POAC'15
Trondheim, Norway

Proceedings of the 23rd International Conference on
Port and Ocean Engineering under Arctic Conditions
June 14-18, 2015
Trondheim, Norway

SEA CURRENTS AND ICE DRIFT IN WESTERN PART OF BARENTS SEA. A COMPARISON OF DATA FROM FLOATING AND FIXED ON ICE BUOYS

N.A.Marchenko [1,2] and A.V.Marchenko[1,2]

[1]*The University Centre in Svalbard, Longyearbyen, Norway*
[2]*Sustainable Arctic Marine and Coastal Technology (SAMCoT), Centre for Research-based Innovations (CRI), Norwegian University of Science and Technology, Trondheim, Norway*
P.O.Box 156 Longyearbyen, Norway

ABSTRACT

Characteristics of ice drift and surface currents in the north-west Barents Sea and Svalbard region are investigated and compared using the data from ice trackers deployed on drift ice and icebergs, and the data of floating buoys provided by NOAA. Ice trackers deployed by a UNIS group provide GPS data with small sampling intervals of 10 or 20 minutes while NOAA buoys deliver the data with a six hour sampling interval. The influence of the sampling interval on statistical characteristics of ice drift speed and direction is analyzed and compared with statistical characteristics of surface water motion. It is shown that maximal speed of drift ice decreases 20-30% when the sampling interval of GPS data increases from 10 minutes to six hours.

INTRODUCTION

Growing industrial activity in the western part of the Barents Sea demands information about characteristics of ice drift in the region. Direction and speed (mean and extreme characteristics) of ice movement are very important for the design of off-shore structures and influence the risk of possible damage.
The current data on ice drift is not sufficient. There is data derived from satellite images and data of drifting buoys. Several institutions and agencies provide so called "sea ice products" (IFREMER, OSI SAF, NSIDC) showing mean ice motion vectors, derived from passive microwave sensors, visible and infrared sensors, and other sources. They widely cover the whole area with sea ice, but they give information with an interval of two to six days, and do not show extreme characteristics. Data from drifting buoys give more detail, but are available only for certain places and short periods of time.
Investigations of sea ice drift by Iridium Ice tracking buoys (IT) Oceanetic Model 703 is carried out at the University Centre in Svalbard (UNIS) since 2008 (Marchenko et al, 2010, 2011 and 2013; Yulemtov et al, 2012-2103). The IT provides information about its GPS coordinates every 10-20 minutes. This information is used for detailed investigations of ice drift under the influence of sea currents and wind. Comparison of this data with data from other drifting buoys (for example floating weather buoys) and "sea ice products" can show differences and similarities, and give ideas on how to extrapolate detail data available only for limited local places for large areas.

In the present paper we consider data provided by NOAA Data Buoy Centre (http://www.ndbc.noaa.gov). NOAA floating buoys (FB) have an underwater drogue and provide information about their locations every six hours. There were 15 FB drifting near Svalbard in the period from 1992 to 2013, sending signals during the periods of more than one year. FBs indicate movements of the surface water layer. Joint consideration of ITs and FBs data will help to assess possible characteristics of ice drift in areas with rare occurrence of drift ice.

WIND AND CURRENTS IN THE WESTERN PART OF THE BARENTS SEA

The influx of Arctic water to the Barents Sea takes place along two main routes: between Spitsbergen and Franz Josef Land, and through the opening between Franz Josef Land and Novaya Zemlya. Prevailing water drag forces tend to make the ice drift from the northwestern Barents Sea in a southwesterly direction. At the same time Atlantic water flows northward with branches of the Atlantic Current into the Barents Sea. When these water masses meet, the warm, salty Atlantic water dives under the colder and fresh Arctic water, and a clockwise current loop is formed above Spitsbergen banken (Bank) (see map in Figure 1a). The branch of Arctic water flowing southward north of Hopen turns west along the southern edge of the Svalbard archipelago and joins the Atlantic Current branch flowing along the west coast of Spitsbergen to the north. The North-West Spitsbergen current carries warm and saline Atlantic waters northwards along the western coasts of Svalbard. The velocity of this northward current exceeds 41 cm/s at the latitude of 76.5°N and 55 cm/s at 78ºN (Osinski et al, 2003).

