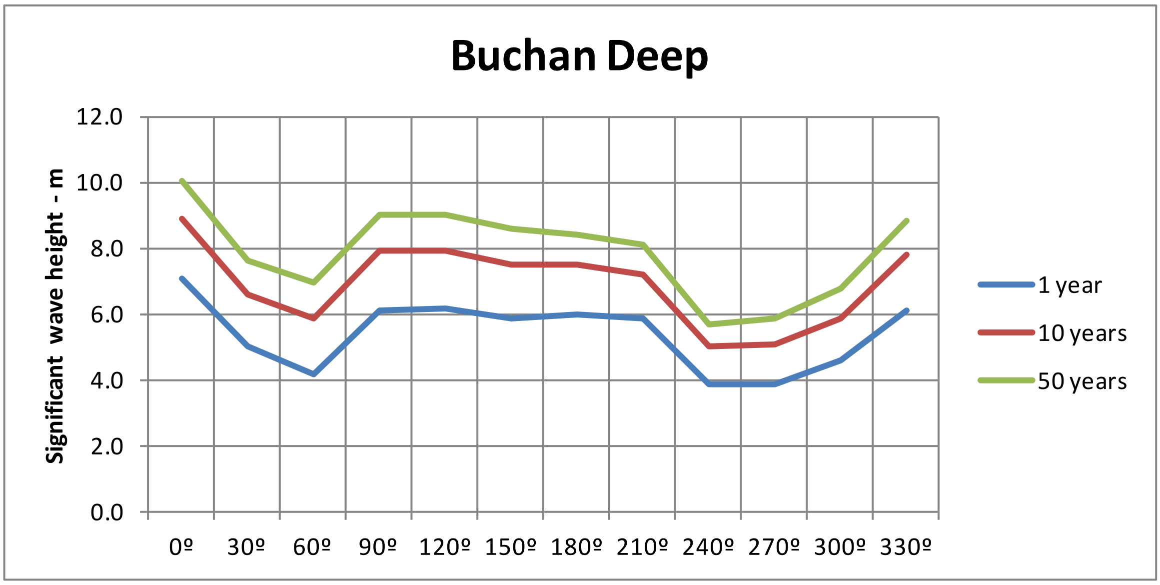


Figure 3.4 Direction variation of significant wave height of return periods 1, 10 and 50 years at the Hywind site at Buchan Deep.

Table 3.3 Directional Weibull parameters and corresponding extreme values for significant wave height at Buchan Deep. Duration of event is 3 hours.

Direction	Sector prob.	Weibull parameters			Return period		
		Shape	Scale	Location	1 year	10 years	50 years
	%	-	m	m	m	m	m
0°	18.20	1.320	1.68	0.34	7.1	8.9	10.1
30°	11.43	1.156	1.02	0.35	5.0	6.6	7.6
60°	4.00	1.145	1.01	0.30	4.2	5.9	7.0
90°	7.60	1.344	1.67	0.26	6.1	7.9	9.0
120°	7.42	1.420	1.84	0.19	6.2	7.9	9.0
150°	10.13	1.376	1.62	0.21	5.9	7.5	8.6
180°	12.26	1.477	1.74	0.24	6.0	7.5	8.4
210°	13.76	1.453	1.61	0.35	5.9	7.2	8.1
240°	3.02	1.629	1.48	0.20	3.9	5.0	5.7
270°	1.97	1.612	1.57	0.19	3.9	5.1	5.9
300°	2.88	1.517	1.62	0.25	4.6	5.9	6.8
330°	7.34	1.395	1.74	0.27	6.1	7.8	8.9
0° - 360°	**100.00**	**1.301**	**1.51**	**0.32**	**7.8**	**9.4**	**10.5**

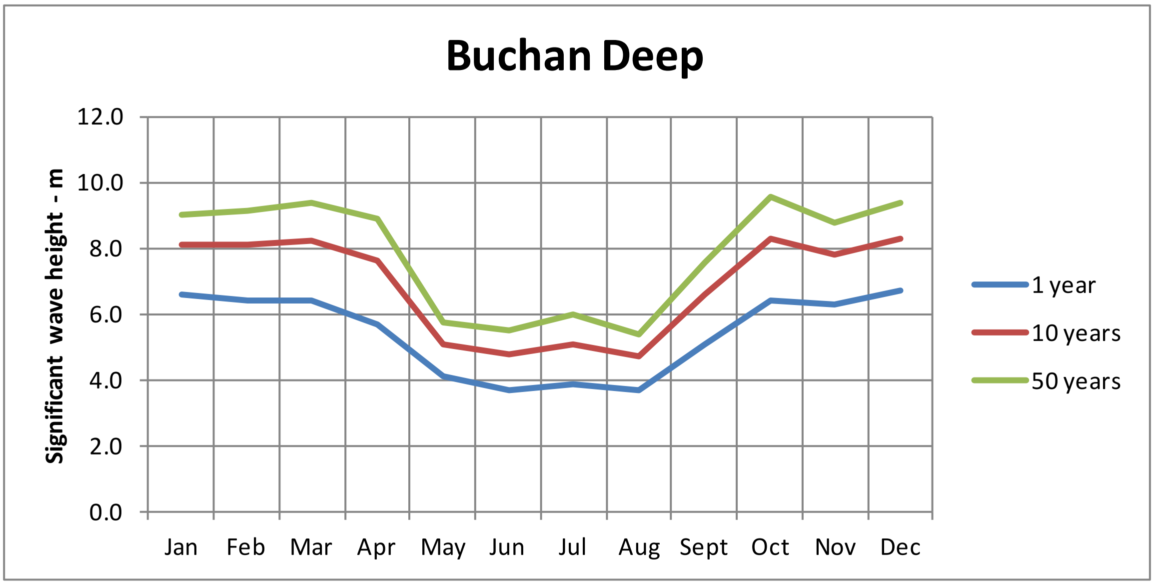


Figure 3.5 **Monthly variation of significant wave height of return periods 1, 10 and 50 years at the Hywind site at Buchan Deep.**

Table 3.4 **Monthly and annual Weibull parameters and corresponding extreme values for significant wave height at Buchan Deep. Duration of event is 3 hours.**

Month	Annual prob.	Weibull parameters			Return period		
		Shape	Scale	Location	1 year	10 years	50 years
	%	-	m	m	m	m	m
Jan	8.33	1.638	2.18	0.42	6.6	8.1	9.0
Feb	8.33	1.447	1.83	0.48	6.4	8.1	9.1
Mar	8.33	1.297	1.56	0.60	6.4	8.2	9.4
Apr	8.33	1.159	1.22	0.44	5.7	7.6	8.9
May	8.33	1.436	1.15	0.28	4.1	5.1	5.8
Jun	8.33	1.309	0.95	0.25	3.7	4.8	5.5
Jul	8.33	1.143	0.81	0.26	3.9	5.1	6.0
Aug	8.33	1.359	1.00	0.18	3.7	4.7	5.4
Sept	8.33	1.240	1.18	0.39	5.1	6.6	7.6
Oct	8.33	1.240	1.47	0.60	6.4	8.3	9.6
Nov	8.33	1.548	1.96	0.46	6.3	7.8	8.8
Dec	8.33	1.473	1.93	0.55	6.7	8.3	9.4
Year	**100.00**	**1.301**	**1.51**	**0.32**	**7.8**	**9.4**	**10.5**

.

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 the scatter diagram of H_S and T_p for the period 1958 – 2010 (53 years). The scatter diagram is obtained from the Nora10 hindcast data

The scatter diagram in Table 3.5 shall not be used for estimating extreme values with annual probability of exceedance less than 10^{-2}. For such a purpose a fitted joint model of H_S and T_p shall be used.

Scatter diagrams for monthly and directional data may be provided upon request.

The long term variation of the wave climate can be described by the joint probability density function for H_s and $T_{p,}$ and is given by:

$$f_{H_sT_p}(h_s, t_p) = f_{H_s}(h_s) \cdot f_{T_p|H_s}(t_p \mid h_s) \tag{3.6}$$

where

$$\begin{aligned} f_{H_s}(h_s) &= \frac{1}{h_s \cdot \varsigma\sqrt{2\pi}\,\cdot} \cdot \exp\left(-\frac{(\ln(h_s) - \nu)^2}{2 \cdot \varsigma^2} \right) \quad \text{for} \quad h_s \le \eta \\ f_{H_s}(h_s) &= \frac{\gamma}{\theta}\left(\frac{h_s}{\theta}\right)^{\gamma-1} \exp\left[-\left(\frac{h_s}{\theta}\right)^{\gamma} \right] \quad \text{for} \quad h_s > \eta \end{aligned} \tag{3.7}$$

and

$$f_{T_p1H_s}(t_p \mid h_s) = \frac{1}{t_p \cdot \sigma\sqrt{2\pi}} \cdot \exp\left(-\frac{(\ln(t_p) - \mu)^2}{2 \cdot \sigma^2} \right) \tag{3.8}$$

where

$$\begin{aligned} \mu &= a_1 + a_2 \cdot h_s^{a_3} \\ \sigma^2 &= b_1 + b_2 \cdot \exp(-b_3 \cdot h_s) \end{aligned} \tag{3.9}$$

Table 3.5 Scatter diagram of significant wave height (H_S) and spectral peak period (T_p) at Buchan Deep for the period 1958 – 2010 (53 years). Duration of sea state is 3 hours.

H_S (m)	Spectral peak period (T_p) - (s)																					
	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	Sum
0-1	177	3746	10423	9068	7551	4984	2983	2033	1142	626	309	167	63	38	12	3	4					**43329**
1-2		57	5281	13966	12849	10034	7653	5074	3720	2476	1254	571	245	109	36	9	3					**63337**
2-3			32	1413	7085	7423	4826	3338	1985	1397	1132	582	228	125	31	12	7					**29616**
3-4				4	599	2588	3559	2404	1332	553	388	204	141	63	20	5	2	1	1			**11864**
4-5					15	168	1046	1398	993	445	152	94	50	22	14	4			1			**4402**
5-6						5	113	429	497	358	114	57	12	10	5							**1600**
6-7							3	55	132	166	103	43	13	3	2							**520**
7-8								2	18	42	57	16	10	4	4							**153**
8-9									1	6	14	7	7	2	1							**38**
9-10												1	2									**3**
10-11											1											**1**
Sum	**177**	**3803**	**15736**	**24451**	**28099**	**25202**	**20183**	**14733**	**9820**	**6069**	**3524**	**1742**	**771**	**376**	**125**	**33**	**16**	**1**	**2**	**0**	**0**	**154863**

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

$$\overline{T_p} = \exp\left(\mu + \frac{1}{2}\sigma^2\right) \tag{3.10}$$

$$\sigma_{Tp} = \overline{T_p} \cdot \sqrt{\exp(\sigma^2) - 1} \tag{3.11}$$

In this formulation the LoNoWe (LogNormal-Weibull) distribution, Equation (3.7), replaces the 3-parameter Weibull distribution, Equation (3.3). This choice is made in order to provide a better fit to the data in the lower tail of the distribution.

The LoNoWe distribution is fitted to the data such that the extreme value corresponding to an annual probability of exceedance of 10^{-2} is equal to the corresponding value obtained when fitting a three-parameter Weibull distribution to the data, i.e. as given in Table 3.3 and Table 3.4. The extreme values corresponding to an annual probability of exceedance of 10^{-4} obtained from the LoNoWe and the three parameter Weibull distributions may differ but generally by no more than 0.1 m.

Table 3.6 shows the coefficients determined for the annual omni-directional distribution for use in long-term response analyses.

Table 3.6 Parameters in the annual omni-directional joint distribution for H_S and T_p.

	Parameters										
	γ	**θ**	**η**	**ζ**	**ν**	**a_1**	**a_2**	**a_3**	**b_1**	**b_2**	**b_3**
	Omni-directional										
Year	1.340	1.648	2.906	0.585	0.373	1.307	0.567	0.369	0.005	0.119	0.425

Figure 3.6 and Table 3.7 show spectral peak period given significant wave height.

The apparent discontinuity in T_p at $T_p \approx 18.8$ s (in Figure 3.6) is due to the discretization of frequencies used in the Nora10 model, and has not been fully resolved by the non-discretization procedure; i.e. by Equation (3.2).

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

Table 3.9 and Table 3.10 show directional and monthly extreme significant wave heights and corresponding spectral peak periods. (See Chapter 1.3.5 if directional extremes are to be used for design).

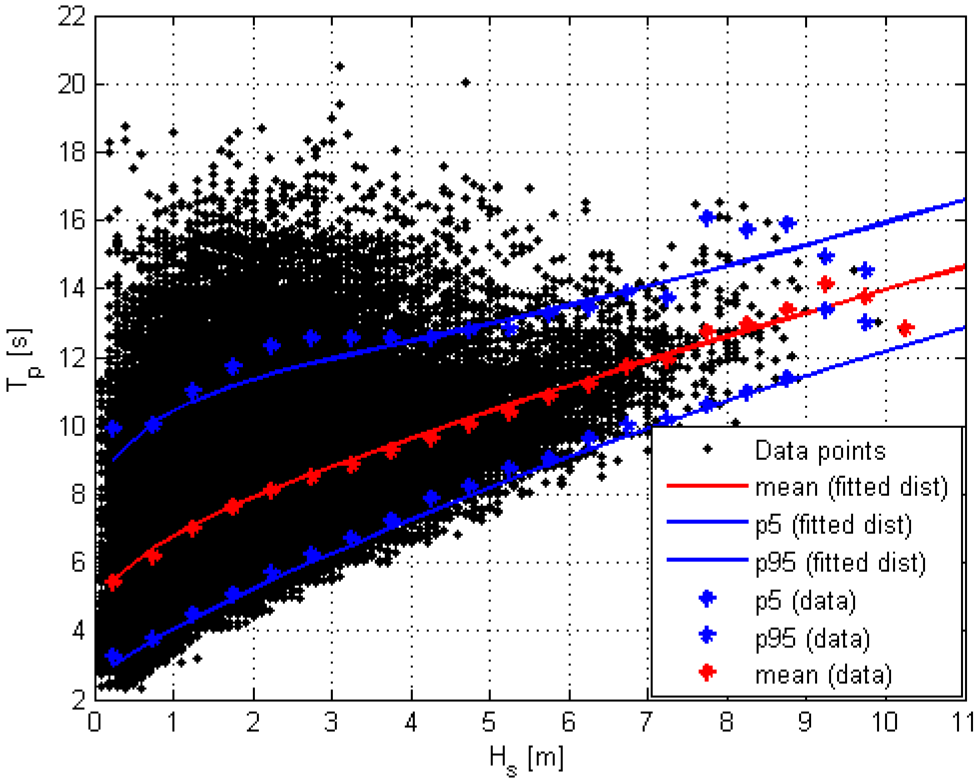


Figure 3.6 Spectral peak period for given significant wave height at Buchan Deep.

Table 3.7 Spectral peak period T_p as a function of significant wave height H_S at Buchan Deep; mean values and 90 % confidence bands.

Significant wave height H_S – (m)	Spectral peak period T_p – (s)		
	P5	Mean	P95
1.0	4.1	6.8	10.5
2.0	5.2	7.9	11.3
3.0	6.3	8.8	11.9
4.0	7.3	9.6	12.4
5.0	8.2	10.4	13.0
6.0	9.1	11.2	13.5
7.0	9.9	11.9	14.1
8.0	10.7	12.6	14.6
9.0	11.5	13.3	15.3
10.0	12.2	14.0	15.9
11.0	12.8	14.6	16.6

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

Return period (years)	Significant wave height H_S – (m)	Spectral peak period T_p – (s)		
		P5	Mean	P95
1	7.8	10.6	12.4	14.5
10	9.4	11.7	13.6	15.5
50	10.9	12.8	14.6	16.5
100	13.8	14.6	16.5	18.6

The most consistent estimate for the q - annual probability load/response is obtained by performing a full long term analysis. Details regarding long-term response analysis are found in e.g. [21]. For a very complex response problem a full long term analysis will typically be out of reach. For such cases one can estimate the q - annual probability response using the environmental contour method. This method is also described into some detail in [21]. The major steps of the method are stated in NORSOK Standard N-003 Section 6.2.2.2 [7]. They are:

i. At first the q-probability contour lines must be established for e.g. significant wave height and spectral peak period. The q - probability contour line provides all pairs of H_s and T_p corresponding to an annual probability of being “exceeded” by q.
ii. For a given response problem one has to find the most unfavourable sea state along the q - probability contour line.
iii. For the worst sea state along the contour the distribution function for the 3-hour maximum response is established.
iv. Finally, the q-probability value of the selected response quantity is estimated by the value of the 3-hour extreme value distribution that is exceeded by probability 1-α. For q = 10^{-2}, NORSOK Standard N-003 Section 6.2.2.3 [7] recommends α = 0.85 – 0.90. For q = 10^{-4} a proper percentile is often in the range 0.90 – 0.95.

It must be remembered that the environmental contour method is an approximate method. The free parameter of the method is α. There are some few examples showing that the best estimate would be obtained for an α-value lower than 0.85 and there are examples that the “correct” value of α is larger than 0.9. The “true” value of α can only be found if it is calibrated to the result of a long term analysis. If more than two slowly varying characteristics are included, e.g. mean wind speed in addition to H_S and T_p, an adequate percentile is likely to be somewhat lower than recommended above.

Figure 3.7 and Table 3.11 show q – probability contour lines of H_s – T_p corresponding to return periods of 1, 10, 50 and 100 years, for omni-directional waves.

Table 3.9 **Directional extreme significant wave height (H_S) and spectral peak period (T_p) at Buchan Deep.**

Direction sector	Sector probability	Return period					
		1 year		10 years		50 years	
		H_S (m)	T_p (s)	H_S (m)	T_p (s)	H_S (m)	T_p (s)
0º	18.20	7.1	11.9	8.9	13.2	10.1	14.0
30º	11.43	5.0	10.4	6.6	11.6	7.6	12.3
60º	4.00	4.2	9.8	5.9	11.1	7.0	11.8
90º	7.60	6.1	11.2	7.9	12.5	9.0	13.3
120º	7.42	6.2	11.3	7.9	12.5	9.0	13.3
150º	10.13	5.9	11.1	7.5	12.3	8.6	13.0
180º	12.26	6.0	11.2	7.5	12.2	8.4	12.9
210º	13.76	5.9	11.1	7.2	12.1	8.1	12.7
240º	3.02	3.9	9.6	5.0	10.4	5.7	10.9
270º	1.97	3.9	9.6	5.1	10.5	5.9	11.1
300º	2.88	4.6	10.1	5.9	11.1	6.8	11.7
330º	7.34	6.1	11.2	7.8	12.4	8.9	13.2
0º-360º	**100.00**	**7.8**	**12.4**	**9.4**	**13.5**	**10.5**	**14.3**

Table 3.10 **Monthly extreme significant wave height (H_S) and spectral peak period (T_p) at Buchan Deep.**

Month	Annual probability	Return period					
		1 year		10 years		50 years	
		H_S (m)	T_p (s)	H_S (m)	T_p (s)	H_S (m)	T_p (s)
Jan	8.33	6.6	11.6	8.1	12.6	9.0	13.3
Feb	8.33	6.4	11.5	8.1	12.6	9.1	13.4
Mar	8.33	6.4	11.5	8.2	12.7	9.4	13.5
Apr	8.33	5.7	11.0	7.6	12.3	8.9	13.2
May	8.33	4.1	9.7	5.1	10.5	5.8	11.0
Jun	8.33	3.7	9.4	4.8	10.3	5.5	10.8
Jul	8.33	3.9	9.5	5.1	10.5	6.0	11.2
Aug	8.33	3.7	9.4	4.7	10.2	5.4	10.7
Sept	8.33	5.1	10.5	6.6	11.6	7.6	12.3
Oct	8.33	6.4	11.5	8.3	12.8	9.6	13.7
Nov	8.33	6.3	11.4	7.8	12.5	8.8	13.1
Dec	8.33	6.7	11.7	8.3	12.8	9.4	13.5
Year	**100.00**	**7.8**	**12.4**	**9.4**	**13.5**	**10.5**	**14.3**

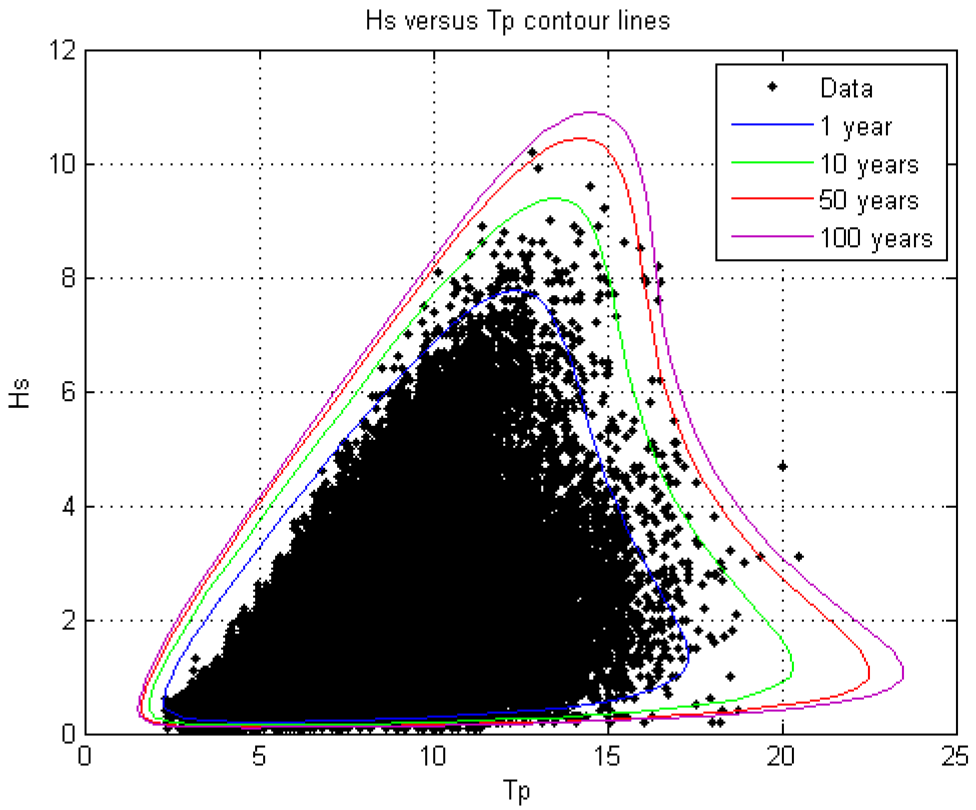


Figure 3.7 **q – probability contour lines of H_S – T_p for return periods of 1, 10, 50 and 100 years, for omni-directional waves at Buchan Deep. Duration of sea state is 3 hours.**

Table 3.11 **q – probability contour values of H_S – T_p for 1, 10, 50 and 100 years return periods for omni-directional waves at Buchan Deep. Duration of sea state is 3 hours. T_{pL} and T_{pH} are lower and higher limits of T_p, respectively.**

Return period											
1 year			10 years			50 years			100 years		
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)
7.8	12.4	12.4	9.4	13.5	13.5	10.5	14.2	14.2	10.9	14.5	14.5
7.0	10.2	13.7	9.0	12.1	14.5	10.0	12.7	15.3	10.0	12.2	15.9
6.0	8.7	14.2	8.0	10.4	15.0	9.0	11.1	15.8	9.0	10.8	16.2
5.0	7.3	14.7	7.0	9.1	15.4	8.0	9.8	16.0	8.0	9.6	16.4
4.0	5.9	15.3	6.0	7.8	15.7	7.0	8.6	16.3	7.0	8.4	16.7
3.0	4.7	16.0	5.0	6.5	16.3	6.0	7.4	16.7	6.0	7.2	17.0
			4.0	5.3	17.0	5.0	6.2	17.3	5.0	6.0	17.7
			3.0	4.1	18.1	4.0	5.0	18.2	4.0	4.8	18.7
						3.0	3.8	19.5	3.0	3.7	20.1

3.4 Short-term sea states

3.4.1 Wave spectra

A sea state may be modelled in terms of a directional wave spectrum of the form, NS-EN ISO 19901-1:2005 Section A.8.6.1 [2]:

$$S(f,\theta) = S(f)D(\theta) \tag{3.12}$$

where S(f) is the frequency spectrum and D(θ) is the direction distribution defined such that:

$$\int_0^{2\pi} D(\theta)d\theta = 1 \tag{3.13}$$

The NORSOK Standard N-003 Section 6.2.2.3 [7] advocates use of the Torsethaugen frequency spectrum [28]:

$$S(f) = S_{Swell}(f) + S_{Windsea}(f) \tag{3.14}$$

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:

$$T_f = a_f H_S^{1/3} \qquad a_f = 6.6 \cdot m^{-1/3} s \tag{3.15}$$

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, [28], but for most offshore sites at the UK and Norwegian continental shelfes, $a_f = 6.6\ m^{-1/3}s$ is a good approximation for storm conditions

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:

$$S(f) = \frac{5}{16} H_S{}^2 T_p \left(\frac{f}{f_p}\right)^{-5} \exp\left\{-\frac{5}{4}\left(\frac{f}{f_p}\right)^{-4}\right\}\left(1 - 0.287\ln(\gamma)\right) \cdot \gamma^{\exp\left\{-0.5\left(\frac{f-f_p}{f_p\sigma}\right)^2\right\}} \tag{3.16}$$

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

$$\sigma = \begin{cases} 0.07 & \text{for} \quad f \le f_p \\ 0.09 & \text{for} \quad f > f_p \end{cases} \tag{3.17}$$

The peak-enhancement factor γ can be computed from [28]:

$$\gamma = \max\left[1.0, 42.2\left(\frac{2\pi H_S}{gT_p^2}\right)^{6/7}\right] \tag{3.18}$$

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

A comparison between the Torsethaugen and JONSWAP spectral models is shown in Figure 3.8.

