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Háafell ehf.

Site survey report and ocean wave modelling

Skötufjörður, 2021

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Summary
Akvaplan-niva has carried out a site survey of the location Skötufjörður with the requirements set out in NS 9415:2009 – Requirements for site surveys, risk analysis, design, dimensioning, production and operation.

50 years return period	Size	Direction (degrees)	Peak period (s)
Max current, 5 meters	80 cm/s	45°	-
Max currents, 15 meters	85 cm/s	45°	-
Significant wave height (Hs) wind induced waves	3,59 m	345°	6,2 s
Significant wave height (Hs) ocean swells	0,93 m	15°	16,7 s
Significant wave height (Hs) combined wind waves and swells	3,49 m	330°	7,1 s

Waves are coming from the given direction, while the current is moving towards the given direction.

Project manager

Arnþór Gústavsson

Arnthor Gustavsson

Quality control

Stine Hermansen

Stine Hermansen

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Foreword

The present investigations were carried out by Akvaplan-niva AS under contract from Háafell ehf. In association with the establishment of a new fish farm at the site Skötufjörður in Ísafjörður the client needed to perform a site survey and a production of a site survey report for the site.

The investigation fulfills the demands of Norwegian standard *NS 9415:2009 – Requirements for site survey, risk analyses, design, dimensioning, production, installation and operation*.

The investigations were carried out and reported by Vegard Holen, Akvaplan-niva AS.

Accredited operations: Akvaplan-niva AS is accredited in accordance with ISO/IEC 17020:2012. The following standards, regulations and procedure descriptions were used: NS 9415 - NYTEK-regulations and Akvaplan-niva AS's internal procedures for project implementation and quality assurance.

Reykjavik,

Arnþór Gustavsson

Arnthor Gustavsson

Project manager

1 Introduction

Akvaplan-niva AS, on behalf of Háafell ehf., conducted a field survey at Skötufjörður. The measurements comply to Norwegian standard *NS 9415:2009 – Requirements for site survey, risk analyses, design, dimensioning, production, installation and operation*.

The site named Skötufjörður, is located on the south side of Ísafjarðardjúp on the east side of the inlet to Skötufjörður in the Westfjord region of Iceland (Figure 1). The site has a sector towards the open ocean in the northwestern direction. This results in a possibility of ocean waves propagating into the fjord, and into the area of interest. Hence an ocean swell modelling has been carried out for the site.

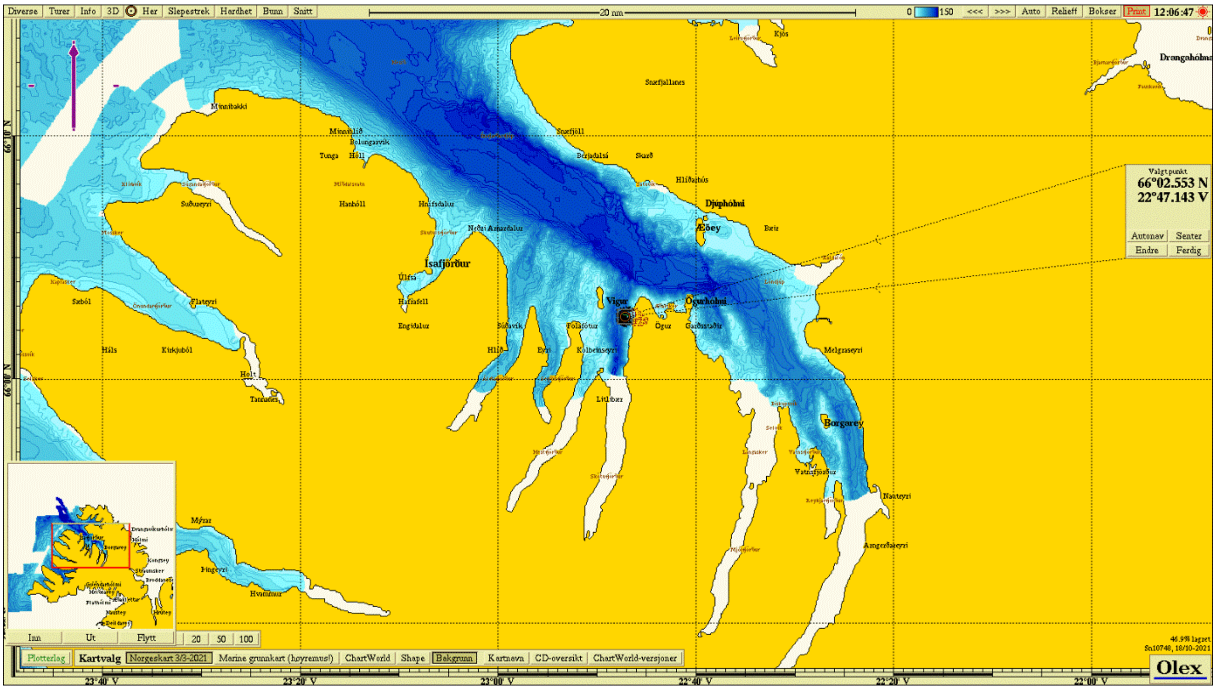

Figure 1. The placement of the site Skötufjörður on sea charts from Olex.

2 Methods

2.1 Currents

2.1.1 Current measurements

Current measurements were made using a Seaguard point doppler during the period 25.05.21 – 01.09.21 at 5- and 15-meters depth, results have been extracted for the period 25.05.21 – 30.08.21. The instruments were calibrated to simultaneously register current velocity and current direction at 10-minutes intervals (see attachment). The measurements were done in position 66°02,280N / 22°47,288W which is considered as representative for the site. Quality assurance was performed by Akvaplan-niva AS.

2.1.2 Tidal currents

There are strong variations in the tidal contribution to overall currents over a given time period (tidal water cycle or a moon phase). The tidal current estimates and the variance of the tidal water is compared with the variance of the total current and is calculated for the period entire measurement period. Further description can be found in appendix 7.1.2.

2.1.3 Temperature and water masses

The areas around Iceland are affected by several water masses. In the west between Greenland and Iceland, the south flowing cold and dense East Greenland current is flowing through the Denmark Strait. Next to this current, the North Icelandic Irminger Current is transporting warm and saline Atlantic water northwards along the Icelandic coastal line. The eastern parts of Iceland are affected by the south flowing cold and dense East Icelandic Current.

The Icelandic Coastal Current is moving clockwards around Iceland affecting the areas along the coast. This current is partly driven by freshwater but is also influenced by wind and tidal currents. Extreme weather conditions with prevailing winds can affect the currents in the fjords and lead to an increased water exchange.

2.2 Ocean swell modelling

CMS-Wave (Coastal Modelling System Wave Model) has been used to model the degree of exposure from wind induced waves, ocean swells and a combination of these two for the site. This is a two-dimensional model using rectangular cartesian grids. The input data for the model are bottom topography, incoming waves (height, direction and energy spectra), wind strength and wind direction. A more detailed description of the model is found in appendix 7.3.

2.2.1 Model setup

The site is located on the south side of Ísafjarðardjúp on the east side of the inlet to Skötufjörður and has an open sector out from the fjord and further to the Denmark Strait towards the northwest. There is little sheltering effect in the area, and propagation of ocean swells into the fjord is likely. Therefore, the model was run for incoming ocean swells, wind induced waves and a combination of these from westerly to northwesterly directions (nine different sectors between 270 and 30 degrees). The model was run with wind-forcing from all directions. The model runs have been split up into sectors of 15 degrees. For the overlapping sectors, the largest wave heights are presented in the report.

To cover all the sectors, three different grids were set up for modelling (Table 1 and Figure 2). Large grids with low resolution were used to model on a regional scale. The results were nested into finer grids closer to the site (Figure 2). The bottom topography of the model can be seen in Figure 3. To present the results, four control points representing the four corners of the fish farm and one point representing the center of the fleet were used (Figure 2 and Figure 3).

Ocean currents at the site were measured from the 25th of May to the 30th of August, with resulting values of 43 cm/s and 46 cm/s at 5- and 15-meters depth respectively. This is equivalent with 80 and 85 cm/s with a 50-year return period. Since these are below 1 m/s, ocean current was not considered in the model.

Reflection was included in the model simulations in the finer grids in the area close to the fish farm.

Table 1 Coverage and size of the cartesian grids.

Grid	Degrees	Coverage area			
		Cell size (m)	Number of cells X & Y	Number of calculation cells in total	Grid area(km²)
Northwest	270° - 330°	70 x 70	1645 x 1288	2 120 048	115 x 90
		20 x 20	1521 x 1344	2 044 224	30 x 27
North	315° - 30°	70 x 70	1581 x 1119	1 769 139	111 x 78
		20 x 20	1511 x 1763	2 663 893	30 x 35
Wind	0° - 345°	20 x 20	1797 x 1620	2 911 140	32 x 36

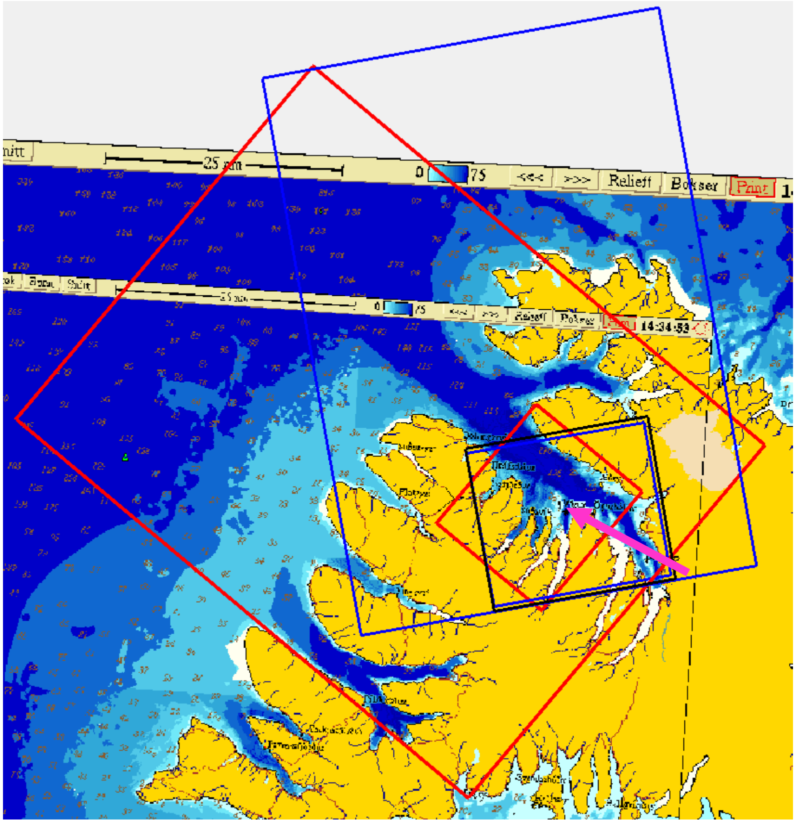

Figure 2. Model area of the CMS-Wave simulations shown in the red square (north-western grid), blue square (northern grid) and black square (wind grid) with arrows showing the directions from where input data have been forced. The nested grids are shown in the same colours as the larger grids. The site is illustrated with a pink arrow (map source: www.olex.no)

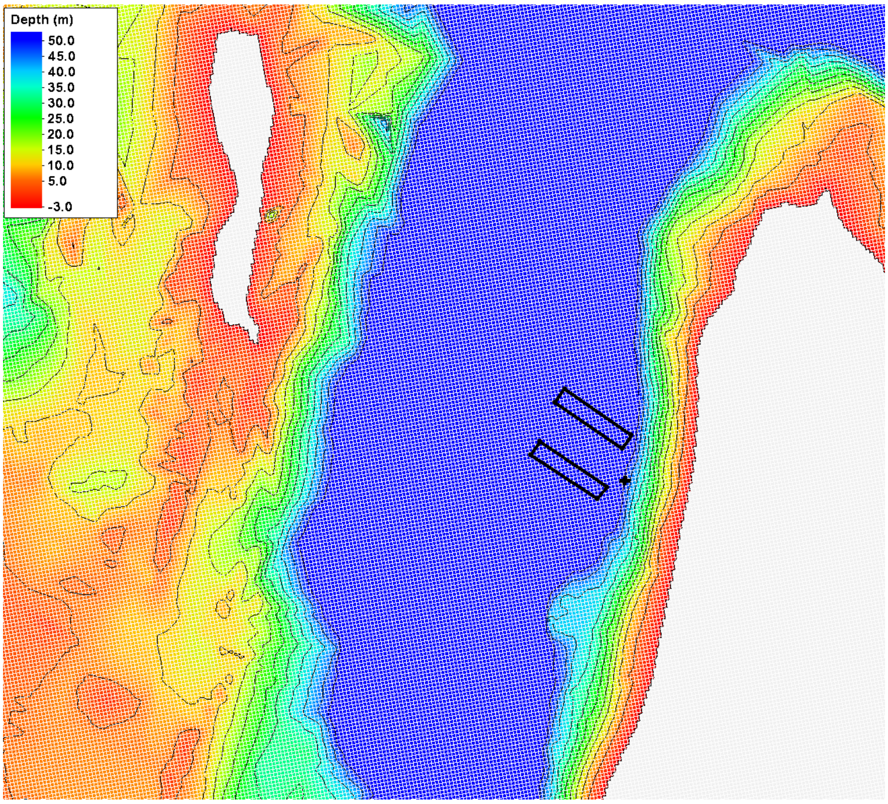

Figure 3. Illustration of the cartesian 20 x 20 m grid (in white squares) used in the CMS-Wave modelling. The colours show the bottom topography. The fish farm is shown with the black square, the fleet is shown with the black cross.

Table 2 Coordinates of the four corner points of the fish farm at Skötufjörður.

	Corner of the site	Geographical coordinates		UTM, ISN 93	
		N	W	X	Y
Northern site	Northwest	66°02,716'	22°47,288	328396.19	621690.82
	Northeast	66°02,592'	22°46,773'	328766.80	621434.00
	Southeast	66°02,550'	22°46,834'	328716.88	621358.79
	Southwest	66°02,674	22°47,349	328341.75	621615.88
Southern site	Northwest	66°02,556	22°47,448	328255.98	621397.59
	Northeast	66°02,432	22°46,934	328631.14	621140.49
	Southeast	66°02,391'	22°46,995'	328577.36	621076.68
	Southwest	66°02,515'	22°47,509'	328206.05	621322.39
	Fleet	66°02,455'	22°46,808'	328728.84	621179.32

2.2.2 CMS-Wave model input data

Bottom topography in this modell is a combination of data from the Icelandic Coastal Guard (http://www.lhg.is) and from EMODnet Bethymetry portal (http://www.emodnet-hydrography.eu), where the latter is used to cover the areas with missing data from the Coastal Guard. A depth of 3 meters above sea map zero has been used in order to calculate for spring flood.