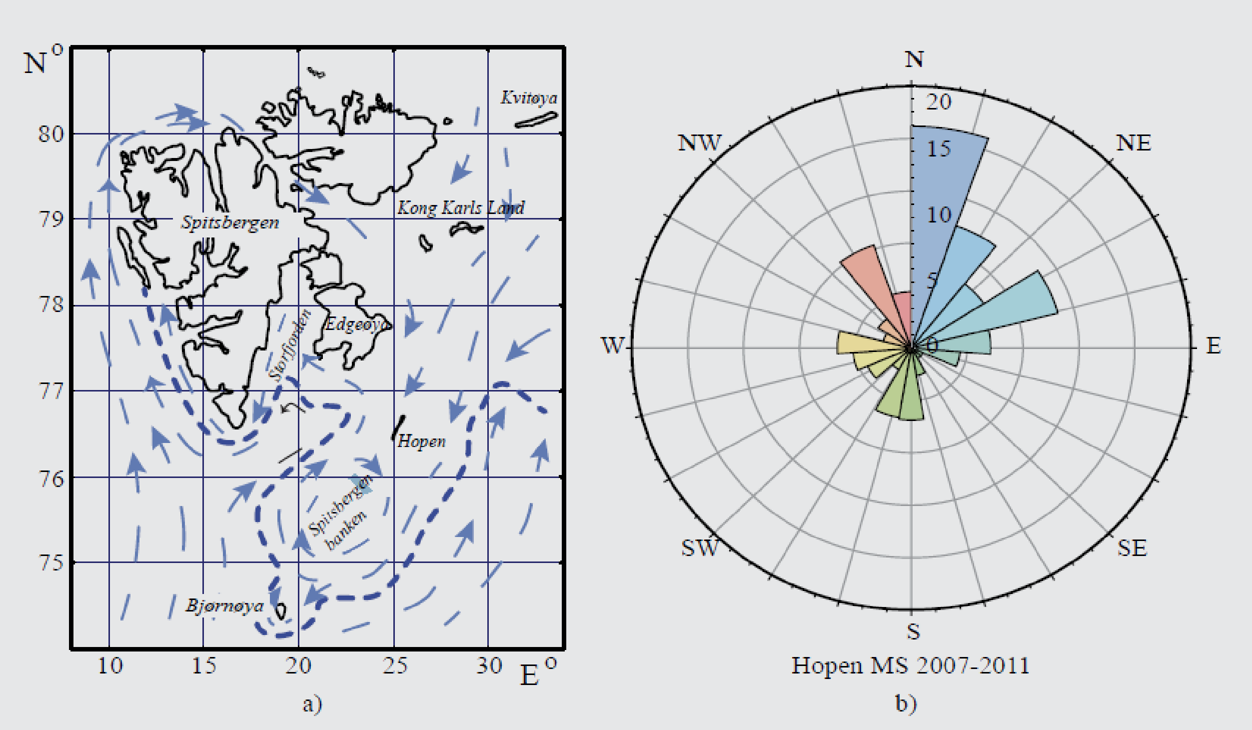


Figure 1. Sea currents in the west Barents Sea (a). Wind rose for meteorological station Hopen (b).

In the northwestern Barents Sea, the wind usually blows from the northeast. The wind rose in Figure 1b shows the wind directions measured at the meteorological stations of Hopen Island from January to June over the five-year period from 2007 to 2011 (data from www.eklima.met.no). One can see that the prevailing winds on Hopen are from the north and north-east. Given the pattern of sea currents (Figure 1a) and winds in the west Barents Sea, the ice should drift to the south-west along eastern Svalbard. Further ice can be captured in the current loop above Spitsbergen banken or drift to the north along the west coast of Svalbard.

HISTORICAL DATA ON DRIFT OF ICE AND ICEBERGS

Features of ice drift in the Barents Sea in the strait between Franz Josef Land (FJL) and Spitsbergen were first described by V.Albanov (1917) (Barr, 1975). In June 1914, he measured a ice drift velocity of 8.5 nm / day (approximately 0.16 m/s) at the point where he saw the FJL for the first time on the way from schooner Svyataya Anna (Saint Anne), frozen in the ice. Albanov estimated the coordinates to be 80°522N and 40°202 E. In his diary Albanov noted that the rate of drift was too large to be caused only by the wind influence. Later, the current which transports water from the strait between Spitsbergen and FJL, was named the Eastern Svalbard Current. In 1988 M/V Polarbjørn drifted from the Arctic Ocean into the Barents Sea together in the ice between Kvitøya and Nordaustlandet (Steele et al, 1995). The objective was to study the properties of sea water and take conductivity-temperature-density (CTD) profiles below continuous ice as well as in the marginal ice zone of the Barents Sea. On the way south, Polarbjørn passed east of Hopen Island before emerging at the ice edge (Fig. 2).

