IRIS
EVK3-CT-2002-00083

ICE RIDGING INFORMATION FOR DECISION MAKING IN SHIPPING OPERATIONS

EM ice thickness measurements during 2005 IRIS field campaign

March 07 to March 18, 2005

IRIS Deliverable 30

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With contributions from the IRIS 2005 field party

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Abstract:
This report summarizes all airborne and ground-based ice thickness measurements performed during the IRIS 2005 field campaign, March 07 to 18, and presents the main results. In total, 10 flights were performed in the Bay of Bothnia, where RV ARANDA served as a base for the helicopter and ground teams. Flights covered the main ice regimes across the basin and to the Swedish coast. The data show a large number of different thickness classes representative of different growth phases. Ground based activities with contributions from all project partners achieved a 2220 m long drill-hole and EM thickness profile, providing a unique opportunity for the validation of EM measurements over level and deformed ice. Flights have also been performed in the operation region of Wagenborg ship Bothniaborg, to support IRIS application test cases. The ship got almost stuck when there was an offset in the channel, leading to increasing ice thickness from 0.6 to 1.3 m.
The report also serves as an introduction for users of the thickness data which are all publicly available on AWI's IRIS internet site at http://www.awi-bremerhaven.de/Modelling/SEAICE/IRIS.

EM ice thickness measurements during 2005 IRIS field campaign, March 07 to March 18, 2005

Christian Haas & Stefan Hendricks, AWI

Executive summary

This report summarizes all airborne and ground-based ice thickness measurements performed during the IRIS 2005 field campaign, March 07 to 18, and presents the main results. In total, 10 flights were performed in the eastern Bay of Bothnia and across to the Swedish coast. The flights covered the main ice regimes in the area. The data show a large number of different thickness classes representative of different growth phases. Ground-based activities with contributions from all project partners achieved a 2220 m long drill-hole and EM thickness profile, providing a unique opportunity for the validation of EM measurements over level and deformed ice. Flights have also been performed in the operation region of Wagenborg ship Bothniaborg, to support IRIS application test cases. The ship got almost stuck when there was an offset in the channel, leading to increasing ice thickness from 0.6 to 1.3 m.
The report also serves as an introduction for user of the thickness data which are all publicly available on AWI's IRIS internet site at

http://www.awi-bremerhaven.de/Modelling/SEAICE/IRIS.

1. Introduction

1.1 RV Aranda cruise

RV Aranda served as a base for the expedition. The ship left Helsinki on March 7, and arrived back on March 18. Between March 10 and 16, the ship was anchored in the fast ice west of the island Hailuoto in the Bay of Bothnia (Fig. 1). Aranda was used as a base for the ground-measurements (drilling, surveying, DC electric measurements), as well as for the helicopter-borne EM thickness measurements. Due to the professionality and carefulness of the Helitour helicopter crew, take-off and landing the EM bird was very feasible, despite the small helicopter deck of RV Aranda (Fig. 2). The AWI team comprised Andi Pfaffling, Torge Martin, Stefan Hendricks, David Flinspach, and Christina Flechzig.

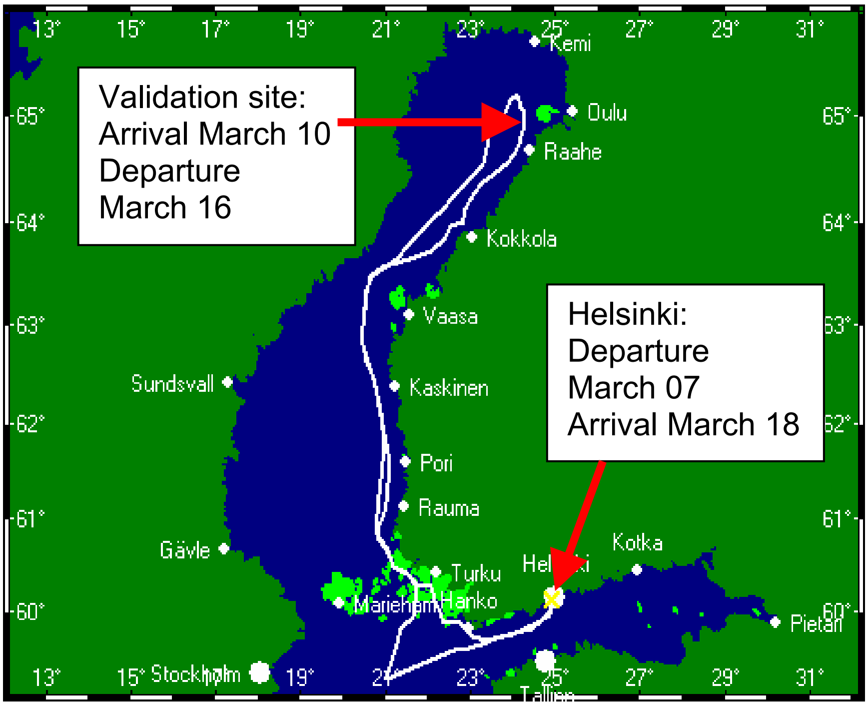


Figure 1: Map of the Baltic Sea, showing the operation area of RV Aranda during the IRIS 2005 cruise.

Figure 2: Landing the EM bird on its trolley on the small heli deck of RV Aranda proved very feasible due to the professionality of the Helitour helicopter crew.

1.2 Ice conditions

The winter of 2004/05 was very mild, leading to a mild ice season with very late ice formation even in the Bay of Bothnia. This actually led to a delay of the Aranda cruise of 2 weeks of the original plan. However, during the cruise, the ice was already thick and deformed in the operation region (Fig. 3), so that Aranda had to fight hard to reach its anchoring position in the fast ice. Due to strong northerly winds shortly before the cruise, a large field of thick and deformed ice had detached from the margins of the northernmost fast ice, and has drifted south. The resulting large polynya only had an ice thickness of 3-10 cm. This resulted in a nice situation for the IRIS observations, as many different ice types and regimes were around.

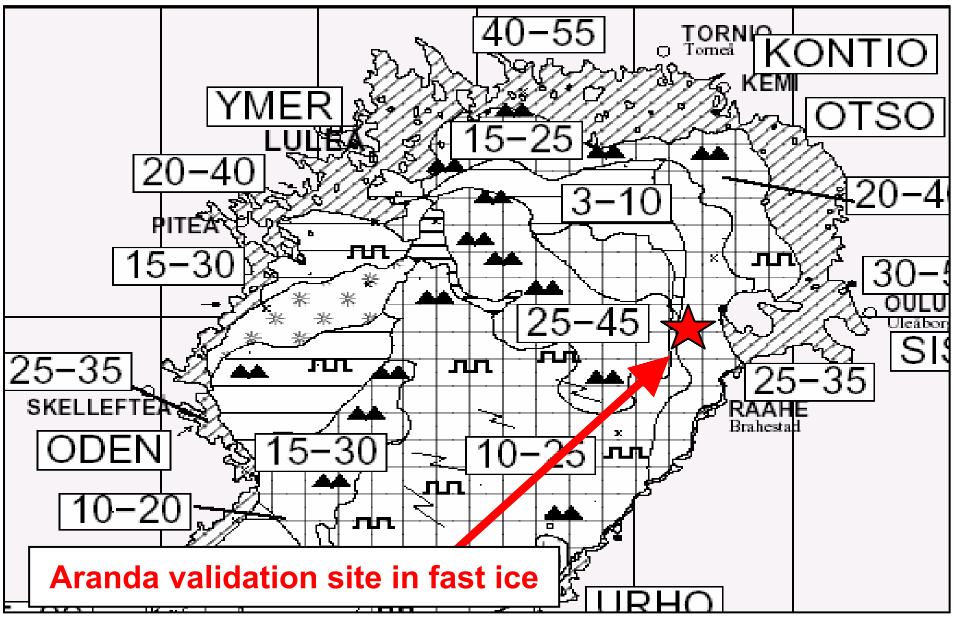


Figure 3: Finish ice chart showing ice conditions in the Bay of Bothnia on March 10. A patch of thick and deformed ice can be seen just west of the Aranda validation site.

2. Measurements

2.1 Ground measurements

On the fast ice at RV Arandas anchoring position, a 2200 m long validation line was established where snow thickness, ice thickness, and freeboard was determined by drilling and surveying. In addition, the fraction of voids in the ice was noted, and some ice cores were taken for salinity measurements. This work was mainly performed by FIMR.
We also used the opportunity to perform some DC electric measurements of the internal structure of a prominent ridge on the validation line. These measurements are processed and presented in the Diploma thesis of David Flinspach.

2.2 Helicopter EM flights

In total 10 helicopter flights have been performed for EM thickness surveys. Flight tracks were designed to survey the validation line and different ice regimes typical for the 2005 winter season (Fig. 4), as well as to provide data of ice conditions in the operation area of MS Bothniaborg for the IRIS application tests (Fig. 5).
Data processing and modelling, which addresses the special problems in the brackish and shallow waters of the Bay of Bothnia, are described in IRIS deliverable D20: EM ice thickness measurements during 2004 IRIS field campaign: February 05 to March 17, 2004. Everything described there is also valid for the data gathered in 2005.
However, please note that in 2005 only Inphase(f1) data have been released, i.e. ice thicknesses retrieved from the inphase component of the low frequency channel of 3680 kHz. These had by far the best signal-to-noise ratios, due to some electrical problems with Quadrature(f1). Although the data quality is very similar between the 2004 and 2005 measurements, it should be noted that the different channel could have some influence on the footprint of the measurements, i.e. with the 2005 data ridge keels might be even more underestimated than in the 2004 data. In addition, Inphase(f1) has a larger penetration depth, making the data over the fast ice more sensitive to bottom topography (see AWI-IRIS report on the 2004 measurements, D20).

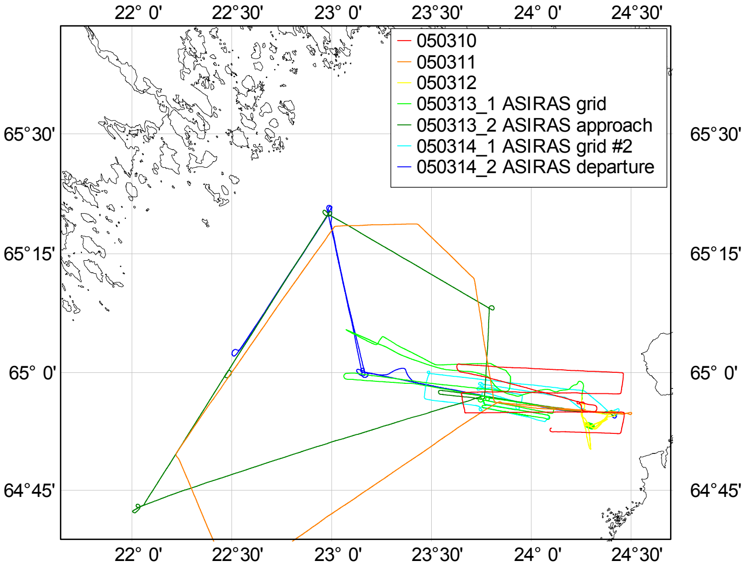


Figure 4: Map of flights tracks in the vicinity of Aranda.

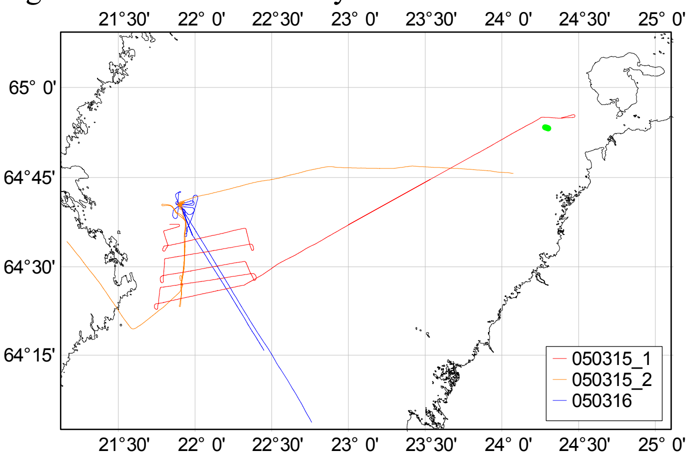


Figure 5: Map of flight tracks performed to survey operation area of Bothniaborg (cf. Sect. 3.2).

3. Results

3.1 Validation line

The photograph on Figure 6 shows the eastern end of the validation line (cf. Fig. 7), and the western extend of the line in the background. The prominent ridge in the foreground is the rightmost ridge in the figures below, where also the DC electric measurements have been performed. In the upper right RV Aranda can be seen at here anchoring position in the fast ice.

Figure 7 summarizes all ice thickness measurements obtained during overflights of the validation line. All the main features are very well represented in the data:

1. Thick ice in the west, which was formed during a deformation event at the fast ice edge during the first days of the ice station.
2. Thin level ice on both ends of the validation line, with a prominent ridge in the center.
3. A large ridge just east of corner reflector 2
4. Some thicker fast ice in the east. However, note that these measurements could also be biased by the shallow water under the fast ice.

All drill-hole results are summarized in the thickness profile in Figure 8 showing the real distribution of freeboard and draft along the line. A comparison of all HEM data with the drill-hole profile are shown in Figure 9. All HEM data have been averaged for the presentation. The EM and drill-hole data agree well over level ice, while the EM measurements underestimate the maximum keel depth considerably. See the discussion in the AWI IRIS report 2004 for more details (D20). The largest ridge with a thickness of 11 m was only 45 m wide. However, please note also that the EM data show some more deformation features which are missed by the one-dimensional profile of the drill-hole measurements. This is also visible in the thickness distributions shown in Figure 10. The mean drill-hole thickness was 1.42±2.15 m, while the mean HEM thickness amounted to 1.10±0.78 m. Note that the spacing of the drill-holes was smaller across the ridges.

Figure 6: View along validation line from E to W. The ridge in the foreground is the prominent ridge at -100 m in Figure 8, and the red arrow points to the radar corner reflector 2 at 0 m (cf. Fig. 7).

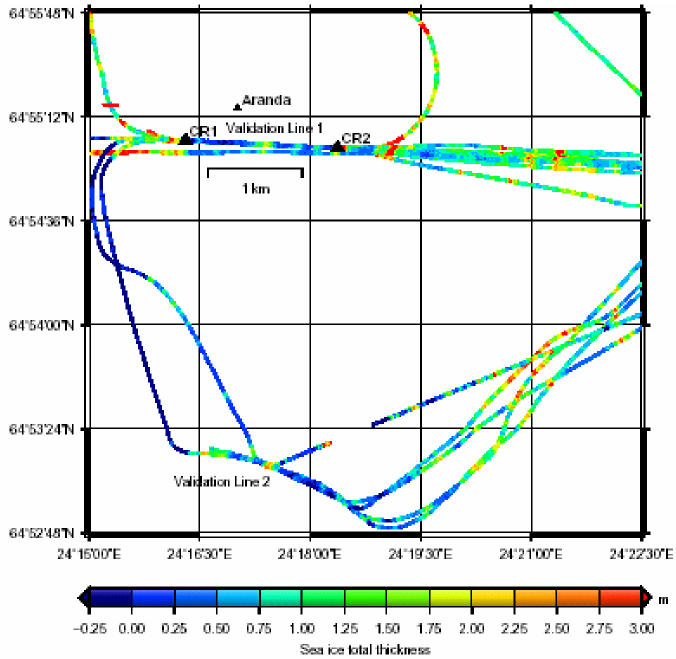


Figure 7: Overview of all ice thickness measurements performed along the validation line (cf. Fig. 8). CR1&2 mark the position of the radar corner reflectors.

