Labrador Shelf Pack Ice and Iceberg Survey, March 2009

S.J. Prinsenberg, I.K. Peterson, J.S. Holladay and L. Lalumiere

Ocean Sciences Division
Maritime Region
Fisheries and Oceans Canada

Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia
Canada B2Y 4A2

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Hydrography and Ocean Sciences 269**

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Labrador Shelf Pack Ice and Iceberg Survey, March 2009

by

**Simon J. Prinsenberg, Ingrid K. Peterson, J. Scott Holladay[1]
and Louis Lalumiere[2]**

**Ocean Sciences Division
Maritimes Region
Fisheries and Oceans Canada
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, N.S., B2Y 4A2**

[1] Geosensors Inc., 66 Mann Ave.,
Toronto, Ontario, M4S 2Y3

[2] Sensors by Design Ltd., 100 Peevers Crescent,
Newmarket, Ontario, L3Y 7T1

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Abstract

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This report presents examples of data collected in March 2009 off the mid-Labrador coast using helicopters from the Canadian Helicopter Company in Goose Bay, Labrador. The week-long survey collected ice thickness and ice roughness data with helicopter-borne Electromagnetic-laser sensors flown at 5-7m altitude along shoreward flight paths, and video and roughness data with a video-laser system flown at 100m altitude along seaward flight paths. A total of 550 kilometres of ice thickness profile data and 550 kilometres of video data was collected. Eight satellite-tracked ice beacons were deployed on both the pack ice and icebergs to monitor their southward drift rates in response to wind and ocean forcing. As indicated by the RADARSAT-2 image, four distinct ice thickness regimes were seen. Offshore, small wave-broken floes existed with a very homogeneous 1.2m modal thickness. Inshore of this region, large floes were observed with the same modal thickness of 1.2m, but with a larger thickness variability than that seen farther offshore. Areas of open water and thin ice with high small-scale roughness were seen offshore of the rough outer region of the land-fast ice. An experimental Ground-Penetrating-Radar (GPR) collected data showing snow thickness on sea ice along most of the flight paths where ice thickness data were collected.

To and from the Labrador coast, the snow and ice cover on Lake Melville was sampled with the EM and GPR systems. Lake Melville is part of a large estuary, with a freshwater surface layer due to outflow from the Churchill River and other rivers, and a saline lower layer. The EM data indicated that the freshwater surface layer was up to 5m thick. Ice samples contained salt, suggesting that the ice formed from salty water after the water column was mixed during fall storms. A hand-lowered CTD capable of going through a 2-inch auger hole in the ice verified the existence of the surface freshwater. The GPR measured snow thicknesses of up to 50cm on the ice of Lake Melville. All data, plots, photographs and reports are available through the DFO Maritimes Region's "SeaIce" Website: http://www.mar.dfo-mpo.gc.ca/science/ocean/seaice/public.html and its FTP data link: ftp://starfish.mar.dfo-mpo.gc.ca/pub/ocean/seaice/.

Résumé

Prinsenberg, S.J., I.K. Peterson, J.S. Holladay and L. Lalumiere, 2011. Labrador Shelf Pack Ice and Iceberg Survey, March 2009. Can Tech. Rep. Hydrogr. Ocean Sci. 269: viii+76pp.

On présente dans le rapport des exemples de données recueillies en mars 2009 au large du milieu des côtes du Labrador, à l'aide d'hélicoptères de la Canadian Helicopter Company à Goose Bay. Le relevé, effectué sur une semaine, consistait à collecter des données sur l'épaisseur de la glace et la rugosité de la glace à l'aide de détecteurs électromagnétiques laser héliportés, dans des appareils volant à une altitude de 5 à 7 m en suivant des trajectoires de vol en direction du rivage, ainsi qu'à collecter des données vidéo et des données de rugosité à l'aide d'un système vidéo laser balayant la zone à une altitude de 100 m le long de trajectoires de vol en direction du large. Au total, on a recueilli des données sur le profil d'épaisseur de la glace sur 550 kilomètres, et des données vidéo, sur 550 kilomètres. Huit balises de glace suivies par satellite ont été placées sur la banquise et sur des icebergs dont on voulait ainsi observer la dérive vers le sud sous l'action du vent et du forçage océanique. Comme le montre l'image de RADARSAT-2, on a enregistré quatre régimes de glaces distincts, du point de vue de l'épaisseur de la place. Au large des côtes, on trouvait de petits floes endommagés par les vagues, d'une épaisseur modale très homogène de 1,2 m. Dans les zones côtières, on a observé de grands floes ayant eux aussi une épaisseur modale de 1,2 m, mais pour lesquels la variabilité de l'épaisseur était plus importante que celle enregistrée plus loin des côtes. On a noté des zones d'eaux libres et de glace mince de grande rugosité à petite échelle au large de la portion rugueuse externe de la banquise côtière. Un géoradar expérimental (GPR) a été employé pour recueillir des données montrant l'épaisseur de la neige sur la glace de mer le long de la plupart des trajectoires de vol empruntées pour la collecte de données sur l'épaisseur de la glace.

On a échantillonné la couverture de neige et la couverture de glace sur le lac Melville à partir des côtes du Labrador et vers celles-ci à l'aide des systèmes EM et GPR. Le lac Melville fait partie d'un grand fjord; il possède une couche d'eau douce en surface provenant du débordement de la rivière Churchill et d'autres cours d'eau, et une couche inférieure d'eau salée. Les données EM ont révélé que la couche d'eau douce en surface faisait jusqu'à 5 m d'épaisseur. Les échantillons de glace prélevés avec une tarière renfermaient du sel, ce qui laisse supposer que la glace s'est formée à partir d'eau salée après mélange de la colonne d'eau pendant des tempêtes automnales. Un CTP capable de passer dans un trou de tarière de 2 pouces dans la glace a été descendu manuellement afin de vérifier la présence d'eau douce. Le GPR a mesuré des épaisseurs de neige allant jusqu'à 50 cm sur la glace du lac Melville. L'ensemble des données, des graphiques, des photographies et des rapports peuvent être consultés à partir du site Web de la région des Maritimes du MPO consacré à l'étude des glaces de mer (http://www.mar.dfo-mpo.gc.ca/science/ocean/seaice/public.html) et à partir de son lien FTP vers les données (ftp://starfish.mar.dfo-mpo.gc.ca/pub/ocean/seaice/).

Introduction

In March 2009, a field program was conducted along the Labrador coast to collect pack ice property data and to deploy satellite-tracked ice beacons on pack ice and icebergs. The observations are used to validate sea ice signatures in RADARSAT-2 imagery and to collect ice thickness distributions for input of offshore regulation codes and engineering structure designs. The observations also contributed to the research by the Canadian Ice Service to identify icebergs within the pack ice in RADARSAT-2 imagery and by the Canadian Geological Service to determine locations of recent iceberg scours. Three separate helicopter-borne observation systems have been developed by Canadian companies and are mounted in a cigar-shaped sensor package attached beneath and in front of a Bell 206L helicopter (Fig. 1). The helicopter-borne electromagnetic (HEM) system (called "Ice Pic") measures ice-plus-snow thickness and ice-surface roughness. The Ground Penetrating Radar (GPR) sensor measures the snow-depths over the sea ice cover and as well as the thickness of low-salinity ice (Lalumiere and Prinsenberg, 2009). The Video-Laser sensor collects video images to make mosaics from overlapping video frames. For the Labrador Sea ice survey, the helicopter-borne systems were mounted on a Bell 206L helicopter chartered for the survey from Canadian Helicopter Company stationed in Goose Bay. A second Bell 206L helicopter on fixed floats flew along with the surveying helicopter for safety concerns and carried the extra survey gear. Iridium GPS and ARGOS ice beacons were deployed on ice floes and on icebergs to track sea ice and iceberg drift rates, and record the locations of grounded icebergs within the pack ice.

Ice and snow properties were also collected from Lake Melville while on route to and from Makkovik on the Labrador coast. Since the GPR instrumentation was still in its early developmental stage, snow thickness tests were performed on Grand Lake just north of Goose Bay. The survey completed most of its planned tasks as described briefly in this technical report. All data, pictures, notes and reports will be available on the DFO's Maritimes Website: http://www.mar.dfo-mpo.gc.ca/science/ocean/seaice/public.html and through its data link on the DFO's Maritimes FTP site: ftp://starfish.mar.dfo-mpo.gc.ca/pub/ocean/seaice/.

Instrumentation

Electromagnetic-Laser Sensor

During the 7-day field survey, ice thickness and ice surface roughness were measured with a helicopter-borne electromagnetic (HEM) system, called the "Ice Pic", built by Geosensors Inc. of Toronto, Canada. The sensor package consists of an electromagnetic (EM) sensor with transmitter and receiving coils (transmitter frequencies of 1.7, 5.0, 11.7 and 35.1 kHz) and a laser altimeter. The laser altimeter data provides ice-surface roughness profiles and the height of the EM sensor above the pack ice. The laser is an ADM 3-Alpha Geophysical unit and has a listed accuracy of 1.5cm. The EM sensor measures the distance to the ocean surface water as it is the nearest conductor and the laser measures the distance to the pack ice surface. Together they provide the snow-plus-ice thickness. The sampling rate for the ice thickness and ice roughness data is 10Hz, corresponding to a spatial sampling interval of about 3-4m for the normal helicopter survey speed of 80mph. The ice thickness and ice conductivity are estimated with a 2-layer inversion model representing ice and seawater layers. The calculations are done in real-time on a computer strapped in the back seat of the helicopter and results displayed approximately 1sec later on a hand-held monitor used by the operator. The data are also post-processed to remove the effects of EM drift.

Fig. 1 Canadian Helicopter 206L showing the fix-mounted sensor equipment. The EM sensor is located in the outer section and the GPR and Video-Laser are located in the middle section of the “cigar” shaped mount.

The footprint size of the EM sensor depends on the height of the EM sensor above the seawater (Kovacs et al., 1995) and is 16-20m for the “Ice Pic” flying at 4m over 2m thick ice. Several studies have validated the EM ice thicknesses collected by both the “Ice Pic” and “Ice Probe”, a towed HEM system, by comparing EM ice thicknesses successfully with ice and snow thicknesses measured via holes drilled through the ice (Peterson et al., 2003 and Prinsenberg et al., 2008). For flat homogeneous ice over sea water such as refrozen leads, no difference can seen between auger observations and EM helicopter data as the difference are usually smaller than the variability in each data set. Over rough deformed ice, one has to average the auger holes to match the footprint size of the EM sensor, and once this is done the data sets again match normally within ±5cm (Peterson et al., 2003 and Prinsenberg et al., 2008).

Ground Penetrating Radar Sensor

Ground Penetrating Radars (GPRs) have the capability to measure snow thickness or freshwater ice thickness (Lalumiere and Prinsenberg, 2009). A one-dimensional processing algorithm provides snow thickness, and if the underlying ice has low salinity, it also provides the ice thickness. For the 2009 survey, the GPR profiles could only be viewed in post-processing mode whereas for the 2010 survey off the Mackenzie Delta (Prinsenberg et al., 2010) it became possible to display the data in real-time on a logging laptop operated in the helicopter to ensure data are being collected.

The GPR system used is a Noggin-NIC 1000 from Sensors and Software Inc. of Mississauga, Ontario. A photograph of a Noggin-NIC 1000 is shown in Fig. 2. The Noggin 1000-NIC is 30cm long by 15cm wide and 12cm high. The GPR system was mounted in the middle section of the 206L helicopter mount, with its bottom plate protruding outside the tube exterior (Fig. 2). The Noggin-NIC 1000 is a unique GPR system which permits operation and control by a computer with no user interaction. This permits the integration of this GPR as an additional sensor into the Video-laser System. The Noggin-NIC 1000 is a very high resolution GPR system, with a center frequency of 1000 MHz and a waveform sampling interval of 0.1 nanoseconds. The Noggin-NIC was configured to collect 500 points per scan with 4 internal stacks. This results in a scan rate of approximately 30 scans per second. When flying at 60-80 knots, the ground sample spacing is approximately one sample per 1.0-1.5m. This fine spacing permits the GPR to collect snow features at the same fine scale as the laser for surface ice roughness.

Fig. 2 Sensors and Software Noggin 1000-NIC GPR System (left) protruding from middle section of the mounting tube along with laser/video camera (right).

Video-Laser System

The Video-Laser system consists of the laser and video camera (Fig. 2). The 3-Alpha laser altimeter, manufactures by Optech Inc., measures the flying height and ice roughness; for a sampling rate of 30 Hz it provides a 1.5m sample spacing at a flying speed of 80 knots. The digital camera used is an Axis 210 by Axis Communications. Images are typically collected at a rate of 2 Hz but the rate is determined by the logging system based on the image field of view, flying height and speed. Each image is 640 by 480 pixels in size, and with a typical flying altitude of 90m each pixel is approximately 30cm by 30cm in size. The width of the video frame image equals 1.1 times the height of the video camera above the pack ice surface. Since the helicopter flies low (altitude 4 to 6m) when logging GPR and EM data; digital video images are not recorded during these survey lines. Video data were collected on the offshore flight paths at an altitude of approximately 90-100m, while EM and GPR data were collected on the in-bound flight paths. The Video-laser system also collects laser altimeter data for additional surface roughness determination.

GPS Sensors

Both the "Ice Pic" and Video-GPR systems have their own GPS sensors so that the systems can be flown independent of each other when either malfunctioned. The GPS units used are Garmin GPS18's made by Garmin International Inc., Olathe, USA. The GPSs include an embedded receiver and an antenna, and track up to 12 satellites at a time, while providing fast time-to-first-fix, precise navigation updates once per second. The units are designed to withstand rugged operations, are waterproof and require minimal additional components to be supplied by a system integrator. The "Ice Pic" and Video-GPR systems provide the GPSs with a source of power, and a clear view of the GPS satellites is required. Listed position accuracy are given as <15m, 95% of the time.

Survey Description

After arriving in Goose Bay at noon on Monday March 16, time was only available to check if all the equipment had arrived at the Canadian Helicopter Company (CHC) base and meet the pilots Chris Rodway and Henry Blake. Only half of the equipment was there, but the remaining equipment arrived the next morning. It took all of the following day (Tuesday) to mount the system and obtain flight approval to survey at low altitude with pop-out floats. Gear required for the Labrador offshore survey was repacked and put into the second helicopter. Finally both helicopters were ready by noon (Wednesday, 18 March) to go to Makkovik via Lake Melville and Rigolet. Chris Rodway was the pilot of the survey helicopter and Henry Blake flew the second helicopter. He was accompanied by helicopter engineer Dylan Pike and his helicopter carried all personal gear and beacons. Pilot Dean Burry replaced Henry Blake after two days.

All systems were tested near Goose Bay before the second helicopter left the CHC base for Makkovik. The EM ice thickness data from Lake Melville were puzzling when they first appeared on the real-time display unit. Constant 3 to 4 m values of “ice” thickness were displayed. On-ice sampling five days later on the way back to Goose Bay showed that there was a surface layer of fresh water present between the salty ice and the low salinity water of Lake Melville and was interpreted by the EM signal as “ice”. The freshwater layer is the result of the runoff from the Churchill and other rivers. The salt within most of Lake Melville ice prevented the GPR from seeing the bottom of the ice.

After dropping off the gear at the hotel and refuelling at the Makkovik airport (14:00), a survey line was flown perpendicular to the coast off Makkovik, with strong SE alongshore winds and an overcast sky (Fig. 3, line FEM09203-18MAR). Starting at 14:35, Video data were collected along the flight line offshore and EM and GPR data along the return onshore flight line. Light and wind conditions were not favourable for this first flight for the pilot Chris Rodway. All Video and EM data were collected successfully, and most of the GPR data were collected as well. Collection of the GPR data for the first time caused some trouble when switching from Video to GPR logging software using the same logging laptop.

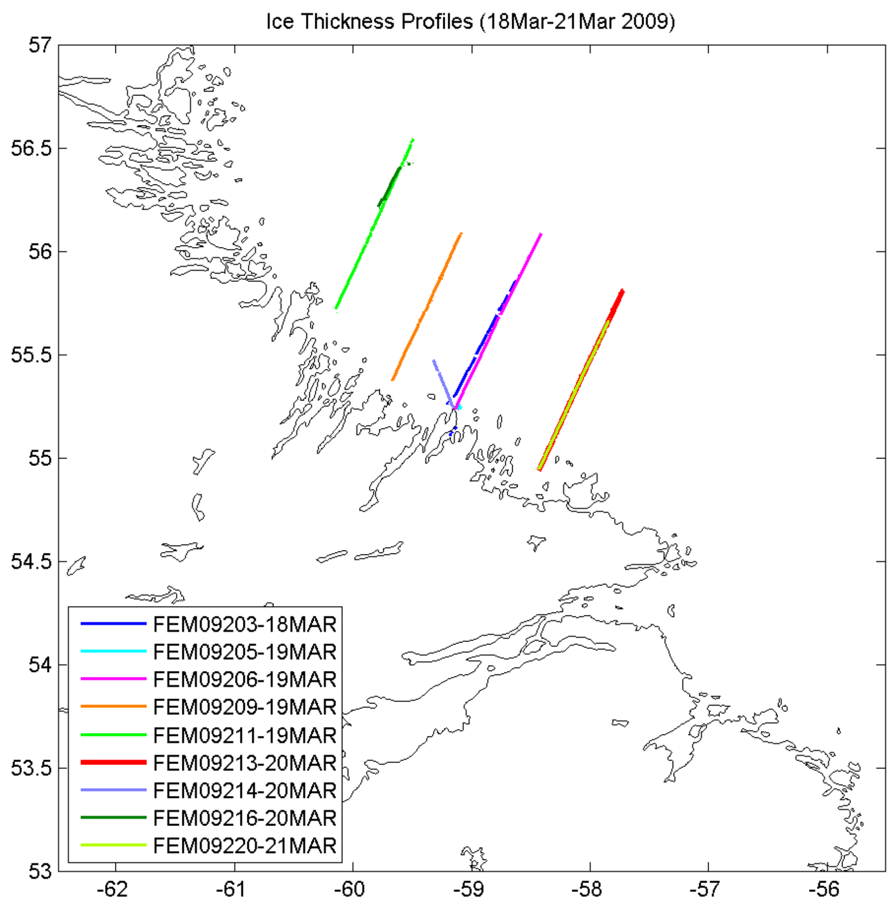

Fig. 3 Survey lines off the Labrador coast along which EM ice thickness, Laser ice roughness and experimental GPR snow thickness data were collected. Line numbers represent the EM file numbers and dates when the data were collected. The four line locations are Hopedale (north), “middle”, Makkovik, and mooring line (south).

For Thursday 19 March, two survey lines were originally planned, both parallel to each other, spaced 20km apart and again perpendicular to the coast line. The first line was off Makkovik (FEM09206-19MAR) and repeated the line surveyed on Wednesday afternoon (March 18). Video data were collected (09:15-09:55) along the offshore flight line of approximately 70miles. EM and GPR data was collected along the shoreward flight line (10:00-11:10), flying slower at 80mph. The second helicopter deployed two ARGOS beacons on sea ice along the line at 20 and 50miles from the land-fast ice. While at the airport, the wind turned from the south to the NNW, a snow squall passed through and the weather cleared by 12:30.

After refuelling, Video data were again collected along the offshore flight line (12:52-13:20), which was 20km north of the Makkovik line. At the end of the line, it became very hazy and a lot of smaller floes were present which appeared to have been broken up by waves. Along both sides of the flight line floating and grounded icebergs were seen. Both helicopters landed on ice to give the auger to the second helicopter, and to deploy ice beacon #12996. The second helicopter flew over to an iceberg to try to deploy an ARGOS beacon on it. The snow layer on the floe we landed on was only 10-15cm thick, with higher snow thicknesses in cracks and ridges. Snow thicknesses looked larger from the air especially at the floe edges. EM and GPR data were collected on the in-bound flight line that ended at 14:45 over land-fast ice; from there we went to Hopedale airport for fuel as enough time remained to do the Hopedale line as well. The second helicopter deployed a beacon on the large iceberg. The beacon was deployed on the lower flat tongue area as it was too windy near the top of the iceberg (height estimated by altimeter difference to be 225ft). The iceberg appeared to be moving relative to the pack ice, but it was found later that the iceberg was grounded and the ice was moving around the iceberg.

Fig. 4 Group of icebergs seen midway along the Hopedale survey line on March 19.

As there was still time left, a third line was flown off Hopedale. Again Video data were collected along the offshore flight line, and EM-GPR along the in-bound line. Winds had turned to NW. The Video was started (15:35 AST) before rough land-fast ice appeared; older shear ridges within the land-fast ice were present. Rough land-fast ice was present between the islands, as these offshore islands appear to anchor the semi-permanent land-fast ice. Small icebergs were seen offshore of the islands and south of the track. Frazil ice with some finger rafting was present offshore of the land-fast ice edge. At the end of the line the wave-broken ice floes again appeared, and about ten large icebergs were clustered just south of the line (Fig. 4). We passed the last iceberg at 16:10 and turned back to Hopedale, collecting EM and GPR data. We reached the land-fast shear ridge by 17:20 and were back at Makkovik airport by 18:00.

Friday March 20. Henry Blake left, and the new pilot Dean Burry had arrived the night before. We were at the airport hangar by 8:30, and it was very windy and cold. The second helicopter on floats did not start due to the cold and needed a battery boost and some fuel-line de-icing. Finally the engines of both helicopters were running and warming up at 09:45. A CCG helicopter also at the airport could not start and needed a battery boost as well. The mooring line south of the Makkovik line was surveyed in the morning. Video data were collected along the offshore flight line (10:10–10:44). During the outbound flight, the second helicopter deployed two Iridium beacons on pack ice along the mooring line, one at the mooring site and one 12miles farther offshore. EM and GPR data were collected along the in-bound flight line between 10:44–12:00. Both helicopters left Makkovik airport at 13:00, and collected EM and GPR data along a flight line to the centre of the northern (Hopedale) line where all the icebergs and some MY ice were seen the previous day. It was too hazy to collect Video data on the way out, so EM-GPR data were collected instead. We could not find the MY ice floe that was seen the previous day, and turned to Hopedale for fuel.

The Hopedale line was repeated after refuelling. Video data were collected on the offshore flight line; first (15:11) at 100m and then (15:27) halfway along the line at 100ft to look for the MY ice floe. An Iridium beacon was placed on the inshore mobile pack ice; it never worked and was probably not started properly. The last ARGOS beacon was placed on a small iceberg, and an Iridium beacon on a small tabular iceberg (16:12). Then the last Iridium beacon was placed father offshore on a large iceberg (16:21). From this offshore position, Video data were collected on the way back to Makkovik (17:20). Still photos were taken of the icebergs and beacons deployed on the icebergs.

The plan for Saturday March 21 was to repeat the mooring line and then return to Goose Bay, with the survey helicopter doing on-ice work on Lake Melville to verify the "ice thicknesses" of 3-4m seen on the trip out to the coast. Video data were again collected along the offshore flight line (09:35-10:08) and EM-GPR data along the in-bound flight line (10:05-11:30). No icebergs were observed along the mooring line, but several large icebergs were seen in the distance to the south. After refuelling at the Makkovik airport (10:55), the second helicopter packed with gear went directly back to Goose Bay.