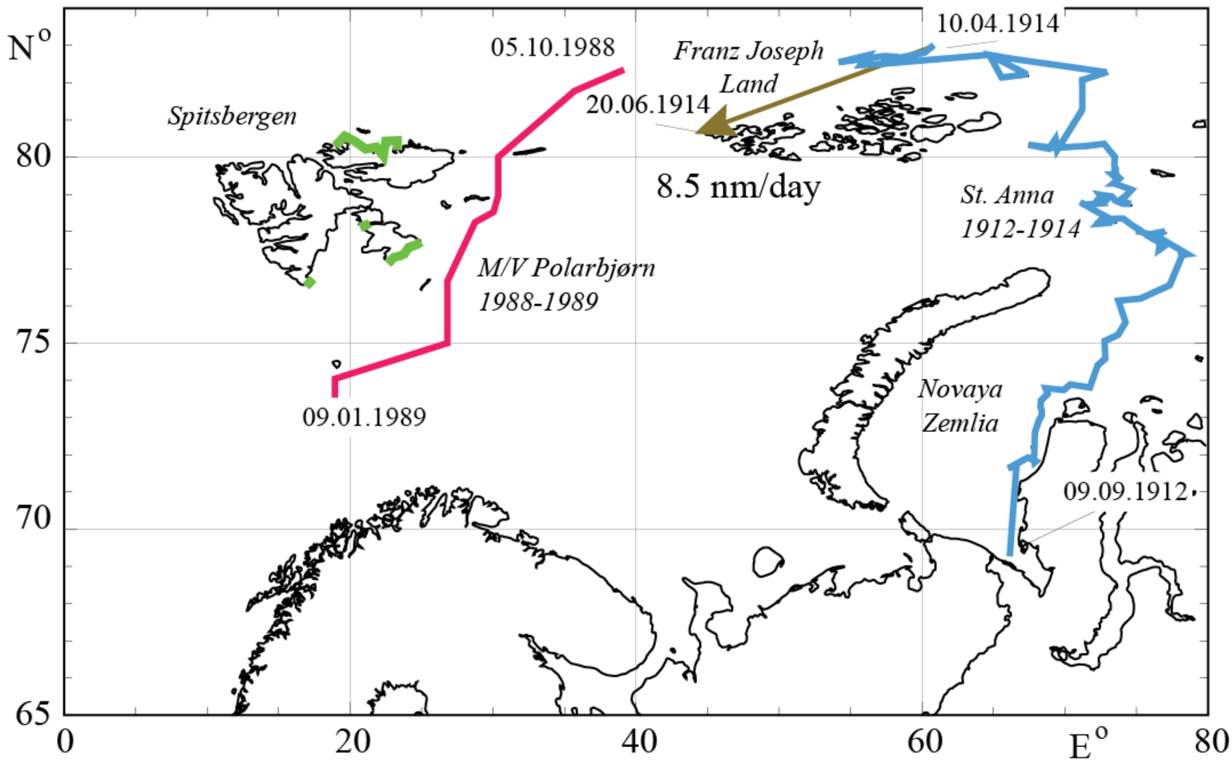


Figure 2. Drift trajectories of St. Anna (1912-1914) (blue line) and M/V Polarbjørn (1988-1989) (red line). The brown arrow indicates Albanov's route to Franz Joseph Land. Green marks the locations of driftwood on the beach, shown on the map of Spitsbergen published by A.Petermann (Petermann, 1865).

DEPLOYMENT OF ICE TRACKERS

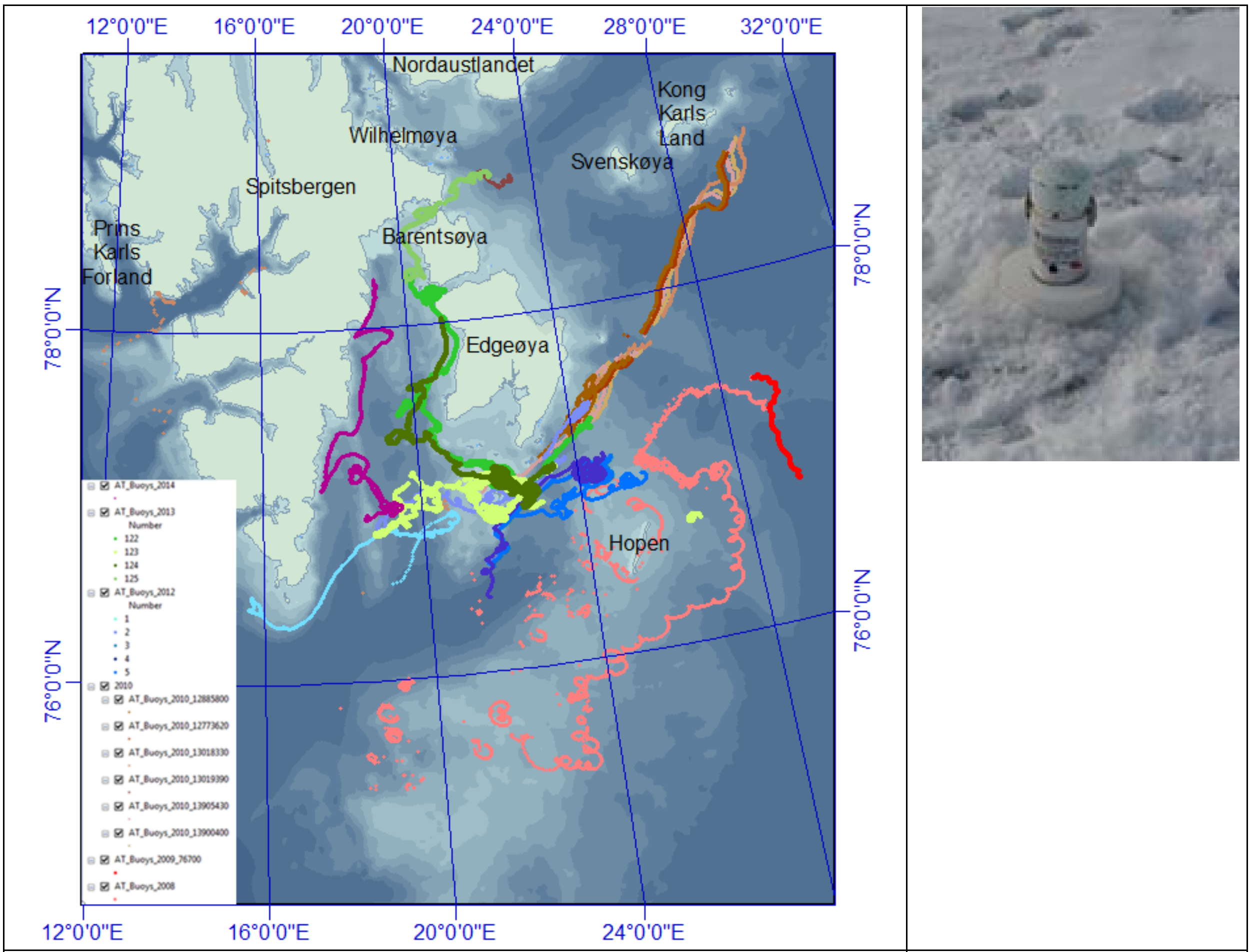
The IT are equipped with GPS, modem Iridium and alkaline battery packs providing continuous work for up to eight months with a minimal sampling interval of 10 min. For stable communication with the satellite, the tracker's antenna must be vertically oriented. Therefore, each IT has a stick going through the ice and a plastic foam ring to support it in a vertical position. Before deployment, the ITs were painted white to mask them from inquisitive polar bears. The length of the IT is about one meter and the diameter is 15 cm. The IT is mounted in a hole drilled in the ice. GPS antenna provides an accurate measurement of the geographic position with an accuracy of five to six meters, when the IT is vertical or is at a slight angle (Fig.3b).

High frequency of measurements allows the determination of ice drift velocity and acceleration with high accuracy. This information is demanded by commercial companies involved in the project arrangement of the Arctic shelf. Interruption to the connection with IT is caused with high incline and the IT falling on ice. After falling into the water the IT can continue to work as long as the water does not penetrate inside. It takes approximately 15 minutes to deploy the IT on ice. A simple deployment technique allows usage of a helicopter to deliver the buoys on the ice and icebergs in hang mode. Accuracy of measurements provides the ability to monitor drift and rotation moments of destruction of ice floes and icebergs. It is possible to update the frequency of measurements remotely (by sending signal).

