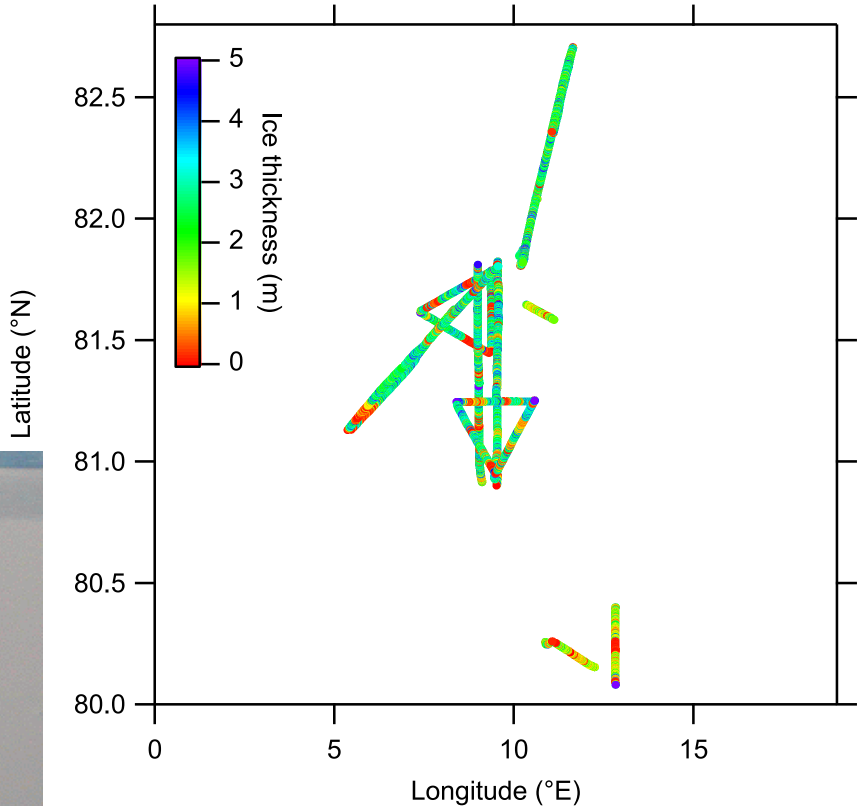
EM ice thickness measurements during GreenICE 2004 field campaign



GreenICE Deliverable D11

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Executive summary

This report summarizes results obtained during the first GreenICE campaign in 2003. It was performed in Fram Strait on board RV Polarstern between March 29 and April 24, 2003. Ice thickness was obtained by means of helicopter-borne electromagnetic induction (EM) sounding. Ice thickness profiles showed the occurrence of both, thick multiyear ice and thin new ice formed in leads in a divergent ice field close to the ice edge in Fram Strait. Modal multiyear ice thicknesses amounted to 2.5-2.7 m, relatively thick compared with earlier measurements of AWI in 1993 and 2001. All data and this report can be downloaded from http://www.awi-bremerhaven.de/Modelling/SEAICE/GreenICE.

Table of content

1. Introduction

The first GreenICE measurement campaign was performed between March 28 and April 24, 2003, during the Polarstern cruise Ark 19/1b in Fram Strait (Haas et al., 2004; see also http://www.awi-bremerhaven.de/Modelling/SEAICE/Ark19/Ark19.html). Figure 1 shows a map of the cruise track. The cruise track crossed the ice edge toe the Northwest of Svalbard, and reached the closed pack ice as far north as 82°N through a series of prominent new ice leads which are well visible on an AVHRR satellite image from April 5 (Figure 2). The cross in the satellite image indicates the approximate location of a longer drift station ("Tomato Island") which has been maintained between April 7 and 18. On that station, numerous ground-based measurements have been performed which are summarized in Deliverable No. 7 (Ice thickness data from ground observations). During the expedition, 7 helicopter electromagnetic (HEM) surveys of sea ice thickness have been performed to obtain representative information on the ice thickness distribution in this region. The flight tracks and dates are also indicated in Figure 1.
This report presents information on the HEM measurements and on the data processing to derive ice thickness, and summarizes the results.

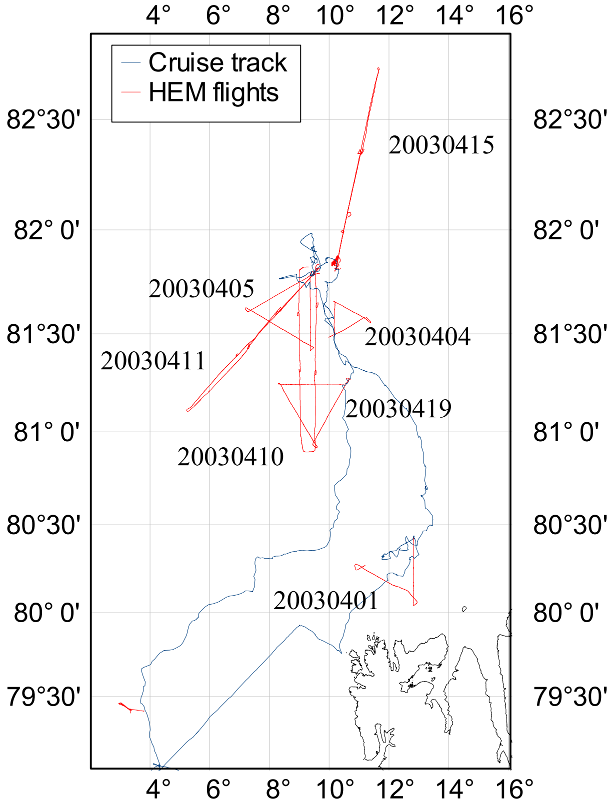


Figure 1: Cruise track of RV Polarstern during the first GreenICE field campaign in 2003 (blue). Red lines show thickness profiles surveyed by helicopter electromagnetic (HEM) sounding.

Figure 2: NOAA-AVHRR NIR satellite image of April 5, 2003, showing the ice situation during the GreenICE campaign in 2003, and the position of RV Polarstern at the time of image acquisition (cross).

2. The AWI EM Bird

2.1 Operation and coil design

Electromagnetic (EM) induction sounding can generally be used to determine the distance to the interface of two layers with different electrical conductivities. The sea ice application is based on the fact the sea water is a conductive medium while sea ice is non-conductive. Thus the distance from the sensor to the ice/water interface, which is coincident with the ice underside, can be determined. The distance between the sensor and the ice surface is measured by a laser distance meter. From the difference of both distances ice thickness is obtained.

Since 2001 Alfred Wegener Institutes (AWI) operates a towed thickness sensor (EM bird). Technical fine tuning and the generation of sophisticated data processing tools are still under development. The EM bird is suspended with a 20 m long below a helicopter (Fig. 3). It uses two operating frequencies of 3.6 and 112 kHz. The length of the bird is 3.4 m and weight 120 kg. The bird is flown at an altitude of 10 to 20 m above the ice surface. The laser altimeter readings are directly displayed to the pilot for real-time altitude control of the bird. The bird requires a power supply of 28 VDC and 16 A (450 W) to be delivered from the helicopter. The power supply and the load hook are the only interfaces with the helicopter, so that the bird is quite platform independent. Data are radio-transmitted to a small notebook operated on the knees of one passenger in the helicopter. Data acquisition is performed at a sampling rate of 10 Hz, corresponding to a point spacing of 3 to 4 m with flight speeds of 60 to 80 knots.

Figure 3: EM bird in operation.

2.2 Laser altimeter

The Riegl LD90-3100HS laser distance meter inside the EM bird is not only used as a supplementary instrument for the computation of ice thickness, but also as a stand-alone laser profiler for measurements of ridge sail distributions and surface roughness. Its measurements enable to relate ridge profiles to overall thickness profiles.
The infrared laser operates at a wavelength of 905 nm with a ray divergence of 2 mrad. It has a range of up to 150 m with an accuracy of 0.002 m. To obtain a higher spatial sampling than with the thickness measurements, the laser is operated at a sampling rate of 100 Hz, corresponding to a point spacing 0f 0.3 to 0.4 m.

2.3 GPS

A standard GPS is included in the EM bird for recording the flight track with high accuracy. This enables later comparison of the data with data from other sources, e.g. satellite imagery.

2.4 Video camera

A downward looking digital video camera inside a metal housing was mounted directly to the helicopter. The video was used to enable detailed investigations of the behaviour of the EM signal over different ice types and to judge the spatial resolution of the EM measurements. It was also used to document overall ice conditions with high flying altitudes.

2.5 Aerial photography

With a conventional digital camera still photographs were taken to document overall ice conditions and whenever there were peculiar ice features or situations. All photographs were documented with a GPS position to be able to specify their exact location when questions regarding interpretation of thickness data or satellite images should occur. All photographs were plotted onto a map with the cruise track to allow for interactive tracking of ice conditions using a web browser. These web pages are published on the AWI GreenICE Website at http://www.awi-bremerhaven.de/Modelling/SEAICE/GreenICE.

3. Processing

For the present report, only the inphase signal of the low frequency (Re(f1); f1 = 3.6 kHz) has been processed, as there was large noise and non-linear drift on all other channels.

3.1 Drift compensation

EM signals are subject to temporal drift due to electronic drift of the analogue electronic components, mainly heating of the coils. The drift can be monitored during high altitude sections, when there should be no signal in the absence of any conductor around the system. The deviation from null between two ascents is the signal drift. This has to be (linearly) interpolated and removed from all other samples in between. The procedure is illustrated in Figure 4. Here, drift amounted to 30 ppm which is relatively low because the profile has been obtained after 0.5 hours of operation, when all electronic components had almost achieved their equilibrium temperature.

