Akvaplan-niva

Rapport Report

Strømmålinger, BARCUT, Bønna (2013) Goliat (2014 - 2015)

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INNHOLDSFORTEGNELSE

Forord

Foreliggende rapport er utarbeidet for BARCUT.

Følgende personer har deltatt i prosjektet:

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Akvaplan-niva vil takke

Tromsø, 25. november 2019

Øyvind Leikvin

Øyvind Leikvin

2 Introduction

2.1 Project description

The BARCUT project seeks, amongst others, mapping the spreading pattern of drill cuttings near the sea floor. Akvaplan-niva have been measuring the currents at two different areas of interest in order to assess the possible transport and accumulation pattern. This is also to validate the standard way of modelling the spreading of drill cuttings, utilising hydrodynamical models with low resolution both horizontally and vertically.

The areas of interest are:

A) Bønna
B) Goliat

These sites do represent a relatively deep site northwest of Tromsø (>1300 m) and a more shallow site in the Barents Sea (<400 m), respectively.

Bønna has been measured between 8th of August and 15th of October 2013.

Goliat has been measured twice at two stations about 4 km apart: first between 29th of November 2014 and 6th of March 2015, and then between 7th of September and 16th of October 2015 (12th of December 2015 for the point current meter near to the seafloor).

The current meter measurements were performed alongside with other measurements and field campaigns in those areas.

The main aim of the study of the currents is to map the features of the currents in the lower part of the water column, in terms of assessing the spreading of drill cuttings.

2.2 Site descriptions

2.2.1 Bønna

Bønna is situated about 130 km northwest of Ringvassøy, which is just outside Tromsø (Figure 1). The site is placed on the continental shelf slope, which at the Bønna area is approximately stretching due north.

2.2.2 Goliat

Goliat is located about 86 km northwest of Hammerfest, on the edge of Ingøydjupet in the southeastern Barents Sea (Figure 1). The two measurement sites are 4.3 km apart.

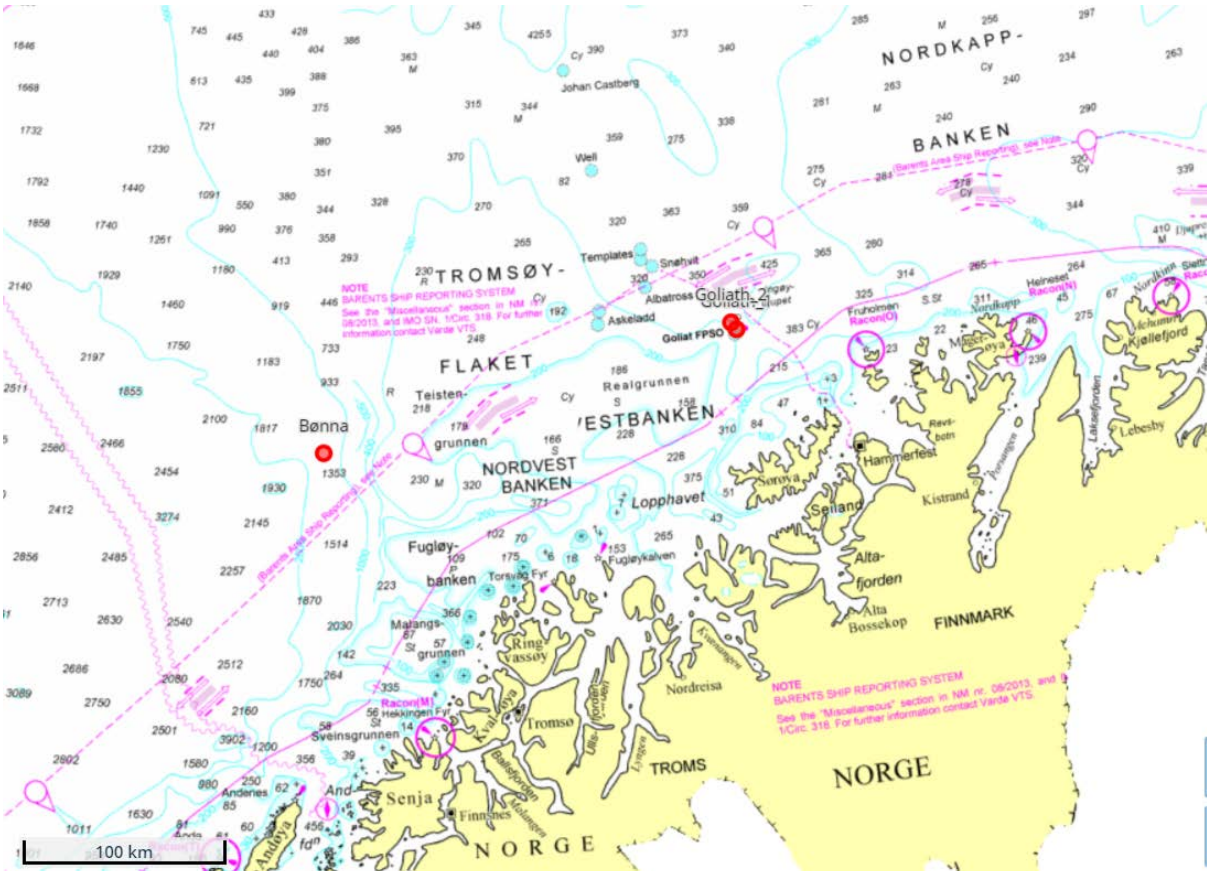


Figure 1: Overview of the positioning of the current meter campaigns at Bønna and Goliat (red dots) (map source: www.kystinfo.no).

3 Instrument & Methods

3.1 Current meters

The profiling current meter Teledyne RDI Long Ranger, 75 kHz (http://www.teledynemarine.com), has been utilised for measuring the currents of the water masses at a specific coordinates at both Bønna and Goliat oil fields. The instrument was located within a spherical buoy and positioned approximately 4 m above the seabed with four transducer beams pointing upwards (Figure 3a), moored to a concrete block.

Because this larger instrument has a minimum blanking distance of 7.04 m, it is difficult to retrieve current meter data from the lowermost 10 m near the seafloor with this instrument. Hence a point current meter from Nortek, an Aquadopp DW 2 MHz, has been included in the mooring set-up just beneath the Teledyne Long Ranger (Figure 3b). The Aquadopp is pointing downwards to measure about 1 m below the instrument itself.

The Teledyne Long Ranger emits acoustic pulses at 4 different beams at 20 degrees angles to the vertical. The width of each beam is 4 degrees. The current meter measures the water mass velocity at specific depth intervals upwards in the water column by means of the shift of the frequency of the reflected acoustic signal from particles in the water (doppler effect).

The Nortek Aquadopp is utilising the same principle regarding measuring the ocean currents, but there is only one measurement level placed a certain distance between 1.1 and 5 m apart from the head of the current meter. At Bønna and Goliat, the measurement level is about 1 m below the head of the current meter. The Nortek Aquadopp DW can withstand depths of maximum 3000 m.

Temperature sensors are integrated in both current meters.

A list of information about the measurement set-up, properties of the instruments and configurations are given in Table 1.

Table 1: Overview regarding some properties and settings of the current meters in action for the BARCUT project at Bønna and Goliat.

Parameter/ property	Bønna		Goliat I		Goliat II	
	1	2	1	2	1	2
Position (geographic, WGS84)	70°50.690' N; 16°33.744' E	70°50.690' N; 16°33.744' E	71°15.453' N; 22°15.877' E	71°15.453' N; 22°15.877' E	71°17.429' N; 22°12.058' E	71°17.429' N; 22°12.058' E
Position (UTM34, ED50,)	X: 337674 Y: 7866233	X: 337674 Y: 7866233	X: 545409 Y: 7906794	X: 545409 Y: 7906794	X: 542995 Y: 7910491	X: 542995 Y: 7910491
Instrument	Teledyne profiling Long Ranger	Nortek point Aquadopp DW (3000 m version)	Teledyne profiling Long Ranger	Nortek point Aquadopp DW (3000 m version)	Teledyne profiling Long Ranger	Nortek point Aquadopp DW (3000 m version)
Depth at position	1381 m	1381	348 m	348 m	367 m	367 m
Measuring depth	1361 - 977 m	1379 m	330 – 34 m	346 m	348 – 34 m	364 m
Start and end time of measurements	08.08.2013 – 15.10.2013	08.08.2013 – 15.10.2013	29.11.2014 – 06.03.2015	29.11.2014 – 06.03.2015	*07.09.2015 – 16.10.2015	07.09.2015 – 12.12.2015
Duration of time series	2 months, 1 week	2 months, 1 week	3 months, 1 week	3 months, 1 week	1 month, 1 week	3 months. 1 week
Number of measurements	Varies throughout the depth	Varies throughout the depth	Varies throughout the depth	Varies throughout the depth	Varies throughout the depth	Varies throughout the depth
Measuring interval	10 min	10 min	10 min	10 min	10 min	10 min
Frequency of acoustic signal	75 kHz	2 MHz	75 kHz	2 MHz	75 kHz	2 MHz
Principle of measuring	Acoustic Doppler	Acoustic Doppler	Acoustic Doppler	Acoustic Doppler	Acoustic Doppler	Acoustic Doppler
Serial no.	19626	9381	19626	9381	19626	9381
Accuracy, standard deviation	± 2.6 cm/s (single measurement)	± 0.3 cm/s (single measurement)	± 2.6 cm/s (single measurement)	± 0.3 cm/s (single measurement)	± 2.28 cm/s (single measurement)	± 0.3 cm/s (single measurement)
Blanking distance	7.04 m	0.5 m	7.04 m	0.37 m	7.04 m	0.37 m
Cell size	6.0 m	0.75 m	4.0 m	0.75 m	4.0 m	0.75 m
Beam width	4 degrees	3.4 degrees	4 degrees	3.4 degrees	4 degrees	3.4 degrees
Power level		High		High		High
Duration of averaging period	600 s	105 s	600 s	120 s	600 s	120 s
Number of pings per measurement ensemble	590	420	590	360	590	360

**The Teledyne Long Ranger had some technical problems, and did stop measuring 16th of October 2015, unintentionally (Goliat II)*

3.1.1 Current meter mooring set-up, Bønna

At the Bønna study site, the current meter was deployed at about 1380 m depth about 85 nautical miles northwest of Tromsø, at position 70°50.690’N; 16°33.744’E (WGS 84). An illustration of the mooring set-up is given in Figure 2. The mooring was deployed 8th of august 2013 and retrieved with 15th of October 2013, both with ROV assistance. The Teledyne Long Ranger instrument was configured to measure the lowermost 450 m of the water column, while the Nortek Aquadopp point current meter was configured to measure about 3 m above the sea floor, at high resolution in time and in the vertical space, during the drilling period. The ADCP was set to measure 6 m depth cells, with a blanking distance of 7 m, sampling every 10th minute.

The configurations and specifications of the current meter set-up are given in Table 1.

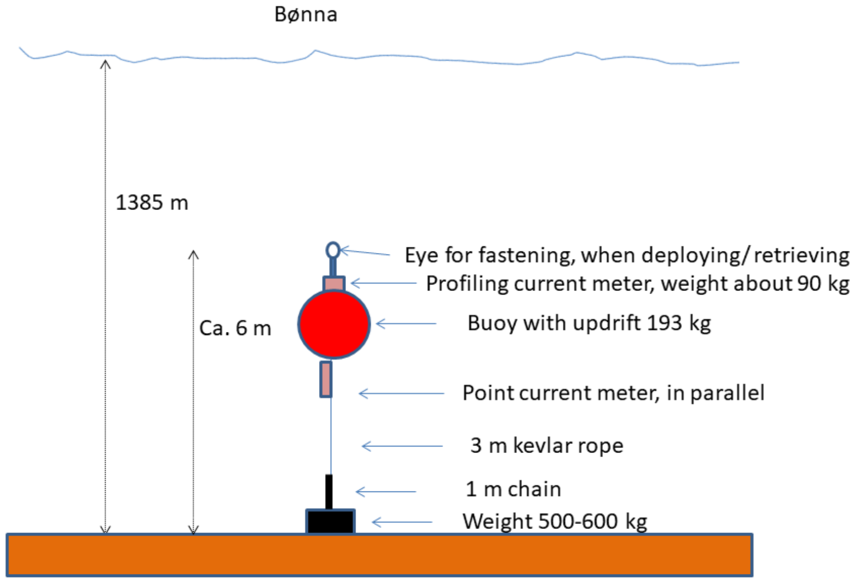
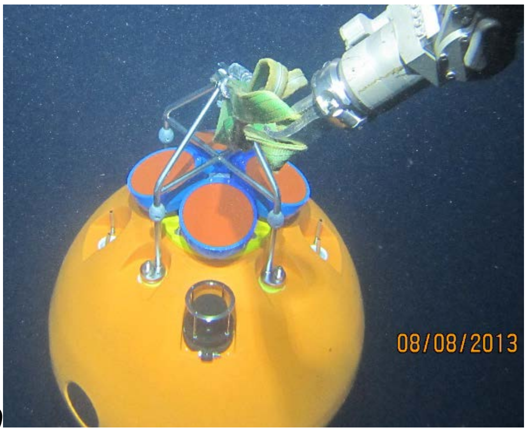


Figure 2: Sketch of the current meter mooring set-up at Bønna.

a) 

