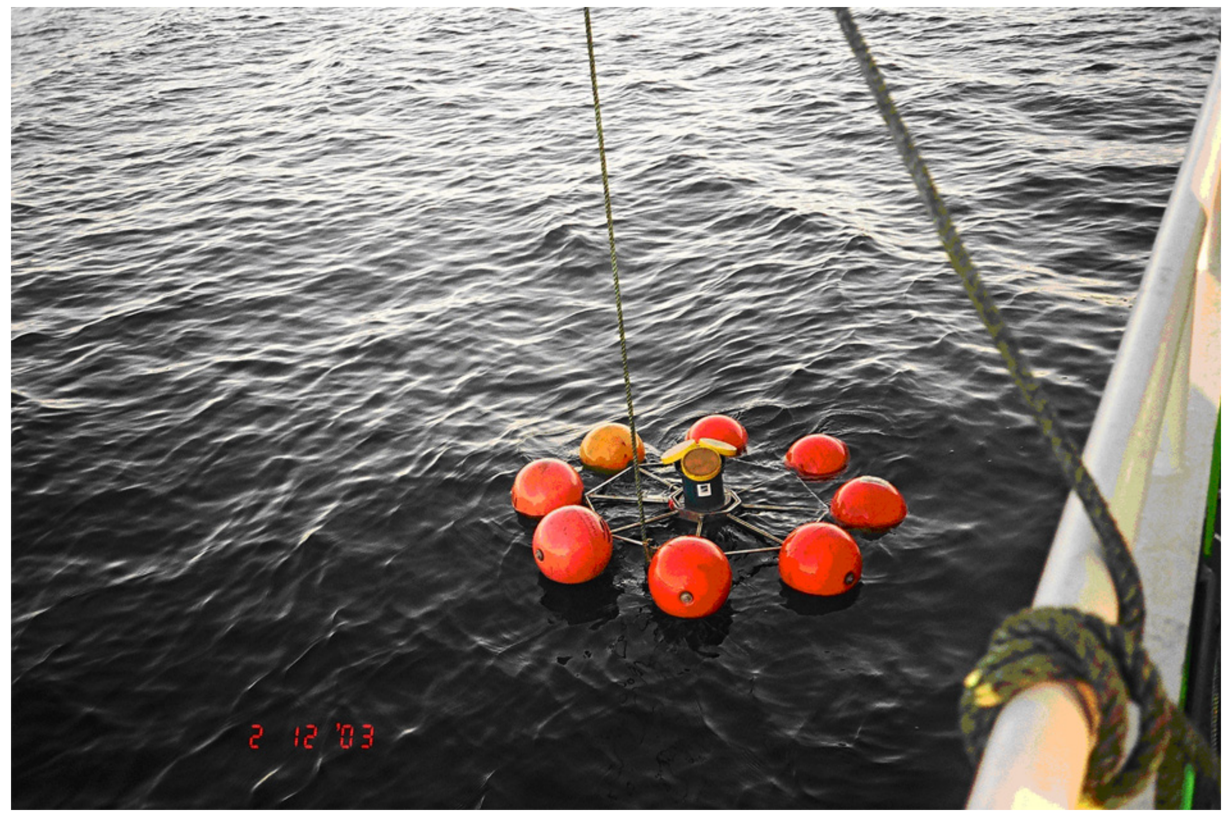
REPORT SNO 4798-2004

Statoil Mongstad Refinery

Measurements of currents at the process water discharge

November 2003

Data report



Norwegian Institute for Water Research
– an institute in the Environmental Research Alliance of Norway

REPORT

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Abstract

A one month measurement series of ADP data with some additional hydrographic data, including historical observations from 1972, are presented. The current measurements were performed in November 2003, near the main process water discharge at the Mongstad refinery. The bottom-mounted ADP measured currents from about 50 m depth and upwards to the surface in 1 m depth bins, at a sampling rate of 15 minutes. The main feature of the results is a dominating flow towards W-SW that only intermittently switches direction towards NE. This was most predominant in the upper layers as the stability factor increased from ca. 0.15 near bottom to 0.53 at 5 m depth. Average current speed increased from ca 6 cm/s near bottom to ca. 10 cm/s near the surface. The data are being further used in dispersion studies by Statoil.

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1. Mongstad raffineriet	1. Mongstad refinery
2. Hovedutslipp	2. Main discharge
3. Strømmåling	3. Current measurements
4. Fensfjorden	4. The Fensfjord

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Preface

The project was initiated in September 2003, after acceptance by Statoil of the proposal from NIVA dated 28 August 2003.

Preparations were made during October, which included a visit to the refinery with a briefing tour there. The field work with deployment of the current meter commenced on 31st October. The instruments were retrieved on 2nd December, 2003.

Later it was decided to deploy a STD probe at the discharge water intake in the sedimentation basin to measure the variability in salinity and temperature. These measurements were completed in April, 2004 and the results are also reported herein.

Contract responsible at Statoil ASA was Kirsten Ravn Hagen, and key contact for co-ordination was Einar Nygaard who also performed the harmonic analysis.

At Statoil Mongstad Gro Kaland was the main contact. Mons Arve Keilen and Bjørn Wellbrock assisted efficiently during instrument deployment and retrieval, by using the contingency boat which served well for the purpose. The University of Bergen - Geophysical Institute, provided some historical hydrographic material from the Fensfjord.

At NIVA Tom Chr. Mortensen, Christine Olseng and Terje Hopen assisted with instrument preparations and graphics. Thanks are due to all involved.

Bergen/Oslo, April 2004

Lars G Golmen

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Summary

The Statoil Mongstad refinery has a large sedimentation reservoir at the head of Mongstadvågen downstream of the water purification and oil separators where process and ballast water from berthing ships is collected after treatment. The discharge from the reservoir is lead through a pipeline to a diffusor arrangement, SW of the main berthing area/main pier at 40-50 m depth. Statoil wanted to study the fate of the discharge water in the recipient area; how it is diluted and dispersed. In this respect it was decided to make measurements of currents at various depths at the discharge location and NIVA, the Norwegian Institute for Water Research was offered the project to perform the measurements. The current data have already been delivered to Statoil for further processing. The present data report gives an overview of the measurement programme and some results. Also, some old and new data on hydrography (stratification) are presented, in addition to a 1 month time series of temperature and salinity measured in the discharge pit.

A NORTEK 500 kHz Acoustic Doppler profiler (ADP) was used for the current measurements. The instrument was suspended in a specially designed “gyroscopic” frame near the bottom at about 50 metres depth, transmitting acoustic beams from three upward looking transducers. The ADP was deployed on 31st October, 2003, and recovered successfully on 2nd December. The first depth cell with valid measurements was at about 45-46 m depth. The ADP cell size was set to 1 m and the profiling interval to 15 minutes so that a 32 days time series of current speed and direction was obtained for every metre in the water column from the deepest cell to near the surface.

The average current speed was around 10 cm/s for the shallowest depths, decreasing to around 5-6 cm/s near the bottom. On the 8th November, a maximum current of 1.7 m/s was recorded at 5 m depth, and currents exceeding 1 m/s were recorded at deeper levels as well around this time. The dominating flow direction was towards SW except for the deepest layers where there was a bimodality, approximate 50/50, between SW and NE directions. This bimodality resulted in a weak residual current at depth (around 1 cm/s), while for the upper layers this parameter exceeded 5 cm/s.

The hydrographic profiles sampled at three different occasions during the winter 2003-2004 showed moderate stratification, with the density profile varying from linearly increasing down to 40 m depth to a more pronounced 2-layer stratification in March, 2004.

Measurements of salinity and temperature in the discharge pit were performed over one month in March, 2004. The salinity varied between 13 and 15.7 PSU and the temperature between 9 and 12.5 ^{o}C.

1. Introduction

1.1 Purpose of the measurements

Process water from the Statoil Mongstad refinery (**Figure 1**) and ballast water from berthing ships is guided through purification and oil separators before being led into a large sedimentation reservoir at the head of Mongstadvågen.

The discharge from the reservoir goes via a ca. 500 mm pipeline to a discharge point SW of the main berthing area/main pier (see **Figure 2**). The discharge depth is at 40-50 m. The discharge pipe ends in a T-shaped diffusor with ca 10 holes each. The diffusor section rests on a slightly defined shelf or ledge, and beyond this location the bottom slopes steeply into the Fensfjord.

Statoil wants to study the fate of the discharge water in the recipient area; how it is diluted and dispersed. I order to make the assessments, there is a need for information about the currents in the area at various depths. It seems that no current measurements were performed prior to the design and construction of the discharge. In this respect, NIVA was asked by Statoil in September 2003 to perform such measurements near the discharge point over an approx. one month period. The data were then to be processed, for further application in modelling and assessments by Statoil.

Additional T-S measurements

Process water is mainly fresh water. Due to the mixing with ballast water and some intermittent inflow of seawater at high tide, the discharged water may be salty. This will affect the way the discharge water is dispersed. After completion of the current measurements NIVA was asked to monitor the salinity and temperature of the discharge water over ca. 1 month, commencing late January 2004. The present data report also describes these measured data.

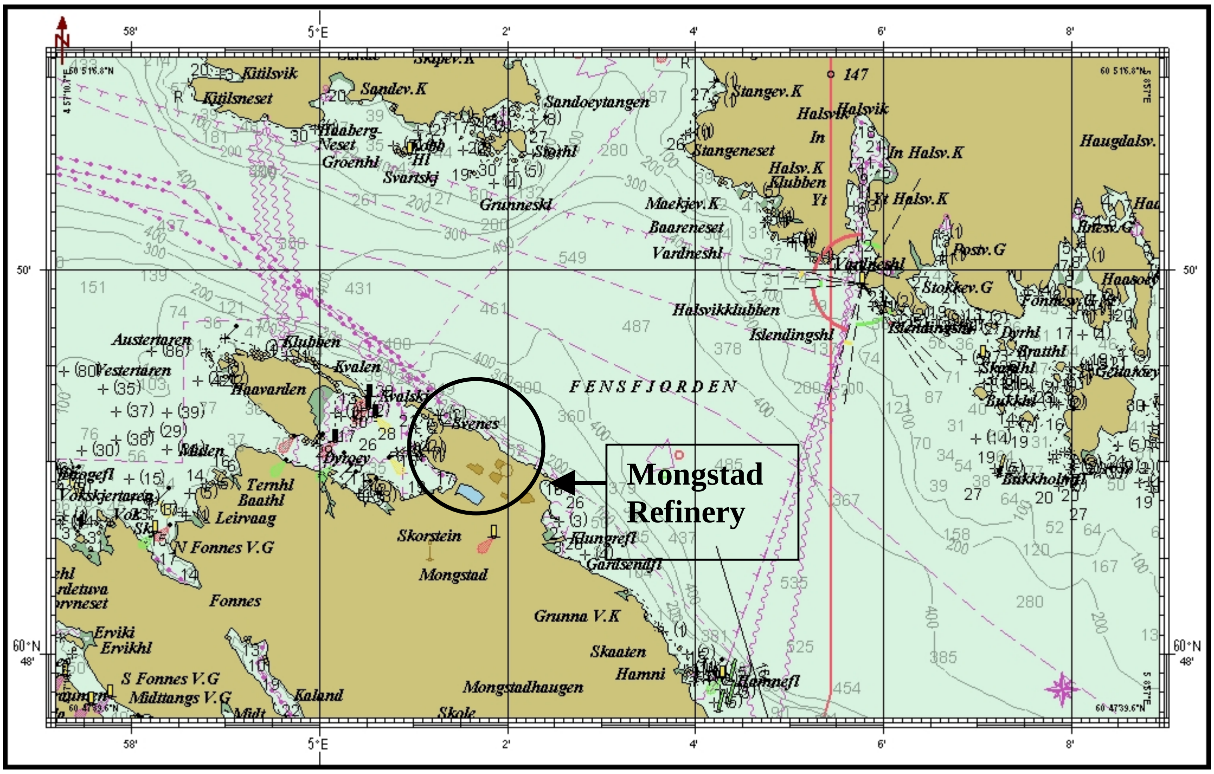


Figure 1. Map of the area around the Mongstad Refinery.

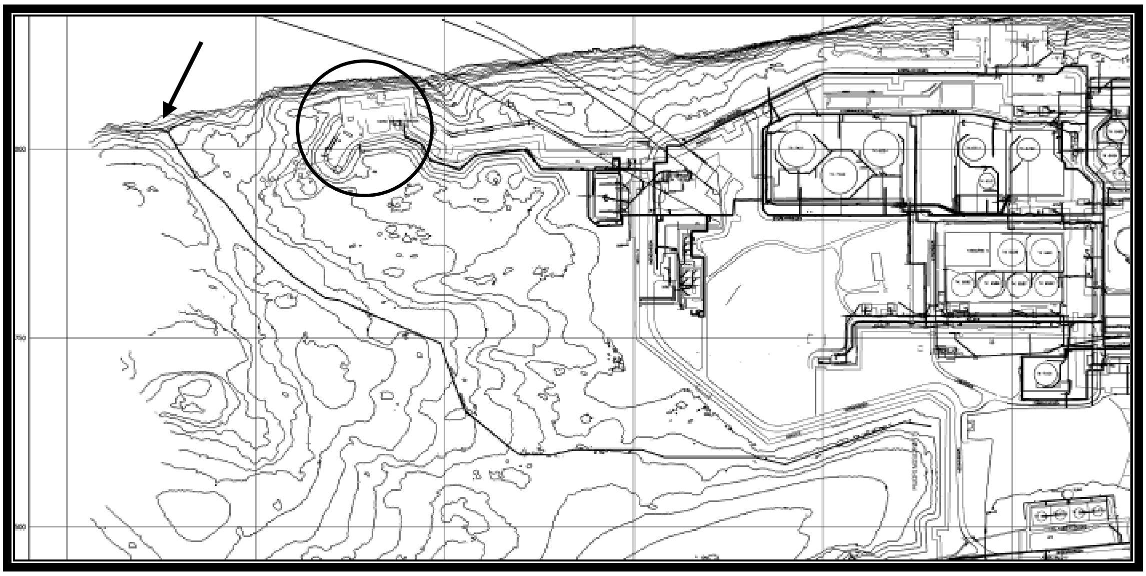


Figure 2. Close-up map of the western part of the refinery area, with the main berthing pier (circle). Depth contours for every 5 m down to 50 m are shown. The discharge pipeline goes from the sedimentation basin in the lower right corner westwards to ca 40 m depth where the T-shaped diffuser is located. The arrow shows approximate position of the ADP instrument, deployed at 50 m depth.

1.2 Description of the area

The Statoil refinery was established around 1972, at a location east of Mongstadvågen in Lindås, ca. 50 km north of Bergen (**Figure 3**). The main recipient is the Fensfjord, which itself is open and quite deep – ca 400 near Mongstad and close to 700 m at the deepest point further to the SE in the extension Austfjorden. The sill depth of the Fensfjord is around 250 m at the mouth of the North Sea north of Fedje, near Holmengrå.

The region around the discharge point (**Figure 2**) is sloping steeply northwards into the Fensfjord. The discharge is located at the northern part of the sound between Mongstad and Håvarden island to the W. This passage is ca 500 m wide, with a sill depth of around 31 m between Håvarden and Terneholmen. This sound or passage has a maximum depth of about 40 m.

Since the discharge water contains significant amounts of fresh water it will likely rise in the water column from the diffusor holes. The more fresh, the higher it is expected to rise towards the surface. After this initial stage the water current will carry the diluted fractions further downstream, according to the instant speed and direction. Possibly some of the discharge water may flow southwards and over the 31 m sill at times, through the passage between Håvarden and Leirvåg. But it is expected that most of the discharge will disperse in the Fensfjord proper.

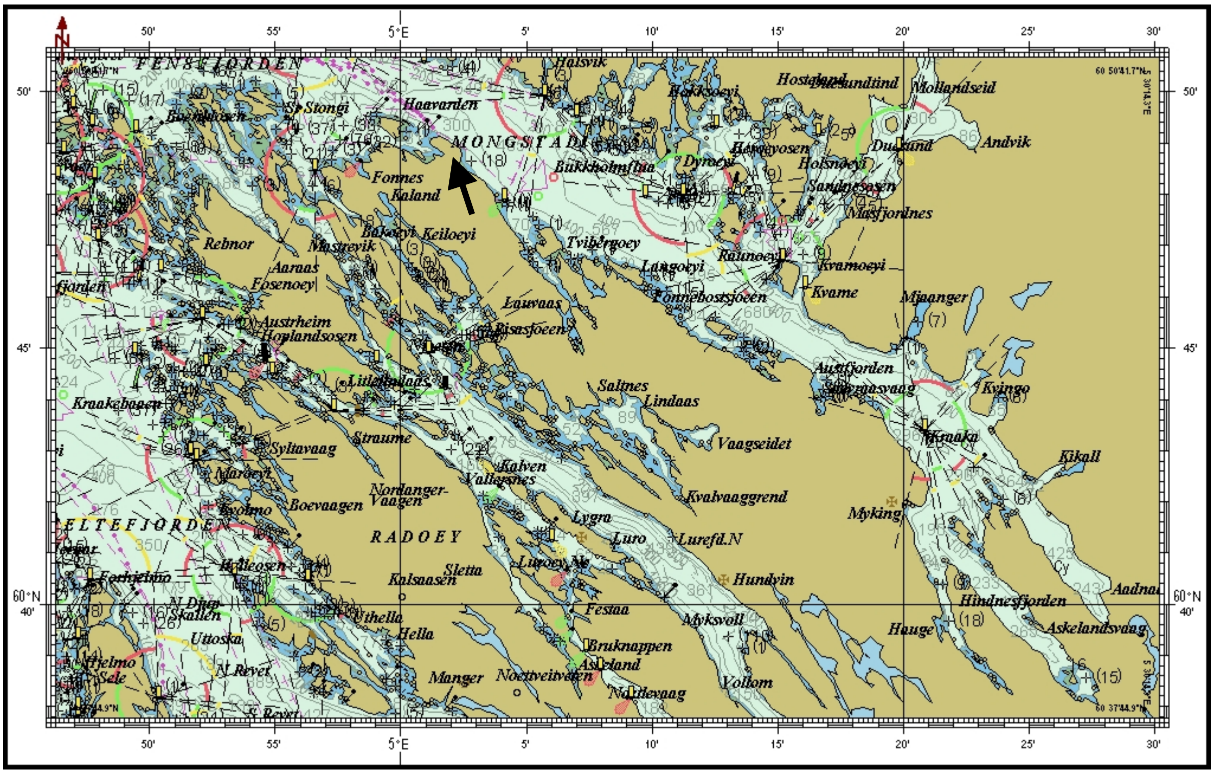


Figure 3. Map showing the Fensfjord and adjacent fjords with Mongstad (arrow) in the top centre.

