Proceedings of the 25th International Conference on
Port and Ocean Engineering under Arctic Conditions
June 9-13, 2019, Delft, The Netherlands

Characteristics of ice drift and waves on Spitsbergen-banken

Aleksey Marchenko, Nataly Marchenko
The University Centre in Svalbard, Longyearbyen, Norway

ABSTRACT

Two ice trackers were deployed on the drifting floe in April 2017 during the Polarsyssel cruises. They provided information about their GPS coordinates with temporal resolution of 10 min. One of the trackers transmitted also the data on wind velocity, and the other tracker transmitted also vertical accelerations. The acceleration records performed with 5 Hz sampling frequency allowed to investigate characteristics of waves penetrating on Spitsbergen-banken from the open ocean. In the present paper the drift patterns of ice trackers are described and spectral analysis of recorded accelerations is performed. The wind velocity and swell spectrum are obtained and compared with the data provided by the web (https://earth.nullschool.net).

KEY WORDS: sea ice, drift, ice trackers, waves.

INTRODUCTION

Region around the Bear Island is of potential interest for offshore development in the Barents Sea. Ice maps systematically show sea ice in winter time to the North of the Bear island in shallow area called Spitsbergen-banken. Drift ice influences navigation on Spitsbergen-banken. Ships without proper ice class drop their speed to minimal values of about 2 kt to avoid collisions with drift ice. Speed of ice drift may have strong influence on ice loads on moored vessels and fixed installations.

There are several reasons for the ice occurrence in this place. Small sea depths varied between 100 m and 20 m and strong tidal currents influence water cooling due to the mixing over cold time of a year. East-Spitsbergen current influences an influx of drift ice from Olga

Strait. Polar cyclones may influence fast ice drift in the region from the North. It was discovered that drift ice in the region consists of floes with relatively small diameters of around 30 m which draft may reach 4-5 m. These floes represent fully consolidated ice ridges. Spitsbergen-banken is open for wind waves and swell potentially coming from all directions excluding North direction where Spitsbergen is located.

Investigation of characteristics of drift ice in Spitsbergen-banken was performed in 2017 and 2018 during UNIS cruises by Polarsyssel. The cruises were organized according to the plan of the course of Arctic Technology Department AT-211 at UNIS. 5 ice trackers manufactured by Oceanetic Measurements Ltd were deployed on drift floes. Two trajectories are shown in Fig. 1 by black and blue lines. Brown line shows the trajectory of similar ice tracker deployed on the drift ice to the North of the Hopen Island in 2008. Two ice trackers deployed in the end of April in 2008 and 2018 survived over long time after the ice melt. They tracked surface currents in summer time. In addition to GPS data some of ice trackers transmitted wind velocity data and vertical accelerations of the floe. In the present paper we analyze the data from two ice trackers deployed on the same floe in 2017, process them to derive wave characteristics and compare it with the data of WAVEWATCH III modeling available on the web (https://earth.nullschool.net).