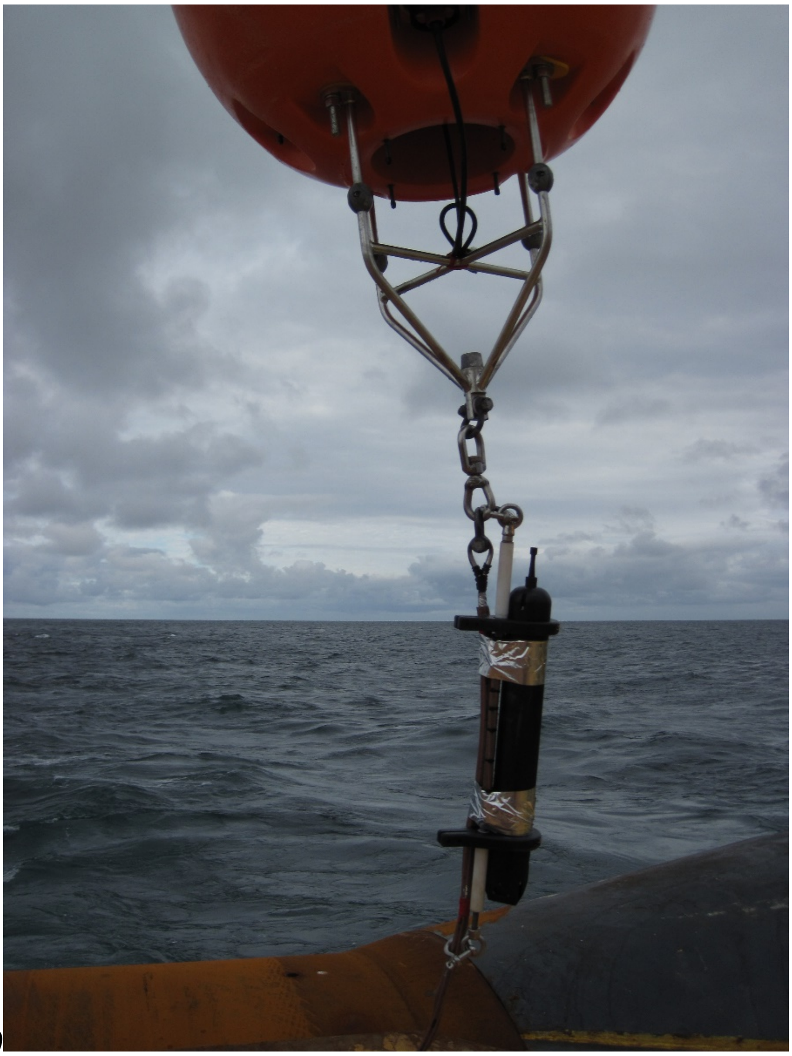
b) 

Figure 3: a) Teledyne Long Ranger Acoustic Doppler Current Profiler (ADCP) under deployment at Bønna, showing the four upwardly-oriented transducer beams, with the main body of the instrument located within the buoy. The image is taken as the ROV was releasing the buoy from the wire with which it was lowered to the seabed (Photo: Oceaneering AS/ Akvaplan-niva).

b) Nortek Aquadopp DW point current meter hanging just beneath the buoy. Photo taken just before deployment 8th of August 2013 at Bønna (Photo: Akvaplan-niva).

3.1.2 Current meter mooring set-up, Goliat

At the Goliat study site, the current meter was deployed at about 350 m depth about 50 nautical miles northwest of Hammerfest, at position 71°15.453’N; 22°15.877’E (WGS 84) (29th of November 2014 – 6th of March 2015) and position 71°17.429’N; 22°12.058’E (WGS 84) (9th of September 2015 - 16th of October 2015). A sketch of the mooring set-up is given in Figure 4. The mooring was deployed and retrieved with ROV-assistance, both times. The Teledyne Long Ranger instrument was configured to measure the whole water column of about 350 m, while the Nortek Aquadopp point current meter was configured to measure about 2 m above the sea floor, at high resolution in space and time. The ADCP was set to measure 4 m depth cells, with a blanking distance of 7 m, sampling every 10th minute.

The configurations and specifications of the current meter set-up are given in Table 1.

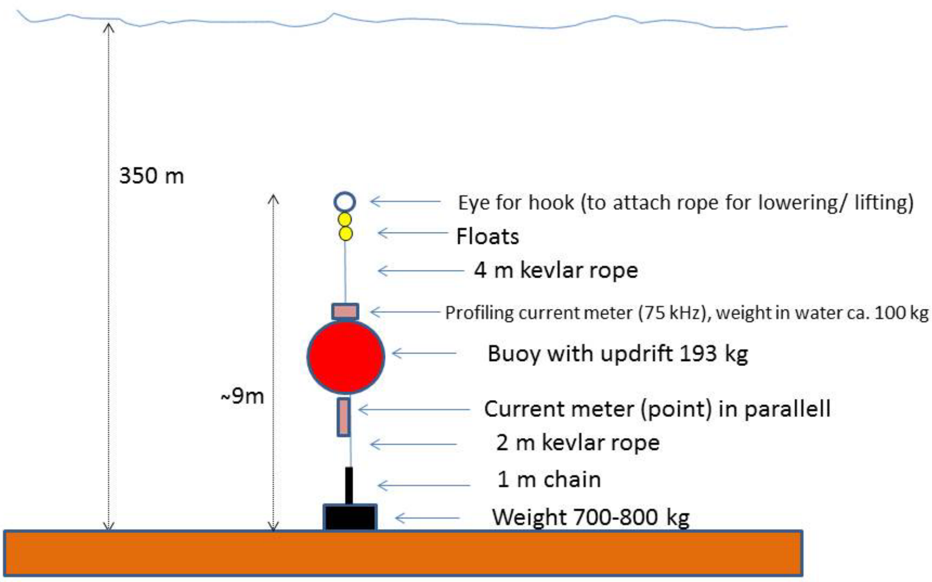


Figure 4: Sketch of the current meter mooring set-up at Goliat.

4 Results

4.1 Bønna

4.1.1 Current meter measurements

The positioning of the current meter mooring at Bønna is on a location where the topography has a meridional direction (south - north, Figure 10).

Statistical data from the deepest measurement at Bønna, from the point current meter at 1379 m depth, give an average current speed of 10.5 cm/s with a residual of 2.1 cm/s towards north-northeast (Table 2).

The time series of the current speed at 1379 m, about 3 m above the seafloor, show a vividly time varying currents with maximum about 40 cm/s (Figure 5). The time series of the direction show that the direction often is sort of constant for several days in a row, only with small fluctuations (Figure 6). This means that the currents are not changing to opposite direction with the M2 tidal cycle with period of 12.42 hours. The tidal analysis with the tool U-tide (Codiga, 2011) given in Figure 9 and Table 3 confirms that the tidal energy is small for the deepest water masses at Bønna, contributing with about 15 % of the total current variance.

The speed vs. current at 1379 m depth at Bønna (Figure 7) illustrates the main current directions towards north and south, with somewhat stronger northerly currents.

The calculated water transport from all directions with 15 degrees sectors are shown in Figure 8, illustrating the main current direction near the seafloor is towards north.

The main current axis from the deepest measurement cell of the current profiler at 1361 m is approximately along the contour lines, as expected (Figure 10).

Current roses from chosen depths from the current profiler further up in the water column are given in Figure 11, including the deepest measurement from the point current meter at 1379 m (Figure 11). This illustrates the main current axis along the north-south direction, with stronger northbound currents in the deeper layers and southwards above 1150 m. The uppermost data is from 950 m.

The variance ellipses for the various depth cells from the current meter are illustrated in Figure 12. The most shallow ones up towards 950 m depth are given in red, and give the strongest variance compared to those closer to the seafloor.

The vertical structure of the current measurements is shown in Figure 13. In the left panel, the average currents at the 50 lowermost depth cells are displayed. The average current did increase from 2.7 cm/s at the lowermost cells to nearly 8 cm/s at about 1300 m depth. Further up in the water column, the average speed did increase even more, to about 9.5 cm/s at 1200 m depth. Note that the point current meter just 3 m above the seafloor is not included in this illustration, and show intensification of the bottom current with an average current speed of 10.5 cm/s.

The variance of the current vectors may be represented as a circle with eccentricity showing directional stability. The eccentricity of the current measurements is given in the middle panel in Figure 13. The currents close to the sea floor showed low eccentricity (0.35) and therefore had a weak directional stability. Maximum eccentricity (ca. 0.48) was higher up in the water column, at about 1250 m depth. The green line at about 1315 m depth emphasizes where the current paradigm changes in the vertical, where currents are becoming weaker and less prominent in direction. Below this green line, in the lower 30-40 m of the water column, the eccentricity of the elliptic shape displaying the current vector variance changed significantly. From around 950 m depth to 1150 m, the mean water flow at the Bønna area during the measuring period was towards a southeasterly direction (right panel). However, at a depth of around 1150 m and below, the direction of water transport shifted to a northwesterly direction.

Table 2: Statistical data from 1379 m depth at Bønna.

	Strøm (cm/s)	Temperatur (°C)
Max	39.1	-0.2
Min	0.1	-0.9
Gj.snitt	10.5	-0.8
% av målinger > 10 cm/s	46.4	
% av målinger < 10 > 3 cm/s	44.5	
% av målinger < 3 > 1 cm/s	8.1	
% av målinger < 1 cm/s	1	
95-prosentil (95 % av målingene er lavere enn denne verdien)	21.8	
Residual strøm	2.1	
Residual retning	327	
Varians	39.6	0
Standardavvik	6.3	0
Stabilitet (Neumanns parameter)	0.2	

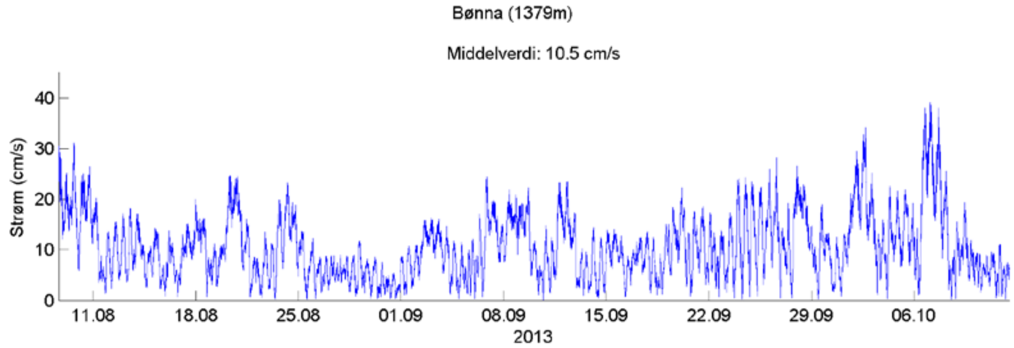


Figure 5: Time series of the current speed from Bønna at the deepest measurement (point current meter) of 1379 m, about 2-3 m above the sea floor.

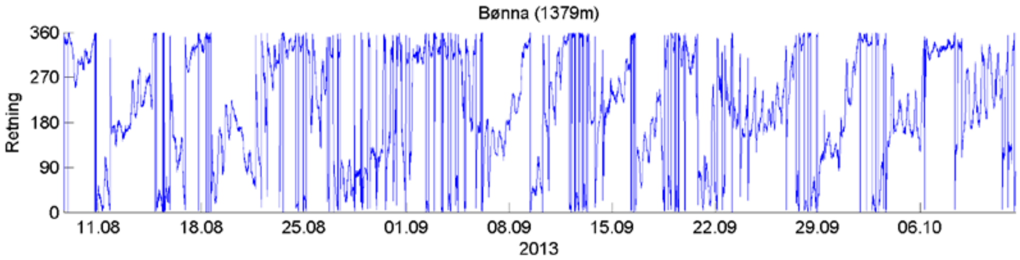


Figure 6: Time series of the current direction at 1379 m depth at Bønna.

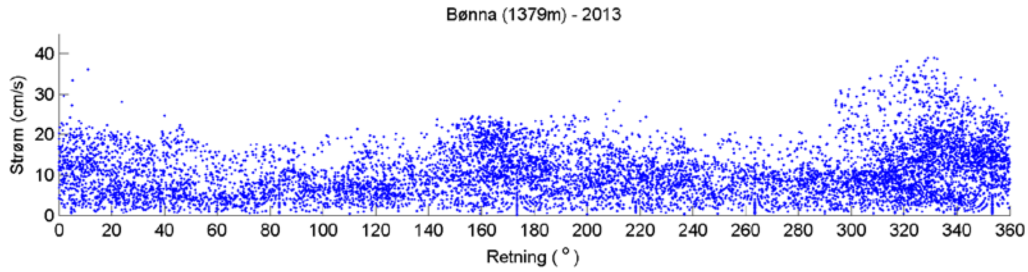


Figure 7: Current speed vs. direction at 1379 m depth at Bønna.

