

Supplementary material: Development of a comprehensive data basis of scattering environmental conditions and simulation constraints for offshore wind turbines

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In the following, supplementary material to "Development of a comprehensive data basis of scattering environmental conditions and simulation constraints for offshore wind turbines" is given. This material sets up an easy to use data basis. Therefore, statistical distributions and their parameters for thirteen, partly dependent, environmental conditions (wind speed and direction, wave height, peak period and direction, turbulence intensity, wind shear exponent, speed and direction of the sub- and near-surface current, and air and water density) and three offshore sites in the North and Baltic Sea (FINO 1-3), displayed in Figure 1, are given.

The raw data freely is available for research purposes: www.fino-offshore.de/en/. For FINO1, 13 years of raw data are used (2004-2016). Data of the years 2008-2016 and 2010-2016 is analysed for FINO2 and FINO3 receptively. As no long-term extrapolation is conducted, this data amount is sufficient. Since dependent parameters are defined in several bins (mainly wind speed bins), the quantity of data in some bins is significantly smaller. Hence, for rarely occurring bins (wind speeds above about 25 m s^{-1}), the statistical distributions are less reliable due to limited data and should be handled with care.

It should be noted that in this data basis all distributions are given as non-truncated. Therefore, theoretically unreasonable values (e.g. negative wave heights for small wind speeds) are possible. A reasonable truncation of each distribution, if needed, is left to the user of this data basis, as an adequate truncation might depend on the application.



Figure 1. Positions of the three FINO platforms in the North and Baltic Sea, adapted from OpenStreetMap.

1 FINO1

1.1 Wind speed

Dependencies: none

Distributions: Weibull

$$f(x|k, \lambda) = \begin{cases} \frac{k}{\lambda} \left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^k} & \text{for } x \geq 0 \\ 0 & \text{for } x < 0 \end{cases} \quad (1)$$

Table 1. Statistical parameters of the wind speed distribution.

Distribution	k	λ
Weibull	2.1810	10.9841

1.2 Turbulence intensity

Dependencies: Wind speed

Distributions: Weibull and gamma

$$f(x|k, \lambda) = \begin{cases} \frac{k}{\lambda} \left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^k} & \text{for } x \geq 0 \\ 0 & \text{for } x < 0 \end{cases} \quad \text{and} \quad (2)$$

$$f(x|k, \theta) = \frac{1}{\Gamma(k)\theta^k} x^{k-1} e^{-\frac{x}{\theta}} \quad (3)$$

Table 2. Statistical distributions and their parameters for the turbulence intensity depending on the wind speed.

Wind speed in m s^{-1}	Distribution	k	λ	θ
0 – 2	Gamma	2.1801	-	0.0779
2 – 4	Gamma	2.1428	-	0.0508
4 – 6	Gamma	2.3289	-	0.0348
6 – 8	Gamma	2.7157	-	0.0238
8 – 10	Gamma	3.6154	-	0.0150
10 – 12	Gamma	4.4576	-	0.0111
12 – 14	Weibull	2.4251	0.0551	-
14 – 16	Weibull	2.6202	0.0552	-
16 – 18	Weibull	2.9585	0.0577	-
18 – 20	Weibull	3.1521	0.0609	-
20 – 22	Weibull	3.8805	0.0667	-
22 – 24	Gamma	20.3696	-	0.0033
24 – 26	Gamma	35.8128	-	0.0020
26 – 28	Gamma	36.2274	-	0.0021
28 – 30	Gamma	57.7748	-	0.0014
30 – 32	Gamma	59.2592	-	0.0014

1.3 Wind direction

Dependencies: Wind speed

Distributions: non-parametric kernel density estimation

For the wind direction, the non-parametric distribution is given as a probability distribution (pd) in MATLAB format (.mat). As the wind direction depends on the wind speed, several pds are defined (pdPsiWind00_02.mat to pdPsiWind32_34.mat). Each pd is for one wind speed bin of 2 m s^{-1} (e.g. pdPsiWind06_08.mat is for $6 - 8 \text{ m s}^{-1}$).

1.4 Wind shear exponent

Dependencies: Wind speed

Distributions: bimodal normal

$$f(x|p, \mu_1, \mu_2, \sigma_1, \sigma_2) = p \frac{1}{\sqrt{2\sigma_1^2\pi}} e^{-\frac{(x-\mu_1)^2}{2\sigma_1^2}} + (1-p) \frac{1}{\sqrt{2\sigma_2^2\pi}} e^{-\frac{(x-\mu_2)^2}{2\sigma_2^2}} \quad (4)$$

Table 3. Statistical parameters of the wind shear exponent distribution depending on the wind speed.

