RAPPORT FRA HAVFORSKNINGEN

Nr. 7-2012

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Jan 2012

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HAVFORSKNINGSINSTITUTTET
INSTITUTE OF MARINE RESEARCH

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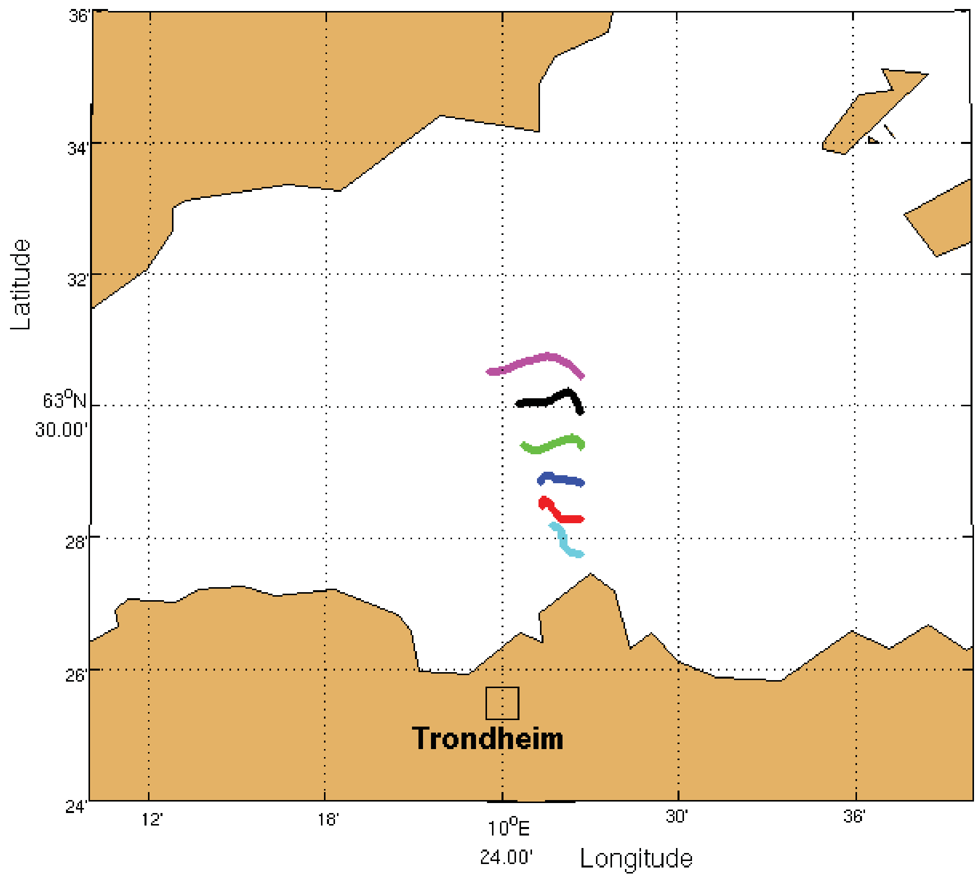


Report to North Energy ASA
Project 13662

HAVFORSKNINGSINSTITUTTET
INSTITUTE OF MARINE RESEARCH

Content

Summary and conclusions

Complicated surface currents make oil protection and clean up a difficult task. This report describes the results from a test of the accuracy of a method that has the potential to be used both to get more detailed knowledge about surface currents in an area and also to collect up to date information of surface current conditions during and after an oil spill event. The method, called Olex SB, is connected to the Olex system and software widely used by fishing vessels for mapping the sea bottom. The reliability of the Olex SB method was tested against data from surface drifters that drift with the upper part of the water column, during a 4-5 hour long field survey with a boat equipped with Olex SB. The drifters were put into the sea from the boat about 1 km apart along a straight line and the boat then followed a track that passed each drifter seven times before all drifters were taken on board the boat again. Comparisons were made between Olex SB data and each drifter when the distance between them was closer than 350 meters. On average the Olex SB estimated surface drift was stronger and shifted to the right from the drifter estimated surface drift. However, the variations in these differences were large, and statistical analysis says that the average is likely not an actual difference. The conclusion of the report is therefore that the Olex SB method is a reliable method for estimation of ocean surface current within reasonable accuracy. The precise accuracy of the method was not possible to deduce from the experiment. We have found no systematic differences between the two methods, and qualitatively the surface current during the experiment agrees with the characteristics of a wind driven current.

1 Introduction

1.1 Background and objectives

The success of oil protection and clean up in connection with a possible oil spill rely on good knowledge and evaluation of the surface currents in the oil spill surroundings. The spreading of the oil spill is determined by the surface currents, and oil spill containment booms are influenced by the current in the upper meter of the water column. Especially near the complicated Norwegian coast it is difficult to have detailed pre hand knowledge about the current systems. Direct measurements of surface currents by fishing vessels would therefore be a valuable resource both for evaluation of the vulnerability of the coastal areas, and during a possible oil spill event. Olex offers such a system; Olex SB. However this system has not been validated against established methods for estimation of surface currents.

One such established method uses surface drifters to estimate the current in the upper water column. It can be constructed to measure the drift at a specific depth below the surface or specifically in the ocean surface. Wind induced currents will be strongest in the surface and diminish with depth even in the upper meter of the water column. For the purpose of the present field comparison experiment, 6 surface drifters were constructed at Institute of Marine Research (IMR), which should estimate the drift in the upper 80 cm of the water column. These were compared with Olex SB measurements at approximately 60 cm depth.

The objective of the field experiment was to collect data that enabled us to evaluate the precision of the Olex SB system for estimation of surface current from a boat. The outline of the present report from the project is to first describe the field experiment, describe the two measuring methods; surface drifters and Olex SB, and present and compare data from the two methods, including possible explanations for discrepancies.

1.2 Field experiment

The field experiment was conducted in Trondheimsfjorden, 9 November 2011, in collaboration with the Olex Company who provided their boat Teist (shown in Figur 1.1) for the field experiment. The Teist had Olex SB mounted. Six drifters were deployed from the boat approximately 1km apart along a straight line from south to north, and then left drifting until they were all recovered after about four hours. During this time the boat steamed at steady pace in back and forth northward/southward laps such that it passed all drifters each lap. The wind came from north-east with varying strength during most of the experiment, so the wind was blowing from the side relative to the heading of the boat. The Teist is a 35 ft fishing vessel. The wheel house is at the front while the engine is towards the stern. Most of the keel is near the stern too. Thus when moving with wind blowing from the side, a certain bias must be expected regarding the real direction of the calculated current. This is quite normal for such fishing vessels.

Figure 1.1. The fishing vessel Teist used during the field experiment in Trondheimsfjorden.

Ship tracks and drifter tracks are shown in Figure 1.2, where also the time (local time) of start and stop of the Olex SB data logging as well as approximate time of turning points in the ship track are displayed. As indicated in the figure, Olex SB data were logged between local time 12:23 and 16:35.

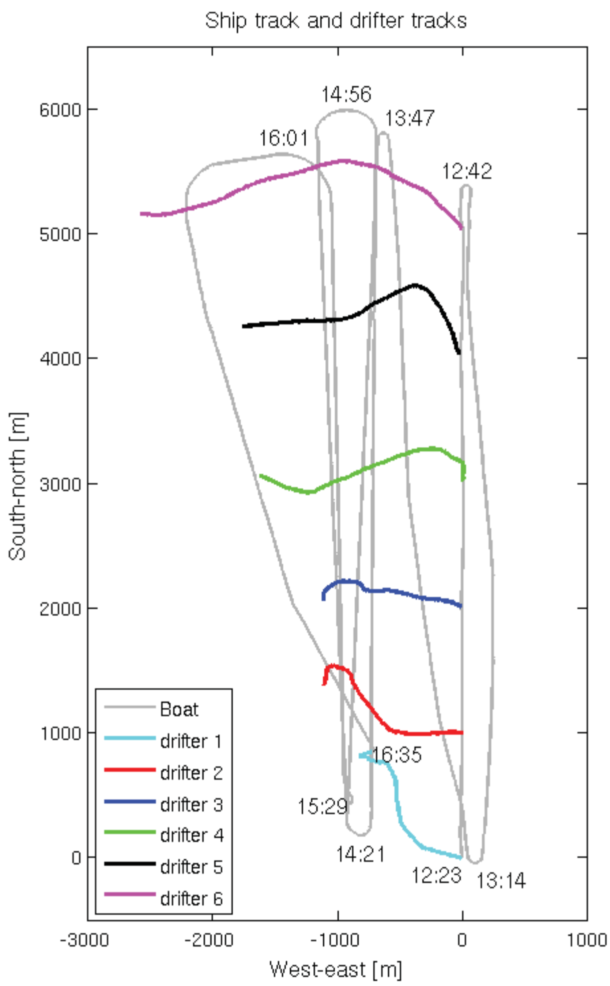


Figure 1.2. Drifter tracks 9 November 2011 of all six drifters in meter-coordinates, plotted on top of the ship track. Starting, turning and ending time (local time) for the boat are marked in the figure.