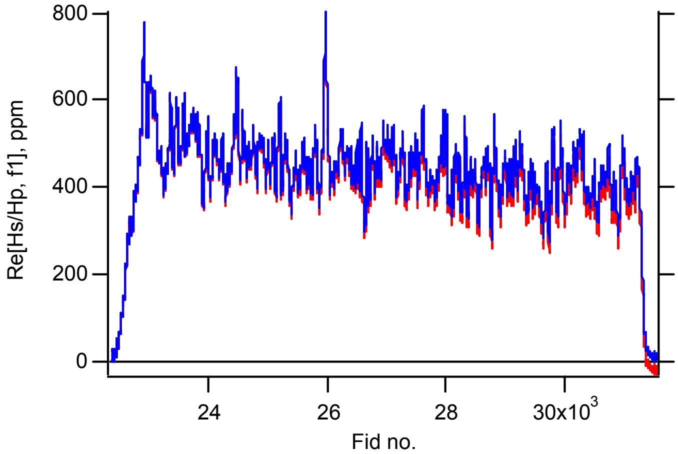


Figure 4: Typical profile of inphase component of f_1 (3.6 kHz) showing original (red, stippled) and drift-corrected trace (blue, solid). February 23, 2nd flight, file 200302231204*.

3.2 Calibration

An essential issue in EM sounding is calibration to be able to convert the measured voltages into EM field strength. Normally, absolute calibration is required to invert underground conductivities from the EM signals. This will also be necessary for the future development of our geophysical inversion procedures.

However, the case of sea ice thickness measurements is comparatively simple, as normally the data contain some open water sections even in winter. As ice thickness is well known to be zero over open water, these sections provide some independent means for calibrating the data. Because the helicopter altitude is quite variable during a flight, open water sections are crossed at different heights and provide thus information on the relation between EM signal and bird distance to the water surface. This is illustrated in Figure 5. Open water and thin ice sections are characterised by a maximum EM signal strength for a given bird height and are therefore easily identifiable. Some open water points can then be picked from a scatter plot of

EM signal versus laser height, and can be used as sampling points for an exponential fit. The fit provides a transformation equation to convert the EM signal into a distance to the water surface.

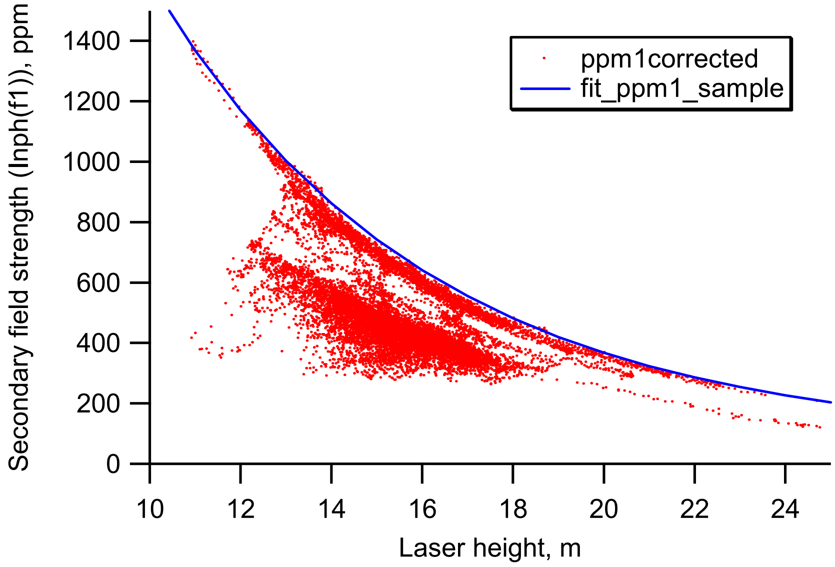


Figure 5: F_1 Inphase signal versus system height above the ice surface for the example for the April 11 flight, which crossed large stretches of thin ice and some open water. The exponential fit is performed only for open water sampling points.

3.3 Thickness computation

Figure 6a presents profiles of electromagnetically derived bird distance to the water surface computed as explained in Section 3.2, and the coincident laser height above the ice surface. For better clarity, only a short section of the profile is shown. Ice thickness is the difference between both curves (Fig. 6b). Figure 7 shows the corresponding thickness distribution. Mean ice thickness along the profile was 1.36 m with a typical thickness of 1.1 m.

3.4 Thickness editing

From the curve in Figure 5 it can be seen that the EM signal becomes very small for greater bird altitudes. With low signal strengths, the signal-to-noise ration becomes rather unfavourable. Therefore, we have removed all data which has been obtained from flying altitudes greater than 25 m. As a results, there are quite some data gaps in the beginning and end of files, and sometimes also in between.

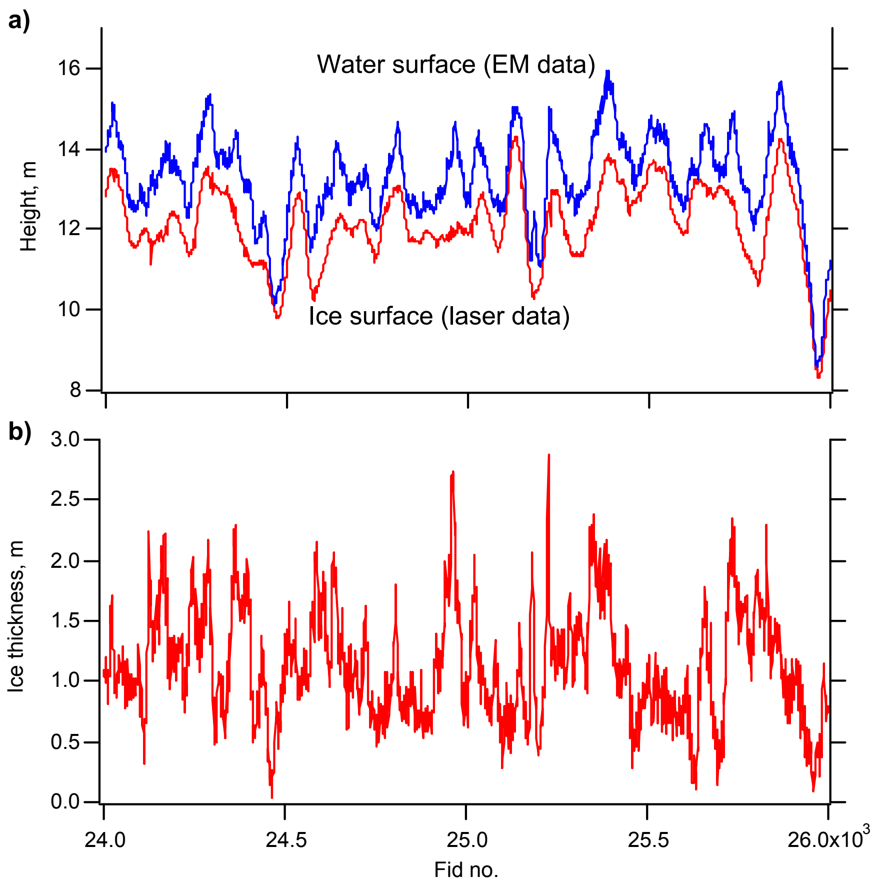


Figure 6: Profiles of bird height above the water (blue) and ice (red) surface **(a)** and ice thickness **(b)** derived by subtracting both curves in a.

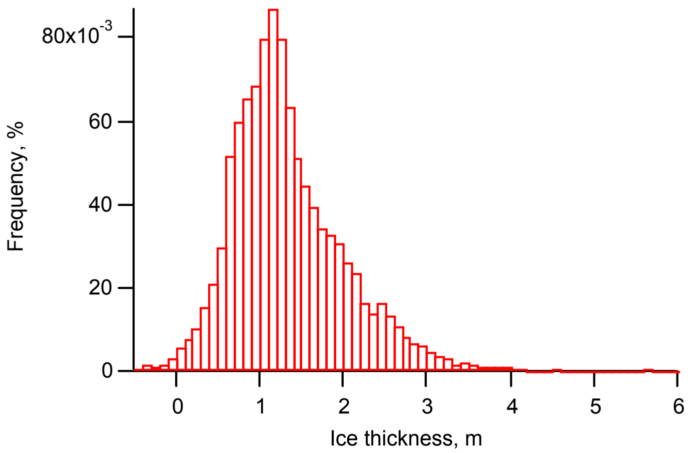


Figure 7: Thickness distribution of the profile shown in Figure 6.

3.5 Data file contents and formats distributed on-line

All data files are available from the AWI GreenICE homepage at http://www.awi-bremerhaven.de/Modelling/SEAICE/GreenICE. There is a single file for every flight. Each flight consists of several profiles, defined as the sections of data acquisition between two ascends for drift compensation and calibration (Section 3.1 & 3.2). Some statistics of each flight and every profile can be found in Tables 1 and 2.

All files are in tab-delimited format so that they can easily be read by analysis programs. There are seven columns containing the following information:

- latitude: Latitude of measurement point
- longitude Longitude of measurement point
- time_utc UTC time of data acquisition
- dx Distance along profile, beginning at first valid thickness measurement of every profile. Note that dx starts at zero for each profile of one flight.
- fid Fiducial number: an internal reference index
- ppm1_thick Ice thickness, obtained from inphase of low frequency signal Inph(f1), f1 = 3.6 kHz
- height_dec Bird height obtained from laser profiler. Data have been resampled (smoothed) to 10 Hz.