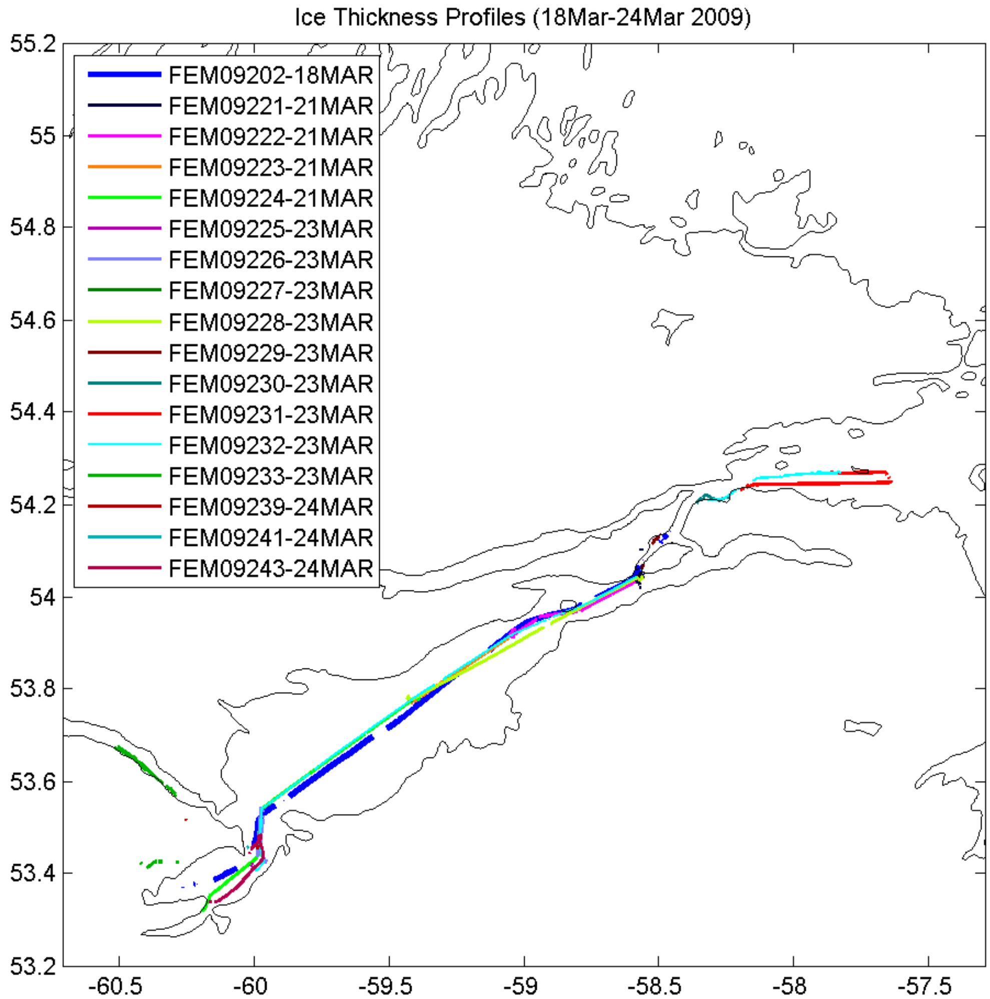

Fig. 5 Lake Melville survey lines of March 18 and 21 done on transit to/from Makkovik, and of March 23 and 24 done during the sampling of Lake Melville snow and water properties. Snow thickness profiles from Grand Lake were collected on March 23 (dark green line FEM09227).

Fig. 5 shows the EM flight lines sampled in the Lake Melville area during the March 2009 ice survey. On March 21, three on-ice sites were visited where ice and snow thicknesses were measured through ice auger holes. A CTD (Idronaut Ocean Seven 304) was used to sample the surface water layer (4-5m) layer properties. Short E-to-W and S-to-N flights were flown over the sites, forming a cross-shaped flight pattern. We returned to CHC Base in Goose Bay by 16:00 and did not fly the next day (Sunday March 22). On Monday, the Melville Lake stations were revisited and additional CTD profiles were obtained to greater depths by connecting the CTD to a metal measuring tape. The surface layer runoff was followed offshore past the narrow entrance to Lake Melville. A total of 5 on-ice stations were completed. On Tuesday March 24, the final survey day, GPR snow thickness tests were done on Grand Lake just north of Goose Bay (Fig. 5). A complete day-to day report on the daily survey tasks and results are listed in the Appendix 1.

Table 1 below lists the EM, GPR and video files collected during the Labrador ice survey of March 2009.

date	area	FEM File	GPR files	Video files	pictures
March 18	Lake Melville	09201-09202	F516-F520	77F205-F214	5201-5213
March 18	Makkovik line	09203-09204	F521-F525	77F215-F218	5214-5235
March 19	Makkovik line	09206-09207	F526-F533	77F219-F223	5236-5292
March 19	Middle line	09209-09210	F534-F540	77F225-F228	5295-5398
March 19	Hopedale line	09211-09212	F541-F546	77F229-F237	5399-5437
March 20	Mooring line	09213-09214	F547-F554	77F238-F241	5438-5526
March 20	to Hopedale line	09214-09215	-----	77F242-F244	5527-5553
March 20	Hopedale line	09216-09217	-----	77F245-F250	5554-5588
March 21	Mooring line	09218-09220	F562-F568	77F521-F	5589-5580
March 21	21-1L Melville	09221	F569-F570	-----	5590-5693
March 21	21-2L Melville	09222	F574-F575	-----	5694 -
March 21	21-3L Melville	09223	F579-F580	-----	-------
March 21	21-3 to Goose	09224	F582-F586	-----	- 5714
March 23	To Stn 23-1	09225	----	CTD 019	------
March 23	To Stn 23-2	09226	F587	CTD 020	------
March 23	To Stn 23-3	09227	F591-F593	CTD 021	------
March 23	To 23-4, 23-5	09228	F594-F601	CTD 022-23	5715-5731
March 23	Back to Goose	09229-09232	F602-F619	------	5732-5751
March 24	Grand Lake 1	09235-	F620-F627	77F257-F259	5752-
March 24	Grand Lake 2	-09238	F628-F631	77F260-F265	-5760
March 24	Lake Melville	09239-09243	F631-F650	------	------

Table 1. File numbers of data collected during the Labrador ice survey of March 2009.

Data Samples

Electromagnetic-Laser Ice Thickness

One of the aims of the program was to collect ice roughness and ice thickness data to identify ice features seen in RADARSAT-2 imagery. Fig. 6 shows the ice thickness data collected off the Labrador coast between March 18 and 21 overlain on a HH RADARSAT-2 image of March 19 (1015Z). The longer lines at the three northern locations (Hopedale, "middle" and Makkovik) were collected on March 19, the same day as the image was acquired.

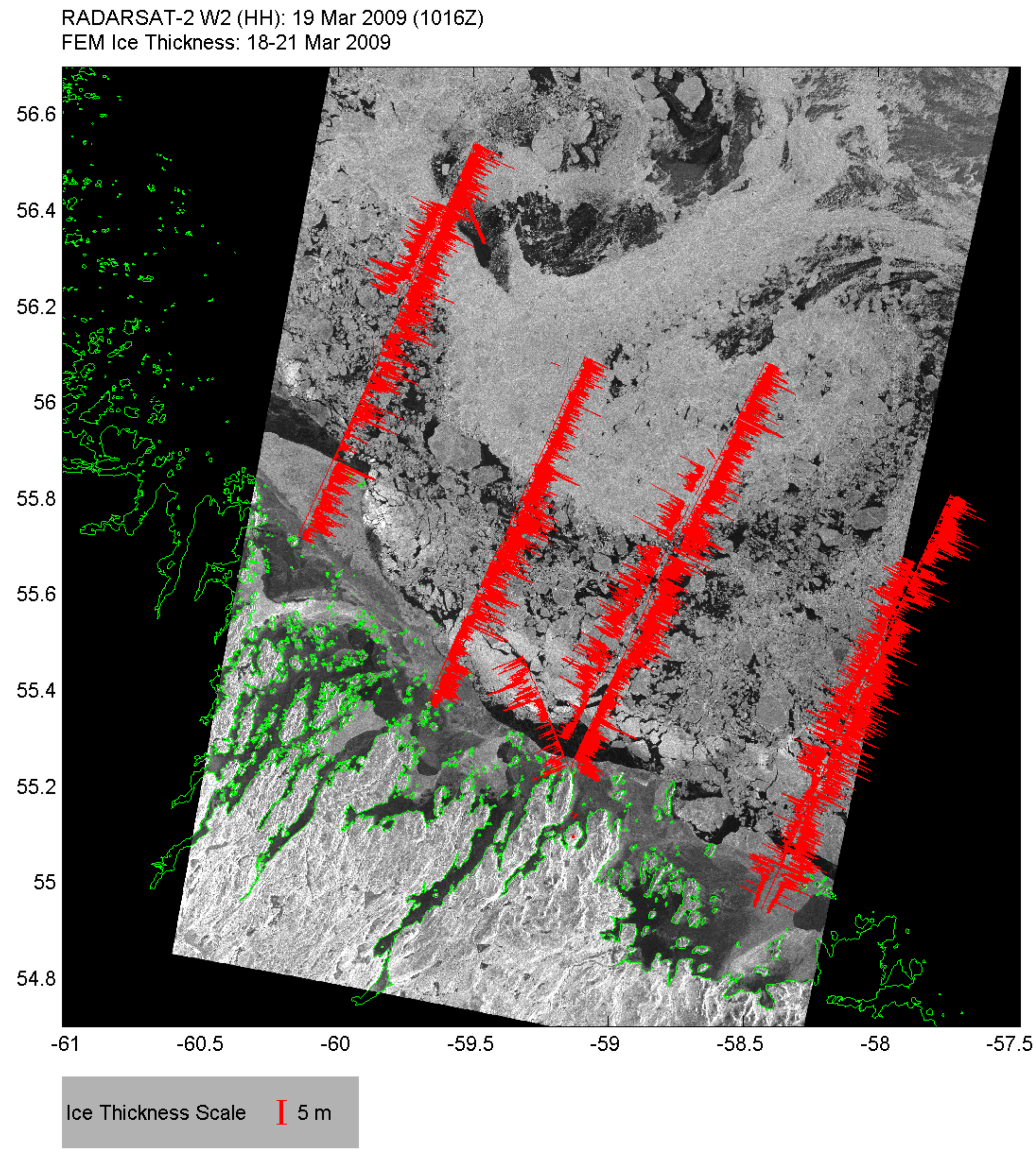

Fig. 6 March 19 RADARSAT-2 image overlain with ice thickness data collected on March 18 to 21(© RADARSAT-2 Data and Products © MacDonald, Dettwiler and Associates Ltd. (2010) - All Rights Reserved).

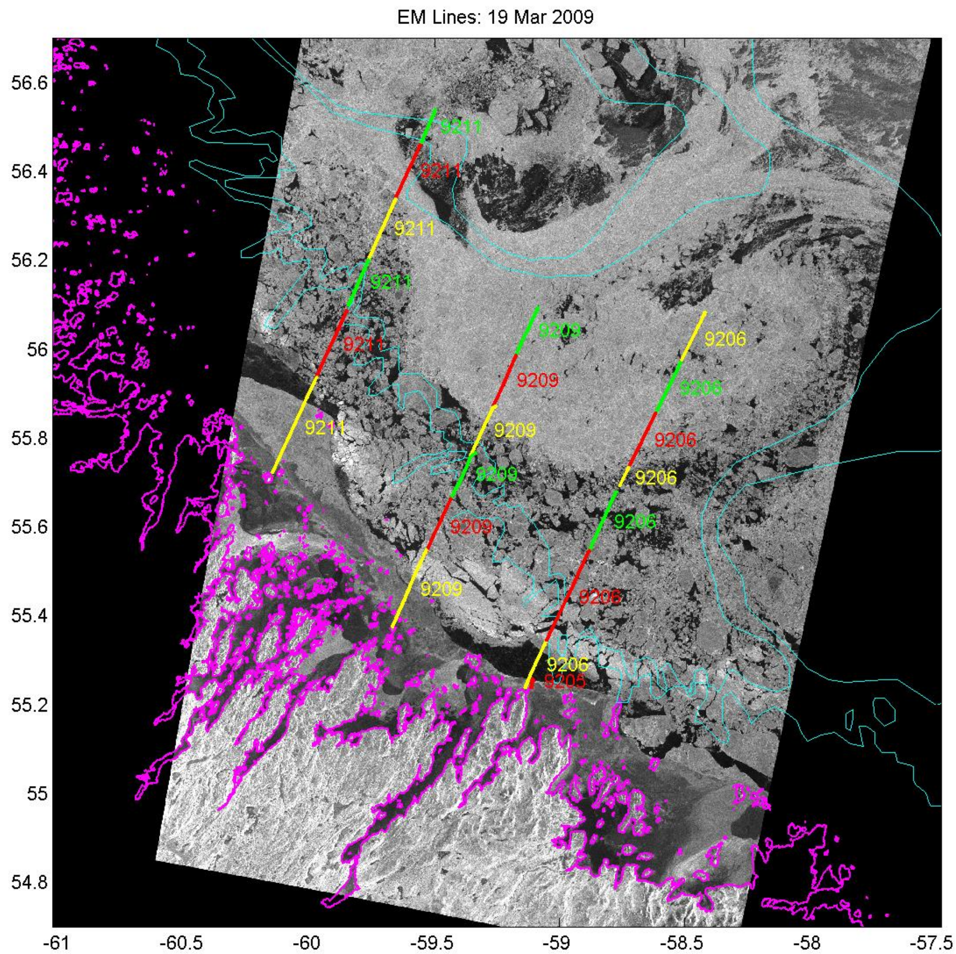

Fig. 7 March 19 RADARSAT-2 image overlain with EM subsection lines flown on March 19 and used referred to in 3 ice thickness profiles, Figs. 8, 11 and 14 (© RADARSAT-2 Data and Products © MacDonald, Dettwiler and Associates Ltd. (2010) - All Rights Reserved).

The images (Figs. 6 and 7) show several distinct SAR ice signature regions. Offshore there is a bright SAR homogeneous region (Region A); then inshore of this is a region with a mixture of dark areas and moderately-bright areas (Region B). Farther inshore of this at 55.4°N, 59.4°W are other bright regions where remnants of frost flowers and small scale roughness features were seen on thin ice (Region C). Just before the land-fast ice area, several large dark areas appear representing open water and scattered frazil ice areas (Region D). The differences in ice thickness of these regions are hard to distinguish in Fig. 6 from the overlain ice thickness data. However, in general the ice thicknesses for the offshore region A are less variable and do not attain the higher extreme values seen in the inshore region B. The outer land-fast area is generally brighter and has thicker and rougher ice, while the inshore land-fast area is darker with low homogeneous ice thicknesses. Near the land-fast areas, the ice thicknesses for both the bright and dark inshore areas are small and appear the youngest ice in the sampled area. The edge of the land-fast ice along the Hopedale line is well captured by the observations, and aligns well with the SAR image features.

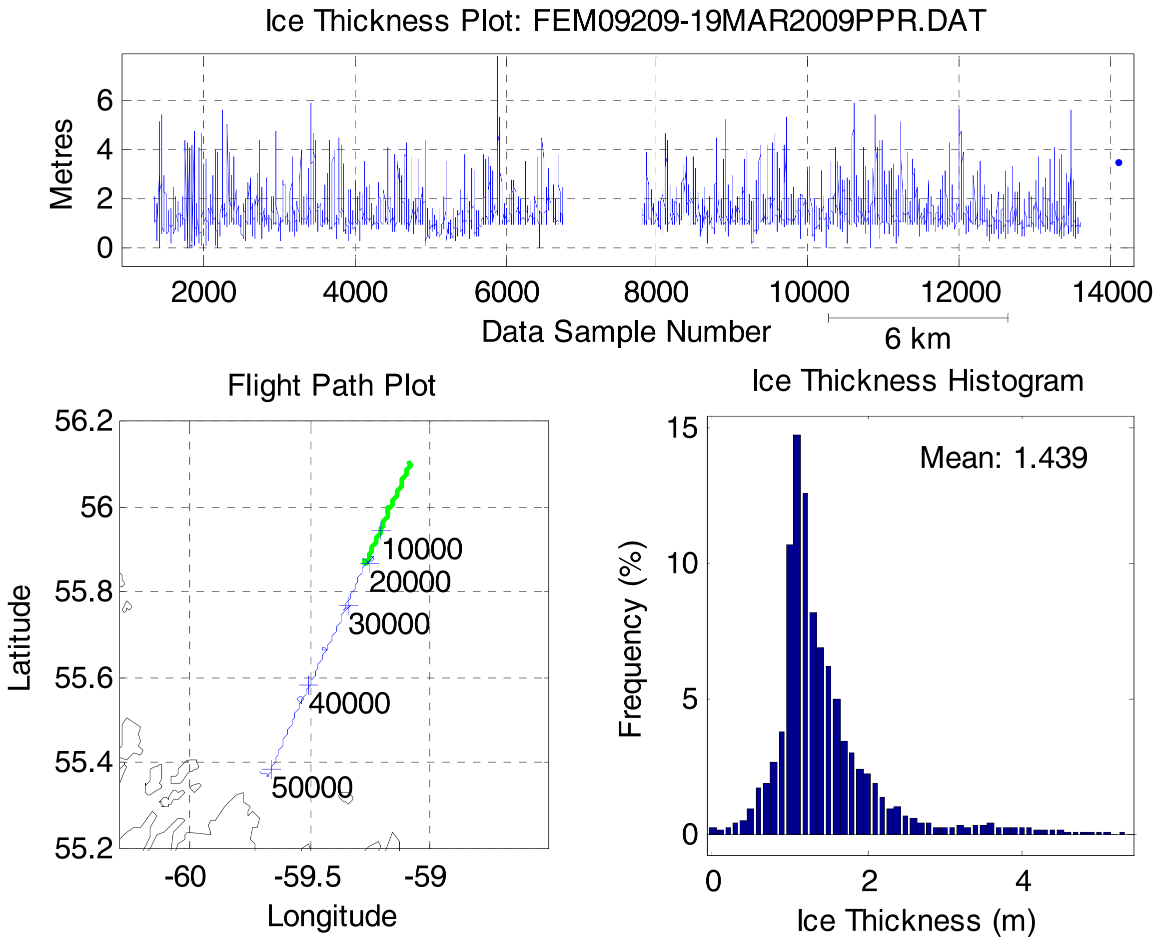

Fig. 8 Offshore sub-section (~30km) of the ice thickness data from the "middle" survey line. The green line in the map shows where the ice thickness profile data plotted and used to derive the histogram were collected.

Fig. 8 shows a sub-section (30km) of the ice thickness profile data (FEM09209) collected along the "middle" line, the line between the Makkovik line to the SE and the Hopedale line to the NW. In the SAR image (Fig. 7), this sub-section profile data covers the offshore bright area represented by the green and red offshore line sections in Fig. 7. The data were collected flying shoreward, so the left of the profile is the offshore end and the right is the inshore end. The ice thickness is very homogeneous and has a modal ice thickness of 1.2m, representing the ice thickness most frequent seen in the line profile, and the total region had a mean thickness of 1.4m. The variability about the modal thickness is small and not many leads (zero ice thicknesses) appear in the ice thickness profile. The photographs in Figs. 9 and 10 show the pack ice conditions along the sub-section where the SAR image shows the presence of very homogeneous pack ice conditions. The photos are from the middle of the thickness plot shown in Fig. 8 where a back-ground measurement was done for the EM system; in Fig. 7 this is where the offshore line of FEM09209 changes colour from green to red.

Fig. 9 Wave-broken pack ice of the offshore section shown by the ice thickness profile of Fig. 8 taken during the back-ground measurement (300ft) at sample #7000.

Fig. 10 Wave-broken pack ice of the offshore section shown by the ice thickness profile of Fig. 8 taken from 5m after back-ground measurement at sample #7000.

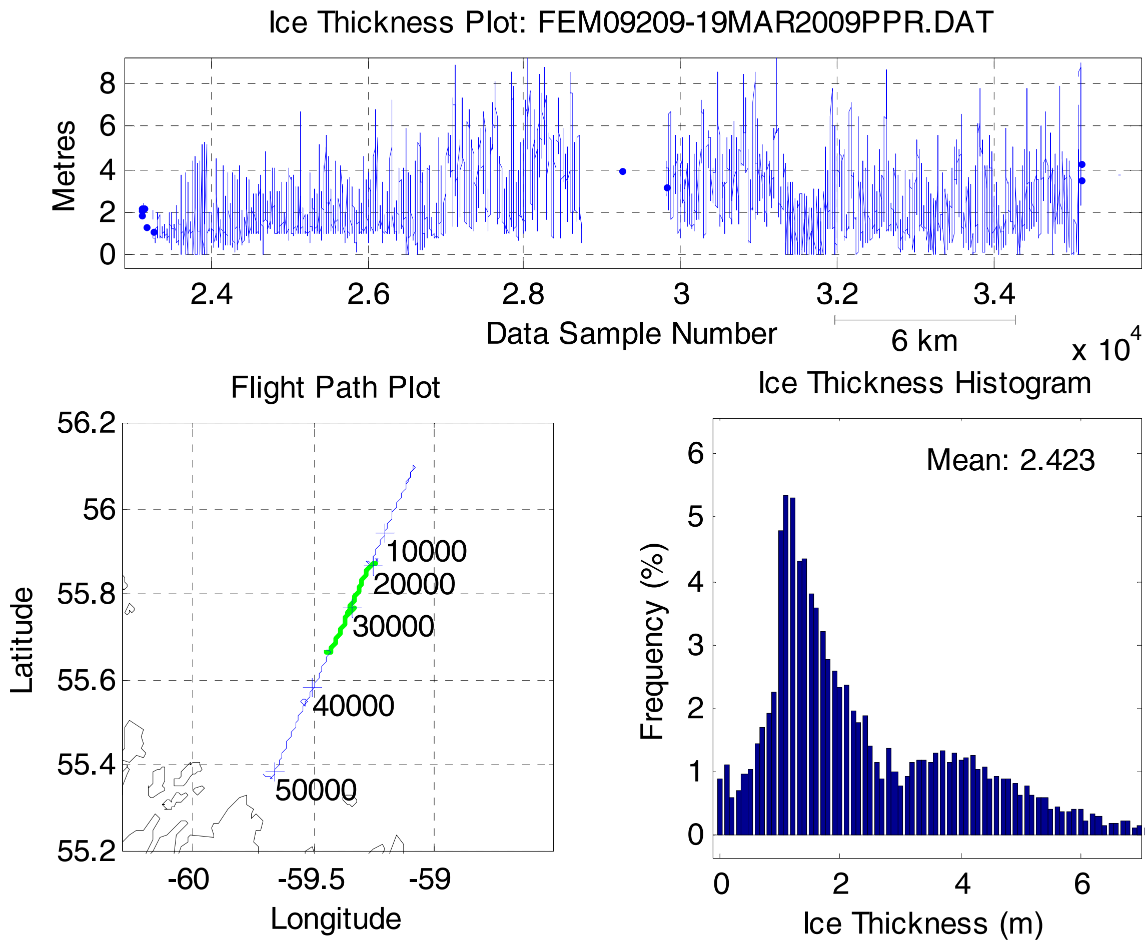

Fig. 11 Middle sub-section (~28km) of the ice thickness data from the "middle" survey line (left is offshore and right inshore). The green line in the map shows where the ice thickness profile data plotted and used to derive the histogram were collected.