2. Instruments and deployment

2.1 ADP current measurements

A NORTEK 500 kHz Acoustic Doppler profiler (ADP) was used for measuring the currents. This instrument transmits 3 acoustic beams at 500 kHz from the upward looking transducers (Figure 4), which gives a maximum range of around 70-90 m, depending on the amount of scattering particles in the water. With a full battery pack the instrument can measure unattended for weeks or even months, depending on the sampling interval chosen. The instrument has built-in compass, tilt, pressure, and temperature sensors and an internal recording chip. The housing is designed for a maximum 200 m depth deployment.

For the deployment at Mongstad, the ADP was suspended in a “gyroscopic” frame, designed by NIVA. **Table 1** gives some technical deployment information. The ADP was deployed on 31st October, 2003 near the diffusor at about 50 m depth. A bottom rope secured the mooring to the nearest pier, allowing for easy retreival by the same rope. The chain and frame extended about 2.5 m above the bottom, so the transducers were at about 47-48 m depth. The first valid depth cell with measurements were beginning 1 m above the transducers. The ADP cell size was set to 1 m and the profiling range to 50 m, so that time series of current speed and direction was obtained for every meter in the water column from ca 45-46 m depth to near the surface.

The profiling interval was set to 15 minutes, allowing the ADP to be deployed for more than one month before batteries would run out. The ADP and frame was successfully recovered on 2nd December, 2003, with no visual damage and no entangling of ropes in the frame.

Figure 4. Photo showing the 3-beam transducer head on a NORTEK Continental ADP, which is a new version of the ADP used at Mongstad. The shape is quite similar for the old and new version. (The picture is from NORTEK's home page.)

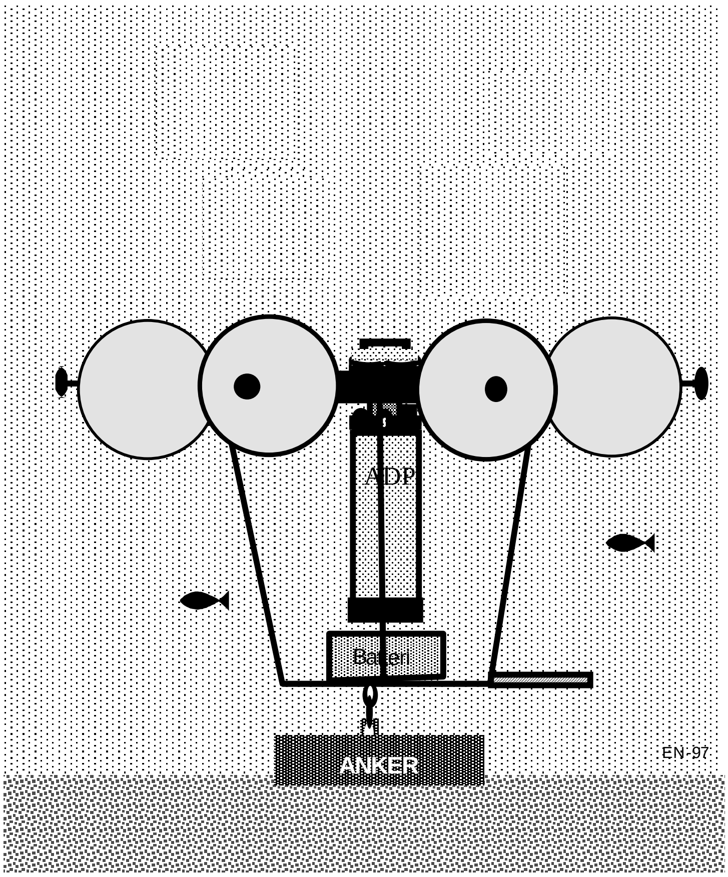


Figure 5. The frame with the ADP in a gyroscopic grip. Figure by E. Nygaard.

Table 1. Deployment information for the NORTEK ADP.

```
PC Time                  : 2003/10/30 14:55:56
System Time              : 2003/10/30 14:55:55
Deployment Time          : 2003/10/31 12:00:00

USER PARAMETERS            from Deploy File     read from ADP Sensor
Averaging Interval (s) :         300                  300
Profile Interval   (s) :         900                  900
Ping Interval      (s) :         1.0                  1.0
Burst Mode             :          NO                   NO
Burst Interval     (s) :         900                  900
Profiles Per Burst     :           1                    1
Water Temp.     (Deg C):        10.0                 10.0
Water Salinity   (ppt) :        33.0                 33.0
Temperature Mode       :    MEASURED             MEASURED
Number of Depth Cells  :          60                   60
Depth Cell Size    (m) :        1.00                 1.00
Blanking Distance  (m) :        1.00                 1.00
Coordinate System      :         ENU                  ENU

ADP STATUS:
Battery Voltage        :       18.60
Total Recorder Size(kb):       20480
Recorder Size Left (kb):       20352

DEPLOYMENT STATUS:
Response from ADP after DEPLOY command:
Checking Deployment Parameters:
Data collection will start on:  2003/10/31 at 12:00:00
```

2.2 Hydrography

2.2.1 Vertical profiles

Hydrographic profiles were taken with a Seabird SBE-19 Seacat STD at the time of deploying the ADP on 31st October and when retrieving it on 2nd December, 2003. Additionally a profile was taken during retrieval of the T-S sensor fixed in the discharge pit. The SBE-19 records data of pressure, temperature and salinity internally at 0.5 sec interval. Accuracy is assumed better than 0.01 for both salinity and temperature.

The SBE-19 was calibrated at the factory in USA in December 2003 -January 2004, and the results showed very small drift in the sensors since the previous calibration, for temperature it was +0.00042 ^{o}C per year, and for salinity 0.0002 PSU/month. It was then decided to use the existing calibrations for the present SBE-19 data.

2.2.2 Measurements at the discharge pit, March-April 2004

For these measurements a Sensordata SD200 STD was used. It records data internally at preset intervals, which was set to 60 minutes in this case. A first deployment in February gave only a ca 1 day time series as the recording interval was set too short. The STD was then redeployed on March 10th and recovered by Statoil on April 5th. **Table 2** shows details about the deployment and **Figure 6** shows the location of the measurements.

Table 2. Overview over the T-S measurements made by the SD200 in the discharge pit. The instrument number was Serial No. 33. Time is given as local time: GMT + 1 hr.

Instrument deployment information	Instrument retrieval and data
SD200 Start time	SD200 recovery time
9th March 2004, 12:48 l.t.	5th April 2004 13:00
SD200 deployment time	SD200 Stop time
10th March 2004, 16:48 l.t.	9th April 12:30
Sampling interval	Number of valid measurements
1 hour	650

Figure 6. Photo showing the pit where the discharge pipeline begins. The STD measurements were taken just at the concrete wall, at ca. 80 cm water depth.

3. Presentation of current data

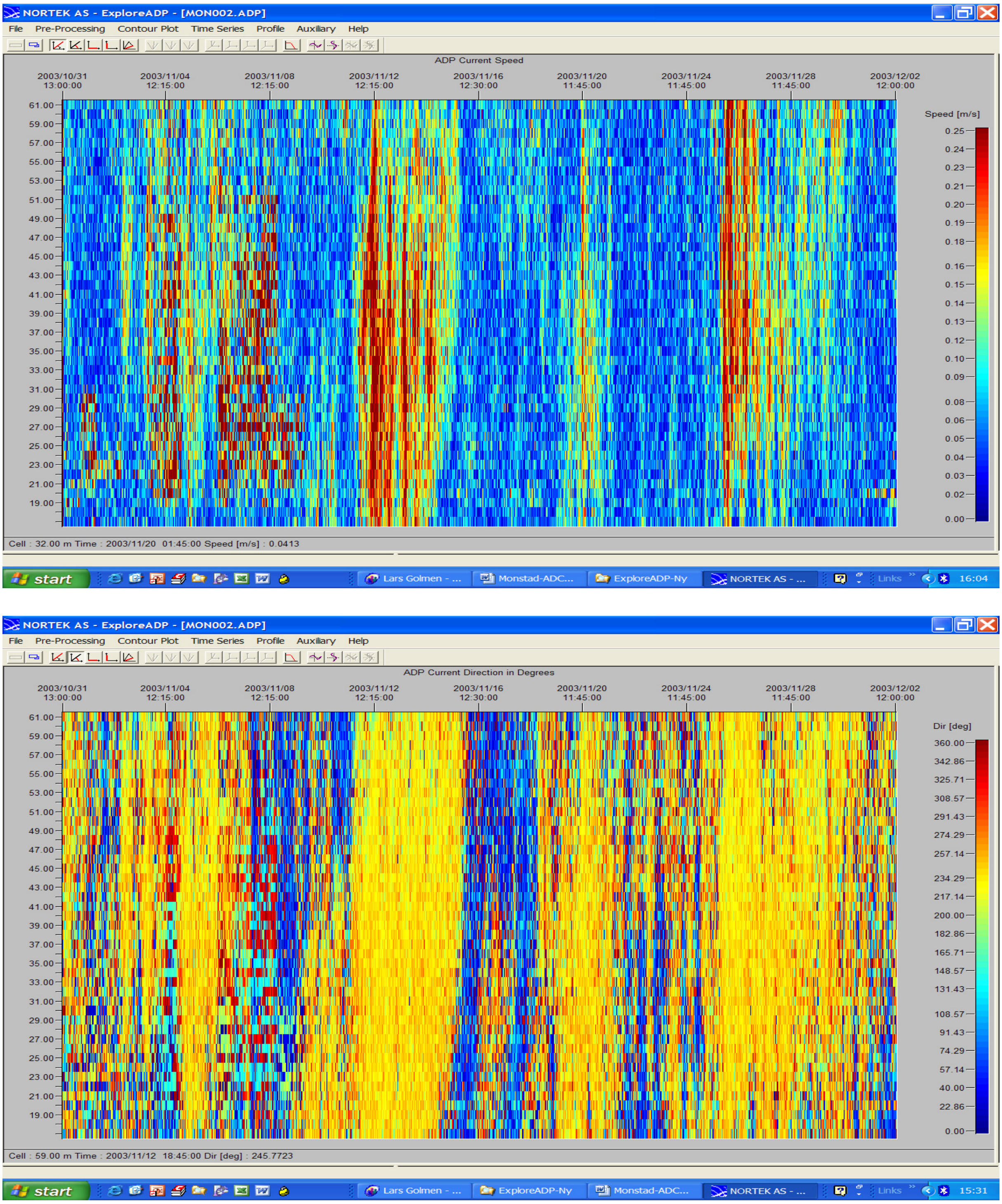
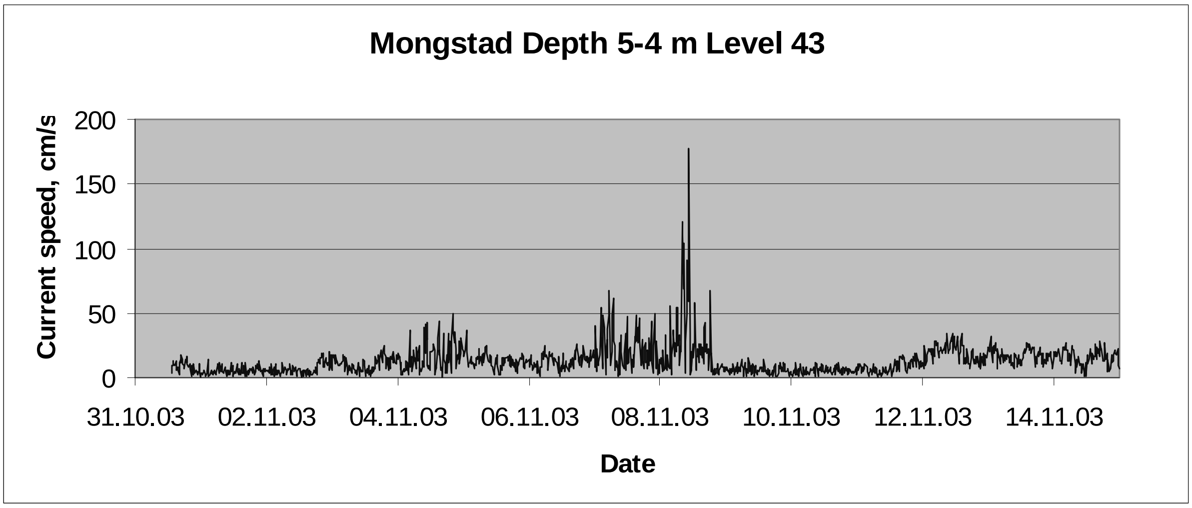


Figure 7. Measured current speed (upper frame) and current direction at Mongstad for the period 31st October - 2nd December, 2003. The vertical axis spans 45 m, from above the ADP to near the surface. Current speed is contoured between 0 and 25 cm/s, i.e. heavily red coloured fields represent speed higher than 25 cm.

Only brief comments are made to the results and the presentations shown for the current measurements (**Figs. 7 -22**). The data are made available for further evaluations and dedicated purposes such as dispersion modelling.

Fig. 7 gives an overview over the full data range - 32 days of measurements over the 26 m water depth span. It is noted that currents were usually moderate or weak, with a couple of intermittent periods of currents exceeding 0.5 m/s. There is a sign of a periodicity in the current with a long return period of about 6 days which may indicate a spring/neap tidal influence. The times of stronger current did not, however, coincide exactly with the predicted times of spring tide (tidal tables). Flow towards SW seemed to be most frequent.

The remaining figures, **Figs. 8-22,** are divided into time series of current speed and current direction for selected depths: 5m, 15m, 25m, 35m and 45m depth, and associated progressive vector diagrams and flux diagrams. A brief summary text for each depth is given in the following.



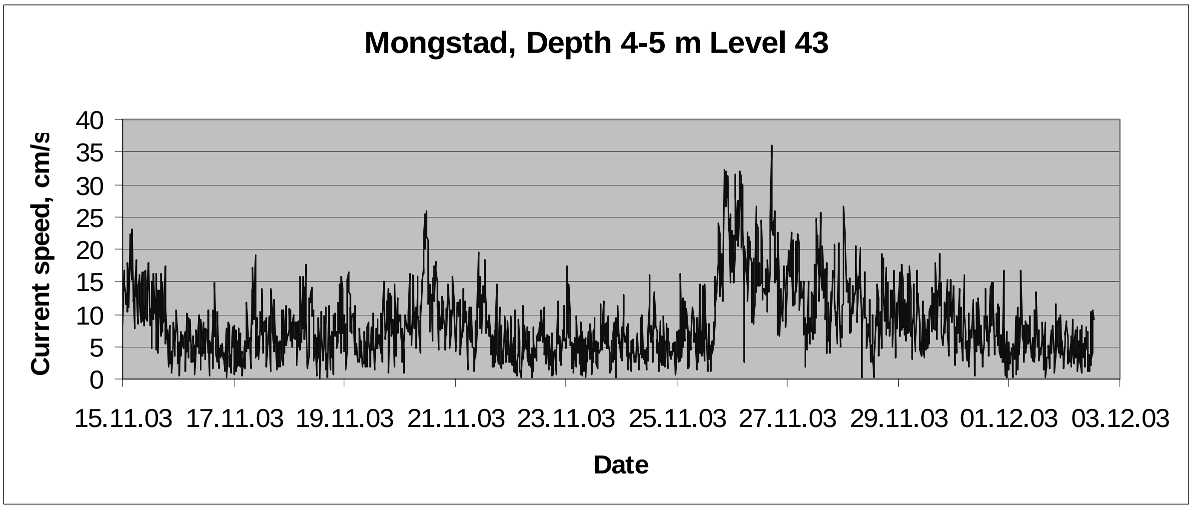
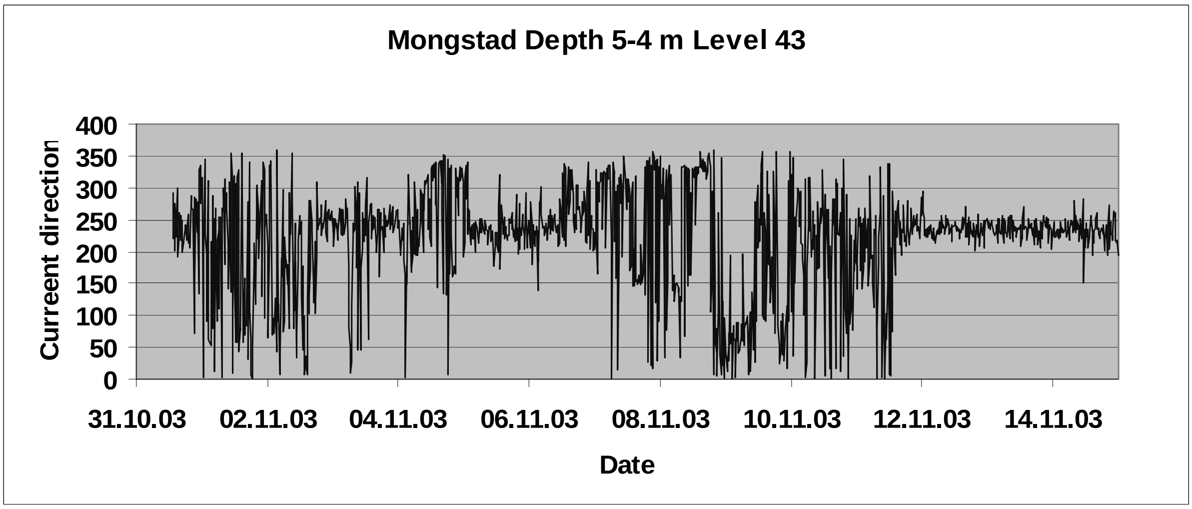


Figure 8. Measured current speed at 5 m depth.