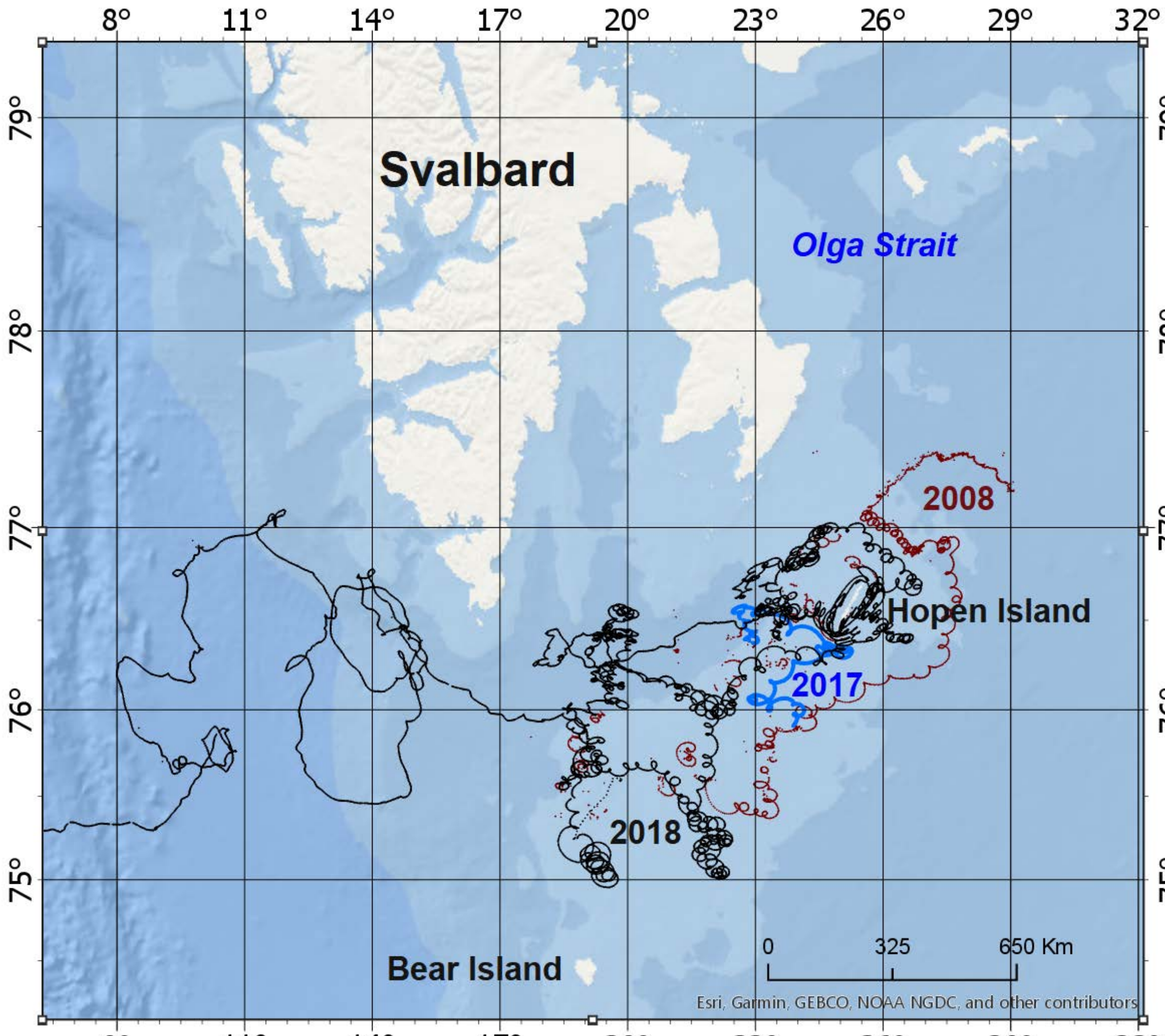


Figure 1. Trajectories of ice trackers deployed on drift ice in 2008, 2017 and 2018.

DEPLOYMENT OF ICE TRACKERS ON DRIFTING FLOE

Polarsyssel was moored to a drift floe in the location around 76.4 N, 22.8 E on April 24, 2017. The ice tracker IT 1 (Oceanetic Measurement Ltd.) equipped with the anemometer was deployed on the same floe (Fig. 2). The windDrift electronics package contains a 3-axis magnetometer and accelerometer which are used to derive tilt-compensated magnetic headings for the instrument. When properly calibrated, the instrument will give a heading of 0 degrees magnetic when the wind sensor vertical arm is pointed to magnetic North. A complete calibration of soft and hard iron errors has been done at the factory. For accurate headings, a brief calibration was also performed at the floe. The instrument collected the data on the wind velocity and geographical location with sampling interval of 10 minutes.

Figure 2. Left panel. Ice tracker Oceanetic Measurement equipped with anemometer. Right panel. Ice tracker deployed on the drifting flow on April 24, 2017.

Similar ice tracker IT 2 without anemometer programmed for high frequency measurement of vertical acceleration was deployed on the same floe on April 26, 2017. Vertical acceleration was measured with sampling frequency of 5 Hz during 5 minutes one time per 2 hours. IT 2 also recorded geographical position with sampling interval of 10 minutes. The distance between IT 1 and IT 2 was 25 m. The ice floe with deployed trackers IT 1 and IT 2 is shown in Fig. 3. The shape of the floe where ice trackers were deployed is shown in Fig. 4. It was constructed using the data of laser scanning and drilling (Marchenko, 2018). Maximal sail height of the floe was 2.16 m, and maximal keel draft was 3.82 m. Total floe volume was $V_i = 3270$ m3 and waterplane area was $S_i = 934$ m2. Mean density of the ice was estimated of around $\rho_i = 850$ kg/m3, and sea water density around the floe was $\rho_i = 1027$ kg/m3.

The frequency of natural oscillations of the floe is estimated with the formula

$$\omega_i = \sqrt{\frac{\rho_w g S_i}{\rho_i V_i}} \approx 1.83 \text{ rad/s}. \quad (1)$$

The period of the floe oscillations is $T_i \approx 3.4$ s.