TRAJECTORIES OF ICE AND ICEBERGS DRIFT

Trajectories of all deployed ITs taken into consideration are presented in Figure 3a. ITs installed and drifted in 2008 are shown in pink, 2009 – red, 2010 – various brown, 2012 – green, 2013 – blue, 2014 – purple. In 2008 the IT was deployed on 9 May in the marginal ice zone (MIZ) of the Barents Sea during an expedition with R/V Lance. It drifted with the ice until mid-June and later floated on the water surface, moving generally in a south west direction with numerous loops. The date when the IT began floating was identified by ice maps. Drift ice disappeared on the ice map in the end of June. Signals sent by the IT after the end of June show only short fragments of the trajectory well visible in Fig. 3a. This tracker sent its last signal on 17 September 2008 from the region of Hopen Island. In May-June the IT trajectory repeats the shape of the MIZ shown in the ice charts. In 2009 the IT was deployed on a drifting iceberg with a diameter of about 100 m and vertical height about 70 m. The IT provided data on the iceberg drift during one week. The red line in Fig. 3a shows the iceberg drift to north-north west during this time period. The iceberg drift was very similar to the ice drift around the iceberg (Marchenko et al., 2010).

In 2010 five ITs were deployed on the drift ice east of Kong Karls Land. This time the ITs were located well into the ice pack, over 200 km from the MIZ. Representative ice floes in the area were estimated to have a diameter of about three km and the ice at the points of deployment was 60-70 cm thick. Two ITs were deployed at different points on the same floe. The surfaces of the floes were flat and the snow thickness was 10-15 cm. From this experiment, we learned that the ice was drifting at a speed of 0.18 m/s, corresponding to about 240 nautical miles in one month. This speed matches well with Albanov's calculated drift speed of 8.5 nautical miles per day. Velocities were also reconstructed using data from remote sensing systems and by studying satellite images which found that drift ice from the Barents Sea is entering Isfjorden. From 15 March to 20 April all ITs drifted southwest as shown in Fig. 1a. Between 5 and 15 April, wind conditions clearly influenced ice drift. For several days, all the ITs drifted northeast, and then resumed their drift in a southwesterly direction. During this event the ice was deformed and the communications with four ITs failed. The deformations of sea ice were reconstructed by the analysis of distances between the ITs (Marchenko et al, 2011). From 15 April only one IT was still functioning and eventually drifted almost all the way back to Longyearbyen. It was picked up in Sassenfjorden and delivered to UNIS on 10 June 2010.



a) b)

Figure 3. Trajectories of ice trackers (a). Appearance of ice tracker deployed on drift ice (b).

In 2010 one IT was deployed on a drifting iceberg in Olga strait, north east from Baretsøya. The size of the iceberg is estimated as 30 m diameter and 5-7 m freeboard. Short trajectory of the IT monitored during one month is shown by the brown line in Fig. 3a. The IT trajectory with many corner points demonstrated very little drift. Finally the IT stopped sending signals when the iceberg drifted into shallow water.

In 2012, four ITs were deployed between Edgeøya and Hopen island on ice floes on 18-22 April. They drifted very slowly making many loops in the shallow between islands during a period of one week. 25 April they escaped into deeper a trough (which can be regarded as a continuation of Storfjordrenna) and drifted fast to the south west. One IT made more than 100 km in less than four days. This gave a mean speed of greater than one km/h. During several parts of the journey the IT drifted with a speed greater than 0.8 m/s during a period of four to five hours. The IT deployed on 17 April steadily drifted along the northern part of

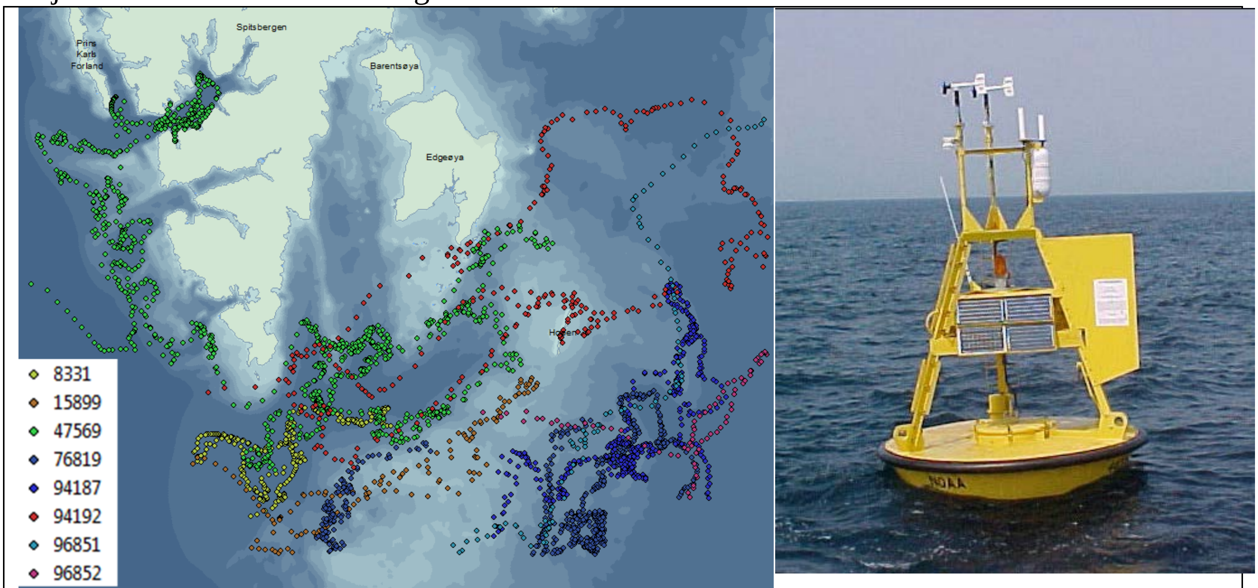
Storfjordrenna, rounding the southern tip of Spitsbergen, showing the speed 0.3-0.8 m/s. On 26 April, near the location with coordinates 76°26N and 17°26N, it drifted for two hours with a speed greater than 1.26 m/s, showing a maximum speed of 1.41 m/s.

