POAC'13
Espoo, Finland

Proceedings of the 22nd International Conference on
Port and Ocean Engineering under Arctic Conditions
June 9-13, 2013
Espoo, Finland

Ice drift and sea current analysis in the Northwestern Barents Sea

Renat Yulmetov[1*], Aleksey Marchenko[2], Sveinung Løset[1,2,3]

[1)] Sustainable Arctic Marine and Coastal Technology (SAMCoT), Centre for Research-based Innovation (CRI), Norwegian University of Science and Technology, Trondheim, Norway
[2)] The University Centre in Svalbard, Longyearbyen, Norway
[3)] Norwegian University of Science and Technology, Trondheim, Norway
[*]RenatY@unis.no

ABSTRACT
Drifting ice and icebergs present in the Barents Sea are a serious threat to offshore oil and gas development. The dynamic characteristics of the ice drift influence ice loads on potential offshore installations and the organisation of ice management. Ice drift characteristics were monitored using four Iridium ice tracking drifters installed on drifting ice during the survey of *RV Lance* in April 2012. A spectral analysis of the data shows the influence of semidiurnal and diurnal tides on the recorded drift characteristics. The drift speed and curvature of ice trajectories depend on the combined influence of wind and water drag forces. The measurement of vertical profiles of the sea current velocities was performed by three ADCPs with different spatial resolutions during the cruise. The structure of under-ice boundary layers was analysed during two ice stations. CTD profiling performed from the drifting ice at two ice stations and during the passage from Edgøya to the Hopen Island revealed a layer of relatively warm and salty water directly under the ice. The collected data are compared with similar data collected in earlier expeditions in the Northwestern Barents Sea.

INTRODUCTION
The exploration and exploitation of hydrocarbons in Arctic waters face challenges related to severe physical environments. Additional loads due to sea ice actions and the presence of icebergs in these waters, as well as low temperatures, lead to more complex solutions and additional costs.

The Shtokman gas and condensate field is the largest natural gas field offshore known to date. The projected environmental conditions include an annual air temperature ranging from -38ºC (100-year condition) to +30ºC, ice-rich waters in the wintertime (Le Marechal, 2011) and the presence of icebergs with a mass up to 4 million tonnes (Shtokman Development AG, 2012). Extracted gas processing and separation may be performed in these waters most like by using a moored Floating Production Unit (FPU) operating at a water depth of 320 m. Thus, it is important to estimate the sea ice loads on the FPU and the probability of collision with an iceberg to perform station keeping during production. For this reason, ice and iceberg drift driven by the sea current, wind and waves should be thoroughly studied.

Conditions similar to those at the Shtokman field can be found in the Northwestern Barents Sea. In the spring of 2012, *RV Lance* was moored to an ice floe and drifted into Storfjordbanken southeast of Spitsbergen. During the survey, we measured the sea currents, performed several CTD-tests and deployed four Ice Tracking Drifters (ITDs) on different ice floes.

Sea current profile is one of the most important input parameters in drift forecasting models because the sea ice drift is mainly governed by the drag forces (Savage, 2001; Lichey and Hellmer, 2001). Sea current is usually measured by an Acoustic Doppler Current Profiler (ADCP), where the vertical resolution depends on the frequency applied and can range from tens of metres down to a few centimetres. We had three ADCPs with different temporal and spatial resolutions that measured the relative sea current, while *RV Lanc*e was moored to and drifted with the ice floe. By knowing the GPS track of the ship, it was possible to estimate the influence of the sea current on the drift.

Kinematical drift characteristics for the longer period (up to 20 days) were provided by the ITDs deployed on several ice floes. We analysed the influence of tides and estimated the velocity of divergence of the ice cover. CTD profiles of the sea water were measured to obtain profiles of the salinity and temperature in the sea water column.

All data processing, manipulation and plotting were performed in MATLAB using standard fast Fourier transform, smoothing and fitting functions.

EQUIPMENT

Four drifters produced by Oceanetic Measurement (2011) were deployed on different ice floes during the survey. A hole of 150 mm diameter and approximately 30 cm deep was drilled in the ice before each deployment to fix the device. The caps of the drifters were painted white to make them less visible to polarbears. Deadweights were attached to the drifters to ensure that the trackers would sink after the deterioration of the ice floes.

