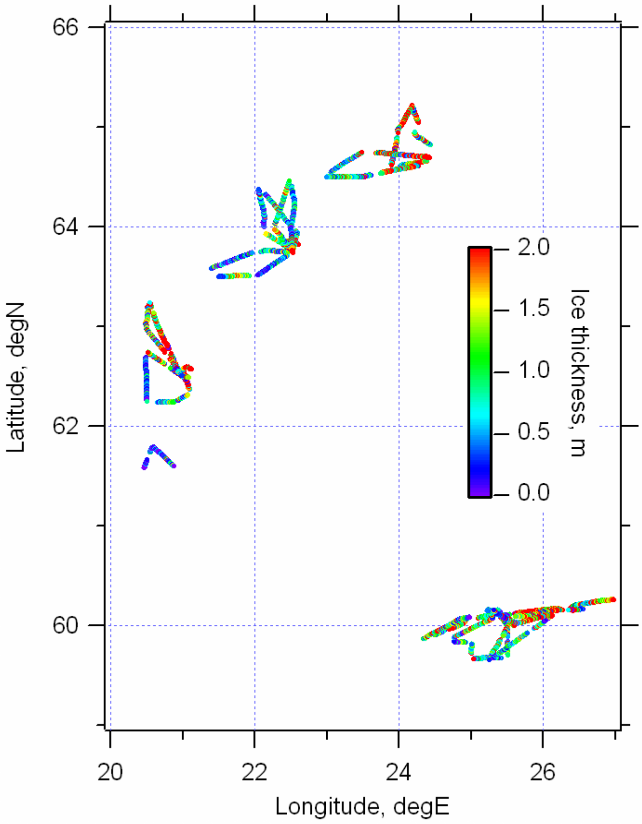
IRIS data report:



Airborne EM measurements of Baltic ice thickness in February 2003

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IRIS — **Ice Ridging Information for Decision Making in Shipping Operations**

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Abstract: This data report summarises results of the ice thickness flights carried out during the first IRIS airborne EM campaign in the Baltic between February 17 and 23, 2003. It presents some statistical properties of the obtained thickness profiles, and it gives a description of data processing and data format for further use of results by the IRIS consortium.

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Executive summary

This report summarizes results of the first IRIS airborne EM ice thickness campaign in February 2003. The data processing as well as the format of the data files made available to all project scientists is presented. Results indicate that the campaign was very successful, and that the AWI EM Bird can be used even with the low seawater conductivities of the Bay of Bothnia. A description of the measurement campaign can be found in the field report, Deliverable No. D9: Airborne EM measurements of Baltic ice thickness in February 2003: The campaign.

1. Introduction

Between February 17 and 23, 2003, we have performed the first IRIS airborne ice thickness surveying campaign over the Gulfs of Finland and Bothnia. Background on the measurement goals, the EM system, and the general flight track layout and ice conditions can be found in the report:

“Airborne EM measurements of Baltic ice thickness in February 2003: The campaign.”,

IRIS deliverable D9, by Haas, Dierking, and Lensu.
This data report summarizes the data processing involved to retrieve the thickness profiles. It presents all thickness profiles obtained, as well as some thickness distributions and statistical information.

2. 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.

2.1 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 drift, which has to be linearly interpolated and removed from all other samples in between. The procedure is illustrated in Figure 1. 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.

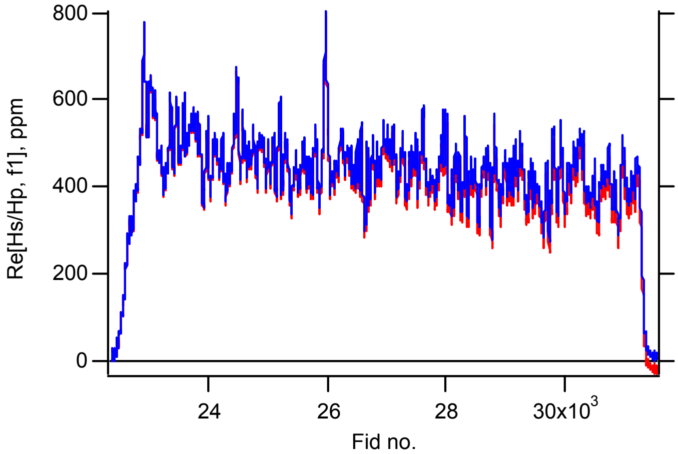


Figure 1: Typical profile of inphase component of f_1 (3.6 kHz) showing original (red, stippled) and drift-corrected trace (blue, solid). February 23, 2nd flight, file 200302231204*.

2.2 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 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 2. Open water 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.

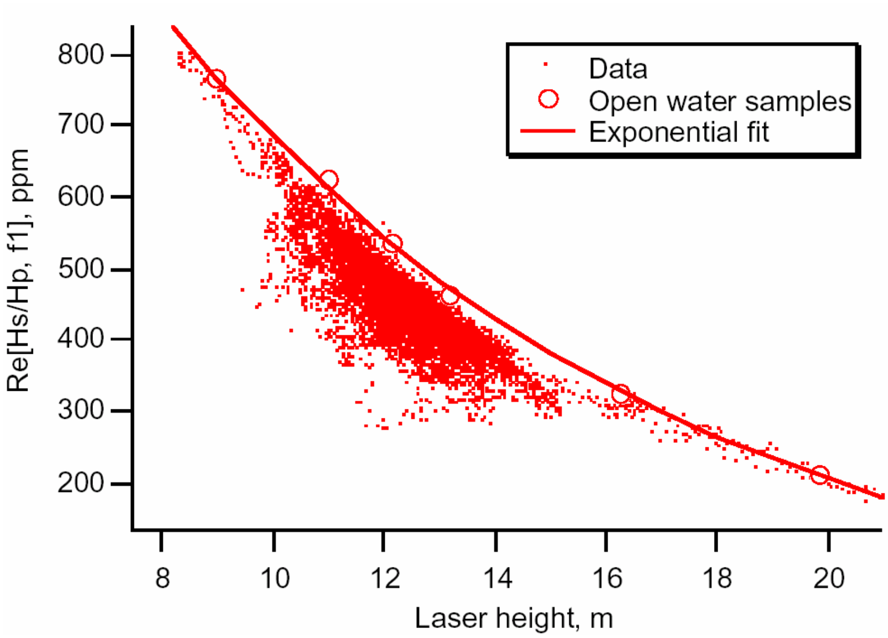


Figure 2: F_1 Inphase signal versus system height above the ice surface for the example from Figure 1. The exponential fit is performed only for open water sampling points.

2.3 Thickness computation

Figure 3a presents profiles of electromagnetically derived bird distance to the water surface computed as explained in Section 2.2, and the coincident laser height above the ice surface. For better clarity, only a short section of the profile in Figure 1 is shown. Ice thickness is the difference between both curves (Fig. 3b). Figure 4 shows the corresponding thickness distribution. Mean ice thickness along the profile was 1.36 m with a typical thickness of 1.1 m.

2.4 Thickness editing

From the curve in Figure 2 it can be seen that the EM signal becomes very small for greater bird altitudes. This is particularly true for the small conductivities of the brackish Baltic Sea water. 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 20 m. As a results, there are quite some data gaps in the beginning and end of files, and sometimes also in between.

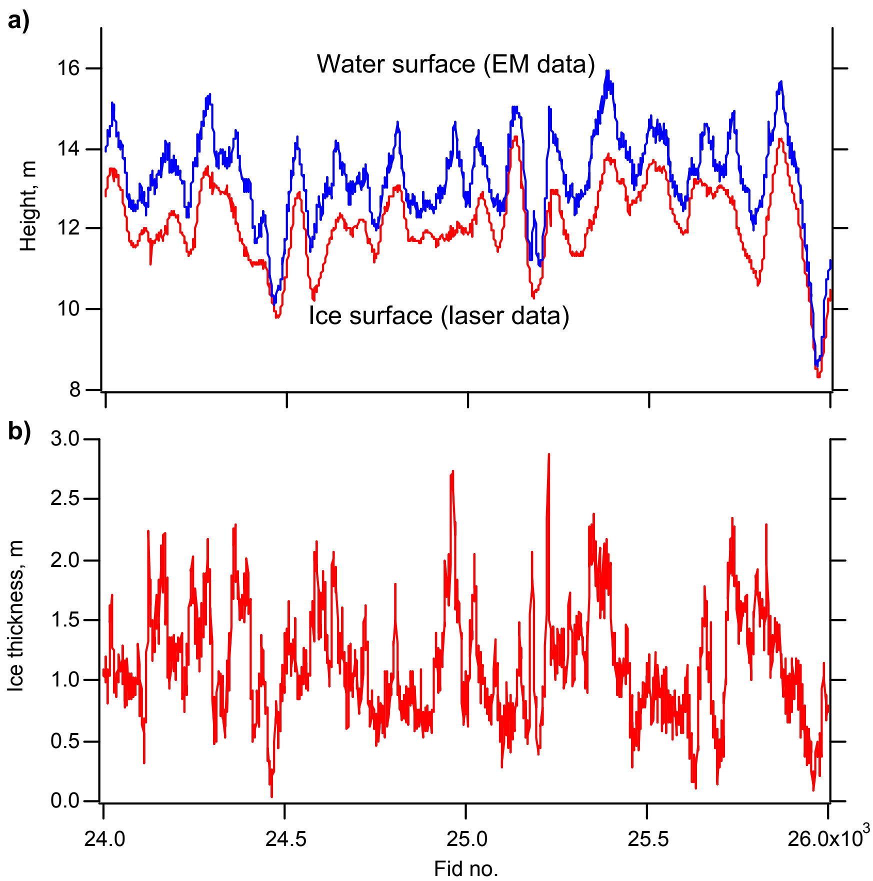


Figure 3: Profiles of bird height above the water (blue) and ice (red) surface **(a)** and ice thickness **(b)** derived by subtracting both curves in a). Section from the profile shown in Figure 1.

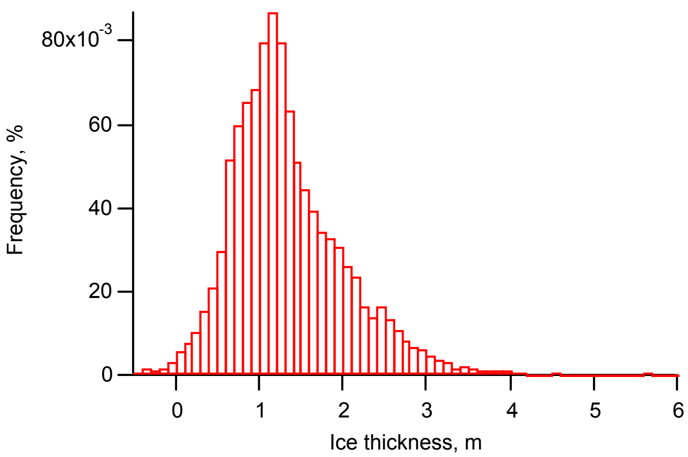


Figure 4: Thickness distribution of the profile shown in Figures 1 and 3.

2.5 Distributed data files

All data files are available from the AWI sea ice homepage at http://www-awi-bremerhaven.de/Modelling/SEAICE, following IRIS links. Later, they will also be available on the IRIS webpage. There are directories for every flight, with a single file for every profile. There are several profiles per flight, numbered according to table 2 and the figures in the Plots Section (Section 6).

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

- lati: Latitude of measurement point
- long Longitude of measurement point
- dx Distance along profile, beginning at first valid thickness measurement
- 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.

3. 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, and partially to certain specific problems of surveys performed over the brackish Baltic Sea water on the one hand, and of the particular flight tracks chosen for the IRIS 2003 flights.
The user should further keep in mind that the presented surveys have been the second campaign only with the AWI EM Bird, and that much of the processing software has only been developed for the processing of IRIS 2003 data. There is still much to be learned with respect to absolute system calibration. The chosen approach (Section 2) 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.
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, than showing a wealth of detail and information.

3.1 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.

3.2 Fast ice

There are several profiles obtained over fast ice, some of which do not contain any open water to perform the exponential fit to derive the thickness transformation. In these cases only the typical level ice thickness can be taken as a reference level, i.e. thicknesses given in the profiles are wrong by as much as the typical level ice thickness. Nevertheless, fast ice data can be used to observe relative changes between different locations, and to investigate the degree of “level-ness” of the ice. It can be seen in many profiles, that the fast ice is actually

quite heavily deformed, and that it consists of drift ice which has frozen to the fast ice at some stage.
Another problem is associated with strong stratification of freshwater entering the sea off river mouths in the fast ice. These fresh water layers cause large overestimates of ice thickness.
Finally, there are problems associated with shallow water below the fast ice (see below).

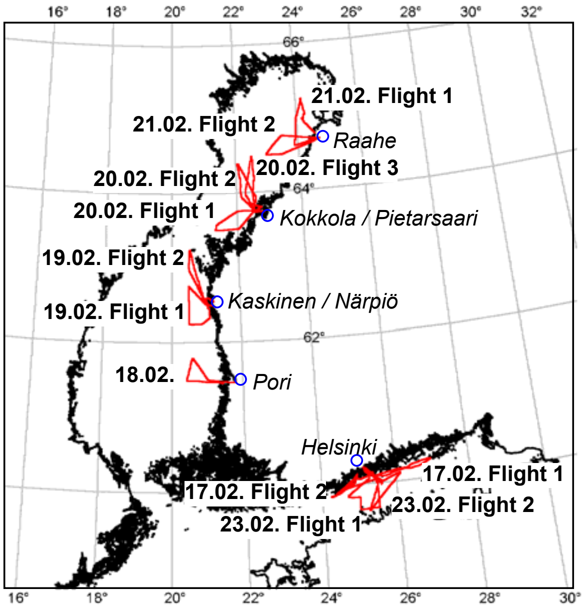
3.3 Shallow water and islands

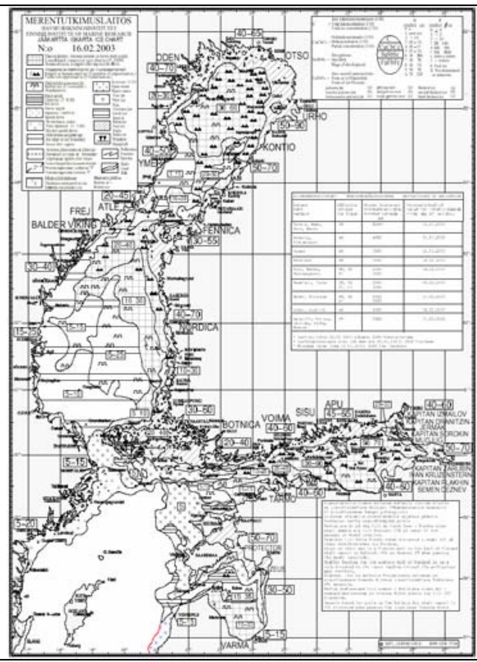
Over shallow water and islands or rock outcrops, which occur frequently in the coastal waters, the bird actually senses the underground below the water, which generally has a much lower electrical conductivity than the sea water. As a consequence, ice thickness is severely overestimated at these locations. Therefore, and for the problems involved with fast ice in general, the user should carefully look at the exact location of the profiles they intend to work with.

3.4 No water

Also over the drift ice, profiles were obtained where there was no 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 30 or 40 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.

4. Results





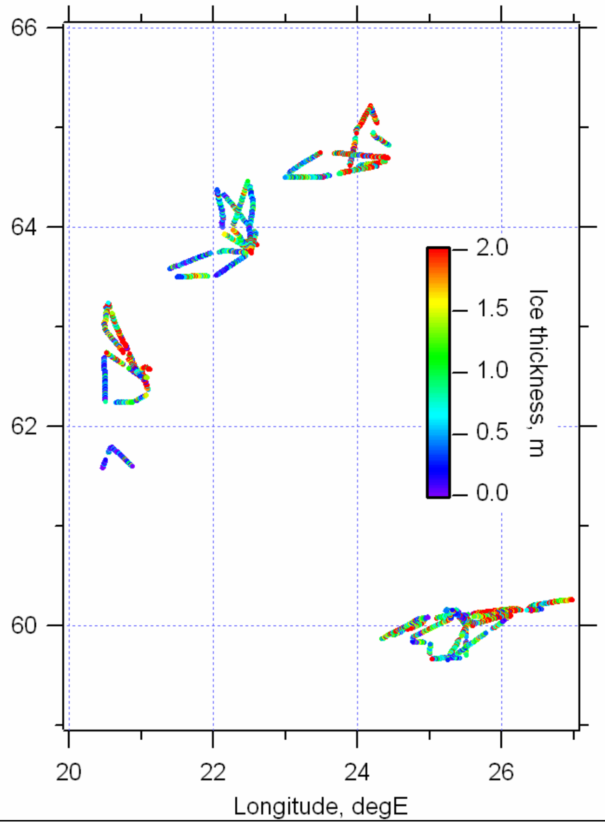


Table 1: Mean and typical (mode) thickness for all 12 flights; cf. table 2 for more details.

Flight	Mean, m	Mode, m
0217_1	1.65±1.51	0.5
0217_2	1.58±1.51	0.4
0218_1	0.35±0.47	0.3
0219_1	1.25±1.79	0.2
0219_2	1.81±1.88	0.6
0220_1	0.77±0.67	0.3
0220_2	0.95±1.24	0.6
0220_3	0.98±1.00	0.6
0221_1	1.84±1.52	1.1
0221_2	1.39±1.53	0.5
0223_1	0.92±0.88	0.6
0223_2	1.08±0.89	0.6

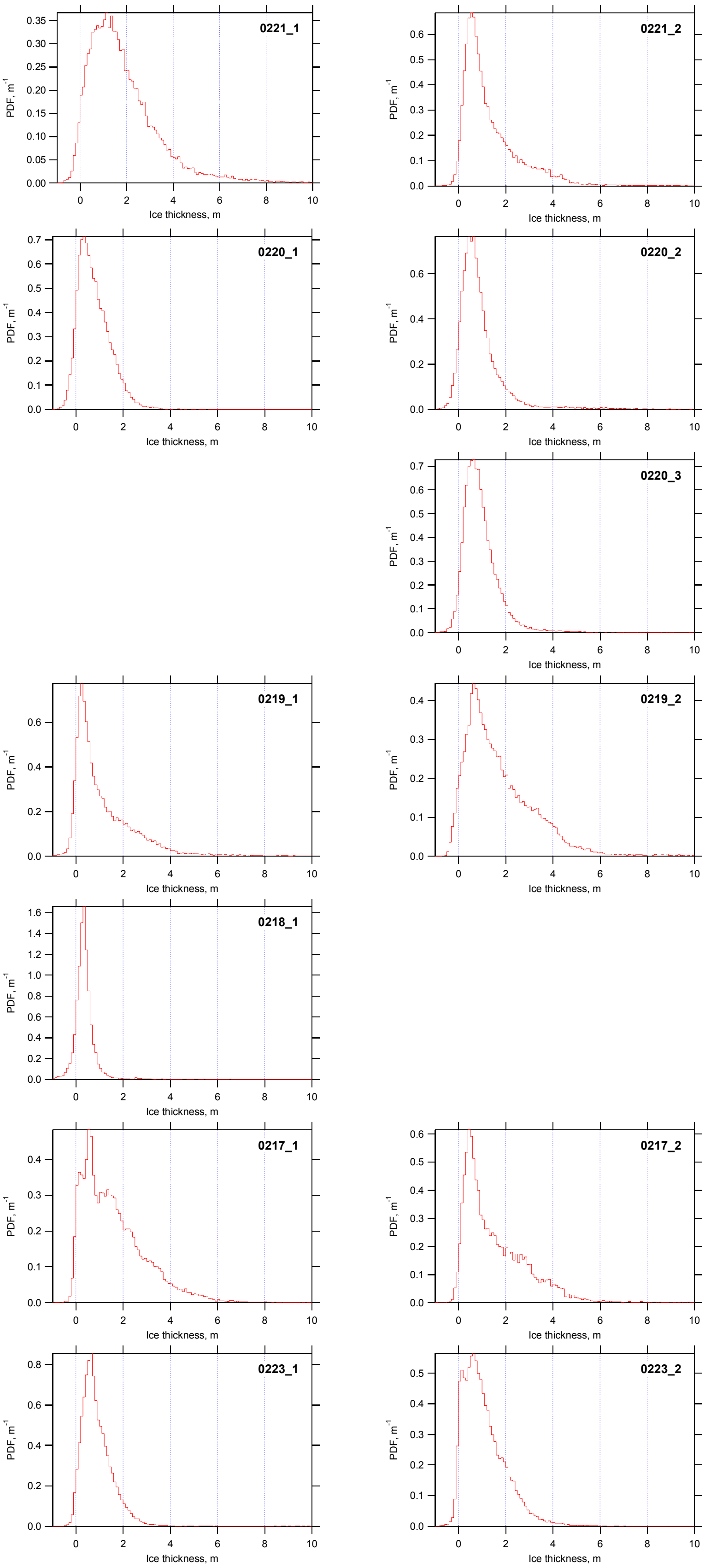

0221_1
0221_2
0220_1
0220_2
0220_3
0219_1
0219_2
0218_1
0217_1
0217_2
0223_1
0223_2
PDF, m-1
Ice thickness, m

Table 2: Mean ice thickness, standard deviation, and typical ice thickness (mode) for each profile

Profile No.	Filename	Mean thickness, m	Typical thickness, m
	February 17, flight 1		
1	200302170937	1.00±1.71	0.5
2	200302170945	2.49±1.09	2.3
3	200302171003	1.63±1.36	0.5
4	200302171029	1.71±1.36	0.2
5	200302171054	0.55±0.87	0.0
6	200302171058	0.77±0.23	0.8
	February 17, flight 2		
1	200302171309	1.44±1.39	0.5
2	200302171320	1.14±0.53	0.6
3	200302171333	1.26±0.97	1.1
4	200302171354	1.12±0.46	0.6
5	200302171404	1.70±1.80	0.4
	February 18		
1	200302181208	0.25±0.13	0.1
2	200302181216	0.35±0.52	0.3
	February 19, flight 1		
1	200302190836	1.79±1.13	0.2
2	200302190846	1.26±0.86	1.1
3	200302190858	0.39±0.34	0.2
4	200302190919	1.19±0.47	0.3
5	200302190925	0.80±0.57	0.2
6	200302190933	1.99±1.88	0.0
	February 19, flight 2		
1	200302191117	1.39±1.27	0.7
2	200302191133	2.21±1.37	0.6
3	200302191152	1.49±0.87	0.9
4	200302191156	1.16±1.17	0.2
5	200302191219	0.97±1.00	0.8
6	200302191228	1.98±1.91	0.1
	February 20, flight 1		
1	200302200811	0.47±0.46	0.2
2	200302200825	1.36±0.61	0.8
3	200302200843	0.54±0.56	0.4
4	200302200858	1.01±0.61	0.8
5	200302200908	1.29±0.78	1.2
	February 20, flight 2		
1	200302201027	1.02±0.57	0.8
2	200302201042	0.48±0.47	0.4
3	200302201105	0.84±0.59	0.4
4	200302201123	1.59±1.34	0.5
	February 20, flight 3		
1	200302201330	1.02±0.57	1.1
2	200302201342	1.13±0.77	0.8
3	200302201407	0.71±0.59	0.4

Table 2, cont'd: Mean ice thickness, standard deviation, and typical ice thickness (mode) for each profile

Profile No.	Filename	Mean thickness	Typical thickness
		February 21, flight 1	
1	200302210844	1.43±1.17	0.7
2	200302210909	1.96±1.25	0.7
3	200302210919	2.84±1.95	1.5
4	200302210936	1.26±1.01	0.3
5	200302210939	1.34±1.11	1.1
6	200302210952	1.72±0.92	0.5
		February 21, flight 2	
1	200302211212	1.82±0.99	0.6
2	200302211228	0.87±0.58	0.5
3	200302211250	0.82±0.81	0.4
4	200302211308	1.70±1.26	0.6
		February 23, flight 1	
1	200302230835	1.14±0.62	0.4
2	200302230845	1.06±0.53	0.6
3	200302230855	0.60±0.62	0.3
4	200302230909	0.45±0.20	0.6
5	200302230916	0.42±0.29	0.4
6	200302230924	0.67±1.33	0.4
	200302230926	1.10±0.73	0.6
		February 23, flight 2	
1	200302231137	1.17±0.82	0.5
2	200302231149	1.09±0.52	0.9
3	200302231204	0.92±0.66	0.5
4	200302231221	0.72±0.79	0.0
5	200302231232	1.34±1.04	0.2

5. Recommendations

Section 3 has summarized the problems involved with data processing and interpretation of the thickness profiles.

