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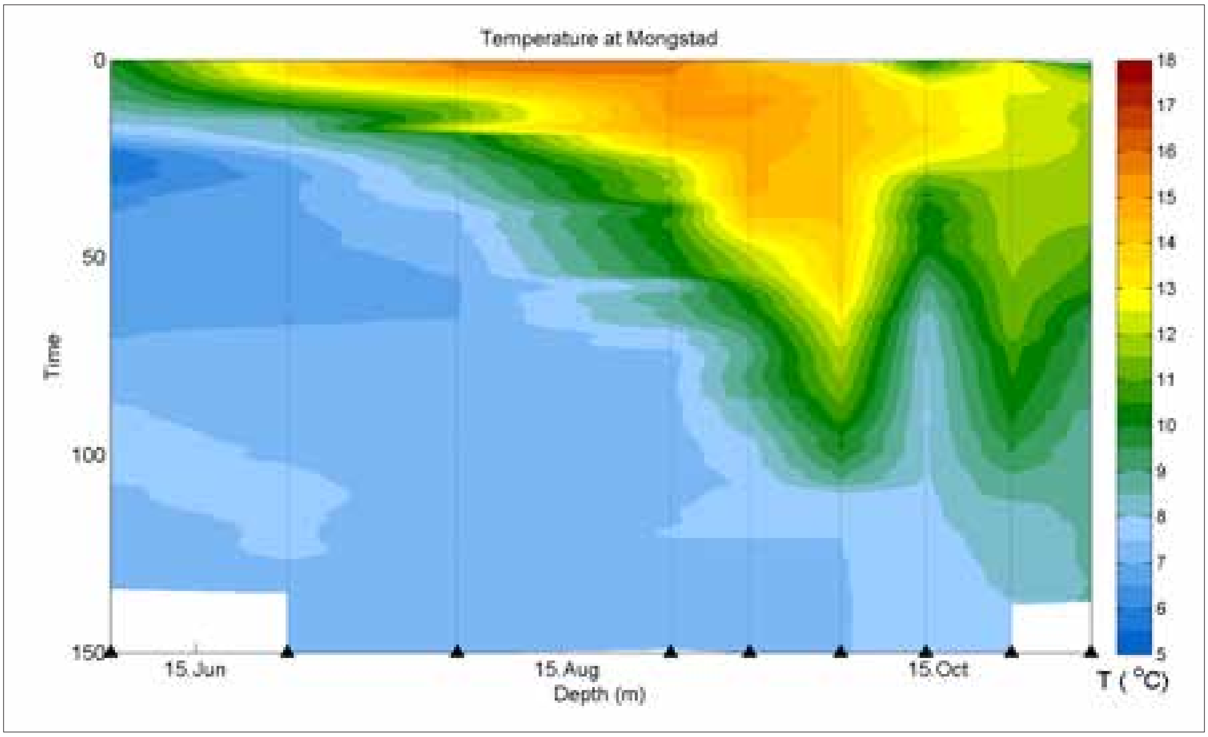
Two years of continuous METOCEAN measurements at Mongstad, Norway, 2011-2013. Summary report



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REPORT

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Abstract As part of the design of the full-scale CO_2 capture plant at Mongstad in Norway (Mongstad CCM project), NIVA conducted measurements of currents, temperature and salinity in the sea area considered for a new cooling water intake, and outlet. The measurements lasted from April 2011 to May 2013. A fixed mooring with currents meters were connected to shore via cable, for continuous data transmission and quality control. Sea temperatures were recorded by a thermistor chain laid out along the bottom, also with continuous monitoring. Additional STD-profiles were taken bimonthly. The data return was regarded as satisfactory, over-all better than 90%, with some failures of thermistors, and some false reflections of ADCP current meter beams from the sloping seabed. The present report summarizes the data collection program and the main findings, mainly based on the 24 extensive Monthly data reports and the Annual reports provided underway.

4 keywords, Norwegian	4 keywords, English
1. Mongstad	1. Mongstad
2. Fensfjorden	2. Fensfjord
3. Metocean data	3. Metocean data
4. Kjølevann	4. Cooling water

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Two years of continuous METOCEAN measurements at

Mongstad, Norway,

2011-2013.

Summary report

Preface

The project with measurements in the sea near the Mongstad Refinery commenced in early 2011, with preparations and safety/HSE issues being clarified with the refinery (MRDA) and NIVA's original customer Gassnova. In March, 2012, Statoil took over the project from Gassnova, and became NIVA's new customer (Company).

The present report is a summary of the measurements, conducted under the VO # 8. During the project period, monthly data reports as well as annual data reports were made, presenting results on which the present report rests.

Many persons contributed to the project during the 2 ½ years. Jon Mongstad (Gassnova) Geir Husebø and Øyvind Strøm were the Company representatives. External companies provided misc. support: Leon Pedersen with the vessel "Solvik" for deployments, Ola V. Halden at Scandpower for HAZID work, Geir A. Fylkesnes and Arne O. Halland at Mongstad elektro/Terne for on-shore installations.

MRDA harbor office provided excellent support regarding coordination, ship traffic data and small boat operations. Thanks in this respect are due to Harbour captain Jan H. Svedhaug and to Magnus I. Fonnes.

At NIVA, several colleagues provided valuable support: Uta Brandt, John R. Selvik, Jan Karud, Emanuele Reggiani, Kjersti L. Daae, Henny Knutsen, Gisle Nondal, Dag Hjermann, Anna B. Ledang, Pierre Jaccard and Ingard Bescan, to mention a few, we are in debt to all.

The project was considered satisfactory in terms of data return, and no HSE incidents were reported.

Bergen, October 2013

Lars G. Golmen

Contents

Summary

The CO_2 Capture Mongstad project (Mongstad CCM) will require significant amounts of cooling water for the CCP plant. The plant is proposed to be located next to the Mongstad Refinery, about 50 km north of Bergen, Norway. The existing cooling water system at Mongstad was regarded as inadequate to carry the added stream from the new plant. It was decided to start a design of a new and separate cooling water system, with a deeper intake and a deeper discharge, tentatively located further SE from the existing discharge point. Intake depth might be around 100 m, and the new discharge around 50-60 m depth.

For a detailed design of this system, there was a demand for Metocean data from the intake/discharge locations. Existing data were sparse or old, so therefore NIVA, the Norwegian Institute for Water Research, was contracted by Gassnova in October, 2010 for making such measurements, including currents and sea temperature over one year of measurements.

Following a period with preparations, the measurements began in April, 2011. Later, the contract was amended to include salinity/temperature profiles at approx. monthly intervals, and the measurement period was extended to cover two years, ending in May, 2013. Company Statoil took over the project from Gassnova in March, 2012.

NIVA submitted data reports to Company on a monthly basis throughout the measurement period. In addition, annual reports and a mid-term report were made. Due to the technical nature of these reports and their large size, it was decided to make a short summary report on the measurements and data, which is reported herein.

The project included on-line measurements of currents from near-surface to 50 m depth, and sea temperatures from surface to 150 m depth. The measurement interval was set to 10 minutes. Additional STD-profiles were collected on a monthly/bimonthly basis from June, 2011, and some extra instruments were deployed underway, to cover gaps in the programme. The current meter mooring with two ADCP instruments was deployed outside quay 14, 100 m from the shore, at 60 m bottom depth, one instrument facing up and the other facing down from the suspension frame at 25 m depth. The 250 m long thermistor chain (cable) with ten sensors was laid out along the bottom, from shore to 150 m depth.

Sea cables supplied power and returned data to shore, one cable per instrument, allowing for long-term deployments and real-time monitoring and recording of data. On shore, two cabinets housed loggers and power supply, and equipment for data transmission to NIVA via mobile internet. The equipment remained operating continuously for over two years.

There were some problems with the current meter data from closed to the bottom, due to beam reflections. Also three thermistor sensors failed underway. To cover the gaps, some internally logging sensors were deployed. The over-all data return was better than 98 % for most depths, and the average considering the failures and gaps, was better than 95 %.

The report contains an overview of existing (older) data from the area. A comparison with the new current data set confirms that the prevailing flow is along the bathymetry, mostly with dominating direction towards NW (out fjord). Current speeds were moderate, with only a few episodes with comparatively high values (0.3-0.4 m/s). No long periods of stagnation were recorded at any depth. The temperature and salinity data indicate some freshening of the upper layers compared to 40 years ago, and also significant warming down to 40- 50 m depth during summer and autumn.

Corrected data from the project are located in separate files, one for each instrument type. Raw data files also exist, as do files with misc. averaging and filtering.

1. Introduction

The CO_2 Capture Mongstad project (Mongstad CCM) includes a large capture plant (CCP) that will require significant amounts of cooling water. The plant is proposed to be located next to the Mongstad Refinery, about 50 km north of Bergen, Norway (Figure 1.).

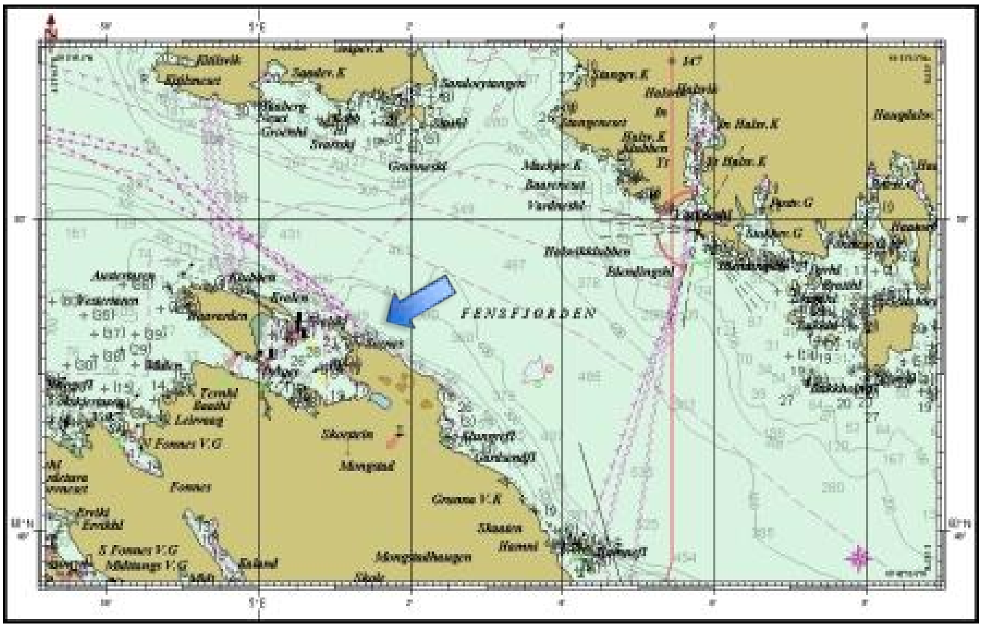

Figure 1. Maps of the fjord area north of Bergen including Mongstad (upper frame) and a hydrographic chart close-up, both highlighting Mongstad with a blue arrow.

The refinery is located next to the Fensfjord which is a long fjord, with a relatively deep (150 m) and unconstricted connection to the outer coastal areas and deep ocean. Depths exceed 500 m NE of Mongstad. Water exchange and renewal, driven primarily by tides, estuarine circulation and larger scale pressure field changes, is thus expected to be good in the depth range relevant for this report, but exact data on this did not exist.

The present cooling water system at Mongstad serves several installations and processes, including the refinery and the EVM power plant. The total discharge is around 36.000 m^3/hr, with an intake at 50 m depth and discharge at 30 m depth. In addition, there is a smaller system for the TCM test centre.

The CCP plant will require cooling water on the order of the existing flux, and it was concluded that the existing system probably could not carry this extra load. Additionally, the existing discharge at 30 m depth has some issues with warm discharge water rising all the way to the surface during certain oceanographic conditions with weak stratification. This issue would probably occur more frequently in a situation with a larger discharge.

On this background, the CCM project decided to start design of a new and separate cooling water system, with a deeper intake and a deeper discharge, tentatively located further SE from the existing discharge point. Intake depth might be as deep as 100 m, and the new discharge around 50-60 m.

In order to make the detailed design, there was a demand for Metocean data from the intake/discharge locations. Such data are critical when calculating the cooling water demand and designing heat exchangers, condensers etc. based on the expected intake temperature, and also when determining the fate of the discharged water plume, at what depth it will disperse.

So NIVA, Norwegian Institute for Water Research, submitted a tender in September, 2010 for making such measurements, including currents and sea temperature over one year of measurements.

Following a long period with procurements and preparations, clarifications with the refinery (MRDA) and HSE/HAZID work, the measurements began in late April, 2011. Later, the contract was amended to include salinity/temperature profiles at approx. monthly intervals, and the measurement period was extended to cover two years.

Data reports were made on a monthly basis throughout the measurement period, so altogether 24 monthly reports were produced. In addition, annual reports and a mid-tem report was made. Data presented were from the original instruments deployed in 2011 and from the hydrographic profiles measured 1-2 times per month from June, 2011, and from extra temperature loggers at 10 and 40 m depth. Data from an extra current meter at 52 m depth, deployed June 2012, was also amalgamated into the data series.

The equipment (see details in Chapter 2), was recovered in May, 2013, and data reporting was completed in May/June, 2013.

Following this, Company Statoil requested this summary report that would include the high-lights of the measurements and key statistics, with some additional descriptions and data interpretations.

The following chapters describes the measurement programme to some detail, the data recovery and data monitoring facilities, then the results, divided into descriptions of current data, temperature data from the thermistor chain, and the STD profiles.

