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Validation of the Numerical Ocean Weather Prediction (NOWP) Model for the Oslofjord, Norway, operated by the Norwegian Meteorological Institute

Master thesis in Geosciences

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Preface and Aknowledgements

Eyvind Aas has been head supervisor for this thesis, and he has always been available with views, ideas and moral support. I owe him great thanks.

Thanks also to Lars Petter Røed at met.no, who often made me think twice about how to solve the task, and steered my thoughts in alternative directions.

None of this thesis work could have been done without a reliable steady vessel and its crew. My sincere thanks to the crew of R/V Trygve Braarud led by Sindre Holm. You all did a fantastic job. It is really a privilege to be working in the field and have such a vessel to your disposal. I hope future students will have the same possibilities as me.

Thanks also to the people at Nortek AS. Arild Olsen for helping out with mounting and running the instrument and Tom Christian Mortensen, who did everything in his power to let us have an instrument when we needed it.

Andrè Staalstrøm at NIVA, thanks very much for helping out with MatLab problems and the tools to find the bottom topography and fjord partition areas.

And finally, thanks to my live-in, Mari, for the moral and economic support. I so much wanted to do this.

Oslo, Blindern, 1st June 2011

Abstract

The Norwegian Meteorological Institute (met.no) runs several Numerical Ocean Weather Prediction (NOWP) Models. Met.no is forecasting ocean weather on the continental shelf and adjacent seas as well as for certain coastal areas, such as fjords. For the Oslofjord, the model referred to in this thesis work is MIPOM (Blomberg and Mellor, 1987; Engedahl, 1995b; Røed and Fossum, 2004). MIPOM is an abbreviation for the Meteorological Institute's revised version of the Princeton Ocean Model.

The resolution is $300m \cdot 300m$, and the grid consists of $240 \cdot 396$ squares covering $72 \cdot 118.8km$ or approximately $8554km^2$. Geographically, the model covers the Oslofjord area from Larvik/Stavern in the southwest, across the fjord mouth to Hvaler Islands in the southeast. The northern boundary for the model is just north of Oslo city center.

The scope of this thesis is to validate the MIPOM model run for the Oslofjord. Field measurements of the currents at specific cross sections in the Oslofjord has been conducted. The north/south components of the measured currents has been further analyzed and compared to the north/south components as predicted by MIPOM. The north/south components were chosen for the possibility to relate it to water level variations in the inner parts of the Oslofjord.

The volume transport through the cross sections has been calculated, both for the field observations and for the MIPOM model. The results varies. The model seems to underestimate the northward and overestimate the southward currents. As a result the volume transports change accordingly. Flow patterns, where and at which depths currents occur, also varies.

The plots of the currents reveals a particular difference between the measured and modeled data. In the plots where the measured data is averaged over a period of $20s$ (corresponding to a $60m \cdot 60m$ grid), the bottom topography is represented in better detail than in the model. The purpose of the model is to predict the direction, strength and location of the current flowing and forecast water levels in the Oslofjord. Higher resolution should be a topic for further work with the MIPOM or a new NOWP model for this area.

Contents

Chapter 1

Introduction

1.1 Background and scope

The Norwegian Meteorological Institute (met.no) runs a number of numerical models to predict the ocean weather in Norwegian waters and adjacent seas. Ocean modeling includes waves, storm surges, tidal currents, hydrography and sea ice. Models for the Northern Atlantic, the Norwegian continental shelf and coastal waters are run daily for the safety of commercial operations and recreation, as well as for environmental issues such as transport of nutrients and contaminants.

As computer science develops, the models can be improved. In the late 80's, met.no started a new research program to improve ocean weather prediction. In 1995, Harald Engedahl described the implementation of the three dimensional Princeton Ocean Model (POM) [Blomberg and Mellor, 1987] at met.no, published in a research report (Engedahl, 1995b). This model has been continually upgraded and is now in use at met.no known as MIPOM, the Meteorological Institute's revised version of the Princeton Ocean Model.

The particular MIPOM version for the Oslofjord consists of 240 x 396 squares of 300 x 300 meters resolution. The model is run daily and produce a 66 hour forecast and an 18 hour hindcast. A control adjustment from the previous run to the next is done at the zero hour.

Measured current data were acquired through field measurements in predestined transects across the Oslofjord. These data were later compared to those stored in the computer at met.no. An analysis of water level data from the official measuring stations represented in the Oslofjord was later performed, as an additional input.

The scope of this master thesis is to verify the MIPOM output data against field measurements.

1.2 Motivation and earlier work

In the early days, merchants or travelers with boats propelled by oars or sail could save hours and days in traveling time, with local knowledge of the area. This knowledge is also very important for today's commercial traffic, fisheries and infrastructural security. A lot of work has been done to understand the currents and the reasons for the water's motion in the Oslofjord throughout the years, as in other fjords and seas.

1.3 million people (www.ssb.no, 11.02.11) live in the municipalities and counties directly bordering the Oslofjord and recreational activity has increased considerably in later years. This again leads to a need for knowledge about how to keep the Oslofjord healthy and environmentally sustainable.

The earliest systematic scientific work were most often related to the surface currents, their behavior and the reasons for their motion. Andre Staalstrøm (2005) refers to work such as that performed by Hjort and Gran (1896 and 1898), Gran and Gaarder (1918), Braarud an Ruud (1937) and Johansen (1959) as mostly researching the wind's influence on the currents.

In the 1960's and 1970's the Oslofjord was heavily polluted, especially the inner part. This led scientists to research the whole circulation of the Oslofjord. Measurements of currents and hydrography of the water column as a whole, got increased focus. As it was the Inner Oslofjord that was most polluted, most of the work were concentrated just south and/or just north of the sill near Drøbak, in the northern end of the Drøbak sound. The depth here is 21 meters.

Ola M. Johannessen (1963) was the first to publicize a time series measurements of the currents, just south of the Drøbak sill, in May/June 1963. F. Beyer, E. Føyn, J. T. Ruud and E. Totland (1967) analyzed time series data collected with Bathyrheographs in August/September 1961, also just south of the sill. Svein Tryggestad (1974) measured currents in three different depths over a period of 6 months. His current meters were placed in the deeper, southern part of the Drøbak sound, at Brenntangen. Ernst Jensen (1977) analyzed a time series of the currents in the whole Drøbak sound, collected at five different stations.

Øyvind Endresen (1995) analyzed current measurements from the Drøbak sound . His results were further analyzed by Eivind Aas and Øyvind Endresen (1999) to find a simplified method of volume transport in narrow sea straits. Andre Staalstrøm (2005) analyzed time series of the currents in the Drøbak sound near the sill, measured in 2001, 2002 and 2004. He also measured the currents on site with an Acoustic Doppler Profiler and compared the results with the water level variations recorded by the Norwegian Hydrographic Service (Norwegian, Statens Kartverk, Vannstand).

1.3 The Oslofjord

The Oslofjord stretches from Færder Fyr in Skagerrak to Oslo city center, a distance of approximately 100 kilometers (54 nautical miles). The southern opening is approximately 26 kilometers wide (14 nautical miles),the eastern sound of the Drøbak passage about 500 meters wide (0.27 nautical miles). The Oslofjord is separated from Skagerrak by a sill at about 120 meters depth (Staalstrøm, 2005).

The coastline is ragged and the entire fjord strewn with islands. The outer Oslofjord is characterized by a deep channel, between 250 and 400 meters deep in the middle, that shallows to about 170 meters at the transect Horten-Moss. Depths of around 250-300 meters is found in the Drøbak sound. The inner Oslofjord is separated from the outer by a sill in the northern end of the Drøbak sound, at 21 meters depth. (Source: NIVA, topography map from 75 meter grid model of the Oslofjord). The middle depth in the inner Oslofjord is 49.3 meters (Staalstrøm, 2005).

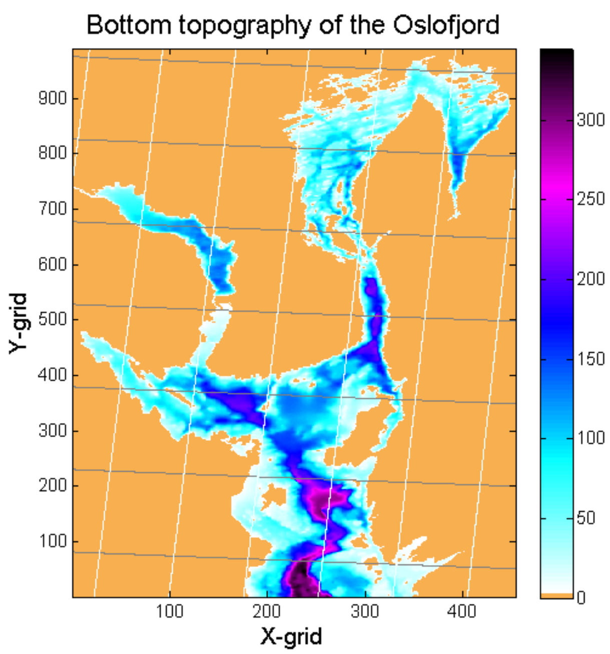


Figure 1.1:
Bottom topography of the Oslo fjord.
Extracted from NIVA 75 m grid model

The tidal variations are relatively small. On August 18th 2010, one of the days data were acquired, the observed water level changes was +25 cm/-28 cm in Oslo city harbor, relative to mean sea level (www.vannstand.no). Forecasting current strength and location is complicated due to the topography of the Oslofjord. Another important factor is the weather. Due the small tidal variations, the weather, high or low pressure and wind direction and speed, is a major factor influencing the currents.

Chapter 2

Instrument

2.1 Instrument Selection

The University of Oslo has at its disposal the research vessel R/V Trygve Braarud (hereafter abbreviated R/V TB). R/V TB used to have a Continental Current Profiler manufactured by the Norwegian company Nortek AS mounted in the hull. The Continental utilizes Doppler technology to measure currents, a technology commonly known as Acoustic Doppler Current Profiling (ADCP). The instrument was capable of measuring currents down to 200 meters depth.

The instrument was taken out of the hull sometime after 2005 and stored at the University of Oslo's facilities at Lysaker. The plan was to mount the Continental on a rugged pole and submerge it over the side of R/V TB.

While testing and controlling the equipment, onshore, prior to a test-cruise in April 2010, it was found that it was no longer possible to contact the instrument using the software package from the manufacturer. Further investigations uncovered that the instrument had been reconfigured and irrevocably rebuilt for bottom mounting, upward looking, current measuring. (The software package is called the Vessel Mounted Survey (VM Survey) package and will be referred to throughout this thesis).

To acquire the field data of the currents in the Oslofjord, another instrument was needed. The choice fell on an AWAC (Acoustic Wave And Current profiler) produced by the same company. The AWAC is produced in two different versions, a 600 kHz version capable of measuring currents down to 40 meters depth and a 1MHz version with a range of 25 meters depth. Both versions can be used for both vessel mounted and bottom mounted applications.

As the MIPOM stores data from 0-3-10-20 and 30 meters depths, the 1MHz version was found too marginal. The 600 kHz version was selected.

2.2 Instrument Functional Description

The AWAC is a Doppler shift based current measuring device. There are four transducers on the submerged sensor head, three positioned around the perimeter and one in the middle. The sole middle transducer is not in use when the AWAC is measuring current; it is used for measuring wave height while mounted on the bottom.

The three transducers in use are placed 120 degrees from each other, forming a triangle. They are all slanted 25 degrees relative to the vertical. The transducers generate sound, 600kHz pings, one every second (1Hz), the energy concentrated in narrow beams. The water itself does not reflect sound. The sound is reflected from particles (zooplankton, suspended sediments) moving with the water and the echo registered by the transducers.

If a particle is moving away from the sensor head the echo will have a longer wavelength than when it was sent out. The opposite will be true if the particle is moving toward the sensor head.

The three Doppler shifted echoes measured by the transducers is used to calculate the 3D velocity of the current. The depth from where the echo originates, is determined by measuring the time passed from when the sound was sent and the sensor receiving the echo.

The number and depth of measuring cells are set by the operator. The mean current velocity calculated by the instrument software is weighted towards the middle of each depth cell. Echoes from, minimum, the first 0.5 meters depth is blanked. The instrument needs this time to recover from sending the ping and prepare to receive echoes. This is called the blanking distance, and is set by the operator.