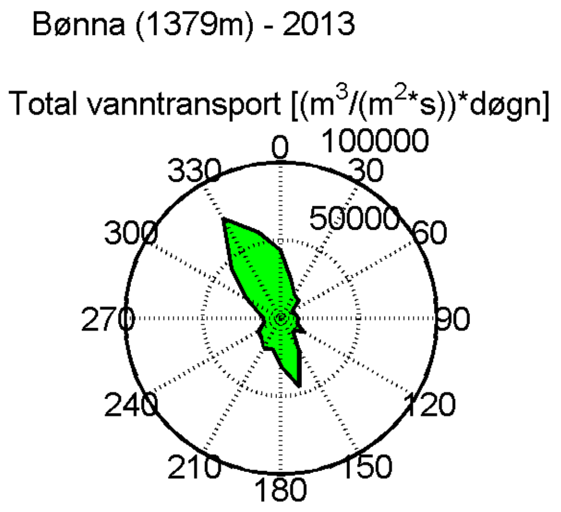


Figure 8: Total water transport per day towards different directions throughout the measurement period, from 1379 m depth at Bønna. The resolution is 15 degrees.

Table 3: Tidal contribution during the measurement period from 1379 m depth at Bønna.

Bønna (1379m) - 2013

Øst-vest (%):	15.3
Nord-Sør (%):	13.1
Maks. tidevannstrøm (cm/s):	10.69
Gj.snitt. tidevannstrøm (cm/s):	4.07
Maks. reststrøm (cm/s):	34.15
Gj.snitt. reststrøm (cm/s):	9.85

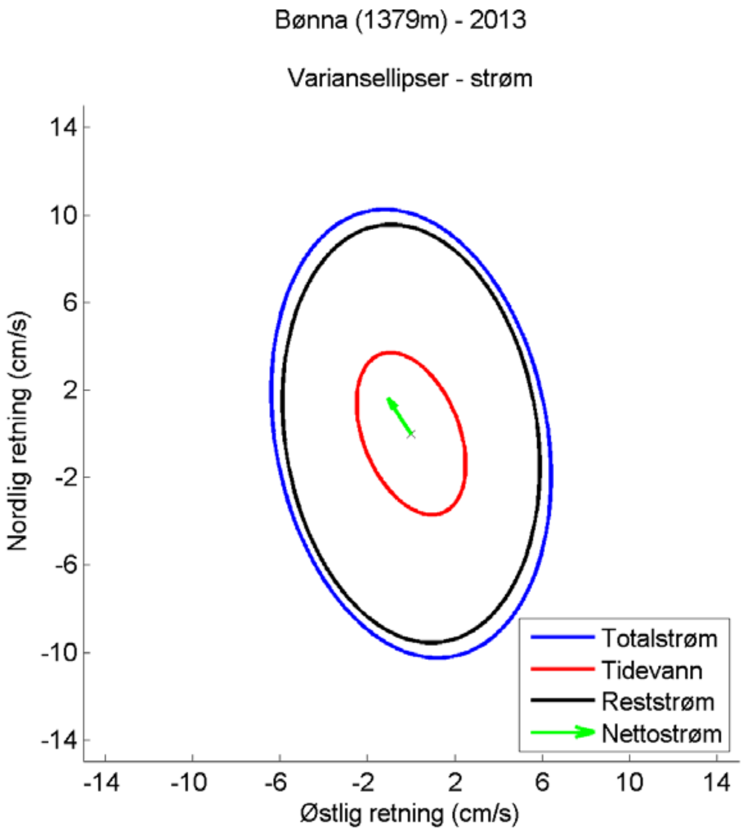


Figure 9: Variance ellipse of the current measurements from 1379 m depth at Bønna. The ellipses represent two standard deviations of the current meter data results. The contribution from the tide is given with red ellipse, while the residual is shown with black ellipse. The total current variance ellipse is given in blue. The net current vector is illustrated with green arrow.

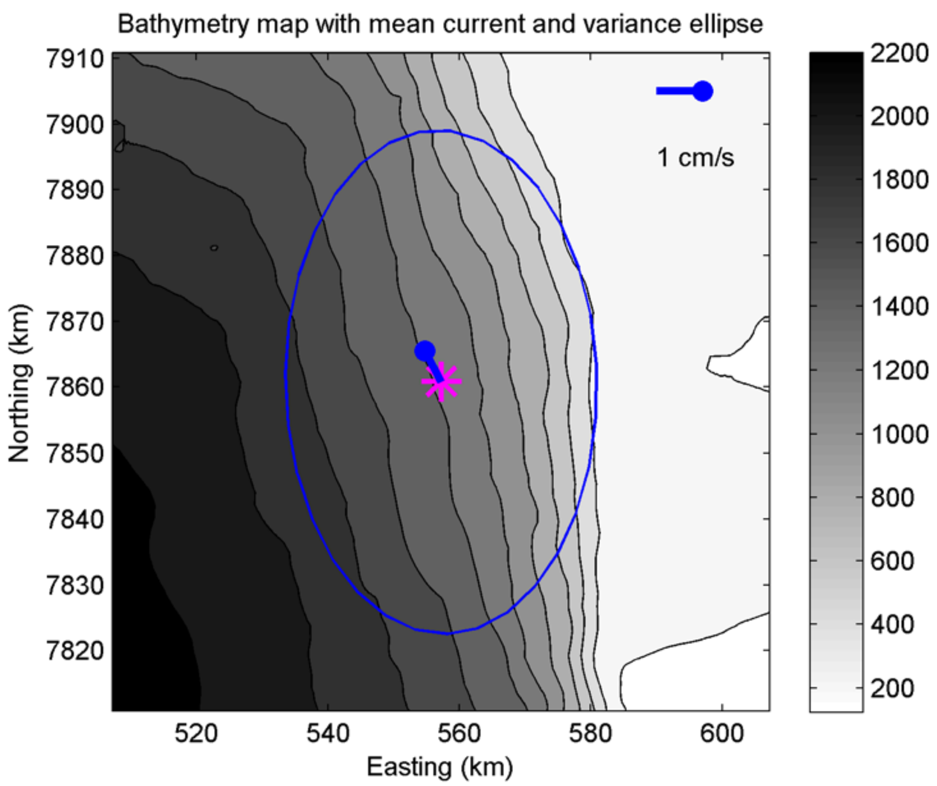
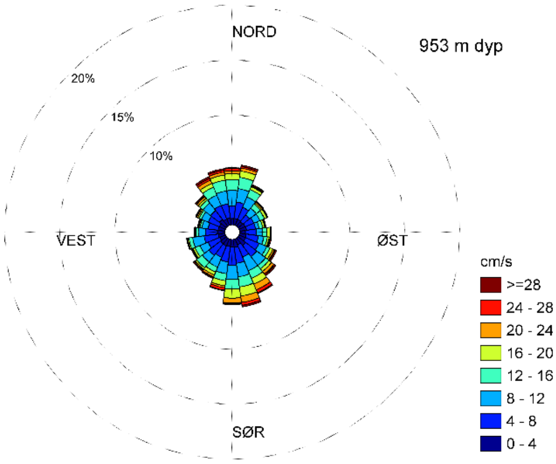


Figure 10: Depth contours in the area of the current meter mooring at Bønna. The blue ellipse is the variance in the various directions (one standard deviation). The pink star is the actual location of the current meter mooring. The blue line emanating from this pink star is the residual current throughout the measuring period of the lowermost cell of the profiling current meter, measuring at 1361 m depth.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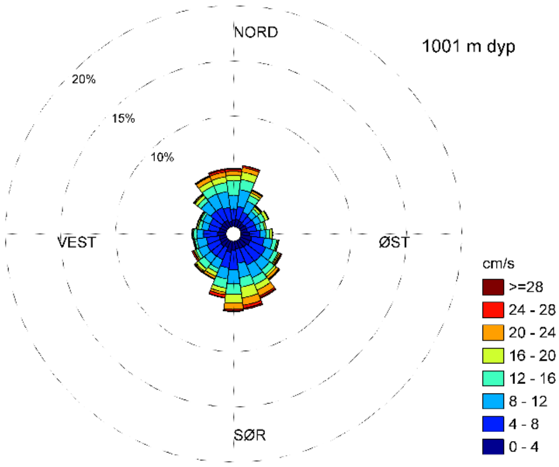
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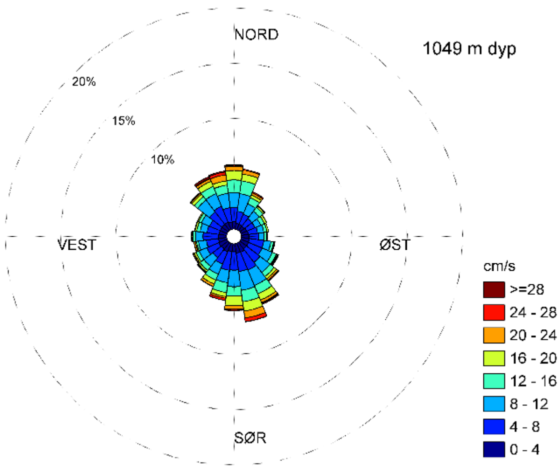
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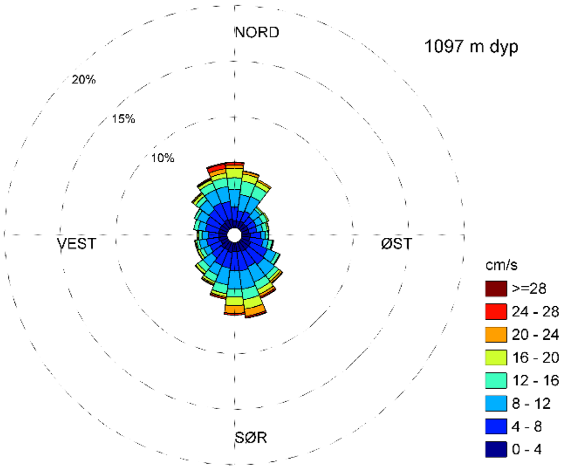
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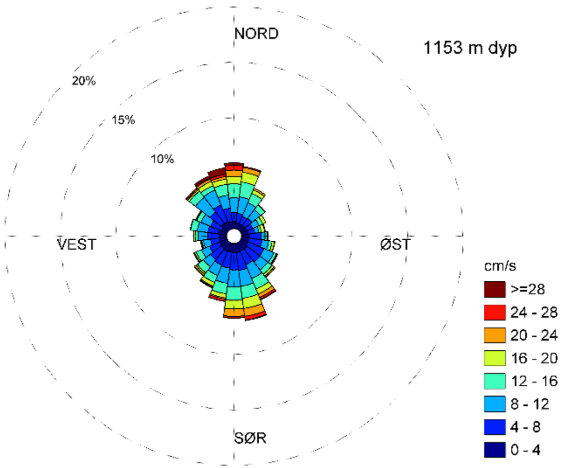
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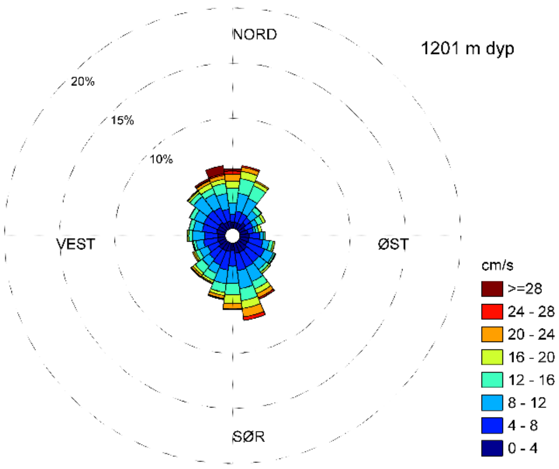
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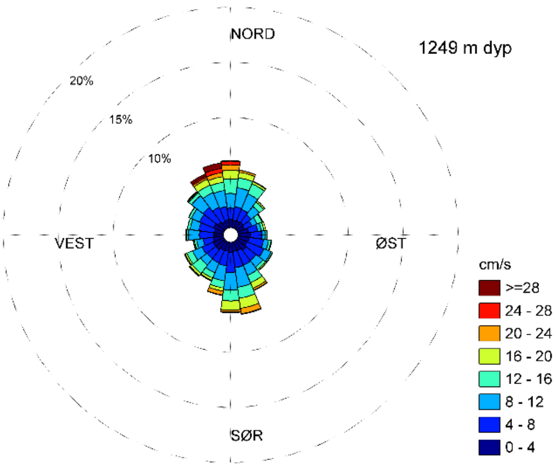

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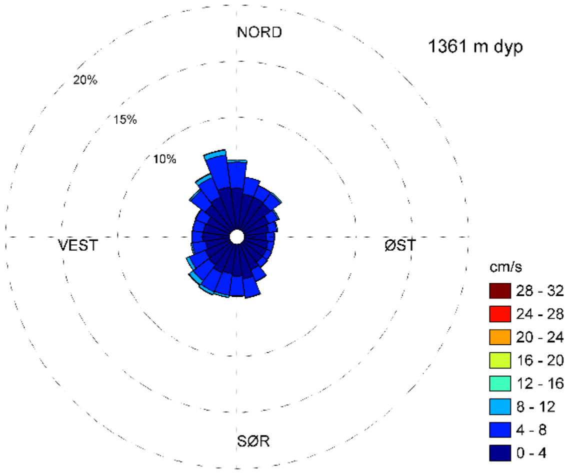