There are two major consequences to improve data interpretation and to avoid mis-interpretation in future campaigns:

First, larger fast ice stretched should be avoided, because data reliability is affected by many factors. Nevertheless, the EM data can give valuable information at least for the fast ice margins, e.g. along coastal polynyas.

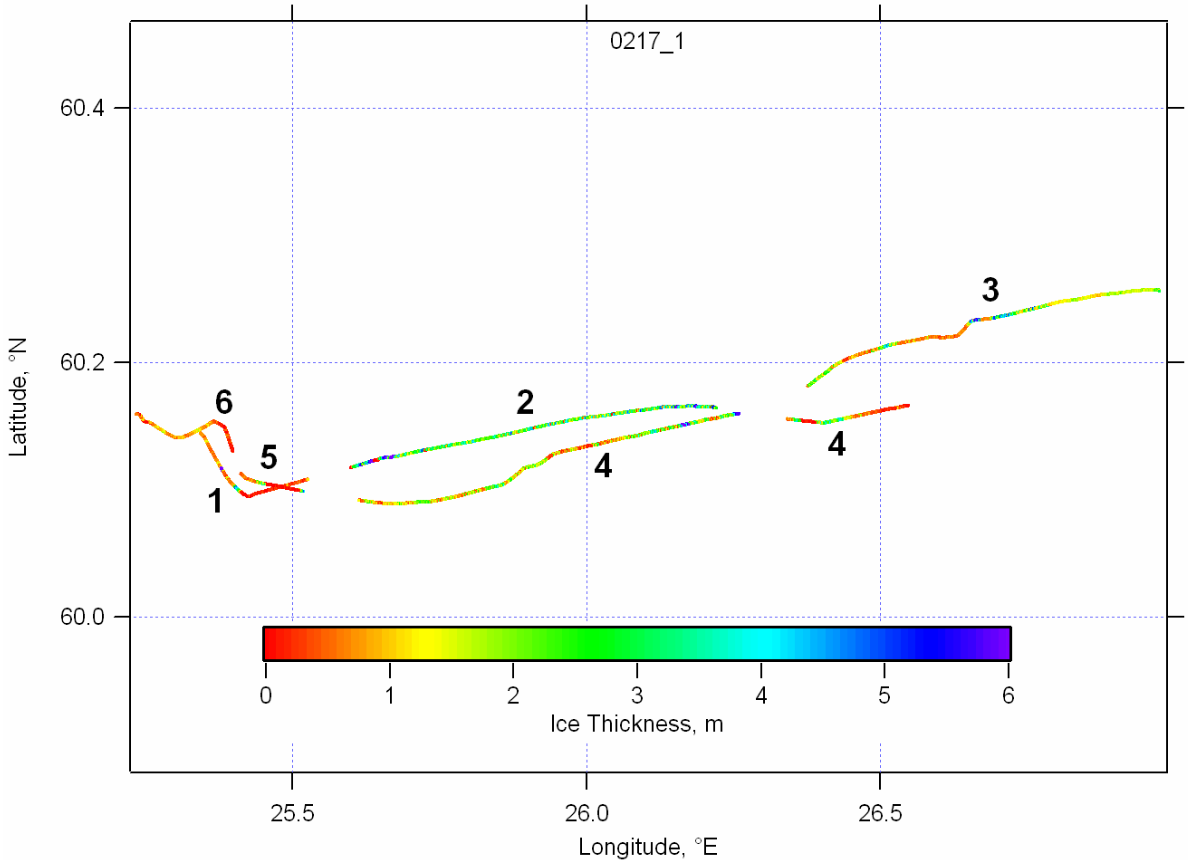
Second, profiles should only be flown along straight lines, to ease geophysical interpretation of the thickness profiles and comparison with other information like e.g. from ice charts. On the one hand this requires to switch on and off data recording on any non-straight-line section of a flight. On the other hand, it requires careful communication between scientists and pilots.

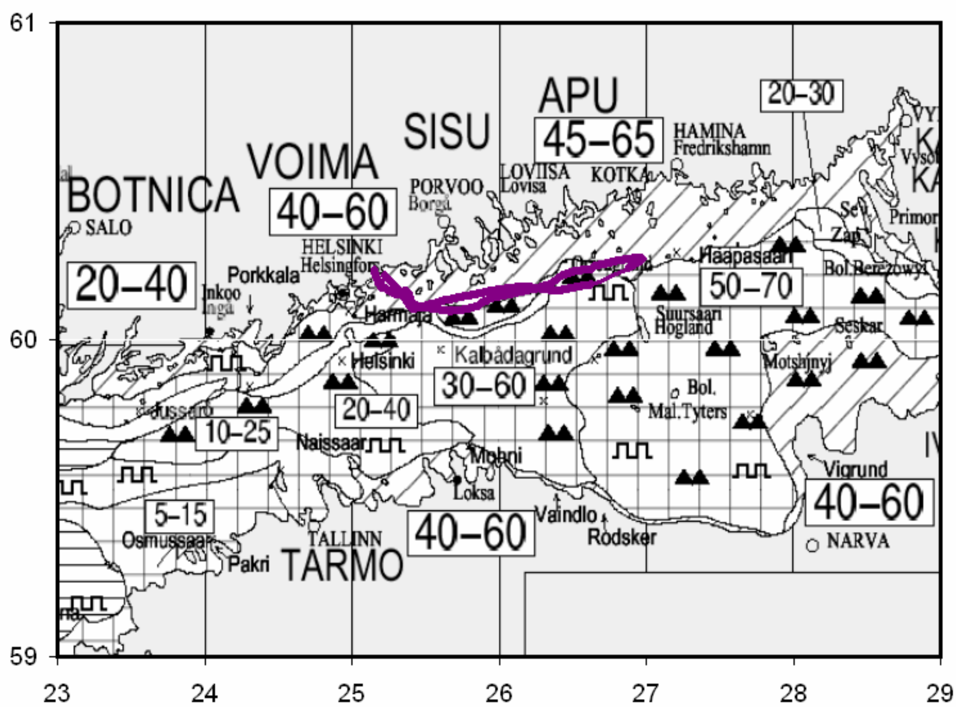
6. Profile plots

This section presents plots of all profiles obtained in February 2003. We define a profile as the section between two calibration ascends of a flight. Therefore, a flight consists of several profiles.
As outlined above, the different scales of the plots (depending on profile length) results in variable appearances of the profiles. Long profiles can look noisy and odd, because the scale does not allow for any detail. The user should visit the original data files to obtain the impressive amount of detail contained in the data.

February 17, 2003, flight 1

Flight from Helsinki along the fast ice/ drift ice boundary towards East.





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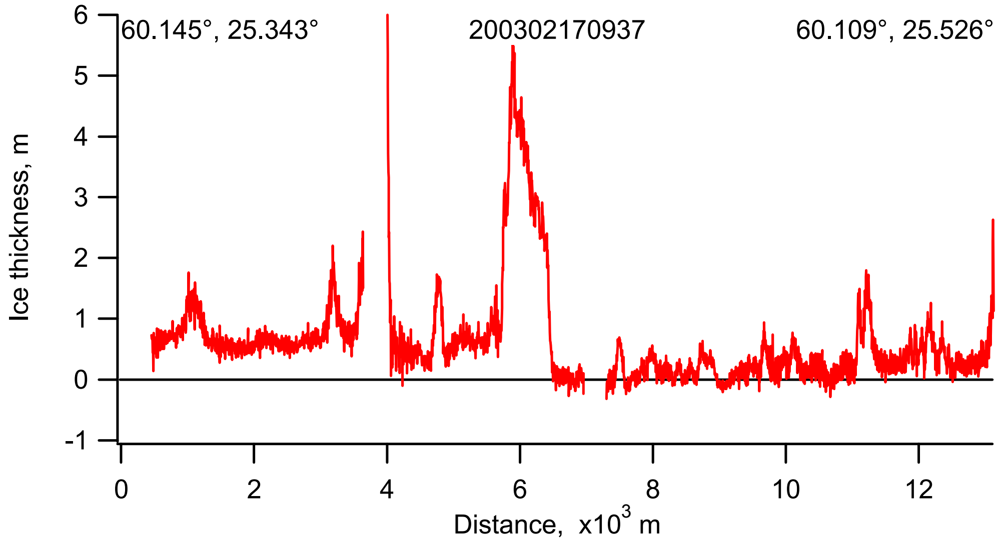

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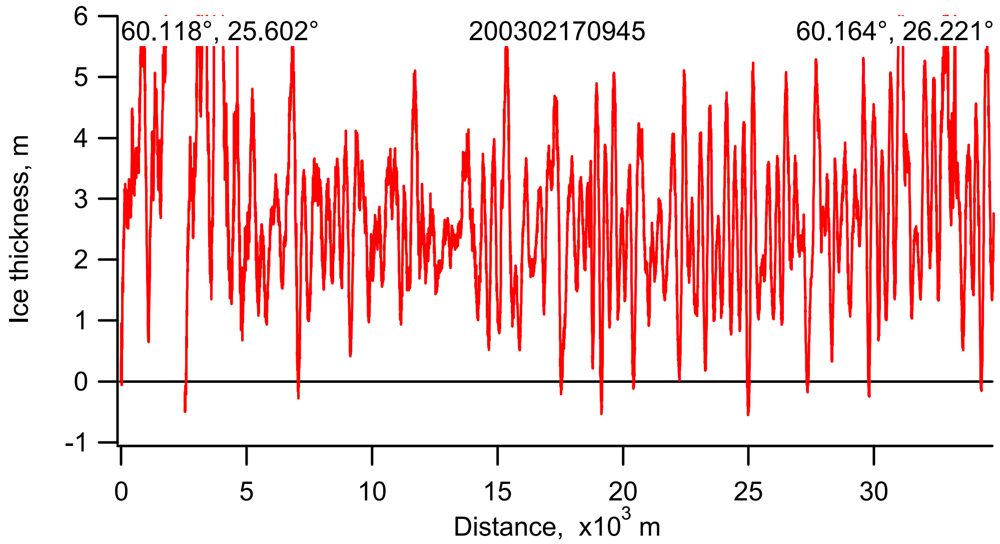

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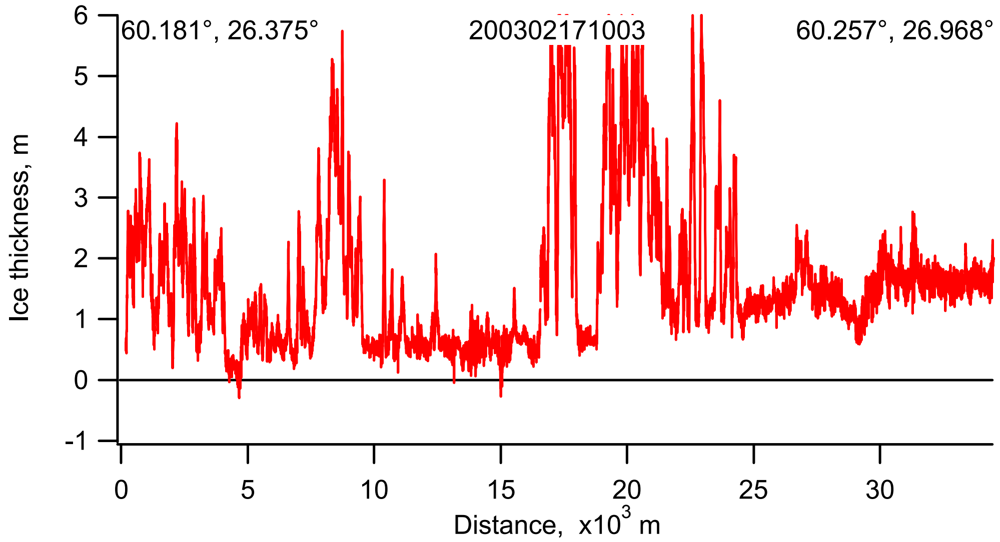

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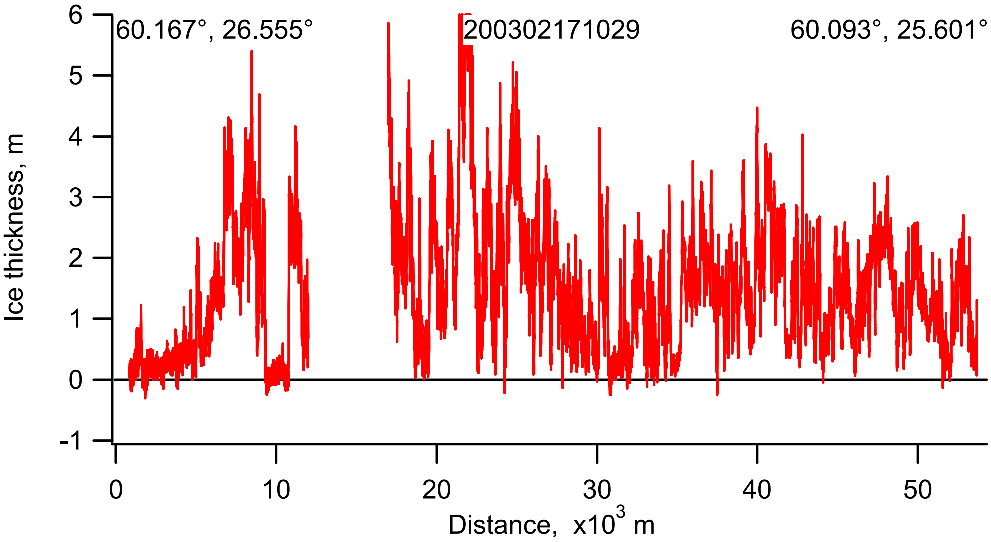

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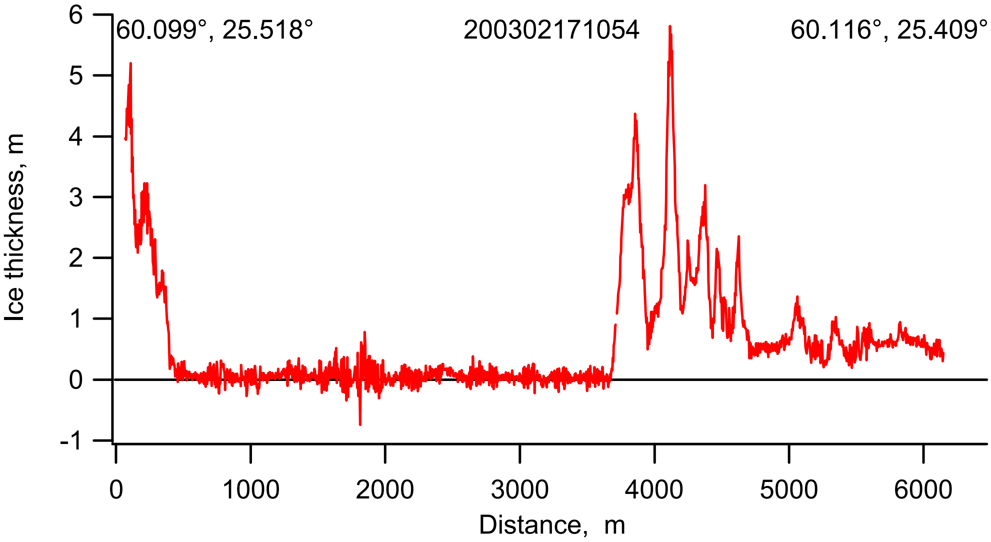

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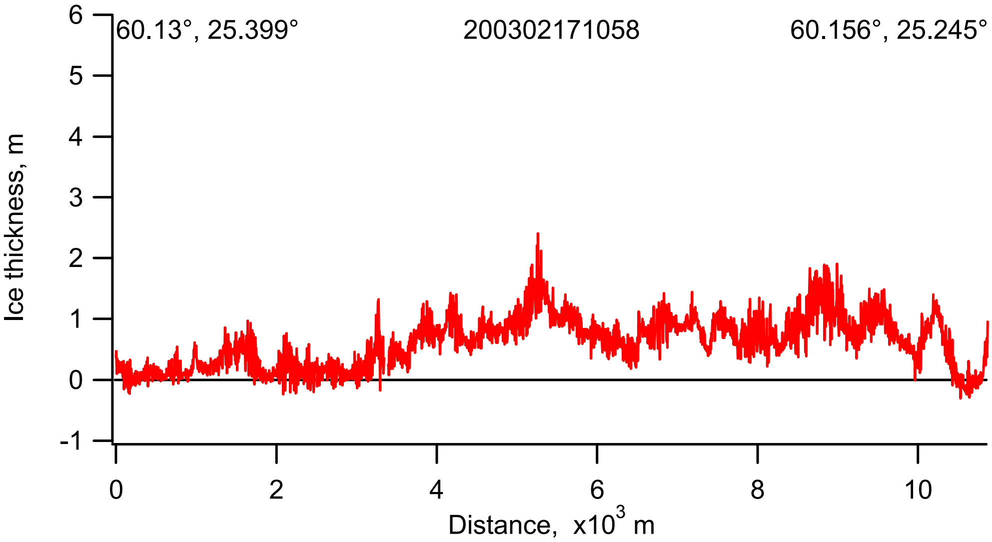
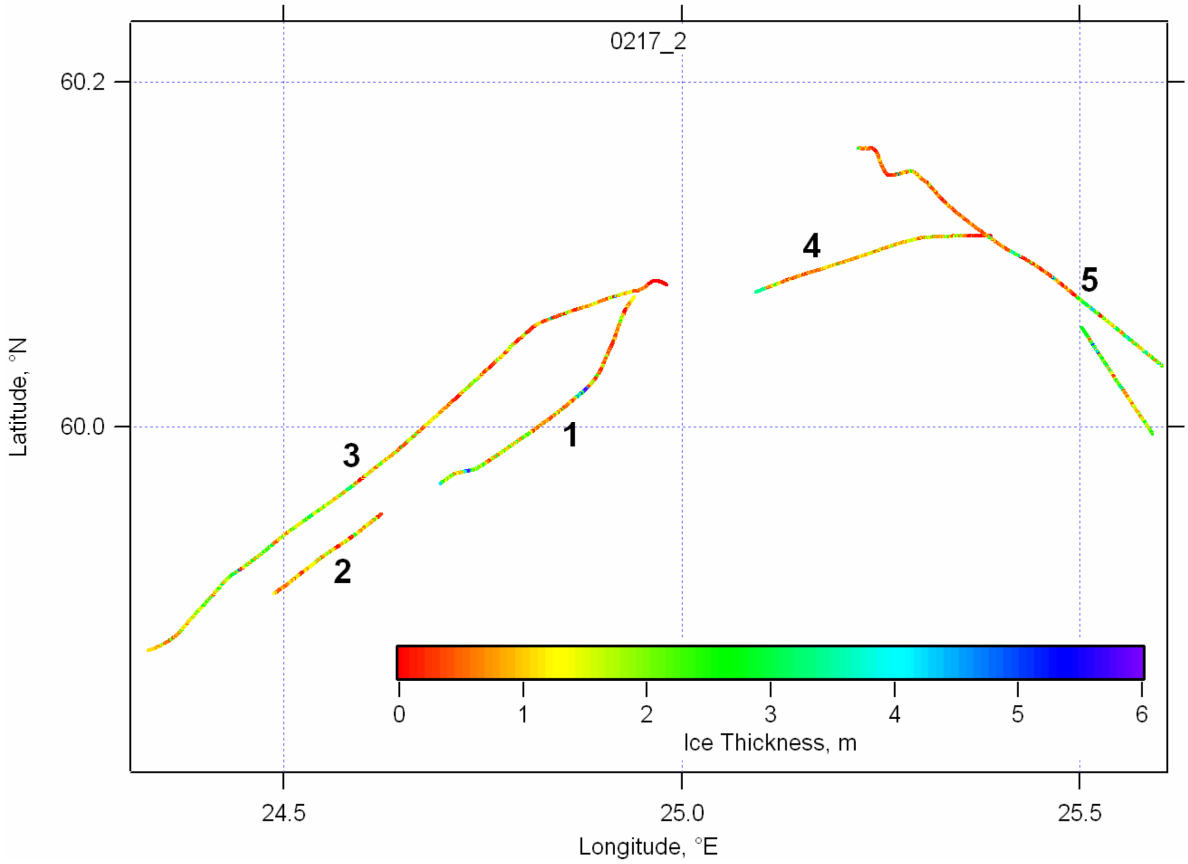
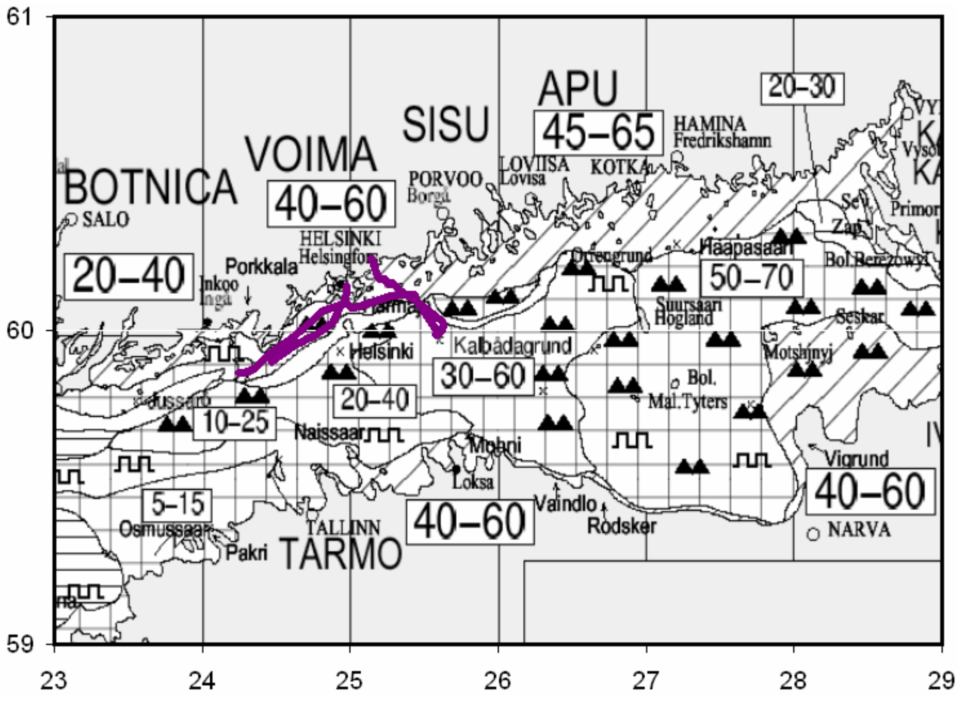


February 17, 2003, flight 2

Flight from Helsinki towards West, and to an extended polynja in the Southeast.