3.1 Measurements at 5 m depth

Current speed measured at around 5 m depth (**Fig. 8**) showed values in the range 0-177 cm/s - the latter value measured on 08 November at 10:30 local time represents a very strong current (direction was 329^{o}) and was not measured at the deeper levels, so it may be due to a surface eddy induced by winds. (The strong current episode may have some implications for navigation and might be further analysed.) The average speed was 10.6 cm/s (**Table 3**). Current direction (**Fig. 9**) was generally to W or SW, which is also reflected in the progressive vector and flux rose (**Fig. 10**).



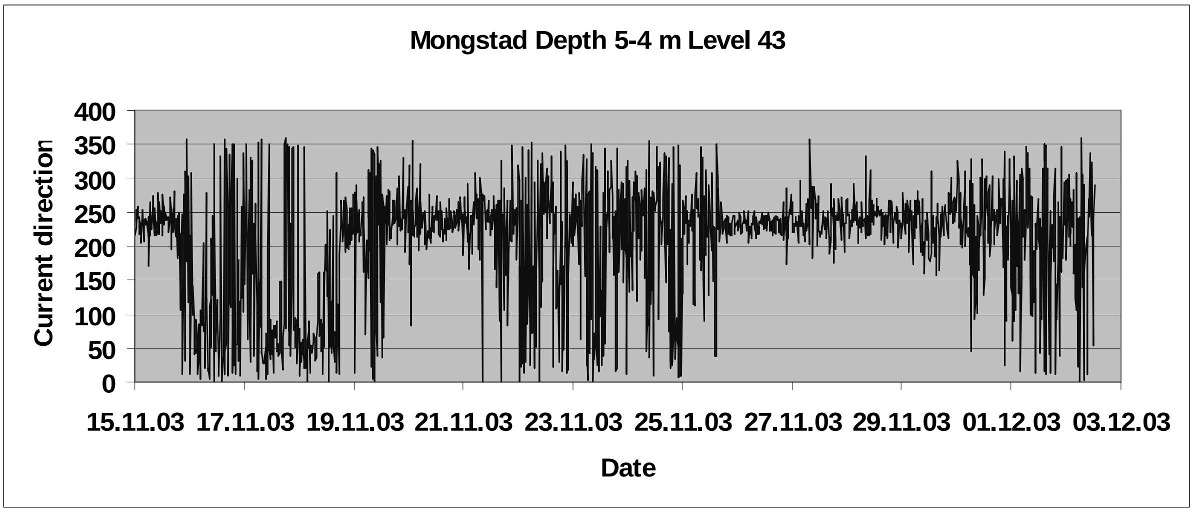
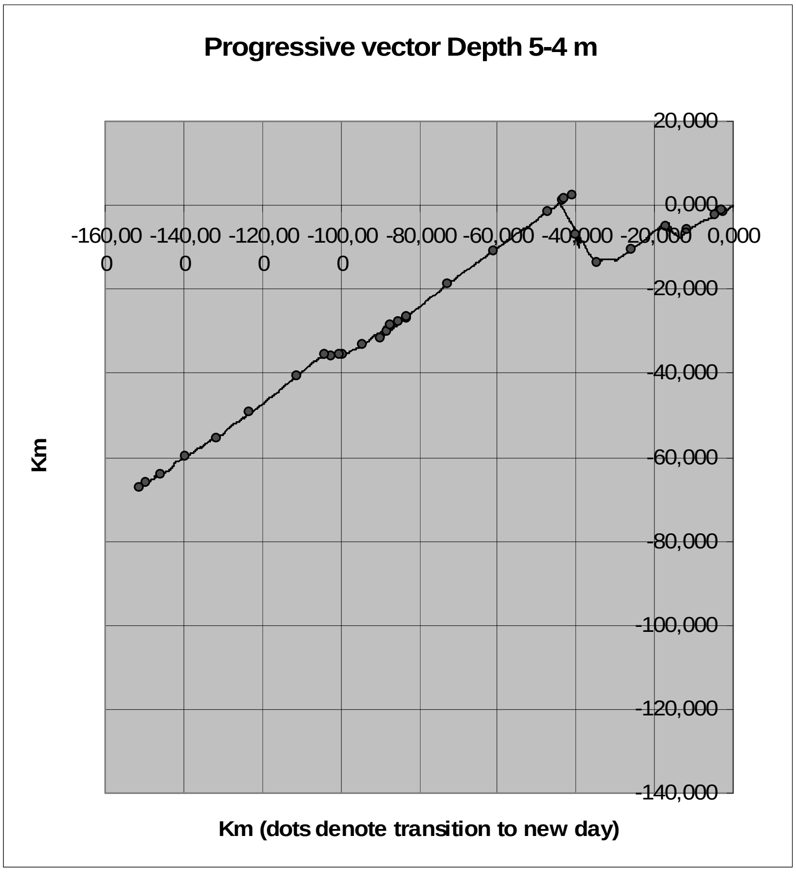


Figure 9. Measured current direction at 5 m depth.



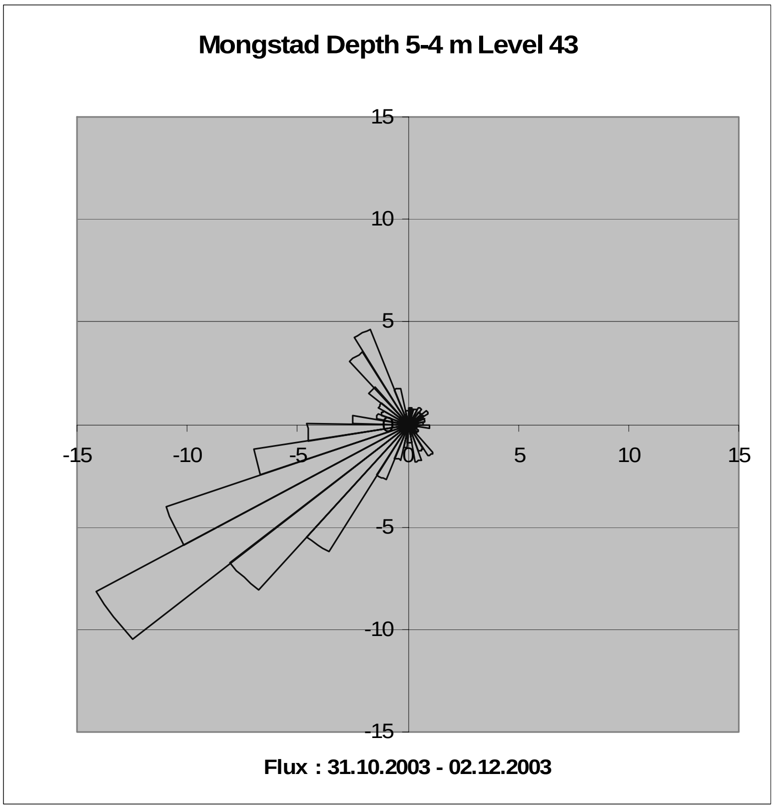
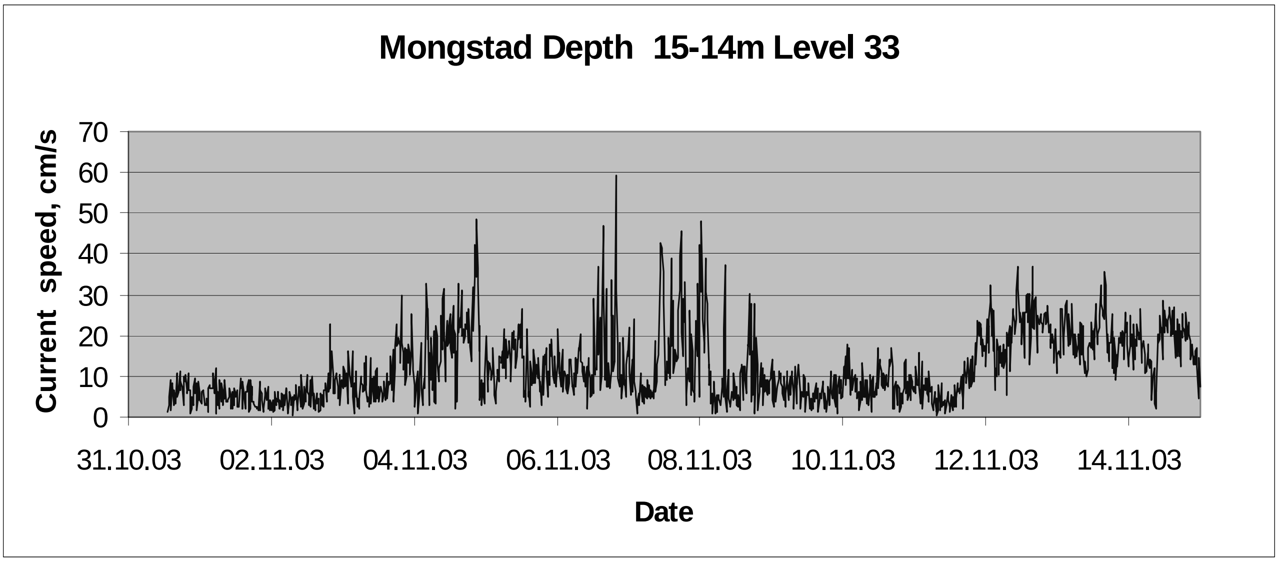


Figure 10. Progressive vector and transport flux at 5 m depth.



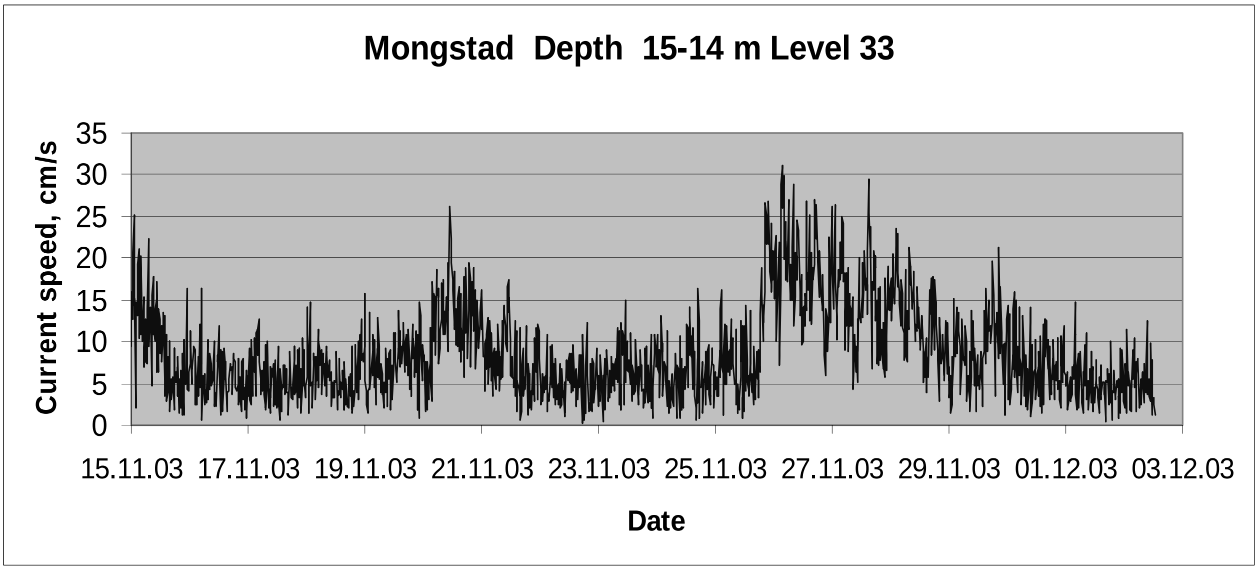
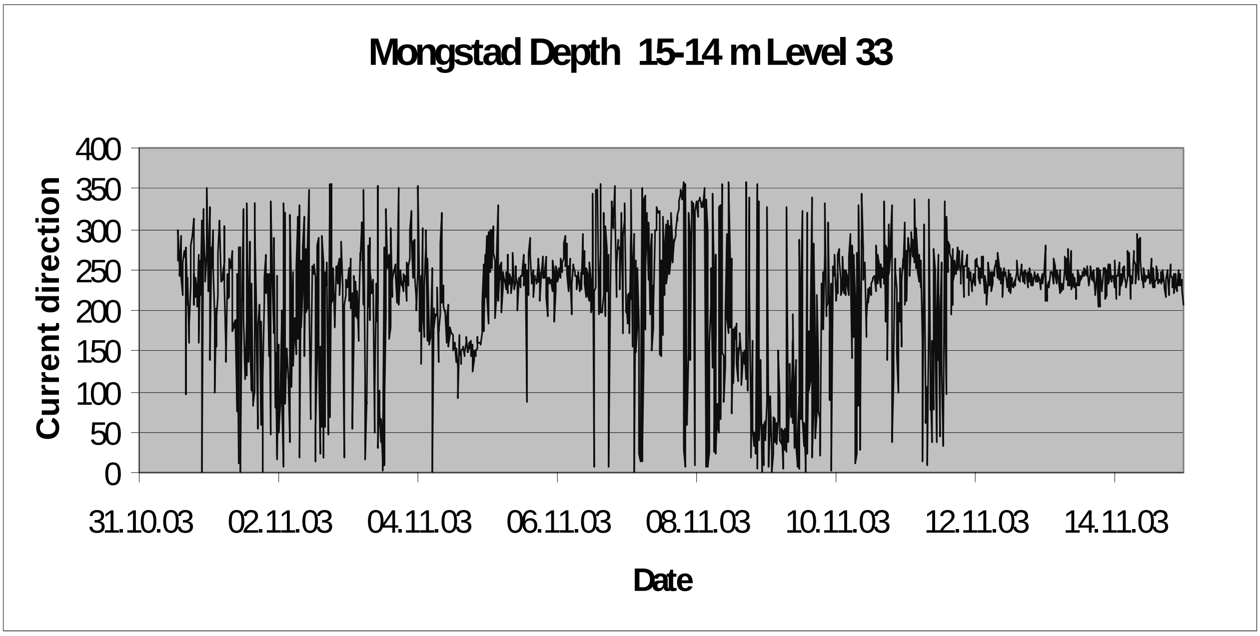


Figure 11. Measured current speed at 15 m depth.

3.2 Measurements at 15 m depth

Results for 15 m depth are shown in **Figs. 11-13**. Current speed was on the average similar to that at 5 m depth, the average was 10.2 cm/s. Maximum speed was 60 cm/s (on 06 November-probably same phenomena as observed at 5 m depth, but with less strong current). General flow direction (**Fig. 12**) was towards the SW-W (around 250 degrees) resulting in a net flow direction and dominating flux direction towards 243 degrees.