Fig. 11 shows the ice thickness profile data of the middle data section of FEM09209, where the ice thickness properties change from the homogeneous offshore bright SAR ice area to the middle ice area, where both bright and dark areas appear in the image. In the SAR image (Fig. 7), the data shown in Fig. 11 are from the middle line sections coloured yellow and green. The change from the offshore SAR bright ice properties occurs at the sample number 2.7×10^4 in the ice thickness profile line plot (Fig. 11). Inshore of this, the ridges frequently reach thickness values of 6-8m whereas offshore, values of only 4-5m were observed. The histogram shows a second minor peak in this region at 4.0m, in addition to the thinner modal peak at 1.2m. Another EM background measurement was done at sample 2.9×10^4 where the photographs shown in Figs. 12 and 13 were taken.

Fig. 12 Photo of rough large floe from the ”middle” line during a background measurement at 300ft at sample number $2.9x10^4$ shown in the ice profile in Fig. 11.

Fig. 13 Photo of rough large floe from the ”middle” line after background measurement at sample number $2.9x10^4$.

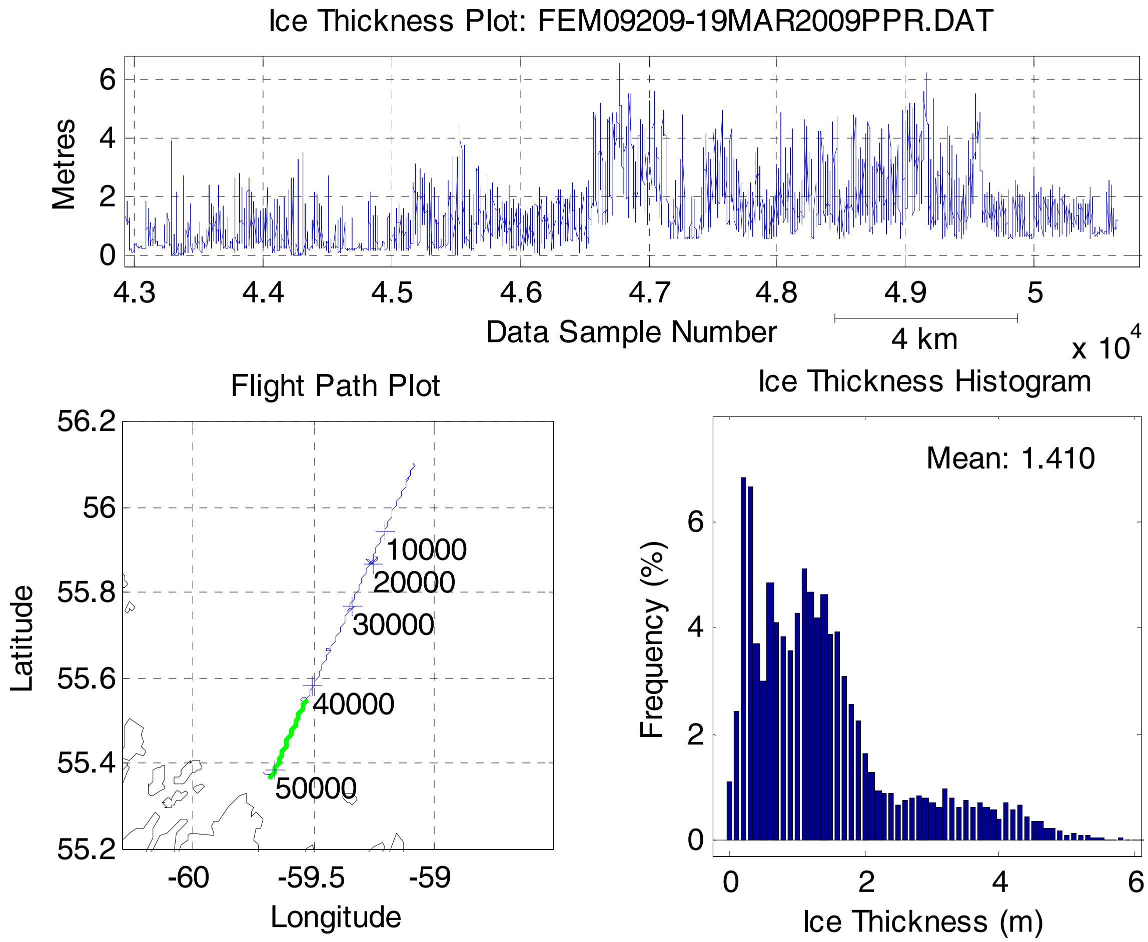

Fig. 14 Inshore sub-section (~24km) of the ice thickness data from the "middle" survey line. The green line in the map shows where the ice thickness profile data plotted and used to derive the histogram were collected. The thin ice area with frost flowers is on the left and the land-fast ice is on the right starting at sample # $4.65\text{x}10^4$.

Fig. 14 shows the inshore sub-section of the "middle" line where the ice properties change from thin ice with frost flowers and small scale roughness properties to land-fast ice. Leads were also present as shown by the zero ice thicknesses, and the land-fast ice section started at sample number $4.65\text{x}10^4$, where the shear ridge of 5m thickness can be seen. In the SAR image (Fig. 7), this line plot covers the inshore yellow line section of the middle line of FEM09209. The histogram for the thin offshore ice thickness has peaks at 0.25m and 0.70m. A photo of the pack ice (0.25m thick) with high small-scale roughness is shown in Fig. 15. The offshore section of the land-fast ice is very rough, and has several shear ridges which appear to have formed as the land-fast grew spatially offshore. Inshore, the land-fast ice is thinner (1.0m) and not as rough. It probably represents the oldest part of the land-fast area, and is thinner than the regional average of 1.07m ice plus 0.15-0.20m snow (Canadian Ice Centre, 1982).

Fig. 15 Photo of the bright area in the image just before reaching the land-fast ice edge. Thin ice is covered with high small-scale roughness features.

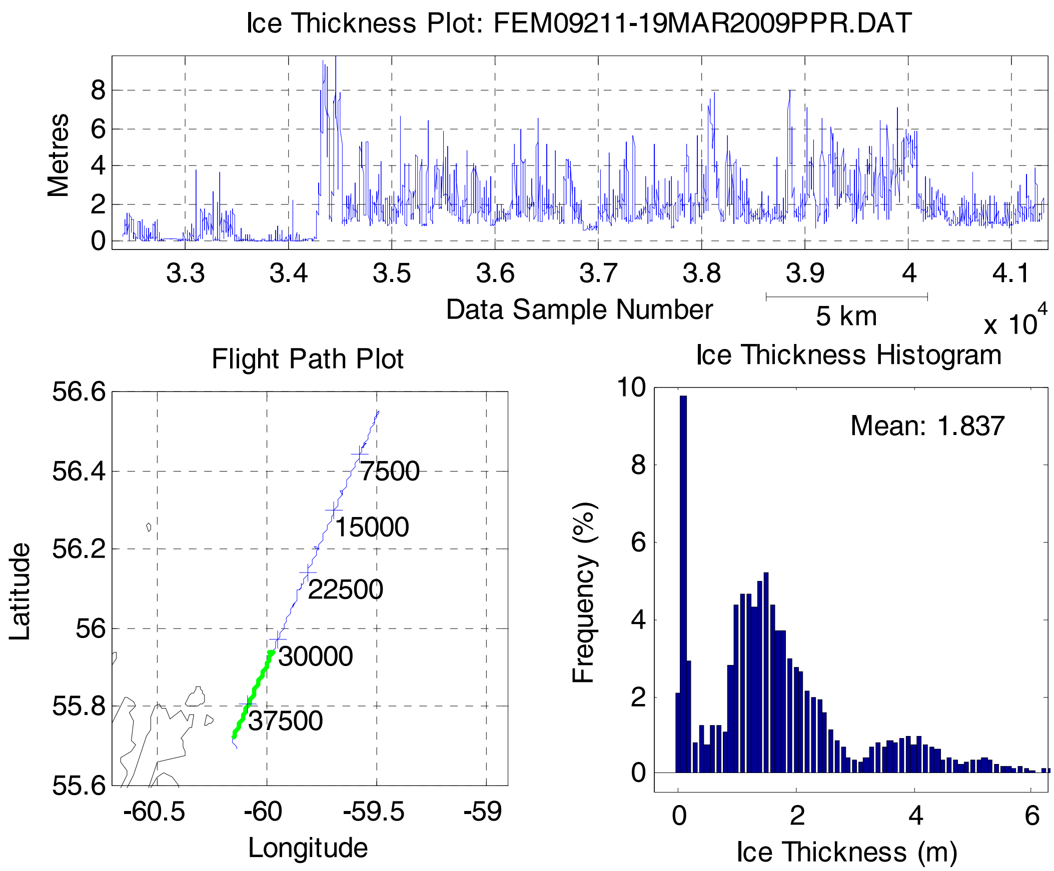

Fig. 16 Inshore sub-section (green line ~32km on map) of the ice thickness data of the Hopedale line, showing shear ridge and land-fast ice (left is offshore and right inshore).

In the RADARSAT-2 image (Fig. 6), the overlain inshore ice thickness for the Hopedale line lined up exactly with the ice features of the image. The large shear ridge of 9m separates the inshore land-fast ice from the thin offshore mobile ice cover. The ice thickness profile of this transition from thin ice and open water area to land-fast ice is shown in Fig. 16. The thin offshore ice and open water is on the left side of the profile and the 9m shear ridge is at sample #3.45×10^4 followed on the right of the profile by land-fast ice. Some older shear ridges of up to 6m are also visible within the rough part of the land-fast ice. The land-fast ice here was anchored by several small offshore islands, and it was noticed that the land-fast ice between the islands was very rough, probably due to ridging. The ice thickness profile data also show that farther inshore, the thinner and older land-fast ice of 1.0m thickness is again present similar in the "middle" line shown in Fig. 14. This older homogeneous land-fast ice is darker in the SAR image (Fig. 6) and appears all along the coast shown in the image.

Fig. 17 Photo of the rough land-fast ice off Hopedale anchored by offshore islands: one island at the top right. Beyond the ice edge, open water and frazil ice can be seen.

The ice thickness histograms can be combined to give a total ice thickness distribution for the total 550km distance sampled (Fig. 19). It captures modal ice thicknesses in the three distinct ice areas: the modal thickness of 1.1-1.2m in the offshore area, the modal thickness of 3.5m in the mid-area with large rough floes, and the modal thickness of 0.5-0.6m in the inshore thin mobile ice region. Up to 7% of the region sampled consisted of large open water leads, and 16% of the area consisted of thin ice less than 0.25m thick and open water.

Fig. 18 Photo of nilas ice with some rafting off Hopedale. The thin ice was covered with frost flowers, making this part of the ice cover very bright in the RADARSAT-2 image (Fig. 6).

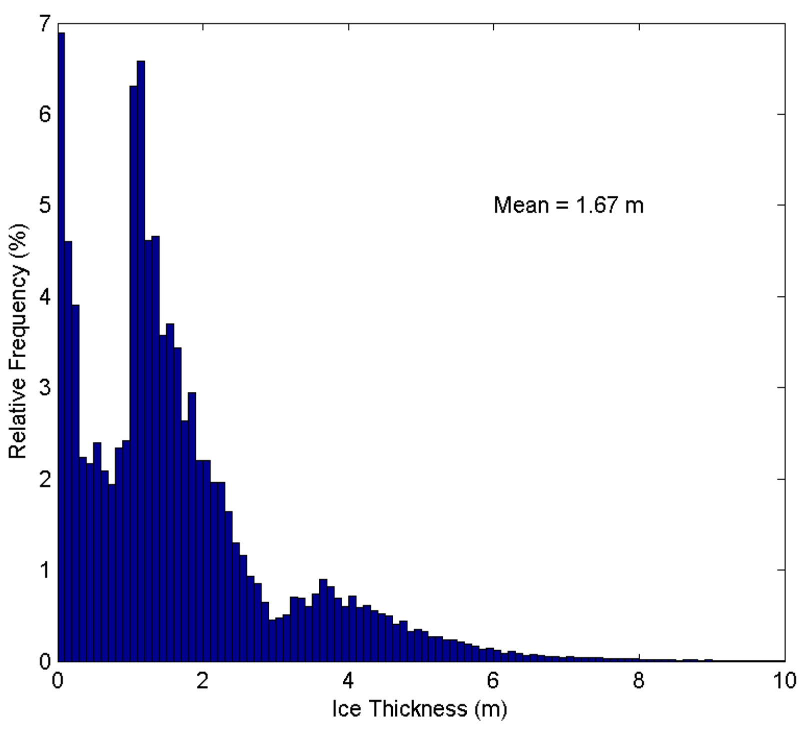

Fig. 19 Combined ice thickness histogram of the ice thickness profiles collected off the Labrador coast during March 2009. (Total profile distance of 550km)

Only some of the ice thickness profiles data have been shown along with a few still photos; all the ice thickness data of the survey in digital and plot forms along with more pictures are available through DFO Maritimes FTP site: ftp://starfish.mar.dfo-mpo.gc.ca/pub/ocean/seaice/. The files used in the field are the "PIC rawfiles" and "PIC datfiles". They are used in the field to quickly plot the observations as line plots and histograms and E-mail the plots to other collaborators and the Canadian Ice Service for their inclusion in the production of ice charts. During the transcribing of the RAW files into "DAT" files, other files are generated in different formats and used in additional analysis and plotting. These files are all on the FPT site along with the "Ice PIC DAT" plots that can be accessed through the DFO Maritimes "Seaice Website". http://www.mar.dfo-mpo.gc.ca/science/ocean/seaice/public.html.

Offshore GPR Snow Thickness and Video Data

Snow thickness data were collected with the Ground-Penetrating-Radar during the low-altitude flights when ice thickness data were collected with the Electromagnetic–Laser system. Software developed for the 2010 Beaufort Sea survey was used to post-process the GPR data, and samples for March 19 will be shown. The file numbers of the GPR data on March 19 is shown overlain on the SAR image of March 19 (Fig. 20).

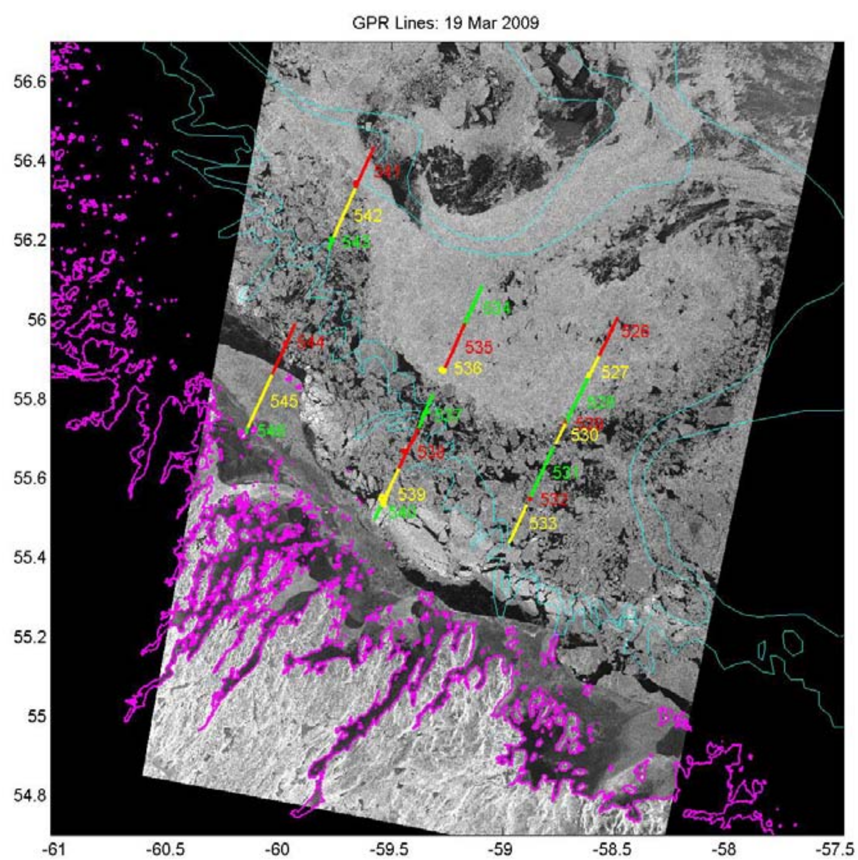

Fig. 20 RADARSAT-2 image overlain with line sections and file numbers of the GPR data collected on March 19 (© RADARSAT-2 Data and Products © MacDonald, Dettwiler and Associates Ltd. (2010)- All Rights Reserved).

As was the case for the EM data, the GPR and Video samples shown will mainly be from the "middle" line. For the offshore bright SAR region, the EM (Fig. 8) and photographs (Figs. 9 and 10) show that this pack ice region consisted of wave-broken floes with a modal 1.2m ice thickness. The GPR data (Fig. 21) from the start of the section line section (#535) shows that very little snow (mean of 0.10-0.20m) is present on these small floes. It is a "screen-grabbed" figure that is generated through the real-time GPR logging-display software now available during the surveys to ensure the data are collected and stored properly. The software can be used to re-display the data in evenings during the survey.

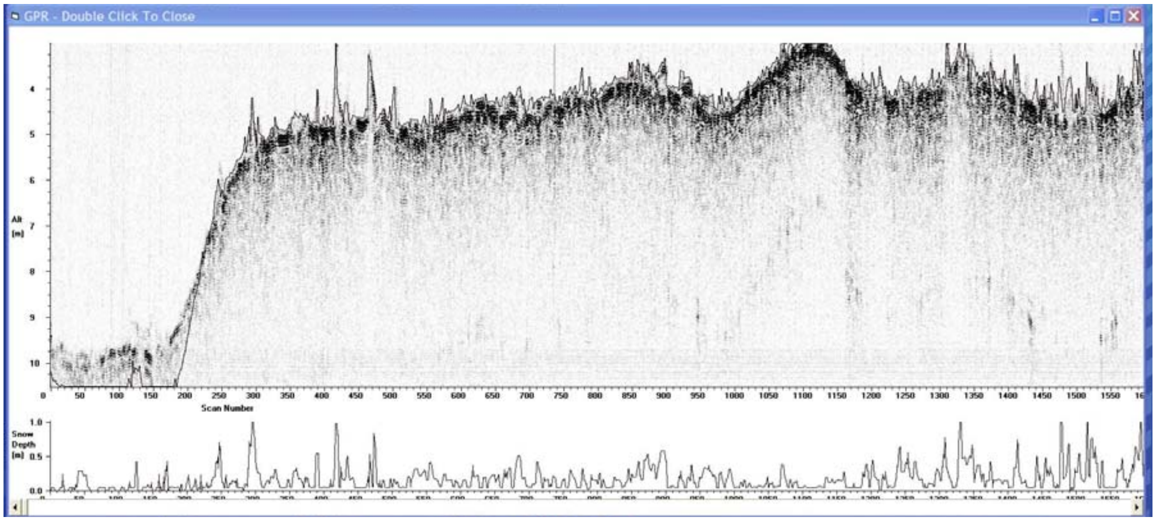

Fig. 21 Start of GPR line #535 showing ~2km of GPR-Laser profile and resulting snow thickness profile. Left side is offshore and right side inshore.

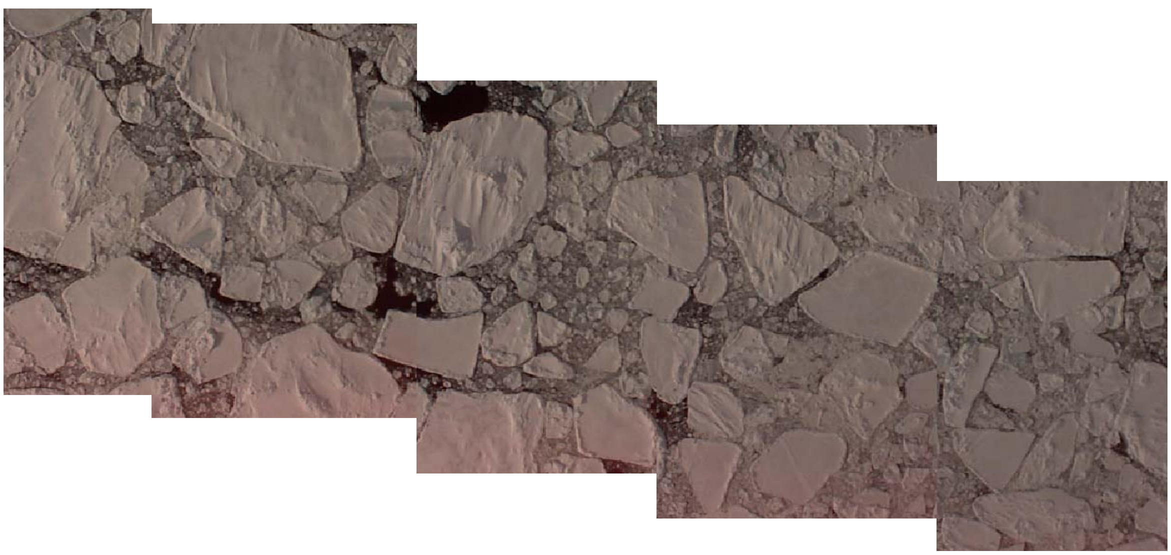

Fig. 22 Mosaic of 5 overlapping video frames (start frame #9390) showing the wave-broken floes during the offshore flight, in the same general area the GPR data shown in Fig. 21 were obtained. The video frame widths are 130m.

As shown in the mosaic (Fig. 22), the floes have snow dune patterns with thicknesses according to the GPR data of over 0.50m (Fig. 21). However, much blowing snow falls in the cracks between the floes, and stimulates the growth of slush ice that appears grey on the mosaic. Since the video mosaic width is 130m, most floe diameters are in the range of 25-30m, with some as high as 60m. Just at the edge of the darker ice in the SAR image along the “middle’ line (the start of the GPR line #537), larger floes of 200m and greater appeared, as shown in the mosaic of Fig. 23. Snow thicknesses are higher than 0.50m on these large floes, as indicated by the GPR #537 data plot (Fig. 24), probably because there is less open water where snow can be lost; the age of the ice as indicated by the modal thickness, is similar to that offshore.