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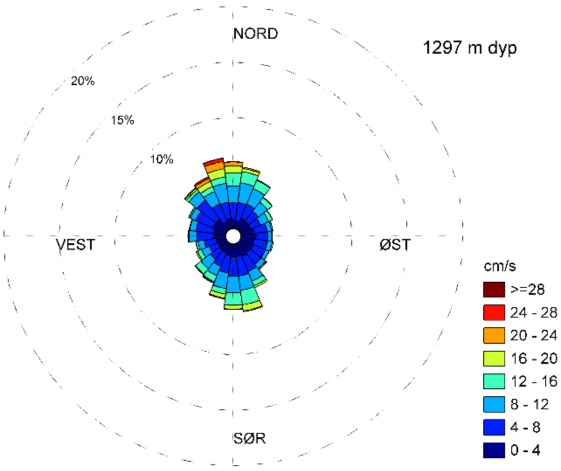

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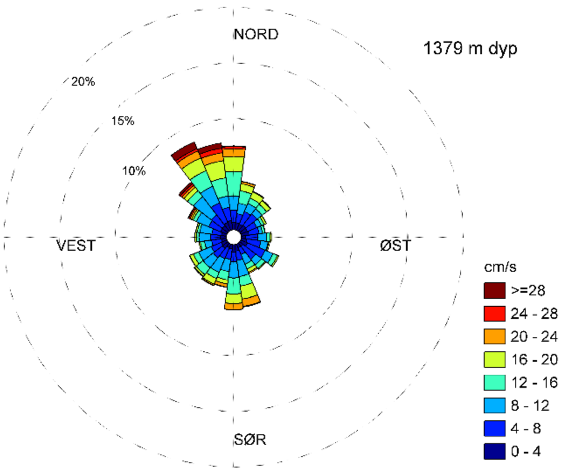

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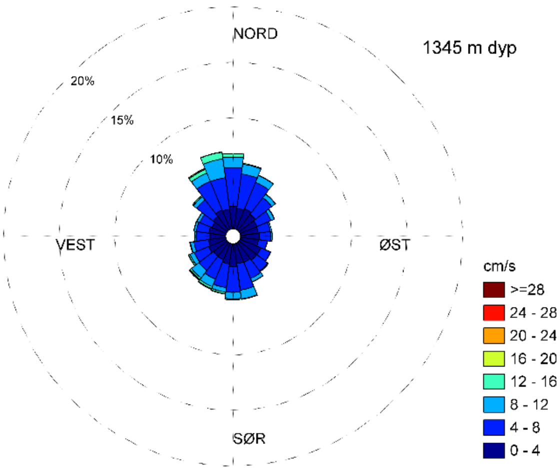


i)

Figure 11: Current roses for the current meter time series between August 8th and October 15th at Bønna for depths at about a) 953 m, b) 997 m, c) 1049 m, d) 1097 m, e) 1153 m, f) 1201 m, g) 1249 m h) 1297 m, i) 1345 m, j) 1361 m and k) 1379 m. The deepest one is from the point current meter, while the rest is from the profiling current meter. The current roses below show the relative proportions of number of measurements in all directional sectors, with resolution of 15 degrees. The colors show, for each sector, the relative proportion of measurements within each speed interval illustrated with the colourbar to the right.

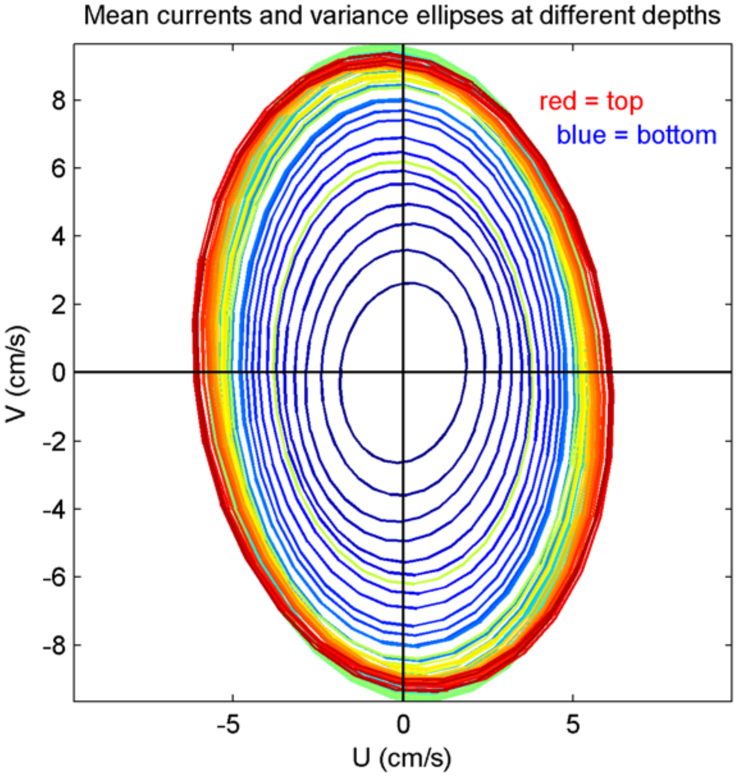


Figure 12: Variance ellipses for the various depth cells at Bønna, where the blue ones are the deepest, near the sea floor.

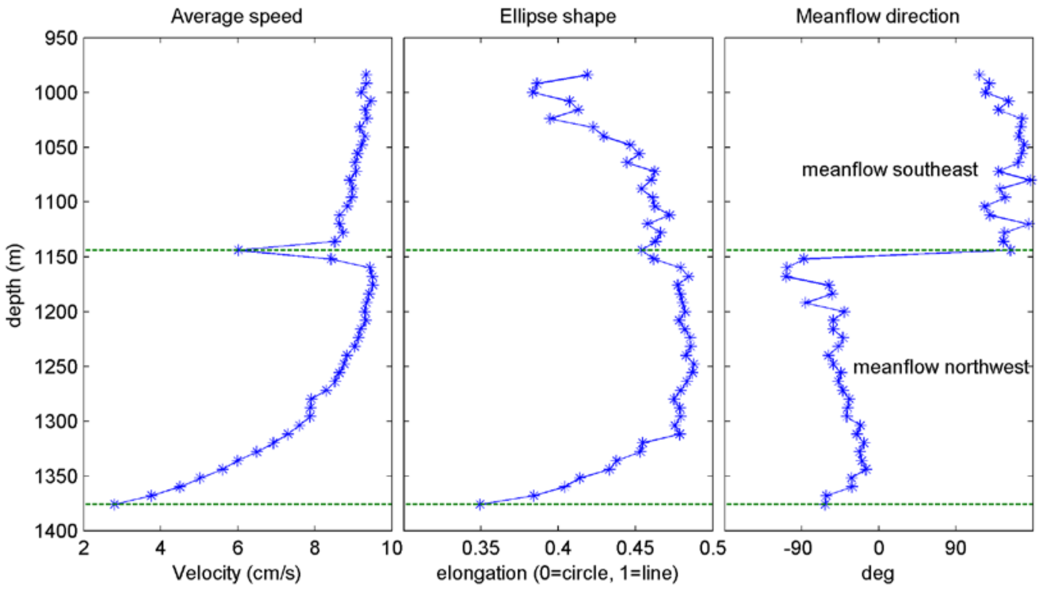


Figure 13: Summarised results from the ADCP current profiler, which measured water flow over the lower 450 m of the water column, between 8th August and 15th October 2013. Note the transitional zone at around 1150 m depth, where the mean current flow (right) switches from a northeasterly direction to southwest. The left panel shows the average current. The middle panel shows the elongation of the variance ellipse, where 0 give a perfect circle and 1 give a perfect line. The right panel gives the direction of the residual currents at the various depths.

4.1.2 Goliat I

The topography at the two Goliat measurement sites are rather flat, with no significant slopes (Figure 1).

Statistical data for the time series from 29th of November 2014 – 6th of March 2015 from the deepest measurement at Goliat I is shown in Table 4. The point current meter at 346 m depth give an average current speed of 17.8 cm/s with a residual of 13.9 cm/s towards east-southeast.

The time series of the current speed at 346 m, about 3 m above the seafloor, show a vividly time varying currents on both shorter and longer time scales, with a maximum of nearly 40 cm/s (Figure 14). The time series of the direction show that the currents is nearly constantly flowing in easterly directions (Figure 15). This means that the currents are not changing to opposite direction with the M2 tidal cycle with period of 12.42 hours. The tidal analysis with the tool U-tide (Codiga, 2011) given in Figure 18 gives that the tidal energy is relatively large for the deepest water masses at Goliat I. The eastward velocity component contributes with 46 % and the northward velocity component contributes with 38 % of the total variation. Hence, the currents are mainly changing speed and not direction, with the M2 tidal cycle. This is confirmed by the relatively big and rapid fluctuations in current speed in Figure 14.

The speed vs. current at 346 m depth at Goliat I (Figure 16) illustrates the main current directions, with both strongest and most frequent registrations towards easterly directions.

The calculated water transport from all directions with 15 degrees sectors are shown in Figure 17, illustrating the main current direction near the seafloor is towards east.

Current roses from chosen depths from the current profiler further up in the water column are given in Figure 19, including the deepest measurement from the point current meter at 346 m. The results show that the main current direction is towards southeast. The direction is shifting from more eastbound near the surface to more southeastbound near the seafloor. The uppermost trustful data is from about 40 m.

The average current speed increases from about 15 cm/s at the lowermost measuring cell of the profiling current meter to nearly 18 cm/s 16 m above. This has tendencies of a bottom intensified current. Further up in the water column the average current decreases to less than 16 cm/s, and then increases gradually further upwards to 18 cm/s again at about 80 m depth (Figure 20).

There are in general more frequently high current speeds higher up in the water column.

Table 4: Statistical data from the deepest current measurements (point current meter) at 346 m at Goliat I.

	Strøm (cm/s)	Temperatur (°C)
Max	39.7	6.5
Min	0.1	4.3
Gj.snitt	17.8	5.5
% av målinger > 10 cm/s	84.8	
% av målinger < 10 > 3 cm/s	13.6	
% av målinger < 3 > 1 cm/s	1.3	
% av målinger < 1 cm/s	0.3	
95-prosentil (95 % av målingene er lavere enn denne verdien)	29.6	
Residual strøm	13.9	
Residual retning	116	
Varians	50.5	0.1
Standardavvik	7.1	0.4
Stabilitet (Neumanns parameter)	0.78	

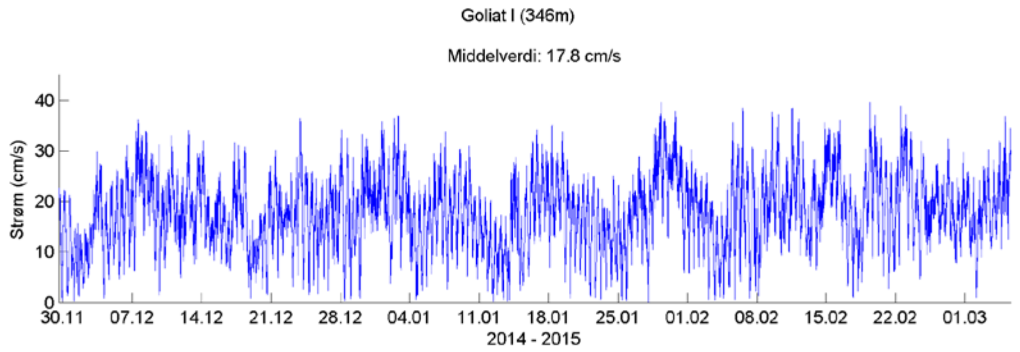


Figure 14: Time series of the current speed from Goliat I at the deepest measurement (point current meter) at 346 m, about 2-3 m above the sea floor.

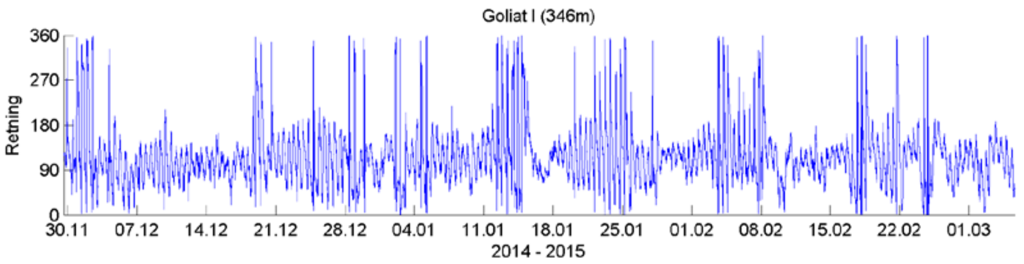


Figure 15: Time series of the current direction at 346 m depth at Goliat I.

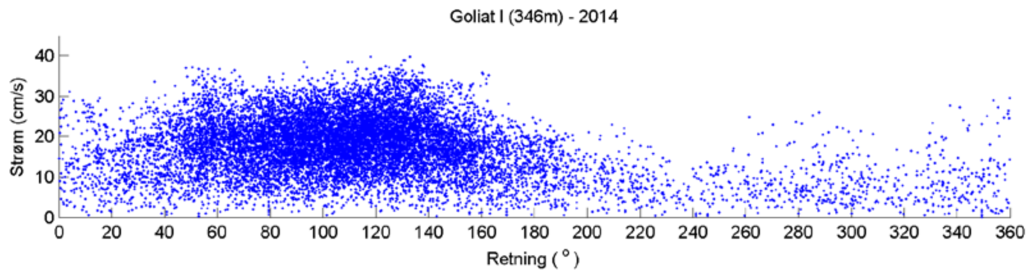


Figure 16: Current speed vs. direction at 346 m depth at Goliat I.

