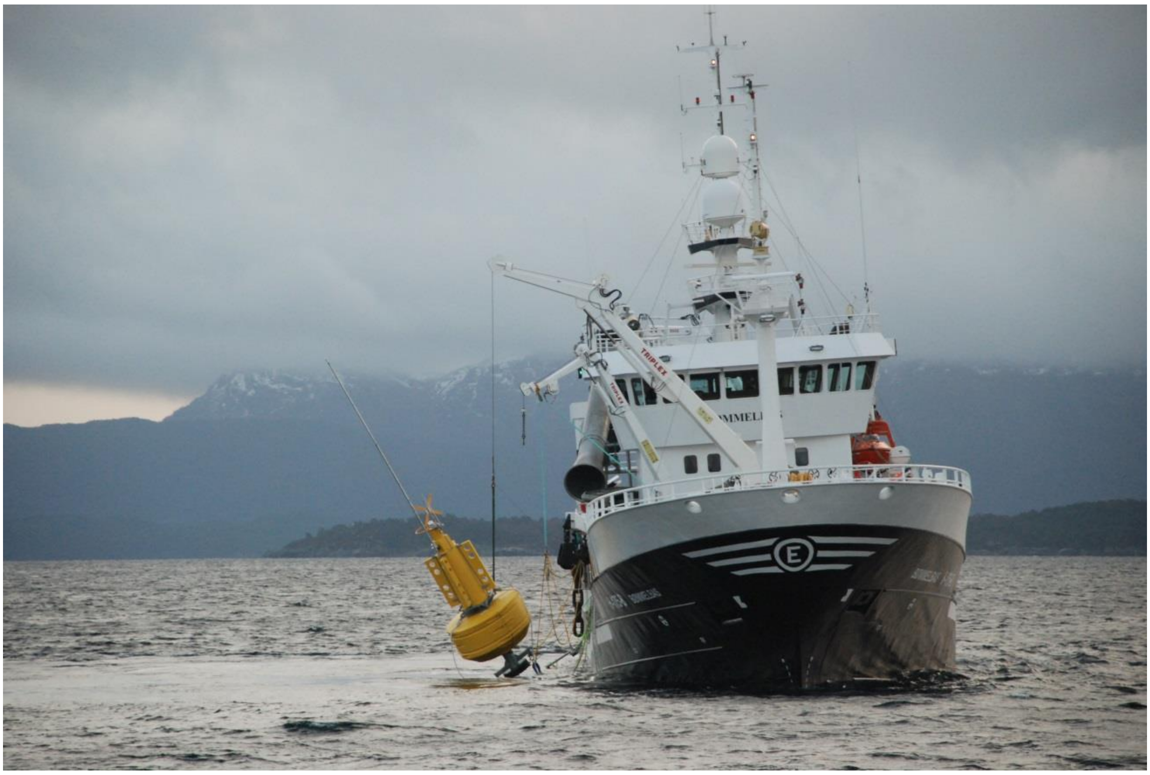
Wave and Current Measurements in Bjørnafjorden, Hordaland, Norway

Data Report

6 January 2015 – 15 April 2015



Statens vegvesen

Report

April 2015

The expert in **WATER ENVIRONMENTS**

Statens vegvesen

This report has been prepared under the DHI Business Management System certified by DNV-GL to comply with ISO 9001 (Quality Management)

Wave and Current Measurements in Bjørnafjorden, Hordaland, Norway

Data Report

6 January 2015 – 15 April 2015

Prepared for	Statens vegvesen
Represented by	Mr. Stian Johannesen

M/S Bömmelbas deploying an instrument buoy

Project manager	Tomas Eidsmo
Authors	Dennis Arreborg Hansen, Lindsey Aies, Anders Jensen
Reviewed by	Patrick Dich Grode, Ole Svenstrup Petersen
Approved by	Jesper Ulrik Fuchs, Head of Projects, Ports and Offshore Technology

Project number	13800440
Date	30 April 2015
Revision	Final 1.0
Classification	Confidential

DHI AS (license registration only) • Abels gate 5 • NO-7030 Trondheim • Norway
Telephone: +47 73 54 03 69 • Telefax: +47 73 54 02 01 • dhi@dhi.no • www.dhi.no

CONTENTS

1 Introduction

The Norwegian Public Roads Administration (NPRA) (Statens vegvesen, SVV) plans to build a fixed link carrying E39 across Bjørnafjorden in Hordaland, Norway. The fixed link shall cross the 5km wide and up to 600m deep Bjørnafjorden between Rekstern to the south and Halhjem to the north. For this project, NPRA has requested information on the hydrographical conditions at the fjord crossing location.

NPRA and DHI Norway A/S (DHI) signed a contract for measuring waves, currents, wind, temperature and salinity at multiple locations across the fjord (transects A and B), and tidal levels from one location on the north shore and one location at the south shore. The locations of the measurement stations are shown in Figure 1.1.

The work was conducted according to contract dated 14 October 2014 between NPRA and DHI, NPRA project number 2014049583. The present report was prepared according to contract change order 2, dated 2015-03-03.

This report presents measured data during the period from 6 January 2015 to 15 April 2015 (i.e. including hurricane Nina) including initial quality assurance and description of sources of uncertainty. Measured wind data during hurricane Nina were adopted from MET Norway (Norwegian Meteorological Institute).

Figure 1.1 Buoy and tidal station positions in Bjørnafjorden (Google Inc.)

1.1 Report structure

The data reporting consists of two parts.

- Part I: Data report (present report)
- Part II: Figure report (DHI 2015b)

The present report describes the measurement system and the instruments in Section 2. Sections 3 to 0 describe the recorded wave, current, tide, temperature, salinity, and wind data along with exemplary figures and tables. The remaining figures and tables are located in the figure report (DHI 2015b).

2 Measurement System

DHI has deployed five monitoring buoys across Bjørnafjorden and two tidal stations at the north and at the south end of the alignment, respectively, see Figure 1.1. The buoys were deployed during January 2015, and have been operational since.

2.1 Buoy deployment

The buoys were moored with a special trolley mooring which keeps the moorings very tight in order to minimize lateral movement of the buoys. A photo and a sketch of the mooring system and the instrument bar are shown in Figure 2.1.

