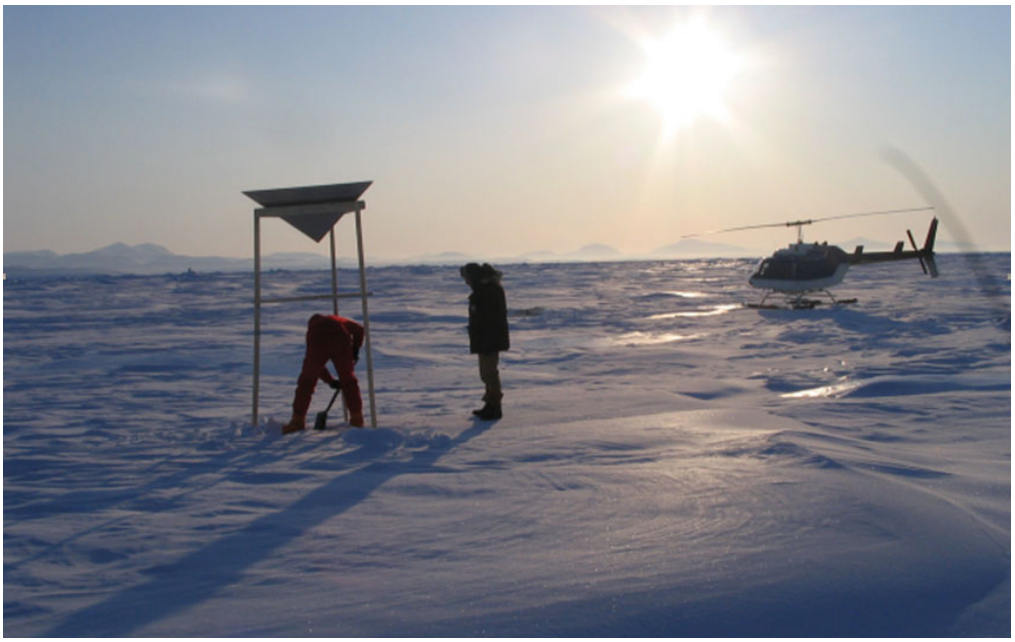
CryoVex 2008

Field report of in-situ validation measurements



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Executive Summary

This report summarizes the ground activities of the Spring 2008 CryoSat Sea Ice validation campaign (CryoVEx 2008), which was performed between April 30 and May 7, 2008, at CFS Alert on Ellesmere Island, Nunavut, Canada. The campaign addressed major uncertainties of the ice thickness retrievals of the upcoming CryoSat mission. Measurements included the detailed gathering of ice and snow property data on selected first-year and multiyear sites, which were then overflown by ESA's ASIRAS airborne radar altimeter. This report discusses ice and snow thickness data obtained by drilling and helicopter-borne electromagnetic sounding, snow properties from snow pits, buoy deployments, as well as the erection of radar corner reflectors, which were all part of the CryoSat Calibration and Validation Concept.

Acknowledgement

The work was only possible through the strong support by the Canadian Polar Continental Shelf Project and Canadian Forces Station Alert, as well as by Jim Milne and Alain Tremblay. In addition to support by ESA, we acknowledge funding by national CryoSat Cal/Val programs as well as by the European Union Damocles project.

1. Introduction

This report summarizes the ground activities of the Spring 2008 CryoSat Sea Ice validation campaign (CryoVEx 2008), which was performed between April 30 and May 7, 2008, at CFS Alert on Ellesmere Island, Nunavut, Canada.

CryoVEx 2008 addressed most uncertainties of CryoSat sea ice freeboard retrievals over both first-year and multiyear ice as discussed in detail in ESA's CryoSat Calibration and Validation Concept (CVC; Wingham et al., 2001). It was undertaken by investigators from AWI, DNSC, the University of Alberta, Norwegian Polar Institute, and Scottish Association of Marine Sciences in the region of the Lincoln Sea, using Canadian Forces Station Alert as a logistical base (Figure 1). This campaign was the second pre-launch campaign in this region, after a successful first campaign in 2006. However, the 2008 campaign focused in particular on open issues remaining from the first campaign. Therefore, overall goals were as follows:

A) High Priority Goals

Assessment of

i) The validity of the overall validation concept of overlapping ground, helicopter, aircraft and satellite tracks over moving ice. This allowed to address uncertainties related to the conversion of freeboard to ice thickness, to variable footprint sizes of methods, and to preferential sampling of larger floes.

ii) the influence of deep snow cover and variable ice properties (first-year versus multiyear ice, rough surface due to ridges) on CryoSat waveforms and freeboard retrievals, in particular over deformed ice.

To meet these objectives the following actions were required.

For objective 1-i) (validation concept)

- Perform coincident surveys of sea ice freeboard, surface elevation, and ice thickness by means of simultaneous flights of ASIRAS and a laser scanner with a Twin Otter, and an EM instrument towed with a helicopter.
- Install some GPS buoys on the mobile ice to characterise drift and permit post-campaign simulation of validation concept
- Simulate a validation line for ASIRAS/Laser and EM acquisitions compensating for drift

For objective 1-ii) (snow influence)

- Identification of deep snow area overlaying ice (more than 30 cm) preferably in static/non-moving ice zone, and including snow over level and adjacent deformed ice
- Installation of corner reflectors and detailed characterization of snow/ice properties including ice thickness for the area beneath the flight tracks.

- Acquisition of joint helicopter and ASIRAS/Laser data over the validation lines demarcated by corner reflectors.

B) Lower Priority Goals
Assessing in detail the three dimensional structure of ridges in a small area, to study its density characteristics and its representation in ASIRAS and HEM data.

This objective required
- Characterisation of ridge properties on ground.
- Over flying with ASIRAS/laser and the helicopter EM system.

This activity was primarily addressed by the operation of an Autonomous-Underwater-Vehicle (AUV) by DAMPT, which gathered extensive data of the three-dimensional underwater morphology at a specific site close to the other main validation sites. Those activities and results are not discussed here, but will be available elsewhere.

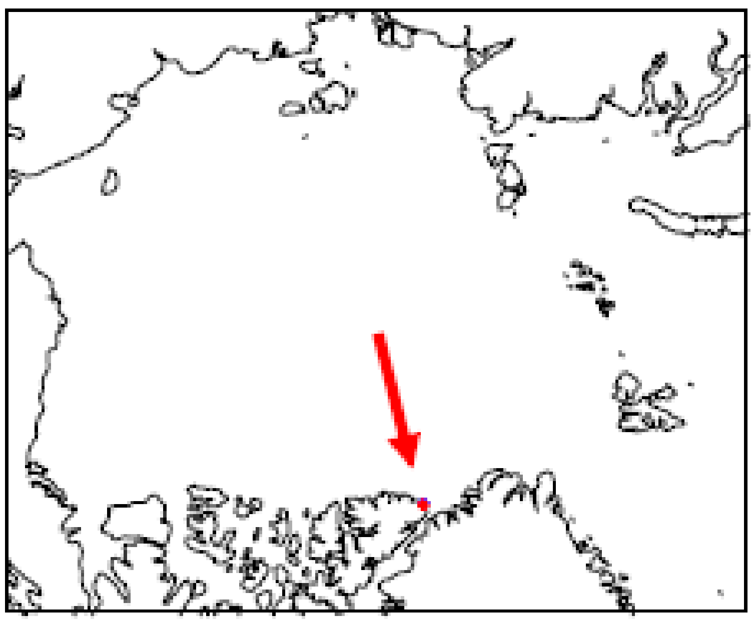


Figure 1: Map of the Arctic Ocean, showing the location of the CryoVex2008 ground measurements north of Ellesmere Island as red dot.

2. Validation sites

As in 2006, a region of fast ice had developed to the west of Alert, primarily composed of immobile multi-year ice floes, with some locally formed, level first year ice in between (Figure 2). This region was accessible by skidoos, and a large patch of first-year ice and an adjacent, virtually level patch of multiyear ice were chosen as main validation sites for the erection of corner reflectors and in-situ study of snow and ice properties (Figure 3).