Figure 2.1:
AWAC Acoustic Wave And Current profiler

Chapter 3

Data acquisition

3.1 Field data acquisition

To obtain material for this thesis, the plan was to acquire current data from three transects in the Oslofjord. One in the vicinity of the line between Moss and Horten and one in the southern part of the Drøbak sound i.e. across the sound near Hvitsten. In addition to these two, a third was planned in the inner Oslofjord, across Vestfjorden, in the vicinity of Søndre Langåra.

On August 18th and 19th 2010 the first two transects was measured. Due to circumstances beyond control of this thesis project, the third transect measurements could not be finished. The AWAC was placed in a rig north of Trondheim. That research project experienced some problems and had to be repeated. The instrument was no longer available within the time frame of this thesis.

The AWAC has an accuracy of 1% of the measured value ± 0.005 m/s. To get good quality data, the decision was made to do three runs through each transect. That way, the time of day and also the tidal currents, would vary. It is favorable for the data quality if the currents are strong.

On August 18th, the fjord was crossed three times between Horten and Moss and three times between Jeløya and Vealøs, while measuring. On the 19th, three crossings were made between Hvitsten and Solbergstøa.

See Figure **??** for an overveiw of the transects and their location.

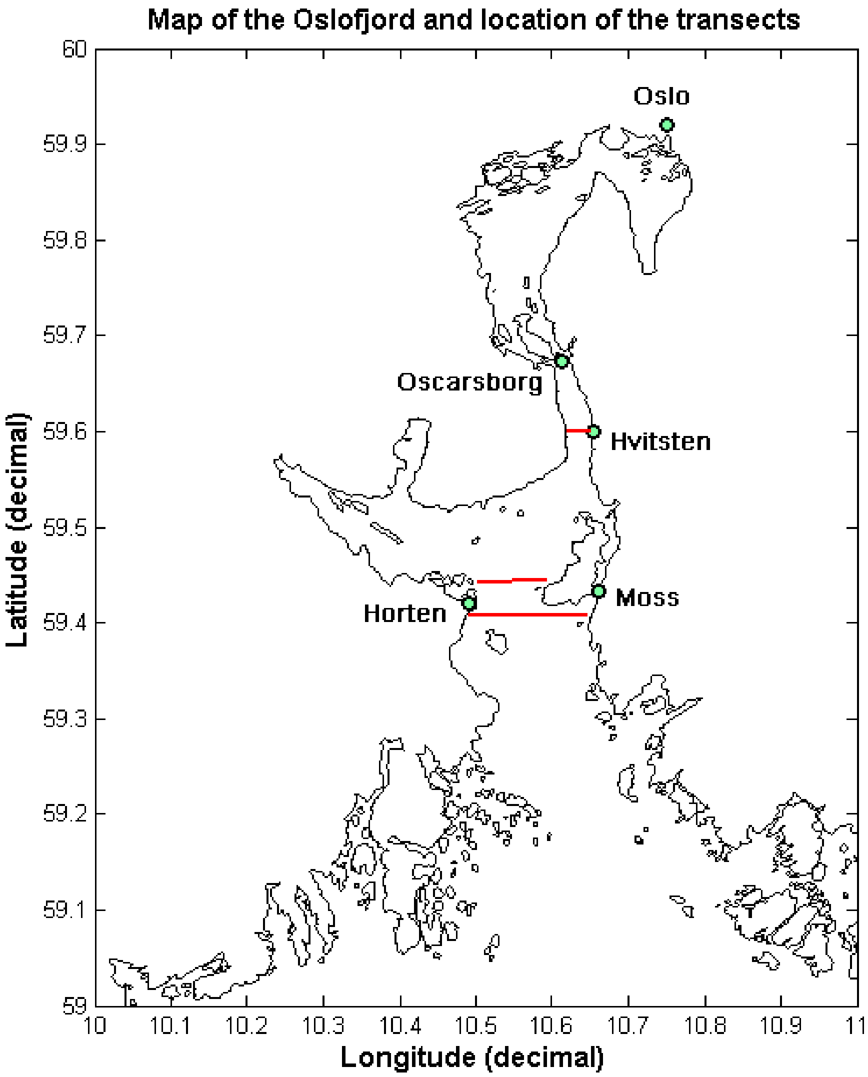


Figure 3.1:
Map of the transects

3.1.1 AWAC mounting

R/V Trygve Braarud draws three meters of water. The AWAC's transducers pings at an angle 25 degrees relative to the vertical. To avoid false reflections from the vessel's hull, the sensor head has to be submerged two meters below the surface.

The sensor head is mounted on a rugged, approximately 6 meter long aluminium pole. On the submerged end, a circular, 1 cm thick aluminium plate is welded to the pole, holding the instrument. The pole is hooked up to a hull mounted bar 50 cm above the sea surface, lifted and held in place by R/V TB's aft deck crane. From the submerged sensor head, wires are running fore and aft, to secure the instrument from lateral movement while sailing. See figure below for an outline sketch of the mounting of the AWAC.

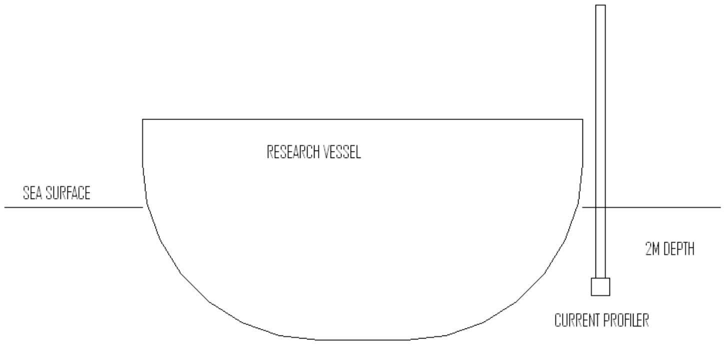


Figure 3.2: Sketch of sensor head mounting

With a minimum blanking of 0.5 meters, this setup gives information of water velocities from 2.5 meters below the surface.

See figure below for a photograph of the rig.

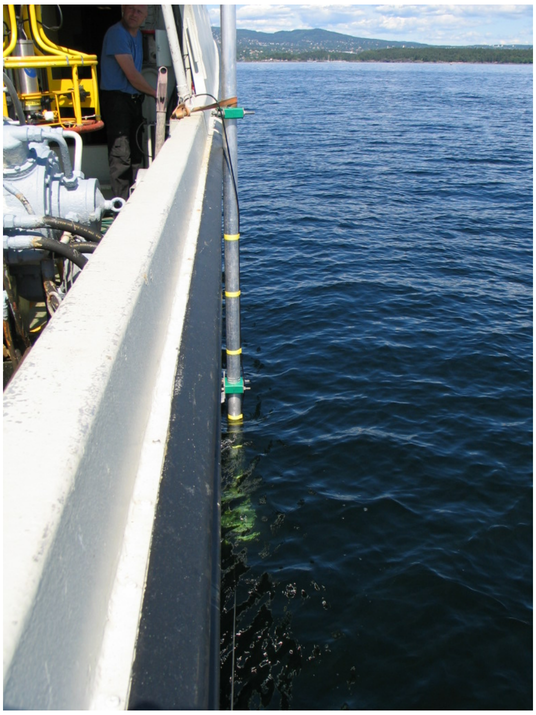


Figure 3.3: AWAC rig on R/V Trygve Braarud

3.1.2 Calibration

The AWAC's basic functional principles is as described in section 2.2. Now the water's velocity over ground as a function of depth, $\vec{v}(z)$, shall be measured while the instrument is fitted to a moving vessel. The instrument measures its own speed, $\vec{v}_{AWAC}(z)$. The vessel's speed over ground, $\vec{v}_{SOG}$, must be subtracted to find the water velocity, $\vec{v}(z)$.

$$\vec{v}(z) = \vec{v}_{AWAC}(z) - \vec{\vec{v}}_{SOG} \tag{3.1}$$

The instrument is direction sensitive. It should be mounted so that the x-axis of the instrument, marked with an arrow on the casing, is parallel with the line that runs from the bow to the aft of the vessel. This is not practically possible to accomplish. There will always be a slight off angle. This is one of the parameters that are corrected during the calibration.

The other parameter that could introduce an error when subtracting the vessel speed over ground, is the speed of sound in the water. This varies with water temperature and salinity and must be set by the operator of the instrument.

Calibration is done in two steps. First, run the vessel for approximately 1 nautical mile straight ahead at a leisurely speed while doing measurements. Stop the measurements and double back on the end of the track that was just finished. When back on track, start measurements again. Stop measurements when back to where the first track started. The two data sets collected by running this track forth and back, are now used by the software calibration routine to adjust for the error in angle between the vessel and instrument.

Second comes adjustment for the speed of sound in water. R/V TB measures this and gives the information to the operator who loads it to the software. If on any other vessel the best thing to do is take a CTD profile and compute the speed of sound in water.

Either way, a CTD profile should be taken in the position of the calibration track. It is possible to reload the raw data collected by the AWAC and use another speed of sound in water when reprocessing data, if necessary.

3.1.3 System setup

To be able to perform the calibration routine, it is important that the vessel instruments, such as GPS and GYRO, are communicating with the instrument software.

This is of course also essential when it comes to storing data in the different transects measured.

It is definitely good advice to have good precheck routines when it comes to the system communication. It is strongly recommended to perform these the day before actually measuring anything, if possible.

See Figure 3.4 for a schematic view of the instrument system setup.

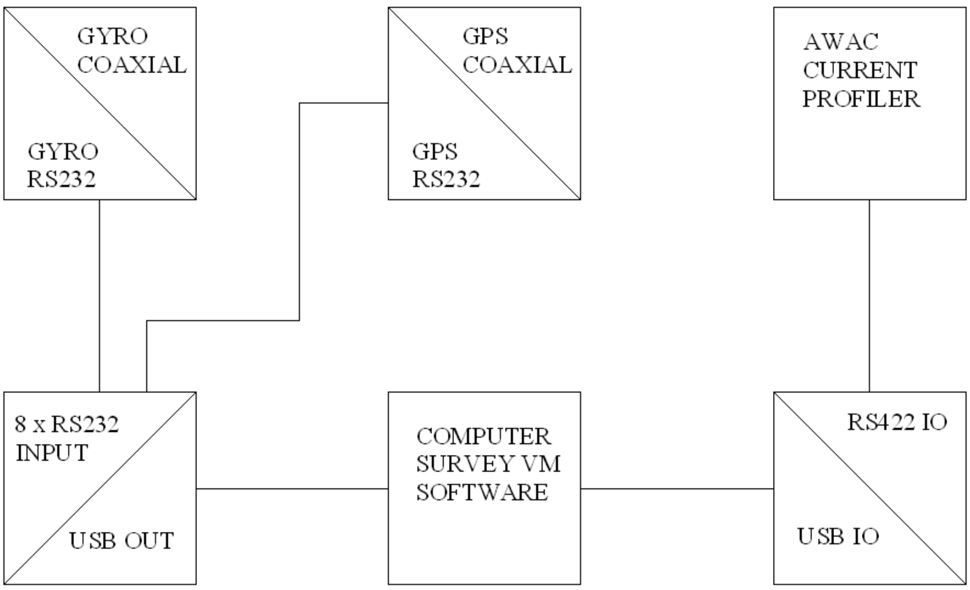


Figure 3.4: *AWAC and vessel instrument setup*

3.2 Data from met.no

The data from the MIPOM model runs are stored on met.no's servers. The files contains a lot of information, such as forecasted seawater density, salinity, temperature, water quality, topography, tides, ice and water level.

They also contain current data from $0, 3, 10, 20, 30m$ depth, in the grid's u/v/w directions. The current data in u and v directions for the dates 18 August 2010 and 19 August 2010, were extracted.

See Section 4, Methods, for a further description of how the data was used.

Chapter 4

Methods

4.1 Processing field data

The AWAC transfers raw data from the sensor head to the computer once every second. The software combines the raw data with the GPS and GYRO signals from the vessel. The data is stored in one file containing time and date, position, heading, vessel speed and water velocities.

The software lets the user chose between x/y/z coordinates for the water velocities or east/north/up (ENU) velocities. As the transects measured during this thesis work was located in an east/west direction, it is the ± north components from the field measurements that are further analyzed.