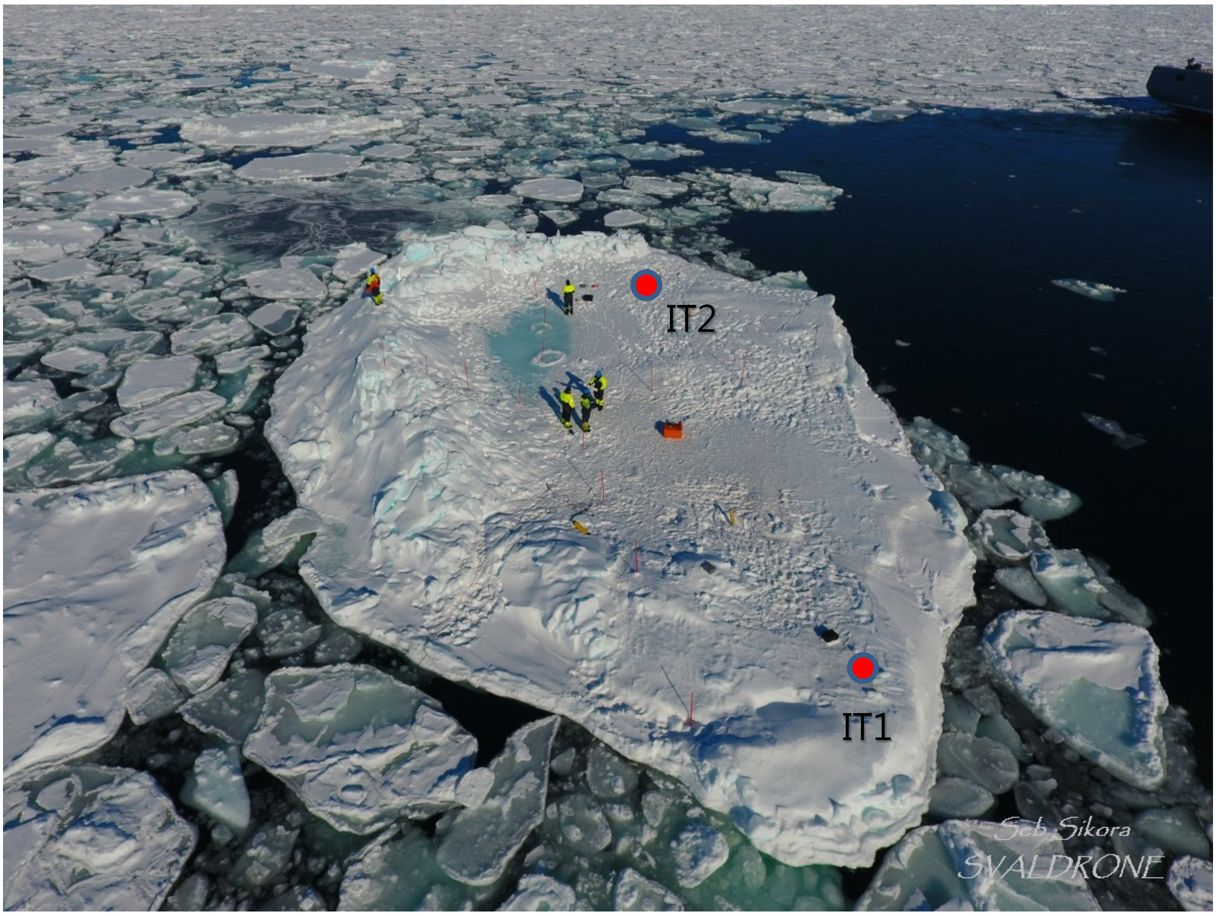


Figure 3. Drifting floe where ice trackers IT 1 and IT 2 were deployed on April 24 – 26, 2017. Photographs of Sebastian Sicora made from the drone.

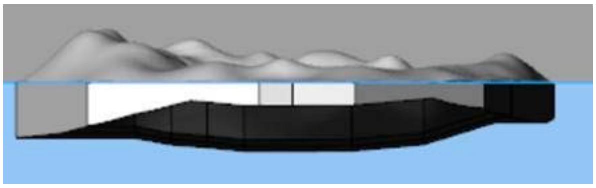
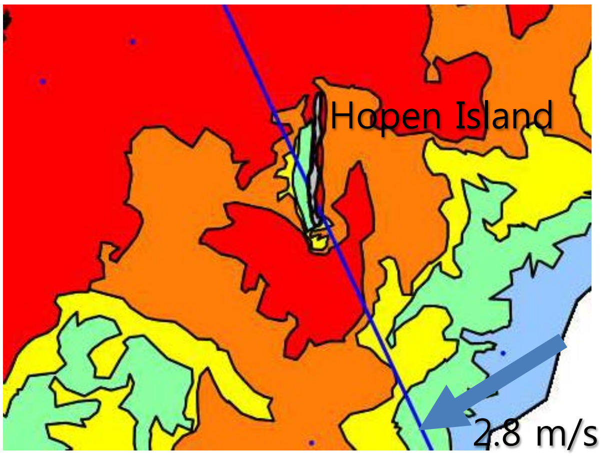
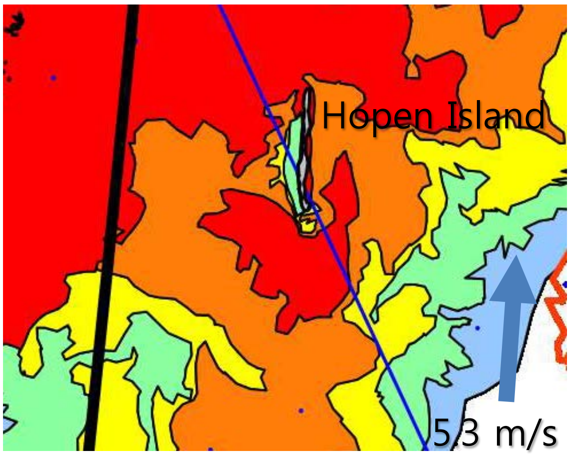