Incoming waves were obtained from the Norwegian Meteorological Institutes (MET.no) wave model, NORA10 (Reistad m.fl, 2011). This model covers the North Sea, the Norwegian Sea and the Barents Sea. Met.no has calculated values with 50-year return period from this regional nested model set from WAM (The Global Ocean Wave Prediction Model). The model has a resolution of 10 km and a direction resolution of 30 °.

Wind velocities in the model domain are calculated from model simulations. There are no available measurement data from the actual area of Skötufjörður, thus data from the meteorological model Harmonie (Nawri, et.al., 20179 have been used. The model has a resolution of 2,5 km, and results from 36 years obtained from the Icelandic Meteorological Office (www.vedur.is) are used in the calculations. Input data for wind utilized in the model is given in Table 3 and Table 4. The extreme value analysis is described in appendix 7.5.

Results have been extracted from the NORA10-model (Table 5 and Table 6) and are used as boundary values for the CMS-Wave simulations. The grid point in met.no's model have the coordinates 66°52N and 23°89W (incoming waves from northwest) and are shown in Figure 2. The wave spectra are assumed to be representative for waves propagating towards the shore from deep water areas in the Greenland Sea in the west or northwest.

Table 3 Statistical extreme values used for wind in the large model domain.

Wind speed, Return period 50 years (m/s)	Wind direction											
	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°
	38,4	38,4	38,4	38,4	38,4	35,4	31,9	30,2	30,3	30,3	30,3	30,3
	180°	195°	210°	225°	240°	255°	270°	285°	300°	315°	330°	345°
	30,3	29,6	32,1	32,1	32,1	32,1	32,1	30,8	28,7	25,3	29,1	32,0

Table 4 Statistical extreme values used for wind in the smaller model domain.

Wind speed, Return period 50 years (m/s)	Wind direction											
	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°
	32,8	33,2	40,0	40,0	40,0	40,0	40,0	30,9	26,9	25,0	25,0	28,3
	180°	195°	210°	225°	240°	255°	270°	285°	300°	315°	330°	345°
	28,3	28,3	28,3	28,3	27,8	28,2	28,2	28,2	28,2	28,2	29,7	32,8

Table 5 Statistical extreme values of significant wave height (m) from Met.no's hindcast wave model NORA10. The positions where the values were extracted from a point in the open ocean.

Return period 50 years	Wave direction				
	255°-285°	285°-315°	315°-345°	345°-15°	15°-45°
Significant wave height [m]	7,4	7,5	7,4	10,9	15,6

Table 6 As in Table 5, but with interpolated values of significant wave height (m). The table also includes the peak period, found as a typical relation between wave height and period in the area.

Returnperiod 50 years	Wave direction								
	270°	285°	300°	315°	330°	345°	0°	15°	30°
Significant wave height [m]	7,4	7,5	7,5	7,5	7,4	9,2	10,9	13,3	15,6
Peak-periode [s]	12,1	12,7	12,7	12,7	12,7	13,7	14,7	16,0	17,2

2.3 Icing

Guest et al. (2005) describe use of wind speed and air temperature to predict the effect of the ice at a given water temperature. Long-term records of air temperature and wind speed at 10 meters above ground are collected from www.vedur.is. This is an advantage compared to Mertins (1968), where air temperature and sea temperature at a given wind speed are used[1].

Observations of temperature and wind combinations is used in a frequency table where the prediction of icing is given in colour codes. Based on this, the possibilities of icing are estimated

[1] Mertins, H. O. (1968). Icing on fishing vessels due to spray. *Marine Observer*, *38*(221), 128-130.

at the site. The results are presented in chapter 4 and further details of the method are explained in attachment 7.4.

2.4 Bottom topography

The bottom data is delivered from the Icelandic Coastal Guard and Háafell ehf. The measurements were done using a multi-beam seismic profiler (WASSP) and OLEX. The drawing of the fish farm was produced in OLEX.

Quality assurance was done by Akvaplan-niva AS. The registration of the bottom data was performed in according to NS 9415:2009. Data resolution is 10x10 meters.

3 Results

Modelling results for waves and currents are presented in Table 11. The current results were adjusted in accordance with NS 9415:2009 chapter 5.2.3 and presented with considerations to the run of the different loading combinations (NS 9415:2009 chapter 6.7).

3.1 Current measurements

The results from the current measurements at 5 meters depth reveal that the main current direction and mass transport of water are towards the northeast (30 degrees). Average current speed is 9,7 cm/s. 1,4 % of measurements are > 30 cm/s, 8,2 % of measurements are > 20 cm/s, 37,9 % of measurements are > 10 cm/s, 50,1 % of measurements are between 10 and 3 cm/s, 10,3 % of measurements are between 3 and 1 cm/s and 1,7 % of measurements are < 1 cm/s.

The results from the current measurements at 15 meters depth reveal that the main current direction and mass transport of water are towards the northeast (45 degrees), with a small residual current towards the southwest (210-225 degrees). Average current speed is 5,7 cm/s. 0,2 % of measurements are > 30 cm/s, 1,2 % of measurements are > 20 cm/s, 12,6 % of measurements are > 10 cm/s, 58,9 % of measurements are between 10 and 3 cm/s, 24,3 % of measurements are between 3 and 1 cm/s and 4,3 % of measurements are < 1 cm/s.

The maximum current speed during the measurement period was 43,2 and 45,9 cm/s at 5 and 15 meters, respectively, which is equivalent to 80 and 85 cm/s for a 50-year return period, respectively.

3.2 Tidal currents

There are large variations in how much the tidal cycles contribute within a given time period (a tidal period or a moon phase). The current measurements that have been carried out at the site shows that the tidal component is small compared to the residual current. Table 7 shows the result from the variance analyses at 5- and 15-meters depth.

The numbers in Table 7 are relatively small. At 5 m and 15 m depth the estimated tidal contribution can explain 7,5 % and 9,5 % in E-W-direction, and 11,5 % and 14,7 % in N-S-direction, respectively, of the variability in the current at the location. This can also be seen in Figure 4, where it can be observed that the tidal ellipse is relatively small compared to that of the total current. This shows that the tidal water is not a dominating factor in the total current picture.

Table 7 Variance explained by the tidal component of the total current (numbers in percentage)

Direction of the current component	**Depth**	
	5 m	15 m
East-West	*7,5 %*	*9,5 %*
North-South	*11,5 %*	*14,7 %*

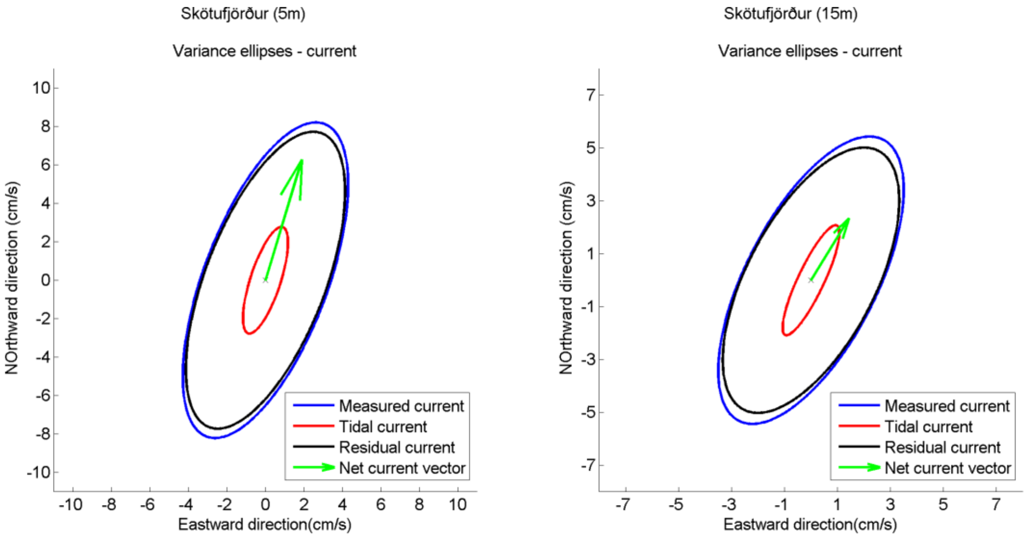

Figure 4. Variance ellipses of the total current (blue), tidal water current (red) and the residual current (black) at 5 and 15 m. The variance ellipse shows the size of one standard deviation of the variance, in both direction and size. The results are estimated from current data during the entire measurement period. The green arrow shows the net current at the same period.

3.3 Wind induced current

Wind is mainly affecting the current at 5 meters depth because the effect of the wind decreases with depth. There must be strong winds from the same direction over a long period of time to affect the current at 15 meters. This is rarely the case in fjords and coastal areas where fish farms are normally located. Wind data have been extracted from the weather station at Ögur (Figure 5). The measurement site is situated approximately 5 km east from the farming site. The geographic distance is short between the site and the measuring station, and they have approximately the same rate of exposure, the farming site might be somewhat more shielded from wind from easterly direction. Ögur is considered to be representative for wind in the area. The wind rose show that the highest windspeed is registered towards north-northeast (21 degrees) with a windspeed of 23,2 m/s.

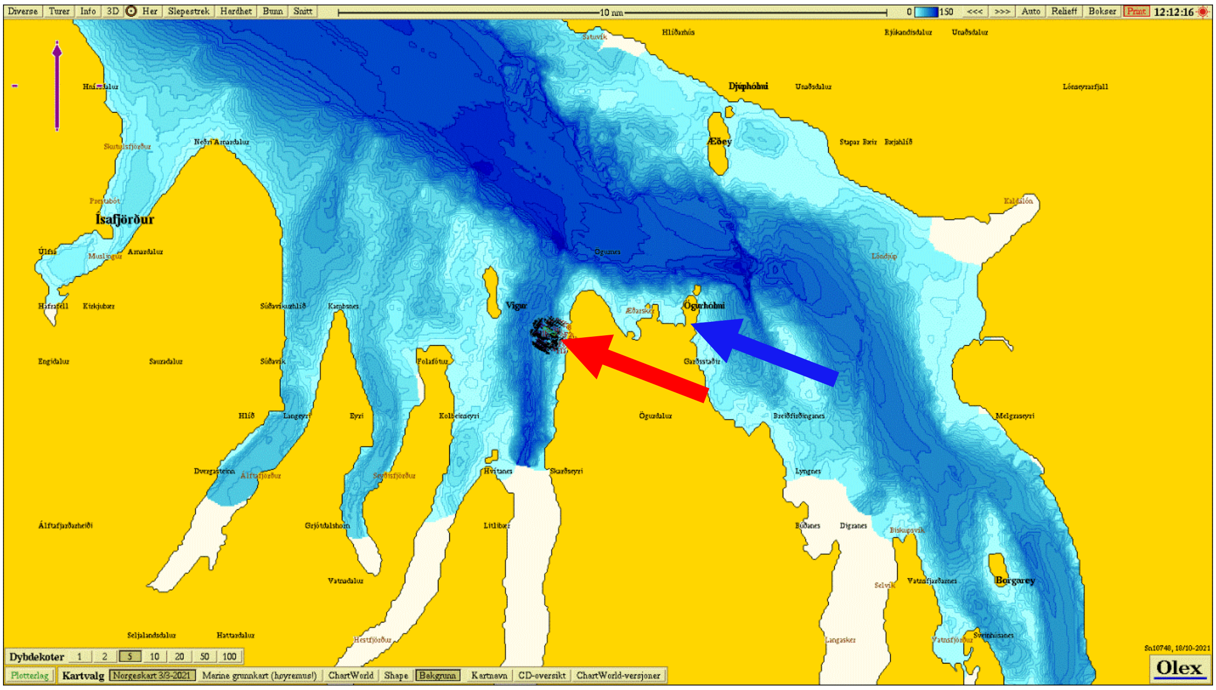

Figure 5. The location of the weather station and the farming site. The weather station Ögur is shown with a blue arrow and the site is shown with a red arrow.

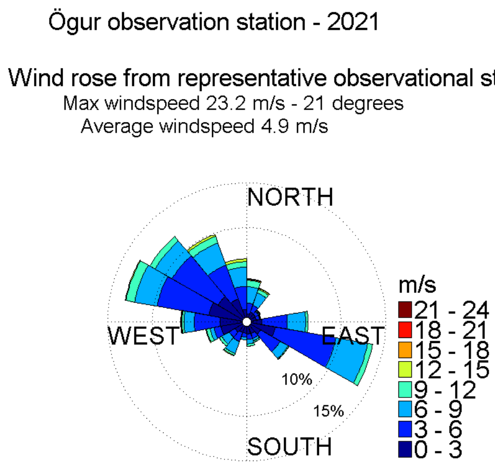

Figure 6. Wind rose for the observations done at the measuring station Ögur in the period 25.05.21 – 30.08.21. The figure show speed and the direction that the wind is moving towards.

There have been several registrations with windspeed above 10 m/s during the period May-August 2021. The highest windspeed was registered on the 25th of June, with a windspeed of 23,2 m/s (Figure 6).

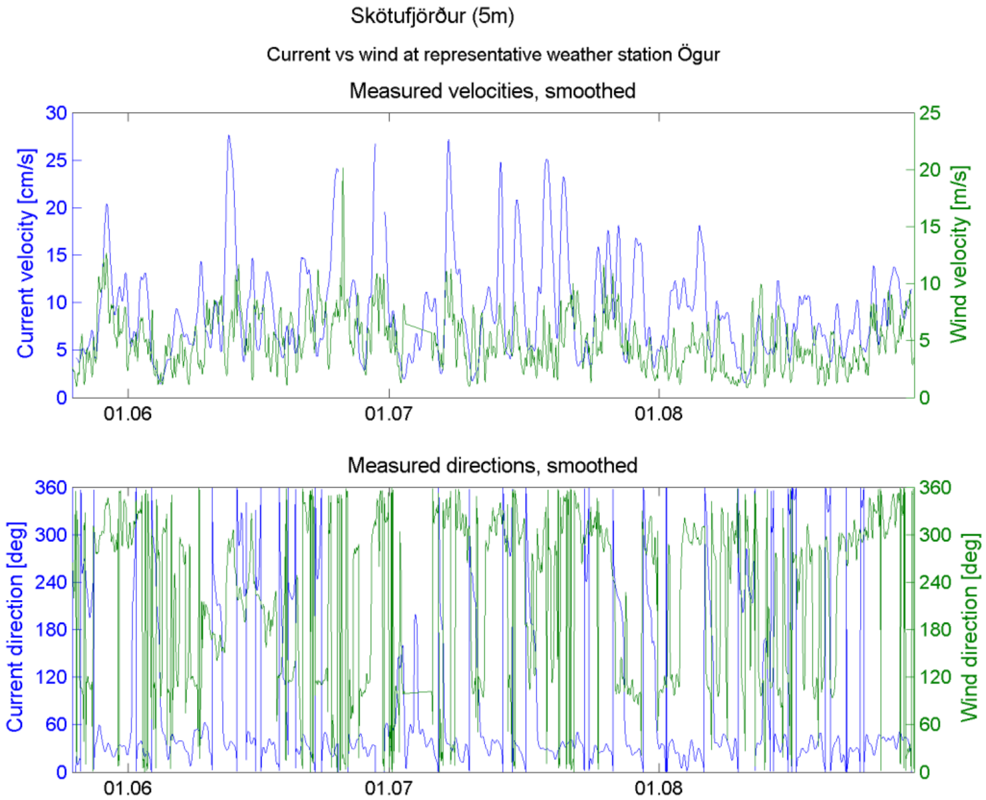

Figure 7. Velocities and directions for current/wind during the measurement period. Wind and current can be read in the same direction and are moving towards the given direction.