Wind speed in m s^{-1}	Distribution	p	μ_1	μ_2	σ_1	σ_2
0 – 2	Bimodal normal	0.8177	-0.0226	-0.1241	0.1843	1.3791
2 – 4	Bimodal normal	0.4680	0.0167	0.0175	0.0467	0.3167
4 – 6	Bimodal normal	0.4144	0.0192	0.0494	0.0311	0.2588
6 – 8	Bimodal normal	0.4107	0.0262	0.0823	0.0270	0.2325
8 – 10	Bimodal normal	0.3950	0.0321	0.1272	0.0256	0.2003
10 – 12	Bimodal normal	0.3656	0.0412	0.1464	0.0259	0.1663
12 – 14	Bimodal normal	0.3599	0.0483	0.1613	0.0256	0.1407
14 – 16	Bimodal normal	0.3911	0.0589	0.1704	0.0271	0.1273
16 – 18	Bimodal normal	0.4961	0.0746	0.1798	0.0319	0.1197
18 – 20	Bimodal normal	0.5752	0.0920	0.1847	0.0367	0.1112
20 – 22	Bimodal normal	0.9115	0.1142	0.1539	0.0472	0.1359
22 – 24	Bimodal normal	0.0351	0.0981	0.1209	0.1794	0.0387
24 – 26	Bimodal normal	0.5004	0.1351	0.1060	0.0500	0.0164
26 – 28	Bimodal normal	0.3475	0.1367	0.1173	0.0536	0.0190
28 – 30	Bimodal normal	0.6902	0.1232	0.1084	0.0294	0.0077

1.5 Air density

Dependencies: none

Distributions: bimodal log-normal

$$f(x|p, \mu_1, \mu_2, \sigma_1, \sigma_2) = p \frac{1}{x\sigma_1\sqrt{2\pi}} e^{-\frac{(\ln(x)-\mu_1)^2}{2\sigma_1^2}} + (1-p) \frac{1}{x\sigma_2\sqrt{2\pi}} e^{-\frac{(\ln(x)-\mu_2)^2}{2\sigma_2^2}} \quad (5)$$

Table 4. Statistical parameters of the air density distribution.

Distribution	p	μ_1	μ_2	σ_1	σ_2
Bimodal log-normal	0.2781	0.1906	0.2208	0.0116	0.0197

1.6 Significant wave height

Dependencies: Wind speed

Distributions: Weibull and extreme value (maximum)

$$f(x|k, \lambda) = \begin{cases} \frac{k}{\lambda} \left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^k} & \text{for } x \geq 0 \\ 0 & \text{for } x < 0 \end{cases} \quad \text{and} \quad (6)$$

$$f(x|\mu, \beta) = \frac{1}{\beta} e^{-\frac{x+\mu}{\beta}} e^{-e^{-\frac{x+\mu}{\beta}}} \quad (7)$$

Table 5. Statistical distributions and their parameters for the significant wave height depending on the wind speed.

Wind speed in m s^{-1}	Distribution	k	λ	μ	β
0 – 2	Extreme value	-	-	-0.5646	0.2782
2 – 4	Extreme value	-	-	-0.5709	0.2792
4 – 6	Extreme value	-	-	-0.6393	0.3040
6 – 8	Extreme value	-	-	-0.7543	0.3442
8 – 10	Extreme value	-	-	-0.9414	0.4080
10 – 12	Weibull	2.6147	1.5594	-	-
12 – 14	Weibull	2.8838	1.9085	-	-
14 – 16	Weibull	3.0507	2.3015	-	-
16 – 18	Weibull	3.4368	2.7813	-	-
18 – 20	Weibull	3.8667	3.2954	-	-
20 – 22	Weibull	4.0745	3.9073	-	-
22 – 24	Weibull	4.2137	4.4743	-	-
24 – 26	Weibull	4.4235	5.0818	-	-
26 – 28	Weibull	5.5782	5.4877	-	-
28 – 30	Weibull	7.0757	5.6941	-	-

1.7 Wave direction

Dependencies: Wind direction and wave height

Distributions: non-parametric kernel density estimation

For the wave direction, the non-parametric distribution is given as a probability distribution (pd) in MATLAB format (.mat). As the wave direction depends on the wind direction and the wave height, several pds are defined (pdPsiWave0_30_0_1.mat to pdPsiWave330_360_6_7.mat). Each pd is for one combined wind direction and wave height of 30° and 1 m respectively (e.g. pdPsiWave270_300_1_2.mat is for a wind direction of $270 - 300^\circ$ and a wave height of 1 – 2 m).

1.8 Water density

Dependencies: none

Distributions: trimodal normal

$$f(x|p_1, p_2, \mu_1, \mu_2, \mu_3, \sigma_1, \sigma_2, \sigma_3) = p_1 \frac{1}{\sqrt{2\sigma_1^2\pi}} e^{-\frac{(x-\mu_1)^2}{2\sigma_1^2}} + p_2 \frac{1}{\sqrt{2\sigma_2^2\pi}} e^{-\frac{(x-\mu_2)^2}{2\sigma_2^2}} + (1 - p_1 - p_2) \frac{1}{\sqrt{2\sigma_3^2\pi}} e^{-\frac{(x-\mu_3)^2}{2\sigma_3^2}} \quad (8)$$

Table 6. Statistical parameters of the water density distribution.