Figure 4. Shape of the floe where ice trackers were deployed.



April 26



April 27

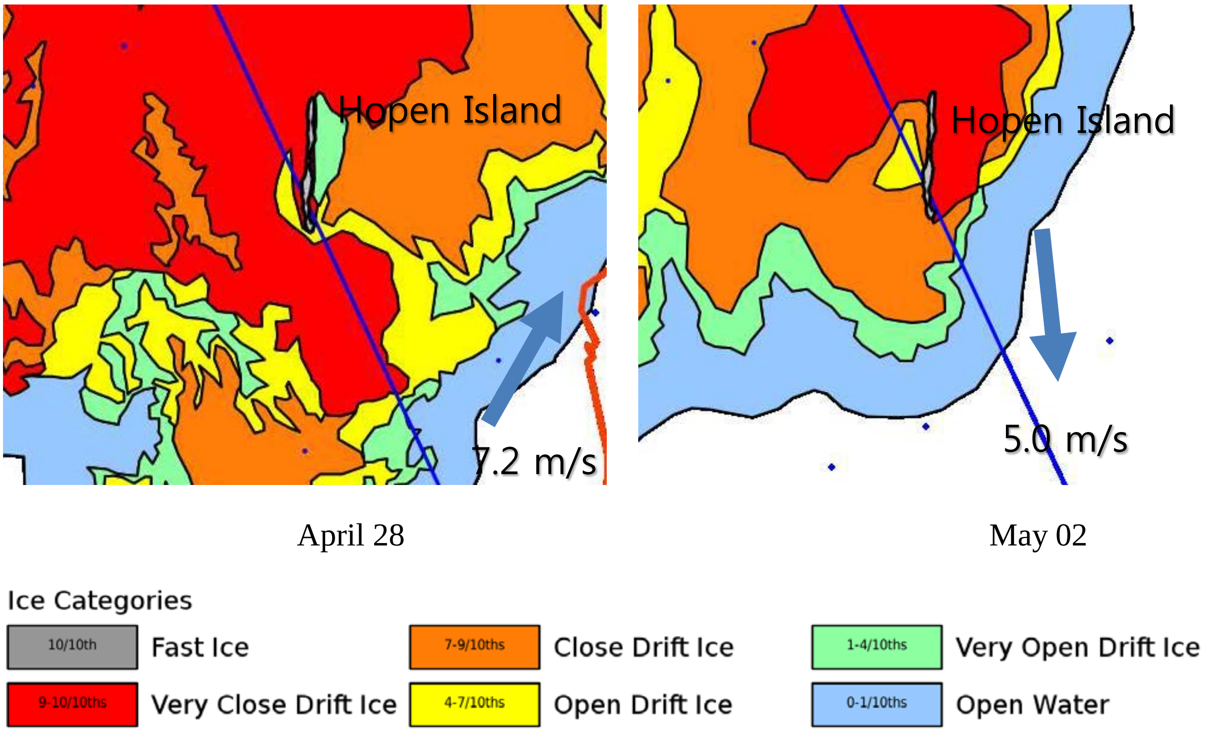


Figure 5. Ice conditions and mean wind velocity averaged over 24 h in the region of the floe drift from April 26 to May 02, 2017. Colors show the drift ice with concentrations of 90-100% (red), 70-90% (brown), 40-70% (yellow). Blue color shows open water.

IT1 transmitted the data from April 24 to May 05. IT2 transmitted data from April 26 to May 02. Ice conditions over this period are shown in Fig. 5. Wind velocity changed over this period significantly. Sea ice tongue extended from the Hopen Island to the South in the direction of Bear Island was well visible on May 26-27 and practically disappeared to May 02. Increase of wind speed on May 28 influenced ice dispersion and drift away from Spitsbergen-banken.