Each drifter measured its position every ten minutes and sent data packages once per hour. The choice of measurement interval was determined by the consideration that the drift speed should be estimated with an accuracy of $1\text{cm/s} \approx 8\text{m}/600\text{s}$. The data transmission was performed through the Iridium channel. The horizontal accuracy in position estimation was less than 5 metres (50%) and less than 8 metres (90%).

We also used three different types of ADCP to measure the sea current velocities. The main characteristics of the devices are presented in Table 1. The onboard ADCP (BB-VM) was fixed under the ship at a depth of 4 metres and was used in the profile calculation. The two others (Nortek AWAC and RDI Workhorse Sentinel) were hung under the ice floes into predrilled holes. The different vertical resolutions of the devices allowed the current profile to be measured in the upper boundary layer under the ice.

Table 1. ADCP main characteristics.

	RDI BB-VM	AWAC	Workhorse Sentinel
# of beams	4	3	4
Transducer frequency, kHz	153.6	400	1228.8
First cell depth, m	15.98	2	0.53
Vertical resolution, m	8	1	0.3
Number of analysed cells	5	50	20
Accuracy, cm/s	---	0.5	0.3

CTD profiling was performed using an SBE 19+, which was manually lowered into the water from the ship and from the sea ice through the predrilled hole. A long wooden stick was attached to the device to protect the pump from the sediments and mud at the sea bottom. The sampling frequency of the device was 4 Hz.

DRIFT TRAJECTORIES AND VELOCITIES

The survey started on the 16th of April, 2012, in Longyearbyen with *RV Lance*. After nearly two days of sailing, *RV Lance* reached the waters northwest of Hopen Island (Figure 1). The two first trackers (ITDs) were deployed on the sea ice, and the ADCP and CTD measurements were performed during an approximately 30-hour-long ice station. During the station, the vessel was moored to an ice floe and drifted together with the pack ice. The position of the ship was measured by GPS and compared with the position of the second ITD, which was deployed on the same ice floe the vessel was moored to. The drift trajectories of the trackers and the vessel show numerous loops that were approximately 10 km in diameter. The initial distance between the ITDs was approximately 5 km and approximately 250 m between the vessel and the second ITD. Both trackers and the ship moved in parallel.

The third tracker was deployed at the second ice station, 30 km to the north of the first one. The ice drift in that region reproduced ellipses with even more stable centres. Finally, the fourth tracker was deployed 30 km to the north of Hopen.

The ice conditions were heavy first-year ice in the region of study. Highly concentrated ice drifting from the north was pushed southwest between Hopen and Edgeøya by the strong north-eastern current. The ice concentration was 0.9 and higher (visual observations), and the ice floe size varied from tens of metres to one kilometre with an ice thickness varying from 0.3 to 0.6 metres.

The drift speed characteristics and lifetime of the different trackers are shown in Table 2. The drift velocity reaches relatively high values and exceeds 1.5 m/s for ITD #3. The mean values are also high, most likely due to strong currents and tidal motion in the shallow water. The sea depth in the region of the drift rarely exceeded 100 m. There are much lower drift velocities (0.1 m/s mean drift speed) and much deeper water (up to 500 m) in the Greenland Sea (Yulmetov et al., 2013).