Distribution	p_1	p_2	μ_1	μ_2	μ_3	σ_1	σ_2	σ_3
Trimodal normal	0.0599	0.4173	1024.1	1024.6	1026.1	0.0587	0.5248	0.3774

1.9 Wave peak period

Dependencies: Wave height

Distributions: bimodal extreme value (maximum)

$$f(x|p, \mu_1, \mu_2, \beta_1, \beta_2) = p \frac{1}{\beta_1} e^{-\frac{x+\mu_1}{\beta_1}} e^{-e^{-\frac{x+\mu_1}{\beta_1}}} + (1-p) \frac{1}{\beta_2} e^{-\frac{x+\mu_2}{\beta_2}} e^{-e^{-\frac{x+\mu_2}{\beta_2}}} \quad (9)$$

Table 7. Statistical parameters of the wave peak period distribution depending on the wave height.

Wave height in m	Distribution	p	μ_1	μ_2	σ_1	σ_2
0.0 – 0.5	Bimodal extreme value	0.7075	-4.0592	-9.6448	1.1180	2.1535
0.5 – 1.0	Bimodal extreme value	0.8393	-4.6805	-10.3276	1.1150	2.0866
1.0 – 1.5	Bimodal extreme value	0.8279	-5.3542	-7.6434	0.9487	2.0194
1.5 – 2.0	Bimodal extreme value	0.9903	-6.2621	-13.1503	0.9887	1.3776
2.0 – 2.5	Bimodal extreme value	0.4118	-7.0134	-6.9957	1.1765	0.7202
2.5 – 3.0	Bimodal extreme value	0.2031	-7.6542	-7.5863	1.2813	0.7235
3.0 – 3.5	Bimodal extreme value	0.5640	-8.1100	-8.2164	0.9494	0.7709
3.5 – 4.0	Bimodal extreme value	0.0153	-7.0007	-8.8094	0.1941	0.8515
4.0 – 4.5	Bimodal extreme value	0.3761	-8.8529	-10.1733	0.4085	0.6046
4.5 – 5.0	Bimodal extreme value	0.5400	-10.0648	-9.9524	1.0952	0.4359
5.0 – 5.5	Bimodal extreme value	0.0222	-8.6699	-10.6711	0.1098	0.7064
5.5 – 6.0	Bimodal extreme value	0.7923	-10.7110	-11.7825	0.7444	0.2584
6.0 – 6.5	Bimodal extreme value	0.1355	-10.3360	-11.4594	0.1006	0.5390
6.5 – 7.0	Bimodal extreme value	0.1826	-11.1332	-12.1079	0.1585	0.6793
7.0 – 7.5	Bimodal extreme value	0.5050	-12.0375	-13.1175	0.1545	0.2667

1.10 Sub-surface current speed

Dependencies: none

Distributions: Weibull

$$f(x|k, \lambda) = \begin{cases} \frac{k}{\lambda} \left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^k} & \text{for } x \geq 0 \\ 0 & \text{for } x < 0 \end{cases} \quad (10)$$

Table 8. Statistical parameters of the distribution of the sub-surface current speed.

Distribution	k	λ
Weibull	2.7089	0.4676

1.11 Sub-surface current direction

Dependencies: none

Distributions: non-parametric kernel density estimation

For the direction of the sub-surface current, the non-parametric distribution is given as a probability distribution (pd) in MATLAB format (.mat): psiV0ss.mat.

1.12 Near-surface current speed

Dependencies: none

Distributions: Weibull

$$f(x|k, \lambda) = \begin{cases} \frac{k}{\lambda} \left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^k} & \text{for } x \geq 0 \\ 0 & \text{for } x < 0 \end{cases} \quad (11)$$

Table 9. Statistical parameters of the distribution of the near-surface current speed.

Distribution	k	λ
Weibull	2.8684	0.6618

1.13 Near-surface current direction / deviation

The near-surface current direction depends significantly on the wind direction. Therefore, it is straightforward to model the deviation (Δ_{NS}) between wind direction (θ_{wind}) and near-surface current direction (θ_{NS}): $\theta_{\text{NS}} = \Delta_{\text{NS}} + \theta_{\text{wind}}$.

Dependencies: (Wind direction)

Distributions: bimodal normal

$$f(x|p, \mu_1, \mu_2, \sigma_1, \sigma_2) = p \frac{1}{\sqrt{2\sigma_1^2\pi}} e^{-\frac{(x-\mu_1)^2}{2\sigma_1^2}} + (1-p) \frac{1}{\sqrt{2\sigma_2^2\pi}} e^{-\frac{(x-\mu_2)^2}{2\sigma_2^2}} \quad (12)$$

Table 10. Statistical parameters of the distribution of the deviation (Δ_{NS}) between wind direction (θ_{wind}) and near-surface current direction (θ_{NS}).

Distribution	p	μ_1	μ_2	σ_1	σ_2
Bimodal normal	0.4836	-5.0073	-5.5757	74.6954	25.6649

2 FINO2

2.1 Wind speed

Dependencies: none

Distributions: Weibull

$$f(x|k, \lambda) = \begin{cases} \frac{k}{\lambda} \left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^k} & \text{for } x \geq 0 \\ 0 & \text{for } x < 0 \end{cases} \quad (13)$$

Table 11. Statistical parameters of the wind speed distribution.