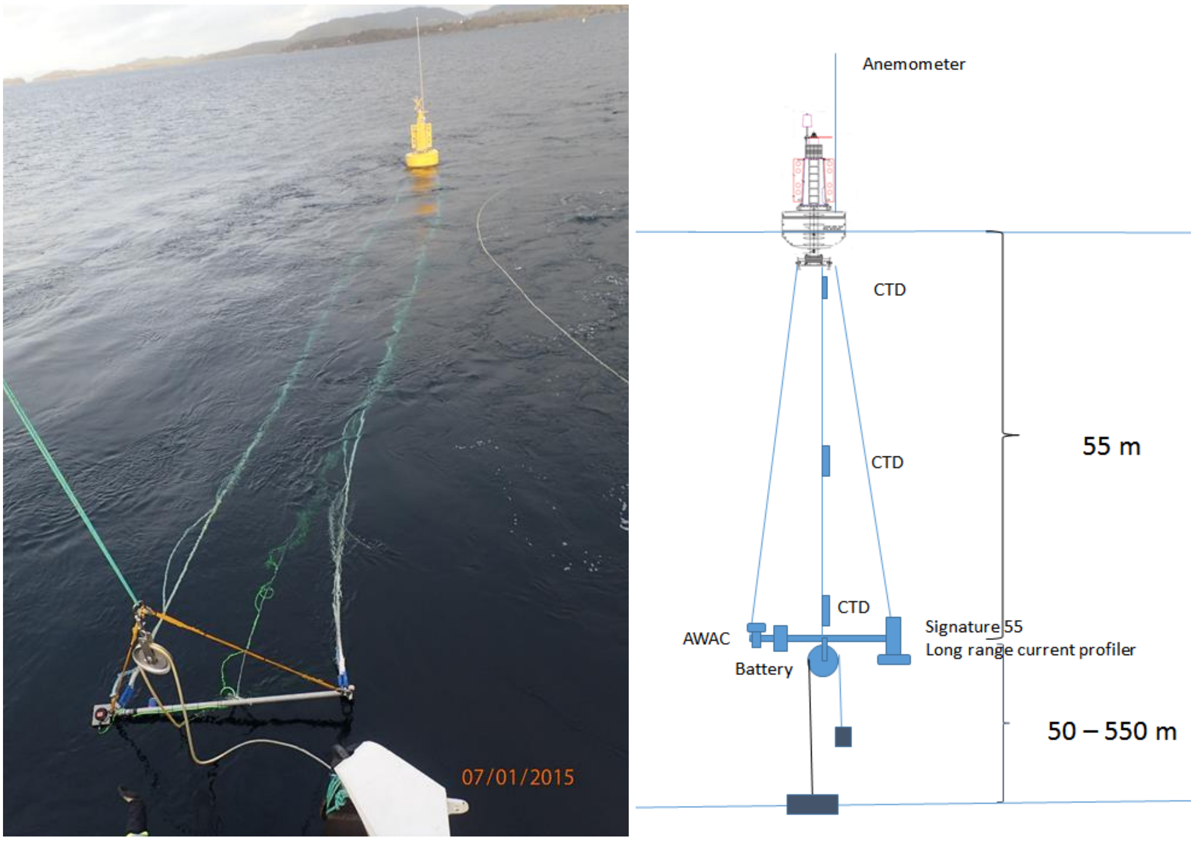


Figure 2.1 Left: Photo of mooring system during deployment. Anchor bloc and counterweight were not deployed when the photo was taken.
Right: Principal sketch of mooring system, instrument bar, CTDs and buoy

The weight of the anchor block is 13.000kg and the counterweight is 750kg which means that the buoy is pulled down by 1.500kg plus its own ballast weight of 750kg.

The buoys are of type Trident 2600, which is 4m high above water and has a diameter of 2.7m.

The buoys contain power supply, transmission equipment, and data recording equipment. All data are transmitted online to DHI where the data are stored. The data are also stored internally in the buoys, for backup purposes and so that data can be retrieved in case of temporary network failure.

2.2 Buoy instrumentation

The buoys are configured with the wave, current and CTD instruments listed in Table 2.1.

All time stamps are in UTC.

Table 2.1 Instruments on buoys and tide stations

Buoy Name	Deployment Date	Wave Instrument	Current Instrument	CTD Instrument	Anemometer
BFA1	6 January 2015; 15:00	600 kHz AWAC	600 kHz AWAC		Airmar 200WX
BFA2	7 January 2015, 11:00	600 kHz AWAC	600 kHz AWAC		Airmar 200WX
BFA3	13 January 2015, 11:00	600 kHz AWAC	600 kHz AWAC Signature 55	-2m MicroCat CTD -25m MicroCat CTD -55m MicroCatCTD	Airmar 200WX
BFA4	8 January 2015, 13:00	600 kHz AWAC	600 kHz AWAC		Airmar 200WX
BFB5	9 January 2015, 17:00	600 kHz AWAC	600 kHz AWAC	-2m MicroCat CTD -25m MicroCat CTD -55m MicroCatCTD	Airmar 200WX
Tidal station	**Deployment Date**	**Water level instrument**			
BFTN	11 January 2015, 13:00	Valeport pressure sensor			
BFTS	12 January 2015, 10:30	Valeport pressure sensor			

2.2.1 AWAC

The 600 kHz AWAC manufactured by Nortek A/S measures wave and current parameters based on acoustic backscatter and on surface tracking. Technical data for the 600 kHz AWAC are listed in Table 2.3. The 600 kHz AWAC looks vertically upward mounted on a tailor-made stainless steel bar located at ~55m water depth, see Figure 2.1.

The AWAC alters between measuring the current profile and measuring the waves. It does so in cycles of 1 hour:

Cycle 1: 16x3 min current measurement + 12 min wave spectra

Cycle 2: 24x1 min current measurement + 34 min wave spectra

Initially all instruments were running Cycle 1, and were changed to Cycle 2 according to Table 2.2. The duration of the individual current measurements was reduced from 3 min to 1 min to be able to capture current fluctuations with lower frequency. The duration of each wave burst was increased from 12 min to 34 min in order to enhance the robustness of the measured wave parameters, in particular for the (potential) occurrence of long-period waves.

Table 2.2 AWAC setting change schedule

Buoy	Setting change date
BFA1	20 March 2015
BFA2	Planned for next service
BFA3	20 March 2015
BFA4	17 February 2015
BFB5	20 March 2015

Table 2.3 Technical data for 600 KHz AWAC

System	
Acoustic frequency	600 kHz
Acoustic beams	4 beams, one vertical, three slanted at 25°
Vertical beam	Opening angle: 1.7°
Operational modes	Online monitoring and local data storage
Sequence	See above
Doppler uncertainty	
Current profile	1cm/s
Current profile	
Maximum depth	60m
Depth cell size	2.0m
Number of cells	27
Maximum output rate:	1 Hz
Velocity measurements	
Velocity range	±10m/s horizontal, ±5m/s along beam
Accuracy	1% of measured value ±0.5cm/s
Wave measurements	
Maximum depth	60m
Data types	Pressure, one velocity along each beam, AST (Acoustic Surface Tracking)
Sampling rate	1Hz velocity, 2Hz AST (600kHz)
No. of samples per burst	1024
Wave estimates	
Range	-15m to +15m
Accuracy/resolution (Hs)	<1% of measured value/1cm
Accuracy/resolution (Dir)	2º / 0.1º
Period range	1–50s
Cut-off period (H_s)	1.5s (at 60m deployment depth)
Cut-off period (dir)	4.2s (at 60m deployment depth)

2.2.2 Signature 55

The Signature 55 long range acoustic doppler current profiler manufactured by Nortek A/S measures current parameters based on acoustic backscatter. The Signature 55 recorder is mounted on station BFA3. Technical data are listed in Table 2.4. The instrument is mounted on a stainless steel bar at ~55m water depth looking downward.