2 Materials and methods

2.1 Olex SB

Olex SB is a commercial system which is more and more used by fishing vessels. The SB software calculates and displays the present water current by continuously monitoring data from simple sensors. The currents are also recorded in a geographical grid with 12 datapoints per cell, each holding a current at a distinct section of the lunar to earth angular variation, enabling the system to estimate currents for a given position at various future sections of the tidal cycle. On the Olex display, the realtime current is shown as an arrow of varying size pointing away from the vessel. A slider may be operated to scan ahead in time and see how the currents will shift over a geographical area. Regardless of the quality or availability of pre-mapped currents, the present one is always independently calculated. Errors or bias in past data will thus not affect the realtime display at the vessels position.

For the purpose of comparing the Olex SB data with drifter data, Olex developed a separate system that continuously stored the measured data to a file. The format of the data is described under data processing.

Calculation method

The system continuously holds the last 60 seconds of NMEA data from GPS, a true heading source, and a water speed sensor. Every second, water speed and true heading is integrated from the oldest position, and the resulting dead reckoning position is compared to the last GPS observation. The difference is assumed to represent the mean water current for the 60-second period. The NMEA data is then shifted one second, and the procedure repeated.

The method relies on the assumption that the vessel moves through water along the reported true heading. This might not be true when turning or swayed by waves, so the system monitors acceleration and centripetal forces, temporarily halting the current mapping when such are deemed out of bonds. GPS course and speed are also integrated and compared to observed positions in a likewise filter of GPS inaccuracies.

Typically, the water speed sensor will exhibit a non-linear speed bias due to the complex water flow under and around the hull. This bias is mapped and compensated for through a special self-learning calibration routine, the SB software guiding the vessel through certain manoeuvers. Currents are only calculated when the sensor operates within the calibrated speed range. Accurate heading rotation bias is also calculated and compensated.

Error sources

The quality of the current calculation will suffer if the vessel does not really move along its heading vector. This may be the case of multi propeller vessels, when towing heavy gear, or when compensating for strong side wind forces. Wind blowing along the vessel heading (ie from front or astern) is not a factor though. A filter to stop calculations as wind increases is under consideration.

Inaccurate sensors, like GPSes that smoothes its outputs, will likewise invalidate the calculations. Such errors are flagged by the SB software filters. Best results have been achieved with satellite compasses for true heading, and simple paddlewheels for water speed. The latter may slowly drift in performance due to wear or contamination; yearly inspection and recalibration (through the SB software) is recommended.

Conventional GPS yields an irregular accuracy of 5-10 meters. This imparts some noise on the calculation, but not a constant bias. The 60 second period is designed to minimize this; better quality GPS (maybe augmented with RTK or PPP) could reduce this time window, making the system more agile and better able to map while manoeuvring or in heavy swells.

On board the Teist, GPS and true heading comes from a Furuno SC-60 satellite compass, while water speed is measured by an Airmar Triducer paddlewheel. Typical 2011 price for such an sensor suite might be 30.000 NOK for the GPS+heading, and 5.000 NOK for the water speed.

2.2 Drifters

The six surface drifters were constructed and built at the Institute of Marine Research. Each drifter construction includes a trawl float, 20 cm in diameter, attached on top of a stiff, cylindrical, 80 cm thick skirt made of a metal skeleton surrounded by a trawl net. An iron chain attached to the bottom of the cylinder ensures that it is positioned upright in the water column. The drifters can be seen in Figure 2.1. The Garmin Astro 220 GPS Dog Tracking system with DC-40 collars was used to track the drifters during the field experiment. A DC-40 collar was mounted on top of each drifter, communicating via VHF with the Astro 220 GPS hand unit on board the boat. As long as a drifter was positioned within about 5 km from the boat, the hand unit could report its GPS position. This system was used solely to keep track of each drifter during the experiment. A second GPS (GARMIN foretrex 401) also mounted on each drifter was logging GPS position every 30 seconds. The foretrex 401 data were downloaded after recovering of the drifters and processed for comparison with the Olex surface current measurements.

Figure 2.1. Mounting of GPS and dog collars to the drifters on board the Teist in Trondheimsfjorden.

2.3 Data processing

Olex SB

Logging of the Olex SB data to a computer file was started when drifter 1 was deployed. An example of the file data format that was especially developed for the purpose of comparing Olex SB measurements with drifter data, is given below:

```
# Hour       X[m]   Y[m] [Heading Speed][Wind dir speed][Current dir speed]
12:24:23   -13.3  142.4   1.9   3.60     94.1   1.4      303.4   0.33
12:24:24   -13.2  146.0   1.8   3.60     94.6   1.5      302.7   0.33
12:24:25   -13.5  149.3   1.7   3.55     94.2   1.4      303.2   0.34
```

'Hour' refers to local time. X (west-east) and Y (south-north) are distances in meter from the origo point, positive in eastward and northward directions respectively. Origo (X and Y are 0) is located at the start of logging to file (deployment of drifter 1). Column 4 and 5 refer to heading and speed of the boat, column 6 and 7 refer to wind direction and speed, and column 8 and 9 to estimated surface current direction and speed. Heading and directions are given in compass direction (note that wind direction is where the wind blows from). All speeds are given in meter/second. Data were logged to file every second, however all direction and speed data were averages from the previous 60 seconds. Surface current was calculated only when ship heading was approximately steady during these 60 seconds.

Foretrex 401 GPS

The foretrex 401 GPS data from the drifters were downloaded with the GARMIN software 'MapSource', giving files with the following data format (example from drifter 2):

Header	Position	Time	Altitude	Depth	Temperature	Leg Length	Leg Time	Leg Speed	Leg Course
Trackpoint	N63 28.290 E10 26.688	09.11.2011 12:28:58	-1 m	-	-	4 m	0:00:30	0.4 kph	294° true
Trackpoint	N63 28.291 E10 26.682	09.11.2011 12:29:28	-2 m	-	-	5 m	0:00:30	0.6 kph	277° true
Trackpoint	N63 28.291 E10 26.677	09.11.2011 12:29:58	-1 m	-	-	5 m	0:00:30	0.6 kph	271° true

Position was recorded as WGS 84 datum latitude, longitude, local time, altitude in meter, (depth and temperature were not available in the GPS used in the experiment), leg length between each trackpoint in meter, leg time in the format HH:MM:SS (always 30 seconds), leg speed in km/hour and leg course as compass direction. Only the GPS positions and time data were included in the Matlab data processing.

Longitude and latitude were converted to metric distances x and y, from the Olex SB origo (position for deployment of drifter 1, and drifter velocity components calculated as distance between each x and y point divided by leg time. Due to scattered errors in GPS positions the velocity data are also rather scattered. Smoothing is therefore performed on the x and y position components, with a lowpass Butterworth filter with cut off frequency corresponding to a 5 minute window in the time series. The data presented in the report are these smoothed values; it is noted in figure texts when raw data are also shown.

3 Results

3.1 Time series comparison

Olex SB velocity data and drifter velocity data can be comparable only when the boat and drifter are relatively close to each other in position and time. In Figure 3.1, the whole time series from all drifter velocity data as well as Olex SB data are shown in the same plot with similar color coding as in Figure 2, just to show that both current speed and direction are approximately within similar range in the two methods.

Figure 3.2 shows the smallest distance between each drifter and the boat, every drifter time step is checked against the time frame ±15 seconds in the Olex SB data file. Rough testing indicates that the boat should be at least closer than 350 m from a drifter before it is realistic to compare the two data types.