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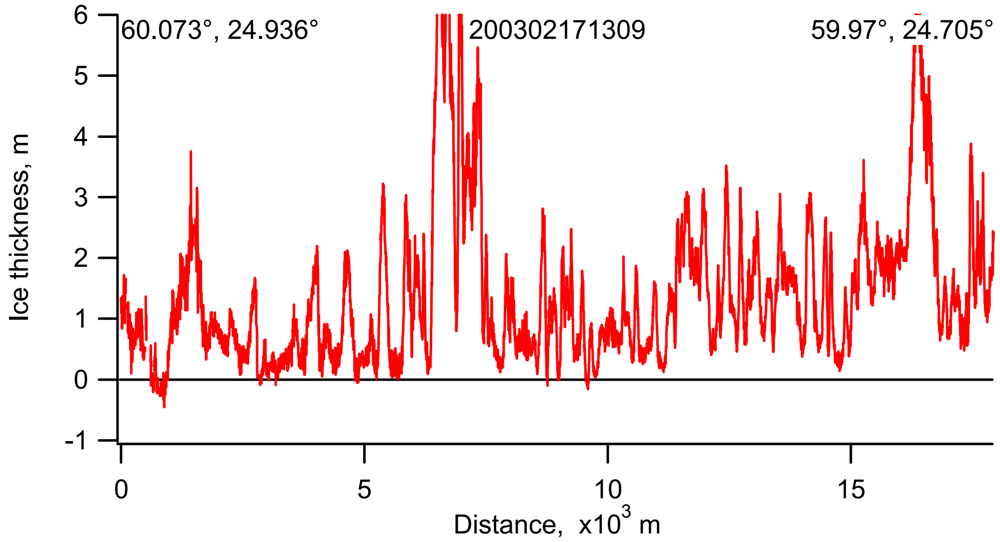

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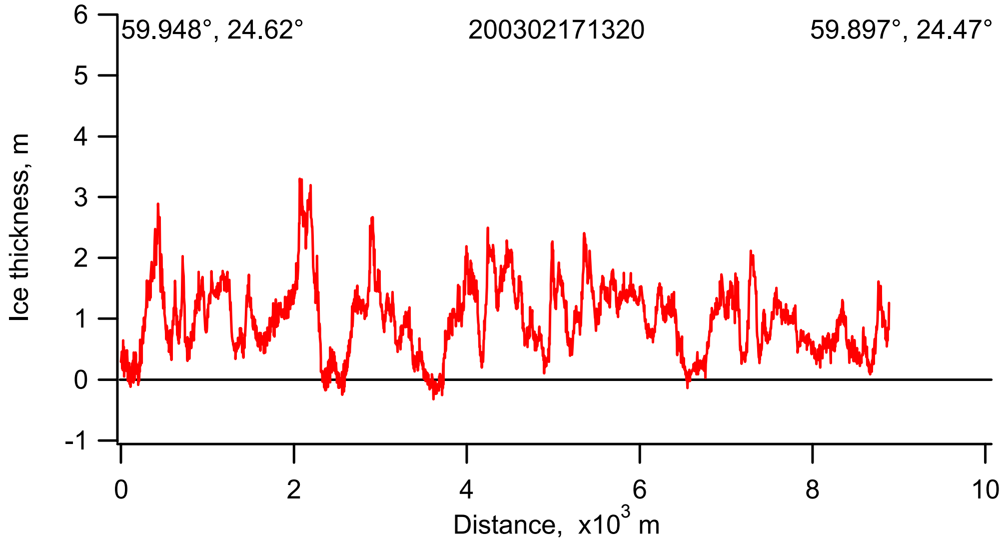

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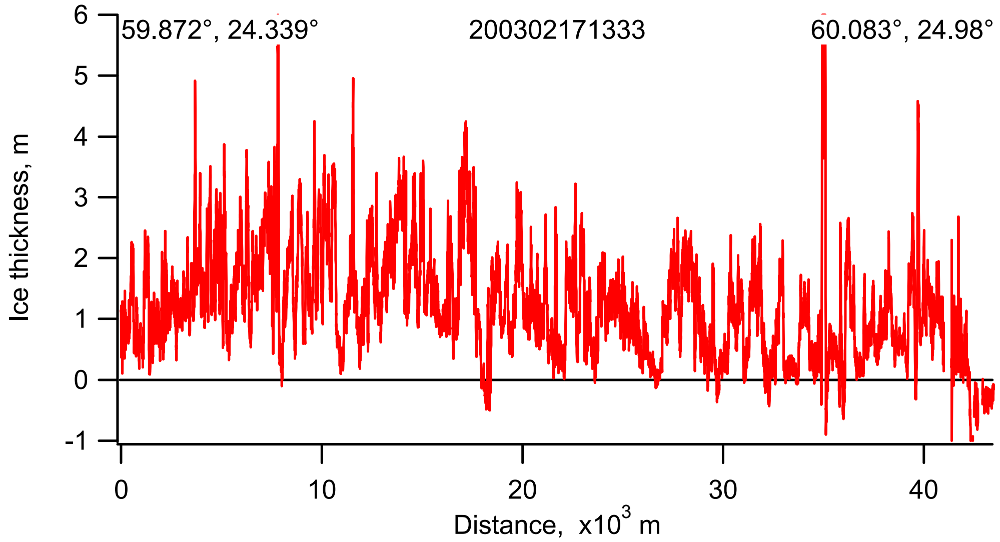

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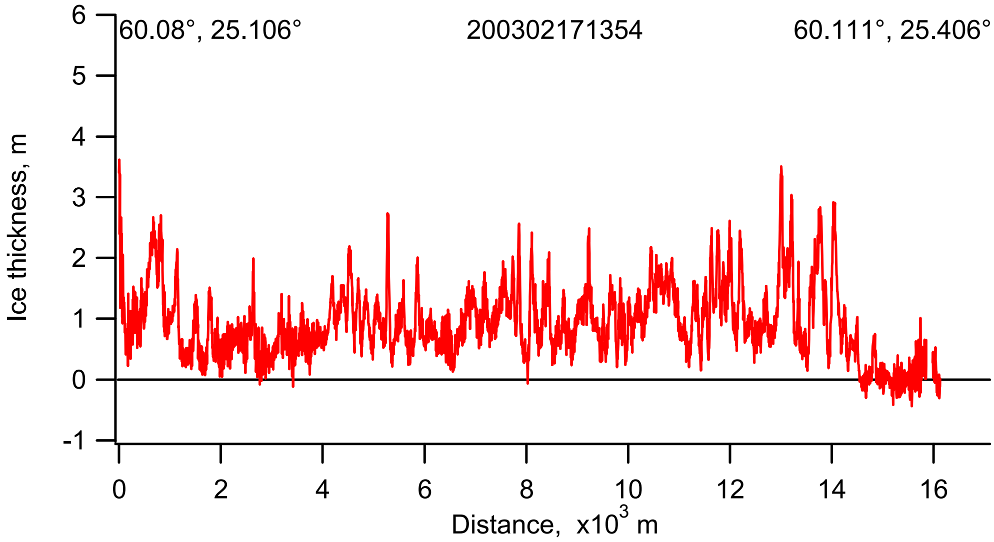

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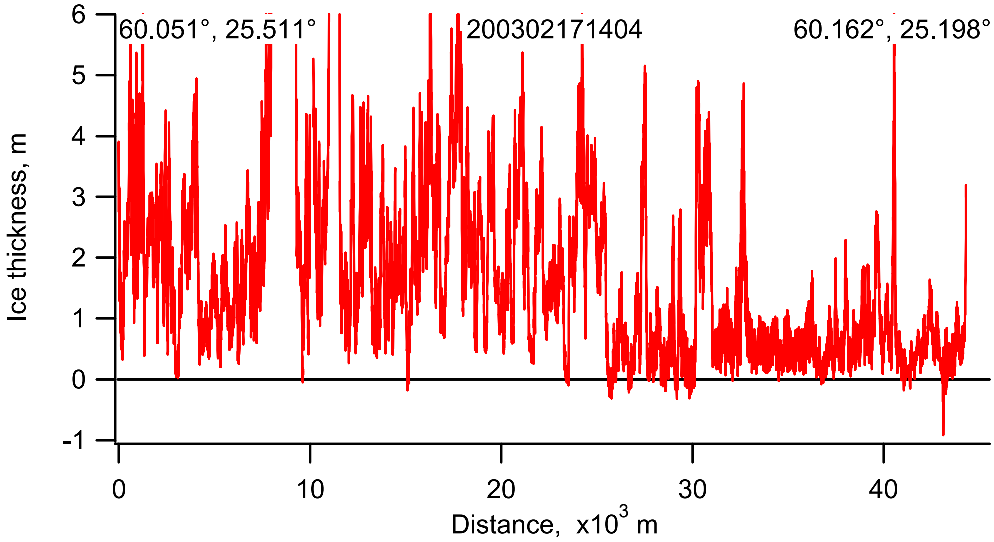
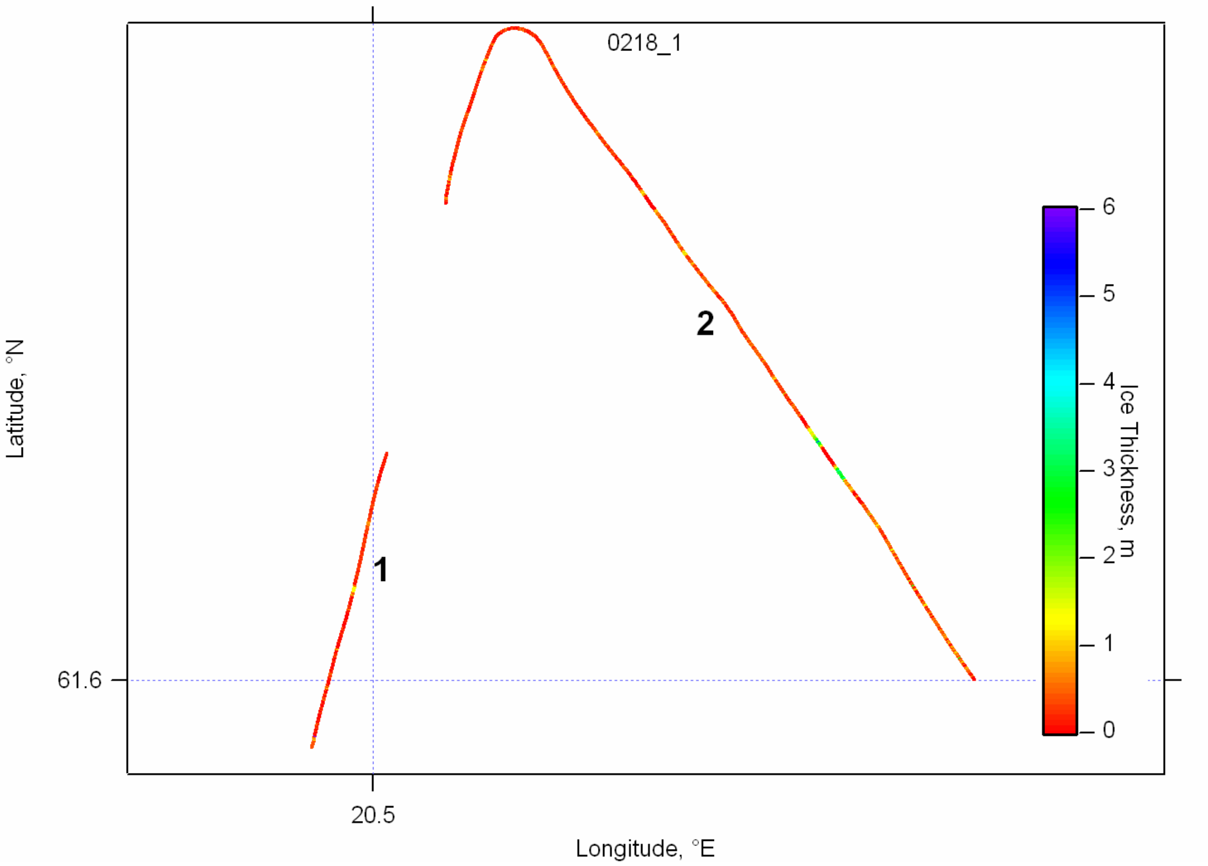
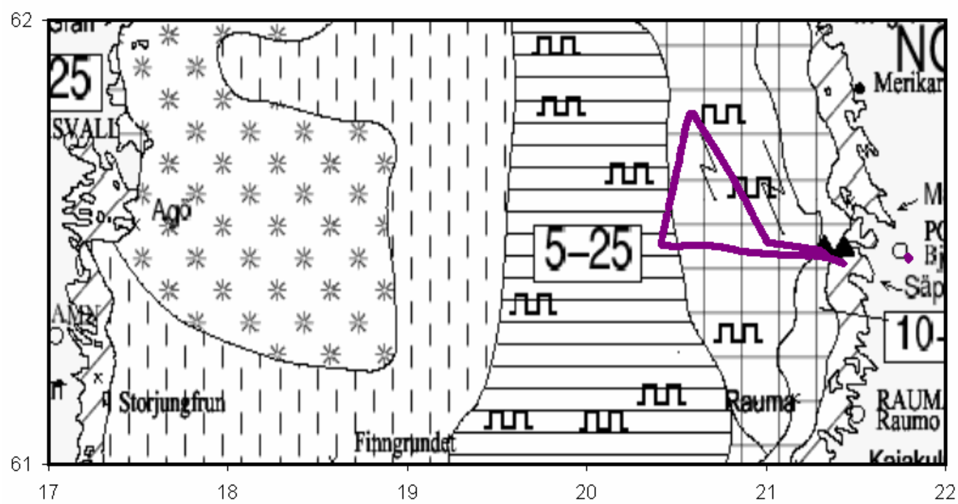


February 18, 2003, flight 1

Flight from Pori into Sea of Bothnia covered by dark and light nilas. Bad noise induced by Pori radio station.





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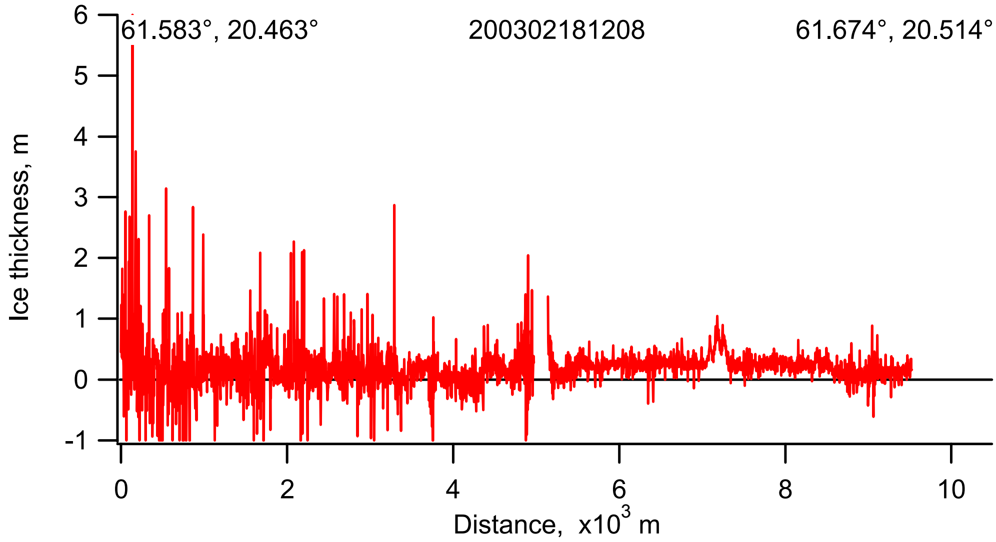

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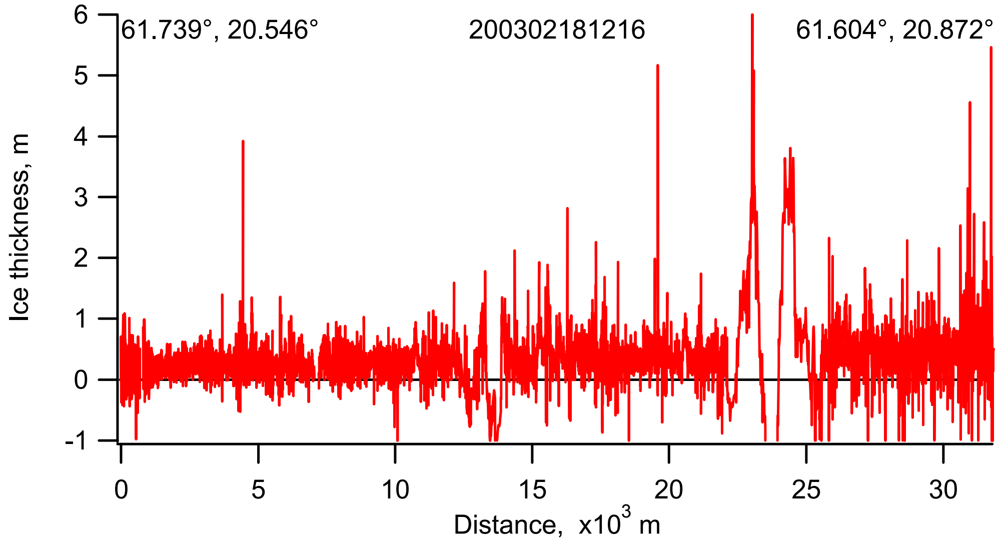
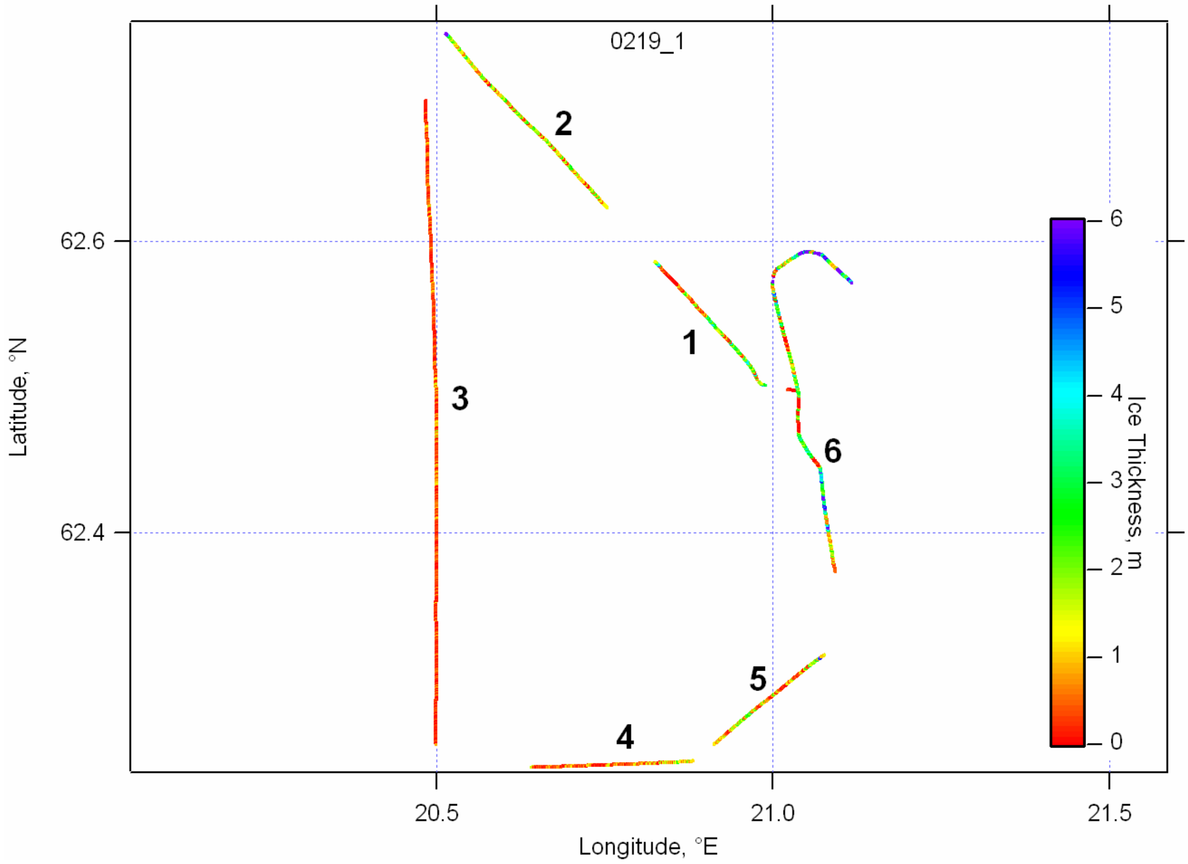
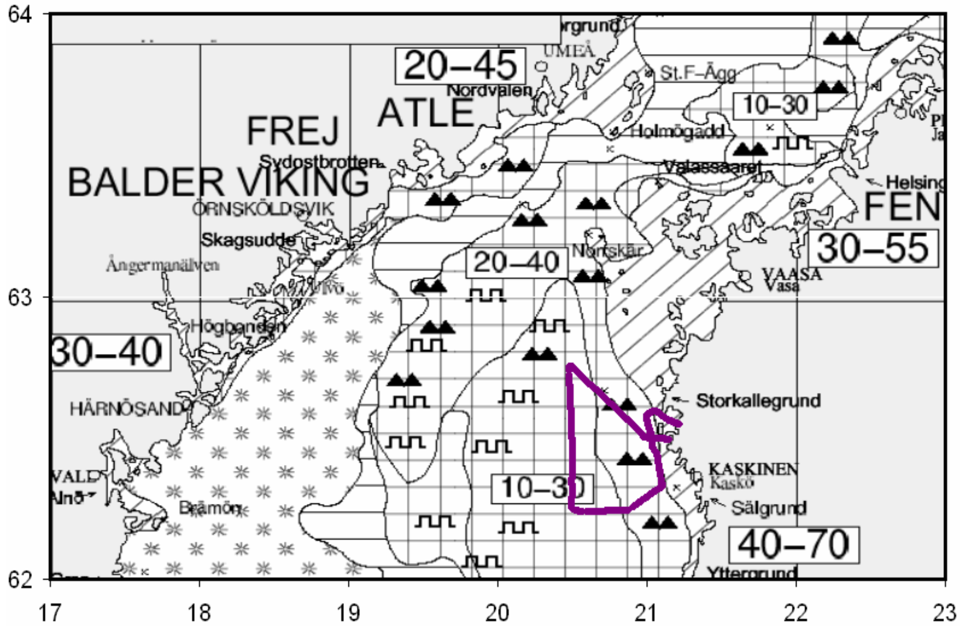


February 19, 2003, flight 1

Flight from Närpiö towards West, from deformed white ice into rafted nilas.