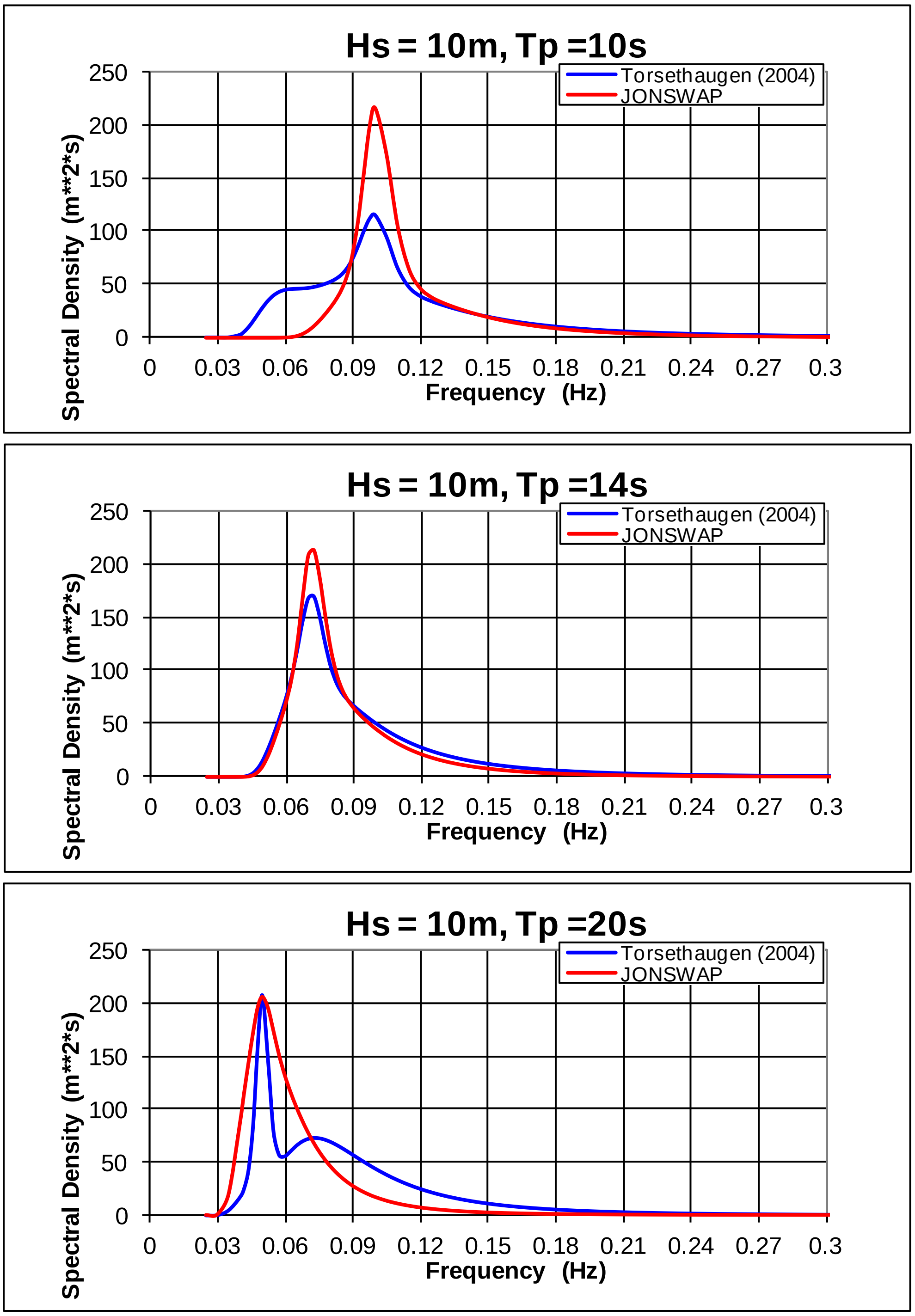
The adequacy of using the JONSWAP spectrum for a sea state characterized by H_s and T_p should be assessed in view of the particular application. As a first assumption it is assumed that if the important sea states are located within a ± 2 s band around the boundary given by Equation (3.15), the JONSWAP gives acceptable results. If for a given application, the JONSWAP spectrum within this range gives larger response than the Torsethaugen spectrum, it is recommended that the most unfavourable spectral model is used. In such cases one should carry out a sensitivity study regarding the peak-enhancement factor and ensure that recommendations are robust regarding uncertainties in this parameter.

One shall be careful by using the JONSWAP spectrum for the whole H_S – T_p scatter diagram. But if the JONSWAP spectrum is used for periods lower than the period band indicated above, a maximum value of γ = 5 should be introduced. For periods higher than those of the suggested JONSWAP band one may apply the γ - value of the upper boundary. An exception to this is if the JONSWAP spectrum is used for representing a pure swell sea. In such a case γ = 10 – 15 is recommended.

Swell is (nearly) always present in the open sea. This is only partly reflected in the H_S – T_p scatter diagram; see Table 3.5. For example, when the spectral peak period T_p is associated with wind sea it may well be that a swell system with markedly higher spectral peak period is present.

Consequently, the information contained in the H_S – T_p scatter diagram is not sufficient for the assessment of operability in the case when the presence of swell (with a critical period for the operation) restrict operations. Using the Torsethaugen spectrum the average partition of wind sea and swell is accounted for, but the direction of propagation is taken to be the same. A more accurate assessment of combined sea can be done by using long term time history of wind sea and swell given by the Nora10 data. This will also account for difference in direction of propagation. Based on these data, scatter diagrams for wind sea and for swell sea can be found.

Information on swell height and period may be provided on request.



(a) (b) (c)

Figure 3.8 **Comparison of JONSWAP and Torsethaugen spectral models for sea states with different spectral peak periods: (a) Wind sea dominated sea state, (b) Boundary sea state and (c) Swell dominated sea state.**

3.4.2 Directional wave spectra

The direction distribution can be modelled by; NS-EN ISO 19901-1:2005 Section A.8.7.1 [2]:

$$D(\theta) = K_W \cos^n(\theta - \theta_m) \qquad -\frac{\pi}{2} \le \theta - \theta_m \le \frac{\pi}{2} \tag{3.19}$$

where K_w is a scaling factor given by:

$$K_W = \frac{\Gamma\left[\frac{n}{2}+1\right]}{\sqrt{\pi}\cdot\Gamma\left[\frac{n}{2}+\frac{1}{2}\right]} \tag{3.20}$$

and θ_m is the mean wave direction. $\Gamma()$ denotes the Gamma function.

The power factor n describes the degree of directional spreading of the waves. For wind seas n should be varied between 2 and 10 if short-crested sea is to be used. Swell seas shall be considered as being long-crested ($n \to \infty$).

Equation (3.19) may not be a very accurate model for the spreading at all frequencies, but it is expected to be of sufficient accuracy regarding response predictions. The underlying spreading function is likely to be bi-modal for high frequencies.

It is for most cases conservative to use long crested sea for extreme value predictions. Ship rolling for a weather vaning ship will be an exception. For final design of a new installation it is recommended that long crested sea is used when it is a conservative approach. However, if short crested sea shall be used, n should be taken as the most conservative value in the range from 2 to 10 for the wind sea. When utilizing short crested sea, it shall as far as possible be verified that the modelling of short crested sea is representative for the wave events causing the governing design loads on the structure under consideration

3.4.3 Wave-induced bottom currents

How to determine wave-induced oscillatory currents at pipeline level (near sea bed) is described in DNV RP-F105 Sections 3.3.5-6 [4]. For most practical cases linear wave theory can be applied. Wave boundary layer effects can normally be neglected.

The velocity spectrum $S_{uu}(f)$ at pipe level is given in term of the wave spectrum S(f):

$$S_{uu}(f) = G^2(f)S(f) \tag{3.21}$$

The transfer function G(f) is given by:

$$G(f) = 2\pi \cdot f \frac{\cosh(k(D+e))}{\sinh(kh)} \tag{3.22}$$

where:

k	Wave number
D	Outer pipeline diameter (including coating)
e	Gap between pipeline and sea bed
h	Water depth (to sea bottom)

Spectral moments M_n of order n are computed from:

$$M_n = \int_0^\infty f^n S_{uu}(f)df \tag{3.23}$$

From the spectral moments the following parameters are computed:

Significant horizontal flow velocity (orbital velocity amplitude) at pipe level:

$$U_S = 2\sqrt{M_0} \tag{3.24}$$

and mean zero up-crossing period of oscillating flow at pipe level:

$$T_u = \sqrt{\frac{M_0}{M_2}} \tag{3.25}$$

The effect of wave directionality and wave spreading may be introduced in the form of a reduction factor R_D on the significant flow velocity; DNV RP-F105 Section 3.4.3 [4]:

$$U_W = R_D U_S \tag{3.26}$$

The reduction factor R_D depends on the wave direction relative to the pipeline normal and the directional spreading given in terms of the n-power in the directional wave spectrum, see Equation (3.19).

3.5 Individual waves

3.5.1 Wave heights

The short term distribution of individual wave heights is modelled using the two parameter Weibull distribution, NS-EN ISO 19901-1:2005 Section A.8.5 [2], Forristall [18].

$$F_H(h) = 1 - \exp\left[-2.263 \left(\frac{h}{h_S} \right)^{2.126} \right] \tag{3.27}$$

where H and h are wave heights and h_S is significant wave height.

The long term distribution of individual wave heights is given by:

$$F_H(h) = \frac{1}{\overline{\nu_0^+}} \int_0^\infty \int_0^\infty \nu_0^+(h_s, t_p) \, F_{H|H_s T_p}(h|h_s, t_p) \, f_{H_s T_p}(h_s, t_p) \, dh_s dt_p \tag{3.28}$$

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:

$$\overline{\nu_0^+} = \int_0^\infty \int_0^\infty \nu_0^+(h_s, t_p) \, f_{H_s T_p}(h_s, t_p) \, dh_s dt_p \tag{3.29}$$

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

$$1 - F_H(h_q) = \frac{q}{n_h} \tag{3.30}$$

where n_h ($\approx 0.5 \cdot 10^7$) is the expected number of waves per year.

Table 3.12 shows the computed design wave heights. The wave periods in Table 3.12 are the peak periods from the q-probability sea states given in Table 3.8 multiplied by 0.90.

Design 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. The wave periods, T_{Hmax}, are computed from T_{Hmax} = 0.90 T_p, were T_p is as given in

Table 3.9 [20]. When using design wave method for predicting estimates for characteristic responses for design, the most unfavorable period within the 90% band shall be adopted.

When using the design wave heights of Table 3.13 for obtaining characteristic response for design for the various directions, it must be verified that the finally selected design response corresponds to an annual exceedance probability being in agreement with governing rules and regulations, see Chapter 1.3.5.

The design waves can serve as input to a simplified fatigue calculation. It is important to keep in mind that the heights should be associated with a Stokes 5^{th} order profile, or a sinusoidal profile if that is expected to give results of sufficient accuracy. The latter assumption is a common approach for design of floaters, but the height and period combination used should be calibrated against long-term response analysis.

In connection with verifying return period for drag dominated platform cases where Stokes 5^{th} order design wave profile is used, it should be kept in mind that the Stokes 5^{th} order profile defined by the q-probability wave height is likely to underestimate the q-probability quasi-static response since the crest height of this Stokes 5^{th} order profile is less than the q-probability crest height, see Table 3.12. It is not obvious that selecting a more unfavorable wave period than the mean wave period will compensate sufficiently for this.

Table 3.14 shows the expected scatter diagram of wave height and wave period for a period of 50 years. The short term distribution of wave heights is modelled by a Rayleigh distribution and the conditional short term distribution of wave periods by a normal distribution. This scatter diagram can be used for a simplified fatigue analysis if the variability of wave period is of importance regarding fatigue accumulation. This is under the condition that a simplified fatigue analysis is sufficiently accurate.

Table 3.12 Design wave heights for selected return periods. Crest heights based on Stokes 5th order theory (for load calculations) and Forristall's theory (for air gap calculations) are given.

Return period (years)	Wave height (m)	Crest height (m)		Wave period (s)		
		Stokes V	Forristall	P5	Mean	P95
1	15.2	8.6	9.3	9.5	11.2	13.1
10	17.8	10.0	11.0	10.6	12.2	14.0
50	19.7	11.2	12.2	11.2	12.8	14.6
100	20.5	11.6	12.8	11.5	13.1	14.9

Table 3.13 Design wave height versus direction for return periods of 50 and 100 years.

Direction	Return period: 50 years				Return period: 100 years			
	Wave height	Wave period			Wave height	Wave period		
		P5	Mean	P95		P5	Mean	P95
o	m	s	s	s	m	s	s	s
345 - 15	18.9	11.0	12.6	14.4	19.9	11.3	12.9	14.7
15 - 45	14.4	9.4	11.1	13.0	15.2	9.7	11.4	13.2
45 - 75	13.1	8.9	10.7	12.6	14.0	9.2	11.0	12.9
75 - 105	17.0	10.3	12.0	13.8	17.9	10.6	12.3	14.0
105 - 135	17.0	10.3	12.0	13.8	17.9	10.6	12.3	14.0
135 - 165	16.1	10.0	11.7	13.5	17.0	10.3	12.0	13.7
165 - 195	15.8	9.9	11.6	13.4	16.5	10.2	11.8	13.6
195 - 225	15.3	9.7	11.4	13.3	16.0	10.0	11.6	13.5
225 - 255	10.7	7.9	9.8	12.0	11.2	8.1	10.0	12.1
255 - 285	11.1	8.1	10.0	12.1	11.6	8.3	10.2	12.2
285 - 315	12.8	8.8	10.6	12.5	13.4	9.0	10.8	12.7
315 - 345	16.7	10.2	11.9	13.7	17.5	10.5	12.1	13.9
0 - 360	**19.7**	**11.2**	**12.8**	**14.6**	**20.5**	**11.5**	**13.1**	**14.9**

Table 3.14 Expected scatter diagram of wave height (H) and wave period (T) for a period of 50 years. *Table continues on following page.*

	Wave period (T) – (s)														
H (m)	**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**
0 – 1	51931693	43368463	38977815	27254815	16532061	8995690	4519463	2163441	1013690	471752	219090	101746	47361	22155	10440
1 – 2		5642200	12948068	18254008	16850210	11673876	6762466	3544924	1727220	793291	349402	150011	63527	26735	11239
2 – 3		347338	1545511	3408237	4518801	4178532	3014359	1817695	957252	458454	204714	86102	34371	13149	4869
3 - 4			185265	634845	1211106	1441761	1228192	819609	459094	227537	102793	43192	17155	6492	2348
4 – 5				133036	298391	462108	475775	359927	216200	109478	48911	20038	7733	2858	1023
5 – 6				20535	70966	144039	180184	155848	101606	53393	23904	9552	3530	1242	426
6 – 7				3297	16345	43015	65739	65702	47138	26156	11941	4725	1693	570	186
7 – 8					4084	12310	23161	26982	21535	12779	6033	2401	847	276	86
8 – 9					835	3408	7900	10794	9670	6200	3063	1242	437	140	42
9 – 10						1080	2610	4209	4265	2981	1555	649	230	73	22
10 - 11						269	838	1602	1847	1417	787	341	123	39	11
11 - 12						66	262	596	785	666	397	180	66	21	6
12 - 13							96	217	328	309	198	95	36	12	3
13 - 14							28	77	135	141	98	50	20	6	2
14 - 15							8	27	54	64	48	26	11	4	1
15 - 16							2	9	22	28	24	13	6	2	1
16 - 17								4	8	12	11	7	3	1	
17 - 18								1	3	5	5	4	2	1	
18 - 19									1	2	3	2	1		
19 - 20										1	1	1			
20 - 21											1				
Sum	**51931693**	**49358001**	**53656659**	**49708773**	**39502799**	**26956154**	**16281083**	**8971664**	**4560853**	**2164666**	**972979**	**420377**	**177152**	**73776**	**30705**

Table 3.14 ***Continued.***

	Wave period (T) – (s)														
H (m)	**17 – 18**	**18 – 19**	**19 – 20**	**20 – 21**	**21 – 22**	**22 – 23**	**23 – 24**	**24 – 25**	**25 – 26**	**26 – 27**	**27 – 28**	**28 - 29**	**29 - 30**	**30 - 31**	**Sum**
0 – 1	4960	2370	1134	540	255	119	54	24	11	4	2	1			**195639149**
1 – 2	4734	1997	838	348	141	56	22	8	3	1					**78805325**
2 – 3	1760	623	215	73	24	8	3	1							**20592091**
3 - 4	814	271	86	26	8	2	1								**6380597**
4 – 5	356	121	40	13	4	1									**2136013**
5 – 6	144	49	16	5	2	1									**765442**
6 – 7	60	19	6	2	1										**286595**
7 – 8	26	8	3	1											**110532**
8 – 9	12	4	1												**43748**
9 – 10	6	2	1												**17683**
10 - 11	3	1													**7278**
11 - 12	2														**3047**
12 - 13	1														**1295**
13 - 14	1														**558**
14 - 15															**243**
15 - 16															**107**
16 - 17															**46**
17 - 18															**21**
18 - 19															**9**
19 - 20															**3**
20 - 21															**1**
Sum	**12879**	**5465**	**2340**	**1008**	**435**	**187**	**80**	**33**	**14**	**5**	**2**	**1**			**304789783**

3.5.2 Crest heights

When the design wave approach is adopted for *load calculations* a 5th order Stokes profile is recommended with respect to wave profile and wave kinematics. This is in accordance with the NORSOK Standard N-003 Section 6.2.2.4 [7] recommendations. If a design wave is calibrated to match the result of a long-term analysis, a first order Stokes wave will possibly be acceptable. If governing failure mode is of «loss of stability type» and margin is limited, the characteristic response obtained by the design wave method should be verified by full long term analysis.

For air gap assessments, 10^{-2} – and 10^{-4} – probability crest heights shall be predicted by a long term analysis using the Forristall distribution [19] as the short term crest height distribution, i.e. by replacing the short term wave height distribution in the integral in Eq. (3.28) with the short term crest height distribution.

The Forristall distribution of crest heights, η, for a given sea state is modelled in terms of a two-parameter Weibull distribution:

$$F(\eta) = 1 - \exp\left[-\left(\frac{\eta}{\alpha H_S} \right)^{\beta} \right] \tag{3.31}$$

where β is the shape parameter and α the scale parameter. The Weibull parameters α and β are expressed as functions of wave steepness and Ursell number.

The steepness parameter, s_1, is defined by:

$$s_1 = \frac{2\pi H_S}{g T_{m01}^2} \tag{3.32}$$

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

$$T_{m01} = \frac{\int_0^{\infty} S(f)df}{\int_0^{\infty} fS(f)df} \tag{3.33}$$

The Ursell number, U_r, is defined by:

$$U_r = \frac{H_S}{k_1^2 d^3} \tag{3.34}$$

where k_1 is the wave number computed from:

$$\sigma_1^2 = gk_1 \cdot \tanh(k_1 d) \tag{3.35}$$

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 [17]:

$$k_1 \approx \frac{\sigma_1^2}{g}\left\{\coth\left[\left(\sigma_1\sqrt{\frac{d}{g}}\right)^{3/2}\right]\right\}^{2/3} \tag{3.36}$$

For long-crested (two-dimensional) seas the parameters α and β are given by [19]:

$$\alpha_2 = 0.3536 + 0.2892 \cdot s_1 + 0.1060 \cdot U_r \tag{3.37}$$

$$\beta_2 = 2 - 2.1597 \cdot s_1 + 0.0968 \cdot U_r^2 \tag{3.38}$$

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

$$\alpha_3 = 0.3536 + 0.2568 \cdot s_1 + 0.0800 \cdot U_r \tag{3.39}$$

$$\beta_3 = 2 - 1.7912 \cdot s_1 - 0.5302 \cdot U_r + 0.2824 \cdot U_r^2 \tag{3.40}$$

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 larger of the two should be used for air-gap assessments.

In reasonably deep water, i.e. depths greater than 80 – 100 m for storm waves, the crest height of the q-probability 5th order Stokes wave with a q-probability wave height will be lower than the underlying q-probability crest height due to the inherent randomness of the crest height given the q-probability wave height. Crest heights computed based on both Stokes 5th order theory and Forristall's model are given in Table 3.12. The crest height for the Stokes 5th order wave is obtained using the mean wave period. Using the P5-period will increase crest height with about 0.5m. For determining air-gap, one should use the unfavourable wave period.

The Forristall crest height model is in agreement with a second order model for the surface elevation process. In extreme sea states with steep waves, higher order non-linearities are likely to result in extreme crest heights slightly in the excess of the Forristall predictions. However, this is assumed to be compensated for by inherent conservatisms introduced when predicting q-probability extremes by a long term analysis assuming statistical independence between all individual crest heights. This compensating conservatism may be lost if a Peaks-Over-Threshold based long term analysis is performed.

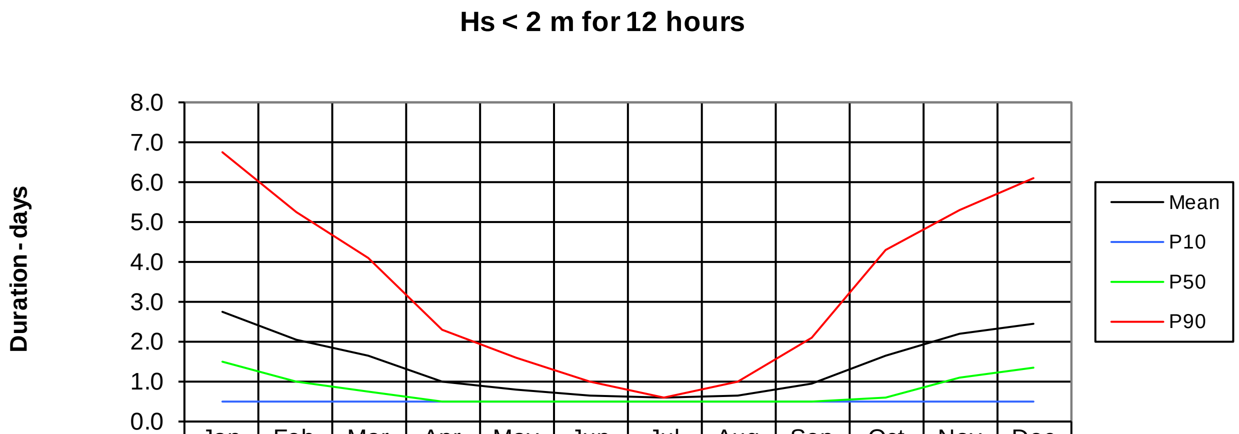
3.6 Operational data

Marine operations may be delayed due to significant wave heights 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 the present report is restricted to critical operations, only. Figure 2.17 illustrates how the duration of a critical operation is defined.

Figure 3.9 - Figure 3.17 show characteristic durations of operations limited by significant wave heights of 2.0, 3.0 and 4.0 m for 12, 24 and 48 hours. The figures show the expected mean duration and 10, 50 and 90 percentiles.

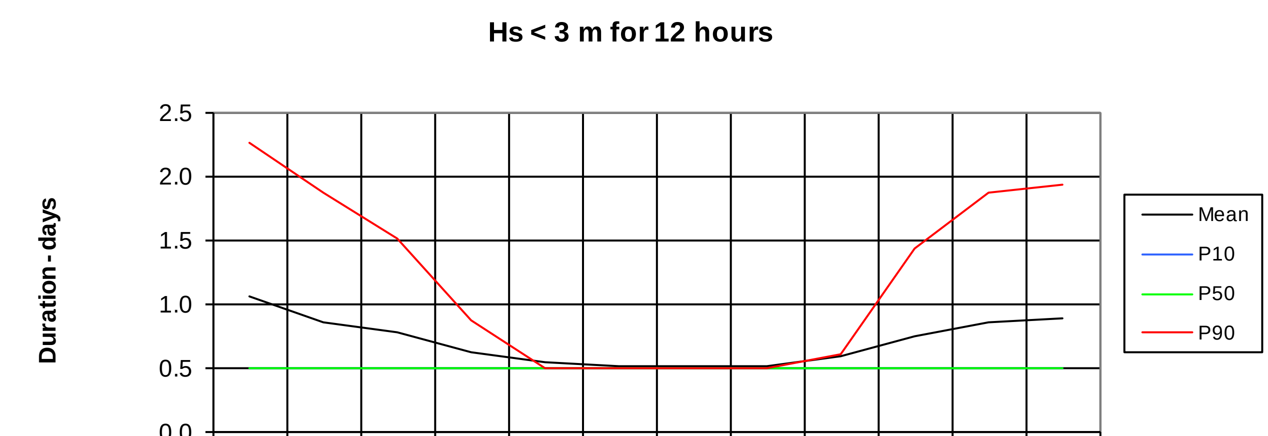
The figures show duration characteristics for completing a critical operation including waiting time. Duration is measured from the day the operation is ready for launching. The day of launching is assumed to be an arbitrary day within the relevant month.

Duration statistics for non-critical operations may be established upon request.



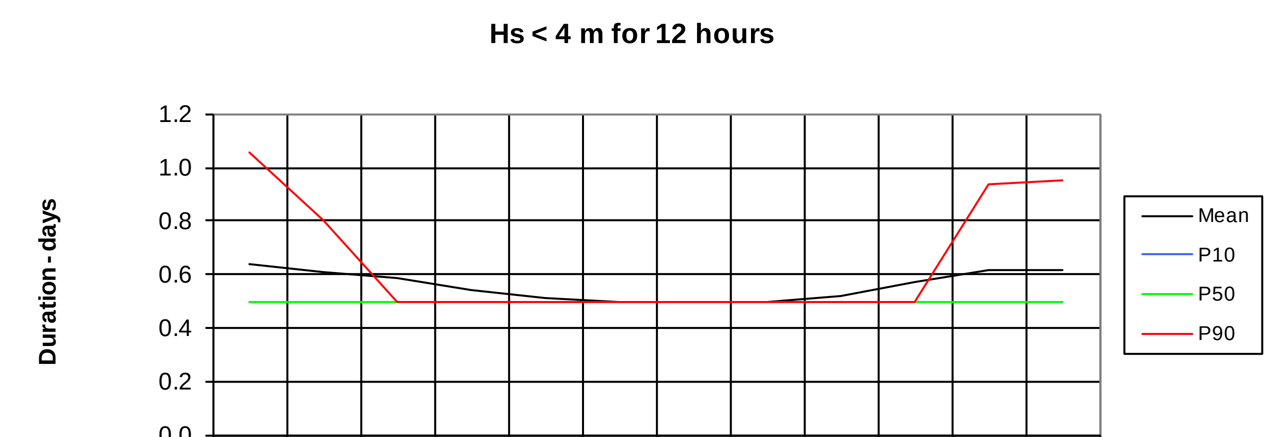
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	2.7	2.1	1.7	1.0	0.8	0.7	0.6	0.6	1.0	1.7	2.2	2.4
P10	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
P50	1.5	1.0	0.8	0.5	0.5	0.5	0.5	0.5	0.5	0.6	1.1	1.4
P90	6.8	5.3	4.1	2.3	1.6	1.0	0.6	1.0	2.1	4.3	5.3	6.1

Figure 3.9 Characteristic durations, including waiting time, in order to perform operations limited by a significant wave height (Hs) of 2.0 m for 12 hours.



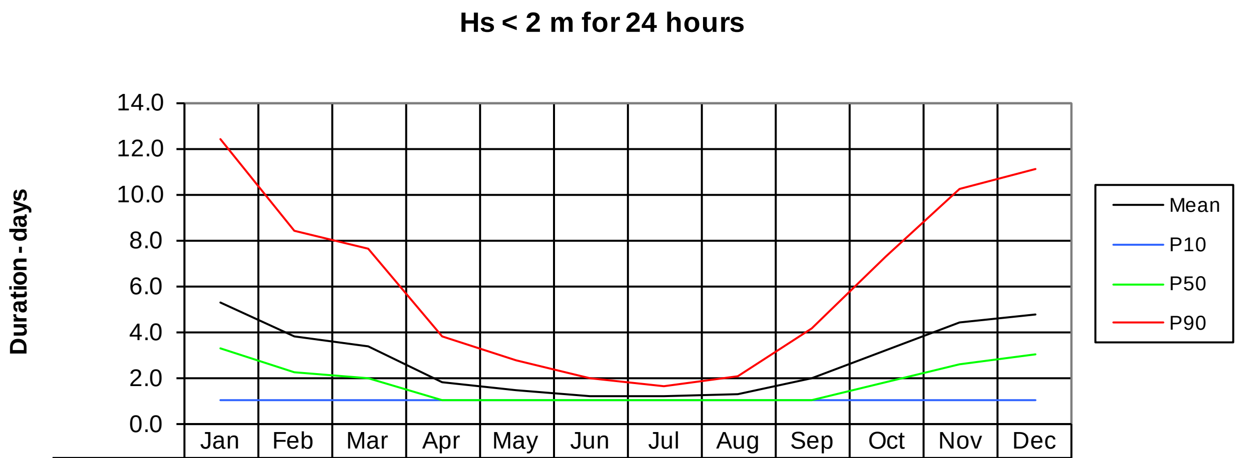
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	1.1	0.9	0.8	0.6	0.6	0.5	0.5	0.5	0.6	0.8	0.9	0.9
P10	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
P50	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
P90	2.3	1.9	1.5	0.9	0.5	0.5	0.5	0.5	0.6	1.4	1.9	1.9

Figure 3.10 Characteristic durations, including waiting time, in order to perform operations limited by a significant wave height (Hs) of 3.0 m for 12 hours.