This introduces an error when trying to compare directly with the model forecasts. The model grid is not strictly east/west - north/south. This is discussed in section 4.2.2.

Choosing the north/south direction also makes it possible to compare the volume transport calculated from the field measurements with the volume transport calculated by observed water levels in the Oslofjord. This is discussed in section 4.3.

4.1.1 Current plots, field data

As mentioned in section 3.1.1, the instrument starts measuring 2.5m below the water surface. During this thesis work, the AWAC was set to measure 10 depth cells, each 4 meters deep. The first cell will then have a mean value weighted towards 4.5m depth, the next at 8.5 meters and so forth.

The data from a file is exported from the AWAC file format to ASCII and then processed in Excel removing information of east and up currents. The Excel file is read into MatLab. In MatLab, the bottom topography is detected and removed by means of the echo strength. When the AWAC's pings hit the bottom, a strong echo is registered by the transducers. This introduces a large error in the measurements as it indicates high water velocities. These echoes are therefore removed.

Nortek recommends 20 seconds averaging time to eliminate noise. The first plot of the currents measured in field is therefore an image averaged over 20 seconds. This corresponds to a cell size 50-60 meters wide, depending on vessel speed.

The second plot is averaged over a period of time, based on vessel speed, corresponding to 300 meters cell size. This to be able to compare data with the MIPOM model on the same premises.

The plots are placed in Chapter 5, Results.

4.1.2 Volume transport, field data

The volume transport has been calculated for both averaging periods, depth $2.5m$ to $42.5m$. The transport is a function of the currents and the area of each cell. We have:

$$v(x_i, z_i) = v_{ij} \tag{4.1}$$

The volume transport then becomes:

$$Q = \sum_{i=1}^{I} \sum_{j=1}^{J} v_{ij} A_{ij} \tag{4.2}$$

where A is the area of the cell, I is the number of vertical cells and J is the number of lateral cells. Here $I = 10$.

4.1.3 Comparison with MIPOM volume transports

These volume transports are not directly comparable to those calculated from the MIPOM model. As the model stores data in 5 depths, $0, 3, 10, 20, 30m$, the field data must be adjusted accordingly.

This is done by adding an extra cell, from $2.5m$ depth to the surface. The water velocity in this added top cell is assumed to be the same as in the first measured depth cell. This is probably an underestimation, but it is the best assumption as we do not have measured data from the surface. (The crew on R/V TB had to correct the vessels course for currents up to two knots, $\approx 1m/s$, but that is just an observation, not measurements).

It is also necessary to remove the 3 deepest cells. This operation gives the volume transport from the surface to $30.5m$ depth. Mathematically we now have:

$$Q_{30.5} = \sum_{j=1}^{J} v_{1,j} \cdot l_{cell} \cdot 2.5m + \sum_{i=1}^{7} \sum_{j=1}^{J} v_{ij} A_{ij} \tag{4.3}$$

This transport is comparable to the transport forecasted by the MIPOM model, although it requires some adding cell work with the model files as well. This is described in section 4.2.2.

4.2 Processing MIPOM data

The current data were read into MatLab using a MatLab program supplied by met.no. Another MatLab program, also supplied by met.no, made conversion from grid points to geographical positions and back, possible.

The MIPOM model is somewhat skewed compared to geographical north. The result is that the north/south current velocities has two components, one u component and one v component. The reader is referred to Engedahl (1995b, p.12) for a description of the grid. Both components are taken into consideration when computing the volume transports for comparison with the field data.

See Figure **??** for an illustration of the MIPOM grid.

4.2.1 Current plots, MIPOM data

The currents are given in 5 layers, $0, 3, 10, 20, 30m$. Plotting these directly, would give little graphical resemblance with the plots of the field data. Here, an interpolation routine in MatLab has been used. The current strength has been interpolated from the surface to $30m$ depth in $1m$ intervals.

Subsequently, the transect positions were plotted into the grid. The grid consists of 240 squares in the u direction and 396 in the v direction. As

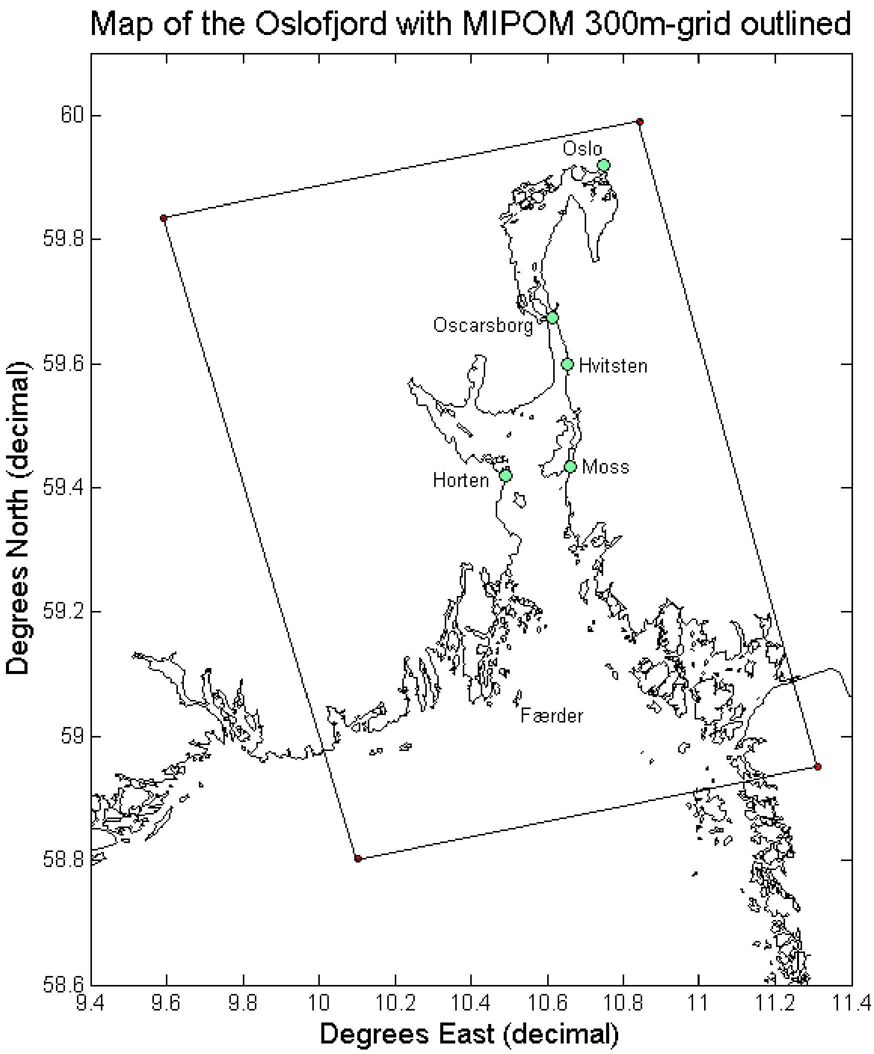


Figure 4.1:
Position of the MIPOM grid in a geographical map.
Map downloaded from:
http://www.ngdc.noaa.gov/mgg/coast/cgi-bin/get_coast.pl

shown in 4.2, the grid is skewed compared to geographical north. As a result the plotted transect makes an angle with the u-directional grid squares.

The current plot from the model data is from the nearest compatible set of u-directional squares. It is the v velocities that are plotted.

See Figure **??** for details.

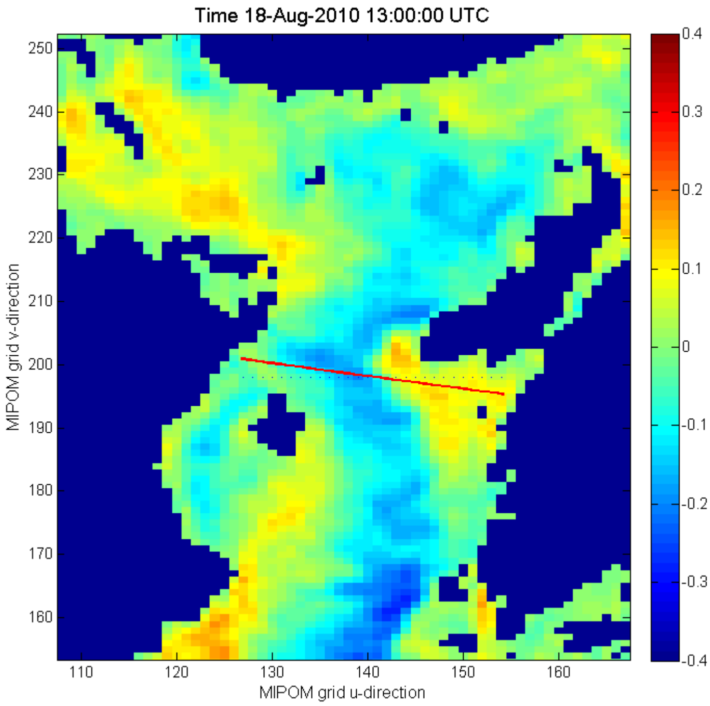


Figure 4.2:
Sailed transect plotted in model grid, in red. The dotted black line shows the position of the MIPOM transect plot, here y = 198. The plot shows the surface currents for transect number 5, Moss to Horten, as predicted by MIPOM

In plotting the currents this way, a small error is introduced. The u component of the current is not represented in the plot. This has very little or no visual consequences. It does not change the plot's appearance in any significant way. The plots are considered good enough for comparison purposes.

It does have an impact on the volume transport calculations. See section 4.2.2 how the error is calculated and what has been done to correct the data.

4.2.2 Volume transport, MIPOM data

The relative error in using only the v-component as the north/south current strength value was investigated. First the angle between the transect run and the length of the plotted u-directional grid squares were calculated using plane trigonometry. We have:

$$u_{length} = (u_{gridpoint}E - u_{gridpoint}W) \cdot 300m \tag{4.4}$$

$$length_{transect} = vessel_{AVGspeed}\, m/s \cdot Ns \tag{4.5}$$

where Ns is the duration of the transect run in seconds. Then:

$$cos\varphi = u_{length}/length_{transect} \tag{4.6}$$

To find the u and v components influence on the north/south current strength and, with that, the influence on the volume transport, the RMS values of both u and v was calculated for all transects.

$$RMS_u = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(u_i^2)} \tag{4.7}$$

$$RMS_v = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(v_i^2)} \tag{4.8}$$

The north/south velocity (RMS) is found by adding the two resulting vectors.

$$u_{comp} = RMS_u \cdot cos\varphi \tag{4.9}$$

$$v_{comp} = RMS_v \cdot cos\varphi \tag{4.10}$$

$$NS_{vel} = u_{comp} \cdot v_{comp} \quad (4.11)$$

The relative error of not including the u-component from the model, is then given by:

$$RE = (NS_{vel} - v_{comp})/NS_{vel} \quad (4.12)$$

The errors were calculated to be approximately 5-10% in the Moss-Horten area, and approximately 7% at Hvitsten. This is not a large error, but a decision was made to include the u-component in further calculations. The volume transports calculated from the MIPOM model, as presented in Chapter 5, Results, are all corrected for this error.

4.2.3 Comparison with measured volume transports

As described in 4.2.1, the plot showing the MIPOM model currents in a transect is an interpolation from the surface to $30m$ depth in 1m intervals. The field data consists of a matrix with 7 depth cells and a number of lateral cells depending on the length of the transect, as described in 4.1.3.

Now it is necessary to arrange the model data accordingly. Applying a linear intepolation technique, this was done in Excel.

The equation used in this interpolation is:

$$v(z) = v(z_i) + (v(z_j) - v(z_i)) \cdot (\frac{z - z_i}{z_j - z_i}) \quad (4.13)$$

Here z is the measuring depths of the AWAC, that is:

$$z = [2.5\ 6.5\ 10.5\ 14.5\ 18.5\ 22.5\ 26.5\ 30.5]m \quad (4.14)$$

z_i is the depths of the stored MIPOM data, that is:

$$z_i = [0\ 3\ 10\ 20\ 30]m \quad (4.15)$$

Furthermore, the condition that

$$z_j > z > z_i \quad (4.16)$$

must be fulfilled. That gives z_j equals:

$$z_j = [3\ 10\ 20\ 30]m \tag{4.17}$$

The next operation is to add an $0.5m$ cell below the $30m$ depth cell, assuming the same veocity in that cell as at $30m$ depth.

