Statens vegvesen

Ferry free E39 – Fjord crossings Bjørnafjorden | 304624

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General

This document reports the metocean conditions for Gjøvåg in Langenuen where a port is considered being built. The port is planned as a launch site for the machineries that are needed to build the roads at Rekstern. The port may later replace the two ferry services Sandvikvåg-Husavika and Krokeidet-Hufthammar.

The meteorological and oceanographical parameters are based on observations and reliable hindcast data from Gjøvåg and adjacent areas. The hindcast data has been validated with use of high quality physical measured data.

The references give the background for the design parameters given in this specification.

Nomenclature

H_s: significant wave height
T_p: spectral peak period
v_m: wind speed
$v_{b,0}$: reference wind speed
T: averaging period
R: return period
z: height above sea level
z_0: roughness length
k_T: terrain factor
α: profile factor for the wind profile
C_r: roughness factor
C_{dir}: directional factor
C_{season}: seasonal factor
C_{alt}: altitude factor
C_{prob}: probability factor
C_0: terrain form factor
k_{tt}: turbulence factor
u, v, w: turbulence components
I_u: longitudinal turbulence intensity
I_v: lateral turbulence intensity
I_w: vertical turbulence intensity
n: frequency
A_i: spectral density coefficients
σ_i: standard deviation
${}^xL_i$: turbulence length scale
Δs_j: distance between points
C_{ij}: coherence coefficients

Table of revisions

Revision	Comments

1 Introduction

A port is considered at Gjøvåg in Tysnes commune as an entry point for the machineries needed to build the planned new E39 across Rekstern. The port may be reused after the building period is finished as the main ferry port to Austevoll, replacing the two existing ferry services Sandvikvåg-Husavika and Krokeidet-Hufthammar with a new ferry service from Rekstern to Austevoll. The area at Rekstern where the ferry port is planned is Gjøvåg, see Figure 1.

Metocean data has not been measured at the planned port area. However, at Bjørnafjorden and Langenuen, wind, waves and currents have been measured. Numerical models of wind, waves and currents have been set up connected to the planned crossing of Bjørnafjorden and validated with the measurements from Bjørnafjorden and for the wind also for sites at Langenuen. It is expected that the models perform adequate also for the rest of Langenuen, even though no validation of the model results are conducted for Gjøvåg.

The modeled data in this report is taken from outside Gjøvåg and are relevant for the area.

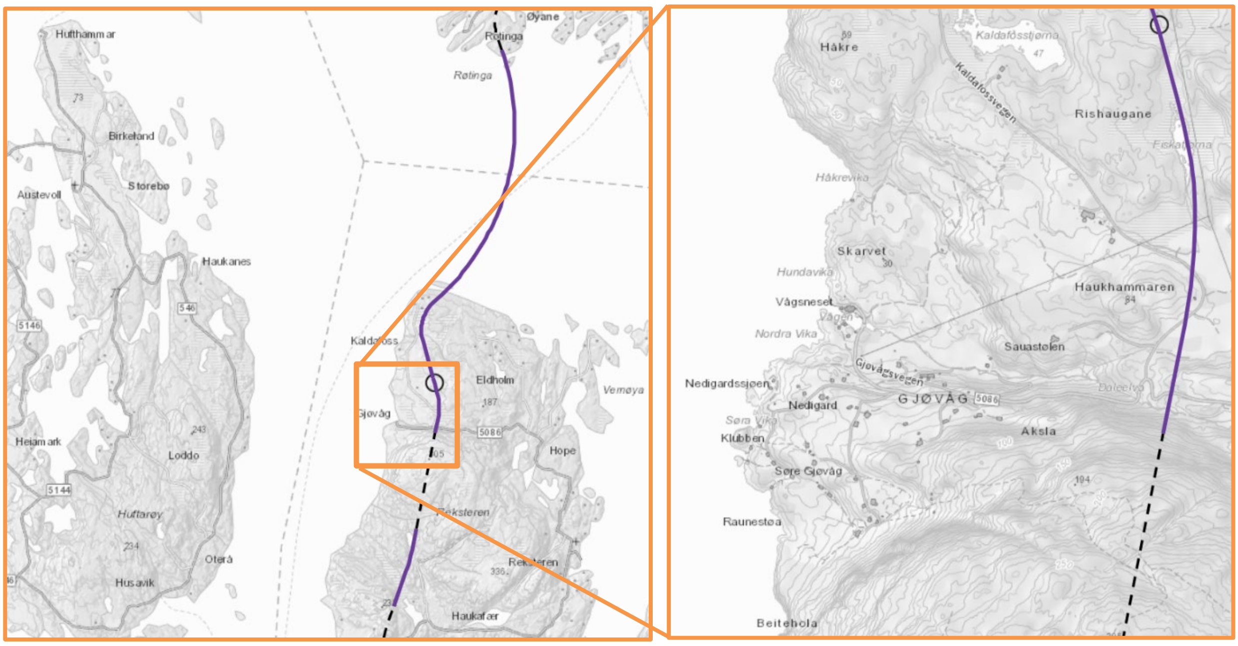

Figure 1. The location of Gjøvåg, where a port is planned.

2 Wind data

The input for wind loading is done following N400 [1] and NS-EN 1991-1-4: 2005+NA [2]. Measurements and simulations are used to validate the recommendations in N400, and as a supplement to give more detailed information about the wind field when necessary [3].

The frequency distribution of wind at 19 m above ground level for 17 years of WRF data is shown in Figure 2. The rose plot shows the directions from which the wind is blowing taken from the single model point in the middle of the crossing.

The wind climate in Gjøvåg is influenced by the surrounding topography resulting in that the most dominant wind directions being along the fjord. The strongest winds are coming from northwest. You also have some episodes with strong winds from the south and southwest.