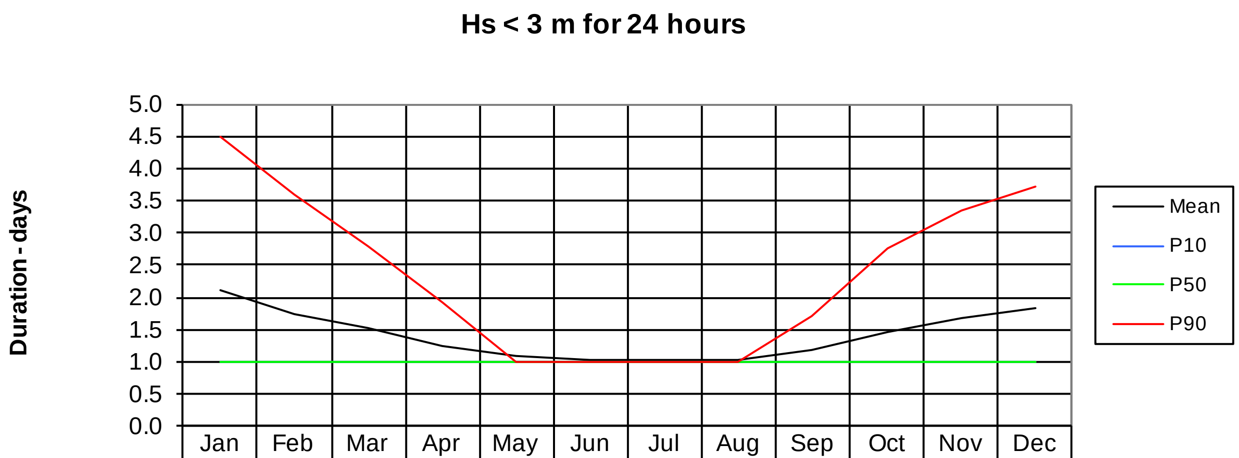
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6
P10	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
P50	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
P90	1.1	0.8	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.9	1.0

Figure 3.11 Characteristic durations, including waiting time, in order to perform operations limited by a significant wave height (Hs) of 4.0 m for 12 hours.



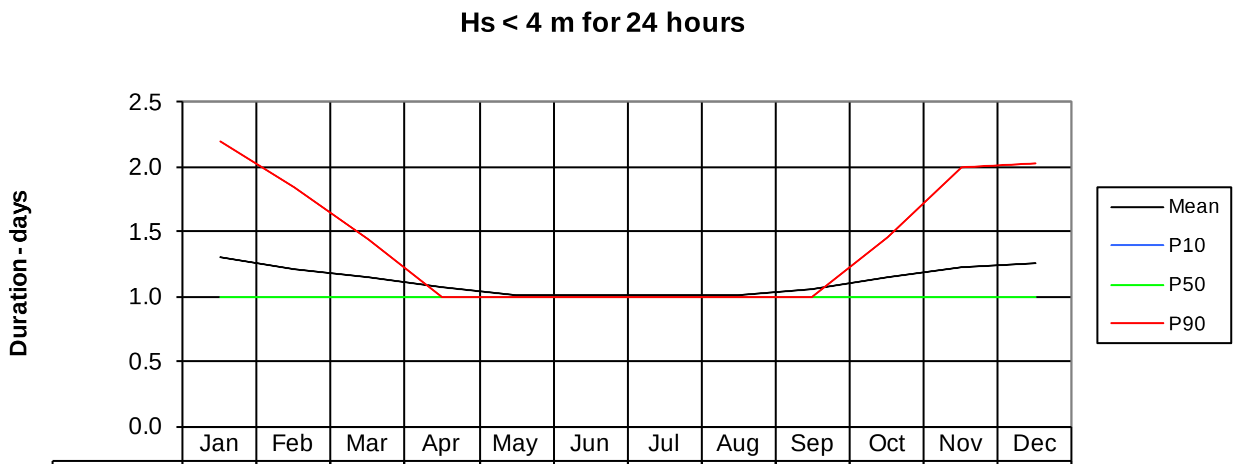
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	5.3	3.8	3.4	1.8	1.5	1.3	1.2	1.3	2.0	3.2	4.4	4.8
P10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
P50	3.3	2.3	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.8	2.6	3.0
P90	12.4	8.4	7.6	3.8	2.8	2.0	1.7	2.1	4.2	7.3	10.3	11.1

Figure 3.12 Characteristic durations, including waiting time, in order to perform operations limited by a significant wave height (Hs) of 2.0 m for 24 hours.



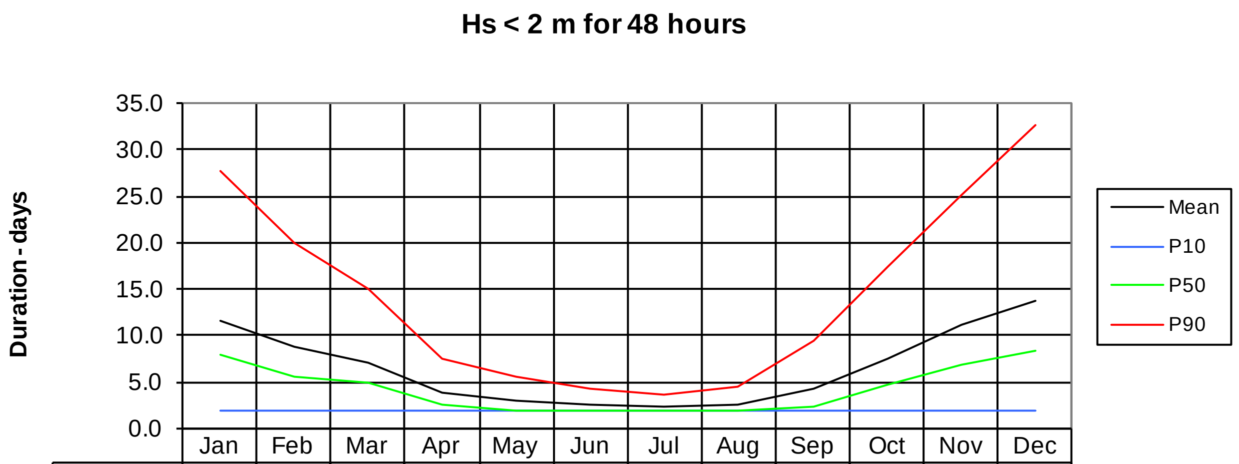
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	2.1	1.7	1.5	1.2	1.1	1.0	1.0	1.0	1.2	1.5	1.7	1.8
P10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
P50	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
P90	4.5	3.6	2.8	1.9	1.0	1.0	1.0	1.0	1.7	2.8	3.4	3.7

Figure 3.13 Characteristic durations, including waiting time, in order to perform operations limited by a significant wave height (Hs) of 3.0 m for 24 hours.



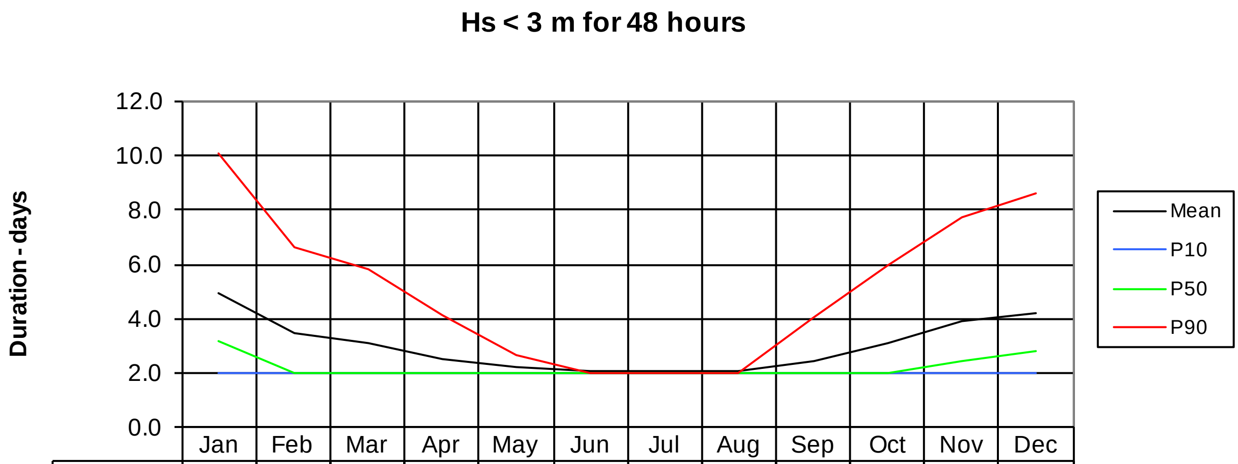
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	1.3	1.2	1.2	1.1	1.0	1.0	1.0	1.0	1.1	1.2	1.2	1.3
P10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
P50	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
P90	2.2	1.8	1.4	1.0	1.0	1.0	1.0	1.0	1.0	1.5	2.0	2.0

Figure 3.14 Characteristic durations, including waiting time, in order to perform operations limited by a significant wave height (Hs) of 4.0 m for 24 hours.



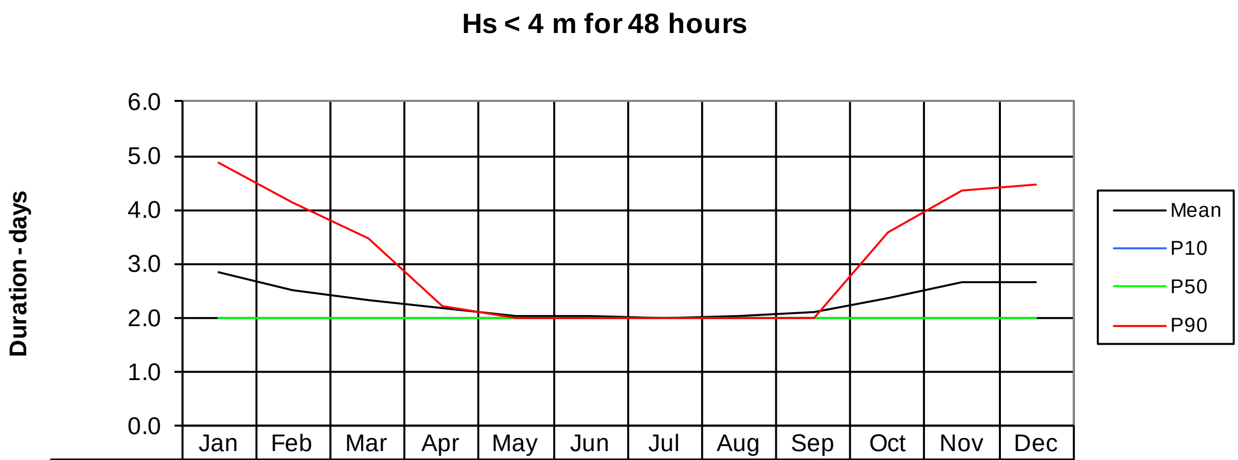
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	11.6	8.7	7.0	3.8	3.1	2.6	2.4	2.7	4.4	7.6	11.2	13.7
P10	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
P50	7.9	5.6	4.9	2.5	2.0	2.0	2.0	2.0	2.3	4.7	7.0	8.3
P90	27.8	20.1	15.1	7.5	5.6	4.3	3.8	4.4	9.4	17.5	25.2	32.8

Figure 3.15 Characteristic durations, including waiting time, in order to perform operations limited by a significant wave height (Hs) of 2.0 m for 48 hours.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	4.9	3.5	3.1	2.5	2.2	2.1	2.1	2.1	2.5	3.1	3.9	4.2
P10	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
P50	3.2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.4	2.8
P90	10.1	6.6	5.8	4.1	2.7	2.0	2.0	2.0	4.1	6.0	7.7	8.6

Figure 3.16 Characteristic durations, including waiting time, in order to perform operations limited by a significant wave height (Hs) of 3.0 m for 48 hours.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	2.8	2.5	2.3	2.2	2.0	2.0	2.0	2.0	2.1	2.4	2.7	2.7
P10	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
P50	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
P90	4.9	4.1	3.5	2.2	2.0	2.0	2.0	2.0	2.0	3.6	4.4	4.5

Figure 3.17 Characteristic durations, including waiting time, in order to perform operations limited by a significant wave height (Hs) of 4.0 m for 48 hours.

4 Currents

4.1 Tidal currents

Figure 4.1 shows estimates of maximum depth-averaged flow of an average spring tidal current (i.e. the tidal current due only to M2 and S2). The maximum tidal current, due to Highest (HAT) or Lowest (LAT) Astronomical Tide, at Buchan Deep may be about 40 – 50 % higher.

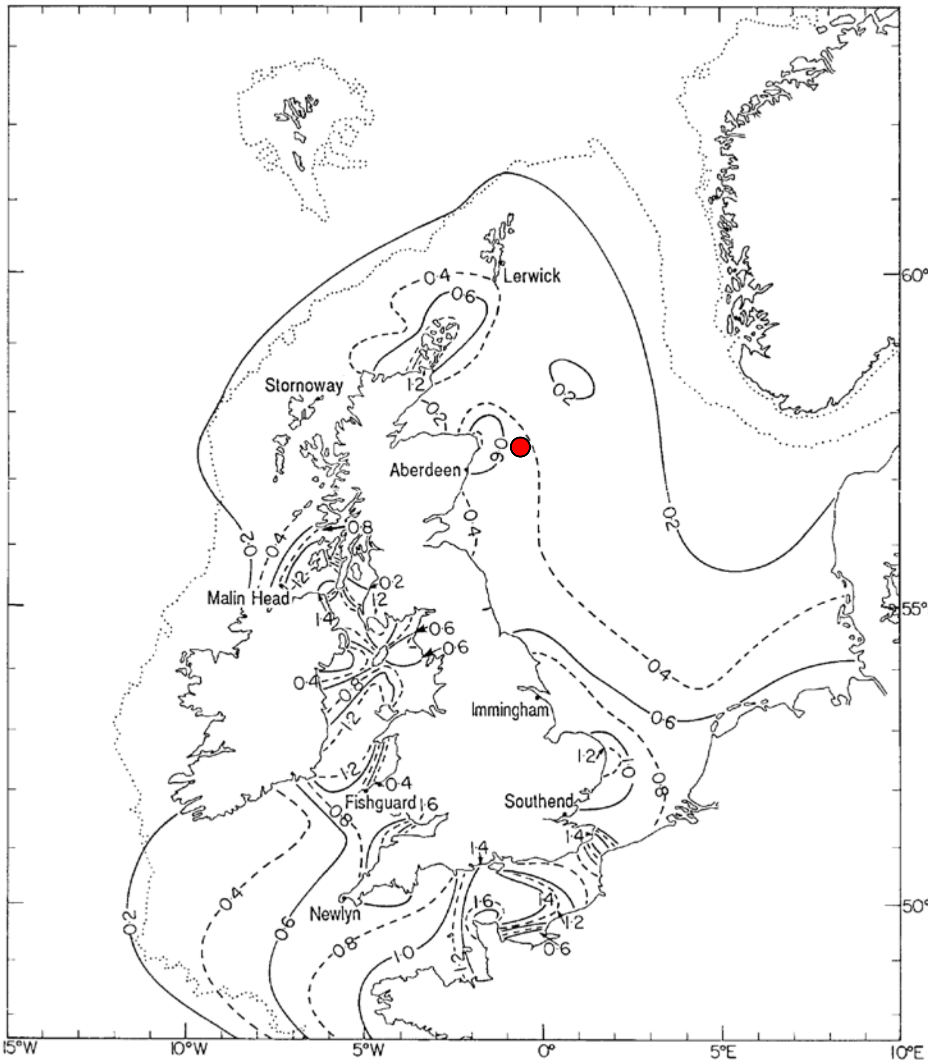


Figure 4.1 Estimates of maximum depth-averaged flow [m/s] of an average spring tidal current, i.e. the tide due only to M2 and S2 [6]. The red circle shows the position of Buchan Deep.

4.2 Storm surge currents

Figure 4.2 shows estimates of 50-year return period depth-averaged hourly-mean storm surge. Estimates of extreme currents at Buchan Deep are presented in Chapter 4.5.

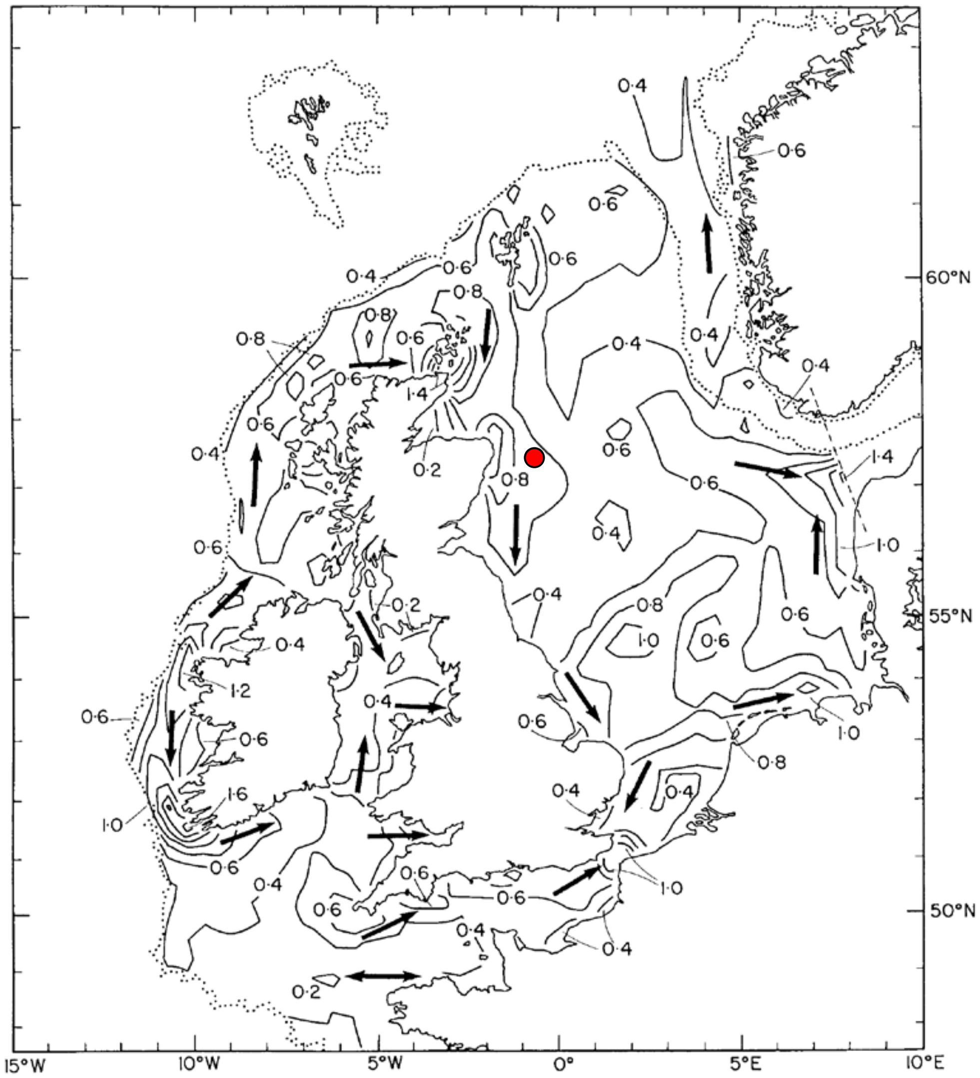


Figure 4.2 **Estimates of 50-year return depth-averaged hourly-mean storm surge currents [m/s] [6]. The arrows indicate the direction of maximum current. The red circle shows the position of Buchan Deep. The map is based on results from numerical simulations.**

4.3 Current data

Information on ocean currents is available from measurements (at 57.43º N, 01.39º W) at Buchan Deep. The measurements were performed using an Acoustic Doppler Current Profilers (ADCP). Table 4.1 shows the depth-range and measurement period of the ADCP. The depth at the measurement site is about 107 m.

Table 4.1 Depth-range and measurement period for the ADCP deployed at Buchan Deep.

No.	Sensor	Depth range (m)	Period
-	ADCP	25-90	05.11.2013-22.03.2014

The measured currents are 10-minute averages. The sample interval is 10 minutes.

Table 4.2 presents summary statistics for the current measurements at Buchan Deep. There are gaps in the current data series so that the effective length (of the data series) is reduced.

Table 4.2 Summary statistics of current measurements at Buchan Deep.

Depth	Mean	Maximum	Direction of maximum	Time of maximum	Effective length
m	cm/s	cm/s	degrees	-	years
25	40.4	141.7	197	05.12.2013 13:20	0.37
40	38.8	132.7	197	05.12.2013 13:10	0.37
60	36.7	127.3	195	05.12.2013 13:10	0.37
70	35.5	124.6	194	05.12.2013 13:10	0.37
90	31.9	112.6	195	05.12.2013 12:50	0.37

Table 4.3 Dominant tidal harmonic constituents measured at 15 m depth at Buchan Deep.

Table 4.3 Dominant tidal harmonic constituents measured at 15 m depth at Buchan Deep.

Species	Symbol	Period	Major	Minor	Inclination
		hr	cm/s	cm/s	degrees
Principal lunar semidiurnal	M2	12.42	52.7	-3.65	3.9
Principal solar semidiurnal	S2	12.00	17.4	-1.86	3.3
Larger lunar elliptic semidiurnal	N2	12.66	11.9	-1.60	3.8
Lunar diurnal	K1	23.93	3.9	0.04	359.6
Lunar Diurnal	O1	25.82	4.5	-0.35	8.7

The current measurement programme is ongoing and will continue until November 2014. Data from these measurements will be included in updates to this report.

Tidal predictions can be generated on request. This should be done for all operations vulnerable for strong currents.

4.4 Current data analysis

Figure 4.3 - Figure 4.7 show current roses for the measurements at Buchan Deep. Table 4.4 - Table 4.8 show the corresponding distributions of non-exceedance of current speed.

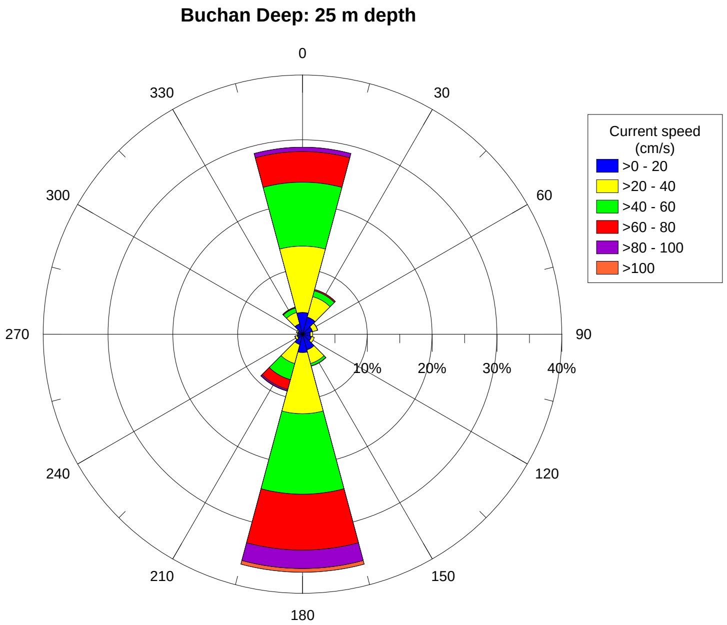


Figure 4.3 Current rose at 25 m depth at Buchan Deep.

Table 4.4 Direction sample distribution of non-exceedance (%) of current speed at 25 m depth at Buchan Deep.

Current speed (cm/s)	**Current direction**												
	0°	**30°**	**60°**	**90°**	**120°**	**150°**	**180°**	**210°**	**240°**	**270°**	**300°**	**330°**	**Omni**
< 10	0.72	0.67	0.43	0.48	0.44	0.56	0.52	0.78	0.48	0.39	0.50	0.60	**6.57**
< 20	3.75	3.33	2.00	1.44	1.41	2.45	3.47	3.71	2.11	1.43	1.60	2.56	**29.27**
< 30	8.97	5.61	2.69	1.60	1.44	2.88	7.97	7.95	2.77	1.53	1.78	4.30	**49.48**
< 40	15.10	7.30	2.71				12.72	12.90	2.95	1.54		5.06	**67.98**
< 50	21.01	8.18					17.43	17.33	3.01			5.32	**84.23**
< 60	24.92	8.37					20.58	20.77				5.35	**94.95**
< 70	26.27	8.37					22.31	21.76				5.36	**99.02**
< 80	26.68						22.62	21.87					**99.85**
< 90							22.67	21.87					**99.91**
< 100							22.69	21.87					**99.93**
< 110							22.72	21.88					**99.96**
< 120							22.75	21.88					**100.00**
< 130													
< 140													
< 150													
Total	**26.68**	**8.37**	**2.71**	**1.60**	**1.44**	**2.88**	**22.75**	**21.88**	**3.01**	**1.54**	**1.78**	**5.36**	**100.00**
Mean	**37.3**	**25.1**	**16.0**	**13.0**	**12.1**	**14.6**	**37.7**	**36.1**	**17.4**	**13.1**	**13.4**	**21.7**	**31.9**
Maximum	**78.0**	**61.7**	**34.0**	**27.8**	**22.0**	**29.4**	**112.6**	**112.6**	**47.2**	**31.1**	**29.2**	**61.5**	**112.6**

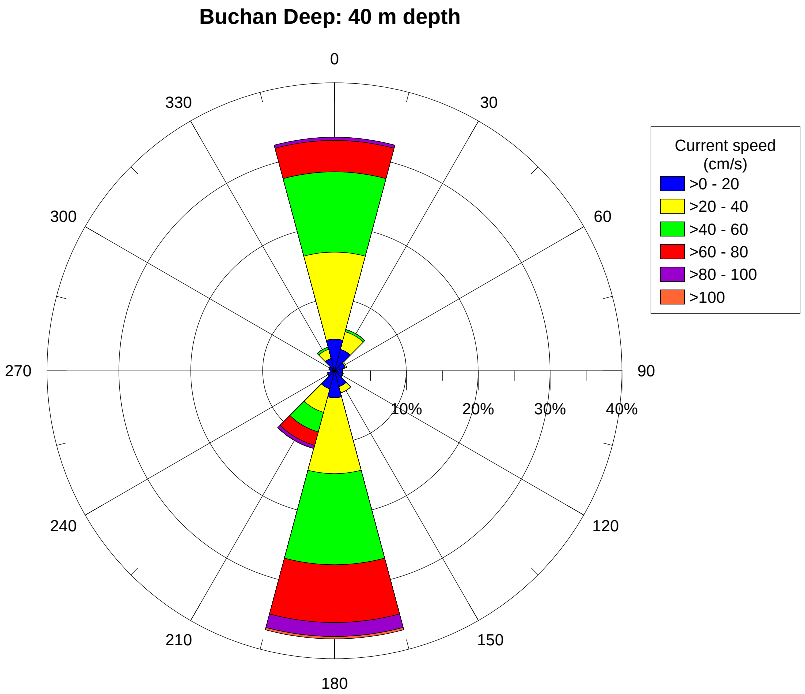


Figure 4.4 Current rose at 40 m depth at Buchan Deep.