Distribution	k	λ
Weibull	2.2901	10.8450

2.2 Turbulence intensity

Dependencies: Wind speed

Distributions: Weibull and gamma

$$f(x|k, \lambda) = \begin{cases} \frac{k}{\lambda} \left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^k} & \text{for } x \geq 0 \\ 0 & \text{for } x < 0 \end{cases} \quad \text{and} \quad (14)$$

$$f(x|k, \theta) = \frac{1}{\Gamma(k)\theta^k} x^{k-1} e^{-\frac{x}{\theta}} \quad (15)$$

Table 12. Statistical distributions and their parameters for the turbulence intensity depending on the wind speed.

Wind speed in m s^{-1}	Distribution	k	λ	θ
0 – 2	Gamma	2.3756	-	0.0727
2 – 4	Gamma	3.1037	-	0.0323
4 – 6	Gamma	2.9820	-	0.0279
6 – 8	Gamma	2.7566	-	0.0251
8 – 10	Gamma	2.9083	-	0.0207
10 – 12	Weibull	2.0652	0.0615	-
12 – 14	Weibull	2.4425	0.0589	-
14 – 16	Weibull	2.8415	0.0598	-
16 – 18	Weibull	3.2566	0.0631	-
18 – 20	Weibull	3.8902	0.0662	-
20 – 22	Gamma	22.4638	-	0.0029
22 – 24	Gamma	31.7966	-	0.0022
24 – 26	Gamma	33.9687	-	0.0021
26 – 28	Gamma	42.8564	-	0.0017
28 – 30	Gamma	64.8855	-	0.0011
30 – 32	Gamma	86.9223	-	0.0009
32 – 34	Gamma	40.5940	-	0.0020
34 – 36	Gamma	151.4248	-	0.0006

2.3 Wind direction

Dependencies: Wind speed

Distributions: non-parametric kernel density estimation

For the wind direction, the non-parametric distribution is given as a probability distribution (pd) in MATLAB format (.mat). As the wind direction depends on the wind speed, several pds are defined (pdPsiWind00_02.mat to pdPsiWind30_32.mat). Each pd is for one wind speed bin of 2 m s^{-1} (e.g. pdPsiWind06_08.mat is for $6 - 8 \text{ m s}^{-1}$).

2.4 Wind shear exponent

Dependencies: Wind speed

Distributions: bimodal normal

$$f(x|p, \mu_1, \mu_2, \sigma_1, \sigma_2) = p \frac{1}{\sqrt{2\sigma_1^2\pi}} e^{-\frac{(x-\mu_1)^2}{2\sigma_1^2}} + (1-p) \frac{1}{\sqrt{2\sigma_2^2\pi}} e^{-\frac{(x-\mu_2)^2}{2\sigma_2^2}} \quad (16)$$

Table 13. Statistical parameters of the wind shear exponent distribution depending on the wind speed.

Wind speed in m s^{-1}	Distribution	p	μ_1	μ_2	σ_1	σ_2
0 – 2	Bimodal normal	0.3934	-0.0114	-0.1875	0.1065	0.5748
2 – 4	Bimodal normal	0.4072	0.0133	-0.0317	0.0492	0.3608
4 – 6	Bimodal normal	0.4508	0.0177	0.0397	0.0322	0.2745
6 – 8	Bimodal normal	0.4219	0.0198	0.1005	0.0224	0.2010
8 – 10	Bimodal normal	0.3801	0.0236	0.1433	0.0189	0.1442
10 – 12	Bimodal normal	0.3458	0.0283	0.1677	0.0172	0.1205
12 – 14	Bimodal normal	0.3541	0.0350	0.1875	0.0184	0.1073
14 – 16	Bimodal normal	0.3147	0.0448	0.1953	0.0199	0.1025
16 – 18	Bimodal normal	0.3849	0.0601	0.2064	0.0246	0.1003
18 – 20	Bimodal normal	0.4618	0.0677	0.2122	0.0241	0.0933
20 – 22	Bimodal normal	0.5520	0.0747	0.1933	0.0229	0.0810
22 – 24	Bimodal normal	0.6356	0.0807	0.1522	0.0198	0.0535
24 – 26	Bimodal normal	0.5346	0.0744	0.1209	0.0138	0.0364
26 – 28	Bimodal normal	0.8666	0.0887	0.1557	0.0203	0.0164
28 – 30	Bimodal normal	0.9654	0.0826	0.1572	0.0174	0.0253
30 – 32	Bimodal normal	0.4978	0.0716	0.0916	0.0052	0.0044

2.5 Air density

Dependencies: none

Distributions: bimodal log-normal

$$f(x|p, \mu_1, \mu_2, \sigma_1, \sigma_2) = p \frac{1}{x\sigma_1\sqrt{2\pi}} e^{-\frac{(\ln(x)-\mu_1)^2}{2\sigma_1^2}} + (1-p) \frac{1}{x\sigma_2\sqrt{2\pi}} e^{-\frac{(\ln(x)-\mu_2)^2}{2\sigma_2^2}} \quad (17)$$

Table 14. Statistical parameters of the air density distribution.