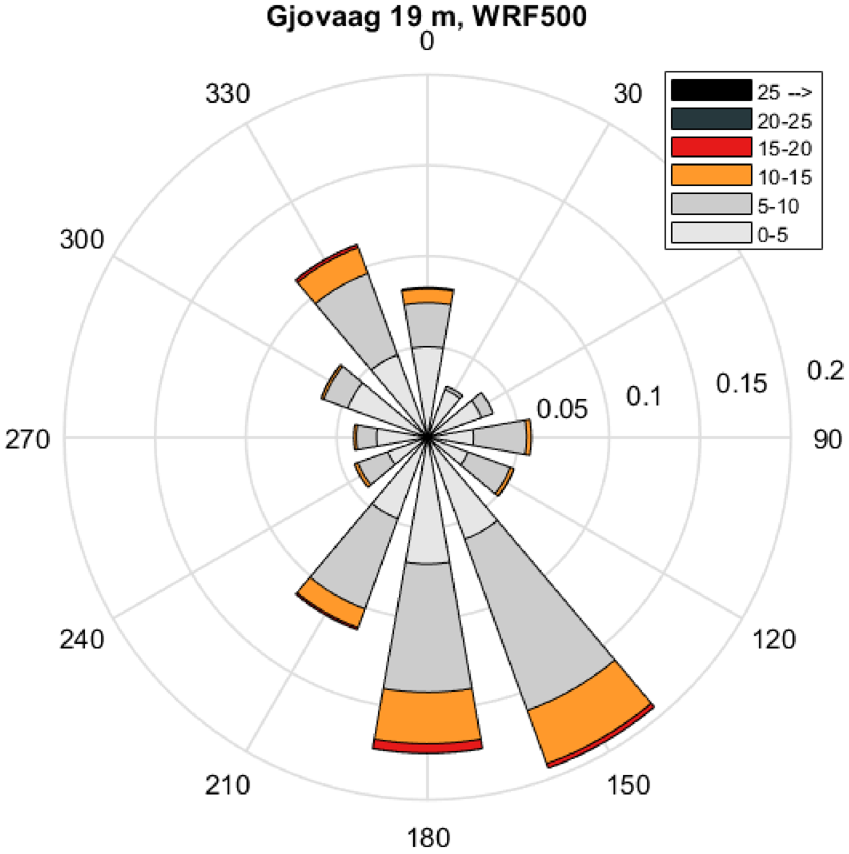

Figure 2. Frequency distribution of the wind [m/s] from simulated data at 19 meter above ground level.

2.1 Return periods

The wind speed v_m is, as described in N400, given by

$$v_m(z,T,R) = v_{b,0} \cdot C_{dir} \cdot C_{season} \cdot C_{alt} \cdot C_{prob} \cdot C_0(z) \cdot C_r(z)$$

where
z – height above the terrain
T – averaging period
R – the return period, $R = 1/p$, where p is the likelihood of yearly exceedance.

$\boldsymbol{v_{b,0}}$: The recommended value for $v_{b,0}$ = 26 m/s

$\boldsymbol{C_{dir}}$: The directional factor C_{dir} is set to 1.0 for southerly and westerly sectors. For N, NE and E the C_{dir} can be reduced following Table 1.

	N	NE	E	SE	S	SV	V	NV
C_{dir}	1.0*	0.7*	0.8	0.9*	1.0	1.0	0.8*	1.0

Table 1. Directional factor C_{dir}, *deviates from [2]

$\boldsymbol{C_{season}}$: The seasonal factor C_{season} is given in Table 2.

	May-August	September-April
C_{season}	0.8	1.0

Table 2. Seasonal factor C_{season}.

$\boldsymbol{C_{alt}}$: The altitude factor $C_{alt} = 1.0$.

$\boldsymbol{C_{prob}}$: The probability factor C_{prob} is given by

$$C_{prob} = \left(\frac{1 - K \cdot \ln(-\ln(1-p))}{1 - K \cdot \ln(-\ln(0.98))}\right)^n$$

where $K = 0.2$ og $n = 0.5$.

$\boldsymbol{C_0(z)}$: The terrain form factor $C_0(z) = 1.0$.

$\boldsymbol{C_r(z)}$: The roughness factor is given by

$$C_r(z) = k_r \cdot \ln\left(\frac{z}{z_0}\right) \qquad \text{for } 1 \le z \le 200$$

where z is height above sea level, k_r is the terrain roughness factor and z_0 is the roughness length. For Gjøvåg we recommend using $z_0 = 0.01$ and $k_r = 0.17$.

2.2 Turbulence intensity

The turbulence intensity can be assumed to follow the equation given in NS-EN 1991-1-4: 2005+NA

$$I_u = \frac{k_{tt}}{\ln\left(\frac{z}{z_0}\right)}$$

where $k_{tt} = 1.0$ and $z_0 = 0.01$ and z is the height above sea level.

<u>**Lateral and vertical turbulence**</u>

The lateral and the vertical turbulence components I_v and I_w are found following N400 eq (5.6.5-3):

$$\begin{bmatrix} I_v \\ I_w \end{bmatrix} = \begin{bmatrix} 0.75 \\ 0.5 \end{bmatrix} I_u$$

2.3 Power spectral density of wind turbulence

The frequency distribution of the turbulence components in all three directions and the statistical dependence between the turbulence components at two points at a given frequency is described following N400.