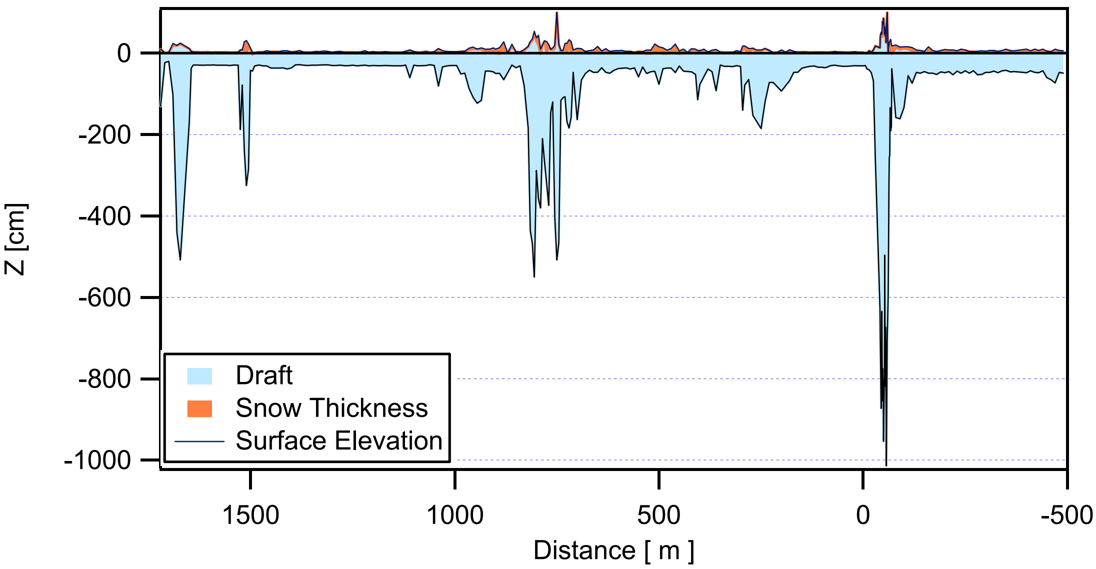


Figure 8: Ice thickness profile of the validation line. 0 m corresponds to the location of corner reflector 2, and west is towards the left of the figure.

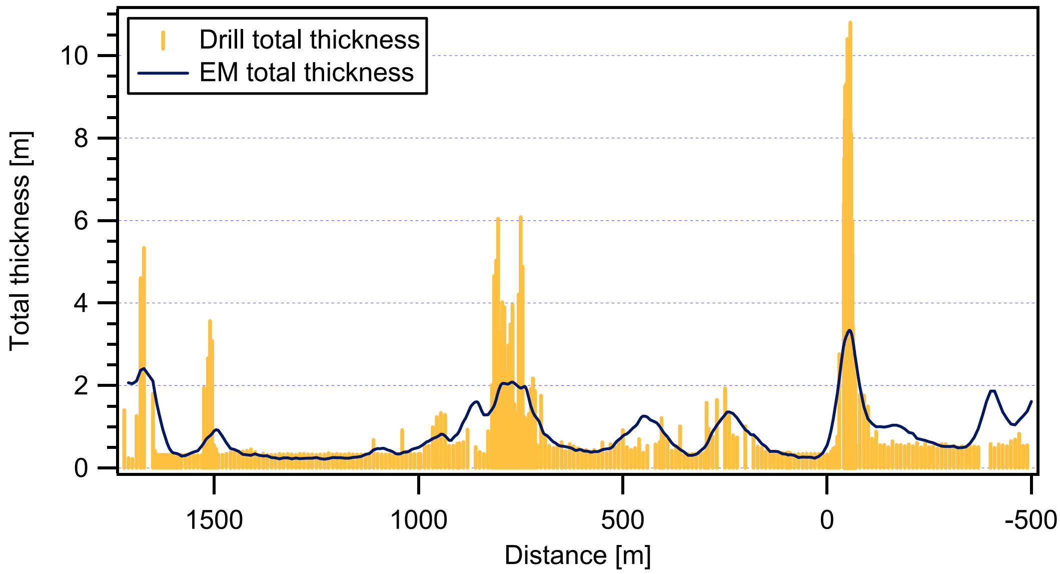


Figure 9: Comparison of the drill-hole thickness profile (Fig. 8) with the mean thickness of all HEM profiles along the validation line (Fig. 7).

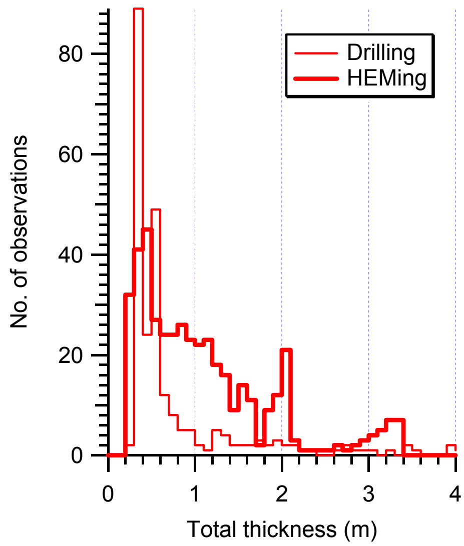


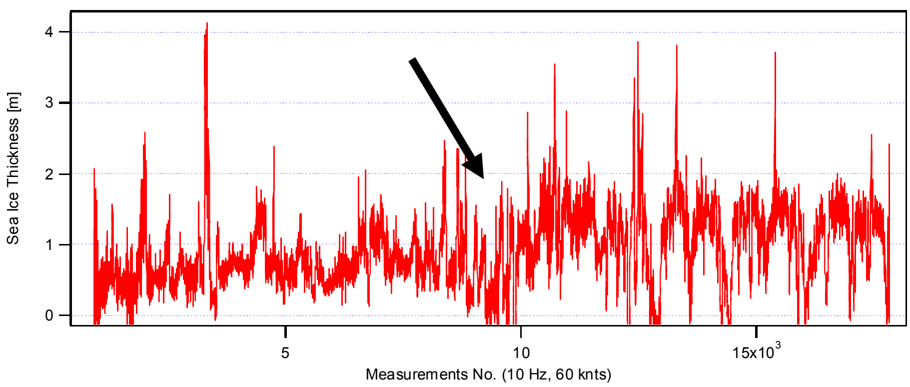
Figure 10: Comparison of the thickness distributions obtained by drilling and HEM sounding along the validation line (Fig. 9).

3.2 Bothniaborg

The operation area of MS Bothniaborg in the western Bay of Bothnia was profiled on March 15 and 16. On March 15, we were able to survey the ice just in front of the ship before it passed along (Fig. 11). The photograph shows the ship when it just entered a region of thicker ice leading almost to a full stop of the ship. HEM thickness data show that this corresponded to a zone where ice thickness increased from an average of 0.6 m to 1.3 m (Fig. 12). The thick ice was formed by former rafting of the thinner ice.

Figure 11: Photograph of MS Bothniaborg entering the thick ice zone where she almost got stuck.

a)



b)

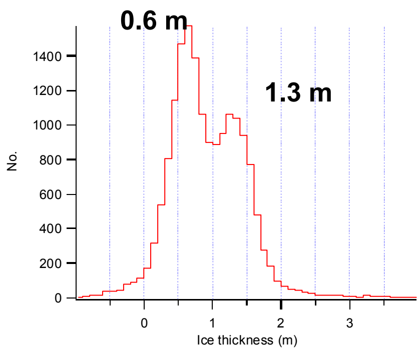


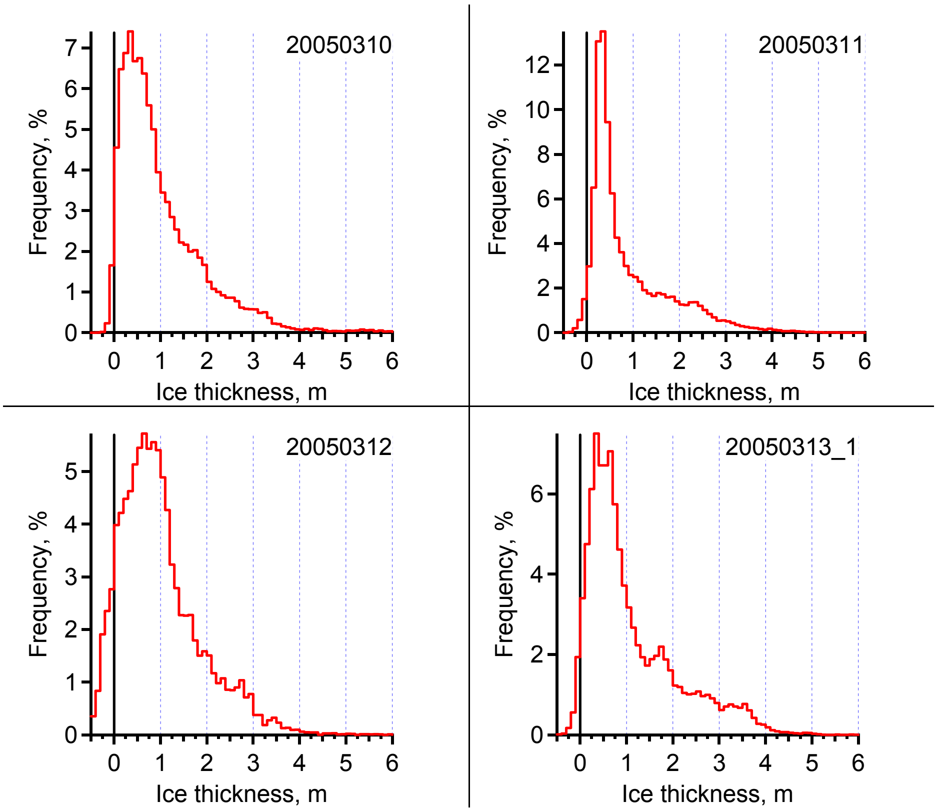
Figure 12: Thickness profile along track of MS Bothniaborg (file 200503151438.dat), showing the transition from thin to thick ice where the ship almost got stuck.

3.3 Summary table and plots

Below, the results of each flight and the corresponding thickness distribution are summarized (Table 1, Fig. 13). Note that these also often comprise flights over the validation line, i.e. from a different region than the main study region of each flight. Therefore, if the users of the data are interested in special regions, they should look at the profile maps below to see the spatial distribution of flights, and need to extract the data of interest from the data files.

Table 1: Summary of results of all HEM flights (cf. Fig. 1). Open water (OW) fraction was computed by summing all thicknesses in a range between -0.1 to +0.1 m. Note that the mode is the maximum of each thickness distribution, and that there were many secondary modes in each thickness distribution (cf. Fig. 13 and plots in Sect. 4).

Date	Mode (m)	Mean±sdev (m)	OW fraction (%)
10.02.2004	0.30	1.02±0.93	12.6
11.02.2004	0.30	0.92±0.90	10.9
12.02.2004	0.60	0.98±0.87	10.9
13.02.2004 Flight 1	0.30	1.12±1.04	10.0
13.02.2004 Flight 2	0.30	0.76±0.72	10.3
14.02.2004 Flight 1	0.10	1.03±0.96	15.6
14.02.2004 Flight 2	0.40	1.12±1.00	10.1
15.02.2004 Flight 1	0.20	0.43±0.43	20.2
15.03.2004 Flight 2	0.40	0.71±0.51	8.1
16.03.2004	0.30	0.59±0.45	12.4



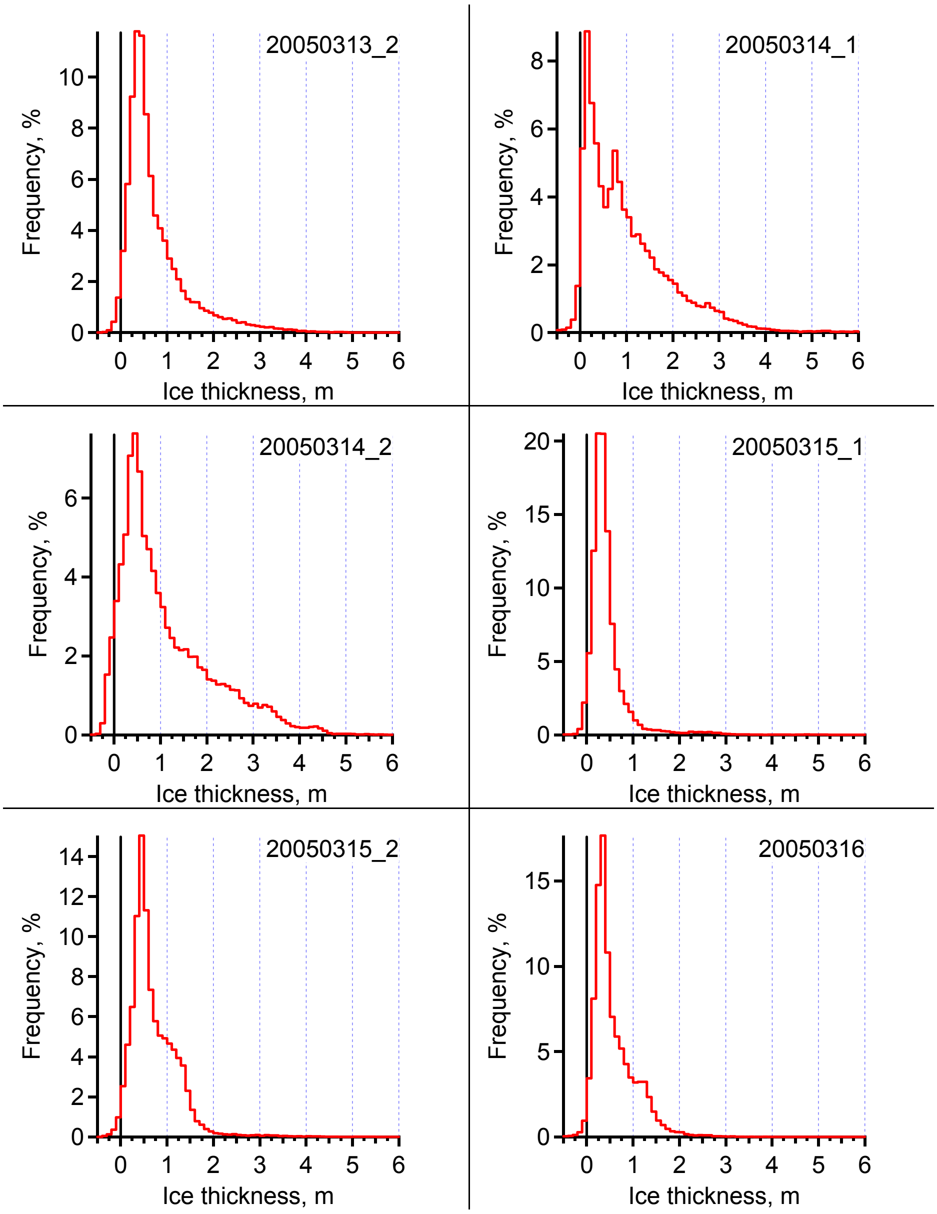
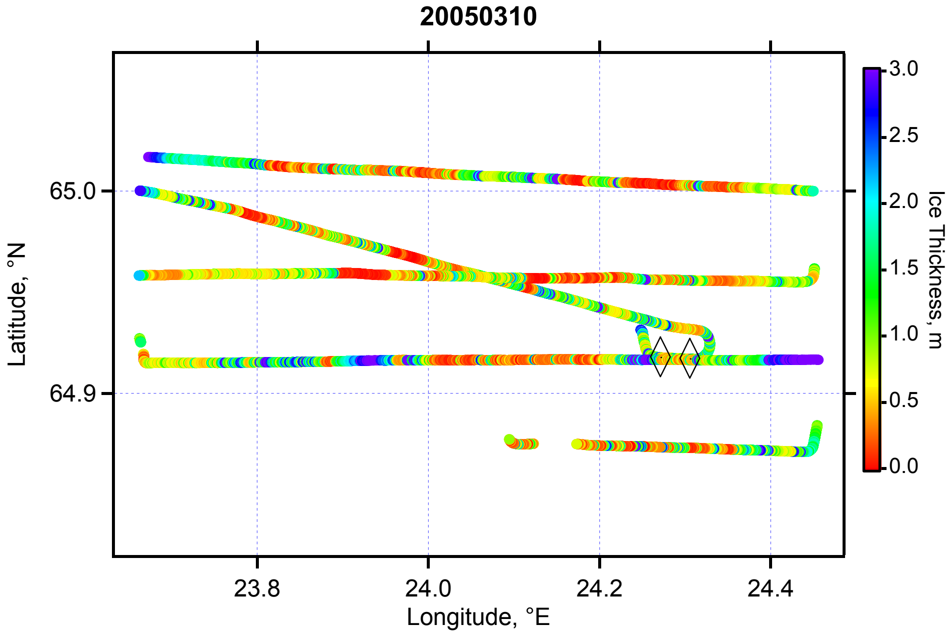