Figure 7 show that episodes of high current velocities periodically coincide with high wind speeds. The highest wind speed was registered on the 25th of June, and high current velocity was observed in the same period, wind and current velocity was directed approximately in the same direction at this time. The measurements indicate that there are larger fluctuations in current velocity than wind velocity, but there seems to be an increase in current velocity when spikes in wind velocity occurs towards northern directions.

An overall picture of the results and an assessment of the station's location in relation to the site indicates that wind had effect on the current in the area during the measurement period.

3.4 Temperature and water masses

The measurement at 5 meters depth shows a relatively stable but increasing temperature during the timeseries. The minimum temperature is registered at the beginning, with a temperature of 4,6 °C. The maximum temperature of 12,5 °C was registered towards the end of the measurement period. The mean sea temperature at 5 m was 8,6 °C. The temperature at 15 meters depth shows the same trend as at 5 meters. The minimum temperature was registered at the beginning with a temperature of 4,2 °C. The maximum temperature was registered toward the end of the period with a temperature of 11,0 °C. The smaller fluctuations in temperature during the period at both depths might be due to influx of warmer/colder water, the temperature increase is due to natural seasonal variations.

3.5 Spring flood and snow and ice melting

Measurements were performed during the period may-august. This is a period when snow and ice melting occur. There are no significant freshwater sources in the immediate vicinity of the site. In heavy melting periods there could however be freshwater runoffs from the nearby mountains that affect the salinity and surface currents in the fjord. Without salinity measurements it is difficult to conclude on the effects during the measurement period.

3.6 Wave modelling

The resulting wave height and the longest wave period at the location with only ocean swells included are presented in Table 8. The results with only wind induced waves are presented in Table 9 and with the combination of ocean swells and wind in Table 10. The results are given at the corners of the fish farm, and at the centre of the fleet. Figure 8 illustrates the reduction of the wave height when the waves are entering shallower water.

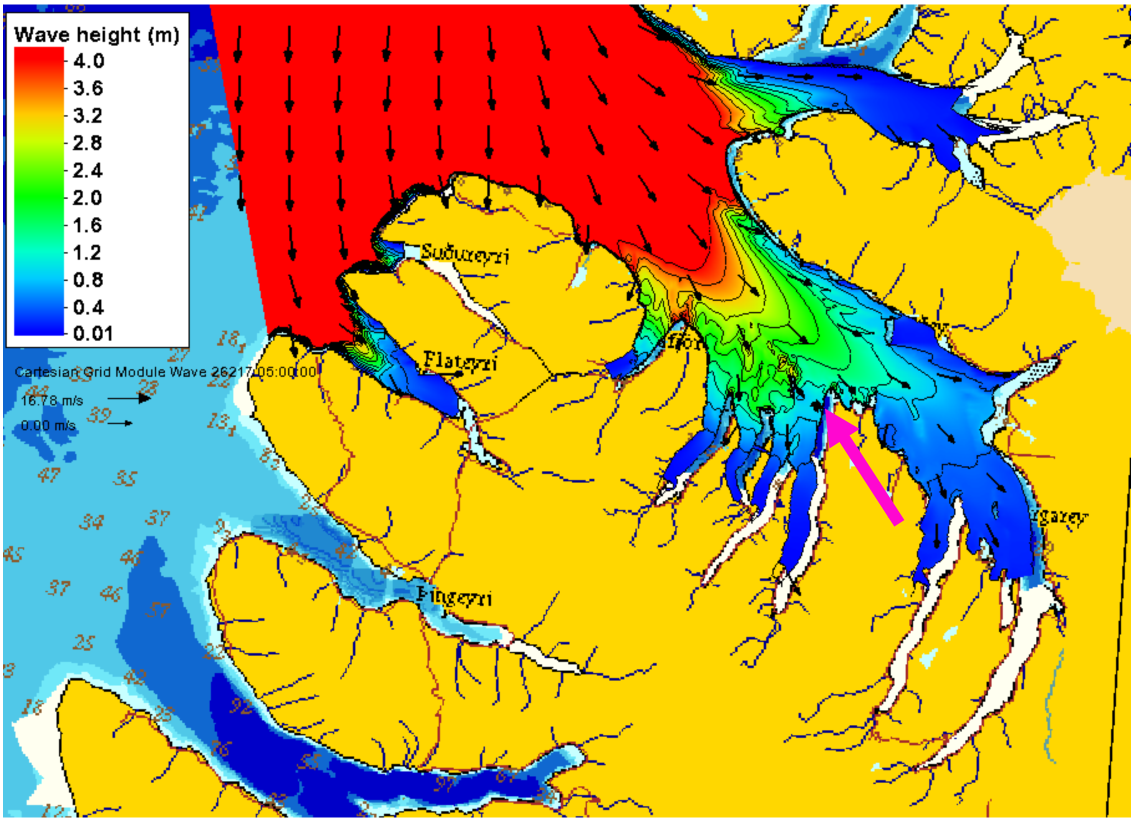

Figure 8. CMS-Wave modelling at the location Skötufjörður (position indicated with pink arrow) with ocean swells from the north-northeast (15 degrees). The wave direction is indicated with the black arrows. Significant wave height is given with color contours (map source: Olex).

3.6.1.1 Ocean waves

Ocean waves are modelled from west to north-northeast (270-30 degrees). The largest wave heights come from north-northeast (15 degrees), with a wave height 0,93 m and a wave period of 16,7 s.

Table 8. CMS-Wave model results for the significant wave height (Hs) from the corners of the fish farm and center-point of the fleet, and the wave period (Tp) at the site Skötufjörður. Only incoming ocean waves are included.

Corner point Northern site	Direction of incoming ocean waves								
	270°	285°	300°	315°	330°	345°	0°	15°	30°
Wave height, NW North (H_s) [m]	0,73	0,84	0,90	0,92	0,87	0,84	0,89	0,93	0,91
Wave height, NE North (H_s) [m]	0,62	0,71	0,76	0,77	0,73	0,81	0,86	0,89	0,88
Wave height, SE North (H_s) [m]	0,64	0,73	0,79	0,80	0,76	0,82	0,86	0,90	0,89
Wave height, SW North (H_s) [m]	0,72	0,83	0,89	0,90	0,86	0,83	0,88	0,92	0,90
Longest wave period at the location North (Tp) [s]	12,5	12,5	12,5	12,5	12,5	14,3	14,3	16,7	16,7
Corner point Southern site	270°	285°	300°	315°	330°	345°	0°	15°	30°
Wave height, NW South (H_s) [m]	0,69	0,79	0,85	0,86	0,82	0,81	0,86	0,90	0,88
Wave height, NE South (H_s) [m]	0,64	0,73	0,78	0,79	0,76	0,80	0,85	0,88	0,87
Wave height, SE South (H_s) [m]	0,64	0,74	0,79	0,80	0,76	0,80	0,85	0,89	0,88
Wave height, SW South (H_s) [m]	0,68	0,78	0,83	0,84	0,80	0,81	0,86	0,89	0,88
Longest wave period at the location South (T_p) [s]	12,5	12,5	12,5	12,5	12,5	14,3	14,3	16,7	16,7
Wave height, fleet (H_s) [m]	0,61	0,70	0,75	0,76	0,73	0,78	0,83	0,87	0,86

3.6.1.2 Wind induced waves

Wind induced waves have been modeled from all directions. The largest waves are coming from north-northwest (345 degrees), with a wave height of 3,59 meters, and have a wave period of 6,2 s.

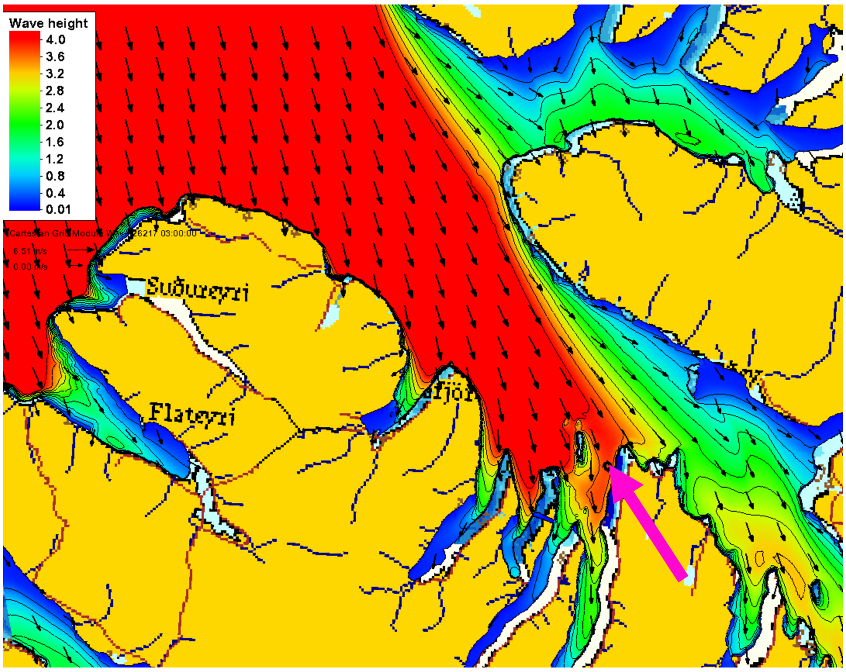

Figure 9. CMS-Wave modelling at the location Skötufjörður (position indicated with pink arrow) with wind induced waves from the north-northwest (345 degrees). It is from this direction that the largest wave heights occur at the location (3,59 m). The wave direction is indicated with the black arrows. Significant wave height is given with color contours (map source: Olex).

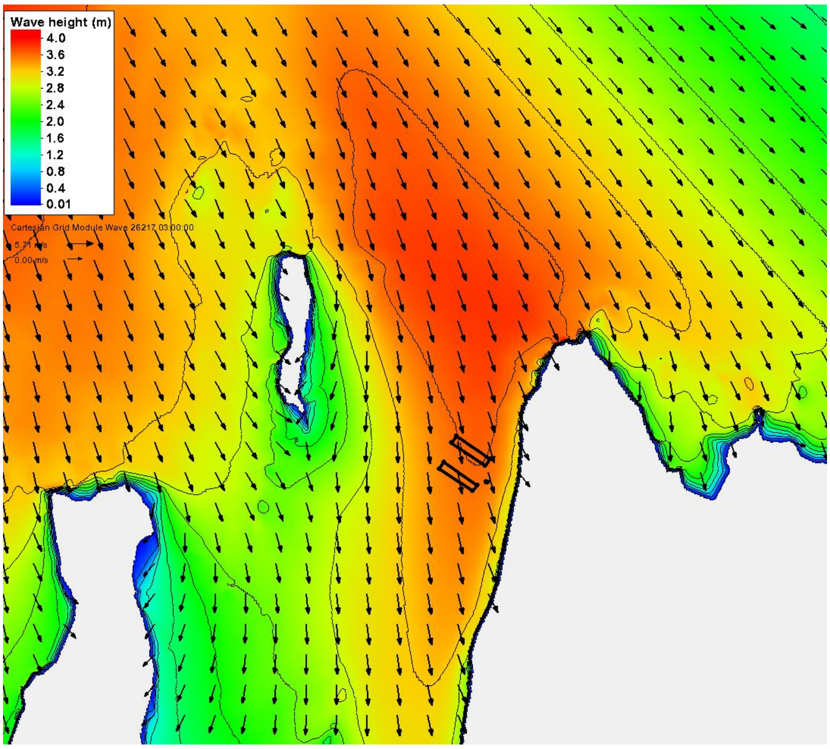

Figure 10. Same as in Figure 9,but with focus on the area close to the location with the nested model run (see Figure 2). The location is marked with two black squares (map source: Olex).

Table 9 CMS-Wave model results for the significant wave height (Hs) from the corners of the fish farm and the wave period (Tp) at the location Skötufjörður. Only wind induced waves are indicated.

Corner point northern site	**Direction of wind induced waves**											
	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°
Wave height, NW North (H_s) [m]	2,74	2,59	2,66	2,04	1,62	1,19	0,94	0,63	0,45	0,16	0,32	1,22
Wave height, NE North (H_s) [m]	2,65	2,37	2,20	1,02	0,75	0,60	0,52	0,37	0,27	0,14	0,25	0,85
Wave height, SE North (H_s) [m]	2,67	2,40	2,24	1,07	0,76	0,61	0,53	0,37	0,28	0,14	0,25	0,88
Wave height, SW North (H_s) [m]	2,75	2,60	2,66	2,02	1,57	1,14	0,90	0,60	0,43	0,16	0,32	1,25
Longest wave period at the location North (T_p) [s]	4,8	4,8	5,0	4,9	4,5	5,0	5,0	3,3	3,0	2,2	2,7	4,1
Corner point southern site	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°
Wave height, NW South (H_s) [m]	2,76	2,61	2,66	1,93	1,43	1,02	0,81	0,54	0,39	0,16	0,33	1,28

Wave height, NE South (H_s) [m]	2,69	2,41	2,24	1,05	0,72	0,57	0,50	0,35	0,26	0,14	0,26	0,90
Wave height, SE South (H_s) [m]	2,70	2,43	2,27	1,09	0,74	0,57	0,50	0,35	0,26	0,14	0,26	0,93
Wave height, SW South (H_s) [m]	2,76	2,61	2,66	1,94	1,42	1,00	0,79	0,53	0,39	0,16	0,34	1,31
Longest wave period at the location South (T_p) [s]	4,8	4,8	5,0	4,8	4,3	5,0	5,0	3,1	2,8	2,2	2,7	3,7
Wave height, fleet (H_s) [m]	2,65	2,34	2,13	0,88	0,63	0,51	0,45	0,32	0,24	0,14	0,25	0,83
Corner point northern site	180°	195°	210°	225°	240°	255°	270°	285°	300°	315°	330°	345°
Wave height, NW North (H_s) [m]	1,85	2,03	1,83	1,75	1,42	1,57	1,82	1,75	1,81	2,66	3,34	3,59
Wave height, NE North (H_s) [m]	1,54	1,87	1,77	1,84	1,56	1,65	2,01	2,07	1,89	2,78	3,42	3,59
Wave height, SE North (H_s) [m]	1,56	1,88	1,77	1,82	1,54	1,62	2,00	2,09	1,90	2,73	3,39	3,59
Wave height, SW North (H_s) [m]	1,86	2,03	1,82	1,73	1,40	1,54	1,85	1,82	1,78	2,59	3,28	3,57
Longest wave period at the location North (T_p) [s]	4,2	4,2	4,2	3,7	3,3	3,3	3,7	4,2	7,7	8,3	7,7	6,2
Corner point southern site	180°	195°	210°	225°	240°	255°	270°	285°	300°	315°	330°	345°
Wave height, NW South (H_s) [m]	1,87	2,01	1,80	1,71	1,37	1,44	1,86	1,98	1,77	2,42	3,14	3,51
Wave height, NE South (H_s) [m]	1,58	1,87	1,75	1,78	1,49	1,52	1,95	2,16	2,03	2,58	3,29	3,56
Wave height, SE South (H_s) [m]	1,60	1,88	1,75	1,76	1,47	1,48	1,92	2,17	2,07	2,52	3,24	3,55
Wave height, SW South (H_s) [m]	1,88	2,01	1,79	1,69	1,35	1,39	1,85	2,01	1,85	2,36	3,08	3,48
Longest wave period at the location South (T_p) [s]	4,2	4,2	4,2	3,7	3,3	3,3	3,7	4,2	4,6	8,3	7,7	6,2
Wave height, fleet (H_s) [m]	1,50	1,83	1,73	1,80	1,53	1,57	1,98	2,17	2,02	2,64	3,32	3,55

3.6.1.3 Combined ocean waves and wind induced waves

Combined ocean swells and wind induced waves have been modelled from west to north-northeast (270-30 degrees). The largest waves are from north-northwest (330 degrees), with a wave height of 3,49 meters and have a wave period of 7,1 s.