DATA ANALYSIS

Figure 6a shows drift trajectory of IT 2. The initial point corresponds to 12:00 UTC of April 26, and the final point corresponds to 16:00 UTC of May 02, 2017. General direction of the drift was from the North-West to South-East. The resulting displacement was 44.5 km over 126 h with the mean speed of 10 cm/s. Blue line in Fig. 6b shows actual speed of IT 2 versus the time which is accounted in hours from 00:00 UTC of April 26, 2017. Local maxima of IT 2 speed repeated over 12 hours are probably related to local current due to semidiurnal tide. Maximal speed of IT 2 exceeded 1.6 m/s by t=75 h. The wind speed reached local maximum of 13 m/s five hours before by t=70 h.

Figure 7 shows speeds and directions of the wind measured over each 2 h by IT 1 and simulated by the National Weather Service. One can see higher spreading of the wind speeds measured by IT 1. Measured wind directions are also wider spread, but their changes are smoother over the time from t=18 h to t =40 h in comparison with simulated wind directions. In general, measured and simulated wind velocities fit well each other.

Figure 8 shows probability density of IT 2 drift speed calculated for 6 intervals of the observation period. Maximal probability density corresponds to drift speed of 0.6 m/s from April 28, 12:00, to April 30, 12:00, UTC. Maximal drift speed of 1.6 m/s was registered around 15:00 UTC of April 29. Circle in Fig. 6a shows the location where the maximal drift speed was reached. Figure 7 shows that the probability density spread from 0 to 0.6 m/s on April 26-27. Then it becomes wider and spreads from 0 to 1.6 m/s on April 28-29, from 0 to 1.2 m/s on April 29-30, and from 0 to 1 m/s on April 30-May 01. The last interval of 4 hours is shorter but the probability density spreads from 0 to 0.8 m/s.

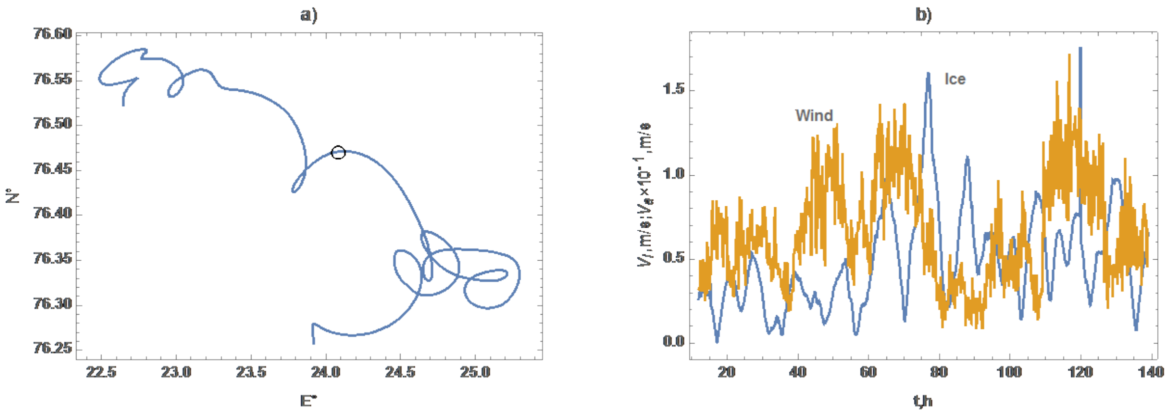


Figure 6. Trajectory of IT 2 from April 26 to May 02, 2017 (a). Floe speed and wind speed recorded by IT 1 and IT 2 (b).

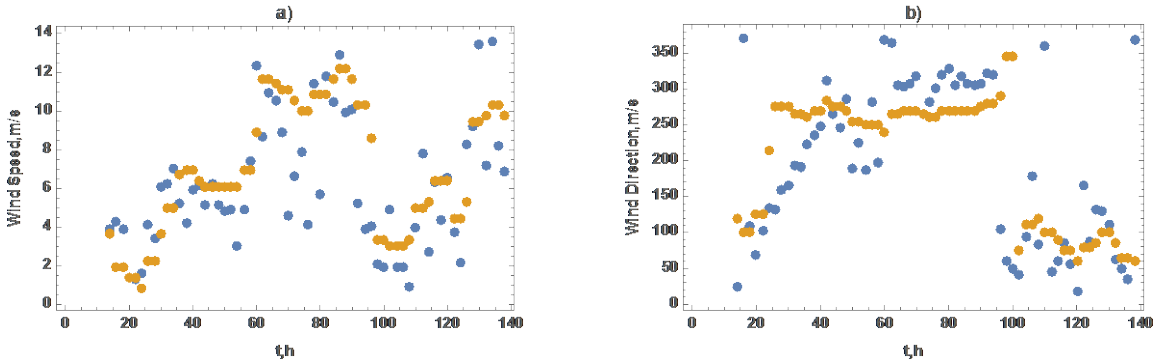


Figure 7. Wind speeds (a) and directions (b) measured by IT 1 (blue points) and provided by the web (https://earth.nullschool.net) (yellow points).