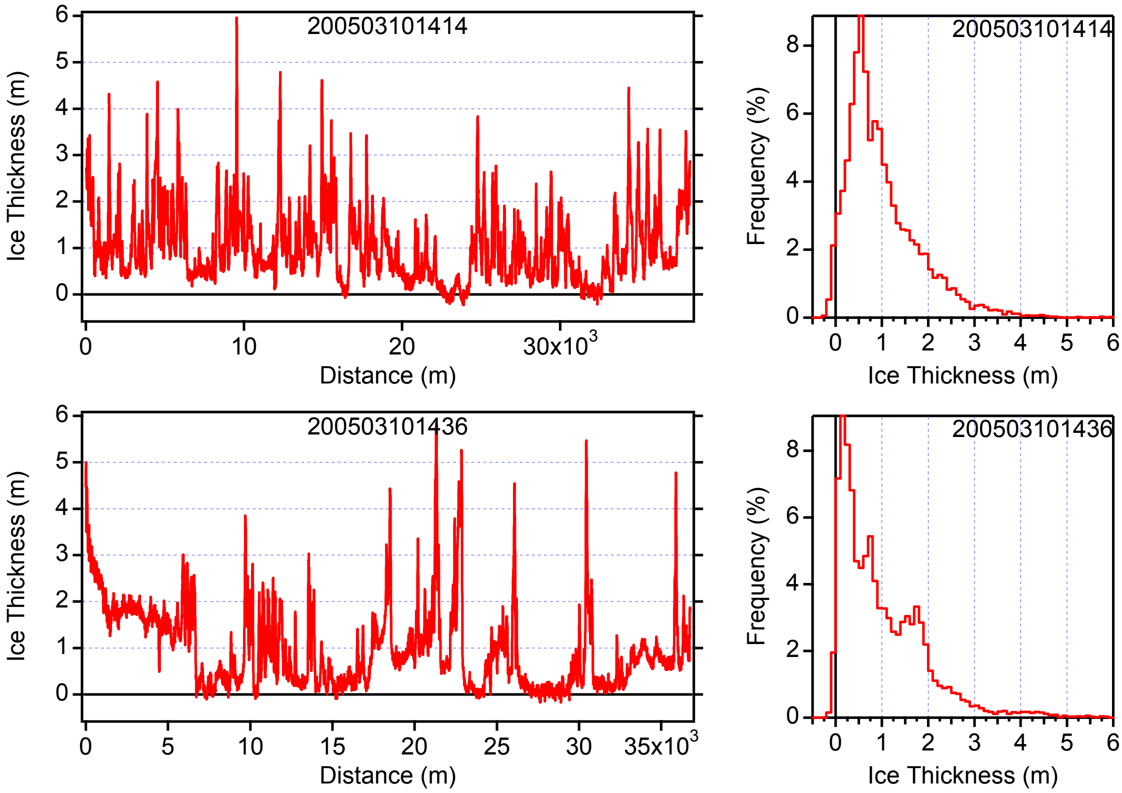
Figure 13: Thickness distributions of all IRIS 2005 flights (cf. Table 1).

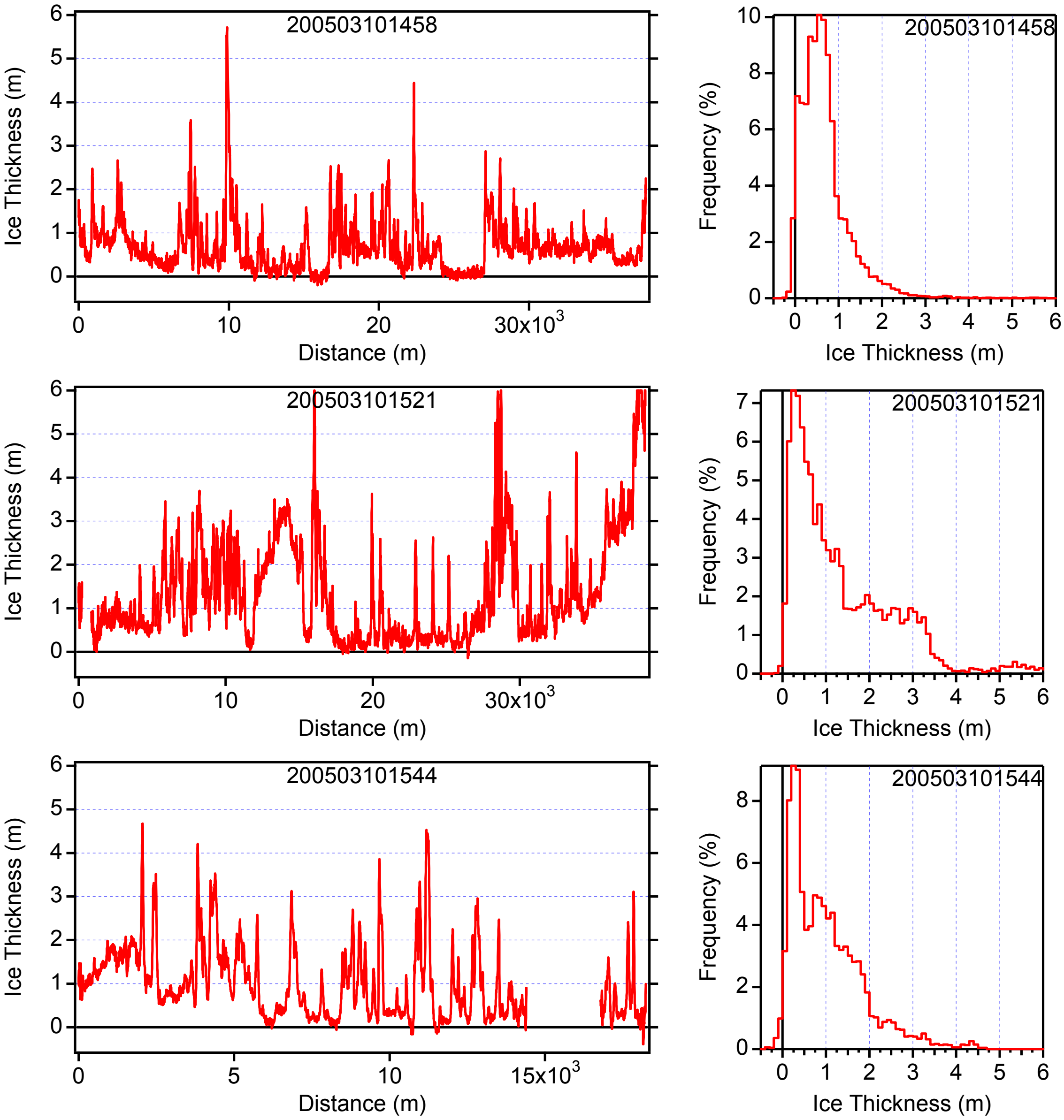
4. Profile plots

The following section presents ice thickness maps for each flight and the corresponding thickness profiles and histograms for each leg. **Diamonds** mark the position of the radar corner reflectors marking the location of the validation line.