2. The measurement programme

This chapter provides a short overview of the main elements of the measurement programme.

2.1 The current meter mooring

The Current meter mooring was deployed outside quay 14 at Mongstad, about 100 m from the shore Figure 2.) on April 27th, 2011, at ca. 60 m bottom depth. A schematic drawing of the mooring is shown in Figure 3. The mooring consisted of two instruments at 25 m depth, with an anchor at the bottom (60 m depth) and an additional mooring chain to the shore to prevent the mooring from sliding down the very steep topography. The mooring was kept in place until the recovery on May 21, 2013, measuring continuously from April, 2011.

One current meter was looking upwards (AADI RDCP-600 kHz) and the other was looking downwards (Nortek Continental 190 kHz), suspended in gimball bearings (Figure 4). Both current meters were Doppler shift instruments and recorded current speed and direction in several levels (depth cells). A list of the measurement depths/cells is given in Table 1. The recording interval was 10 minutes for both instruments. Power was supplied via combined data and power cables from shore, one cable per instrument.

2.2 The thermistor chain

An AADI thermistor chain (cable) was also deployed on April 27th, 2011. It was laid out along the bottom, from shore to 150 m depth (Figure 2). The cable route was analysed prior to deployment, in order to prepare the pre-fabricated 250 m long chain with thermistors at the desired depths. The shallowest thermistor was at 2 m depth, the deepest at 150 m depth (all sensor depths are given in Table 1). The recording interval was set to 10 minutes also for the thermistor chain. The chain was equipped with two pressure sensors, at 40 m and 150 m depth. The chain was connected to a data logger and power supply in the cabinets on-shore, for continuous data transmission, monitoring and recording, as for the current meters.

Table 1. Measurement depths of the different instruments.

Instrument	Measurement depths (m below sea level)
AADI RDCP600	**3, 5, 7, 9, 11, 14, 16, 18, 20, 22, 24 (m below SL)**
Nortek Continental	**29, 34, 40, 46, 51**
Thermistor chain temperature sensors	**2, 10, 20, 30, 40, 50, 75, 100, 125, 150**
Thermistor chain pressure sensors	**40, 150**

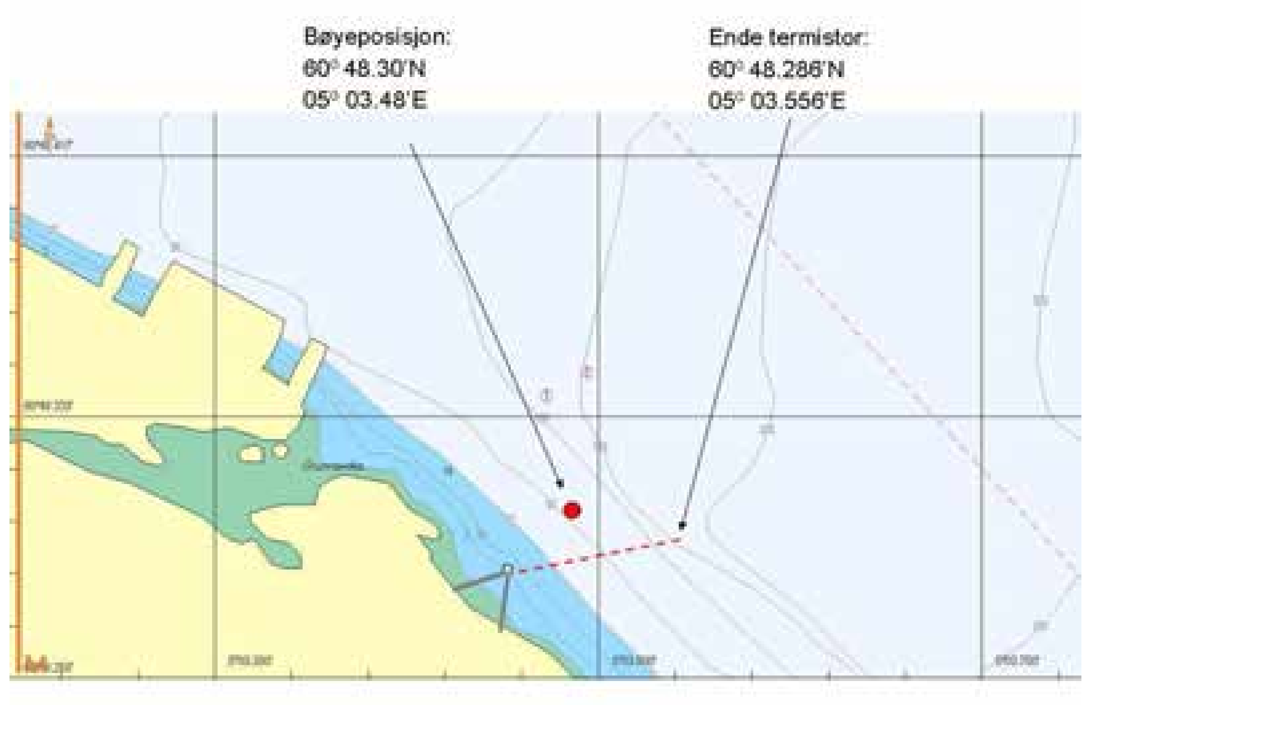

Figure 2. Map of the area with position of current meters and thermistor chain indicated.

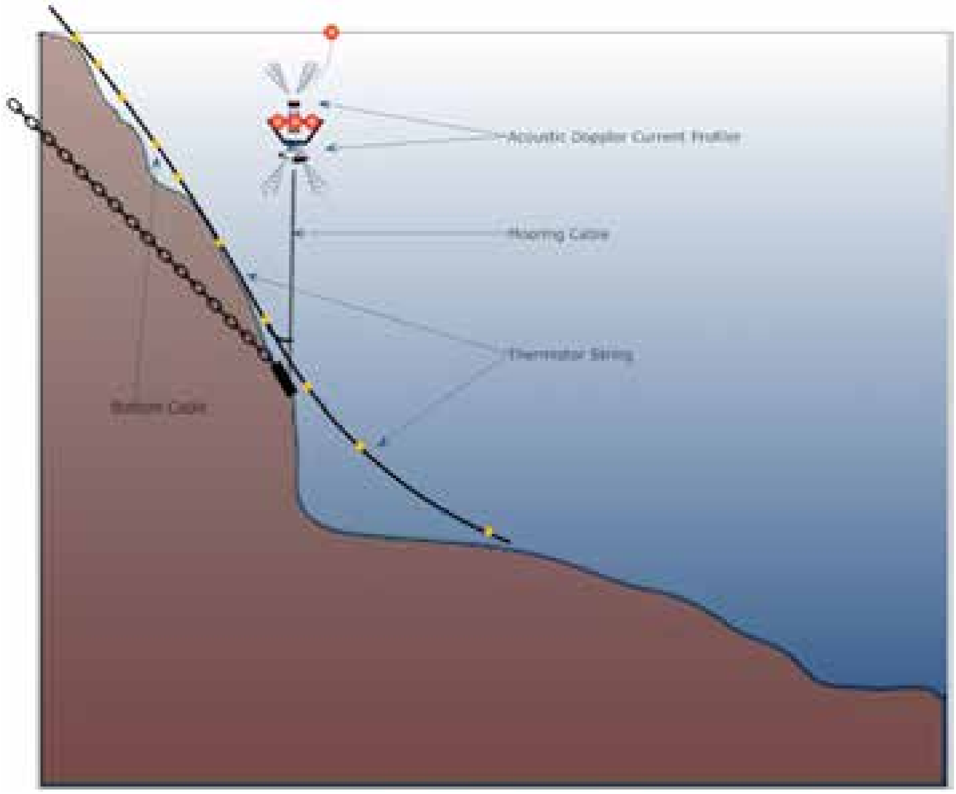

Figure 3. Schematic drawing of the current meters and the thermistor chain.

2.3 Additional sensors and instruments

Beginning in June, 2011, hydrographic profiles were taken from surface to 150 m depth at a monthly/bimonthly frequency, in a position about 300 m from shore, by lowering from the vessel a self-recording instrument suspended in a string. The main instrument used was a Seabird SBE-19 STD that was factory calibrated prior to start-up. A SAIV SD202 STD was the back-up instrument. Both instruments recorded temperature, pressure (depth) and conductivity/salinity at 1 or 2 Hz frequency, with data stored internally. Table 2 shows the dates for these measurements.

Table 2. Dates for the hydrographic profiles, 2011-2013.

Month, 2011-12:	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep
Survey date (x):	1. 30.	28.		8 14 30	13 27	9 16 [illegible]	15	31	09	06 26	12 24	7 24	08	19	02	04 25

Month, 2012/2013:	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Survey date (x):	22	20	03	15	01	06 26	09 26	16 21

Supplementary temperature loggers (RBR) were deployed at 10 m depth and 40 m depth, to replace thermistors that failed. These were battery powered, internally logging sensors, that were recovered and redeployed at ca. 6 weeks intervals. Data were merged with the remaining thermistor data.

Due to dubious data from the lowest ADCP depth cells near the bottom, a supplementary, self-recording ADCP instrument was deployed at 53 m depth, in July, 2012. This upward looking Doppler instrument (NORTEK 600 kHz) recorded currents form 50 m depth to near the surface. It was recovered each ca. 6 weeks, to tap recorded data and replace batteries. Data were merged with the other ADCP data.

Figure 4. Top of the current meter gimball frame after recovery in May, 2013.

2.4 On-shore equipment

Two EX-cabinets were mounted on the railing of the nearest pier, and provided with 230 VAC supply. The three sea cables were pulled through a 110 mm PEL pipe from approx. 2 m depth on to the shore near the cabinets. The pipe was secured to bolts on the rocky shore. From the end of the pipe, the cables run a short distance up to the cabinets. One cabinet contained an uninterrupted power supply (UPS) for the electronic components mounted in the second cabinet. The next cabinet (Figure 5.) contained misc. electronic components:

- Earth-leakage circuit breaker
- Power central – marine type, high and low voltage.
- Industrial PC – Advantech UNO-2173A
- Nortek external housing with DC/DC converter
- AADI galvanic isolator unit
- 2 x AADI data loggers
- Mobile broadband router
- Antenna for GSM mobile data transmission

Figure 6 shows the lay-out of the inside of the cabinets, Figure 7 shows the location of the cabinets.

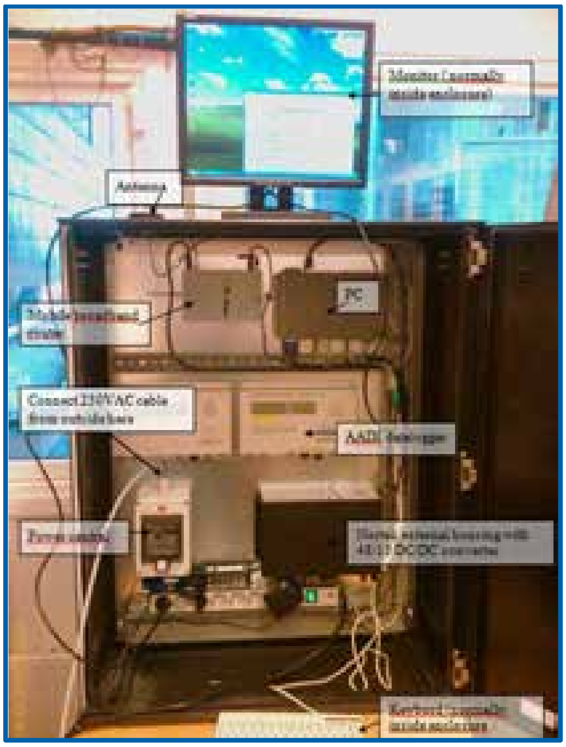

Figure 5. The cabinet containing the electronics.

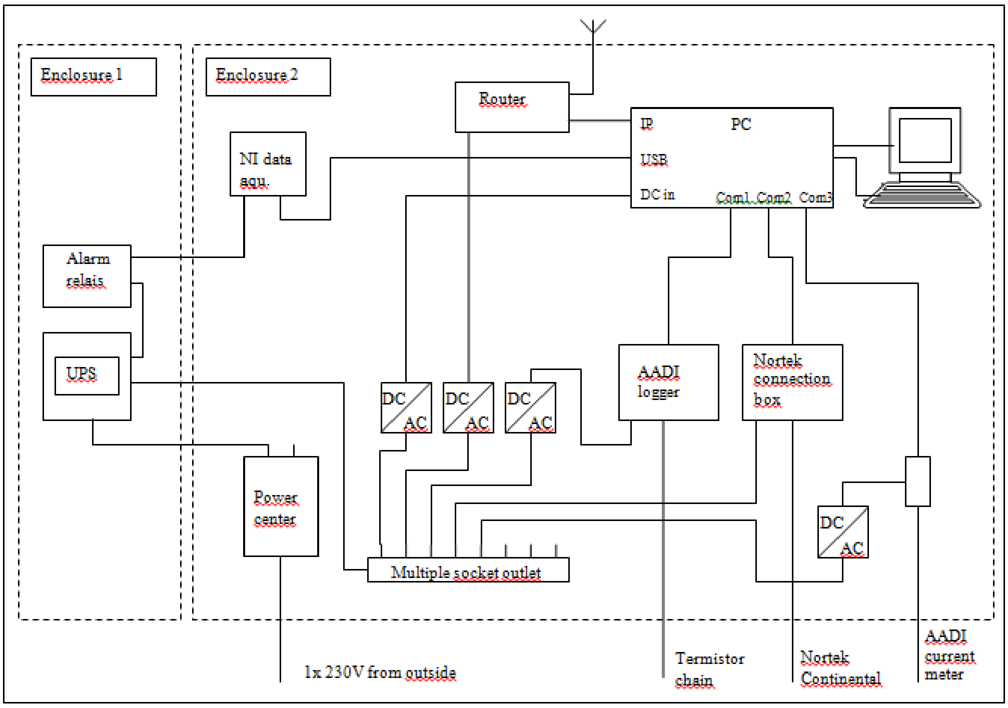

Figure 6. Lay-out of the component assembly in the two on-shore cabinets.