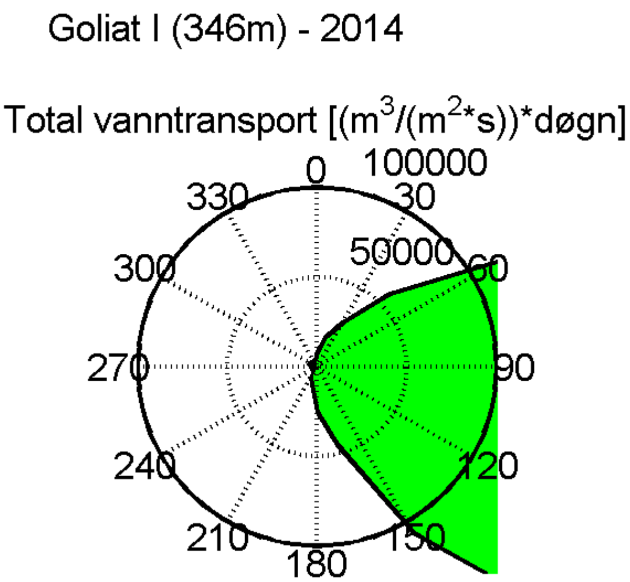


Figure 17: Total water transport per day towards different directions throughout the measurement period, from 346 m depth at Goliat I.

Table 5: Tidal contribution during the measurement period from 346 m depth at Goliat I.

Goliat I (346m) - 2014

Øst-vest (%):	46.4
Nord-Sør (%):	38.6
Maks. tidevannstrøm (cm/s):	16.86
Gj.snitt. tidevannstrøm (cm/s):	8.1
Maks. reststrøm (cm/s):	41.4
Gj.snitt. reststrøm (cm/s):	15.74

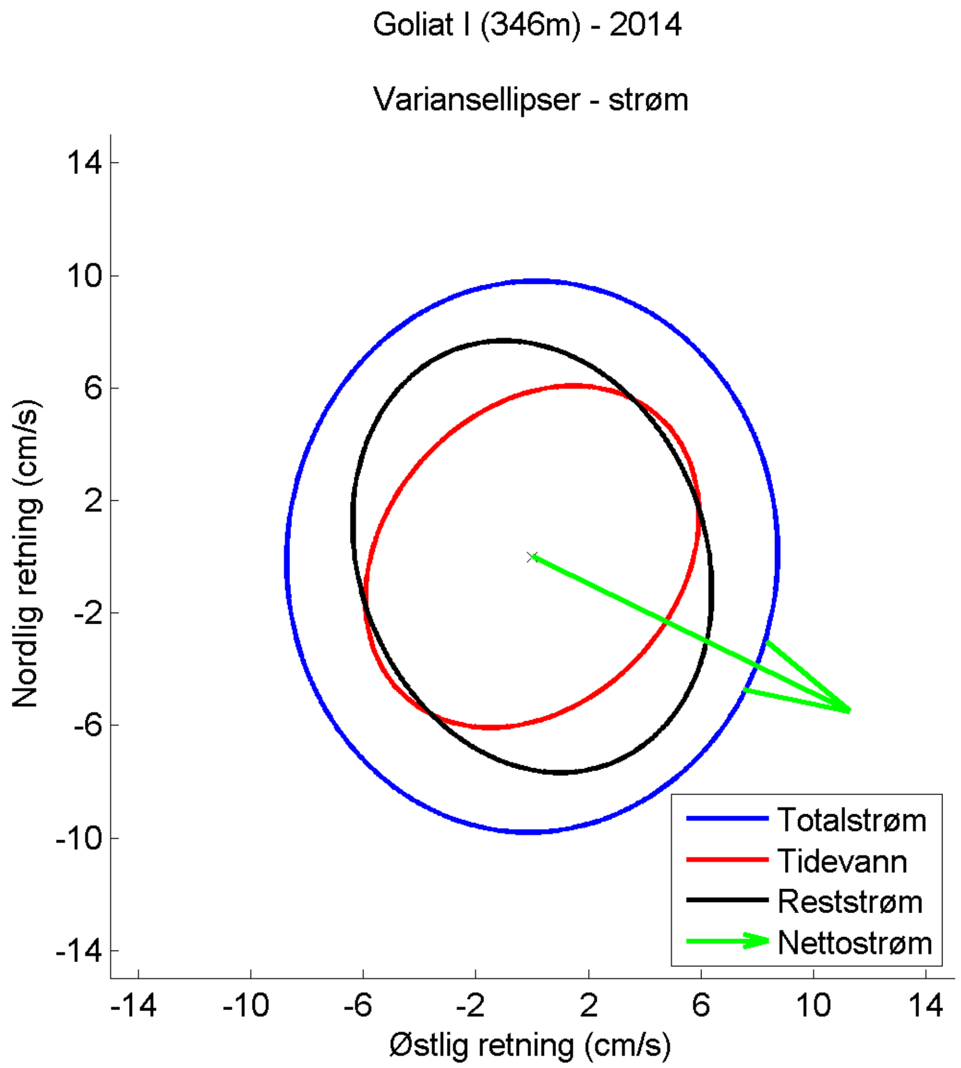
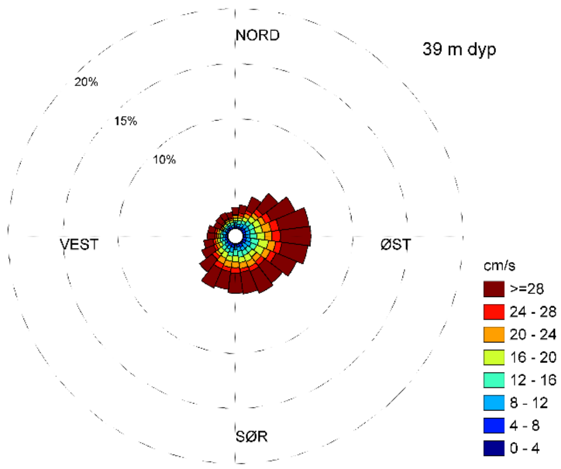


Figure 18: Variance ellipse of the current measurements from 346 m depth at Goliat I. The ellipses represent two standard deviations of the current meter data results. The contribution from the tide is given with red ellipse, while the residual is shown with black ellipse. The total current variance ellipse is given in blue. The net current vector is illustrated with green arrow.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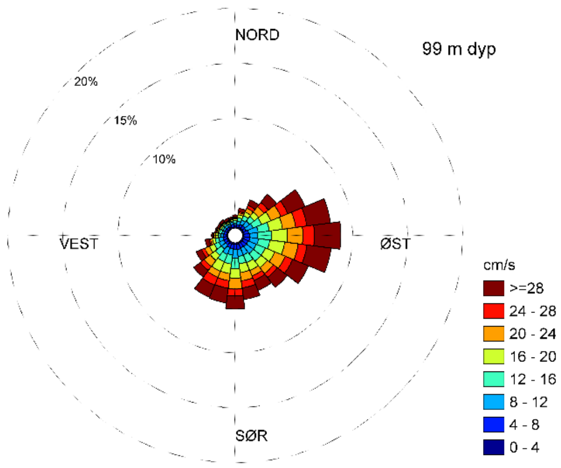
a)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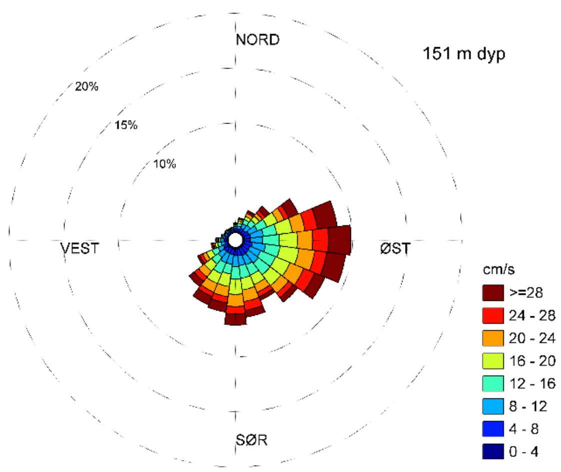
b)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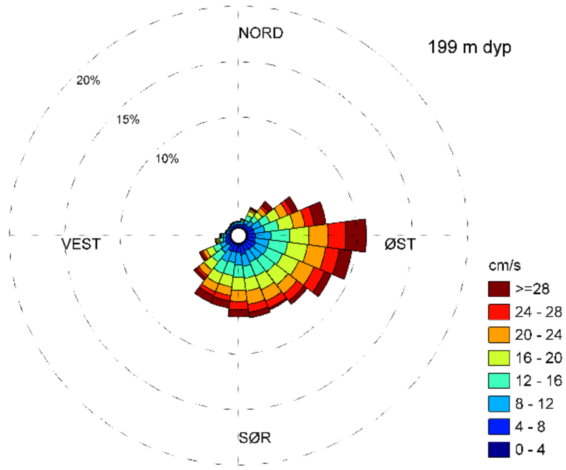
c)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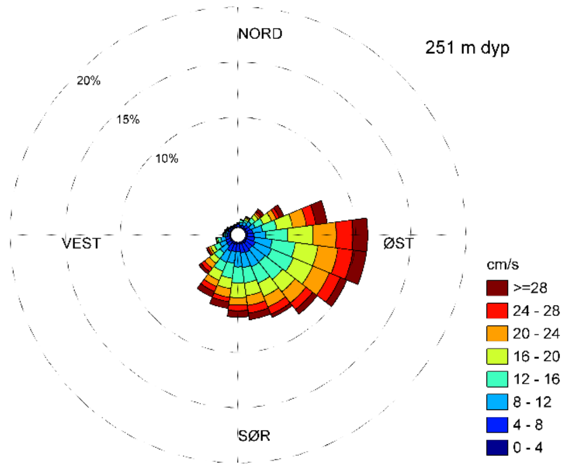
d)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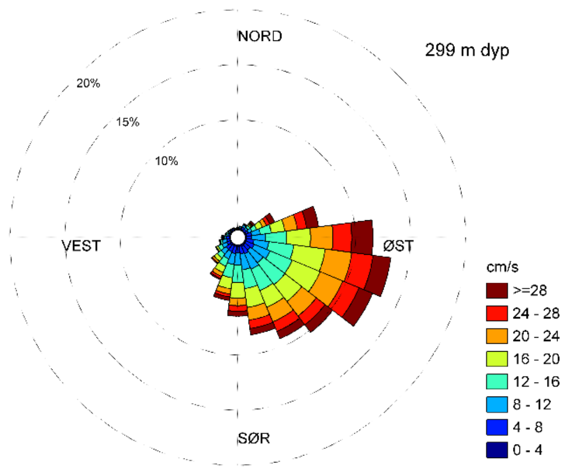
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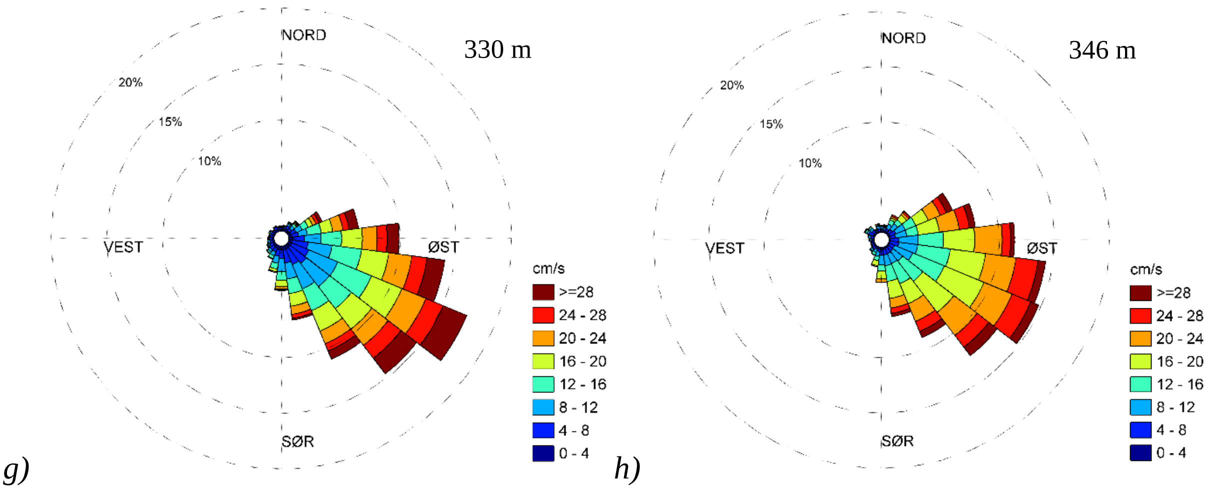


Figure 19: Current roses for the current meter measurements time series between November 29th 2014 and 6th March 2015 at Goliat I for depths at about a) 39 m, b) 99 m. c) 151 m, d) 199 m, e) 251 m, f) 299 m, g) 330 m and h) 346 m. The deepest one is from the point current meter, while the rest is from the profiling current meter. The current roses below show the relative proportions of number of measurements in all directional sectors, with resolution of 15 degrees. The colors show, for each sector, the relative proportion of measurements within each speed interval illustrated with the colorbar to the right.