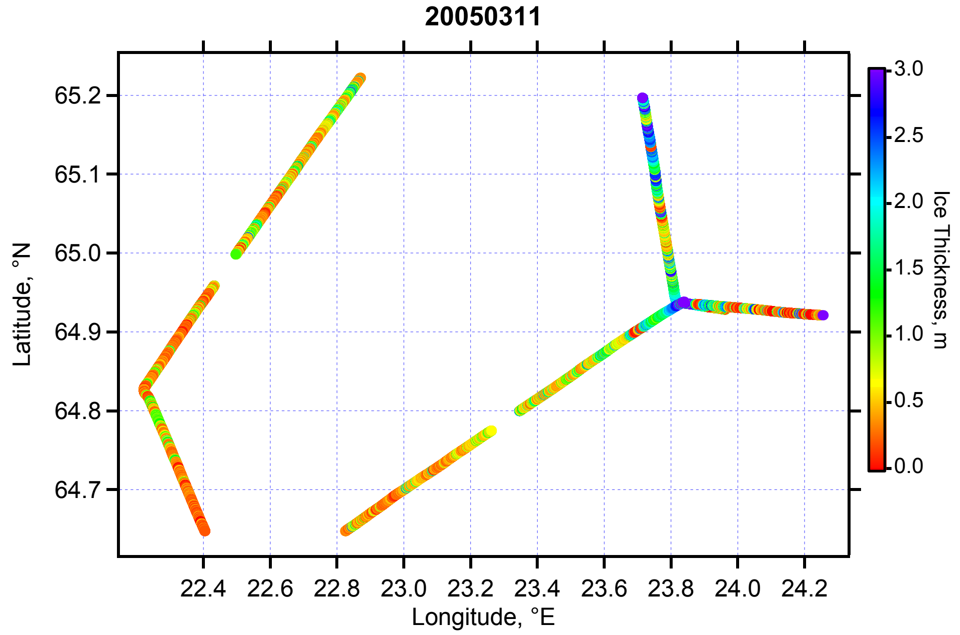
10.03.2005

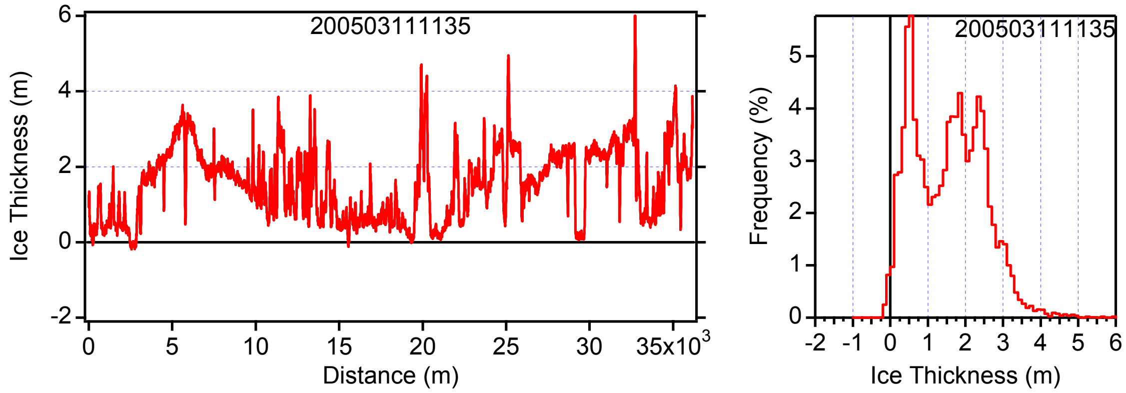

20050310
Latitude, °N
Longitude, °E
Ice Thickness, m
65.0
64.9
23.8
24.0
24.2
24.4
3.0
2.5
2.0
1.5
1.0
0.5
0.0

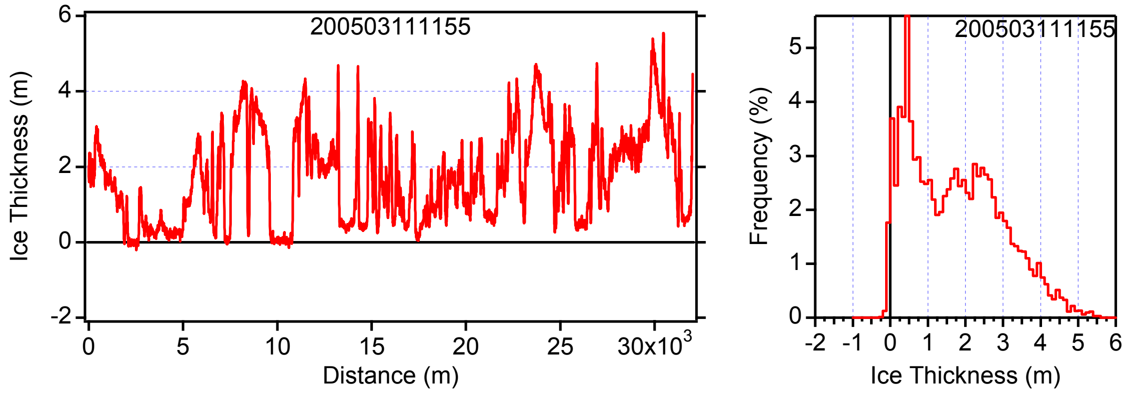

200503101414
Ice Thickness (m)
Distance (m)
30x10^3
Frequency (%)
Ice Thickness (m)
200503101436
Distance (m)
35x10^3


200503101458
Ice Thickness (m)
Distance (m)
Frequency (%)
200503101521
200503101544
30x10^3
15x10^3

11.03.2005


20050311
Latitude, °N
Longitude, °E
Ice Thickness, m


200503111135
Ice Thickness (m)
Distance (m)
Frequency (%)
Ice Thickness (m)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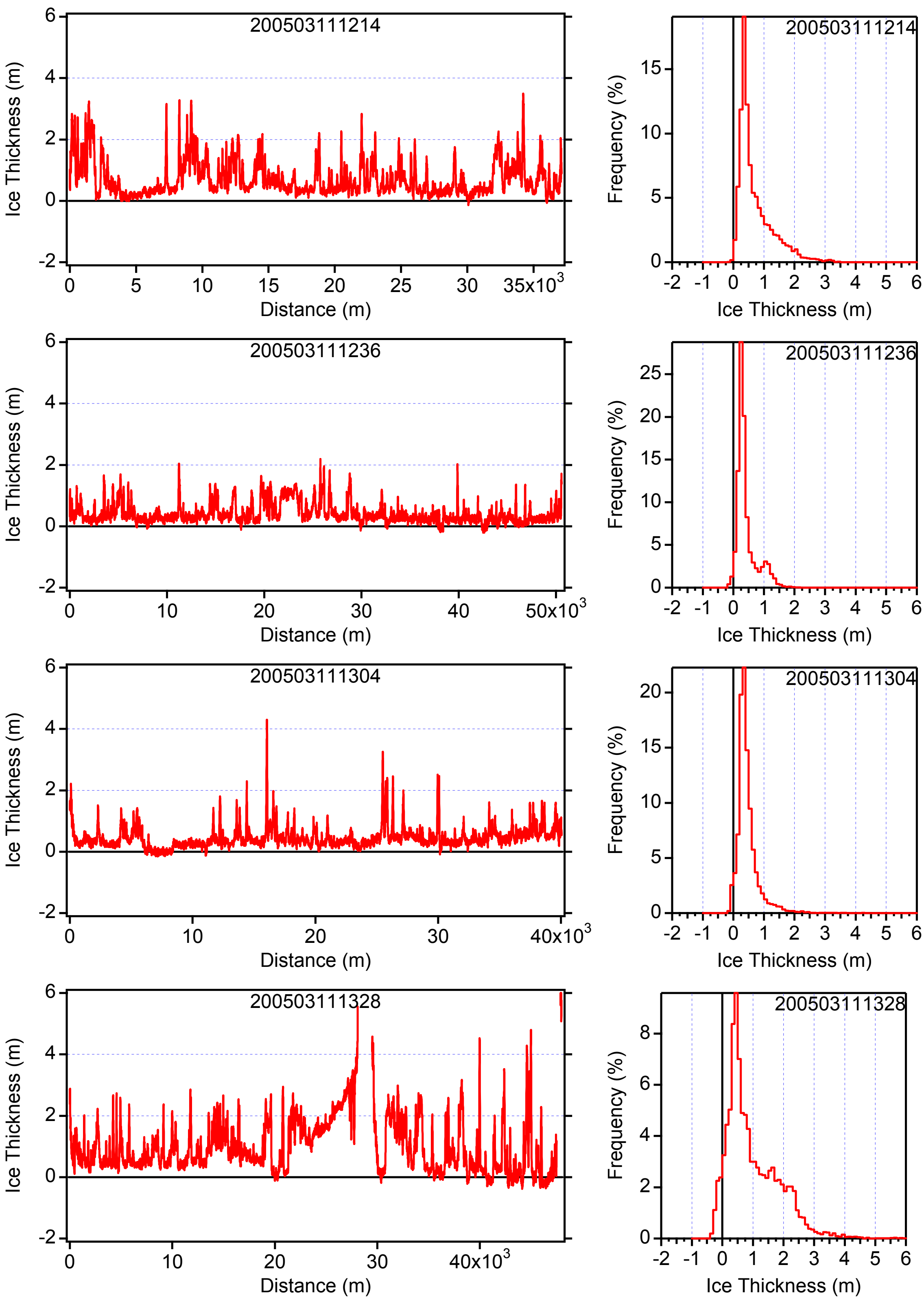
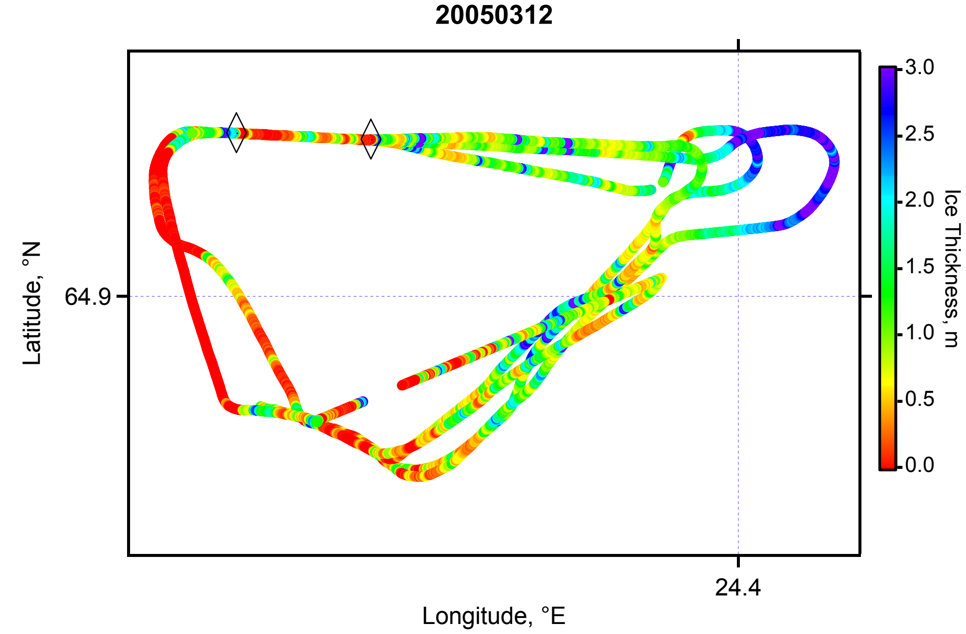
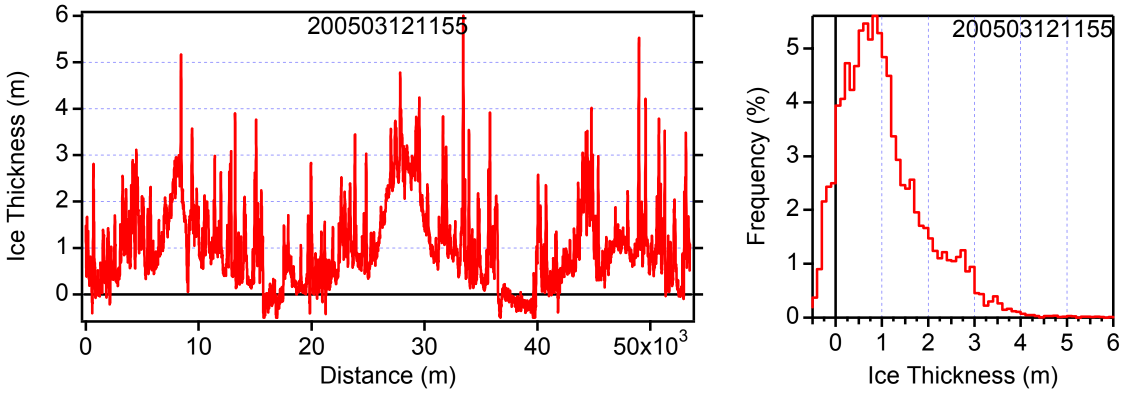
Ice Thickness (m)
Distance (m)
Frequency (%)
Ice Thickness (m)


200503111214
Ice Thickness (m)
Distance (m)
35x10^3
Frequency (%)
Ice Thickness (m)
200503111236
Ice Thickness (m)
Distance (m)
50x10^3
Frequency (%)
Ice Thickness (m)
200503111304
Ice Thickness (m)
Distance (m)
40x10^3
Frequency (%)
Ice Thickness (m)
200503111328
Ice Thickness (m)
Distance (m)
40x10^3
Frequency (%)
Ice Thickness (m)

12.03.2005


20050312
Latitude, °N
64.9
24.4
Longitude, °E
Ice Thickness, m
3.0
2.5
2.0
1.5
1.0
0.5
0.0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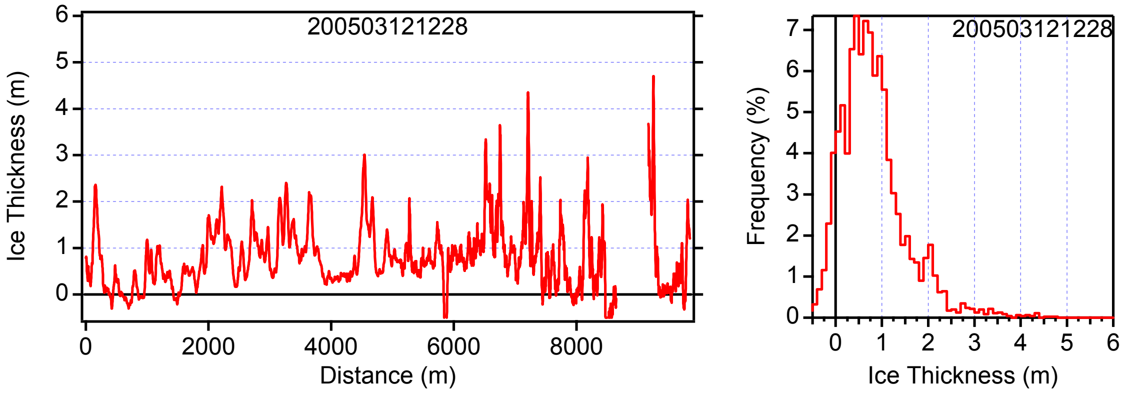
Ice Thickness (m)
Distance (m)
50x10^3
Frequency (%)
Ice Thickness (m)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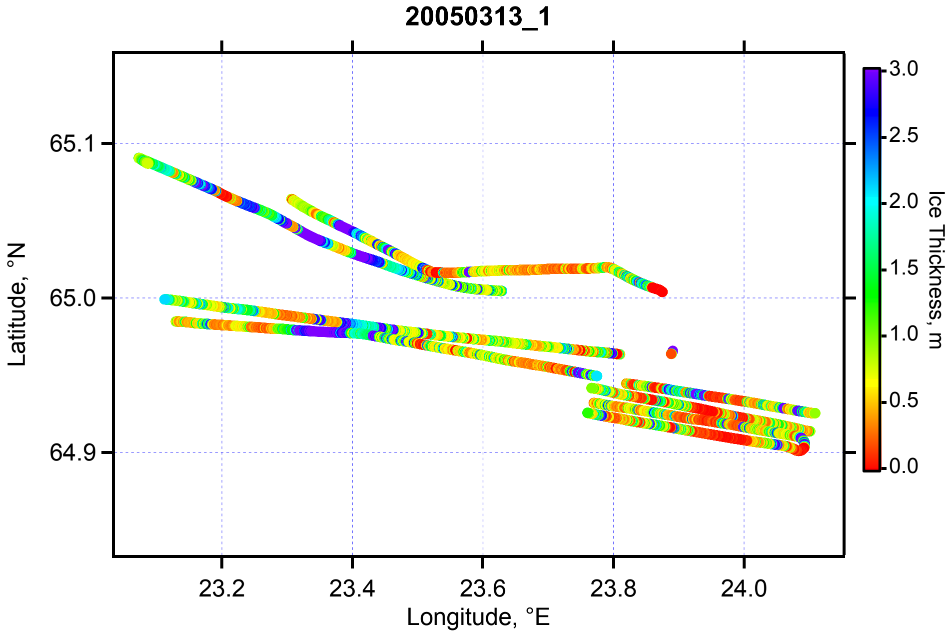
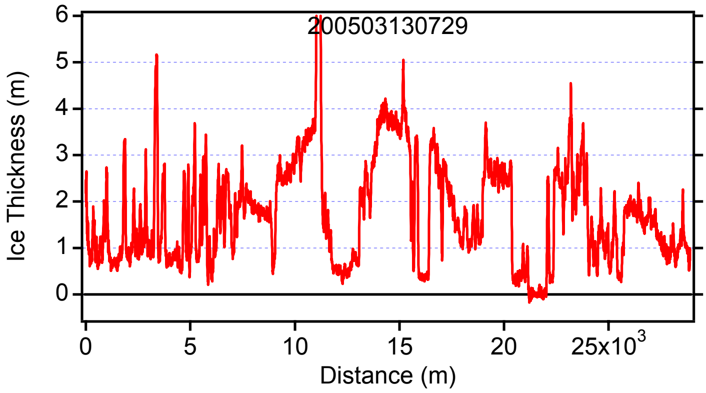
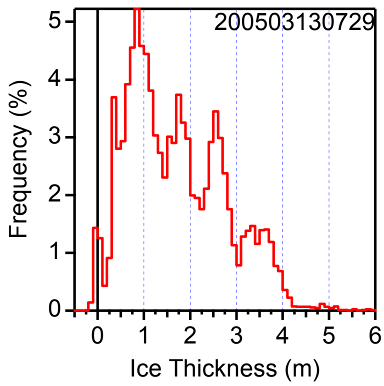
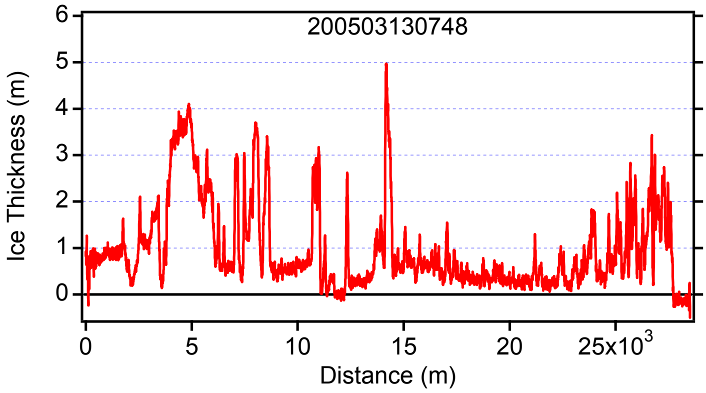
Ice Thickness (m)
Distance (m)
Frequency (%)
Ice Thickness (m)