Table 4.5 Direction sample distribution of non-exceedance (%) of current speed at 40 m depth at Buchan Deep.

Current speed (cm/s)	**Current direction**												
	0°	**30°**	**60°**	**90°**	**120°**	**150°**	**180°**	**210°**	**240°**	**270°**	**300°**	**330°**	**Omni**
< 10	0.64	0.58	0.42	0.38	0.37	0.44	0.48	0.47	0.23	0.23	0.23	0.41	**4.88**
< 20	4.38	3.09	1.55	1.09	1.18	2.26	3.70	2.57	0.97	0.63	0.76	1.79	**23.98**
< 30	9.94	4.70	1.75	1.13	1.26	2.98	8.45	4.41	1.07	0.64	0.82	2.65	**39.80**
< 40	16.47	5.62				3.15	14.27	5.94				3.08	**55.20**
< 50	22.31	5.86				3.17	20.62	7.48				3.31	**69.43**
< 60	27.62	5.93					26.90	8.76				3.38	**82.43**
< 70	30.63	5.95					31.65	9.82				3.39	**91.27**
< 80	31.99						34.94	10.69				3.40	**96.80**
< 90	32.39						36.31	11.03					**98.92**
< 100	32.44						36.88	11.14					**99.64**
< 110							37.14	11.15					**99.91**
< 120							37.17	11.16					**99.95**
< 130							37.19	11.16					**99.97**
< 140							37.21	11.17					**100.00**
Total	**32.44**	**5.95**	**1.75**	**1.13**	**1.26**	**3.17**	**37.21**	**11.17**	**1.07**	**0.64**	**0.82**	**3.40**	**100.00**
Mean	**40.6**	**21.6**	**13.7**	**11.9**	**12.7**	**17.0**	**47.4**	**40.3**	**13.3**	**11.4**	**12.4**	**22.1**	**38.7**
Maximum	**93.8**	**66.8**	**29.9**	**25.3**	**27.1**	**47.9**	**131.8**	**132.7**	**27.1**	**20.8**	**22.3**	**76.7**	**132.7**

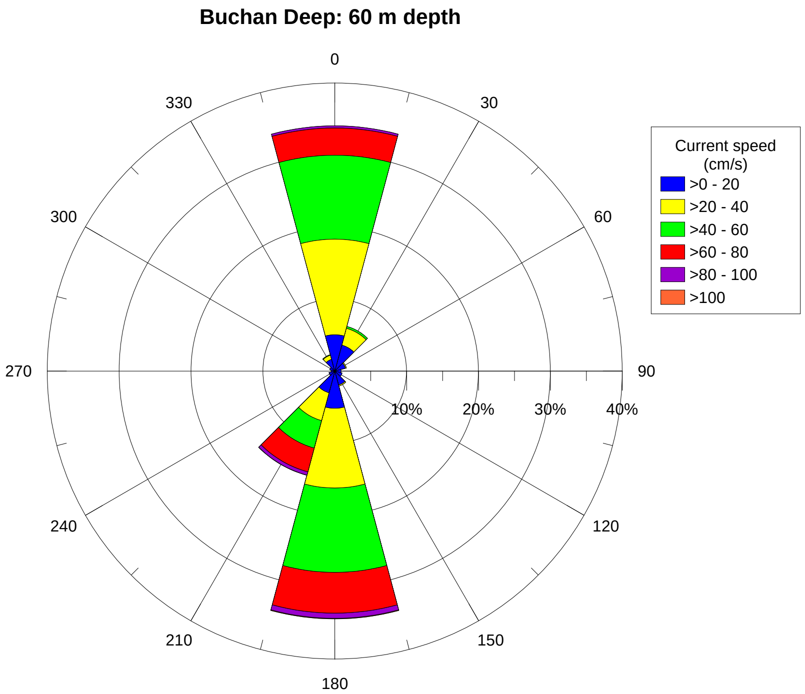


Figure 4.5 Current rose at 60 m depth at Buchan Deep.

Table 4.6 Direction sample distribution of non-exceedance (%) of current speed at 60 m depth at Buchan Deep.

Current speed (cm/s)	Current direction											
	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°	Omni
< 10	0.81	0.87	0.51	0.33	0.48	0.62	0.84	0.60	0.35	0.31	0.36	0.52	**6.60**
< 20	5.03	3.73	1.53	0.86	1.04	1.99	5.15	3.11	0.80	0.50	0.72	1.68	**26.15**
< 30	11.20	5.33	1.67			2.15	10.42	5.12	0.82			2.09	**41.92**
< 40	18.31	6.15				2.16	16.22	7.11				2.27	**57.84**
< 50	24.69	6.41					22.77	9.20				2.35	**73.20**
< 60	29.97	6.42					27.94	11.05				2.36	**85.52**
< 70	32.69						31.82	13.02					**94.08**
< 80	33.75						33.60	14.48					**98.39**
< 90	34.06						34.15	14.80					**99.57**
< 100							34.32	14.95					**99.89**
< 110							34.35	14.95					**99.92**
< 120							34.38	14.95					**99.95**
< 130							34.41	14.98					**100.00**
Total	**34.06**	**6.42**	**1.67**	**0.86**	**1.04**	**2.16**	**34.41**	**14.98**	**0.82**	**0.50**	**0.72**	**2.36**	**100.00**
Mean	**39.0**	**20.0**	**12.7**	**11.0**	**10.6**	**12.8**	**41.9**	**42.6**	**10.9**	**9.5**	**10.1**	**17.1**	**36.7**
Maximum	**89.5**	**52.5**	**27.8**	**19.7**	**18.7**	**31.5**	**126.9**	**127.3**	**22.5**	**18.7**	**19.0**	**53.9**	**127.3**

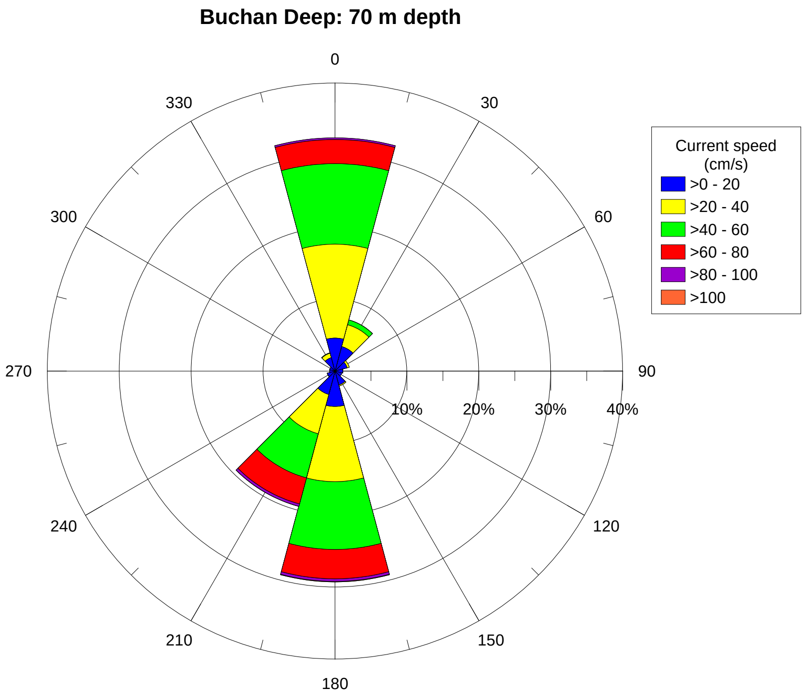


Figure 4.6 Current rose at 70 m depth at Buchan Deep.

Table 4.7 Direction sample distribution of non-exceedance (%) of current speed at 70 m depth at Buchan Deep.

Current speed (cm/s)	Current direction											
	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°	Omni
< 10	0.73	0.81	0.50	0.45	0.41	0.56	0.74	0.76	0.45	0.39	0.36	0.55	**6.70**
< 20	4.58	3.53	1.74	1.08	0.96	1.98	4.89	3.35	1.10	0.73	0.76	1.93	**26.62**
< 30	10.45	5.53	2.04	1.10	0.96	2.15	9.92	6.14	1.12	0.73	0.77	2.38	**43.30**
< 40	17.61	6.66	2.05				15.34	9.00				2.56	**60.06**
< 50	23.78	7.24					20.68	12.48				2.62	**75.69**
< 60	28.80	7.35					24.76	15.34				2.63	**87.76**
< 70	31.30	7.37					27.71	18.13					**96.03**
< 80	32.15						28.84	19.09					**98.96**
< 90	32.39						29.12	19.41					**99.81**
< 100							29.20	19.43					**99.91**
< 110							29.21	19.44					**99.92**
< 120							29.24	19.44					**99.96**
< 130							29.27	19.45					**100.00**
Total	**32.39**	**7.37**	**2.05**	**1.10**	**0.96**	**2.15**	**29.27**	**19.45**	**1.12**	**0.73**	**0.77**	**2.63**	**100.00**
Mean	**38.8**	**22.7**	**13.8**	**11.2**	**11.2**	**12.9**	**39.7**	**41.7**	**11.1**	**9.7**	**10.4**	**17.0**	**35.5**
Maximum	**87.2**	**66.6**	**33.7**	**22.0**	**19.7**	**28.9**	**124.6**	**121.4**	**27.4**	**21.9**	**20.5**	**54.2**	**124.6**

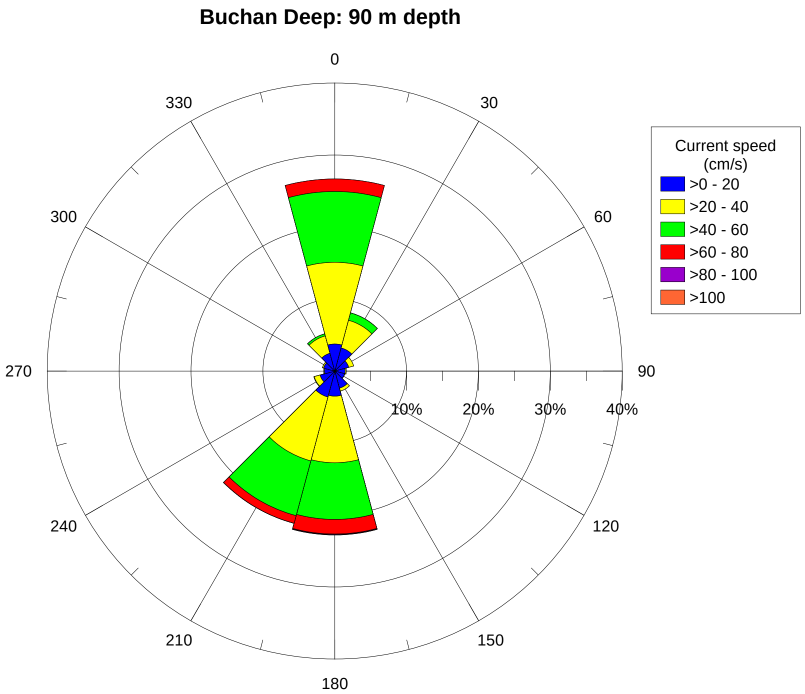


Figure 4.7 **Current rose at 90 m depth at Buchan Deep.**

Table 4.8 **Direction sample distribution of non-exceedance (%) of current speed at 90 m depth at Buchan Deep.**

Current speed (cm/s)	Current direction											
	0°	**30°**	**60°**	**90°**	**120°**	**150°**	**180°**	**210°**	**240°**	**270°**	**300°**	**330°**	**Omni**
< 10	0.72	0.67	0.43	0.48	0.44	0.56	0.52	0.78	0.48	0.39	0.50	0.60	**6.57**
< 20	3.75	3.33	2.00	1.44	1.41	2.45	3.47	3.71	2.11	1.43	1.60	2.56	**29.27**
< 30	8.97	5.61	2.69	1.60	1.44	2.88	7.97	7.95	2.77	1.53	1.78	4.30	**49.48**
< 40	15.10	7.30	2.71				12.72	12.90	2.95	1.54		5.06	**67.98**
< 50	21.01	8.18					17.43	17.33	3.01			5.32	**84.23**
< 60	24.92	8.37					20.58	20.77				5.35	**94.95**
< 70	26.27	8.37					22.31	21.76				5.36	**99.02**
< 80	26.68						22.62	21.87					**99.85**
< 90							22.67	21.87					**99.91**
< 100							22.69	21.87					**99.93**
< 110							22.72	21.88					**99.96**
< 120							22.75	21.88					**100.00**
Total	**26.68**	**8.37**	**2.71**	**1.60**	**1.44**	**2.88**	**22.75**	**21.88**	**3.01**	**1.54**	**1.78**	**5.36**	**100.00**
Mean	**37.3**	**25.1**	**16.0**	**13.0**	**12.1**	**14.6**	**37.7**	**36.1**	**17.4**	**13.1**	**13.4**	**21.7**	**31.9**
Maximum	**78.0**	**61.7**	**34.0**	**27.8**	**22.0**	**29.4**	**112.6**	**112.6**	**47.2**	**31.1**	**29.2**	**61.5**	**112.6**

4.5 Long-term current statistics

The long-term distribution of current speed peaks (i.e. local maxima) is modelled in terms of a Weibull distribution:

$$F(u) = 1 - \exp\left\{-\left[\frac{u-\varepsilon}{\theta}\right]^{\gamma}\right\} \qquad \text{where} \quad u \geq \max(0;\varepsilon) \qquad (4.1)$$

where:

u	Current speed
ε	Location parameter
θ	Scale parameter
γ	Shape parameter

Extreme values, u_R, corresponding to a return period, R, are obtained by inverting Equation (4.1) for a cumulative probability F = 1 – τ/pR, i.e.:

$$u_R = \varepsilon + \theta \cdot \left[-\ln\left(\frac{\tau}{pR}\right)\right]^{1/\gamma} \qquad (4.2)$$

where

τ	Average time between current speed peaks
p	Sector or monthly probability (=1/12 for monthly omni-directional distributions)
R	Return period

The annual probability of exceedance, q, is given by:

$$q = 1 - \exp\left(-\frac{T}{R}\right) \qquad T = 1 \text{ year} \qquad (4.3)$$

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.

Figure 4.8 - Figure 4.14 and Table 4.9 - Table 4.15 show Weibull parameters and corresponding sector and omni-directional extremes for current speed. The surface current is set equal to the current at 25 m depth increased by 5 %.

The current near the bottom is assumed to follow the power representative for tidal currents [6, Chapter 6.3]:

$$u(z) = \left(\frac{z}{0.32 \cdot h}\right)^{1/7} \cdot \overline{u_t} \qquad \text{for } 0 < z < 0.5\text{ h} \qquad (4.4)$$

Where

u	Height above sea bottom
h	Water depth
u(z)	Current speed at height z above sea bottom
u_t	Depth-averaged current speed

By inserting for z = 3 m and z = 17 m in the above formula it is found that the current speed at 3m above sea bottom is equal to 0.78 x the current speed at 90 m depth. Consequently, the current at 3 m above sea bottom is set equal to the current speed at 90 m depth reduced by about 20 %.

Uncertainties (in the estimated extremes) shall be accounted for by selecting the highest values from three neighbouring months or sectors. For example, extremes for May shall be taken as the highest extremes for April, May and June. Extremes for the 180º sector shall be taken as the highest extremes for the 150º, 180º and 210º sectors.

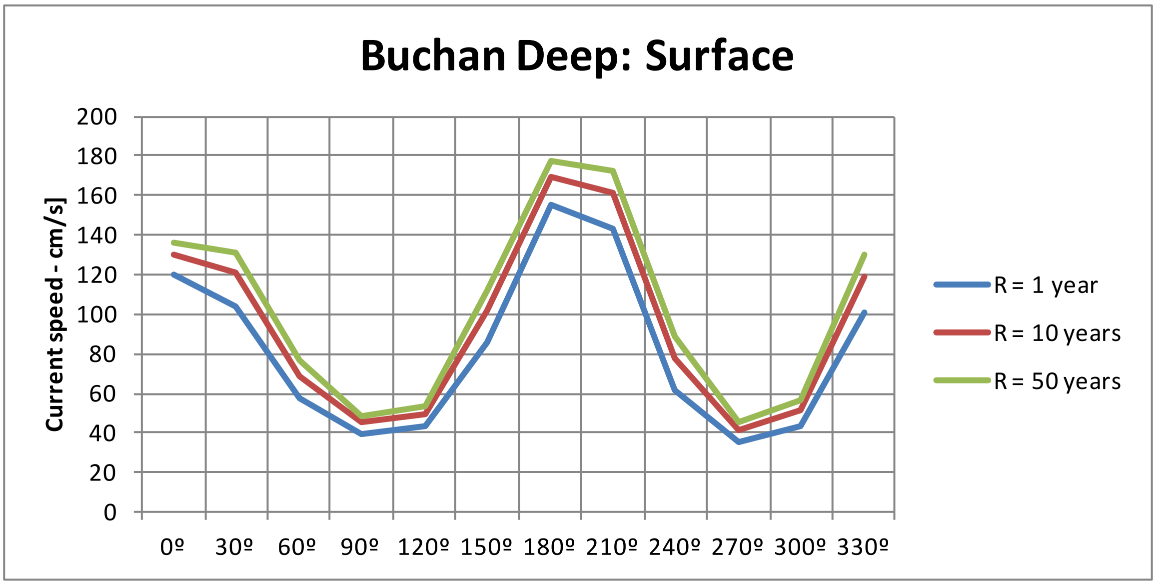


Figure 4.8 **Direction variation of current speed of 1, 10 and 50 year return period at the surface at Buchan Deep. Current speed at surface is assumed to be 5 % higher than the current at 25 m depth.**

Table 4.9 **Weibull parameters and corresponding extreme values for the sector and omni-directional distributions of current speed at the surface at Buchan Deep. Duration of extreme event is 10 minutes.**

Direction sector	Sector prob.	Weibull parameters			Annual probability of exceedance			
		Shape	Scale	Location	1 year	10 years	50 years	100 yrs
	%	-	cm/s	cm/s	cm/s	cm/s	cm/s	cm/s
0º	28.86	2.783	55.08	-4.36	120	130	136	139
30º	7.15	1.513	24.07	6.50	103	121	132	136
60º	2.41	1.368	11.88	7.78	58	69	76	80
90º	1.57	2.001	13.47	4.81	40	45	49	50
120º	1.87	1.700	11.79	6.21	43	50	54	56
150º	5.10	1.374	17.34	8.04	86	102	112	117
180º	36.73	2.500	63.35	-3.05	155	169	178	181
210º	9.08	2.100	53.30	-3.76	144	162	173	177
240º	1.22	1.136	10.19	8.89	62	78	89	93
270º	0.75	1.804	11.26	5.13	35	41	45	47
300º	0.95	1.587	11.65	6.17	43	51	56	58
330º	4.31	1.542	25.34	5.70	101	119	130	135
0º-360º	**100.00**	**2.131**	**51.90**	**-3.57**	**155**	**170**	**180**	**184**

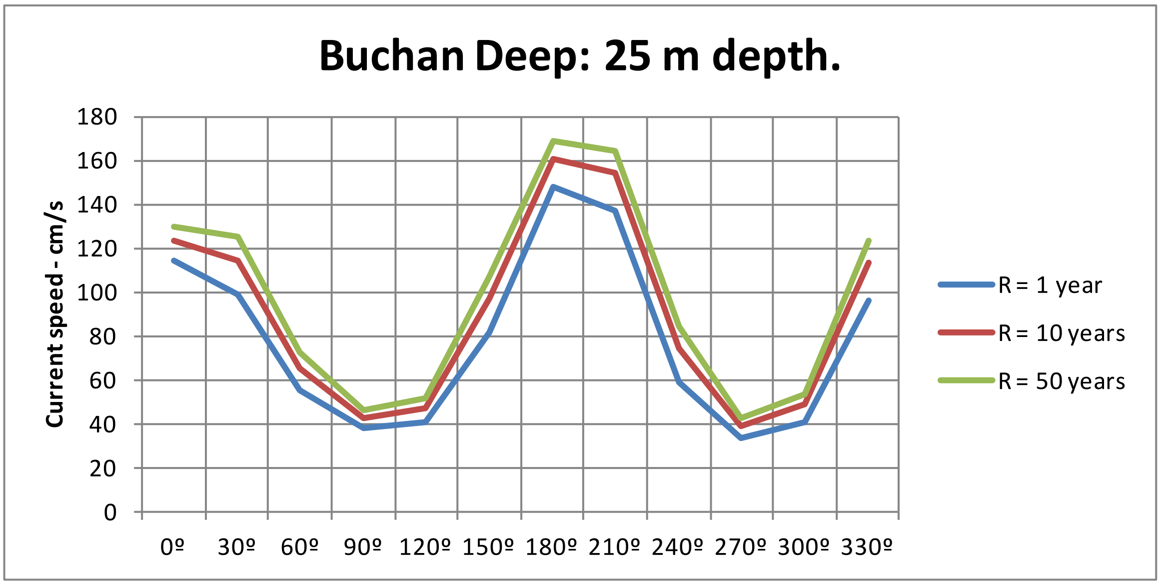


Figure 4.9 **Direction variation of current speed of 1, 10 and 50 year return period at 25 m depth at Buchan Deep.**

Table 4.10 **Weibull parameters and corresponding extreme values for the sector and omni-directional distributions of current speed at 25 m depth at Buchan Deep. Duration of extreme event is 10 minutes.**

Direction sector	Sector prob.	Weibull parameters			Annual probability of exceedance			
		Shape	Scale	Location	1 year	10 years	50 years	100 yrs
	%	-	cm/s	cm/s	cm/s	cm/s	cm/s	cm/s
0º	28.86	2.783	52.46	-4.15	114	124	129	132
30º	7.15	1.513	22.92	6.19	99	115	125	130
60º	2.41	1.368	11.31	7.41	55	66	73	76
90º	1.57	2.001	12.82	4.58	38	43	46	48
120º	1.87	1.700	11.23	5.91	41	47	51	53
150º	5.10	1.374	16.51	7.65	82	97	107	111
180º	36.73	2.500	60.33	-2.90	148	161	169	173
210º	9.08	2.100	50.76	-3.58	137	154	164	169
240º	1.22	1.136	9.71	8.47	59	74	84	89
270º	0.75	1.804	10.73	4.89	34	40	43	44
300º	0.95	1.587	11.10	5.88	41	49	53	56
330º	4.31	1.542	24.13	5.43	96	113	124	128
0º-360º	**100.00**	**2.131**	**49.43**	**-3.40**	**148**	**162**	**171**	**175**

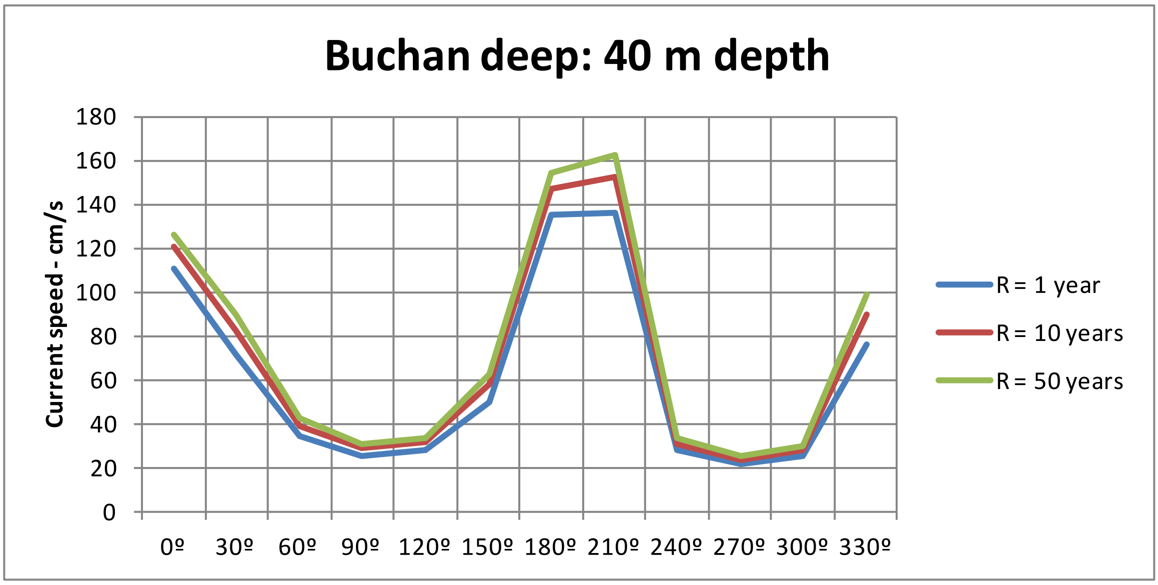


Figure 4.10 **Direction variation of current speed of 1, 10 and 50 year return period at 40 m depth at Buchan Deep.**

Table 4.11 **Weibull parameters and corresponding extreme values for the sector and omni-directional distributions of current speed at 40 m depth at Buchan Deep. Duration of extreme event is 10 minutes.**

Direction sector	Sector prob.	Weibull parameters			Annual probability of exceedance			
		Shape	Scale	Location	1 year	10 years	50 years	100 yrs
	%	-	cm/s	cm/s	cm/s	cm/s	cm/s	cm/s
0º	32.44	2.767	50.85	-4.66	111	120	126	128
30º	5.95	1.636	18.60	4.92	72	83	90	92
60º	1.75	1.759	9.74	5.04	34	39	43	44
90º	1.13	2.066	8.80	4.09	26	29	31	32
120º	1.26	2.120	9.85	3.98	28	31	34	35
150º	3.17	1.593	12.47	5.80	50	58	63	65
180º	37.21	2.600	57.79	-3.92	136	147	154	157
210º	11.17	2.200	53.77	-7.27	136	153	163	167
240º	1.07	2.275	10.62	3.89	28	31	33	34
270º	0.64	3.091	11.47	1.19	22	24	25	26
300º	0.82	2.294	9.74	3.70	25	28	30	31
330º	3.40	1.551	19.72	4.34	77	90	99	102
0º-360º	**100.00**	**2.224**	**50.36**	**-5.85**	**141**	**155**	**163**	**167**