Table 10. CMS-Wave model results for the significant wave height (Hs) from the corners of the fish farm and the wave period (Tp) at the location Skötufjörður. Numbers represent a combination of ocean waves and wind induced waves.

Corner point northern site	**Direction of combination of ocean waves and wind induced waves**								
	270°	285°	300°	315°	330°	345°	0°	15°	30°

Wave height, NW North (H_s) [m]	1,18	1,53	1,90	2,60	3,41	3,48	2,53	1,57	1,33
Wave height, NE North (H_s) [m]	1,05	1,38	1,80	2,69	3,49	3,47	2,43	1,51	1,30
Wave height, SE North (H_s) [m]	1,07	1,40	1,82	2,65	3,46	3,48	2,46	1,51	1,30
Wave height, SW North (H_s) [m]	1,17	1,50	1,87	2,52	3,34	3,45	2,54	1,56	1,31
Longest wave period at the location North (T_p) [s]	12,5	12,5	12,5	9,1	7,1	6,2	14,3	14,3	14,3
Corner point southern site	270°	285°	300°	315°	330°	345°	0°	15°	30°
Wave height, NW South (Hs) [m]	1,12	1,44	1,81	2,37	3,20	3,39	2,57	1,56	1,26
Wave height, NE South (Hs) [m]	1,06	1,38	1,79	2,51	3,35	3,45	2,50	1,51	1,25
Wave height, SE South (Hs) [m]	1,06	1,37	1,78	2,45	3,30	3,44	2,53	1,52	1,25
Wave height, SW South (Hs) [m]	1,10	1,42	1,78	2,32	3,13	3,36	2,58	1,56	1,24
Longest wave period at the location South (Tp) [s]	12,5	12,5	12,5	9,1	7,1	6,2	14,3	14,3	14,3
Wave height, fleet (H_s) [m]	1,03	1,35	1,77	2,56	3,38	3,44	2,45	1,48	1,25

3.6.1.4 Summary wave modelling

The wave modelling of significant wave height with 50 years return values at site Skötufjörður has shown that the largest exposure is with wind generated waves from north-northwest (345 degrees). The largest wave height is (H_s) 3,59 m at the location with a period of 6,2 s. The local wind generated waves from the simulated direction have a period of typically between 2 and 8 s. The combination of wind induced waves and ocean waves have resulted in a wave height of 3,49 m from north-northwest (330 degrees) with a corresponding wave period of 7,1 s. The largest exposure with ocean swells only is from north-northeast (15 degrees) with a wave height of 0,93 meters with a corresponding period of 16,7 s. In general, the southern and northern site experience similar exposure, but the southern site reaches somewhat lower wave heights. The largest wave height for the fleet is 3,55 m from north-northwest (345 degrees), also this by wind generated waves. The largest wave condition regardless of forcing is shown in Table 11.

From Figure 5 it can be seen that the site is sheltered by the island Vigur. Thus, the site has a limited fetch length in western to northwestern directions. Waves are allowed to build up in Ísafjarðardjúp due to the long fetch length towards the open sea, the results show that in northern direction, where the site is not sheltered by Vigur, rather large wave heights are able to reach the site. It can also be seen that wind induced waves are able to build up in northeastern and southerly directions due smaller, but still considerable fetch length.

3.7 Bottom type

According to local knowledge (Pers.mes. Geirsson) the bottom is for the most part soft, with harder bottom types close to shore. The bottom at the site is relatively flat with a slight slope towards the middle of the fjord. The depth under the installations varies from 50 meters in east towards shore, to 80 meters in west. There is considered to be little risk of chafing on mooring lines.

3.8 Ship-generated waves

The site is situated in an area with some ship-traffic. The customer has specified that there are some shrimp-fishing vessels and tourist boats sailing in the area, smaller fishing vessels usually sails further out in the fjord and larger vessels rarely sails so far into the fjord. A review has been carried out regarding wave height in accordance with distance and size of passing ships. It is not expected that these waves will exceed the local generated wind induced waves.

Table 11 Results from the wave modelling. The direction of the wind and waves is given so that they can be read together with the current.

Lokalitet: Skötufjördur							Lokalitet: Skötufjördur			Vindbølger				Havbølger (CMS)				Havdønning og vind (CMS)			
	Strøm (5 m)			Strøm (15 m)				Vind		10 års retur		50 års retur		10 års retur		50 års retur		10 års retur		50 års retur	
Retning (grader)	Maks (cm/s)	10 års retur	50 års retur	Maks (cm/s)	10 års retur	50 års retur	Retning vind, bølger (grader)	10 års retur	50 års retur	Hs (m)	Tp (s)	Hs (m)	Tp (s)	Hs (m)	Tp (s)	Hs (m)	Tp (s)	Hs (m)	Tp (s)	Hs (m)	Tp (s)
0	23	37	42	15	24	27	180	25	28	1,69	3,8	1,88	4,2								
15	37	61	68	21	34	39	195	25	28	1,83	3,8	2,03	4,2								
30	40	66	73	37	61	68	210	25	28	1,65	3,8	1,83	4,2								
45	43	71	80	46	76	85	225	25	28	1,66	3,3	1,84	3,7								
60	29	48	54	42	69	77	240	25	28	1,40	3,0	1,56	3,3								
75	31	51	58	28	47	53	255	25	28	1,49	3,0	1,65	3,3								
90	20	33	37	14	23	26	270	25	28	1,81	3,3	2,01	3,7	0,66	11,3	0,73	12,5	1,06	11,3	1,18	12,5
105	10	17	19	10	16	18	285	25	28	1,95	3,8	2,17	4,2	0,76	11,3	0,84	12,5	1,38	11,3	1,53	12,5
120	10	16	18	8	13	15	300	25	28	1,86	4,1	2,07	4,6	0,81	11,3	0,90	12,5	1,71	11,3	1,90	12,5
135	7	12	14	10	16	18	315	25	28	2,50	7,5	2,78	8,3	0,83	11,3	0,92	12,5	2,42	8,2	2,69	9,1
150	10	17	19	10	17	19	330	27	30	3,08	6,9	3,42	7,7	0,78	11,3	0,87	12,5	3,14	6,4	3,49	7,1
165	12	19	21	9	15	17	345	30	33	3,23	5,6	3,59	6,2	0,76	12,9	0,84	14,3	3,13	4,8	3,48	5,3
180	18	30	34	12	19	22	0	30	33	2,48	4,3	2,76	4,8	0,80	12,9	0,89	14,3	2,32	12,9	2,58	14,3
195	20	33	37	14	23	26	15	30	33	2,35	4,3	2,61	4,8	0,84	15,0	0,93	16,7	1,41	12,9	1,57	14,3
210	23	37	42	15	24	27	30	36	40	2,39	4,5	2,66	5,0	0,82	15,0	0,91	16,7	1,20	12,9	1,33	14,3
225	25	42	47	18	30	33	45	36	40	1,84	4,4	2,04	4,9								
240	21	34	38	15	25	28	60	36	40	1,46	4,1	1,62	4,5								
255	18	29	33	10	17	19	75	36	40	1,07	4,5	1,19	5,0								
270	19	31	34	7	11	12	90	36	40	0,85	4,5	0,94	5,0								
285	17	27	31	7	12	13	105	28	31	0,57	3,0	0,63	3,3								
300	11	18	20	8	13	15	120	24	27	0,41	2,7	0,45	3,0								
315	13	22	24	10	16	18	135	23	25	0,14	2,0	0,16	2,2								
330	16	26	29	9	15	17	150	23	25	0,31	2,4	0,34	2,7								
345	20	33	37	12	19	21	165	25	28	1,18	3,3	1,31	3,7								
Maks	**43**	**71**	**80**	**46**	**76**	**85**	**Maks**	**36**	**40**	**3,23**	**7,5**	**3,59**	**8,3**	**0,84**	**15,0**	**0,93**	**16,7**	**3,14**	**12,9**	**3,49**	**14,3**

4 Ice load

The exposure of snow and ice for the site has been investigated.

According to people with local knowledge, freezing occurs mostly in the innermost parts of the fjords that form the fjord system Ísafjarðardjúp. In Skötufjörður freshwater can freeze in the innermost part of the fjord, and when this breaks up the ice can be transported towards the site with southerly winds, but by the time the ice will have reached the site, it will have been broken up. It has been indicated that the fish farmer has internal procedures to handle eventual ice loads (Geirsson, pers.mess).

During the investigations calculations of ice loads have been performed. By use of long term statistics for wind and air temperature, a frequency table has been extracted (Table 12), based on an ice prediction table (Table 13).

Statistics from the nearest weather observation station, Ögur, was extracted from the Icelandic Meteorological Office (www.vedur.is). The available data is from the period 16.09.1997-24.04.2021.

The number of observations of combinations of the given wind strength and temperature during the measurement period is shown in Table 12, and the different color zones are shown in Table 13. The description of the method used to calculate ice loads is shown in appendix 7.4.

Table 12 Number of observations of the given wind strength and temperature at the weather observation station Ögur during the period 16.09.1997-24.04. 2021.Interpretation of the colour code is provided in Table 13.

Sjøvannstemp	**1**																														
Vind (m/sek)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
Lufttemperatur																															
0	508	855	1199	1257	1324	1153	939	846	727	662	600	454	373	316	248	175	120	100	80	60	31	28	24	14	8	7	2	1	6	2	
-1	390	746	968	1078	1001	863	726	618	555	557	455	353	321	265	219	128	119	85	42	32	24	26	13	10	2	4	2	4			1
-2	286	556	809	879	820	641	576	460	429	400	332	315	279	217	176	106	100	57	57	34	26	11	10	16	3	7	2	2	3	1	
-3	192	442	594	616	577	503	412	323	355	375	273	227	215	174	128	91	84	43	32	30	15	12	14	11	4	5					
-4	140	338	447	480	475	383	360	279	241	232	202	188	143	135	100	74	50	15	28	12	9	7	8	10	1	2	2				
-5	88	241	311	305	294	208	186	159	145	140	112	86	78	82	40	38	31	11	10	4	6	7	1								
-6	51	111	249	194	159	137	104	87	71	91	73	69	38	29	26	20	20	12	7	4											
-7	16	84	133	142	96	90	60	61	55	33	38	33	32	25	18	13	13	7	3	1			2		2						
-8	11	65	102	76	62	55	35	32	32	25	33	36	25	21	14	14	4	3	1			2	3		1						
-9	3	34	53	47	33	26	31	28	26	29	46	31	29	22	7	2	3		1	1	2										
-10	1	12	22	24	22	18	13	12	10	10	9	12	9	4	3	3															
-11	1	10	19	11	6	6	6	12	6	7	4	1	1	1		4															
-12		9	15	3	5	2	1	1		3		1	1		2	1	1														
-13		2	4	4				1	1	2	2	3	1		1	1															
-14			1		1						2	2	5	3	1	1															
-15																															
-16																															
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-31																															
-32																															
-33																															
-34																															
-35																															
Ant. av tot. obs. (%)	3,7	7,6	10,7	11,1	10,6	8,9	7,5	6,3	5,8	5,6	4,7	3,9	3,4	2,8	2,1	1,5	1,2	0,7	0,6	0,4	0,2	0,2	0,2	0,1	0,0	0,1	0,0	0,0	0,0	0,0	0,0

Table 13 Ice loads of the different zones. The color code is based on the formula of the ice prediction (Guest et al., 2005).

Ice prediction (PPR) w/color code	<0	0-22,4	22,4-53,3	53,3-83,0	>83,0
Ice class	None	Some	Moderate	Heavy	Extreme
Ice rate (cm/hour)	0	<0,7	0,7-2,0	2,0-4,0	>4,0
Ice rate (kg/m^2/hour)	0	0,8-6,0	6-17	17-34	>34

Table 12 show that there have been one observation of wind/temperature combinations that would lead to heavy icing. In cases with heavy icing the estimated ice load will be 2,0-4,0 cm/h which indicates an ice load between 17 and 34 kg/m^2/hour. Further, the table shows that during the period of 24 years there have been 347 observations that indicate risk of moderate icing. In cases with moderate icing the estimated ice load will be 0,7-2 cm/h, which indicates an ice load between 6 and 17 kg/m^2/hour.

The site is exposed of wind and waves from north-northwest (Table 11 and Figure 11), thus mostly exposed to icing during cold periods with strong winds from the same direction. Breaking of wind induced waves that coincides with strong winds and low temperatures from the same directions might lead to sea spray icing. The main current direction is towards the north-northeast; hence it is likely that these conditions might occur.

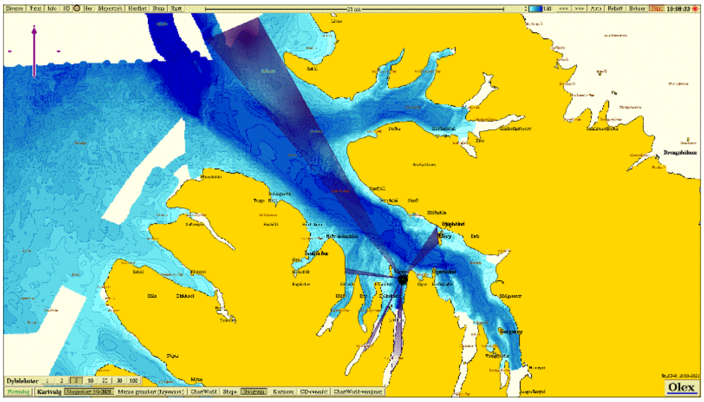


Figure 11. Wave exposure at the site Skötufjörður.