4. Uncertainties

The user of the presented data should be aware of certain possible inaccuracies of the data, which are due partially to the general properties of EM ice thickness retrievals. The user should further keep in mind that the presented surveys have been the third campaign only with the AWI EM Bird, and that much of the processing software has only been developed for the processing of GreenICE 2003 data. There is still much to be learned with respect to absolute system calibration. The chosen approach (Section 3) for thickness inversion is however independent of absolute system calibration, and therefore from experience from the Arctic we believe that the accuracy of measurements over well behaved, level drift ice is ± 10 cm. This is also confirmed by comparisons with ground-data presented in the Ground-measurement Deliverable D7.

Looking at the profile plots presented below, one should also keep in mind that their appearance depends strongly on the length of these profiles. For a 20 or 40 km long profile, actually ridges dominate the plots, which at that scale only look like random noise and spikes. The user is referred to the original data files, which allow to zoom in into a better scale, then showing a wealth of detail and information.

4.1 Ridges

The largest and most significant inaccuracy occurs with estimates of the maximum thickness of ridges. Both, the extended footprint of the EM measurements (approximately equal to the bird altitude, i.e. 10-20 m) as well as the large porosity of the keels, which is filled with seawater, lead to underestimates of the maximum thickness of as much as 50%. However, the “apparent” thickness of different ridges can very well be compared with each other, giving some estimate of the relative ice volume contained in these ridges. More importantly, the frequency, spacing, and extent of keels or rubble can very well be determined from the profile data.

4.2 No water

Some profiles were obtained where there was hardly any open water, but where leads were covered by dark, thin ice. Although this ice looked quite thin, it is actually not unlikely that it could have been up to 20 or 30 cm at some locations. In these cases, the typical ice thickness of the whole profiles would be underestimated by that new ice thickness, because it cannot be distinguished from open water sections during data processing. Here, multi-frequency analysis and processing of the video material will lead to future improvements.

5. Results

Figure 8 summarizes ice thicknesses obtained during all flights. The data are also presented in Table 1 and 2. Table 2 summarizes results obtained from each profile, thus giving an impression of the variability within each flight. Note that the mode of each distribution can be dominated by the amount of thin ice, like on April 05. In fact, multiyear modal ice thickness amounted to 2.6 m like for the other flights in the same region. Unfortunately, the flights did not fully cover the thickness gradient from the ice edge to the closed pack ice, which is indicated by the clearly smaller ice thicknesses on April 01. All other flights are very similar, except for the amount of thin ice. The amount of thin ice also determines the mean ice thickness of each flight and profile (Tables 1&2). Therefore, the modes of each thickness distribution are much more indicative of multiyear ice thickness than the mean thicknesses. This is also shown in Figure 9, which presents thickness distributions for all flights in Figure 8.

This was only the first GreenICE campaign, and therefore any comparison of the interannual variability will only be possible after more campaigns in the same region at the same time. However, it should be noted that ice thicknesses observed in 2003 were significantly thicker than those measured in 1993 during the Polarstern winter cruise Ark 9/1 in the same region. In 1993, Haas et al. (1997) observed modal and mean thicknesses of 2.2 and 2.85±0.66, respectively. Similarly, modes between 2.5 and 2.7 m in the winter of 2003 compare with summer observations of 1.95 m in the same region in 2001 (Haas, 2004).

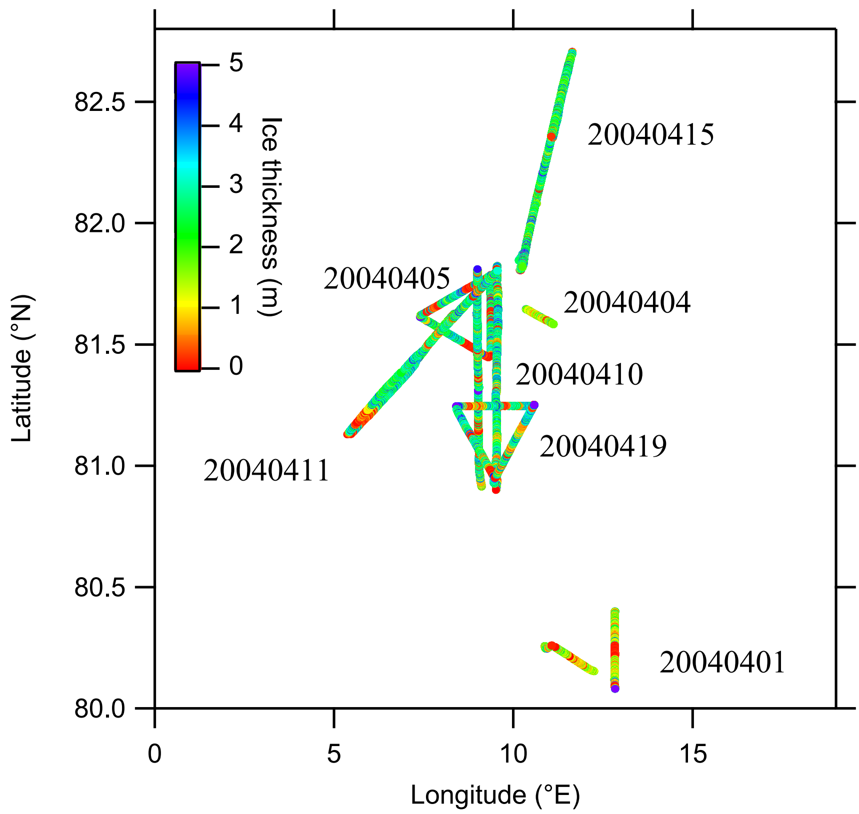


Figure 8: Ice thicknesses observed during all GreenICE 2003 flights.

Flight No. (Date)	Modal thickness (m)	Mean thickness (± 1 sdev), (m)
20030401	1.1	1.22±0.89
20030404	1.2	1.44±0.86
20030405	0.1	2.11±1.78
20030410	2.6	2.42±1.54
20030411	2.6	2.36±1.41
20030414	2.6	2.76±0.97
20030415	2.4	2.79±1.29
20030419	2.7	2.20±1.47

Table 1: Modal and mean thicknesses of each flight during the GreenICE 2003 campaign.

Profile (Date & Time)	Modal thickness (m)	Mean thickness (± 1 sdev), (m)
200304011312	0.1	1.19±1.22
200304011342	0.9	1.22±0.67
200304011400	1.7	1.52±0.94
200304041335	1.1	1.42±0.84
200304051503	0.1	2.19±1.87
200304051527	0.1	1.82±1.55
200304051550	0.1	2.36±1.92
200304100841	2.5	2.29±1.39
200304100855	2.7	2.77±1.24
200304100916	2.6	2.28±1.99
200304100942	2.5	2.18±1.32
200304101005	2.5	2.45±1.14
200304101022	2.5	2.68±1.48
200304111112	2.5	2.54±1.47
200304111128	2.0	1.93±1.27
200304111143	2.6	2.45±1.39
200304111211	2.3	1.93±1.34
200304111233	2.6	2.61±1.11
200304111251	2.6	2.70±1.66
200304141641	2.6	2.74±1.01
200304151043	2.4	3.23±1.49
200304151055	2.4	2.71±1.18
200304151118	2.6	3.15±1.21
200304151139	2.2	2.49±1.01
200304151219	2.3	2.61±1.55
200304191737	0.2	2.08±1.51
200304191758	2.6	2.34±1.44
200304191818	0.5	2.16±1.46

Table 2: Modal and mean thicknesses of each profile during the GreenICE 2003 campaign.