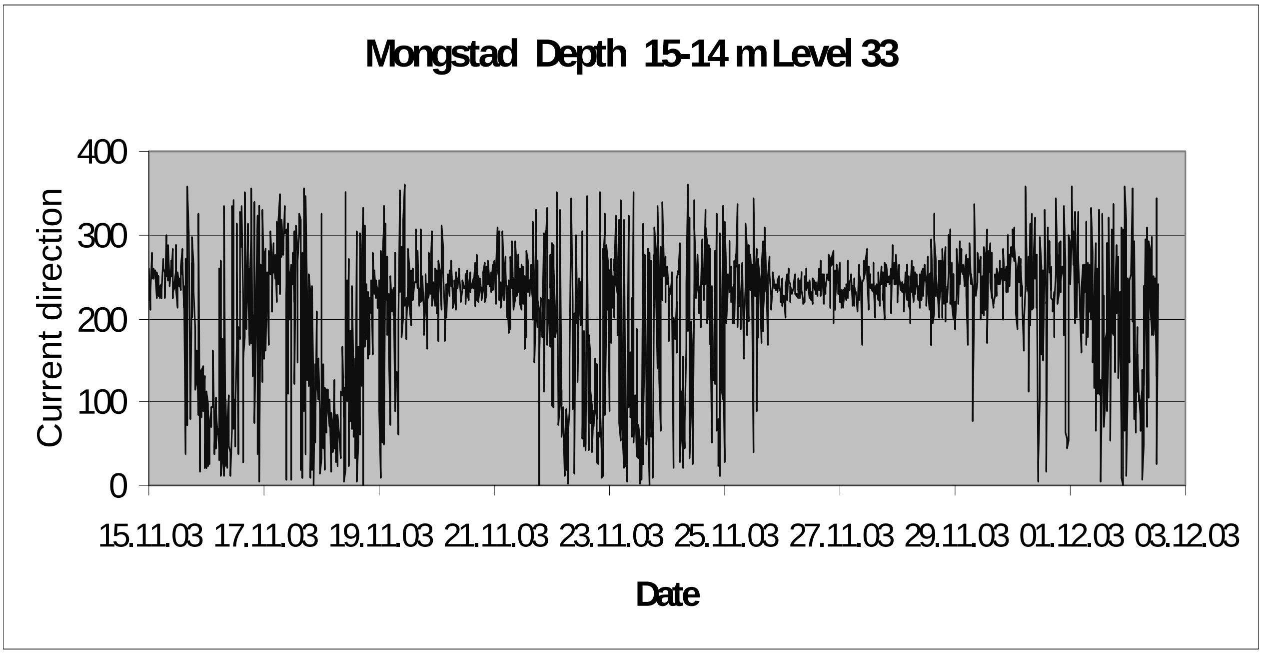
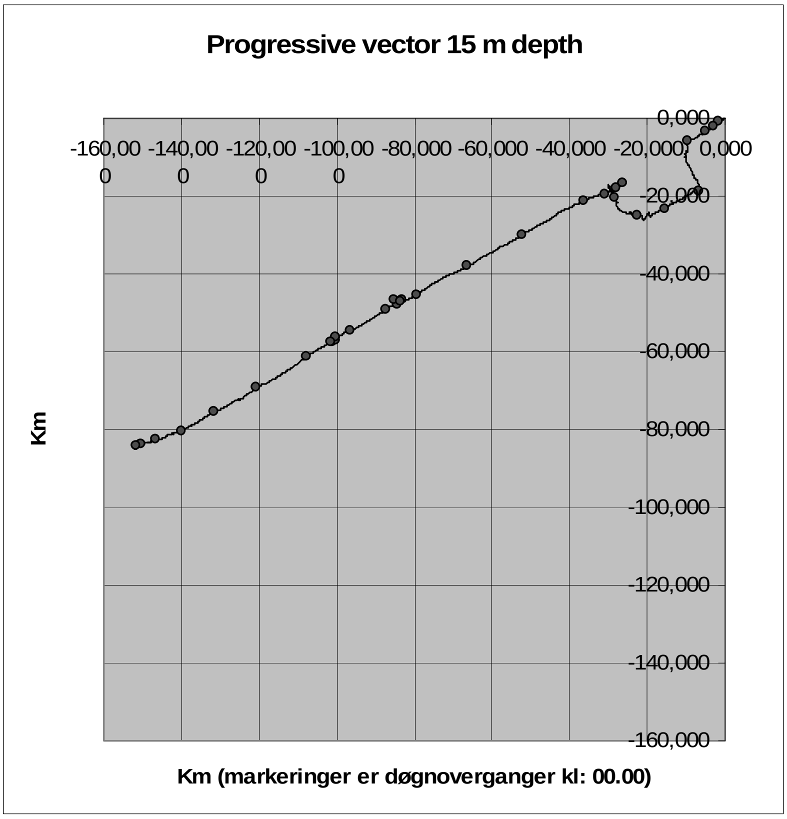


Figure 12. Measured current direction at 15 m depth.



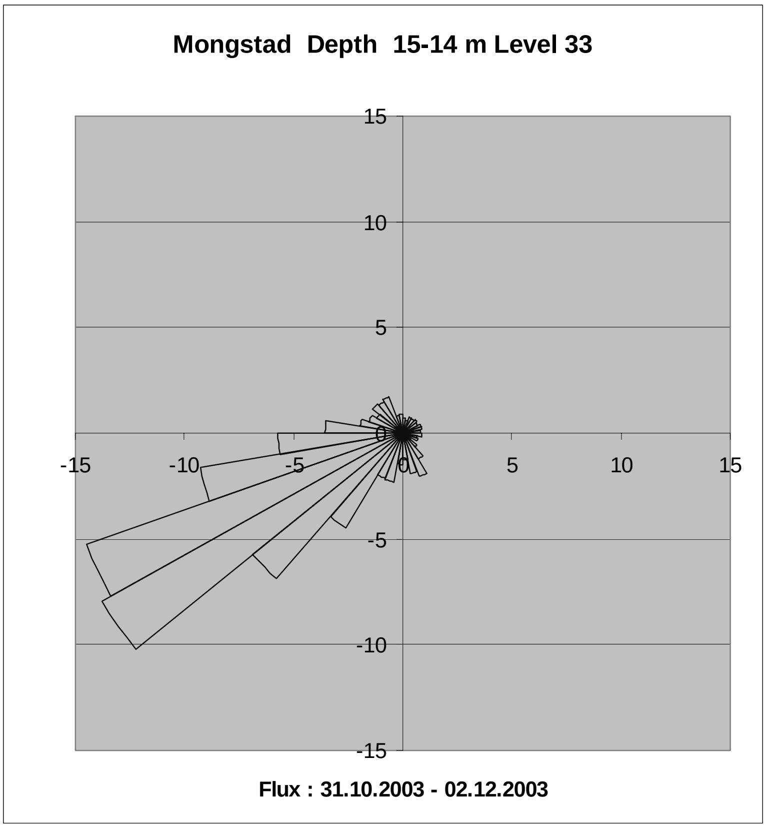
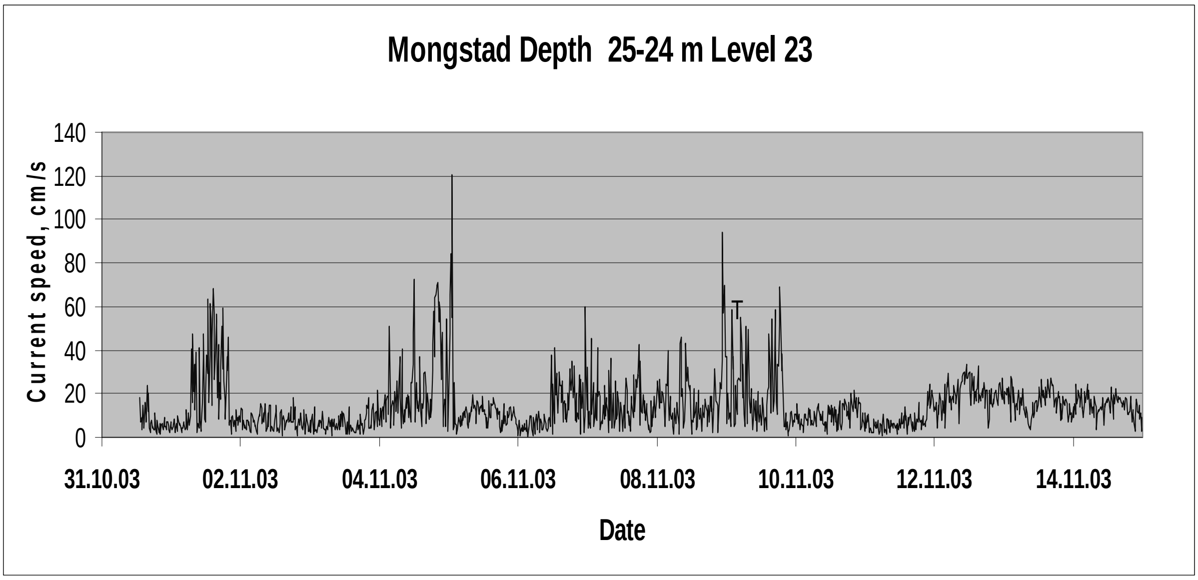


Figure 13. Progressive vector and transport flux at 15 m depth.

3.3 Measurements at 25 m depth

Results for the measurements at 25 m depth are shown in **Figs. 14-16**. Maximum current speed was 120 cm/s (on 5th November), and the average speed was 10.6 cm/s, i.e. somewhat higher than for the two previous shallower levels. Net current direction was towards SW as for the other depths (**Figs. 15-16**). The residual current was around 2.7 cm/s (20 m depth **- Table 3**), or about 50% of the value for the two upper layers.



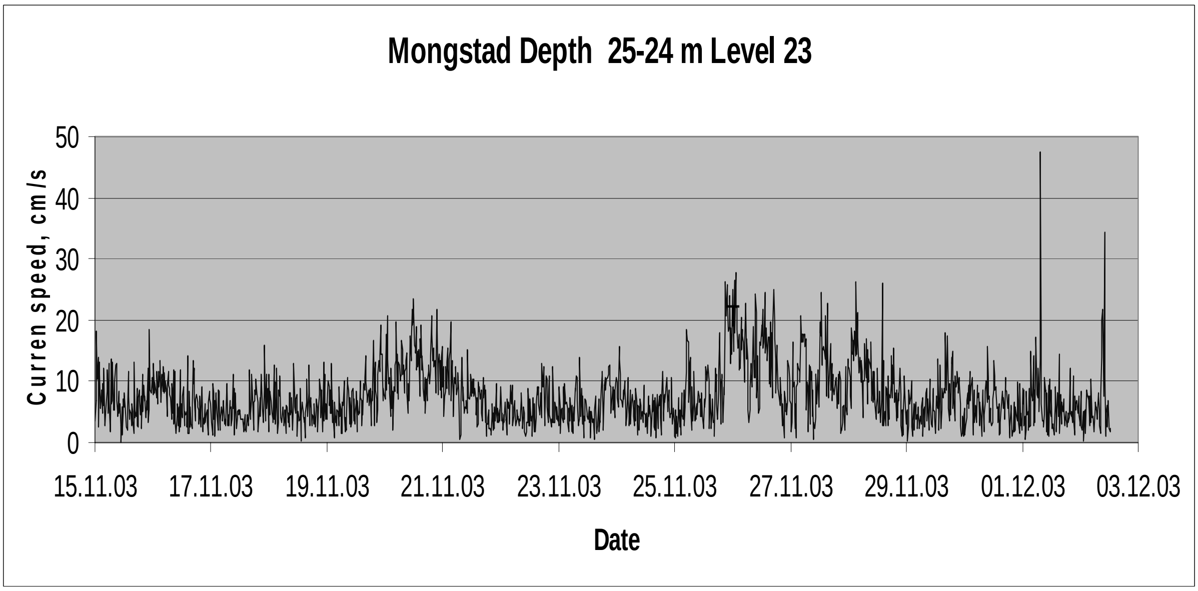
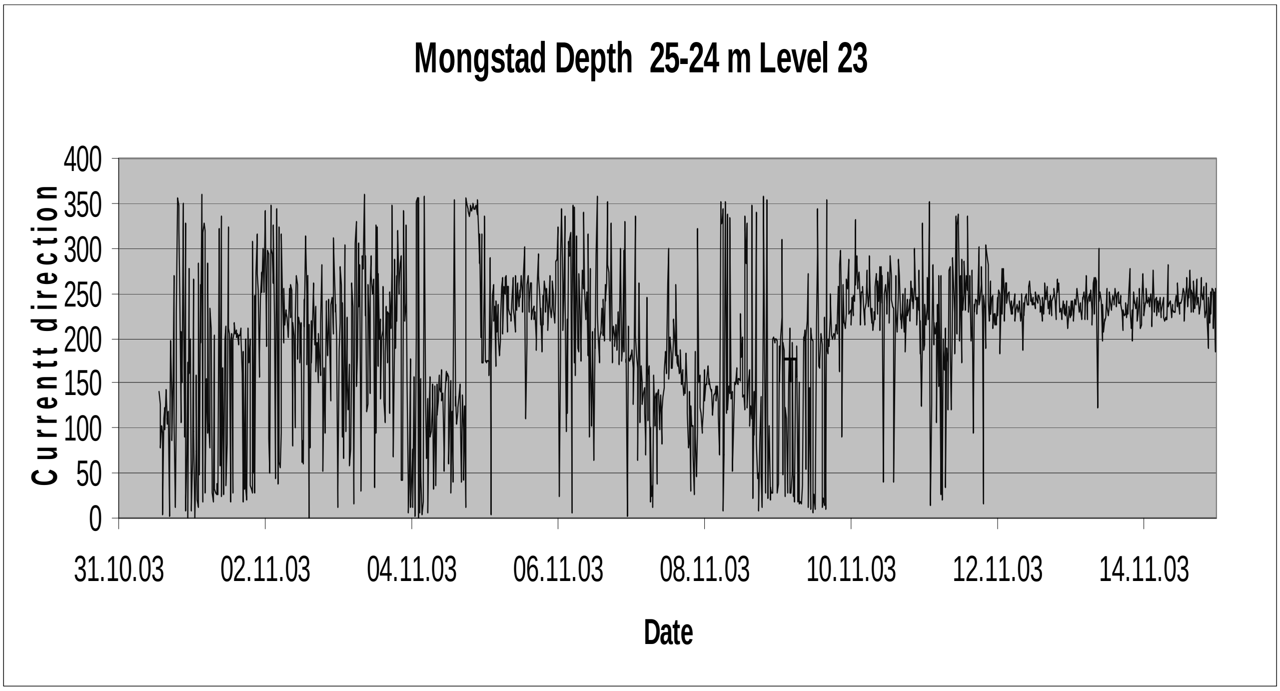


Figure 14. Measured current speed at 25 m depth.



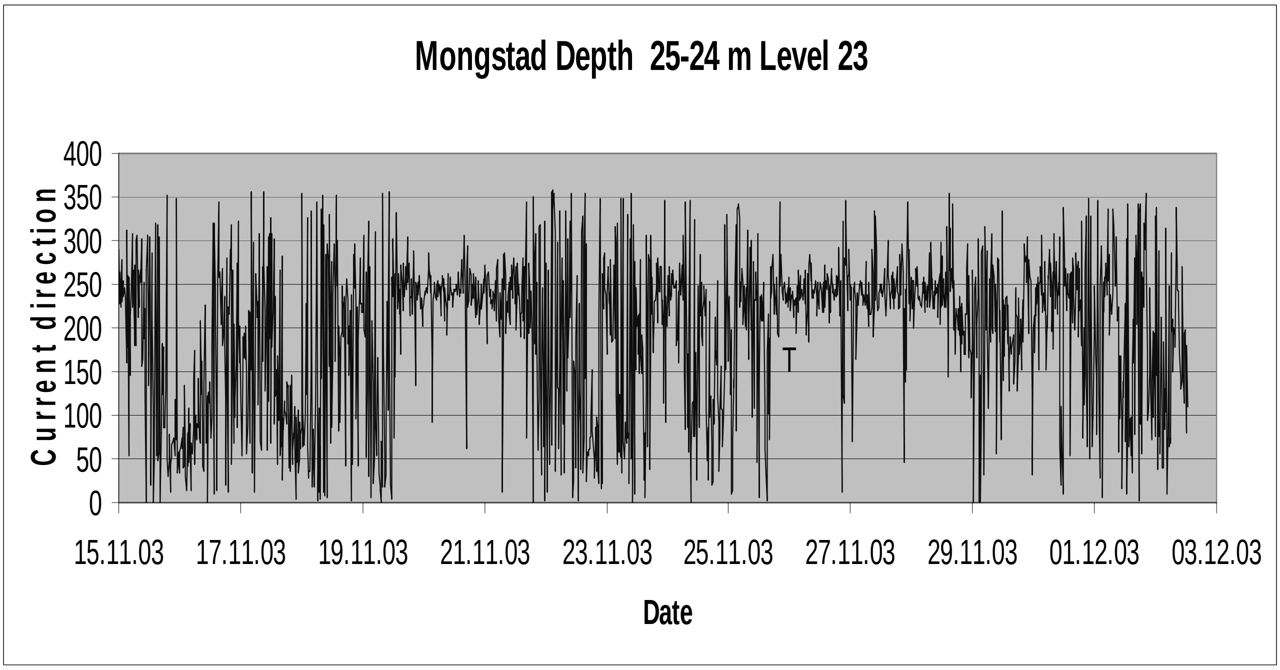
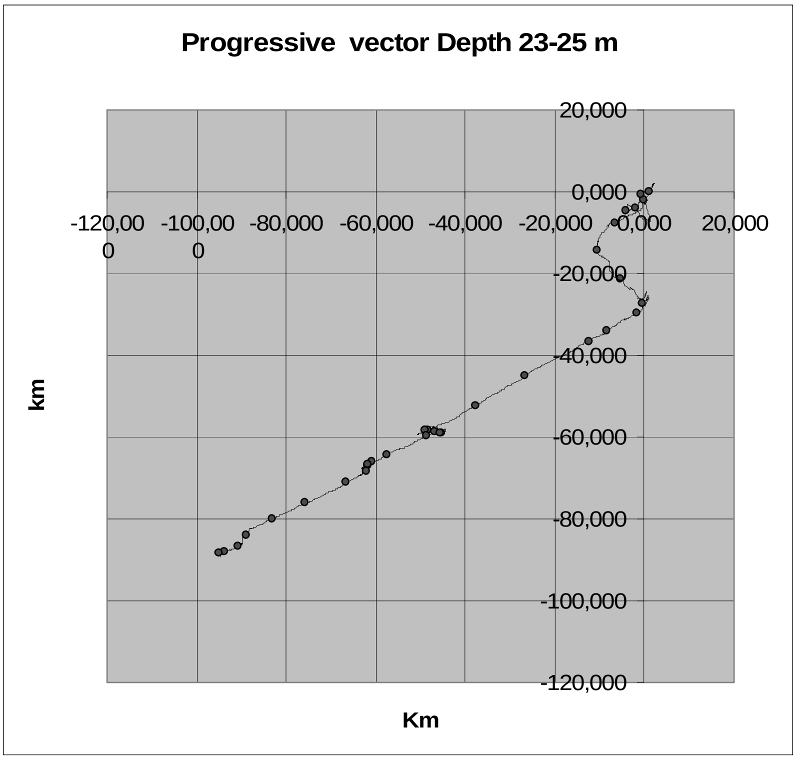


Figure 15. Measured current direction at 25 m depth.