Distribution	p	μ_1	μ_2	σ_1	σ_2
Bimodal log-normal	0.2532	0.1862	0.2173	0.0110	0.0244

2.6 Significant wave height

Dependencies: Wind speed

Distributions: Weibull and extreme value (maximum)

$$f(x|k, \lambda) = \begin{cases} \frac{k}{\lambda} \left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^k} & \text{for } x \geq 0 \\ 0 & \text{for } x < 0 \end{cases} \quad \text{and} \quad (18)$$

$$f(x|\mu, \beta) = \frac{1}{\beta} e^{-\frac{x+\mu}{\beta}} e^{-e^{-\frac{x+\mu}{\beta}}} \quad (19)$$

Table 15. Statistical distributions and their parameters for the significant wave height depending on the wind speed.

Wind speed in m s^{-1}	Distribution	k	λ	μ	β
0 – 2	Extreme value	-	-	-0.2116	0.0844
2 – 4	Extreme value	-	-	-0.2559	0.1144
4 – 6	Extreme value	-	-	-0.3577	0.1631
6 – 8	Extreme value	-	-	-0.4879	0.2175
8 – 10	Weibull	2.8017	0.9148	-	-
10 – 12	Weibull	3.1283	1.1611	-	-
12 – 14	Weibull	3.3253	1.4535	-	-
14 – 16	Weibull	3.5553	1.7712	-	-
16 – 18	Weibull	4.2502	2.0655	-	-
18 – 20	Weibull	6.1355	2.3730	-	-
20 – 22	Weibull	11.9340	2.7208	-	-
22 – 24	Weibull	12.7816	2.9295	-	-
24 – 26	Weibull	13.8183	3.4611	-	-
26 – 28	Weibull	14.0869	3.4659	-	-
28 – 30	Weibull	19.2799	4.1056	-	-

2.7 Wave direction

Dependencies: Wind direction and wave height

Distributions: non-parametric kernel density estimation

For the wave direction, the non-parametric distribution is given as a probability distribution (pd) in MATLAB format (.mat). As the wave direction depends on the wind direction and the wave height, several pds are defined (pdPsiWave0_30_0_1.mat to pdPsiWave330_360_1_2.mat). Each pd is for one combined wind direction and wave height of 30° and 1 m respectively (e.g. pdPsiWave270_300_1_2.mat is for a wind direction of $270 - 300^\circ$ and a wave height of 1 – 2 m).

2.8 Water density

Dependencies: none

Distributions: trimodal normal

$$f(x|p_1, p_2, \mu_1, \mu_2, \mu_3, \sigma_1, \sigma_2, \sigma_3) = p_1 \frac{1}{\sqrt{2\sigma_1^2\pi}} e^{-\frac{(x-\mu_1)^2}{2\sigma_1^2}} + p_2 \frac{1}{\sqrt{2\sigma_2^2\pi}} e^{-\frac{(x-\mu_2)^2}{2\sigma_2^2}} + (1 - p_1 - p_2) \frac{1}{\sqrt{2\sigma_3^2\pi}} e^{-\frac{(x-\mu_3)^2}{2\sigma_3^2}} \quad (20)$$

Table 16. Statistical parameters of the water density distribution.

Distribution	p_1	p_2	μ_1	μ_2	μ_3	σ_1	σ_2	σ_3
Trimodal normal	0.6218	0.1104	1025.1	1024.2	1026.5	0.8108	0.1638	0.2126

2.9 Wave peak period

Dependencies: Wave height

Distributions: bimodal extreme value (maximum)

$$f(x|p, \mu_1, \mu_2, \beta_1, \beta_2) = p \frac{1}{\beta_1} e^{-\frac{x+\mu_1}{\beta_1}} e^{-e^{-\frac{x+\mu_1}{\beta_1}}} + (1-p) \frac{1}{\beta_2} e^{-\frac{x+\mu_2}{\beta_2}} e^{-e^{-\frac{x+\mu_2}{\beta_2}}} \quad (21)$$

Table 17. Statistical parameters of the wave peak period distribution depending on the wave height.

Wave height in m	Distribution	p	μ_1	μ_2	σ_1	σ_2
0.0 – 0.5	Bimodal extreme value	0.1249	-2.9688	-3.3666	0.2442	0.7571
0.5 – 1.0	Bimodal extreme value	0.8278	-3.8502	-4.1777	0.5495	0.2412
1.0 – 1.5	Bimodal extreme value	0.7542	-4.7146	-5.1505	0.3720	0.2122
1.5 – 2.0	Bimodal extreme value	0.5871	-5.3324	-5.8044	0.3516	0.2448
2.0 – 2.5	Bimodal extreme value	0.4614	-5.9072	-6.4436	0.3068	0.2187
2.5 – 3.0	Bimodal extreme value	0.4087	-6.3356	-7.0365	0.2864	0.2850
3.0 – 3.5	Bimodal extreme value	0.5392	-7.0541	-7.7134	0.5756	0.1922
3.5 – 4.0	Bimodal extreme value	0.4568	-7.0205	-8.0684	0.2311	0.1317

2.10 Sub-surface current speed

Dependencies: none

Distributions: extreme value (maximum)

$$f(x|\mu, \beta) = \frac{1}{\beta} e^{-\frac{x+\mu}{\beta}} e^{-e^{-\frac{x+\mu}{\beta}}} \quad (22)$$

Table 18. Statistical parameters of the distribution of the near-surface current speed.