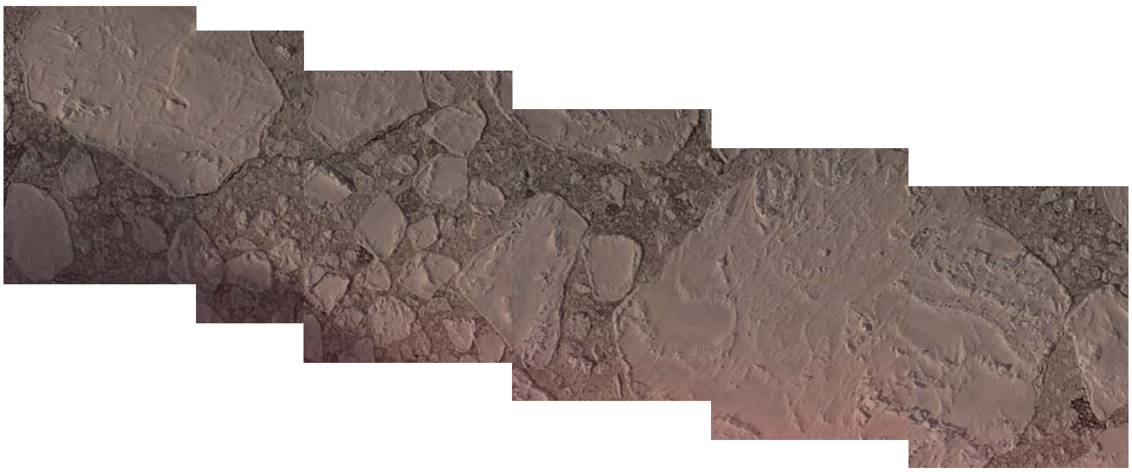

Fig. 23 Mosaic of 6 overlapping video frames (frame #9298) showing larger but still wave-broken floes at about 3.5km farther into the pack from location shown in Fig. 22. Video frame widths are 125m.

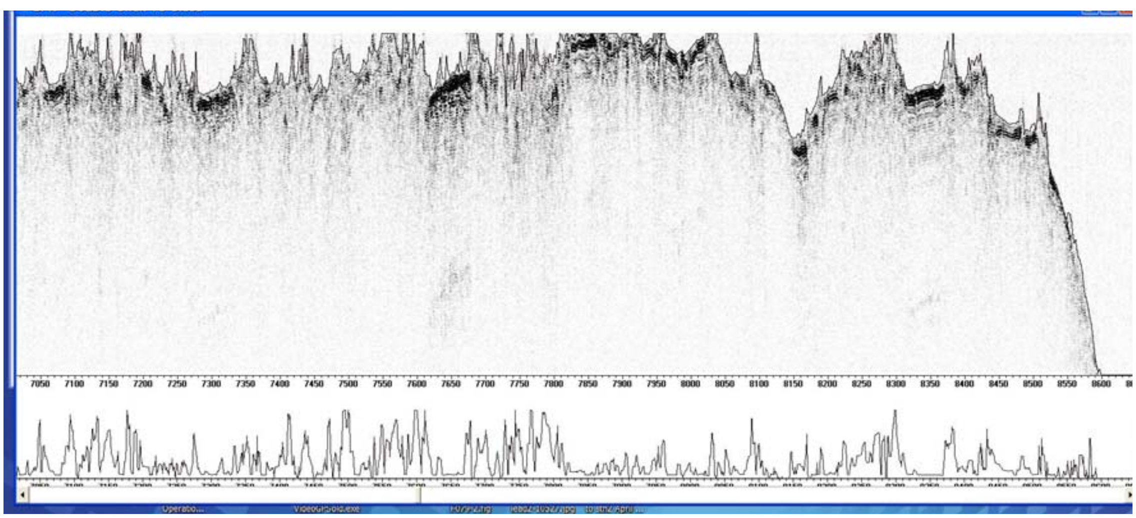

Fig. 24 Middle of GPR line #537 showing ~2km of GPR-Laser profile and resulting snow thickness profile Left side is offshore and right side inshore.

The GPR profile (Fig. 24) also shows less of the dark radar echo areas where no ice is present (laser, snow surface and ice surface echos all fall together). Higher snow thicknesses are more persistent than on the smaller floes seen offshore (Fig. 22). Farther inshore, 1-2km floes appeared (Fig. 25).

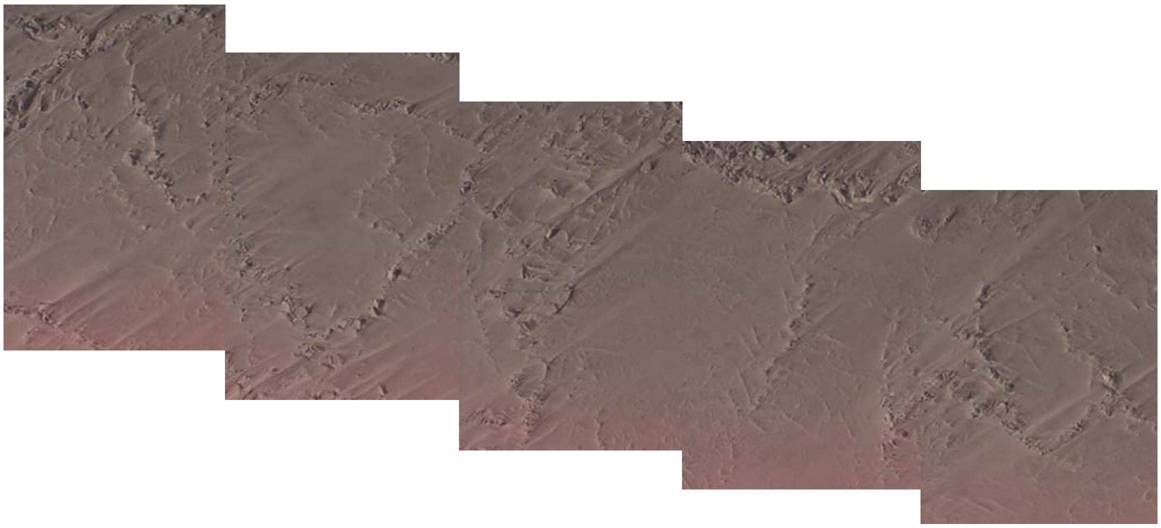

Fig. 25 Mosaic of 5 overlapping video frames (start frame #9124) showing a large floe not broken by wave action. It was observed 4.5km further into the pack from the wave-broken floes shown in Fig. 22. The location is just inshore of sample #3000 on EM line profile (Fig. 11) and photo in Fig. 12. Video frame widths are 120m.

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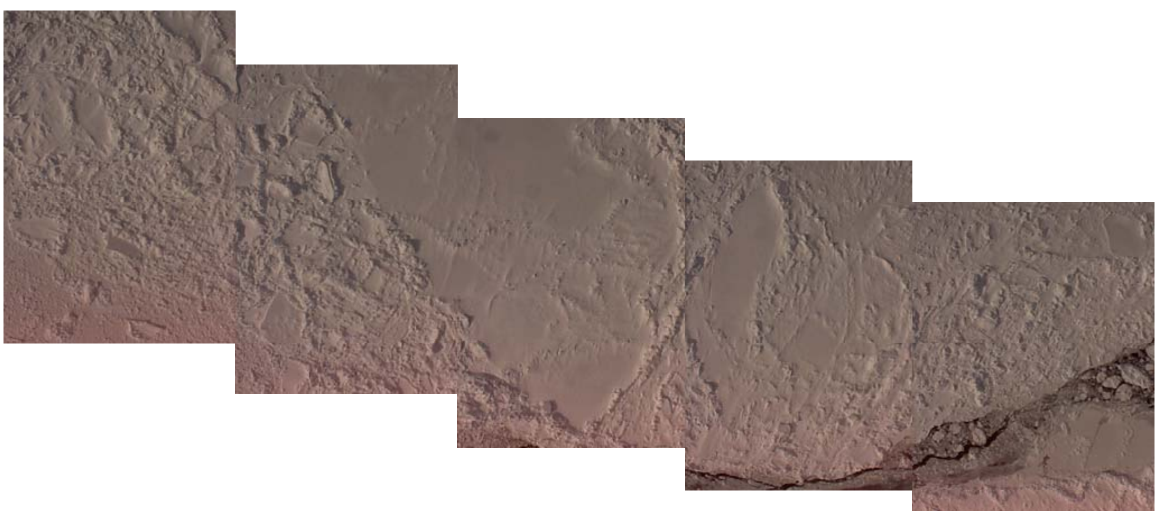

Fig. 26 Mosaic of 5 overlapping video frames (frame #8662) showing the ice properties from the middle of the GPR section #538 (Fig. 26) about 18km from the land-fast ice edge, and the end of the EM line plot Fig. 11. Video frame widths are 130m.

As seen in the SAR image (Fig. 20), the two inshore GPR flight sections 538 and 539 cover thinner ice regions according to the EM data (Figs. 11 and 14). The data at the end of EM plot Fig. 11 and the end of GPR line 539 correspond to thin ice just offshore of the land-fast ice. Ice thicknesses in the land-fast area are shown in Fig. 14. The mosaic (Fig. 26) and the GPR plot # 538 (Fig. 27) show the ice and snow properties at about 18km from the land-fast ice edge. High ice concentrations were seen with most of the leads being covered with thin frazil ice (Mosaic Fig. 26). The GPR plot (Fig. 27) shows areas where no snow is seen, and which are assumed to be the thin frazil ice areas. The remaining pack ice exhibits thick snow and rough ice topography.

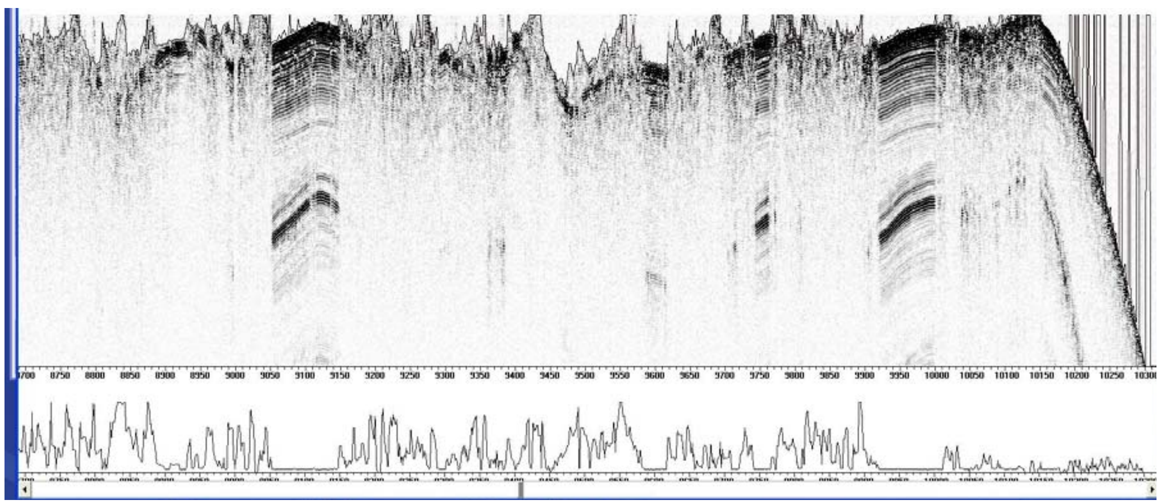

Fig. 27 Middle of GPR line #538 showing ~2km of GPR-Laser profile and resulting snow thickness profile. Section is about 18km from the land-fast ice edge, with the offshore side on the left and the inshore side on the right.

Fig. 28 Mosaic of 5 overlapping video frames (frame #8418) showing the rough ice properties from the middle of GPR line #539 (Fig. 29), about 7km from the land-fast ice edge (bright area of the SAR image in Fig. 20). Video frame widths are 130m.

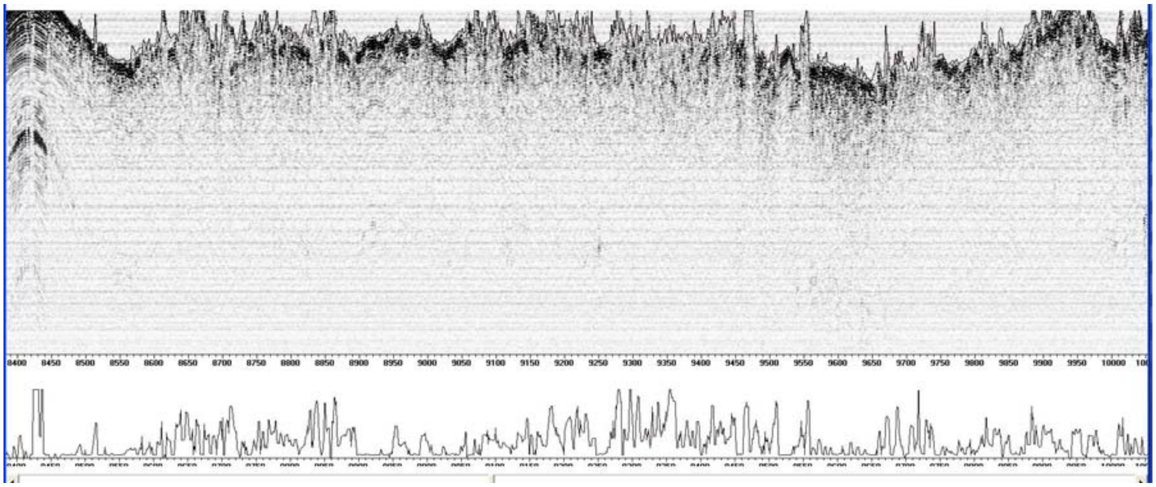

Fig. 29 Middle of GPR line #539 showing ~2km of GPR-Laser profile and resulting snow thickness profile. Section is about 7km from the land-fast ice edge with the offshore side on the left and the inshore side on the right.

The video mosaic shown in Fig. 28 and the GPR snow profile in Fig. 29 are from the pack ice area 7km from the land-fast ice edge and located in the middle of GPR line #539 shown on the SAR image (Fig. 20). It is an area where the SAR shows very bright regions which correspond to small scale surface pack ice roughness features (Fig. 28), shown before in the photo Fig. 15. The GPR plot (Fig. 29) shows the region in general has a thin snow cover and lower large-scale surface roughness features than seen offshore.

Land-fast Ice

Several examples in the preceding section showed land-fast ice, which is one part of the coastal ice regime. Our understanding of the seasonal and geographic variability of the sea ice within Canadian waters have largely been derived from ice thickness and snow thickness data from monitoring stations on land-fast ice, in conjunction with atmospheric monitoring stations by Environment Canada (Can. Ice Centre, 1982). Land-fast ice areas evolve spatially in time both through thermodynamic and dynamic ice growth, and their snow thickness should reflect the maximum value that would be expected on the mobile offshore ice of the same age (thermodynamic thickness).

The inshore section of the Hopedale survey line shows two different SAR ice signatures over land-fast ice (Fig. 7). The ice thickness profile is shown in Fig. 16, and a photograph of the area is shown in Fig. 17. Fig. 30 shows the ice draft (derived from the ice thickness and snow-surface roughness) plotted downward, and the snow-surface roughness plotted upward. The plot shows the ice draft along the in-bound flight path, with the thin ice and open water area and an 8m shear ridge on the left (sample numbers 3.4-3.5x10^4). At the end of the profile (4.0-4.1x10^4), where the RADARSAT-2 SAR image shows a reduction in radar backscatter, the mean ice thickness of the land-fast ice decreases from 2.4m to 1.4m, while the modal thickness decreases from 1.5m to 1.0m. However the mean snow-surface roughness shows less of a decrease (from 0.26m to 0.20m).

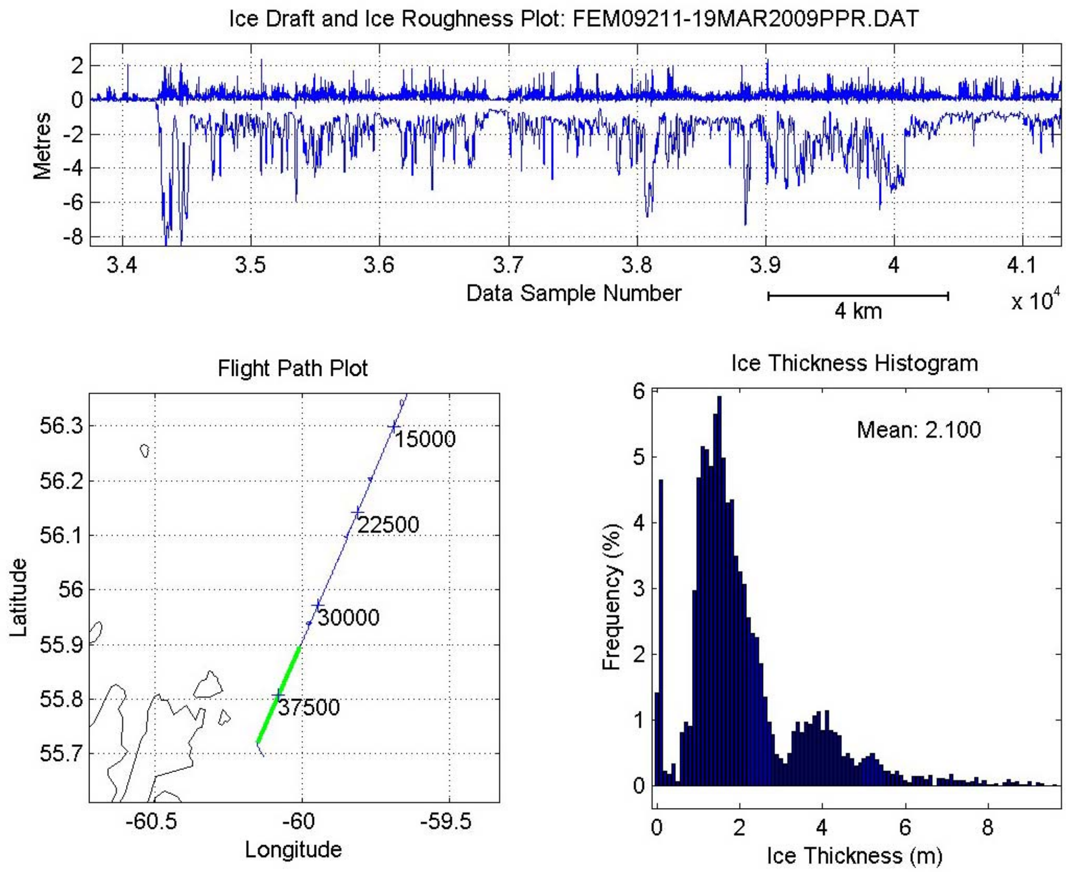

Fig. 30 Land-fast ice section plot off Hopedale, March 19. Thin ice offshore of the shear ridge located at sample number $3.45x10^4$ with the left side representing the offshore end and right the inshore end of the profile plot.

The large-scale ice-surface roughness, inferred from the ice draft profile, is lower for the inshore land-fast section where thinner ice was present, than for the offshore section (Fig. 30). The GPR plot (Fig. 31) is from the transition region of thick land-fast ice and high radar backscatter to thin land-fast ice and low radar backscatter. At sample number $1.68x10^4$, the rough ice topography on the left changes to flatter ice topography (red line). This suggests that the inshore part of the land-fast ice underwent less deformation (ridging and rafting) than the outer section of the land-fast ice. The brighter SAR signature is probably related to the higher ice surface roughness features. The snow thickness is up to 0.7m in the offshore land-fast ice region and up to 0.4m in the inshore land-fast ice region. There appears to be less of a change in snow-surface roughness than in ice-surface roughness between the two areas.

Several other GPR plots from this land-fast ice area (GPR file 078F545) are shown in Figures 32 and 33 and in the Appendix. Figure 32 shows GPR data from the rough land-fast ice region about 1.5km inshore of the shear ridge. It shows mostly very rough ice-surface topography (red curve) and high snow thickness (0.50m). However some flat areas can be seen (sample numbers 1050-1150) where snow thicknesses decreased to 0.10-0.15m. Another GPR plot (Fig. 33) is from the inshore end of the Hopedale survey line where the lower radar backscatter and ice thicknesses were seen. The GPR data shows thinner snow thickness and smoother ice surface topography. It should be possible to derive ice-surface roughness profiles from the GPR data, in addition to the snow-surface profiles from the laser altimeter data. These profiles would be useful for studies of radar backscatter, snow catchments and marine habitats.

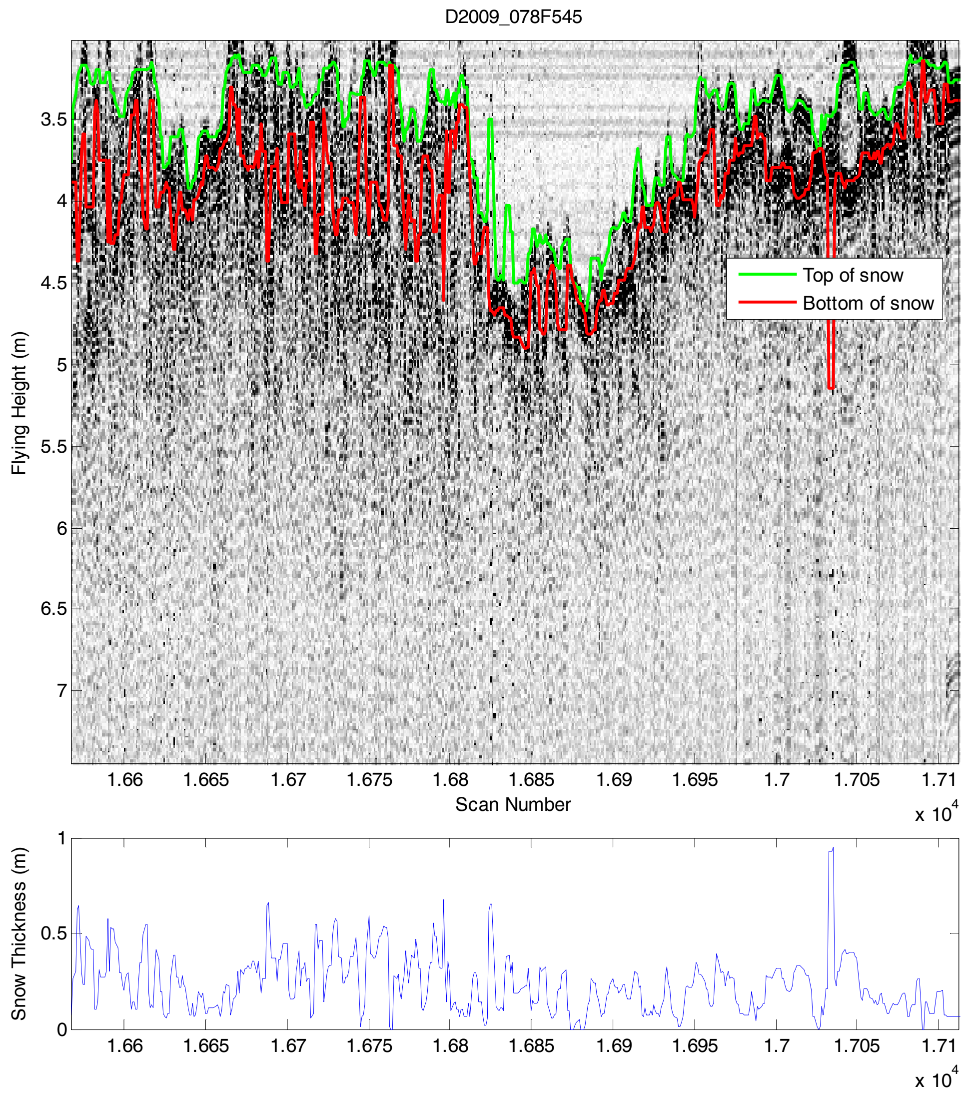

Fig. 31 GPR line section plot of F545 at transition from rough land-fast ice to mainly smooth land-fast ice. The EM plot for the same area (Fig. 30) indicated a change from thick to thinner land-fast ice.