Now the mean value between z-levels is calculated. The result is matrix with current values in 7 depths and a number of lateral cells depending on the length of the transect. This matrix is directly comparable to the one prepared from the AWAC data.

4.3 Observed water level changes, volume transports

In the Oslofjord, there are two official water level measuring stations. One is in Oslo harbor and one at Oscarsborg. Both of these stations are inside the measured transects. Further south, there is an official station at Helgeroa near Larvik. All stations are run by the Norwegian Hydrographic Services (a division within Statens Kartverk) and data for use in this thesis was downloaded from

http://vannstand.no/index.php/nb/vannstandsdata/malt-vannstand

The changes in observed water level in Oslo harbor and Oscarsborg practically follows each other in time and amplitude. At Helgeroa, the observed water level changes for August 18th and 19th 2010 differed from those in Oslo harbor and Oscarsborg. This made it possible to estimate the water level changes in the vicinity of the Moss to Horten transects on the 18th and in the transect near Hvitsten on the 19th.

The distance from Oslo harbor to a line drawn east/west across the Oslofjord between the two southernmost transects is approximately $53km$. The distance from Oslo harbor to a line drawn east/west across the Oslofjord at Helgeroa is approximately $101km$. Both distances has been found using a chartplotter and measuring the distance between choosen waypoints. In that sense they are not accurate, but is considered sufficient for this calculation.

Values of observed water level are stored every 10 minutes. These data were extracted for each transect run and $\frac{dh}{dt}$ calculated for the corresponding period of time using linear interpolation:

$$\frac{dh}{dt}(t)_{Moss} = \frac{dh}{dt}(t)_{Osl/Osc} + (\frac{dh}{dt}(t)_{Helgeroa} - \frac{dh}{dt}(t)_{Oslo/Osc})) \cdot (\frac{53}{101}) \quad (4.18)$$

The area of the fjord inside the transects was calculated counting pixels in the NIVA 75 meter grid. For the transects Moss-Horten and Vealøs-Jeløy, Drammensfjorden is included. For Solberstøa-Hvitsten it is not, because it connects with the Oslofjord south of that transect.

4.3.1 The continuity equation

The calculations described in 4.3 now allows use of the continuity equation to calculate volume transport. We have:

$$A\frac{dh}{dt} = Q + R + P - E \quad (4.19)$$

where A is the area of the Oslofjord north of the transects, Q is volume transport, R is river runoff, P is precipitation and E is evaporation.

There was no precipitation and the evaporation term has a value of approximately $1m^3$. These two terms can be removed. Checking the river runoff term showed that the rivers in the inner Oslofjord including Sandvika river in Bærum is $13m^3$, 20 latest years average. Values downloaded 20.05.10 from

http://www.vann-og-avlopsetaten.oslo.kommune.no/vassdrag_og_fjord

Data on river runoff from the Drammenselva for those particular dates in August 2010 were not available. In a report from NIVA from 2009;

Jarle Molvær. Consequences of currents changes by filling Gilhusbukta, Lier kommune 6 May 2009

the median of the runoff is reported to be $287m^3$. Even if this is a much larger amount than the runoff from the Oslo region rivers, it is still only 1/30 of the total volume transports we are looking at here. The river runoff term can then be excluded, and the continuity equation simplifies to

$$A\frac{dh}{dt} = Q \quad (4.20)$$

The volume transport calculated using this method will be compared with the results from the field measurements and the MIPOM model forecasts.

Chapter 5

Results

In the beginning of this Result chapter the reader will find figures of the observed water level changes, measured by the Norwegian Hydrographic Services, for August 18th and 19th 2010. These figures gives an indication of what currents to expect in the vertical transect plots.

Then the results are arranged in the sequence they were obtained. In section 5.2, currents in the vertical of each transects are plotted. All transects are shown. There are three plots for each transect.

The first is a plot where the field measured currents are averaged over $20s$. In the second, averaging the field measured data to $300m$ cells are shown. The third is the plot of the currents from the MIPOM model.

In section 5.3, the current data are analyzed further. Histograms, the frequency distribution of the occurring currents, are presented. All transects are shown. The current data for the histograms are from the files prepared for comparison, as described in Chapter 4. One histogram of north/south velocities, averaged over $20s$, is also shown.

Subsequently, the east/west currents of the first transect between Vealøs and Jeløy is presented in an histogram. This transect was chosen because it was here that the consequence of not including the u-component of the MIPOM model forecast was most visible. The volume transport increased by approximately 10% here, when including the u-component.

Section 5.4 is about volume transports. The $300m$ cell measured data and the MIPOM model data are plotted against volume transport calculated from the variations in mean water level.

5.1 Observed water level changes

These are the water level changes for the Oslo harbor station, the Oscarsborg station and the Helgeroa station. The times for field measurements in each section are plotted.

It is easy to see when to expect an inward motion and when to expect an outward motion. As the vertical plots of the currents in the transects show, it is not necessarily an indication of water motion in the upper 30m.

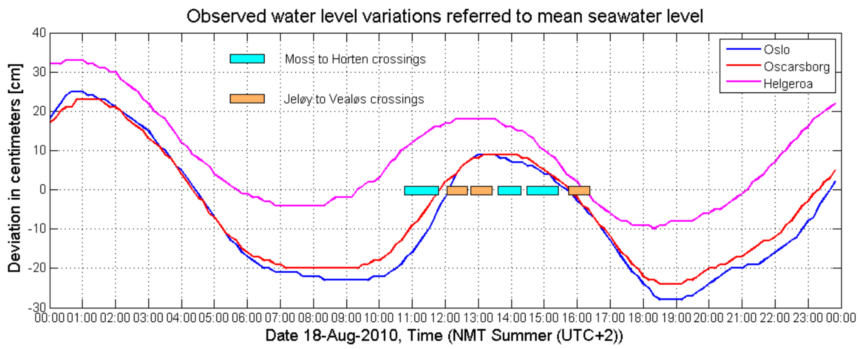


Figure 5.1:
Water level variations, the Oslofjord 18.08.2010

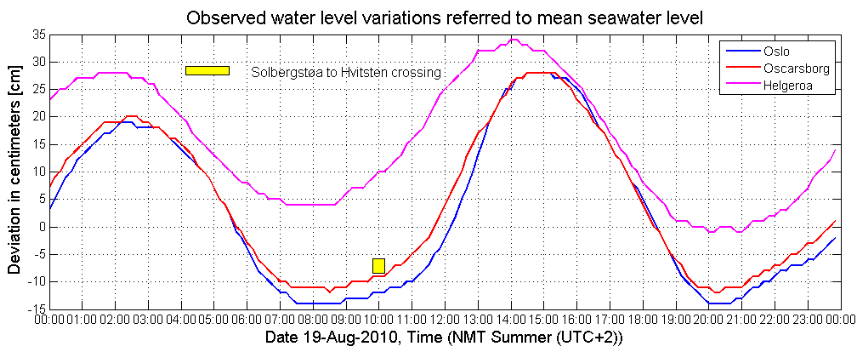


Figure 5.2:
Water level variations, the Oslofjord 19.08.2010

5.2 Current plots, field data and MIPOM

In this section current plots from all transects are shown. The plots will be discussed further in Chapter 6, Discussion

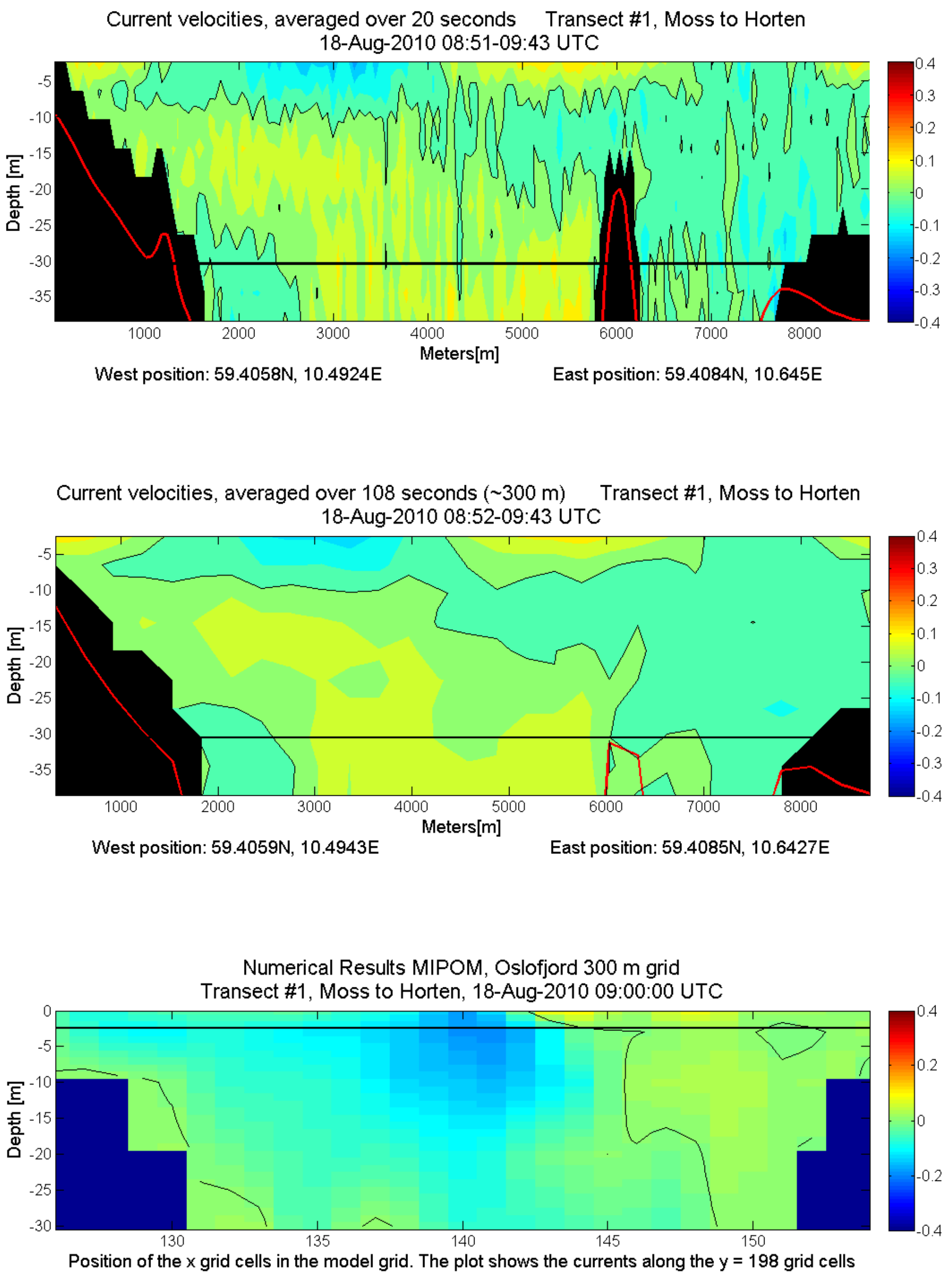


Figure 5.3:
Current plots, Moss to Horten, transect 1

The black lines in the upper two plots indicates the depth of the MIPOM model plot. The black line in the MIPOM plot indicates the depth $2.5m$, the top of the field measured current plot.