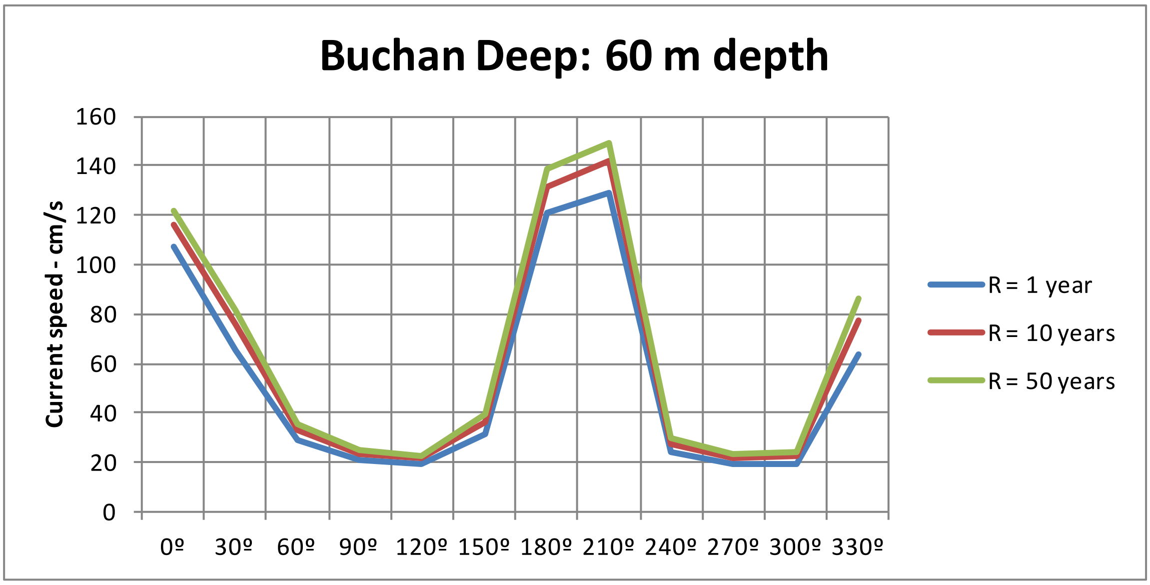


Figure 4.11 **Direction variation of current speed of 1, 10 and 50 year return period at 60 m depth at Buchan Deep.**

Table 4.12 **Weibull parameters and corresponding extreme values for the sector and omni-directional distributions of current speed at 60 m depth at Buchan Deep. Duration of extreme event is 10 minutes.**

Direction sector	**Sector prob.**	**Weibull parameters**			**Annual probability of exceedance**			
		Shape	**Scale**	**Location**	**1 year**	**10 years**	**50 years**	**100 yrs**
	%	**-**	**cm/s**	**cm/s**	**cm/s**	**cm/s**	**cm/s**	**cm/s**
0º	34.06	2.755	48.72	-4.35	107	116	122	124
30º	6.42	1.706	18.16	3.77	66	76	82	84
60º	1.67	2.234	11.33	2.65	29	33	35	36
90º	0.86	2.472	8.66	3.30	21	24	25	26
120º	1.04	3.025	9.55	2.09	20	22	23	23
150º	2.16	1.793	9.11	4.68	32	36	39	40
180º	34.41	2.606	52.41	-4.65	121	132	138	141
210º	14.98	2.750	65.02	-15.33	129	142	149	152
240º	0.82	1.987	8.16	3.70	24	28	30	31
270º	0.50	2.137	7.17	3.13	19	22	24	24
300º	0.72	1.840	5.43	5.31	20	22	24	25
330º	2.36	1.339	13.71	4.52	64	78	87	90
0º-360º	**100.00**	**2.341**	**49.80**	**-7.45**	**131**	**142**	**150**	**153**

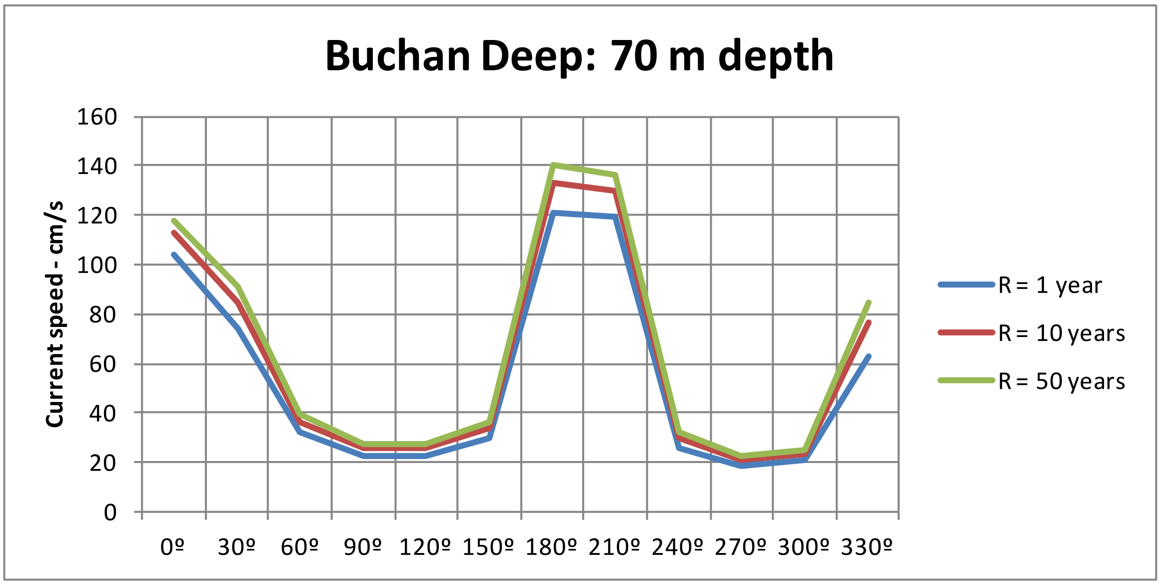


Figure 4.12 **Direction variation of current speed of 1, 10 and 50 year return period at 70 m depth at Buchan Deep.**

Table 4.13 **Weibull parameters and corresponding extreme values for the sector and omni-directional distributions of current speed at 70 m depth at Buchan Deep. Duration of extreme event is 10 minutes.**

Direction sector	Sector prob.	Weibull parameters			Annual probability of exceedance			
		Shape	Scale	Location	1 year	10 years	50 years	100 yrs
	%	-	cm/s	cm/s	cm/s	cm/s	cm/s	cm/s
0º	32.39	2.820	48.43	-4.28	104	113	118	120
30º	7.37	1.827	22.65	2.63	75	85	91	94
60º	2.05	2.127	11.65	3.49	33	37	39	40
90º	1.10	2.129	7.88	4.23	23	26	28	28
120º	0.96	2.136	7.74	4.40	23	26	27	28
150º	2.15	1.891	8.95	4.97	30	34	37	38
180º	29.27	2.340	46.65	-1.66	121	133	140	143
210º	19.45	3.000	64.52	-16.09	119	130	136	139
240º	1.12	1.699	7.08	4.84	26	30	33	34
270º	0.73	2.241	6.91	3.56	19	21	23	23
300º	0.77	2.451	8.65	2.75	21	23	25	25
330º	2.63	1.326	13.04	5.00	63	76	85	89
0º-360º	**100.00**	**2.369**	**47.93**	**-6.97**	**124**	**135**	**142**	**145**

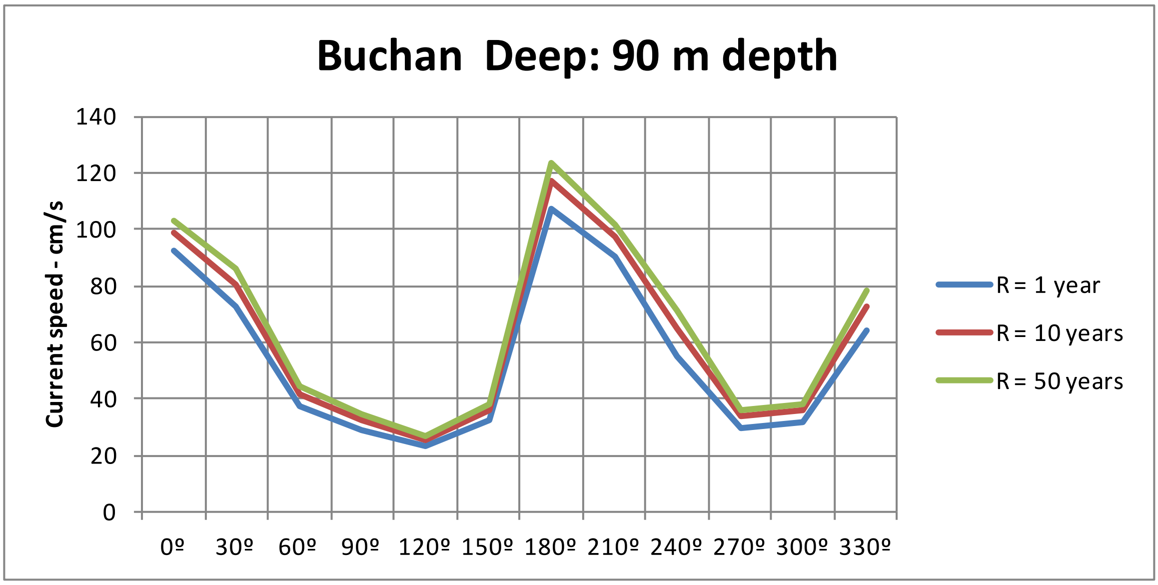


Figure 4.13 **Direction variation of current speed of 1, 10 and 50 year return period at 90 m depth at Buchan Deep.**

Table 4.14 **Weibull parameters and corresponding extreme values for the sector and omni-directional distributions of current speed at 90 m depth at Buchan Deep. Duration of extreme event is 10 minutes.**

Direction sector	**Sector prob.**	**Weibull parameters**			**Annual probability of exceedance**			
		Shape	**Scale**	**Location**	**1 year**	**10 years**	**50 years**	**100 yrs**
	%	**-**	**cm/s**	**cm/s**	**cm/s**	**cm/s**	**cm/s**	**cm/s**
0º	26.68	3.240	49.47	-7.04	92	99	103	105
30º	8.37	2.259	28.26	0.10	73	81	86	88
60º	2.71	2.430	15.79	1.92	38	42	44	46
90º	1.60	2.229	11.00	3.24	29	33	35	36
120º	1.44	3.098	12.06	1.30	24	26	27	28
150º	2.88	2.411	12.95	3.02	33	36	38	39
180º	22.75	2.410	42.09	0.43	107	117	123	126
210º	21.88	3.307	50.76	-9.42	90	97	101	103
240º	3.01	1.497	12.99	5.68	55	65	71	74
270º	1.54	2.145	10.77	3.61	30	34	36	37
300º	1.78	2.146	11.70	3.04	32	36	38	39
330º	5.36	1.945	21.12	2.93	64	73	78	80
0º-360º	**100.00**	**2.331**	**40.48**	**-3.97**	**109**	**118**	**124**	**127**

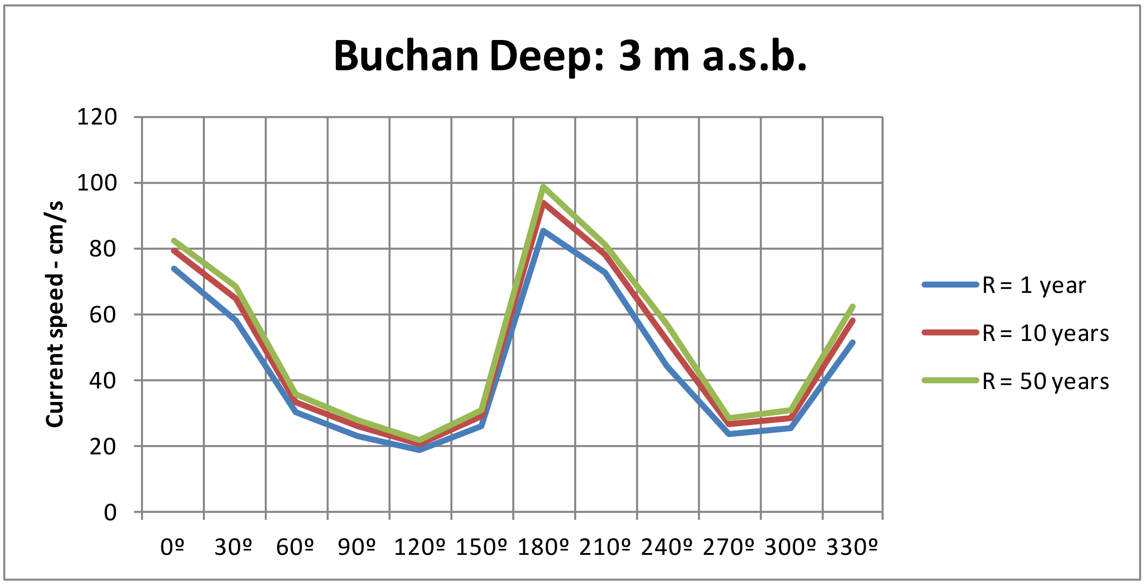


Figure 4.14 **Direction variation of current speed of 1, 10 and 50 year return period at 3 m above sea bottompth at Buchan Deep. Current speed at 3 m a.s.b is assumed to 20 % lower than the current speed at 90 m depth.**

Table 4.15 **Weibull parameters and corresponding extreme values for the sector and omni-directional distributions of current speed at 3 m above sea bottom at Buchan Deep. Duration of extreme event is 10 minutes.**

Direction sector	Sector prob.	Weibull parameters			Annual probability of exceedance			
		Shape	Scale	Location	1 year	10 years	50 years	100 yrs
	%	-	cm/s	cm/s	cm/s	cm/s	cm/s	cm/s
0º	26.68	3.240	39.57	-5.63	74	79	83	84
30º	8.37	2.259	22.61	0.08	58	65	69	70
60º	2.71	2.430	12.63	1.53	30	34	36	36
90º	1.60	2.229	8.80	2.59	23	26	28	29
120º	1.44	3.098	9.65	1.04	19	21	22	22
150º	2.88	2.411	10.36	2.42	26	29	31	31
180º	22.75	2.410	33.67	0.34	86	94	99	101
210º	21.88	3.307	40.61	-7.54	72	78	81	82
240º	3.01	1.497	10.39	4.54	44	52	57	59
270º	1.54	2.145	8.62	2.89	24	27	29	30
300º	1.78	2.146	9.36	2.43	25	29	31	32
330º	5.36	1.945	16.90	2.34	51	58	62	64
0º-360º	**100.00**	**2.331**	**32.39**	**-3.18**	**87**	**95**	**100**	**102**

5 Water Levels

5.1 Tidal elevations

Tidal variations at Buchan Deep have been computed using the NAO99.b tidal prediction system [12]. Figure 5.1 shows characteristic tidal variations during a lunar month (27.55 days). The highest astronomical tide (HAT) is found to be 181 cm (above means sea level).

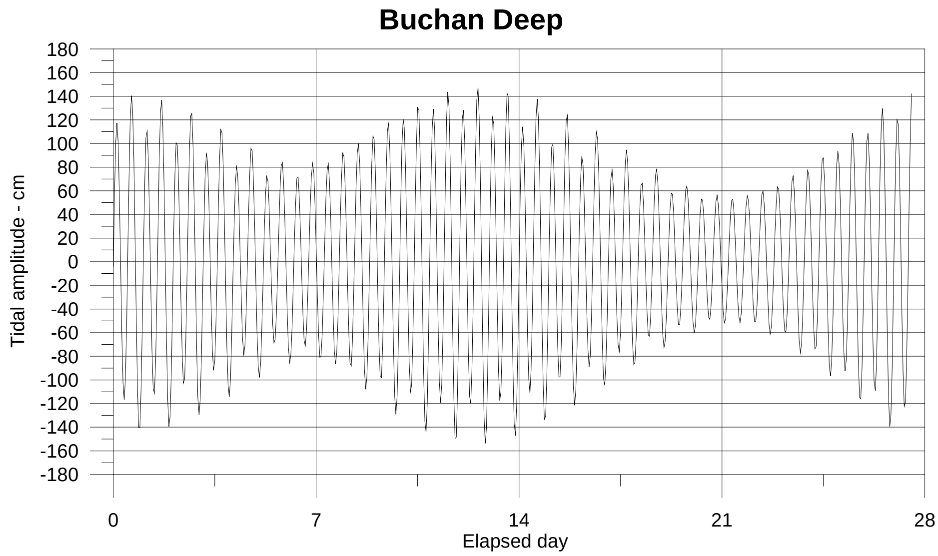


Figure 5.1 Characteristic tidal variations during a lunar month (27.55 days) at Buchan Deep.

5.2 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 [6, Figure 5]. The storm surge with annual probability of exceedance of $2 \cdot 10^{-2}$ (50-year return period) is found to be about 125 cm.

5.3 Total water level

Table 5.1 shows estimates of total extreme water levels to be expected at Buchan Deep. The tidal amplitude of $2 \cdot 10^{-2}$ annual probability of exceedance is equal to half the difference between the highest (HAT) and the lowest (LAT) astronomical tide.

Table 5.1 Estimates of extreme water levels (m) above mean sea level.

	Annual probability of exceedance	
	$2 \cdot 10^{-2}$	**10^{-4}**
Tidal amplitude	1.9	-
Storm surge	1.3	
Wave crest height	12.2	
Total water level	**15.4**	

5.4 Sea level rise

An additional increase in water level may be due to climatic effects; e.g. thermal expansion of the oceans and melting of glaciers. This effect is estimated to be in the range 0.2 – 0.6 m by the year 2100; IPCC Table SPM.1 [22]. The present rate of sea level rise is about 3 mm/year.

6 Marine growth

Recommendations regarding marine growth are provided in the NORSOK Standard N-003 Section 6.6.1 [7]:

Marine growth is a common designation for a surface coat on marine structures, caused by plants, animals and bacteria. Marine growth may cause increased hydrodynamic actions, increased weight and increased hydrodynamic additional mass and may influence hydrodynamic instability as a result of vortex shedding and possible corrosion effects.

Table 6.1 provides information on the thickness of marine growth that may be used in the calculation of structural actions.

Table 6.1 Thickness of marine growth at Buchan Deep. Data from NORSOK Standard N-003 Section 6.6.1 [7]

Water depth (m)	Thickness (mm)
Above + 2	0
+2 to -40	100
Below -40	50

The thickness of marine growth may be assumed to increase linearly to the given values over a period of 2 years after the structure has been placed in the sea.

Unless more accurate data are available, the roughness height may be taken as 20 mm below + 2 m. The roughness should be taken into consideration when determining the coefficients in Morison’s equation.

The weight of marine growth is classified as a variable functional action. Unless more accurate data are available, the specific weight of the marine growth in air may be set equal to 13 kN/m^3.

If marine growth exceeds the values for which the installation is documented, cleaning may be omitted if a new analysis shows that the structure has sufficient strength.

The recommendations regarding marine growth may be changed if (more accurate) data from measurements at Buchan Deep become available.

7 Snow and icing

7.1 General requirements

For Ultimate Limit State (ULS) conditions icing with annual probability of exceedance equal to 10^{-2} shall be considered in combinations with other environmental conditions with annual probability of exceedance equal to 10^{-1}. Snow is considered a separate load, NORSOK Standard N-003 Section 6.7 [7].

7.2 Snow

Characteristic snow action may be set equal to 0.5 kPa; NORSOK Standard N-003 Section 6.4.1 [7]. Shape factors as given in NS-EN 1991-1-3 [9] may be used.

7.3 Icing

Two types of icing may occur: atmospheric icing and ice accretion by sea spray.

Atmospheric icing caused by rain and snow gives a hard and even surface. Glazed frost appears on upward and windward facing surfaces between 5 m above mean sea level and the top of the structure. Ice accretion by sea spray depends mainly on wind speed and temperature.

Table 7.1 show the ice characteristics (with annual probability of 10^{-2}) for the two types of icing.

Table 7.1 Ice characteristics with annual probability of 10^{-2}. The data are from NORSOK Standard N-003 Section 6.4.2 [7].

Height above sea level (m)	Ice caused be sea spray		Ice caused by rain and snow	
	Thickness (mm)	Density (kg/m^3)	Thickness (mm)	Density (kg/m^3)
5 – 10	80	850	10	900
10 – 25	Linear reduction from 80 to 0	Linear reduction from 850 to 500	10	900
Above 25	0	-	10	900

Because accumulation of snow and glazed frost occurs mostly at temperatures in the range 0 – 3 ºC and sea spray occurs at temperatures well below these (temperatures), simultaneous occurrence of ice caused by rain and snow and ice caused by sea spray is unlikely.

8 Temperatures

8.1 Sea temperature profiles

Sea temperature profiles for Buchan Deep are available from the World Ocean Atlas 2009 [13].

Figure 8.1 shows monthly mean sea temperature profiles.

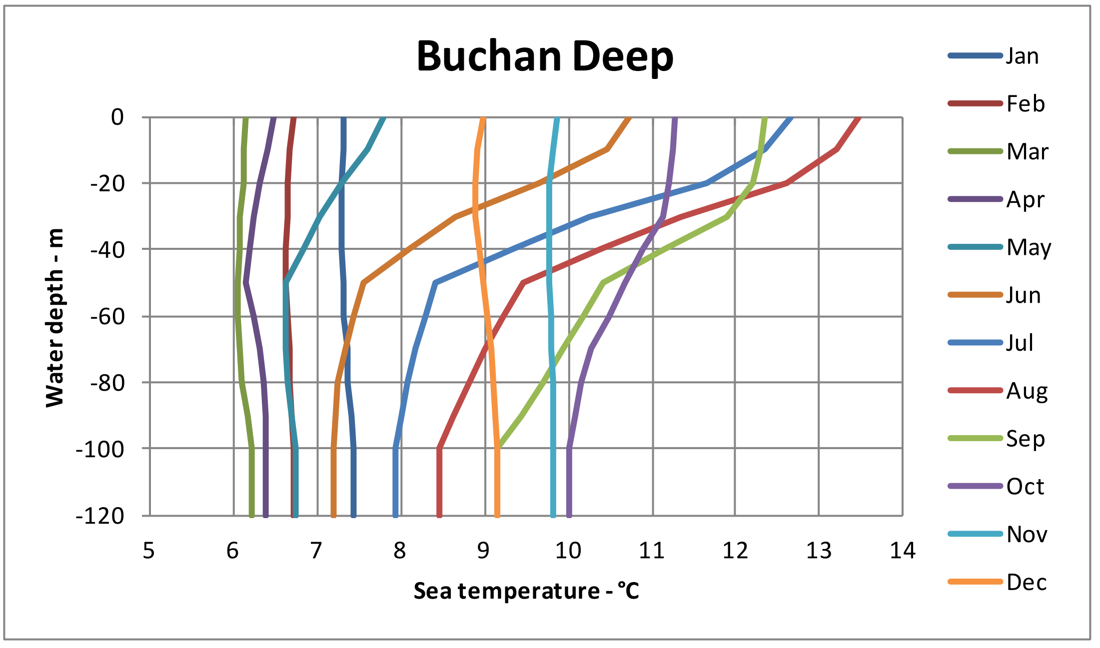


Figure 8.1 Monthly mean sea temperature profiles at Buchan Deep.

Table 8.1 shows monthly variation in sea temperature at selected depths. Table 8.2 shows the corresponding standard deviations.

Minimum and maximum sea temperatures may be approximated by:

$$T_{Minimum} = T_{Mean} - 3.5\,\sigma_T \quad (8.1)$$
$$T_{Maximum} = T_{Mean} + 3.5\,\sigma_T \quad (8.2)$$

where σ_T is the standard deviation in sea temperature as given in the tables.

The sea surface temperature around the coast of Scotland is increasing. The rate of increase shows geographic variation, but has generally been greater than 0.2º C per decade; to the south-east of Scotland the rate over the past 25 years has been 0.5º C per decade [27, Part 9]

Table 8.1 Monthly mean sea temperature (ºC) at selected water depths at Buchan Deep.

Depth (m)	Month											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
0	7.31	6.71	6.15	6.48	7.78	10.72	12.65	13.47	12.34	11.27	9.86	8.97
-10	7.32	6.67	6.12	6.40	7.60	10.45	12.34	13.21	12.29	11.25	9.81	8.92
-20	7.28	6.65	6.11	6.31	7.28	9.66	11.66	12.62	12.20	11.19	9.78	8.89
-30	7.28	6.64	6.07	6.24	7.02	8.65	10.24	11.34	11.90	11.12	9.77	8.88
-40	7.29	6.63	6.06	6.19	6.83	8.10	9.33	10.40	11.16	10.90	9.77	8.93
-50	7.30	6.63	6.04	6.14	6.63	7.54	8.42	9.45	10.42	10.68	9.77	8.98
-60	7.32	6.64	6.05	6.23	6.63	7.43	8.30	9.23	10.18	10.48	9.79	9.03
-70	7.35	6.66	6.06	6.31	6.62	7.33	8.18	9.01	9.94	10.28	9.80	9.07
-80	7.37	6.67	6.09	6.35	6.64	7.25	8.08	8.81	9.69	10.14	9.81	9.11
-90	7.41	6.70	6.16	6.37	6.68	7.22	8.00	8.63	9.43	10.08	9.82	9.13
-100	7.44	6.72	6.22	6.38	6.73	7.18	7.93	8.45	9.16	10.01	9.82	9.15
-110	7.44	6.72	6.22	6.38	6.73	7.18	7.93	8.45	9.16	10.01	9.82	9.15
-120	7.44	6.72	6.22	6.38	6.73	7.18	7.93	8.45	9.16	10.01	9.82	9.15

Table 8.2 Standard deviation of monthly mean sea temperature (ºC) at selected water depths at Buchan Deep.

Depth (m)	Month											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
0	0.69	0.75	0.65	0.76	1.01	1.20	1.05	0.81	0.67	0.61	0.74	0.88
-10	0.67	0.76	0.65	0.72	0.92	1.17	1.00	0.80	0.58	0.60	0.77	0.84
-20	0.64	0.74	0.65	0.68	0.84	1.00	1.04	0.82	0.56	0.59	0.76	0.84
-30	0.65	0.72	0.65	0.64	0.78	0.93	1.06	0.87	0.52	0.59	0.72	0.82
-40	0.64	0.71	0.64	0.63	0.73	0.93	1.03	0.88	0.57	0.58	0.71	0.79
-50	0.63	0.70	0.64	0.61	0.67	0.93	1.00	0.89	0.61	0.57	0.69	0.77
-60	0.62	0.69	0.63	0.61	0.68	0.83	0.93	0.89	0.72	0.63	0.67	0.73
-70	0.62	0.68	0.62	0.61	0.68	0.73	0.85	0.89	0.82	0.70	0.65	0.68
-80	0.60	0.69	0.62	0.62	0.67	0.68	0.82	0.90	0.93	0.74	0.64	0.64
-90	0.56	0.72	0.64	0.63	0.64	0.68	0.84	0.91	1.04	0.76	0.64	0.60
-100	0.53	0.75	0.65	0.64	0.62	0.68	0.85	0.93	1.15	0.77	0.64	0.56
-110	0.53	0.75	0.65	0.64	0.62	0.68	0.85	0.93	1.15	0.77	0.64	0.56
-120	0.53	0.75	0.65	0.64	0.62	0.68	0.85	0.93	1.15	0.77	0.64	0.56

8.2 Air temperature

Air temperature data are available from the Nora10 hindcast model operated by the Norwegian Meteorological Institute [26]. The data are from the grid point at 57.40º N, 01.28º W. The air temperature data cover the period 1958 – 2011 (54 years). The sample interval is 3 hours.