Table 2.4 Technical data for Signature 55 long range current profiler

Parameter	Value
Profiling range	1000m (55 kHz)
Cell size	10m
Blanking	2m
Number of cells	67
Number of cells	65
Velocity range	1.25m/s
Accuracy	1% of measured value ± 0.5cm/s
Velocity resolution	0.1cm/s
Max sampling rate	1Hz

2.2.3 MicroCat

The SBE 37-SMP MicroCat is a high-accuracy conductivity, temperature and pressure recorder with serial interface (RS-485), internal batteries, memory. The MicroCat is designed for moorings or other long-term, fixed-site deployments. The MicroCat CTD recorder is mounted at water depths of -2, -25 and -50m at stations BFA3 and BFB5. The technical specifications are shown in Table 2.5.

Table 2.5 Technical specification for MicroCat CTD probe

Measurement Range	
Conductivity	0 to 7S/m (0 to 70mS/cm)
Temperature	-5 to +45°C
Pressure	1000m
Initial Accuracy	
Conductivity	± 0.0003S/m (0.003mS/cm)
Temperature	± 0.002°C (-5 to +35°C); ±0.01 (+35 to +45°C)
Pressure	± 0.1% of full-scale range
Typical Stability	
Conductivity	0.0003S/m (0.003mS/cm) per month
Temperature	0.0002°C per month
Pressure	0.05% of full-scale range per year
Resolution	
Conductivity	0.00001S/m (0.0001mS/cm)
Temperature	0.0001°C
Pressure	0.002% of full scale range

2.2.4 Anemometer

Each buoy is fitted with an ultrasonic anemometer mounted on a pole 10 m above the water surface and measures wind speed components every 5s, which are then average to 10min values. The anemometers compensate for movements using accelerometers and GPS. Technical specifications of the instrument from AIRMAR are listed in Table 2.6.

Table 2.6 Technical specifications of AIRMAR 200WX

Wind Speed range	0 m/s to 40 m/s
Wind speed resolution	0.1 m/s
Accuracy	0 m/s to 5 m/s; 0.5 m/s +10% of reading 5 m/s to 40 m/s; 1 m/s or 5%, whichever is greater
Wind direction resolution:	0.1°

2.3 Tide stations

Two tide stations were deployed at the north and south end of the alignment as seen in Figure 1.1.

The tidal stations were equipped with pressure gauges from Valeport Inc. The tide gauge has an accuracy of 0.01% of measured value. Water levels were measured every 10 min.

2.4 Sources of uncertainty

Two of the main factors influencing the wave and current measurements are briefly described below. A more thorough description is given in (Nortek AS 2013).

2.4.1 Tilt of the acoustic wave and current profilers

The current profilers measure the current speeds in cells along three beams, each tilted 25° from the vertical axis of the instrument and distributed evenly along the circumference of the instrument, i.e. spaced 120°. The reported current speed and direction are obtained from measurements in each beam, where it is assumed that the instrument is oriented vertically, so the n'th cell along each beam is at the same depth. This assumption is violated when the instrument is not vertically aligned, as illustrated in Figure 2.2.

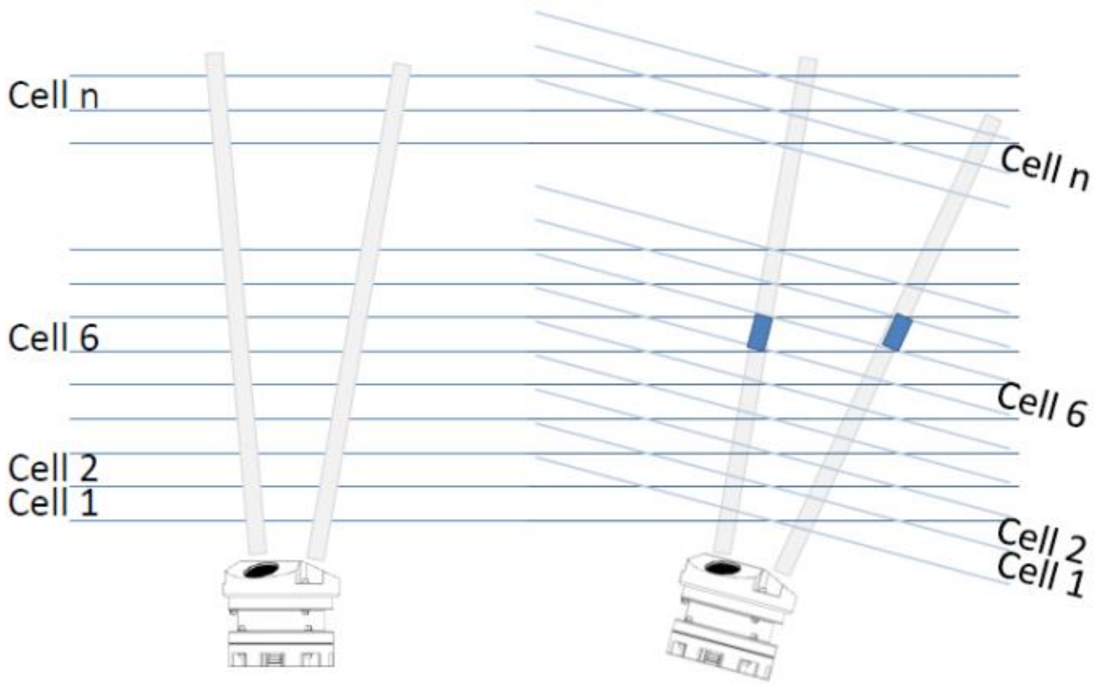


Figure 2.2 Tilting of the instrument results in measurements from different cells at the same depth. From (Nortek AS 2013, fig.5–14)

According to (Nortek AS 2013), if the tilt reading is less than 20° the measurements are within the specifications in Section 2.2.1.

For acoustic surface tracking (AST) tilt reading less than 5° is targeted. The AWAC automatically switches from AST mode to pressure-based PUV mode when tilt is larger than 15°. At the current deployment depth of ~55m below the surface, the information about waves based on pressure is doubtful and has been removed from the dataset. Time series of instrument tilt is presented in Section 2.2.1.

The vertical position of the current measurements is not compensated for tilt of the instrument. A tilt of 15 degrees imply that the position of the measurement the farthest away from the instrument is 2m closer to the instrument in the vertical direction than reported.

2.4.2 Sidelobe interference

The acoustic beams of the current profilers are focused in the centre of the beam; however, energy will travel in other directions. The signal strength will, however, be low, and will not affect the measurements, except for the case where the *leaked* energy reaches the sea surface, which creates a stronger echo than suspended particles in the water. This causes interference in the measurement near the boundary. The thickness of the affected layer is a function of the tilt of the instrument.

The current measurements likely to be disturbed by sidelobe interference have been removed from the presented data.

2.4.3 Vertical movement of the instruments

Due to wind and currents, the instrument moves horizontally and up to 2 m vertically in the water column. The current profiles are measured relative to the instrument, and hence movement of the buoy will affect the absolute position of the cells. The profiles presented herein are not corrected for this movement.

2.5 Deployment log

A summary of the deployment log relevant to data coverage is given below for each station. Wind is presented separately in Section 2.5.6.

2.5.1 BFA1

Any gaps in data are due to the online telemetry being down. However, all data are stored in the AWAC and will be collected at next service visit.

2.5.2 BFA2

Any other gaps in data are due to the online telemetry being down. However, all data are stored in the AWAC and will be collected at next service visit.