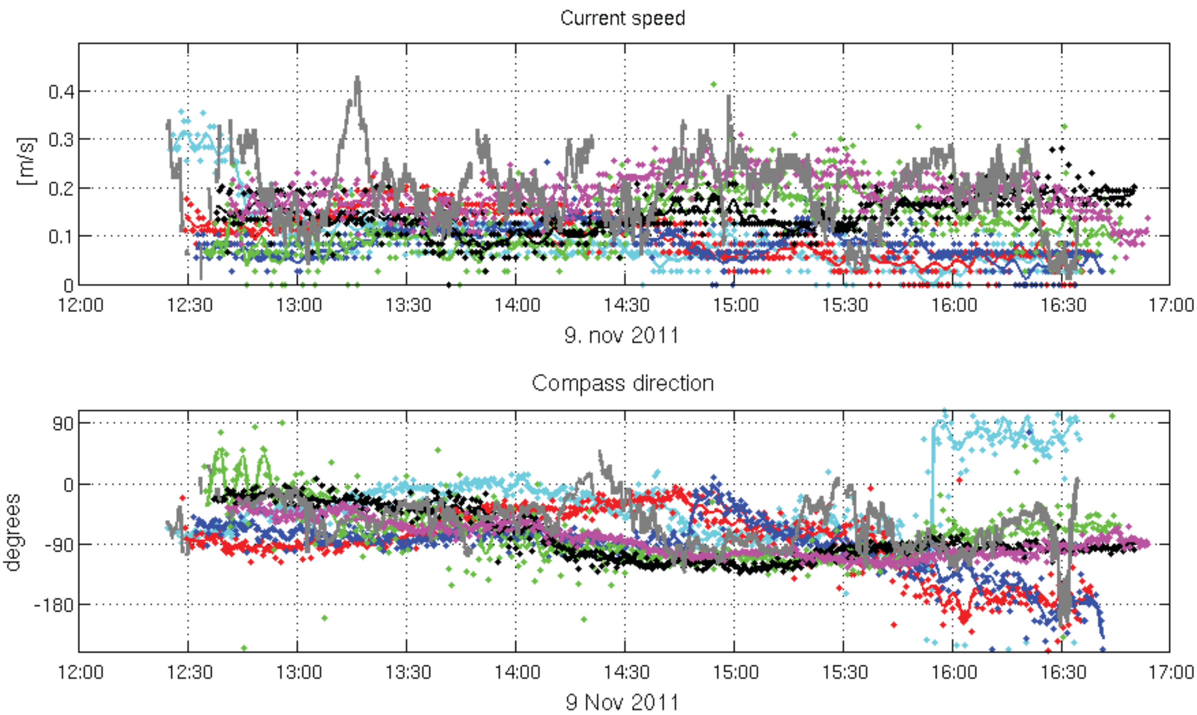


Figure 3.1. Current speed and compass direction measured by the boat with the Olex system (grey) together with corresponding data derived from drifter tracks, all measurements included. Dotted points refer to raw data (derived from positions stored in GPS), while lines refer to smoothed data (low pass filtering with 5 minutes time window). Color codes are the same as in Figure 1.2.

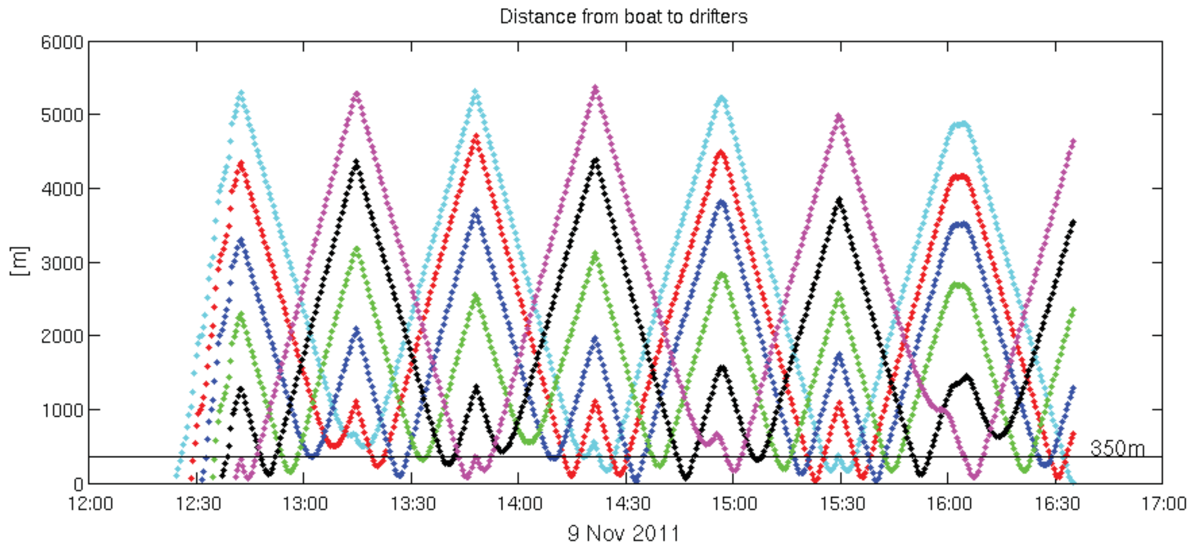


Figure 3.2. Distance in meters from the boat for each drifter, plotted with time. Color codes are the same as in Figure 1.2.

A data selection is then made of drifter time steps when each drifter is closer to the boat than 350 m, and Figure 3.3 displays current speed and compass direction of these selected drifter time steps together with the total Olex SB time series. There is a tendency of the drifter speed being slightly lower than the Olex SB speed, and the drifter current direction being slightly to the left of the drifter current speed, in extreme cases up to an angle of 90° to the left. There is however not a systematic difference that is visible directly from the time series.

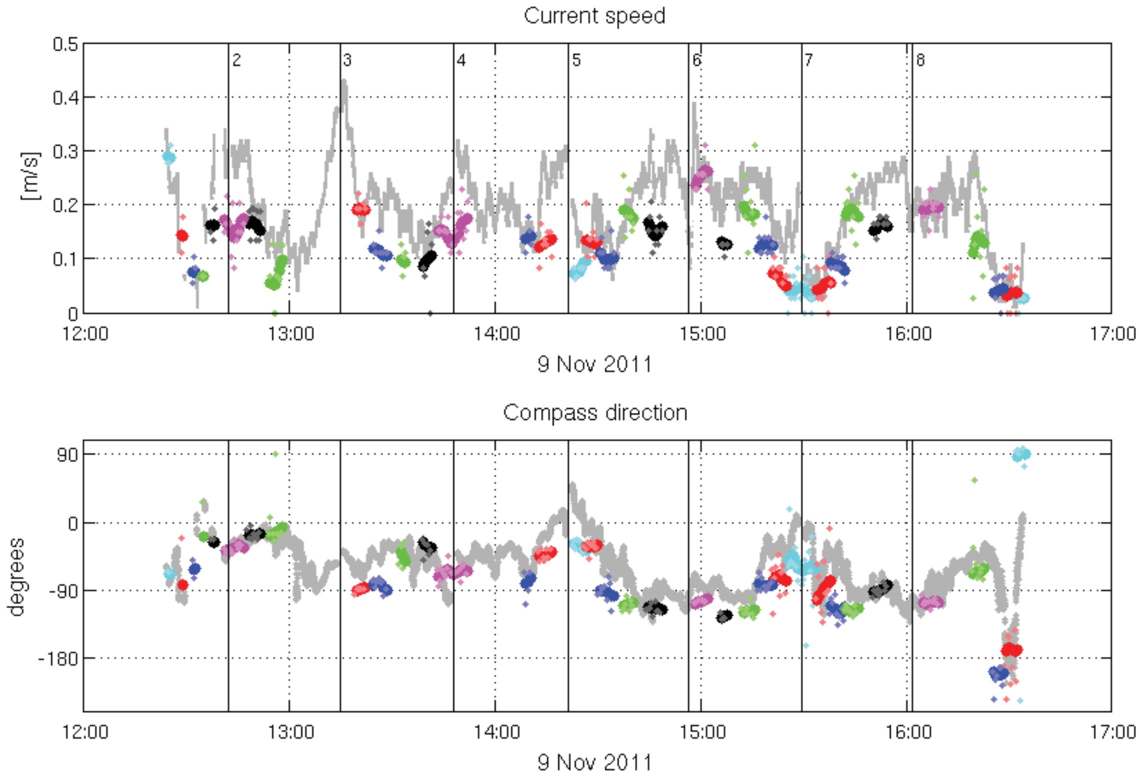


Figure 3.3. Current speed and compass direction measured by the boat with the Olex system is plotted as grey lines with time. Corresponding values derived from drifter tracks are plotted as colored dots when the drifters are closer than 350m from the boat (see Figure 3.2). Color codes are the same as in Figure 1.2. The largest dots refer to values deduced from smoothed drifter tracks (low pass filtered with 5 minute time window), while the smallest dots are derived directly from positions stored in each GPS. The time series is divided into 8 legs representing alternating northward and southward bound ship track.

The colored drifter current arrows are plotted as a rose plot in Figure 3.4 together with selected (30 seconds apart) corresponding arrows of Olex SB current. Arrow plots of Olex SB and drifter currents as well as wind, at their respective location in their tracks are shown in Appendix from the closest point every time the boat passed a drifter, also when this distance was larger than 350 m. Wind speed and compass direction (direction the wind blows towards for easier comparison with currents) are also shown as time series in Figure 3.5, and as rose plots in Figure 3.6. Note that the wind is generally strongest to the north, furthest away from the shore.