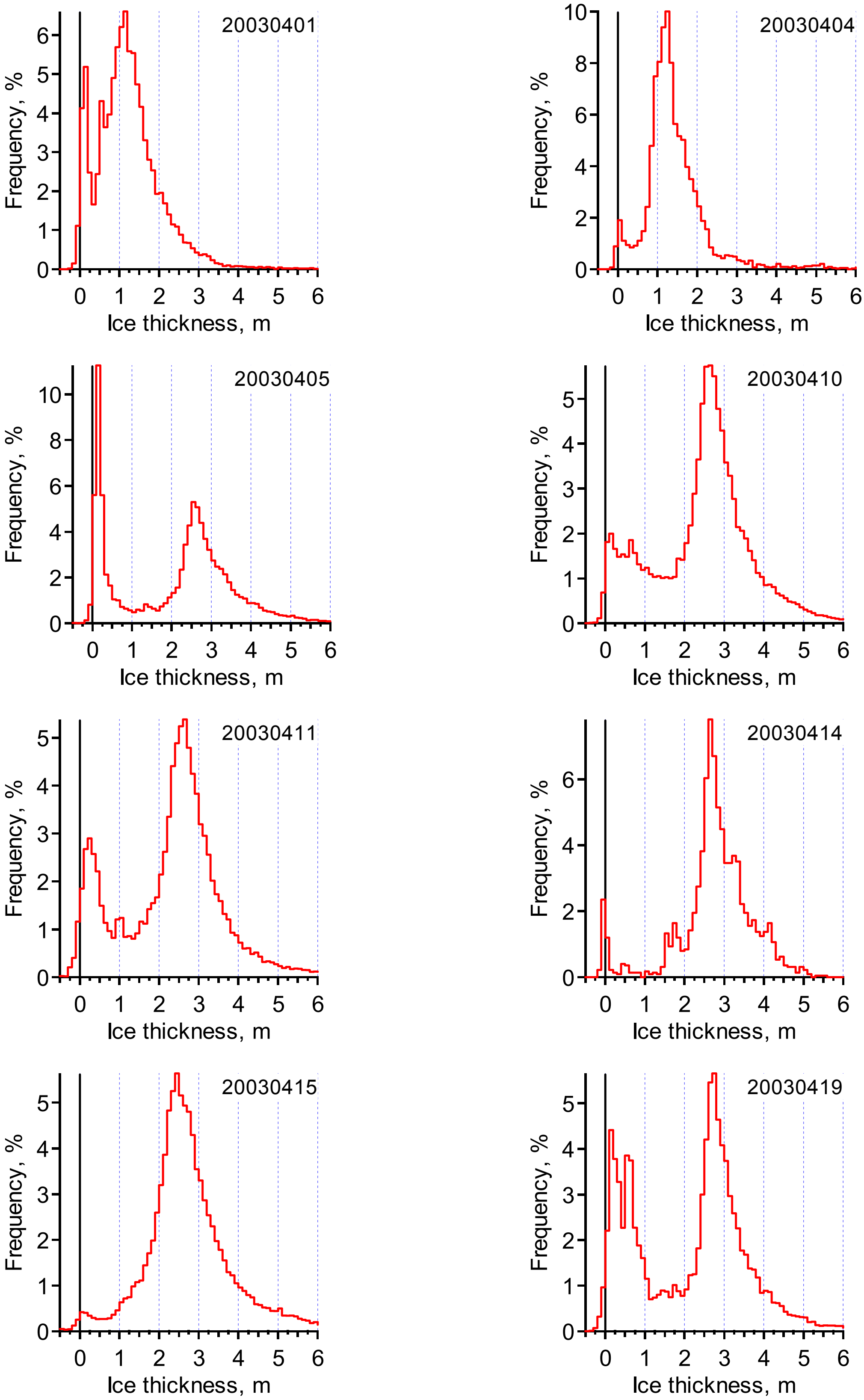


Figure 9: Thickness distributions of all flights obtained during the GreenICE 2003 campaign in Fram Strait.

6. References

Haas, C., J. Lieser, J. Lobach, T. Martin, A. Pfaffling, S. Willmes, V. Alexandrov, S. Kern, 2004, Sea Ice Physics. In: Schauer, U., and G. Kattner (Eds.), The expedition ARKTIS XIX/a,b and XIX/2 of the Research Vessel “POLARSTERN” in 2003. Reports on Polar and Marine Research, 481, 13-46.

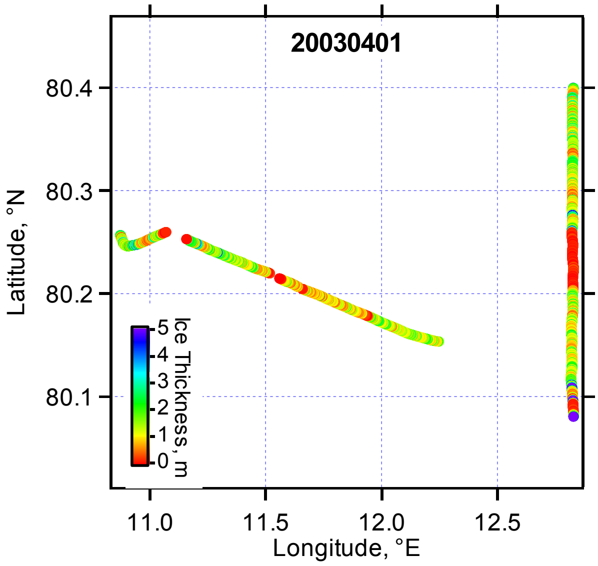
Haas, C., Gerland, S., Eicken, H., Miller, H., 1997, Comparison of sea-ice thickness measurements under summer and winter conditions in the Arctic using a small electromagnetic induction device, Geophysics,62/3,749-757.

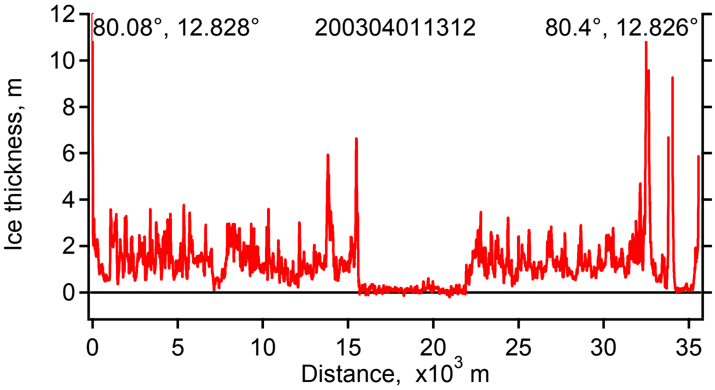
Haas, C., 2004, Late-summer sea ice thickness variability in the Arctic Transpolar Drift 1991--2001 derived from ground-based electromagnetic sounding, Geophysical research letters, VOL. 31, L09402, doi:10.1029/2003GL019394,5pp.

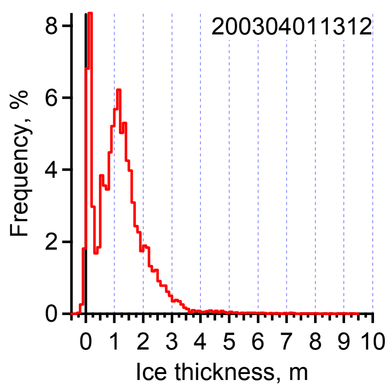
7. Profile plots

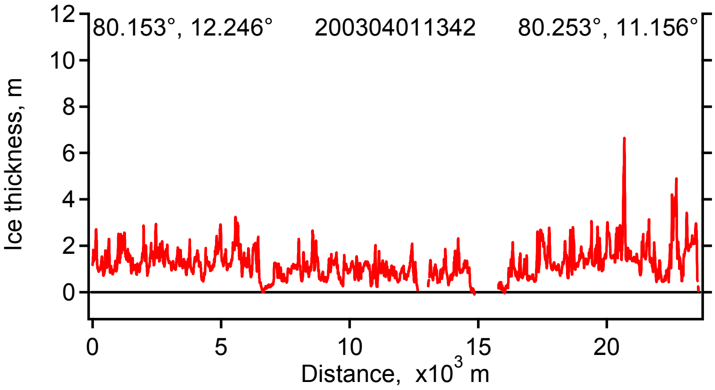
This section presents thickness profiles and histograms obtained from each profile. All profiles of one flight are summarized by a colour thickness map of that flight.
Note that all data can be downloaded from
http://www.awi-bremerhaven.de/Modelling/SEAICE/GreenICE

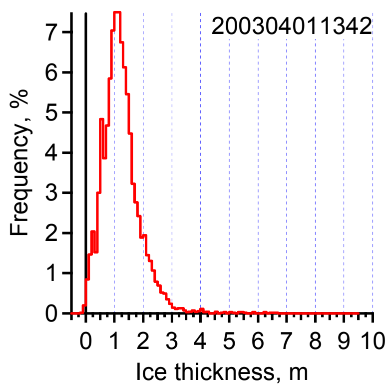
April 01, 2003

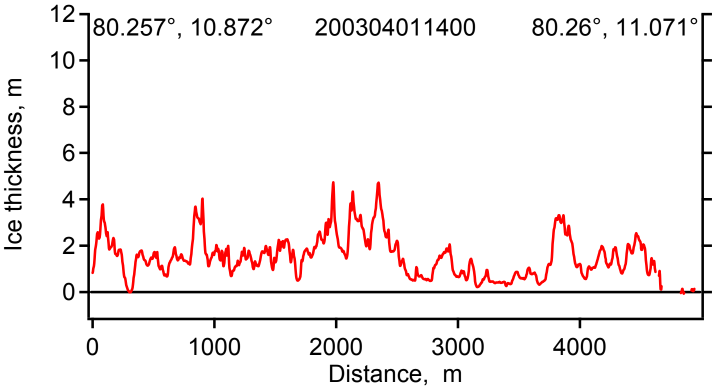


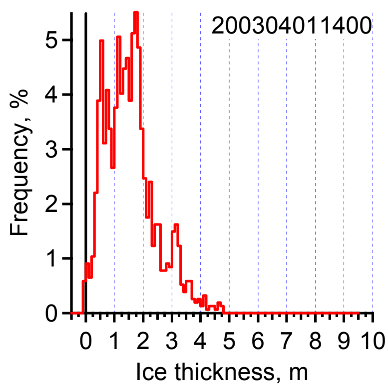












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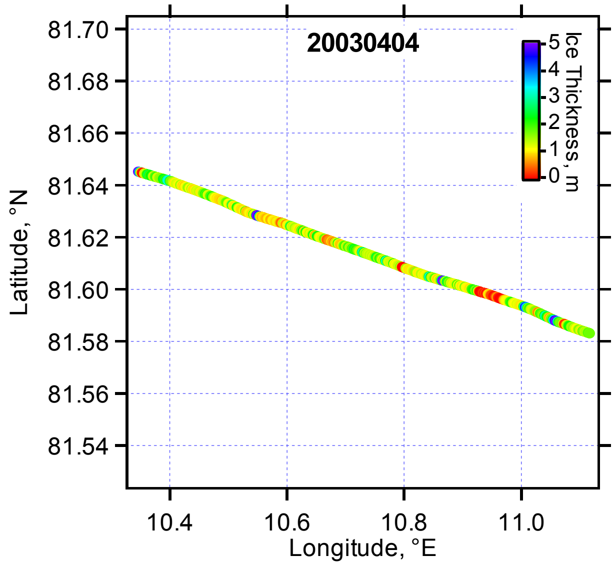