2.5.3 BFA3

There was a premature battery failure on the CTD instruments. The instrument deployed at 50m water depth failed on 3 April, 00:10, the instrument at 25m water depth on the 3 April 2015, 14:00 and the instrument located at 2.5m water depth failed on the 4 April 2015, 18:00. All three instruments are expected to be operational again from early May 2015.

Any other gaps in data are due to the online telemetry being down. However, all data are stored in the AWAC and will be collected at next service visit.

2.5.4 BFA4

At 23:00 on 30 January 2015 the internal wave processors (ProLog) of the AWAC failed. This meant that internal wave processing and storage of current and wave data was no longer possible.

This was fixed at 14:30 on 3 February 2015 upon which data were transmitted in real time to a server which collected as much data as possible. Unfortunately, due to connection dropouts there were gaps in the data.

There are more data to be retrieved from this period than what is shown (especially from 7 to 11 February 2015), but that requires additional processing.

A new instrument was installed and deployed at 14:00 on 11 February 2015.

During a service visit at 09:00 on 13 March 2015, a cable got damaged. The cable was repaired and the system redeployed at 16:00 on 14 March 2015.

Any other data gaps are due to the online telemetry being down. The missing data are expectedly stored in the AWAC and will be collected at next service visit.

2.5.5 BFB5

During deployment at 17:00 on 9 January 2015, a hydraulic line on the crane broke causing the mooring to be incorrectly deployed. This caused the AWAC to be heavily tilted.

Since the storm Nina was approaching, the mooring was not set straight until 13 January 2015 at 17:00.

The mooring to the station broke at 23:00 on 25 January 2015. The station was recovered and redeployed at 15:00 on 30 January 2015.

Any other data gaps are due to the online telemetry being down. The missing data are expectedly stored in the AWAC and will be collected at next service visit.

2.5.6 Wind

During, or shortly after, the hurricane Nina, winds caused the anemometer masts on the measurement buoys to break. New anemometers were installed on reinforced masts according to the schedule in Table 2.7.

Table 2.7 Wind mast collapse and reinstallation times

Station	Wind mast collapse	Wind mast reinstallation
BFA1	10 January 2015	25 February 2015
BFA2	21 January 2015	25 February 2015
BFA3	30 January 2015	12 March 2015
BFA4	22 January 2015	11 March 2015
BFB5	23 January 2015	25 February

The anemometers do not store the data internally, meaning that whenever there is a gap in the telemetry system, the data are lost.

2.5.7 Tide stations BFTN and BFTS

Both tide stations have been operating uninterrupted since deployment.

2.6 Data coverage

Table 2.8 On-line data coverage in the period from deployment to 15 April 2015

Station	Parameter	On-line coverage
BFA1	Waves	91 %
	Current	97 %
	Wind	44 %
BFA2	Waves	92 %
	Current	96 %
	Wind	44 %
BFA3	Waves	56 %
	Current	99 %
	Wind	14 %
	CTD	84 %
BFA4	Waves	45 %
	Current	51 %
	Wind	24 %
BFB5	Waves	85 %
	Current	96 %
	Wind	49 %
	CTD	96 %
BFTN	Water level	100 %
BFTS	Water level	100 %

3 Waves

The wave parameters and spectra were measured by the AWAC recorders. Data have been successfully collected and quality assured for the period 6 January to 15 April 2015 (~3.5 months) as presented below.

It is planned to deploy a directional wave rider (DWR) at next service visit to provide wave directions.

3.1 Quality assurance

When the AWAC is tilted more than 15°, it automatically switches from acoustic surface tracking (AST) to pressure based measurements. At the present deployment depths, pressure-based wave data are not reliable, and were removed from the presented datasets.

Especially for BFA3 and BFB5, tilt is an issue. It is most likely due to the fact that these buoys carry more instruments than the other buoys, i.e. the long range current profiler and CTD instruments. It is currently being investigating how to improve the set-up.

T_p values larger than 6s were not presented since these are likely to be caused by the wave spectrum having a low-frequency peak with higher magnitude than the main peak, see Section 3.5.

The AST-based measurements of H_{m0} from BFA3 have some outliers which may be caused by the tilt, being close to the cut-off limit of 15°. These data are presently kept in the dataset for further investigation.

With regard to T_p, there are a number of spikes in the time series. These spikes are primarily in sea states with H_{m0} < 0.5-1.0m, see Section 3.3.

More detailed presentations of the wave height and spectra during hurricane Nina are presented in (DHI 2015a).

3.2 Time series

Figure 3.1 below presents time series of significant wave height, $H_{m0,}$ the spectral peak period, T_p, and the spectral mean period, $T_{02,}$ during March 2015. Statistical data, including number of data points, mean, min and max values and standard deviation are also presented. Figures covering the remaining period (on a monthly basis) are presented in Section 2.1 in the Figure report (DHI 2015b).

The time series plots show good correlation between the individual measurement buoys. Wave heights are in general slightly higher at BFA1 and BFB5. The wave height is in general less than 1m. The maximum wave height was measured at BFA1 during Hurricane Nina with a significant wave height of 3.55m. The mean periods are generally within 1.5-3.0s.

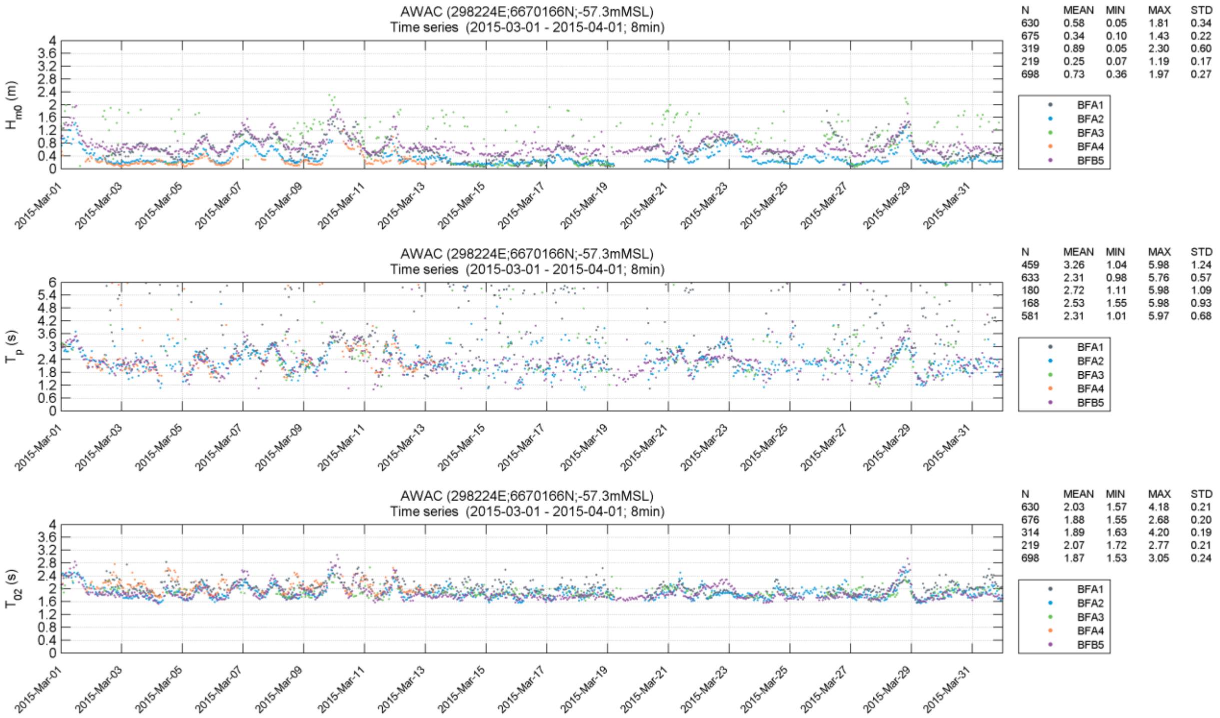


Figure 3.1 Time series of integrated wave parameters from the AWAC at all five buoys in the period from 01.03.2015 to 01.04.2015. A larger version is available in (DHI 2015b, sec.2.1)