Wind driven surface currents are generally shifted 15°-45° to the right of the wind and the current speed is typically 3-5% of wind speed. These characteristics are effects of friction and the rotation of the earth. For similar reasons there is a weakening with depth of current speed and deviation to the right with depth in current direction. The observed surface currents generally follow these characteristics and thus appear to be mostly wind driven. The data discrepancies between the two methods might also be explained by the wind driven theory, due to differences in representing depth. Explanations of the differences are not elaborated on any further, instead the report proceed with a statistical analysis of whether the differences are significantly different from zero, and whether the differences are systematically dependent on other factors.

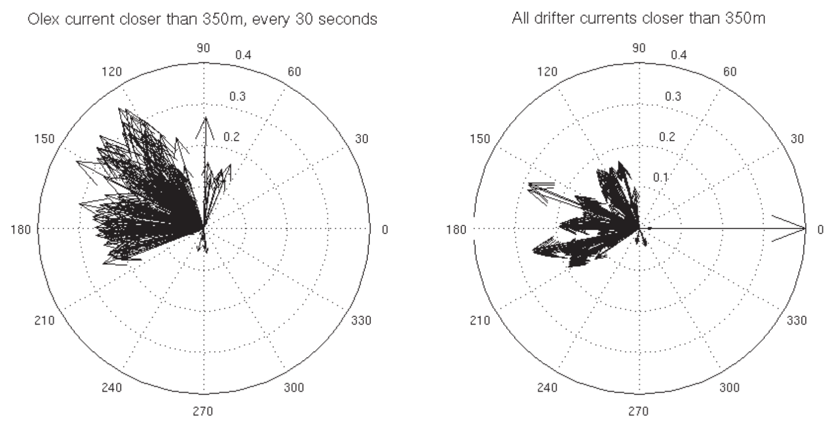


Figure 3.4. Rose plot of selected Olex SB current arrows and drifter current arrows, occurring when the boat is closer than 350 m to a drifter. Every 30 measurement of the Olex SB arrows are selected. Note that 90° is to the north and 0° to the west. The westward drifter arrow is plotted to make the arrow lengths in the two plots comparable.

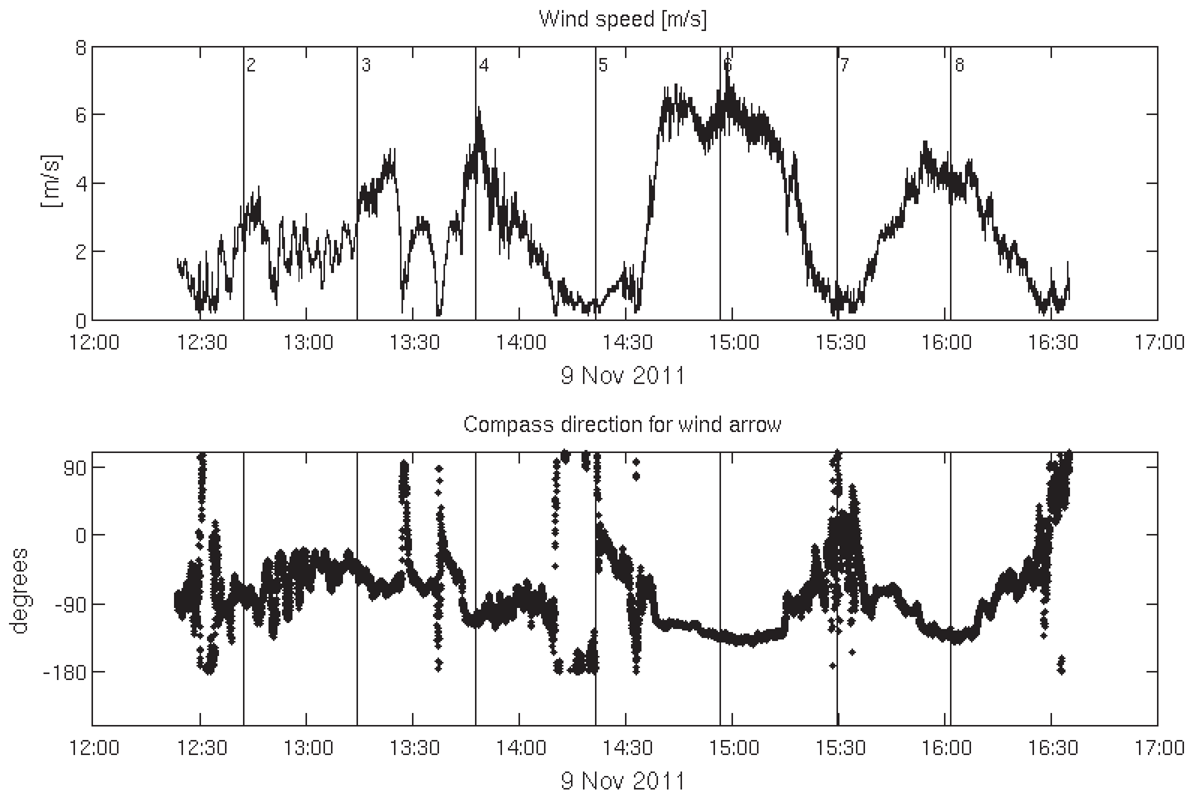


Figure 3.5. Wind speed and compass direction of wind arrow (direction the wind blows towards) plotted with time. Wind is measured on board the boat.

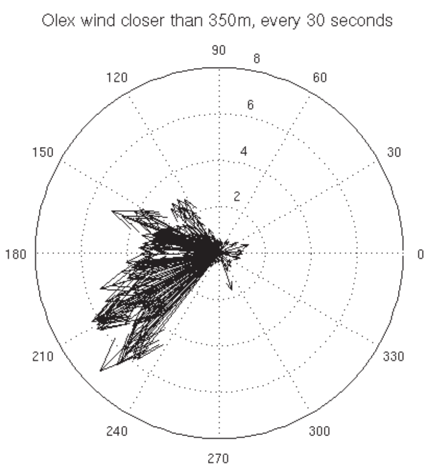


Figure 3.6. Rose plot of wind arrows showing the direction that the wind blows towards at selected times corresponding to the current arrows in Figure 3.4.

3.2 Statistical comparison

Every occurrence of a drifter being closer than 350 m sum up to 258 incidences, making up an ensemble that is used for statistical analysis. The ensemble include drifter current, corresponding Olex SB current, wind, time of each specific incidence and distance from the boat to the drifter. It is further assumed that the drifter speed relates to the Olex SB speed according to a fraction, and that drifter current direction is shifted a certain angle to the Olex SB current direction. Four incidents are excluded because they are not included in the interval (mean ± 2 standard deviations) when considering the fraction values, giving 254 incidents for further analysis.

In Figure 3.7, five time series from these incidents are shown, including from top to bottom panel; speed fraction between Olex SB and drifter measurements, speed difference in m/s between Olex SB and drifter measurements, compass angle difference between Olex SB and drifter measurements, and finally wind speed and wind arrow direction. The upper three panels also include the mean value drawn as a dotted line. The largest compass direction difference variations (third panel) occur during the last few minutes of the experiment, possibly due to an overall change in wind direction in the area (see bottom panel). The last 18 measurements are therefore also excluded from the statistical analysis, leaving 236 incidents. If the current speed and direction differences between the two measuring methods have a normal histogram distribution (Gaussian distribution), one can use Students t-statistics to test the hypothesis that the mean difference is significantly different from zero. We postulate the zero hypotheses, H_0 that the mean difference is zero. The fraction [Z=(mean value)/(standard deviation)] then has to be smaller than a given value depending on confidence interval (from a lookup table of cumulative t-distribution) and degrees of freedom. We postulates that the degrees of freedom in our experiment is at least the number of times the boat passes closer than 350 m from a drifter, around 40 times, giving $T_{0.05} = 1.684$ as the 95% limit for Z.

The histograms of surface current differences of speed and direction between the Olex SB and drifter measurements are shown in Figure 3.8, together with histogram of the speed fraction between the two methods (upper panel). The Z-values are for speed difference 1.12 and direction difference 0.92. Both values are smaller than $T_{0.05} = 1.684$, so H_0 cannot be rejected; the differences are not significantly different from zero within the 95% confidence limit.

We can conclude that the two measuring methods are significantly similar, although there appear to be tendency of the Olex SB measurements to be slightly stronger and direction turned to the right of the drifter measurements. We are not able to find systematic explanations for these differences, and encourage further testing to out rule or explain the differences. The most likely error source is the wind blowing sideways relative to the ship heading. Some preliminary tests are shown in the following figures. First shown is, similarly as the rose plots in Figure 3.4; histogram plots of the 236 selected incidents in Figure 3.9.