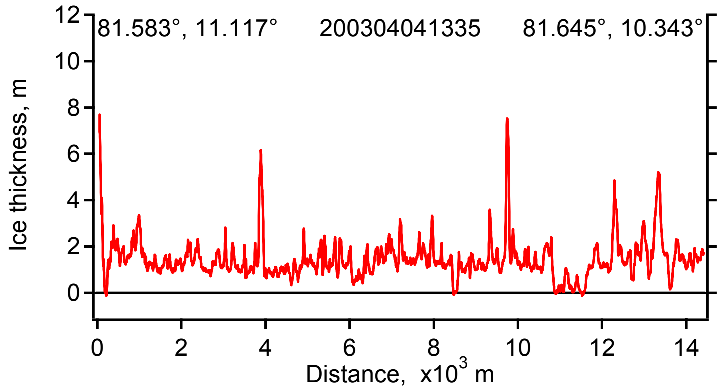

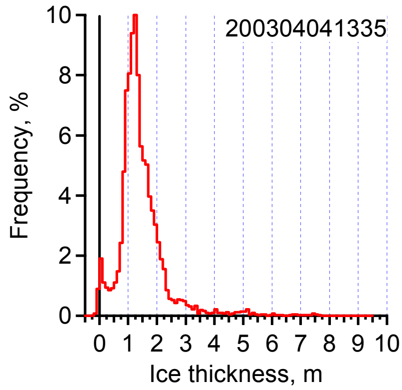

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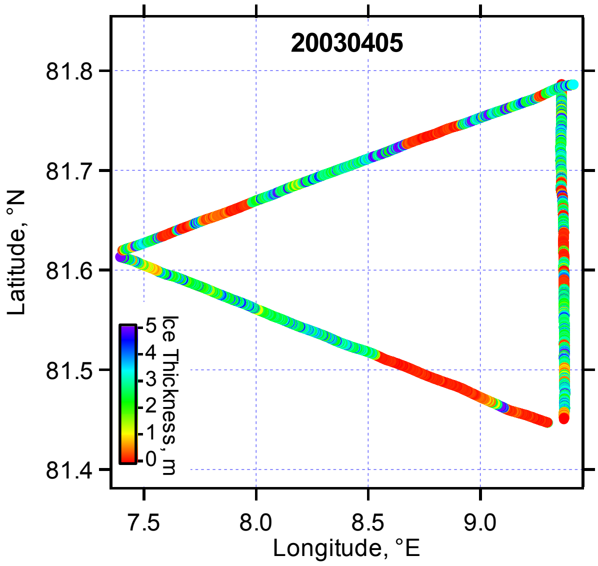

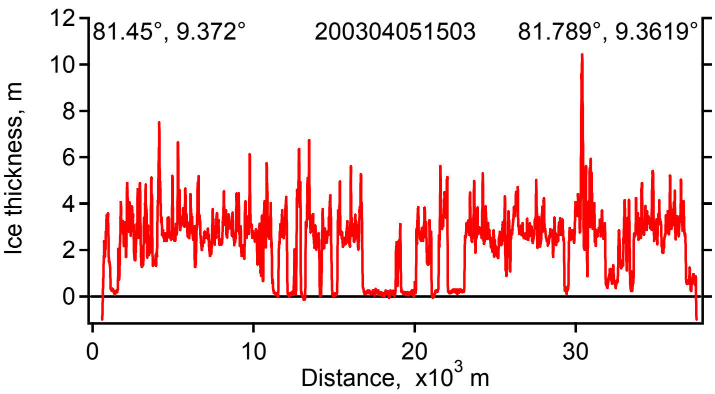

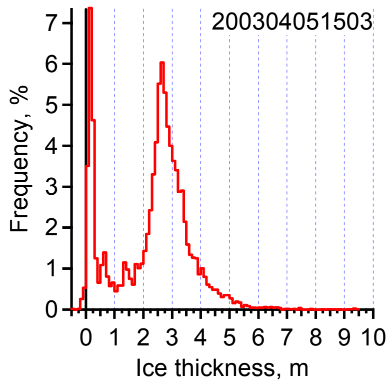

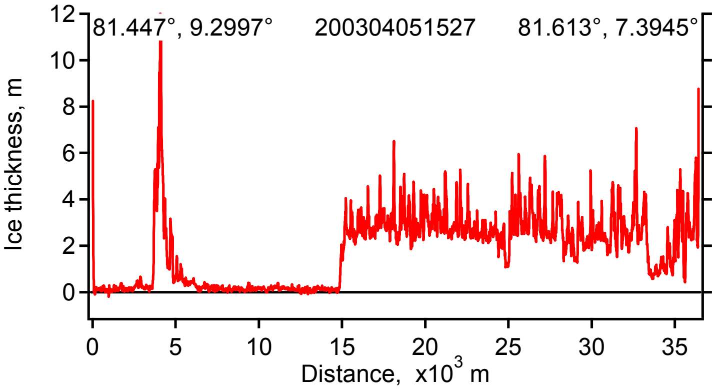

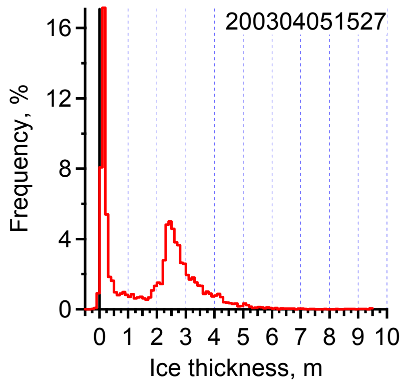

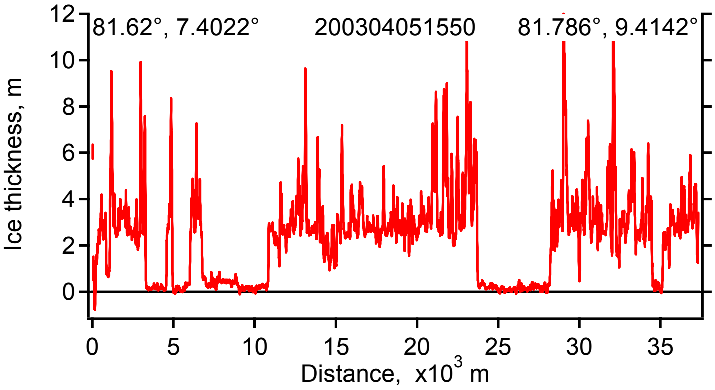

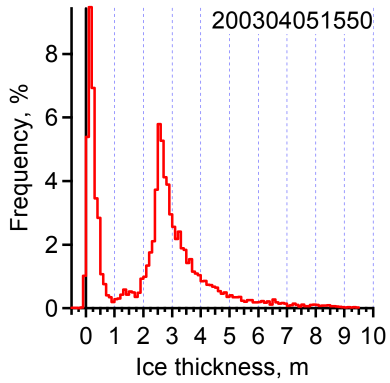

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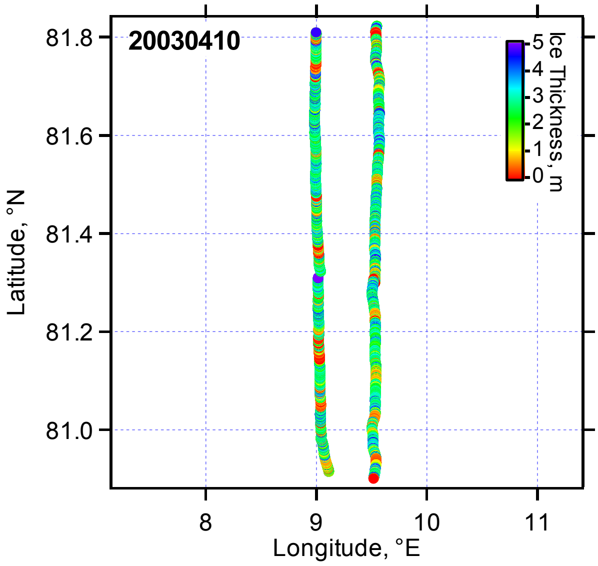