3.3 Scatter plots

H_{m0} vs T_p and H_{m0} vs T_{02} and scatter plots are presented in (DHI 2015b, sec.2.4 and 2.5) for all five wave measurement stations. The scatter plots cover the full period from 1 January 2015 to 15 April 2015. Each plot is followed by scatter tables of the same data. An example of scatter plot of H_{m0} vs T_p at BFA2 and corresponding table is shown in Figure 3.2 and Table 3.1. More than half of the time, the wave height is less than 0.5m and the associated peak wave period is generally between 1.5s and 2.5s.

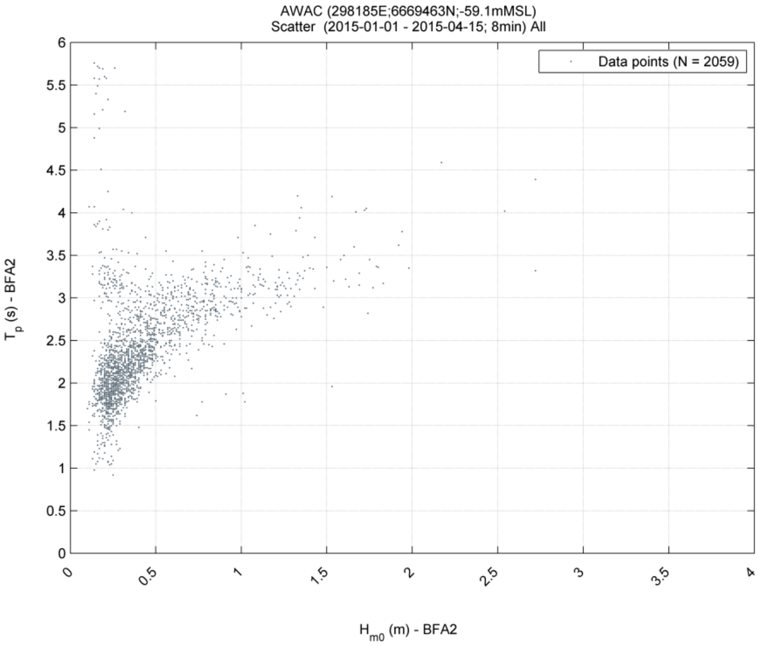


Figure 3.2 Scatter plot of significant wave height vs. spectral peak period from the AWAC at BFA2 in the period from 01.01.2015 to 15.04.2015.

Table 3.1 Scatter table of significant wave height vs. spectral peak period from the AWAC at BFA2 in the period from 01.01.2015 to 15.04.2015.

AWAC
Frequency of Occurrence [%] (2015-01-01 - 2015-04-15; 8min) All

H_{m0} (m) - BFA2

T_p (s) - BFA2	[0-0.5[	[0.5-1[	[1-1.5[	[1.5-2[	[2-2.5[	[2.5-3[	[3-3.5[	[3.5-4[	Total	Accum
[5.5-6[	0.437	-	-	-	-	-	-	-	0.437	100.000
[5-5.5[	0.291	-	-	-	-	-	-	-	0.291	99.563
[4.5-5[	0.146	-	-	-	0.049	-	-	-	0.194	99.271
[4-4.5[	0.243	-	0.097	0.194	-	0.097	-	-	0.631	99.077
[3.5-4[	0.777	0.146	0.340	0.194	-	-	-	-	1.457	98.446
[3-3.5[	4.711	4.954	2.768	0.631	-	0.049	-	-	13.113	96.989
[2.5-3[	9.082	10.345	0.729	0.049	-	-	-	-	20.204	83.876
[2-2.5[	35.454	2.865	-	-	-	-	-	-	38.320	63.672
[1.5-2[	22.535	0.194	0.097	0.049	-	-	-	-	22.875	25.352
[1-1.5[	2.380	-	-	-	-	-	-	-	2.380	2.477
[0.5-1[	0.097	-	-	-	-	-	-	-	0.097	0.097
[0-0.5[	-	-	-	-	-	-	-	-	-	-
Total	76.153	18.504	4.031	1.117	0.049	0.146	-	-	100.000	-
Accum	76.153	94.658	98.689	99.806	99.854	100.000	100.000	100.000	-	-

3.4 Spectra

The wave energy spectra, measured once every hour, are presented as Hovmöller diagrams, which in the lower window show the temporal evolution of the wave energy density spectra together with the significant wave height in the upper window. An example is shown in Figure 3.3. Note that the colour scale is logarithmic. Remaining plots are presented in (DHI 2015b, sec.2.2).

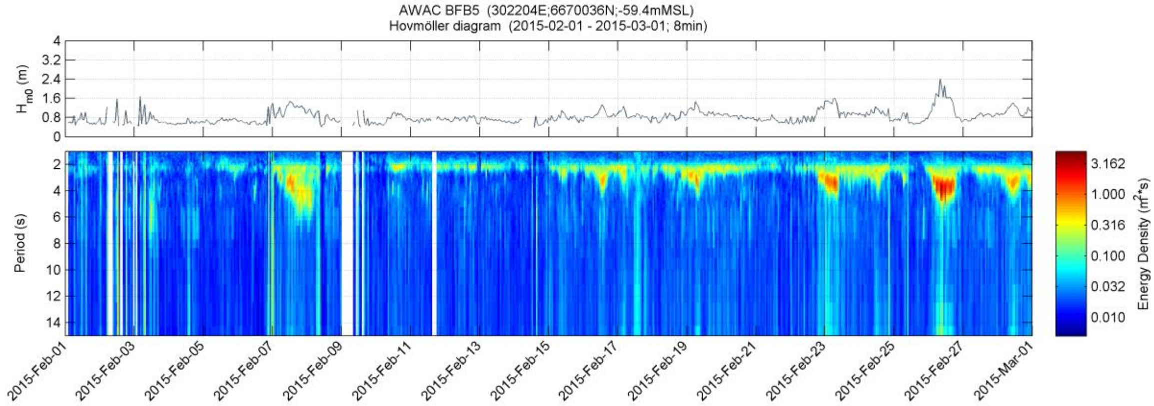


Figure 3.3 Time series of wave energy density spectra from the AWAC at BFB5 in the period from 01.02.2015 to 01.03.2015.