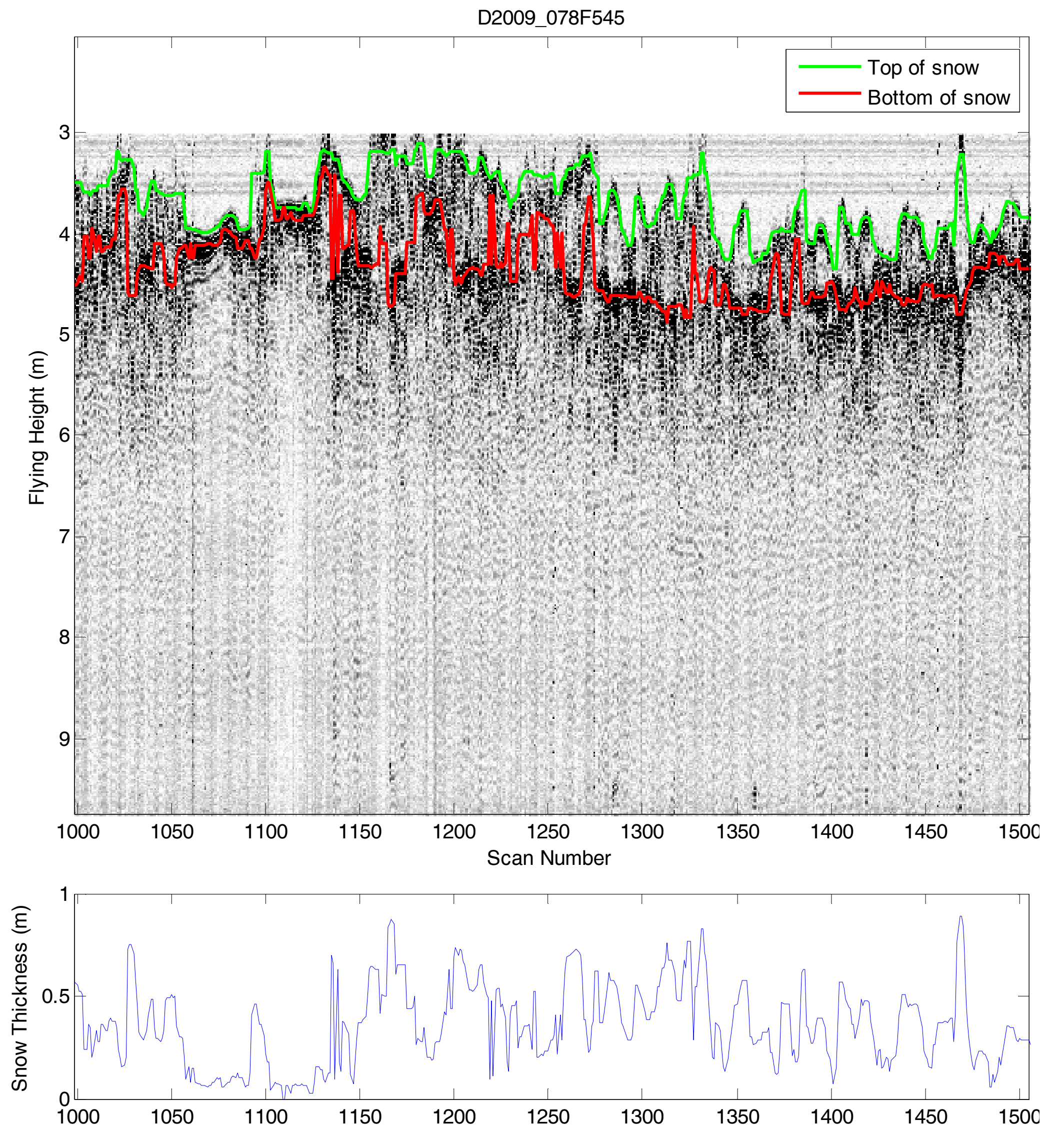

Fig. 32 GPR snow thickness profile (~0.5km) of the rough/thick land-fast ice off Hopedale at about 1.0 to 1.5km inshore of the shear ridge (start of GPR line section 545 Fig. 20).

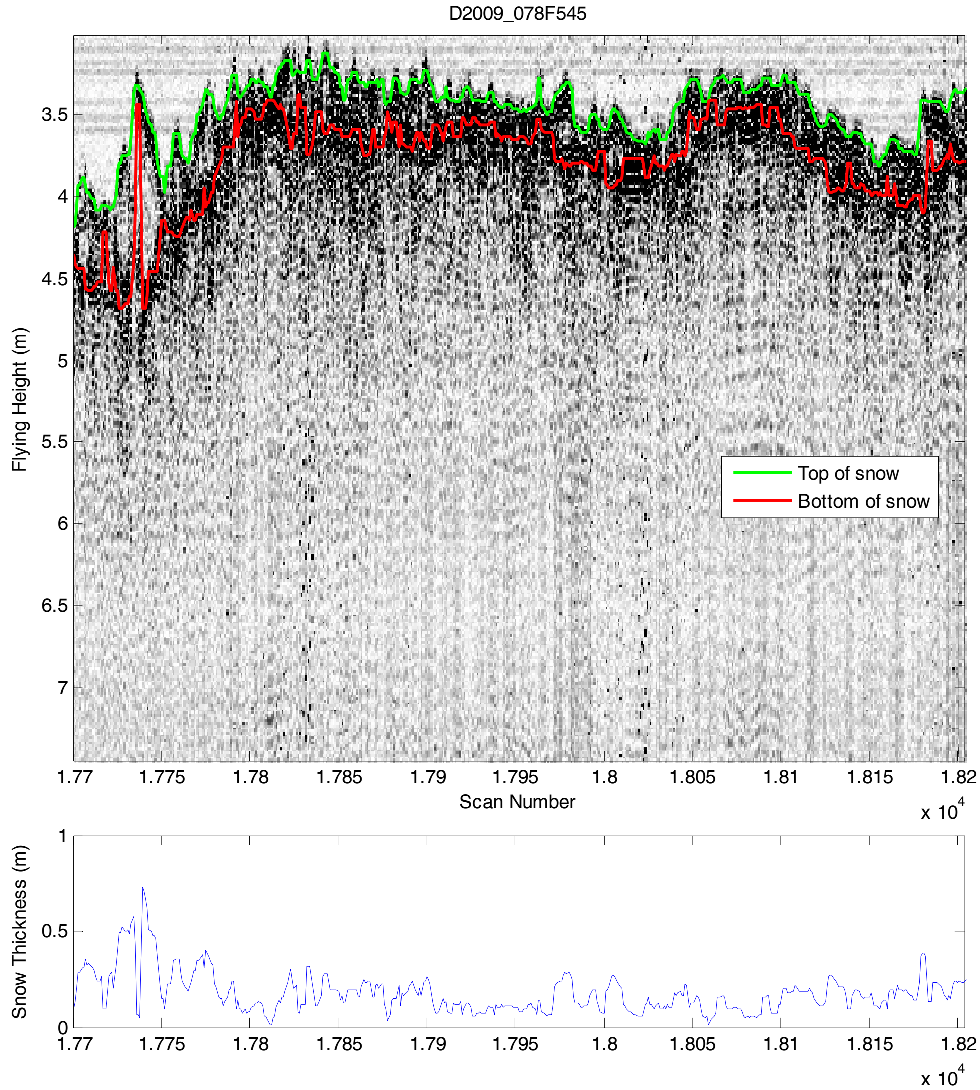

Fig. 33 GPR snow thickness profile (~0.5km) of the smooth/thin land-fast ice off Hopedale at about 18km inshore of the shear ridge (end of GPR line section 545 Fig. 20).

Ice Beacon Data

ARGOS ice beacons provided by Canadian Ice Service and prototype Iridium-GPS beacons build by personnel at the Bedford Institute of Oceanography were deployed on sea-ice floes and icebergs to monitor their drift patterns. They were deployed by CHC's helicopter engineer Dylan Pike using the second helicopter. Four beacons of each type for a total of eight beacons were successfully deployed; one additional beacon placed on the inshore ice off Hopedale was not deployed properly or fell through the ice shortly after deployment. Fig. 34 shows the pack ice and iceberg tracks as monitored by the beacons. Table 2 lists the starting position and deployment time of the beacons.

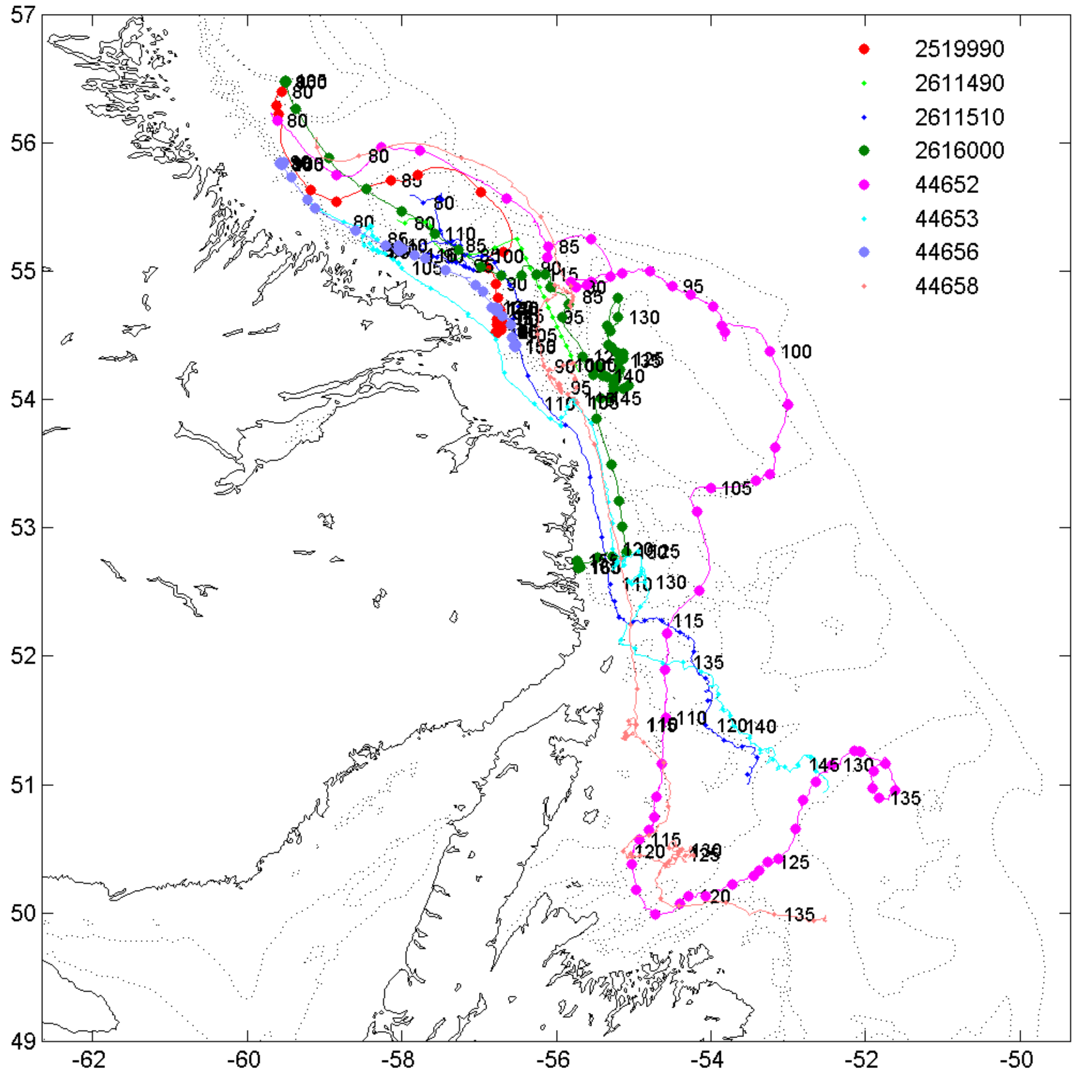

Fig. 34 Ice beacon trajectories representing iceberg (large dots) and pack ice (small dots) drift pattern reported by beacons deployed off Labrador coast during the 2009 ice survey.

Table 2 Listing of the start and end position and times of the beacons deployed during the Labrador Shelf sea ice survey, March 2009.

ID number	I=Iridium, A=Argos Iceberg Dimensions	Start time (MM/DD/YYYY HH)	Start Lat Long	End time (MM/DD/YYYY HH)	End Lat Long
2519990	I 23'H	03/20/2009 20	56.418 -59.538	06/10/2009 16	54.532 -56.768
2611490	I	03/20/2009 14	55.401 -58.050	04/10/2009 16	54.224 -55.719
2611510	I	03/20/2009 14	55.598 -57.896	05/04/2009 17	51.007 -53.524
2616000	I 290'H x 350'L	03/20/2009 20	56.482 -59.503	06/17/2009 13	52.689 -55.708
44652	A 40'H	03/20/2009 20	56.241 -59.690	05/17/2009 21	51.206 -51.731
44653	A	03/19/2009 14	55.530 -59.172	05/27/2009 14	50.940 -52.545
44656	A 225'H x 350'L	03/19/2009 19	55.850 -59.546	06/04/2009 14	54.400 -56.526
44658	A	03/19/2009 17	56.036 -59.132	05/16/2009 22	49.966 -52.533

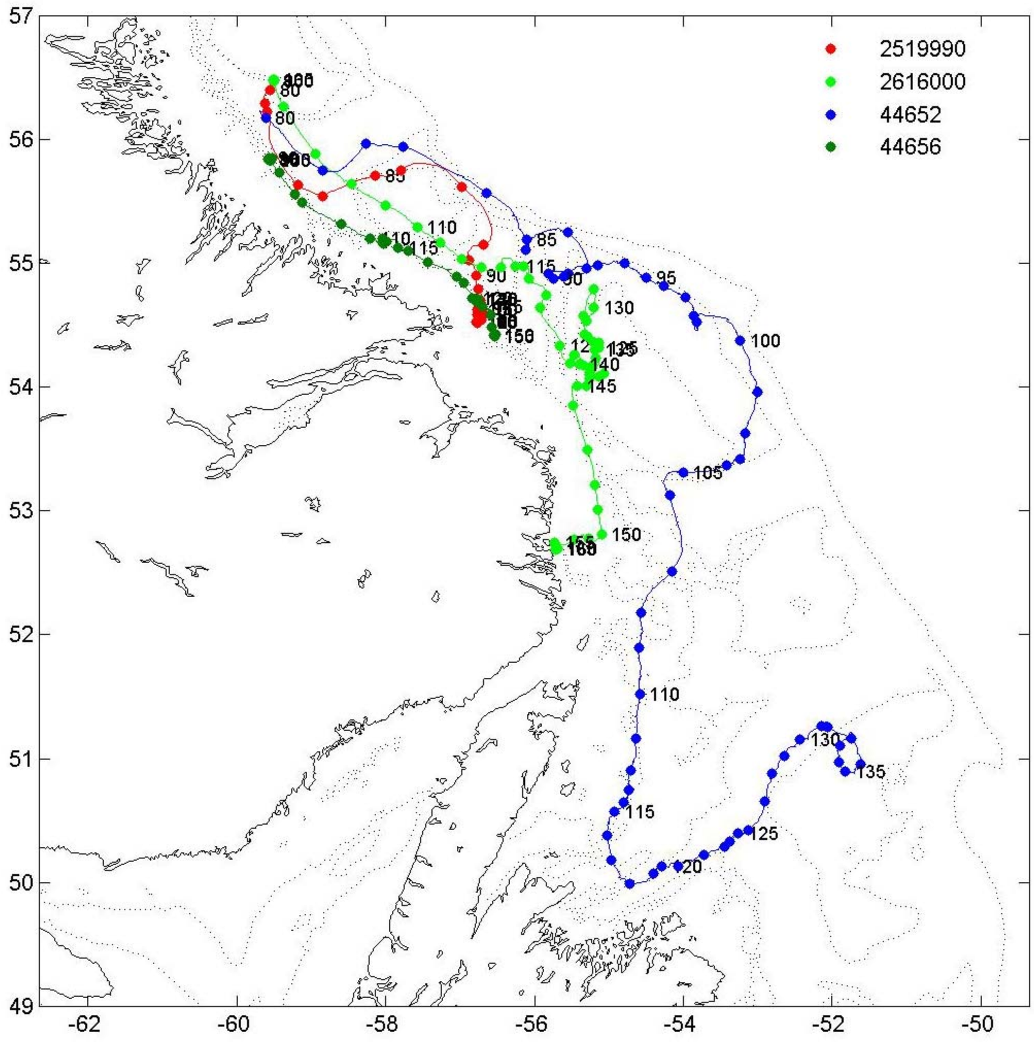

Fig. 35 Four iceberg trajectories as reported by the ice beacons. Dots represent daily locations with every fifth dot labelled by JDays.

Of the eight beacons deployed, only half reached the Northeast Newfoundland shelf. One beacon on a small iceberg (#44652) drifted in the offshore branch of the Labrador Current) and three beacons on pack ice drifted in the inshore branch (Fig. 34). They reached the northern part of the Northeast Newfoundland shelf between JDay 110 and 140, representing a transit time of 30 to 50 days and a average daily distance travelled between 12 and 20km/day for the total 600km distance. They stopped transmitting between JDay 125 and JDay 145, when they probably sank due to the decay of the ice or iceberg. The beacon on the iceberg and one beacon on pack ice reached as far south as 50^o; none of the beacons on icebergs or pack ice reached the Grand Banks. Fig. 35 shows the daily locations of the four icebergs being tracked by ice beacons. Photographs of these four icebergs are shown in Figs. 36 to 39.

The two large icebergs, tracked with beacon #44656, dark green dot and with beacon #262000, light green dot, were grounded at the time the beacons were deployed. Because of their deep draft and the shallow bathymetry, they did not drift very far over the first 30days (JDay 110) while the smaller iceberg (tracked by beacon #44652, blue dot) reached just east of the northern tip of Newfoundland during this time. The other smaller iceberg (tracked by beacon #2519990, red dot) initially drifted as fast as the other smaller iceberg, but grounded around JDay 103 in shallow water about 50km from the coast at 54.5^{o}N, and its beacon stopped transmitting on Jday 161. It was near the location where one of the large icebergs (tracked with beacon #44656 dark, green dot) grounded, and its beacon stopped transmitting on JDay 155. The other large iceberg, tracked with beacon #262000, remained farther offshore (and in deeper water). It reached as far south as 52.75^{o}N before drifting inshore, and its beacon stopped transmitting on JDay 168 (the longest lasting beacon).

In both Figs. 34 and 35, it can be seen that the two small icebergs (red and blue dots, Fig. 35) drift around the banks in the deeper parts of the shelf areas (saddles). These saddles represent important narrow deep passages, have larger currents than over the banks, and are large contributors to the cross-shelf oceanographic fluxes between the Labrador Sea and the shelf. The currents tend to follow the bathymetry around banks, with the shallow depths to the right of the currents, and transport both pack ice and icebergs along with them. The SAR image also shows the pack ice stream flowing offshore through Hopedale Saddle, just north of the “middle” line (Fig. 7). To simulate these features, numerical forecast models will require spatial grids that can represent this variability in currents controlled in part by the varying bathymetry.

Iridium 2616000: 290’H x 350’L

Figure 36

Iceberg #2616000

Viewed from
SSW

Light winds from
Northwest

Iridium beacon
Iceberg
#26216000

Grounded iceberg
290’H x 350”L

Iceberg #2616000
Viewed from
Southeast

Beacon placed on
flat top of iceberg

Figure 37

Iceberg #44656

Viewed from
South-East

Winds from NNE

ARGOS #44656 225’H X 350’L

ARGOS beacon
Iceberg #44656

Grounded iceberg
225’H x 350”L

Berg #44656
Viewed from
South

Berg #44656

Viewed from
Southwest

Beacon placed on
flat NW tongue of
iceberg

Figure 38

Iridium beacon
#2519990

Viewed from
ESE

Light winds
from NW

2519990: 23’H x 350’L

Viewed from
SSW

Cross winds
from left to right

Figure 39

Small iceberg
#44652

Viewed from
West

#44652: 40'H

Small iceberg
#44652

Viewed from
Northwest

Lake Melville On-Ice Data

On-ice data were collected in Lake Melville on March 21 on the way back from the Labrador coast, and again on March 23 when the freshwater layer was sampled out to Hamilton Inlet. The stations' locations are shown in Fig. 40. At each station, an Idronaut Ocean Seven 304 CTD was used to collect CTD profiles of the top 30m (or less) of the water column. Ice and snow thickness measurements and ice chip samples were also collected. CTD profiles are shown from March 23, when larger profile depths were attained with the use of a longer measuring tape.