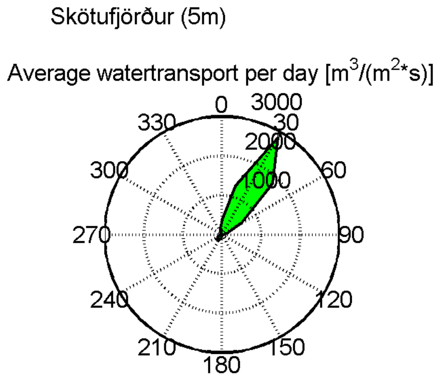


Figure 12 Main current direction 5 m.

The results from the calculations suggest that there is a risk that icing might occur on the installations and cause damage. Thus, there should be taken certain precautions. If there are wind/temperature combinations that indicate moderate or heavy icing, the farmer must implement actions for monitoring and possible de-icing. From table Table 12 it can be seen that in the period of 24 years, 3,7 % of the observations at minus degrees correspond to 0-1 m/s wind speed. This indicates that the risk of drift ice and freezing is present, but low as there are relatively few observations with little wind and minus degrees. In addition, there are relatively high current speeds at the site, which reduces the risk of drift ice and freezing.

5 Instrument description

The current measurements were carried out using point doppler instruments from Aanderaa and methods in accordance with NS 9425 - 1.

Table 14 Instrument description

Measurement depth	5 m	15 m
nstrument	Aanderaa	Aanderaa
Model	Seaguard 4420	Seaguard 4420
Measurement principle	Point doppler	Point doppler
Serial number	1832	1455
Accuracy	± 1 %	± 1 %
Resolution	0,5 mm/s	0,5 mm/s
Area of response	0 – 3 m/s	0 – 3 m/s
Averaging periode	10 min	10 min
Modifications	None	None
Calibrations	APN-log	APN-log
Instrument log	APN-log	APN-log

The results from the current measurements are analysed in Akvaplan-niva's software, AdFontes. First the results are filtered through a rough cleaning where all outliers beyond the given criteria from the producers are removed, and where all data points where the pressure sensor has registered over 2 meters above the sea surface is removed. Further, data are visually quality checked through AdFontes. The cleaned dataset is stored in Akvaplan-niva's archive.

The results that are presented are directly transferred from the raw data. There are no reductions of noise or data compression. The tidal water is filtered with a ½ hour time interval.

Calibrations of the instruments are performed in accordance to recommodations from the manufacturers. The calibration history is stored at Akvaplan-niva.

Topography is mapped using a multibeam echo sounder. The installations is drawn using an OLEX system.

6 Literature list

Codiga, D.L. Unified Tidal Analysis and Prediction Using the UTide Matlab Functions (2011)

Guest et al. 2005. Vessel Icing. Mariners Weather Log, Vol 49, No3. Desember 2005.

Hasselmann K., T.P. Barnett, E. Bouws, H. Carlson, D.E. Cartwright, K. Enke, J.A. Ewing, H. Gienapp, D.E. Hasselmann, P. Kruseman, A. Meerburg, P. Müller, D.J. Olbers, K. Richter, W. Sell, and H. Walden, 1973. *Measurements of wind-wave growth and swell decay during the Joint North Sea Wave Project (JONSWAP)*. Ergänzungsheft zur Deutschen Hydrographischen Zeitschrift Reihe, A(8) (Nr. 12), p. 95.

Jensen Ø. 2006 SINTEF rapport: Islaster-isvekst og forslag til tiltak.

Nasjonalt tillegg, NA - Eurokode 1: *Laster på konstruksjoner - Del 1-4: Allmenne laster – Vindlaster*, 2009. NS-EN 1991-1-4:2005/NA:2009. ICS: 91.010.30, 91.080.01. 48 sider.

NS 9415:2009. Flytende oppdrettsanlegg - Krav til lokalitetsundersøkelse, risikoanalyse, utforming, dimensjonering, utførelse, montering og drift. ICS: 65.150, 67.260. 108 sider.

NS 9425-1. 1999. Oseanografi – Del 1. Strømmålinger i faste punkter.

Nygaard, E. & Eik, K. J., 2004. Application of STWAVE in Norwegian coastal water. In: Proceedings, 8th International Workshop on Wave Hindcasting and Forecasting. 9 sider.

Personal message: Gauti Geirsson, Háafell ehf.

Reistad, M., Breivik, Ø., Haakenstad, H., Aarnes, O.J., Furevik, B. and Bidlot, J.-R., 2011. A high-resolution hindcast of wind and waves for the North Sea, the Norwegian Sea and the Barents Sea. Journal of Geophysical Research, Vol. 116, C05019, doi: 10.1029/2010JC006402.

Sanchez, A., Lin, L., Demirbilek, Z., Beck, T., Brown, M., Li, H., Rosati, J.D., Wu, W. and Reed, C., 2012. Draft CMS User Manual, June 20, 2012. (No. ERDC/CHL-TR-11-X). Engineer Research and Development Center Vicksburg MS Coastal and Hydraulics Lab. pp 332.

Smith, J. M., Militello, A., and Smith, S. J., 1998. "Modelling waves at Ponce de Leon Inlet, Florida." Proc. 5th International Workshop on Wave Hindcasting and Forecasting, Environment Canada, Downsview, Ontario, 201-214.

Superstructure spray and ice accretion on a large U.S. Coast Guard cutter C.C. Ryerson, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, USA. Received 14 October 1993. Accepted 23 February 1994. Available online 16 March 2000.

www.vedur.is

7 Appendix

7.1 Current measurements

7.1.1 Current measurement

According to the NS 9415:2009 the expected maximum velocity should be estimated for the site. This is calculated by multiplication of the highest velocity during the measurement period with given multiplication factors of 1,65 and 1,85 for 10 and 50 years return period, respectively. NS 9415:2009 states: "*If the highest dimensional current velocity with a return period of 50 years based on a measuring period for one month is less than 50 cm/s the dimensional current velocity will be set to 50 cm/s. The other values of the currents will be increased at the same percental rate*".

7.1.2 Tidal water

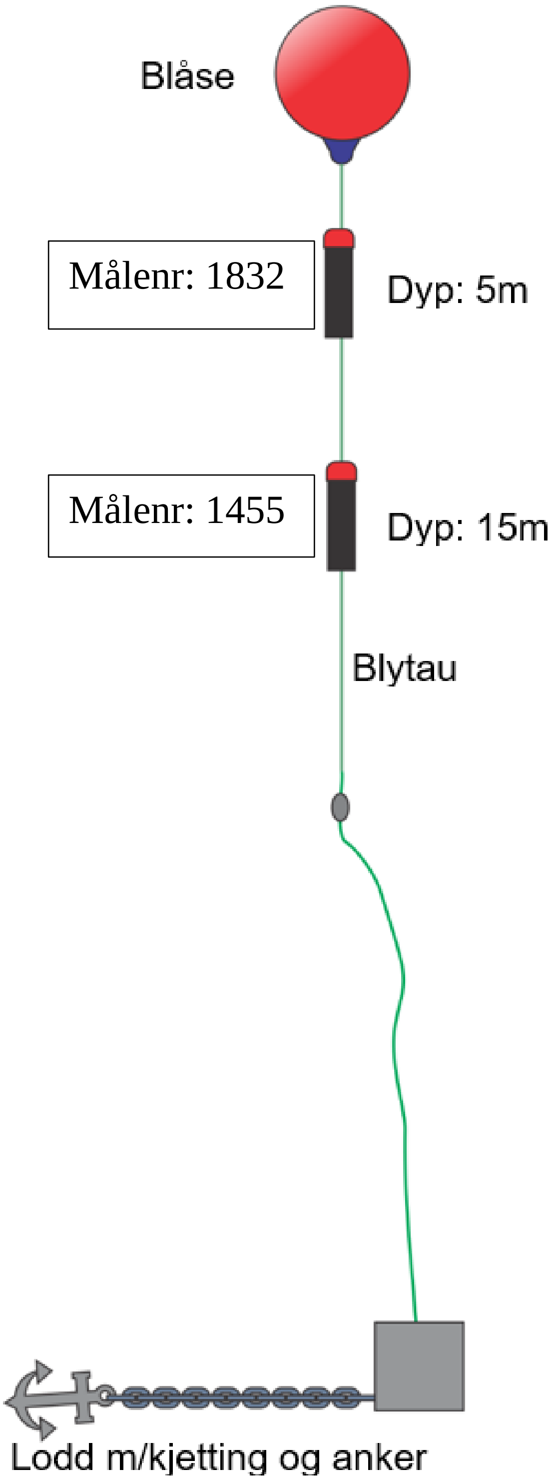
To extract the tidal water component from the total current a harmonic analysis of the current is performed. The current velocity is first averaged over ½- hour to remove noise from the time series before the analysis is performed.

The results from the harmonic analysis was used to reproduce the tidal current contribution in the data set using a tidal water model (Codiga, 2011). The total current is averaged over ½-hour before the variance ellipse is estimated, so that the variance of the two components are estimated using the basis. The variance ellipses show a standard deviation of the two components for a) all the measurements and b) the reproduced tidal water component. Variance explained is estimated from the correlation (r) between the total current and the tidal water current and is calculated using the formula:

Variance explained = [correlation coefficient (speed_tidal water, speed_total current)]^2.

This gives a measurement of how much of the total variance that can be explained by the estimated tidal water component. It is important to note that these ellipses are not a classical tidal water ellipse but a variance ellipse of the tidal water component of the current, and that the tidal water is estimated from a model and is not an actual measurement.

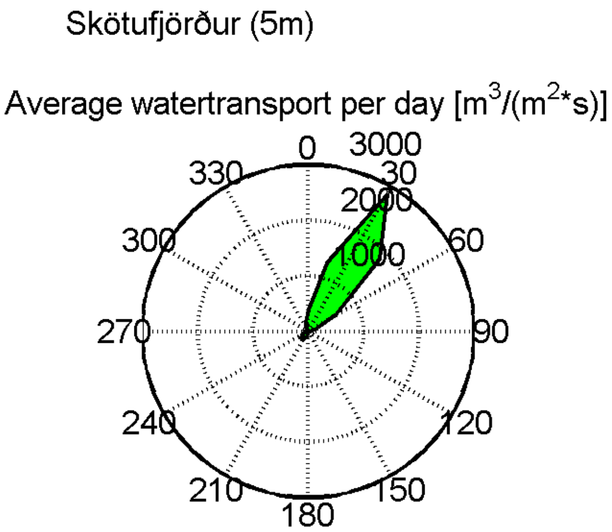
7.1.3 Rig sketch



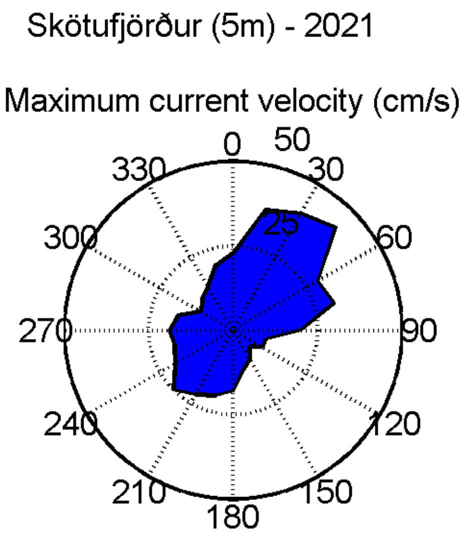
7.1.4 5 meters depth

Summary of results from Skötufjörður 5 meter

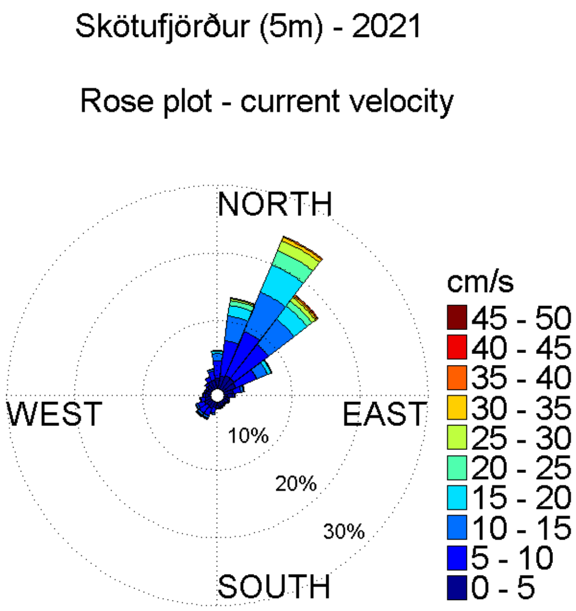
	Speed (cm/s)	Temperature (°C)
Max	43.2	12.5
Min	0.1	4.6
Mean	9.7	8.6
% of the measurements > 60 cm/s	0	
% of the measurements > 50 cm/s	0	
% of the measurements > 40 cm/s	0	
% of the measurements > 30 cm/s	1.4	
% of the measurements > 20 cm/s	8.2	
% of the measurements > 10 cm/s	37.9	
% of the measurements < 10 > 3 cm/s	50.1	
% of the measurements < 3 > 1 cm/s	10.3	
% of the measurements < 1 cm/s	1.7	
95-prosentil (95 % of the measurements is lower than this value)	23.6	
Residual current speed	7.3	
Residual current direction	17	
Variance	45.1	3.9
Standard deviation	6.7	2
Stability (Neumanns parameter)	0.75	



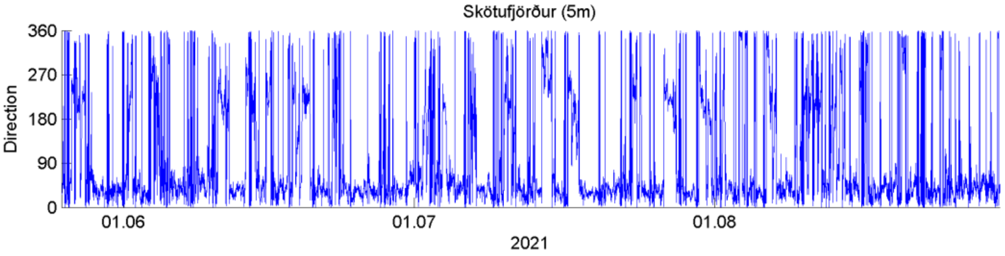
Total water transport



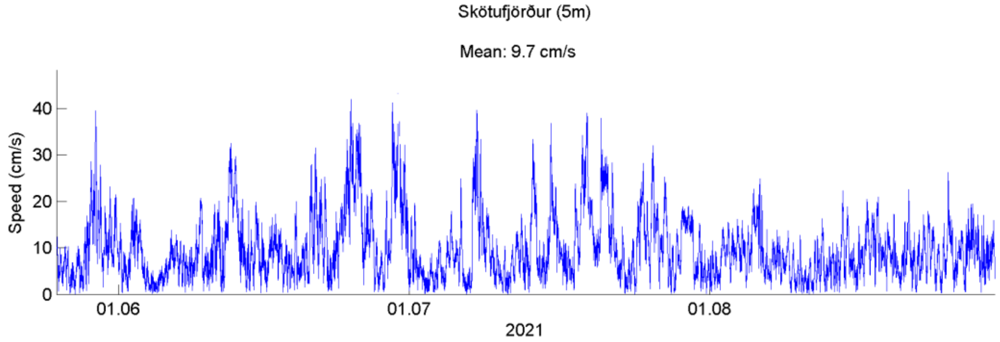
Maximum velocity



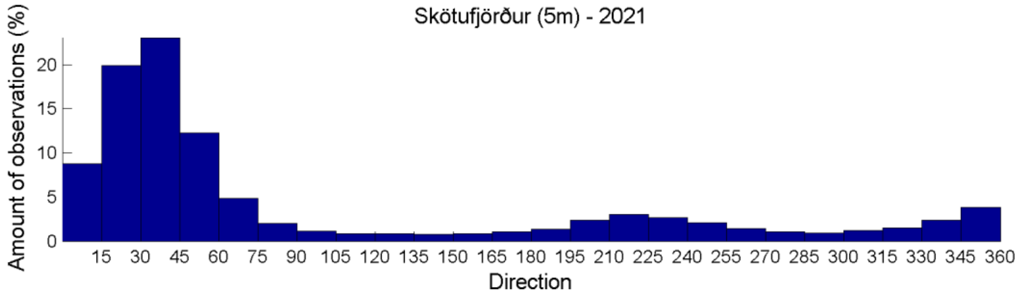
Current strength and direction distribution. The total length of the sectors indicates the number of measurements (%) in the respective directions. The length of every color segment in each sector determines the relative portion of measurements with the corresponding current strength within every sector.