In 2013, four ITs were deployed to the south from the Edgeøya in the period 30 April- 3 May. Three of the ITs were pulled into Storfjorden, and drifted along east coast of Edgeøya until Bjørnøya. One of these three ITs passed Heley Strait and headed to Nordaustlandet on 30 June. It is interesting that they passed through the ridge of Thousands Islands and stayed there for several days, performing tidal curves. The fourth buoy wandered in the mouth of Storfjord with a general westerly direction until 2 June. Suddenly on 25 June it sent signal from a point 28 km east from northern cape of Hopen Island, made the loop and disappeared the next day. Most likely it was floating at that time.

In 2014 two ITs were deployed in the far inner part of Storfjorden near Mohn Bay on 25 April and drifted together in parallel until 20 May along the east coast of Spitsbergen. They split at the mouth of Storfjord and during four days each performed separate loops.

FLOATING BUOYS

We analyzed the data from National Data Buoy Center (http://www.ndbc.noaa.gov/). Data for the west Barents Sea has been stored by request in NOAA ftp archive and downloaded. There were 15 FBs, which passed within territory. They sent coordinates every six hours. We took the eight most representative buoys to compare with the data from the ITs deployed on ice. These eight buoys existed quite long and sent signal during a period over one year. Their trajectories are shown in the Figure 4a.



a) b)

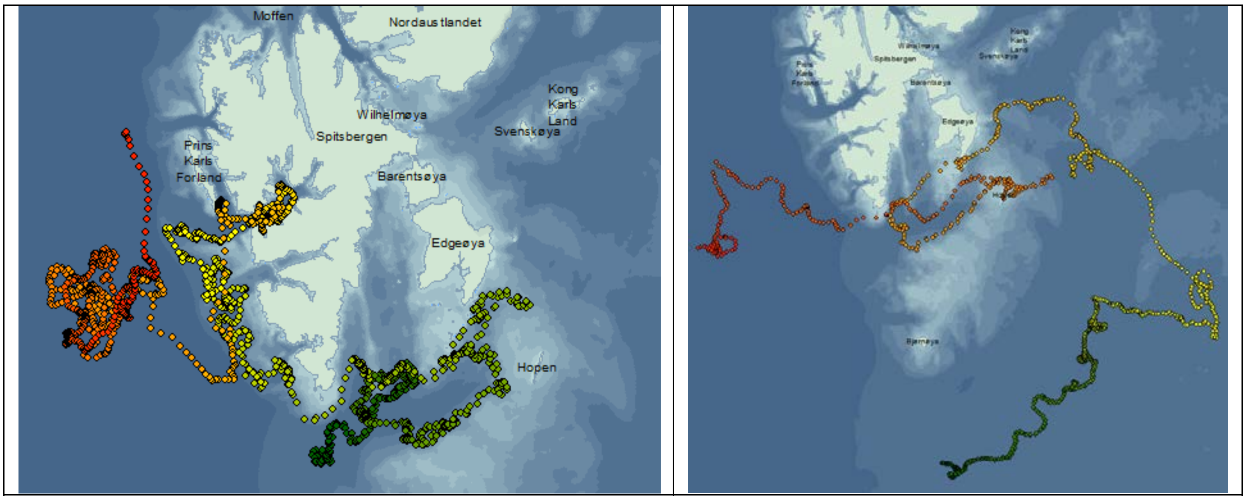
Figure 4. Trajectories of floating buoys (a). Appearance of floating buoys (b).

TRAJECTORIES OF FLOATING BUOYS

Trajectories of two FBs shown in Figure 5 illustrate the complicated drift patterns. Color symbolizes time of FBs existing from green to red via yellow and orange (start – green, finish

– red). Both of the FBs moved initially to the north-east with Atlantic water, and were captured by the East Spitsbergen Current, then rounded Spitsbergen and joined the West Spitsbergen Current. On the way they made many loops and returned back several times.

The first FB number 47569 (Fig. 5a) started on 19 July 2007 at the point located 75 km to the south of the South Cape of Spitsbergen. It made one loop here, traveled 30 km to the north, went 20 km south, headed along Svalbardrenna (trench) to Thousands Islands in a north-east direction, went 70 km back south-west, and headed to Hopen Island. During the second part of October 2007 and through November, it wandered between Edgeøya and Hopen Islands. It went further along bathymetry lines 100-150, rounded Spitsbergen from the south and came to Isfjord in February 2008. This part of the way was similar to one of the ITs deployed in 2010. It spent almost two months in Isfjord, making intricate loops. Leaving Isfjord, it headed to Prins Karls Forland, rounded its south cape, went 170 km to the south with great speed, and then moved quickly 140 km to the north. May-August 2008 it wandered 150 km west from Spitsbergen, headed to the north and disappeared on 26 August near 80^{o} N.