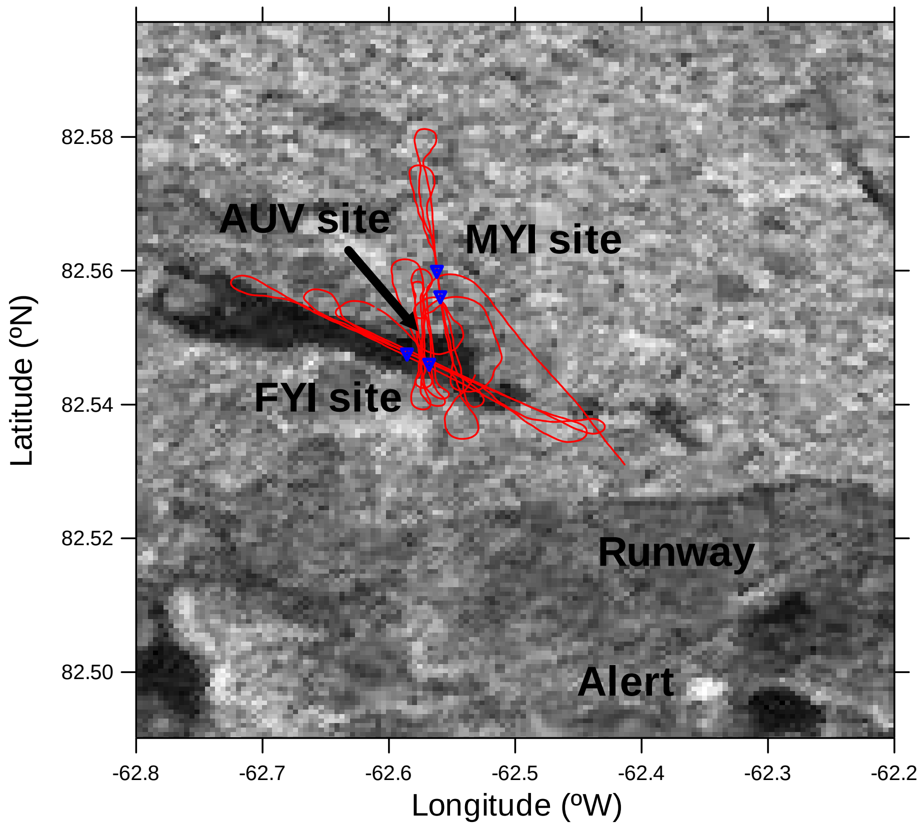


Figure 2: Envisat WSM SAR image (May 2, 2008) of fast ice region showing the two validation sites. Corner reflector locations are indicated by blue triangles, and HEM flight tracks are shown by red lines.

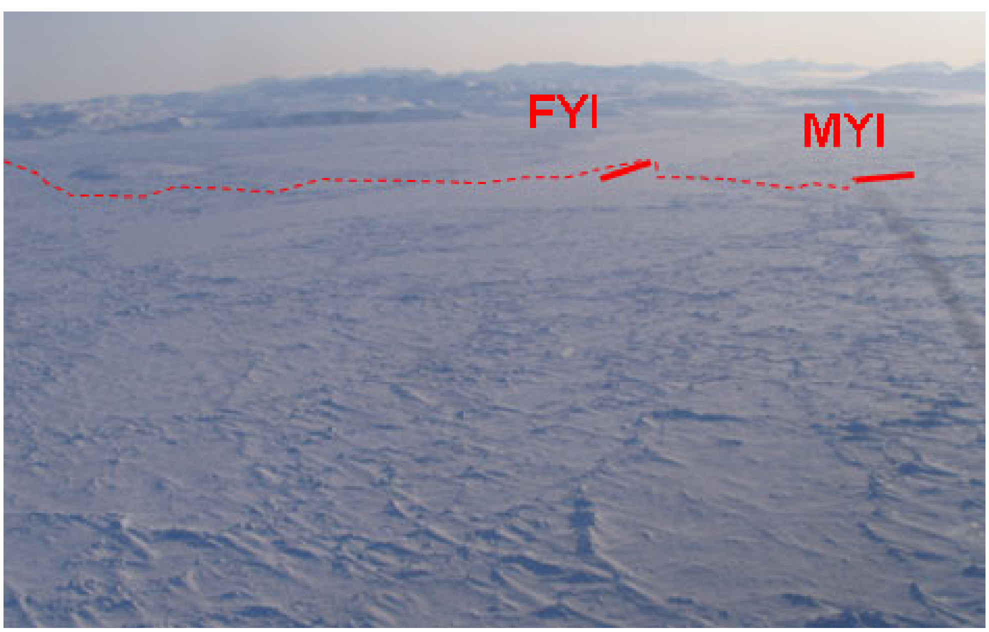


Figure 3: Aerial overview of first-year and multiyear ice validation sites of CryoVex 2006 on the fast ice at Alert. Stippled line indicates skidoo access route.

3. Measurements

On the validation sites, the following snow and ice properties were measured:

- Ice thickness profiles were obtained by means of drilling with cordless power drills and 5 cm diameter ice augers. Additional snow thickness measurements were performed with a 0.5 cm diameter metal meter stick with a pointed end. This metal stick was expected to be able to penetrate the high-density snow which caused a bias in the CryoVex2006 observations.
- Snow temperature, stratigraphy, density, grain size, and salinity were measured in few snow pits by standard glaciological means.
- Freeboard and surface elevation were measured by means of airborne surveys with a laser scanner and ASIRAS. All validation sites have been extensively overflown by ASIRAS on May 1, 2008 (Figure 4). Those flights are described in more detail and summarized in another report by S. M. Hvidegaard, H. Skourup, L. Stenseng, and R. Forsberg (2008), CryoVex 2008, Data acquisition report, DTU Space, July 2008, 33pp.
- Total ice thickness was measured by means of a helicopter-borne electromagnetic induction (HEM) sounder (Haas et al., 2008).

In addition, corner reflectors were erected at the endpoints of the validation lines and at a site on the drifting pack ice to provide reference and calibration of the radar altimeter measurements.

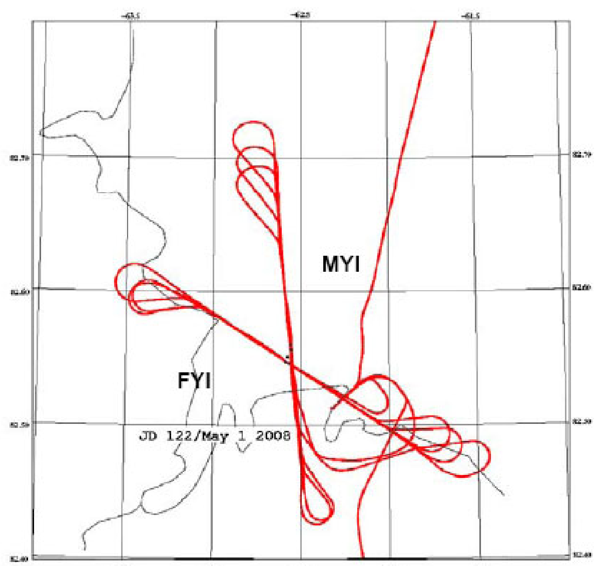


Figure 4: ASIRAS flight tracks over validation sites, obtained on May 1, 2008.