Figure 8.2 show the monthly minimum, mean and maximum air temperatures 2 m above sea level at Buchan Deep during the period 1958 – 2011.

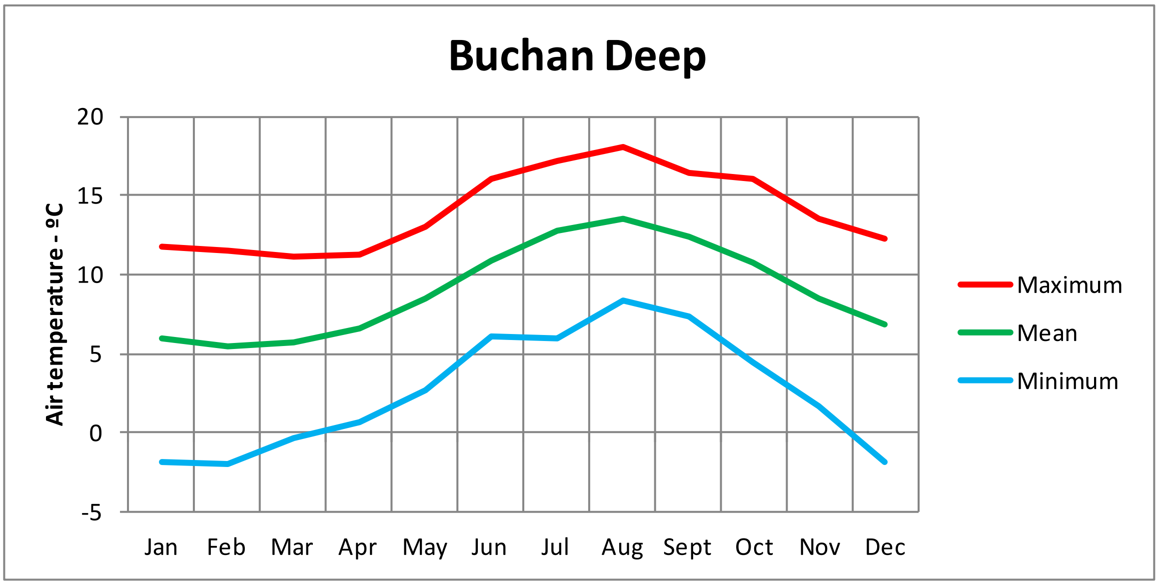


Figure 8.2 Monthly minimum, mean and maximum air temperature 2 m above sea level at Buchan Deep during the period 1958 – 2011.

Table 8.3 shows monthly and annual frequency of non-exceedance of air temperature at Buchan Deep.

The probable minimum and maximum air temperature at Buchan Deep is estimated to about -5 ºC and 23 ºC [6, Figures 10 and 11].

Table 8.3 Monthly and annual sample frequency of non-exceedance (%) of air temperature at Buchan Deep during the period 1958 - 2010.

Tempe-rature (ºC)	Month												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Year**
< - 2		0.01											**0.00**
< -1	0.11	0.05										0.05	**0.02**
< 0	0.19	0.10	0.03									0.07	**0.03**
< 1	0.42	0.48	0.31	0.01								0.11	**0.11**
< 2	1.34	2.46	1.43	0.22							0.05	0.58	**0.50**
< 3	4.20	9.84	5.70	1.31	0.04						0.23	2.32	**1.92**
< 4	13.01	22.50	15.57	4.81	0.35						1.34	6.70	**5.25**
< 5	28.20	39.80	31.18	14.54	1.61					0.03	4.44	15.95	**11.13**
< 6	49.41	61.07	53.60	31.02	5.01		0.01			0.38	10.56	31.24	**19.93**
< 7	72.72	82.52	79.97	58.18	14.40	0.25	0.02			2.32	22.13	51.41	**31.66**
< 8	89.76	94.03	94.03	85.86	36.33	1.53	0.03		0.14	6.69	38.44	71.85	**42.89**
< 9	97.18	98.24	98.92	97.72	67.27	7.56	0.07	0.03	1.12	15.06	59.87	88.68	**52.35**
< 10	99.37	99.79	99.92	99.78	89.61	25.12	0.97	0.20	5.18	29.88	80.95	96.85	**60.38**
< 11	99.96	99.98	99.99	99.99	97.72	51.55	7.32	2.02	16.03	53.42	94.42	99.64	**68.29**
< 12	100.00	100.00	100.00	100.00	99.70	80.39	25.97	11.88	36.77	81.19	98.84	99.97	**77.72**
< 13					100.00	95.36	58.32	36.44	68.11	95.71	99.95	100.00	**87.72**
< 14						99.47	85.58	69.48	91.41	99.67	100.00		**95.42**
< 15						99.95	96.13	89.84	98.72	99.99			**98.70**
< 16						99.98	99.35	97.80	99.93	100.00			**99.75**
< 17						100.00	99.99	99.62	100.00				**99.97**
< 18							100.00	99.99					**100.00**
< 19								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	**-1.8**	**-2.0**	**-0.3**	**0.7**	**2.7**	**6.1**	**6.0**	**8.3**	**7.4**	**4.5**	**1.7**	**-1.9**	**-2.0**
Mean	**6.0**	**5.4**	**5.7**	**6.6**	**8.4**	**10.9**	**12.8**	**13.5**	**12.4**	**10.7**	**8.4**	**6.9**	**9.0**
Maximum	**11.8**	**11.5**	**11.1**	**11.2**	**13.0**	**16.1**	**17.2**	**18.1**	**16.4**	**16.0**	**13.5**	**12.3**	**18.1**

9 Salinity

Salinity profiles for Buchan Deep are available from the World Ocean Atlas 2009 [13].

Figure 9.1 shows monthly mean salinity profiles.

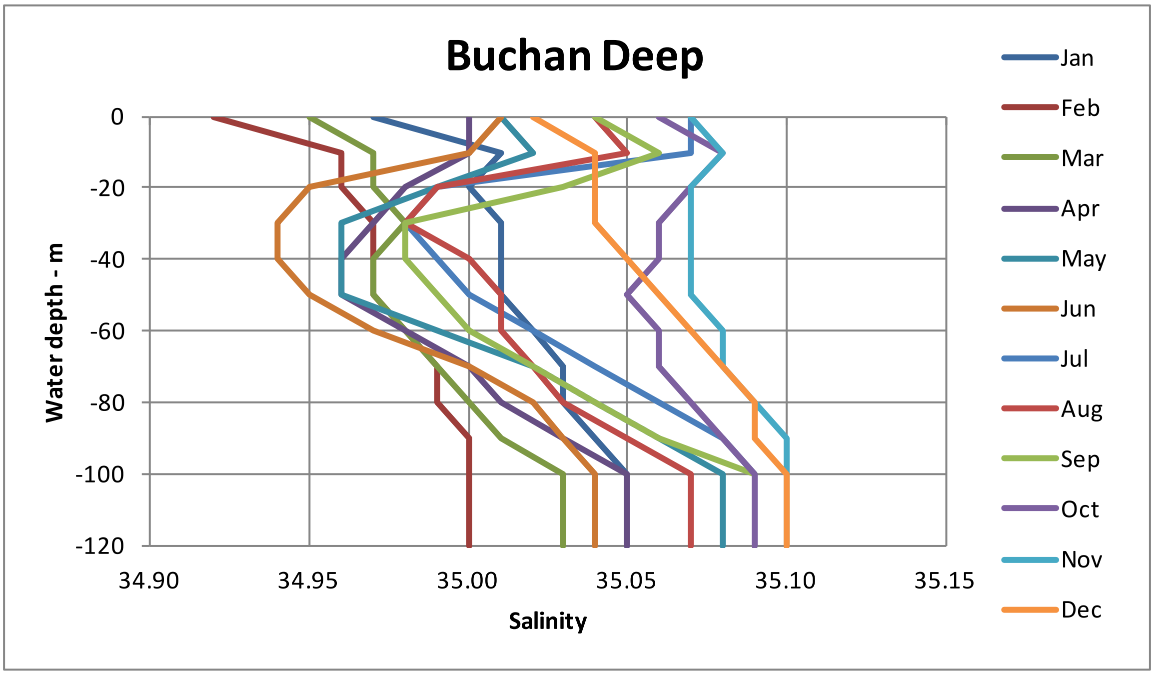


Figure 9.1 Monthly mean salinity profiles at Buchan Deep.

Table 9.1 shows monthly mean salinity at selected depths. Table 9.2 shows the corresponding standard deviations.

Table 9.1 Monthly mean salinity at selected water depths at Buchan Deep.

Depth (m)	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
0	34.97	34.92	34.95	35.00	35.01	35.01	35.07	35.04	35.04	35.06	35.07	35.02
-10	35.01	34.96	34.97	35.00	35.02	35.00	35.07	35.05	35.06	35.08	35.08	35.04
-20	35.00	34.96	34.97	34.98	34.99	34.95	34.99	34.99	35.03	35.07	35.07	35.04
-30	35.01	34.97	34.98	34.97	34.96	34.94	34.98	34.98	34.98	35.06	35.07	35.04
-40	35.01	34.97	34.97	34.96	34.96	34.94	34.99	35.00	34.98	35.06	35.07	35.05
-50	35.01	34.97	34.97	34.96	34.96	34.95	35.00	35.01	34.99	35.05	35.07	35.06
-60	35.02	34.98	34.98	34.98	34.99	34.97	35.02	35.01	35.00	35.06	35.08	35.07
-70	35.03	34.99	34.99	35.00	35.02	35.00	35.04	35.02	35.02	35.06	35.08	35.08
-80	35.03	34.99	35.00	35.01	35.04	35.02	35.06	35.03	35.04	35.07	35.09	35.09
-90	35.04	35.00	35.01	35.03	35.06	35.03	35.08	35.05	35.06	35.08	35.10	35.09
-100	35.05	35.00	35.03	35.05	35.08	35.04	35.09	35.07	35.09	35.09	35.10	35.10
-110	35.05	35.00	35.03	35.05	35.08	35.04	35.09	35.07	35.09	35.09	35.10	35.10
-120	35.05	35.00	35.03	35.05	35.08	35.04	35.09	35.07	35.09	35.09	35.10	35.10

Table 9.2 Standard deviation of monthly mean salinity at selected water depths at Buchan Deep.

Depth (m)	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
0	0.34	0.28	0.24	0.24	0.20	0.23	0.19	0.17	0.18	0.20	0.23	0.22
-10	0.24	0.20	0.20	0.19	0.18	0.19	0.19	0.15	0.18	0.19	0.23	0.21
-20	0.19	0.19	0.19	0.19	0.18	0.17	0.18	0.14	0.17	0.17	0.22	0.19
-30	0.18	0.18	0.18	0.19	0.18	0.16	0.18	0.14	0.16	0.16	0.20	0.19
-40	0.18	0.17	0.18	0.19	0.17	0.16	0.18	0.15	0.16	0.15	0.18	0.17
-50	0.17	0.15	0.17	0.20	0.17	0.17	0.18	0.15	0.16	0.15	0.17	0.16
-60	0.16	0.14	0.17	0.19	0.17	0.17	0.18	0.16	0.17	0.15	0.16	0.15
-70	0.14	0.14	0.17	0.18	0.17	0.17	0.18	0.16	0.17	0.16	0.15	0.15
-80	0.13	0.13	0.17	0.18	0.17	0.17	0.18	0.16	0.17	0.16	0.14	0.15
-90	0.11	0.13	0.17	0.19	0.18	0.17	0.17	0.16	0.18	0.16	0.14	0.15
-100	0.08	0.13	0.17	0.19	0.18	0.16	0.16	0.17	0.18	0.16	0.14	0.15
-110	0.08	0.13	0.17	0.19	0.18	0.16	0.16	0.17	0.18	0.16	0.14	0.15
-120	0.08	0.13	0.17	0.19	0.18	0.16	0.16	0.17	0.18	0.16	0.14	0.15

10 Wind and waves

10.1 Wind and wave data

The wind and wave data presented in this chapter are Nora 10 hindcast data from the grid point at 57.40º N, 01.28º W. The sample period is 3 hours.

In the analyses the wind data at 10 m above MSL cover the period 1958 – 2010 and the wind data at 100 m above MSL the period 1980 – 2010.

10.2 Wind speed and wave height

Figure 10.1 shows a scatter diagram of significant wave height versus 1-hour mean wind at 100 m above mean sea level. The figure shows that wave height and wind speed are highly correlated.

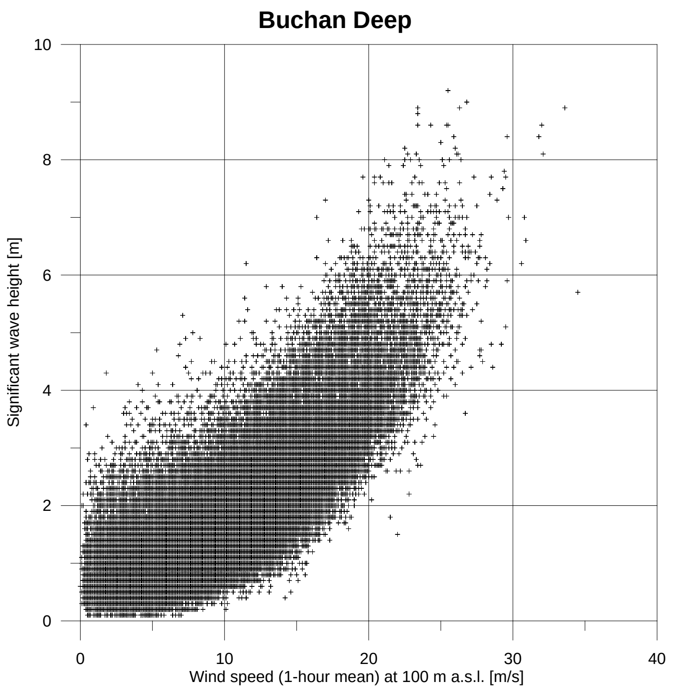


Figure 10.1 Significant wave height versus 1-hour mean wind speed at 100 m height at Buchan Deep. Data: Nora 10 hindcast data for the period 1958 – 2010.

Table 10.1 and Table 10.2 show scatter tables of significant wave height versus wind speed and vice versa.

Figure 10.2 and Figure 10.3 show significant wave height as a function of 1-hour mean wind speed at 100 m above sea level and vice versa. The relationships obtain by fitting an exponential function and a power function to the data are:

$$H_S = 0.719 \cdot \exp(0.0832 \cdot U) \tag{10.1}$$

$$U = 7.873 \cdot H_S^{0.5495} \tag{10.2}$$

where H_S is significant wave height and U is 1-hour mean wind speed at 100 m above sea level.

Table 10.1 Scatter table of significant wave height versus 1-hour mean wind speed at 100 m above sea level at Buchan Deep. Data: Nora 10 hindcast data for the period 1958 – 2010.

Wspd	Significant wave height [m]										
m/s	**0-1**	**1-2**	**2-3**	**3-4**	**4-5**	**5-6**	**6-7**	**7-8**	**8-9**	**9-10**	Sum
0.5	391	208	28	2	0	0	0	0	0	0	**629**
1.5	1161	649	77	2	1	0	0	0	0	0	**1890**
2.5	1899	1014	122	4	0	0	0	0	0	0	**3039**
3.5	2260	1427	170	17	0	0	0	0	0	0	**3874**
4.5	2586	1799	263	22	2	0	0	0	0	0	**4672**
5.5	2632	2268	333	25	3	0	0	0	0	0	**5261**
6.5	2668	2876	421	51	3	0	0	0	0	0	**6019**
7.5	2374	3422	604	63	5	2	0	0	0	0	**6470**
8.5	1880	4018	862	78	5	0	0	0	0	0	**6843**
9.5	1097	4527	1014	144	12	0	0	0	0	0	**6794**
10.5	593	4634	1397	217	17	0	0	0	0	0	**6858**
11.5	292	4029	1789	333	24	5	1	0	0	0	**6473**
12.5	84	3309	2126	508	58	3	0	0	0	0	**6088**
13.5	35	2264	2355	673	88	5	0	0	0	0	**5420**
14.5	13	1214	2447	746	163	12	0	0	0	0	**4595**
15.5	4	509	2282	868	256	26	0	0	0	0	**3945**
16.5	0	170	1587	897	290	48	2	1	0	0	**2995**
17.5	0	38	959	969	342	83	8	1	0	0	**2400**
18.5	0	14	490	922	353	122	23	0	0	0	**1924**
19.5	0	0	166	747	342	170	30	2	0	0	**1457**
20.5	0	0	52	466	351	145	41	7	0	0	**1062**
21.5	0	1	9	195	302	125	42	12	1	0	**687**
22.5	0	1	4	72	232	105	54	8	4	0	**480**
23.5	0	0	4	22	130	86	40	16	5	0	**303**
24.5	0	0	0	7	38	86	38	12	1	0	**182**
25.5	0	0	0	2	12	48	29	9	7	1	**108**
26.5	0	0	0	1	9	22	17	9	5	1	**64**
27.5	0	0	0	0	5	5	12	2	0	0	**24**
28.5	0	0	0	0	2	2	3	3	0	0	**10**
29.5	0	0	0	0	1	2	0	6	1	0	**10**
30.5	0	0	0	0	0	0	2	1	0	0	**3**
31.5	0	0	0	0	0	0	0	0	1	0	**1**
32.5	0	0	0	0	0	0	0	0	2	0	**2**
33.5	0	0	0	0	0	0	0	0	1	0	**1**
34.5	0	0	0	0	0	1	0	0	0	0	**1**
Sum	**19969**	**38391**	**19561**	**8053**	**3046**	**1103**	**342**	**89**	**28**	**2**	**90584**
Mean	**5.64**	**8.99**	**12.7**	**15.91**	**18.52**	**20.64**	**22.43**	**23.99**	**25.74**	**26.15**	
Std	**2.59**	**3.31**	**3.52**	**3.39**	**3.2**	**2.97**	**2.72**	**2.87**	**3.19**	**0.65**	

Table 10.2 Scatter table of 1-hour mean wind speed at 100 m above sea level versus significant wave height at Buchan Deep. Data: Nora10 hindcast data for the period 1958 – 2010.

Hs	**1-hour mean wind speed [m/s] at 100 m a.s.l.**																	
m	**0-2**	**2-4**	**4-6**	**6-8**	**8-10**	**10-12**	**12-14**	**14-16**	**16-18**	**18-20**	**20-22**	**22-24**	**14-26**	**26-28**	**28-30**	**30-32**	**32-34**	**34-36**	**Sum**
0.5	1552	4159	5218	5042	2977	885	119	17	0	0	0	0	0	0	0	0	0	0	**19969**
1.5	857	2441	4067	6298	8545	8663	5573	1723	208	14	1	1	0	0	0	0	0	0	**38391**
2.5	105	292	596	1025	1876	3186	4481	4729	2546	656	61	8	0	0	0	0	0	0	**19561**
3.5	4	21	47	114	222	550	1181	1614	1866	1669	661	94	9	1	0	0	0	0	**8053**
4.5	1	0	5	8	17	41	146	419	632	695	653	362	50	14	3	0	0	0	**3046**
5.5	0	0	0	2	0	5	8	38	131	292	270	191	134	27	4	0	0	1	**1103**
6.5	0	0	0	0	0	1	0	0	10	53	83	94	67	29	3	2	0	0	**342**
7.5	0	0	0	0	0	0	0	0	2	2	19	24	21	11	9	1	0	0	**89**
8.5	0	0	0	0	0	0	0	0	0	0	1	9	8	5	1	1	3	0	**28**
9.5	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	**2**
Sum	**2519**	**6913**	**9933**	**12489**	**13637**	**13331**	**11508**	**8540**	**5395**	**3381**	**1749**	**783**	**290**	**88**	**20**	**4**	**3**	**1**	**90584**
Mean	**0.91**	**0.93**	**1.03**	**1.18**	**1.40**	**1.71**	**2.09**	**2.54**	**3.08**	**3.68**	**4.29**	**4.93**	**5.66**	**6.01**	**6.53**	**7.05**	**8.53**	**5.7**	
Std	**0.50**	**0.51**	**0.53**	**0.55**	**0.57**	**0.62**	**0.67**	**0.73**	**0.8**	**0.88**	**0.93**	**1.02**	**0.99**	**1.08**	**1.13**	**0.83**	**0.33**	**0.00**	

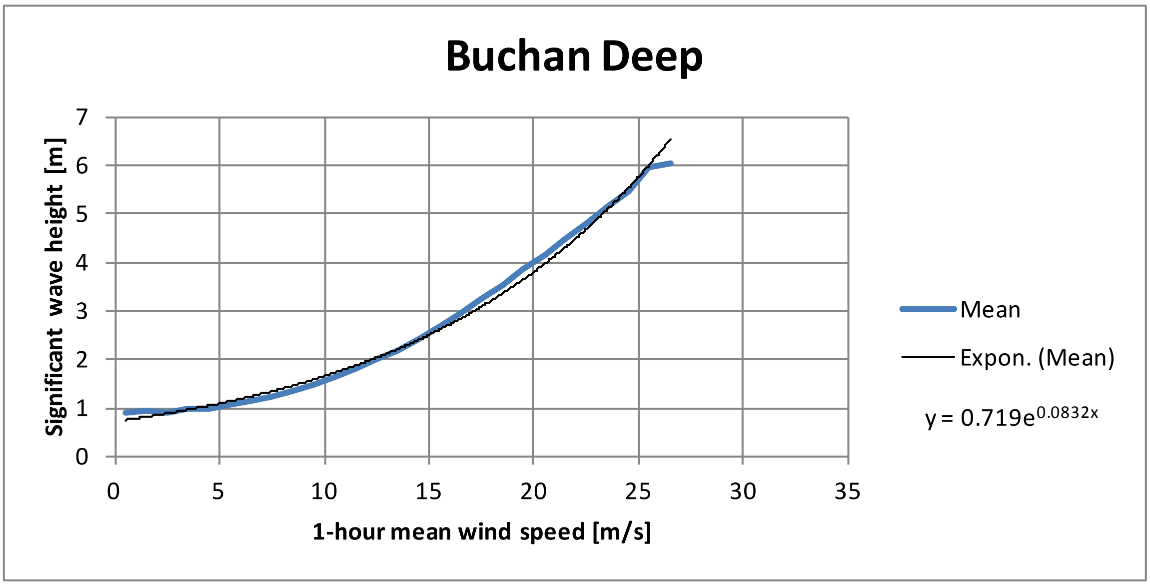


Figure 10.2 **Mean significant wave height as a function of 1-hour mean wind speed at 100 m a.s.l. The black line shows the result of an exponential function fit to the data.**

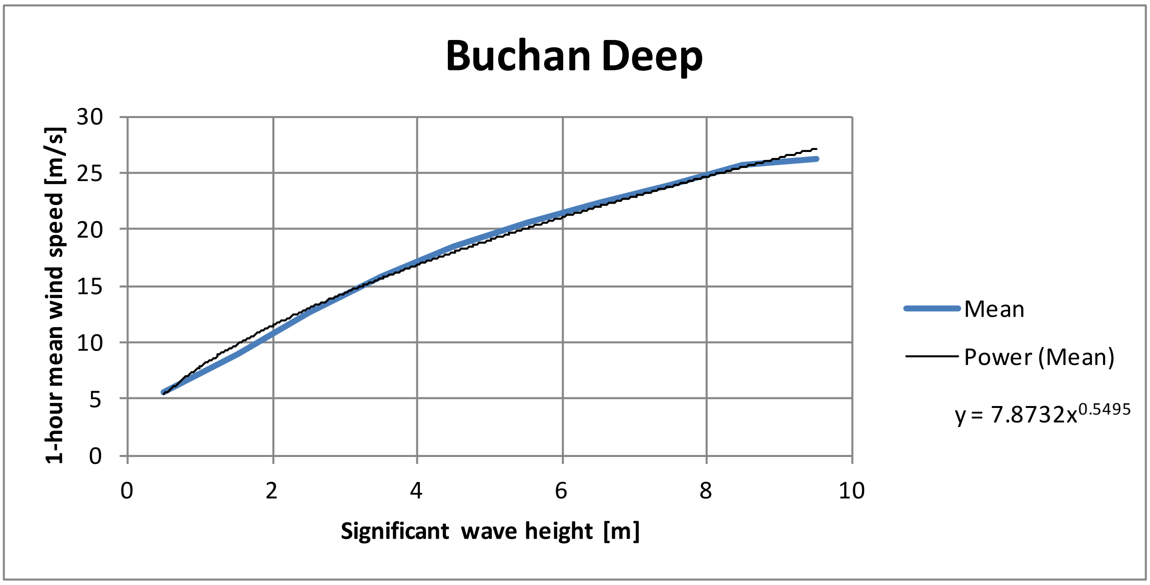


Figure 10.3 **1-hour mean wind speed at 100 m a.s.l. as a function of significant wave height. The black line shows the result of a power function fit to the data.**

10.3 Wind and wave direction

10.3.1 Summary

Joint probability tables of wind and wave directions are presented for the following 4 cases of data selection:

1. Wave direction and wind direction at 10 m above MSL sorted by the wind speed intervals: 0 – 5, 5 – 8, 8 – 12, 12 – 15, 15 – 20, 20 – 25 and greater than 25 m/s.
2. Wave direction and wind direction at 100 m above MSL sorted by the wind speed intervals: 0 – 5, 5 – 8, 8 – 12, 12 – 15, 15 – 20, 20 – 25 and greater than 25 m/s.
3. Wave direction and wind direction at 10 m above MSL sorted by significant wave height intervals: 0 – 1, 1 – 3, 3 – 5, 5 – 7, 7 – 9 and 9 - 11 m.
4. Wave direction and wind direction at 100 m above MSL sorted by significant wave height intervals: 0 – 1, 1 – 3, 3 – 5, 5 – 7, 7 – 9 and 9 - 11 m.

The joint probability data are presented in tables as shown below:

- Class 1: Table 10.3 - Table 10.9
- Class 2: Table 10.10 - Table 10.16
- Class 3: Table 10.17 - Table 10.22
- Class 4: Table 10.23 - Table 10.28

10.3.2 Data sorted by wind speed at 10 m above MSL

Table 10.3 Joint probability (%) of wind direction at 10 m above MSL and wave direction for wind speed in the interval 0 - 5 m/s. Data: Nora10 hindcast data for the period 1958 – 2010.