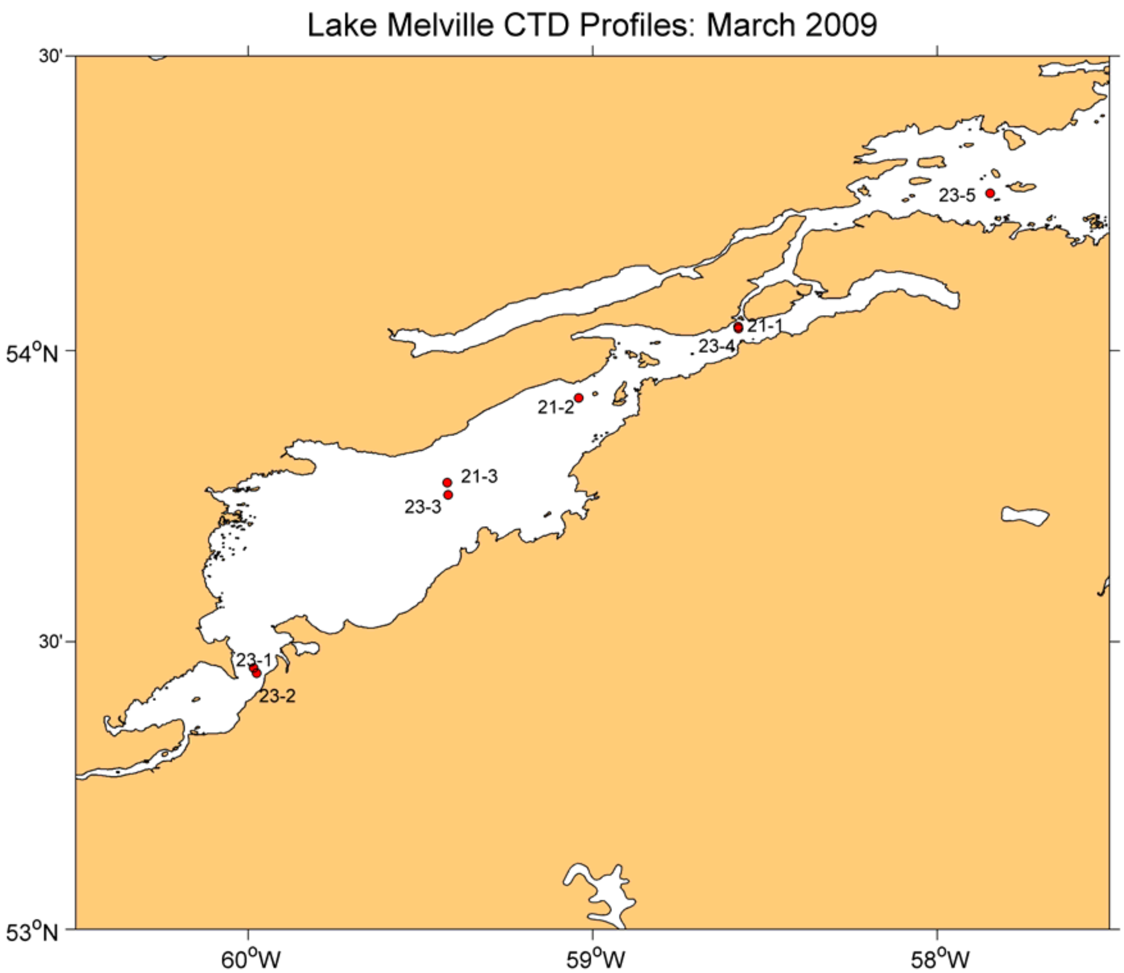

Fig. 40 Lake Melville CTD Station map.

The CTD profile from Stn. 23-1 (Fig. 41) shows that most of the shallow water column consists of freshwater with temperature near the freezing point, with a more saline layer (20ppt) near the bottom. The station is in a shallow region (5m depth) where the Churchill River runoff enters the deeper part of Lake Melville. At Station 23-3 (Fig. 42) in the middle of the Lake, the surface freshwater layer depth remained 5m with the saline layer beneath it reaching a salinity of 25ppt. The surface layer depth decreased to three meters at the eastern end of Lake Melville (Stn. 23-4). Open water was present throughout the narrow passage between Hamilton Inlet and Lake Melville (Fig. 44), and for another 50km at the eastern end of the Lake, probably due to strong tidal currents. Station 23-5 (Fig. 43) was located in Hamilton Inlet on land-fast ice anchored by islands, with more open water to the north. The CTD data at this site shows a distinct surface mixed layer 5m deep, with an increased salinity of 27ppt, similar to the deeper layers in Lake Melville. Below the surface layer, salinities reached 33ppt.

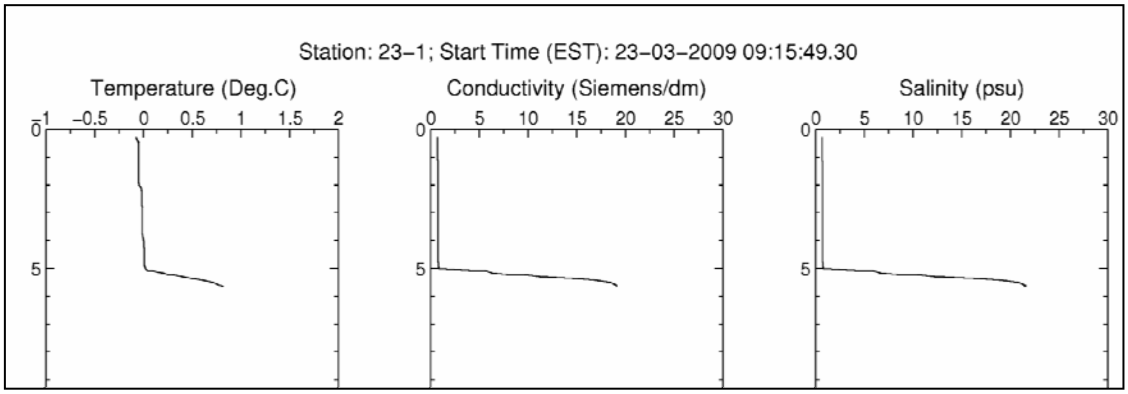

Fig. 41 Salinity-conductivity-temperature profiles of Lake Melville Stn. 23-1.

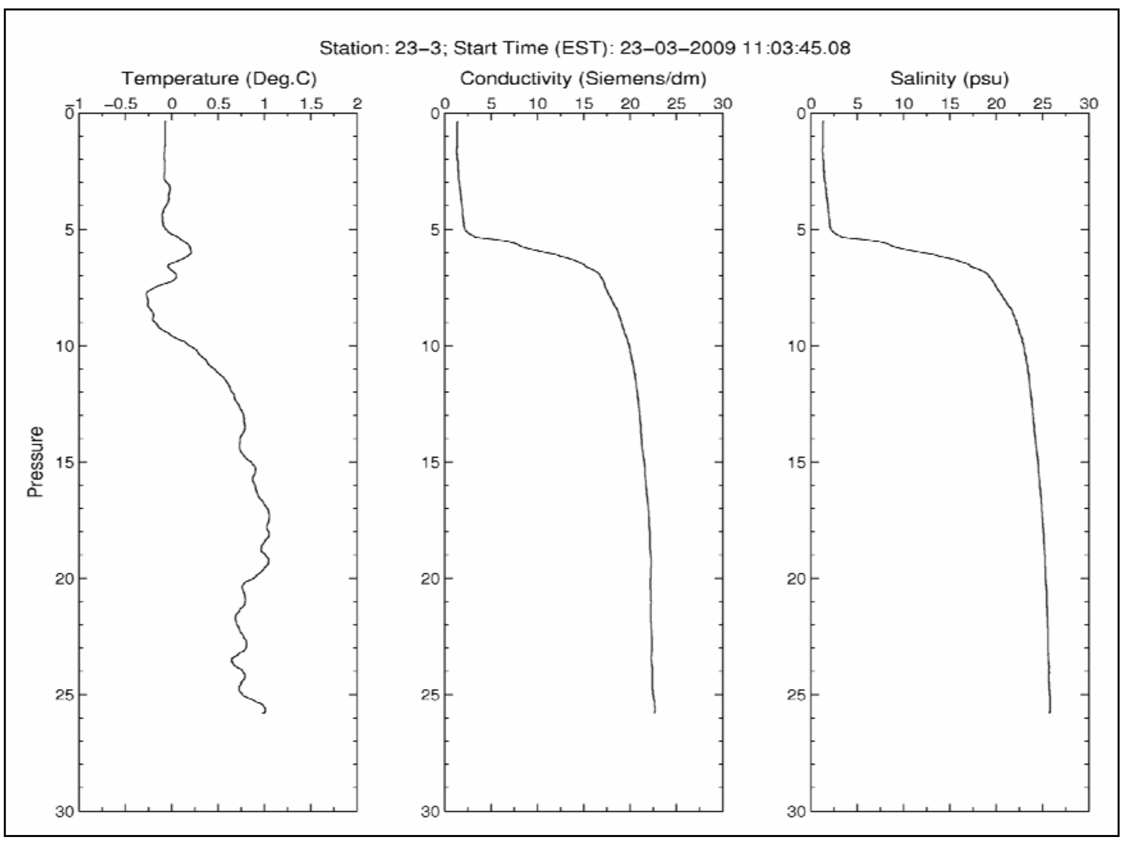

Fig. 42 Salinity-conductivity-temperature profiles of Lake Melville Stn. 23-3.

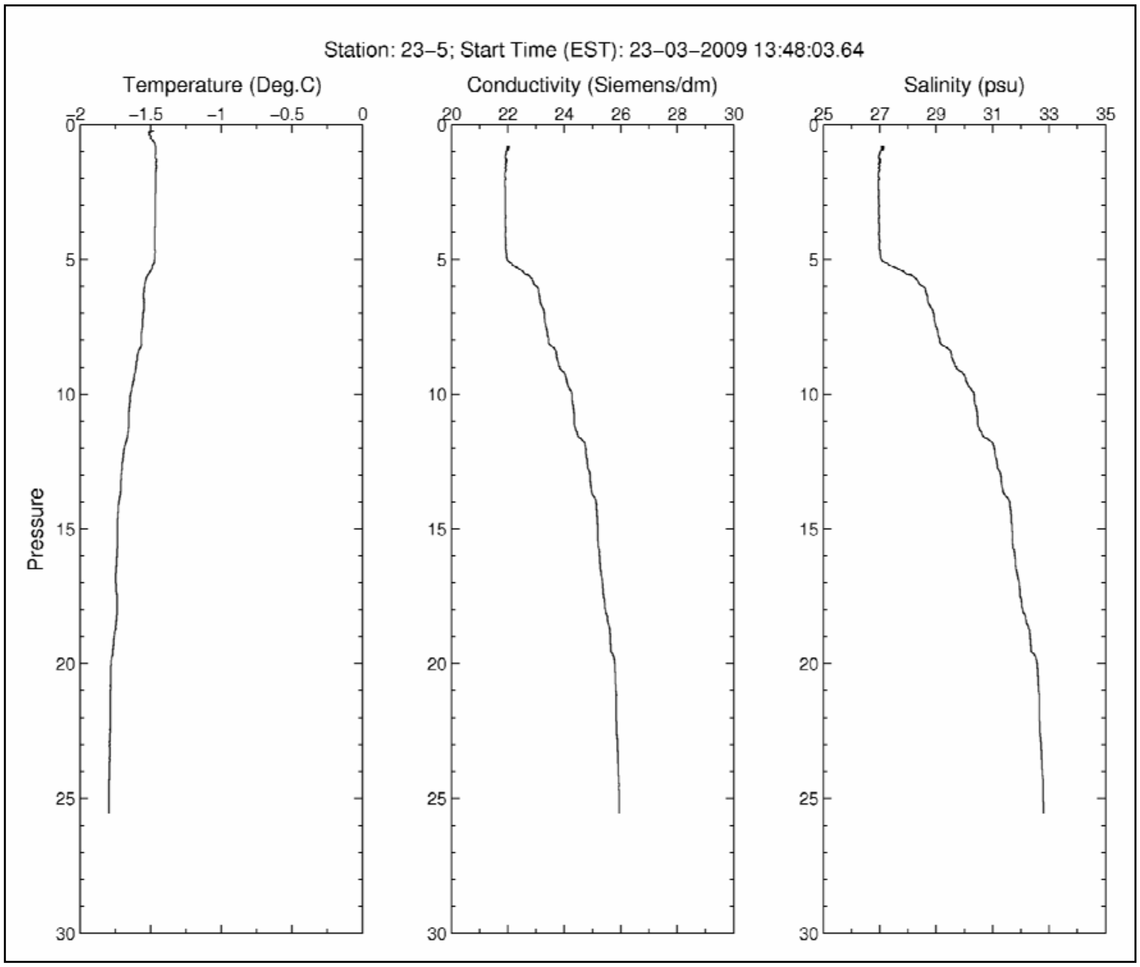

Fig. 43 Salinity-conductivity-temperature profiles of Stn. 23-5 in Hamilton Inlet.

Fig. 44 Photo of the open water area in the narrow entrance to Lake Melville from Hamilton Inlet (March 23, 2009).

Table 3 Lake Melville on-ice station data (March 2009).

		Stn. 21-3	Stn. 21-2	Stn. 21-1	
	Stn. 23-2	**Stn. 23-3**		**Stn. 23-4**	**Stn. 23-5**
Lat. (°N)	53.46	53.77	53.92	54.038	57.846
Long. (°W)	59.973	59.422	59.041	58.578	54.268
Time (EDT)	10:00	15:15	14:30	13:30	14:30
Snow depths (cm) E-W line	44, 60, 23, **44,** 45, 46, 49	56, 51, 38, **28,** 40, 54, 40	89, 60, 53, **48**, 50 48, 51	35, 33, 35, **45**, 19, 15, 20	3-4cm
Snow depths (cm) S-N line	38, 40, 43, **44,** 37, 32, 36	70, 49, 60, **28**, 41, 50, 46	54, 59, 69, **48**, 55, 55, 65	30, 29, 18, **45**, 21, 20, 23	-----
Mean snow depth (cm)	41	47	57	28	3.5
Ice (cm)	70	158	98	79	40
Freeboard (cm)	-7	-4	-1	-10	----
Salinity (at)	0ppt (5cm)	8ppt (5cm)	10ppt (5cm)	8ppt (5cm)	10ppt (5cm)
Salinity (at)	1ppt (25cm)	7ppt (48cm)	12ppt (35cm)	6ppt (29cm)	9ppt (22cm)
Salinity (at)	0ppt (45cm)	---	9ppt (42cm)	9ppt (45cm)	9ppt (33cm)
Surface water from CTD	1.0ppt	2.0ppt	2.0ppt	3.5ppt	27ppt
GPR# S-N	587	580	574	570	----
GPR# E-W	----	579	575	569	----

Table 3 lists the snow and ice data collected at the Lake Melville stations. The first part of the station number refers to the March day they were collected and the last part refers to the order in succession they were collected. Two station locations have two station numbers as they were visited twice. It was expected that the spatial variability of snow thickness would be large due to wind-generated snow dunes, but the large spatial variability of ice thickness was not foreseen. There are regions of open water at the western end of Lake Melville near station 23-2, probably because of strong currents caused by high runoff in this shallow region. In the middle of the lake, the ice thickness reached 158cm. At the shallower ends of the lake, the ice thickness only reached 70 and 79cm, probably because ice formation was delayed due to strong currents. There does not seem to be a strong relationship between snow thickness and ice thickness. Snow thickness increased eastwards away from Goose Bay, as far as station 21-2 (Fig. 45). It then decreased eastward, perhaps because of snow being blown into open water by westerly winds. Compared to the offshore land-fast ice snow thicknesses, the mean value of 57cm at station 21-2 is comparable but larger. All stations do show a negative freeboard when an ice auger hole was drilled and indicate that the snow weight was larger than the ice could support. Any crack would flood bottom of the snow and incorporate it into the thickness once it freezes. However, the surface ice-chip samples at about 5cm within the ice does not show this process to have occurred at the stations sampled. Except for the shallow west station 23-2, all surface ice chip samples show ice salinities of 8-10 ppt resulting from the freezing of high salinity ocean water not refrozen snow that was flooded by fresh runoff water.

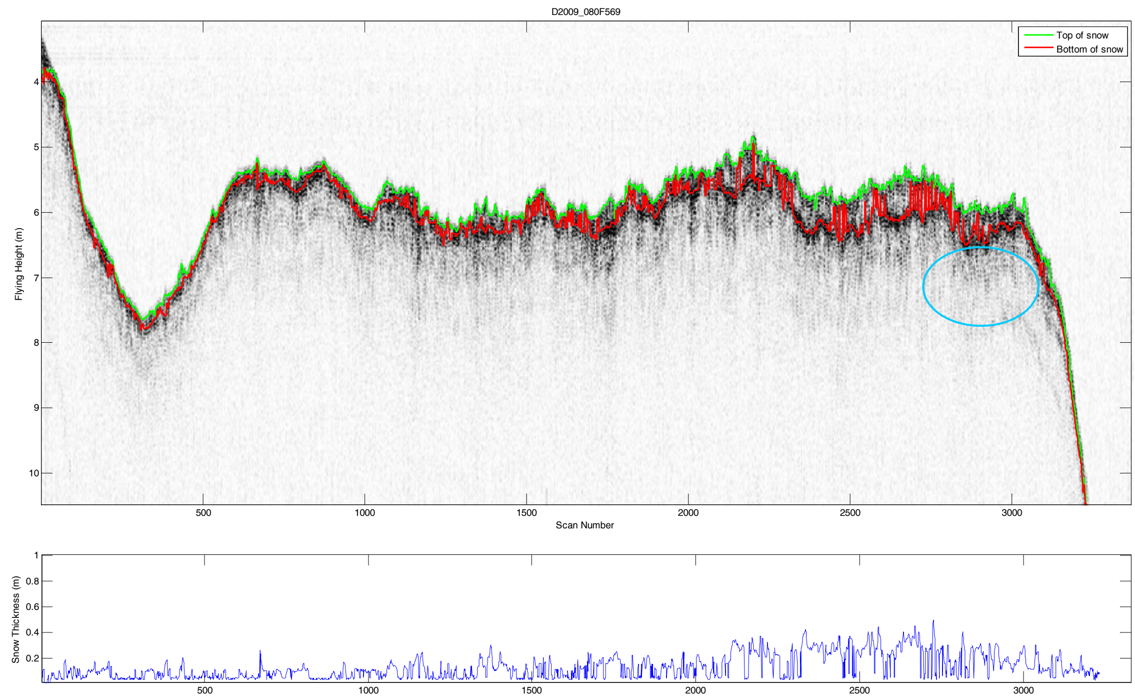

Fig. 45 GPR line plot and snow thickness of First Site 21-1 GPR 570 line flown South to North.

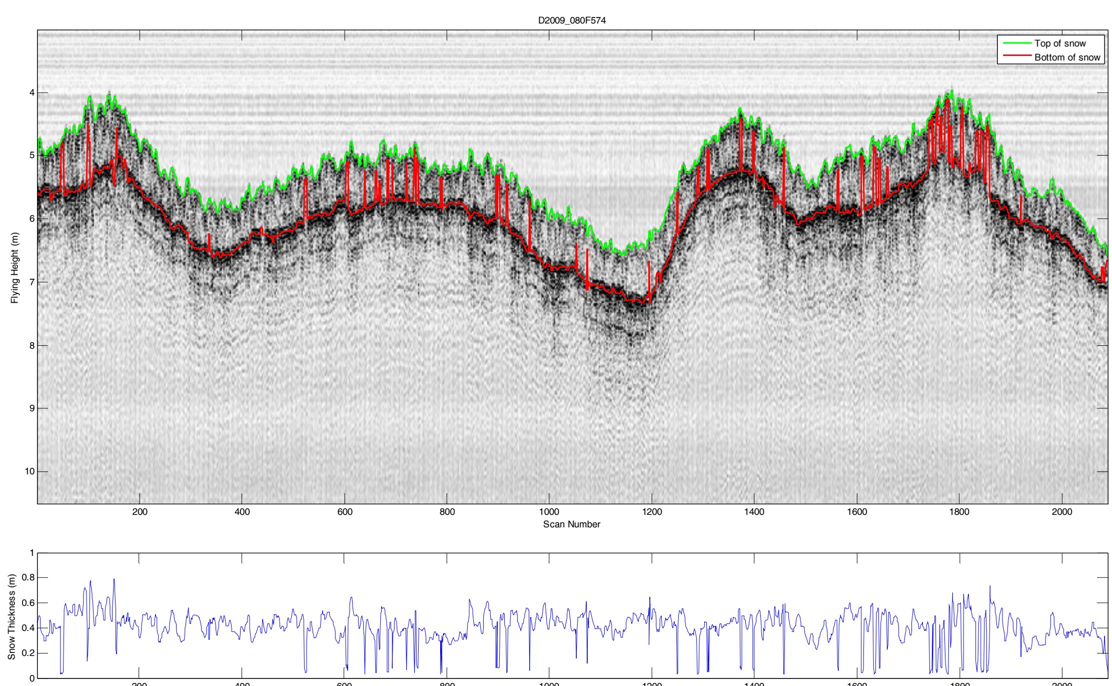

Fig. 46 GPR line plot and snow thickness of second Site 21-2 GPR 574 line flown South to North.

Short GPR flights were done in E-W and N-S at each on-ice station of Lake Melville. These GPR plots are shown in Appendix 2 and two are shown above. Fig. 45 shows a south to north snow thickness profile at Stn. 21-1 where open water starts as the lake narrows and currents increase preventing ice to form. The closer to the open water (south) the less snow is observed by the GPR. Near the station end of the profile the snow thicknesses reach values near the mean value of 28cm what was measured at the station (Table 3). In Fig. 46 the GPR snow profile of stn. 21-2 flight is shown. Here as seen by on-ice measurements (Table 3) the snow was deep and had a mean value of 57cm. The GPR snow profile (Fig. 46) show that indeed values range from 40 to 60cm.

Conclusion

This technical report described data collected during the March, 2009 Sea Ice Survey over the Labrador Shelf. No instrumentation delays were encountered during the week survey of which 4 days were spent in Makkovik on the Labrador coast. Offshore data of March 19 were highlighted in this report as a SAR image of that day was available to validate ice signature seen in the image with observations.

The GPR, although new as a survey tool, worked continuously and collected snow thicknesses from the sea ice and from Lake Melville. A total of 550km of ice thickness profile and video data was collected from the Labrador Shelf. Three mobile ice regions can be differentiated and seen in the SAR image; the offshore homogeneous wave-broken floe region, the mid-shelf region with large floes and the inshore thin ice region were large floes existed with very little snow. The extent of the land-fast ice region was identifiable in the SAR image and ice thickness data.

Ice thickness and snow thicknesses data were collected from Lake Melville during flights to and from the coast. The data shows the existence of a surface freshwater layer due to runoff from the Churchill and other rivers between the ice cover and the remaining ocean water column of Lake Melville. Snow thicknesses of up to 60cm were observed with the GPR helicopter-borne sensor and verified by on-ice measurements. The salinity content of the Lake Melville ice was similar to that of sea ice (9-10 ppt) indicating that the total water column was well mixed in the fall before ice formed, and that the freshwater runoff layer evolved after the ice formed.

All raw and processed data, plots, reports and papers will be available through the "SeaIce" website:http://www.mar.dfo-mpo.gc.ca/science/ocean/seaice/public.html and through the website's data link to the DFO Maritimes' FTP site: ftp://starfish.mar.dfo-mpo.gc.ca/pub/ocean/seaice/.

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Appendix 1: Field Notes: Labrador Sea Ice Survey 2009

Monday 16 March, 2009 Clear -15^{o}C, light NW winds

12:00 Arrived in Goose Bay and rented a car at the airport. Scott was not on the plane as planned. Drove to CHC; shipments #1 and #3 from BIO and the CIS ARGOS beacons there; shipment from Halifax airport not there.

Unpacked some boxes and went to hotel and picked up Scott at 19:30 at airport. Hotel packed with members of Skidoo racing teams.

Tuesday 17 March, 2009 Clear -10^{o}C, light NW winds

8:15 at hangar

- Engineers working on mounting brackets, moving the plumbing for the pop-out floats and removing the hook and mirror.
- Labair brought in the final shipment from St. Johns; picked up by CHC personnel by 10:00.
- Scott working on centre tube to mount Video/laser and GPR. Scott needed to take the PIC cable lead tube off so that video could slide in.
- Removed the parachutes of 4 of 6 ARGOS beacons, too many lines for helicopter work. We repacked gear that should go on to the coast. No final permission to fly yet as the pop-out floats of CHC are a bit different.
- Have to wait for paper work; probably leave in the morning, it is warming up.