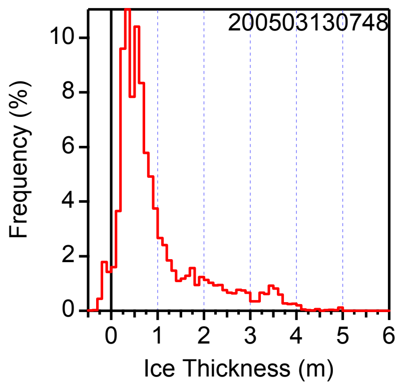
13.03.2005 Flight 1

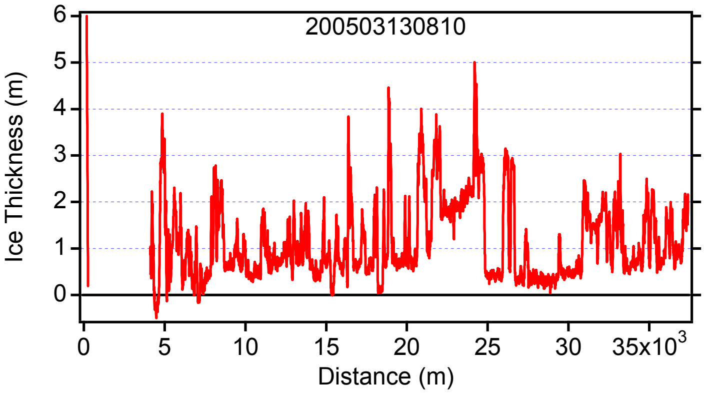


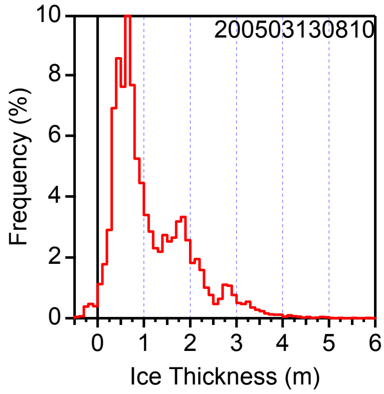









200503130810
Ice Thickness (m)
Distance (m)
35x10^3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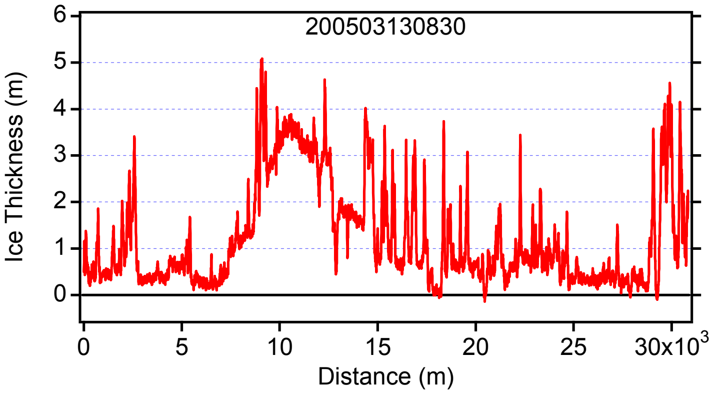
Frequency (%)
Ice Thickness (m)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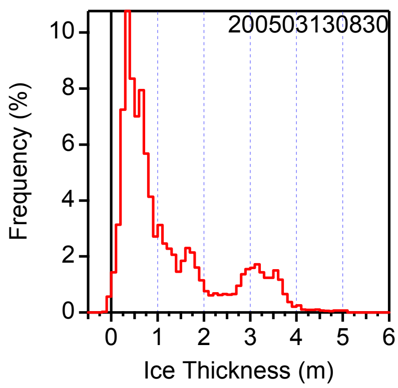
Ice Thickness (m)
Distance (m)
30x10^3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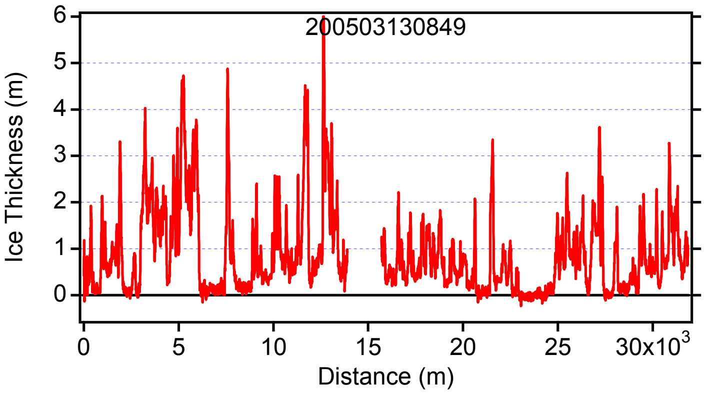
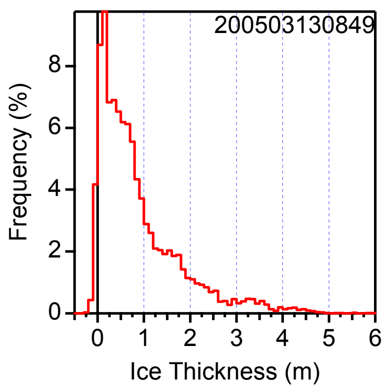
Frequency (%)
Ice Thickness (m)


200503130849
Ice Thickness (m)
Distance (m)
30x10^3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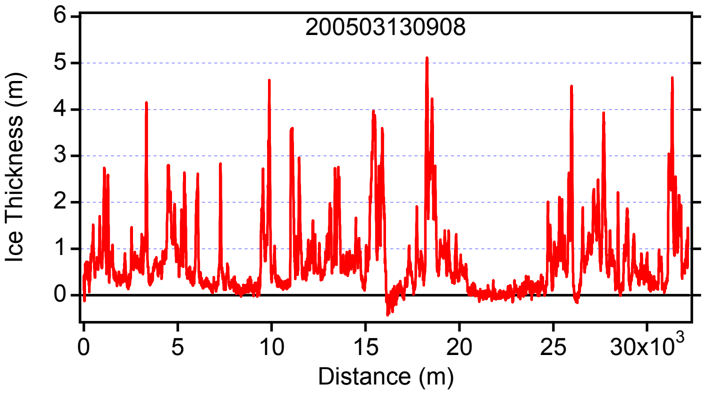
Frequency (%)
Ice Thickness (m)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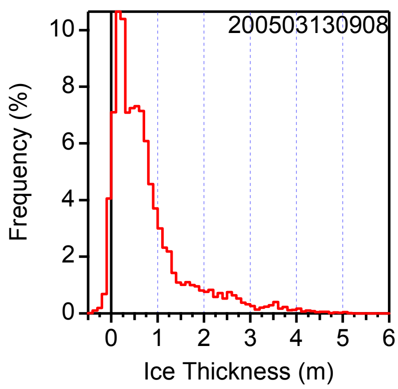
Ice Thickness (m)
Distance (m)
30x10^3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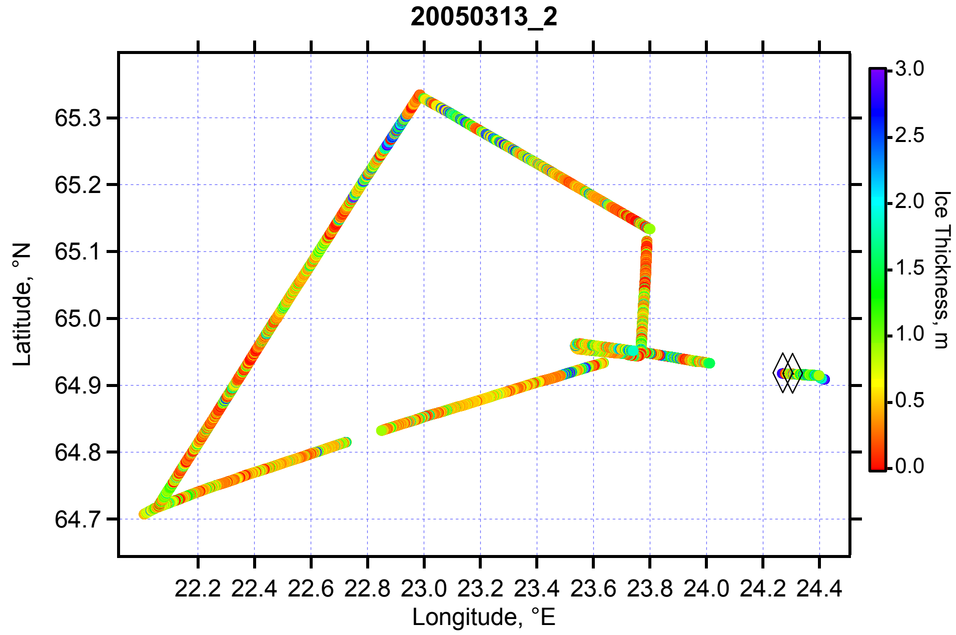
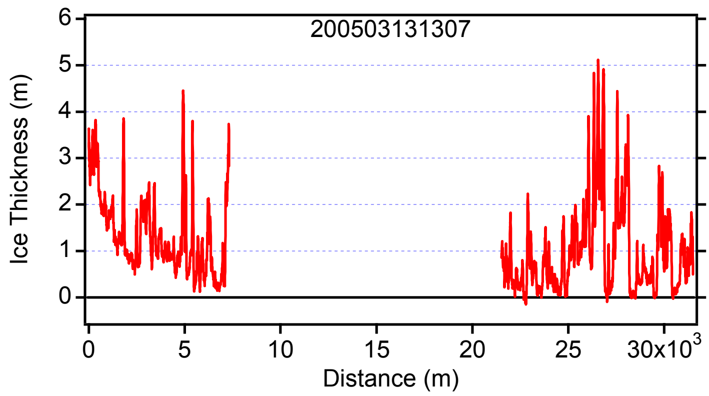
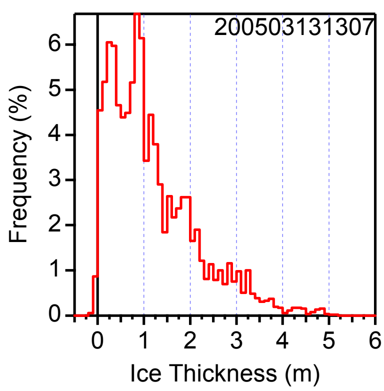
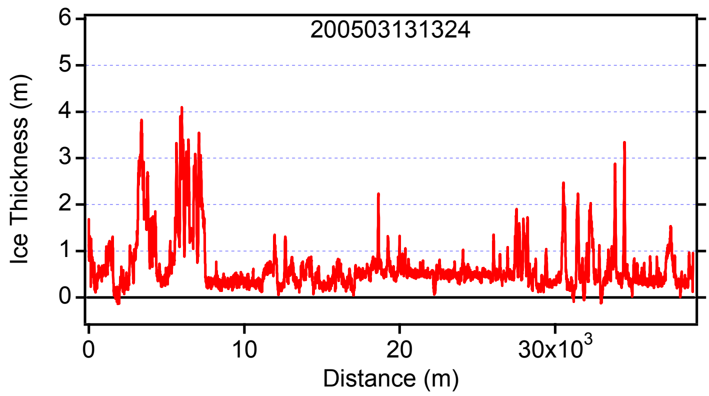
Frequency (%)
Ice Thickness (m)

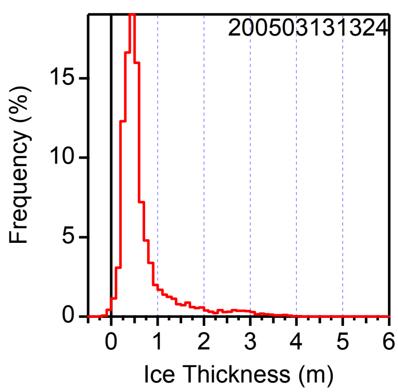
13.03.2005 Flight 2

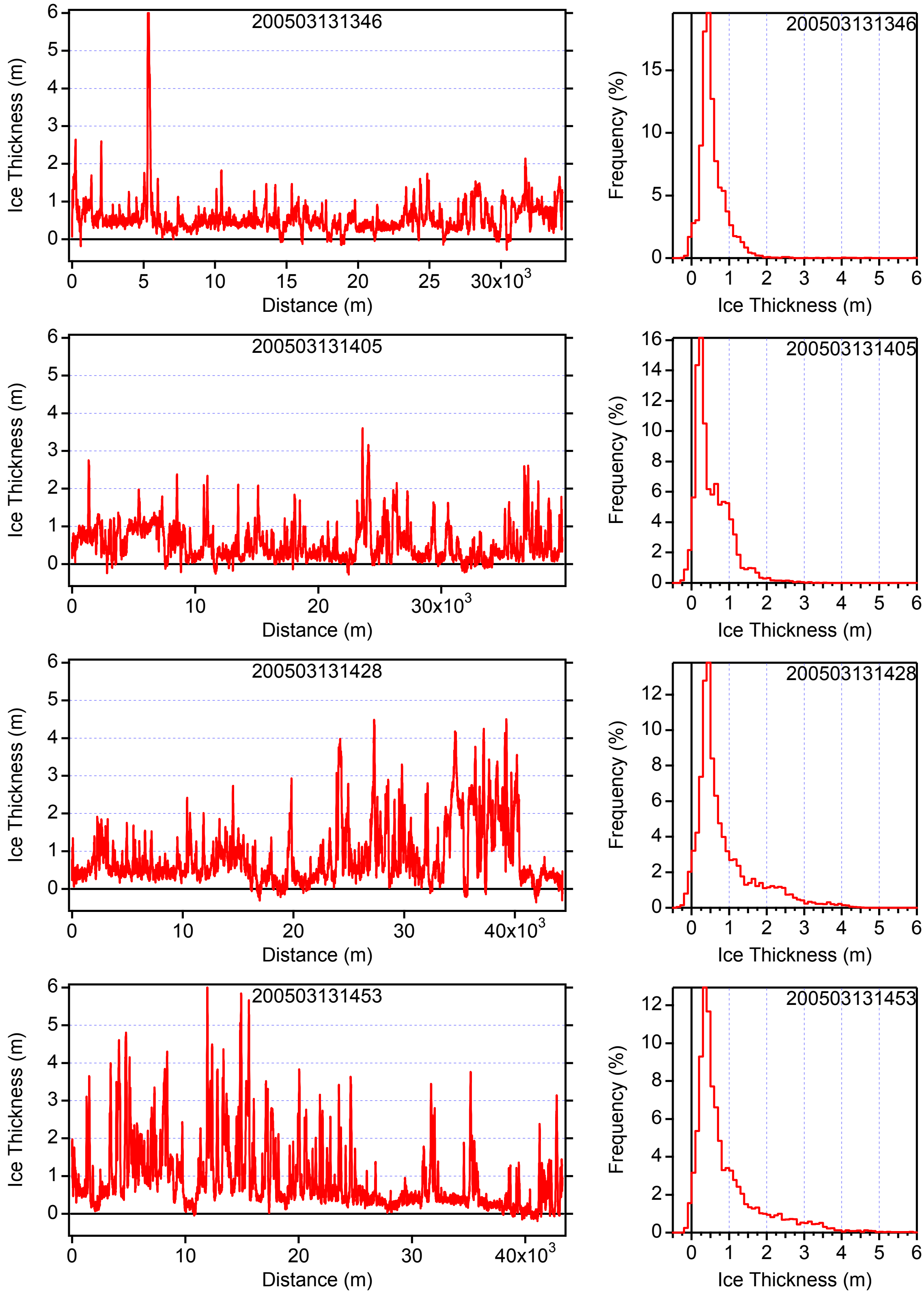


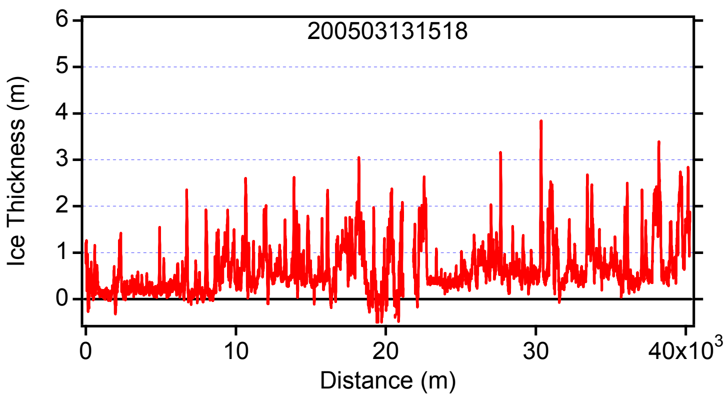


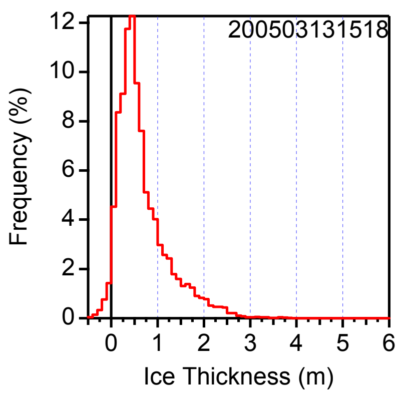


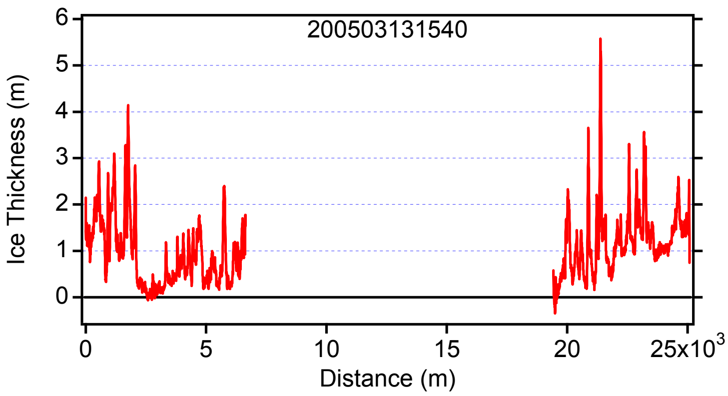


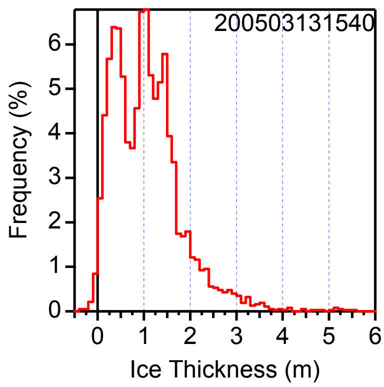



200503131346
Ice Thickness (m)
Distance (m)
Frequency (%)
Ice Thickness (m)
200503131405
Ice Thickness (m)
Distance (m)
Frequency (%)
Ice Thickness (m)
200503131428
Ice Thickness (m)
Distance (m)
Frequency (%)
Ice Thickness (m)
200503131453
Ice Thickness (m)
Distance (m)
Frequency (%)
Ice Thickness (m)