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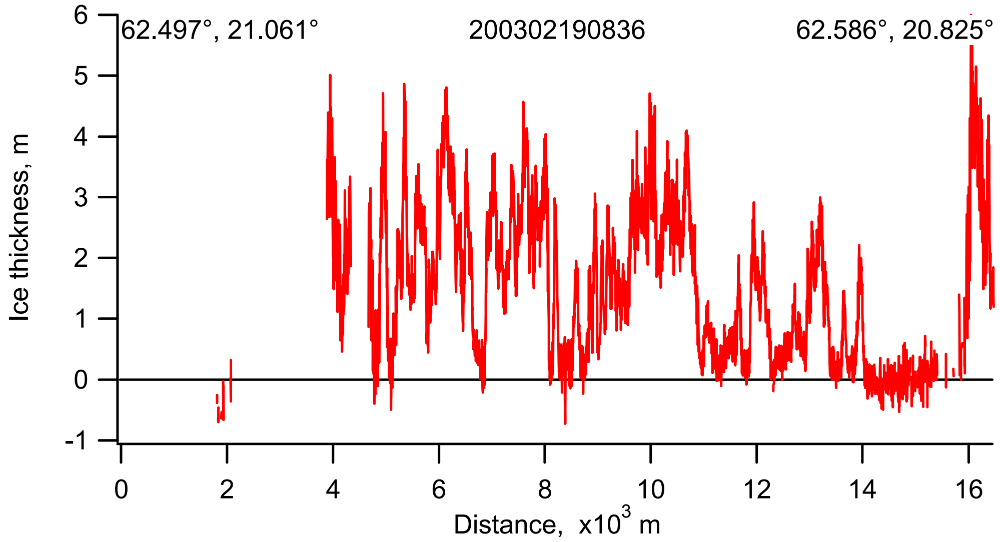

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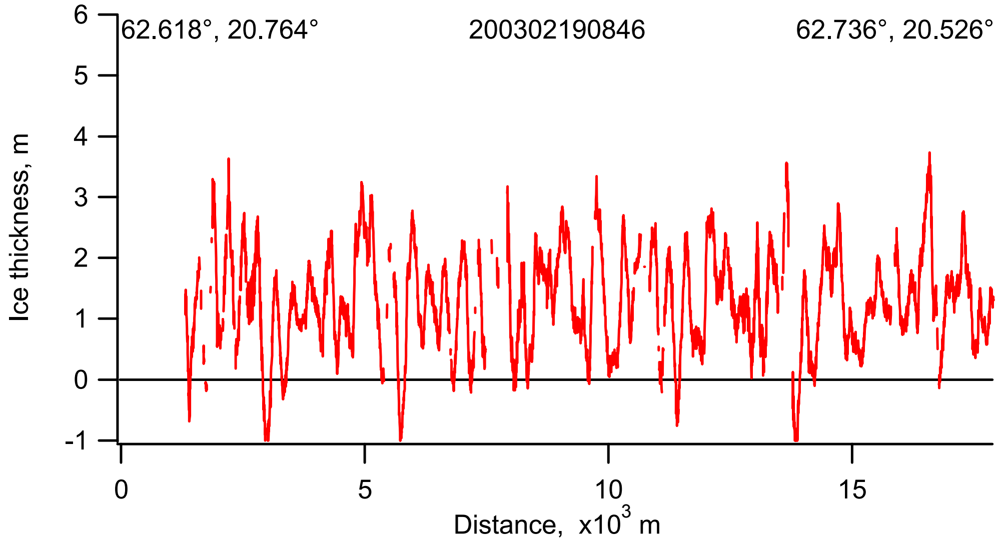
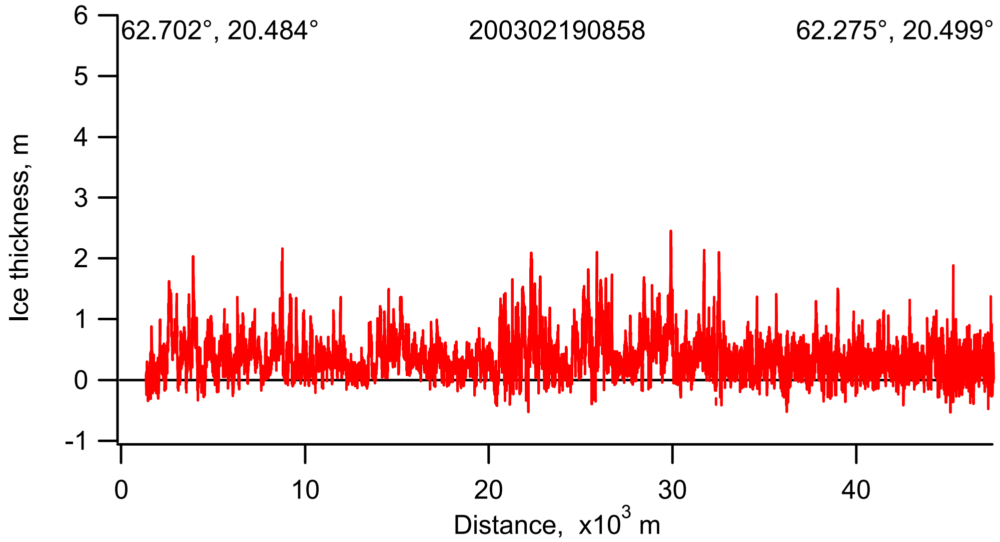
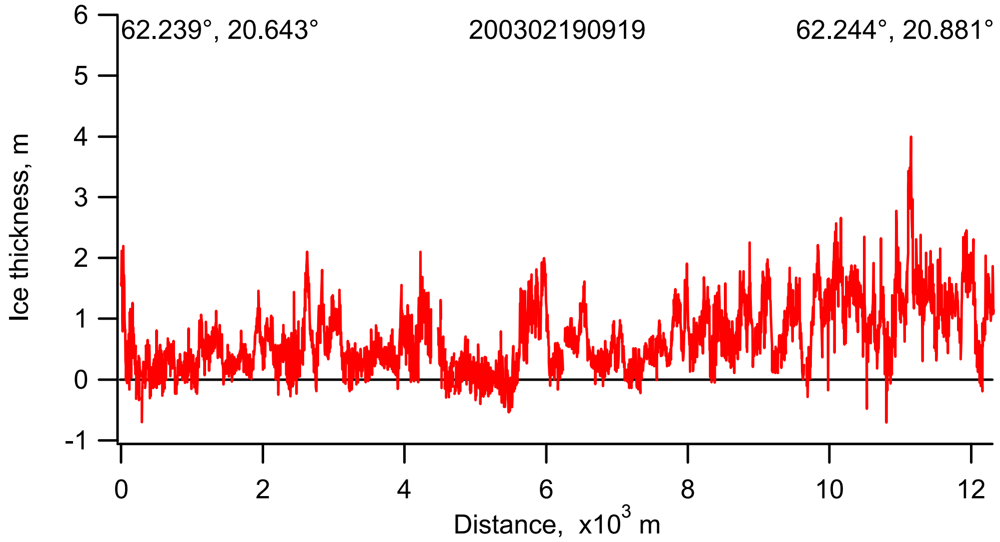


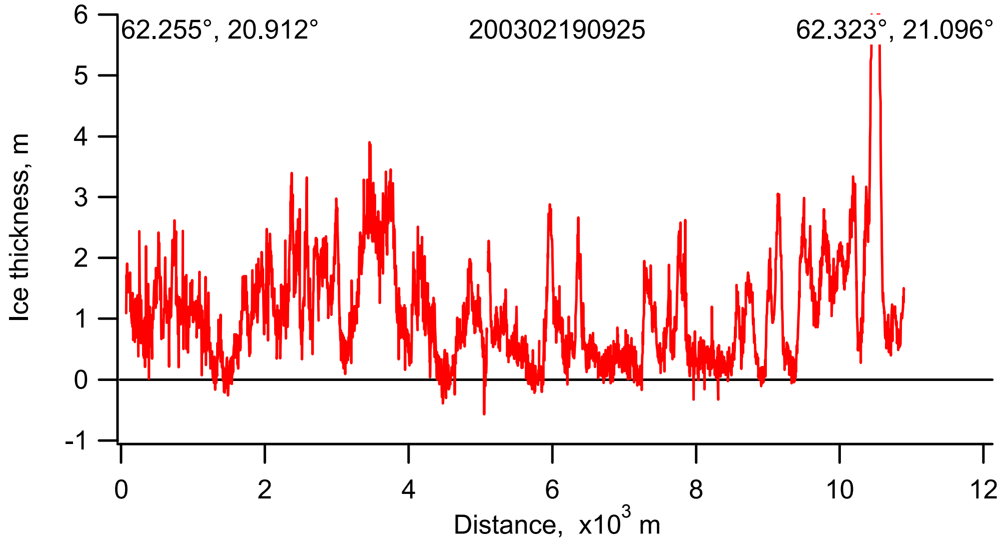
Profile 3



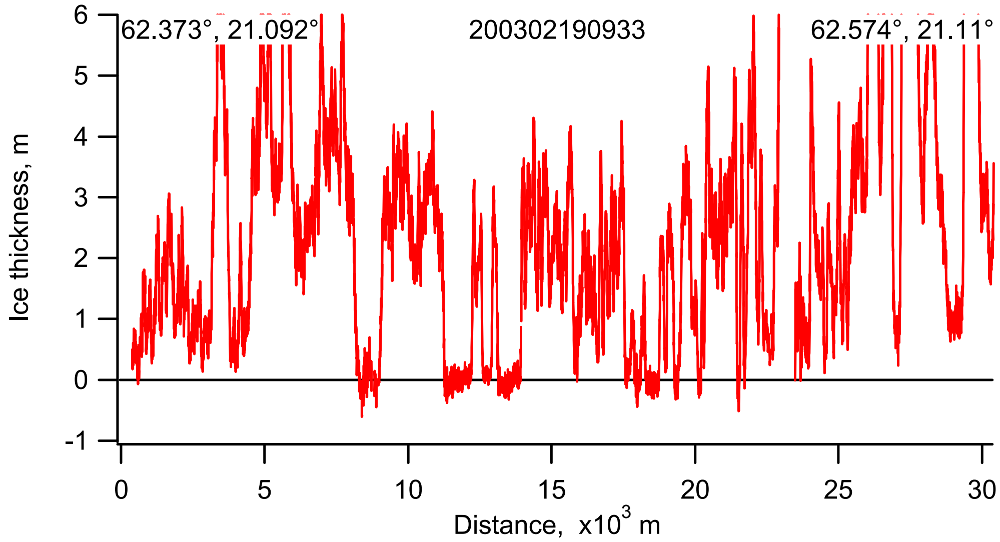
Profile 4



Profile 5

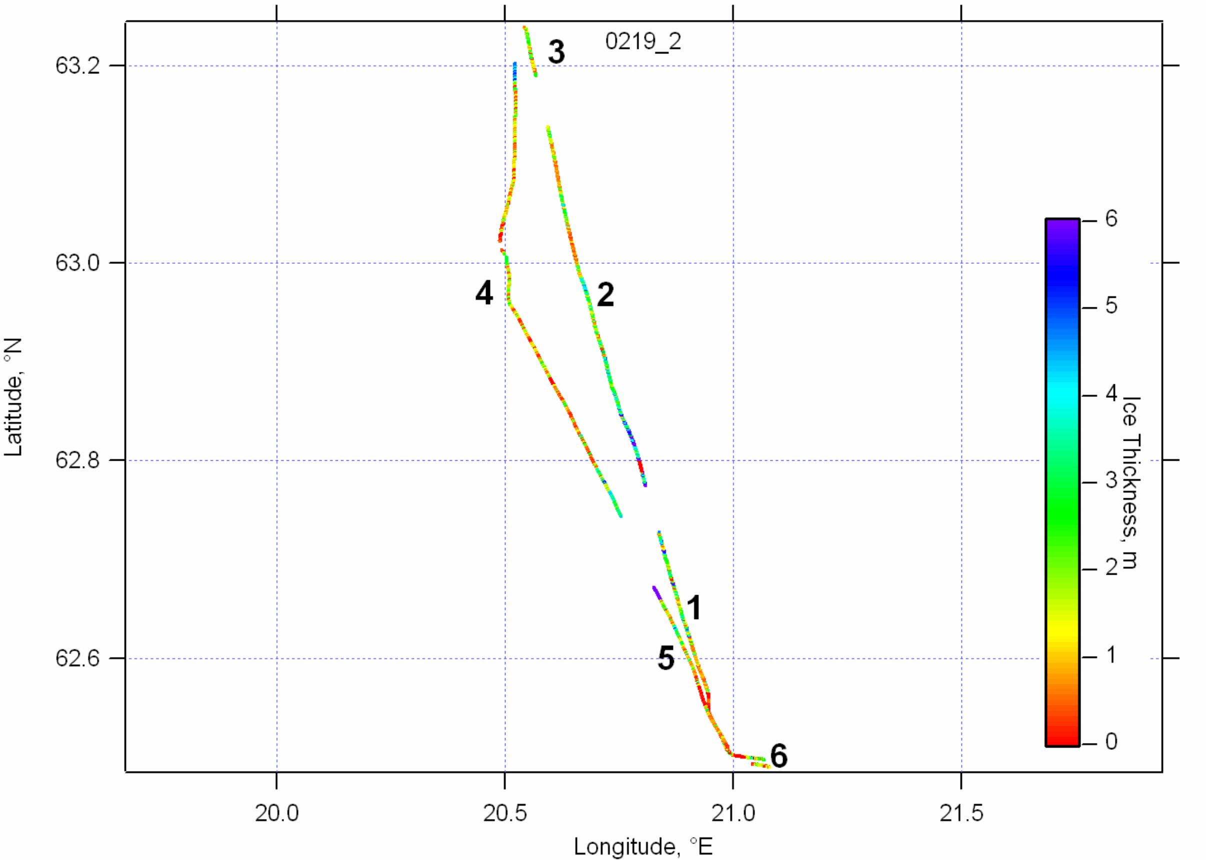


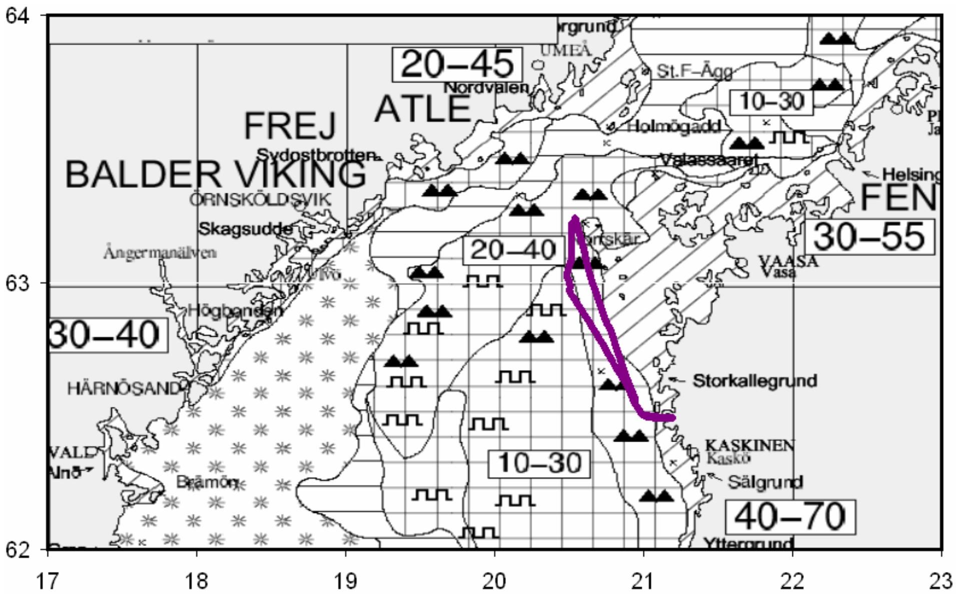
Profile 6



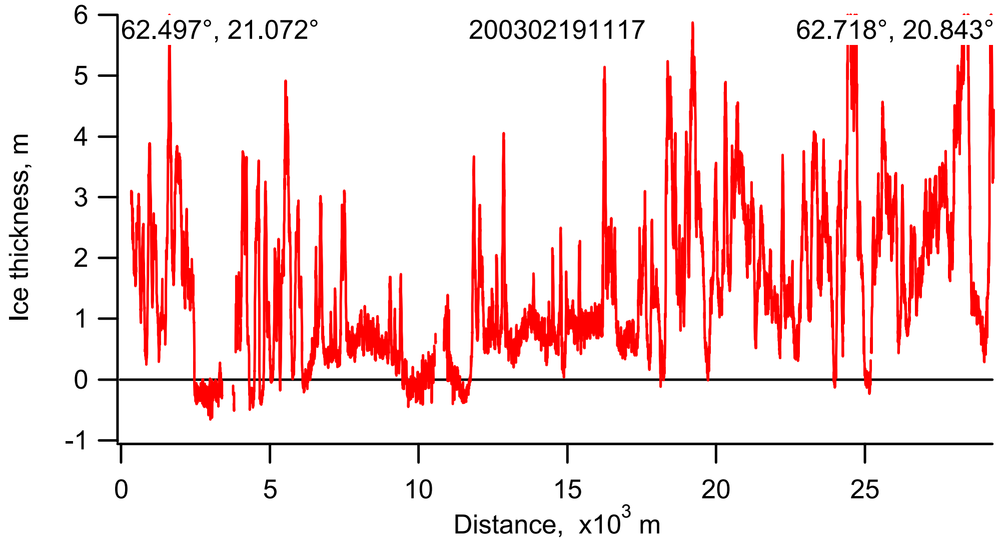
February 19, 2003, flight 2

Flight from Närpiö across deformed white ice parallel to fast ice edge.