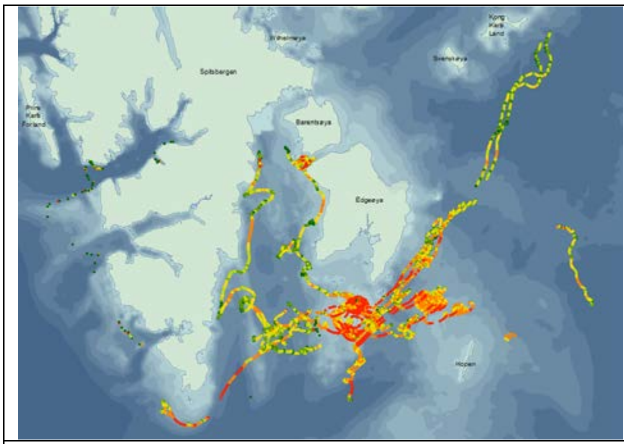
a) Buoy 47569 19.07.2007- 26.08.2008	b) Buoy 94192 28.06.2009 – 29.03.2010

Figure 5. Trajectories of two floating buoys

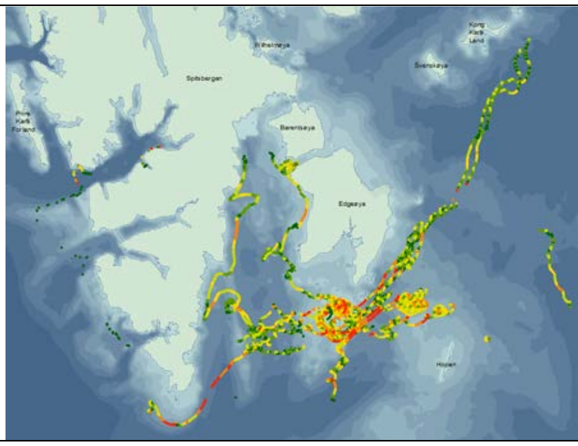
Trajectory of FB 94192 (Fig. 5b), started 200 km to the south of Bjørnøya on 28 June 2009, and was more steady. It made consecutive large loops and zigzags, moving first 1100 km north-east, then 400 km north-west, then 350 km south-west, then back 300 km east, and 650 km west. Several parts of its movement coincide with our buoy's trajectories.

COMPARISON

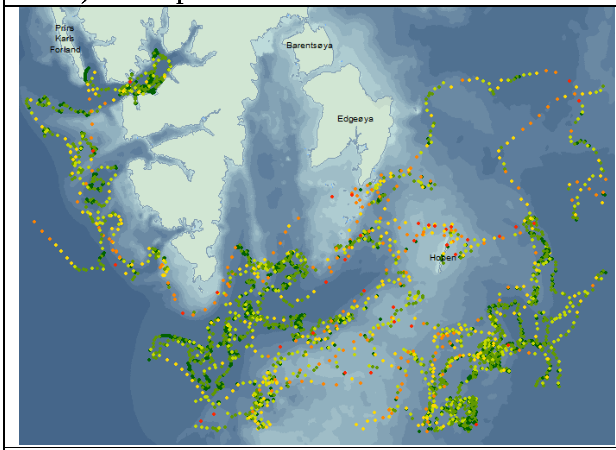
We calculated speed in m/s and direction in degrees of the ITs and FBs movement and compare them. For ITs we defined drift speed and direction using GPS data collected with a short sampling interval (20 minutes for ITs deployed in 2008-2010 and 10 minutes for ITs deployed in 2012-2014) to find an extremely detailed picture. To compare ITs with the FBs data collected a long sampling interval (six hours), we calculated speed and direction, taking into consideration the difference in location for two points with the same interval. In other words, we found the distance covered by buoy during six hours and divided into six hours. We consider patterns and estimate statistics for the whole region (Fig. 6, 7) and for it particular parts, for example location with tidal loops to the south-east of Edgeøya (Fig. 8).



a) ITs speed. 10-20 min interval.



b) ITs speed. Six hours interval.



c) FBs speed. Six hours interval.

- 0,000000 - 0,100000
- 0,100001 - 0,200000
- 0,200001 - 0,300000
- 0,300001 - 0,400000
- 0,400001 - 0,600000
- 0,600001 - 1,000000

d) Scale, m/s

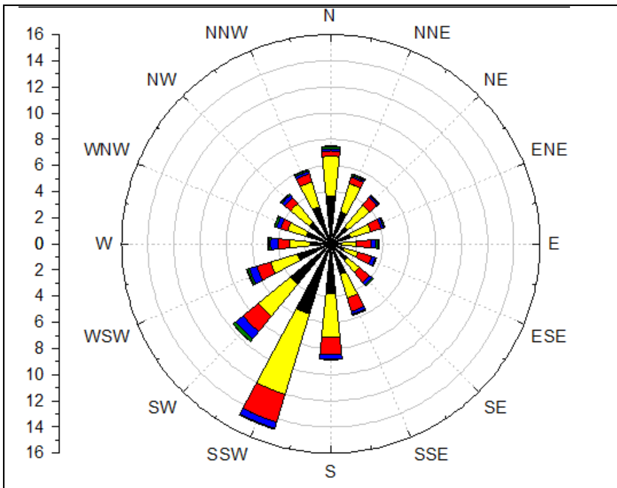
Figure 6. Drift speed of the ice trackers and floating buoys.

Generally, analysis of GPS data collected with short sampling intervals shows higher drift speeds. For example, mean speed of the ITs reconstructed from the data collected with 20 min sampling interval is 0.319 m/s, while mean speed reconstructed from the data with six hours sampling interval is 0.214 m/s. Respectively their maximum speeds are 1.41 m/s and 1.16 m/s and their standard deviations are 0.176 m/s and 0.303 m/s. For NOAA floating buoys these parameters are 0.187 m/s, 0.846 m/s and 0.137 m/s. It should be mentioned that during calculation we found the value of speed greater than two m/s several times. But as long as they occurred sporadically – isolated cases, surrounded by the values of the order of 0.2 m/s – we estimated such cases as mistakes and took them out of consideration. To find out geographical particularities of speed distribution we used a detailed bathymetry map with depth contours of 20 m.