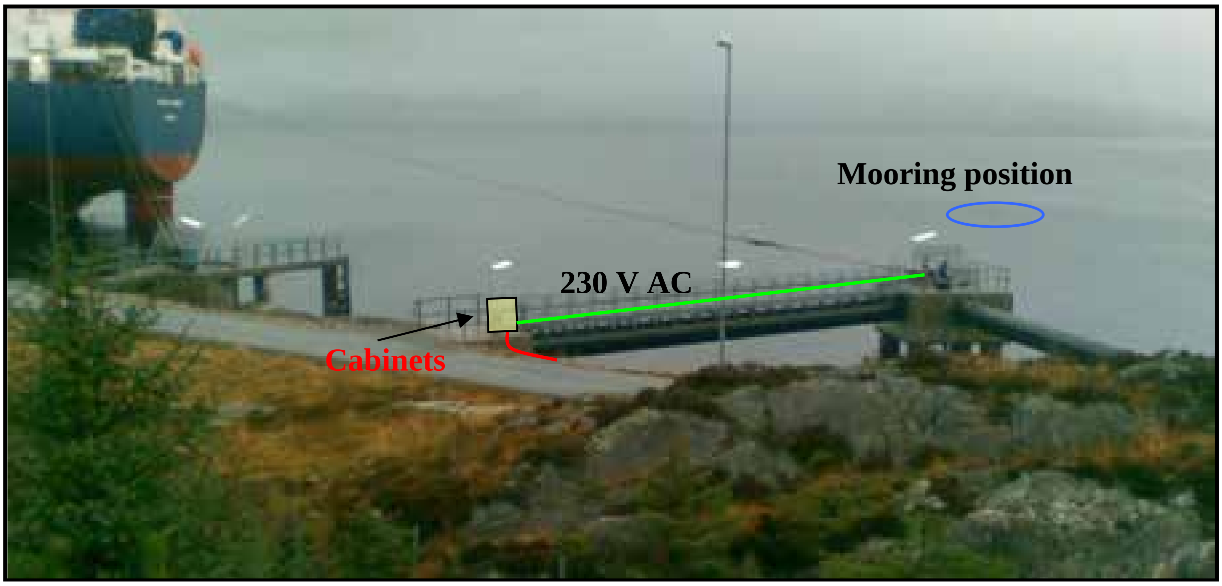

Figure 7. Location of the on-shore cabinets.

2.5 Data storage, transmission and monitoring

The PC inside the cabinet was connected to the mobile internet. Data were recorded in the PC and also transmitted continuously to NIVA and the data base (Oracle) server there. The PC could be remotely operated, and had the Labview software installed. This software allowed for data visualization (at NIVA), automatic monitoring of data quality (high/low levels, interruptions) with alarm settings.

This also allowed NIVA's web-based monitoring AquaMonitor to be applied to the data. Company and other certified users, could then log on to the website to monitor data via internet. Data were monitored on a daily basis, to allow for any corrective actions.

2.6 Overall performance

Both instruments packages, the current meters and the thermistor chain, worked continuously since deployment, and for most depths (cells), the data return was 100%. There was no detectable long-term trend that could be due to contamination of the transducers, although the frame became quite loaded with marine growth (Figure 4). It was therefore decided to not recover the mooring mid-way, just let it continue to operate. A recovery might theoretical cause harm to the cables and cause interruptions.

For some depths, however, there were some deviations. The deepest cells of the down-looking current meter, covering the depths 40 and 50 m showed frequent episodes of anomalous data and intermittently high current speeds. This was most likely due to beam reflections from the nearby, very steep bottom. The extra current meter covered these depths, from June 2012. In late November 2012, the current data from the 20 m cell started to deviate, with rendering anomalously high speed values, and a bias in direction. The extra current meter covered also this depth.

The thermistor sensor at 150 m depth was damaged during deployment and was not replaced, in agreement with Company. The thermistor sensor at 10 m depth was damaged during the 17th of September 2011. This sensor was replaced with an RBR temperature logger on the 13th of October 2011. In early 2012, the pressure sensor at 40 m and the 40 m thermistor failed, and was replaced by a separate temperature logger (June 2012).

2.7 Data quality control and data return

Besides the continuous numeric data quality control, a special attention was put on the possible effects on ship traffic, especially from ships (and assisting tugs) arriving at or departing from the nearby Quay 14 or the BOH jetty.

In addition, the impact from wind was studied, although this was not part of the data control as such, but a means to try explain certain high current values.

The analysis done for 2011 data collected during times of ship operations, showed that the traffic did not seem to influence the current measurements. Figure 8 shows a comparison of the current speed near the arrival (departure) time and the period before and after arrival (departure). There was no clear pattern of neither stronger nor weaker current speed imposed by the ship traffic.

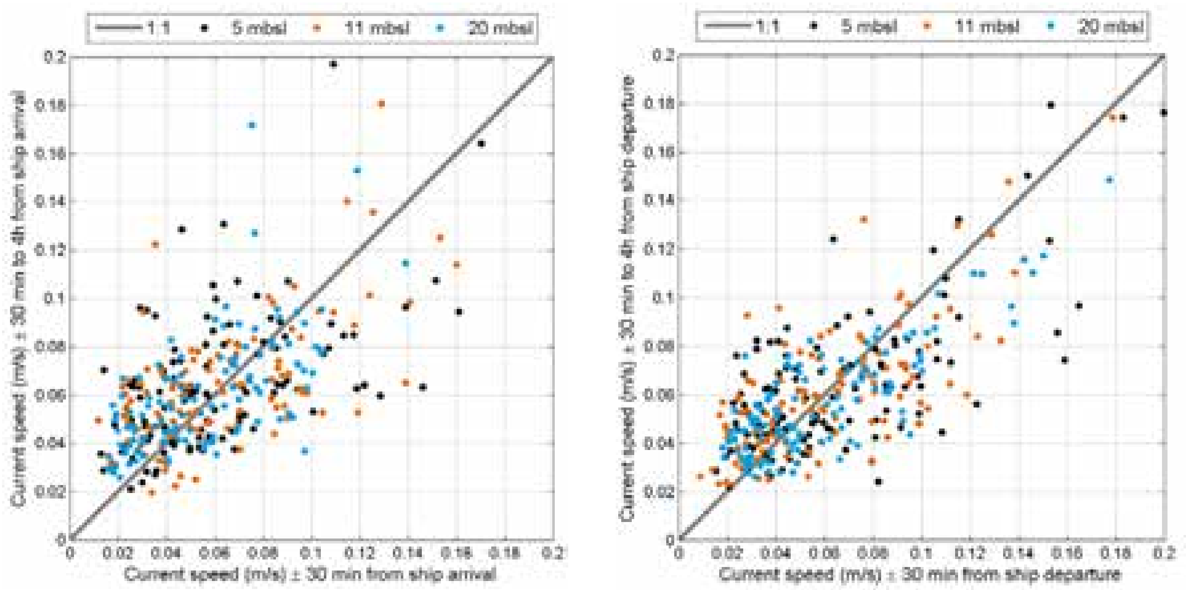

Figure 8. Comparison of current speed near ship arrival (left panel) and ship departure (right panel) and current speed in the 4 hour period before and after the arrival/departure. The different colours indicate different measurement depths.

Five events from 2011 where the measured current speeds were above 0,3 m/s were inspected to check if the values are likely to be real (e.g. impact by wind) or not. High current speed events tended to coincide with periods of high wind speed registered at the meteorological observation site at Fedje (source: www.eklima.no). The events were also characterized by similar behaviour in several of the measurement depth levels, and higher speeds in upper than in lower levels. Episodes with current speeds above 0,3 m/s were recorded from the surface to 11 m depth.

The total data return was for most measuring depths around 95% or better, see Table 3.

Table 3. Statistics for 2012, with number of measurements and the data return. Figures for 2011 and 2013 were similar, see the Annual reports. Return for the 40 and 50 m current cells were improved after deploying the extra current meter. Mbsl means meters below sea level.

	Depth (mbsl)	Minimum (°)	Mean (°)	Maximum (°)	Standard deviation (°)	Number of datapoints	Data return (%)
Temperature	2m	2.97	8.38	16.80	2.35	190042	97.79
	10 m	7.27	10.49	16.40	1.91	169716	87.33
	20 m	6.09	10.34	16.60	2.11	192304	98.96
	30 m	6.15	10.19	15.44	1.90	191575	98.58
	40 m	5.00	-4.98	9.34	0.56	194324	100.00
	50 m	6.61	10.37	17.73	1.48	191029	98.30
	75 m	6.52	9.04	11.12	0.78	190931	98.25
	100 m	6.85	8.35	10.24	0.44	191618	98.60
	125 m	7.70	8.07	9.91	0.29	191453	98.52
Current speed	**Depth (mbsl)**	**Minimum (m/s)**	**Mean (m/s)**	**Maximum (m/s)**	**Standard deviation (m/s)**	**Number of datapoints**	**Data return (%)**
	5 m	0.0001	0.0578	0.4115	0.0425	52790	94.69
	7 m	0.0002	0.0573	0.3679	0.0414	52790	94.69
	9 m	0.0002	0.0571	0.3780	0.0402	52790	94.69
	11 m	0.0001	0.0565	0.3733	0.0398	52790	94.69
	14 m	0.0001	0.0553	0.3483	0.0391	52790	94.69
	16 m	0.0002	0.0537	0.2975	0.0380	52790	94.69
	18 m	0.0001	0.0516	0.3278	0.0367	52790	94.69
	20 m	0.0002	0.0832	1.3548	0.0949	52790	94.69
	29 m	0.0000	0.0399	0.2580	0.0264	55753	100.00
	34 m	0.0000	0.0399	0.2850	0.0271	55753	100.00
	40 m	0.0000	0.0424	0.2490	0.0305	36891	66.17

3. Current meter data

Current measurements were reported by depth cell, from 5 m and to 50 m depth in the monthly and annual reports. From the several hundred monthly plots we present an example from January 2012 in Figure 9, from 5 m and 29 m depth. Current speed generally remained below 25 cm/s, and the direction varied between NW and SE. The pattern, as shown, prevailed at most depths and during most months, as seen in the statistics in Appendix 1. The average current speed at 5 m depth is about 6 cm/s for the 2011, 2012 and 2013 data, while at 40 m the average current speed is about 4 cm/s for 2011 and 2012 data. At 20 m depth in 2013 the average current speed was between 31 and 9 cm/s from January to May, at 40 m depth between 8 and 13 cm/s and at 50 m depth between 6 and 5 cm/s in the same period. The high speeds at 20 m seem suspicious, particularly since these are average values and similar values are not seen in the data from 2011 and 2012 from the same depths.

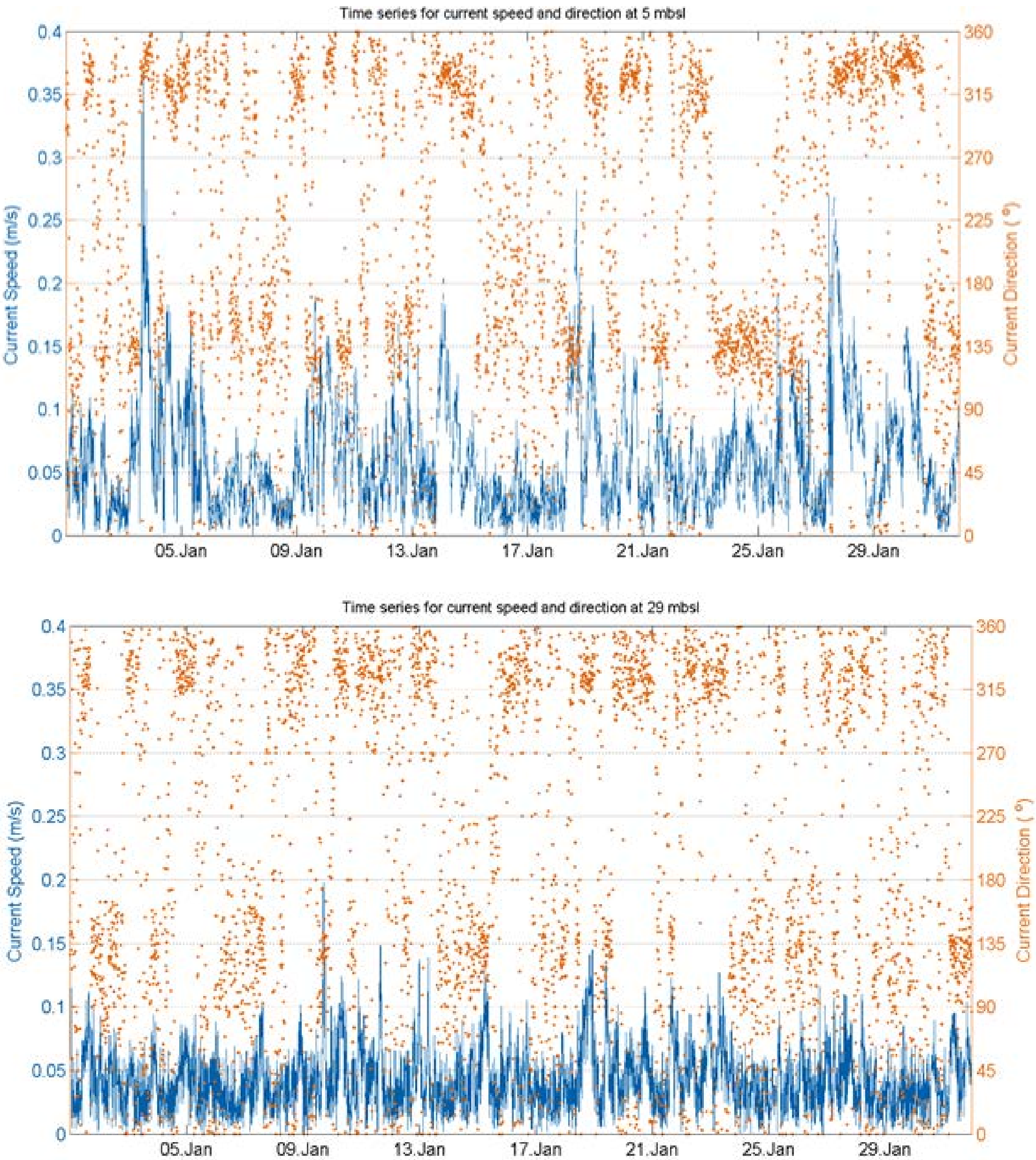

Figure 9. Measured current speed (blue line) and current direction in January 2012, at 5 m and 29 m depth.