Raw GPS data of IT 1 and IT 2 were processed using Mathematica 11.2 software. The interpolating functions ILat [t] and ILon [t] were constructed to interpolate the dependencies of latitudinal and longitudinal coordinates of the ice trackers from the time as follows

ILat [t]= Interpolation[Lat, InterpolationOrder -> 1], (2)

ILon [t]= Interpolation[Lon, InterpolationOrder -> 1],

where Lat and Lon are the series of latitudes and longitudes measured with sampling interval of 10 minutes. Points with coordinates ILat (t) and ILon (t) belong to the IT trajectory on the plane (N,E) tangential to the Earth surface (Fig. 6a).

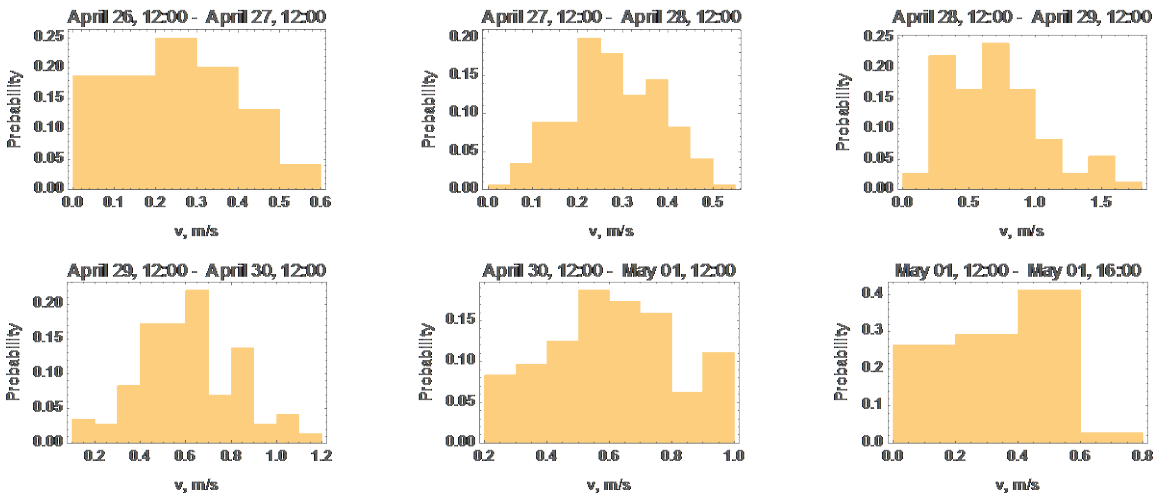


Figure 8. Probability density of IT 2 speed calculated for 6 intervals of the floe drift.

Series of the raw data Lat and Lon were smoothed using MovingAverage procedure over 10 samples and then interpolated

IMALat [t]= Interpolation[MovingAverage[Lat,10], InterpolationOrder -> 1], (3)

IMALat [t]= Interpolation[MovingAverage[Lat,10], InterpolationOrder -> 1].

Points with coordinates IMALat (t) and IMALon (t) belong to the smoothed IT trajectory on the plane (N,E) tangential to the Earth surface.

The function

δ[t]=GeoDistance [{ILat[t],ILon[t]},{IMALat[t],IMALon[t]}] (4)

was used to calculate distances between the points of the IT trajectory and smoothed IT trajectory. The function δ[t] characterizes the dispersion of IT displacements around the smoothed IT trajectory. Figure 9a shows the dispersion of IT 2 displacements around the smoothed trajectory of IT 2.