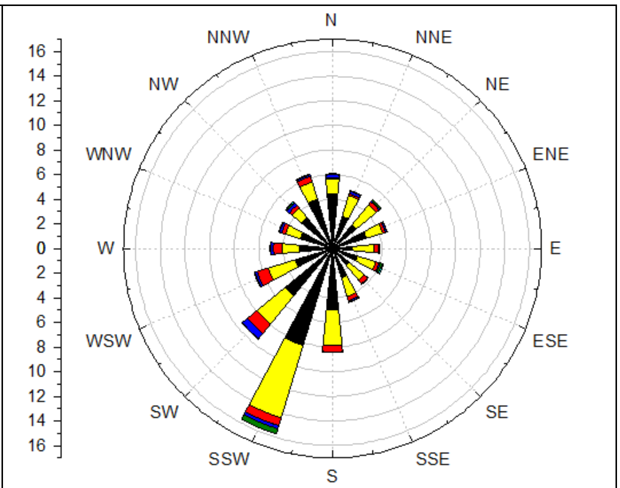
The high speeds (red and orange colors in Fig. 6) were registered in tidal loops and when the ITs and FBs rounded the south part of Spitsbergen, following the sea current. Remarkably smaller speeds of the FBs inherent the area with deep water. It is significantly higher on shallow and especially in the boundary zone.

Figure 7 shows a frequency of angular distribution of the drift direction of the buoys movements in polar coordinate system, with color bands showing speed ranges. The directions with the longest spikes show the direction with the greatest frequency. For all cases of ITs, it is south-south-west, for FBs south west. For the ITs, south-south-west direction is the most prevalent. For the FBs, south west is only slightly bigger than east-south-east and opposite east-north-east. In general, frequency of all direction is almost equal.

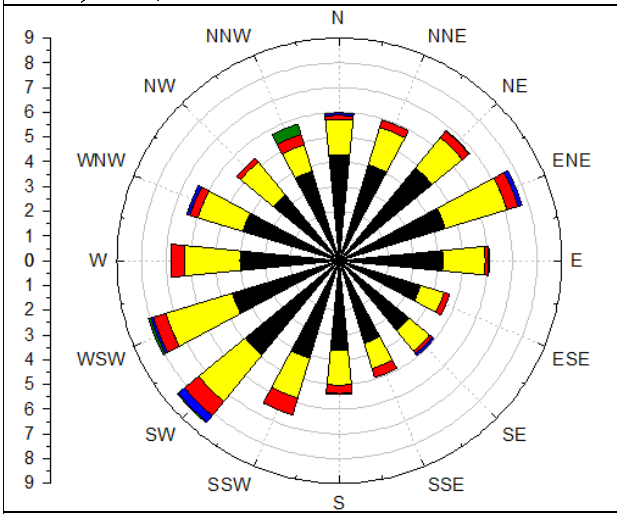
The large variations of drift speed and direction are typical for cases when buoys performed tidal loops during tidal cycles of about 12 hours. The typical situation is shown in Fig. 8 for the area located 30 km north of Hopen Island. ITs deployed in 2012 are on the left side, and ITs deployed in 2008 are on the right side. The loops have an elliptical shape: 6-8 km in south west-north east direction and two to four km in north west south east direction. The ITs drifted by the loops during five to seven days and were displaced 17 km to the south west. In 2008, the IT drifted to the south east and traveled 40 km during nine days in May, with 15 loops taking a more round shape, four to six km long stretched in the same direction south west to north east. The highest drift speed was calculated when the ITs passed long parts of ellipses.



a) ITs, 2008-2010. 20 min interval



b) ITs, 2008-2010. Six hours interval



c) FBs. Six hours interval.

d) Speed scale, m/s

Figure 7. Charts of drift speed and direction.