Wednesday 18 March, 2009 Clear -15^{o}C, light NW winds

8:15 at hangar

- Approval message came by mid-morning and the rest of morning spent on helicopter weight balances and paper work.

12:00 - Finally packed and going to Rigolet and inland to Makkovik, Chris Rodway as pilot of the survey helicopter and Henry Blake in second helicopter with engineer Dylan Pike and all the gear. Pilot Dean Burry replaced Henry Blake after two days.

GPR has Lat/Long and so does Video, slowed down video frame grabbing then went back to GPR seems to work and I saw a display plot of GPR traces but never could find it afterwards, just a big list of files (later learned click on latest and it will show what is being collected).

12:09 GPR file, hope it is logging as I see no changes in the frame number but that may be just (and is) for the video collection. It is storing as the storage space is reducing.

Over Lake Melville, PIC gave strange numbers (very thick –many meters and relatively high apparent ice conductivity) as it turned out the calibration numbers were put incorrectly this morning (also a large of freshwater layer beneath the ice was present). GPS data has Lat\long and frame #, and is changing but very flat light so video data is not much use.
Flying 3-4m over lake ice, sometimes hard to see screen when the sunlight is coming in the side window. When going back and forth between GPR and Video, one has to disconnect the GPR power once sampling is done. GPR and Video do not share GPS data, so either has to be shut down, and GPR has to be disconnected.

GPR 519 done at 12:23. Video F210; too much light backscatter from flat snow pack. 12:35 - GPR file F520 and then Video, at first narrows where salinity profiles should be well-mixed but possibly lower than offshore values. The polynya has a large area of open water, so there must be lots of tidal currents going both ways, and perhaps a strong freshwater flux.

Short high video 211 and short low video 212 (12:46); no GPR as you have to unplug the GPR once you shut the GPR window down and send GPS data to Video (they do not share GPS data).
High video over open water of polynya then to low video 213.
Over land to Makkovik; did some more tests to go from Video-GPR-GPS (No lat/long) – GPR (nothing there). Into Makkovik at 1:35 to fuel up and drop gear off.

14:00 Off from airport Makkovik – Overcast and cloudy. Flying out with video, some trouble with cross wing and flying easterly direction and actually going over ground to 45Degrees. Strong SE alongshore winds at 30mph.

Video looks fine but dull light. Still some contrast as there were lots of ridged features, all small floes, nothing more that 300m, lead along the shore, then thin ice to some crushed nilas and finally the rough pack ice. Pack ice 85% concentration without any pressure features seen. Some young nilas between older pack ice, reached an area where it appears that strong swells had broken up the pack ice. Small icebergs here and there but nothing to really land on (We did not deviate from course to look at the icebergs).

Turned back at 14:35, could actually have reached farther offshore.
Light and wind not too good, so this flight is more a learning trip. Will go slower from now on in: 60-80mph. Some of the Background loops (BG) were done too quickly. End over thin ice and stopped before land-fast ice. Pic real-time results showed ice about 15cm too thick due to calibration error mentioned earlier. 16:00 at hotel and typing.

Files: FEM09201 – 2002 Lake Melville
FEM09203 -204 Makkovik Line with the main offshore line 203,
Video: 77F205 - F214 Lake Melville:
77F215 – F218 Makkovik Line out at 45Degrees.
GPR: F516 – F520 Lake Melville
F521 – F525 Makkovik Line in.

Still pictures: In CHC hangar 5201 – 5212
Polynya 5213
Makkovik line coming back 5-10m height 5214 – 5235

Thursday 19 March **no wind, local snow showers, -11^{o}C**

07:00 Breakfast - plan two parallel lines at 45 degrees to coast, Makkovik and Cape about 20miles NW of first Makkovik Cape.

Off airport at 09:00, at ice edge not good visibility, too clear, circle to start PIC so it logs Lat/long in case we need it. Video out at 400m and EM in.
09:15 start at Cape 55 14N and 59 09W.
At edge frame 5122 on Video file 220 frame grab automatic 0.73sec snowing so video over large floes shows no contrast.

Lead until 5394 09:21.38 more snow, second lead 5574 to 5639 until 09:25.08
Large lead is to SE east of and parallel to track. SSE light wind, large floe see picture at 09:38.00. Thin ice and open water between floes (no pressure on pack ice).
At frame 6880 wave-broken floes 09:42.99. Large iceberg to left of track at frame 7000 09:44 (55.875N and 58.607W). All wave-broken floes 09:45 frame 7112. No sign anymore of new ice forming. Video 223 running. End Video at 09:55 about 70nmiles from start.

EM back starting at ~10:00. Grease ice at 10:15 then BGround loop again, end and start over grease ice in a lead. 10:08.25. Ice appears to have lots of freeboard but may all be snow at the edges. Second iceberg on way back now on right of track, 10:15.22. Still picture of it. Some big ridge piles of 2m sail heights or up to 14m thick.

Restart GPR at 10:19.0 EST or Pic 13:19.0 GMT; another BGround at 10:29.
Restart over open water at edge 10:30.42 (file 530), snow starting at 10:33.
BGround over open water again the rough old floe 10:35.46 (File 531), three pictures.
Short video at BGround 10:47. End and start GPR (file 533) over open water 10:58.0.
Much less or no snow on young thin ice, more open leads appearing 10:59.48.

Overcast inshore, appears a system coming and moving north. 11:01.0 large lead, took until 11:01.54 to pass over. Lead more than 1 minute flying at 80mph. Pancake ice and nilas at end large field of pancake ice 11:03.25 to 11:04.0. BGround over lead at 11:07.13. File 533 continues.

Next lead at 11:08, large final lead; wind and snow starting 11:09.47. Wind still at 25mph from south. Landed at airport just before snow squall hits and wind turns to NNW.
Second helicopter deployed two ARGOS beacons on sea ice at 20 and 50miles from the land waypoint.

Afternoon, off at 12:30 after the weather cleared. Going to next line NE of Makkovik, half way to Hopedale. ~55 18.0N and 59 45.0W.

Video 225, starts just before shore lead 12:52.16. No shore lead here, it may have closed as the wind reversed and is from the north. Now Video file 226. Some open water with snow, frazil ice 12:58.27. Iceberg to north of line 13:00.0.
Flying at 110m frame grab at 0.82sec. Large lead parallel to track south of track from 13:03.46 to 13:07.30. Still picture 5312. Large lead seems to make its own cloud/snow.

Wave-broken ice floes start near frame 9400, still pictures to 5317 at 13:09.46. Video now 227. Hazy weather starts around frame 9607 at 13:12.15. Wave-broken floes with some partly washed surfaces (clear ice). Later wave-broken floes were gelled together into composite floes. Pictures 5327–5328.

13:20 turning back, very hazy. GPR on (534), PIC data coming (53 miles out).

At first BGround the iceberg is now Right (or North). Still picture 5348 at 13:30.
Another BGround 13:32.4 GPR 535. GPS fine.
Another iceberg to south (left) at 13:34; four still pictures 13:36, some massive pack ice with block thicker than 1m. Freeboard of 20-30cm.
BGround over lead picture to 5355. GPR file 536 at 13:43.14.

Stopped on ice to give auger to other helicopter. And started ice beacon 12996. Second helicopter is going over to the iceberg to see if they can deploy the ARGOS beacon. Snow not deep on floe we landed on, 10-15cm on level ice, deeper in cracks. Snow looks deeper from the air.

BGround at 14:19.42 still picture 5369. GPR 538. Iceberg pictures to 5377.
Other helicopter placed beacon on iceberg, on lower flat area, top was too windy, height of iceberg by altimeter difference is 225ft; seems to be moving relative to pack ice (later found it was grounded and pack ice moved relative to fixed position of the iceberg).

14:22 over pancake ice with light snow cover (could be bright on SAR Image).
Stop GPR (539). Then restarted it to capture snow on land-fast ice, GPR 540 at 14:36.30, possibly over the land-fast ice. Stopped files at 14:43 at end of the line and going over to Hopedale to do next line. Second helicopter deployed two more ARGOS beacons out during the video line out.

At Hopedale checked what ARGOS beacon we have left #16792.

Restarted PIC at 15:35 over the land-fast ice, Now NW winds. Started Video before rough land-fast ice started. Saw an older shear ridge within the land-fast ice near 10100. Rough ice between the islands, last island seems to anchor the land-fast ice; island and small iceberg all offshore of this island south of track. Offshore frazil ice with some finger rafting. Video 230. Waves parallel to lead going to the south. 10964. Loose pack ice with open water and new nilas. 15:52.08. Camera backwards, signatures move up not down in consecutive images!!

15:58.38. Ten icebergs just off line south 11420. Some large composite floes. Frame 11670 at 16:03.30. Wave-broken floes at frame 11825 at 16:08.59 F231. Passed last iceberg and turned back towards Hopedale.

EM on and GPR 541 many still pictures, we are passing over what looks like multi-year ice (over 10m) plus some very thick old rough FY ice. See still pictures.
GPR was turned on after the EM was on for a while. Then back into wave-broken floes, which at low level make up a very rough topography.
BGround where iceberg is at 9 o'clock, at 16:37.27. Winds are picking up from NW. Some more MY ice at 16:42.37 over 10m thick, slowly thinner ice, and no snow on ice starts to appear. Stopped GPR 16:45. Several short videos at low level and at high level when doing a BGround 16:50.

Restarted GPR 17:03 over thin mobile 8/10 ice concentration, still some old floes thin ice and finger rafting. 17:05.39 – 17:06.10, nilas and old nilas crunched. BGround at 10miles to go. Still pictures low again at 17:09.0, GPR on (544). Flying low at 3.5 – 4.0 meters. Lots more nilas, 17:10.35, lots of rubble floes that broke loose from land-fast ice. More snow on ice. 17:13.39 more snow on ground, now maybe GPR can see it. Very thick shear ridge of the land-fast ice. Over flat ice 17:18.48, more flat ice at 17:22, BGround at 17:23 and stopping everything. ~ 18:00 at airport and packing helicopter for the night.

Makkovik Line

EM in	FEM09206	10:00 – 10:56
Video out	219 – 223	09:08 – 09:55
GPR in	526 – 533	10:42 – 10:56
Still Pictures out	5236 – 5258	09:14 – 09:58
Still Pictures in	5259 – 5292	09:58 – 10:55

Middle N line

EM in	FEM09209	13:20 – 14:35
Video out	225 – 228	12:48 – 13:18
GPR in	534 – 540	13:31 – 14:35
Still Pictures out	5295 – 5327	11:05 – 13:17
Still Pictures in	5329 – 5398	13:24 – 14:34

Hopedale Line

EM in	FEM09211	16:05 – 17:24
Video out	229 – 232	15:38 – 16:08
Video in	233 – 237	16 49 – 16:55 (short files)
GPR in	541 – 546	16:36 – 17:24
Still Pictures out	5399 – 5411	15:15 – 16:06
Still Pictures in	5412 – 5437	16:09 – 17:07

Friday 20 March **Strong W-N wind, local snow showers, -17°C**

07:00 Breakfast clear but windy outside.
Henry is leaving and a new Pilot Dean Burry arrived last night. At Hangar by 8:30 but very windy. Helicopter on floats did not start, needed to use battery and some fuel line de-icing and finally both helicopters going and warming up at 09:45. CCG helicopter here also and could not start.

To southern mooring line. Video out #230, frame 12500 started at 10:09.20.
Flat and then very rough land-fast ice at ice edge. 12600 10:10.10.
Mobile pack ice started with thin frazil ice and then frazil finger rafting,
Thin ice has snow blown on it, 13160 at 10:19.56. Later this ice thickness and some crushed ridges 13:25.00. Rougher ice starts at 13390 at 10:22.00. Some nilas.

Composite floe starts to appear at 10:23.10 frame 13450.
Large floes but haze is starting 13548 at 10:24.40 winds WSW. Some clearing, Video now at 239. Some large floes 13700. Picture 1355.

Some wave-broken floe areas but not as severe as along other lines and are present in between larger floes. 13920 at 10:29.50. Haze off/on 10:32 large floes 14276 at 19:36. Beacon #2 out here somewhere. Large floes but also new young ice (1 day old). One extra large floe at end 14647 at 10:40.53. Ready to turn and doing background for EM.

Turn at 10:44.07 to 55.80 and at 57.73 start video frame 15000 on #241. Still pictures 5456 and 5457. Started the GPR #547 at 10:48.13. BackGround at 10:54.53 winds 55mph from NW. Hard to come back on line because of the wind. Flying now higher at 15ft or around 5m.

Second BGround at 11:06 and stop\start GPR now #550. 11:09.52. Blowing snow and hard to fly/see. Snow continuing blowing into leads and pre-conditioning ice growth. Most blocks in this rough ice are thick ½ to 3/4 meters. But ice is very clean, not like blocks of inshore rough pack ice.

BGround at 11:19.55 GPR#551 large floe areas but not as rough any more.
Two Iridium beacons were placed out, one at the mooring site and one 12miles further along the line flown out by Video. Still pictures 5492 at 11:29.49, GPR 552.
Dirty ice blocks starts 11:31.06. Still pictures to 5495 at BGround 11:36.28 (552).
Still pictures 5500 11:38.99. Restarted GPR 553.

No Icebergs along this mooring line. Thinner ice starting, less rough as well blocks thinner 30cm.
Picture 5506, at 11:44.42. End GPR no snow here.
BGround at 11:48.00, some very rough ice before land-fast ice, GPR started at 11:51 (#554). Picture 5516-5521 looking back along line flown. Rough pack ice before the

shore lead 11:54.50. Rough land-fast ice old shear lead 11:59.35, stopped GPR, done at 12:00 and heading into the wind to airfield.

13:00 - Nobody at airfield so we fuelled up and ate lunch on-the-way to centre of Hopedale line where MYice was (later found it moved offshore). Too cold at airport.

EM out into the wind starting off the Makkovik Cape point. Lots of wind and hazy conditions not too good to work or take pictures/video. BGround done in line as the wind holds you back anyway. 13:29.00 lots of thin ice with blown snow on it, possibly frost flowers here and there.

Ice starts to become rough at 13:13.15. BGround 13:16 still picture. Another BGround at 13:26 start/stop GPR now 556. Passing old iceberg (right along track, other helicopter saw the beacon on it, first iceberg with ARGOS beacon. Passed this area 13:44. Bands of rafted pancake ice. Clearing up at 13:45 and wind appears to be dying.

Stop/start GPR at BGrounds now at file #558, 13:45.
End GPR at 14:00 Passing 3 iceberg on left of track too windy to put beacons on smaller beacons showed movement relative to pack ice, larger one did not. (video clips).
Could not find the MY Ice, heading into Hopedale for fuel. 14:00 GPR 560.
Crossing shear ridge at 14:27-30, still pictures 5553.

Left Hopedale at 15:11, still windy but clearing and wind dying.
Video out of Hopedale to centre of line, then going to 100ft to see MYice.
Video 242 at 120m 15:27. Very distinct shear ridge. Again some frost flowers. Beacon was placed 20Nmiles from land just at the edge of rougher pack ice edge.

Down lower to 40m at 15:40. Found a small flat iceberg, parked on it and waited for second helicopter, it placed the last ARGOS beacon on it. 56 15 15N and 59 43 44.5W. Farther along the line on the right we found what we thought was MYIce, but it was a small tabular iceberg, pothole surface texture. 56 25 17.1N and 59 31 59.1W. Waited again for second helicopter to come, and it placed an Iridium beacon on it while we EM sampled and Video profiled the area, somewhere a video frame has a helicopter on the iceberg (if I started to log video?).

Second helicopter went to single large iceberg North of tabular iceberg, and placed last Iridium beacon on it. Iceberg even higher than last iceberg ~290ft high and 500ft long. Pictures by engineer 2015. About ten icebergs to the SE. (right of track line). 56.374N 59.291W at 16:31 Small tabular iceberg 16:12 and large iceberg 12:21. Looked at the grounded icebergs, they are in an arch starting at 56 25 17.1N and 59 26 39.2 W and ended at 56 23 00.1N and 59 17 10.9W (and beacon track map shows a shallow area in an arc as well).

Video back to Makkovik (1hr), 17:02 it started to clear up so better videos are being collected. Some large floes, Video #248, frame #20595. Cleared thin overcast 17:09 Video 248. Video height 130-140m 212002 at 17:13 Video #249.

Lots of thin ice at end of Video 21435 at 17:17.
Frazil ice piling up 21400, 17:19. Still pictures of frazil ice piling up along land-fast ice edge. Stopped at 17:20.

Files: Mooring line

EM in	FEM09213	10:40 – 11:57
EMGPS out	FEM09212	19:10 – 10:40
GPR in	F547 – F554	10:57 – 12:00
Video out	F238 – F241	10:09 – 10:44
Still Pictures out	5438 – 5455	10:10 – 10:44
Still Pictures in	5456 – 5526	10:45 – 11:57

Files Makkovik –Hopedale line and to Hopedale and out

EM to Hopedale	FEM09214	13:20 – 14:30
EMGPS Hopedale out	FEM09216	15:30 – 16:20
Video back	F242 – F244	15:37 – 16:18 to tabular iceberg
Video back	F245 – F250	16:31 – 17:21 from tabular iceberg
Still Pictures	5527 – 5553	13:19 – 14:29
Still Pictures	5554 – 5573	15:32 – 16:24 Hopedale-tabular berg
Still pictures	5574 – 5588	16:24 – 17:20 icebergs to Makkovik

Saturday 21 March **Strong W-N wind, clear, -18^{o}C**

7-8 Breakfast and packing all gear. Both helicopters will go offshore to do the mooring line and then move back to Goose Bay.

Off at 9:15; Video #251 over land to shore way point of mooring line. End at 9:36 at 21860.

Video 252 started at 9:38, very calm at the shear zone in spite of the wind. Some nilas but no snow on it. Then pancake ice 22174 9:43. Flying at 120m. Cape Makkovik directly at 9 O'clock 22494 at 9:45 with an iceberg directly off the coast at 10miles. Iceberg far off the south at 2 and 4 O'clock. Large field of thin nilas of 15cm with snow on it. Winds from the SW. Still pictures 5501 – 5504.

8.5 to 9 tenth ice concentration. Still pictures at frame #23280 9:57 (5507 and 5508). Cannot see icebergs off Hopedale but you can see icebergs to the south (i.e. less than 50miles.
More ice appears 9.5 tenth concentration. And floes large 23570 at 10:01 -10:03.
5616 picture of other helicopter. Closed video.

10:11 large blocks covered with snow. GPR 562 at 10:12.

BackGround at 10:16 still pictures looking back along the track 5518 and 5519. Hazy during the first part of the return trip. But started to clear up at 10:20. Open water areas covered with nilas 10:21. Now ridges made up of both thin and thick blocks 10:22. Flying at 65mph. Small MY floes (2). BGround at 10:28 (pictures may be on wrong setting). Stop and restart GPR just after BGround. 10:31. GPR#564. Lead at 10:33 just before mooring to 5644 (5) and lead after mooring 10:39. Most lead large and parallel to coast. Flying at 5 – 5.5m.

BGround 10:41 pictures to 5650; stop and start GPR #566. Pictures to 5653 at 19:43. Large older leads covered with nilas with snow. Some new lead with open water 10:46 flat floes 10:48 20cm thin blocks pictures to 5661 at 10:49.3. Young pancake ice 10:58 pictures to 5680. Still blowing from SW at 25mph. Shore ridge at 10:39, land-fast ice restarted GPR because it was off over thin ice (no snow). Back to Makkovik airport.

10:55 off from Makkovik. Second helicopter directly to Goose Bay. Having lunch while flying over to Rigolet. Note CTD still on daylight saving time for three profiles taken on March 21.

<u>First Site (21-1):</u> FEM 221 54.038N and 58.5776W.

Just north of the polynya: CTD done to just 4m (20090002), up and down profile at 12:28:33 + 1hr. GPR 570 to North and GPR 569 to E. On ice date: ice 79cm with 45cm snow at hole. Snow at 2m interval E-W and S-N lines: 35, 33, 35, (45), 19, 15, 20. W-E: 30, 29, 18, (45), 21, 20, 23

Salinity ice chips:	Surface	bag 9	8ppt
	At 29cm	bag 1	6ppt
	At 45cm	bag 8	9ppt

Done at 13:34 GPR 571 at 5.5 m BackGround at 13:36 end GPR at 13:43. Going through Narrows. 13:45 GPR 572. Background at 13:50, passing island in Narrows 13:53 GPR 573 file ended before the second site.

<u>Second Site (21-2):</u> at end of FEM222 53.919N and 59.041W.

13:58 GPR 574 to North and GPR 575 going West. Deeper snow. CTD 20090005, one up and down profile to 4.5m at 13:27:27 +1hr.
At hole snow was 48cm, ice 98cm and –1cm freeboard. Snow to W at 2m intervals: 89, 60, 53, (48), 50, 48, 51. Going North 54, 59, 69, (48), 55, 55, 65.

Salinity ice chips:	Surface	bag 4	10ppt
	At 35cm	bag 10	12ppt
	At 42cm	bag 2	9ppt

Done 14:33 GPR on after BGround #576. BGround 14:35 end had to restart because of power glitches?? Restart done at 14:39, #578 14:40. BGround at 14:46 and end GPR, before third site.

Third Site (21-3): at end of FEM223 53.7745N and 59.422W

GPR 579 to West and GPR 580 towards North. Ice thickness 158cm and snow 28cm. Freeboard -4cm. some of bottom snow was actual snow-ice but loose from the original ice.
Snow thickness: West 56, 51, 38, (28), 40, 54, 40. North 70, 49, 60, (28), 41, 50, 46.
Salinity ice chips: very wet ice needed to drill second hole.

Surface	bag 6	8ppt
At 48	bag 3	7ppt
Ice block	bag 7	2ppt

CTD two up and down profiles – 20090006. 14:17:50 + 1hr
FEM 224 way to Goose Bay. Restart GPR after BGround GPR 582 15:26.36.
Second BGround 15:32.30 GPR 583. Third background at 15:45 GPR 585.
Going on to Churchill River entrance by turning right 5.0 – 6.0m. Then turn left to river entrance rest, closing 15:58.

Files: Mooring line

EM in	FEM09220	10:05 – 11:30
GPR in	F562 – F568	10:57 – 11:04
Video out	F251 – F255	09:31 – 10:08
Still Pictures out	5590 – 5613	09:39 – 10:08
Still Pictures in	5614 – 5693	10:08 – 11:27

Lake Melville Files:

EM	EM09221-224	12:30 - 15: 58
GPR	F569 – F586	12:54 – 15:58
Still Pictures	5694 - 5714	12.59 – 16:15

Monday 23 March No wind, clear-overcast, -11°C

08:45 – 10 miles off airport an area of open water exists, just south of Rabbit Island.

Site 23-1 estimated location from FEM225 53.4463N and 59.97335W

09:18 – Ice area without snow along the track we flew several times. Lots of new and old cracks. Stopped at this site 23-1 and took ice chips. Ice thickness is only 33cm, no snow, 2 CTDs to 5m. Ice chips surface 0ppt; note CTD had mud on it so upward trace may be off (20090019) at 09:15:43 two up and down traces to 5m bottom).