In Figure 10 the current roses for depths 5 m and 29 m for each of the three years are presented. The directional distribution along the NW-SE axis, as also shown in Figure 9, is evident.

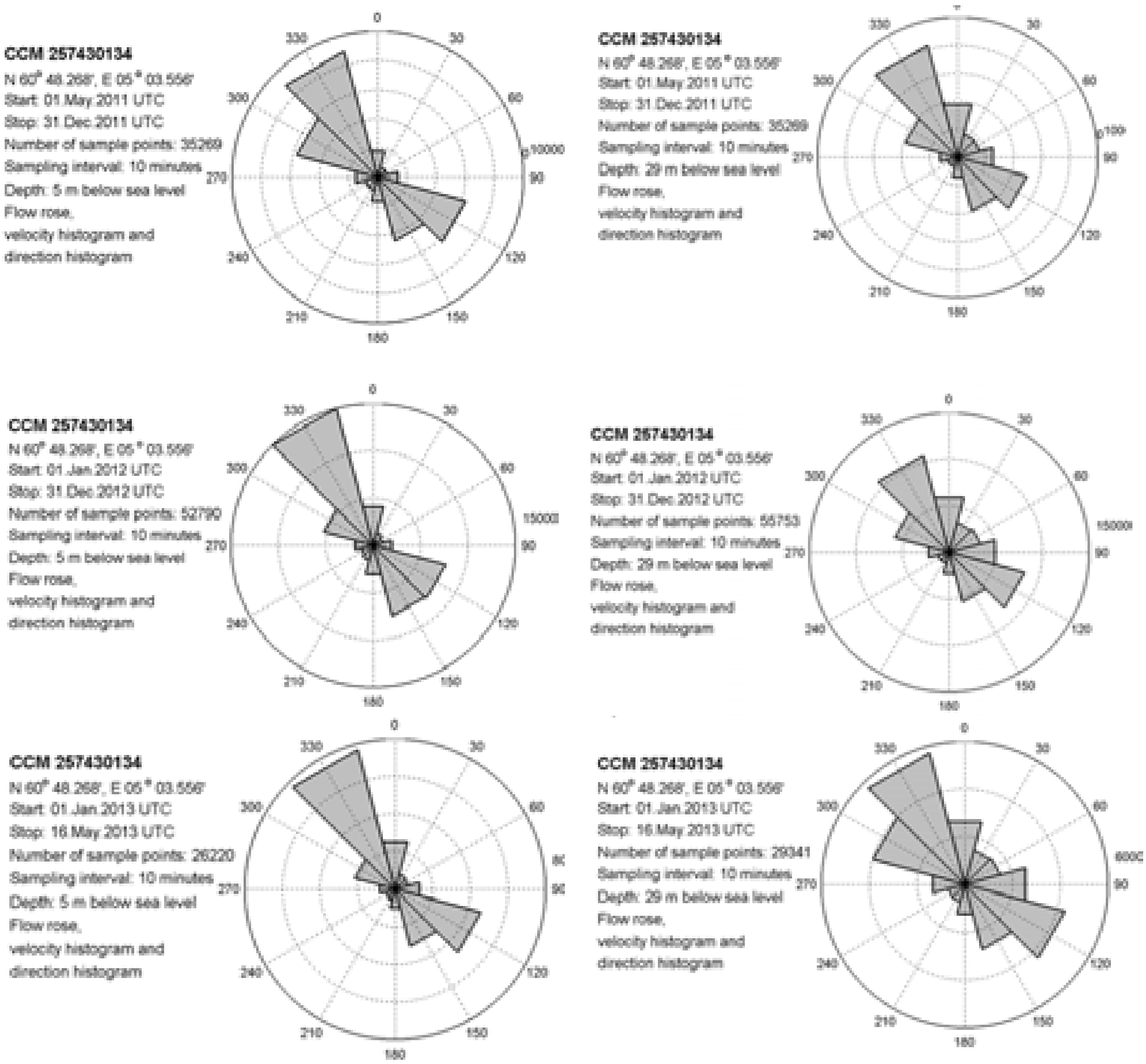

Figure 10. Current roses for 5 m and 29 m depth, in 2011, 2012 and 2013.

Contoured current speed is shown in Figure 11, based on monthly averaged speed for each depth cell. The decay of speed with depth is evident. Intermittently the cell at 20 m depth recorded high speed values, (> 50 cm/s), that probably was due to some obstruction in the water, e.g. a rope or cable. We kept these data plotted, while still storing the 20 m data from the extra current meter (after June 2012) for future reference and use. Plotting contours of averaged direction seemed to have no scientific value.

The increase of speed seen around October 2011 can also be seen in the contour plot for 2012 but here already in September. When comparing the current speed increase with the wind speed from the weather station at Fedje shown in Figure 12, the current speed increase is in good correspondence with the wind speed increase seen here. The highest wind speed in the period May to December 2011 can be seen in October 2011, while in 2012 the wind speed is increasing already in September, with highest speed in November 2012.

The current speed is for the highest speed cases, between 0.6 and 0.8 % of the wind speed in the 5 to 15 m layer. A rule of thumb says that the wind generated surface current speed will be about 3 % of the wind speed, and in general the current speed decreases with depth due to friction between the adjacent layers.

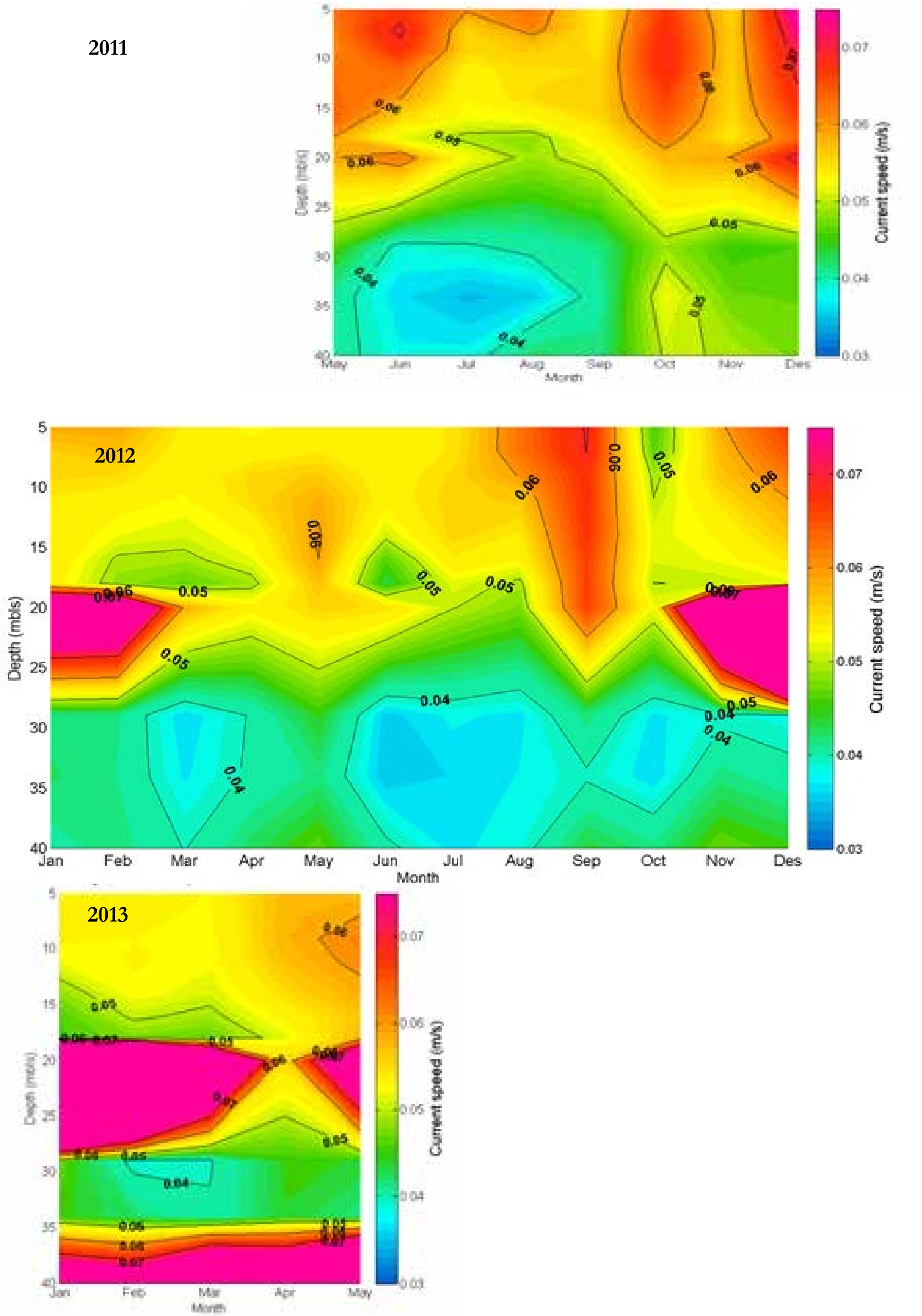

Figure 11. Hov-Möller plots of current speed for 2011, 2012 and 2013.

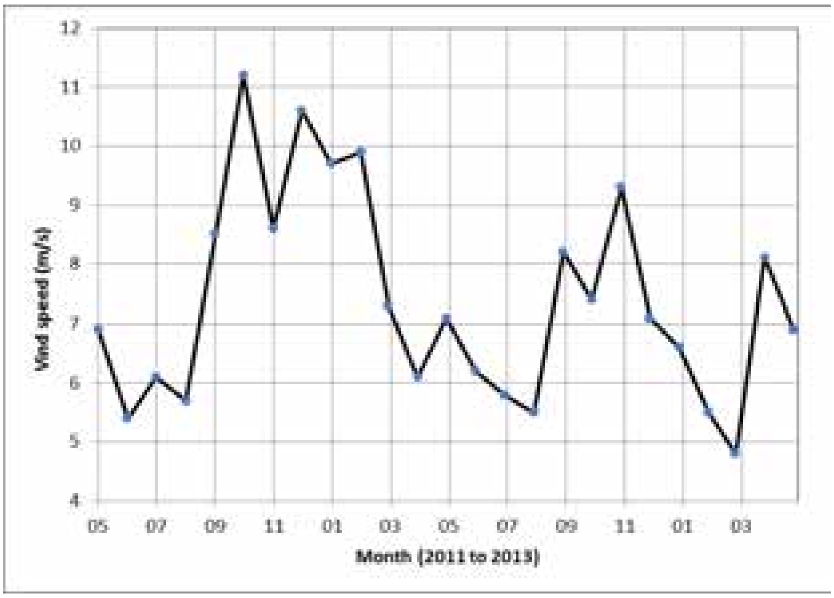

Figure 12. Monthly averaged wind speed from the weather station at Fedje in the period May 2011 to May 2013.

4. Thermistor chain data

Data from the thermistor chain gave time series at each of the measurement depths, except where there were sensor failures (see Chapter 2). Figure 13 shows plots of the time series for 2012, documenting the both the seasonal cycles and the decay of the amplitude with depth.

Statistics are found in Appendix B and in Table 2. The Box plots in Figure 14 shows Box statistics at 50 m and 100 m depth, plotted per month. **Figure 15** presents the contoured data, based on monthly averages for each depth.

