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 $\mathrm{m\,s^{-1}}$), 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 $\mathrm{m\,s^{-1}}$	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, firstly, given as a probability distribution (pd) in MATLAB format (.mat). Secondly, the relevant data is given in ASCII format. As the wind direction depends on the wind speed, several pds are defined (pdPsiWind00_02 to pdPsiWind32_34). Each pd is for one wind speed bin of $2\,\mathrm{m\,s^{-1}}$ (e.g. pdPsiWind06_08 is for $6-8\,\mathrm{m\,s^{-1}}$). For all fits, the kernel smoothing function is a normal distribution which is truncated at 0 and 360°. The truncation is already included for the MATLAB format, but, as it is important for the normalisation of the probability density function, has to be conducted for data given in ASCII format. In ASCII format, for all bins, band width and data is given.

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 $\mathrm{m\,s^{-1}}$	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)

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

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

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, firstly, given as a probability distribution (pd) in MATLAB format (.mat). Secondly, the relevant data is given in ASCII format. As the wave direction depends on the wind direction and the wave height, several pds are defined (pdPsiWave0_30_0_1 to pdPsiWave330_360_6_7). Each pd is for one combined wind direction and wave height of 30° and 1 m respectively (e.g. pdPsiWave270_300_1_2 is for a wind direction of $270-300°$ and a wave height of $1-2$ m). For all fits, the kernel smoothing function is a normal distribution which is truncated at 0 and $360°$. The truncation is already included for the MATLAB format, but, as it is important for the normalisation of the probability density function, has to be conducted for data given in ASCII format. In ASCII format, for all bins, band width and data is given.

1.8 Water density

Dependencies: none
Distributions: trimodal normal

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

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)

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

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

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

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, firstly, given as a probability distribution (pd) in MATLAB format (.mat): psiV0ss.mat. Secondly, the relevant data is given in ASCII format. The kernel smoothing function is a normal distribution which is truncated at 0 and $360°$. The truncation is already included for the MATLAB format, but, as it is important for the normalisation of the probability density function, has to be conducted for data given in ASCII format. In ASCII format, band width and data is given.

1.12 Near-surface current speed

Dependencies: none
Distributions: Weibull

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

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

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

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

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

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

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

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

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

Wind speed in $\mathrm{m\,s^{-1}}$	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, firstly, given as a probability distribution (pd) in MATLAB format (.mat). Secondly, the relevant data is given in ASCII format. As the wind direction depends on the wind speed, several pds are defined (pdPsiWind00_02 to pdPsiWind30_32). Each pd is for one wind speed bin of $2\,\mathrm{m\,s^{-1}}$ (e.g. pdPsiWind06_08 is for $6-8\,\mathrm{m\,s^{-1}}$). For all fits, the kernel smoothing function is a normal distribution which is truncated at 0 and 360°. The truncation is already included for the MATLAB format, but, as it is important for the normalisation of the probability density function, has to be conducted for data given in ASCII format. In ASCII format, for all bins, band width and data is given.

2.4 Wind shear exponent

Dependencies: Wind speed
Distributions: bimodal normal

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

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

Wind speed in $\mathrm{m\,s^{-1}}$	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

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

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)

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

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

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

Wind speed in $\mathrm{m\,s^{-1}}$	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, firstly, given as a probability distribution (pd) in MATLAB format (.mat). Secondly, the relevant data is given in ASCII format. As the wave direction depends on the wind direction and the wave height, several pds are defined (pdPsiWave0_30_0_1 to pdPsiWave330_360_1_2). Each pd is for one combined wind direction and wave height of 30° and 1 m respectively (e.g. pdPsiWave270_300_1_2 is for a wind direction of $270-300°$ and a wave height of $1-2\,\mathrm{m}$). For all fits, the kernel smoothing function is a normal distribution which is truncated at 0 and $360°$. The truncation is already included for the MATLAB format, but, as it is important for the normalisation of the probability density function, has to be conducted for data given in ASCII format. In ASCII format, for all bins, band width and data is given.

2.8 Water density

Dependencies: none
Distributions: trimodal normal

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

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)

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

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)

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

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, firstly, given as a probability distribution (pd) in MATLAB format (.mat): psiV0ss.mat. Secondly, the relevant data is given in ASCII format. The kernel smoothing function is a normal distribution which is truncated at 0 and 360°. The truncation is already included for the MATLAB format, but, as it is important for the normalisation of the probability density function, has to be conducted for data given in ASCII format. In ASCII format, band width and data is given.

2.12 Near-surface current speed

Dependencies: none
Distributions: Weibull

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

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

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

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

3 FINO3

3.1 Wind speed

Dependencies: none
Distributions: Weibull

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

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

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

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

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

Wind speed in $\mathrm{m\,s^{-1}}$	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, firstly, given as a probability distribution (pd) in MATLAB format (.mat). Secondly, the relevant data is given in ASCII format. As the wind direction depends on the wind speed, several pds are defined (pdPsiWind00_02 to pdPsiWind32_34). Each pd is for one wind speed bin of $2\,\mathrm{m\,s^{-1}}$ (e.g. pdPsiWind06_08 is for $6-8\,\mathrm{m\,s^{-1}}$). For all fits, the kernel smoothing function is a normal distribution which is truncated at 0 and 360°. The truncation is already included for the MATLAB format, but, as it is important for the normalisation of the probability density function, has to be conducted for data given in ASCII format. In ASCII format, for all bins, band width and data is given.

3.4 Wind shear exponent

Dependencies: Wind speed
Distributions: bimodal normal

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

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

Wind speed in $\mathrm{m\,s^{-1}}$	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

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

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)

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

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

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

Wind speed in $\mathrm{m\,s^{-1}}$	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, firstly, given as a probability distribution (pd) in MATLAB format (.mat). Secondly, the relevant data is given in ASCII format. As the wave direction depends on the wind direction and the wave height, several pds are defined (pdPsiWave0_30_0_1 to pdPsiWave330_360_4_5). Each pd is for one combined wind direction and wave height of 30° and 1 m respectively (e.g. pdPsiWave270_300_1_2 is for a wind direction of $270-300°$ and a wave height of $1-2\,\mathrm{m}$). For all fits, the kernel smoothing function is a normal distribution which is truncated at 0 and 360°. The truncation is already included for the MATLAB format, but, as it is important for the normalisation of the probability density function, has to be conducted for data given in ASCII format. In ASCII format, for all bins, band width and data is given.

3.8 Water density

Dependencies: none
Distributions: trimodal normal

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

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)

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

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

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

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, firstly, given as a probability distribution (pd) in

MATLAB format (.mat): psiV0ss.mat. Secondly, the relevant data is given in ASCII format. The kernel smoothing function is a normal distribution which is truncated at 0 and 360°. The truncation is already included for the MATLAB format, but, as it is important for the normalisation of the probability density function, has to be conducted for data given in ASCII format. In ASCII format, band width and data is given.

3.12 Near-surface current speed

Dependencies: none
Distributions: Weibull

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

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

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

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