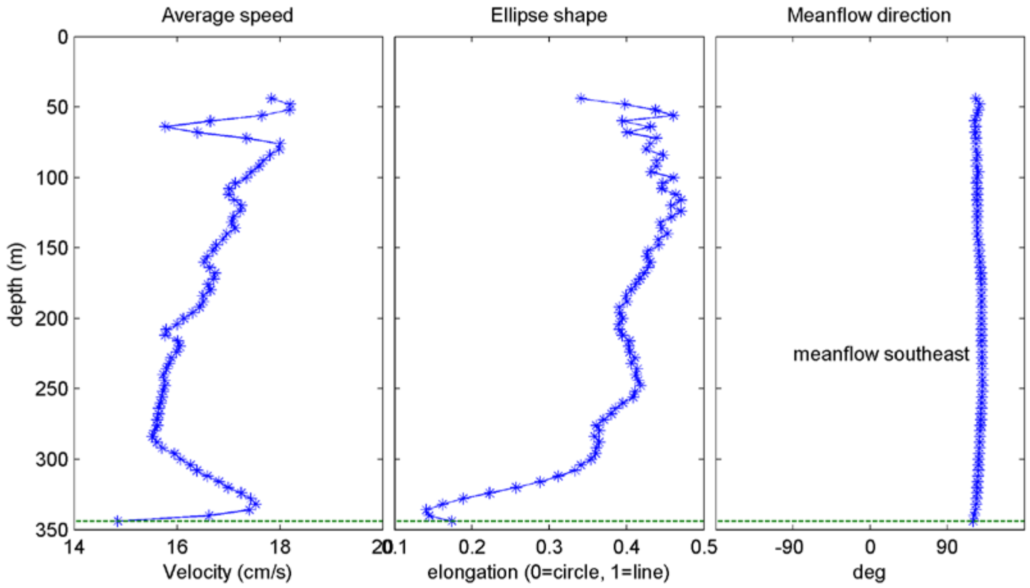


Figure 20: Summarised results from the ADCP current profiler, which measured water flow over the water column, between November 29th 2014 and 6th March 2015. The left panel shows the average current. Note the intensification of the average current speeds from about 290 to 335 m depth, near the sea floor. The middle panel shows the elongation of the variance ellipse, where 0 give a perfect circle and 1 give a perfect line. The right panel gives the direction of the residual currents at the various depths.

4.1.3 Goliat II

The results from from 7th of September to 16th of October 2015 at Goliat II resembles the results from Goliat I about 4 km away from winter 2015. The main current direction near the seafloor is towards east-southeast, while it shifts to more easterly directions further up in the water column (Figure 26).

Statistical data for the time series fall 2015 from the deepest measurement at Goliat II, the point current meter at 364 m depth, give an average current speed of 14.1 cm/s with a residual of 9.6 cm/s towards east-southeast (Table 6). This is slightly weaker than that of Goliath I.

The time series of the current speed at 364 m, about 3 m above the seafloor, show a vividly time varying currents on shorter time scales, and larger variation on longer time scales at the end of the measurement period. The maximum current speed is about 40 cm/s (Figure 21). The time series of the direction show that the currents are predominantly flowing in easterly directions (Figure 22), with some interruptions of a westerly flow. This means that the currents are most often not changing to opposite direction with the M2 tidal cycle with period of 12.42 hours. The results from tidal analysis with the tool U-tide (Codiga, 2011) given in Table 7 and Figure 25 gives that the tidal energy is relatively large for the deepest water masses at Goliat II, contributing with nearly 50 % of the total current variation in both the east-west and the north-south components. Hence, the currents are mainly changing speed and not direction, with the M2 tidal cycle. This is confirmed by the relatively big and rapid fluctuations in current speed in Figure 21.

The speed vs. current at 364 m depth at Goliat II (Figure 23) illustrates the main current directions, with both strongest and most frequent observation to easterly directions. However, there is also a significant number of current registrations in the opposite directions, towards west.

The calculated water transport from all directions with 15 degrees sectors are shown in Figure 24, illustrating again that the main current direction near the seafloor is towards east.

Current roses from chosen depths from the current profiler further up in the water column are given in Figure 26, including the deepest measurement from the point current meter at 364 m. The results show that the main current direction is towards southeast throughout the water column. The uppermost data is from about 40 m. The point current meter and the lowermost data cell from Hekla show good agreement, where the main current direction is towards east-southeast. There is a smaller amount of current events towards west, where also stronger current velocities my occur. In southerly directions, there are also some registrations, but these are in general weaker.

The average current speed increases from about 10 cm/s at the lowermost measuring cell of the profiling current meter to just above 16 cm/s at about 50 m depth (Figure 27).

There are in general more frequently high current speeds higher up in the water column.

Table 6: Statistical data from the deepest current measurements (point current meter) at 364 m at Goliat II.

	Strøm (cm/s)	Temperatur (°C)
Max	40.7	6.6
Min	0.1	5
Gj.snitt	14.1	5.6
% av målinger > 10 cm/s	67.3	
% av målinger < 10 > 3 cm/s	29.9	
% av målinger < 3 > 1 cm/s	2.4	
% av målinger < 1 cm/s	0.3	
95-prosentil (95 % av målingene er lavere enn denne verdien)	27.3	
Residual strøm	9.6	
Residual retning	120	
Varians	50.6	0.1
Standardavvik	7.1	0.3
Stabilitet (Neumanns parameter)	0.68	

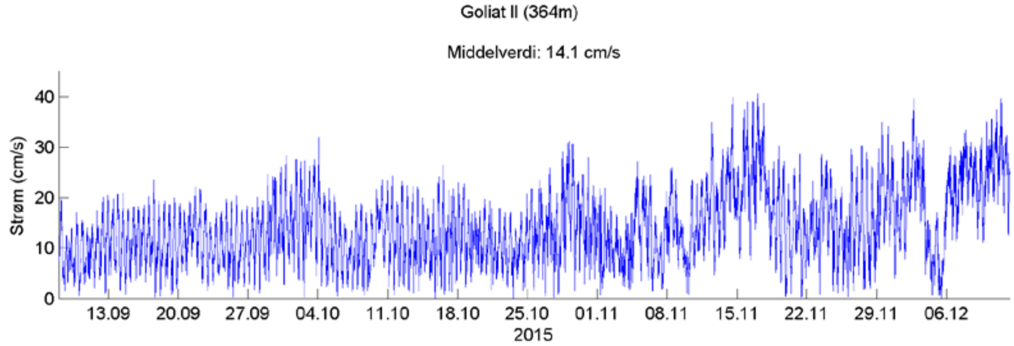


Figure 21: Time series of the current speed from Goliat II at the deepest measurement (point current meter) at 364 m, about 2-3 m above the sea floor.

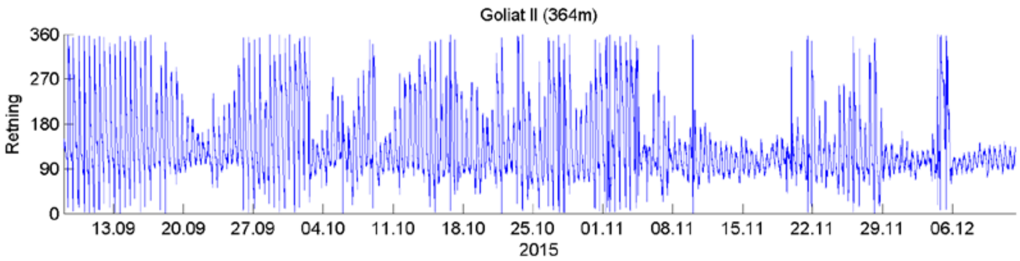


Figure 22: Time series of the current direction at 364 m depth at Goliath II.

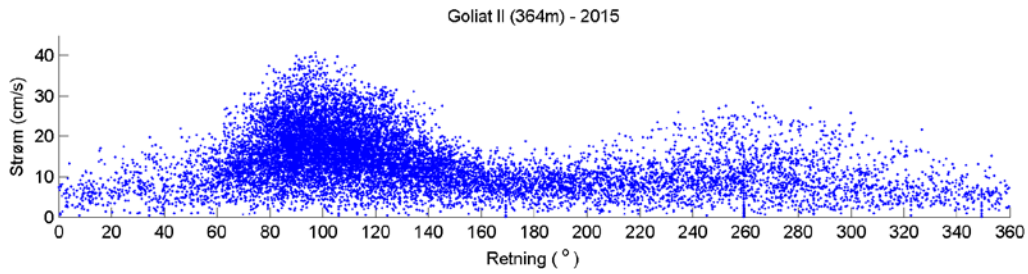


Figure 23: Current speed vs. direction at 364 m depth at Goliat II.

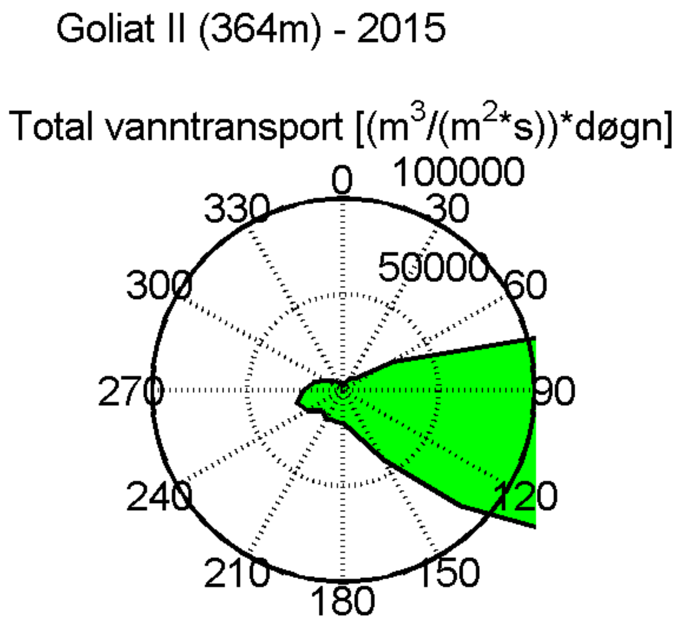


Figure 24: Total water transport per day towards different directions throughout the measurement period, from 364 m depth at Goliat II.

Table 7: Tidal contribution during the measurement period from 364 m depth at Goliat II.

Goliat II (364m) - 2015

Øst-vest (%):	48
Nord-Sør (%):	48.7
Maks. tidevannstrøm (cm/s):	19.4
Gj.snitt. tidevannstrøm (cm/s):	8.07
Maks. reststrøm (cm/s):	39.64
Gj.snitt. reststrøm (cm/s):	10.99