4. Properties of FYI

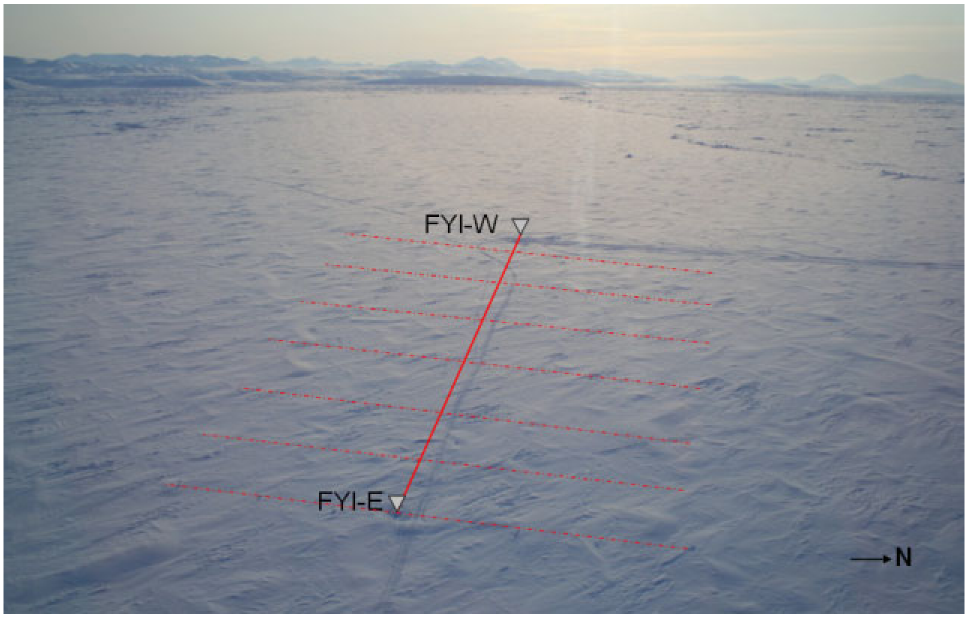


Figure 5: Aerial photo of the first-year ice validation site (view to the West), showing the location of the main line (solid) and cross-lines (stipled), and corner reflectors (triangles). Photo: Susanne Hanson.

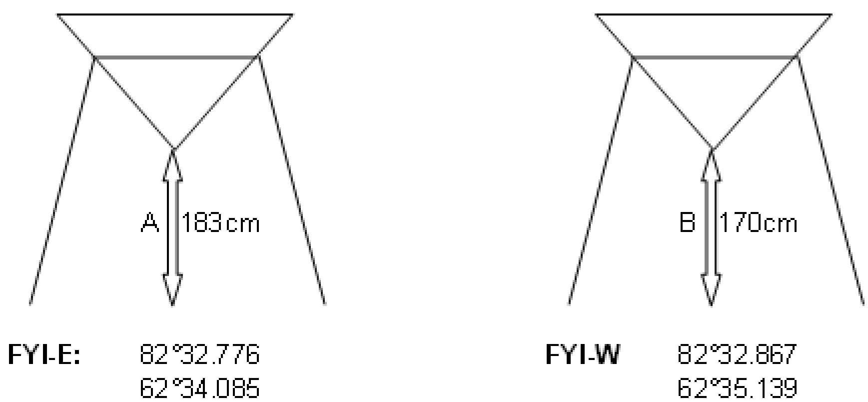


Figure 6: Locations and characteristics of the FYI corner reflectors

Ice thickness along the FYI validation line was very uniform with a clear mode of 1.5 m, and a mean ice thickness of 1.57±0.12 m (Figure 7). Mean snow thickness and freeboard amounted to 0.33±0.09 and 0.03±0.04 m. Figure 8 shows the resulting freeboard distribution. The modal freeboard was 0.08 m, and there were few locations with negative freeboard. As shown in Figure 5, ice and snow thickness have also been measured along 60 m long lines crossing the main line perpendicularly at X = 0, 50, 100, 150, 200, 250, and 306 m. Mean ice and snow thickness, and freeboard for all those measurements amounted to 1.51 ± 0.12, .34 ± 0.10, and 0.02 ± 0.05 m, showing the uniformity of the FYI patch.

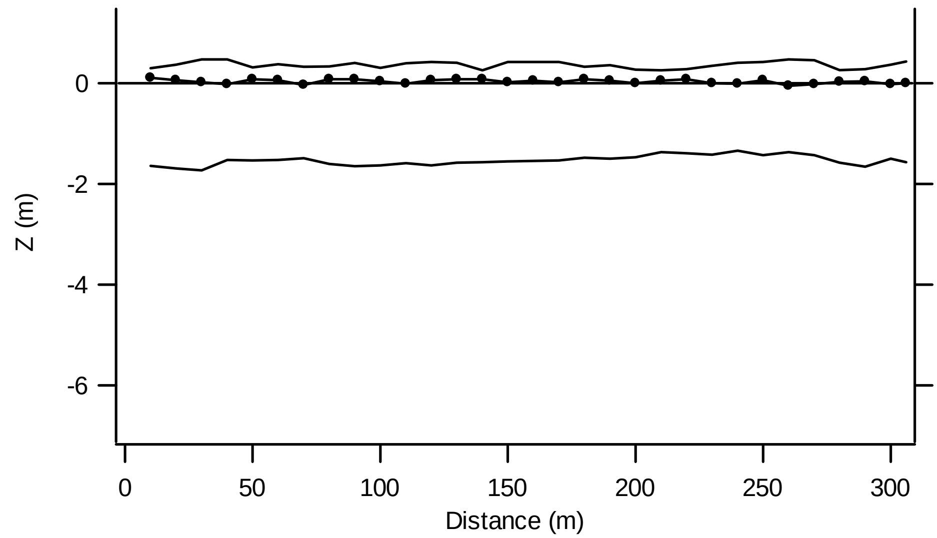


Figure 7: Drill-hole ice thickness profile along FYI validation line between eastern (at x = 0 m) and western (at x = 306 m). From top to bottom, surface elevation, freeboard, and draft are shown. Z = 0 m indicates the vertical location of the water level.

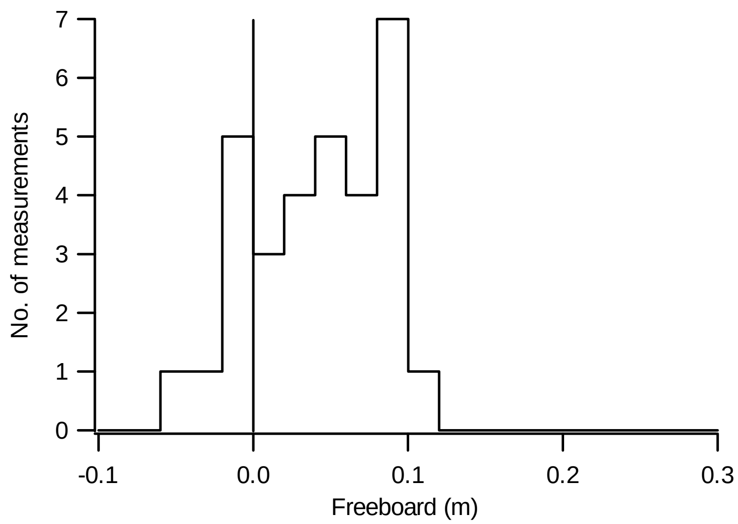
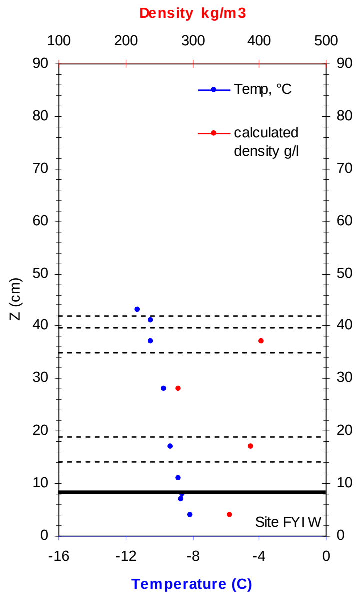


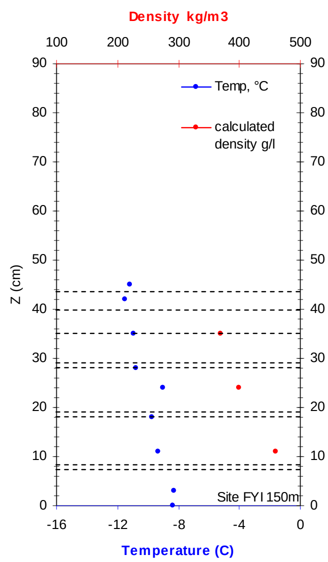
Figure 8: Freeboard distribution at FYI validation site (bin width 0.02 m).