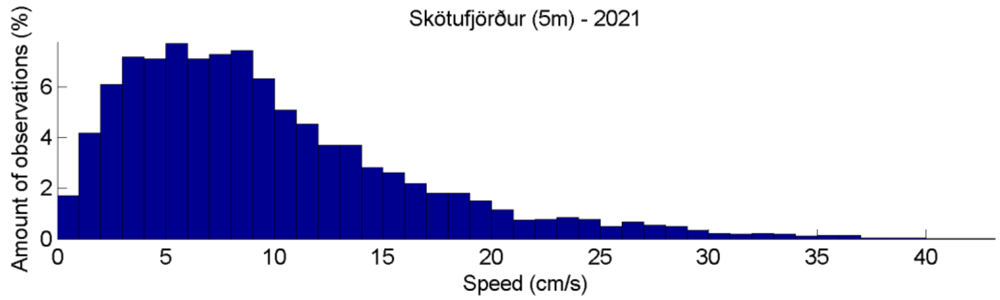
Current direction (time series)



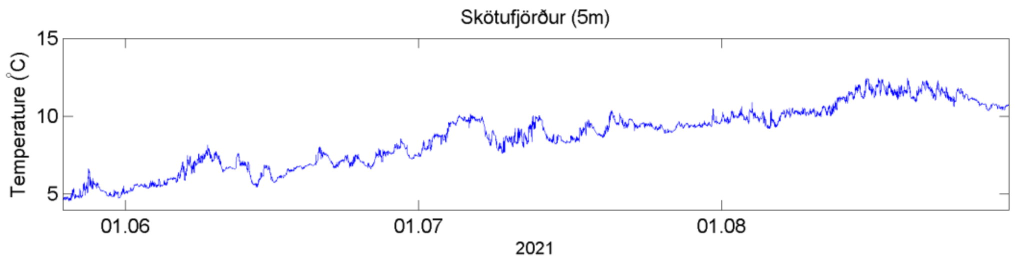
Current velocity (time series)



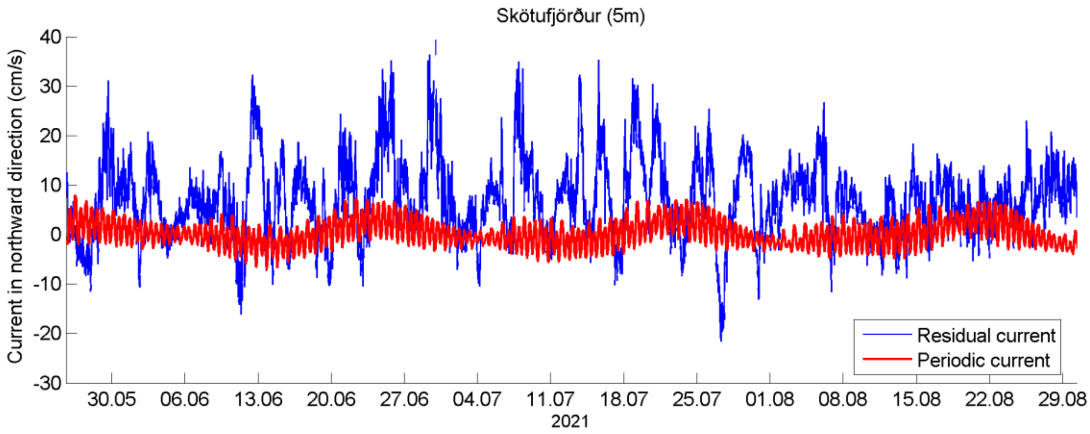
Directional histogram



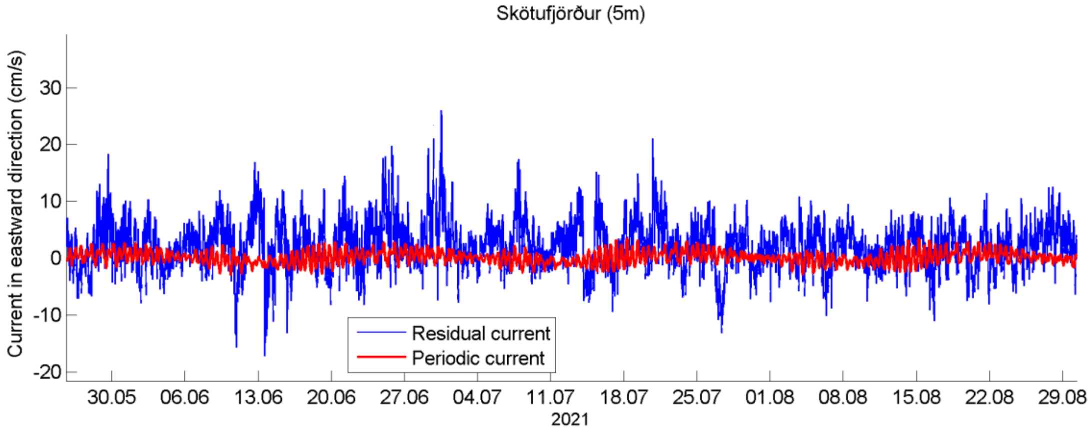
Current velocity histogram



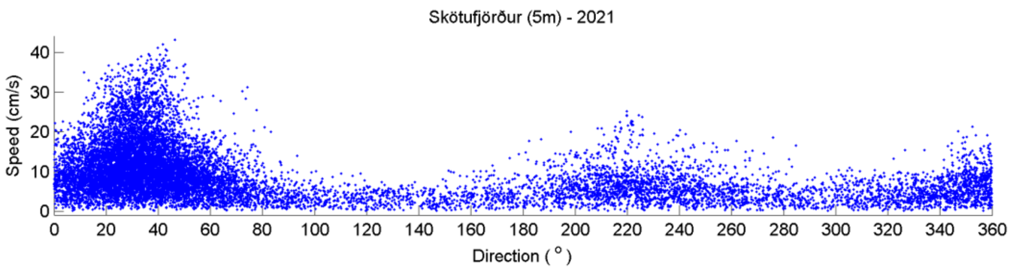
Temperature time series



Estimated tidal water current in the north/south direction at 5 meters depth. Negative values indicate currents towards the south. The red curve represents the tidal water current, and the blue line represent the remaining current.



Estimated tidal water current in the east/west direction at 5 meters depth. Negative values indicate currents towards the west. The red curve represents the tidal water current, and the blue line represent the remaining current.



Scatter plot for registrations of speed vs direction.

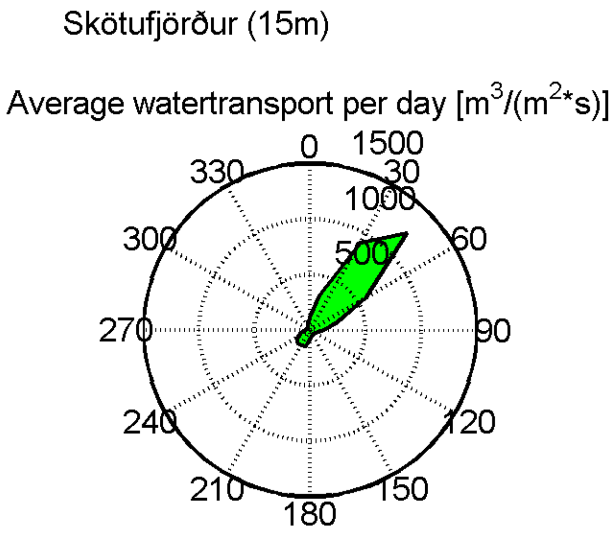
Table showing the number of measurements, maximum velocity, total water transport and the daily water transport in the different sectors.

Direction	Num. of measurem.(N)	Max speed (cm/s)	Total watertransport ($m^3/(s\ m^2)$)	Water transport per day ($m^3/(s\ m^2)$)
352.5 - 7.4	777	22.6	37874.9	391.6
7.5 - 22.4	1876	36.8	122215.5	1263.5
22.5 - 37.4	3383	39.7	276080.9	2854.2
37.5 - 52.4	2476	43.2	177370.5	1833.7
52.5 - 67.4	1072	29.1	54137.9	559.7
67.5 - 82.4	418	31.2	16384.7	169.4
82.5 - 97.4	219	20.1	5384.5	55.7
97.5 - 112.4	116	10.1	2562.6	26.5
112.5 - 127.4	133	9.5	2763.7	28.6
127.5 - 142.4	99	7.3	2070.2	21.4
142.5 - 157.4	113	10.3	2187.3	22.6
157.5 - 172.4	137	11.6	3465.5	35.8
172.5 - 187.4	136	18.2	4042.6	41.8
187.5 - 202.4	258	20.1	9355.1	96.7
202.5 - 217.4	395	22.5	16707.5	172.7
217.5 - 232.4	408	25.3	18092.1	187
232.5 - 247.4	348	20.5	12755	131.9
247.5 - 262.4	225	17.7	7443.6	77
262.5 - 277.4	167	18.6	4572.7	47.3
277.5 - 292.4	141	16.6	3179.9	32.9
292.5 - 307.4	129	10.9	3308.5	34.2
307.5 - 322.4	185	13.2	4641.9	48
322.5 - 337.4	270	15.5	7137.4	73.8
337.5 - 352.4	411	20.1	15345.4	158.6

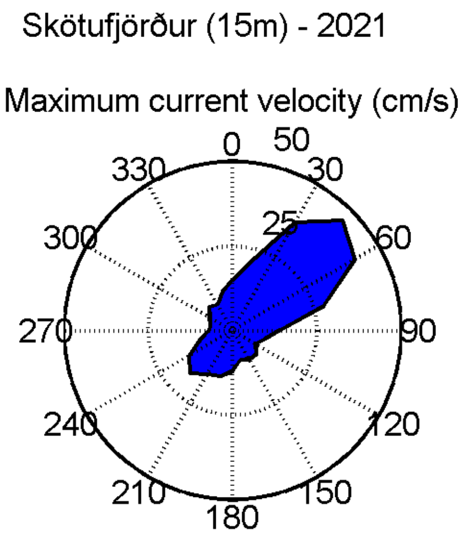
7.1.5 15 meters depth

Summary of the results from Skötufjörður 15 meters

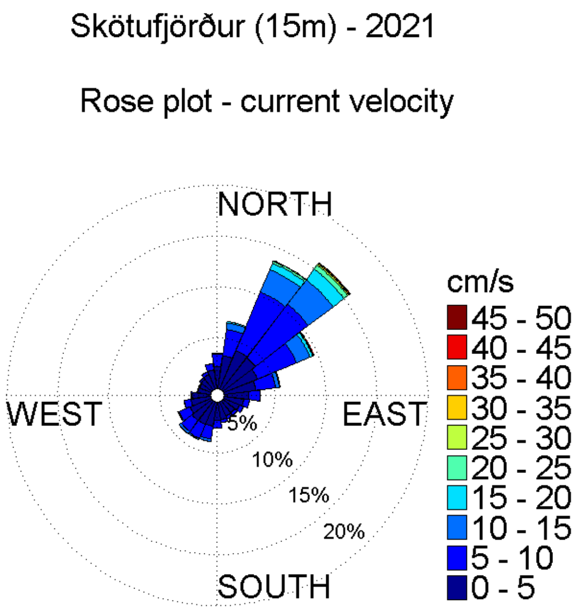
	Speed (cm/s)	Temperature (°C)
Max	45.9	11
Min	0.1	4.2
Mean	5.7	8
% of the measurements > 60 cm/s	0	
% of the measurements > 50 cm/s	0	
% of the measurements > 40 cm/s	0	
% of the measurements > 30 cm/s	0.2	
% of the measurements > 20 cm/s	1.2	
% of the measurements > 10 cm/s	12.6	
% of the measurements < 10 > 3 cm/s	58.9	
% of the measurements < 3 > 1 cm/s	24.3	
% of the measurements < 1 cm/s	4.3	
95-prosentil (95 % of the measurements is lower than this value)	13.7	
Residual current speed	3.1	
Residual current direction	32	
Variance	18.6	3.5
Standard deviation	4.3	1.9
Stability (Neumanns parameter)	0.54	