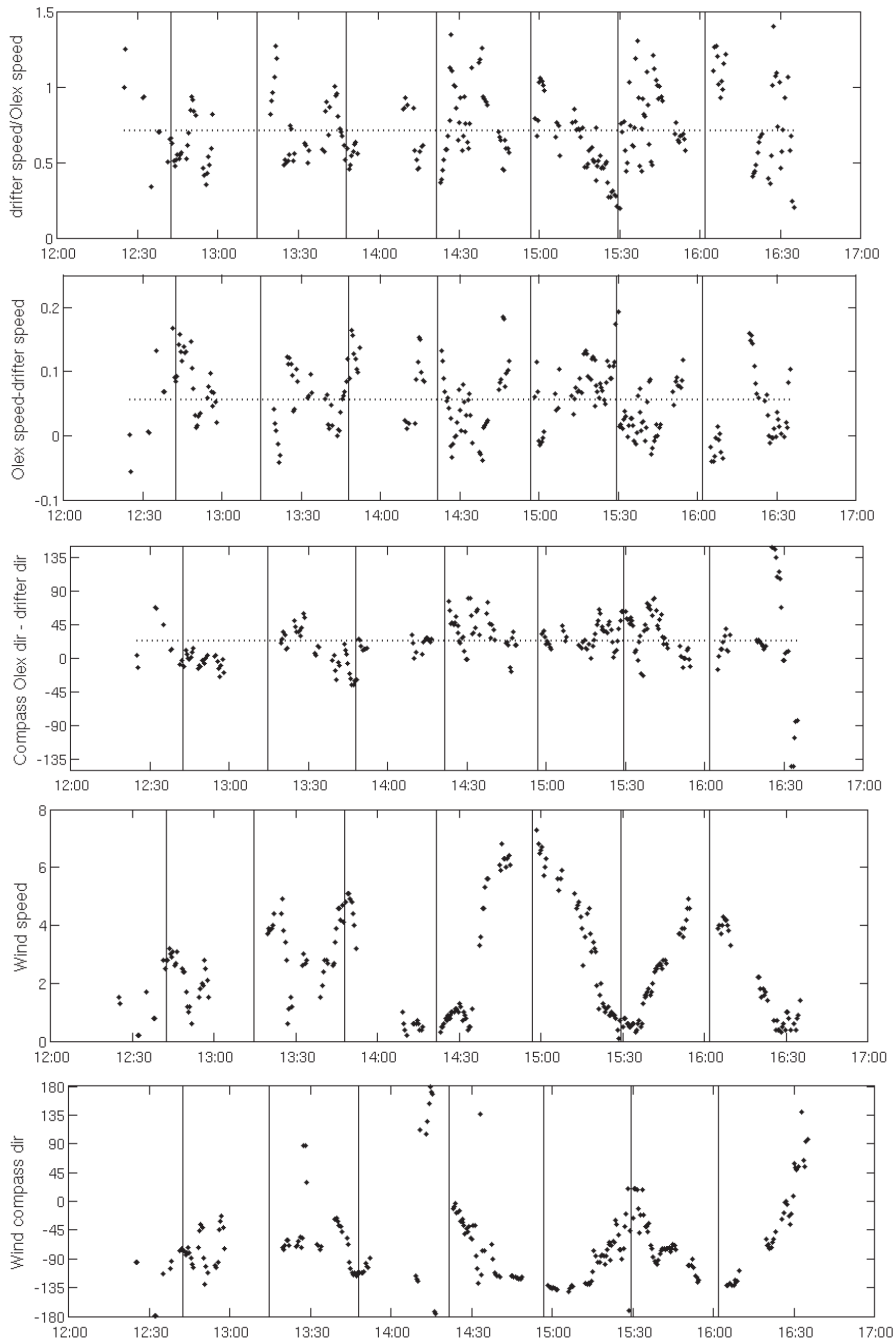


Figure 3.7. Time series of speed fraction, speed and direction differences between Olex SB measurements and drifter measurements at 254 selected times when the boat is closer than 350 m from a drifter. The corresponding wind speed and directions are plotted also.

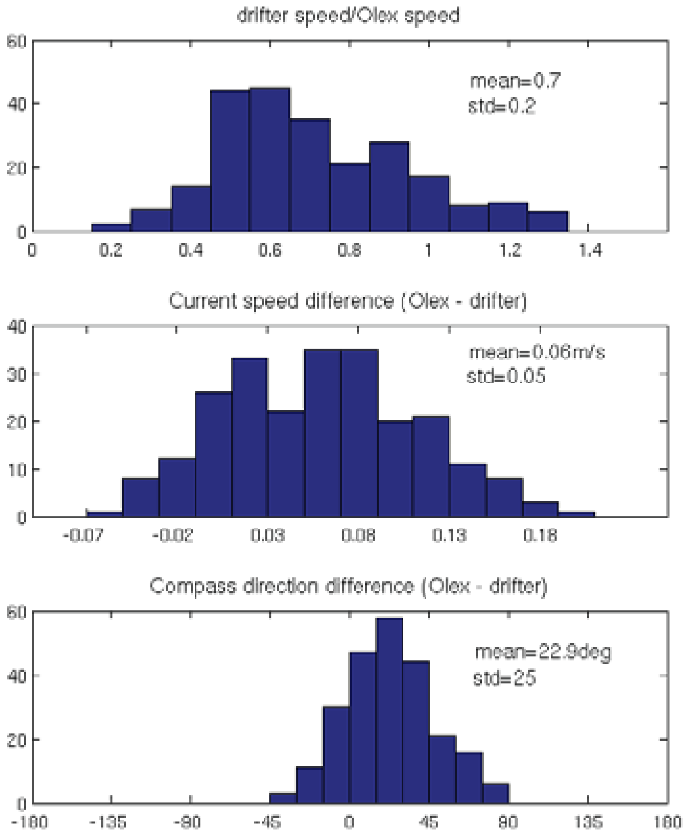


Figure 3.8. Histograms of surface current speed fraction, speed and direction differences between Olex SB measurements and drifter measurements at 236 selected times when the boat is closer than 350 m from a drifter.

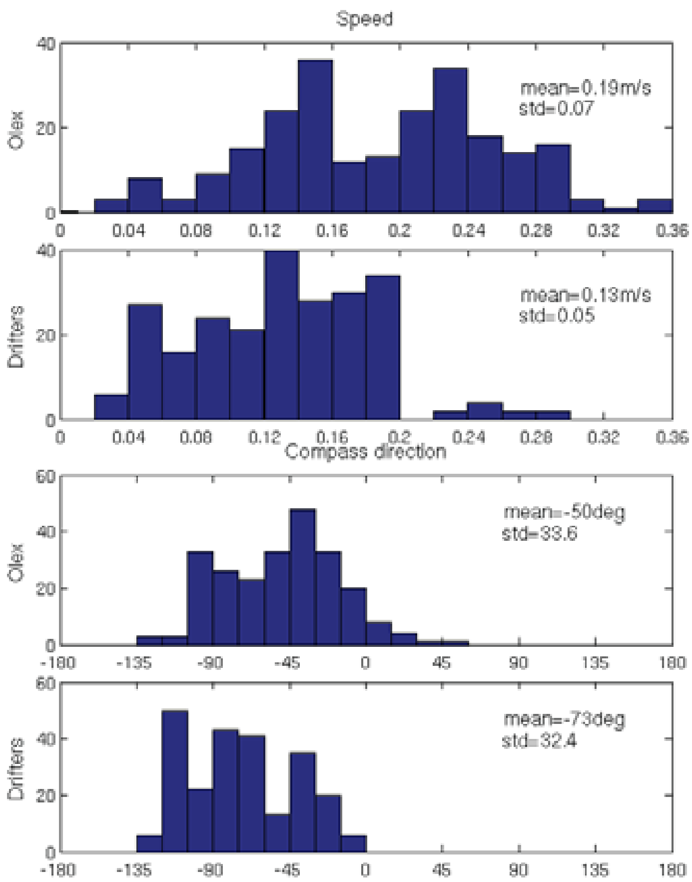


Figure 3.9. Histograms of surface current speed and direction of 236 incidents measured by Olex SB (upper two panels) and drifters (lower two panels).

Figures 3.10, 3.11 and 3.12 show the same data plotted against distance between drifter and boat, Olex SB speed and wind speed respectively. The scatter is somewhat larger during week winds, otherwise there are no clear trends in the plots.