One point spectra $S_i(n)$ is given by

$\frac{nS_i}{\sigma_i^2} = \frac{A_i \hat{n}_i}{(1+1.5A_i\hat{n}_i)^{5/3}}$ for $i = u, v, w$

where n is the frequency, u, v, w is the turbulence components, A_i is the spectral density coefficients given in Table 3, σ_i is the standard deviation of the turbulence components and

$\hat{n}_i = \frac{n\,{}^xL_i(z)}{v_m(z)}$

where $v_m(z)$ is the 10 minute wind speed in height z and ${}^xL_i(z)$ is the turbulent length scales given by

$${}^xL_u(z) = L_1(z/z_1)^{0.3} \text{ for } z > z_{\min}$$

where L_1 is 100 m and $z_1 = 10$ m. And

$$\begin{bmatrix} {}^yL_u \\ {}^zL_u \\ {}^xL_v \\ {}^yL_v \\ {}^zL_v \\ {}^xL_w \\ {}^yL_w \\ {}^zL_w \end{bmatrix} = \begin{bmatrix} 1/3 \\ 1/5 \\ 1/4 \\ 1/4 \\ 1/12 \\ 1/12 \\ 1/18 \\ 1/18 \end{bmatrix} {}^xL_u$$

The normalized cospectra $S_{i_1 i_2}$ for separation normal to the main flow, horizontal (*y*) or vertical (*z*), is given by

$$\frac{\mathrm{Re}[S_{i_1 i_2}(n, \Delta s_j)]}{\sqrt{S_{i_1}(n) \cdot S_{i_2}(n)}} = exp\left(-C_{ij}\frac{n\Delta s_j}{v_m(z)}\right)$$

where Δs_j is the horizontal or vertical distance between the points of interest,
$i_1, i_2 = u, v, w$
$j = y, z$
and C_{ij} is given in Table 3.

Parameter	N400
A_u	6.8
A_v	9.4
A_w	9.4
C_{uy}	10.0
C_{uz}	10.0
C_{vy}	6.5
C_{vz}	6.5
C_{wy}	6.5
C_{wz}	3.0

Table 3. Spatial density coefficients A_i and $C_{i,j}$ parameters.

3 Wave data

Design wave conditions for wind sea are based on simulations from [4], which is validated by measurements in Bjørnafjorden [5] . The wave conditions are reported at the point closet to the opening of the planned quay location. The coordinate of the data used for this analysis is 60.059049N, 5.357677E which is very near the shore at Gjøvåg.

Figure 3 shows the wave roses for the simulated wave data available from 2002 to 2017. The figure shows that the waves align with the fjord to a very large extent, and there are very little waves in the cross fjord direction.

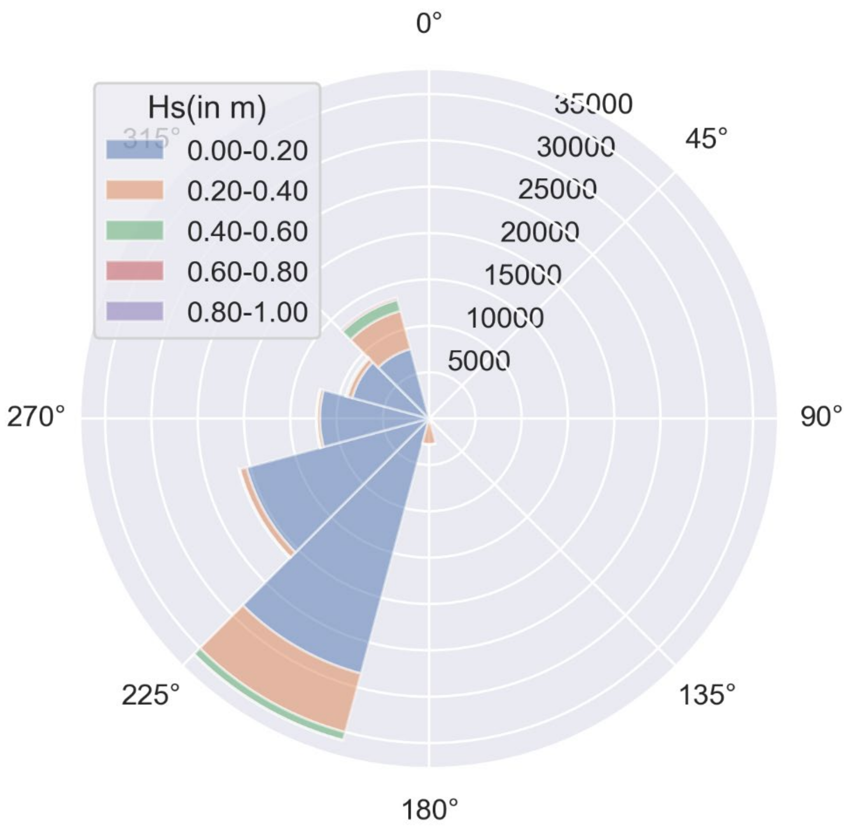

Figure 3. Wave rose for the planned ferry crossing, data for 2002-2017.

3.1 Swells

Figure 4 shows a scatter plot of the simulated data for the area of interest in Gjøvåg. Most of the waves have a Tp under 4 seconds, which means that it is very little energy at lower frequency and thus swells are not a substantial part of the waves in Langenuen. It should be noted that for Bjørnafjorden the model results typically underestimated the swell energy. However, Gjøvåg is more sheltered and narrower than the Bjørnafjord and we therefore do not expect any swells of significance to enter the port location.

3.2 Wind sea

Hs/Tp contour lines from the extreme value calculations are presented in this report. The contour plots for omnidirectional data is shown in Figure 4. The sector wise contour plots are presented in Appendix A. For clarity, the extreme values for both omnidirectional data and sector wise data for various return periods are given in Table 4.

The different sectors refer to the direction from which the waves are coming from. 0°/360° means waves coming from the north, 90° coming from the east, 180° from the south and 270° from the west. Wave conditions are given as constant within each sector.

The parametric description of the Weibull 3P model used to calculate the extreme values and the associated log normal distribution parameters have been presented in the Appendix A.