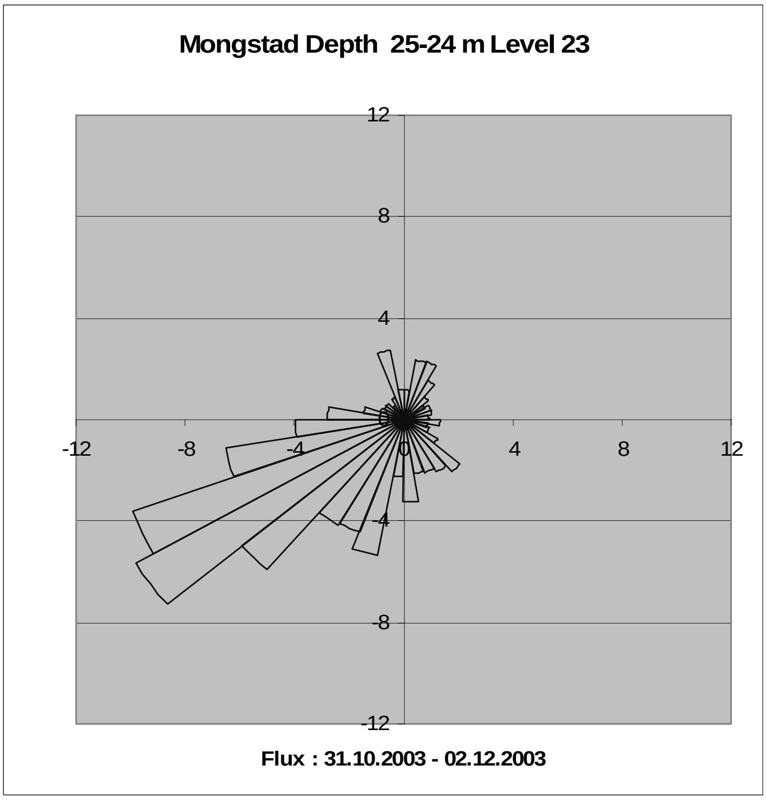
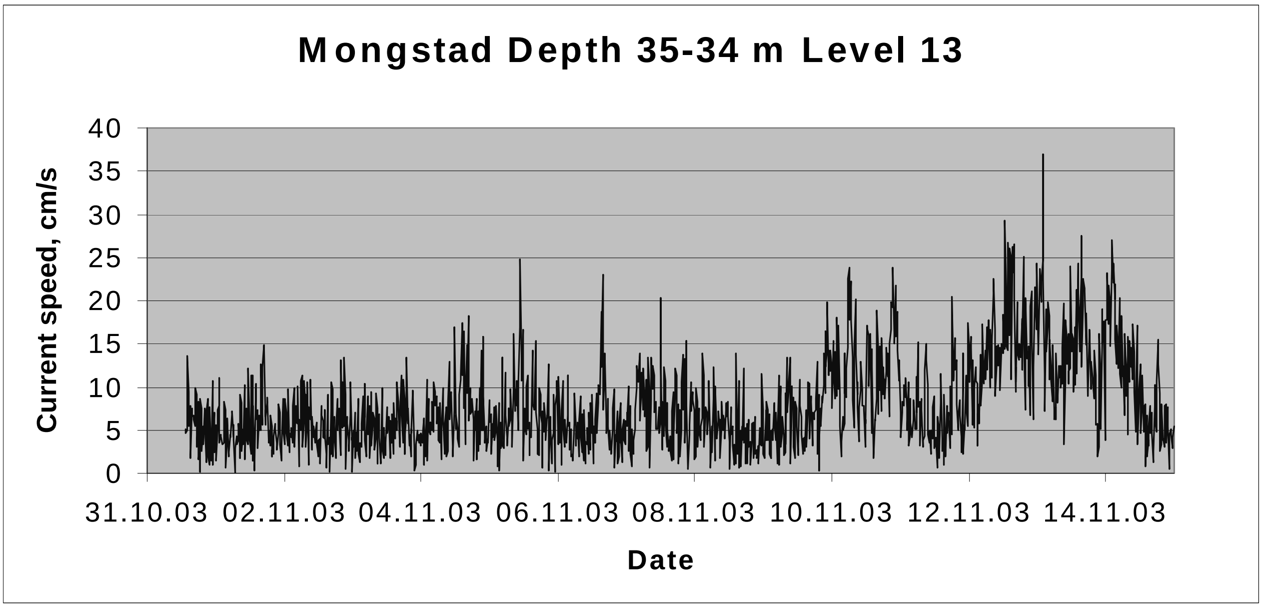


Figure 16. Progressive vector diagram and flux for the measurements at 25 m depth.

3.4 Measurements at 35 m depth

Results for the measurements at 35 m depth are shown in **Figs. 17-19**. Maximum current speed was 37 cm/s (on 13 November), and the average speed was 7.4 cm/s, I.e. somewhat lower than for the two previous shallower levels. Net. (residual) current direction was towards SW as for the other depths (**Figs. 15-16**). The residual current was around 2.5 cm/s.



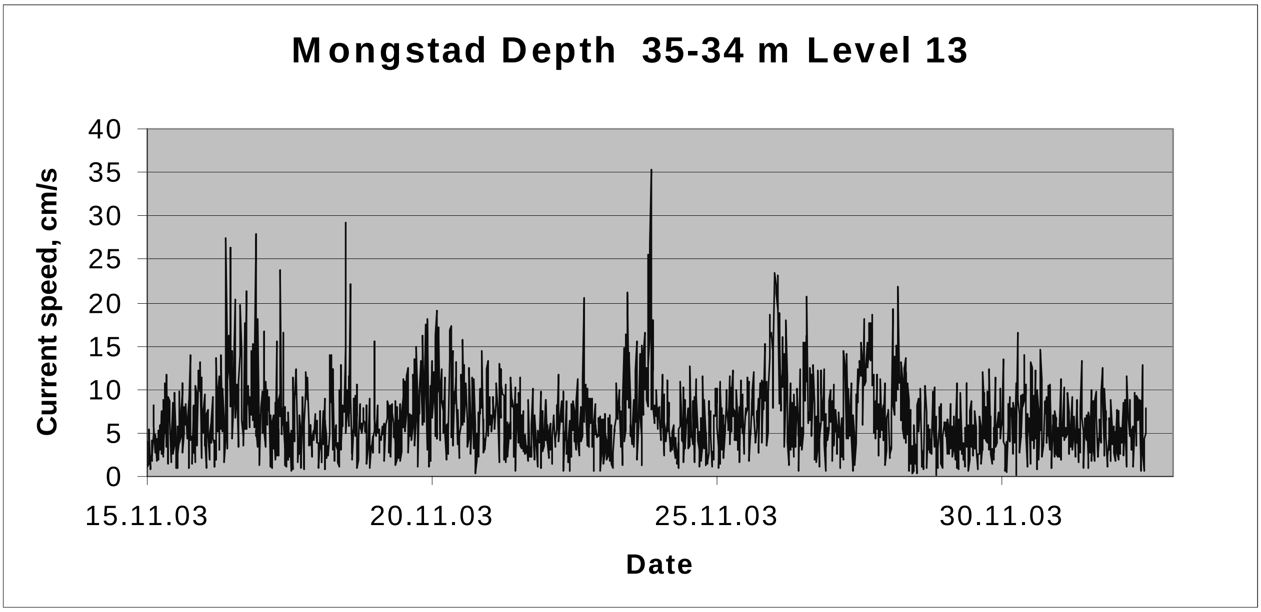
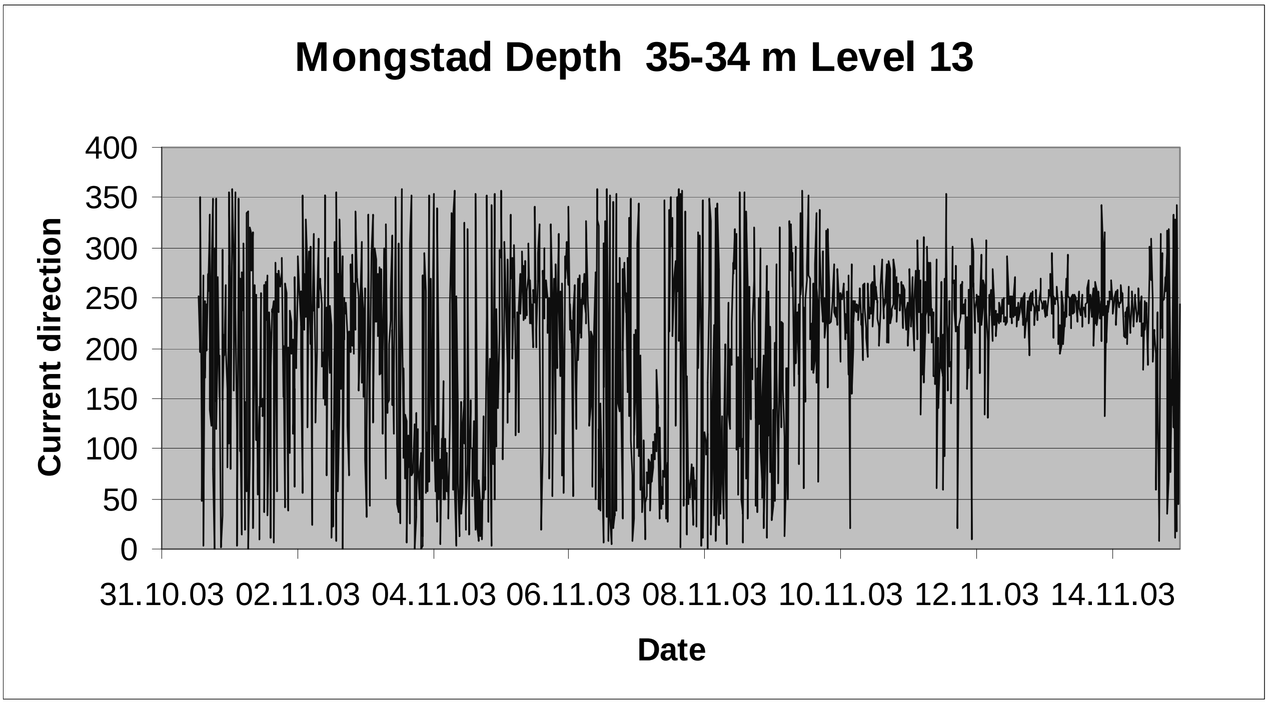


Figure 17. Current speed at 35 m depth.



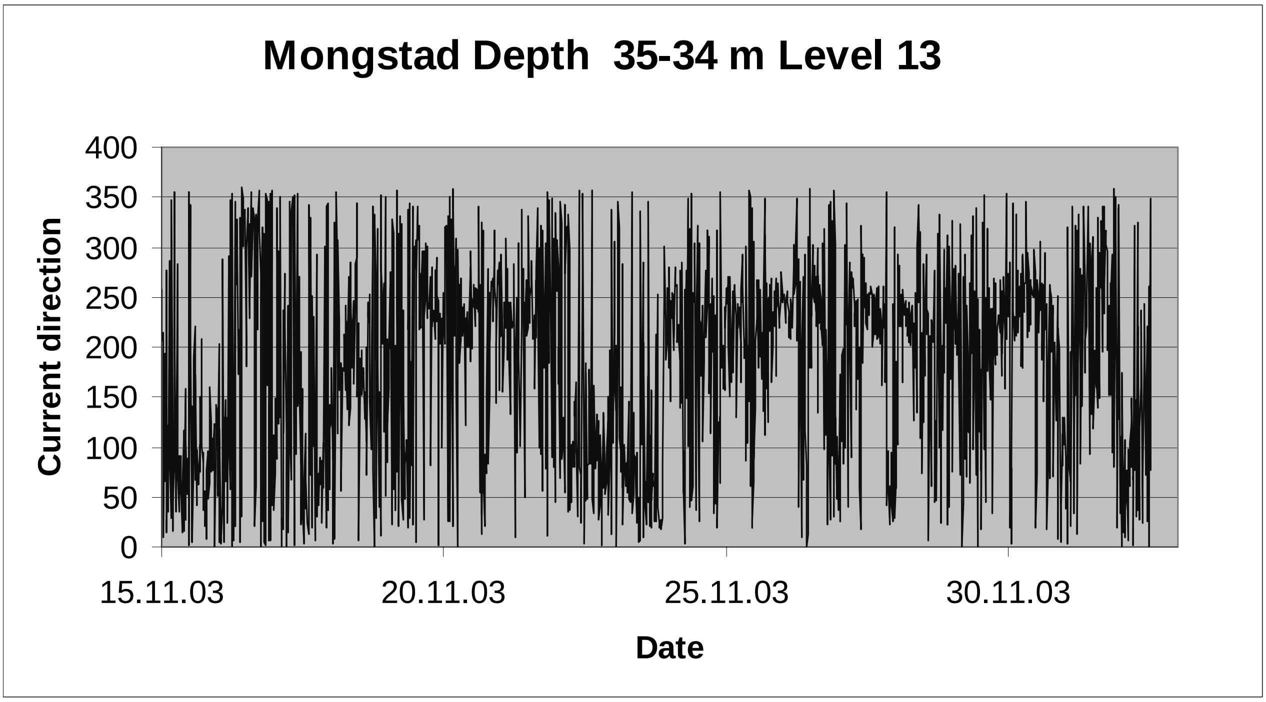
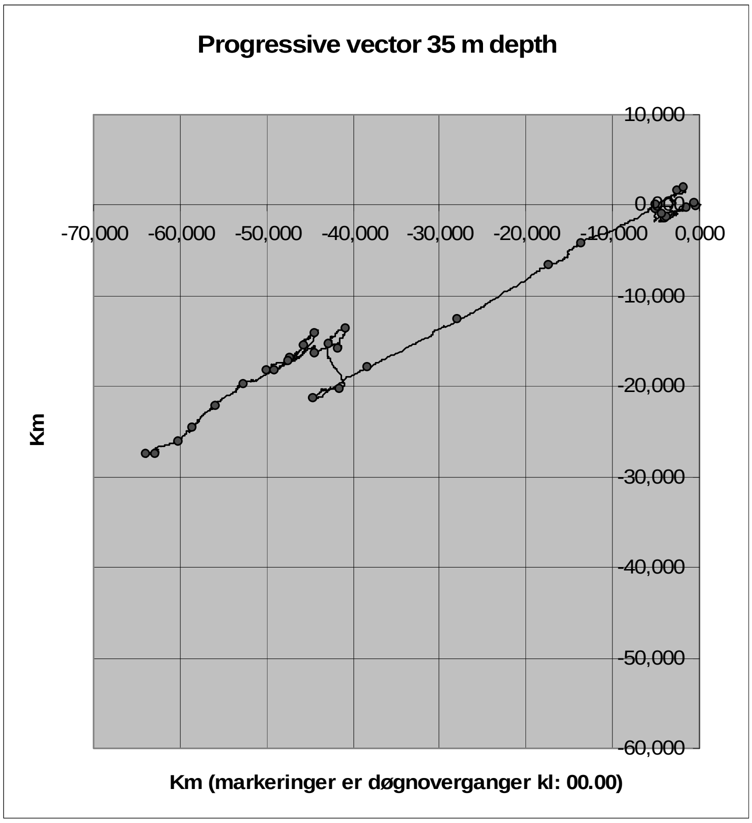


Figure 18. Current direction at 35 m depth.