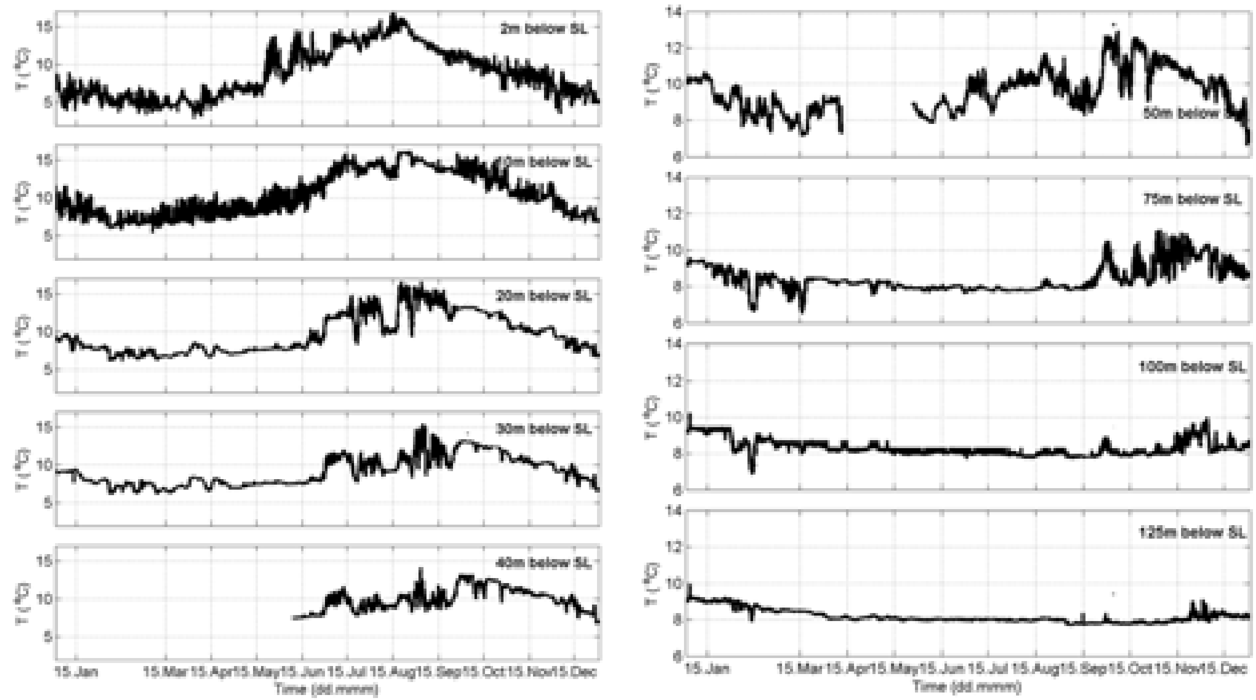

Figure 13. Time series of measured temperatures by the thermistor chain in 2012.

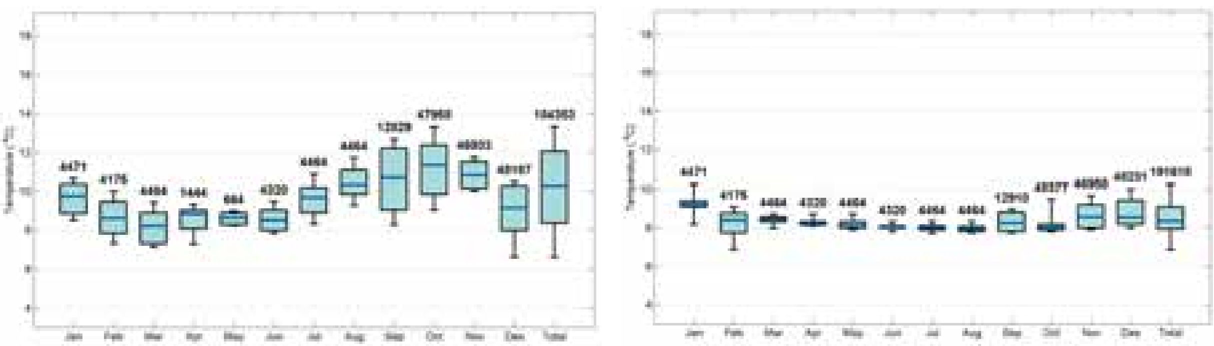

Figure 14. Box plots showing general statistics of the data per month in 2012 and for the total time series at 50 m (left) and 100 m (right) depth. The blue line indicates the mean temperature; the shaded box gives the range from the 10- and 90-percentiles. The thin black lines indicate the range from the minimum to the maximum registered temperature. The numbers of good data points per month is given above each box.

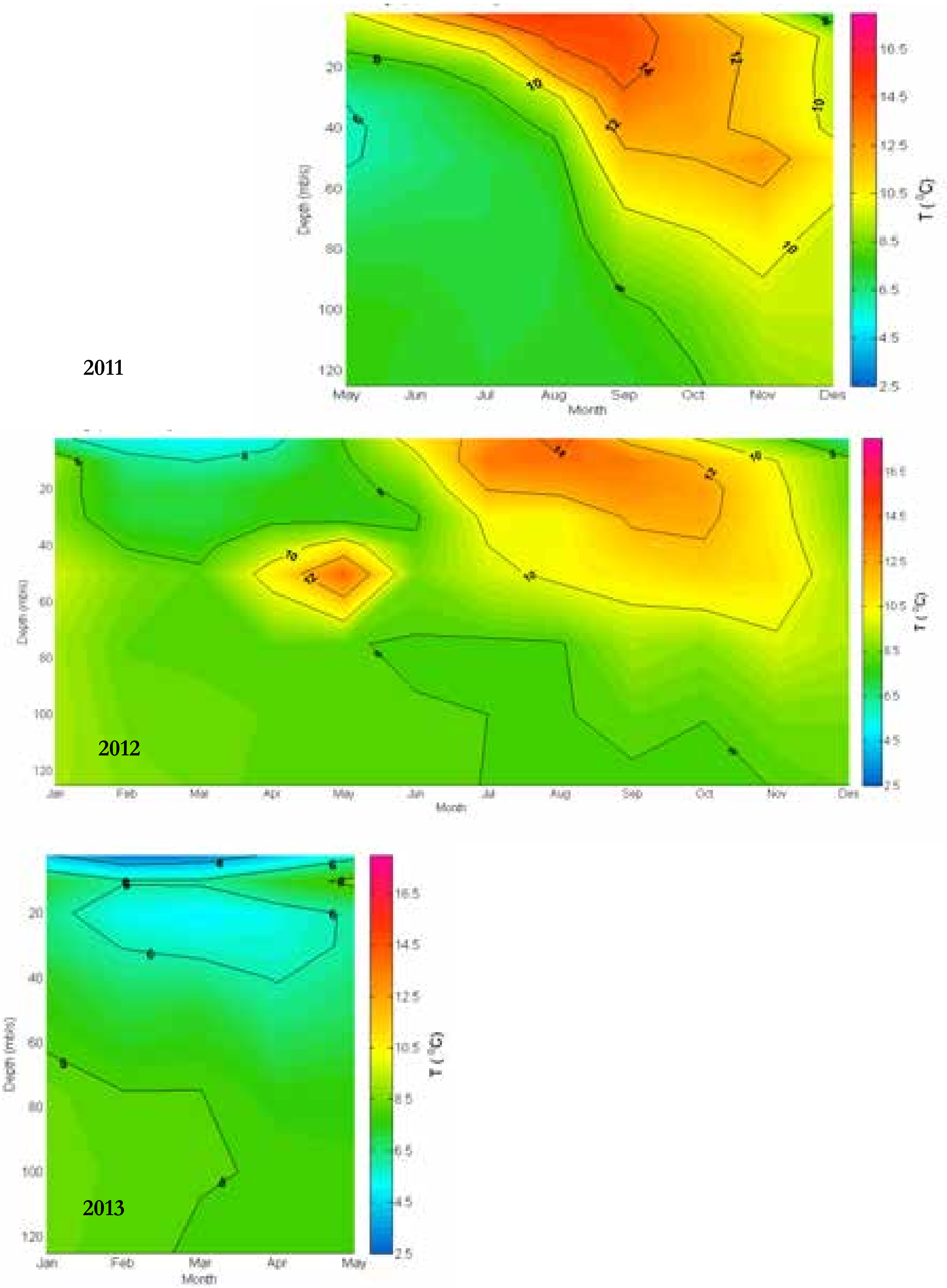

Figure 15. Contour plots of sea temperature as measured by the thermistor chain, May 2011 – May 2013.

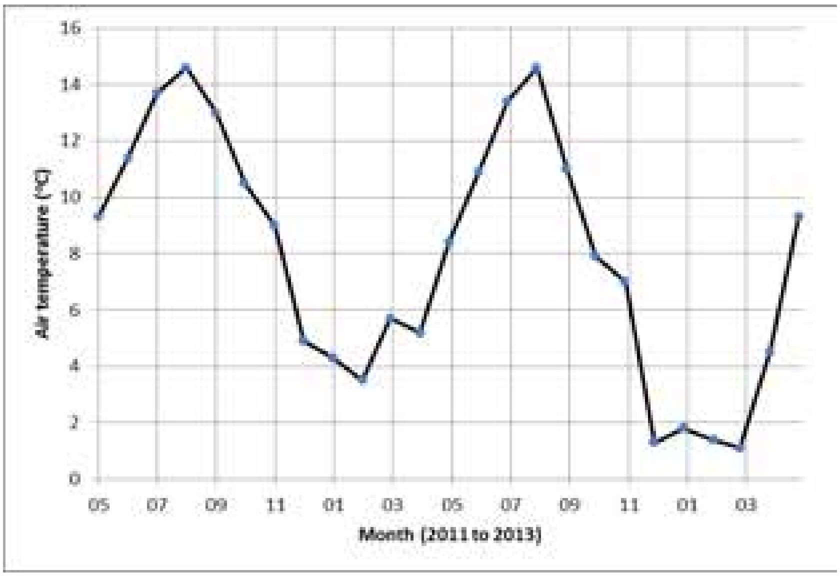

Figure 16. Monthly averaged air temperature from the weather station at Fedje in the period May 2011 to May 2013.

The monthly average of air temperature from the Fedje weather station seen in Figure 16 clearly shows the seasonal variation in air temperature. This is also very evident in the contour plots of sea temperature measured by the thermistor chain. During spring and summer the sea temperature increases with a maximum in August-September in the surface layer. This maximum penetrates deeper into the water column during autumn with a maximum temperature around 70 m in November, while the surface temperature decreases.

5. Hydrographic data from profiles

The data collected by the lowered STD profiles constitute an important material for evaluation of the characteristics of the fjord water and changes over time, and for use in technical and numerical studies.

We present below the individual 14 profiles from 2012, the only full calendar year in the series. The seasonal cycle is revealed in the upper layers, with only small variations at 150 m depth. The division between upper and lower layer was around 30-40 m deth, slightly varying with time.

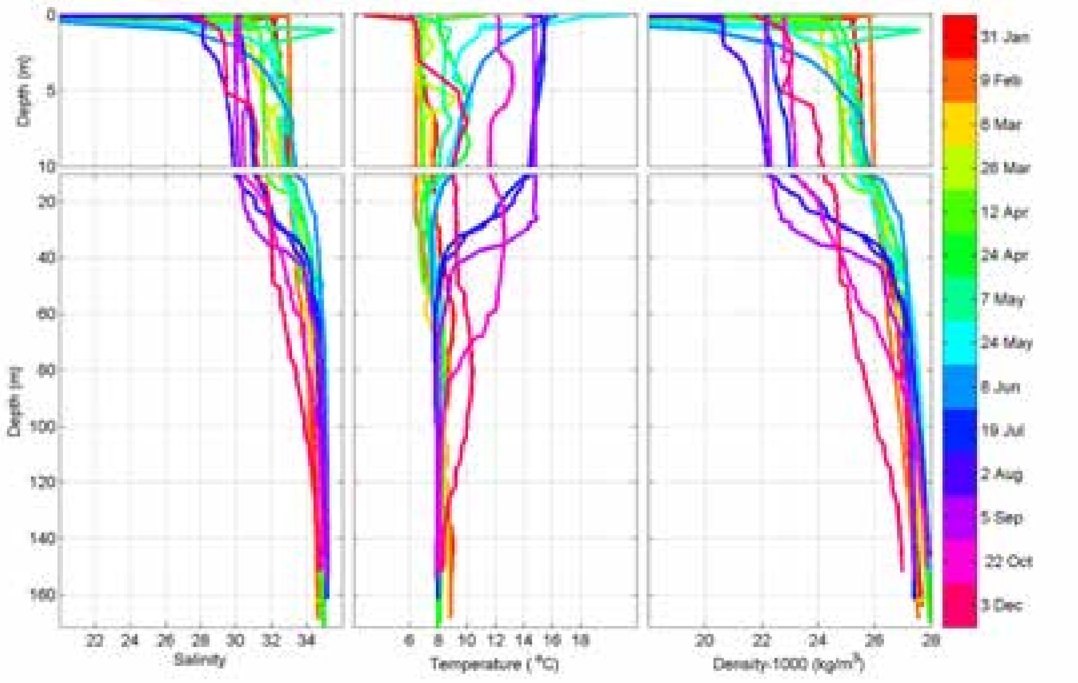

Figure 17. Vertical profiles of salinity (left panel), temperature (center panel) and density (right panel) at Mongstad for all measurements throughout 2012. Note the break in X-axis (depth) scale at 10 m.

The following three pages contain Hov-Möller contour plots of the full data series, for temperature, salinity and density.