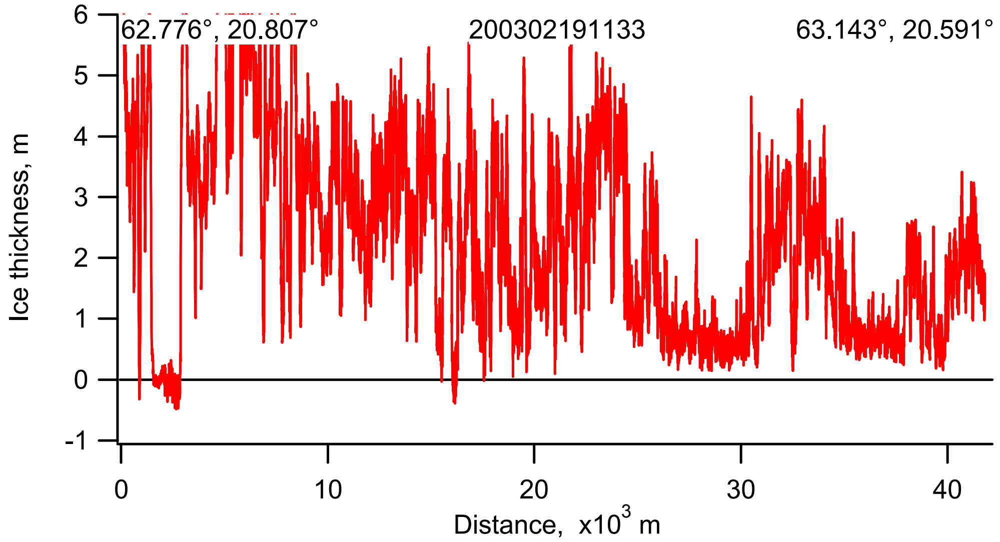




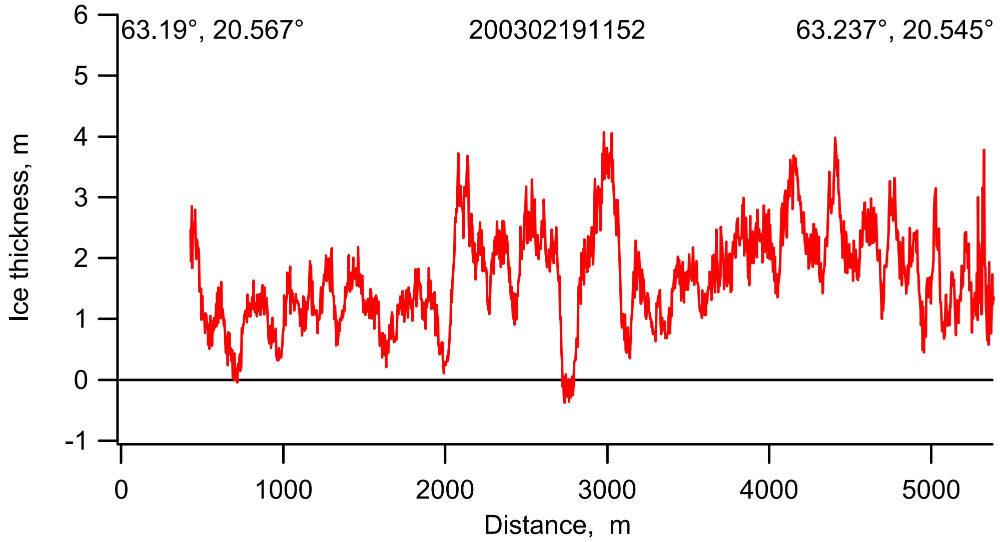
Profile 1



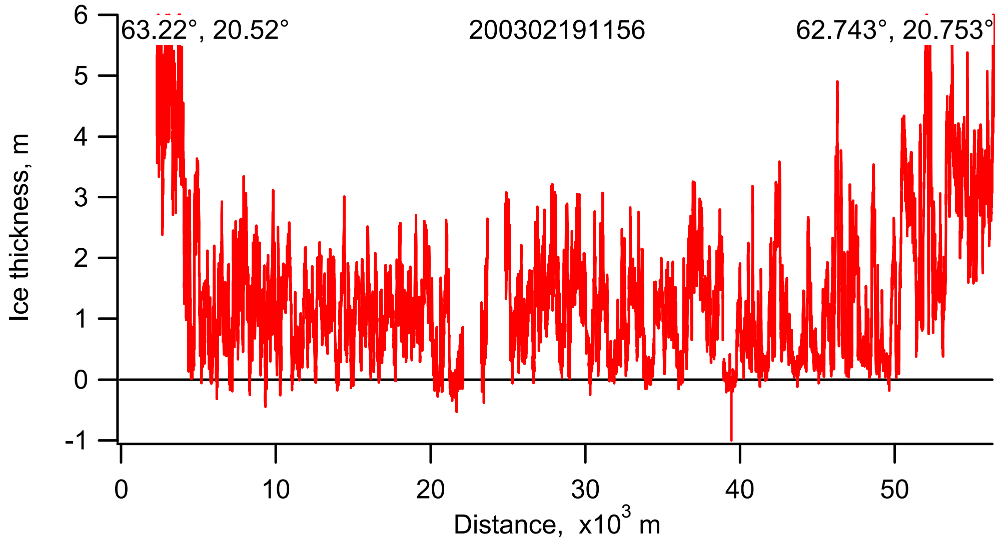
Profile 2



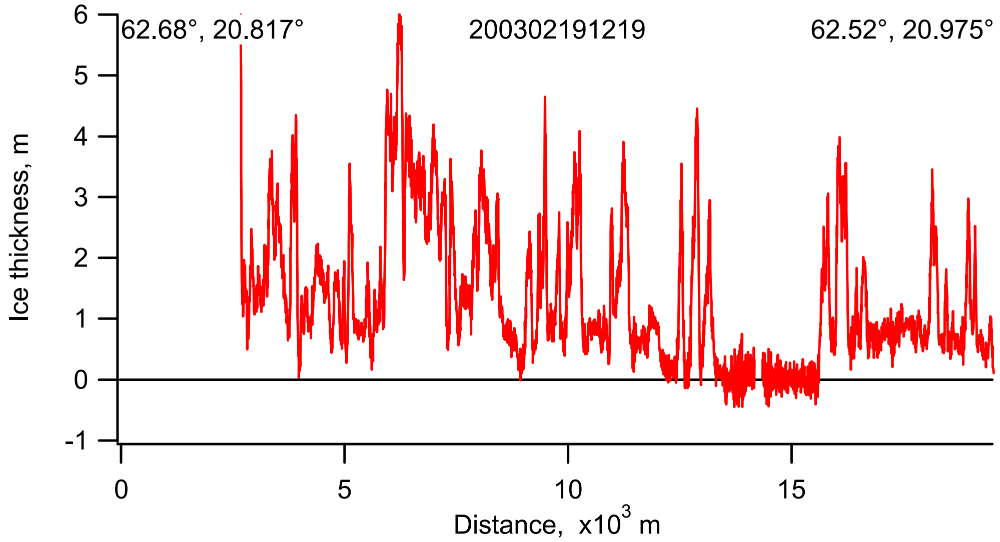
Profile 3



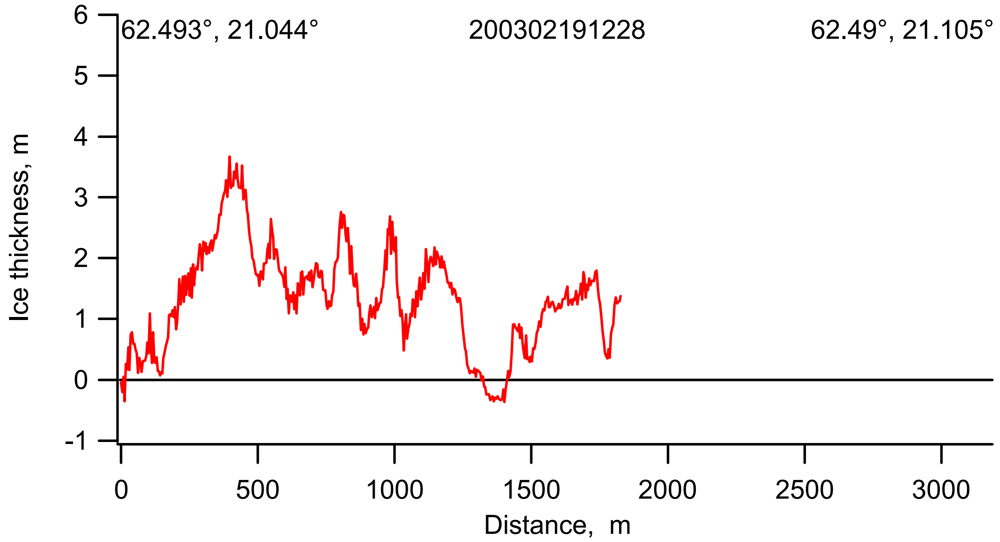
Profile 4



Profile 5

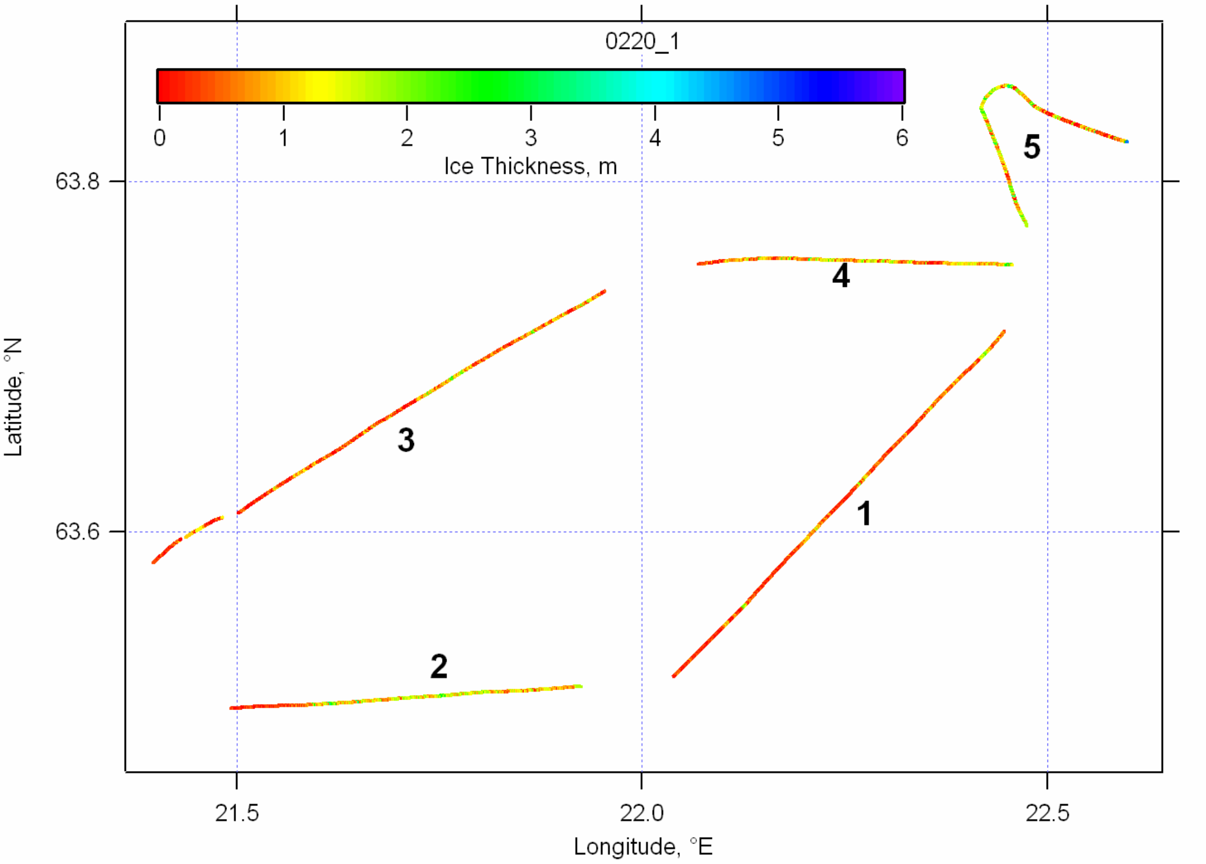


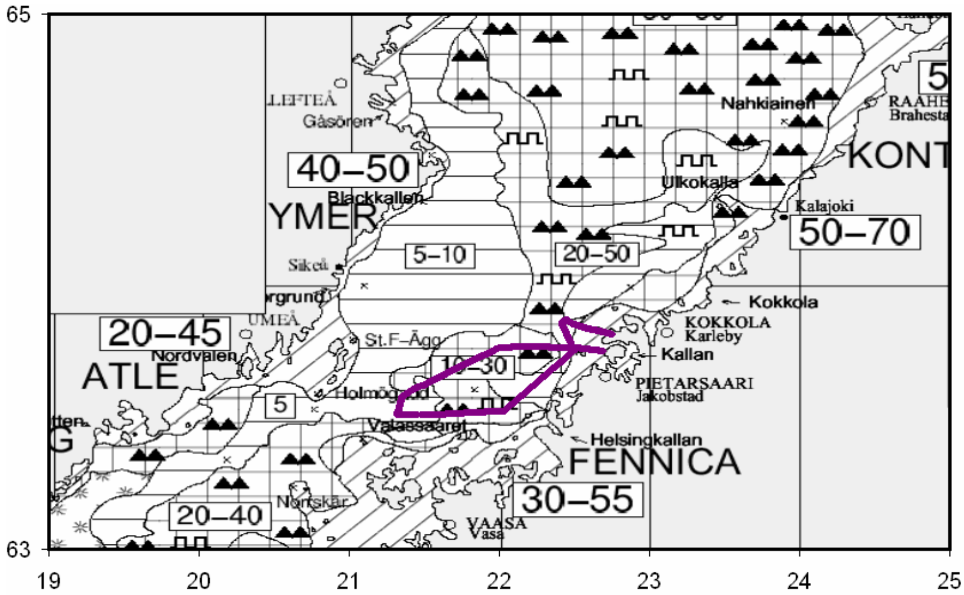
Profile 6



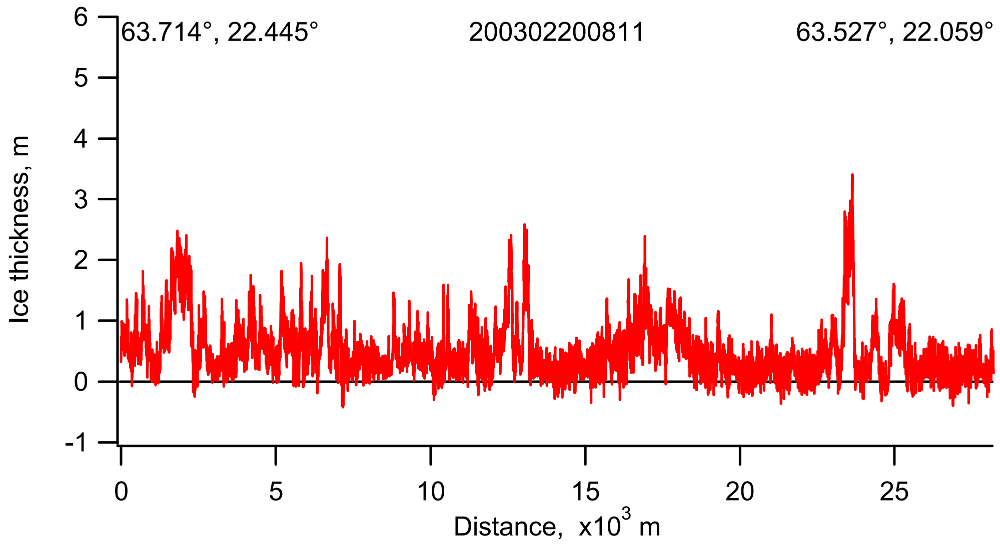
February 20, 2003, flight 1

Flight from Kokkola/Pietarsaari into Quarken, from deformed white ice into dark nilas.

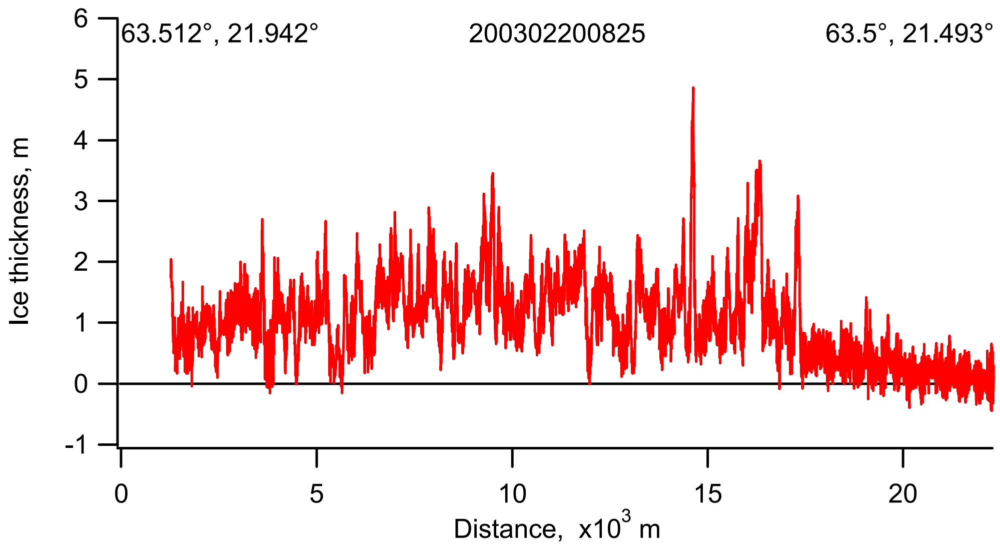




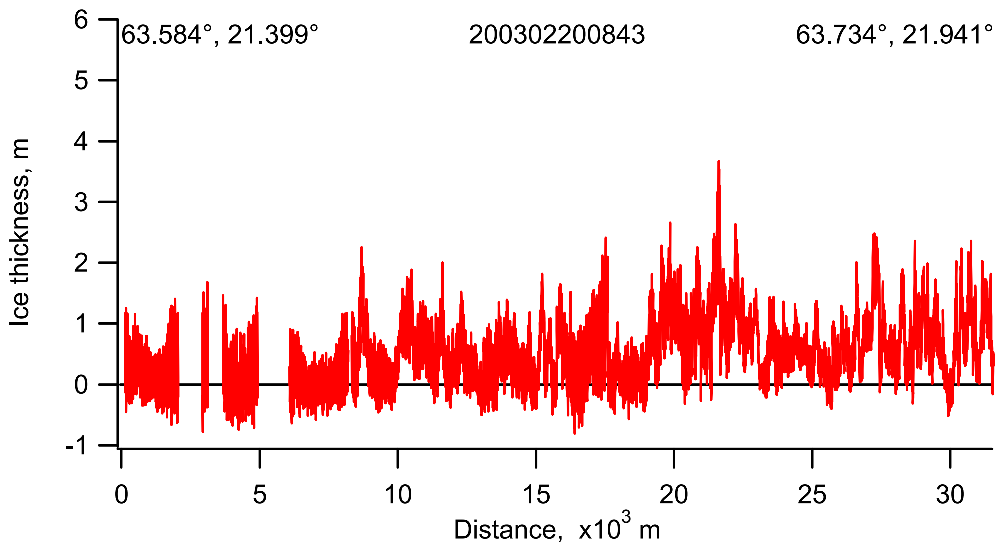
Profile 1



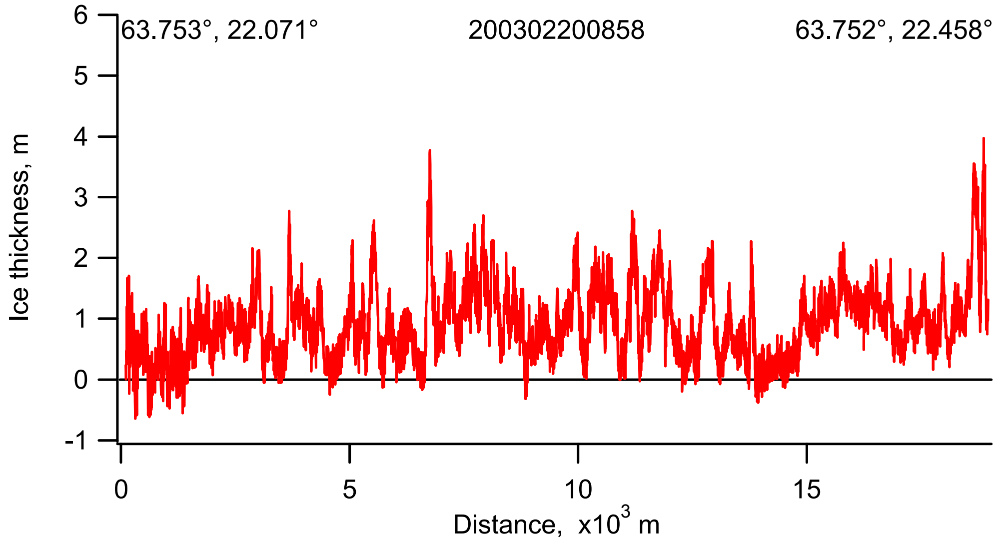
Profile 2



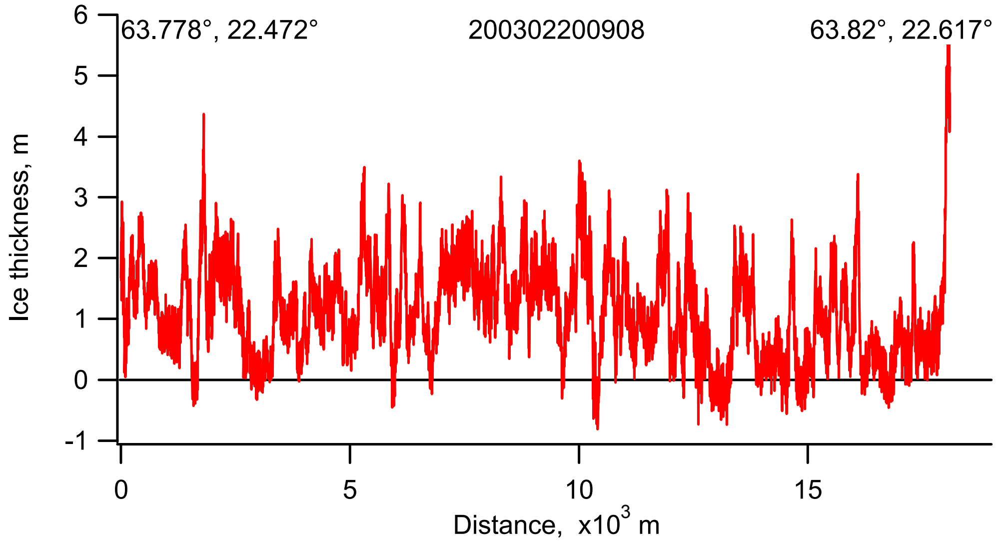
Profile 3



Profile 4

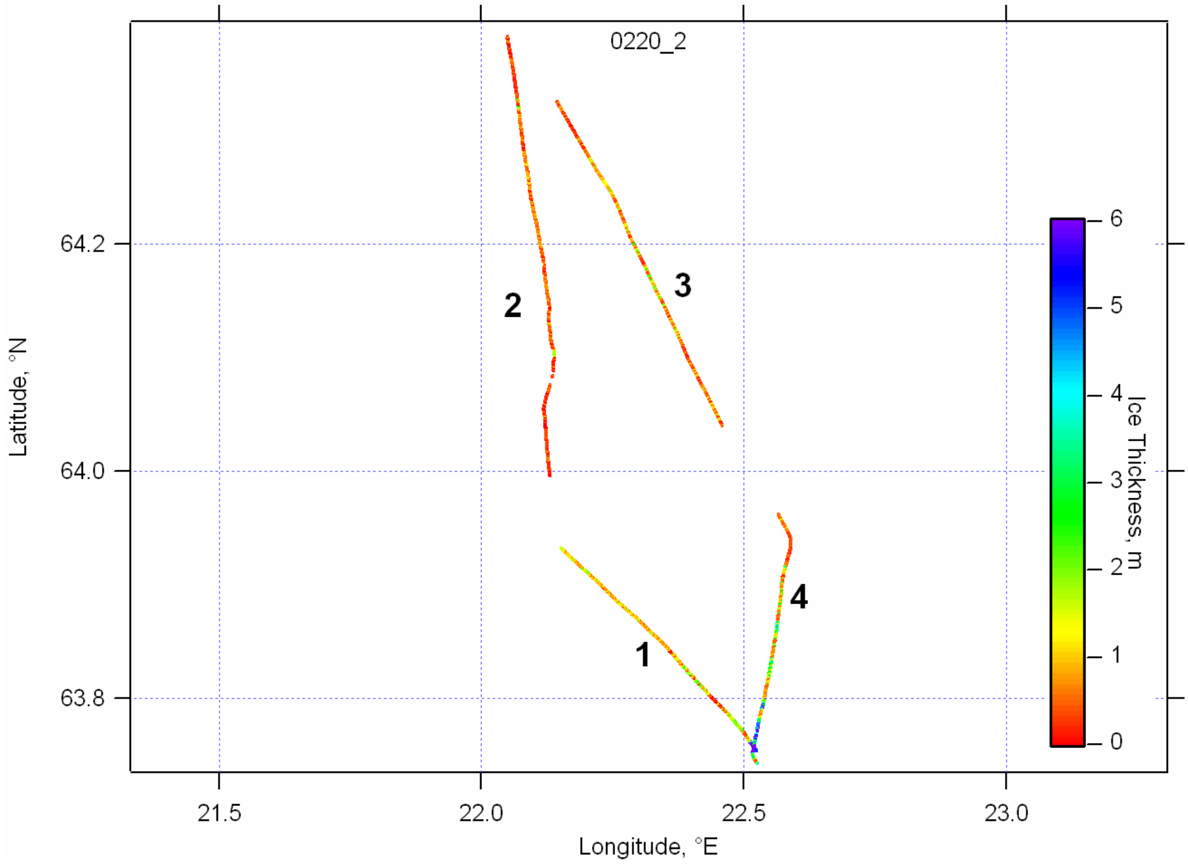


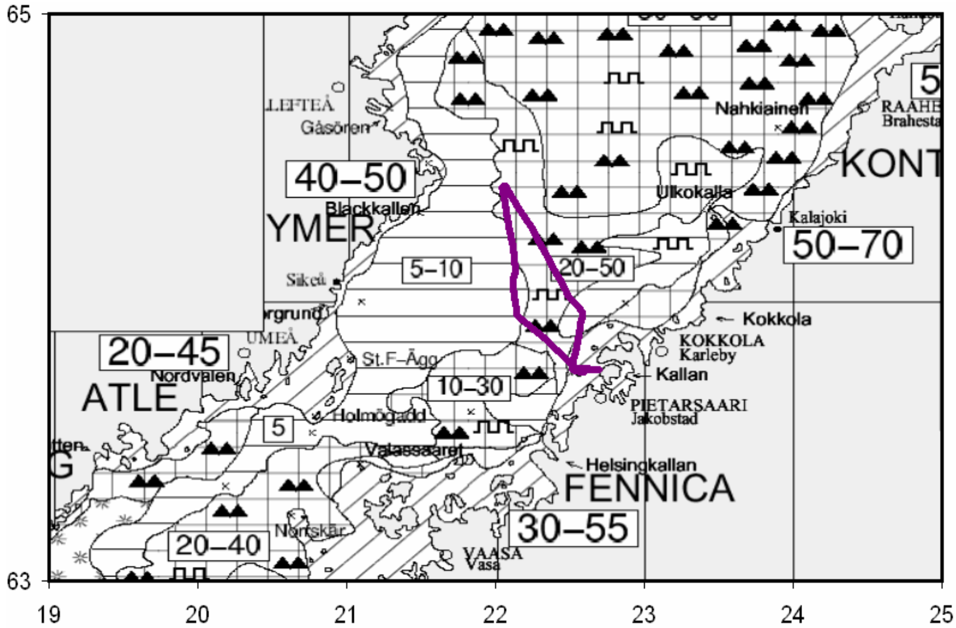
Profile 5



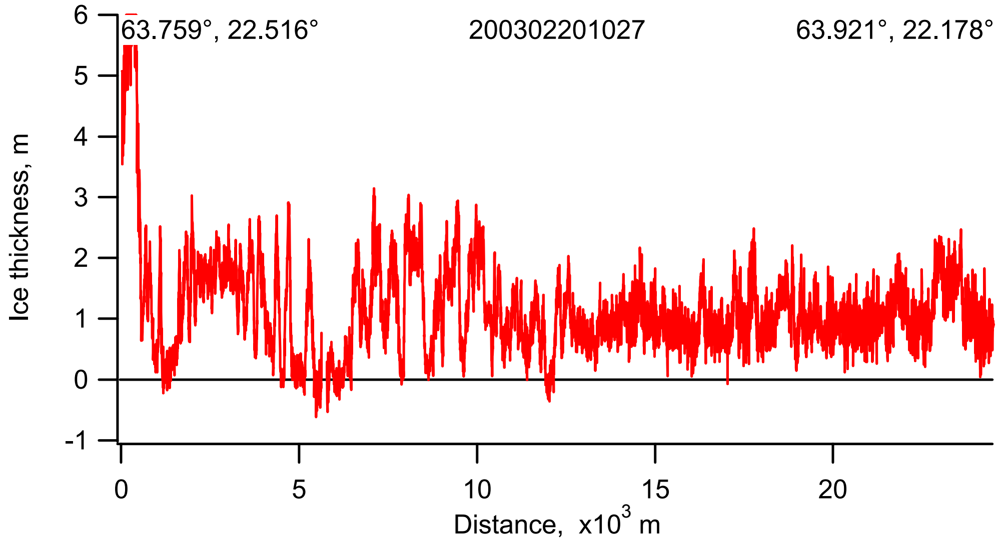
February 20, 2003, flight 2

Flight from Kokkola/Pietarsaari along boundary between rafted nilas and deformed white ice.