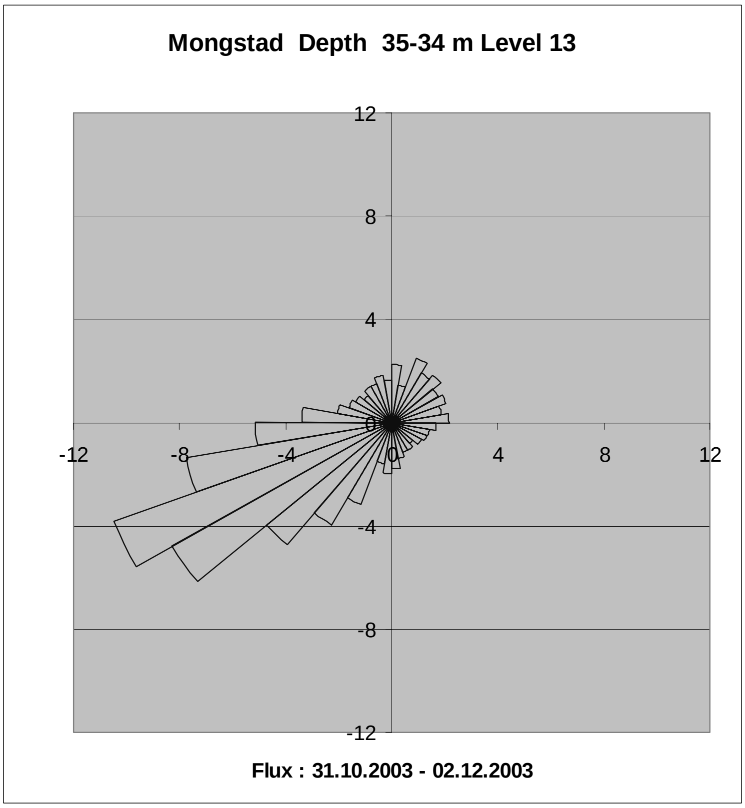
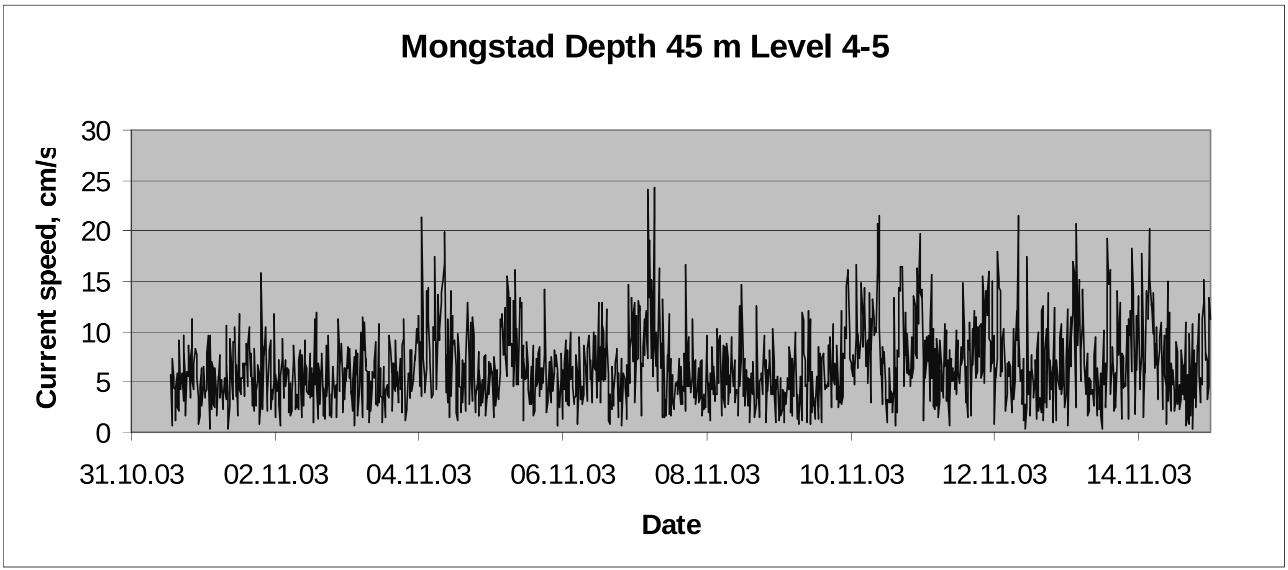


Figure 19. Progressive vector diagram and flux for the measurements at 35 m depth.

3.5 Measurements at 45 m depth

Results for the measurements at 45 m depth are shown in **Figs. 20-22**. Maximum current speed was 24 cm/s (on 7th November), and the average speed was 5.9 cm/s, i.e. the lowest average for the selected depths. Most frequent current direction was still towards SW, but several periods showed current with a prevailing NE direction. Net (residual) current direction was still towards SW as for the other depths but the residual current was only around 1 cm/s as the influence on currents towards NE was significant (flux diagram, **Fig. 22**).



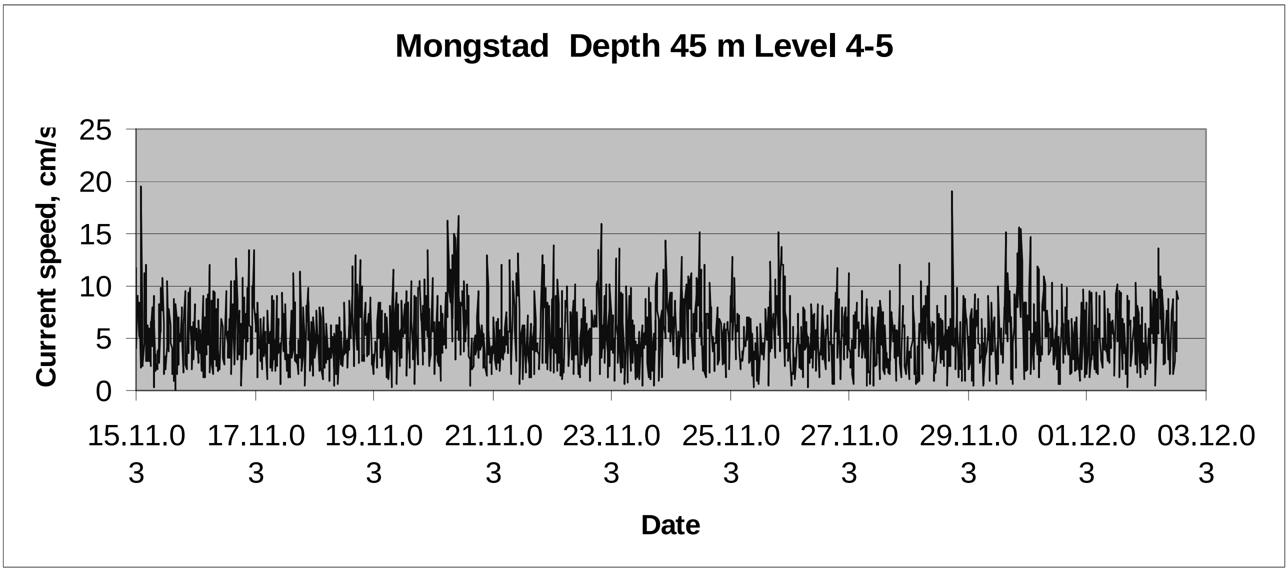
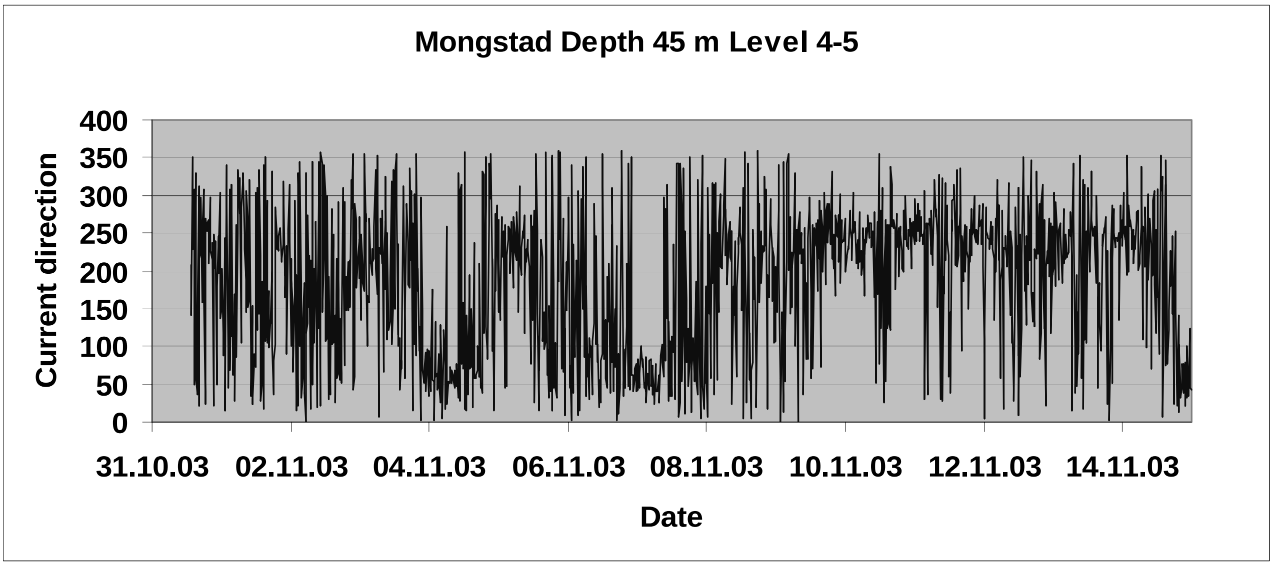


Figure 20. Measured current speed at 45 m depth.



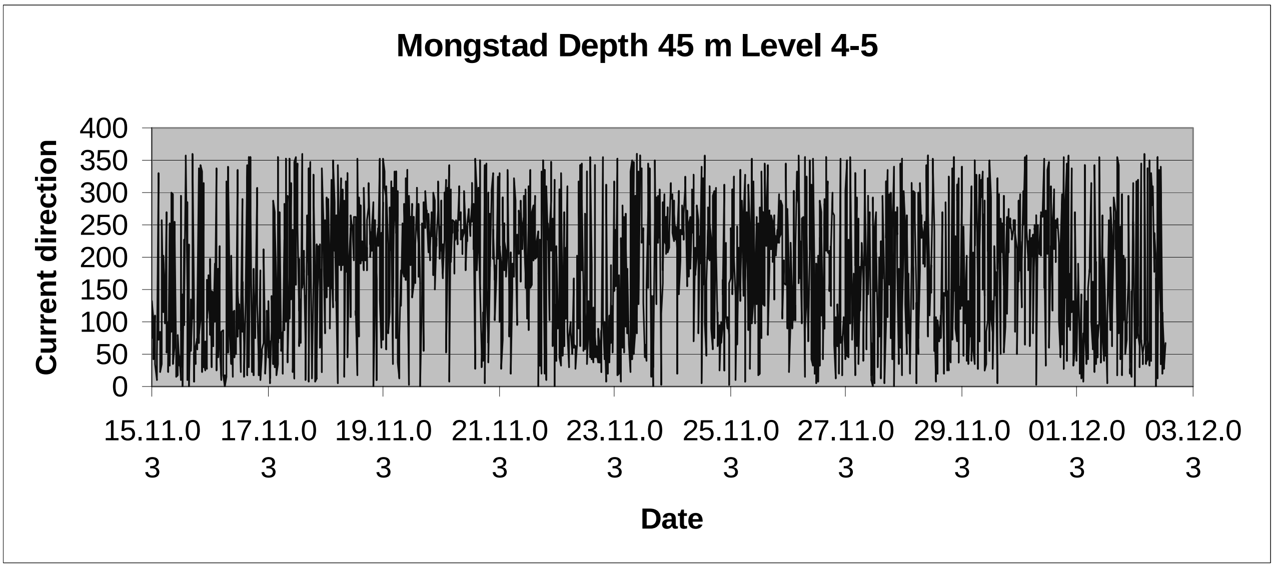
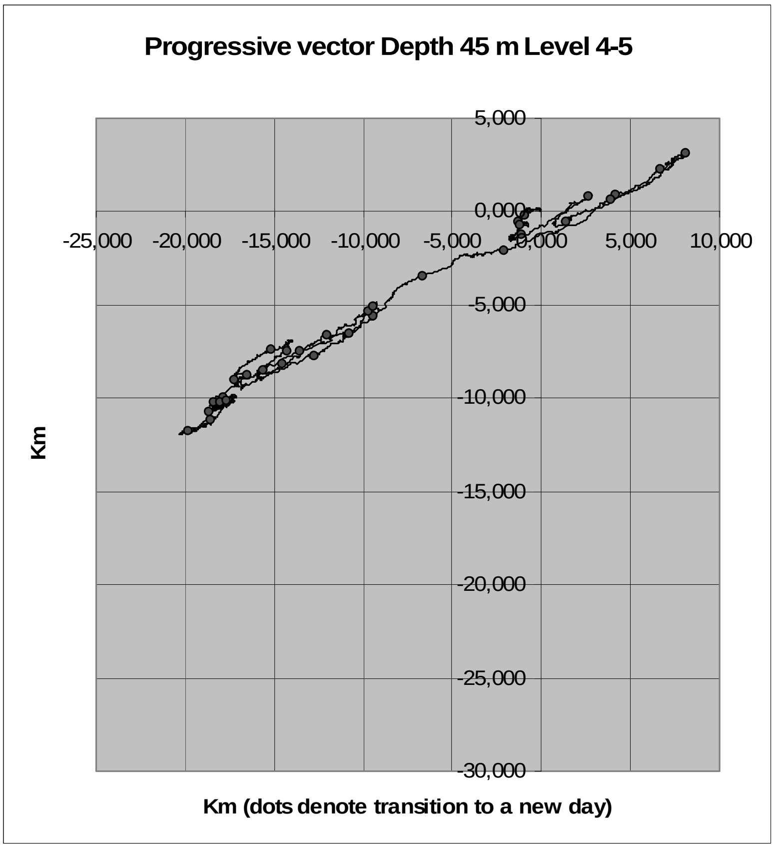


Figure 21. Measured current direction at 45 m depth.



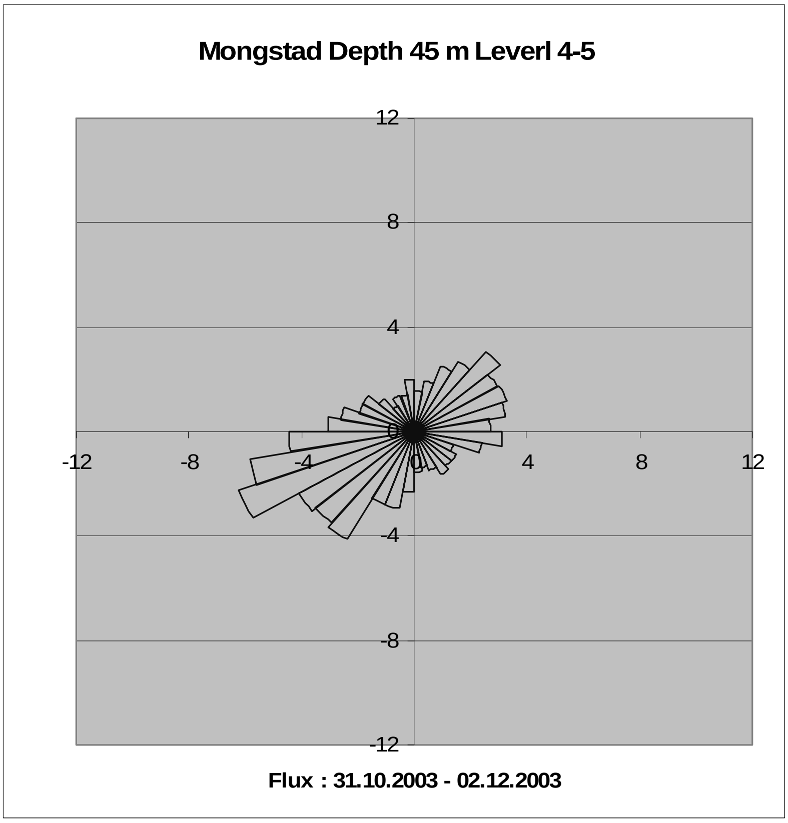


Figure 22. Progressive vector diagram and flux for the measurements at 45 m depth.

3.6 Statistics and harmonic analysis

Some statistics for some selected depths are shown in **Table 3**, and **Table 4** shows results of tidal harmonic analyses for the time series at 5 m, 20 m, 39 and 46 m.

The statistics reflect the trends already described with a decreasing current with depth, as expected, and with a dominating flow towards SW. Close to the bottom, however, the current direction was more evenly distributed between the NE and SW sectors, also resulting in diminishing residual current speed there.

The harmonic analysis (**Table 4**) shows a significant or dominating influence by the M2 (lunar semidiurnal) and S2 (Solar semidiurnal) components. Also the M4 and S4 components and higher modes as well show some influence above the background in the series at depth, which may reflect the periodicity of around 6 hrs /+/-) as indicated by the contour diagram in **Fig. 7**.

Table 3. Some statistical results from some of the current measurements at the process water discharge.

Depth (m)	Scalar values							Current vector	
	Average speed (cm/s)	Stability-factor	P01	P10	P50	P90	P99	**Mean current (cm/s)**	Direction (°)
5	**10.6**	**0.53**	**0.8**	**2.7**	**7.9**	**18.4**	**29.6**	**5.0**	**245**
20	**10.1**	**0.52**	**0.8**	**2.7**	**8.0**	**20.3**	**40.6**	**5.3**	**243**
40	**7.7**	**0.35**	**0.7**	**2.4**	**6.5**	**14.7**	**23.5**	**2.7**	**235**
45	**5.9**	**0.15**	**0.6**	**2.1**	**5.5**	**10.8**	**16.7**	**0.9**	**238**

Table 4. Harmonic analyses for selected depths according to MATLAB toolbox routines by Pawlowicz et al. (Computers and Geosciences Vol 28, 2002, 929-937).