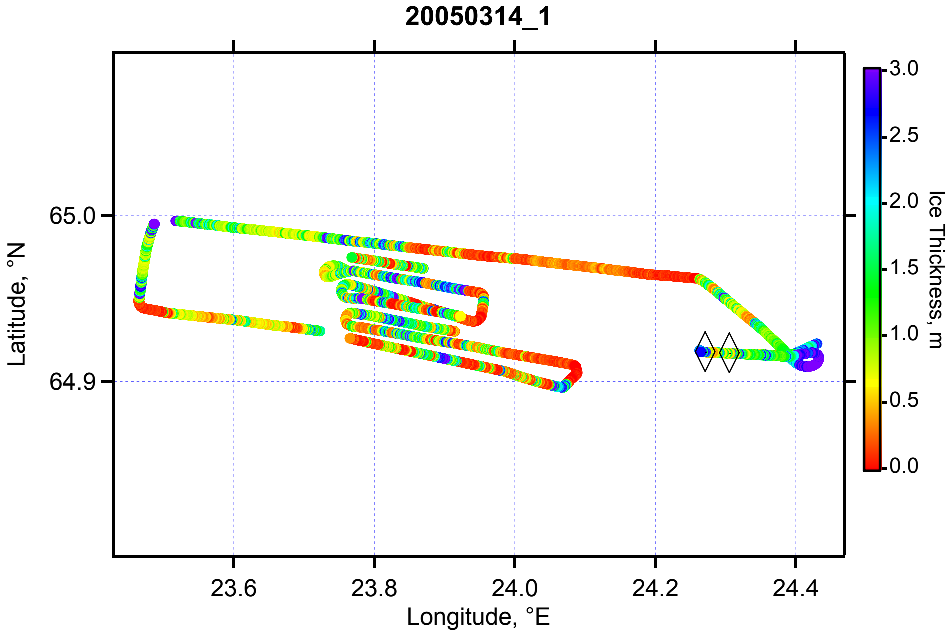

200503131518
Ice Thickness (m)
Distance (m)
0
10
20
30
40x10^3
0
1
2
3
4
5
6

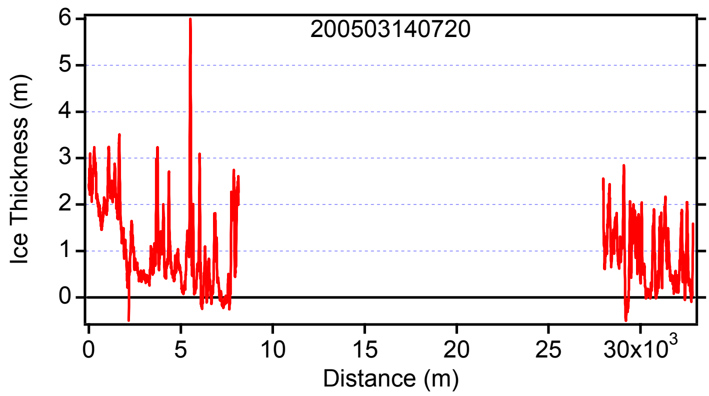

200503131518
Frequency (%)
Ice Thickness (m)

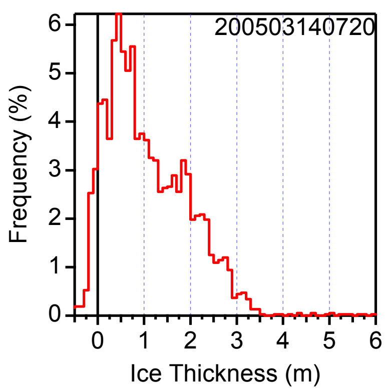

200503131540
Ice Thickness (m)
Distance (m)
0
5
10
15
20
25x10^3

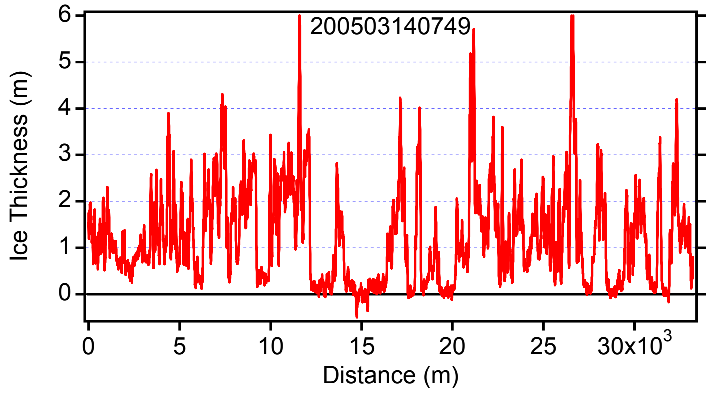

200503131540
Frequency (%)
Ice Thickness (m)

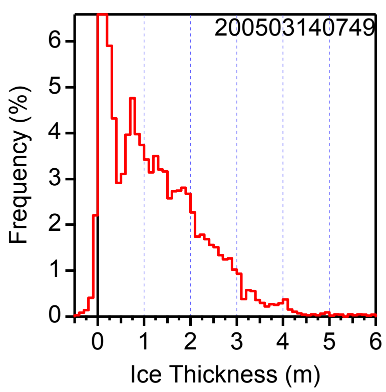
14.03.2005 Flight 1

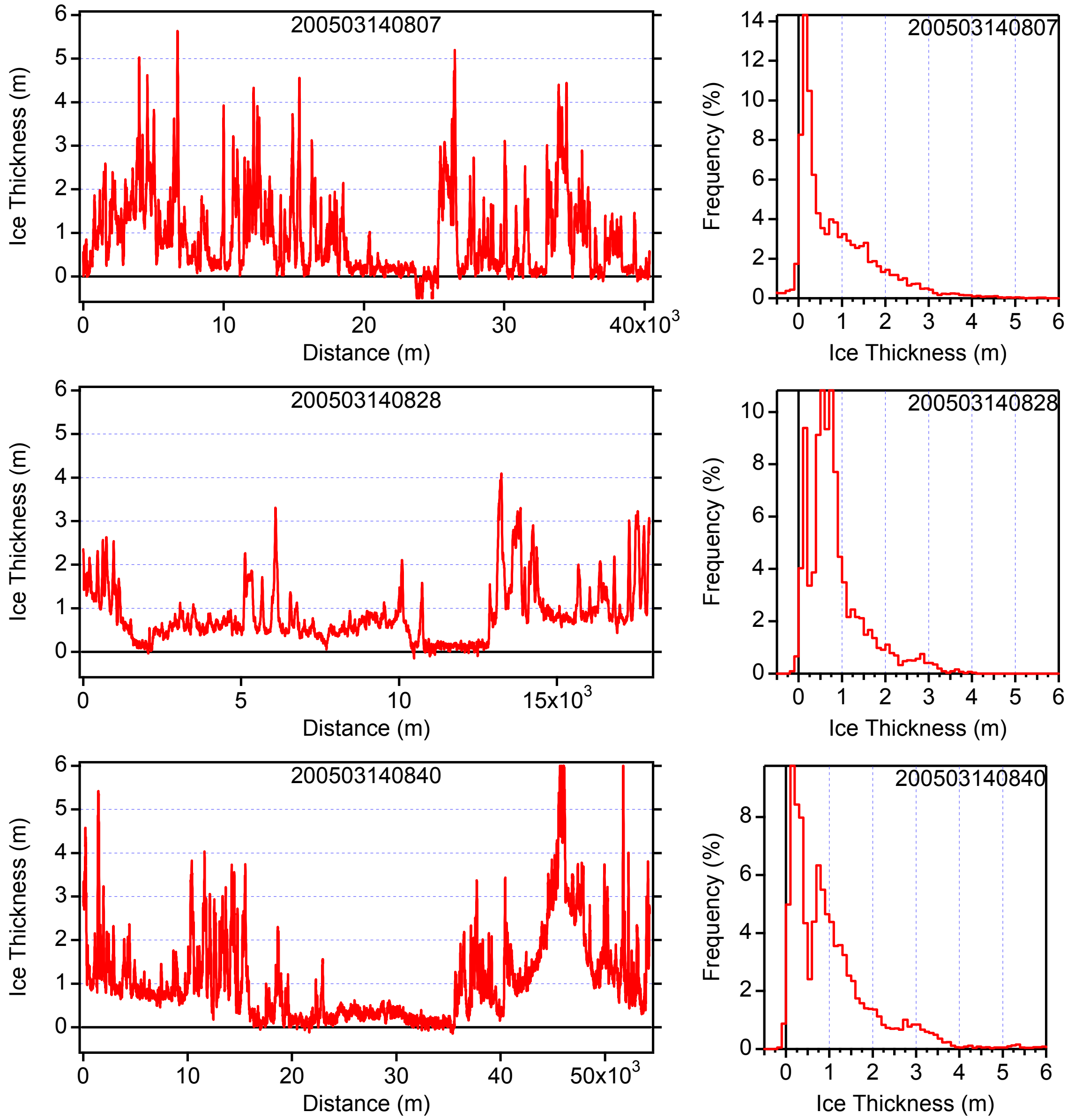




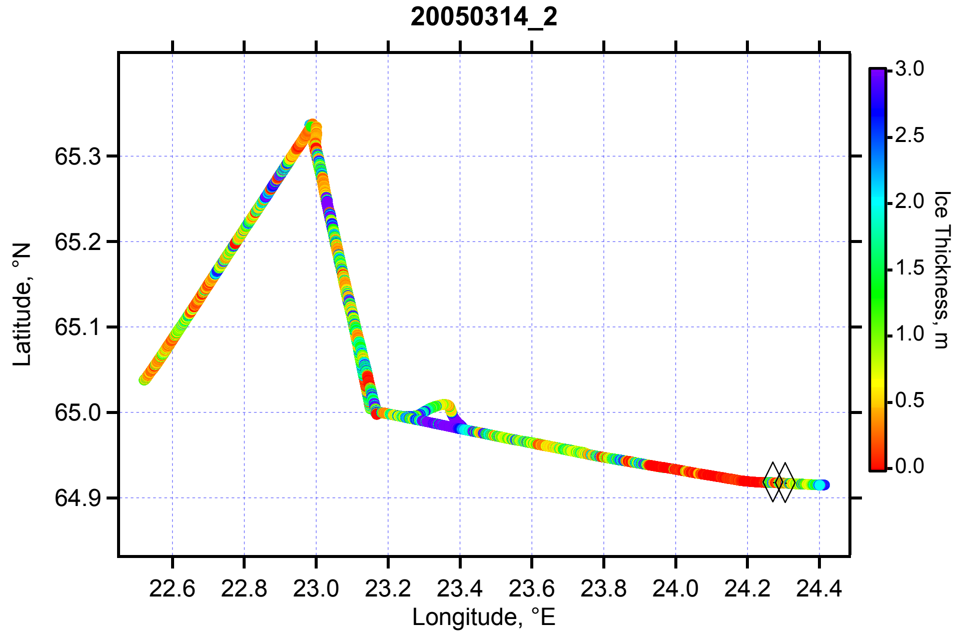


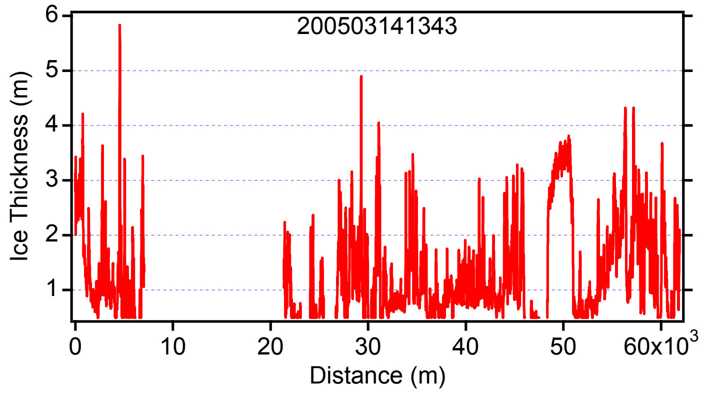


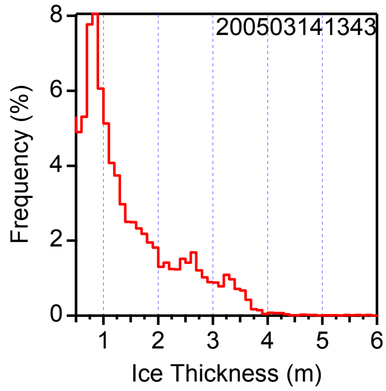


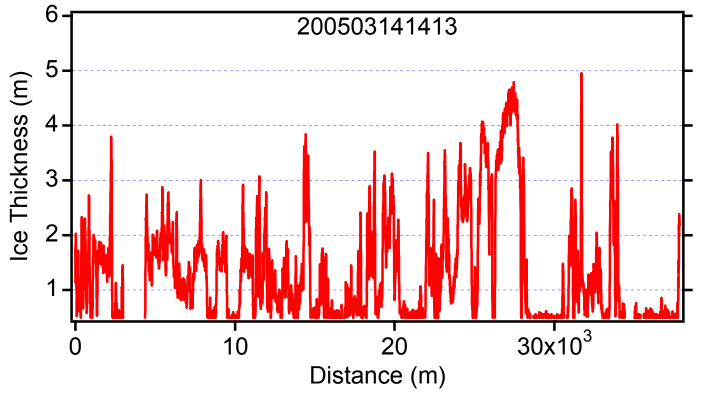

200503140807
Ice Thickness (m)
Distance (m)
40x10^3
Frequency (%)
200503140807
Ice Thickness (m)
200503140828
Ice Thickness (m)
Distance (m)
15x10^3
Frequency (%)
200503140828
Ice Thickness (m)
200503140840
Ice Thickness (m)
Distance (m)
50x10^3
Frequency (%)
200503140840
Ice Thickness (m)