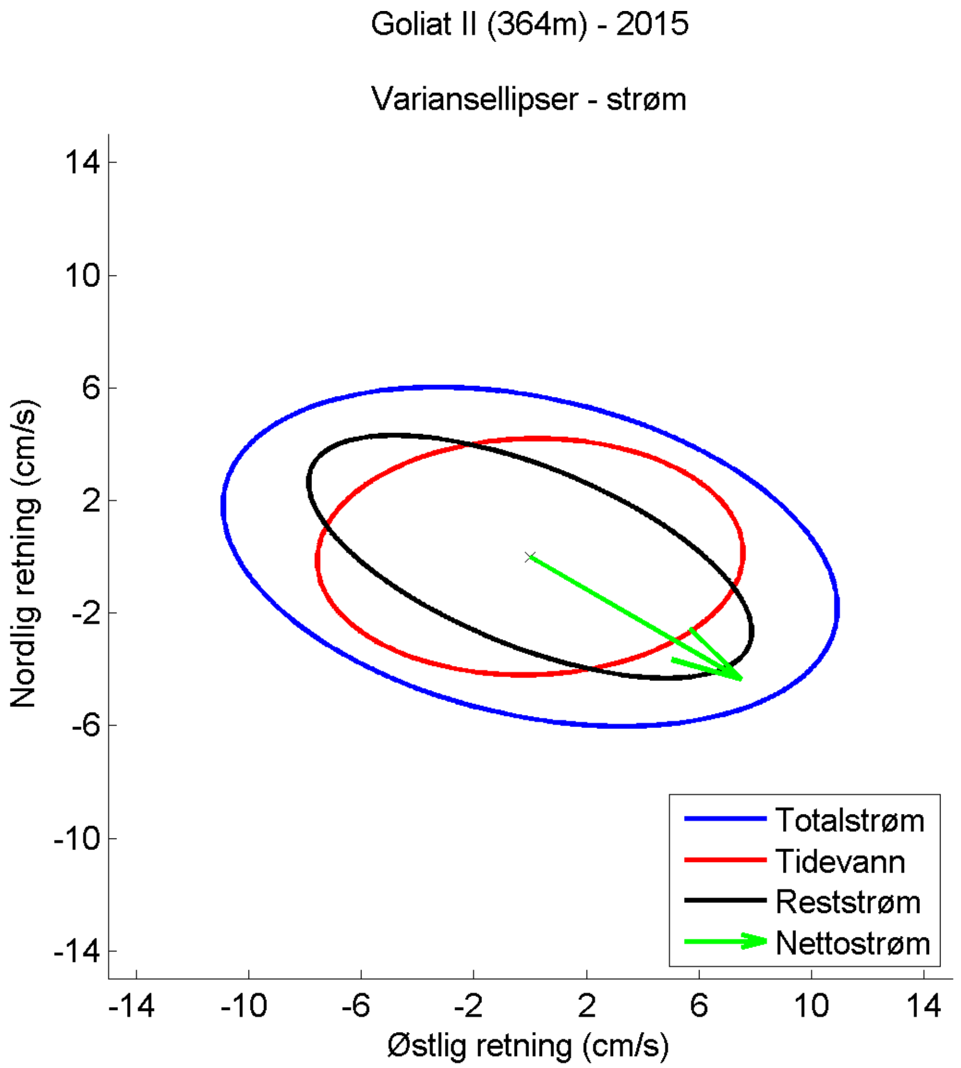
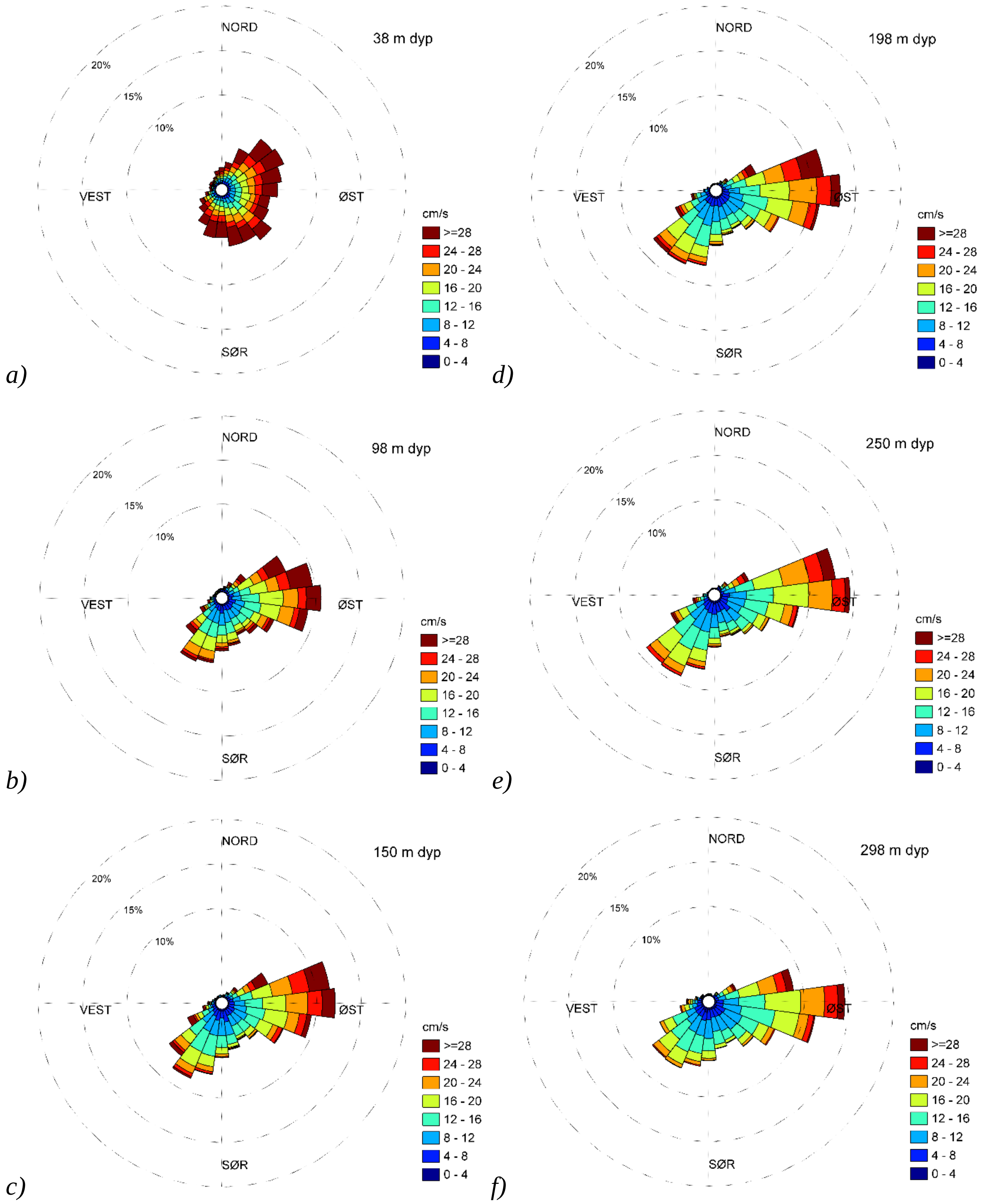


Figure 25: Variance ellipse of the current measurements from 364 m depth at Goliat II. The ellipses represent two standard deviations of the current meter data results. The contribution from the tide is given with red ellipse, while the residual is shown with black ellipse. The total current variance ellipse is given in blue. The net current vector is illustrated with green arrow.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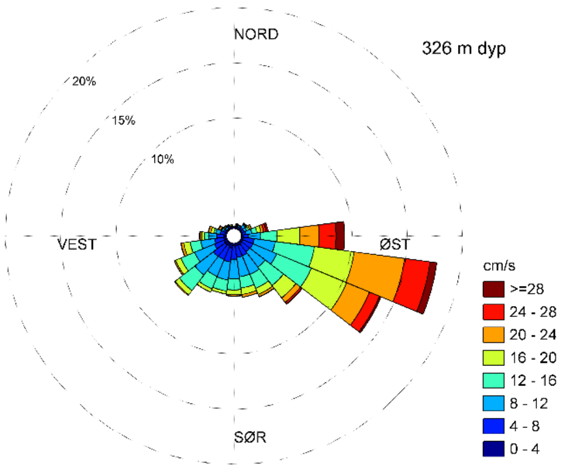
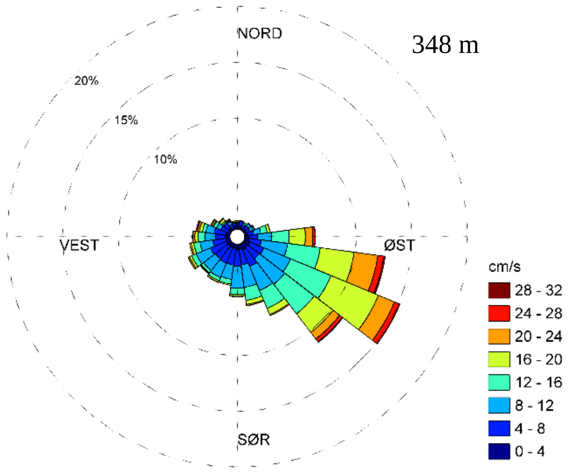
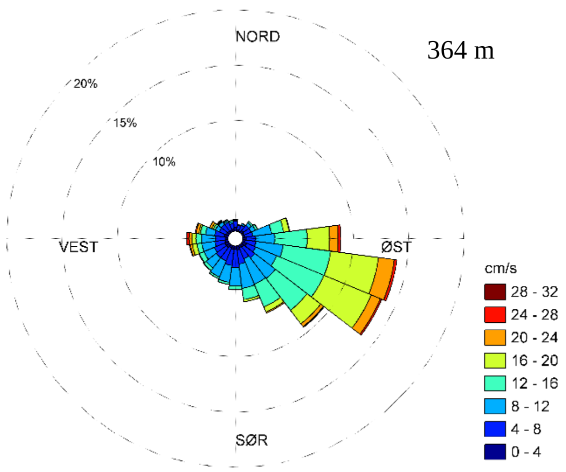


g)



h)



i)

Figure 26: Current roses for the current meter measurements time series between September 7th 2015 and October 16th 2015 at Goliat II for depths about a) 38 m, b) 98 m. c) 150 m, d) 198 m, e) 250 m, f) 298 m, g) 324 m, h) 348 m and i) 364 m. The deepest one is from the point current meter, while the rest are from the profiling current meter. The current roses below show the relative proportions of number of measurements in all directional sectors, with resolution of 15 degrees. The colors show, for each sector, the relative proportion of measurements within each speed interval illustrated in the color bars to the right.

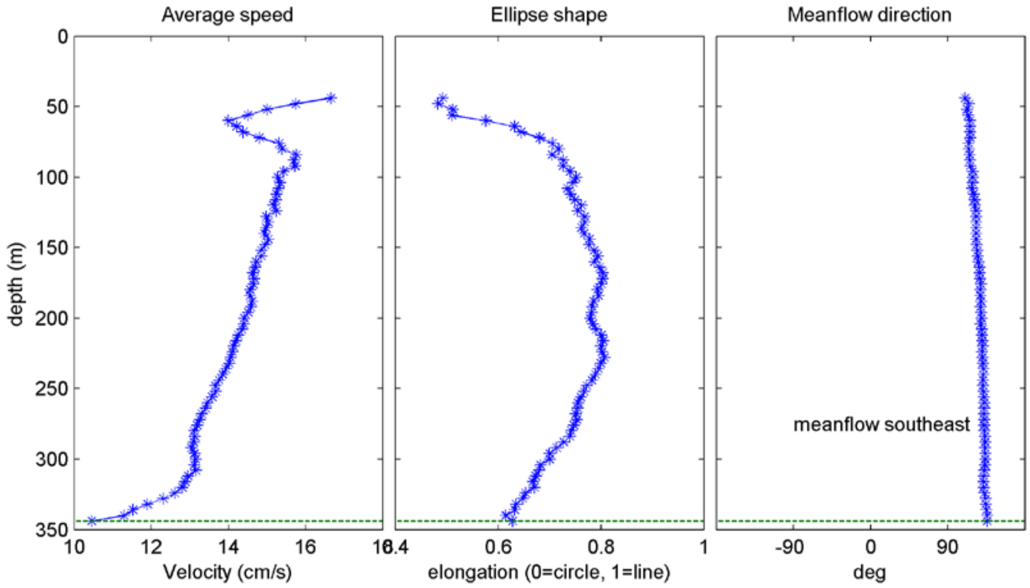


Figure 27: Summarised results from the ADCP current profiler, which measured water flow over the water column, between September 7th 2015 and October 16th 2015. The left panel shows the average current. The middle panel shows the elongation of the variance ellipse, where 0 give a perfect circle and 1 give a perfect line. Note that the elongation is higher than at Goliat I. The right panel gives the direction of the residual currents at the various depths.

5 Hydrography

5.1 Bønna

Measurements of the water column on the 8th August, 2013 with a SAIV CTD, showed the water temperature to drop from nearly 12 °C at the surface to 8 °C in the upper water mass layer at 40 m depth (Figure 28). Down to around 650 m, the temperature dropped to below 4 °C, and from approximately 900 m depth, the water reached sub-zero temperatures. The bottom water temperature was - 0.96 °C.

These measurements show that the bottom waters of the Bønna area were characterized mainly by cold Norwegian Sea Deep Water (NSDW) with temperatures below - 0.5 °C. Between 700 and 1100 m depth lies the Norwegian Sea Arctic Intermediate Water (NSAIW). Above the NSAIW was typical Atlantic Water (AW), of which the upper layer was influenced by fresher (not shown) and warmer water. This is likely to be a branch of the Norwegian Coastal Current, with coastal runoff warmed by solar irradiation.

The temperature at the instrument location of the point current meter, at 1379 m, has been plotted vs. time in Figure 29, and confirms the cold temperature of the deep water given by the CTD-profile mentioned above.

The temperature is rather stable throughout the measuring period from beginning of August to middle of October 2013, varying between -0.7°C and -0.9°C.

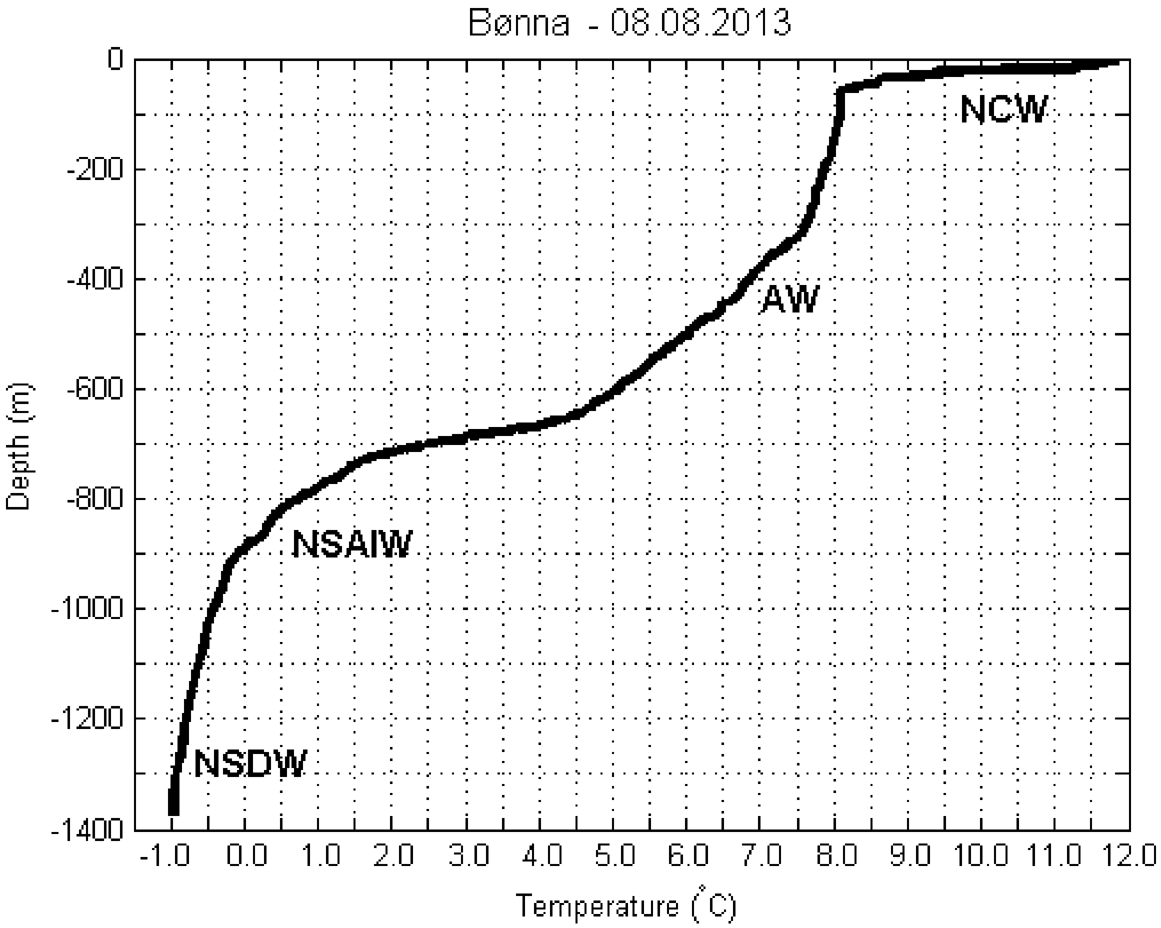


Figure 28: Results from temperature profile in from Bønna captured with a SAIV CTD 8th of August 2013.