Harmonic analysis,5 m depth

	NAME	SPEED	MAJOR	MINOR	INC	G	G+	G-
1	Z0	.00000000	4.961	.000	25.5	180.0	154.5	205.5
2	MSF	.00282193	2.750	.433	58.1	90.2	32.1	148.3
3	O1	.03873065	.796	-.169	6.1	236.1	229.9	242.2
4	K1	.04178075	.886	.378	175.8	108.6	292.8	284.5
5	M2	.08051140	1.556	.134	29.5	265.5	236.1	295.0
6	S2	.08333334	1.051	.513	12.1	98.1	86.0	110.1
7	M3	.12076710	.424	-.057	61.9	77.8	16.0	139.7
8	SK3	.12511410	.527	.027	153.1	331.0	177.9	124.1
9	M4	.16102280	.906	-.113	104.6	329.8	225.2	74.4
10	MS4	.16384470	.934	.059	56.7	48.0	351.3	104.8
11	S4	.16666670	.851	-.070	99.7	304.0	204.3	43.7
12	2MK5	.20280360	.586	.072	124.5	237.9	113.4	2.4
13	2SK5	.20844740	.494	-.069	103.3	125.3	22.0	228.6
14	M6	.24153420	.833	-.002	118.3	217.1	98.8	335.4
15	2MS6	.24435610	.508	-.222	179.8	302.3	122.5	122.1
16	2SM6	.24717810	.577	.185	56.9	314.6	257.7	11.5
17	3MK7	.28331490	.338	.218	165.6	236.9	71.3	42.5
18	M8	.32204560	.712	-.033	130.1	35.4	265.3	165.5

Table 4, continued.

Harmonic analysis,20 m depth

	NAME	SPEED	MAJOR	MINOR	INC	G	G+	G-
1	Z0	.00000000	6.034	.000	28.0	180.0	152.0	208.0
2	MSF	.00282193	3.854	-.062	25.3	84.3	59.1	109.6
3	O1	.03873065	.800	-.033	83.9	195.9	112.1	279.8
4	K1	.04178075	1.516	-.021	79.6	285.7	206.1	5.3
5	M2	.08051140	1.796	-.668	62.0	196.4	134.4	258.4
6	S2	.08333334	.830	-.263	12.9	26.1	13.2	39.1
7	M3	.12076710	.576	-.004	130.9	79.2	308.3	210.1
8	SK3	.12511410	.770	.055	42.9	332.6	289.7	15.4
9	M4	.16102280	.765	.365	49.1	12.0	322.9	61.1
10	MS4	.16384470	1.213	.265	96.0	255.3	159.3	351.3
11	S4	.16666670	.327	-.182	137.8	45.3	267.6	183.1
12	2MK5	.20280360	.307	.092	173.0	23.6	210.5	196.6
13	2SK5	.20844740	.632	-.164	121.9	318.5	196.6	80.5
14	M6	.24153420	.469	.204	60.3	287.1	226.8	347.4
15	2MS6	.24435610	.557	.017	88.4	68.0	339.6	156.3
16	2SM6	.24717810	.609	.017	65.7	294.4	228.7	.1
17	3MK7	.28331490	.648	-.127	4.5	47.7	43.2	52.2
18	M8	.32204560	.661	-.403	22.2	177.9	155.7	200.1

Harmonic analysis, 39 m depth

	NAME	SPEED	MAJOR	MINOR	INC	G	G+	G-
1	Z0	.00000000	3.556	.000	32.0	180.0	148.0	212.0
2	MSF	.00282193	4.403	-.221	33.2	59.1	25.9	92.3
3	O1	.03873065	.460	.198	9.1	356.6	347.5	5.8
4	K1	.04178075	.333	-.096	85.1	195.9	110.9	281.0
5	M2	.08051140	.668	-.344	8.6	218.9	210.3	227.6
6	S2	.08333334	.967	-.171	38.9	29.5	350.6	68.3
7	M3	.12076710	.674	-.355	140.3	79.9	299.5	220.2
8	SK3	.12511410	.360	-.035	67.7	14.0	306.3	81.7
9	M4	.16102280	.442	.264	133.7	358.5	224.8	132.3
10	MS4	.16384470	.242	-.086	19.0	70.7	51.7	89.7
11	S4	.16666670	.750	.077	162.4	196.7	34.3	359.1
12	2MK5	.20280360	.462	-.087	43.4	334.8	291.3	18.2
13	2SK5	.20844740	.596	-.102	146.5	73.7	287.3	220.2
14	M6	.24153420	.508	.312	45.6	229.6	183.9	275.2
15	2MS6	.24435610	.662	-.483	28.7	295.0	266.3	323.7
16	2SM6	.24717810	.633	-.061	89.2	196.4	107.2	285.7
17	3MK7	.28331490	.143	.065	70.1	320.2	250.1	30.3
18	M8	.32204560	.449	.200	59.7	182.0	122.2	241.7

Harmonic analysis,46 m depth

	NAME	SPEED	MAJOR	MINOR	INC	G	G+	G-
1	Z0	.00000000	1.468	.000	31.1	180.0	148.9	211.1
2	MSF	.00282193	2.869	-.042	20.7	50.7	29.9	71.4
3	O1	.03873065	.944	-.410	15.1	327.8	312.7	342.8
4	K1	.04178075	.621	.474	165.0	142.5	337.5	307.5
5	M2	.08051140	.614	.154	7.2	254.8	247.7	262.0
6	S2	.08333334	.368	-.126	173.2	90.0	276.8	263.2
7	M3	.12076710	.412	.115	29.2	309.0	279.8	338.2
8	SK3	.12511410	.449	-.083	157.4	291.0	133.5	88.4
9	M4	.16102280	.300	-.224	100.2	278.6	178.4	18.7
10	MS4	.16384470	.386	.217	92.7	359.4	266.7	92.2
11	S4	.16666670	.225	-.099	174.8	111.0	296.1	285.8
12	2MK5	.20280360	.790	-.068	161.1	131.8	330.7	292.9
13	2SK5	.20844740	.506	.170	147.7	304.5	156.8	92.1
14	M6	.24153420	.426	.216	66.6	28.9	322.3	95.4
15	2MS6	.24435610	.289	-.132	49.4	255.4	205.9	304.8
16	2SM6	.24717810	.331	.042	140.2	53.6	273.3	193.8
17	3MK7	.28331490	.670	.143	21.9	279.7	257.7	301.6
18	M8	.32204560	.399	.173	146.3	44.9	258.7	191.2

4. Hydrography

4.1 New STD-profiles

The profiles taken during deployment and retrieval of the current meter are shown in **Figures. 23-25**. The profile on 31st October was taken to 63 m, while the next profile was taken to ca 150 m depth. The water column from surface to 50 m depth (interval of possible most interest for the dispersion) was moderately stratified, with a difference of about 1 or 2 kg/m^3 between the 50 m and the surface level.

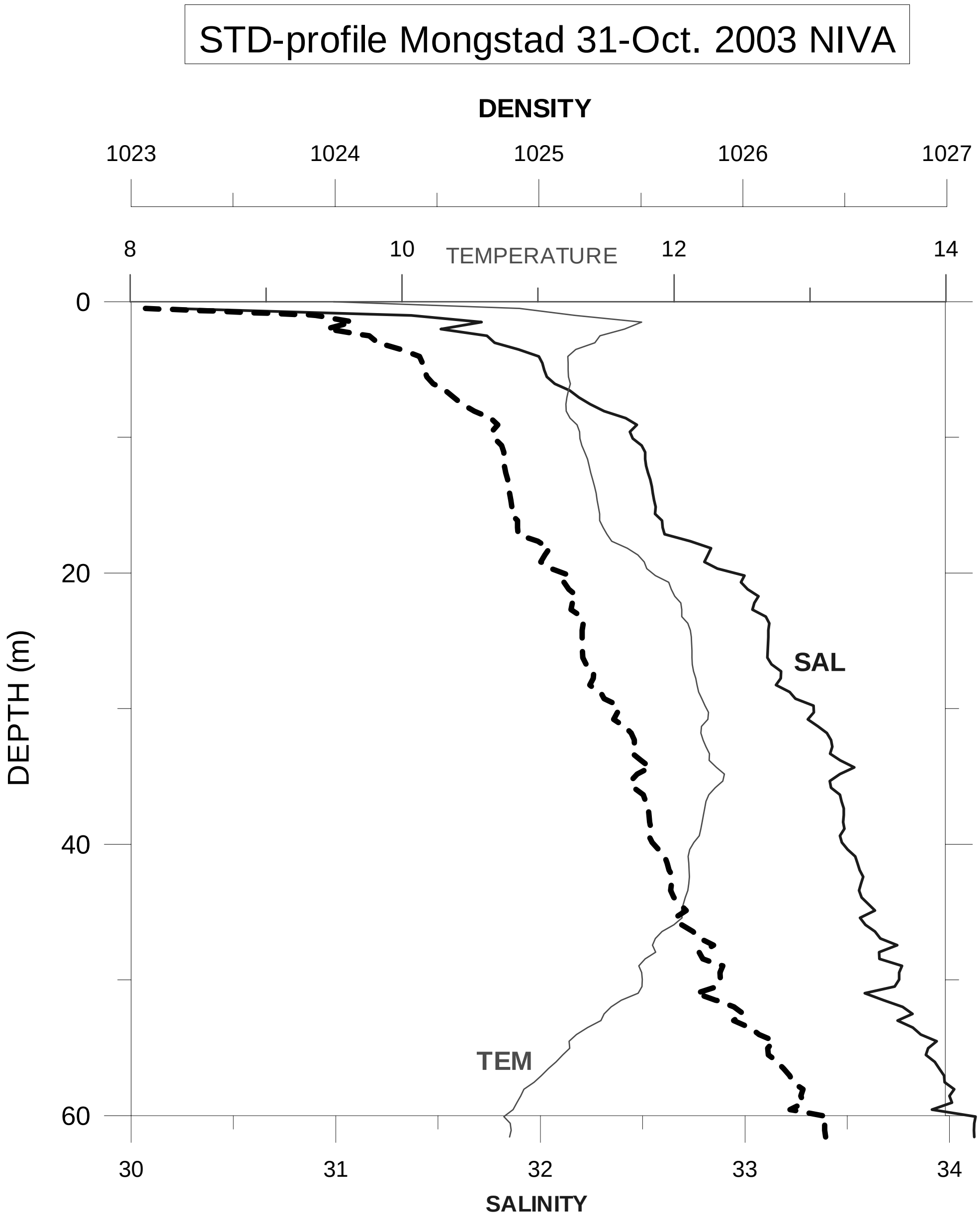


Figure 23. Hydographic profile measured on 31st October 2003 in the Fensfjord close to the discharge location.

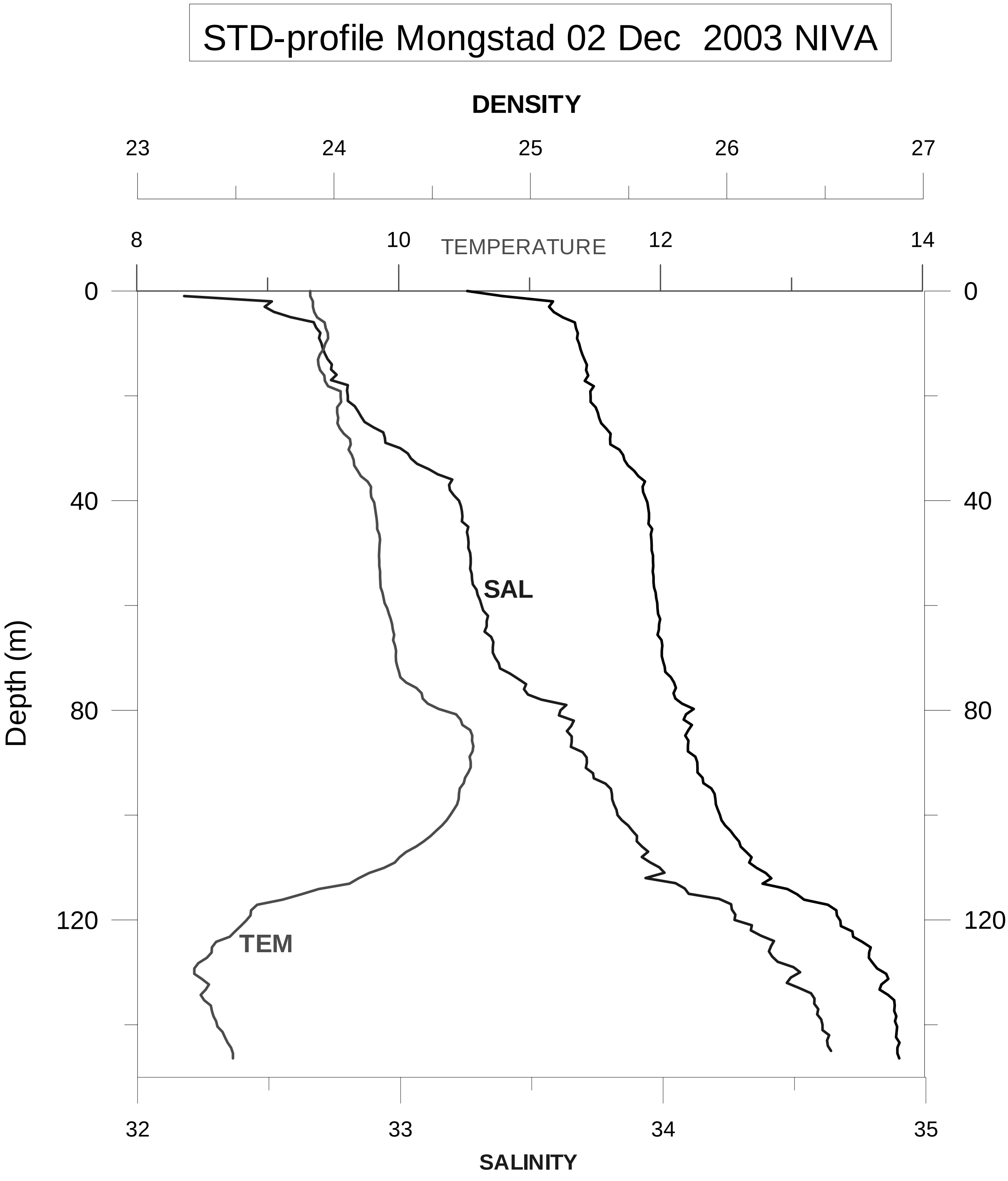


Figure 24. Hydographic profile measured on 02 December 2003 in the Fensfjord near the discharge location.

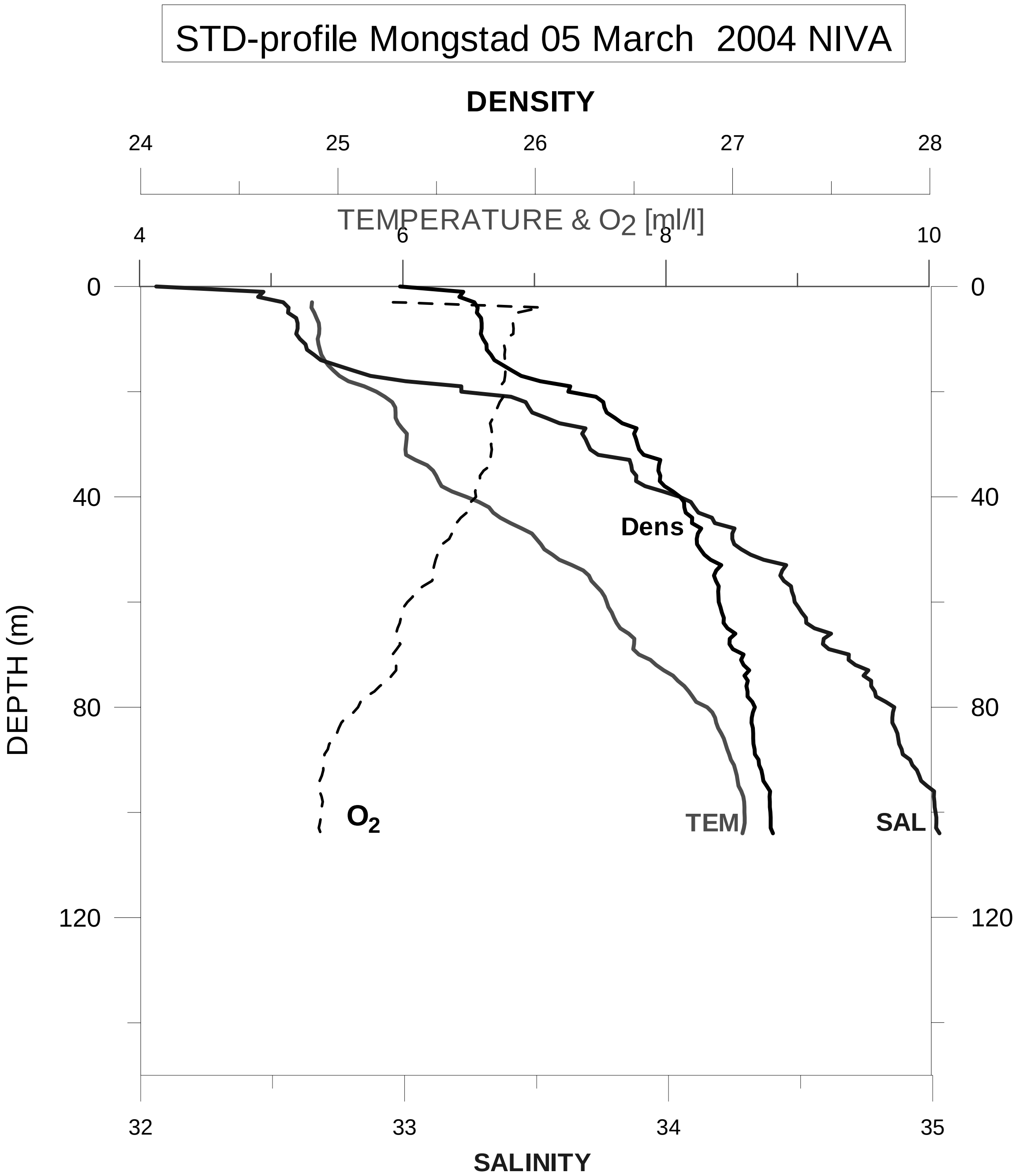
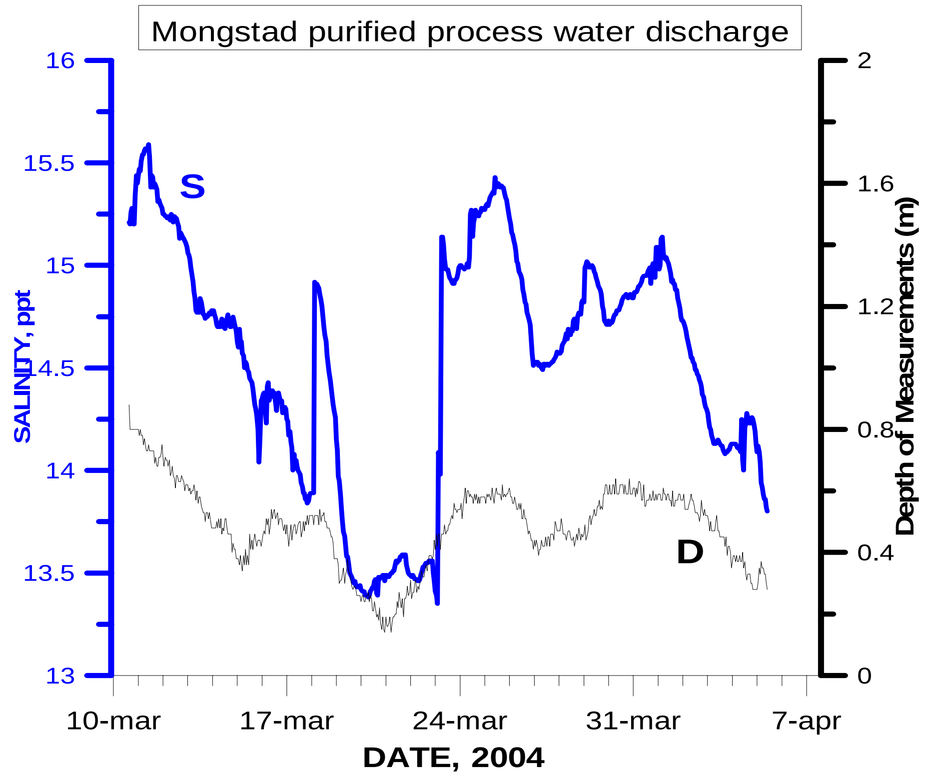