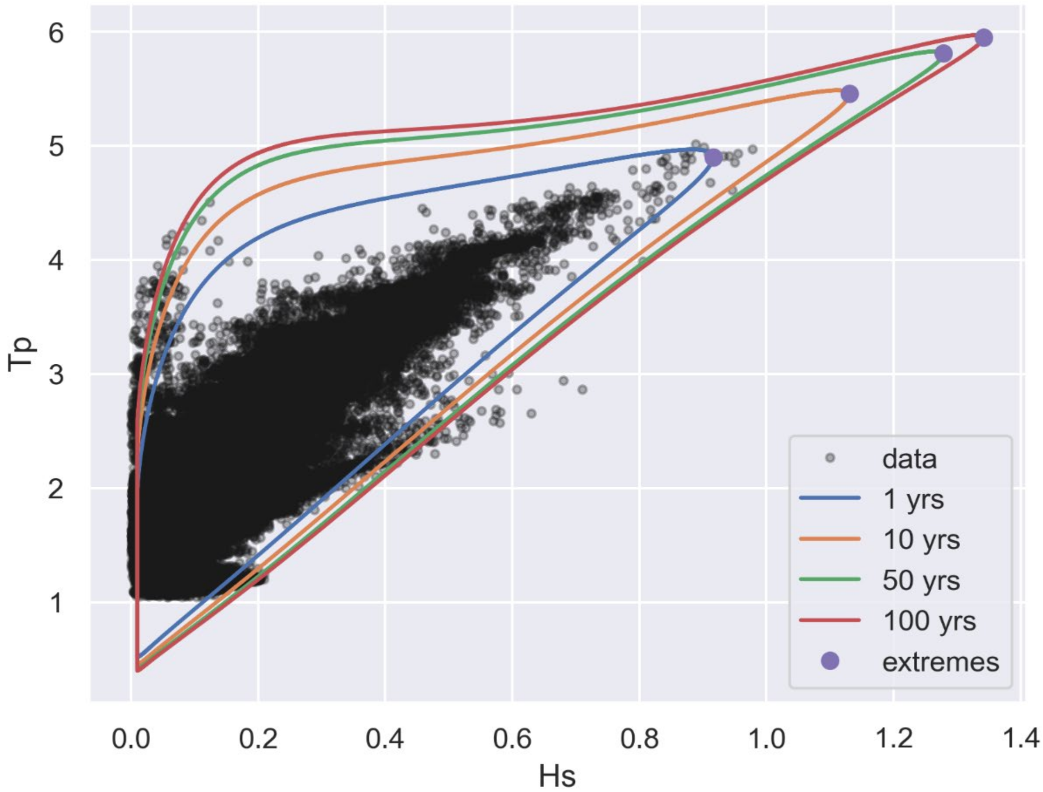

Figure 4. Contour plot for omni-directional sea waves 2002-2017.

Return Period →	1 Years		10 Years		50 Years		100 Years	
Sectors ↓	Hs(m)	Tp(s)	Hs(m)	Hs(m)	Hs(m)	Tp(s)		
Omni	0.916	4.900	1.130	5.459	1.278	5.813	1.342	5.953
345°-15°	-	-	-	-	-	-	-	-
15°-45°	-	-	-	-	-	-	-	-
45°-75°	-	-	-	-	-	-	-	-
75°-105°	-	-	-	-	-	-	-	-
105°-135°	-	-	-	-	-	-	-	-
135°-165°	-	-	-	-	-	-	-	-
165°-195°	-	-	-	-	-	-	-	-
195°-225°	0.720	4.112	0.878	4.486	0.984	4.720	1.029	4.815
225°-255°	0.553	3.025	0.793	3.652	0.975	4.091	1.056	4.292
255°-285°	0.502	2.524	0.755	3.051	0.952	3.437	1.041	3.608
285°-315°	0.627	3.677	0.891	4.332	1.084	4.805	1.170	4.984
315°-345°	0.878	4.794	1.067	5.186	1.190	5.427	1.242	5.523

Table 4. Wind generated waves, all year, relevant for the port location.

The rows indicated with '-' in Table 4, represents sectors where very few data points were observed and thus would not contain any useful results. The sector wise values are sometimes overestimated in the extreme value calculations.

4 Current data

A short overview of the currents mid fjord between Gjøvåg and Huftarøy is presented in this section. The currents closer to Gjøvåg will experience topographic effects that may influence the velocity and introduce changes in the current direction. This is not accounted for in the results. However, it is not expected that the topographic effects will result in higher maximum velocities at Gjøvåg.

The current data presented here are extracted from the NorFjord160 Hardangerfjord numerical results run by the Institute of Marine Research. The model was originally set up for the Hardangerfjord, where Langenuen is a part of the model domain. The model has 160 m horizontal resolution and been used to produce high-resolution current data for Bjørnafjorden for almost 2 years. For a validation and comparison between measured and model results for the Bjørnafjord and the Hardangerfjord, see [6] and [7] respectively. For further information about the methods and results, see [8].

Numerical current data at 1 m depth is used to estimate the extreme values and directions of the currents for the middle of fjord between Gjøvåg and Huftarøy. The current data is hourly and the current directions refer to the direction towards which the current is flowing.

4.1 Return periods

The extreme values of the hourly modeled current (m/s) with return periods of 1, 10 and 50 years are found in Table 5. A three parameter Weibull distribution has been fitted to the data. Due to the short time series the estimates for extreme values for the 50 years return period is uncertain.

Return period [year]	Velocity [m/s]
1	1.24
10	1.39

50	1.50

Table 5. Extreme values of hourly fjord currents [m/s] at the middle of the crossing between Gjøvåg and Huftarøy.