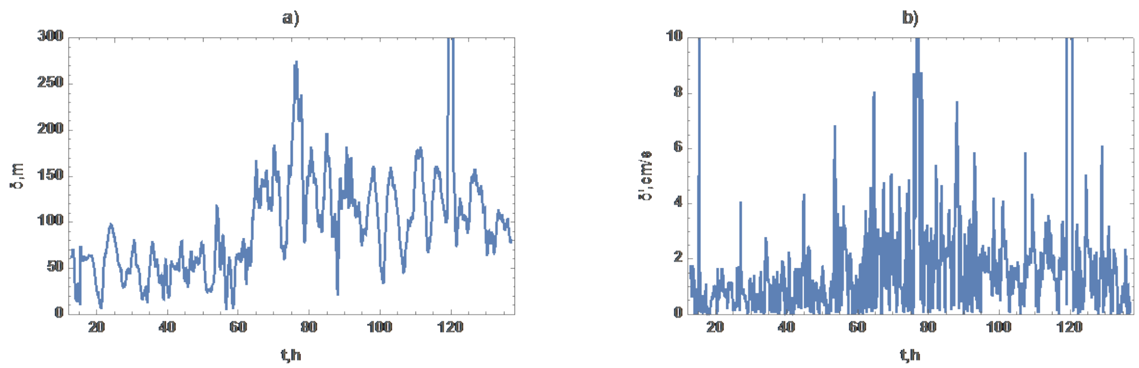


Figure 9. Dispersions of IT2 displacements around smoothed IT2 trajectory (a) and dispersions of IT2 speeds around smoothed IT2 speeds (b) versus the time.

The interpolating functions ISP[t] were constructed to interpolate the dependence of IT speeds from the time as follows

ISP[t]=Interpolation[Table[{ti, GeoDistance [{Lat[t_i],Lon[t_i]}},[{Lat[t_{i+1}],Lon[t_{i+1}]}] (5)

Δt^{-1}]},{i,N}],InterpolationOrder->1].

Operation GeoDistance was used to calculate the distance between two locations of the same ice tracker over sampling interval $\Delta t = t_{i+1} - t_i = 10$ min. The same procedure was applied to the values of the smoothed functions MALat[t_i] and MALon[t_i] for the calculation of the smoothed IT speed IMASP[t].

The dispersion of IT speed was calculated as absolute value of a difference

δ'[t]=Abs[ISP[t]-IMASP[t]]. (6)

Figure 9b shows that dispersion of IT2 speed increases synchronously with dispersion of IT2 displacements.

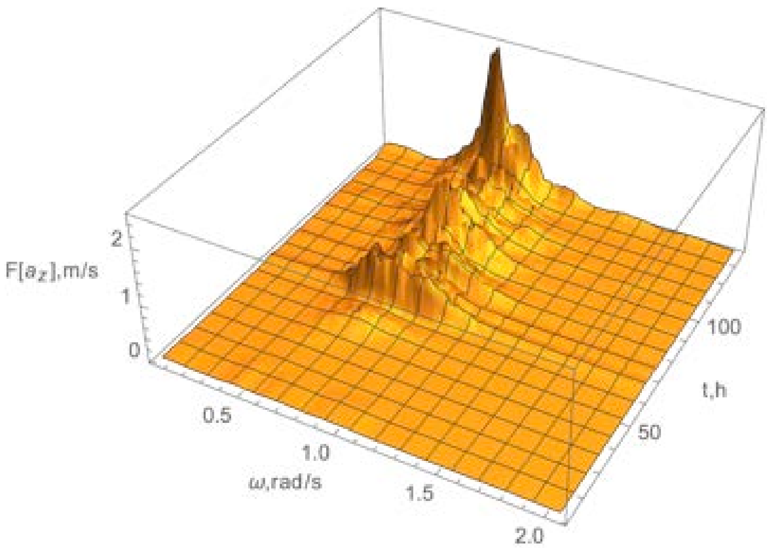


Figure 10. Spectrum of vertical accelerations of IT2 versus the time.

Spectrum of vertical accelerations a_r recorded by IT2 was calculated for each 5 min interval of the measurements using operation Fourier in Mathematica 11.2 software. It calculates the discrete Fourier transform $f[a_s]$ of the list of measured accelerations with components a_r by the formula

$$f[a_s] = \frac{1}{\sqrt{n}} \sum_{r=1}^{n} a_r e^{2\pi i (r-1)(s-1)/n}, \quad (7)$$

where $n = 1500$ is a number of measurements over 5 min interval. Figure 10 shows the absolute value $F[a_s] = \text{Abs}[f[a_s]]$ versus the frequency $\omega = 2\pi(s-1)/n$ and the time. It is obvious that the increase of the dispersions of IT2 displacements and speeds corresponds to the increase of wave energy.