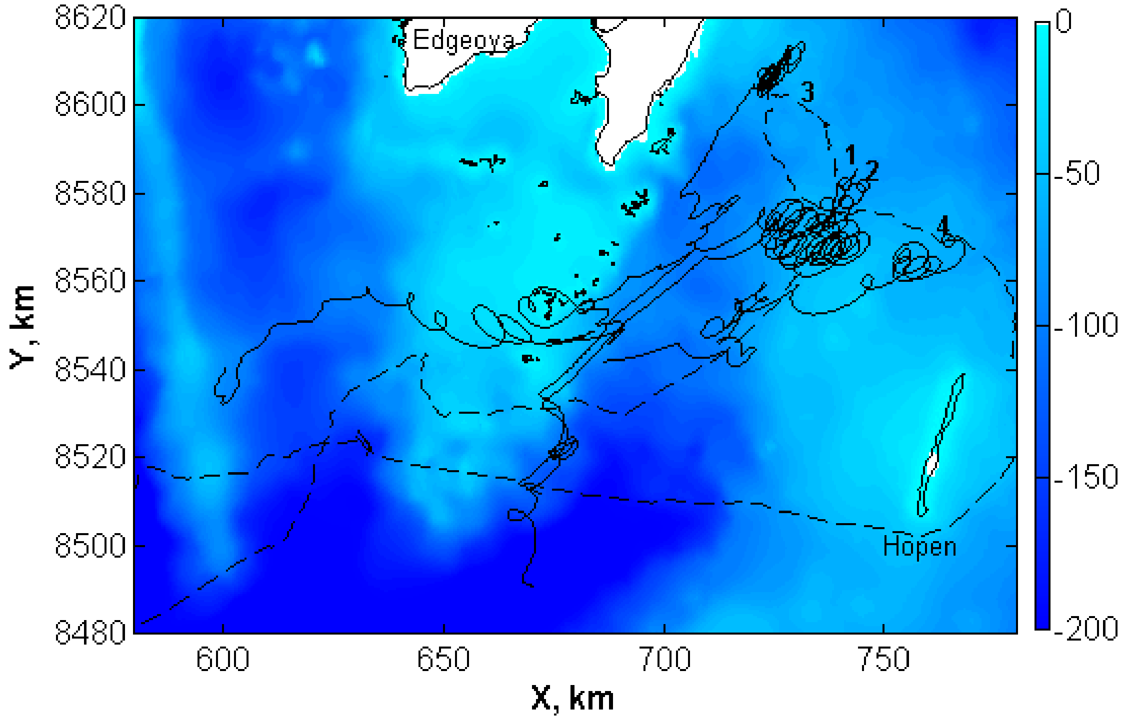

Figure 1. Trajectories of the ITDs (solid line) and the *RV Lance* track (dashed line). Deployment places are marked by numbers.

Table 2. ITD data; $\langle V \rangle$ is the mean drift speed, σ_V is the standard deviation, $\max(V)$ is the maximum drift speed.

ITD	First signal	Life time, days	$\langle V \rangle$, m/s	σ_V, m/s	$\max(V)$, m/s
#1	2012-04-18, 08:00:00	11.2	0.41	0.18	1.06
#2	2012-04-18, 14:00:00	9.8	0.43	0.18	1.08
#3	2012-04-20, 13:00:00	19.9	0.33	0.20	1.53
#4	2012-04-22, 02:00:00	8.7	0.37	0.18	1.06

The high initial concentration of ice coming from the north resulted in stresses in the ice field to the southwest of Edgeøya. The relatively thin ice cover could have been destroyed by gravity waves, explaining the short lifetime of the drifters.

The loops consisting of trajectories and cyclically changing velocities were analysed to determine how quickly the drift direction can change if the ice floe drifts with a given velocity. To provide quantitative analysis, we used the equation

$$\frac{1}{R} = \frac{\left|\vec{V} \times \vec{a}\right|}{\left|\vec{V}\right|^3} \tag{4}$$

Here, R is the radius of the curvature, $\vec{V}$ is drift velocity, and $\vec{a}$ is acceleration.

Noise and error reduction in the second derivative calculations were implemented by fitting velocity values with the sum of the harmonic functions. The entire data array was divided into equally sized blocks containing 75 points, corresponding to the semidiurnal period. On each block, we used the standard MATLAB fit function with the *"fourier8"* fit type.

The resulting data were smoothed using a "*moving average"* algorithm with a 200-point span. The smoothed curves show (Figure 2) that the fast-drifting ice is less likely to turn than the ice with low drift speeds. However, the derived dependence for Storfjordbanken is not as strong as in the Greenland Sea for the same latitude (Yulmetov et al., 2013), mostly because the ice drifting in from the Fram Straight is more massive, and its drift speed is lower.