4.2 Current roses

In Figure 5 one can see that the typical flow at 1 m depth in Langenuen close to Gjøvåg is northward independent on the tide. (The currents in Figure 5 are showed in the oceanographic convention, going to) Approximately 80% of the time the flow is directed northward. The main direction is North-North-East, which is in accordance with the fjord direction. It is also in this direction one finds the strongest currents, with approximately 1% of the time the currents are above 1 m/s.

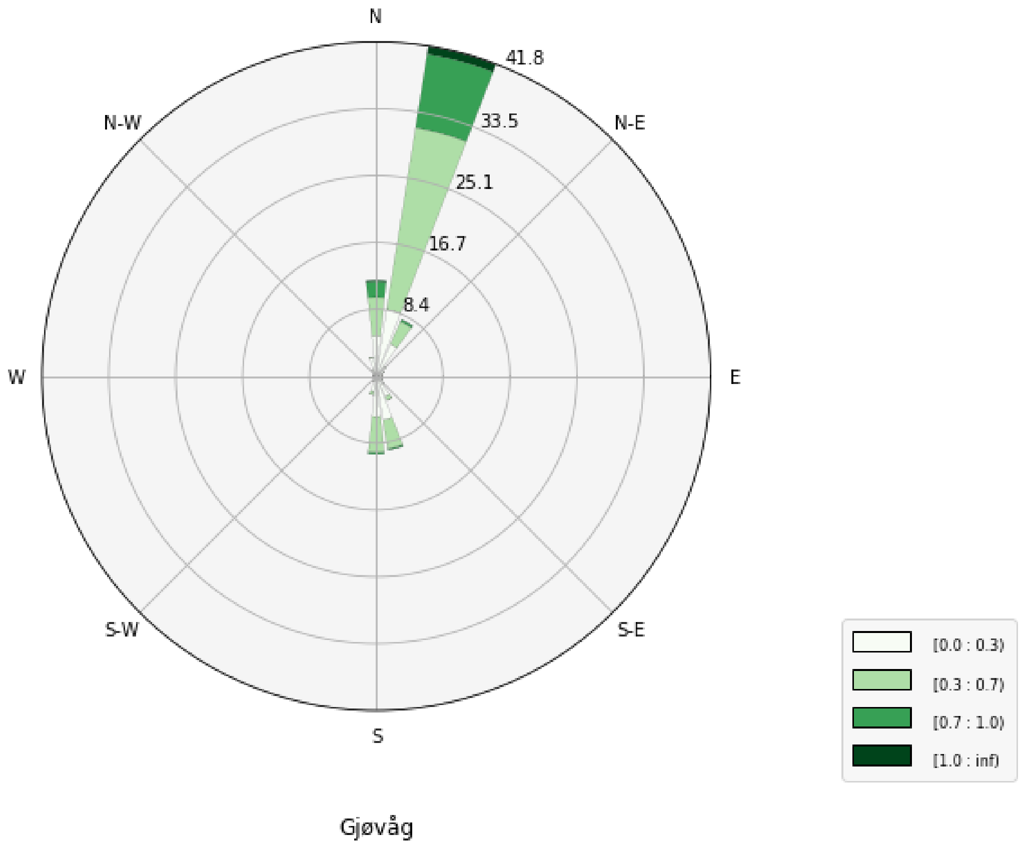

Figure 5. Current direction. The legend shows current strength in m/s.

5 Water level variations

This section is taken from the Metocean specification for Langenuen [9], but is relevant for Gjøvåg.

The water level variation at Langenuen are calculated by taking the data provided by Kartverket for Bergen measurement station and multiplying it by a factor of 0.79. This is a scaling factor used for interpolation between measurement stations. The values provided in Table 6 and Table 7 can be used for the port location.

The water level variation is defined as the sum of the astronomical component and the surge component. The surge component includes effects from low/high atmospheric pressure and storm surge. The astronomical component is independent of the environmental conditions, whereas the surge component is governed by the atmospheric conditions.

The reference level for the tidal amplitudes in Table 6 and the water level in Table 7 is chart datum (LAT). The values are based on data from Kartverket [10].

Tidal amplitudes [m]	
Lowest Astronomical Tide (LAT)	0.0
Mean Low Water (MLW)	0.36
Mean Sea Level (MSL)	0.72
Mean high water (MHW)	1.07
Highest Astronomical Tide(HAT)	1.42
NN 2000	0.79

Table 6. Tidal amplitudes.

The water level for different return periods may be taken from Table 7.

Return periods [years]	Highest water level [m]	Lowest water level [m]
1	1.66	-0.17
10	1.82	-
100	1.95	-

Table 7. Water level related to return periods relative to LAT.

The quantities marked with '-' do not have available data.

The surge component (air pressure effect, storm surge etc) may for simplicity and until more reliable data are collected be taken as the difference between the values in Table 7 and MSL.

The mean water level shall be increased by 0.74 m due to climate change where this is unfavorable, see [11]. This number includes the effect of land elevation rise. The increase in water level will affect all water levels. For more information on climate change implication, refer to section 6.

6 Climate change

The future wind, wave, current, sea level and temperature conditions might change due to climate change. The lifetime of the bridge exceeds 100 years and climate change should be accounted for. Future metocean conditions can be predicted by running global climate models in combination with regional downscaling and numerical wind and wave models. However, the accuracy in the predictions is at the present not sufficient to quantify the consequence on the extreme conditions [12].