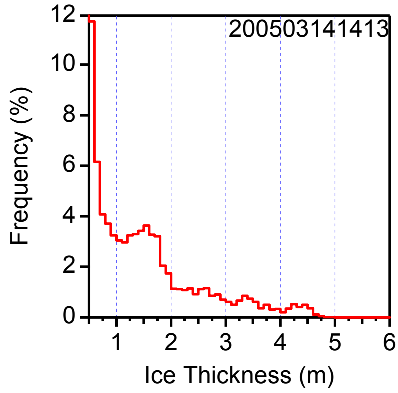
14.03.2005 Flight 2

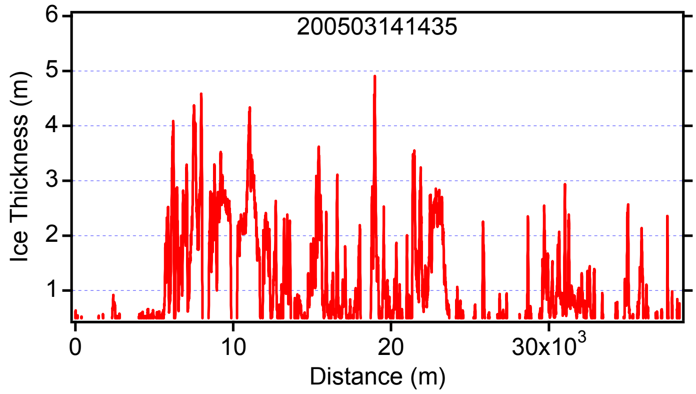


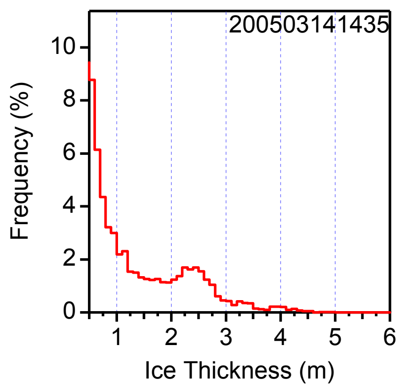


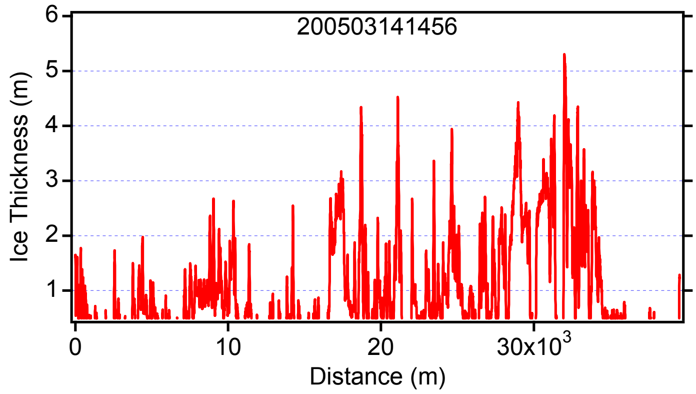


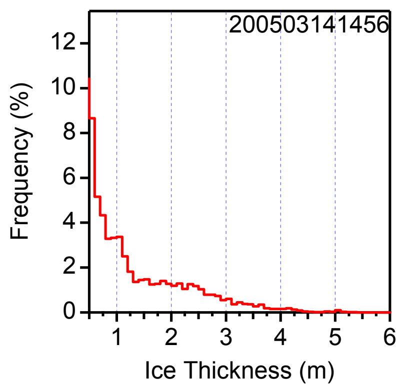


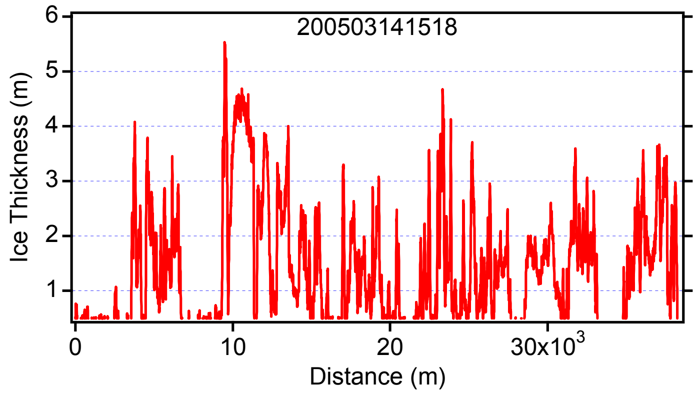


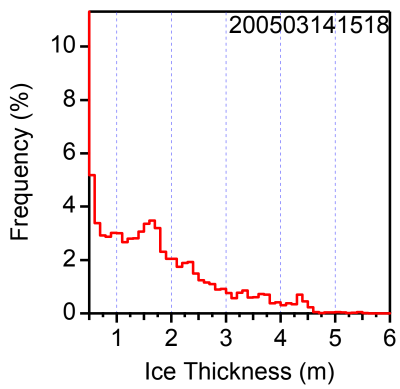

200503141435
Ice Thickness (m)
Distance (m)
30x10^3

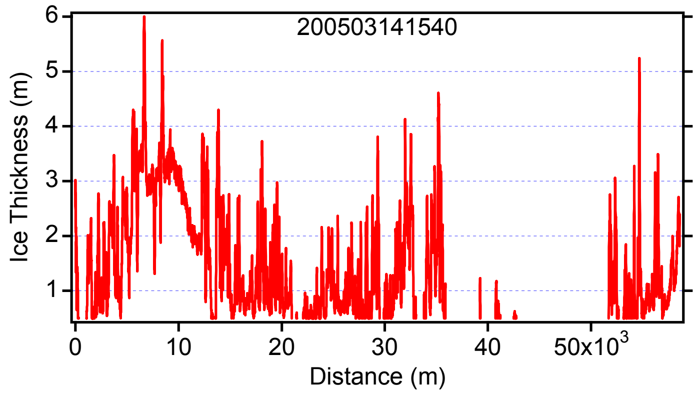

200503141435
Frequency (%)
Ice Thickness (m)

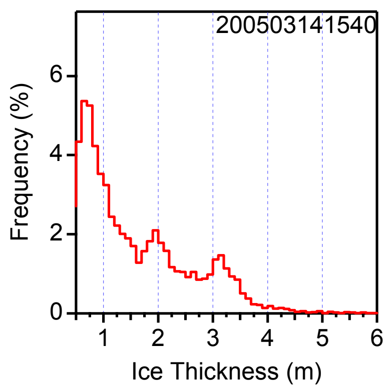

200503141456
Ice Thickness (m)
Distance (m)
30x10^3


200503141456
Frequency (%)
Ice Thickness (m)

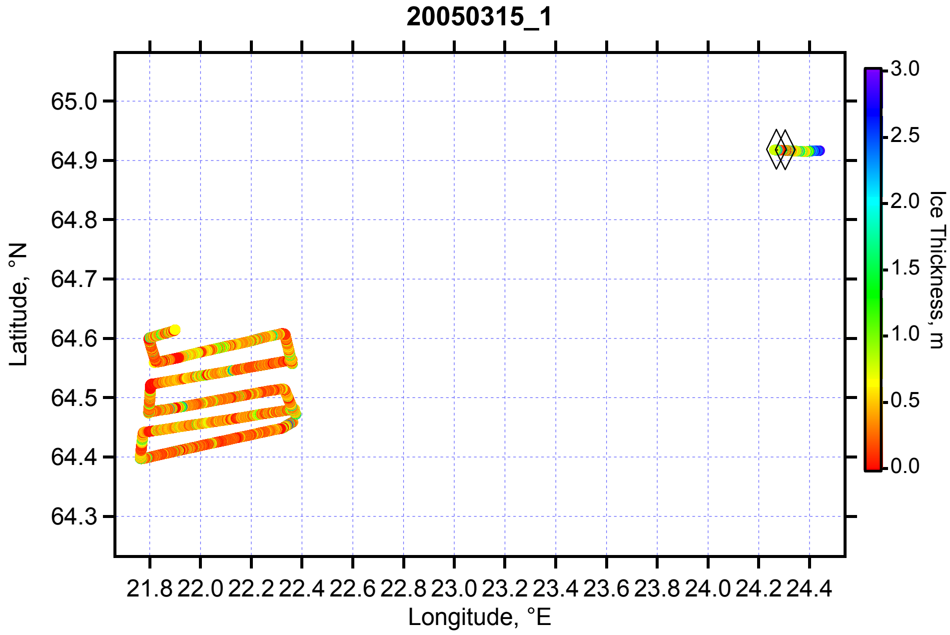

200503141518
Ice Thickness (m)
Distance (m)
30x10^3

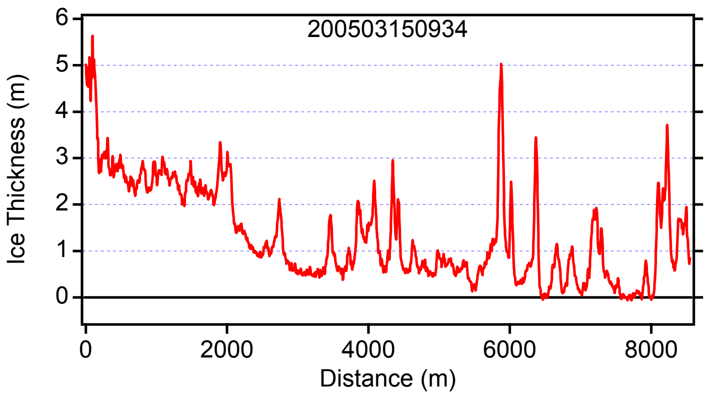

200503141518
Frequency (%)
Ice Thickness (m)

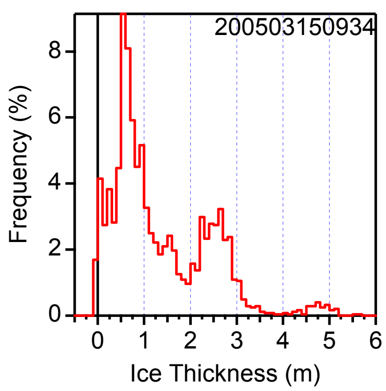

200503141540
Ice Thickness (m)
Distance (m)
50x10^3

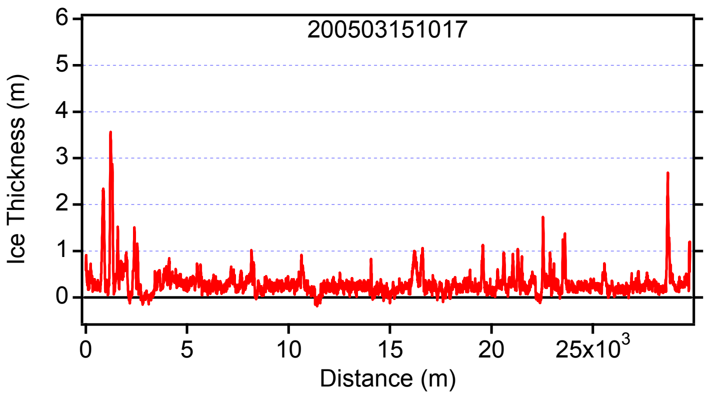

200503141540
Frequency (%)
Ice Thickness (m)

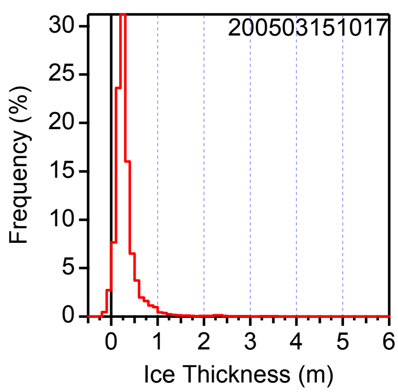
15.03.2005 Flight 1

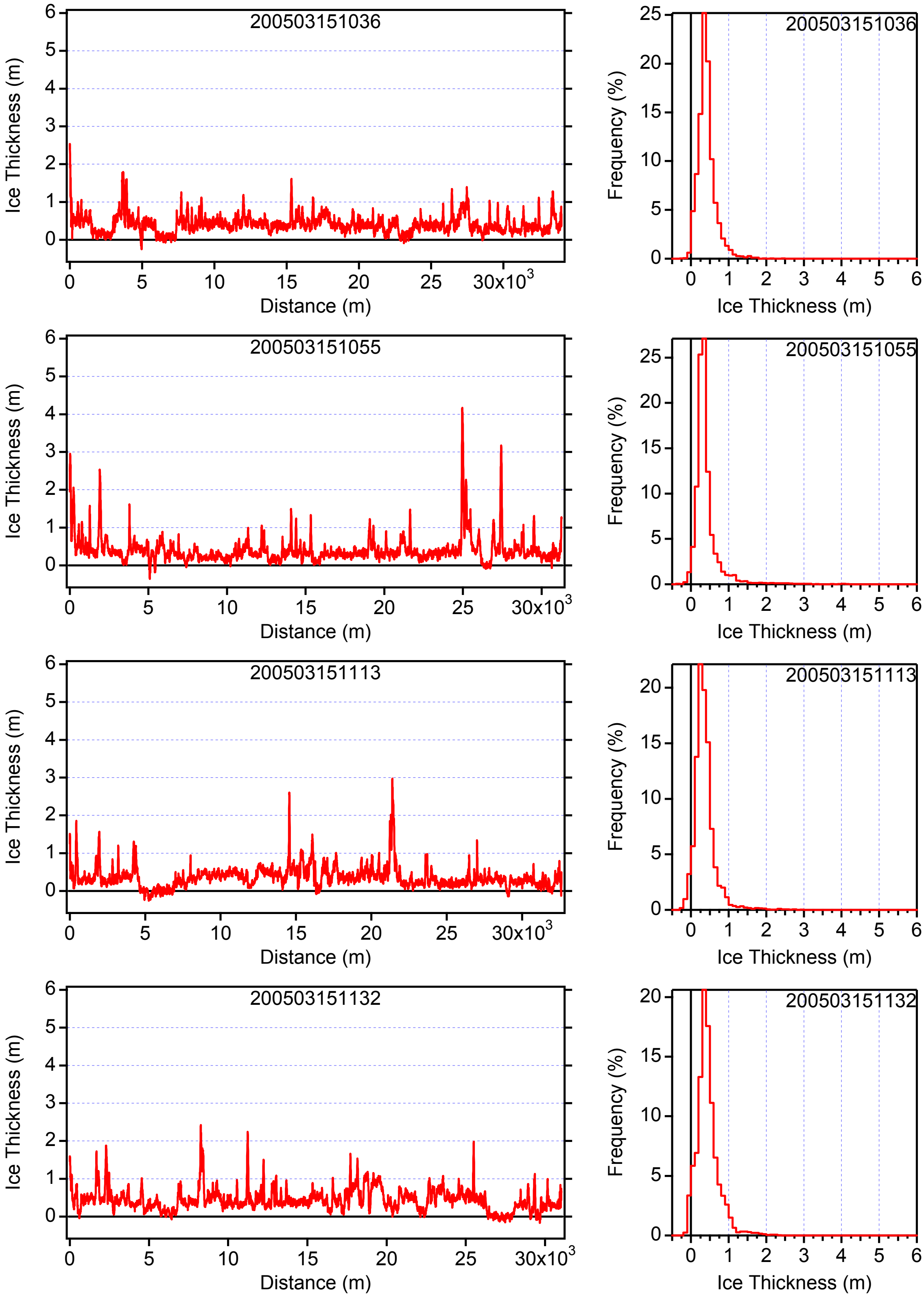


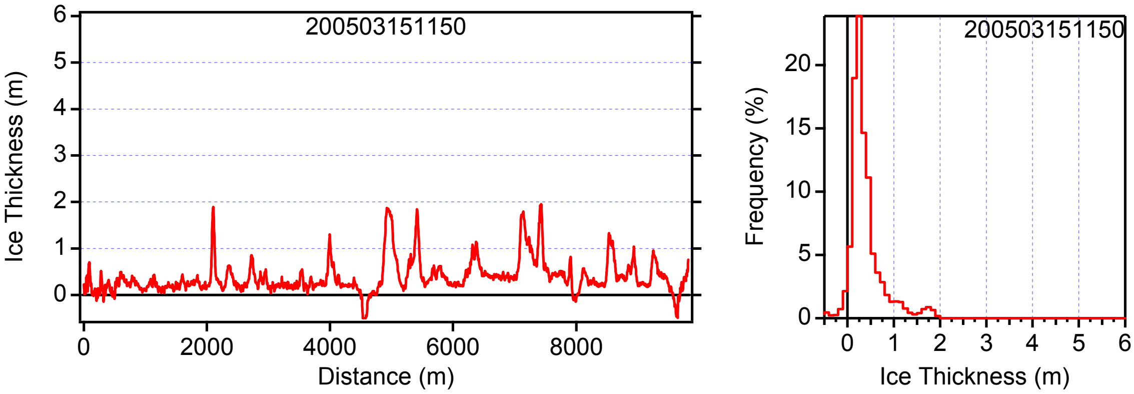






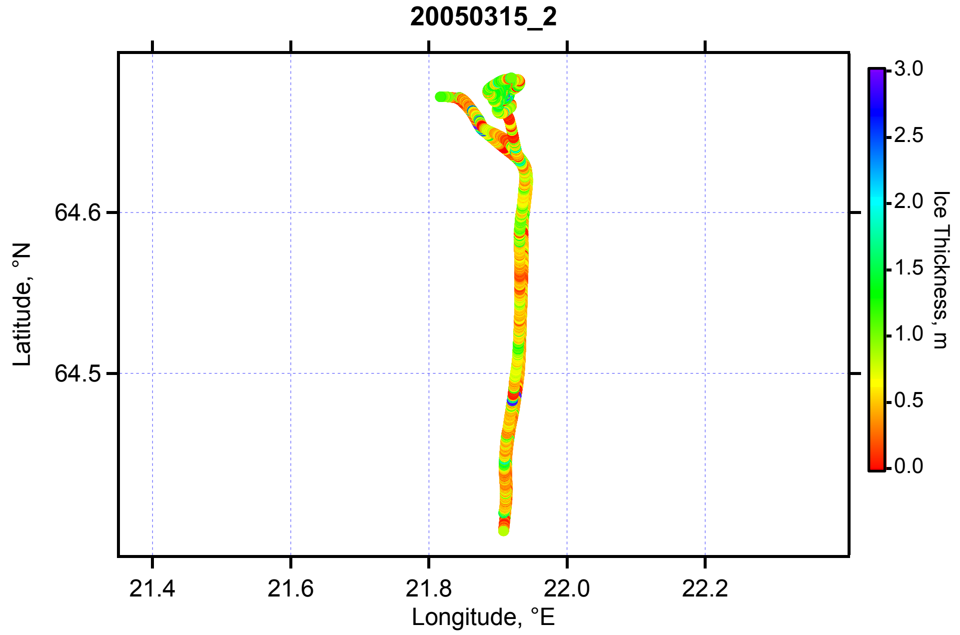