3.5 Fitted spectra

All measured sea states were divided into bins based on H_{m0} and T_{02}. Each bin covers a H_{m0} range of 0.5m and a T_{02} range of 0.5s. For each bin, the average spectrum was found and the best-fit JONSWAP, Person-Moskowitz and Ochi-Hubble spectra were determined.

In the Figure report section 2.3, the mean spectra and fitted spectra for each bin are presented. The plots are followed by tables which summarises the parameters for each theoretical spectrum. An example is given in Table 3.2 for JONSWAP parameter α.

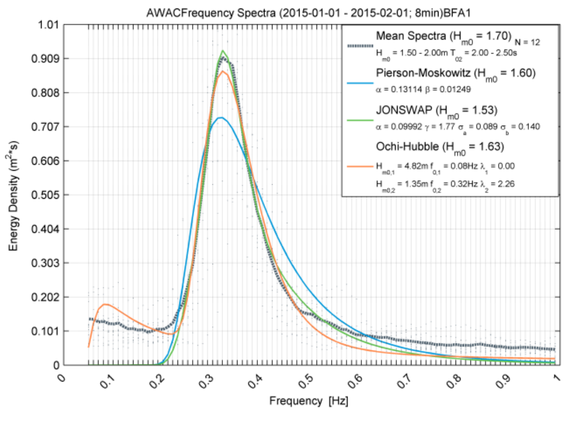


Figure 3.4 Wave energy density spectrum for H_{m0} = 1.0-1.5m and T_{02} = 2.0-2.5s at BFA1 in the period from 01.01.2015 to 15.04.2015.

Table 3.2 JONSWAP parameter α at BFA1 in the period from 01.01.2015 to 15.04.2015.

AWAC
JONSWAP Parameter: α (2015-01-01 - 2015-04-15; 8min)BFA1

H_{m0} (m)

T_{02} (s)	[0-0.5[	[0.5-1[	[1-1.5[	[1.5-2[	[2-2.5[	[2.5-3[	[3-3.5[	[3.5-4[
[0-0.5[	-	-	-	-	-	-	-	-
[0.5-1[	-	-	-	-	-	-	-	-
[1-1.5[	-	-	-	-	-	-	-	-
[1.5-2[	-	-	-	-	-	-	-	-
[2-2.5[	0.00023	0.06470	-	-	0.11042	-	-	-
[2.5-3[	0.00025	0.01213	0.02821	-	0.03323	0.07080	0.09838	-
[3-3.5[	-	-	-	-	0.04132	0.04348	0.08823	0.09311
[3.5-4[	-	-	-	-	-	-	-	-

4 Current

The current profiles were measured by the AWAC at all five measurement buoy locations. The AWACs are located at 55-60m water depth, and measure the current in 27 vertical bins of 2m each between the instrument and the surface. The raw measurements are 3min averages measured 16 times every hour (allowing 12min for wave sampling). This was changed to 1min averages measured 26 times every hour (allowing for 34min wave sampling) at BFA1, BFA3, BFA4 and BFB5 on between 13 February 2015 and 20 March 2015, as stated in Section 2.2.1.

4.1 Quality assurance

The presented profiles are smoothed by 3-hour moving average, and pooled into 13 vertical bins. The top layer, suspected to be influenced by sidelobe interference described in Section 2.4.2, has been removed.

Only data from the AWACs measuring the currents above ~50m depth are presented below. As stated in Section 2.2.2, a long-range profiler was deployed at BFA3, looking downward. The mounting of this instrument does, however, cause the instrument to tilt and move. Due to the long range, this instrument is more sensitive to these movements, and the on-line transmitted data are thus not reliable. The settings of the instrument have been updated, according to NORTEK recommendations, which should increase reliability of the data. Raw data will be retrieved at the next service visit for re-processing in order to provide reliable data from the period up until now, however, probably with a lower sampling frequency. Further, possibilities to improve the mounting of the instrument are considered.

4.2 Time series

Time series of current is presented in Hovmöller diagrams, as in Figure 4.1. The upper window presents the current speed at 15, 25 and 40m water depth, respectively.

In the lower window, the colour indicates the current speed and the arrows mark the cardinal direction and the speed of the current. Note that the colour scale is logarithmic.

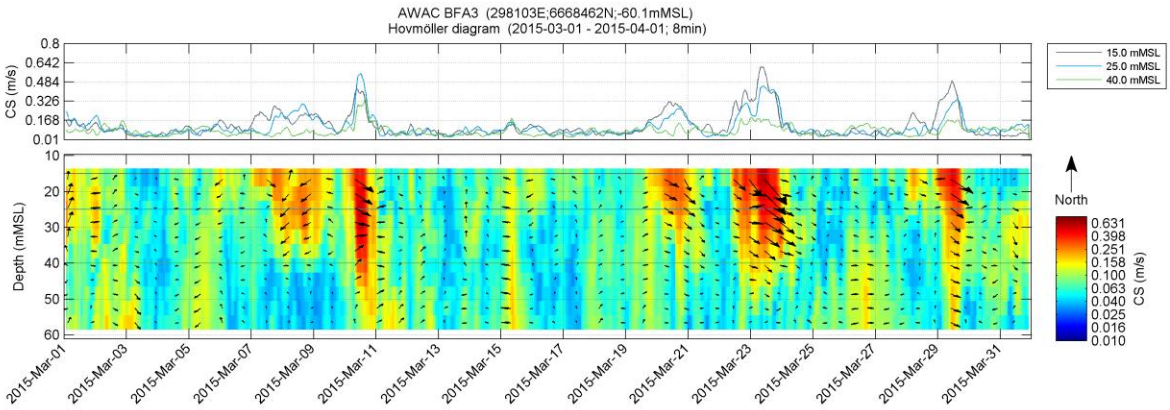


Figure 4.1 Time series of current speed and direction from the AWAC at BFA3 in the period from 01.03.2015 to 01.04.2015.

It is seen that the current speeds in general are below 0.1m/s, but shorter periods of higher current velocities, up to 0.6-0.8m/s are seen in the top 20m – 40m of the water column.

4.3 Current roses

The high velocities are often directed into Bjørnefjorden, i.e. going eastward. This is also present in the rose plot of the current speed and direction at 20m water depth, presented in (DHI 2015b, sec.3.2). An example, from BFA3 is presented in Figure 4.2 and Table 4.1.