		Wave direction												
		345-015	015-045	045-075	075-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345	Sum
Wind direction	345-015	0.5366	0.6335	0.1595	0.1421	0.0852	0.0852	0.0458	0.0323	0.0161	0.0084	0.0142	0.0594	1.8184
	015-045	0.3022	0.5644	0.1653	0.1937	0.0768	0.0717	0.0362	0.0168	0.0071	0.0065	0.0052	0.0303	1.4761
	045-075	0.2454	0.4236	0.2008	0.2370	0.0807	0.0601	0.0349	0.0161	0.0032	0.0026	0.0058	0.0220	1.3321
	075-105	0.2195	0.4068	0.1911	0.2919	0.1324	0.0833	0.0316	0.0258	0.0077	0.0071	0.0071	0.0258	1.4303
	105-135	0.2712	0.4249	0.1989	0.3526	0.2241	0.1608	0.0491	0.0239	0.0058	0.0032	0.0071	0.0342	1.7557
	135-165	0.3584	0.5799	0.1763	0.3287	0.3145	0.2815	0.1208	0.0478	0.0239	0.0194	0.0181	0.0620	2.3311
	165-195	0.4727	0.5185	0.1640	0.2357	0.2370	0.2609	0.1937	0.1266	0.0465	0.0258	0.0465	0.1085	2.4363
	195-225	0.4901	0.3958	0.0930	0.1511	0.1446	0.2028	0.2267	0.2357	0.0555	0.0362	0.0562	0.1375	2.2252
	225-255	0.4042	0.2467	0.0839	0.1201	0.0833	0.1240	0.2002	0.2402	0.0691	0.0413	0.0562	0.1220	1.7913
	255-285	0.4075	0.2254	0.0775	0.0904	0.0613	0.0975	0.1227	0.1756	0.0672	0.0465	0.0568	0.1466	1.5749
	285-315	0.4875	0.2338	0.0801	0.0833	0.0607	0.1053	0.0949	0.1098	0.0368	0.0213	0.0413	0.1382	1.4929
	315-345	0.6406	0.4191	0.0930	0.1169	0.0775	0.1053	0.0588	0.0639	0.0187	0.0194	0.0258	0.1350	1.7738
Sum		4.8359	5.0722	1.6834	2.3434	1.5782	1.6382	1.2153	1.1145	0.3577	0.2376	0.3403	1.0215	21.4383

Table 10.4 Joint probability (%) of wind direction at 10 m above MSL and wave direction for wind speed in the interval 5 - 8 m/s. Data: Nora10 hindcast data for the period 1958 – 2010.

		Wave direction												
		345-015	015-045	045-075	075-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345	Sum
Wind direction	345-015	0.8537	0.9537	0.1550	0.0930	0.0465	0.0375	0.0181	0.0065	0.0019	0.0019	0.0052	0.0478	2.2207
	015-045	0.2531	0.6522	0.2518	0.1388	0.0271	0.0187	0.0090	0.0039	0.0006	0.0006	0.0013	0.0052	1.3625
	045-075	0.0956	0.3074	0.2421	0.3151	0.0555	0.0181	0.0045	0.0039	0.0013	0.0006	0.0006	0.0026	1.0474
	075-105	0.0652	0.1731	0.1621	0.5327	0.2150	0.0349	0.0039	0.0052	0.0013	0.0006	0.0013	0.0058	1.2011
	105-135	0.0936	0.1743	0.1240	0.4985	0.4959	0.1976	0.0213	0.0045	0.0019	0.0013	0.0032	0.0103	1.6266
	135-165	0.2202	0.2828	0.1414	0.3920	0.6625	0.9977	0.2215	0.0342	0.0077	0.0065	0.0077	0.0310	3.0052
	165-195	0.3758	0.3648	0.1240	0.2699	0.3836	0.9731	0.9680	0.2886	0.0439	0.0213	0.0310	0.0775	3.9215
	195-225	0.3816	0.2118	0.0517	0.1266	0.1472	0.3293	0.7077	0.8459	0.1647	0.0743	0.0672	0.1130	3.2209
	225-255	0.2719	0.0807	0.0220	0.0536	0.0420	0.1059	0.2680	0.7407	0.2441	0.1111	0.1085	0.1634	2.2116
	255-285	0.3319	0.0704	0.0207	0.0362	0.0271	0.0788	0.1240	0.3254	0.2034	0.1382	0.1982	0.2848	1.8390
	285-315	0.7213	0.1272	0.0265	0.0555	0.0349	0.0684	0.0704	0.0910	0.0749	0.0633	0.1556	0.4766	1.9656
	315-345	1.3218	0.3868	0.0652	0.0665	0.0465	0.0710	0.0342	0.0316	0.0181	0.0194	0.0458	0.3590	2.4661
Sum		4.9857	3.7853	1.3864	2.5784	2.1839	2.9310	2.4506	2.3815	0.7639	0.4391	0.6257	1.5769	26.0882

Table 10.5 Joint probability (%) of wind direction at 10 m above MSL and wave direction for wind speed in the interval 8 - 12 m/s. Data: Nora10 hindcast data for the period 1958 – 2010.

		Wave direction												
		345-015	**015-045**	**045-075**	**075-105**	**105-135**	**135-165**	**165-195**	**195-225**	**225-255**	**255-285**	**285-315**	**315-345**	**Sum**
Wind direction	**345-015**	1.4897	0.8252	0.0633	0.0174	0.0090	0.0181	0.0077	0.0019	0.0026	0.0006	0.0039	0.0400	2.4796
	015-045	0.1485	0.5999	0.1621	0.0465	0.0052	0.0039	0.0019	0.0006	-	0.0006	-	0.0026	0.9718
	045-075	0.0284	0.1317	0.1950	0.3061	0.0123	0.0032	0.0013	-	0.0006	-	-	0.0006	0.6793
	075-105	0.0168	0.0452	0.1065	0.7193	0.2215	0.0065	0.0006	-	-	-	-	-	1.1165
	105-135	0.0265	0.0523	0.0613	0.4740	0.8517	0.2460	0.0045	-	0.0006	-	-	-	1.7170
	135-165	0.0446	0.0749	0.0504	0.1711	0.8240	1.5569	0.2079	0.0084	0.0013	0.0006	0.0026	0.0071	2.9497
	165-195	0.1421	0.1007	0.0278	0.0814	0.2208	1.3005	2.4273	0.3836	0.0239	0.0116	0.0136	0.0226	4.7558
	195-225	0.1685	0.0633	0.0129	0.0381	0.0833	0.2589	1.7286	2.9000	0.1763	0.0588	0.0452	0.0704	5.6043
	225-255	0.0943	0.0149	0.0032	0.0129	0.0142	0.0626	0.3100	1.8997	0.4740	0.1375	0.0730	0.0704	3.1667
	255-285	0.1782	0.0116	0.0103	0.0149	0.0155	0.0375	0.0814	0.3668	0.4766	0.4307	0.4908	0.3416	2.4557
	285-315	0.6134	0.0316	0.0187	0.0207	0.0213	0.0452	0.0491	0.0607	0.0768	0.1130	0.3965	1.2650	2.7121
	315-345	2.3763	0.1698	0.0355	0.0245	0.0207	0.0336	0.0174	0.0155	0.0090	0.0129	0.0381	0.8866	3.6400
Sum		5.3273	2.1212	0.7471	1.9269	2.2995	3.5728	4.8378	5.6372	1.2417	0.7665	1.0635	2.7069	32.2485

Table 10.6 Joint probability (%) of wind direction at 10 m above MSL and wave direction for wind speed in the interval 12 – 15 m/s. Data: Nora10 hindcast data for the period 1958 – 2010.

		Wave direction												
		345-015	**015-045**	**045-075**	**075-105**	**105-135**	**135-165**	**165-195**	**195-225**	**225-255**	**255-285**	**285-315**	**315-345**	**Sum**
Wind direction	**345-015**	0.6231	0.1446	0.0058	0.0006	-	0.0026	-	-	0.0006	0.0006	0.0006	0.0181	0.7968
	015-045	0.0458	0.1453	0.0439	0.0026	0.0006	0.0006	-	-	-	-	-	-	0.2389
	045-075	0.0006	0.0187	0.0523	0.0749	0.0039	-	-	-	-	-	-	-	0.1505
	075-105	0.0006	0.0052	0.0161	0.2996	0.0756	0.0013	-	-	-	-	-	-	0.3984
	105-135	0.0032	0.0052	0.0045	0.1388	0.5011	0.0839	0.0013	-	-	-	-	-	0.7381
	135-165	0.0084	0.0058	0.0065	0.0181	0.2738	0.7542	0.0923	0.0019	-	-	0.0006	0.0013	1.1630
	165-195	0.0168	0.0058	0.0019	0.0052	0.0239	0.3984	1.2605	0.1053	0.0019	0.0006	0.0019	0.0006	1.8229
	195-225	0.0265	0.0052	0.0006	0.0019	0.0052	0.0381	0.8847	1.9307	0.0413	0.0103	0.0103	0.0065	2.9613
	225-255	0.0052	-	-	0.0006	0.0006	0.0052	0.0827	0.9053	0.1330	0.0168	0.0052	0.0052	1.1597
	255-285	0.0136	0.0006	0.0006	0.0013	0.0006	0.0013	0.0142	0.1072	0.2544	0.2460	0.2338	0.0633	0.9370
	285-315	0.1078	0.0039	0.0019	0.0013	0.0026	0.0097	0.0071	0.0123	0.0226	0.0433	0.2576	0.5928	1.0629
	315-345	1.1352	0.0065	0.0045	0.0019	0.0045	0.0039	0.0045	0.0013	0.0013	0.0019	0.0155	0.5450	1.7260
Sum		1.9869	0.3468	0.1388	0.5469	0.8924	1.2992	2.3472	3.0640	0.4552	0.3196	0.5256	1.2327	13.1555

Table 10.7 Joint probability (%) of wind direction at 10 m above MSL and wave direction for wind speed in the interval 15 - 20 m/s. Data: Nora10 hindcast data for the period 1958 – 2010.

		Wave direction												
		345-015	015-045	045-075	075-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345	Sum
Wind direction	345-015	0.3655	0.0349	0.0013	0.0013	-	0.0006	-	0.0006	-	-	-	0.0136	0.4178
	015-045	0.0161	0.0510	0.0161	0.0006	-	-	-	-	-	-	-	-	0.0839
	045-075	0.0006	0.0065	0.0161	0.0316	0.0006	-	-	-	-	-	-	-	0.0555
	075-105	-	0.0006	0.0045	0.1040	0.0316	-	-	-	-	-	-	-	0.1408
	105-135	0.0013	0.0013	0.0006	0.0452	0.2861	0.0336	-	-	-	-	-	-	0.3681
	135-165	0.0013	0.0013	-	0.0019	0.0988	0.3836	0.0478	-	-	-	-	-	0.5347
	165-195	0.0019	0.0019	-	0.0013	0.0019	0.1931	0.7051	0.0400	-	-	-	0.0006	0.9460
	195-225	0.0006	-	0.0006	-	0.0006	0.0045	0.4501	0.9964	0.0039	0.0013	0.0019	0.0039	1.4639
	225-255	0.0006	-	-	-	0.0013	-	0.0252	0.3319	0.0245	-	0.0006	0.0006	0.3849
	255-285	0.0013	-	-	-	0.0019	0.0006	0.0039	0.0232	0.1408	0.1601	0.0878	0.0084	0.4281
	285-315	0.0284	-	0.0006	-	-	0.0045	0.0032	0.0077	0.0084	0.0213	0.1860	0.3358	0.5960
	315-345	0.5308	-	0.0006	0.0019	0.0006	0.0019	0.0006	0.0013	0.0013	0.0019	0.0026	0.3358	0.8795
Sum		0.9486	0.0975	0.0407	0.1879	0.4236	0.6225	1.2359	1.4012	0.1789	0.1847	0.2790	0.6987	6.2991

Table 10.8 **Joint probability (%) of wind direction at 10 m above MSL and wave direction for wind speed in the interval 20 - 25 m/s. Data: Nora10 hindcast data for the period 1958 – 2010.**

		Wave direction												
		345-015	015-045	045-075	075-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345	Sum
Wind direction	345-015	0.0394	0.0006	-	-	-	-	-	-	-	-	0.0006	-	0.0407
	015-045	-	0.0058	0.0032	-	-	-	-	-	-	-	-	-	0.0090
	045-075	-	-	0.0006	0.0019	-	-	-	-	-	-	-	-	0.0026
	075-105	-	-	-	0.0045	0.0019	-	-	-	-	-	-	-	0.0065
	105-135	-	-	-	0.0058	0.0310	0.0013	-	-	-	-	-	-	0.0381
	135-165	-	-	-	-	0.0084	0.0504	0.0090	-	-	-	-	-	0.0678
	165-195	-	-	-	0.0006	-	0.0129	0.1104	0.0026	-	-	-	-	0.1266
	195-225	-	-	-	-	-	-	0.0465	0.1091	-	-	-	-	0.1556
	225-255	-	-	-	-	-	-	0.0013	0.0342	0.0013	-	-	-	0.0368
	255-285	-	-	-	-	-	0.0006	0.0006	0.0032	0.0168	0.0168	0.0123	-	0.0504
	285-315	0.0006	-	-	0.0006	0.0006	-	0.0006	-	0.0019	0.0045	0.0297	0.0452	0.0839
	315-345	0.0710	0.0006	-	-	-	0.0019	-	0.0006	-	-	0.0006	0.0504	0.1253
Sum		0.1111	0.0071	0.0039	0.0136	0.0420	0.0672	0.1685	0.1498	0.0200	0.0213	0.0433	0.0956	0.7432

Table 10.9 **Joint probability (%) of wind direction at 10 m above MSL and wave direction for wind speed greater than 25 m/s. Data: Nora10 hindcast data for the period 1958 – 2010.**

		Wave direction												
		345-015	015-045	045-075	075-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345	Sum
Wind direction	345-015	-	-	-	-	-	-	-	0.0006	-	-	-	0.0013	0.0019
	015-045	-	-	-	-	-	-	-	-	-	-	-	-	-
	045-075	-	-	-	-	-	-	-	-	-	-	-	-	-
	075-105	-	-	-	-	-	-	-	-	-	-	-	-	-
	105-135	-	-	-	-	-	-	-	-	-	-	-	-	-
	135-165	-	-	-	-	-	-	0.0006	-	-	-	-	-	0.0006
	165-195	-	-	-	-	-	0.0006	0.0006	0.0006	-	-	-	-	0.0019
	195-225	-	-	-	-	-	-	0.0019	0.0065	-	-	-	-	0.0084
	225-255	-	-	-	-	-	-	-	0.0013	-	-	-	-	0.0013
	255-285	-	-	-	-	-	-	-	-	0.0013	0.0019	-	-	0.0032
	285-315	-	-	-	-	-	-	-	-	-	0.0013	0.0006	0.0019	0.0039
	315-345	0.0052	-	-	-	-	-	-	-	-	-	-	0.0006	0.0058
Sum		0.0052	-	-	-	-	0.0006	0.0032	0.0090	0.0013	0.0032	0.0006	0.0039	0.0271

10.3.3 Data sorted by wind speed at 100 m above MSL

Table 10.10 Joint probability (%) of wind direction at 100 m above MSL and wave direction for wind speed in the interval 0 - 5 m/s. Data: Nora10 hindcast data for the period 1980 – 2010.

		Wave direction												
		345-015	**015-045**	**045-075**	**075-105**	**105-135**	**135-165**	**165-195**	**195-225**	**225-255**	**255-285**	**285-315**	**315-345**	**Sum**
Wind direction	**345-015**	0.4670	0.4791	0.1027	0.1181	0.0707	0.0773	0.0386	0.0364	0.0132	0.0077	0.0077	0.0508	1.4694
	015-045	0.2970	0.4659	0.1159	0.1325	0.0740	0.0695	0.0353	0.0199	0.0044	0.0088	0.0055	0.0210	1.2497
	045-075	0.2274	0.3389	0.1214	0.1590	0.0607	0.0695	0.0287	0.0199	0.0066	0.0033	0.0055	0.0166	1.0576
	075-105	0.2109	0.3168	0.1424	0.1844	0.0707	0.0508	0.0331	0.0166	0.0066	0.0044	0.0033	0.0287	1.0686
	105-135	0.2285	0.3235	0.1270	0.1921	0.0883	0.0839	0.0265	0.0166	0.0044	0.0022	0.0055	0.0309	1.1293
	135-165	0.2826	0.4195	0.1247	0.1965	0.1700	0.1137	0.0607	0.0309	0.0088	0.0144	0.0144	0.0375	1.4738
	165-195	0.3466	0.4051	0.1203	0.1744	0.1667	0.1159	0.0872	0.0464	0.0144	0.0121	0.0287	0.0552	1.5731
	195-225	0.3820	0.3201	0.0651	0.1104	0.0872	0.1336	0.0927	0.0883	0.0177	0.0155	0.0232	0.0883	1.4241
	225-255	0.3168	0.2098	0.0695	0.1016	0.0640	0.1082	0.1225	0.1236	0.0364	0.0110	0.0408	0.0729	1.2773
	255-285	0.3235	0.2053	0.0740	0.0707	0.0508	0.0850	0.1071	0.1071	0.0353	0.0188	0.0298	0.0773	1.1845
	285-315	0.3941	0.2009	0.0729	0.0795	0.0519	0.0927	0.0707	0.0883	0.0243	0.0155	0.0265	0.0806	1.1978
	315-345	0.5608	0.3643	0.0850	0.0828	0.0629	0.0872	0.0530	0.0530	0.0155	0.0144	0.0177	0.0684	1.4649
Sum		4.0371	4.0493	1.2210	1.6018	1.0178	1.0874	0.7562	0.6469	0.1877	0.1281	0.2086	0.6281	15.5701

Table 10.11 Joint probability (%) of wind direction at 100 m above MSL and wave direction for wind speed in the interval 5 - 8 m/s. Data: Nora10 hindcast data for the period 1980 – 2010.

		Wave direction												
		345-015	015-045	045-075	075-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345	Sum
Wind direction	345-015	0.7187	0.7352	0.1159	0.0839	0.0508	0.0508	0.0188	0.0155	0.0110	0.0022	0.0066	0.0585	1.8679
	015-045	0.2296	0.5685	0.1667	0.1479	0.0431	0.0309	0.0177	0.0055	0.0011	0.0011	0.0033	0.0110	1.2265
	045-075	0.1038	0.2815	0.2064	0.1799	0.0431	0.0298	0.0121	0.0022	0.0022	0.0022	-	0.0011	0.8644
	075-105	0.0596	0.1910	0.1402	0.3212	0.1049	0.0420	0.0055	0.0088	0.0033	-	0.0011	0.0055	0.8832
	105-135	0.1060	0.1998	0.1391	0.3389	0.2937	0.1424	0.0144	0.0044	0.0022	0.0033	0.0011	0.0077	1.2530
	135-165	0.2230	0.2914	0.1380	0.3003	0.3941	0.3886	0.0861	0.0177	0.0044	0.0033	0.0044	0.0342	1.8855
	165-195	0.3212	0.3720	0.1247	0.2329	0.3047	0.4935	0.2760	0.0971	0.0331	0.0199	0.0243	0.0762	2.3757
	195-225	0.4007	0.2627	0.0883	0.1601	0.1612	0.3290	0.3279	0.3235	0.0861	0.0508	0.0497	0.1027	2.3426
	225-255	0.2716	0.1071	0.0287	0.0618	0.0574	0.1314	0.2385	0.3654	0.1203	0.0695	0.0607	0.1159	1.6283
	255-285	0.3400	0.0883	0.0221	0.0386	0.0265	0.0938	0.1512	0.2616	0.1093	0.0994	0.1192	0.1987	1.5488
	285-315	0.6138	0.1369	0.0265	0.0552	0.0541	0.0938	0.0806	0.1027	0.0530	0.0408	0.0971	0.2749	1.6294
	315-345	1.0962	0.3643	0.0629	0.0574	0.0453	0.0684	0.0420	0.0651	0.0177	0.0166	0.0320	0.2219	2.0898
Sum		4.4842	3.5989	1.2596	1.9783	1.5786	1.8944	1.2706	1.2695	0.4438	0.3091	0.3996	1.1084	19.5951

Table 10.12 Joint probability (%) of wind direction at 100 m above MSL and wave direction for wind speed in the interval 8 - 12 m/s.
Data: Nora10 hindcast data for the period 1980 – 2010.

		Wave direction												
		345-015	015-045	045-075	075-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345	Sum
Wind direction	345-015	1.2662	0.8280	0.0916	0.0431	0.0232	0.0309	0.0155	0.0044	0.0033	0.0011	0.0044	0.0508	2.3624
	015-045	0.1612	0.6723	0.2031	0.0740	0.0177	0.0088	0.0055	0.0011	-	-	-	0.0066	1.1503
	045-075	0.0408	0.1987	0.2672	0.3102	0.0276	0.0066	0.0011	-	0.0011	-	0.0011	0.0011	0.8556
	075-105	0.0298	0.0673	0.1612	0.6116	0.2098	0.0099	0.0022	-	-	-	-	0.0022	1.0940
	105-135	0.0508	0.0762	0.0817	0.4603	0.7065	0.1391	0.0044	-	-	-	-	0.0022	1.5212
	135-165	0.0795	0.1148	0.0916	0.2738	0.8909	1.1415	0.1512	0.0099	0.0033	0.0022	0.0022	0.0166	2.7775
	165-195	0.1954	0.2153	0.0618	0.1711	0.3731	1.3369	1.3148	0.2605	0.0265	0.0188	0.0265	0.0408	4.0416
	195-225	0.2716	0.1325	0.0386	0.0983	0.1788	0.4670	1.3446	1.5533	0.1711	0.0773	0.0607	0.0894	4.4831
	225-255	0.1612	0.0298	0.0088	0.0243	0.0287	0.1270	0.4085	1.4638	0.4007	0.1358	0.0894	0.0949	2.9729
	255-285	0.2440	0.0298	0.0066	0.0199	0.0309	0.0607	0.1413	0.4957	0.3963	0.3014	0.3676	0.3212	2.4154
	285-315	0.6745	0.0574	0.0210	0.0320	0.0276	0.0684	0.0762	0.0960	0.1126	0.1181	0.3179	1.0664	2.6682
	315-345	2.1019	0.2451	0.0486	0.0475	0.0265	0.0552	0.0298	0.0265	0.0121	0.0276	0.0552	0.7529	3.4289
Sum		5.2769	2.6671	1.0819	2.1659	2.5413	3.4520	3.4951	3.9113	1.1271	0.6822	0.9251	2.4452	29.7713

Table 10.13 Joint probability (%) of wind direction at 100 m above MSL and wave direction for wind speed in the interval 12 – 15 m/s. Data: Nora10 hindcast data for the period 1980 – 2010.

		Wave direction												
		345-015	015-045	045-075	075-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345	Sum
Wind direction	345-015	0.8280	0.2694	0.0077	0.0022	0.0011	0.0022	-	-	0.0011	-	0.0011	0.0265	1.1393
	015-045	0.0707	0.2506	0.0596	0.0022	0.0011	0.0011	-	-	-	-	-	-	0.3853
	045-075	0.0055	0.0431	0.0883	0.0994	0.0011	-	-	-	-	-	-	-	0.2373
	075-105	0.0011	0.0088	0.0342	0.3400	0.0971	-	-	-	-	-	-	-	0.4813
	105-135	0.0055	0.0121	0.0144	0.2120	0.5476	0.1181	0.0011	-	-	-	-	-	0.9108
	135-165	0.0110	0.0199	0.0110	0.0375	0.4482	0.8721	0.0938	0.0011	-	-	0.0011	0.0033	1.4992
	165-195	0.0420	0.0210	0.0110	0.0121	0.0927	0.7463	1.3866	0.1579	0.0066	0.0011	0.0044	0.0077	2.4894
	195-225	0.0519	0.0210	0.0022	0.0044	0.0243	0.1612	1.3976	1.9452	0.0894	0.0265	0.0155	0.0144	3.7534
	225-255	0.0210	0.0022	-	0.0011	0.0022	0.0232	0.2053	1.5367	0.2484	0.0408	0.0276	0.0199	2.1284
	255-285	0.0420	0.0011	0.0011	0.0011	0.0011	0.0088	0.0408	0.2329	0.3511	0.2948	0.2716	0.1203	1.3667
	285-315	0.1855	0.0055	0.0044	0.0044	0.0055	0.0132	0.0177	0.0320	0.0320	0.0850	0.2826	0.7507	1.4186
	315-345	1.2254	0.0177	0.0055	0.0044	0.0110	0.0121	0.0099	0.0066	0.0044	0.0011	0.0243	0.6447	1.9672
Sum		2.4894	0.6723	0.2396	0.7209	1.2331	1.9584	3.1529	3.9124	0.7330	0.4493	0.6281	1.5875	17.7769

Table 10.14 Joint probability (%) of wind direction at 100 m above MSL and wave direction for wind speed in the interval 15 - 20 m/s. Data: Nora10 hindcast data for the period 1980 – 2010.

		Wave direction												
		345-015	015-045	045-075	075-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345	Sum
Wind direction	345-015	0.6050	0.0905	0.0044	-	-	-	-	-	-	-	0.0011	0.0188	0.7198
	015-045	0.0420	0.1270	0.0353	0.0011	-	-	-	-	-	-	-	-	0.2053
	045-075	-	0.0210	0.0508	0.0629	0.0022	-	-	-	-	-	-	-	0.1369
	075-105	-	0.0022	0.0110	0.2429	0.0585	-	-	-	-	-	-	-	0.3146
	105-135	0.0011	0.0055	0.0022	0.1071	0.5189	0.0629	0.0022	-	-	-	-	-	0.6999
	135-165	0.0066	0.0055	0.0033	0.0121	0.2241	0.8114	0.0817	0.0011	-	-	-	0.0011	1.1470
	165-195	0.0099	0.0044	-	0.0022	0.0088	0.4957	1.5157	0.0872	-	-	-	-	2.1240
	195-225	0.0121	0.0011	0.0011	-	0.0044	0.0431	1.3501	2.2565	0.0309	0.0077	0.0055	0.0077	3.7203
	225-255	0.0044	-	-	-	0.0022	0.0033	0.1016	1.1371	0.0861	0.0077	0.0022	0.0033	1.3479
	255-285	0.0055	-	-	-	0.0033	0.0011	0.0132	0.1170	0.2937	0.2649	0.1987	0.0342	0.9317
	285-315	0.0596	0.0022	0.0022	0.0011	0.0011	0.0099	0.0099	0.0144	0.0287	0.0519	0.3378	0.5983	1.1172
	315-345	0.9880	0.0044	0.0044	0.0022	0.0022	0.0044	0.0044	0.0011	-	0.0044	0.0144	0.5487	1.5786
Sum		1.7343	0.2638	0.1148	0.4316	0.8258	1.4318	3.0789	3.6143	0.4394	0.3367	0.5597	1.2121	14.0433

Table 10.15 Joint probability (%) of wind direction at 100 m above MSL and wave direction for wind speed in the interval 20 - 25 m/s. Data: Nora10 hindcast data for the period 1980 – 2010.