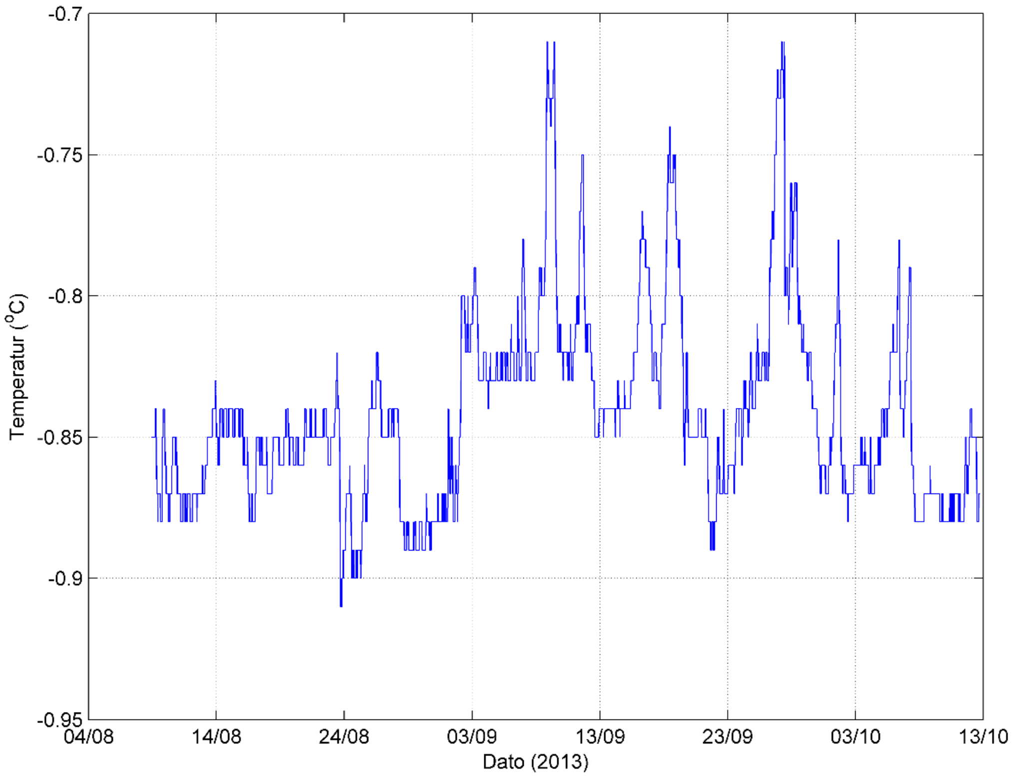


Figure 29: Temperature time series from the Nortek Aquadopp DW point current meter instrument at Bønna at 1379 depth, with measurement period between 8th of August and 13th of October 2013.

5.2 Goliat I

The temperature at the instrument location of the point current meter, at 345 m, has been plotted vs. time in Figure 30.

The temperature is fluctuating rather fast in time, most often with a range between 0.5 and 1°C. From the end of November 2014, the temperature is in general increasing till middle of December 2014 to about 6°C. From the end of December 2014 to end of January 2015, the temperature stabilizes at about 5.6°C. Thereafter, there is a drop to beneath 4.5°C in the beginning of February, and again a slow decrease from 5.5 to about 5 °C in the beginning of March 2015.

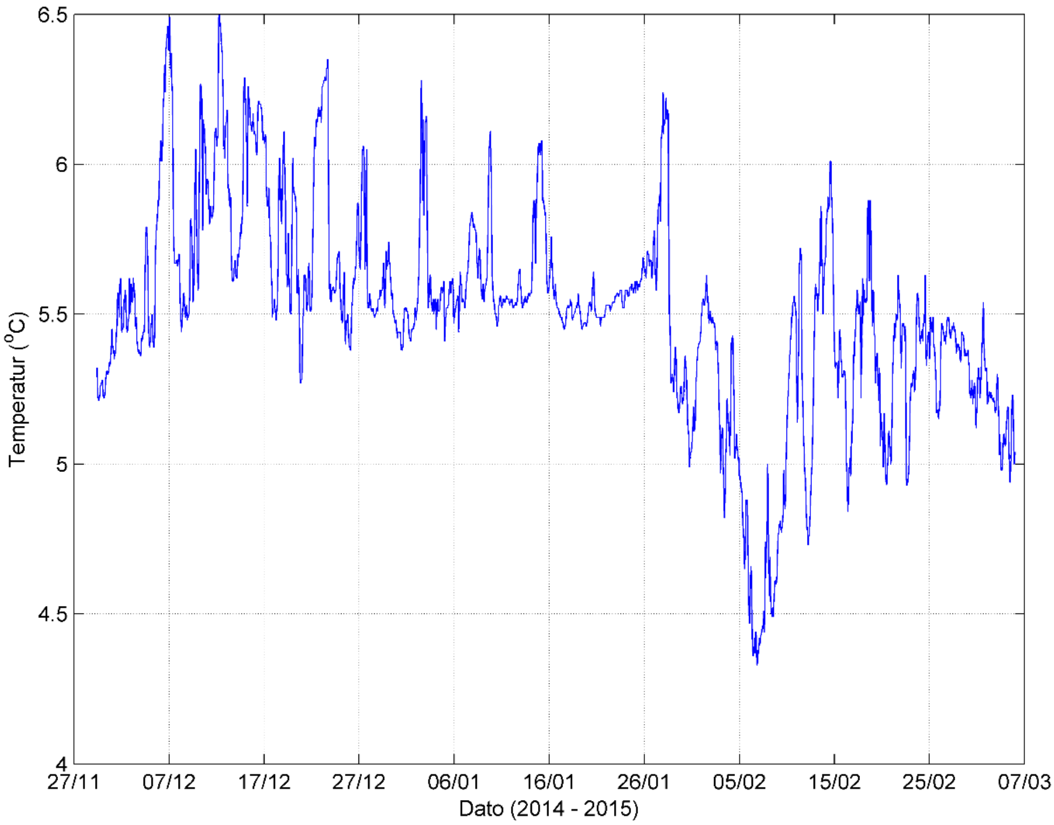


Figure 30: Temperature time series from the Nortek Aquadopp DW point current meter instrument at Goliat I at 345 m depth, with measurement period between 29th of November 2014 and 6th of March 2015.

5.3 Goliat II

The temperature at the instrument location of the point current meter at 363 m, has been plotted vs. time in Figure 31.

The temperature is fluctuating rather often in time, most often with around 0.5°C range. There are also some larger rapid changes in temperature of more than 1°C in the end of November and beginning of December 2015.

From the beginning of September 2015, the temperature is in general increasing from 5.0 °C to 6.6°C in the middle of November 2015. Thereafter, the temperature trend is decreasing to about 5.4° in the middle of December 2015.

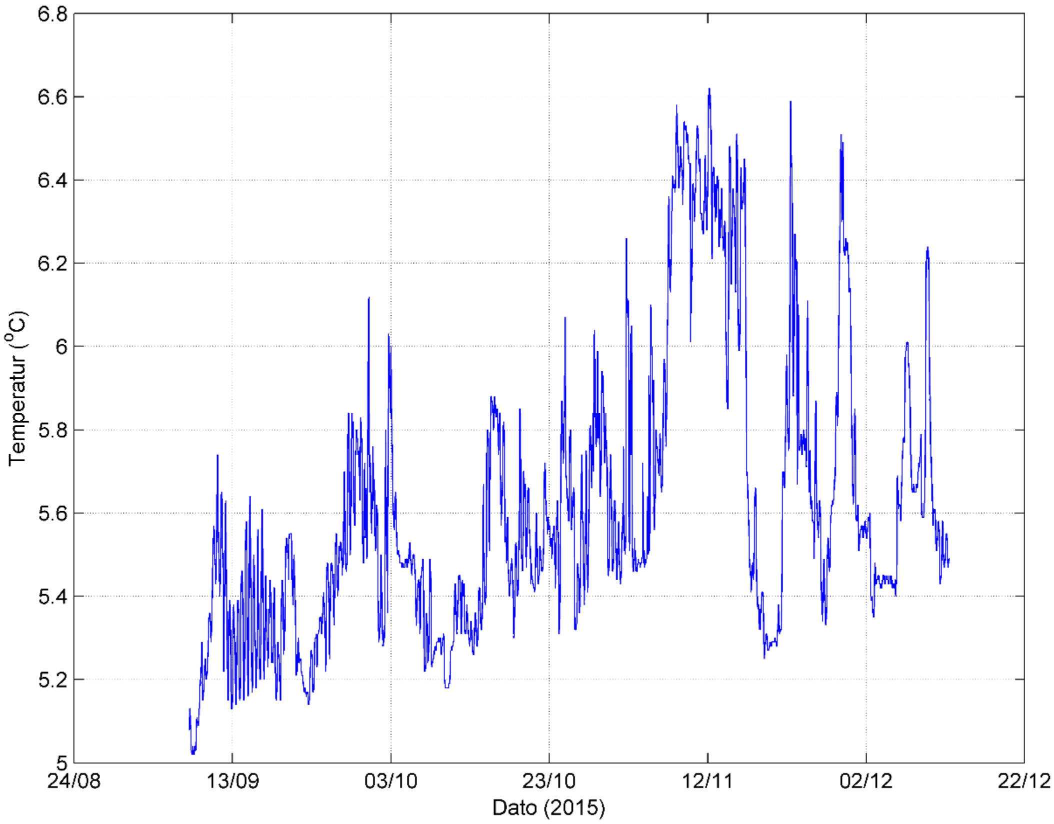


Figure 31: Temperature time series from the Nortek Aquadopp DW point current meter instrument at Goliat II at 363 m depth, with measurement period between 7th of September and 12th of December 2015.

6 Summary & discussion

Current measurements with a Teledyne Long Ranger (75 kHz) and a Nortek Aquadopp Point current meter (2 MHz) have been conducted at Bønna (70°50.690' N; 16°33.744' E) and twice at Goliat (71°15.453' N; 22°15.877' E and 71°17.429' N; 22°12.058' E), the two latter about 4 km apart. The depths at Bønna was about 1380 m, while at Goliat the depth was 350 – 370 m.

At both Bønna and Goliat I, a bottom intensified current took place, especially at Bønna. The main current direction at Bønna was along the north-south direction with a minor residual current. Goliat had an eastbound main current at both measurement periods and measurement sites, that rotated somewhat towards southeast near the seafloor. There was a strong residual current towards east and southeast.

The average current of the deepest measurements 2 – 3 m above the seafloor at Bønna was 10.5 cm/s, while at Goliat it was 17.8 cm/s and 14.1 cm/s.

The residual currents near the seafloor at Bønna was relatively weak, 2.1 cm/s, towards east-northeast. The bottom residual currents at Goliat I and Goliat II were much stronger, with 13.9 and 9.6 cm/s towards east-southeast.

This indicates forth-and-back-currents, not due to the tides, at Bønna. At Goliat, the tidal signal is much more present, but the currents are nearly always flowing towards easterly or southeasterly directions.

The spreading patterns of drill cuttings near the seafloor are likely to roughly correspond to the patterns of the water transport/ water fluxes. Hence, at Bønna the likely spreading is both northwards, but also southwards mainly along the bathymetry contours. At Goliat I, the likely spreading pattern of the drill cuttings is nearly completely in easterly and southeasterly directions. At Goliath II, there would also be some drill cuttings spreading in the western direction.

At all the three sites, resuspension of drill cuttings is likely, due to the intermittently strong currents. Depending on the size and properties of the drill cuttings, there is a likelihood for increased turbidity close to the seafloor in the vicinity of the release point.

7 References

Codiga. D.L., 2011. Unified Tidal Analysis and Prediction Using the UTide Matlab Functions. Technical Report 2011-01. Graduate School of Oceanography, University of Rhode Island, Narragansett, RI. 59pp.