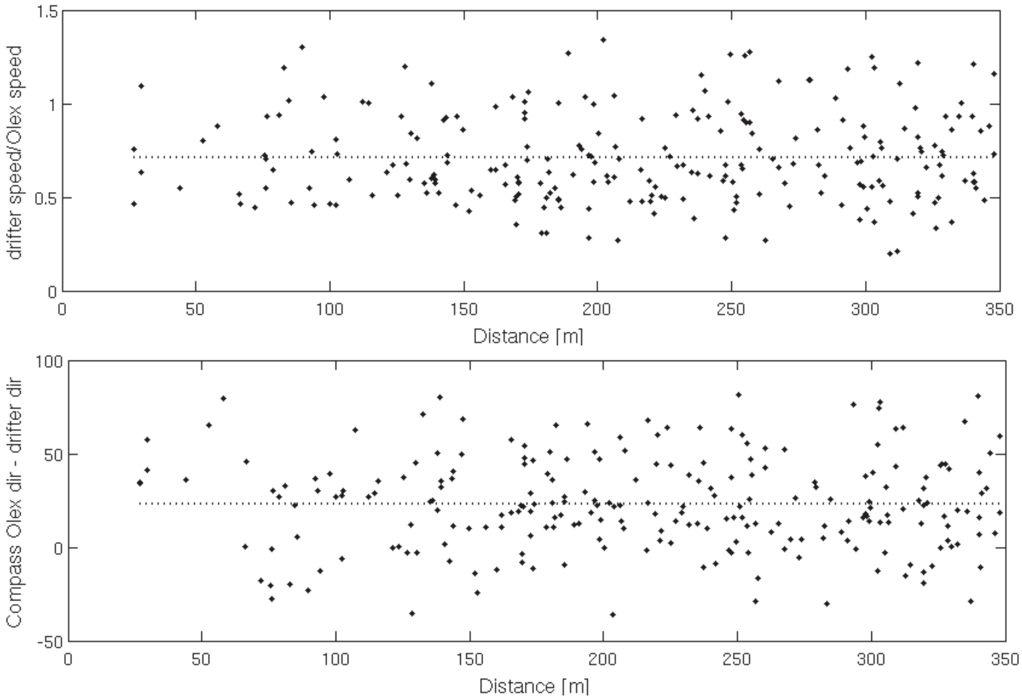


Figure 3.10. Surface current speed fraction and direction differences between Olex SB measurements and drifter measurements at 236 incidents when the boat was closer than 350 m from a drifter, plotted against distance to the selected drifter.

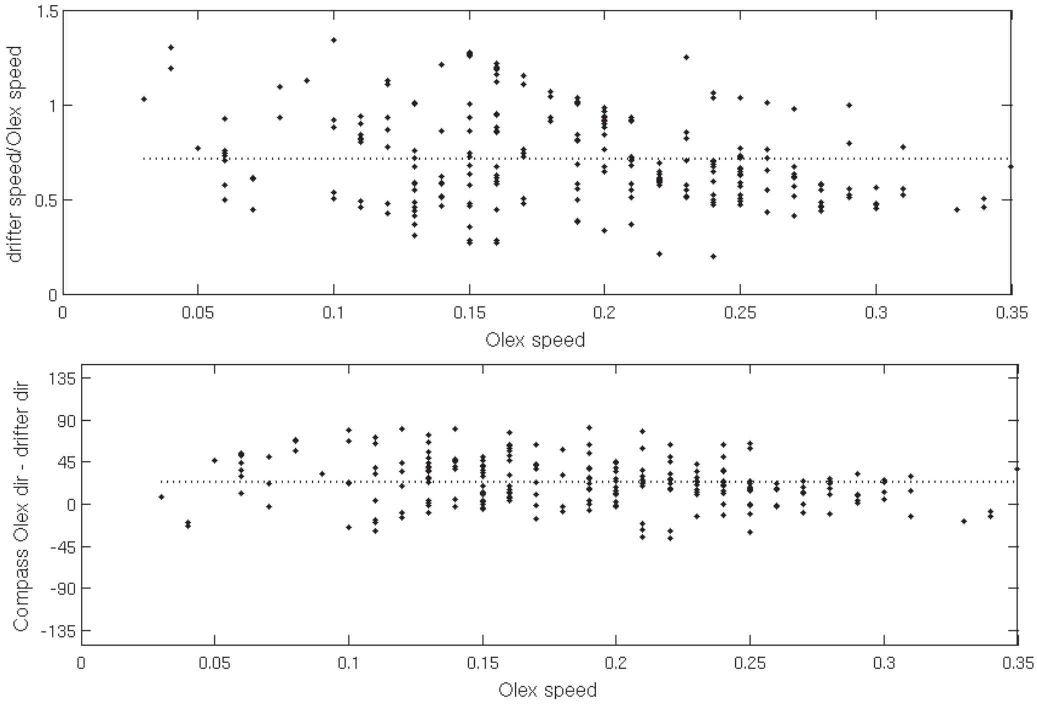


Figure 3.11. Surface current speed fraction and direction differences between Olex SB measurements and drifter measurements at 236 incidents when the boat was closer than 350 m from a drifter, plotted against surface current speed measured by Olex SB.

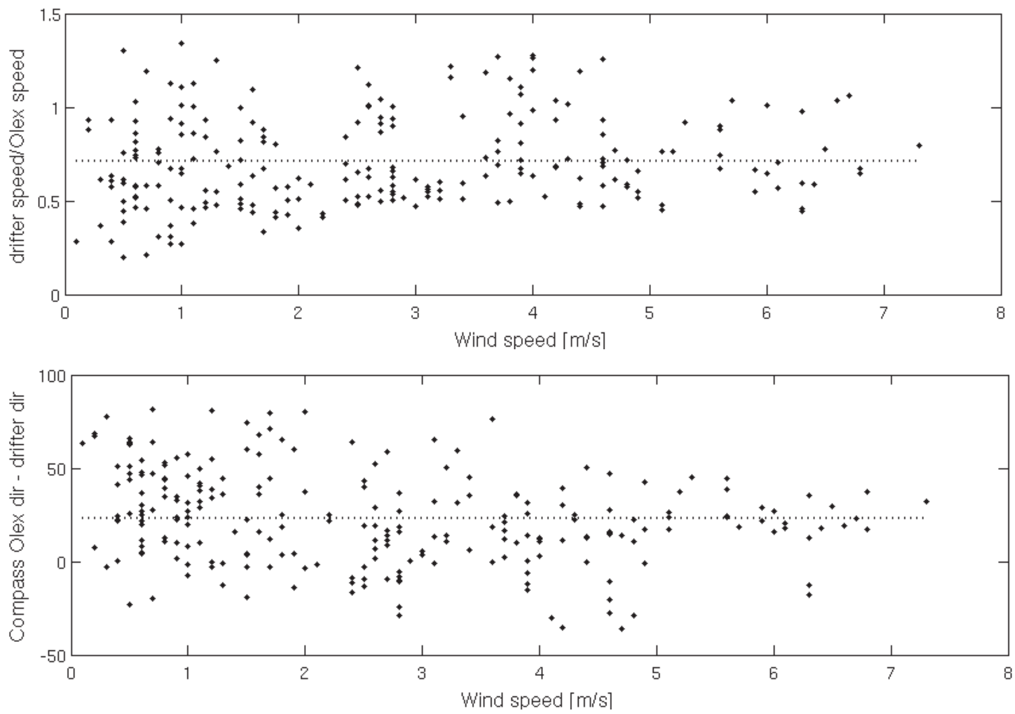


Figure 3.12. Surface current speed fraction and direction differences between Olex SB measurements and drifter measurements at 236 incidents when the boat was closer than 350 m from a drifter, plotted against wind speed.

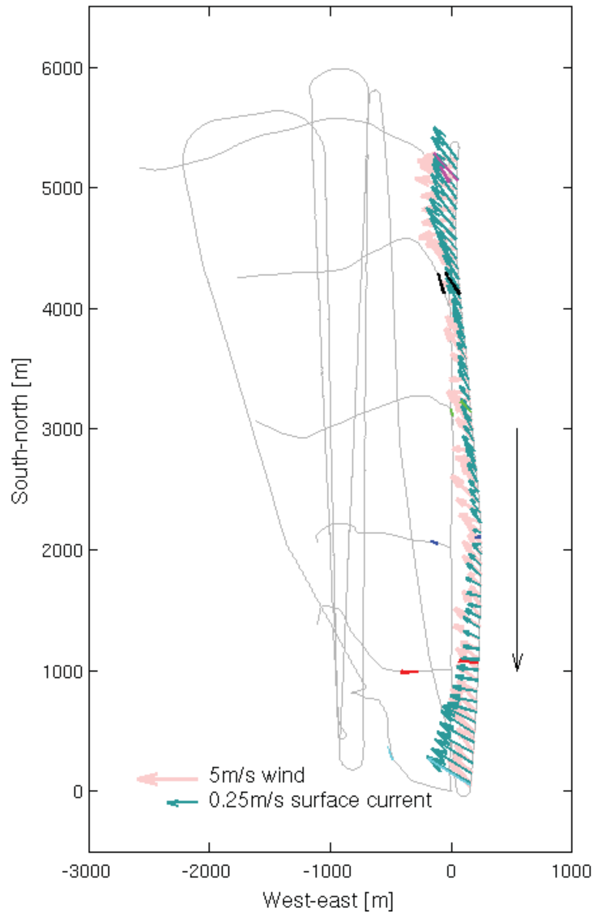
4 Conclusion

Based on Students t-statistics, the Olex SB method for measuring surface current is, within 95% confidence interval, not significantly different from the method using surface drifters. However, there is a tendency that Olex SB measurements are shifted to the right in direction and has stronger speed than the drifter measurements. No explanation for this is found in the present report. However, this could be investigated further, especially the sensitivity to varying wind speed and direction relative to ship heading.