In lack of detailed documentation, the recommendations stated in NORSOK N-003:2017 Action and Action Effects [12] may be used:

- extreme wind speeds: 4% increase on q-probability values;

For sea level change, we recommend using the projected 95-percentile for the RCP8.5 (high emission) scenario for the year of 2100. This value is obtained from Kartverket.no [13]:

- Projection for sea level in Langenuen 2100: + 0,74 m

The report "Klima i Norge 2100" [11] gives an estimate for change in annual air temperature of 2-3 degrees Celsius for Langenuen and surrounding areas. A trend analysis of measurements from Flesland shows that the max temperature might have increased by 1 degree Celsius from 1956 – 2017 [14]. Based on the limited information available we recommend

- an increase of 2 degrees Celsius on the maximum air temperature
- no change for the minimum air temperature

7 References

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[10] P. Jena, *SBJ-01-C4-SVV-01-TN-005 Comparision of Tidal water level data,* Statens Vegvesen, 2018.

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[12] NORSOK Standard, "N-003:2017 Actions and action effects".

[13] kartverket, "https://kartverket.no/sehavniva/sehavniva-lokasjonside/?cityid=77514&city=Bj%C3%B8rnafjorden#tab3," [Online].

[14] Kjeller vindteknikk, "Bjørnafjorden, Hordaland Temperaturanalyse," 2018.

Appendix A
Wind Sea Scatter Diagrams and Hs Tp Contours

Distribution Parameters

The following table shows the parameters used to describe the extreme value description of the waves presented in this report.

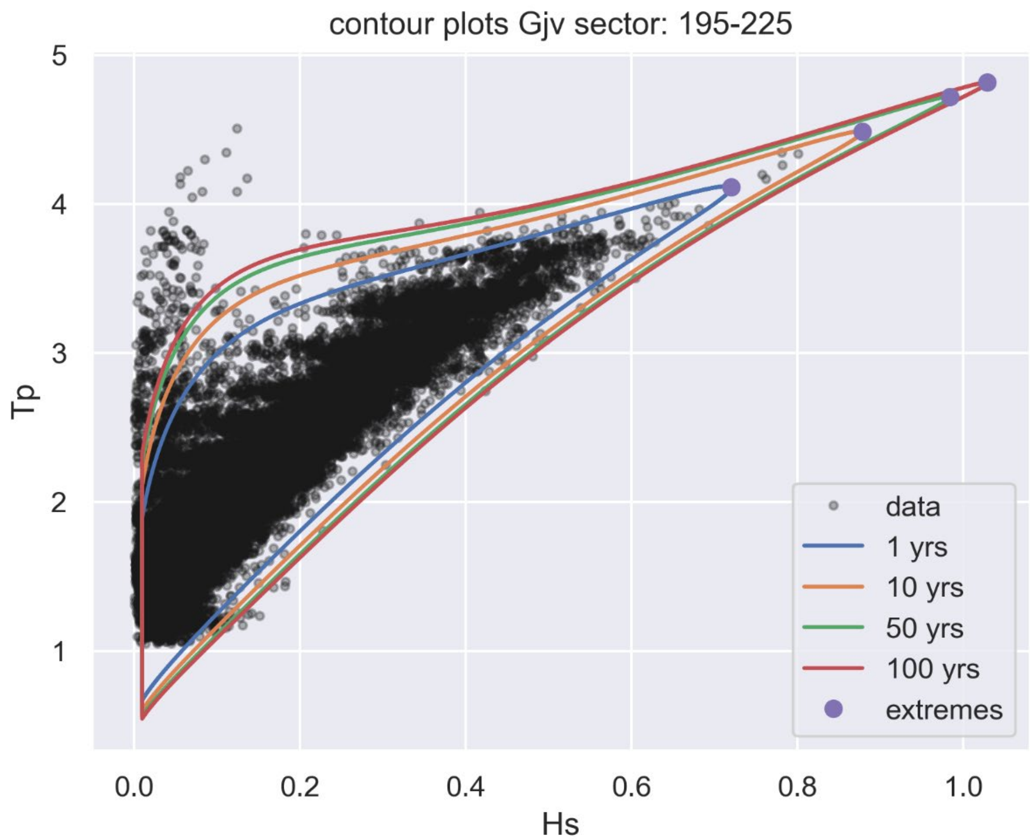
The significant wave height extremes are described a Weibull 3 parameter distribution. The parameters λ, α and β are presented in the table below. The Tp is distributed log-normally conditional on Hs. The log normal distribution parameters μ and σ can be described as the equations below and the coefficients for omnidirectional and sectorwise extremes are presented in Table 8

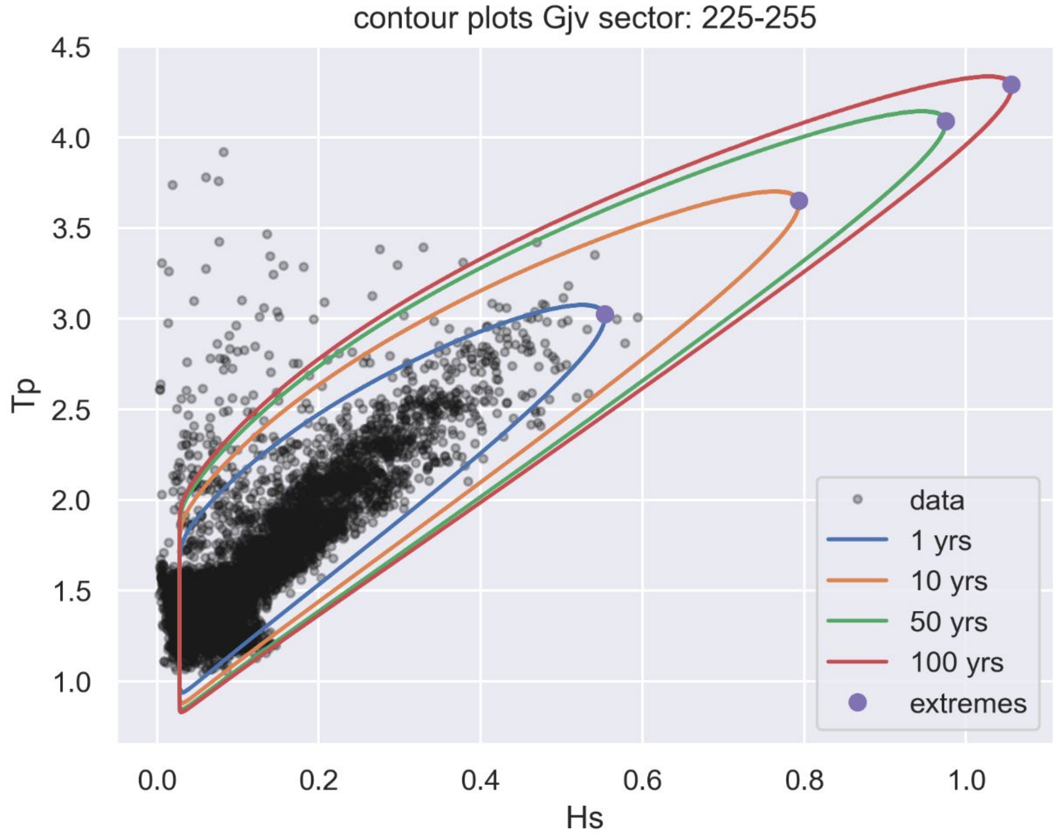
$$\mu(h) = a + b * h\hat{}c$$
$$\sigma(h) = p * exp(h * q)$$