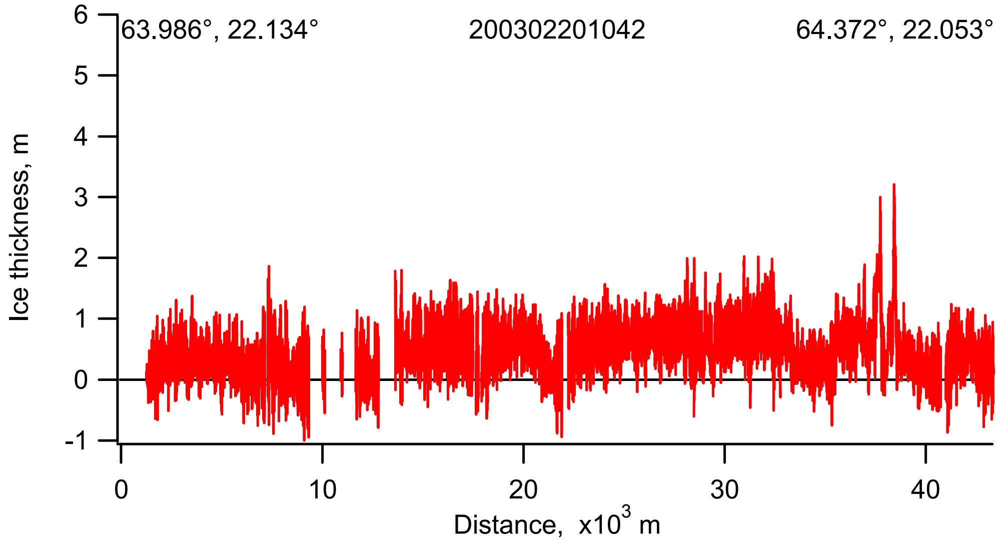




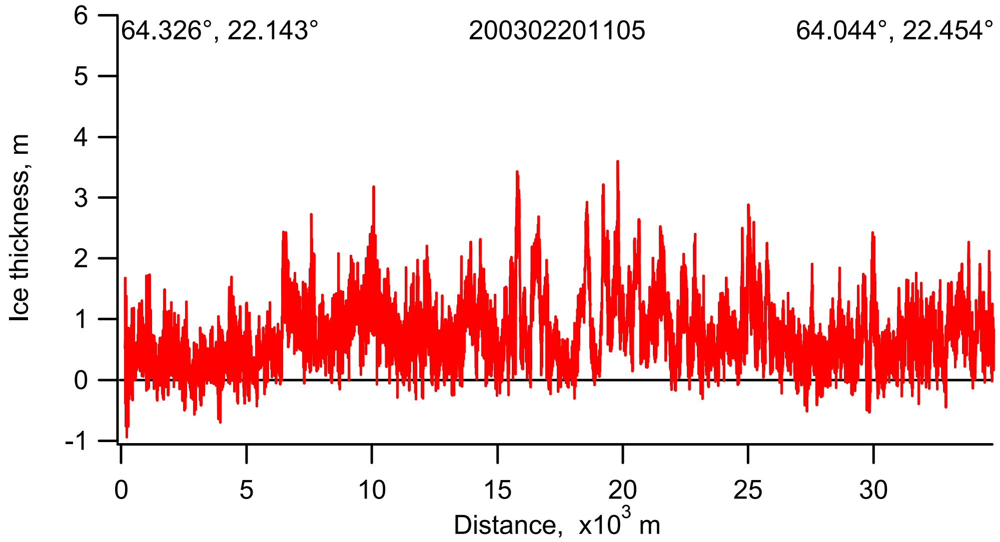
Profile 1



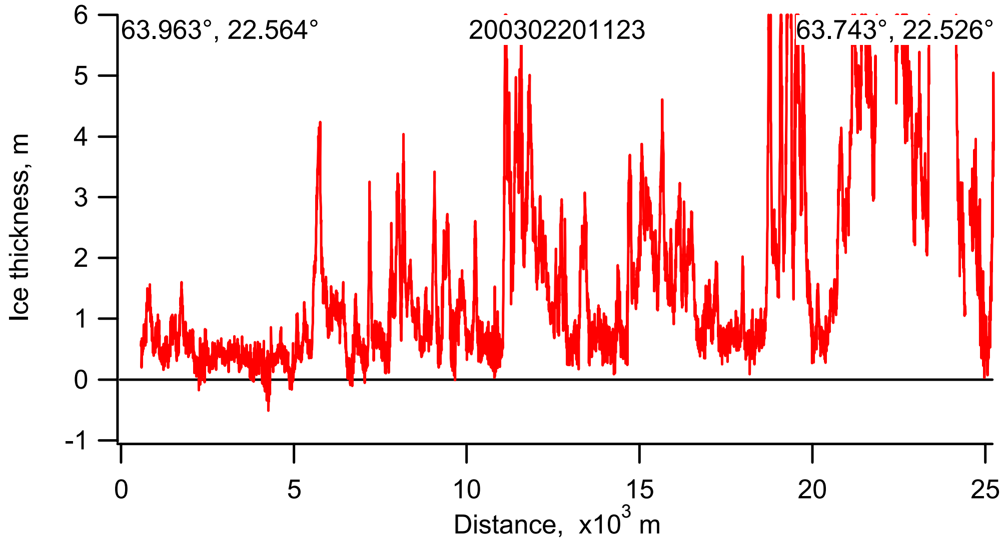
Profile 2



Profile 3



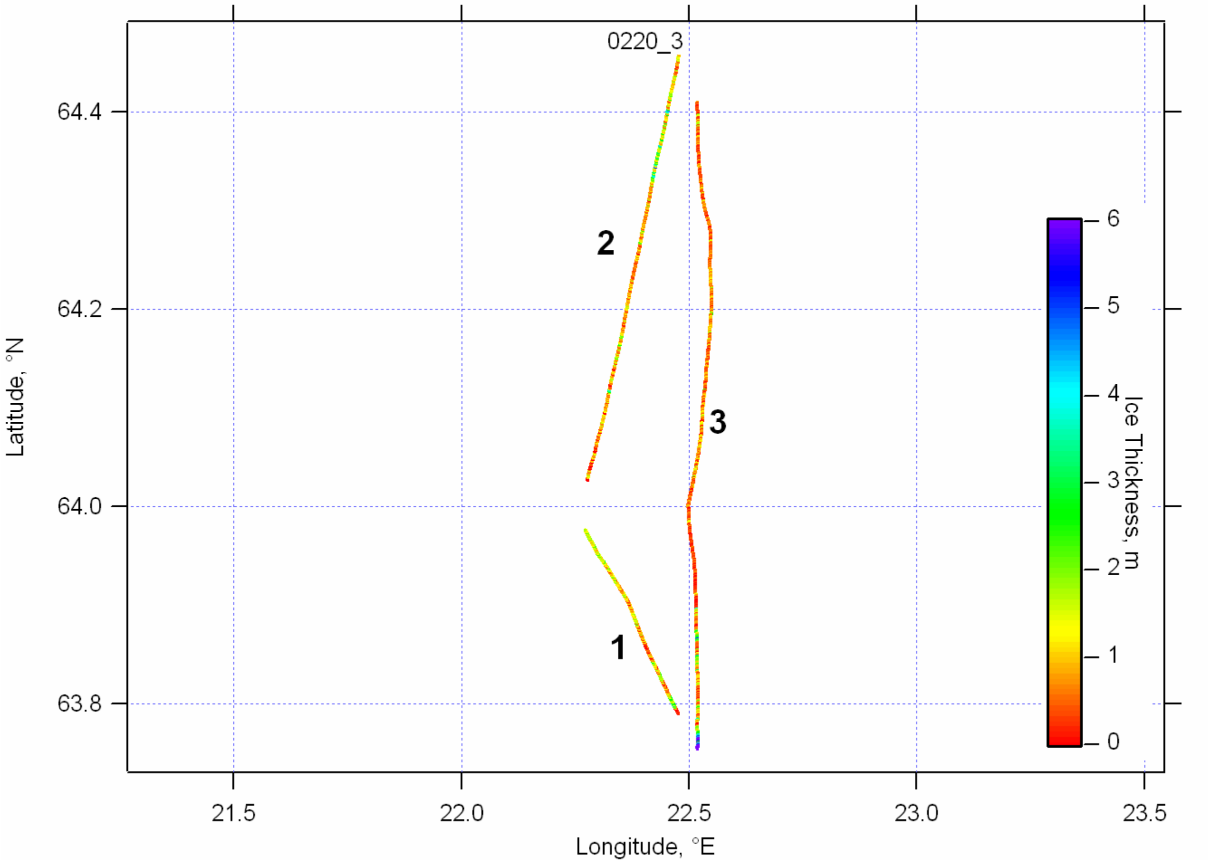
Profile 4

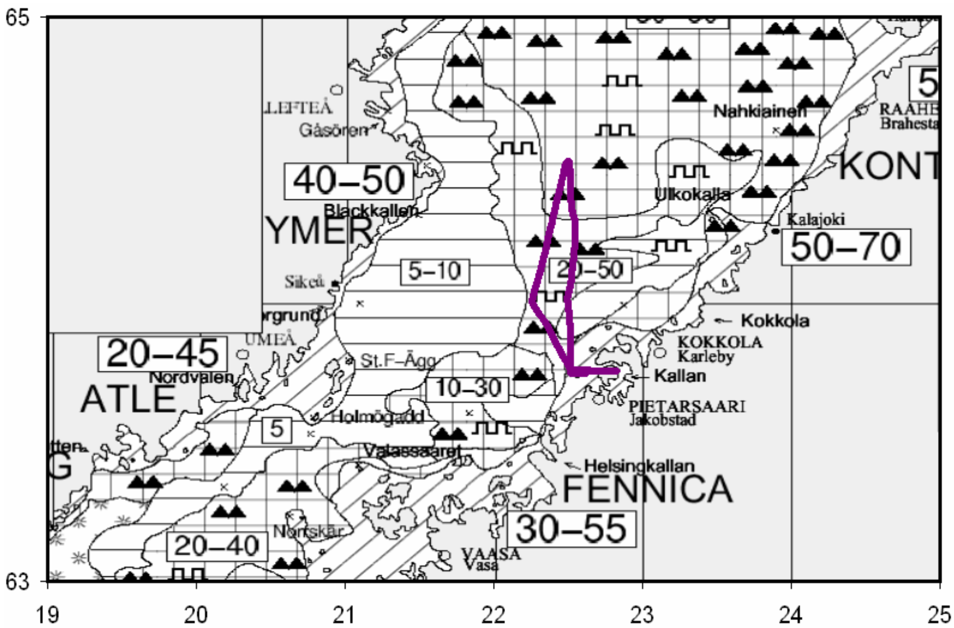


63.963°, 22.564°
200302201123
63.743°, 22.526°
Ice thickness, m
6
5
4
3
2
1
0
-1
0
5
10
15
20
25
Distance, x10^3 m

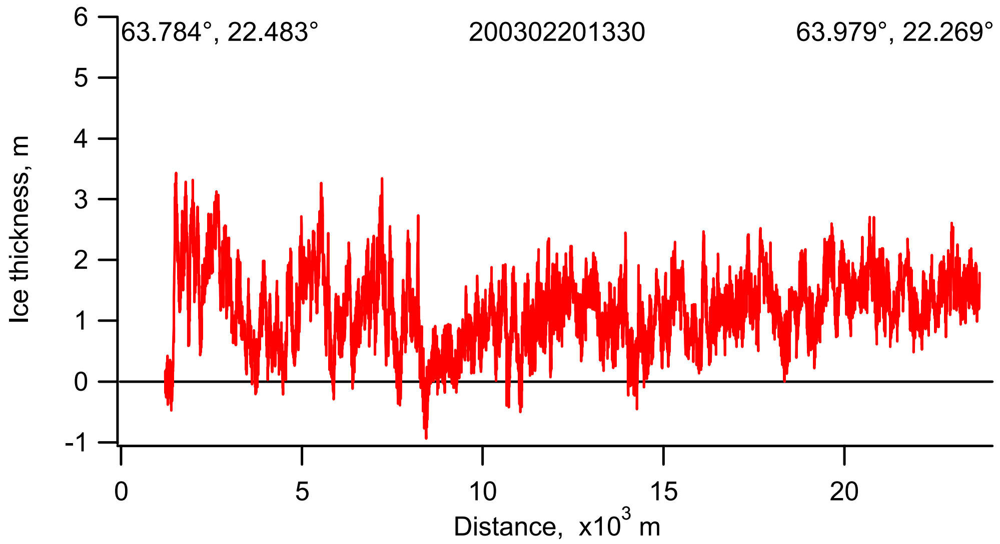
February 20, 2003, flight 3

Flight from Kokkola/Pietarsaari into thicker and older ice in the North.

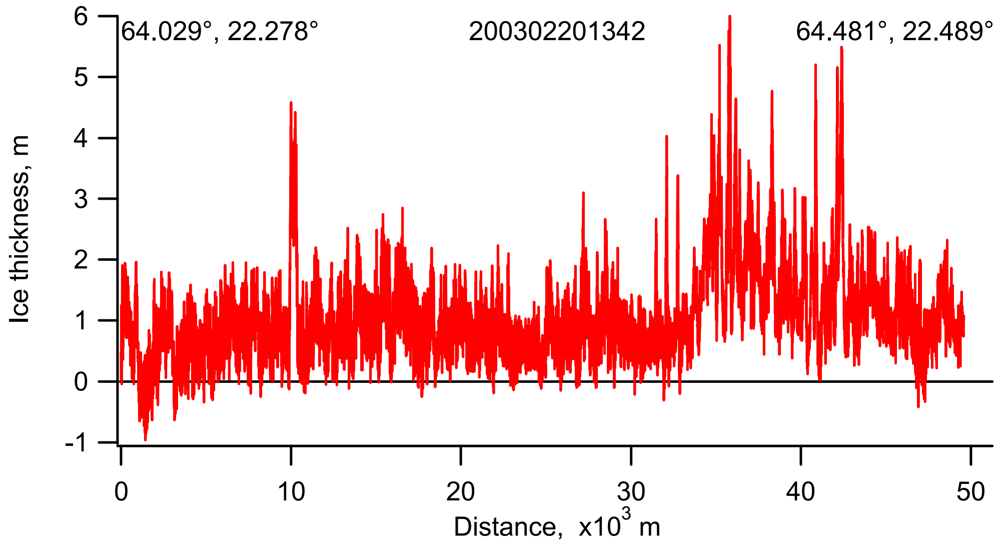




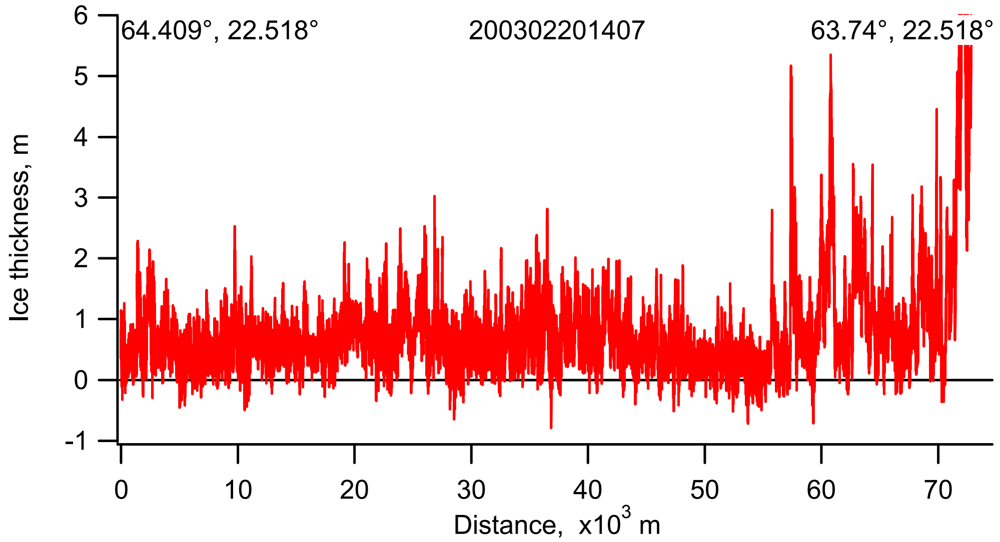
Profile 1



Profile 2

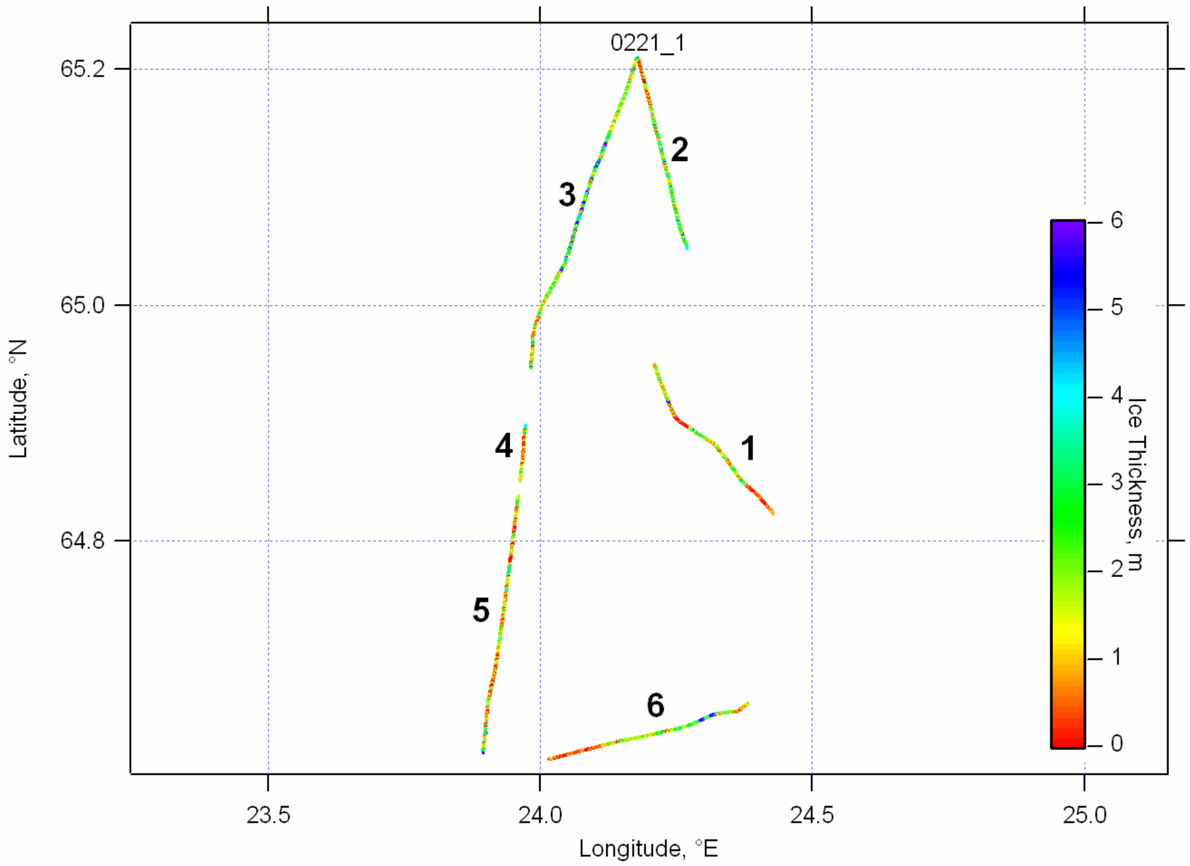


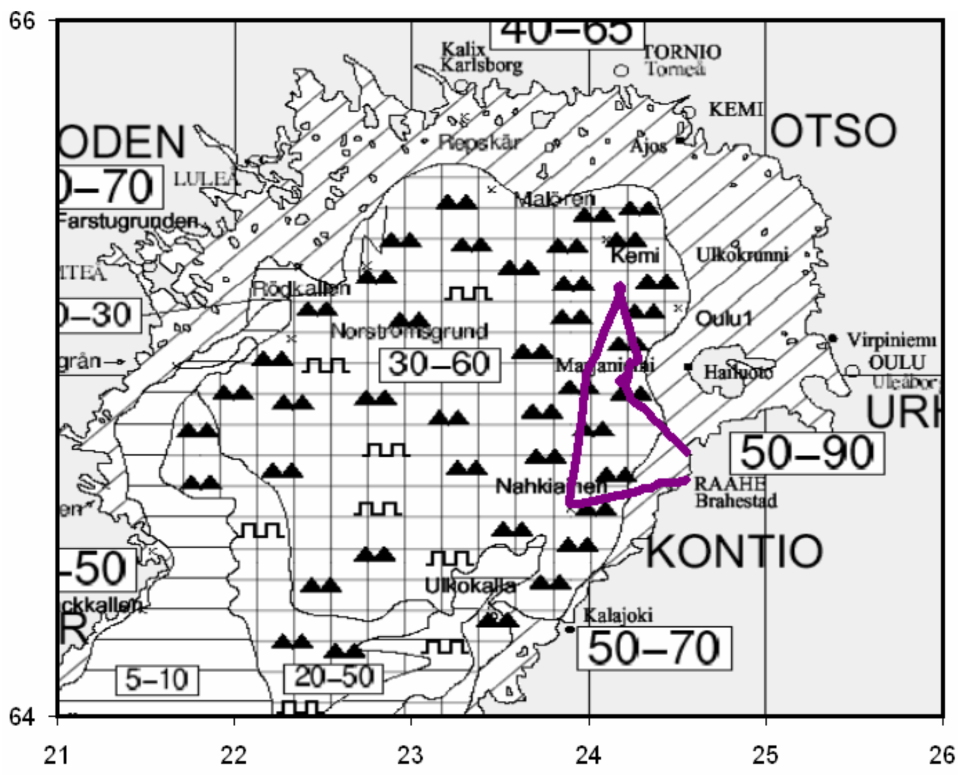
Profile 3



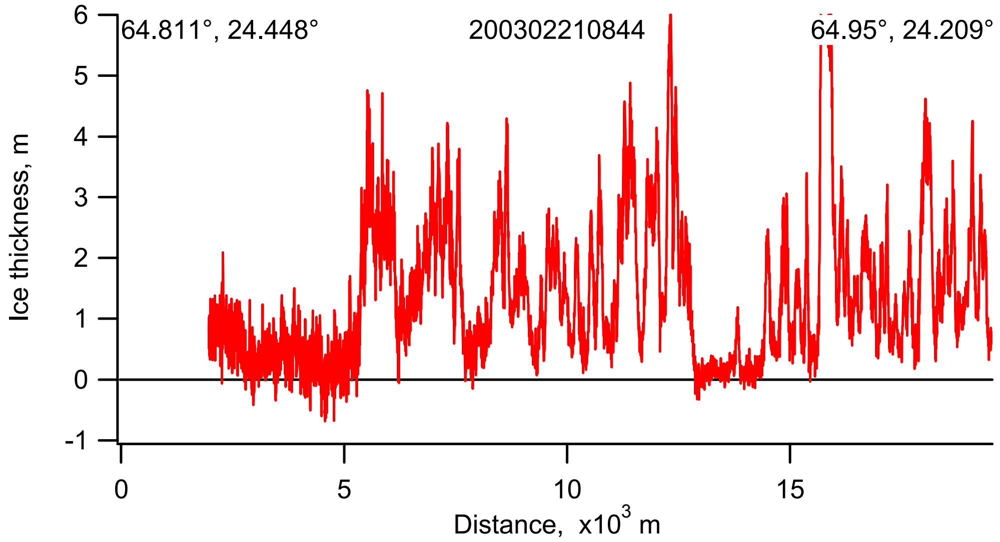
February 21, 2003, flight 1

Flight from Raahe into thick deformed, snow covered white ice; Some searching for earlier FMHI surface profiles close to Hailuoto.