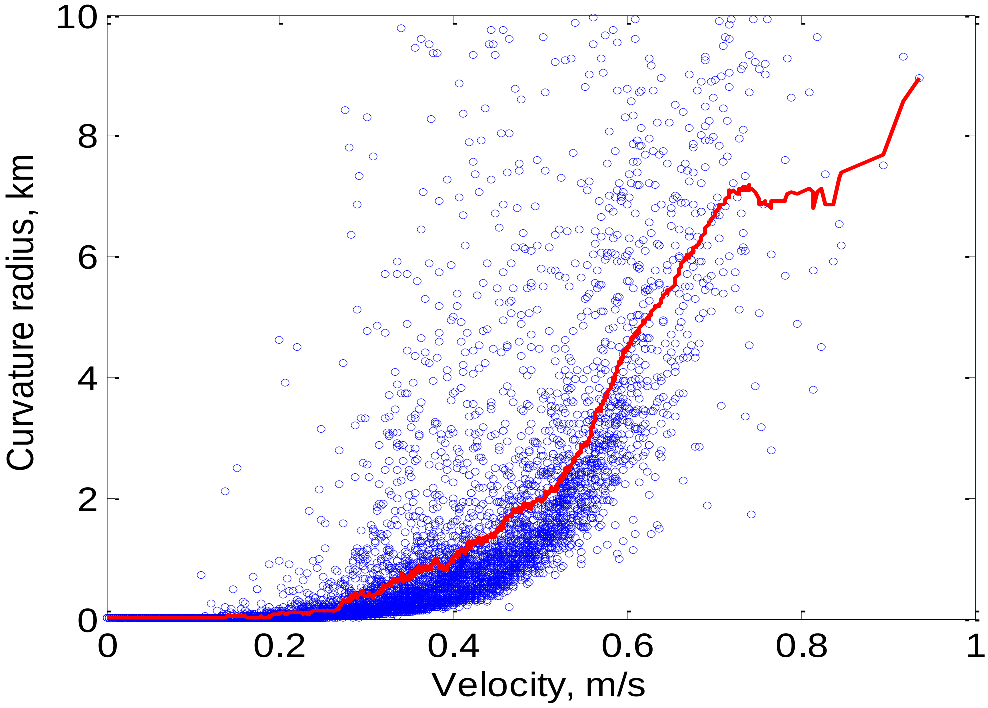

Figure 2. Curvature radius vs. drift speed. Smoothed trajectory (red).

VELOCITY SPECTRUM

To clarify the role of tidal motion and the Coriolis forcing, we analysed the velocity spectrum of the drift. The discrete Fourier transform was used to obtain the spectrum. If one has a number of measured quantities, x_n, one can use the equation

$$X_k = \sum_{n=0}^{N-1} x_n \cdot e^{-i2\pi \frac{k}{N} n} \tag{5}$$

where N is the number of measurements, and X_k are the complex numbers that reflect the amplitude and phase of a certain harmonic component in a signal. The fast Fourier transform (FFT) algorithm was used in MATLAB for the calculation of harmonic components. The amplitude-frequency spectrum is shown in Figure 3.

We cannot distinguish between the roles of the Coriolis force and semidiurnal tides because their periods are very similar. The period of the M_2 tide is 12 hours and 25 minutes, while the Coriolis force period is 12 hours and 19 minutes for 77°N. In any case, the tides and Coriolis force play an important role in the drift of the ice in these waters. Shallow waters in the region amplify the effect.