Distribution	μ	β
Extreme value	-0.0729	0.0456

2.11 Sub-surface current direction

Dependencies: none

Distributions: non-parametric kernel density estimation

For the direction of the sub-surface current, the non-parametric distribution is given as a probability distribution (pd) in MATLAB format (.mat): psiV0ss.mat.

2.12 Near-surface current speed

Dependencies: none

Distributions: Weibull

$$f(x|k, \lambda) = \begin{cases} \frac{k}{\lambda} \left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^k} & \text{for } x \geq 0 \\ 0 & \text{for } x < 0 \end{cases} \quad (23)$$

Table 19. Statistical parameters of the distribution of the sub-surface current speed.

Distribution	k	λ
Weibull	1.3645	0.1660

2.13 Near-surface current direction / deviation

The near-surface current direction depends significantly on the wind direction. Therefore, it is straightforward to model the deviation (Δ_{NS}) between wind direction (θ_{wind}) and near-surface current direction (θ_{NS}): $\theta_{\text{NS}} = \Delta_{\text{NS}} + \theta_{\text{wind}}$.

Dependencies: (Wind direction)

Distributions: bimodal normal

$$f(x|p, \mu_1, \mu_2, \sigma_1, \sigma_2) = p \frac{1}{\sqrt{2\sigma_1^2\pi}} e^{-\frac{(x-\mu_1)^2}{2\sigma_1^2}} + (1-p) \frac{1}{\sqrt{2\sigma_2^2\pi}} e^{-\frac{(x-\mu_2)^2}{2\sigma_2^2}} \quad (24)$$

Table 20. Statistical parameters of the distribution of the deviation (Δ_{NS}) between wind direction (θ_{wind}) and near-surface current direction (θ_{NS}).

Distribution	p	μ_1	μ_2	σ_1	σ_2
Bimodal normal	0.1028	62.0902	65.8208	23.3685	80.9743

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3.1 Wind speed

Dependencies: none

Distributions: Weibull

$$f(x|k, \lambda) = \begin{cases} \frac{k}{\lambda} \left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^k} & \text{for } x \geq 0 \\ 0 & \text{for } x < 0 \end{cases} \quad (25)$$

Table 21. Statistical parameters of the wind speed distribution.

Distribution	k	λ
Weibull	2.3200	10.9444

3.2 Turbulence intensity

Dependencies: Wind speed

Distributions: Weibull and gamma

$$f(x|k, \lambda) = \begin{cases} \frac{k}{\lambda} \left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^k} & \text{for } x \geq 0 \\ 0 & \text{for } x < 0 \end{cases} \quad \text{and} \quad (26)$$

$$f(x|k, \theta) = \frac{1}{\Gamma(k)\theta^k} x^{k-1} e^{-\frac{x}{\theta}} \quad (27)$$

Table 22. Statistical distributions and their parameters for the turbulence intensity depending on the wind speed.

Wind speed in m s^{-1}	Distribution	k	λ	θ
0 – 2	Gamma	2.8383	-	0.0605
2 – 4	Gamma	3.7704	-	0.0238
4 – 6	Gamma	4.1359	-	0.0164
6 – 8	Gamma	4.8377	-	0.0121
8 – 10	Gamma	5.2449	-	0.0104
10 – 12	Gamma	6.1983	-	0.0085
12 – 14	Weibull	2.9580	0.0588	-
14 – 16	Weibull	3.1796	0.0617	-
16 – 18	Weibull	3.7288	0.0658	-
18 – 20	Weibull	4.1203	0.0696	-
20 – 22	Weibull	4.3019	0.0725	-
22 – 24	Gamma	28.9161	-	0.0025
24 – 26	Gamma	35.8010	-	0.0021
26 – 28	Gamma	41.0894	-	0.0019
28 – 30	Gamma	44.4187	-	0.0019
30 – 32	Gamma	97.8133	-	0.0009
32 – 34	Gamma	97.4714	-	0.0009

3.3 Wind direction

Dependencies: Wind speed

Distributions: non-parametric kernel density estimation

For the wind direction, the non-parametric distribution is given as a probability distribution (pd) in MATLAB format (.mat). As the wind direction depends on the wind speed, several pds are defined (pdPsiWind00_02.mat to pdPsiWind32_34.mat). Each pd is for one wind speed bin of 2 m s^{-1} (e.g. pdPsiWind06_08.mat is for $6 - 8 \text{ m s}^{-1}$).

3.4 Wind shear exponent

Dependencies: Wind speed

Distributions: bimodal normal

$$f(x|p, \mu_1, \mu_2, \sigma_1, \sigma_2) = p \frac{1}{\sqrt{2\sigma_1^2\pi}} e^{-\frac{(x-\mu_1)^2}{2\sigma_1^2}} + (1-p) \frac{1}{\sqrt{2\sigma_2^2\pi}} e^{-\frac{(x-\mu_2)^2}{2\sigma_2^2}} \quad (28)$$

Table 23. Statistical parameters of the wind shear exponent distribution depending on the wind speed.