Snow pit at western corner reflector:



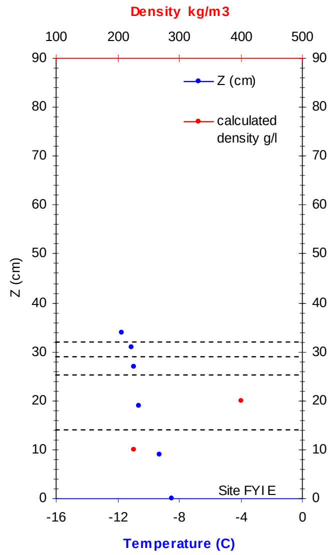
Notes:
Top: < 1 mm; II-A-2
40-35 cm: <1.5 mm; II-B-2; pencil
35-19 cm: 2-4mm; III-A-2 ; fist
19-14 cm: 1-5mm; III-A-2 ;finger
14-11: 1-3 mm:III-A-2 : finger
11-8 cm:1-3mm; III-B-2; pencil
8 cm: icy layer, individual grain recognizable, IV-A
8-0 cm: 2-5mm; III-A-2 ;
Surface wet, transition clear

Snow pit at 150 m along center thickness profile



Notes:
Top: < 1 mm; II-A-2
44-40 cm; 1 mm; II-B-2
40-29 cm: < 1mm; III-A-1 ; pecil
29-28 cm: 1-3mm;IV-A ; finger
28-19: 1-3mm; II-A-1; pencil
19-18 cm: 1-5 mm; III-A-1 -> III-A-2
18-7 cm: 1-2 mm; III-A-1 -> III-A-2 ; knife
7-0 cm: 1-5 mm; III-A-1 -> III-A-2 ; pencil
surface wet but well defined

Snow pit at eastern corner reflector



Note:
Top: <1mm; II-A-2
29-25cm: 1-2mm; III-A-1 ; finger
25-14cm: 0,5-2mm; III-A-2; pencil
14-0cm:1-7mm; III-A-3;fist
surface dry and clear

Table 2: Summary of data files for first-year ice site.

File name	Description
icethickness_snowdepth_FB.xls	Ice and snow thickness drill-hole data
snowpits_FYI.xls	Snow property data, photos, and plots
Cornerreflectors_sha.xls	Corner reflector information

5. Properties of MYI

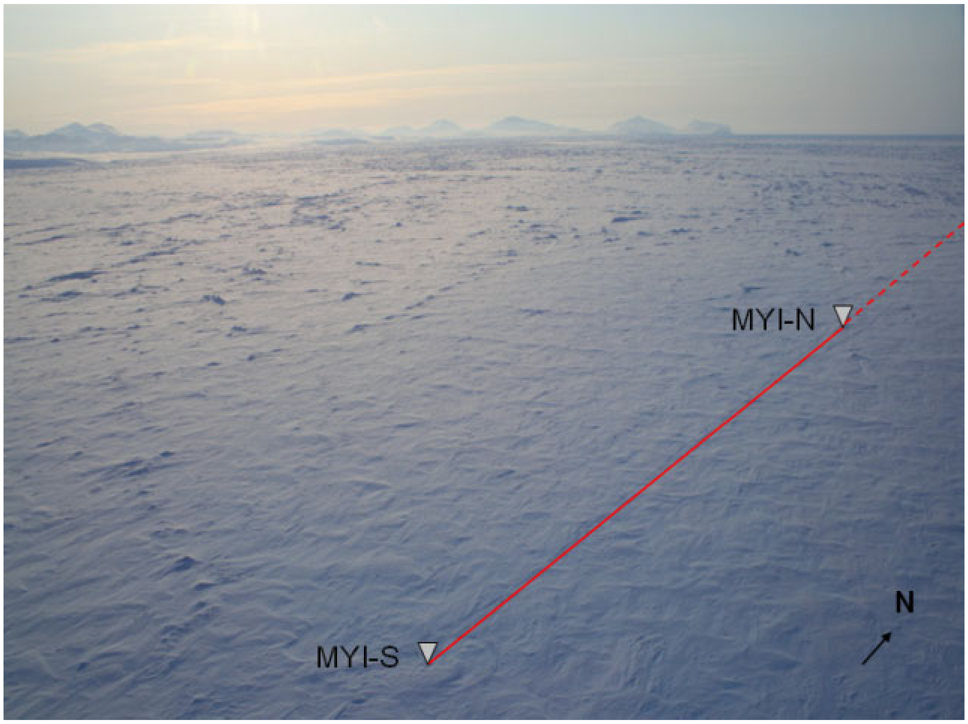


Figure 9: Aerial photo of the multiyear ice validation site (view to the Northwest), showing the location of the main line (solid) and cross-lines (stippled), and corner reflectors (triangles). Photo: Susanne Hanson.

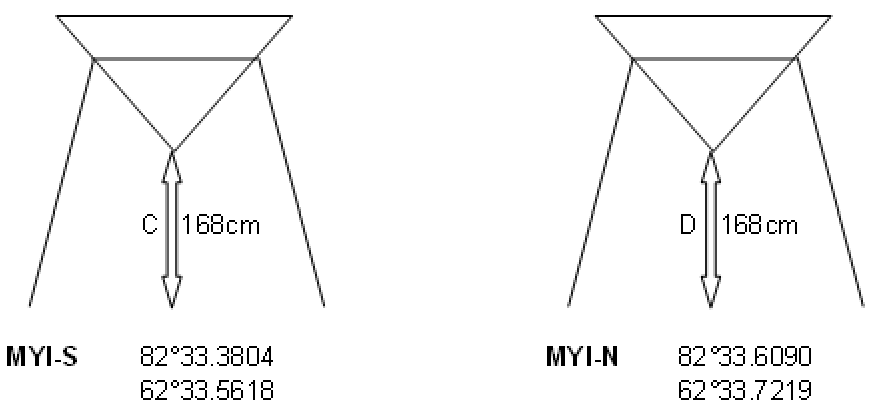


Figure 10: Locations and characteristics of the MYI corner reflectors.

There are too few measurements to calculate reliable statistics for the validation profile. However, the thickness distribution had two modes of 3.0 and 4.4 m, with a mean ice thickness of 4.47±1.45 m (Figure 11). Mean snow thickness and freeboard amounted to 0.43±0.19 and 0.39±0.29 m. Figure 12 shows the resulting freeboard distribution. The modal freeboard was 0.3 m, and there were even few locations with negative freeboard.

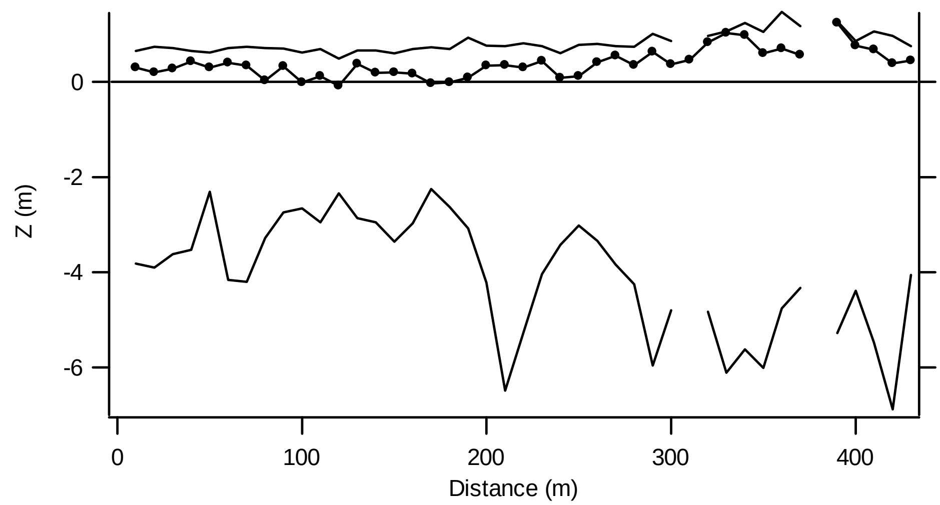


Figure 11: Drill-hole ice thickness profile along MYI validation line between southern (at x = 0 m) and northern (at x = 430 m). From top to bottom, surface elevation, freeboard, and draft are shown. Z = 0 m indicates the vertical location of the water level.