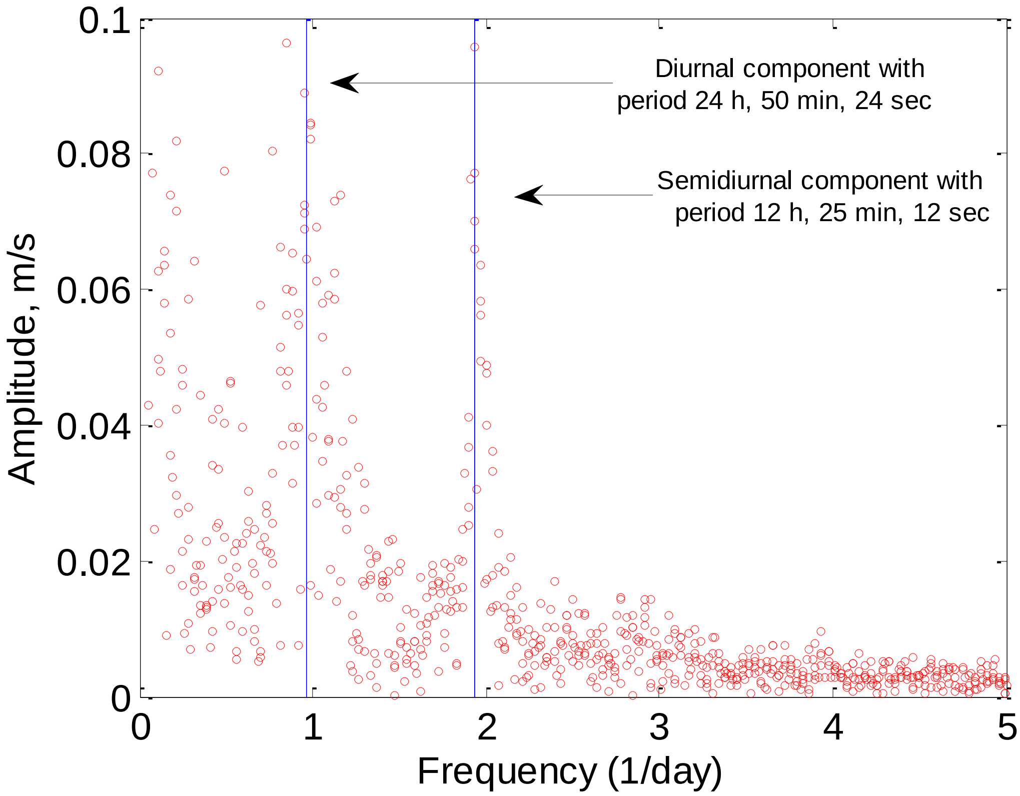

Figure 3. Velocity spectrum.

ADCP MEASUREMENTS

The measurements of the vertical profiles of the sea current velocities were performed using three ADCPs (RDI, Nortek, onboard ADCP) with different spatial resolutions at one ice station. Low-spatial-resolution onboard ADCP measurements were compared with the data provided by the high-resolution ADCPs installed on the ice adjacent to the vessel. The distance between the vessel and the deployment place on the ice was approximately 100 m (Figure 4). The ice floe contained a ridge; consequently, a turbulent wake from the geometrical irregularities and from the ship could have caused a difference in the measured values. The heading of *RV Lance* was nearly constant the entire time, and the vessel trajectory consisted of two nearly full loops during the observation period from 16:00, 18th of April, until 21:00, 19th of April.

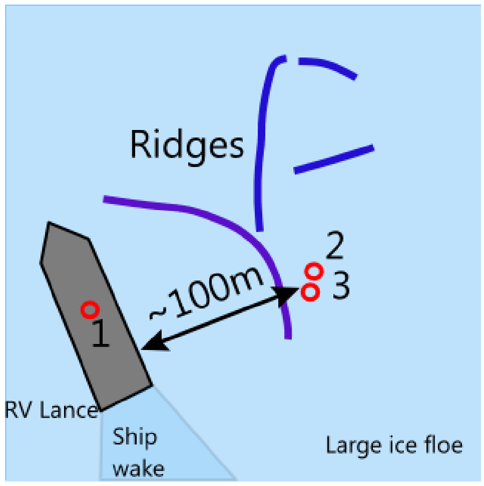

Figure 4. ADCP deployment positions. 1 – Onboard ADCP, 2 – Nortek, 3 – RDI

The devices measured current velocity relatively the ice floe. The sea current maintained direction to the south-west while the ship was making loops. The current direction was measured in degrees, clockwise, starting from direction to the North. The devices measured the sea currents in different depth ranges; thus, the values obtained were different for the devices. The measured current characteristics are plotted in Figure 5. We averaged the data among 50 (51 m) and 20 bins (6.23 m) for Nortek and RDI ADCPs, respectively. For the onboard ADCP, we took the first bin, which measured the current at a depth of 20 m.

In general, there is no sufficient difference between velocities of different water layers, but values are scattered within one layer. It can be seen that the relative velocity magnitude is lower for top layers due to viscous friction.

The relative current velocity magnitude did not exceed 0.2 m/s for all the devices, while the drift speed (black line) was up to 0.55 m/s. The magnitude has two minima during the observation period, with approximately 18 hours between them.