Wind speed in m s^{-1}	Distribution	p	μ_1	μ_2	σ_1	σ_2
0 – 2	Bimodal normal	0.3242	-0.0987	0.0354	0.6595	0.1058
2 – 4	Bimodal normal	0.6809	0.0242	0.0630	0.0411	0.3098
4 – 6	Bimodal normal	0.6574	0.0248	0.0984	0.0265	0.2099
6 – 8	Bimodal normal	0.5767	0.0269	0.1253	0.0216	0.1627
8 – 10	Bimodal normal	0.5174	0.0277	0.1452	0.0195	0.1379
10 – 12	Bimodal normal	0.5017	0.0322	0.1610	0.0205	0.1218
12 – 14	Bimodal normal	0.4976	0.0395	0.1711	0.0213	0.1091
14 – 16	Bimodal normal	0.5587	0.0474	0.1721	0.0226	0.1015
16 – 18	Bimodal normal	0.6658	0.0584	0.1830	0.0270	0.1146
18 – 20	Bimodal normal	0.7832	0.0721	0.1984	0.0318	0.1285
20 – 22	Bimodal normal	0.9424	0.0852	0.1966	0.0337	0.1164
22 – 24	Bimodal normal	0.8546	0.0842	0.1401	0.0236	0.0200
24 – 26	Bimodal normal	0.4135	0.0804	0.1079	0.0158	0.0233
26 – 28	Bimodal normal	0.6327	0.0821	0.1102	0.0133	0.0164
28 – 30	Bimodal normal	0.7596	0.0911	0.0958	0.0170	0.0111
30 – 32	Bimodal normal	0.6000	0.0736	0.1078	0.0038	0.0017

3.5 Air density

Dependencies: none

Distributions: bimodal log-normal

$$f(x|p, \mu_1, \mu_2, \sigma_1, \sigma_2) = p \frac{1}{x\sigma_1\sqrt{2\pi}} e^{-\frac{(\ln(x)-\mu_1)^2}{2\sigma_1^2}} + (1-p) \frac{1}{x\sigma_2\sqrt{2\pi}} e^{-\frac{(\ln(x)-\mu_2)^2}{2\sigma_2^2}} \quad (29)$$

Table 24. Statistical parameters of the air density distribution.

Distribution	p	μ_1	μ_2	σ_1	σ_2
Bimodal log-normal	0.3377	0.1908	0.2146	0.0120	0.0220

3.6 Significant wave height

Dependencies: Wind speed

Distributions: Weibull and extreme value (maximum)

$$f(x|k, \lambda) = \begin{cases} \frac{k}{\lambda} \left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^k} & \text{for } x \geq 0 \\ 0 & \text{for } x < 0 \end{cases} \quad \text{and} \quad (30)$$

$$f(x|\mu, \beta) = \frac{1}{\beta} e^{-\frac{x+\mu}{\beta}} e^{-e^{-\frac{x+\mu}{\beta}}} \quad (31)$$

Table 25. Statistical distributions and their parameters for the significant wave height distribution depending on the wind speed.

Wind speed in m s^{-1}	Distribution	k	λ	μ	β
0 – 2	Extreme value	-	-	-0.6560	0.3000
2 – 4	Extreme value	-	-	-0.6556	0.3060
4 – 6	Extreme value	-	-	-0.7266	0.3281
6 – 8	Extreme value	-	-	-0.8911	0.3747
8 – 10	Weibull	2.8261	1.5117	-	-
10 – 12	Weibull	3.1707	1.8483	-	-
12 – 14	Weibull	3.3350	2.2044	-	-
14 – 16	Weibull	3.6293	2.6840	-	-
16 – 18	Weibull	4.0416	3.2098	-	-
18 – 20	Weibull	4.2792	3.8607	-	-
20 – 22	Weibull	4.3819	4.4707	-	-
22 – 24	Weibull	6.3162	5.4948	-	-
24 – 26	Weibull	5.4228	5.6527	-	-
26 – 28	Weibull	8.8297	6.3406	-	-

3.7 Wave direction

Dependencies: Wind direction and wave height

Distributions: non-parametric kernel density estimation

For the wave direction, the non-parametric distribution is given as a probability distribution (pd) in MATLAB format (.mat). As the wave direction depends on the wind direction and the wave height, several pds are defined (pdPsiWave0_30_0_1.mat to pdPsiWave330_360_4_5.mat). Each pd is for one combined wind direction and wave height of 30° and 1 m respectively (e.g. pdPsiWave270_300_1_2.mat is for a wind direction of $270 - 300^\circ$ and a wave height of 1 – 2 m).

3.8 Water density

Dependencies: none

Distributions: trimodal normal

$$f(x|p_1, p_2, \mu_1, \mu_2, \mu_3, \sigma_1, \sigma_2, \sigma_3) = p_1 \frac{1}{\sqrt{2\sigma_1^2\pi}} e^{-\frac{(x-\mu_1)^2}{2\sigma_1^2}} + p_2 \frac{1}{\sqrt{2\sigma_2^2\pi}} e^{-\frac{(x-\mu_2)^2}{2\sigma_2^2}} + (1 - p_1 - p_2) \frac{1}{\sqrt{2\sigma_3^2\pi}} e^{-\frac{(x-\mu_3)^2}{2\sigma_3^2}} \quad (32)$$

Table 26. Statistical parameters of the water density distribution.