Figure 25. Hydographic profile measured on 05 March 2004 in the Fensfjord near the discharge location.

4.2 Time series TS data at the discharge water intake pit

Fig. 26 shows the measured temperature and salinity in the water prior to being discharged through the pipeline into the sea. See **Table 2** for details about the measurements. The salinity (which may have the largest influence on the density of the discharged water) varied between 13 and 15.7 over the period of measurements. This reflects a significant mixing between seawater (oceanic water) and fresh water of different origin in the basin. The temperature varied between 9 and 12.5 °C, gradually increasing as the measurements progressed.



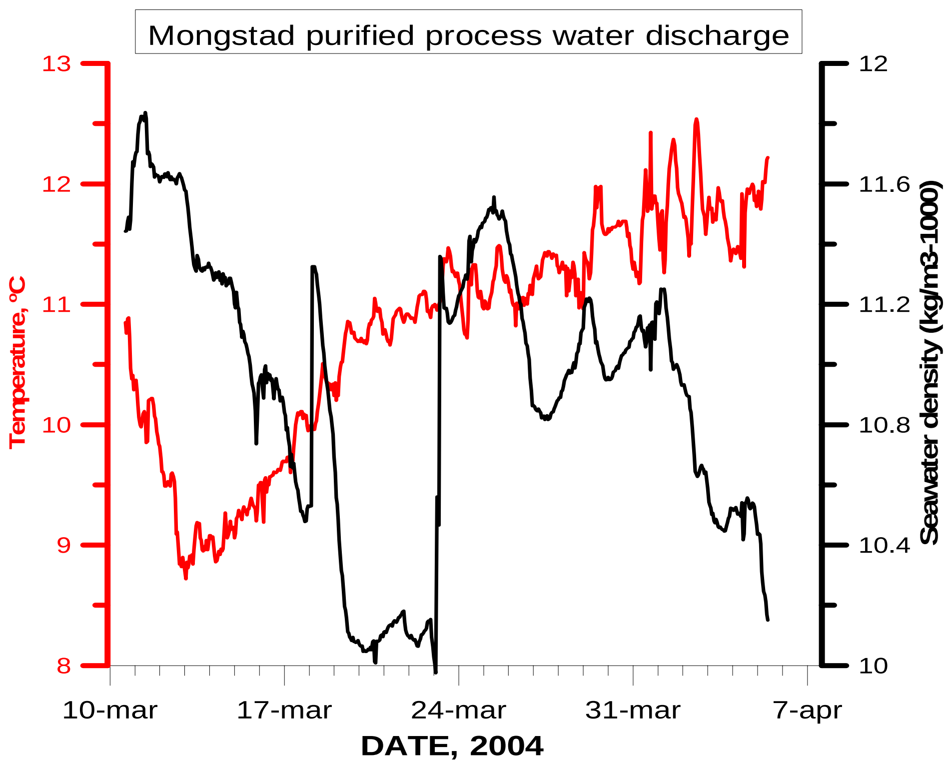


Figure 26. Measured salinity and water level (upper frame), and temperature and calculated seawater density at the discharge water intake during 10th March - 5th April 2004.

4.3 Older hydrographic data

The University of Bergen collected hydrographic data in the Fensfjord in 1972, during the initial construction phases of the refinery. These data were from water samples (salinity) and reversing thermometers. The accuracy is expected to be good, but the depth resolution is limited. **Figs. 27 and 28** presents these data, with two different depth intervals. The data are tabulated in Appendix A.

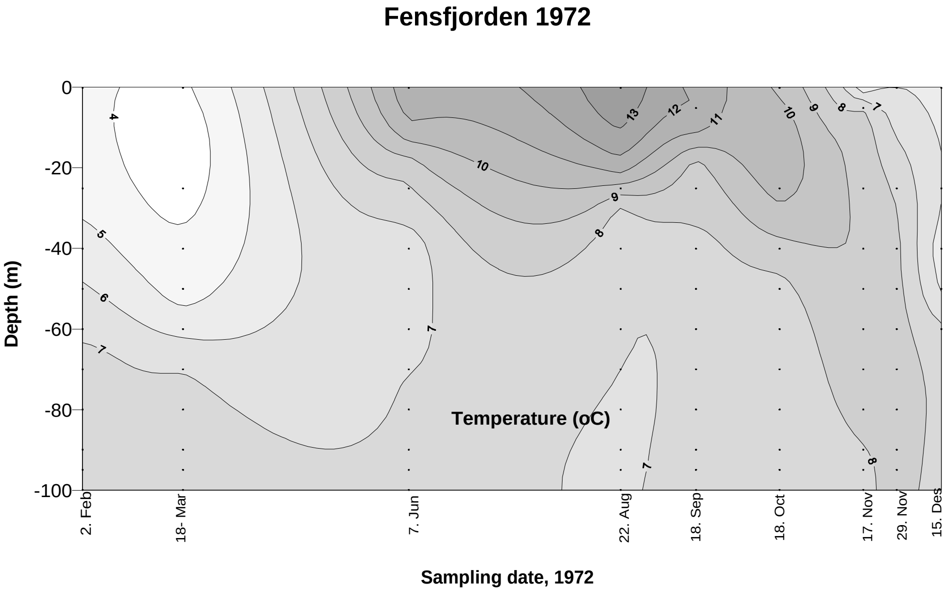


Figure 27. Seawater temperature and salinity in the Fensfjord in 1972 from surface to 100 m depth as measured by the University of Bergen.

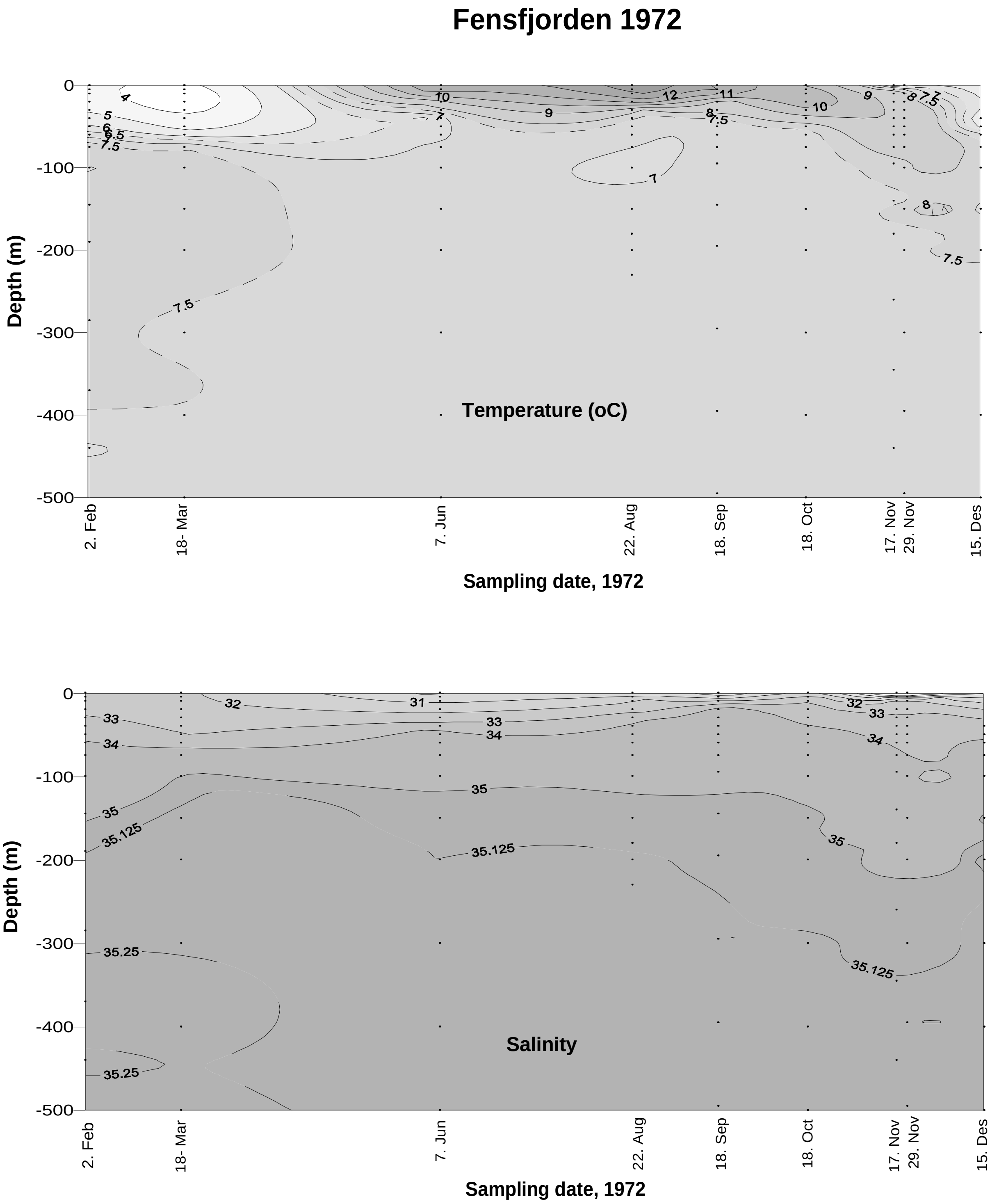


Figure 28. Seawater temperature and salinity in the Fensfjord in 1972 from surface to 500 m depth as measured by the University of Bergen.

Appendix A. Tabulated hydrographic data

Fensfjorden
1972

Date	Depth (m)	Temp. (°C)	Salinity
72.02.11	0	4,25	32,820
	5	4,32	32,778
	10	4,35	
	20	4,59	32,922
	30	4,82	33,049
	40	5,53	33,534
	50	6,11	33,807
	60	6,74	34,090
	75	7,92	34,263
	100	7,42	34,463
	145	7,90	34,956
	190	7,86	35,122
	285	7,68	35,225
	370	7,75	35,312
	440	6,93	35,231
72.03.18	0	3,82	32,128
	5	3,76	32,124
	10	3,40	32,125
	20	3,48	32,326
	30	3,86	32,503
	40	4,20	32,808
	50	4,43	32,997
	60	5,76	33,616
	75	7,41	34,667
	100	7,82	35,054
	150	7,66	35,181
	200	7,67	35,241
	300	7,32	35,238
	400	7,44	35,284
	500	7,42	35,289
72.06.07	0	11,65	29,824
	5	11,25	30,455
	10	10,85	30,948
	20	8,31	31,887
	30	7,58	32,322
	40	6,36	33,769
	50	6,78	34,402
	60	6,84	34,543
	75	7,06	34,713
	100	7,15	34,886
	150	7,17	35,042
	200	7,32	35,124
	300	7,24	35,167
	400	7,18	35,184
	500	7,18	35,184
72.08.22	0	13,75	29,867
	5	13,38	32,058
	10	13,05	32,276
	20	11,54	32,758
	30	7,79	33,941
	40	7,40	34,317
	50	7,08	34,462
	60	7,05	34,630
	75	6,99	34,787
	100	6,98	34,885
	150	7,06	35,058
	180	7,05	35,085
	200	7,15	35,154
	180	7,02	35,087
	230	7,10	
72.09.18	0	11,50	29,144
	5	12,15	30,811
	10	11,38	32,632
	20	8,50	34,817
	30	8,42	34,353
	40	7,51	34,524
	50	7,29	34,638
	60	7,16	34,717
	75	7,09	34,797
	95	7,10	34,911
	145	7,09	35,004
	195	7,11	35,039
	295	7,12	35,123
	395	7,20	35,200
	495	7,19	35,219
72.10.18	0	9,72	31,187
	5	10,25	32,531
	10	10,59	32,993
	20	10,56	33,211
	30	9,92	33,536
	40	8,66	34,039
	50	7,65	34,489
	60	7,37	34,615
	75	7,26	34,737
	100	7,20	34,920
	150	7,16	35,028
	200	7,13	35,073
	300	7,13	35,150
	400	7,20	35,201
	500	7,18	35,222
72.11.17	0	5,15	23,861
	5	8,03	31,839
	10	8,42	32,528
	20	8,52	32,644
	30	8,76	33,191
	40	8,89	33,528
	50	8,86	33,667
	60	8,70	33,888
	75	8,41	34,086
	95	7,80	34,521
	140	7,32	34,885
	180	7,20	35,000
	260	7,14	35,081
	345	7,13	35,128
	440	7,12	35,170
72.11.29	0	5,97	27,531
	5	6,70	31,512
	10	6,75	31,653
	20	7,55	32,792
	30	8,03	33,324
	40	8,24	33,521
	50	8,32	33,611
	60	8,42	33,717
	75	8,45	33,780
	100	8,28	33,522
	150	8,45	33,888
	200	7,53	34,789
	300	7,23	35,026
	395	7,16	35,116
	495	7,14	35,175

Fensfjorden 1972

Date	Depth (m)	Temp. (^{o}C)	Salinity
72.12.15	40	5,49	33,587
	50	5,83	33,715
	60	7,19	34,333
	75	7,72	34,764
	100	7,66	35,024
	150	7,36	35,151
	200	7,61	35,208
	300	7,37	35,220
	400	7,30	35,220
	500	7,31	35,233

South of Byrknesøy 1991

Date	Depth (m)	Temp. (^{o}C)	Salinity
91.10.31	1	8,82	30,200
	2,1	8,84	30,220
	3,2	2,90	30,420
	4,1	9,18	30,510
	5,1	9,33	30,730
	6,1	9,57	30,960
	7	9,70	31,150
	8,1	9,90	31,270
	9,1	10,15	31,380
	10,2	10,30	31,490
	12,1	10,70	31,900
	14,1	10,88	31,970
	16,1	11,01	32,100
	18	11,35	32,370
	20,1	11,47	32,440
	24,9	11,55	32,680
	30	11,60	32,930
	34,9	11,56	33,060
	39,9	11,51	33,360
	44,9	11,17	33,620
	50	10,82	33,880
91.11.08	1	10,19	32,140
	2,1	10,20	32,090
	3,3	10,19	32,150
	4,1	10,19	32,160
	4,9	10,19	32,190
	5,6	10,19	32,180
	6,5	10,23	32,250
	7,5	10,23	32,230
	8,3	10,23	32,180
	9,5	10,23	32,300
	10,5	10,23	32,250
	11,5	10,22	32,240
	13,3	10,23	32,260
	15,3	10,23	32,300
	17,3	10,23	32,280
	19,3	10,21	32,290
	24,1	10,19	32,320
	29,1	10,38	32,430
	34,1	10,44	32,580
	39	10,65	32,720
	43,9	10,75	32,280
	49,2	10,83	32,980