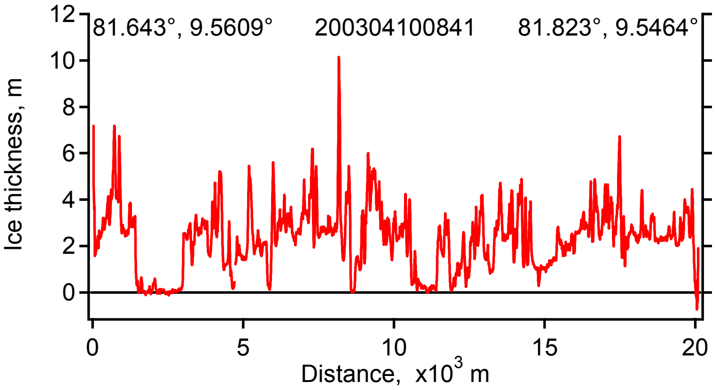

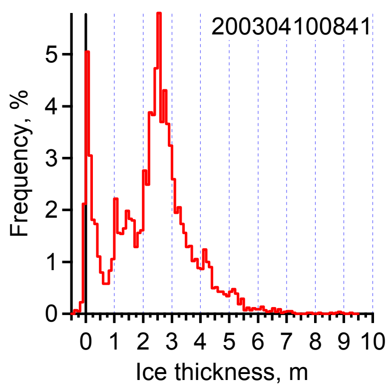

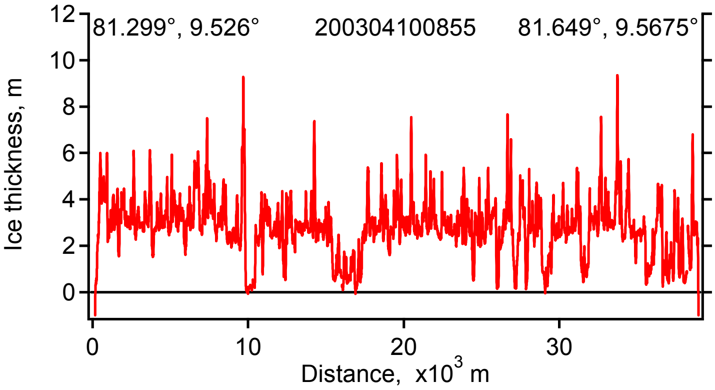

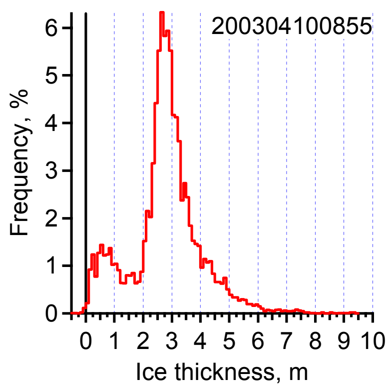

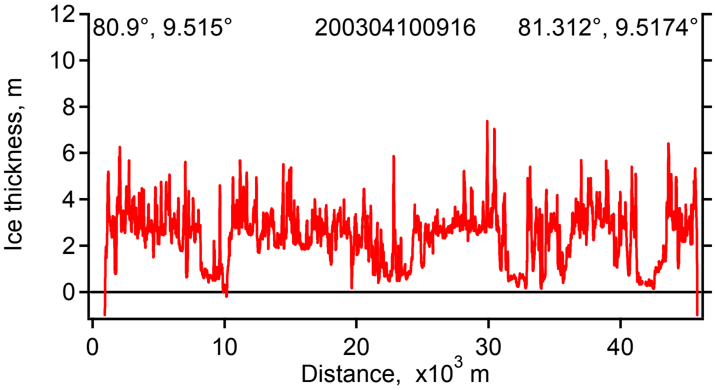

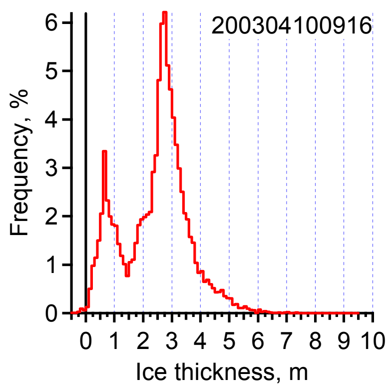

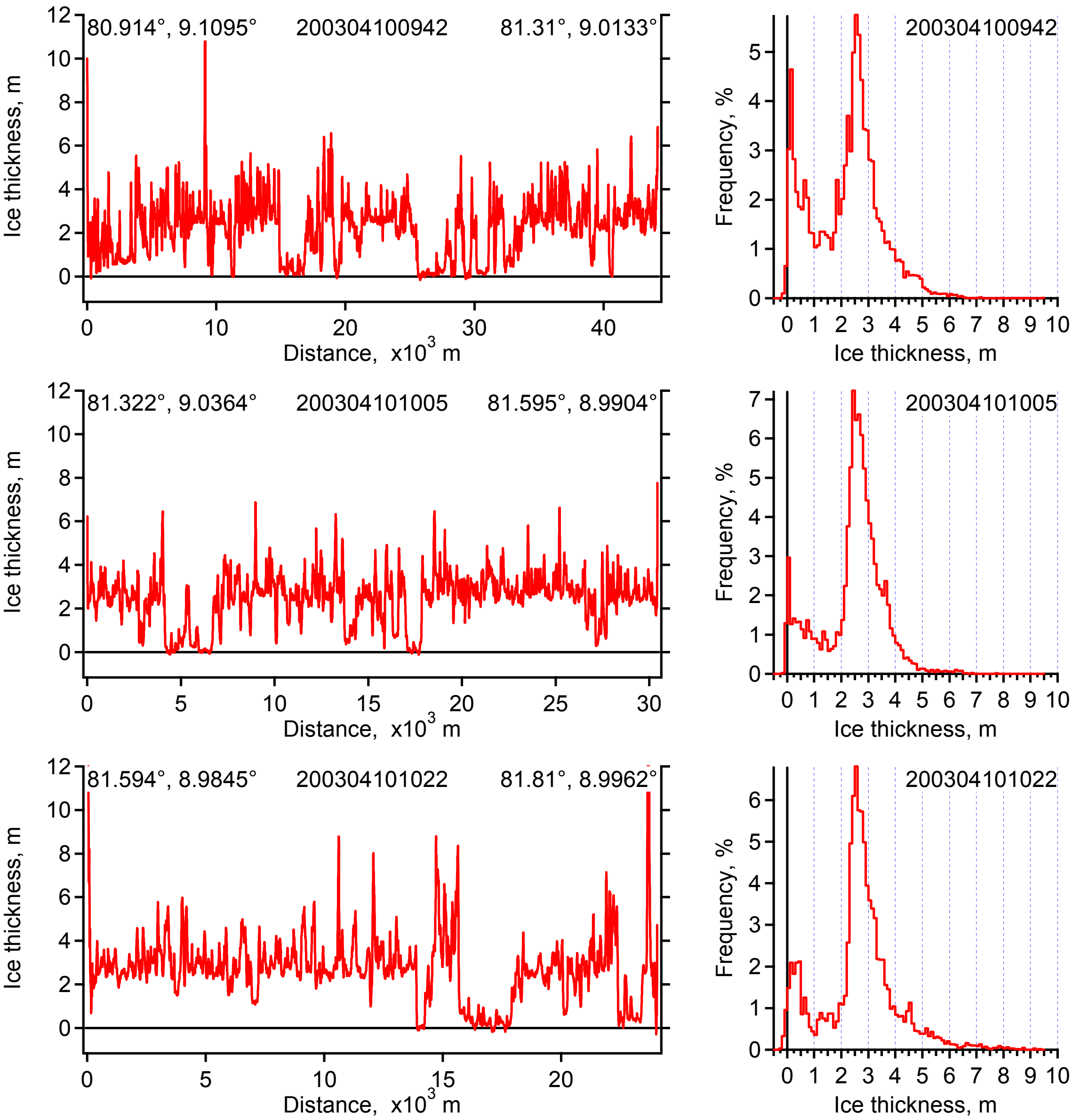
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Distance, x10^3 m
Frequency, %
Ice thickness, m
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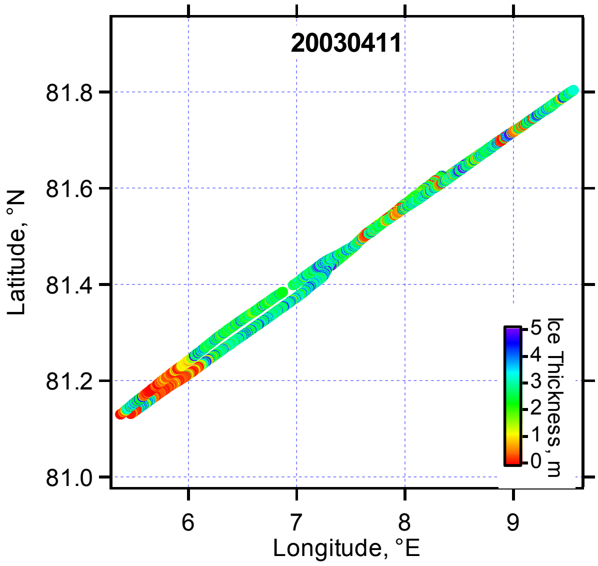
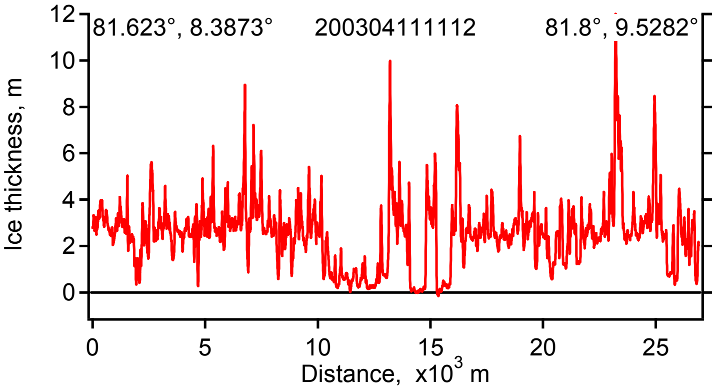
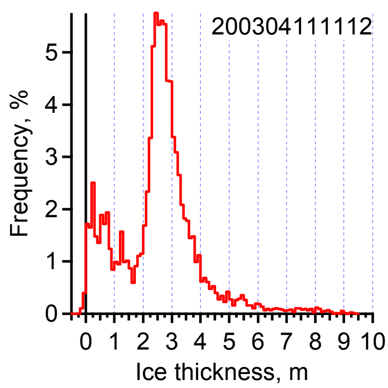
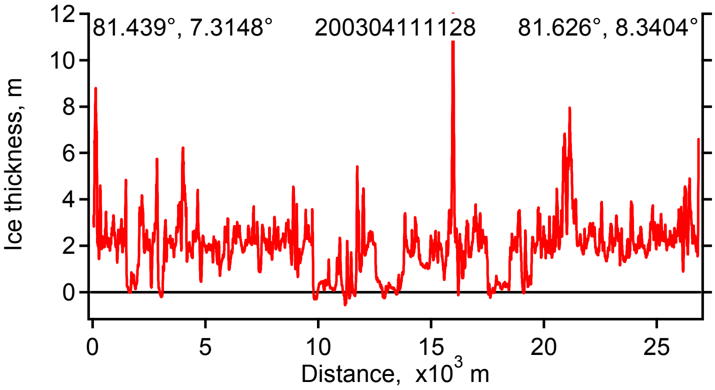
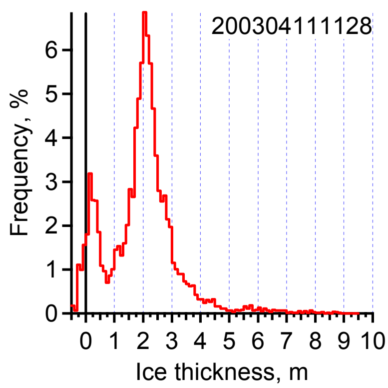
April 11, 2003