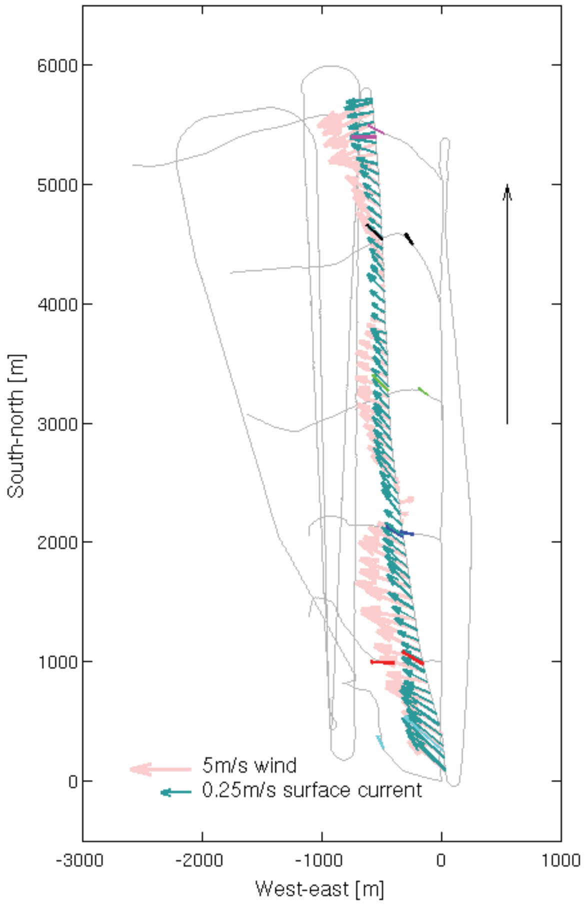
5 Acknowledgements

We express our gratitude to Stein Arne Rånes and North Energy ASA for organizing field operations in collaboration with Olex AS. Thanks also to Atein Arne Rånes for valuable contributions in the field work. Our gratitude also to Olex AS for providing their ‘Teist’ for the field operations, and in particular to Ole Benjamin Hestvik (Olex AS) for offering his time to join the planning of and preparation for field logistics, being crew on the Teist and for designing a file format for Olex SB data especially suited for our comparison with drifter data.

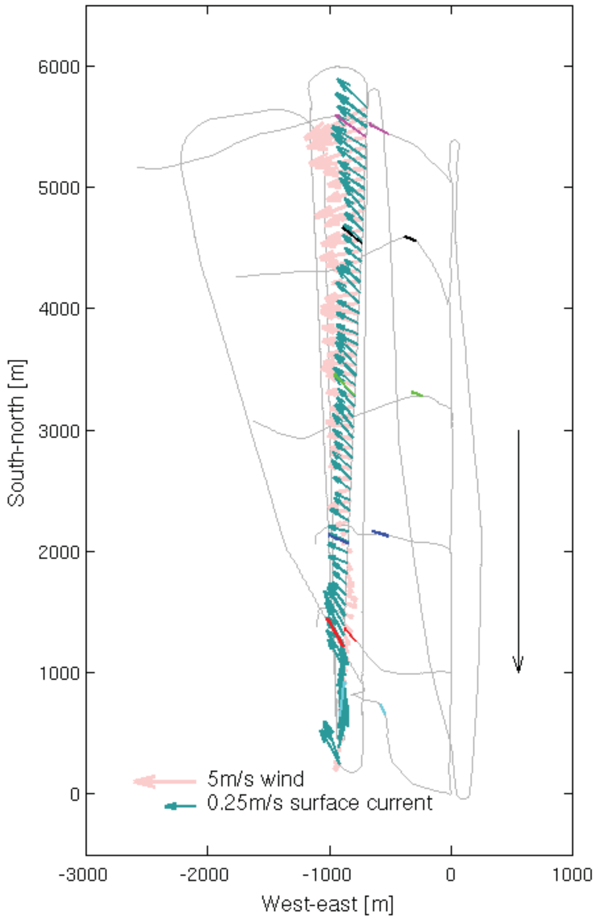
Appendix



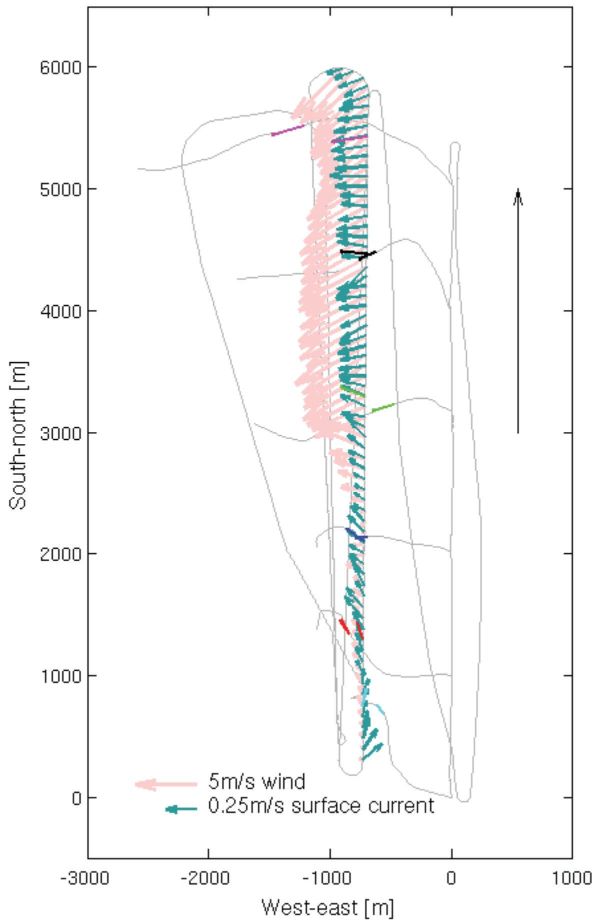
A1 Arrow plots of Olex SB measured surface current and wind (where the wind blows towards) for leg 2, each arrow separated by 30 seconds. Surface current arrows measured by the drifters are indicated with color corresponding to Figure 1.2. The closest Olex SB surface current arrow is plotted in same color.



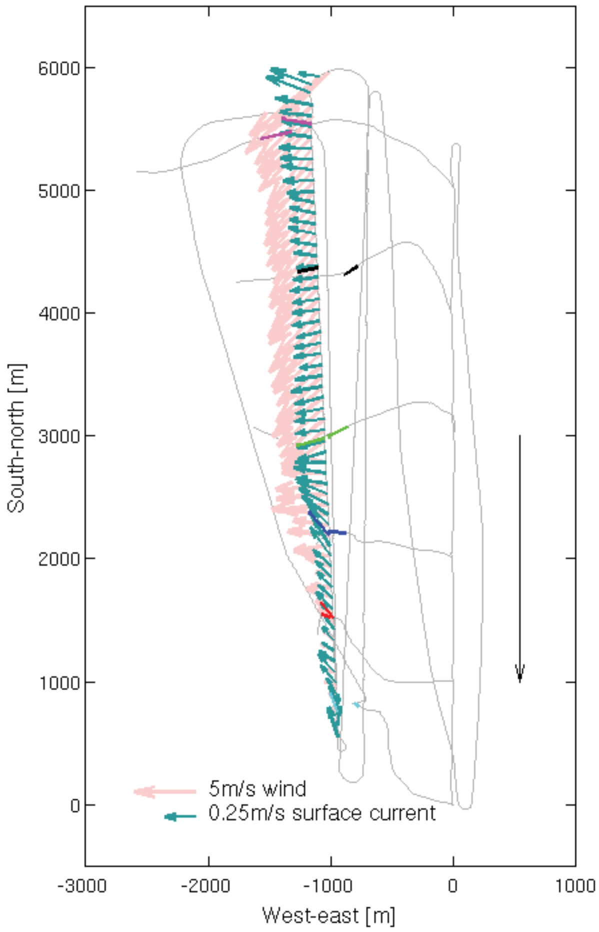
A2 Arrow plots of Olex SB measured surface current and wind (where the wind blows towards) for leg 3, each arrow separated by 30 seconds. Surface current arrows measured by the drifters are indicated with color corresponding to Figure 1.2. The closest Olex SB surface current arrow is plotted in same color.