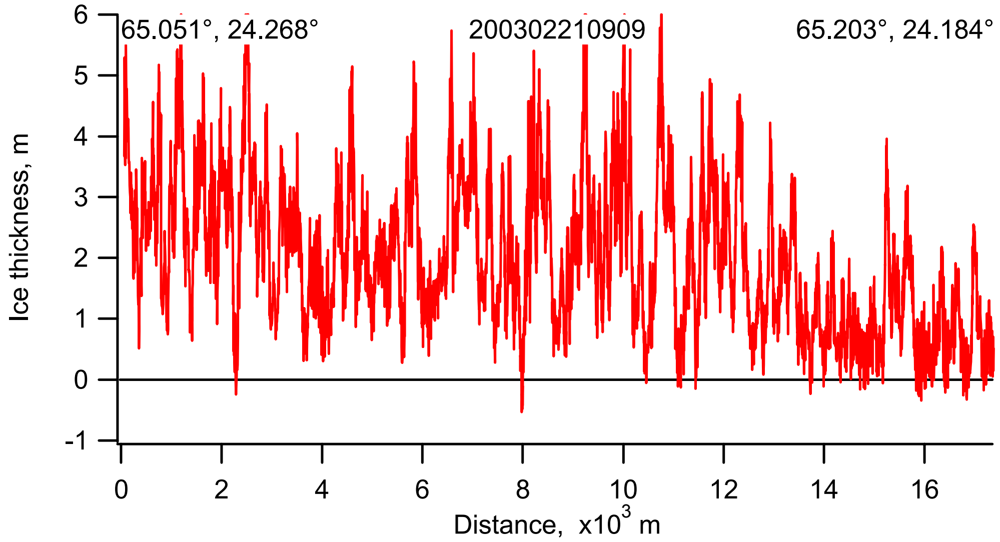




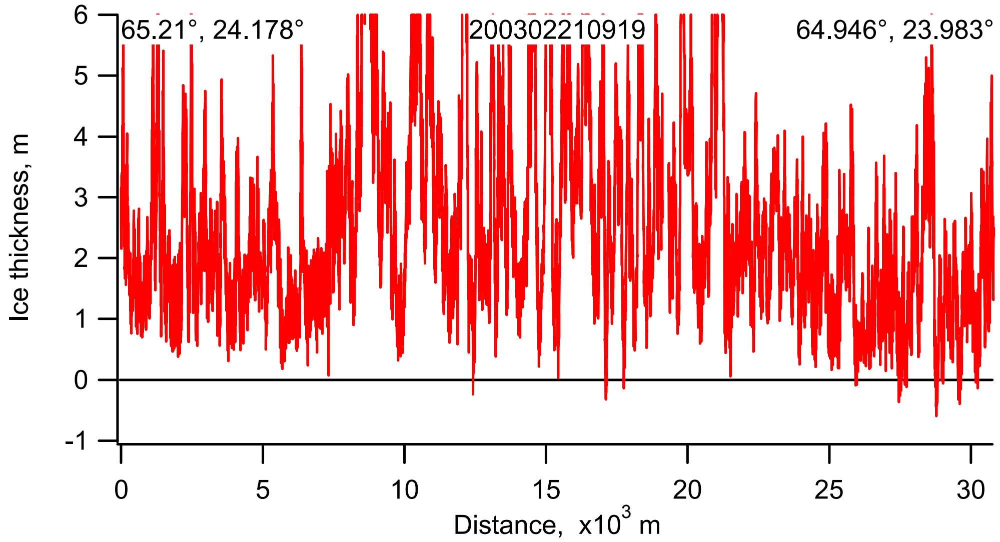
Profile 1



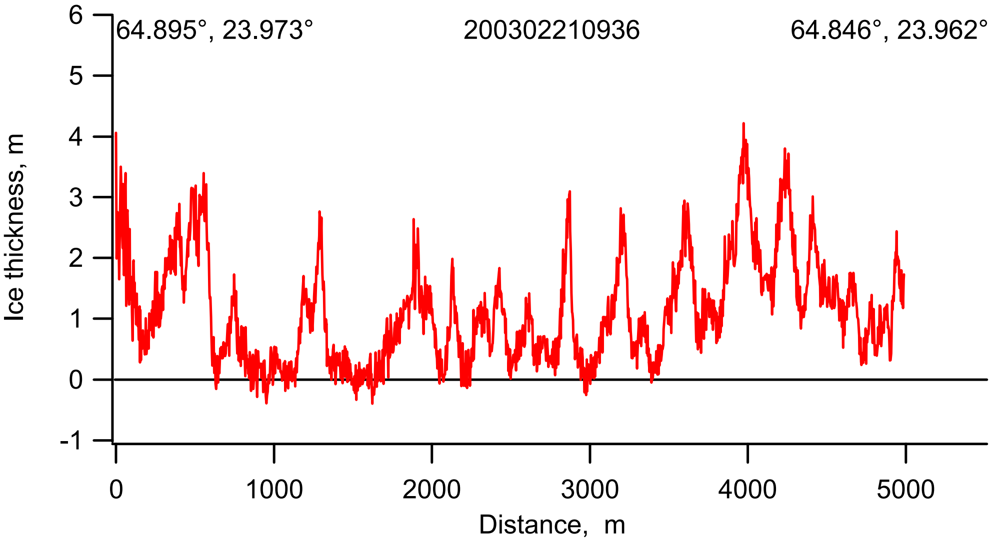
Profile 2



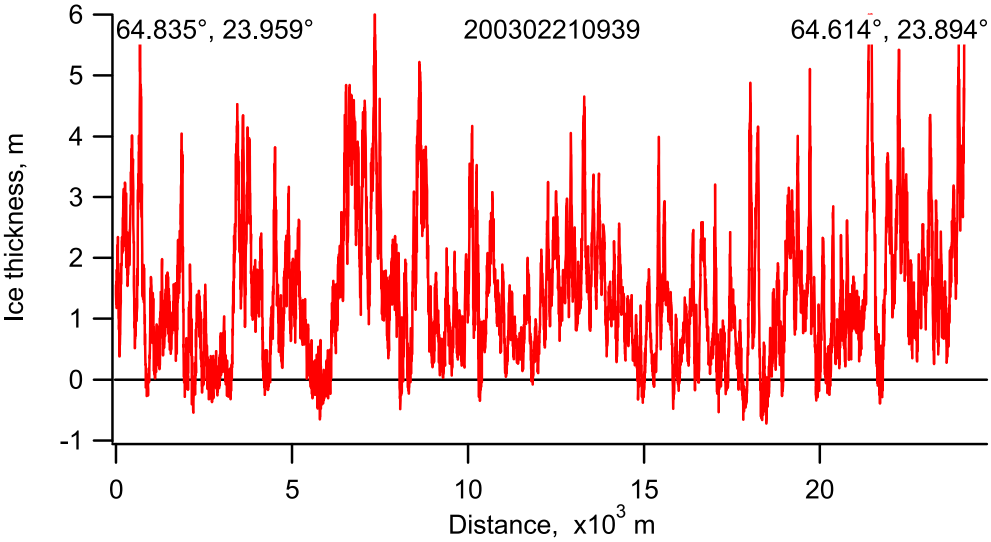
Profile 3



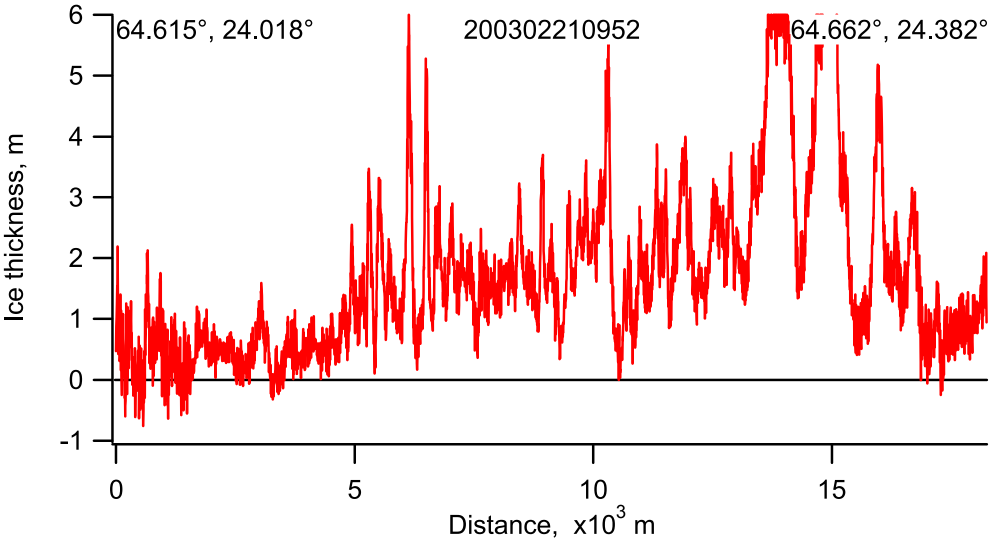
Profile 4



Profile 5

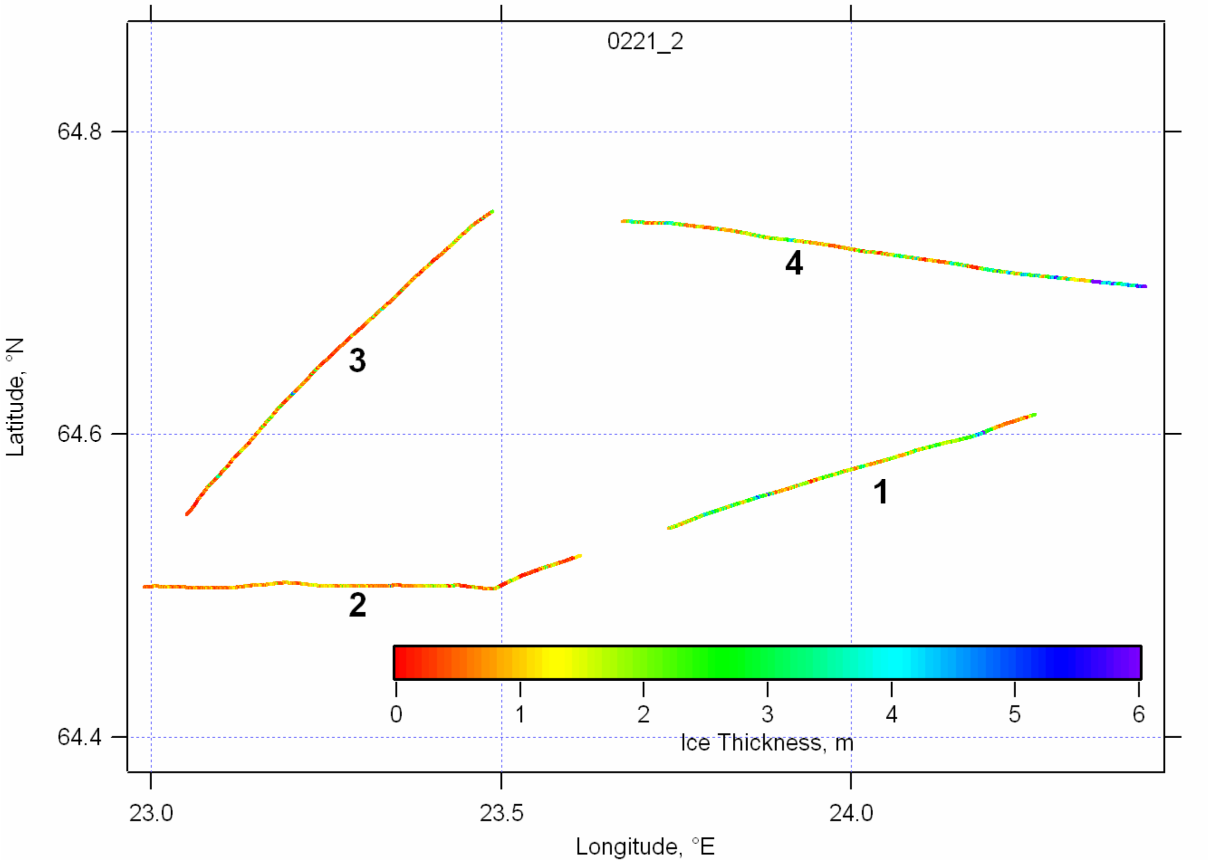


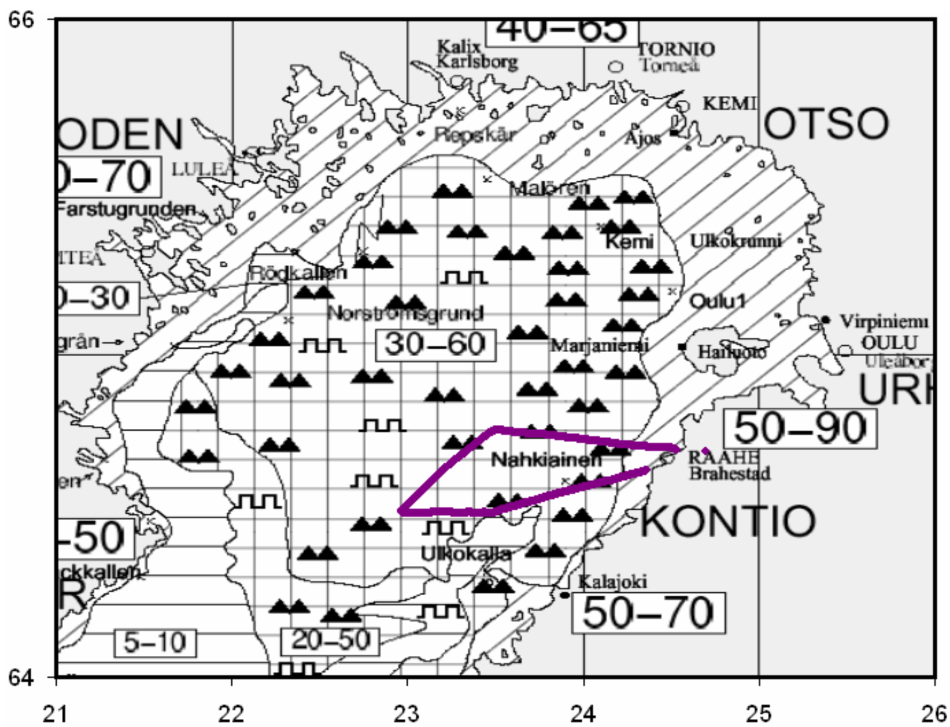
Profile 6



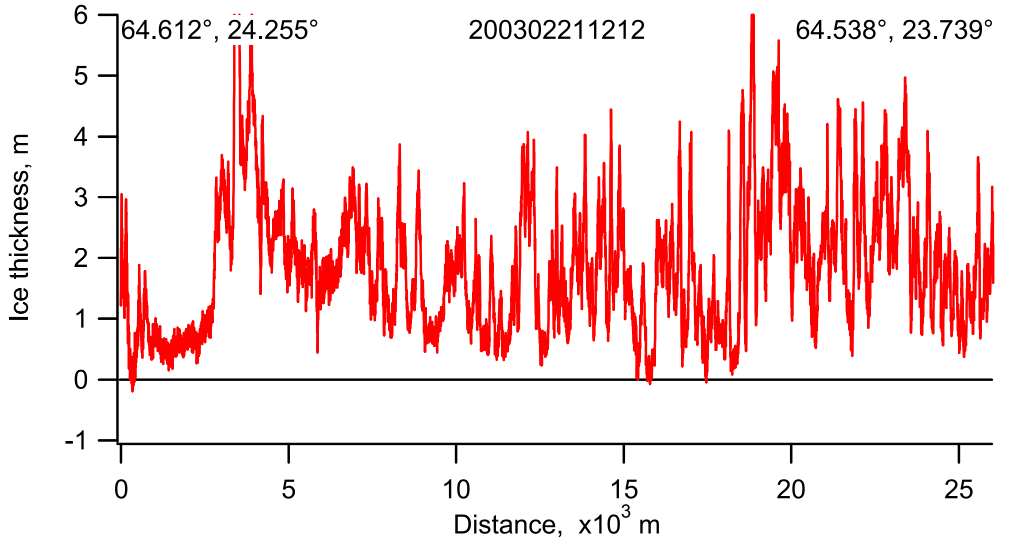
February 21, 2003, flight 2

Flight from Raahe towards west, into more broke ice fields with refrozen leads in between.

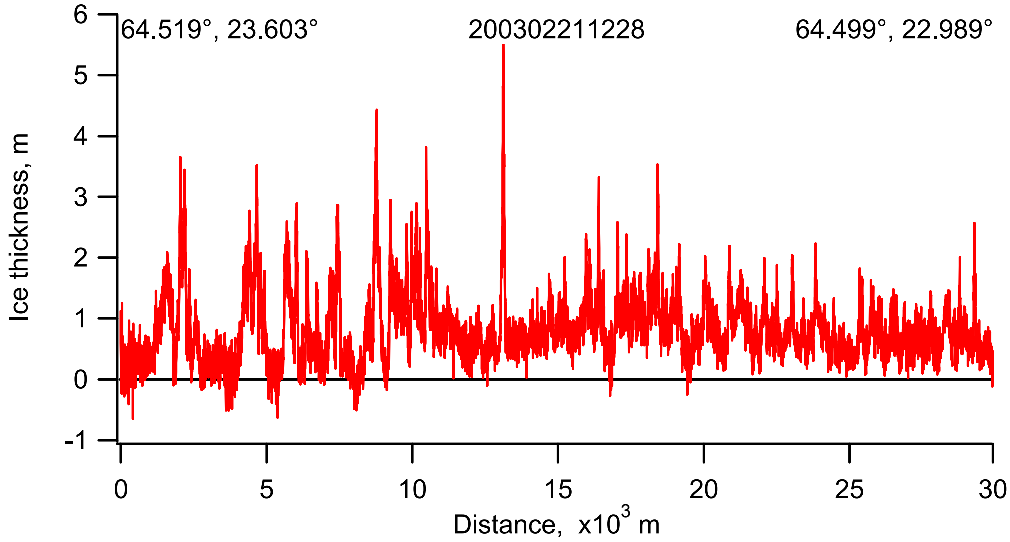




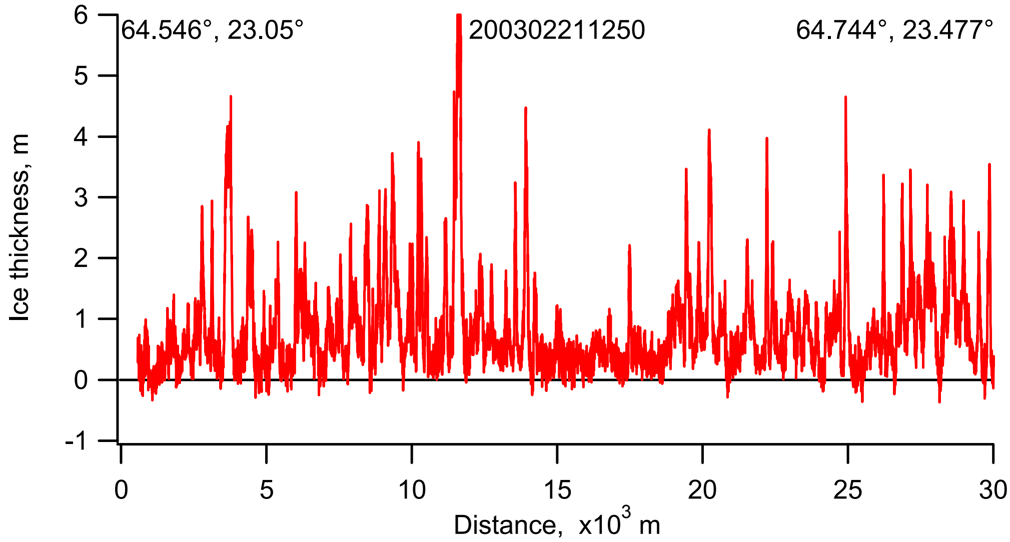
Profile 1



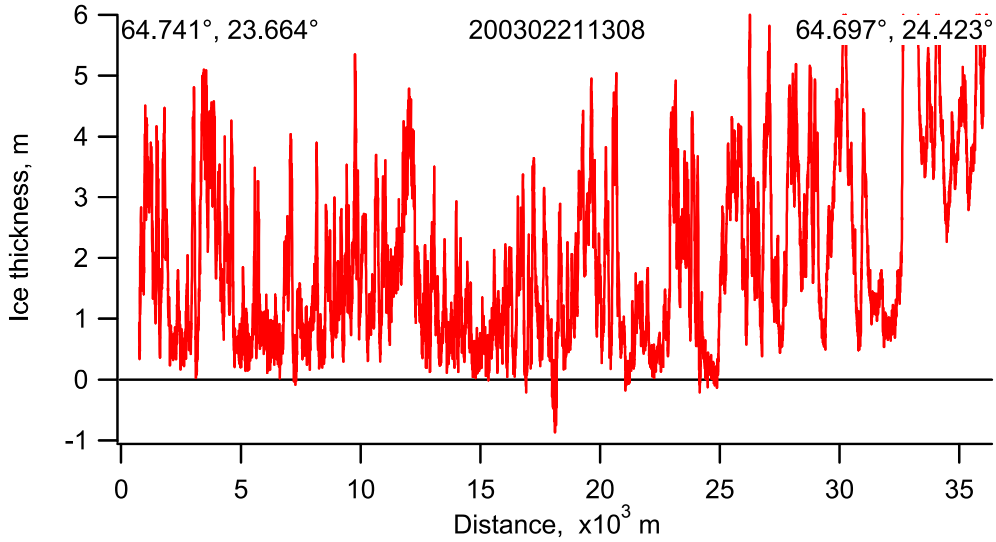
Profile 2



Profile 3

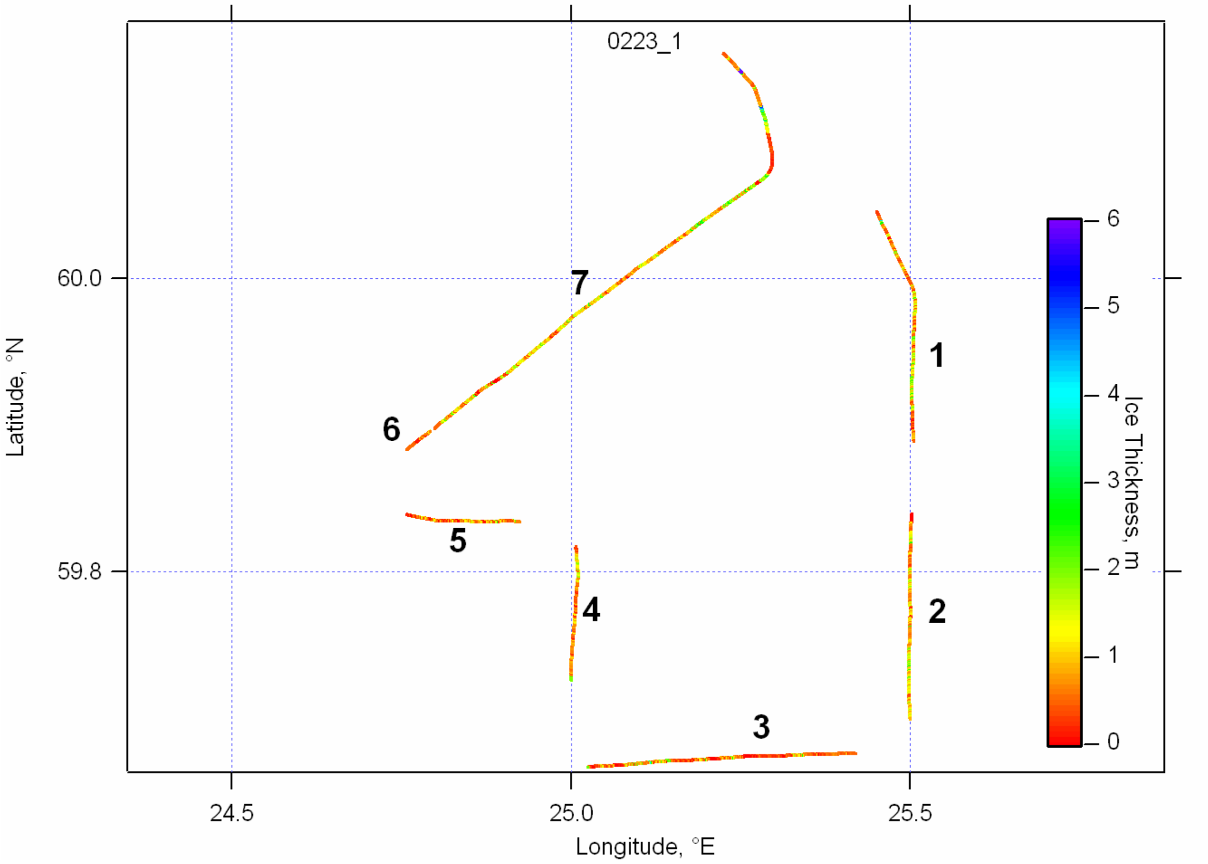


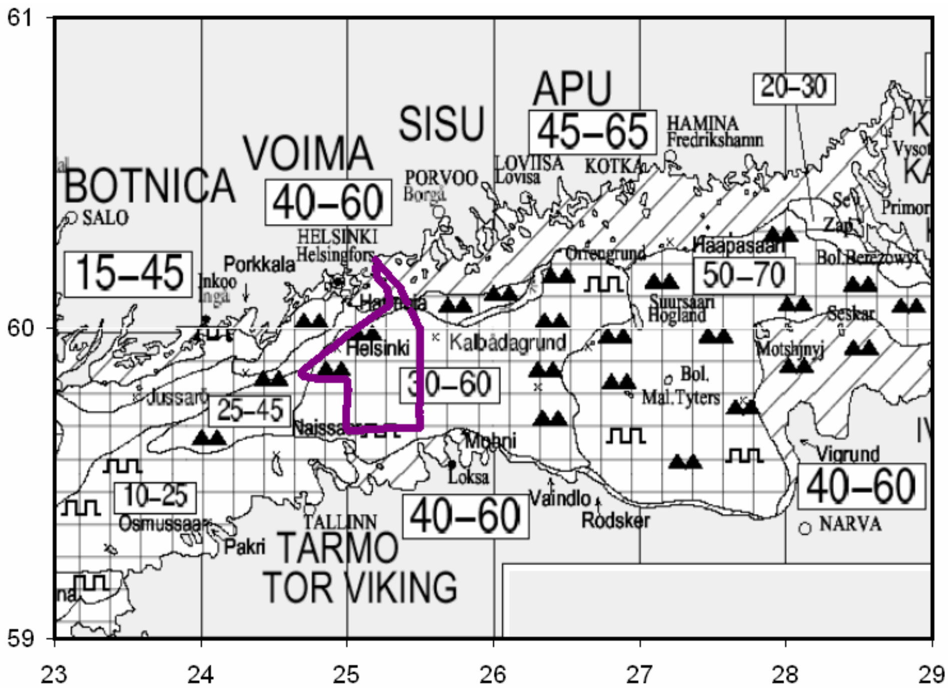
Profile 4


64.741°, 23.664°
200302211308
64.697°, 24.423°
Ice thickness, m
Distance, x10^3 m
6
5
4
3
2
1
0
-1
0
5
10
15
20
25
30
35

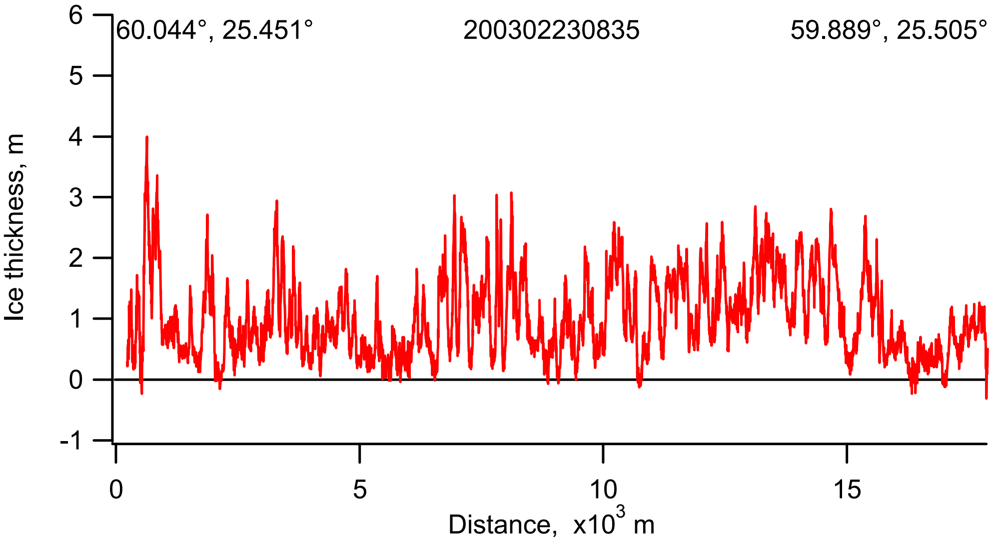
February 23, 2003, flight 1

Western flight from Helsinki to Estonia, over white ice floes with refrozen leads and open water in between.