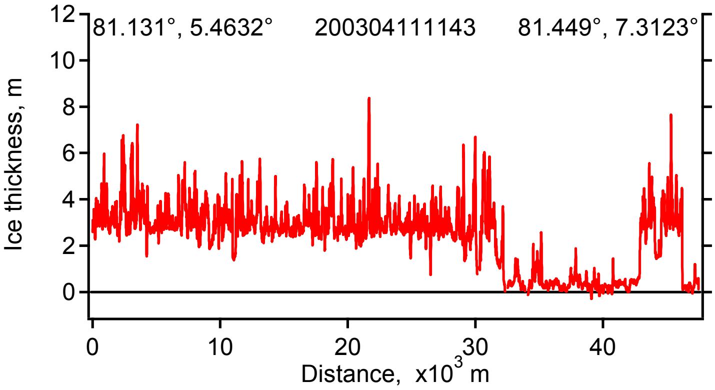


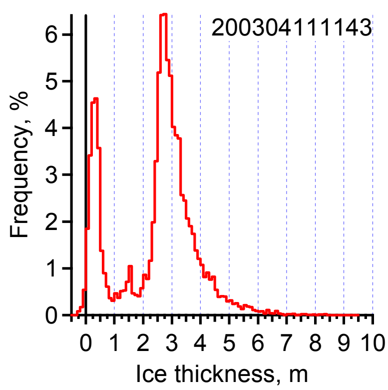


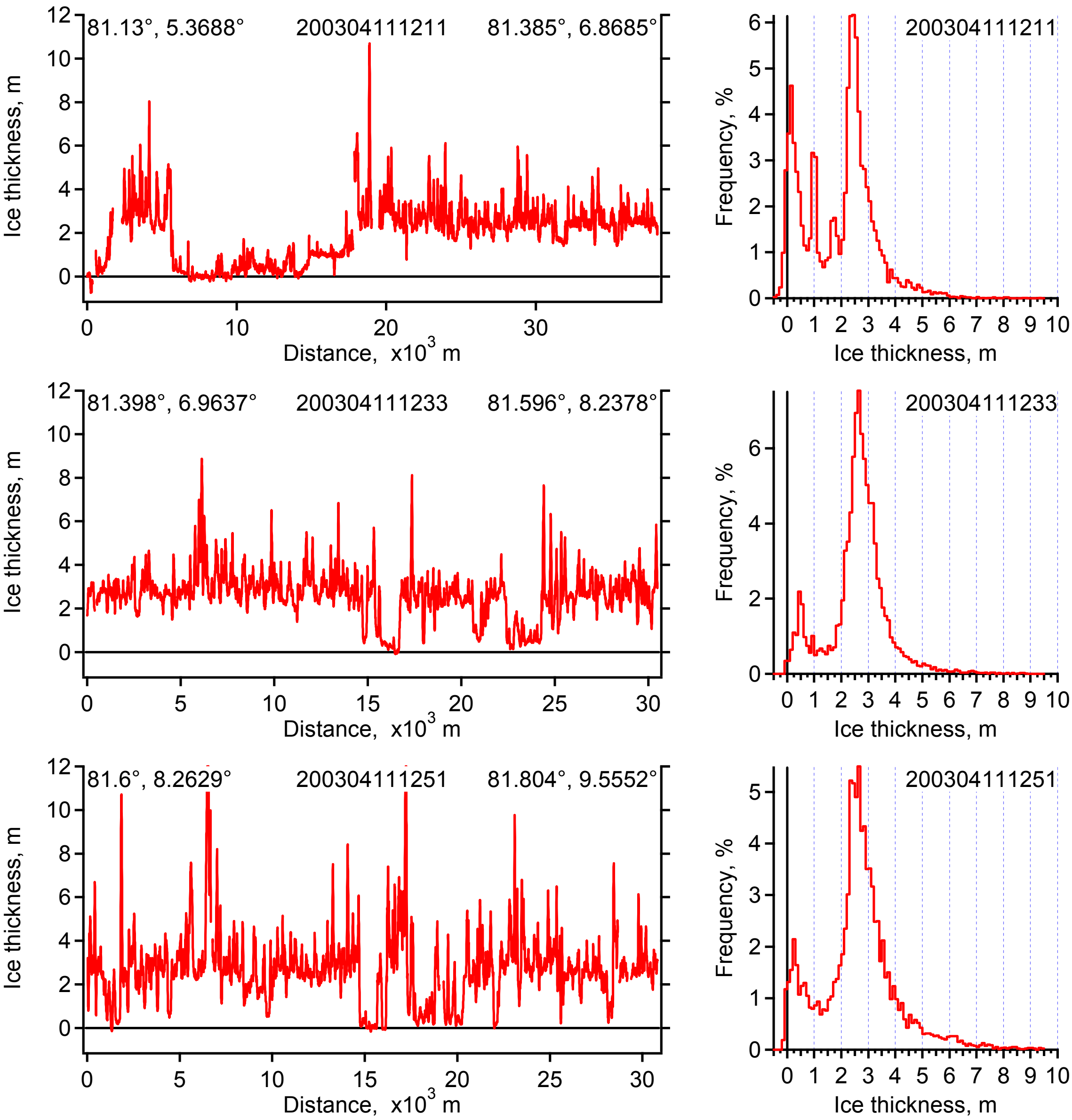




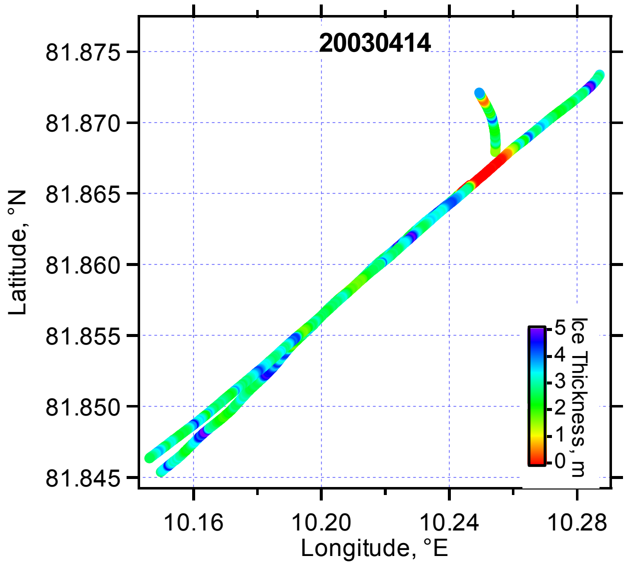


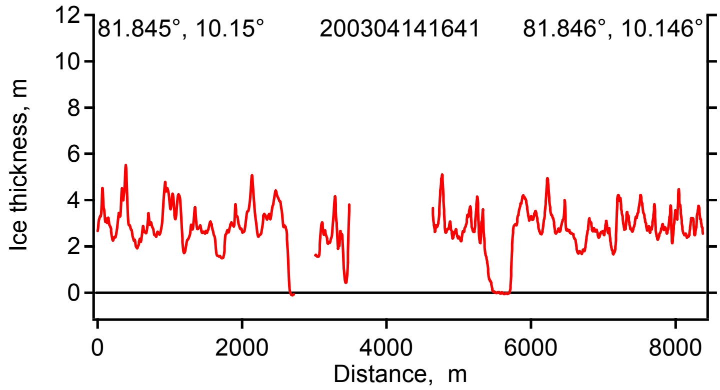


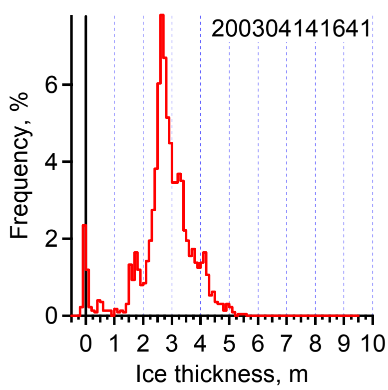



81.13°, 5.3688°
200304111211
81.385°, 6.8685°
Ice thickness, m
Distance, x10^3 m
Frequency, %
Ice thickness, m
200304111211
81.398°, 6.9637°
200304111233
81.596°, 8.2378°
Ice thickness, m
Distance, x10^3 m
Frequency, %
Ice thickness, m
200304111233
81.6°, 8.2629°
200304111251
81.804°, 9.5552°
Ice thickness, m
Distance, x10^3 m
Frequency, %
Ice thickness, m
200304111251