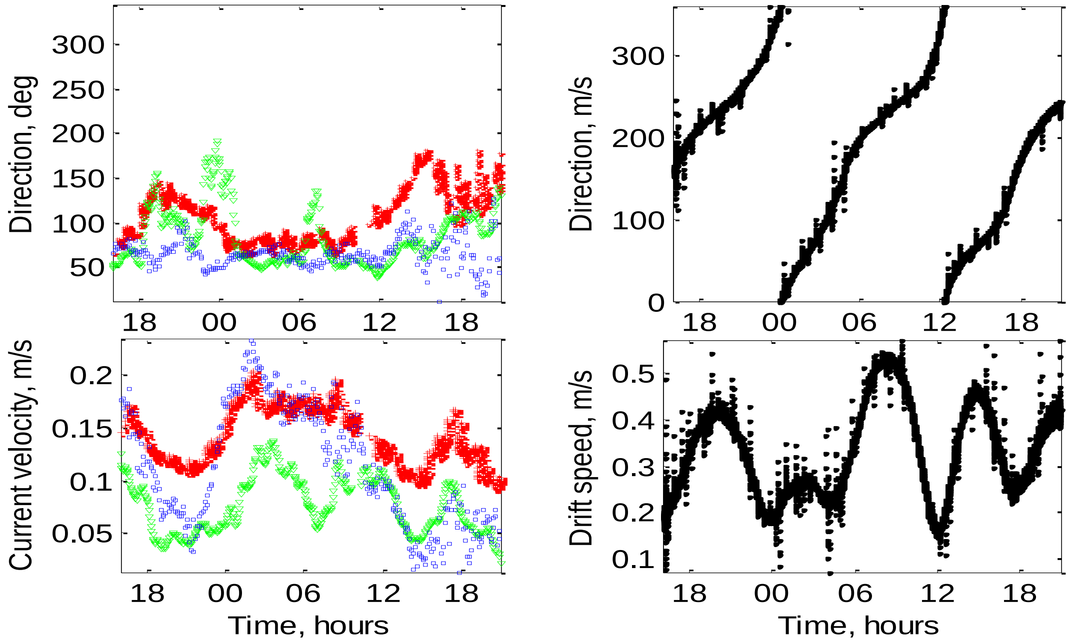

Figure 5. ADCP measurements. Nortek (red), RDI (green), onboard ADCP (blue). The drift direction and speed of RV Lance are plotted in black.

The sea current profiles measured by different devices and averaged in time for the whole observation period show that the velocity profile is mostly uniform deeper than 10 metres (Figure 6). The boundary layer has a thickness of approximately 7 metres, which can be seen clearly.

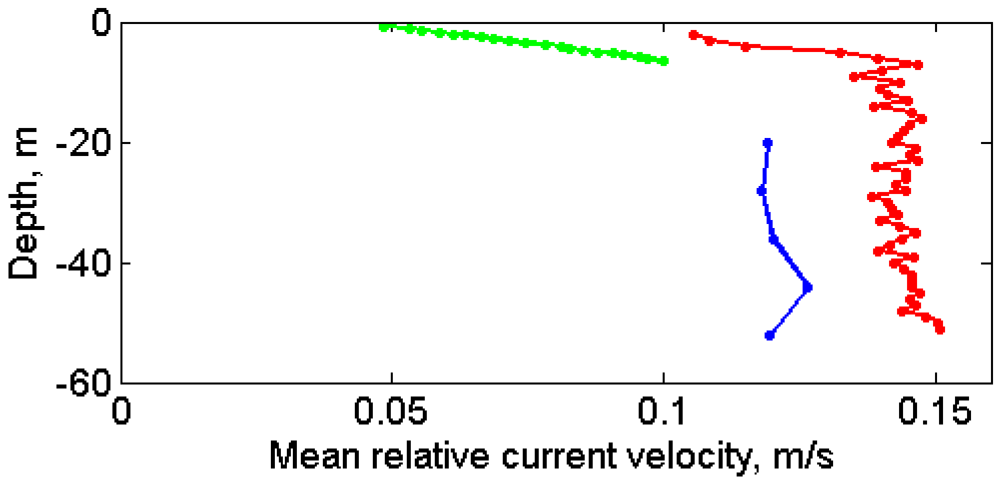

Figure 6. Current velocity profiles. Nortek (red), RDI (green), onboard ADCP (blue).

CTD PROFILES

Several CTD profiles were measured during the survey, five of which were taken at a distance of approximately 80 km starting at the northwest of Hopen (Figure 7). Data obtained with CTD were smoothed by 50 points moving average. The temperature profiles generally show warm water layers on the top and cold temperatures varying from -1.55 to -1.9°C at the bottom (Figure 8). The salinity varied from 34.3 to 34.9 ppt, with a value of approximately 34.4 ppt at the lower levels. Density profiles evidence heavier water in the top layers which are from 10 to 40 meters deep.