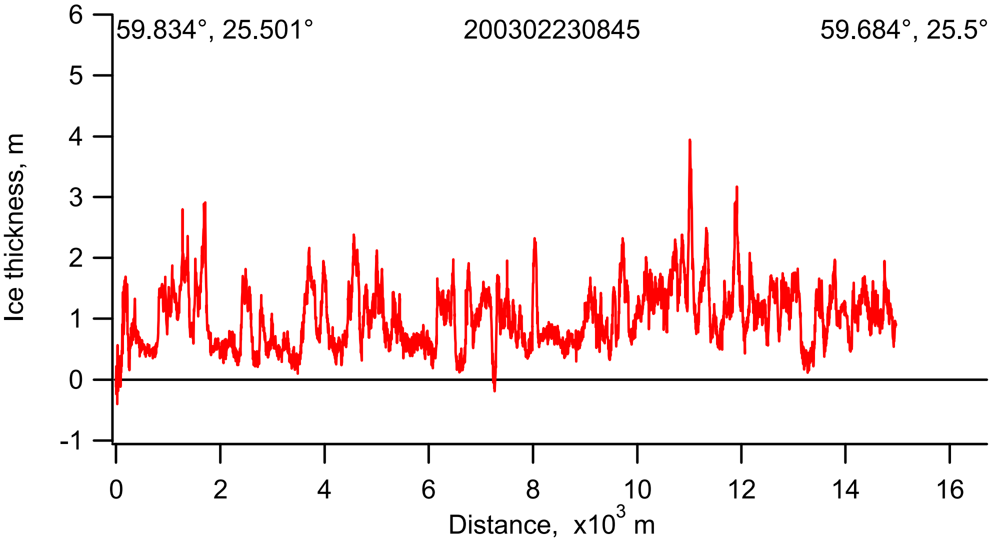




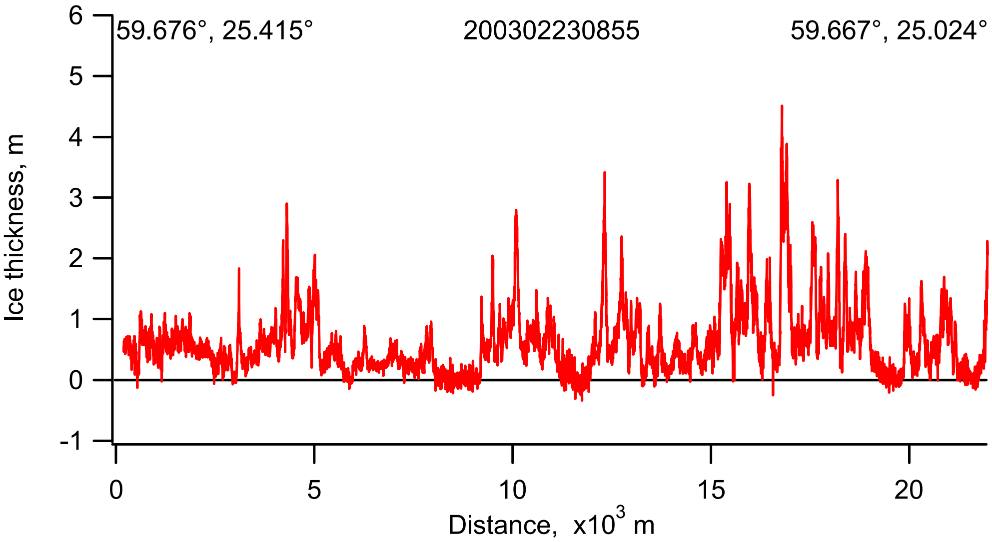
Profile 1



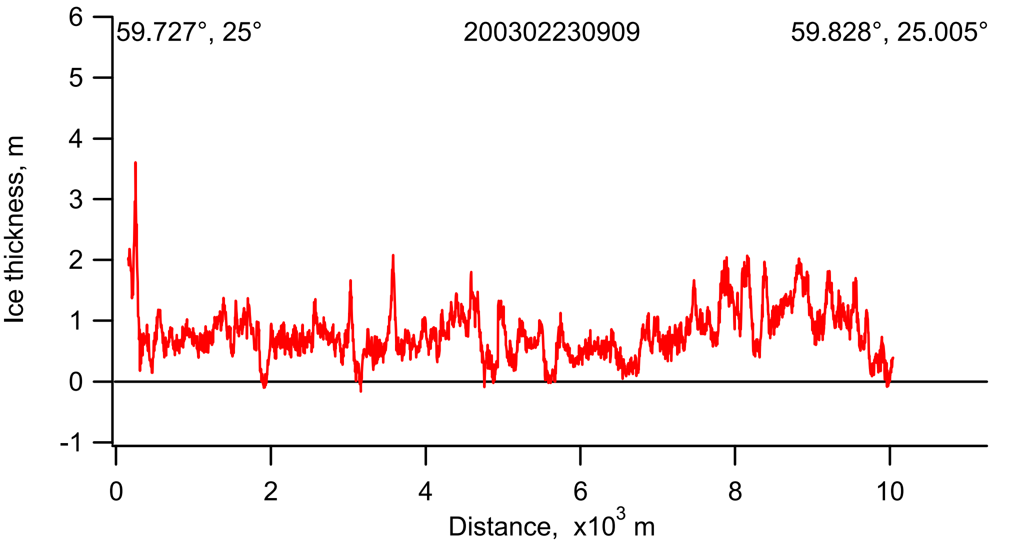
Profile 2



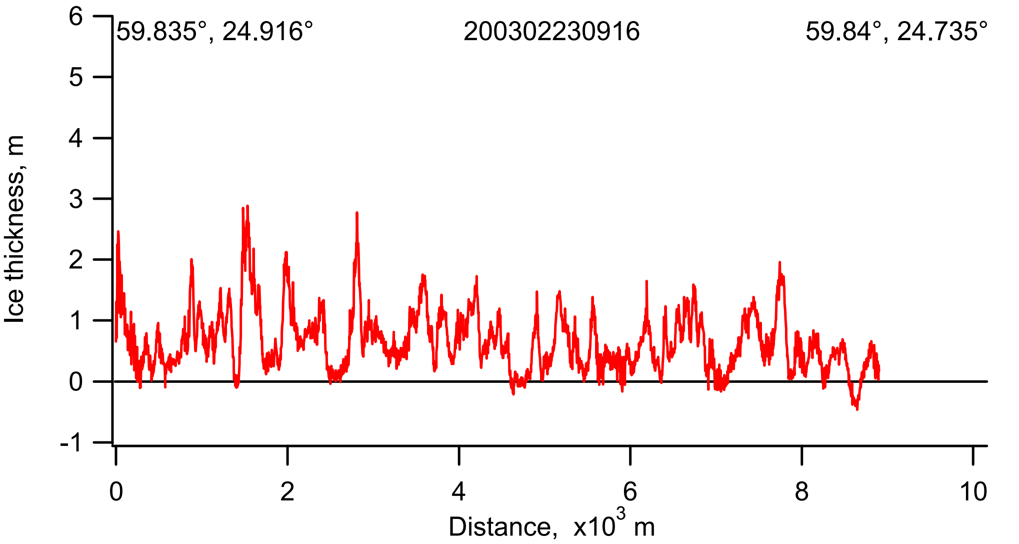
Profile 3



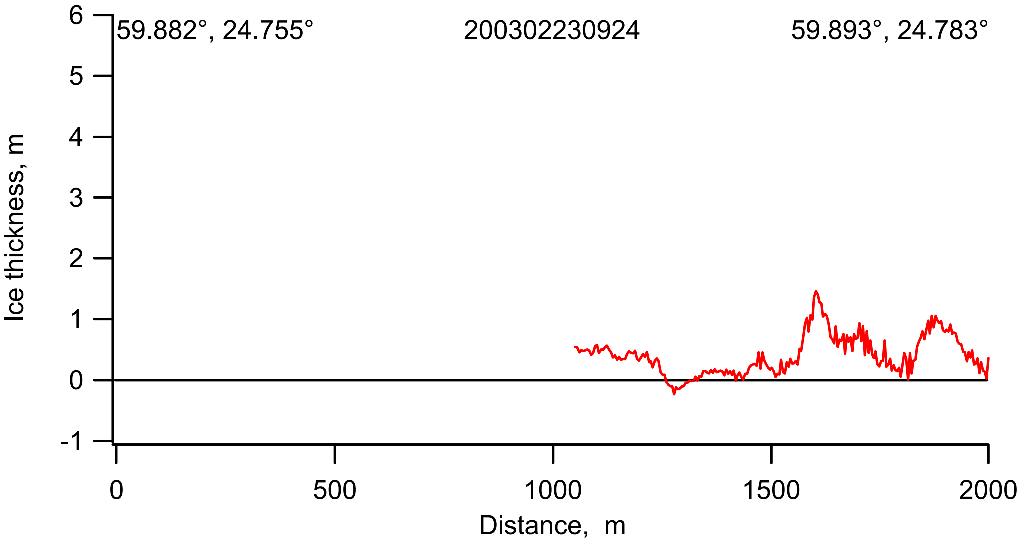
Profile 4



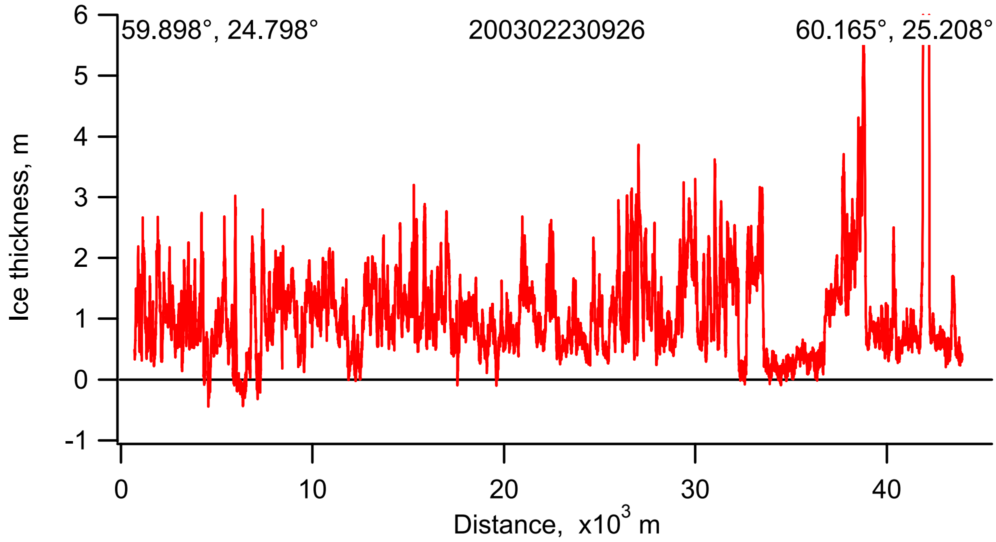
Profile 5



Profile 6



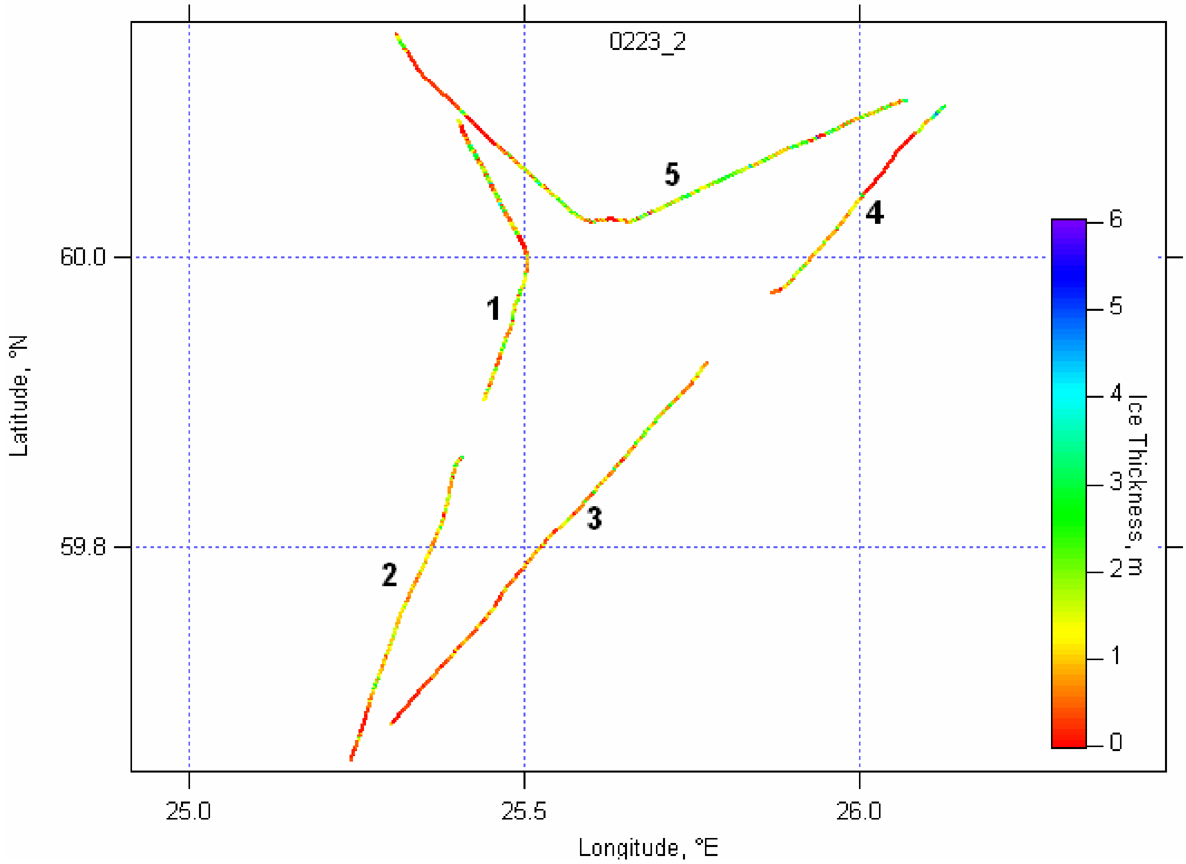
Profile 7

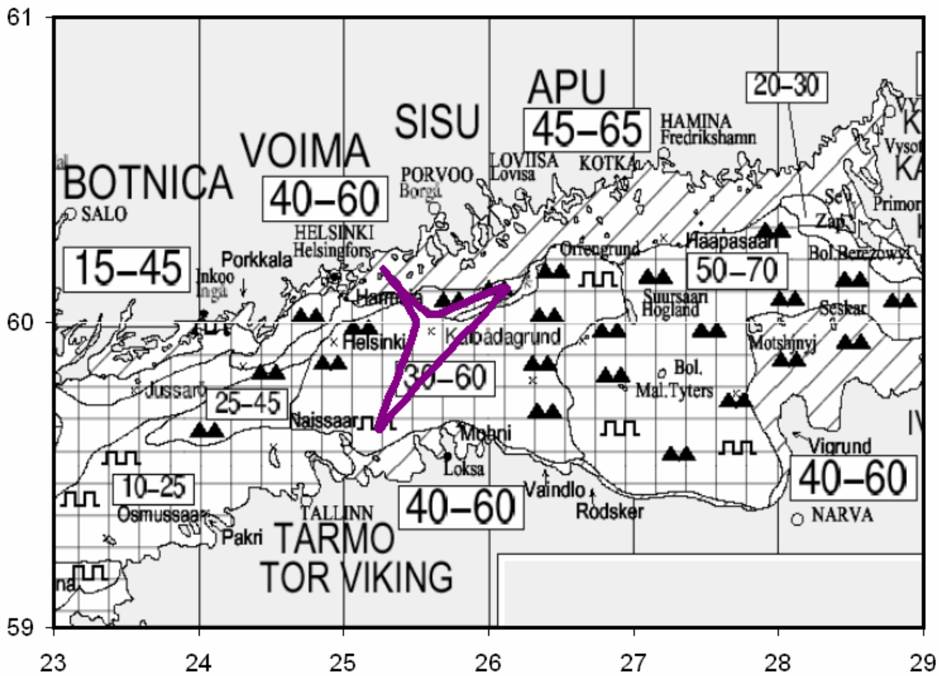


59.898°, 24.798°
200302230926
60.165°, 25.208°
Ice thickness, m
6
5
4
3
2
1
0
-1
0
10
20
30
40
Distance, x10^3 m

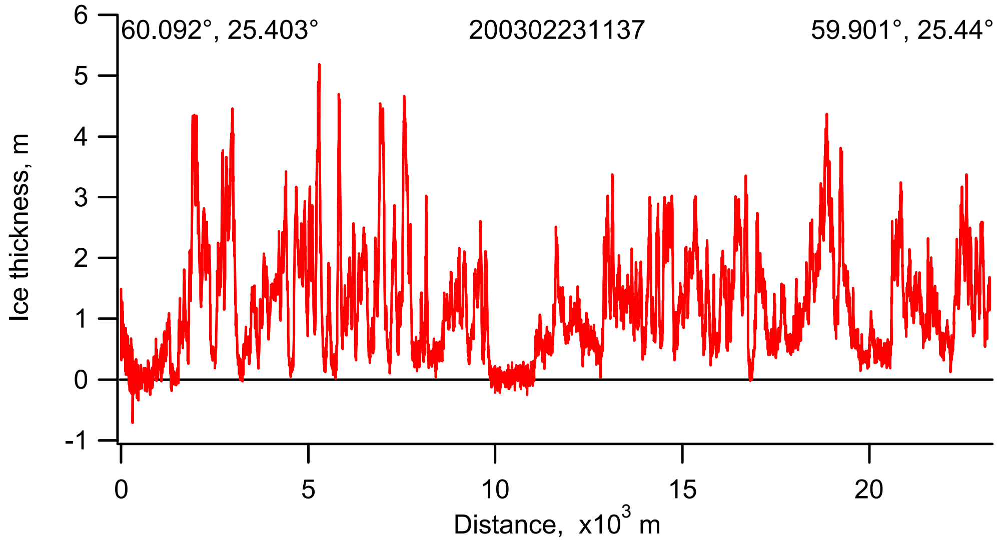
February 23, 2003, flight 2

Eastern flight from Helsinki to Estonia, over white ice floes with refrozen leads and open water in between.

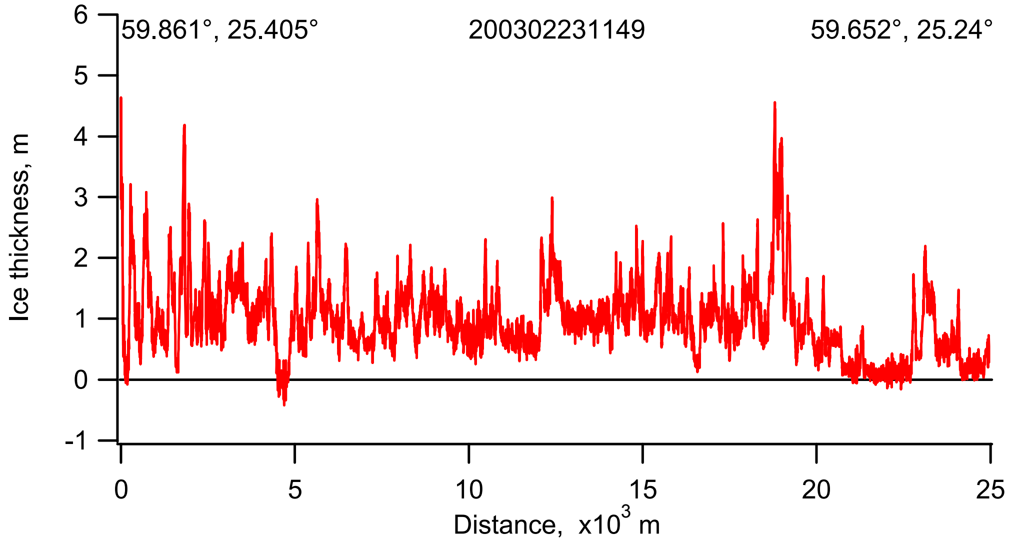




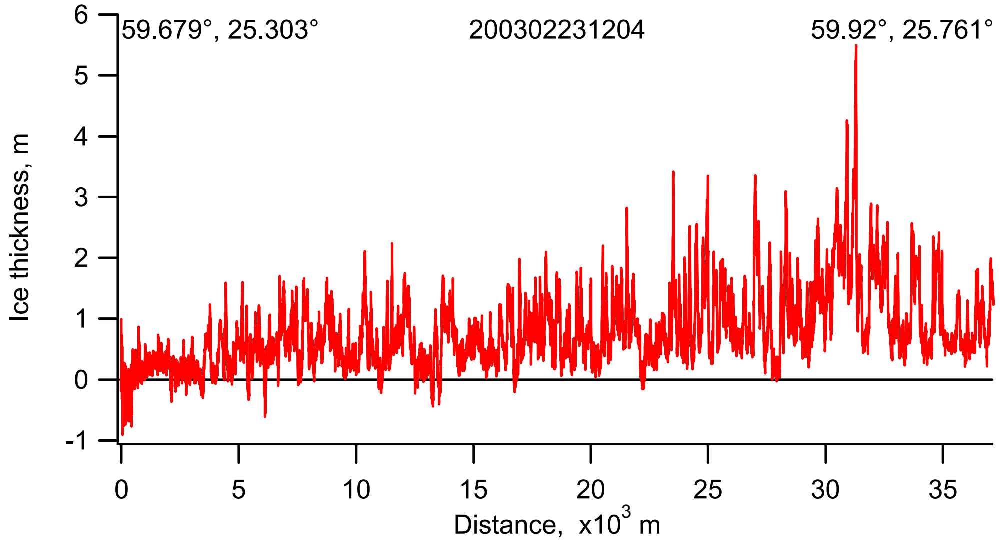
Profile 1



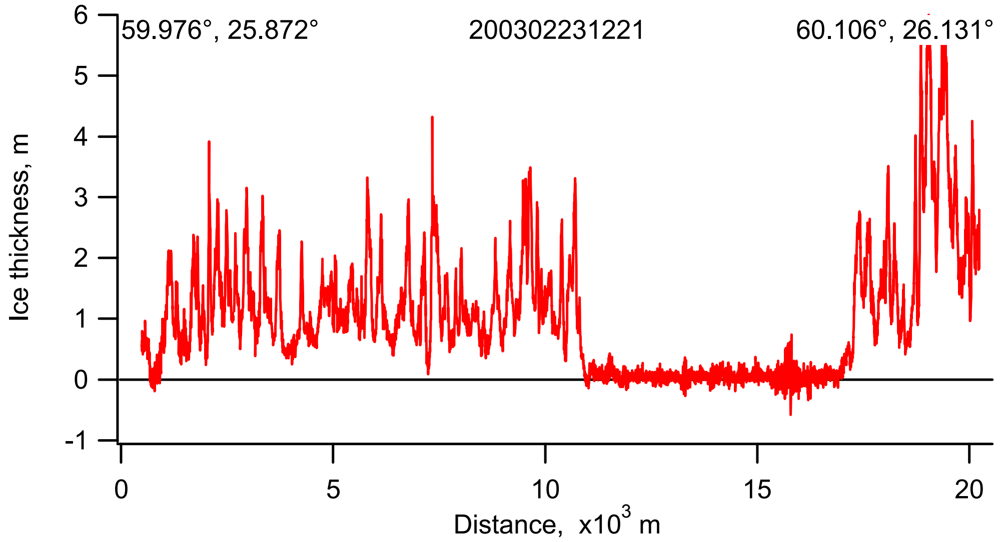
Profile 2



Profile 3



Profile 4



Profile 5