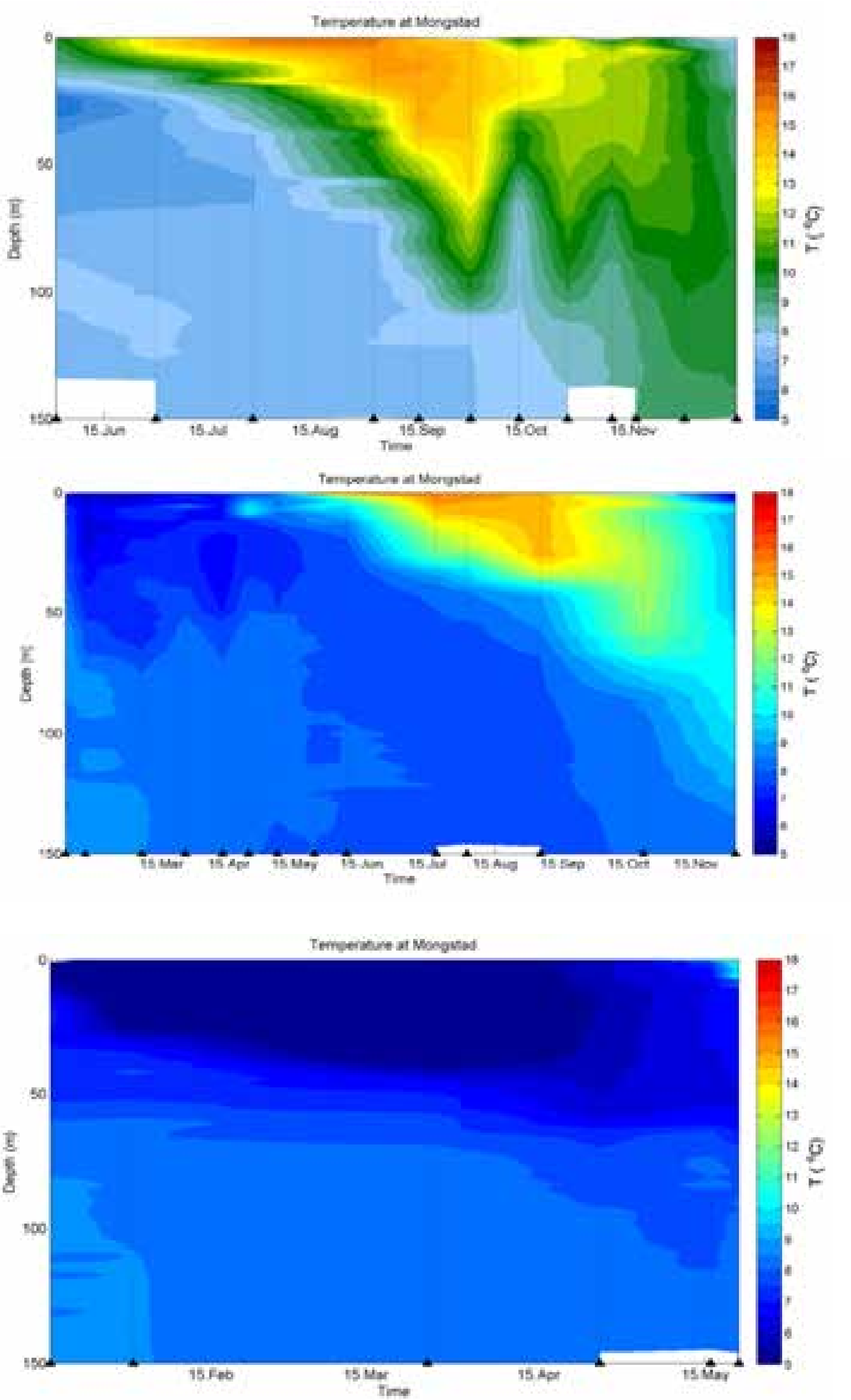

Figure 18. Hov Möller contour plots of measured temperature at Mongstad from the profiles, in 2011 (upper panel), 2012 (mid) and 2013. The black triangles indicate the measurement dates.

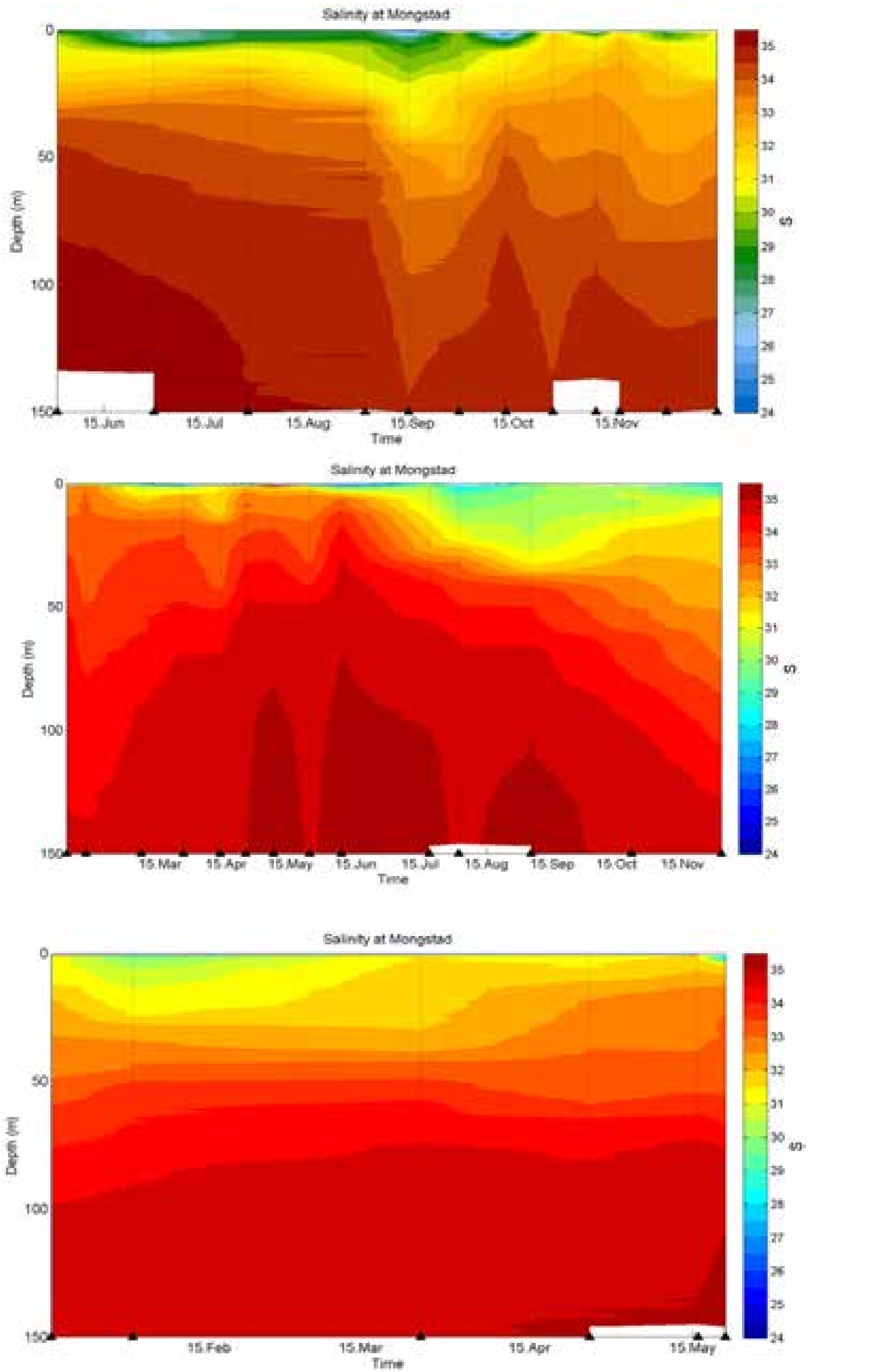

Figure 19. Measured salinity 2011-2013, as Hov-Möller plots.

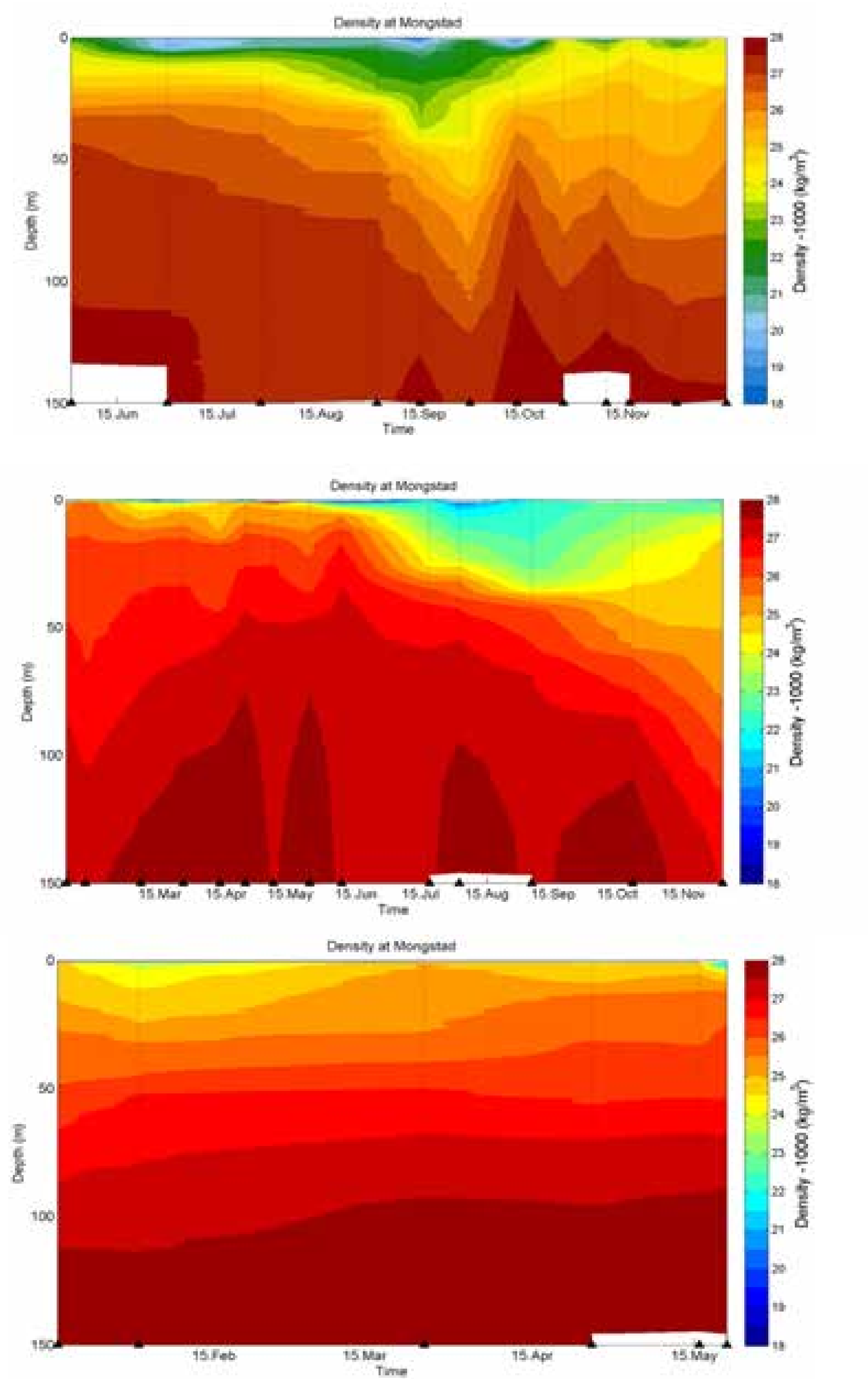

Figure 20. Hov-Möller contour plot of calculated seawater density (sigma-t) from profiles at Mongstad in 2011 (upper panel), 2012 (mid) and 2013. The black triangles indicate the measurement dates.

6. Summary and discussion

6.1 Previous studies and monitoring at Mongstad

The Fensfjord was never subject to a fully integrated oceanographic study. Only recently have there been discussions about conducting such work, as the fjord receives effluents from misc. industrial plants and seafarms and many of the fresh water sources (rivers, streams) have been regulated for hydropower purposes. In the inner extension, the Masfjord, several studies has been performed, as there is a large hydropower discharge and an aquaculture research station. See e.g. Kaartvedt et al. (1988).

6.1.1 Hydrographic data

In connection with the establishment of the refinery at Mongstad, a measurements program was carried out in Fensfjorden in 1971-72. During this campaign, undertaken by the Geophysical Institute, University of Bergen, hydrographic measurements were made on a monthly basis through a one-year period (Gade 1973). Measurement depths were surface, 5, 10, 20, 30 and 40 m. Current measurements near the fjord sill, north-west of Mongstad, were also made as part of this programme. The vertical resolution of the 1971-72 hydrographic data series is rather coarse.

Figure 21 shows contour plots of the data from 1972. It appears to have been only moderate stratification in the area, but with a low-salinity upper layer during the months April-June. The surface values for salinity were around 30, and above 34 at 50 m depth. Temperatures ranged from 13-14 °C during summer at the surface to 7-8 °C during winter in the whole water column, and in the deeper layers throughout the year.