The Fourier transform $f[\eta_s]$ of the vertical displacements of IT2 was calculated by the formula

$$f[\eta_s] = \frac{1}{\sqrt{n}} \sum_{r=1}^{n} \frac{a_r}{(2\pi i(s-1)/n)^2} e^{2\pi i(r-1)(s-1)/n}. \quad (8)$$

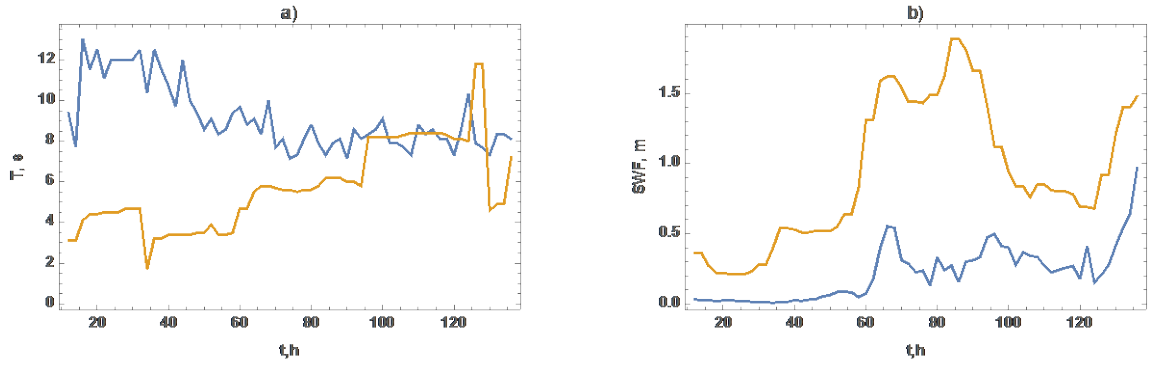


Figure 11. Calculated from the IT2 data (blue lines) and simulated (yellow lines) peak wave periods (a) and significant wave heights (b) versus the time.

The inverse Fourier transform was applied to calculate the values of the vertical displacements of IT2 as follows

$$\eta_r = \frac{1}{\sqrt{n}} \sum_{s=\alpha}^{n-\alpha} \frac{f[a_s]}{(2\pi i(s-1)/n)^2} e^{-2\pi i(r-1)(s-1)/n}, \quad (9)$$

where the value of $\alpha = 20$ was chosen to reduce the influence of low frequency oscillations on the results.

Significant wave height was calculated using the formula

$$SWH = 4 \cdot \text{StandardDeviation}[\text{Re}[\eta_r]]. \quad (10)$$

Blue lines in Fig. 11 shows peak waves periods corresponding to maxima of the spectrum in Fig. 10 and significant wave heights calculated from formula (9) versus the time. Yellow lines show the same characteristics obtaining by WAVEWATCH III modeling (https://earth.nullschool.net). The modeling doesn't account the influence of drift ice on waves. It is probably the reason that simulated peak wave periods are smaller and significant wave heights are greater than it is estimated from the field data.

CONCLUSIONS

The data of two ice trackers deployed on the drifting floe and transmitting the data during 138 h were analyzed and processed. The data includes measurements of the geographical locations and wind velocity with sampling interval of 10 min, and measurements of vertical accelerations with sampling frequency of 5 Hz during 5 min over each two hours. Records of wind velocity correspond well to simulated wind velocities provided by the web (https://earth.nullschool.net). Analysis of acceleration data shows that wave energy increased after 60 h of the data transmission. It influences an increase of the floe movements around its smoothed trajectory reflected by the dispersion of the floe displacements and speeds. Drift speeds registered by the ice tracker change in the time with semidiurnal period. Their correlation with the recorded wind speed is less evident than correlation with semidiurnal tidal currents. Maximal drift speed of the ice tracker reached 1.6 m/s on approximately 75th hour of the data transmission.

Peak periods of the vertical floe accelerations recorded by the ice trackers varied between 8 s and 12 s. Oscillations with maximal energy had period of 8 s. WAVEWATCH III simulations (https://earth.nullschool.net) predicted smaller periods of peak waves over 100 h of the data transmission. The simulated peak wave period of 8 s during next 20 h corresponds well to the ice tracker data. The simulated significant wave heights were larger than the wave height calculated from the ice tracker data. Thus, it is shown that even relatively small ice infested areas of ocean have strong influence on the wave spectrum due to the wave damping by ice.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of the Research Council of Norway through the Centre for Sustainable Arctic Marine and Coastal Technology (SAMCoT), AOCEC project of IntPart program, and DOFI project of Petromaks2 program.

REFERENCES

Marchenko, A.V., Diansky, N.A., Onishchenko, D.A., Chumakov, M.M., Nikitin, M.A., Fomin, V.V., Marchenko, N.A., 2016. Studies of ice drift and ridge consolidated layer evolution in the North-West Barents Sea. *Proceedings of Hydrometcentre of Russia*. V. 361, 229-258.

Marchenko, N., 2018. Sea ice observation and comparison with ice maps during the cruise in the Western Barents Sea in April 2017. *Proceedings of the 24th IAHR International Symposium on Ice*, ISSN – 2414-6331, Vladivostok, Russia, Paper -011.