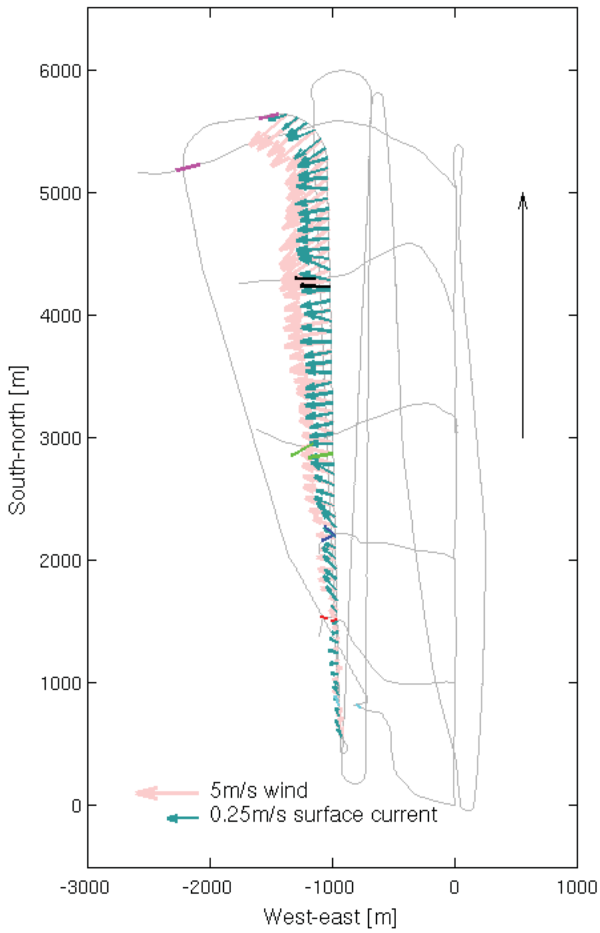
A3 Arrow plots of Olex SB measured surface current and wind (where the wind blows towards) for leg 4, each arrow separated by 30 seconds. Surface current arrows measured by the drifters are indicated with color corresponding to Figure 1.2. The closest Olex SB surface current arrow is plotted in same color.



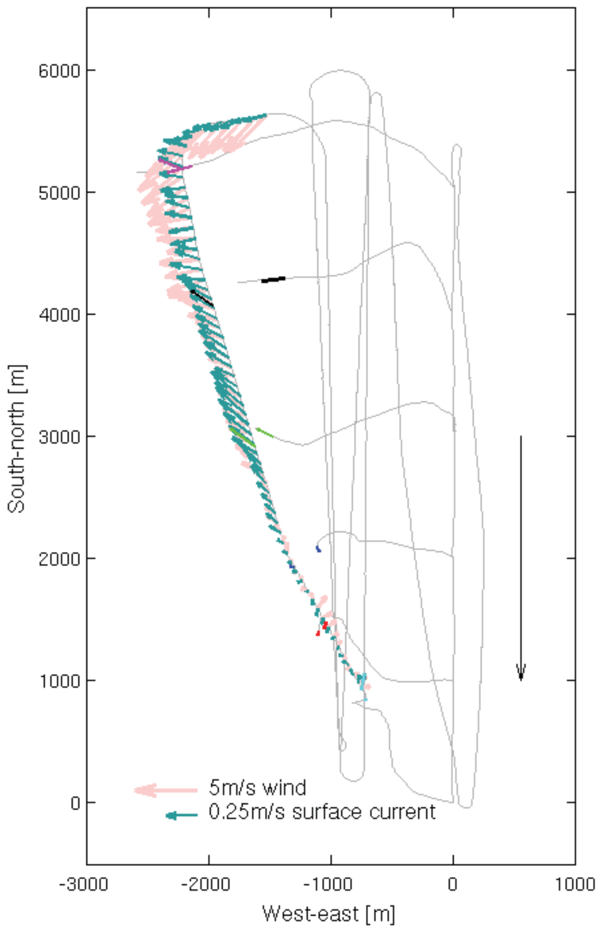
A4 Arrow plots of Olex SB measured surface current and wind (where the wind blows towards) for leg 5, each arrow separated by 30 seconds. Surface current arrows measured by the drifters are indicated with color corresponding to Figur 1.2. The closest Olex SB surface current arrow is plotted in same color.



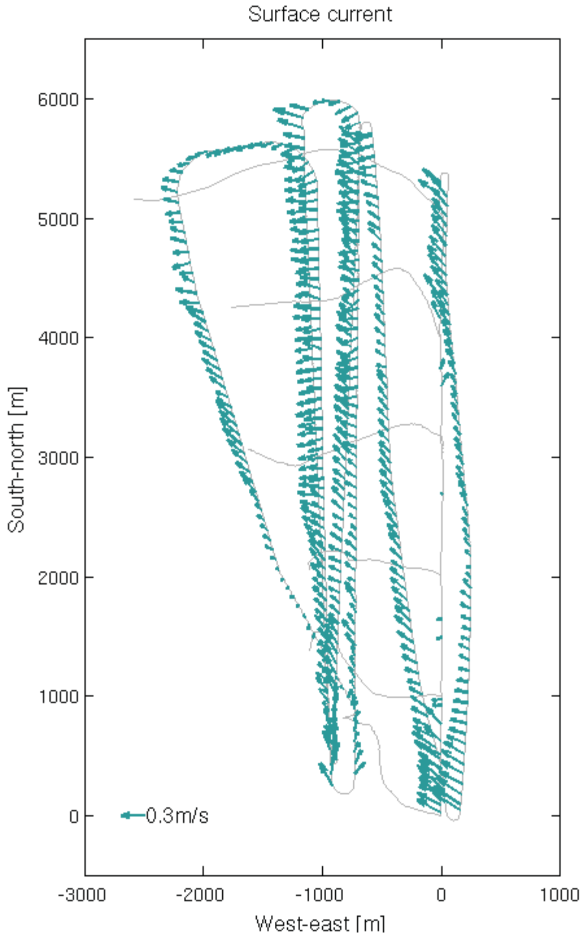
A5 Arrow plots of Olex SB measured surface current and wind (where the wind blows towards) for leg 6, each arrow separated by 30 seconds. Surface current arrows measured by the drifters are indicated with color corresponding to Figure 1.2. The closest Olex SB surface current arrow is plotted in same color.



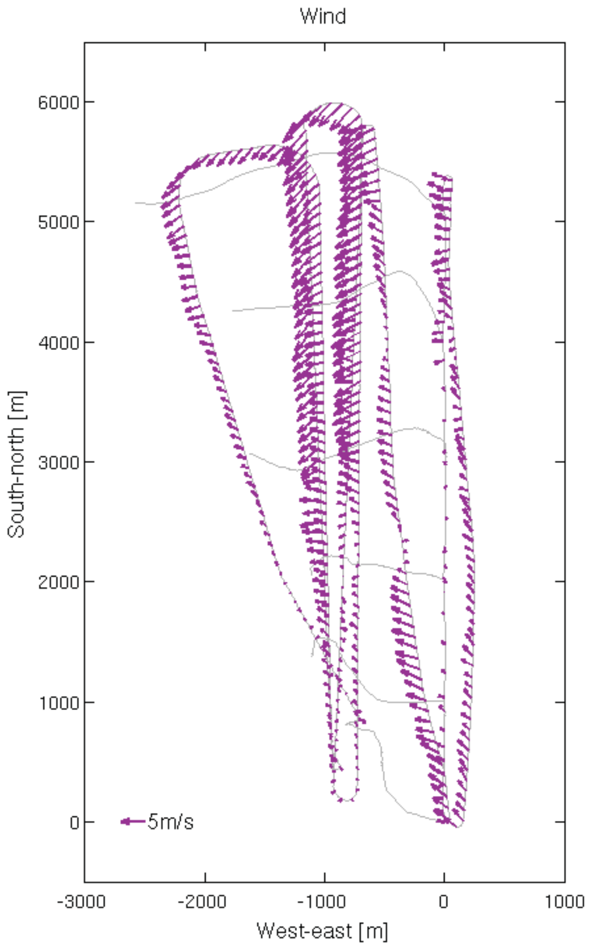
A6 Arrow plots of Olex SB measured surface current and wind (where the wind blows towards) for leg 7, each arrow separated by 30 seconds. Surface current arrows measured by the drifters are indicated with color corresponding to Figure 1.2. The closest Olex SB surface current arrow is plotted in same color.



A7 Arrow plots of Olex SB measured surface current and wind (where the wind blows towards) for leg 8, each arrow separated by 30 seconds. Surface current arrows measured by the drifters are indicated with color corresponding to Figure 1.2. The closest Olex SB surface current arrow is plotted in same colour.



A8 Olex SB measured surface current arrows, 30 seconds apart.



A9 Wind arrows measured from the boat, 30 seconds apart.