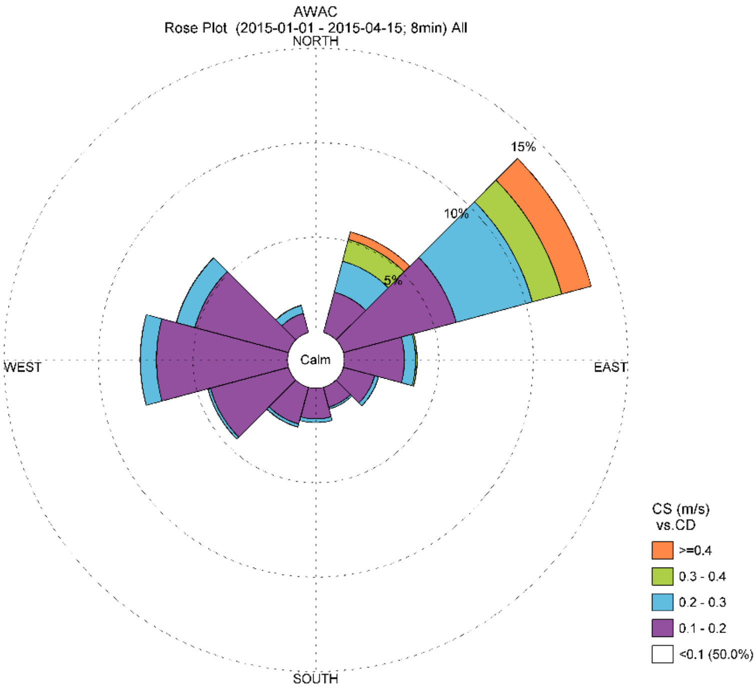


Figure 4.2 Rose plot of current speed and direction at 20m water depth from the AWAC at BFA3 in the period from 01.01.2015 to 15.04.2015.

Table 4.1 Scatter table of current speed and direction at 20m water depth from the AWAC at BFA3 in the period from 01.01.2015 to 15.04.2015.

AWAC
Frequency of Occurrence [%] (2015-01-01 - 2015-04-15; 8min) All

CS (m/s) - BFA3 at 20 mMSL

CD (°N-to) - BFA3 at 20 mMSL	[0-0.1[	[0.1-0.2[	[0.2-0.3[	[0.3-0.4[	[0.4-0.5[	[0.5-0.6[	[0.6-0.7[	[0.7-0.8[	Total	Accum
[315-345[	0.111	1.059	0.444	0.015	-	-	-	-	1.629	99.881
[285-315[	2.930	5.166	1.020	0.013	-	-	-	-	9.130	98.252
[255-285[	7.609	6.989	0.862	0.008	-	-	-	-	15.468	89.122
[225-255[	8.629	4.278	0.142	0.008	-	-	-	-	13.057	73.654
[195-225[	5.967	1.967	0.163	0.005	0.003	-	-	-	8.105	60.597
[165-195[	5.895	1.624	0.199	-	-	-	-	-	7.717	52.493
[135-165[	5.538	1.095	0.108	-	-	-	-	-	6.741	44.776
[105-135[	5.417	1.730	0.209	0.008	-	-	-	-	7.364	38.034
[75-105[	4.203	3.202	0.602	0.077	0.003	-	-	-	8.087	30.671
[45-75[	3.140	6.230	4.203	1.621	1.172	0.447	0.013	-	16.826	22.584
[15-45[	0.194	2.233	1.707	1.195	0.230	0.188	0.010	-	5.758	5.758
[-15-15[	-	-	-	-	-	-	-	-	-	-
Total	49.632	35.574	9.659	2.951	1.407	0.635	0.023	-	99.881	-
Accum	49.632	85.206	94.865	97.816	99.223	99.858	99.881	99.881	-	-

5 Tilt of Wave and Current Profiler Instruments

In (DHI 2015b, sec.4) time series of tilt of the AWAC instruments was presented.

As described in Section 2.4.1, excessive tilt of the instruments may influence the measurements. We have removed all data measured with tilt of the instrument larger than 30° from the reported datasets, according to the guidelines of the manufacturer.

As mentioned previously, we note that BFA3 and BFB5 exhibit more tilt than the other stations, which is most likely related to the additional measurement instruments located at these stations.

There is a correlation between high current speeds and the tilt of the instruments, caused by the lateral movement of the surface buoy; however, there is also a permanent tilt of the BFA3 and BFB5 AWACs. This is probably caused by an unbalance in the submerged rig. Possibilities to improve the balance of the rig are presently being investigated.

BFA1 is more dynamic. This is because the rope connecting the anchor and the counter weight is too long, causing the counter weight to be submerged in the mud on the bottom of the fjord, and hence the mooring is not completely tight. This is planned to be fixed at next service visit.

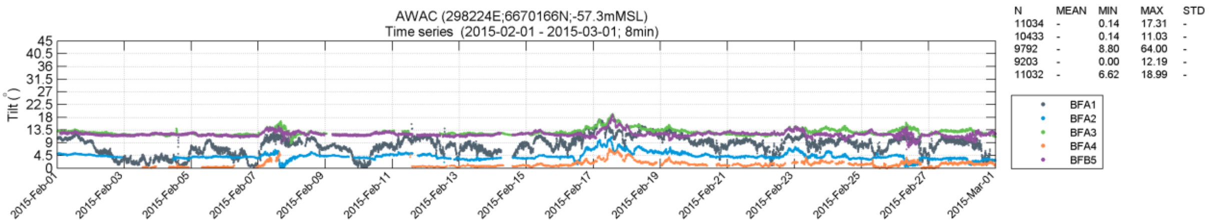


Figure 5.1 Time series of tilt of the wave and current profilers in the period from 01.02.2015 to 01.03.2015. Larger version is available in (DHI 2015b).

6 Tide

Tidal water level constituents were derived applying the IOS method, (Foreman 1977) based on the water level data measured at BFTN and BFTS in the period from 1 January 2015 to 15 April 2015.

(DHI 2015b, sec.5) presents the magnitude, period and phase of the tidal constituents. The predicted water level, based on the 33 shortest constituents, was subtracted from the total measured water level to determine the residual water level from e.g. storm surge and basin resonance. During the hurricane Nina, the residual level reached higher than 0.6m at BFTN.

LAT and HAT were determined as the highest and lowest predicted tidal level during the considered period, which is likely too short for these parameters to be reliable. Mean high and low water springs and neap were estimated from the main tidal constituent amplitudes, see (Beer 1996). The residual levels HRL and LRL are the max and min value of the residual in the considered period. The still water levels HSWL and LSWL are the highest and lowest measured water levels in the considered period.

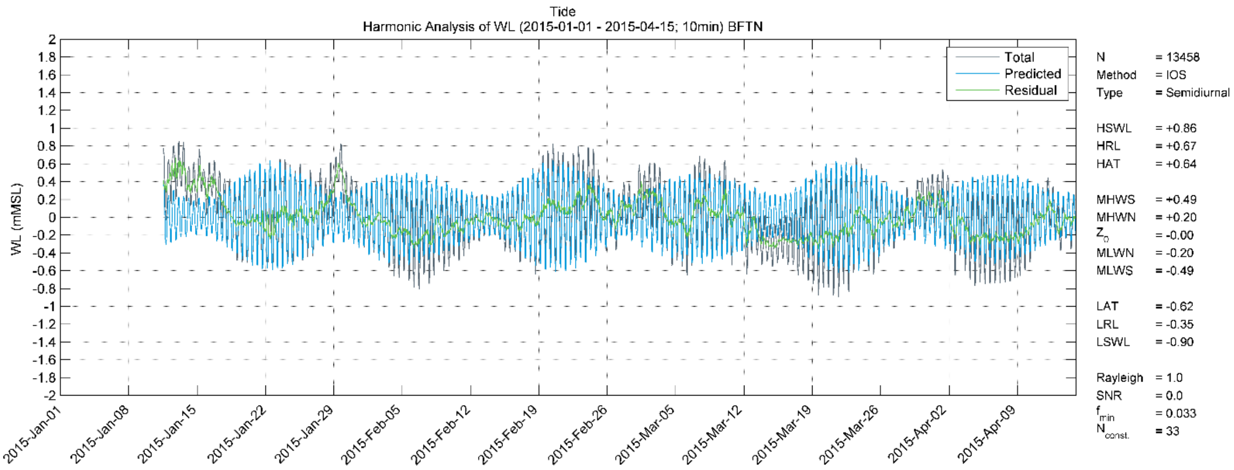


Figure 6.1 Time series of measured and predicted water level at BFTN in the period from 01.01.2015 to 15.04.2015.