Distribution	p_1	p_2	μ_1	μ_2	μ_3	σ_1	σ_2	σ_3
Trimodal normal	0.4973	0.2214	1024.6	1025.8	1026.4	0.4586	0.3351	0.2179

3.9 Wave peak period

Dependencies: Wave height

Distributions: bimodal extreme value (maximum)

$$f(x|p, \mu_1, \mu_2, \beta_1, \beta_2) = p \frac{1}{\beta_1} e^{-\frac{x+\mu_1}{\beta_1}} e^{-e^{-\frac{x+\mu_1}{\beta_1}}} + (1-p) \frac{1}{\beta_2} e^{-\frac{x+\mu_2}{\beta_2}} e^{-e^{-\frac{x+\mu_2}{\beta_2}}} \quad (33)$$

Table 27. Statistical parameters of the wave peak period distribution depending on the wave height.

Wave height in m	Distribution	p	μ_1	μ_2	σ_1	σ_2
0.0 – 0.5	Bimodal extreme value	0.5737	-3.8062	-9.6127	0.9832	1.8418
0.5 – 1.0	Bimodal extreme value	0.6858	-4.7316	-10.2428	1.0712	2.0139
1.0 – 1.5	Bimodal extreme value	0.8162	-5.4894	-10.2422	0.9454	1.4559
1.5 – 2.0	Bimodal extreme value	0.3118	-5.5211	-6.8836	0.4455	1.2348
2.0 – 2.5	Bimodal extreme value	0.1768	-5.9440	-7.3284	0.3170	0.8894
2.5 – 3.0	Bimodal extreme value	0.1685	-6.4029	-7.9309	0.3039	0.7368
3.0 – 3.5	Bimodal extreme value	0.1253	-6.9704	-8.4911	0.3666	0.7506
3.5 – 4.0	Bimodal extreme value	0.0426	-7.1868	-8.9434	0.1008	0.7000
4.0 – 4.5	Bimodal extreme value	0.3122	-9.0135	-9.7482	0.7127	0.6340
4.5 – 5.0	Bimodal extreme value	0.6425	-9.9037	-10.0665	0.8089	0.2466
5.0 – 5.5	Bimodal extreme value	0.4934	-10.4280	-10.5649	1.0207	0.4092
5.5 – 6.0	Bimodal extreme value	0.9107	-10.8287	-13.4061	0.7092	0.0854
6.0 – 6.5	Bimodal extreme value	0.2000	-10.6463	-12.3016	0.0049	0.7595
6.5 – 7.0	Bimodal extreme value	0.4355	-13.2074	-15.0451	0.2501	0.6086

3.10 Sub-surface current speed

Dependencies: none

Distributions: Weibull

$$f(x|k, \lambda) = \begin{cases} \frac{k}{\lambda} \left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^k} & \text{for } x \geq 0 \\ 0 & \text{for } x < 0 \end{cases} \quad (34)$$

Table 28. Statistical parameters of the distribution of the sub-surface current speed.

Distribution	k	λ
Weibull	2.1033	0.3213

3.11 Sub-surface current direction

Dependencies: none

Distributions: non-parametric kernel density estimation

For the direction of the sub-surface current, the non-parametric distribution is given as a probability distribution (pd) in MATLAB format (.mat): psiV0ss.mat.

3.12 Near-surface current speed

Dependencies: none

Distributions: Weibull

$$f(x|k, \lambda) = \begin{cases} \frac{k}{\lambda} \left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^k} & \text{for } x \geq 0 \\ 0 & \text{for } x < 0 \end{cases} \quad (35)$$

Table 29. Statistical parameters of the distribution of the near-surface current speed.

Distribution	k	λ
Weibull	1.8153	0.4959

3.13 Near-surface current direction / deviation

The near-surface current direction depends significantly on the wind direction. Therefore, it is straightforward to model the deviation (Δ_{NS}) between wind direction (θ_{wind}) and near-surface current direction (θ_{NS}): $\theta_{\text{NS}} = \Delta_{\text{NS}} + \theta_{\text{wind}}$.

Dependencies: (Wind direction)

Distributions: bimodal normal

$$f(x|p, \mu_1, \mu_2, \sigma_1, \sigma_2) = p \frac{1}{\sqrt{2\sigma_1^2\pi}} e^{-\frac{(x-\mu_1)^2}{2\sigma_1^2}} + (1-p) \frac{1}{\sqrt{2\sigma_2^2\pi}} e^{-\frac{(x-\mu_2)^2}{2\sigma_2^2}} \quad (36)$$

Table 30. Statistical parameters of the distribution of the deviation (Δ_{NS}) between wind direction (θ_{wind}) and near-surface current direction (θ_{NS}).

Distribution	p	μ_1	μ_2	σ_1	σ_2
Bimodal normal	0.2350	3.0734	-1.6825	67.2774	17.4324