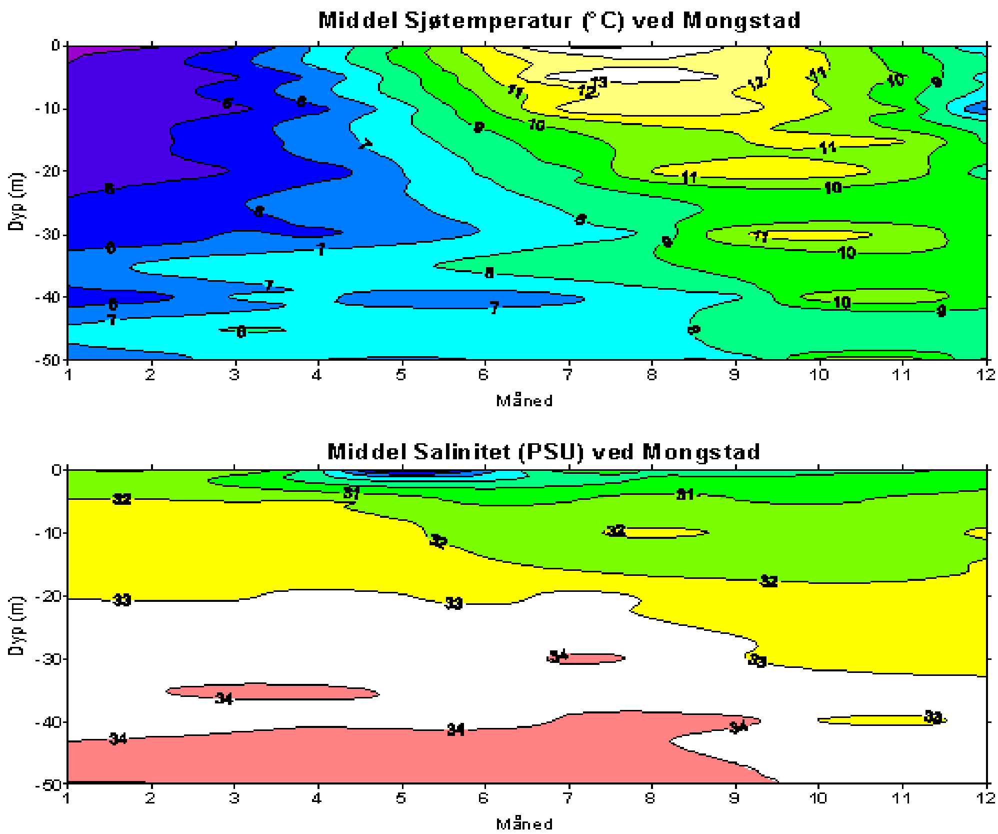

Figure 21. Annual cycle of sea temperature and salinity near Mongstad from surface to 50 m depth based on measurements in 1972. Data from UoBergen (Gade 1973), figure from Golmen and Nygaard, 2006.

To our knowledge, only sporadic measurements were made near Mongstad between 1972 and 2005. Some new data were collected around 1980, in connection with oil spill contingency plans (Aure et al. 1979, 1982). 25 years later NIVA made measurements of dilution and spreading of the cooling water discharge at Mongstad (Golmen and Nygaard 2006). This study comprised measurements of currents and hydrography, and first and foremost a tracer release experiment where the spatial distribution of the discharge was tracked in time.

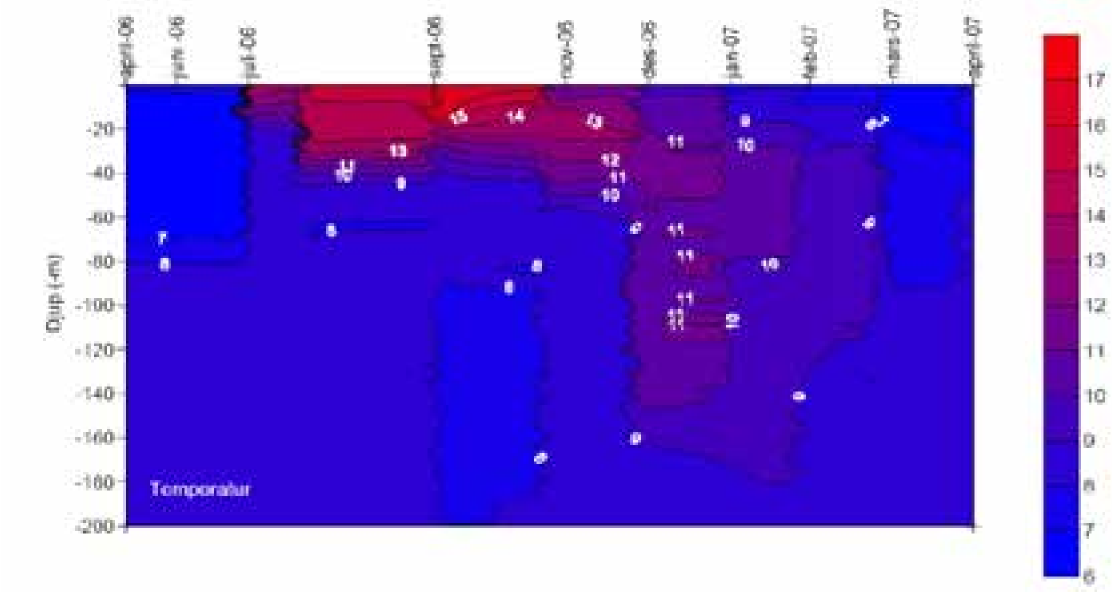

Figure 22. Temperature data measured in 2006, off Monstad Sør. From Skarðhamar et al, 2007.

In 2007, 2008 and 2010, NIVA carried out a field programme for hydrography and nutrients (Skarðhamar et al. 2007, Golmen et al. 2008, Golmen and Lundmark 2010). These projects also comprised tracer release experiments for both the cooling water discharge and the process water discharge. These recent studies showed, both through visual observations, hydrographic measurements, and tracer release experiments, that the existing cooling water does reach the surface at times. This appears to occur during the least stratified part of the year – winter and early spring, and indicates that the discharge should not receive additional used cooling water from the CCM/CCP plant.

In the period April 2006 to April 2007, 10 semi-monthly vertical profiles of salinity and temperature were measured near the cooling water discharge at Mongstad (Skarðhamar et al. 2007). This programme was carried out by NIVA and Akvaplan-niva, on behalf of Mongstad Vekst AS. Figure 20 shows a plot of sea temperatures in 2006, down to 200 m depth.

6.1.2 Current data

As part of the project for Mongstad Vekst AS, one month (16. June to 14. July 2006) of current data was collected, using an acoustic Doppler current meter which measures a vertical profile of data (Skarðhamar et al. 2007). The currents were primarily directed parallel with the shoreline, changing direction with the tides.

NIVA conducted current measurements by an ADCP at the process water discharge (ca. 2 km NW of the present location) during October-December 2003 (Golmen and Nygaard 2003). The results showed an average speed of ca. 10 cm/s in the upper layers and 6 cm/s at 45 m depth. Dominating direction was towards west in the upper layers, and more fluctuating between SW and NE in the deeper layers.

SINTEF performed current measurements in that same area during March-August 2005 (Eidnes 2005). Average speed was around 20-27 cm/s in the upper layers, 13-15 cm/s at 35-45 m depth and 10 cm/s at 70 m depth. Dominating direction was towards SE in upper layers, and towards NE in deeper layers, i.e. direction into the fjord.

6.2 Comments and brief comparison between data sets

The older current data seem to be too sparse or dis-located geographically, relative to the new data set, to make any ideal basis for comparison. However, the prevailing flow along the bathymetry is seen in all data. Dominating direction towards NW (out fjord) in the new data set, is supported by some older data, and contradicted by others.

Current speeds were moderate in the new data set, although there were episodes of comparatively high current speed, between 0.3 and 0.4 m/s (disregarding the occasions with even higher speed at 20 m depth). Events with strong wind seemed to affect the current speed down to at least 11 m depth, coinciding with stronger currents than normal.

It was noted that no long periods of stagnation were recorded at any depth in the present project, and this seems to be in line with previous measurements.

The temperature and salinity data indicate some freshening of the upper layers compared to 40 years ago, and also significant warming down to 40- 50 m depth during summer and autumn.

7. Literature

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Gade, H. G. 1973. Oseanografiske observasjoner i Fensfjorden 1972. Rapport til Norsk Hydro; Geofysisk Institutt, Universitetet i Bergen. 20 sider.

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Golmen, L.G. og K. L. Daae 2010: Mongstad raffineri: Marine undersøkelser 2010. Sluttrapport. Rapp. NIVA-Vest, 26 s.

Kaartvedt, S., D. Aksnes og A. Aadnesen 1988: Winter distribution of macroplankton and micronekton in Masfjorden, western Norway. Mar. Ecol. Progr. Ser. Vol 45, s 45-55.

Skarðhamar, J., L. G. Golmen og L. O. Sparboe, 2007. Vurdering av resipientforholdene utenfor Mongstad havbrukspark. Akvaplan-niva-rapport nr. APN- 412.3627.2.

Appendix A. Current statistics

2011 current statistics

Month	Depth (mbsl)					
	Parameter (m/s)	5	11	20	29	40
May	Mean	0.0627	0.0623	0.0597	0.0463	0.0412
	Minimum	0.0006	0.0007	0.0000	0.0000	0.0000
	Maximum	0.2789	0.2777	0.2622	0.2370	0.1910
	St. deviation	0.0443	0.0468	0.0427	0.0306	0.0248
June	Mean	0.0677	0.0635	0.0624	0.0390	0.0383
	Minimum	0.0001	0.0009	0.0011	0.0000	0.0000
	Maximum	0.3701	0.3303	0.2464	0.2040	0.1580
	St. deviation	0.0486	0.0445	0.0394	0.0267	0.0230
July	Mean	0.0606	0.0543	0.0524	0.0396	0.0384
	Minimum	0.0006	0.0002	0.0010	0.0000	0.0010
	Maximum	0.2586	0.2558	0.2830	0.1890	0.1960
	St. deviation	0.0408	0.0387	0.0356	0.0245	0.0236
August	Mean	0.0627	0.0559	0.0491	0.0408	0.0434
	Minimum	0.0004	0.0010	0.0000	0.0000	0.0000
	Maximum	0.2732	0.2677	0.3116	0.1820	0.1890
	St. deviation	0.0426	0.0388	0.0338	0.0258	0.0268
September	Mean	0.0543	0.0560	0.0516	0.0423	0.0426
	Minimum	0.0004	0.0004	0.0010	0.0000	0.0000
	Maximum	0.2403	0.2519	0.2690	0.2930	0.1890
	St. deviation	0.0353	0.0385	0.0362	0.0293	0.0274
October	Mean	0.0674	0.0691	0.0587	0.0489	0.0504
	Minimum	0.0009	0.0015	0.0008	0.0000	0.0000
	Maximum	0.3372	0.3016	0.3287	0.2100	0.2460
	St. deviation	0.0480	0.0493	0.0414	0.0332	0.0348
November	Mean	0.0559	0.0566	0.0601	0.0453	0.0497
	Minimum	0.0000	0.0009	0.0017	0.0000	0.0000
	Maximum	0.3293	0.3111	0.2304	0.2020	0.2350
	St. deviation	0.0443	0.0410	0.0363	0.0307	0.0350
December	Mean	0.0775	0.0711	0.0719	0.0460	0.0476
	Minimum	0.0008	0.0005	0.0007	0.0000	0.0000
	Maximum	0.3961	0.4298	0.3410	0.2310	0.2470
	St. deviation	0.0583	0.0521	0.0456	0.0297	0.0324
Total	Mean	0.0636	0.0611	0.0582	0.0435	0.0441
	Minimum	0.0000	0.0002	0.0000	0.0000	0.0000
	Maximum	0.3961	0.4298	0.3410	0.2930	0.2470
	St. deviation	0.0462	0.0444	0.0397	0.0291	0.0293

2012 current statistics

Month	Depth (mbsl)					
	Parameter (m/s)	5	11	20	29	40
January	Mean	0.0595	0.0549	0.0943	0.0424	0.0414
	Min	0.0004	0.0002	0.0004	0.0000	0.0010
	Max	0.3673	0.2661	0.4685	0.1980	0.1830
	std	0.0440	0.0387	0.0565	0.0247	0.0258
February	Mean	0.0599	0.0539	0.0930	0.0421	0.0426
	Min	0.0008	0.0001	0.0010	0.0000	0.0000
	Max	0.2819	0.2442	0.6126	0.2580	0.2470
	std	0.0418	0.0355	0.0704	0.0303	0.0330
March	Mean	0.0545	0.0528	0.0590	0.0371	0.0399
	Min	0.0007	0.0006	0.0015	0.0000	0.0000
	Max	0.3819	0.2588	0.4083	0.1880	0.2190
	std	0.0418	0.0380	0.0542	0.0236	0.0273
April	Mean	0.0525	0.0561	0.0535	0.0403	0.0435
	Min	0.0003	0.0009	0.0005	0.0000	0.0000
	Max	0.3003	0.2242	0.2178	0.1800	0.2110
	std	0.0380	0.0367	0.0362	0.0251	0.0283
May	Mean	0.0542	0.0592	0.0564	0.0452	0.0467
	Min	0.0008	0.0007	0.0003	0.0010	0.0000
	Max	0.3298	0.3733	0.2776	0.2190	0.2470
	std	0.0422	0.0416	0.0347	0.0330	0.0357
June	Mean	0.0548	0.0539	0.0557	0.0365	0.0407
	Min	0.0008	0.0009	0.0012	0.0000	0.0000
	Max	0.2215	0.1960	0.2514	0.1470	0.2130
	std	0.0390	0.0337	0.0387	0.0222	0.0261
July	Mean	0.0550	0.0565	0.0501	0.0383	0.0376
	Min	0.0007	0.0003	0.0002	0.0000	0.0000
	Max	0.2509	0.2352	0.1933	0.1640	0.2490
	std	0.0385	0.0370	0.0307	0.0249	0.0279
August	Mean	0.0624	0.0573	0.0478	0.0376	0.0389
	Min	0.0006	0.0004	0.0004	0.0000	0.0000
	Max	0.3235	0.3202	0.2711	0.1720	0.2260
	std	0.0472	0.0413	0.0354	0.0241	0.0284
September	Mean	0.0704	0.0679	0.0665	0.0427	0.0445
	Min	0.0010	0.0001	0.0008	0.0000	0.0000
	Max	0.3345	0.3524	0.2933	0.2460	0.2210
	std	0.0518	0.0543	0.0476	0.0315	0.0333
October	Mean	0.0456	0.0500	0.0520	0.0377	0.0424
	Min	0.0001	0.0001	0.0005	0.0000	0.0010
	Max	0.2629	0.2030	0.1977	0.1540	0.2320
	std	0.0306	0.0339	0.0310	0.0241	0.0317
November	Mean	0.0595	0.0556	0.1095	0.0393	0.0470
	Min	0.0005	0.0007	0.0008	0.0000	0.0000
	Max	0.4115	0.3286	0.7690	0.1920	0.2410
	std	0.0430	0.0401	0.0878	0.0271	0.0361
December	Mean	0.0663	0.0599	0.2636	0.0385	0.0453
	Min	0.0010	0.0007	0.0016	0.0000	0.0010
	Max	0.2697	0.2450	1.3548	0.1830	0.2410
	std	0.0437	0.0411	0.1985	0.0236	0.0311
Total	Mean	0.0578	0.0565	0.0832	0.0399	0.0424
	Min	0.0001	0.0001	0.0002	0.0000	0.0000
	Max	0.4115	0.3733	1.3548	0.2580	0.2490
	std	0.0425	0.0398	0.0949	0.0264	0.0305