7 Temperature and Salinity

Temperature and salinity are presented in (DHI 2015b, sec.6 and 7) in form of time series. An example is presented below. Temperature and salinity are measured at three depths at two locations (BFA3 and BFB5). The instrument measures conductivity, temperature and depth (CTD), from which the salinity is calculated according to (UNESCO 2010).

The temperature was constant over the 50m depth within 5-8°C during the considered period, while the salinity gradually increases with depth from about 30 at the surface to about 34 at 50m. There is no indication of significant thermo or pycnoclines in the top 50m. The salinity shows little variation in time for the 25m and 50m probe, while the salinity fluctuates somewhat near the surface.

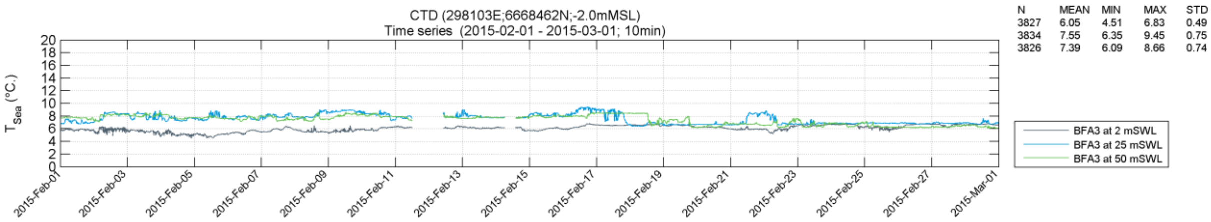


Figure 7.1 Time series of temperature measured at BFA3 in the period from 01.02.2015 to 01.03.2015.

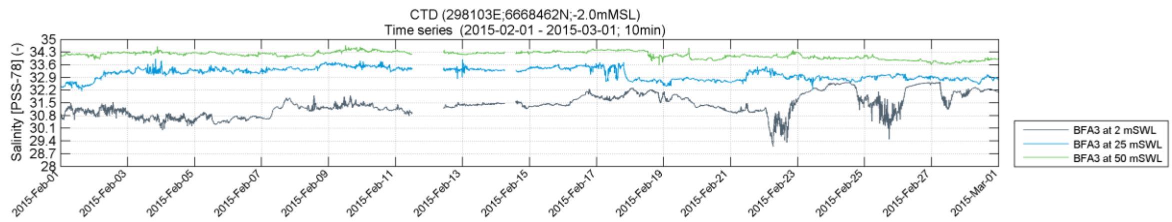


Figure 7.2 Time series of salinity measured at BFA3 in the period from 01.02.2015 to 01.03.2015.

8 Wind

Winds were measured at all five measurement buoys. However, the wind masts turned out to be too weak for the winds, and collapsed between 20 January 2015 and 30 January 2015. New reinforced masts were installed between 25 February 2015 and 12 March 2015, see Section 2.5.6.

During hurricane Nina, wind data were obtained from Slåtterøy Fyr (59.908047°N, 5.067182°E) 30km south west of the measurement area. Data were provided by Norwegian Meteorological Institute and show good correlation with the data recorded by the buoys across Bjørnafjorden.

Data are 10min mean, and are presented as a time series of speed direction and as a wind rose for each station and Slåtterøy Fyr, respectively.

The wind roses show that the winds primarily coming from directions between west and south-east. This can be seen in the example in Figure 8.1. Remaining figures are presented in (DHI 2015b, sec.8.2).

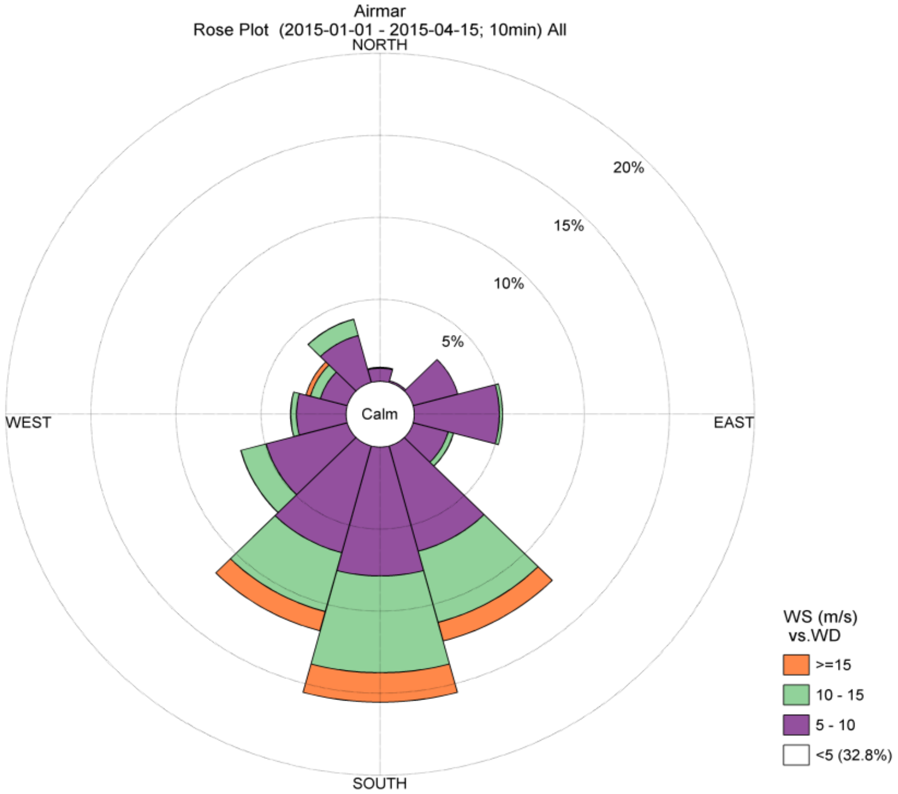


Figure 8.1 Rose of wind speed and direction from Airmar at BFA2 in the period from 01.01.2015 to 15.04.2015.

9 References

Beer, T., 1996. *Environmeltal Oceanography*

DHI, 2015a. *Foreløbige bølgespekter under januar 2015 stormen*

DHI, 2015b. *Wave and Current Measurements in Bjørnafjorden, Hordaland, Norway. 1. January 2015 - 15. April 2015. Figure report.*

Foreman, M.G.G., 1977. *Manual for Tidal Heights Analysis and Prediction*, Patricia Bay, Sidney, B.C.

Nortek AS, 2013. Comprehensive manual, p.138.

UNESCO, 2010. *The international thermodynamic equation of seawater – 2010: Calculation and use of thermodynamic properties*