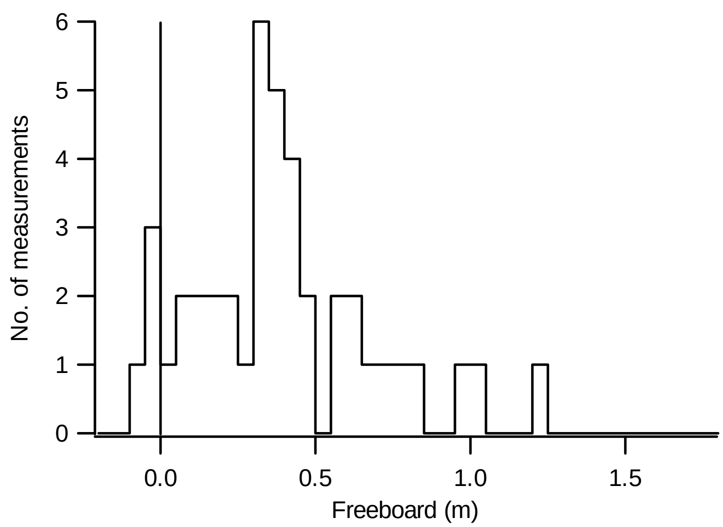


Figure 12: Freeboard distribution at MYI validation site (bin width 0.05 m).

During CryoVex2006, later analysis of ASIRAS data revealed that it would have been advantageous if snow thickness data would also have had been measured over the deformed ice regions. Therefore, here we extended the snow thickness measurements beyond the main validation line, including regions of more deformed multiyear ice to the north of the northern corner reflector, which were also overflown by the aircrafts. Figure 13 shows the snow thickness profile this obtained, and Figure 14 summarizes the snow thickness distribution. The mean snow thickness along this line was 0.58 ± 0.32 m, with several modes at 0.3, 0.4, and 0.7 m. Note that this snow thickness is lager than the 0.43 m thick snow on the relatively level main validation site.

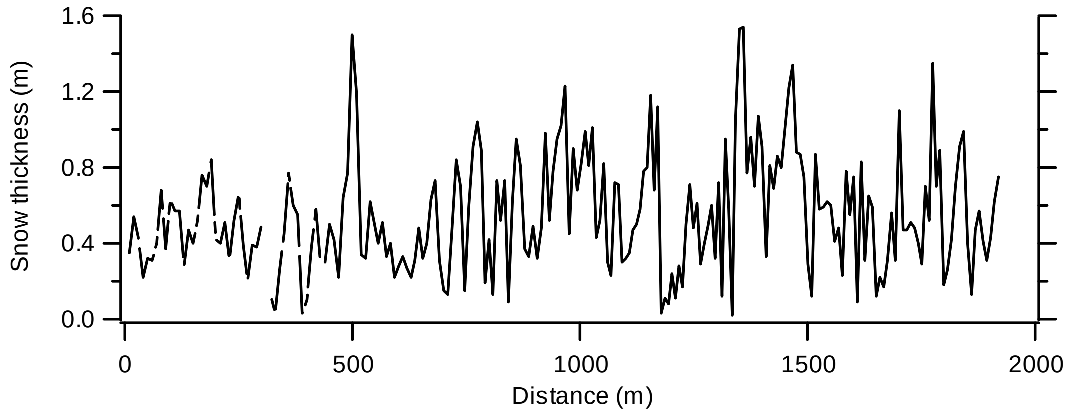


Figure 13: Snow thickness profile on the multiyear site. Stippled line shows measurements along main validation line (cf. Fig. 11), and solid line extends north from the northern corner reflector at x=0 m, in the same direction as the main line and aircraft surveys.

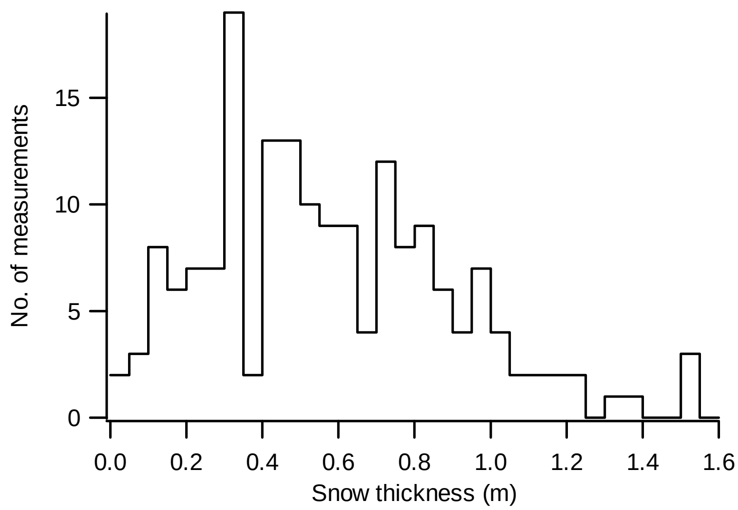
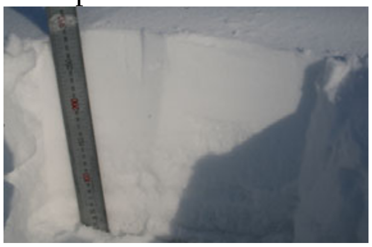
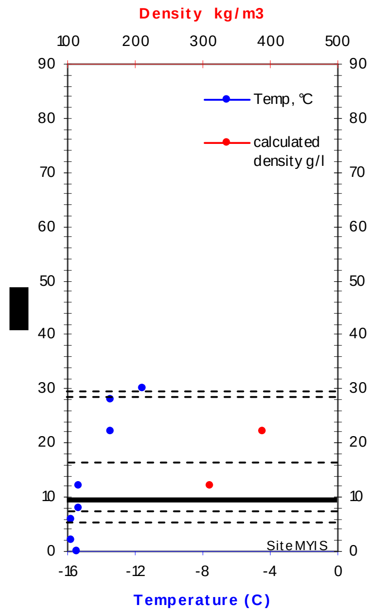


Figure 14: Snow thickness distribution along long snow profile on multiyear ice (cf. Figure 13).