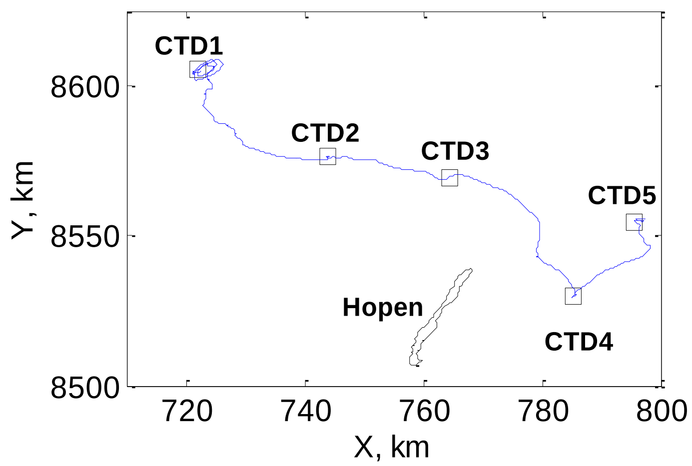

Figure 7. CTD profile positions.

Increased salinity and temperature on top in general repeats the measurements of Fer and Drinkwater (2012), that were performed to the South of Hopen in April-May, 2008. Such profile shapes are determined by warm Atlantic Water propagating from the Southwest. For the density profiles we suggest that the measurements were done in the area where warm North Atlantic current meets cold Arctic water and dense water is not yet at the bottom.