Sector (°)	Weibull 3P parameters			Log Normal distribution parameters				
	λ	α	β	a	b	c	p	q
Omni	0.0075	0.1146	1.0660	0.7268	4.3929	0.5878	0.2259	1.9561
195-225	-0.0051	0.1380	1.2635	0.8011	3.9485	0.5424	0.1752	3.2072
225-255	0.0273	0.0336	0.7251	1.0847	3.0538	0.7848	0.1050	0.8183
255-285	0.0325	0.0278	0.6772	1.1589	2.3658	0.8106	0.1427	2.4644
285-315	0.0260	0.0597	0.8195	1.1310	3.4493	0.6774	0.2081	1.1444
315-345	-0.0135	0.2203	1.4258	0.8452	4.2039	0.4925	0.1899	3.4656

Table 8. Distribution parameters.

Sector-wise contour plots for wind sea

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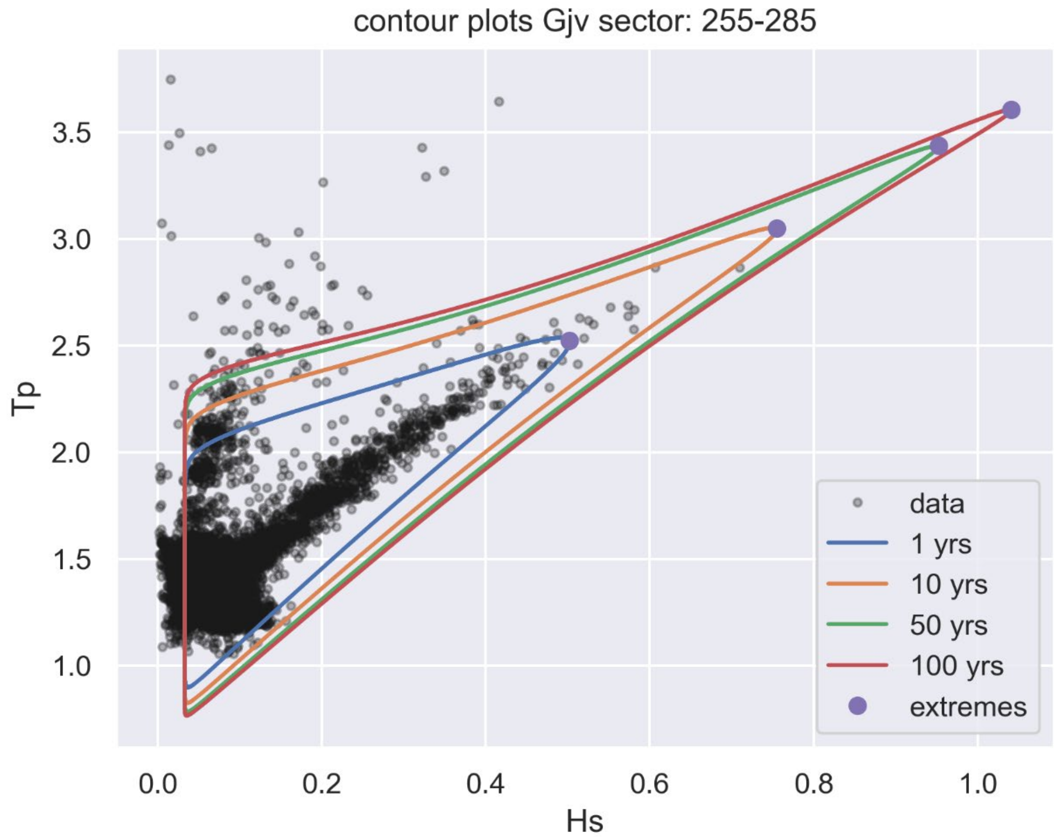
Tp
Hs