2013 current statistics

Month		Depth (mbsl)					
	Parameter (m/s)	5	11	20	29	40	50
January	Mean	0.0549	0.0522	0.3153	0.0469	0.0889	0.0600
	Min	0.0008	0.0004	0.0073	0.0000	0.0028	0.0040
	Max	0.3018	0.2454	1.5195	0.1950	0.3611	0.3286
	std	0.0434	0.0405	0.2218	0.0292	0.0551	0.0373
February	Mean	0.0545	0.0532	0.2136	0.0389	0.0835	0.0831
	Min	0.0002	0.0005	0.0020	0.0000	0.0030	0.0054
	Max	0.2484	0.1795	0.8697	0.1990	0.4201	0.4709
	std	0.0373	0.0326	0.1388	0.0238	0.0509	0.0545
March	Mean	0.0529	0.0524	0.1103	0.0397	0.1099	0.0973
	Min	0.0005	0.0008	0.0006	0.0000	0.0067	0.0041
	Max	0.2610	0.2290	0.6759	0.1500	0.4080	1.0576
	std	0.0380	0.0370	0.0994	0.0228	0.0636	0.0832
April	Mean	0.0584	0.0581	0.0560	0.0453	0.1018	0.0499
	Min	0.0003	0.0002	0.0004	0.0000	0.0022	0.0022
	Max	0.3568	0.3348	0.2664	0.1680	0.6014	0.2028
	std	0.0426	0.0420	0.0334	0.0302	0.0687	0.0286
May	Mean	0.0587	0.0608	0.0956	0.0449	0.1390	0.0525
	Min	0.0012	0.0016	0.0003	0.0010	0.0120	0.0014
	Max	0.1991	0.1990	0.2953	0.2030	0.3507	0.1690
	std	0.0396	0.0416	0.0499	0.0332	0.0679	0.0287
	std	0.0516	0.0538	0.0474	0.0311	0.0327	0.0253

Appendix B. Temperature statistics

Monthly temperature statistics from the thermistor chain data at different depths, 2012.

Month	Parameter (°C)	Depth (mbsl)								
		2	10	20	30	40	50	75	100	125
January	Mean	6.20	8.36	8.50	8.57	NaN	9.74	9.09	9.22	9.08
	Minimum	3.94	6.53	7.41	7.53	NaN	8.51	8.00	8.18	8.51
	Maximum	8.99	11.60	9.83	9.45	NaN	10.66	9.58	10.24	9.91
	st.deviation	0.93	1.01	0.65	0.64	NaN	0.63	0.32	0.18	0.09
February	Mean	5.33	6.85	7.09	7.22	NaN	8.60	8.22	8.40	8.67
	Minimum	3.57	5.85	6.09	6.15	NaN	7.32	6.61	6.85	7.89
	Maximum	7.34	8.92	8.26	8.30	NaN	9.99	9.00	9.09	9.09
	st.deviation	0.69	0.48	0.53	0.55	NaN	0.60	0.61	0.46	0.19
March	Minimum	4.91	7.30	7.03	7.04	NaN	8.20	8.06	8.45	8.43
	Maximum	3.38	5.38	6.28	6.20	NaN	7.13	6.52	7.99	8.13
	Max	6.78	10.04	7.88	8.35	NaN	9.41	8.52	8.71	8.61
	st.deviation	0.56	0.74	0.32	0.43	NaN	0.53	0.45	0.11	0.09
April	Mean	5.48	8.11	7.58	7.68	NaN	8.82	8.24	8.21	8.09
	Minimum	2.97	6.29	6.65	6.58	NaN	7.27	7.52	8.09	7.94
	Maximum	7.77	10.85	8.59	8.44	NaN	9.32	8.43	8.71	8.27
	st.deviation	0.96	0.80	0.53	0.55	NaN	0.42	0.10	0.08	0.06
May	Mean	8.07	8.71	7.58	7.46	NaN	8.61	8.04	8.14	8.07
	Minimum	5.70	7.35	7.08	6.91	NaN	8.22	7.57	7.90	7.89
	Maximum	13.78	11.96	8.54	8.01	NaN	8.98	8.38	8.71	8.27
	st.deviation	1.91	0.81	0.24	0.25	NaN	0.24	0.16	0.13	0.07
June	Mean	10.65	10.40	8.46	7.84	7.79	8.51	7.92	8.04	8.01
	Minimum	7.39	7.89	7.55	7.44	7.44	7.84	7.61	7.80	7.94
	Maximum	14.51	13.00	11.98	10.95	9.62	9.46	8.09	8.32	8.08
	st.deviation	1.42	1.06	0.83	0.43	0.31	0.40	0.10	0.06	0.04
July	Minimum	12.79	13.87	12.09	10.35	9.40	9.66	7.84	8.00	8.00
	Maximum	9.85	11.76	8.35	7.73	7.75	8.32	7.66	7.70	7.89
	Max	14.85	15.85	14.84	12.01	11.65	10.90	8.09	8.32	8.08
	st.deviation	1.01	0.82	1.05	1.07	0.86	0.48	0.08	0.07	0.04
August	Mean	14.51	14.62	12.49	10.17	9.55	10.34	7.91	7.93	7.99
	Minimum	13.06	12.45	9.30	8.35	8.20	9.27	7.71	7.75	7.89
	Maximum	16.80	16.16	16.55	14.75	12.40	11.72	8.47	8.32	8.13
	st.deviation	0.86	1.00	2.04	1.12	0.70	0.48	0.13	0.09	0.05
September	Mean	11.36	14.00	13.19	12.31	10.26	10.73	9.08	8.26	7.86
	Minimum	9.85	12.93	11.36	8.63	8.32	8.27	7.76	7.75	7.70
	Maximum	13.64	15.93	16.60	15.44	14.12	12.69	10.49	8.95	8.37
	st.deviation	0.70	0.54	0.65	1.00	1.26	1.24	0.79	0.35	0.09

Temperature statistics, 2012, continued

Month	Parameter (°C)	Depth (mbsl)								
		2	10	20	30	40	50	75	100	125
October	Mean	9.76	12.91	12.61	12.42	12.08	11.34	8.72	8.02	7.82
	Minimum	6.59	10.62	11.02	10.46	9.57	9.03	8.00	7.80	7.70
	Maximum	11.90	15.54	14.01	14.21	13.23	13.32	10.49	9.47	9.42
	st.deviation	1.01	1.03	0.51	0.52	0.74	0.96	0.52	0.12	0.05
November	Mean	8.33	10.26	10.34	10.43	10.80	10.84	9.80	8.55	8.02
	Minimum	5.33	9.33	9.49	9.50	10.18	9.99	8.19	7.90	7.75
	Maximum	10.80	12.66	11.36	11.53	11.78	11.77	11.12	9.67	9.04
	st.deviation	0.81	0.53	0.32	0.32	0.39	0.49	0.54	0.46	0.20
December	Mean	6.15	8.05	8.36	8.53	8.90	9.13	9.23	8.53	8.27
	Minimum	3.57	6.61	6.70	6.53	6.77	6.61	8.23	7.99	7.84
	Maximum	9.14	11.38	10.54	10.32	10.67	10.51	10.35	10.00	9.09
	st.deviation	1.04	0.82	0.82	0.82	0.91	0.98	0.54	0.44	0.15
Total	Mean	8.38	10.30	10.34	10.19	9.90	10.25	9.04	8.35	8.07
	Minimum	2.97	5.38	6.09	6.15	6.77	6.61	6.52	6.85	7.70
	Maximum	16.80	16.16	16.60	15.44	14.12	13.32	11.12	10.24	9.91
	st.deviation	2.35	2.85	2.11	1.90	1.48	1.31	0.78	0.44	0.29

2013 temperature statistics

Month	Parameter (°C)	Depth (mbsl)								
		2	10	20	30	40	50	75	100	125
January	Mean	4.10	7.21	6.39	6.68	7.49	7.64	8.33	8.38	8.32
	Minimum	1.22	4.18	3.21	3.32	5.12	5.25	6.61	7.51	8.04
	Maximum	8.71	10.73	8.26	8.87	9.17	8.98	9.00	8.71	8.56
	st.deviation	1.67	1.45	1.39	1.16	0.66	0.61	0.36	0.15	0.10
February	Mean	2.85	6.10	5.27	5.94	6.52	7.08	8.00	8.19	8.14
	Minimum	0.04	4.92	3.67	3.79	3.45	4.87	7.09	7.70	7.89
	Maximum	6.50	10.30	7.74	7.77	7.88	8.08	8.33	8.37	8.32
	st.deviation	1.07	0.92	1.01	1.11	0.86	0.71	0.22	0.08	0.09
March	Minimum	3.10	6.16	4.92	5.68	6.49	7.30	8.01	8.04	7.92
	Maximum	0.95	5.02	3.34	3.32	4.67	5.25	6.66	7.85	7.70
	Max	5.47	9.16	7.97	8.06	8.07	8.13	8.19	8.13	8.08
	st.deviation	0.71	0.79	1.26	1.71	1.17	0.79	0.20	0.05	0.07
April	Mean	4.24	7.33	5.39	5.56	5.94	6.35	7.60	8.11	7.94
	Minimum	1.96	5.53	3.76	4.97	4.97	4.97	5.95	7.51	7.56
	Maximum	6.54	9.92	5.95	6.72	7.04	7.65	8.04	17.14	16.65
	st.deviation	0.78	0.69	0.34	0.33	0.50	0.74	0.43	0.36	0.16
May	Mean	5.55	8.34	6.16	6.14	6.48	6.72	7.70	7.77	7.76
	Minimum	4.17	7.41	5.67	5.63	5.87	5.95	7.52	7.61	7.56
	Maximum	7.20	10.83	7.31	6.44	7.55	7.75	7.90	7.94	7.89
	st.deviation	0.65	0.62	0.15	0.13	0.19	0.40	0.06	0.09	0.06

Appendix C. Data files

```
[This is the contents of the README.txt file that follows
the data.]

The files are named as follows:

Datatype_Year_Variable

Where:
  Datatype = Current: data from the two current instruments: An
RDCP looking upwards, and Nortek looking downwards (both deployed 25 m
below sea level), suppplied with an Aquadopp looking upwards (deployed
about 55 m blsl)
  Datatype = Temperature: data from termistor chain (2-150 m),
supplied with separate temperature loggers (deployed at 10 and 40
m depth)

  Year = 2011, 2012 or 2013

  Variables:
    for Current:
      Speed
      Direction (0-360 degrees)
      U directional component of speed
      V directional component of speed
    for Temperature:
      rawdata = data from the thermistor chain
      interpolated = data from the thermistor chain, supplied
                     with data from loggers (adjusted for
                     systematic differences between the
                     instruments)

In all files:
  Column 1 = Time, as the number of days since 1.1.1950 at 00:00
                (i.e., following Matlab convention)
  Column 2 and up: variables for each depth
  Row 1 contains column names; the first column is named
    "Time" and subsequent columns are named according to depth
    (e.g. "5m", "7m", etc.)

The CTD data are in a separate folder called CTD. The data files are
named according to date and format. The files have one out of
three formats (depending on the instrument used), which has the
following variables:

TCM format:
  Ser Meas Sal Temp OxPerc OxMgL T Density Pressure Date Time
TCM2 format:
  Ser Meas Sal Temp T Density Pressure Date Time
TCM3 format:
  Ser Meas Sal Temp Ox OxMgL Density Pressure Date Time
```

```
TCM4 format:
  Ser Meas Sal Temp Density Pressure Date Time AMPM
Seabird format:
  Depth Pressure Temp Cond Sal Density Flag Nbin
```

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