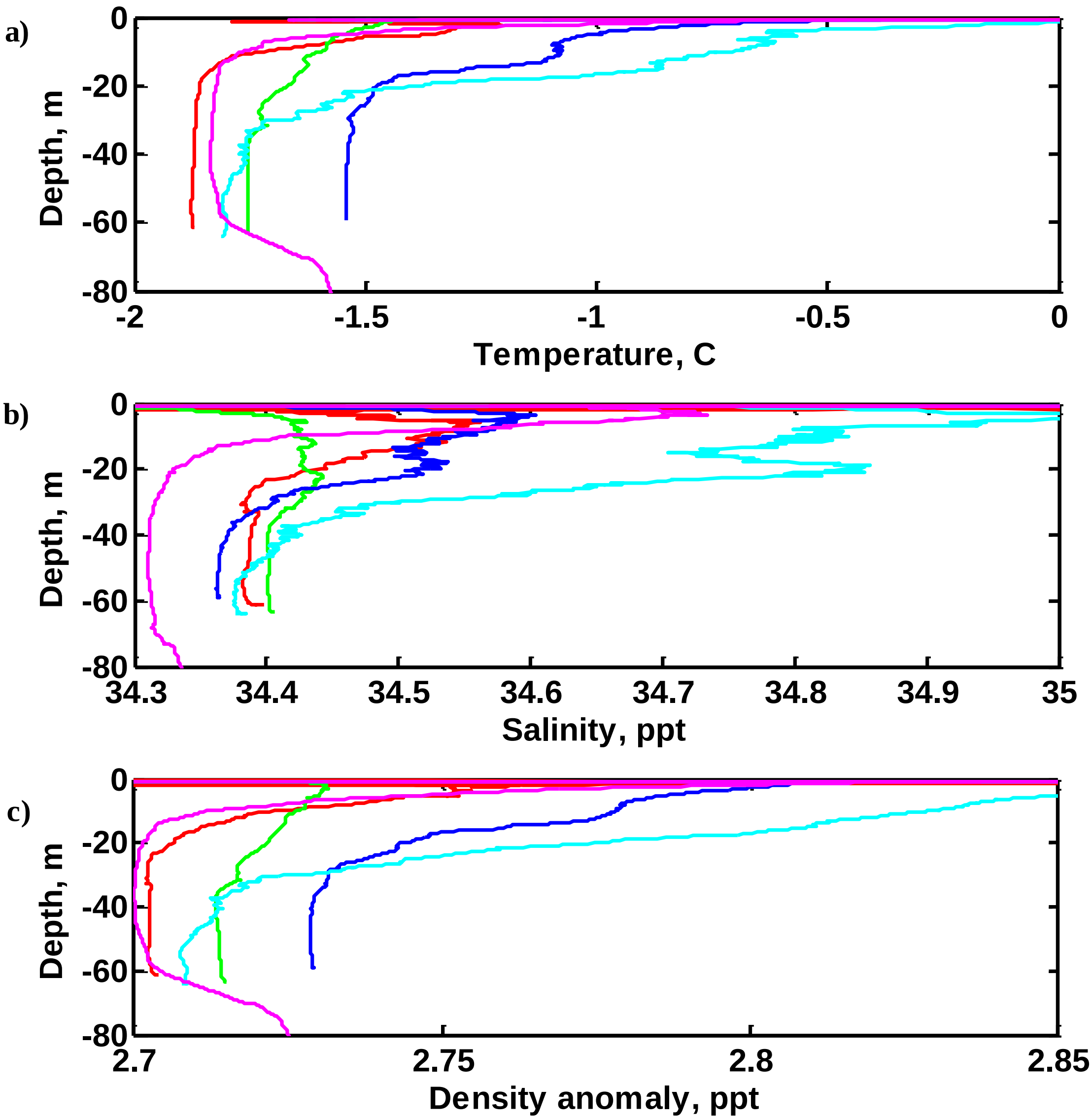

Figure 8. CTD profiles. a) temperature profiles b) salinity profiles c) density anomaly profiles.

CONCLUSIONS

Ice loads induced by drifting ice are a subject of great interest to the offshore industry. Drift characteristics are important for the validation of ice drift models. Data collected about the ice drift in a particular area can be used to predict ice motion and ice loads. These data can also be used for ice management operations.

In this paper, we carried out analyses of the data collected during a survey that took place in the waters to the southeast of Spitsbergen in April of 2012. The analysis included drift characteristics derived from the coordinates provided by Ice Tracking Drifters deployed on four different ice floes, current velocity measurements provided by three different ADCPs and, finally, CTD profiles. The major findings are the following:

- The ice drift between Hopen and Edgeøya is directed south-westwards. The drift speeds are relatively high due to the shallow water in the area. The maximum drift speed measured during a period of 20 days was 1.5 m/s, and the average drift speed was approximately 0.38 m/s.
- There was strong influence from tidal motion and Coriolis forcing. Spectral analyses of the velocity revealed two maxima corresponding to semidiurnal and diurnal cycles.

- There is a higher curvature radius for higher drift speeds.
- The mean relative current velocity was approximately 0.1 m/s. The differences in velocity measurements were caused by different spatial resolutions and slightly different positions.
- The CTD tests show high temperatures of the top layers due to warm water influx. However, the top layers have anomalously high density and salinity.

The measured current velocities and drift velocities can be used as input data for e.g. validation of drift forecasting models and oil spill drift models.

ACKNOWLEDGEMENTS
The authors wish to acknowledge the support from the Research Council of Norway through the Centre for Research-based Innovation SAMCoT and the support from all SAMCoT partners.

REFERENCES
Shtokman Development AG (2012): http://www.shtokman.ru/en/project/gasfield/
Guillaume Le Marechal, Philippe Anslot, Zoran Mravak, Pavel Liferov and Stephane Le Guennec (2011): "Design of a Floating Platform Hull for Arctic Conditions in the Barents Sea." Arctic Technology Conference, February 7-9, 2011, Houston, USA.
Savage, S.B. (2011): "Aspects of iceberg deterioration and drift." *Geomorphological Fluid Mechanics*, pp. 279-318.
Lichey, Christoph, and Hartmut H. Hellmer (2001): "Modelling giant-iceberg drift under the influence of sea ice in the Weddell Sea, Antarctica." *Journal of Glaciology* 47, no. 158, pp. 452-460.
Nortek (2012): http://www.nortek-as.com/lib/data-sheets/datasheet-awac
RDI (2012): http://www.rdinstruments.com/datasheets/wh_sentinel.pdf
Yulmetov, R., S. Løset and K. J. Eik (2013): "Analysis of Drift of Sea Ice and Icebergs in the Greenland Sea." Proceedings of the 22nd International Conference on Port and Ocean Engineering under Arctic Conditions, June 9-13, 2013, Espoo, Finland.
Fer, I. and K. Drinkwater (2012): "Mixing in the Barents Sea Polar front near Hopen in spring." Journal of Marine Systems.