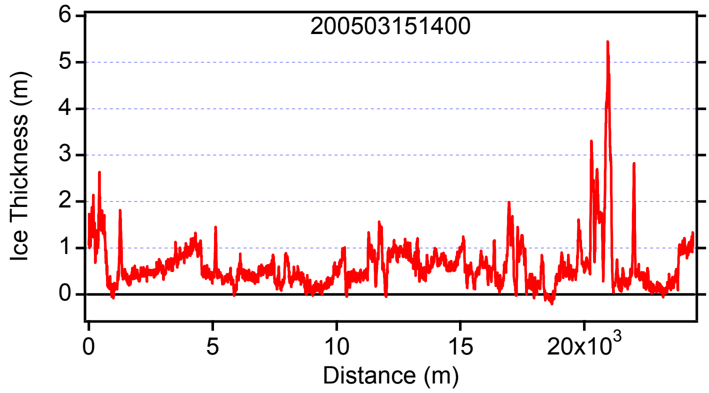

200503151036
Ice Thickness (m)
Distance (m)
30x10^3
Frequency (%)
Ice Thickness (m)
200503151055
200503151113
200503151132

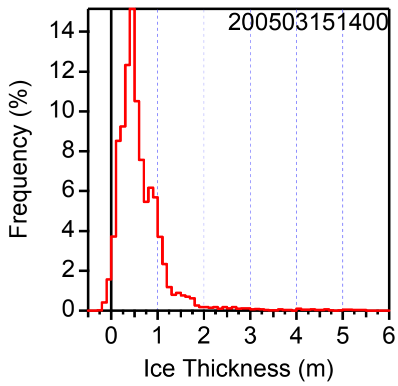


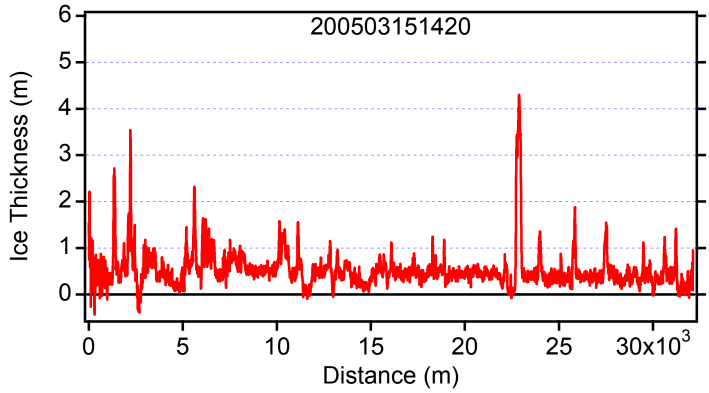
200503151150
Ice Thickness (m)
0
1
2
3
4
5
6
0
2000
4000
6000
8000
Distance (m)
200503151150
Frequency (%)
0
5
10
15
20
0
1
2
3
4
5
6
Ice Thickness (m)

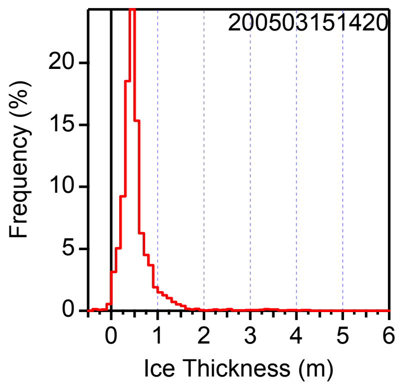
15.03.2005 Flight 2

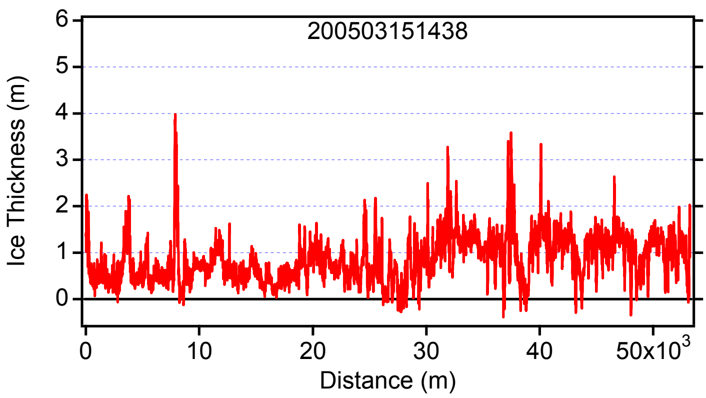


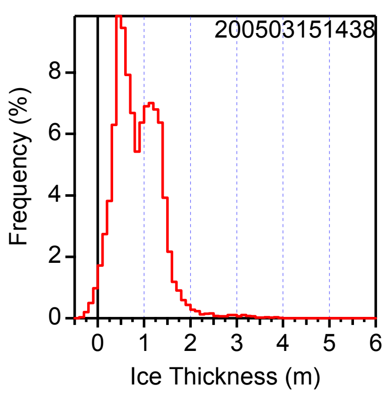




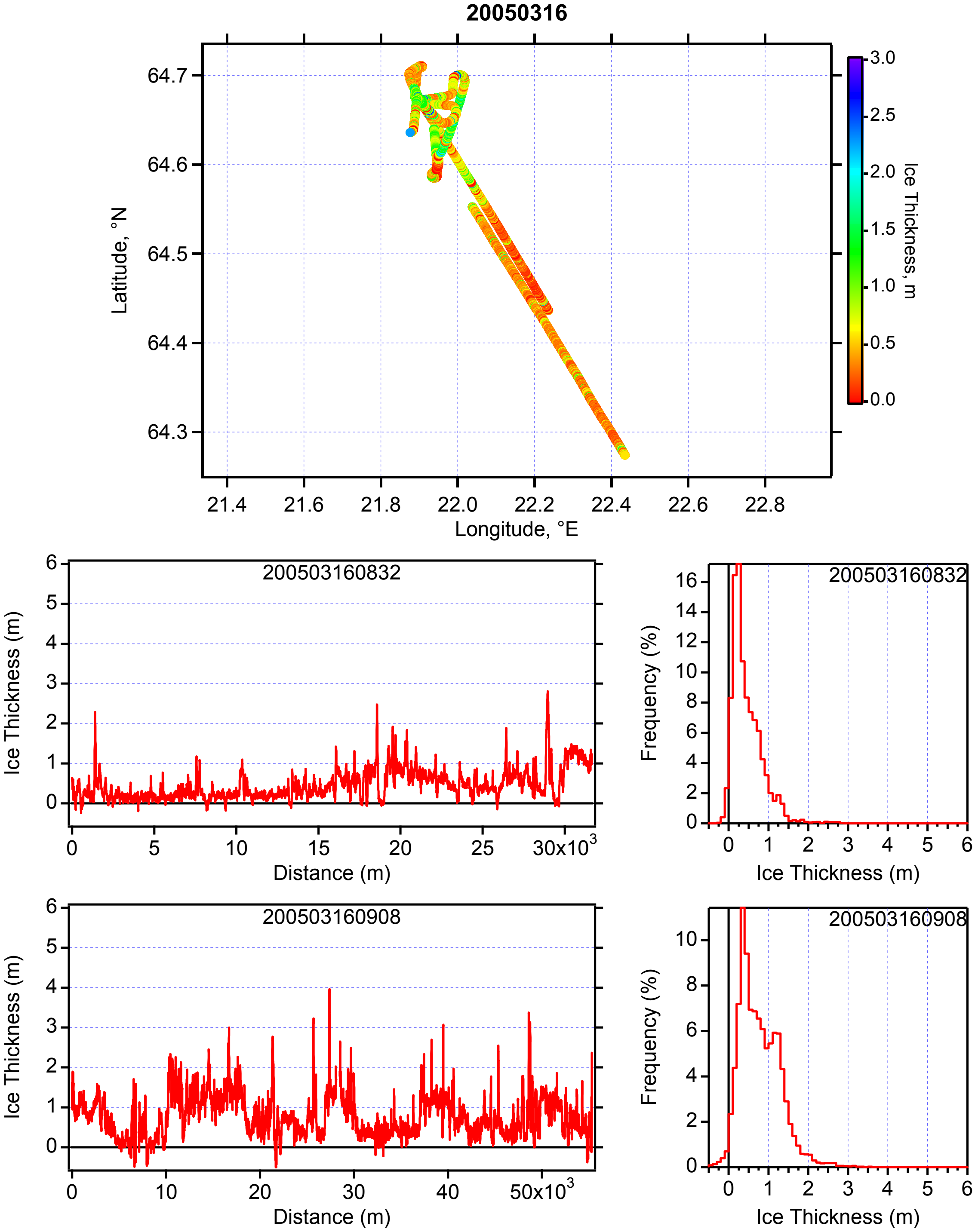


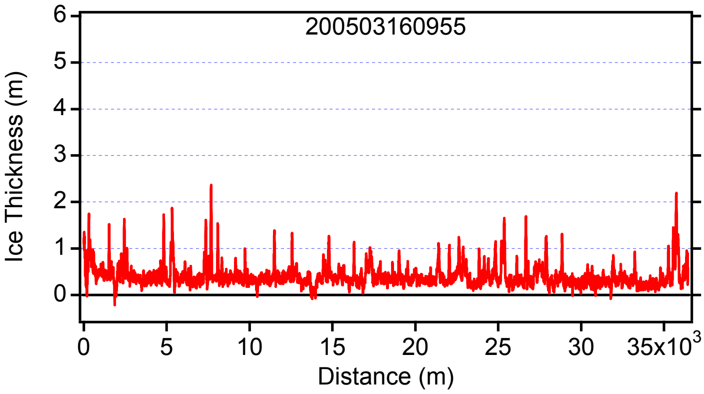


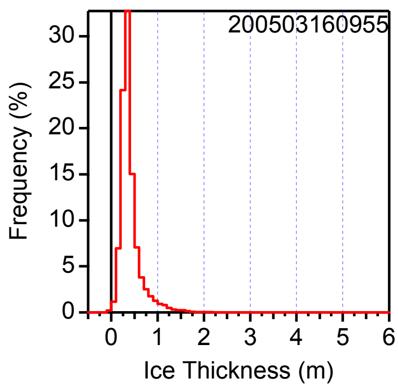

200503151438
Ice Thickness (m)
6
5
4
3
2
1
0
0
10
20
30
40
50x10^3
Distance (m)


200503151438
Frequency (%)
8
6
4
2
0
0
1
2
3
4
5
6
Ice Thickness (m)

16.03.2005


20050316
Latitude, °N
Longitude, °E
Ice Thickness, m
200503160832
200503160908
Ice Thickness (m)
Distance (m)
Frequency (%)
30x10^3
50x10^3


200503160955
Ice Thickness (m)
Distance (m)
0
1
2
3
4
5
6
0
5
10
15
20
25
30
35x10^3


200503160955
Frequency (%)
Ice Thickness (m)
0
5
10
15
20
25
30
0
1
2
3
4
5
6