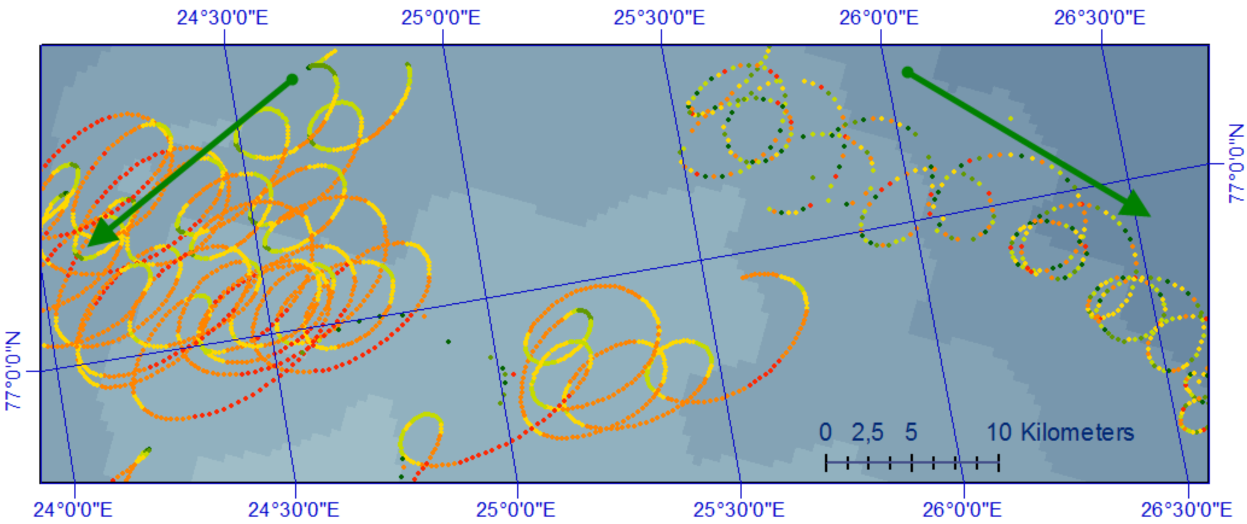
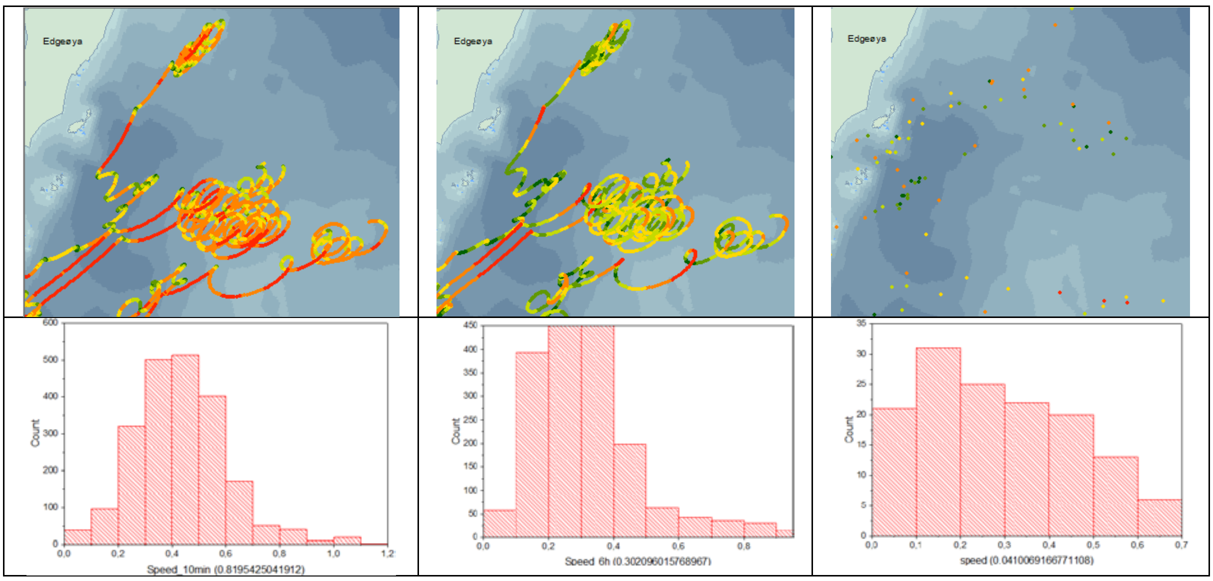


Figure 8. Tidal loops (speed scale the same like on Figure 6).

Figure 9 illustrates the difference of drift speed and directions reconstructed with the GPS data of short sampling interval (10 min) and long sampling interval (six hours). The analysis is performed for ice drift trajectories with tidal loops registered in the region with the center 40 km to the south-east of Edgeøya. It is visible that the six hours sampling interval reduces the results significantly: the maximum of histogram accounts for speed interval 0.2-0.4 m/s and most likely will not show speed greater than one m/s. Calculations performed for the data with 10 minutes sampling interval show extreme speed greater than one m/s, and the maximum of histogram accounts for a speed interval of 0.4-0.5 m/s. This regularity is even more visible on the chart, showing frequency of different direction and speed. For the FBs the histogram shows rather equal distribution with a logical decreasing with higher speed: the maximum goes to an interval of 0.1-0.2 m/s. On the chart, the prevailing directions south west and north east are visible, but speed distribution according direction is quite chaotic.



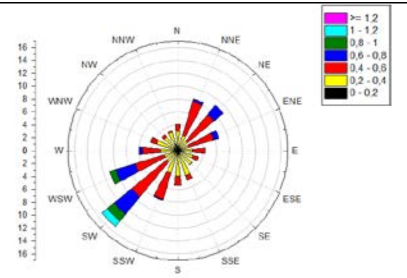
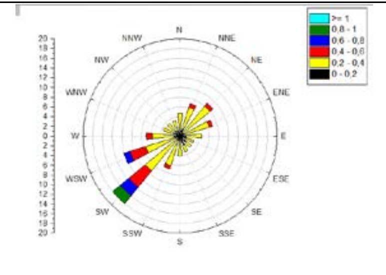
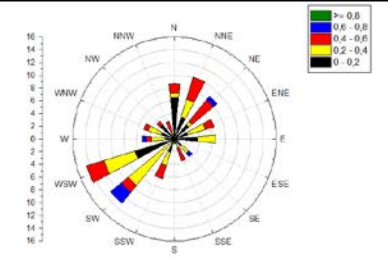
		
Ice trackers (ITs)		Floating buoys (FBs)
a) 10 min interval	b) six hour interval	b) six hour interval

Figure 9. Comparison of buoys speed in the region with tidal loops for different intervals

CONCLUSION

Both ITs and FBs demonstrated the possibility of ice and surface water drift into the Isfjord from the Barents Sea. This motion is supported by sea currents system around Spitsbergen and local counter clockwise circulation of sea water inside the Isfjord.
Mean drift speed of ITs calculated using GPS data with six hours sampling interval is higher than mean speed of FBs calculated using GPS data with the same sampling interval. In considered examples a mean speed of ITs was estimated in an interval of 0.2-0.4 m/s, while mean speed of floating buoys was within 0.1-0.2 m/s. Maximum drift speed of ITs is higher than maximum drift speed of FBs by 30%.
Maximum speed of ITs calculated using GPS data with six hours sampling interval is lower than the maximum speed of ITs calculated using a 10 or 20 minutes sampling interval. The difference reached 20-30% in considered examples.

ACKNOWLEDGEMENTS

The authors would like to thank the SAMCoT project (funded by the Research Council of Norway), the SMIDA project (funded by the Norwegian Centre for International Cooperation in Education) and the colleagues for supporting this study.

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