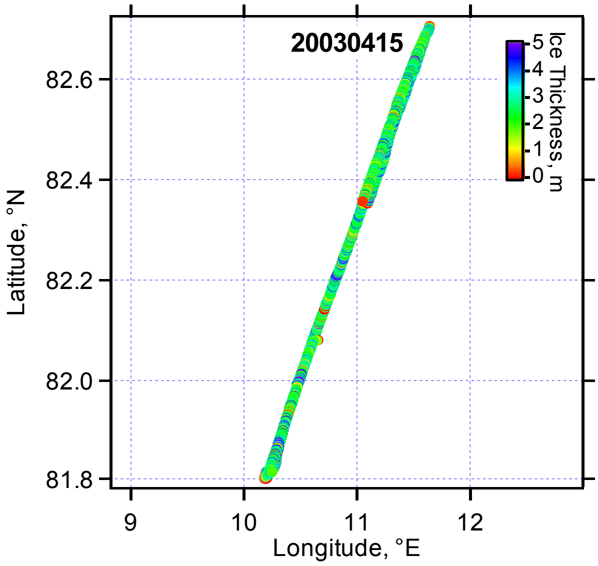
April 14, 2003

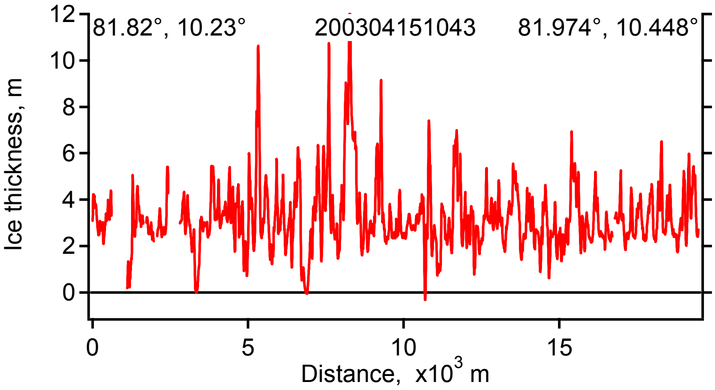


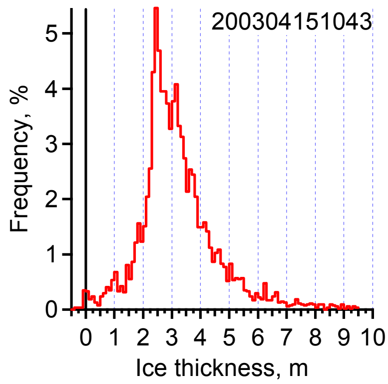


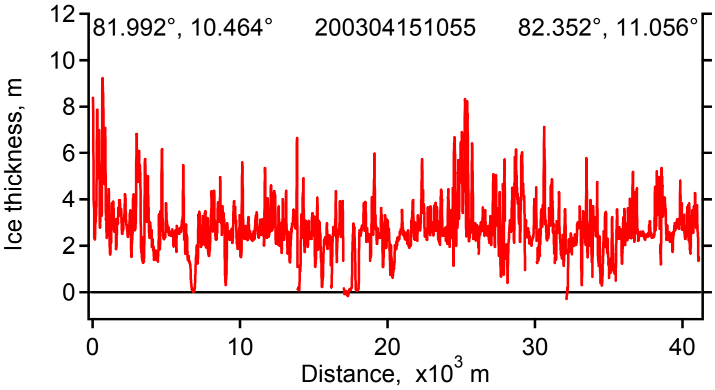


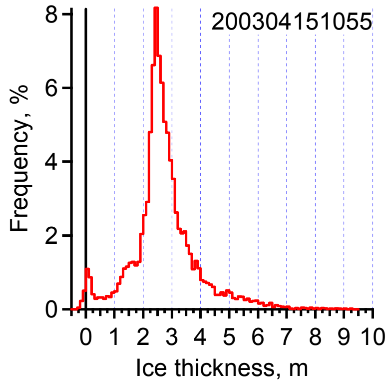
April 15, 2003

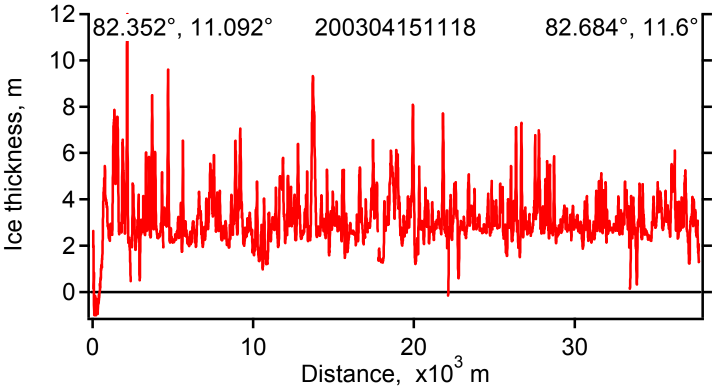


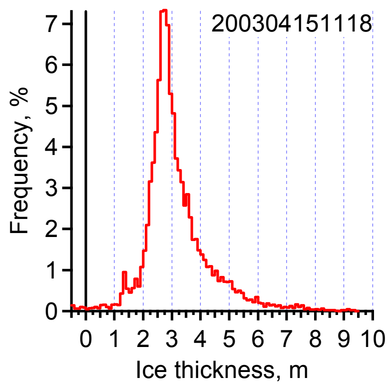


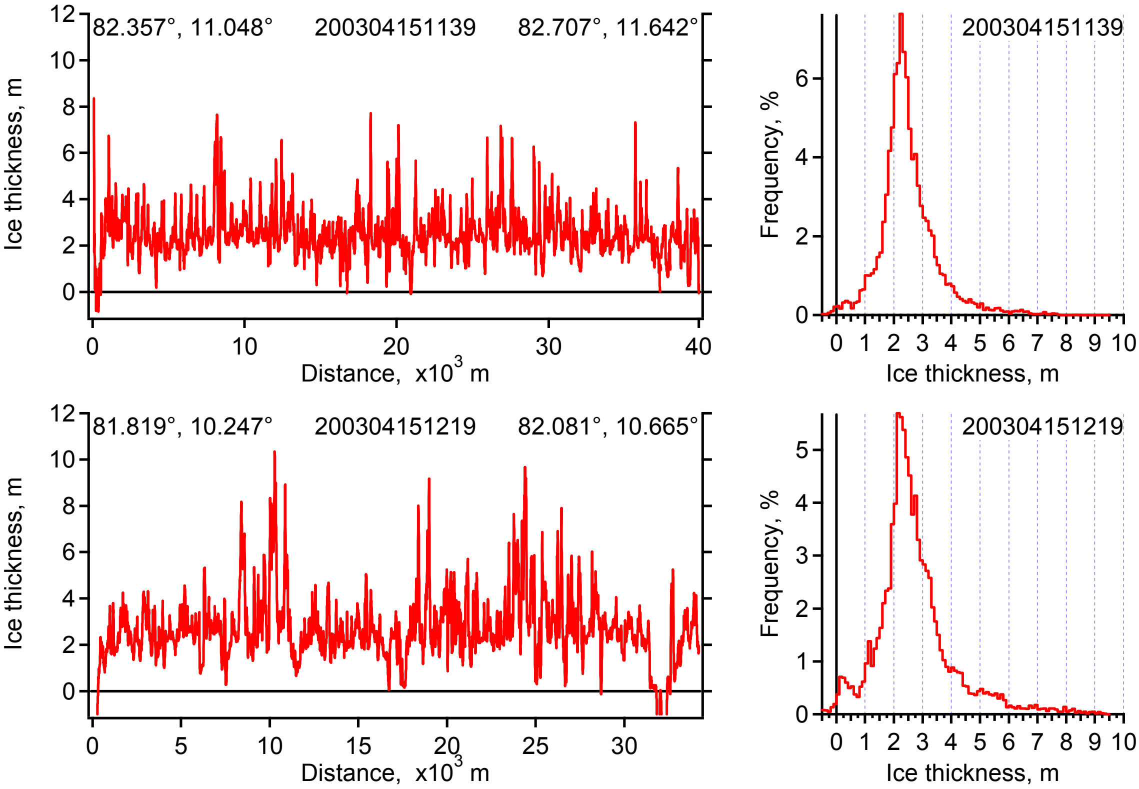











82.357°, 11.048°
200304151139
82.707°, 11.642°
Ice thickness, m
Distance, x10^3 m
200304151139
Frequency, %
Ice thickness, m
81.819°, 10.247°
200304151219
82.081°, 10.665°
Ice thickness, m
Distance, x10^3 m
200304151219
Frequency, %
Ice thickness, m

April 19, 2003