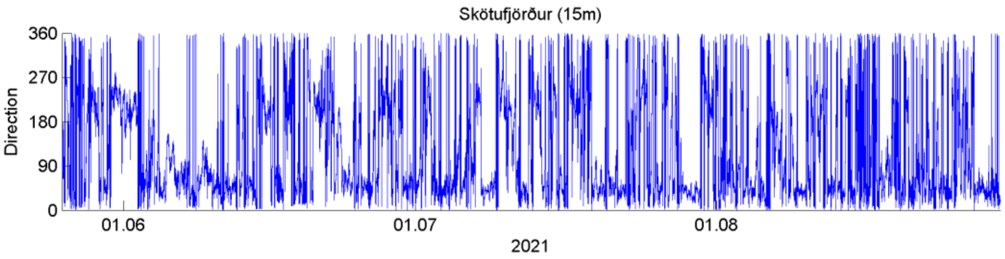
Total water transport



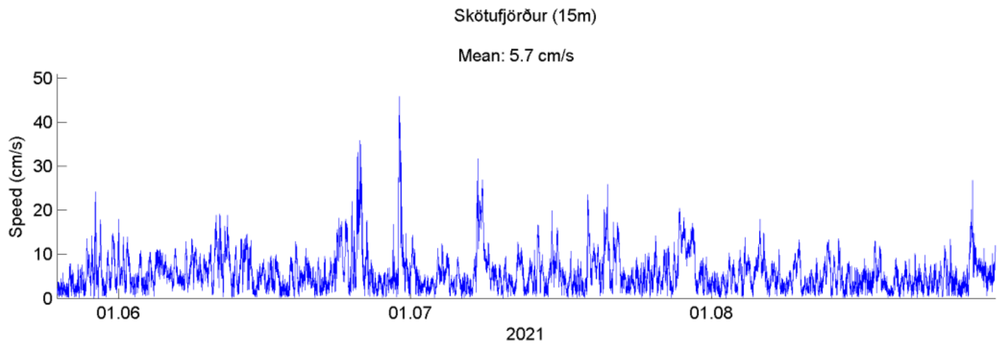
Maximum velocity



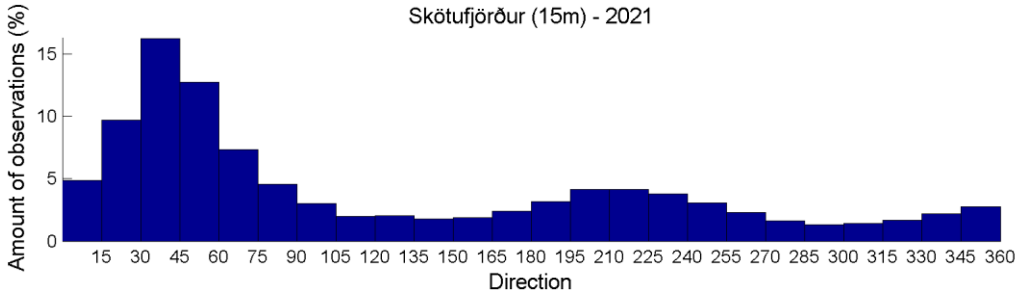
Current strength and direction distribution. The total length of the sectors indicates the number of measurements (%) in the respective directions. The length of every color segment in each sector determines the relative portion of measurements with the corresponding current strength within every sector.



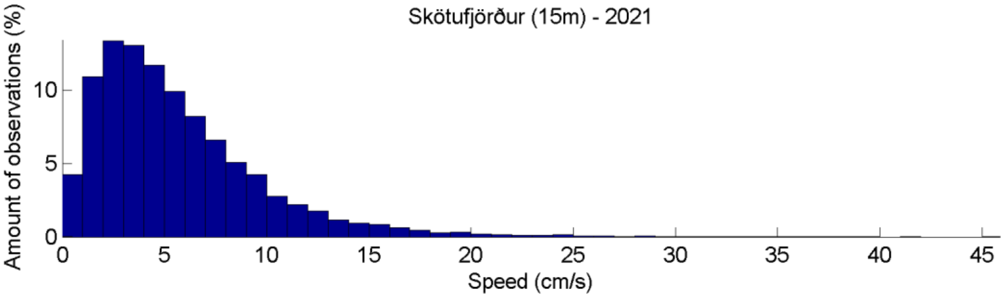
Current direction (timeseries)



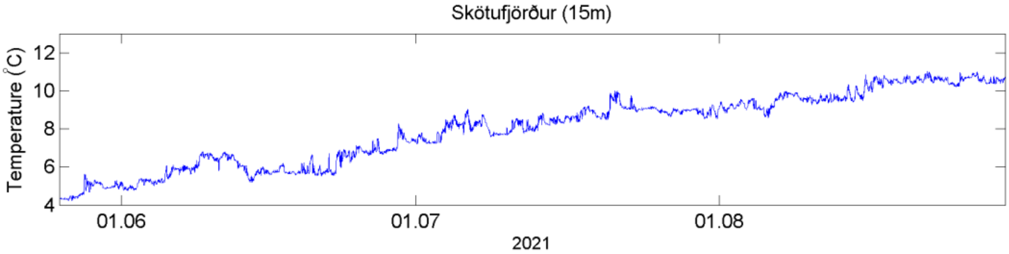
Current velocity (timeseries)



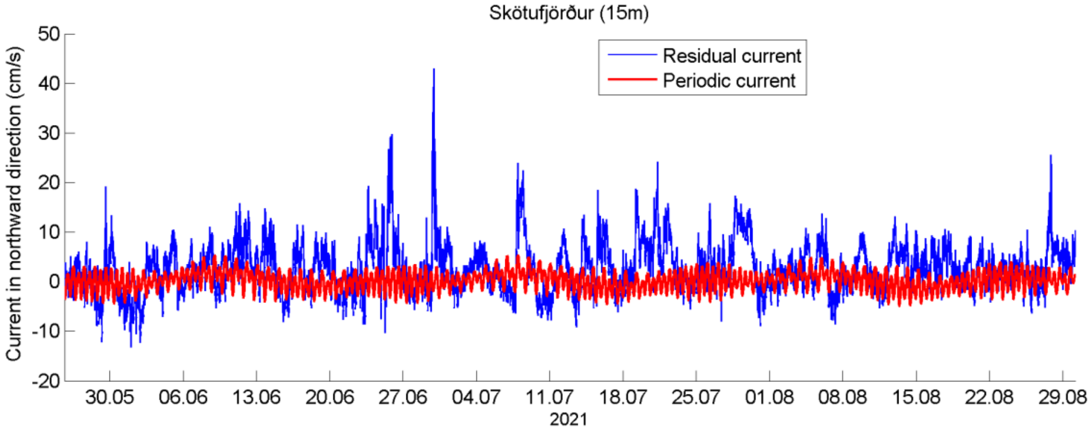
Directional histogram



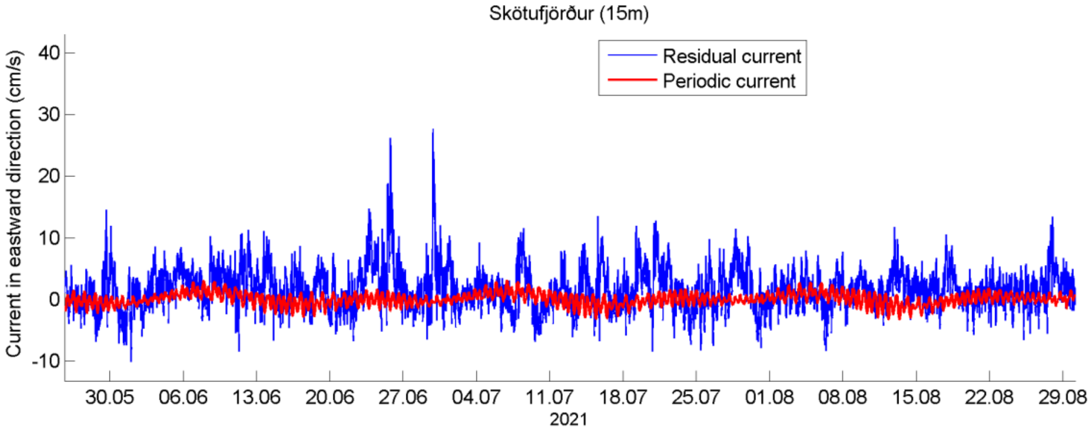
Current velocity histogram



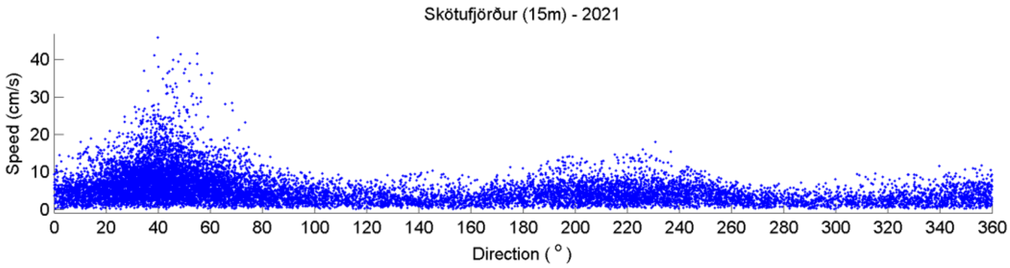
Temperature timeseries



Estimated tidal water current in the north/south direction at 15 meters depth. Negative values indicate currents towards the south. The red curve represents the tidal water current, and the blue line represent the remaining current.



Estimated tidal water current in the east/west direction at 15 meters depth. Negative values indicate currents towards the west. The red curve represents the tidal water current, and the blue line represent the remaining current.

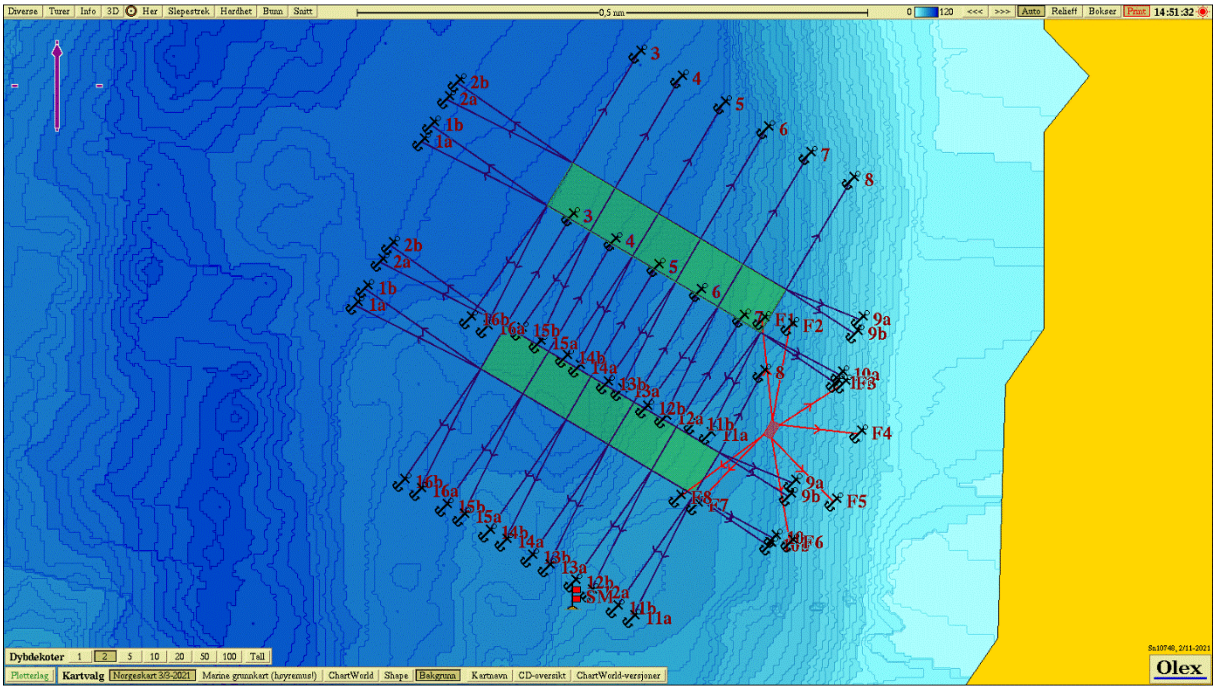


Scatter plot for registrations of speed vs directions

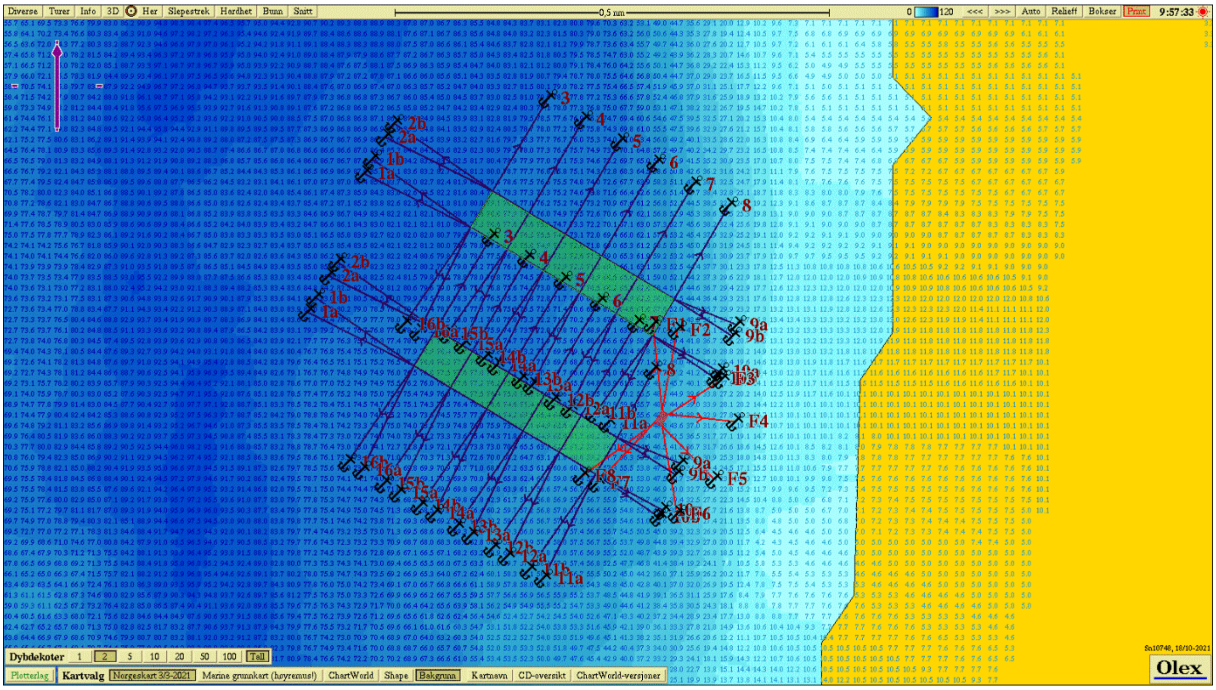
Table showing the number of measurements, maximum velocity, total water transport and the daily water transport in the different sectors.