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.0
0.2
0.4
0.6
0.8
1.0
data
1 yrs
10 yrs
50 yrs
100 yrs
extremes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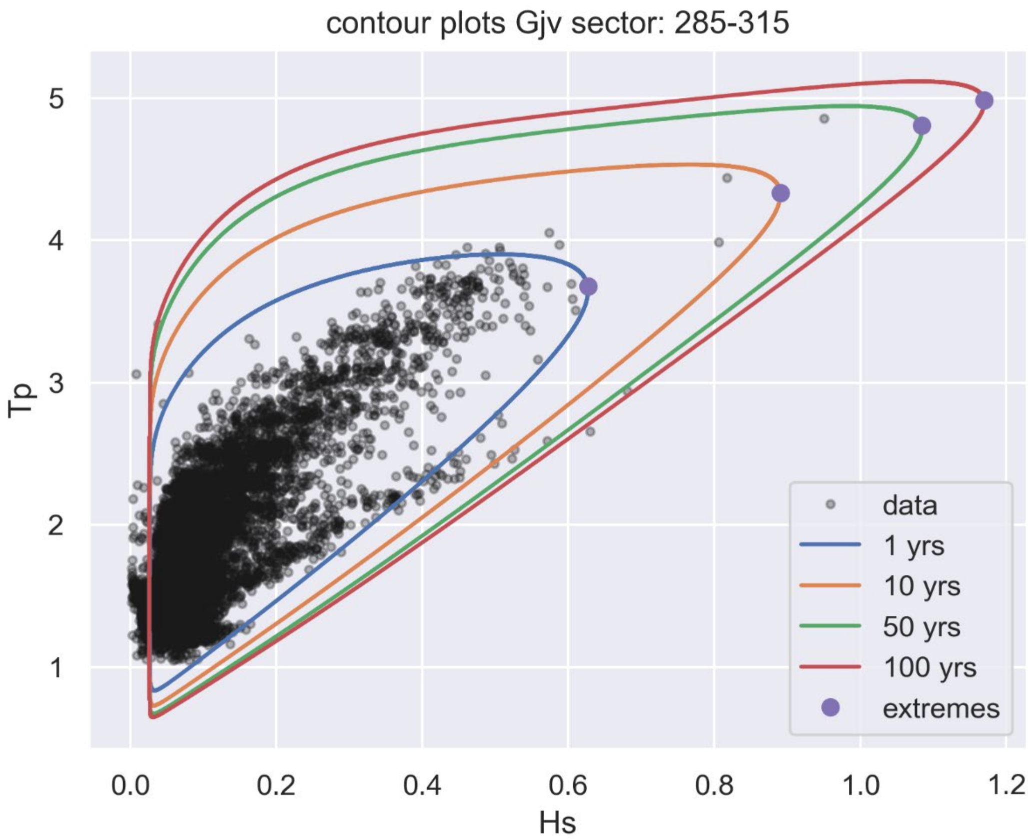
Tp
Hs
3.5
3.0
2.5
2.0
1.5
1.0
0.0
0.2
0.4
0.6
0.8
1.0
data
1 yrs
10 yrs
50 yrs
100 yrs
extremes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Tp
Hs
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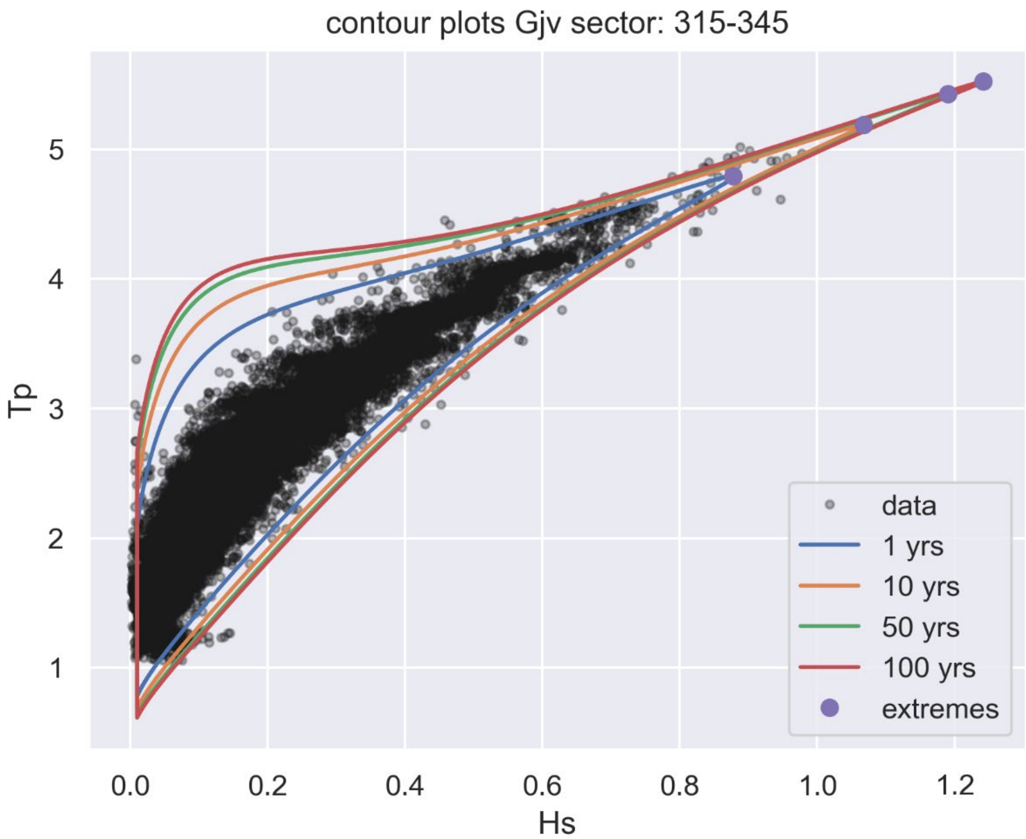
0.2
0.4
0.6
0.8
1.0
1.2
1
2
3
4
5
data
1 yrs
10 yrs
50 yrs
100 yrs
extremes


contour plots Gjv sector: 315-345
Tp
Hs
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1
2
3
4
5
data
1 yrs
10 yrs
50 yrs
100 yrs
extremes