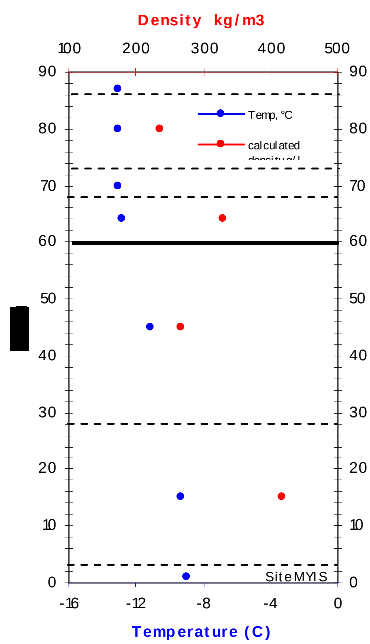
Snow pit at southern corner reflector





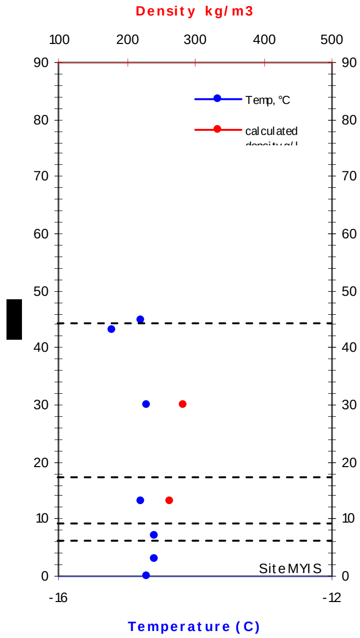
Note:
29-28cm:< 1 mm; II-A-2
28-16cm: < 1mm; II-B-2 ; fist
16-9cm: 1 mm; II-B-1 -> II-B-2 ; finger
9-7 cm: 2-3mm; III-A-1 ;fist?
7-5 cm; 1-3mm; III-A-1; knife
5-0 cm; 1-5mm; III-A-3 medium grained ; fist
Note:
29-28cm:< 1 mm; II-A-2
28-16cm: < 1mm; II-B-2 ; fist

Snow pit at 200 m along MYI thickness profile



Note:
86-73cm: <1m; I-B;finger
73-68 cm: <1mm; I-B;knife
68-60 cm:1 mm; II-B-2;finger
60 cm : ice lense
60-28 cm:1-6mm;III-A-2;fist
18-3cm:1-4 mm;III-A-3 medium grained;pencil
3-0 cm:1-8mm; III-A-3 mature
surface:dry

Snow pit at northern corner reflector



Note
44-17,5 cm: <1 mm;II-B-2;finger
17,5-9 cm: 1-6mm;III-A-2;fist
9-6cm: 1-3mm;III-A-2; knife
1-6 cm: 1-5mm;III-A-3 medium grained;fist

Table 2: Summary of data files for multiyear ice site.

File name	Description
icethickness_snowdepth_FB_allData.xls	Ice and snow thickness data
snowpits_MYI.xls	Snow property data, photos, and plots
Cornerreflectors_sha.xls	Corner reflector information

6. Fuel cache

A fifth corner reflector was deployed at a fuel cache at 83.73ºN, 65.17ºW, and was overflown by ASIRAS and HEM on the long, coincident flight on May 2, 2008. Information about the corner reflector is summarized in Figure 15. The corner reflector was located on a refrozen lead with very uniform ice conditions. Eight snow and ice thickness measurements revealed a mean snow thickness of 0.069 ± 0.02 m, mean ice thickness of 1.28 ± 0.02 m, and freeboard of 0.11 ± 0.01 m.

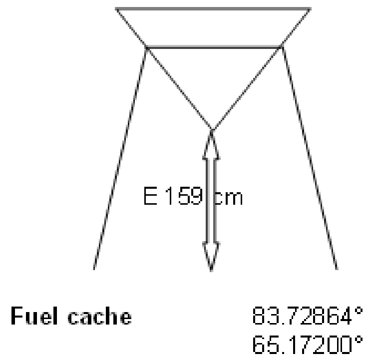


Figure 15: Locations and characteristics of the corner reflector deployed on FYI at the fuel cache.

13 drill-hole measurements were also performed over an approximately 180 m long, North-South profile over multiyear ice due south of the corner reflector, which lay directly over the coincident flight tracks of ASIRAS and the HEM surveys. Results are shown in Figure 16. In summary, mean ice and snow thickness, and freeboard were 2.31±0.28, 0.31±0.15, and 0.17±0.09 m, respectively. Note that this was significantly less than on the MYI validation site.

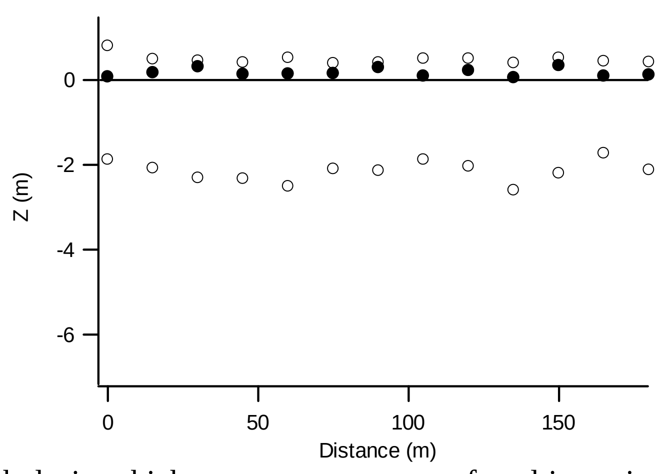


Figure 16: Drill-hole ice thickness measurements of multiyear ice south of the corner reflector location at the fuel cache. Symbols indicate surface elevation (top), freeboard, and draft (bottom), and have not been connected as distances are approximate. Z = 0 m indicates the vertical location of the water level.

Table 3: Summary of data files for fuel cache site.

File name	Description
Fuel_cashe_icethickness_snowdepth_FB_sha.xls	Ice and snow thickness data under corner reflector on FYI
fuel_cache_ice_rf.doc	Ice and snow thickness data of multiyear ice south of corner reflector

7. Buoy deployment sites

Snow thickness measurements with a spacing of ca. 8 m were also performed on three sites along the South-North coincident flight track. The sites were reached by helicopter and were also visited for the deployment of three GPS buoys to track the ice motion (see Section 9). Table 4 summarizes the results.

Table 4: Overview of snow thickness measurements at buoy deployment sites along South-North coincident flight track.

Buoy No.	Latitude	Longitude		N	Mean snow thickness (m)	Modal snow thickness (m)
6	83.2121	-65.0736	Level grey ice with uniform snow	19	0.05±0.00	0.05
8	83.4541	-65.0853	Heavily deformed MYI	53	0.50±0.16	0.35
4	84.2027	-65.5247	Heavily deformed MYI	47	0.40±0.18	0.2 & 0.35

Filename: SnowThickness bouy deployment_Haas.xls

8. HEM surveys

The validation lines were surveyed on May 1, 2008, after corner reflectors had been erected. Navigation was performed visually by the pilot aiming to over fly the corner reflectors as closely as possible.

8.1 First-year ice validation site

Figure 17 shows the repeated overpasses over the FYI validation line. The center line was surveyed 4 times with high navigational accuracy while two additional passes to the sides (Figure 18) sampled the ice at a distance of 30 to 60 meters to the center line. Within the validation line sea ice thickness showed only small variations (Figure 19). No significant thickness variations were observed to both sides of the line either.

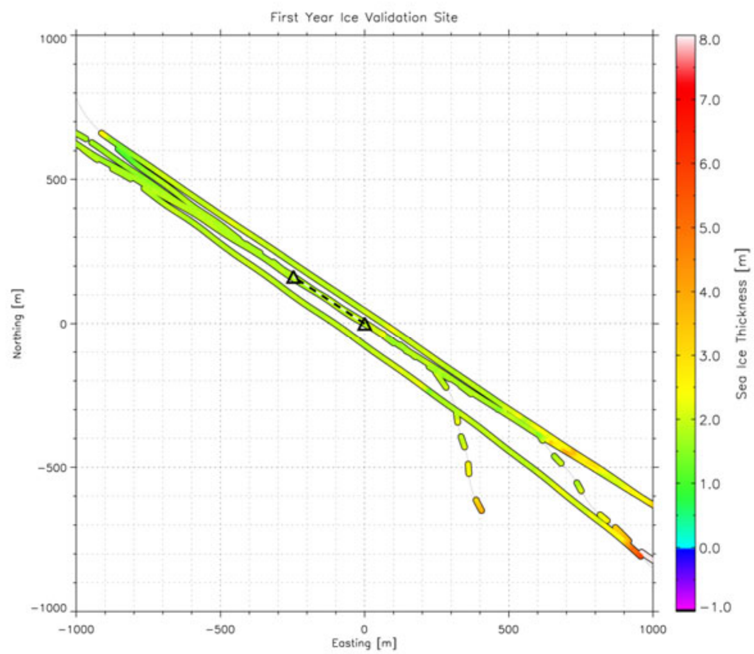


Figure 17: Map of FYI validation site with AEM sea ice thickness measurements. Triangles denote corner reflector positions.