		Wave direction												
		345-015	015-045	045-075	075-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345	Sum
Wind direction	345-015	0.1027	0.0066	-	-	-	0.0011	-	-	-	-	0.0011	0.0033	0.1148
	015-045	0.0055	0.0320	0.0044	-	-	-	-	-	-	-	-	-	0.0420
	045-075	-	0.0011	0.0088	0.0166	-	-	-	-	-	-	-	-	0.0265
	075-105	-	-	-	0.0232	0.0144	-	-	-	-	-	-	-	0.0375
	105-135	-	-	-	0.0022	0.1225	0.0166	-	-	-	-	-	-	0.1413
	135-165	-	-	-	-	0.0265	0.1976	0.0276	-	-	-	-	-	0.2517
	165-195	-	-	-	0.0011	-	0.0894	0.3996	0.0121	-	-	-	0.0011	0.5034
	195-225	-	-	-	-	-	0.0022	0.3257	0.5376	-	-	-	-	0.8655
	225-255	-	-	-	-	0.0011	-	0.0155	0.1910	0.0033	-	-	-	0.2109
	255-285	-	-	-	-	-	0.0011	0.0033	0.0155	0.0817	0.0773	0.0265	0.0022	0.2075
	285-315	0.0077	-	-	0.0011	-	0.0011	-	0.0044	0.0044	0.0155	0.0861	0.1104	0.2307
	315-345	0.2109	0.0011	-	0.0011	-	0.0022	-	0.0011	0.0011	0.0011	0.0011	0.1446	0.3643
Sum		0.3268	0.0408	0.0132	0.0453	0.1645	0.3113	0.7717	0.7617	0.0905	0.0938	0.1148	0.2616	2.9961

Table 10.16 Joint probability (%) of wind direction at 100 m above MSL and wave direction for wind speed greater than 25 m/s. Data: Nora10 hindcast data for the period 1980 – 2010.

		Wave direction												
		345-015	**015-045**	**045-075**	**075-105**	**105-135**	**135-165**	**165-195**	**195-225**	**225-255**	**255-285**	**285-315**	**315-345**	**Sum**
Wind direction	**345-015**	0.0044	-	-	-	-	-	-	0.0011	-	-	-	0.0011	0.0066
	015-045	-	-	0.0011	-	-	-	-	-	-	-	-	-	0.0011
	045-075	-	-	-	-	-	-	-	-	-	-	-	-	-
	075-105	-	-	-	0.0011	-	-	-	-	-	-	-	-	0.0011
	105-135	-	-	-	0.0011	0.0022	-	-	-	-	-	-	-	0.0033
	135-165	-	-	-	-	0.0011	0.0099	0.0033	-	-	-	-	-	0.0144
	165-195	-	-	-	-	-	0.0066	0.0375	0.0011	-	-	-	-	0.0453
	195-225	-	-	-	-	-	-	0.0199	0.0420	-	-	-	-	0.0618
	225-255	-	-	-	-	-	-	-	0.0199	-	-	-	-	0.0199
	255-285	-	-	-	-	-	-	-	0.0022	0.0099	0.0088	0.0044	-	0.0254
	285-315	0.0011	-	-	-	-	-	-	-	0.0011	0.0022	0.0121	0.0144	0.0309
	315-345	0.0155	-	-	-	-	-	-	-	-	-	0.0011	0.0210	0.0375
Sum		0.0210	-	0.0011	0.0022	0.0033	0.0166	0.0607	0.0662	0.0110	0.0110	0.0177	0.0364	0.2473

10.3.4 Wind speed at 10 m above MSL, Data sorted by significant wave height

Table 10.17 Joint probability (%) of wind direction at 10 m above MSL and wave direction for significant wave heights in the interval 0 - 1 m. Data: Nora10 hindcast data for the period 1958 – 2010.

		Wave direction												
		345-015	015-045	045-075	075-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345	Sum
Wind direction	345-015	0.4998	0.5799	0.1505	0.1053	0.1027	0.1053	0.0549	0.0342	0.0161	0.0090	0.0161	0.0756	1.7493
	015-045	0.1879	0.4313	0.1737	0.1246	0.0717	0.0743	0.0420	0.0168	0.0071	0.0065	0.0052	0.0316	1.1726
	045-075	0.1272	0.2544	0.1860	0.1653	0.0736	0.0626	0.0355	0.0168	0.0052	0.0019	0.0045	0.0220	0.9550
	075-105	0.1291	0.2570	0.1679	0.2279	0.1621	0.0891	0.0329	0.0278	0.0090	0.0071	0.0065	0.0258	1.1423
	105-135	0.1782	0.3125	0.1601	0.2712	0.3371	0.2777	0.0607	0.0278	0.0071	0.0032	0.0090	0.0362	1.6808
	135-165	0.3216	0.5269	0.1802	0.2835	0.4372	0.8530	0.3196	0.0807	0.0297	0.0245	0.0226	0.0794	3.1589
	165-195	0.4501	0.5218	0.1808	0.1821	0.2531	0.6302	0.9060	0.3907	0.0820	0.0446	0.0717	0.1382	3.8511
	195-225	0.3784	0.3403	0.0820	0.1046	0.1175	0.2247	0.5172	0.7510	0.1524	0.0710	0.0833	0.1608	2.9833
	225-255	0.2454	0.1601	0.0581	0.0710	0.0484	0.0749	0.2047	0.4598	0.1582	0.0827	0.0768	0.1317	1.7719
	255-285	0.2273	0.1350	0.0510	0.0465	0.0316	0.0517	0.1014	0.2531	0.1440	0.1040	0.1311	0.1756	1.4523
	285-315	0.3151	0.1608	0.0530	0.0491	0.0387	0.0820	0.0994	0.1375	0.0762	0.0646	0.1143	0.2654	1.4561
	315-345	0.5837	0.3016	0.0756	0.0917	0.0710	0.1195	0.0730	0.0762	0.0265	0.0323	0.0575	0.2886	1.7971
Sum		3.6439	3.9816	1.5188	1.7228	1.7448	2.6449	2.4473	2.2723	0.7135	0.4514	0.5986	1.4309	23.1708

Table 10.18 **Joint probability (%) of wind direction at 10 m above MSL and wave direction for significant wave heights in the interval 1 - 3 m. Data: Nora10 hindcast data for the period 1958 – 2010.**

		Wave direction												
		345-015	**015-045**	**045-075**	**075-105**	**105-135**	**135-165**	**165-195**	**195-225**	**225-255**	**255-285**	**285-315**	**315-345**	**Sum**
Wind direction	**345-015**	2.3828	1.8055	0.2228	0.1472	0.0375	0.0375	0.0168	0.0071	0.0052	0.0026	0.0084	0.0917	4.7649
	015-045	0.4998	1.3715	0.4171	0.2434	0.0375	0.0207	0.0052	0.0045	0.0006	0.0013	0.0013	0.0065	2.6094
	045-075	0.2363	0.5986	0.4520	0.6348	0.0749	0.0174	0.0052	0.0032	-	0.0013	0.0019	0.0032	2.0289
	075-105	0.1705	0.3681	0.2932	1.1778	0.4197	0.0349	0.0032	0.0032	-	0.0006	0.0019	0.0058	2.4790
	105-135	0.2150	0.3384	0.2254	0.9331	1.2734	0.3784	0.0155	0.0006	0.0013	0.0013	0.0013	0.0084	3.3920
	135-165	0.3093	0.4139	0.1911	0.5547	1.3606	2.4112	0.3319	0.0116	0.0032	0.0019	0.0065	0.0220	5.6179
	165-195	0.5534	0.4649	0.1362	0.3803	0.5598	2.0198	3.8227	0.5282	0.0336	0.0149	0.0207	0.0710	8.6057
	195-225	0.6780	0.3332	0.0762	0.1995	0.2428	0.5405	2.7747	5.1897	0.2796	0.1065	0.0943	0.1679	10.6830
	225-255	0.5185	0.1815	0.0504	0.1059	0.0885	0.2041	0.5883	3.1402	0.7523	0.2189	0.1614	0.2234	6.2333
	255-285	0.6606	0.1705	0.0575	0.0910	0.0704	0.1524	0.2286	0.6896	0.8885	0.8007	0.8323	0.6070	5.2492
	285-315	1.4083	0.2292	0.0730	0.1053	0.0794	0.1414	0.1220	0.1382	0.1395	0.1873	0.7704	2.0005	5.3944
	315-345	3.7982	0.6574	0.1182	0.1143	0.0775	0.0949	0.0426	0.0368	0.0220	0.0220	0.0691	1.5123	6.5652
Sum		11.4307	6.9326	2.3130	4.6874	4.3219	6.0531	7.9567	9.7531	2.1257	1.3593	1.9695	4.7197	63.6227

Table 10.19 **Joint probability (%) of wind direction at 10 m above MSL and wave direction for significant wave heights in the interval 3 - 5 m. Data: Nora10 hindcast data for the period 1958 – 2010.**

		Wave direction												
		345-015	015-045	045-075	075-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345	Sum
Wind direction	345-015	0.7975	0.1918	0.0116	0.0019	0.0006	0.0013	-	0.0006	-	-	-	0.0123	1.0177
	015-045	0.0723	0.2021	0.0439	0.0129	0.0006	-	-	-	-	-	-	-	0.3319
	045-075	0.0071	0.0342	0.0646	0.1485	0.0045	0.0013	-	-	-	-	-	-	0.2602
	075-105	0.0026	0.0058	0.0187	0.4727	0.0801	0.0019	-	-	-	-	-	-	0.5818
	105-135	0.0026	0.0071	0.0039	0.2635	0.5870	0.0639	-	-	-	-	-	-	0.9279
	135-165	0.0019	0.0039	0.0032	0.0697	0.3261	0.6670	0.0452	-	-	-	-	-	1.1171
	165-195	0.0058	0.0052	0.0006	0.0303	0.0497	0.4385	0.8117	0.0278	0.0006	-	0.0006	0.0006	1.3715
	195-225	0.0110	0.0026	0.0006	0.0136	0.0187	0.0665	0.6851	1.0164	0.0097	0.0032	0.0032	0.0026	1.8332
	225-255	0.0123	0.0006	0.0006	0.0103	0.0045	0.0187	0.0923	0.5211	0.0355	0.0052	0.0052	0.0065	0.7129
	255-285	0.0446	0.0026	0.0006	0.0052	0.0045	0.0123	0.0149	0.0575	0.1259	0.1330	0.1117	0.0620	0.5747
	285-315	0.2215	0.0065	0.0019	0.0071	0.0019	0.0097	0.0039	0.0058	0.0058	0.0149	0.1679	0.5411	0.9880
	315-345	1.3528	0.0232	0.0052	0.0058	0.0013	0.0032	-	0.0013	-	0.0013	0.0019	0.4236	1.8197
Sum		2.5319	0.4856	0.1556	1.0416	1.0797	1.2844	1.6531	1.6305	0.1776	0.1576	0.2906	1.0487	11.5366

Table 10.20 **Joint probability (%) of wind direction at 10 m above MSL and wave direction for significant wave heights in the interval 5 - 7 m. Data: Nora10 hindcast data for the period 1958 – 2010.**

		Wave direction												
		345-015	**015-045**	**045-075**	**075-105**	**105-135**	**135-165**	**165-195**	**195-225**	**225-255**	**255-285**	**285-315**	**315-345**	**Sum**
Wind direction	**345-015**	0.2002	0.0155	-	-	-	-	-	-	-	-	-	0.0006	0.2163
	015-045	0.0058	0.0123	0.0077	0.0013	-	-	-	-	-	-	-	-	0.0271
	045-075	-	0.0006	0.0045	0.0181	-	-	-	-	-	-	-	-	0.0232
	075-105	-	-	0.0006	0.0659	0.0155	-	-	-	-	-	-	-	0.0820
	105-135	-	-	-	0.0375	0.1724	0.0032	-	-	-	-	-	-	0.2131
	135-165	-	-	-	0.0039	0.0542	0.0878	0.0026	-	-	-	-	-	0.1485
	165-195	-	-	-	0.0013	0.0045	0.0491	0.1220	0.0006	-	-	-	-	0.1776
	195-225	-	-	-	-	0.0019	0.0019	0.0652	0.0620	-	-	-	-	0.1311
	225-255	-	-	-	-	-	-	0.0019	0.0316	-	-	-	-	0.0336
	255-285	-	-	-	-	-	-	0.0019	0.0013	0.0019	0.0026	0.0045	-	0.0123
	285-315	0.0142	-	-	-	-	-	-	-	-	0.0013	0.0149	0.0433	0.0736
	315-345	0.3093	0.0006	-	-	-	-	-	-	-	-	-	0.0781	0.3881
Sum		0.5295	0.0291	0.0129	0.1279	0.2486	0.1421	0.1937	0.0956	0.0019	0.0039	0.0194	0.1220	1.5265

Table 10.21 Joint probability (%) of wind direction at 10 m above MSL and wave direction for significant wave heights in the interval 7 - 9 m. Data: Nora10 hindcast data for the period 1958 – 2010.

		Wave direction												
		345-015	015-045	045-075	075-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345	Sum
Wind direction	345-015	0.0278	-	-	-	-	-	-	-	-	-	-	-	0.0278
	015-045	-	0.0013	-	-	-	-	-	-	-	-	-	-	0.0013
	045-075	-	-	-	-	-	-	-	-	-	-	-	-	-
	075-105	-	-	-	0.0077	0.0006	-	-	-	-	-	-	-	0.0084
	105-135	-	-	-	0.0097	0.0200	-	-	-	-	-	-	-	0.0297
	135-165	-	-	-	-	0.0039	0.0052	0.0006	-	-	-	-	-	0.0097
	165-195	-	-	-	-	-	0.0019	0.0032	-	-	-	-	-	0.0052
	195-225	-	-	-	-	-	-	0.0039	0.0052	-	-	-	-	0.0090
	225-255	-	-	-	-	-	-	-	0.0006	-	-	-	-	0.0006
	255-285	-	-	-	-	-	-	-	-	-	-	-	-	-
	285-315	-	-	-	-	-	-	-	-	-	-	-	0.0052	0.0052
	315-345	0.0336	-	-	-	-	-	-	-	-	-	-	0.0097	0.0433
Sum		0.0613	0.0013	-	0.0174	0.0245	0.0071	0.0077	0.0058	-	-	-	0.0149	0.1401

Table 10.22 Joint probability (%) of wind direction at 10 m above MSL and wave direction for significant wave heights in the interval 9 - 11 m. Data: Nora10 hindcast data for the period 1958 – 2010.

		Wave direction												
		345-015	015-045	045-075	075-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345	Sum
Wind direction	345-015	-	-	-	-	-	-	-	-	-	-	-	-	-
	015-045	-	-	-	-	-	-	-	-	-	-	-	-	-
	045-075	-	-	-	-	-	-	-	-	-	-	-	-	-
	075-105	-	-	-	-	-	-	-	-	-	-	-	-	-
	105-135	-	-	-	-	-	-	-	-	-	-	-	-	-
	135-165	-	-	-	-	-	-	-	-	-	-	-	-	-
	165-195	-	-	-	-	-	-	-	-	-	-	-	-	-
	195-225	-	-	-	-	-	-	-	-	-	-	-	-	-
	225-255	-	-	-	-	-	-	-	-	-	-	-	-	-
	255-285	-	-	-	-	-	-	-	-	-	-	-	-	-
	285-315	-	-	-	-	-	-	-	-	-	-	-	-	-
	315-345	0.0032	-	-	-	-	-	-	-	-	-	-	-	0.0032
Sum		0.0032	-	-	-	-	-	-	-	-	-	-	-	0.0032

10.3.5 *Wind speed at 100 m above MSL, Data sorted by significant wave height*

Table 10.23 Joint probability (%) of wind direction at 100 m above MSL and wave direction for significant wave heights in the interval 0 - 1 m. Data: Nora10 hindcast data for the period 1980 – 2010.

		Wave direction												
		345-015	015-045	045-075	075-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345	Sum
Wind direction	345-015	0.5144	0.5321	0.0872	0.0960	0.1027	0.1192	0.0519	0.0475	0.0232	0.0077	0.0110	0.0850	1.6780
	015-045	0.1987	0.3985	0.1314	0.1126	0.0927	0.0938	0.0530	0.0188	0.0055	0.0077	0.0055	0.0254	1.1437
	045-075	0.1049	0.2197	0.1645	0.1424	0.0662	0.0817	0.0364	0.0199	0.0099	0.0044	0.0055	0.0166	0.8721
	075-105	0.1170	0.2020	0.1777	0.2009	0.1104	0.0718	0.0364	0.0232	0.0088	0.0033	0.0022	0.0309	0.9847
	105-135	0.1557	0.2594	0.1347	0.2407	0.2815	0.2263	0.0364	0.0210	0.0066	0.0044	0.0066	0.0320	1.4053
	135-165	0.3003	0.4339	0.1656	0.2351	0.4096	0.6359	0.1833	0.0497	0.0144	0.0177	0.0144	0.0707	2.5302
	165-195	0.3952	0.5100	0.1777	0.1998	0.3091	0.7562	0.7032	0.2318	0.0530	0.0364	0.0640	0.1148	3.5514
	195-225	0.3952	0.3654	0.1049	0.1192	0.1490	0.3809	0.6436	0.6811	0.1347	0.0618	0.0618	0.1512	3.2489
	225-255	0.2329	0.1523	0.0442	0.0640	0.0530	0.1159	0.2638	0.5133	0.1336	0.0629	0.0662	0.1038	1.8061
	255-285	0.2098	0.1281	0.0442	0.0386	0.0309	0.0651	0.1490	0.3124	0.1380	0.1038	0.1093	0.1457	1.4749
	285-315	0.3113	0.1413	0.0475	0.0331	0.0464	0.0949	0.1093	0.1590	0.0905	0.0740	0.1347	0.2672	1.5091
	315-345	0.6193	0.2903	0.0695	0.0751	0.0596	0.1259	0.0817	0.1104	0.0342	0.0331	0.0596	0.2815	1.8403
Sum		3.5547	3.6331	1.3490	1.5577	1.7111	2.7676	2.3481	2.1880	0.6524	0.4173	0.5409	1.3247	22.0447

Table 10.24 Joint probability (%) of wind direction at 100 m above MSL and wave direction for significant wave heights in the interval 1 - 3 m. Data: Nora10 hindcast data for the period 1980 – 2010.

		Wave direction												
		345-015	**015-045**	**045-075**	**075-105**	**105-135**	**135-165**	**165-195**	**195-225**	**225-255**	**255-285**	**285-315**	**315-345**	**Sum**
Wind direction	**345-015**	2.4508	1.6526	0.2263	0.1479	0.0431	0.0397	0.0210	0.0088	0.0055	0.0033	0.0110	0.1115	4.7216
	015-045	0.5266	1.4782	0.4029	0.2351	0.0431	0.0166	0.0055	0.0077	-	0.0022	0.0033	0.0132	2.7345
	045-075	0.2627	0.6215	0.4913	0.5133	0.0640	0.0243	0.0055	0.0022	-	0.0011	0.0011	0.0022	1.9893
	075-105	0.1788	0.3776	0.2914	1.0212	0.3577	0.0276	0.0044	0.0022	0.0011	0.0011	0.0022	0.0055	2.2708
	105-135	0.2329	0.3477	0.2230	0.7926	1.2088	0.2771	0.0121	-	-	0.0011	-	0.0088	3.1043
	135-165	0.3014	0.4129	0.1998	0.5189	1.3910	2.1527	0.2716	0.0110	0.0022	0.0022	0.0077	0.0221	5.2934
	165-195	0.5144	0.5012	0.1402	0.3654	0.5818	2.0136	3.2909	0.3996	0.0265	0.0155	0.0188	0.0651	7.9330
	195-225	0.7098	0.3687	0.0905	0.2462	0.2837	0.6800	3.2533	4.8596	0.2473	0.1148	0.0916	0.1479	11.0936
	225-255	0.5288	0.1965	0.0607	0.1181	0.0971	0.2550	0.7076	3.5624	0.7264	0.1965	0.1479	0.1943	6.7915
	255-285	0.6900	0.1932	0.0585	0.0894	0.0784	0.1755	0.2870	0.8434	0.9792	0.8103	0.7971	0.5454	5.5473
	285-315	1.3821	0.2528	0.0773	0.1380	0.0905	0.1788	0.1391	0.1722	0.1601	0.2329	0.8246	2.0533	5.7019
	315-345	3.8528	0.6734	0.1325	0.1115	0.0872	0.0983	0.0574	0.0408	0.0166	0.0298	0.0828	1.6118	6.7948
Sum		11.6312	7.0763	2.3945	4.2977	4.3264	5.9392	8.0555	9.9101	2.1648	1.4108	1.9882	4.7812	63.9760

Table 10.25 Joint probability (%) of wind direction at 100 m above MSL and wave direction for significant wave heights in the interval 3 - 5 m. Data: Nora10 hindcast data for the period 1980 – 2010.

		Wave direction												
		345-015	015-045	045-075	075-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345	Sum
Wind direction	345-015	0.8202	0.2120	0.0088	0.0033	-	0.0033	-	0.0011	-	-	-	0.0132	1.0620
	015-045	0.0718	0.2153	0.0453	0.0099	-	-	-	-	-	-	-	-	0.3422
	045-075	0.0099	0.0420	0.0784	0.1512	0.0044	-	-	-	-	-	-	-	0.2859
	075-105	0.0055	0.0066	0.0188	0.4416	0.0751	0.0033	-	-	-	-	-	-	0.5509
	105-135	0.0033	0.0099	0.0066	0.2495	0.5961	0.0563	-	-	-	-	-	-	0.9218
	135-165	0.0011	0.0044	0.0033	0.0640	0.3069	0.6326	0.0442	-	-	-	-	-	1.0565
	165-195	0.0055	0.0066	-	0.0276	0.0486	0.4515	0.8909	0.0309	0.0011	-	0.0011	0.0011	1.4649
	195-225	0.0132	0.0033	-	0.0077	0.0221	0.0729	0.8677	1.1216	0.0132	0.0011	0.0011	0.0033	2.1273
	225-255	0.0132	-	0.0022	0.0066	0.0055	0.0221	0.1181	0.7065	0.0353	0.0055	0.0066	0.0088	0.9306
	255-285	0.0552	0.0033	0.0011	0.0022	0.0033	0.0099	0.0177	0.0740	0.1568	0.1468	0.1093	0.0629	0.6425
	285-315	0.2252	0.0088	0.0022	0.0022	0.0033	0.0055	0.0066	0.0066	0.0055	0.0199	0.1833	0.5387	1.0079
	315-345	1.3722	0.0320	0.0044	0.0088	0.0011	0.0055	-	0.0022	-	0.0022	0.0033	0.4283	1.8602
Sum		2.5965	0.5442	0.1711	0.9748	1.0664	1.2629	1.9452	1.9429	0.2120	0.1755	0.3047	1.0565	12.2527

Table 10.26 Joint probability (%) of wind direction at 100 m above MSL and wave direction for significant wave heights in the interval 5 - 7 m. Data: Nora10 hindcast data for the period 1980 – 2010.

		Wave direction												
		345-015	**015-045**	**045-075**	**075-105**	**105-135**	**135-165**	**165-195**	**195-225**	**225-255**	**255-285**	**285-315**	**315-345**	**Sum**
Wind direction	**345-015**	0.1822	0.0121	-	-	-	-	-	-	-	-	-	-	0.1943
	015-045	0.0077	0.0221	0.0066	-	-	-	-	-	-	-	-	-	0.0364
	045-075	-	0.0011	0.0088	0.0210	-	-	-	-	-	-	-	-	0.0309
	075-105	-	-	0.0011	0.0541	0.0110	-	-	-	-	-	-	-	0.0662
	105-135	-	-	-	0.0276	0.1855	0.0033	-	-	-	-	-	-	0.2164
	135-165	-	-	-	0.0022	0.0464	0.1049	0.0044	-	-	-	-	-	0.1579
	165-195	-	-	-	0.0011	0.0066	0.0596	0.1281	-	-	-	-	-	0.1954
	195-225	-	-	-	-	0.0011	0.0022	0.0905	0.0751	-	-	-	-	0.1689
	225-255	-	-	-	-	-	-	0.0022	0.0541	-	-	-	-	0.0563
	255-285	-	-	-	-	-	-	0.0033	0.0022	0.0033	0.0044	0.0022	-	0.0155
	285-315	0.0177	-	-	-	-	-	-	-	-	0.0022	0.0177	0.0320	0.0695
	315-345	0.3168	0.0011	-	-	-	-	-	-	-	-	-	0.0695	0.3875
Sum		0.5244	0.0364	0.0166	0.1060	0.2506	0.1700	0.2285	0.1314	0.0033	0.0066	0.0199	0.1016	1.5952

Table 10.27 Joint probability (%) of wind direction at 100 m above MSL and wave direction for significant wave heights in the interval 7 - 9 m. Data: Nora10 hindcast data for the period 1980 – 2010.

		Wave direction												
		345-015	015-045	045-075	075-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345	Sum
Wind direction	345-015	0.0243	-	-	-	-	-	-	-	-	-	-	-	0.0243
	015-045	0.0011	0.0022	-	-	-	-	-	-	-	-	-	-	0.0033
	045-075	-	-	-	-	-	-	-	-	-	-	-	-	-
	075-105	-	-	-	0.0066	0.0011	-	-	-	-	-	-	-	0.0077
	105-135	-	-	-	0.0033	0.0077	-	-	-	-	-	-	-	0.0110
	135-165	-	-	-	-	0.0011	0.0088	0.0011	-	-	-	-	-	0.0110
	165-195	-	-	-	-	-	0.0033	0.0044	-	-	-	-	-	0.0077
	195-225	-	-	-	-	-	-	0.0033	0.0088	-	-	-	-	0.0121
	225-255	-	-	-	-	-	-	-	0.0011	-	-	-	-	0.0011
	255-285	-	-	-	-	-	-	-	-	-	-	-	-	-
	285-315	-	-	-	-	-	-	-	-	-	-	-	0.0044	0.0044
	315-345	0.0353	-	-	-	-	-	-	-	-	-	-	0.0110	0.0464
Sum		0.0607	0.0022	-	0.0099	0.0099	0.0121	0.0088	0.0099	-	-	-	0.0155	0.1292

Table 10.28 Joint probability (%) of wind direction at 100 m above MSL and wave direction for significant wave heights in the interval 9 - 11 m. Data: Nora10 hindcast data for the period 1980 – 2010.

		Wave direction												
		345-015	015-045	045-075	075-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345	Sum
Wind direction	345-015	-	-	-	-	-	-	-	-	-	-	-	-	-
	015-045	-	-	-	-	-	-	-	-	-	-	-	-	-
	045-075	-	-	-	-	-	-	-	-	-	-	-	-	-
	075-105	-	-	-	-	-	-	-	-	-	-	-	-	-
	105-135	-	-	-	-	-	-	-	-	-	-	-	-	-
	135-165	-	-	-	-	-	-	-	-	-	-	-	-	-
	165-195	-	-	-	-	-	-	-	-	-	-	-	-	-
	195-225	-	-	-	-	-	-	-	-	-	-	-	-	-
	225-255	-	-	-	-	-	-	-	-	-	-	-	-	-
	255-285	-	-	-	-	-	-	-	-	-	-	-	-	-
	285-315	-	-	-	-	-	-	-	-	-	-	-	-	-
	315-345	0.0022	-	-	-	-	-	-	-	-	-	-	-	0.0022
Sum		0.0022	-	-	-	-	-	-	-	-	-	-	-	0.0022

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