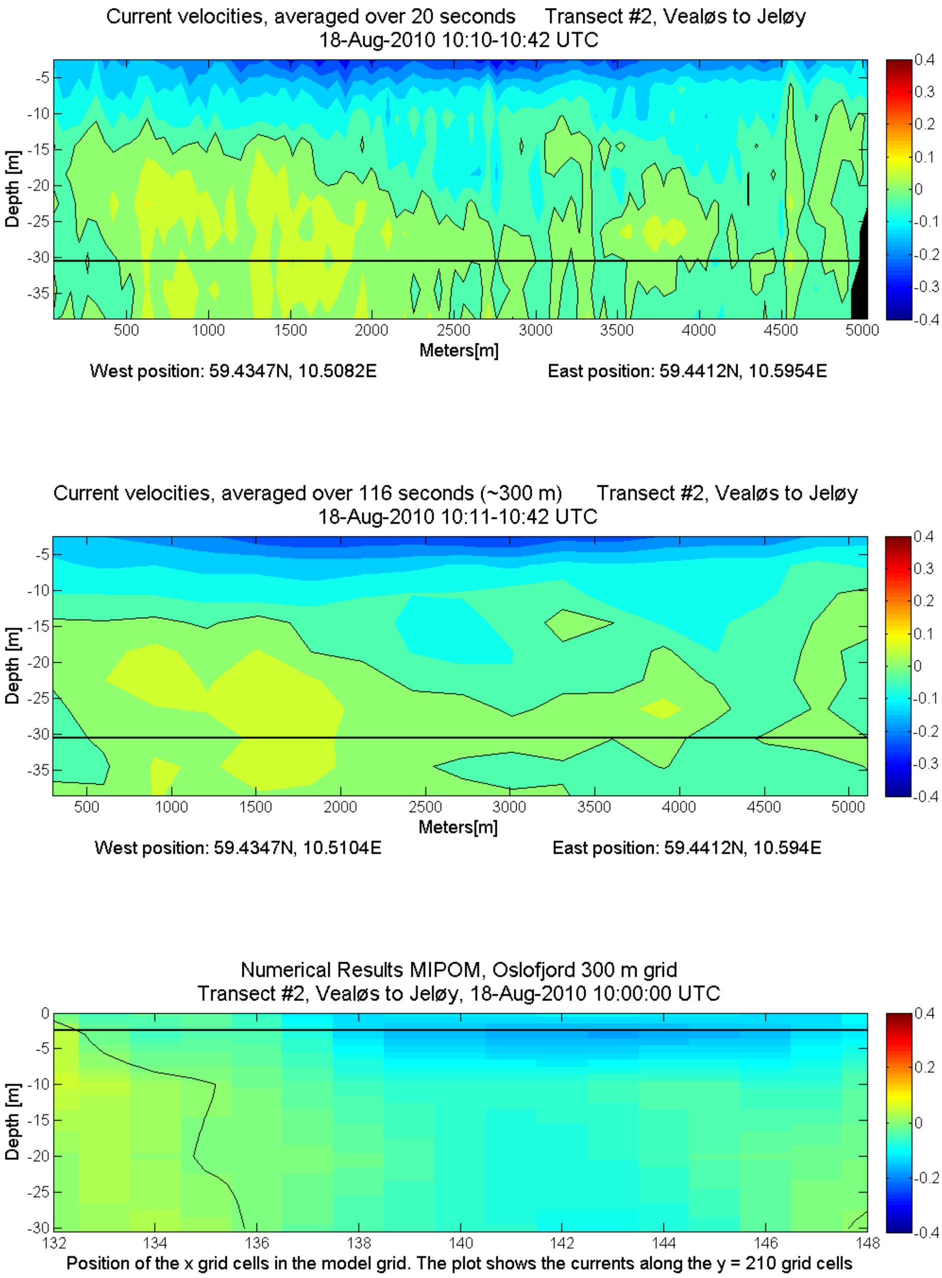


Figure 5.4:
Current plots, Vealøs to Jeløy, transect 2

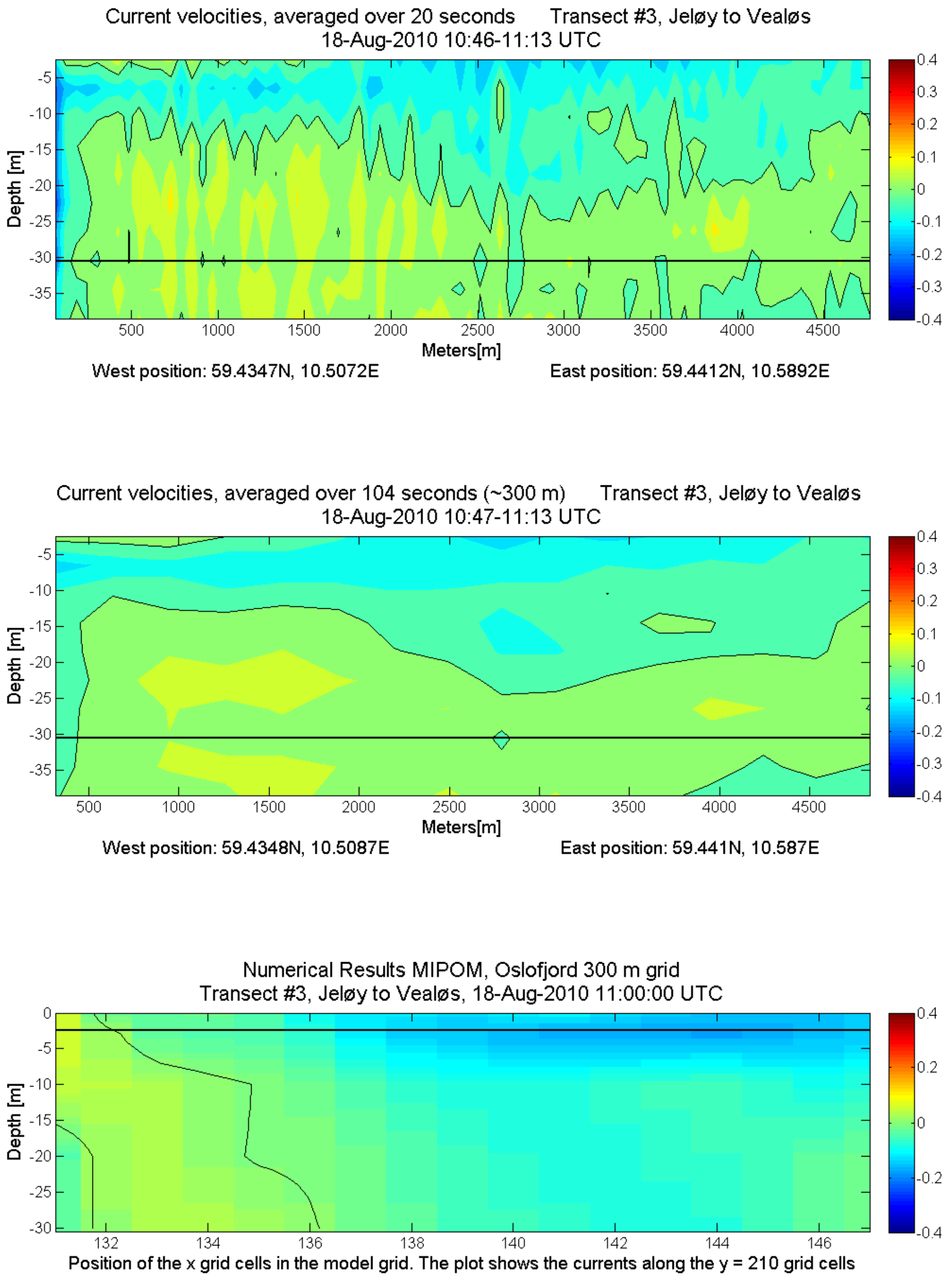


Figure 5.5:
Current plots, Jeløy to Vealøs, transect 3

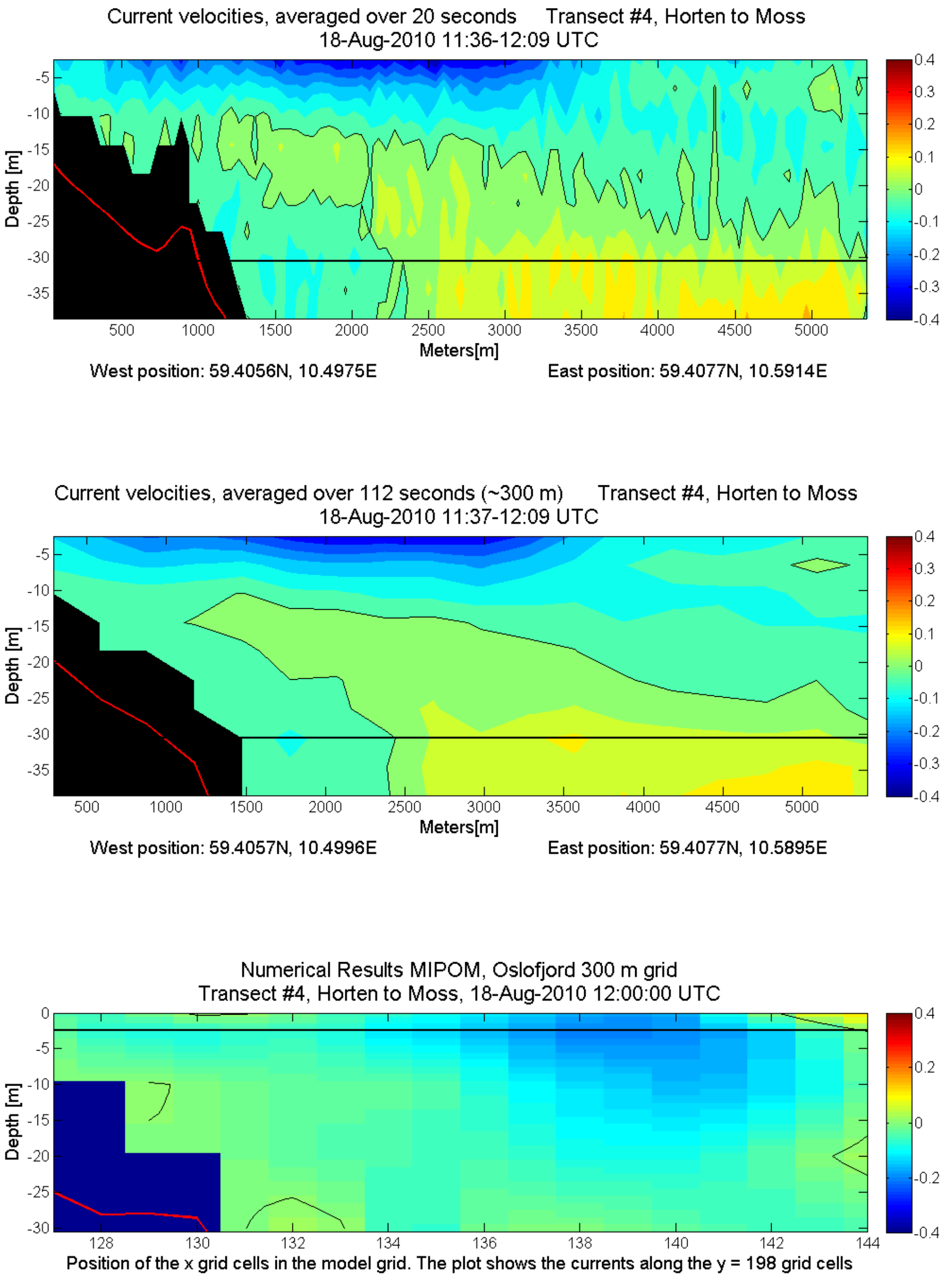


Figure 5.6:
Current plots, Horten to Moss, transect 4

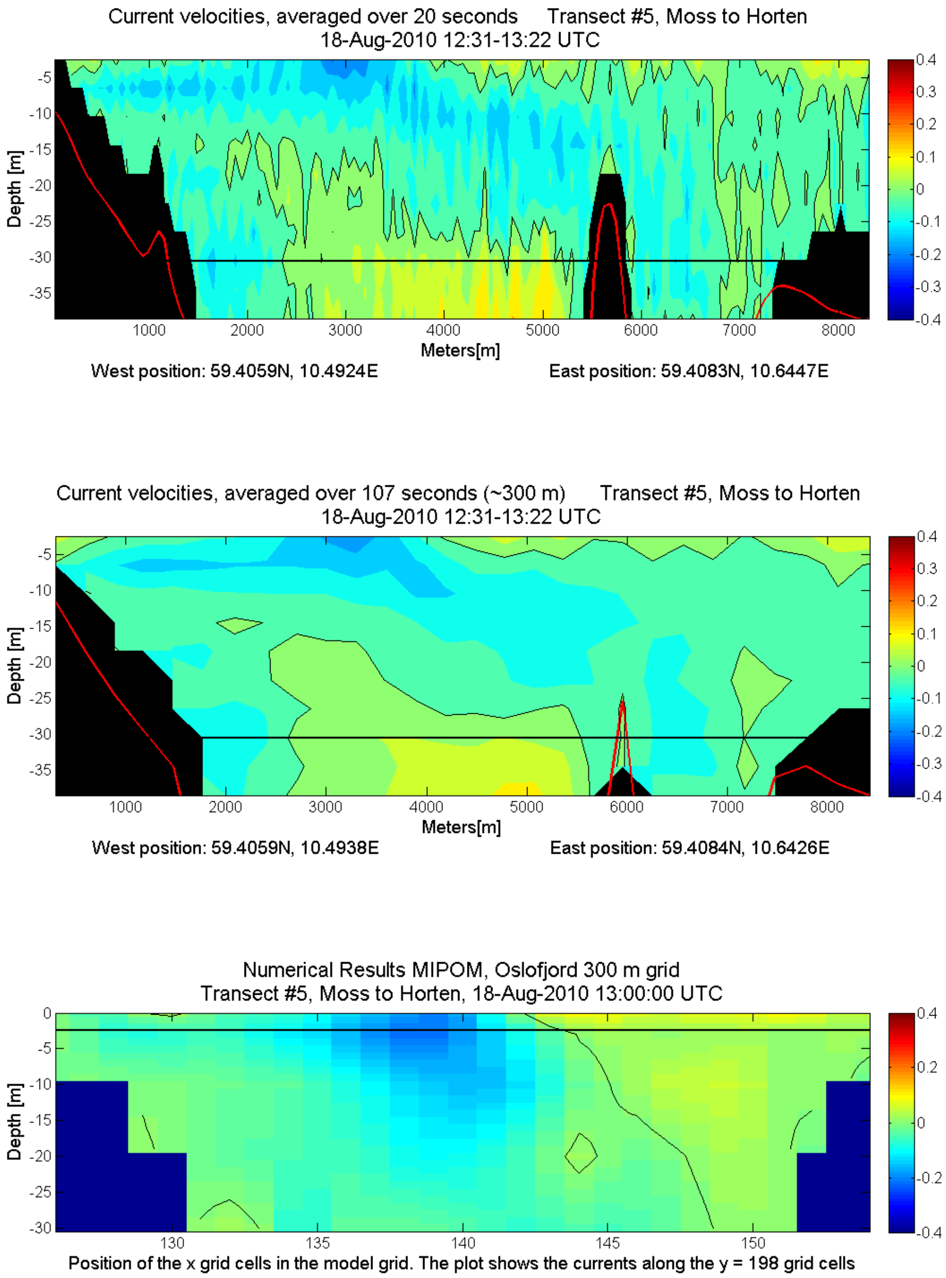


Figure 5.7:
Current plots, Moss to Horten, transect 5

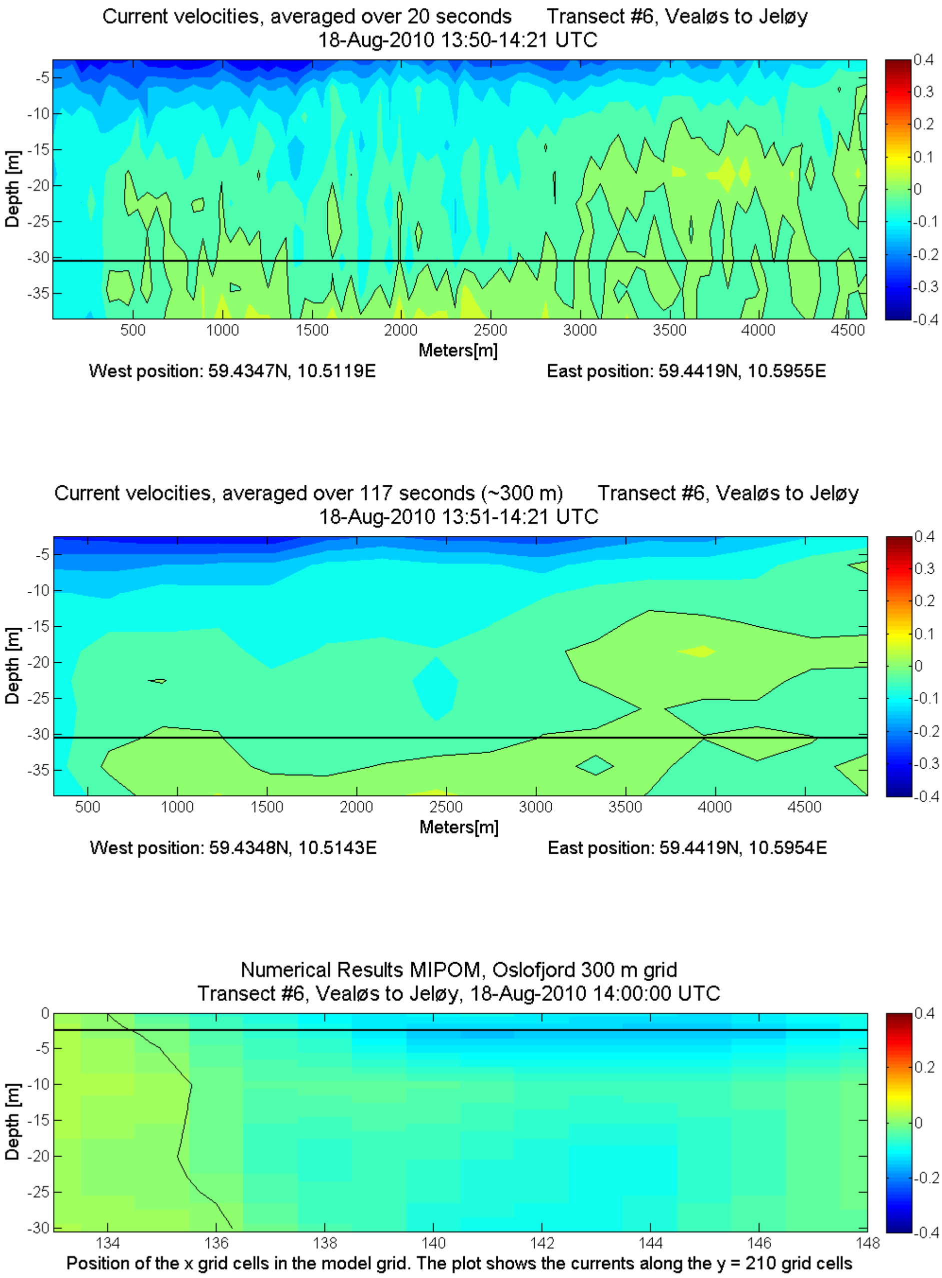


Figure 5.8:
Current plots, Vealøs to Jeløy, transect 6

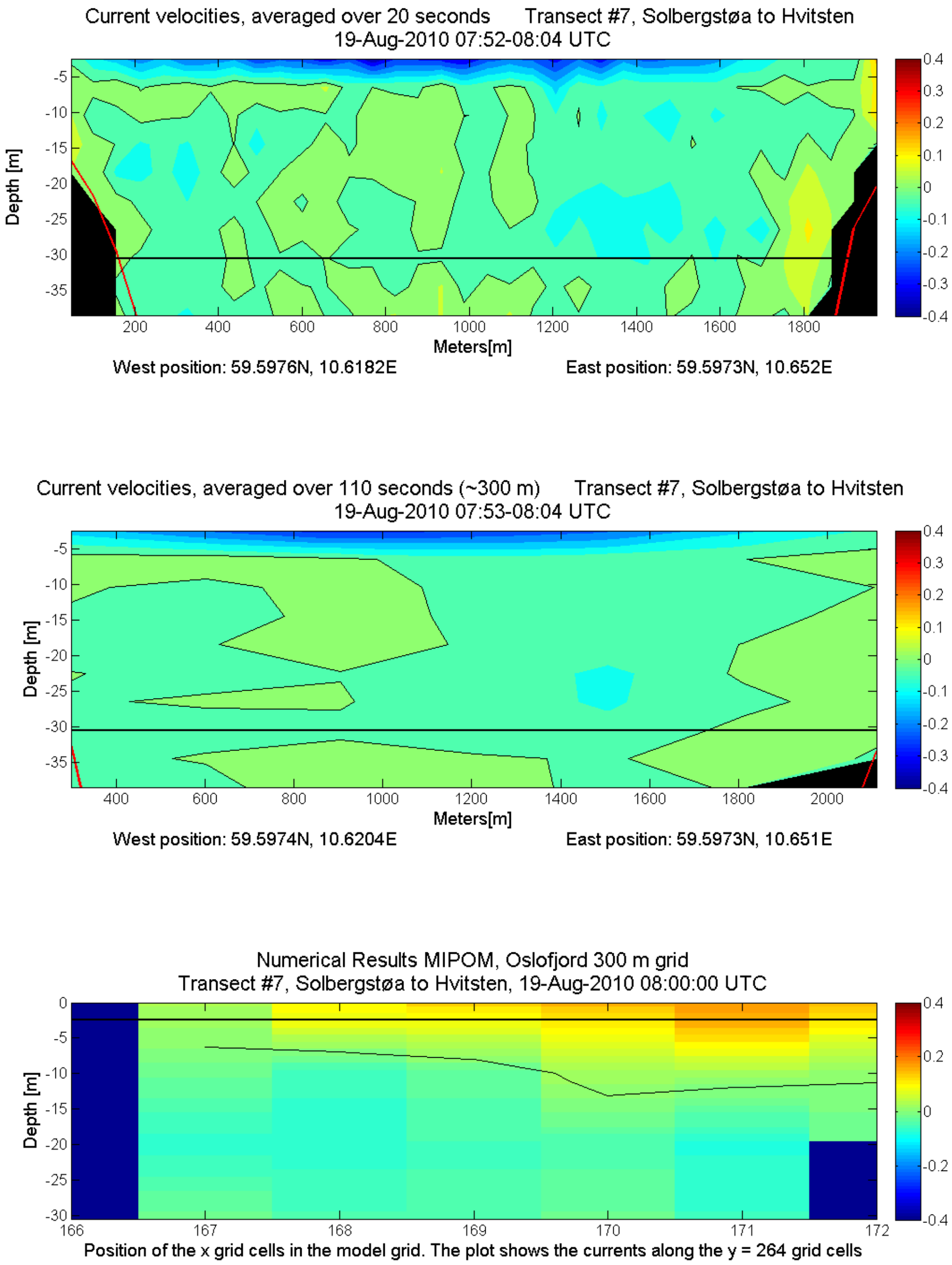


Figure 5.9:
Current plots, Solbergstøa to Hvitsten, transect 7

5.3 Current frequency distribution

To analyze the current velocity distribution, the currents are presented in histograms. If the MIPOM model forecast is accurate, the distribution of currents should be the same as for the distribution of the field measured currents.

The general tendency shown in the histograms, is that the field measured currents has a higher representation of currents going north, into the Oslofjord. This is also reflected in the volume transport calculations in section 5.4.

The tendency is true for all of the transects, except for Solbergstøa to Hvitsten on August 19th, where the situation is reversed.

See section 5.3.1 for a comparison of the north/south velocity using $20s$ averaging and $300m$ averaging.