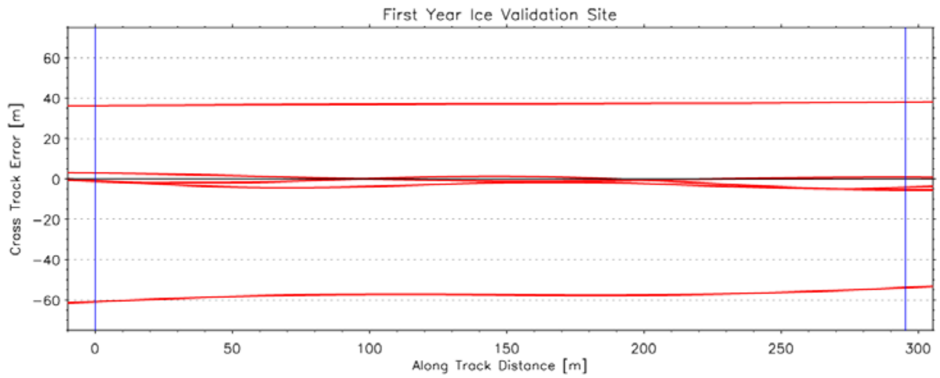


Figure 18: Navigational accuracy over repeated surveys of the FYI validation site. Vertical lines mark corner reflector positions

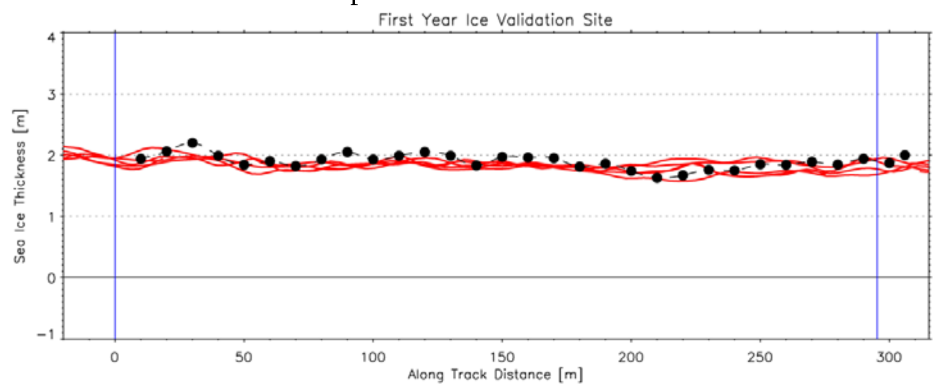


Figure 19: Ground truthing of AEM sea ice thickness with onsite drill hole measurements along the FYI validation site. Continous line: AEM data, Black dots: Drill hole measurements (snow depth+ice thickness). Vertical lines mark corner reflector positions.

8.2 Multiyear ice validation site

The validation line on the multiyear ice showed significantly higher ice thickness and thickness variations. On this site overpasses with an offset to the center line were omitted leaving 4 repeated surveys. The length of the line amounts to roughly 430 meters with a more north-south orientation (Fig. 20). Again navigational accuracy was better than 5 meters, yielding good agreement between the thickness results of the different overpasses (Figs 21 and 22).

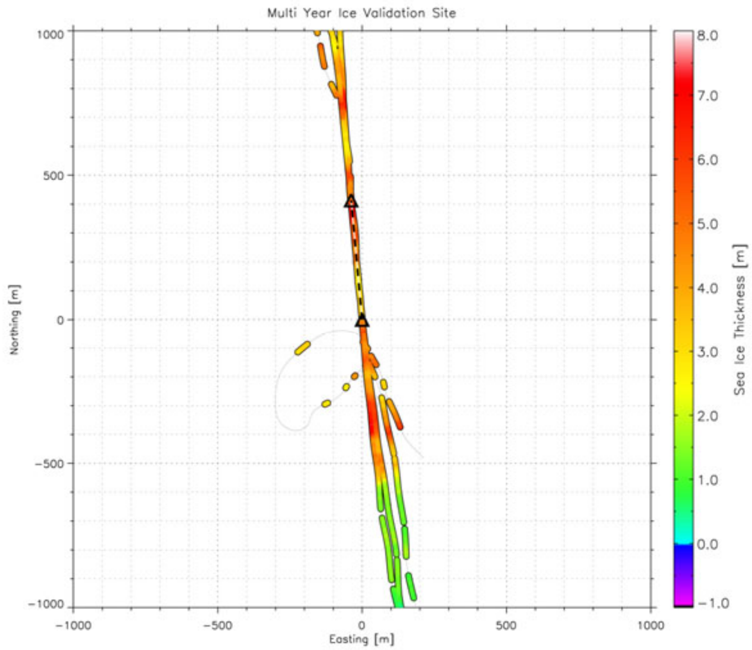


Figure 20: Map of MYI validation site with AEM sea ice thickness measurements. Triangles denote corner reflector positions.

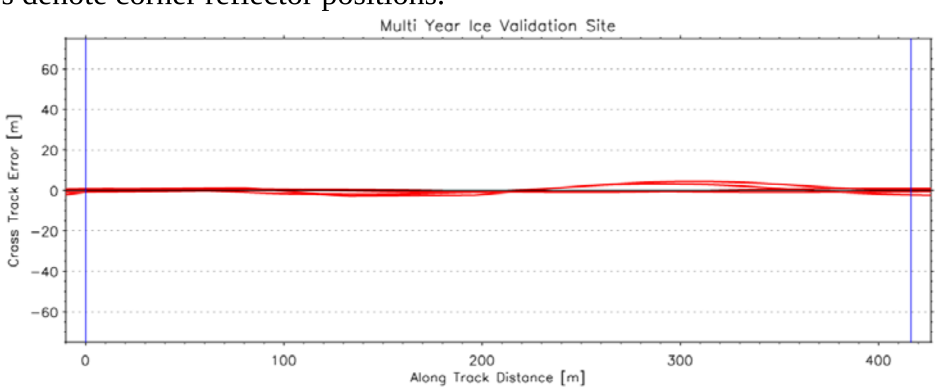


Figure 21: Navigational accuracy over repeated surveys of the MYI validation site. Vertical lines mark corner reflector positions.

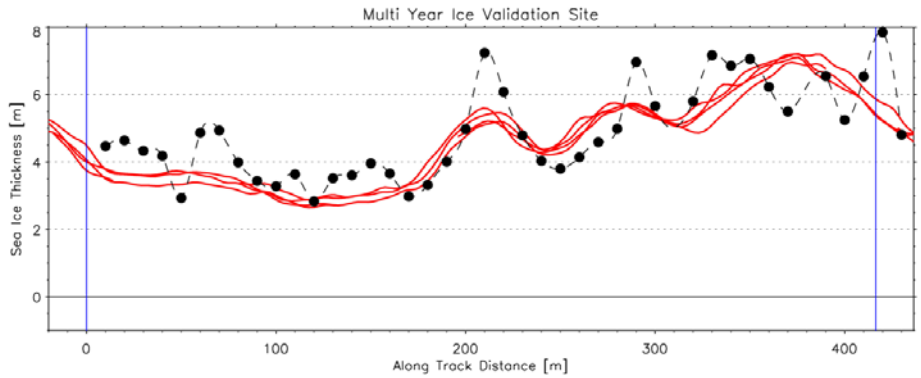


Figure 22: Ground truthing of AEM sea ice thickness with onsite drill-hole measurements along the MYI validation site. Continous line: AEM data, Black dots: Drill hole measurements (snow depth+ice thickness). Vertical lines mark corner reflector positions.