Direction	Num. of measurem.(N)	Max speed (cm/s)	Total watertransport ($m^3/(s\ m^2)$)	Water transport per day ($m^3/(s\ m^2)$)
352.5 - 7.4	488	14.6	13020.9	134.9
7.5 - 22.4	920	20.9	31429	325.6
22.5 - 37.4	1904	37	87751.6	909.2
37.5 - 52.4	2194	45.9	118606.6	1228.9
52.5 - 67.4	1339	41.6	56634.6	586.8
67.5 - 82.4	766	28.4	24263.9	251.4
82.5 - 97.4	498	14	12409.9	128.6
97.5 - 112.4	349	9.8	7467.3	77.4
112.5 - 127.4	297	8	5766.6	59.7
127.5 - 142.4	253	9.7	5077.7	52.6
142.5 - 157.4	253	10.4	4670.8	48.4
157.5 - 172.4	283	9.2	5401.5	56
172.5 - 187.4	358	11.7	8684	90
187.5 - 202.4	543	14.2	15316.9	158.7
202.5 - 217.4	564	14.7	15810.2	163.8
217.5 - 232.4	563	18	16457.7	170.5
232.5 - 247.4	494	15.3	13214.3	136.9
247.5 - 262.4	368	10.2	8565.2	88.7
262.5 - 277.4	268	6.7	4427.8	45.9
277.5 - 292.4	189	7.2	2790.1	28.9
292.5 - 307.4	188	8	2963.6	30.7
307.5 - 322.4	214	9.6	3668.3	38
322.5 - 337.4	256	9.3	4735.6	49.1
337.5 - 352.4	349	11.5	7620.2	79

7.2 Construction drawing and bottom mapping



Bottom mapping with the placement of the fish farm at the site Skötufjörður. Equidistance 5 m.



Bottom mapping with placement of the fish farm Skötufjörður. Equidistance 5m. Depth in numbers.

7.3 CMS-wave

CMS-Wave is a two-dimensional wave model that simulates propagation of swells towards coastal areas. Both wind and currents can be included in the simulations.
The source code is written and maintained by the U.S. Army Corps of Engineers (Sanchez m.fl., 2012).

The model use SMS (www.aquaveo.com) as a graphical interface.
The input data to the model is bottom topography, incoming waves (height, direction ang energy spectra), wind strength and wind direction. The model assumes constant boundary conditions (wind, waves and currents) and calculates a steady state solution.

The incoming waves are extracted from the Norwegian Meteorological Institutes (MET) regional model (NORA10), which covers the North Sea, Norwegian Sea and the Barents Sea (Reistad m.fl., 2011). MET has calculated values for 50 years return period from this regional nested model from the wave model WAM (The global ocean Wave prediction Model). The model has a solution of approximately 10 km and a direction solution of 30°.

The wind speed in the model area is calculated from a 50 year return period in accordance with the Norwegian standard for wind load NS-EN 1991 (2009). The wind field is assumed to be constant in time and space. The wind load is translated to terrain category I: coastal areas. Directions are included in accordance to NS-EN 1991 (2009).

The model calculates the change in wave parameters (wave height, direction and spectral distribution) when the wave propagates from the open ocean and enters the near coastal shallow waters. Hence a well described bottom topography is needed.

Included wave effects:

1. Refraction (rotation of the waves due to the change in water depth and current.
2. Diffraction (rotation of waves due to obstructions)
3. Shallowing effects (increased wave height due to reduced group velocity/ wavelength due to bottom friction)
4. Wave-to-wave interaction

The following effects can also be implemented:

5. Wave generation due to wind
6. Reflection

If the ocean currents in the nearby areas are expected to be much lower than 1 m/s they will according Smith m.fl. (1998) not contribute to significant changes in the transformation of the ocean waves. According to maximum values of the measured ocean currents at the site it is considered that the currents are not included in this simulation.

The model is run with multiple rectangular grids with a resolution of 10-100 m. The boundary of the grid where the waves and wind are expected to enter is placed at least 50 meters away from the site for the waves to build up.

7.3.1 Energy spectra

The results from the regional NORA 10-model gives an estimate of the upper limits for the wave height at the boundary. This wave height is used to define the energy spectra at the boundary, a typical distribution of wave energy as a function of period. The wave energy that enters the model area will normally change depending on the direction it is coming from.

The shape of the energy spectra on the boundary is described by a JONSWAP energy spectra. The spectra explain wave heights as a function of periods.

The incoming wave train is described with two parameters: the spreading factor for the frequency (gamma), which is set to 2.1, and the spreading factor for the direction (nn), which is set to 10. These numbers give conservative values (high energy, which means a large wave height and a ling period) compared to typical wave heights along the Norwegian coastline (Nygaard & Eik, 2004).

7.4 Calculation ice table

The table is based on Guest et al,'s formula: $PPR = \frac{Va(Tf-Ta)}{1+0,3(Tw-Tf)}$

PPR	=	Ice predictor
Va	=	Wind speed (m/s)
Tf	=	Freezing point of seawater (-1,7 °C)
Ta	=	Air temperature
Tw	=	Sea temperature

By using the formula above for PPR with different wind and temperature combinations, a frequency table as shown in Tabell 1 can be generated. The different PPR are shown in the table and is color coded to specify which ice-class they are within. By using this frequency table of the given temperature and wind combinations, the number of observations of the different types of icing is calculated and thereby an estimate the degree of ice exposure at the site.

This formula estimates the icing on ships and is not directly usable for floating fish farms. Experienced based knowledge indicates that accumulated icing on floating fish farms is nearly half of what is calculated on ships and quay constructions. This is due to the effect of the flushing from the waves. Therefore the PPR is halved to get an approximation of the ice load on floating fish farms.

Sjøvannstemp	1																														
Vind (m/sek)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
Lufttemperatur																															
0	0	-1	-1	-2	-2	-3	-3	-4	-4	-5	-5	-6	-6	-7	-7	-8	-8	-8	-9	-9	-10	-10	-11	-11	-12	-12	-13	-13	-14	-14	-15
-1	0	0	-1	-1	-1	-1	-1	-2	-2	-2	-2	-2	-3	-3	-3	-3	-3	-3	-4	-4	-4	-4	-4	-5	-5	-5	-5	-5	-6	-6	-6
-2	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	3
-3	0	1	1	1	2	2	3	3	3	4	4	4	5	5	5	6	6	6	7	7	8	8	8	9	9	9	10	10	10	11	11
-4	1	1	2	3	3	4	4	5	6	6	7	8	8	9	10	10	11	11	12	13	13	14	15	15	16	17	17	18	18	19	20
-5	1	2	3	4	5	5	6	7	8	9	10	11	12	13	14	15	15	16	17	18	19	20	21	22	23	24	25	26	26	27	28
-6	1	2	4	5	6	7	8	10	11	12	13	14	15	17	18	19	20	21	23	24	25	26	27	29	30	31	32	33	34	36	37
-7	1	3	4	6	7	9	10	12	13	15	16	18	19	20	22	23	25	26	28	29	31	32	34	35	37	38	40	41	42	44	45
-8	2	3	5	7	9	10	12	14	16	17	19	21	23	24	26	28	30	31	33	35	37	38	40	42	44	45	47	49	50	52	54
-9	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	63
-10	2	5	7	9	11	14	16	18	21	23	25	28	30	32	34	37	39	41	44	46	48	50	53	55	57	60	62	64	66	69	71
-11	3	5	8	10	13	15	18	21	23	26	28	31	33	36	39	41	44	46	49	51	54	57	59	62	64	67	69	72	75	77	80
-12	3	6	9	11	14	17	20	23	26	28	31	34	37	40	43	46	48	51	54	57	60	63	65	68	71	74	77	80	83	85	88
-13	3	6	9	12	16	19	22	25	28	31	34	37	41	44	47	50	53	56	59	62	66	69	72	75	78	81	84	87	91	94	97
-14	3	7	10	14	17	20	24	27	31	34	37	41	44	48	51	54	58	61	65	68	71	75	78	82	85	88	92	95	99	102	105
-15	4	7	11	15	18	22	26	29	33	37	40	44	48	51	55	59	62	66	70	73	77	81	85	88	92	96	99	103	107	110	114
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-17	4	8	13	17	21	25	30	34	38	42	46	51	55	59	63	68	72	76	80	85	89	93	97	101	106	110	114	118	123	127	131
-18	5	9	14	18	23	27	32	36	41	45	50	54	59	63	68	72	77	81	86	90	95	99	104	108	113	117	122	126	131	135	140
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-20	5	10	15	20	25	30	35	40	45	51	56	61	66	71	76	81	86	91	96	101	106	111	116	121	126	131	136	142	147	152	157
-21	5	11	16	21	27	32	37	43	48	53	59	64	69	75	80	85	91	96	101	107	112	117	123	128	133	139	144	149	155	160	165
-22	6	11	17	22	28	34	39	45	50	56	62	67	73	79	84	90	95	101	107	112	118	123	129	135	140	146	151	157	163	168	174
-23	6	12	18	24	29	35	41	47	53	59	65	71	76	82	88	94	100	106	112	118	124	129	135	141	147	153	159	165	171	177	182
-24	6	12	18	25	31	37	43	49	55	62	68	74	80	86	92	99	105	111	117	123	129	136	142	148	154	160	166	172	179	185	191
-25	6	13	19	26	32	39	45	51	58	64	71	77	84	90	97	103	109	116	122	129	135	142	148	154	161	167	174	180	187	193	200
-26	7	13	20	27	34	40	47	54	60	67	74	81	87	94	101	107	114	121	128	134	141	148	154	161	168	175	181	188	195	201	208
-27	7	14	21	28	35	42	49	56	63	70	77	84	91	98	105	112	119	126	133	140	147	154	161	168	175	182	189	196	203	210	217
-28	7	15	22	29	36	44	51	58	65	73	80	87	94	102	109	116	124	131	138	145	153	160	167	174	182	189	196	203	211	218	225
-29	8	15	23	30	38	45	53	60	68	75	83	90	98	106	113	121	128	136	143	151	158	166	173	181	189	196	204	211	219	226	234
-30	8	16	23	31	39	47	55	63	70	78	86	94	102	109	117	125	133	141	149	156	164	172	180	188	195	203	211	219	227	235	242
-31	8	16	24	32	40	49	57	65	73	81	89	97	105	113	121	130	138	146	154	162	170	178	186	194	202	210	219	227	235	243	251
-32	8	17	25	33	42	50	59	67	75	84	92	100	109	117	126	134	142	151	159	167	176	184	193	201	209	218	226	234	243	251	259
-33	9	17	26	35	43	52	61	69	78	86	95	104	112	121	130	138	147	156	164	173	182	190	199	208	216	225	233	242	251	259	268
-34	9	18	27	36	45	54	62	71	80	89	98	107	116	125	134	143	152	161	170	178	187	196	205	214	223	232	241	250	259	268	277
-35	9	18	28	37	46	55	64	74	83	92	101	110	120	129	138	147	156	166	175	184	193	202	212	221	230	239	248	258	267	276	285

Values that represent none, some, moderate, heavy and extreme icing.

Ice prediction (PPR) w/color code	<0	0-22,4	22,4-53,3	53,3-83,0	>83,0
Ice class	None	Some	Moderate	Heavy	Extreme
Ice rate (cm/hour)	0	<0,7	0,7-2,0	2,0-4,0	>4,0
Ice rate (kg/m^2/hour)	0	0,8-6,0	6-17	17-34	>34

7.5 Ekstremverdianalyse (Norwegian)

Ekstremverdi-teorien er et kraftig og samtidig robust verktøy for å studere «hale»-oppførselen til en statistisk fordeling. Embrechts m.fl. (1997) er en god kilde til beskrivelsen av ekstremverdi-teorien i finans- og forsikringsverdenen. Reiss og Thomas (1997) og Berlaint m.fl. (1996) har også omfattende dekning av ekstremverdi-teorien. Ekstremverdi-analysen har funnet stor nytteverdi i klimatologi, meteorologi og nylig også i oseanografi.

Det finnes datasett fra fjernmålinger, faktiske målinger og atmosfæriske/ oseanografiske modeller. Både faktiske in-situ målinger og fjernmålinger har større eller mindre måleusikkerheter, lider ofte av begrenset representativitet og er sporadiske i rom og tid. På den annen side, så er de tilgjengelige modellene avhengig av observasjoner for å kunne bli validert og få kvantifisert usikkerheter. Selv om modeller kan skaffe lange datasett, er det altså likevel nødvendig med observasjoner for å kunne vurdere og heve kvaliteten for eksempel ved å redusere unøyaktigheten i modellene. Dessuten er observasjoner og operasjonelle modeller svært kostbare.

Argumentene ovenfor rettferdiggjør den brede anvendelsen til ekstremverdi-analysen i geofluid-dynamikk, spesielt når det er snakk om ekstremsituasjoner, som for eksempel angående vær og vind. I denne forbindelse er muligheten til å estimere returperioder basert på relativt korte tidsserier en spesielt viktig rolle for blant annet kosteffektiv ingeniørvirksomhet.

Normalfordelingen er den viktigste fordelingskurven for en tilfeldig måleserie, oppsummert i det såkalte sentralgrenseteoremet.

Likeledes vil gruppen av ekstremverdi-fordelinger være de optimale å benytte seg av når man skal studere fordelingskurve av maksima til en måleserie. Denne gruppen kan bli presentert som en enkelt parametrisering kjent som generell ekstremverdi-fordeling (GEV). Teoremet til Fisher og Tippett (1928) står fremdeles sentralt i ekstremverdi-teorien. Teorien behandler konvergensen til maksimalverdiene.

Det antas at $x_1, x_2, \dots, x_m$ er en rekke av uavhengige og identisk fordelte tilfeldige variabler fra en ukjent fordelingsfunksjon $F(x)$ hvor $x \sim (\mu, \sigma^2)$, m er størrelsen til dataserien, μ er gjennomsnittet og σ^2 er variansen. Maksimum av de første $n < m$ observasjoner av x er gitt ved $M_n = max(x_1, x_2, \dots, x_n)$. Gitt en rekke av $a_n > 0$ og b_n , slik at $(M_n - b_n)/a_n \leq x$, så vil rekken av normaliserte maksima konvergere i den følgende GEV fordeling:

$$H(x) = \begin{cases} e^{-(1+\xi\frac{x}{\beta})^{-1/\xi}} & if\ \xi \neq 0 \\ e^{-e^{-x/\beta}} & if\ \xi = 0, \end{cases} \qquad (1)$$

Der $\beta > 0$, x er slik at $1 + \xi x > 0$ og ξ er en parameter til formen (haleindeksen er definert som $\alpha = \xi^{-1}$).

Når $\xi > 0$, er fordelingen kjent som en Frechet-fordeling, og har en tykk hale. Jo større form-parameteren er, jo tykkere hale har fordelingen.

Dersom $\xi < 0$, er fordelingen kjent som en Weibull-fordeling.

Dersom $\xi = 0$, vil det være en Gumbel-fordeling.

Teoremet til Fisher-Tippett foreslår at den asymptotiske fordelingen av maksima tilhører en av de tre fordelingene ovenfor, uansett hvordan den opprinnelige fordelingen til de observerte data er. Derfor kan halefordelingen til dataserien bli estimert utfra en av de tre fordelingene.

I denne studien har en Gumbel-fordeling vist seg å være mest konservativ angående å finne ekstremverdier, og derfor er 50 års returperioder estimert utfra denne.