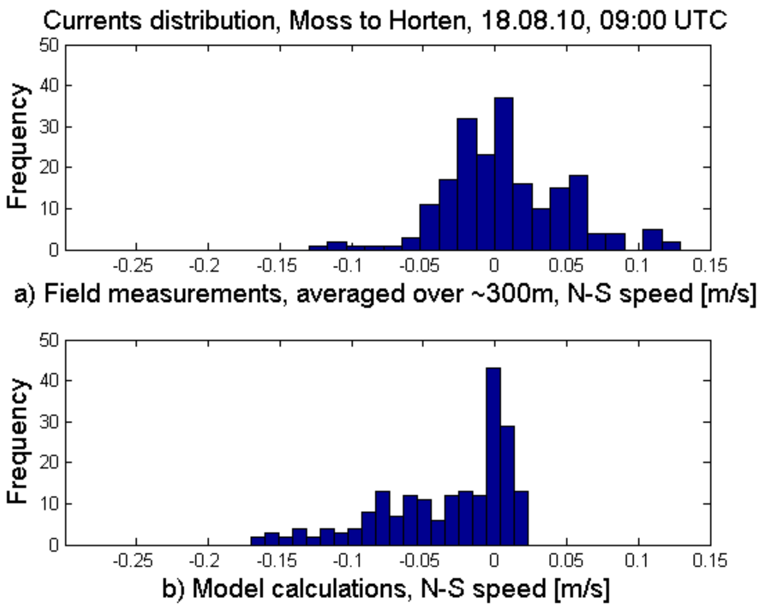


Figure 5.10:
Current distribution, Moss to Horten, transect 1

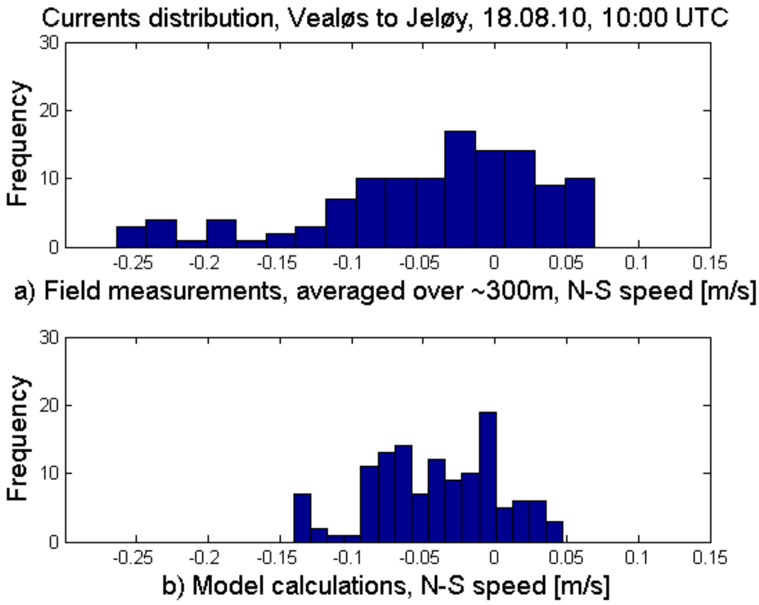


Figure 5.11:
Current distribution, Vealøs to Jeløy, transect 2

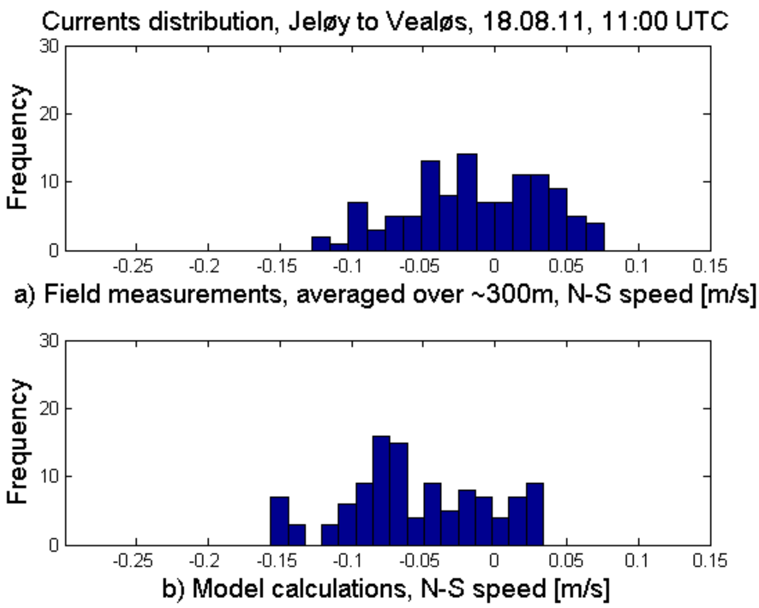


Figure 5.12:
Current distribution, Jeløy to Vealøs, transect 3

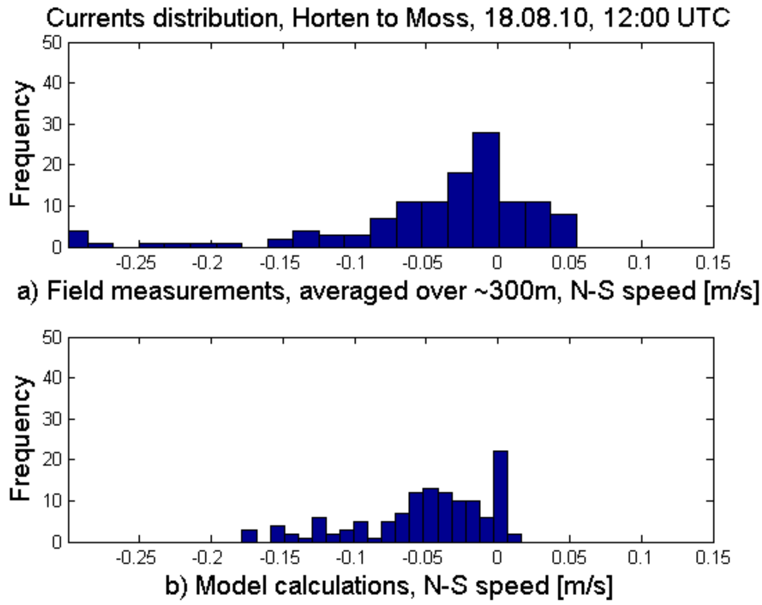


Figure 5.13:
Current distribution, Horten to Moss, transect 4

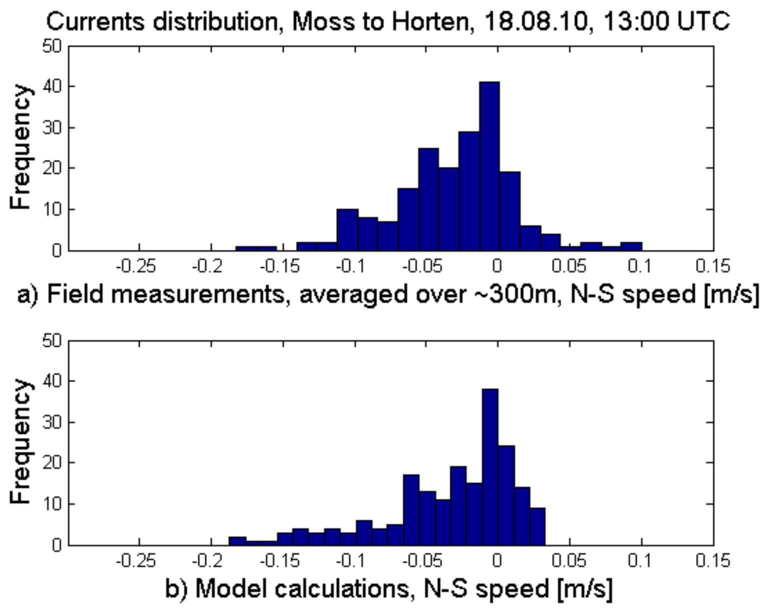


Figure 5.14:
Current distribution, Moss to Horten, transect 5

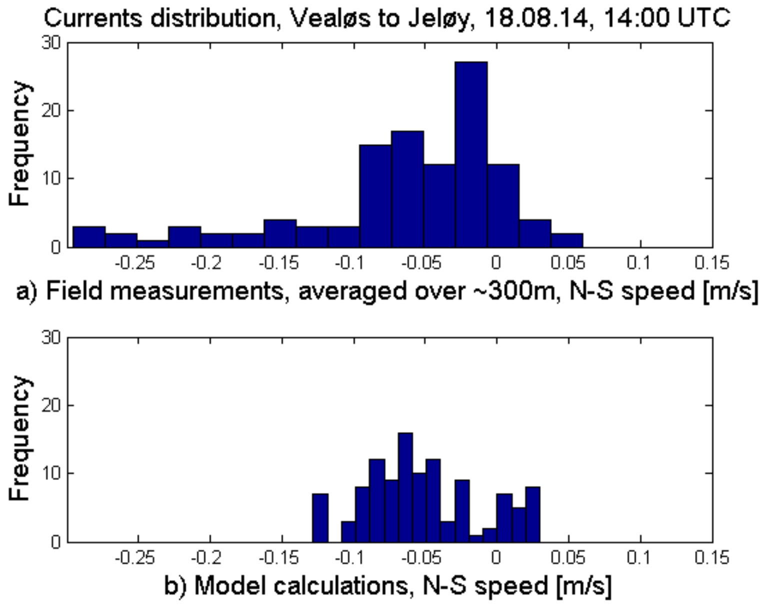


Figure 5.15:
Current distribution, Vealøs to Jeløy, transect 6

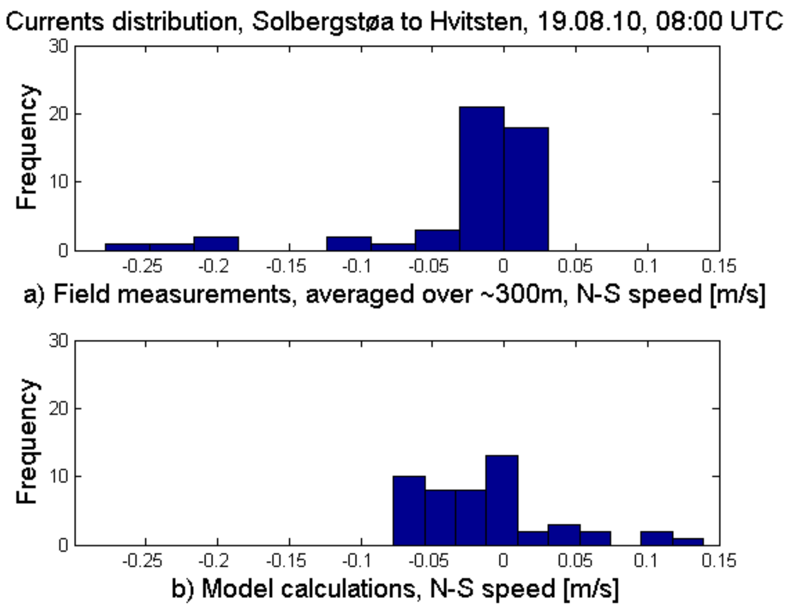


Figure 5.16:
Current distribution, Solbergstøa to Hvitsten, transect 7

5.3.1 North/south velocity, $20s$ averaging

For this comparison, the first Moss to Horten transect, at 09:00 UTC was chosen. According to the changes in water level plotted in section 5.1, the tidal wave should be on its way into the Oslofjord.

The expectation is that averaging over a long period of time, reduces the speed of the currents.

First, here is the histogram from the $300m$ averaging and the model:

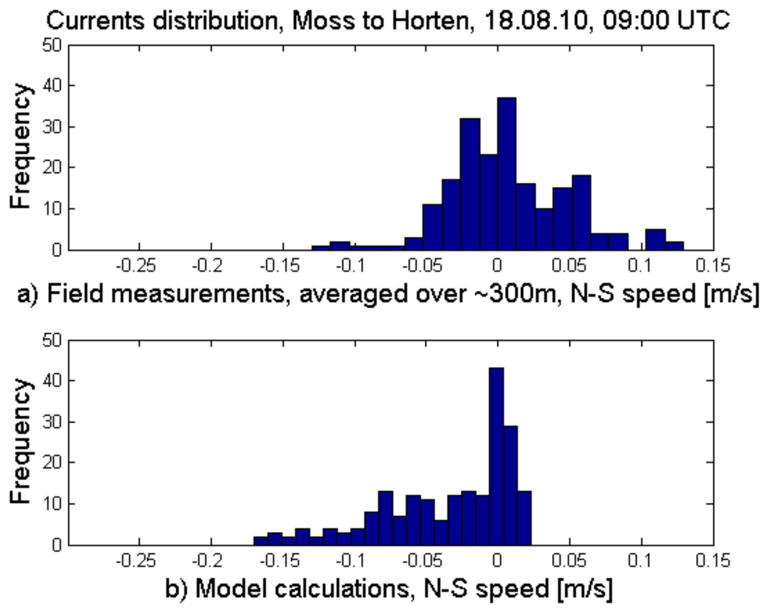


Figure 5.17:
Current distribution, Moss to Horten, transect 1

We have the histogram for the $20s$ averaging:

As expected, the north/south velocity has some larger current components that has disappeared in the long time averaging and in the current data from the MIPOM model.

It can be shown that this is the case for all the transects. In this transect, the difference is noticable, even if not very large. There are bigger differences in other transects.