8.3 Coincident flight with ASIRAS

On May 2, 2008, a long northward HEM flight was performed to obtain ice thickness data together with ASIRAS. It was agreed to fly a straight line between two GPS waypoints defined by two buoys at the end point of the profile. The profile had been laid over the thicker multiyear ice to the west because the helicopter was not allowed to fly over the thin ice of the polynya. Preliminary analysis shows that coordination between the helicopter and the Twin Otter functioned very well, and the Twin Otter was overtaking the helicopter halfway along the profile. Navigation of the helicopter was controlled by monitoring the deviation of the helicopter from the predefined flight track by means of a handheld GPS. Whenever the helicopter deviated more than 50 m from the line, the pilot was instructed to change his heading accordingly. With this procedure, it was possible to keep the helicopter within 75 m of the center line throughout the profile, and well within the swath covered by the laser scanner on the Twin Otter. Figure 23 shows the ice thickness profile thus obtained.

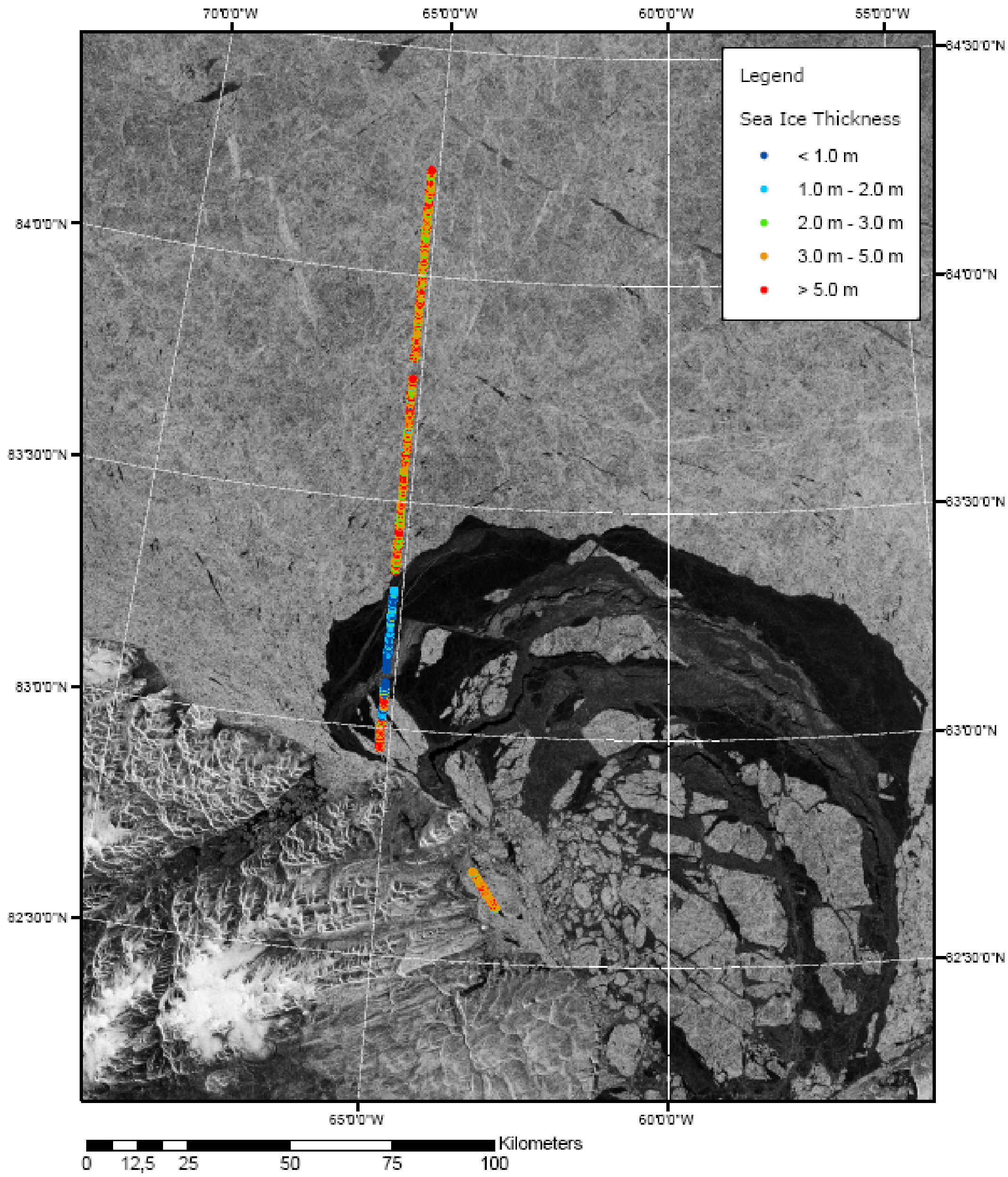


Figure 23: Envisat WSM SAR image of the Lincoln Sea (May 2, 2008, 23:16 UTC), showing ice thickness along the coincident flight track of ASIRAS and the HEM system surveyed on May 2, 2008, between 20:49 and 21:52 UTC.

9. Buoy operation

To ascertain that ASIRAS and the HEM were profiling the same ice, ice motion along the South-North coincident ASIRAS and HEM profile was monitored by means of four GPS buoys operated by Jeremy Wilkinson of SAMS. Buoys were deployed on the following positions:

	Latitude (º)	Longitude (º)
Buoy 4	84.2028	-65.5167
Buoy 1	83.7285	-65.1694
Buoy 8	83.4539	-65.0879
Buoy 6	83.2119	-65.0717

Figure 24 shows the relative buoy tracks between 19:00 and 24:00 UTC on May 2, 2008, during which period the flights were performed. The figure shows that ice drift was minimal, and amounted to less than 20 m of s-N and E-W displacement, respectively. It was hardly distinguishable from the noise inherent in the GPS measurements.

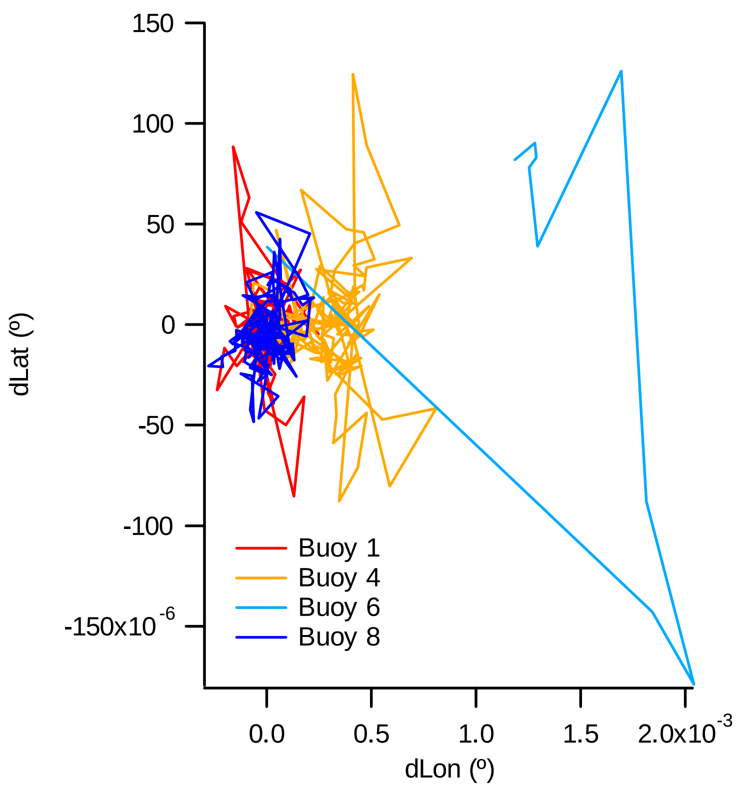


Figure 24: Displacements of buoys relative to their deployment position between 19:00 and 24:00 on May 2, 2008, along the ASIRAS/HEM coincident profile. The length of the abscissa and ordinate are approximately 25 and 30 m, respectively.