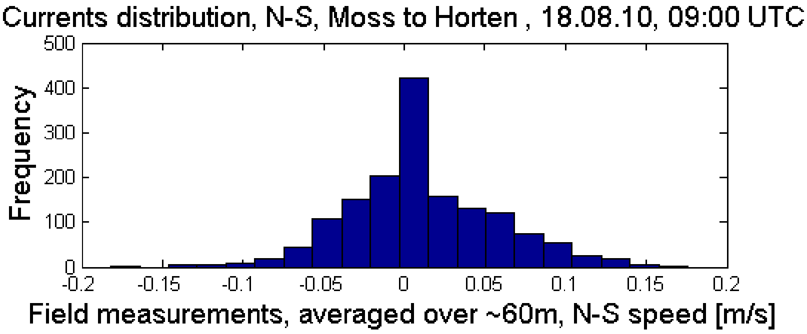


Figure 5.18:
Current distribution, Moss to Horten, transect 1, 20s averaging

5.3.2 Velocity in u-direction, an example

As mentioned initially in chapter 5, the currents in the grids u-direction influences the true north/south currents. Here is an example. For this illustration the first transect from Vealøs to Jeløy, was chosen. It was here the relative error was largest, 9.8%, if the u-component was overseen.

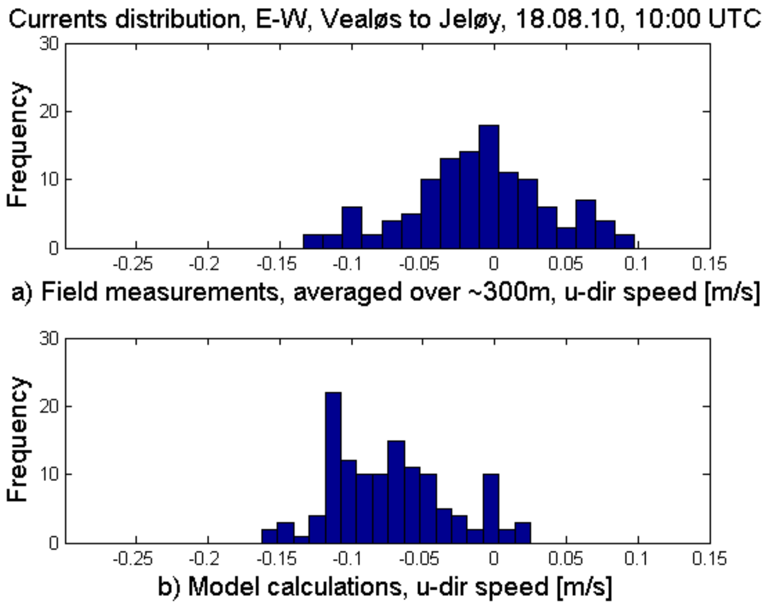


Figure 5.19:
u-directional currents, Vealøs to Jeløy, transect 2

It is obvious that the current values extracted from the model, has a larger absolute value than those measured. This was why the decision was made to include the u-directional currents in the true north/south current.

5.4 Volume transports

The net volume transports has been calculated for all the transects. Volume transports from the field data has been calculated both for $30.5m$ depth and for the full measured depth, $42.5m$. Both of these calculations have used data from the $300m$ averaging matrix, for comparison with the MIPOM data. The methods for obtaining the current values are described in Chapter 4.

The volume transports from water level changes are calculated using equation 4.20, $Q = A\frac{dh}{dt}$.

The areas inside of the transects measured $528km^2$, $501km^2$ and $203km^2$ for Moss-Horten, Vealøs-Jeløy and Solberstøa-Hvitsten, respectively.

The water level changes were calculated for each transect as described in 4.3. Their values are listed in table 5.1

Table 5.1: Water level change $\frac{dh}{dt}$ in $10^{-5}m/s$

Transect	$\frac{dh}{dt}$
MH1	2.38
VJ1	1.61
VJ2	-0.53
MH2	-0.85
MH3	-1.33
VJ3	-2.35
SH2	0.44

Net volume transport for the transects are listed in Table 5.2 and 5.3.

Table 5.2: Net volume transport 18.08.2010 in m^3/s

Transect	Field 40m	Field 30m	MIPOM 30m	$A\frac{dh}{dt}$
MH1	3824.1	1922.3	-10060.3	12552.1
VJ1	-8571.3	-9320.5	-7891.8	8066.4
VJ2	-1280.2	-2527.1	-9293.9	-2642.9
MH2	-6061.7	-8701.9	-9302.4	-4468.4
MH3	-6414.8	-7122.5	-9066.8	-9296.5
VJ3	-11508.1	-11464.9	-8454.4	-11782.9

Table 5.3: Net volume transport 19.08.2010 in m^3/s

Transect	Field 40m	Field 30m	MIPOM 30m	$A\frac{dh}{dt}$
SH2	-2641.0	-2598.6	-223.7	887.7

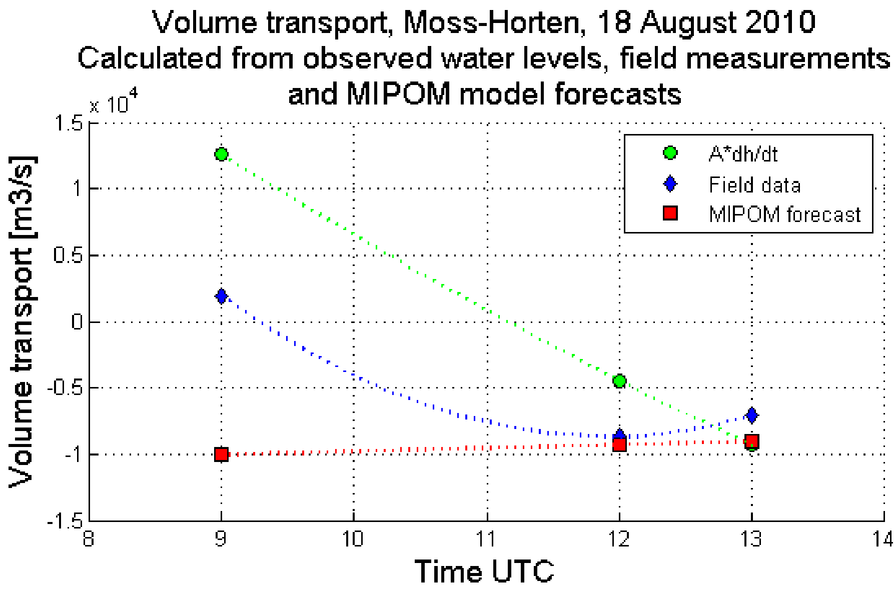
The values listed in table 5.2 are graphically presented in figure 5.19. It is the $30m$ transports that are plotted.

The volume transport as a function of $\frac{dh}{dt}$ changes from positiv to negative with time, which is natural.

The measured volume transports show the same tendency. They are not as large, but that is also natural. The total depth here is much larger than $30m$ and as the tide change, water will flow under the measured depth.

It is possible that the first, 10:00 UTC measurement in the Veløs-Jeløy transect is false. The data has been checked repeatedly, and no errors has been found; no reason to remove it.

The volume transport forecasted by the model is always negative, which means that the model forecasts no inflow.



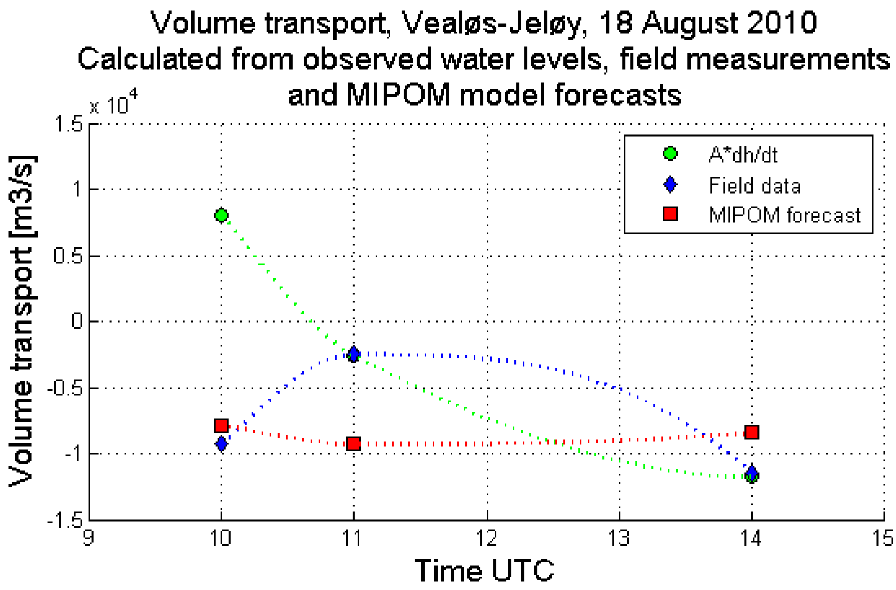


Figure 5.20:
Volume transport 18.08.2010, 300m averaging

Chapter 6

Discussion

The volume transports, currents distribution and position in predestined transects has been measured in field. They have been compared to volume transports, currents distribution and position forecasted by the met.no MIPOM model for the same period of time and place.

There are clearly differences between the field measured currents and the MIPOM model forecasted currents. As a function of the currents, the volume transports also differ. This is seen again in the histograms.

6.1 The volume transports

The strongest indicator of difference between the MIPOM model, field measurements and water level changes, is the calculated difference in volume transport. The data extracted from the model data stored at met.no, showed no net volume transport into the Oslofjord, northward flows.

The reasons for this can be a combination of things. When the model is run, it makes forecasts to $80m$ depth. For capacity reasons, only data from the upper $30m$ are stored. Northward flows could have been forecasted further down.

However, looking at the current plots from the measurements, northward flows can be seen up to $10m$ depth, under the estuarine outflow.

Another explanation may be that there is some kind of time delay in the model. In the last Vealøs to Jeløya transect, at 14:00 UTC, the model forecasted a less negative flow.

To validate such a time delay, more measurements must be obtained. This could include measuring a number of transects for a duration of at least 24 hours each. One of the most pronounced problems with validation of models such as the MIPOM, is availability of time series. Time series cannot be obtained by placing current meters in a rig. A rig is stationary and cannot cover a 9km wide transect.

This thesis also suggest that the model is updated every day with observed water levels and that a routine to interpolate changes in observed water level throughout the grid is implemented. This can help correct the volume transport forecasts and with that increase security in spring tide, very high water level warnings.

6.2 The grid resolution

The MIPOM grid is horizontally built by $300m \cdot 300m$ squares. For an ocean model, this is a high resolution. For the Oslofjord model, it may be too coarse. Details about the coastal- and bottom topography is lost. Especially the bottom topography is important for the positioning (east/west, depth) of the currents in a transect.

Bottom topography shown in the plots where the currents are averaged over $20s$ ($60m$), i.e. Moss to Horten, differs substantially from those averaged over $300m$ or the MIPOM model plots. In the first transect, Figure 5.3, what may be topographic steering of the rising tide is visible in the field plot.

The most direct visual comparison is between the measured field currents averaged over 300m and the 300m grid model currents. In the plot of the measured field data averaged over $300m$, the input is the same as for the $20s$ average. That means that the general position of the in- and out-flows are kept.

The MIPOM model places the currents in different positions compared to what is measured in field. It tends to position transports out of the Oslofjord in the middle of the transect or slightly on the eastern side.

This may be caused by the coarse bottom topography or it may be that there is a Coriolis influenced rotational motion that is not implemented in the model.

Whatever the reason, there is a difference between the positions of the currents in the measured data and in the output data from the model. This thesis work suggests a higher resolution in the grid. It is important that the topography is represented as accurately as possible.

Chapter 7

Conclusion

The original task was to validate the MIPOM model through field measurements. To obtain this, more field work is required. Methods to gather reliable time series should be in focus. The obvious way is to stay in field for longer periods of time. It could be time consuming, but probably the only method that ensures the required results.

This thesis work has uncovered differences in the output data from the MIPOM model and the field measured values. At times, the currents and volume transports differs substantially. Then a period of time follows when there is correspondence between the measured values and the modeled ones. These phenomena should be looked into and seeked solved.

A higher resolution should definately be considered. For coastal areas the topography seems to influence the flow patterns heavily, especially the bottom topgraphy. A higher resolution should detect topographic steering and result in better knowledge of where the currents are positioned.

The validation process was instructive, most because of the complexity of the issue at hand. Contributing to make the NOWP better has been the main issue of this master thesis.

Chapter 8

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