Site 23-2 started 09:24 estimated location from FEM226 53.455N and 59.984W

3 miles to SE of 23-1, ice 70cm, snow 44cm and freeboard -7cm
N 48, 44, 60(3), 23, (44), 45, 46, 49. W 38, 40, 43, (44), 37, 32, 36.

2CTDs to 25m at 09:45. (20090020 at 09:46:47 tow up and down profiles). Salinities: surface ice 0ppt, at 25cm 1ppt, at 45cm 0ppt. (mud on CTD before we used it).

10:00 Start to profile EM and GPR to North, end of old track turn and then back to South past site 23-1. 10:03 GPR on 587 at 15ft, over 23-2 at 10:04.3.
Background at 10:09 stopped logging GPR, back to south along this line 10:13.19. At 23-1 at 10:1500 cracks continue to 17:15.45. Start and restart GPR Plot keeps given "Time Error" message. Restart GPR and 590 if okay.

Site 23-3 CTD at 11:00 from FEM228 53.753N and 59.42W (difficult landing)

At an old station where we did a GPR criss-cross. Ice 105cm, freeboard -6cm and snow 33cm, 2 CTDs to 25m at 11:00. Salinities: surface ice 4ppt, at 25cm 5ppt, wet at 45cm 3ppt, surface water 1ppt. Snow N 35, 34, 34, (33), 35, 38, 38 W 63, 30, 36, (33), 42, 35, 40. CTD# 20090021 at 10:59:47).

Profilling: Background at site 23-3 before going to polynya. GPR logging 591 at 11:27.04. Active Desktop Notice on because I did not stop laptop properly. Can not plot GPR alive but can plot older files? Finally after awhile and restart whole laptop we got rid of Active desktop message and are logging GPR 594. I stopped the GPR as we are at the next site: 12:05.

Site 23-4 , end of FEM228 54.041N and 59.5778N

Just west of polynya: 1 CTD at 12:05 to 25m, ice 80cm and freeboard -10cm. Did not measure snow as that was done before. Surface water sample 4ppt. CTD# 20090022.

Started EM and GPR for short run over grounded beach ice near Rigolet (FEM 229). Needed to dig out fuel drum 12:55.

BackGround at 13:13 Restart GPR at 13:14 #598, FEM 230. Offshore now but still all open water. Polynya has strong currents. Rough ice here and there and some very flat thin ice. All ice probably washed and blown offshore to the SE to join the southward moving pack ice.

Turn back at 13:24 FEM231 (still picture 5736 and 5738 at 13:26). Start GPR 599 on way back.
Thin ice then open water and ice again just west of island, it took long to pass the island 13:28.27 Rough ice SW of island (Shoal??).

Site 23-5 just NW of island. 57.846N and 54.2685W

13:45 2CTDs to 25m; 40cm of ice and 3-4cm snow. CTD# 20090023 two up and down profiles. Salinities: Surface water 26ppt, surface ice 10ppt, at 22cm depth 9ppt and at 33cm 9ppt.

14:01 on line GPR #600. 14:05, stopped GPR because display was dark and line white,. GPR 601 good display. Stop GPR and flying over Rigolet and lots of open water (14:28). Start west of the polynya, 14:31 GPR#602 and 603. Why black screen again; what does a black or white background mean? Bad or good GPR? Finally #604 display looks good. 14:41. FEM 232 back to Goose Bay, no stops. Stop/start GPR 606. Background 14:54 stop logging GPR and start 607 at 20m. Display good. Start/stop still black at 611.

Background Restart GPR at 20m #613 display now all white, it tries to plot snow thickness?? Restart and display fine #614. End after all the sampling is done #616 is a bad test stopped at 15:30. Going to Gosselin Lake and after that to Grande Lake.

Files: Going out to Rigolet

EM out	09225 - 228	09:07 – 11:52
EM offshore and in	09229 - 232	12:05 – 15:31
GPR out	F587 – F594	10:09 – 11:46
GPR Rigolet Beach	F595 – F596	12:18 – 13:04
GPR offshore	F598 – F601	13:21 – 14:11
GPR Lake in	F602 – F619	14:34 – 15:54
Still Polynya-Rigolet	5715 – 5731	11:49 – 13:05
Still Offshore	5732 – 5744	13:11 – 14:11
Still Rigolet in	5745 – 5751	14:19 – 14:30

Tuesday 24 March **No wind, clear-overcast, -14^{o}C**

Leaving hangar at 9:00, off to Grand Lake. We stopped on ice and set out line three bags, one a lead-up bag on the bare ice, and two on snow towards the NW. Two set of runs video and GPR and then measure snow thicknesses at every 2m and past the NW bag. Then another set of passes (video and GPR) before removing the bags and measuring 60m more past the last bag (total distance past the last bag is 90m). 53 38.88N and 60 26.42W (bare ice)

Three Video run to NW with cliff on the left of helicopter

Run 1 Video 257 at 50m start bag at 24470, end bag at 244500.
Run 2 Video 258 at 90m start bag at 24571.
Run 3 Video 259 at 450ft, start bag at 24753.

Six GPR runs at 80mph all flying same direction as Video to NW

GPR 620 at 5.3m no snow area at 10:08 17.63 to 37.60.

GPR 621 start over snow – no snow – snow, end bag 10:10 15.70.
GPR 622 start over no snow, end bag 10:11 34.30
GPR 623 Stop/start logging because of white blank plot 626
GPR 627 after start/stop.

Stopped on ice and measures from NW bag, but first one 14m past the bag, then several 24m length of tape to the SE bag which was on thin snow. Farther to SE was the lead-up bag on No-snow area.

Second set of Video/GPR lines starting at 10:12 19.00
Video 260 at 31m bag 25106 and 23
Video 261 at 29m bag at 25266
Video 262 at 70m bag 25350 11:17 10, video on past turn.
Video 263 at 71m Bag 25546 and 54
Video 264 at 500ft bag at 25596 21:17
Video 265 23:17 bag at 25635.

GPR 628 at 65.5m Snow/ no snow / snow run no snow 02.75 to 15.00
GPR 630 26:60 stop/start at 5.2m
GPR 631 at 6.5m 11:31 26.30 start snow
GPR 631 at 6.1m 11:33 27.00 start snow.

Stopped on the ice to remove the bags and sample two more 30m tap length NW of NW bag so total length measured past NW bag is 90m. 12:05

Back to Lake Melville test site 23-2 measured some GPR.
Back to hangar to change constants, and off to site 23-2 at 13:00.
GPR in area and video towards it end at 13:23.

Snow thickness at station 23-2 (13:30-13:40) at three paces (~2m).
50,42,45,38,38,42,56,50,45.North of helicopter.
48,50,50,55,56,45,44,46,45,48,40 back to helicopter. Parallel to east of out going line.
Video and GPR back (real struggle to get white GPR plot??)

Files: GPR Grande Lake test.

EM-GPS Grande Lake	09235-238	10:01 – 11:33
EM calibration tests	09239-243	12:32 – 13:42
GPR set one	F620 – F627	10:08 – 10:20
GPR set two	F628 – F631	11:28 – 11:33
GPR Melville Lake	F631 – F 650	12:00 – 14:00
Video set one	F257 – F259	10:01 – 10:06
Video set two	F260 – F265	11:13 – 11:23
Still Grande Lake	5752 – 5760	09:10 – 11:17
Still 206L mount	5761 – 5768	12:52 – 12:56

Back to hangar and repack all the gear for BIO, total 12 boxes. All clothes in double hockey bags, black tool box in one on the black boxes. Tupperware from hotel has laptop bag 1. All 12 pieces back at BIO in one day!

Snow thickness tables from Grande Lake.

Depths at every 2m, zero distance is at NW end bag, walking back from there downwind and measuring every 2m, also more samples NW from point zero to see if snow thicknesses increased beyond 30cm. three tape lengths or 90m in negative direction (NW).

site	snow	site	snow	Site (m)	Snow(cm)
-30	24	-30	20		
-28	13	-28	15		
-26	14	-26	14	-25	22
-24	16	-24	10	-23	23
-22	15	-22	15	-21	30
-20	20	-20	14	-19	10
-18	19	-18	15	-17	10
-16	30	-16	15	-15	15
-14	29	-14	15	-13	23
-12	24	-12	15	-11	23
-10	22	-10	21	-09	28
-8	14	-8	22	-07	20
-6	16	-6	20	-05	22
-4	18	-4	24	-03	19
-2	17	-2	25	-01	19
0 (-30)	20	0 (-25)	22	NW bag	26

Site(m) #1	snow (cm)	site(m)#2	snow(cm)	site(m)#3	snow(cm)
-01	19	24 (0)	18	24 (0)	6
2 NW bag	26	2	6	2	8
4	33	4	12	4	10
6	28	6	10	6	10
8	33	8	4	8	16
10	30	10	14	10	10
12	32	12	24	12	14
14	28	14	20	14	12
16	16	16	4	16	18
18	16	18	8	18	22
20	18	20	6	20	10
22	18	22	6	22	12
24	18	24	6	24	10

Site(m) #4	snow (cm)	site(m)#5	snow(cm)	site(m)#6	snow(cm)
24 (0)	10	24 (0)	5	24 (0)	3
2	12	2	23	2	6
4	8	4	18	4	2
6	2	6	14	6 SE bag	3
8	5	8	5		
10	12	10	10		
12	10	12	12		
14	5	14	5		
16	8	16	6		
18	18	18	4		
20	10	20	2		
22	12	22	2		
24	5	24	3		

Iceberg data:

ID number	I=Iridium, A=Argos Iceberg Dimensions	Start time (MM/DD/YYYY HH)	Start Lat Long	End time (MM/DD/YYYY HH)	End Lat Long
2519990	I 23’H	03/20/2009 20	56.418 -59.538	06/10/2009 16	54.532 -56.768
2611490	I	03/20/2009 14	55.401 -58.050	04/10/2009 16	54.224 -55.719
2611510	I	03/20/2009 14	55.598 -57.896	05/04/2009 17	51.007 -53.524
2616000	I 290’H x 350’L	03/20/2009 20	56.482 -59.503	06/17/2009 13	52.689 -55.708
44652	A 40’H	03/20/2009 20	56.241 -59.690	05/17/2009 21	51.206 -51.731
44653	A	03/19/2009 14	55.530 -59.172	05/27/2009 14	50.940 -52.545
44656	A 225’H x 350’L	03/19/2009 19	55.850 -59.546	06/04/2009 14	54.400 -56.526
44658	A	03/19/2009 17	56.036 -59.132	05/16/2009 22	49.966 -52.533

Table LabSea 2009 CTD profiles (station 21-3 and 23-3 are at the same location but occupied at different days.

Profile #	Stn #	Profile time	latitude	longitude	Depth	profiles
20090002	21-1	12:28:33*	54.038	58.577	4.1**	2
20090005	21-2	13:27:27*	53.919	59.041	4.8	2
20090006	21-3	14:17:59*	53.774	59.422	4.7	4
20090019	23-1	09:15:43	53.446	59.975	4.6	4
20090020	23-2	09:46:47	53.455	59.984	20**	4
20090021	23-3	10:59:47	53.753	59.420	24	4
20090022	23-4	11:59:29	54.041	58.578	20**	2
20090023	23-5	13:48:00	54.268	57.846	25	4

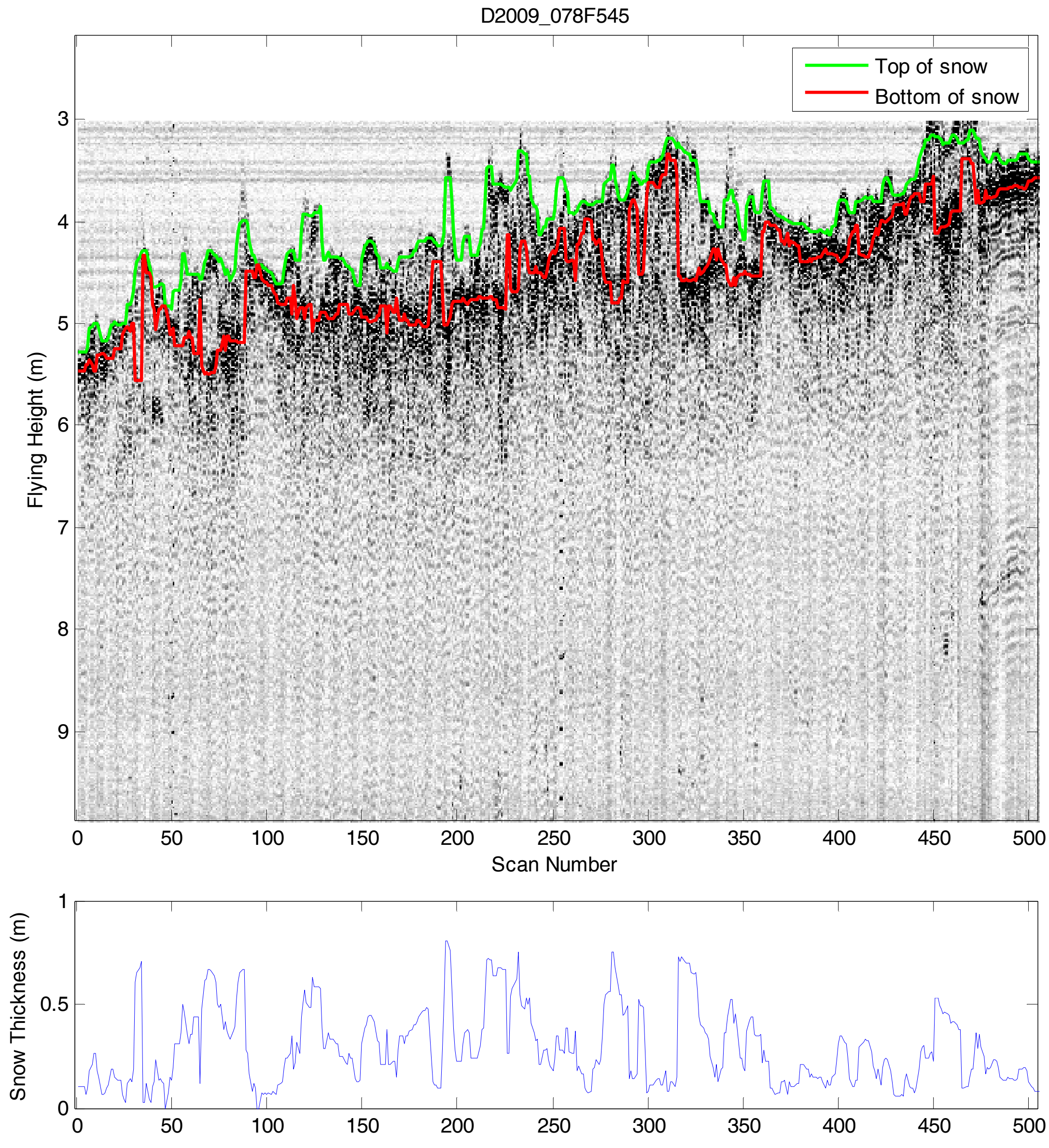
*   add one hour for Eastern Standard Time.

** profiled to 5m and 25m line lengths but reached only 20m (possibly current effect)

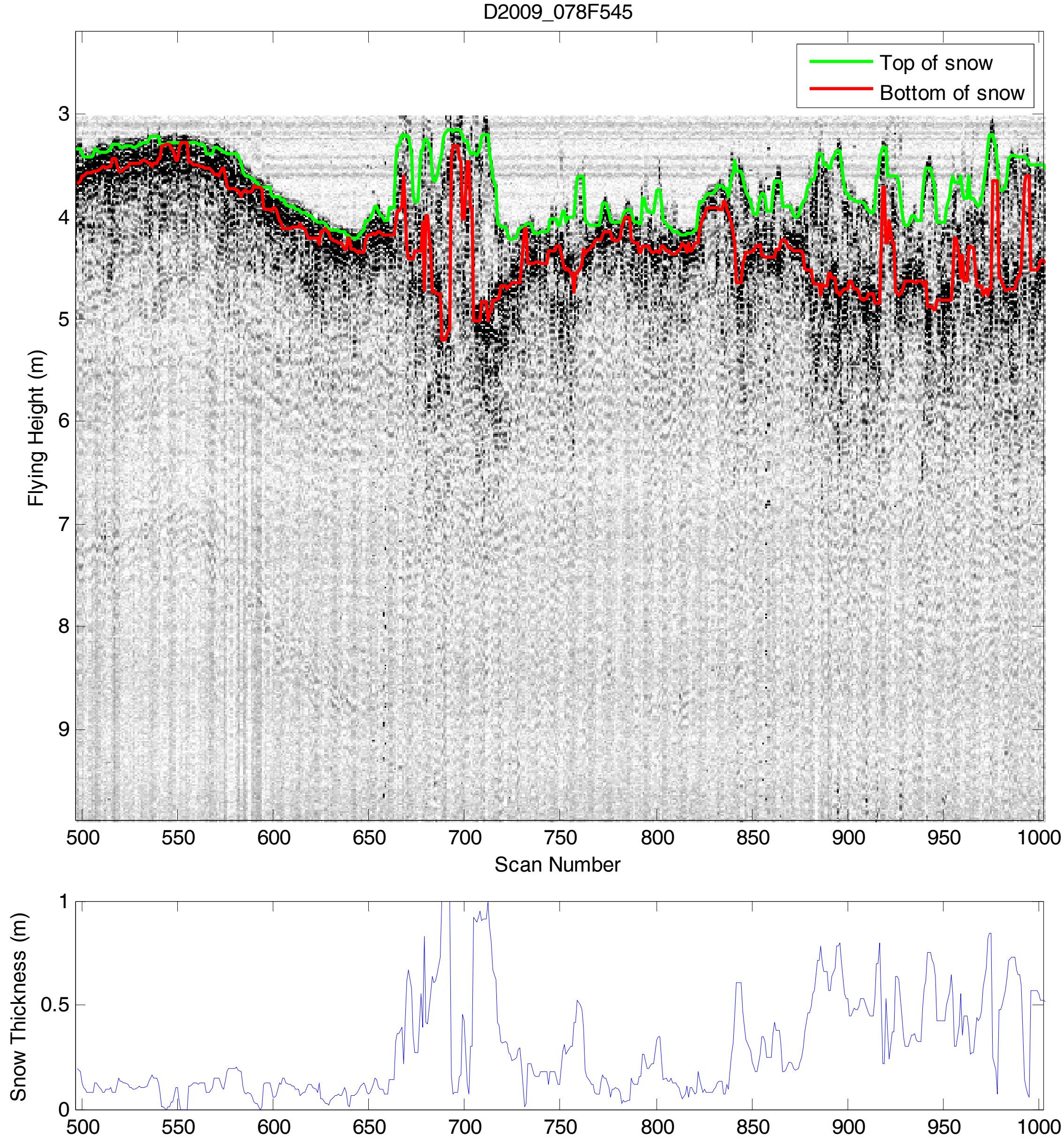
Appenxix 2: GPR Land-fast Snow thicknesses

Plots represent data collected from the Hopedale land-fast on March 19 (File 545)

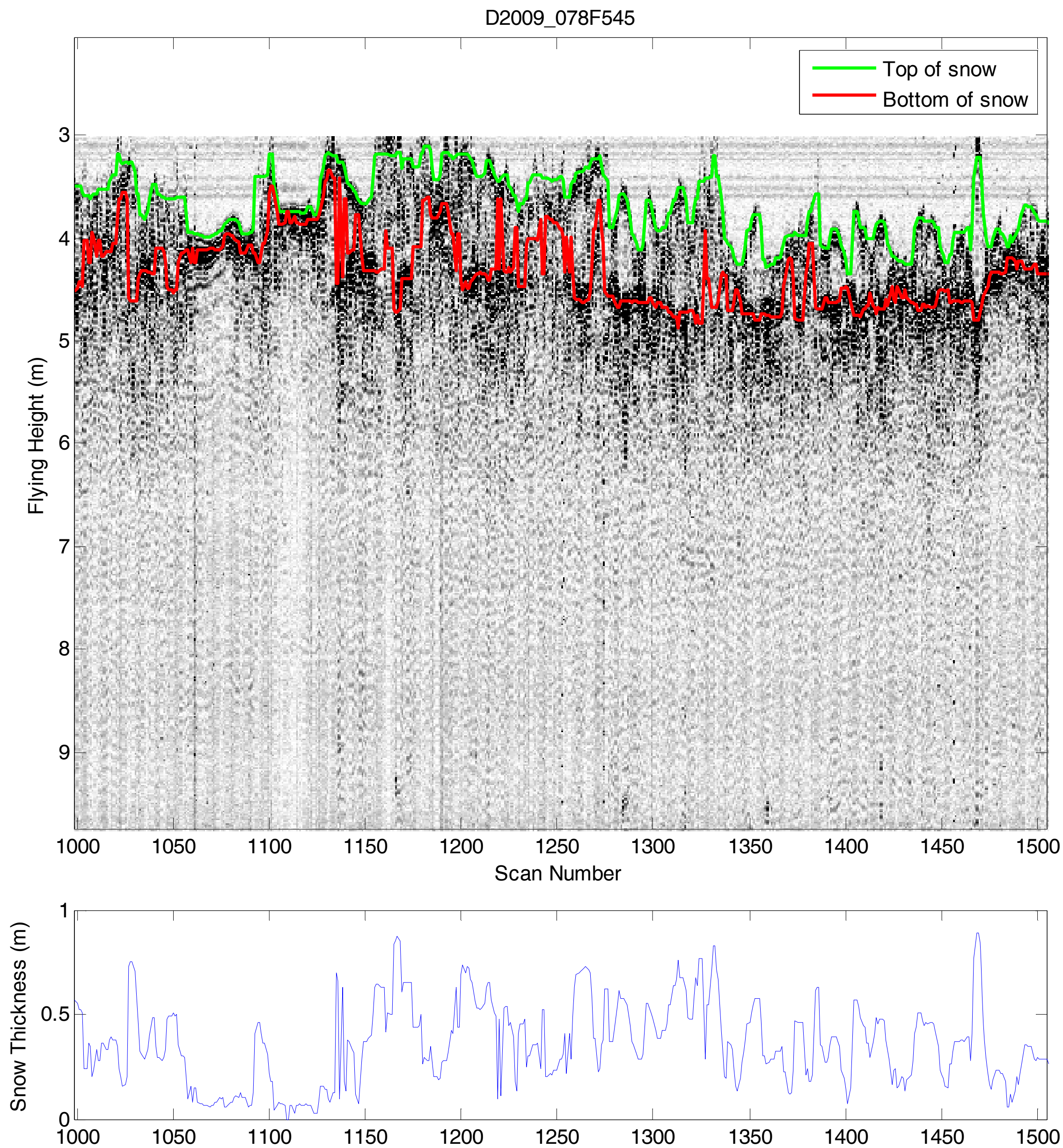
Sample 545: 0-500 - Offshore end



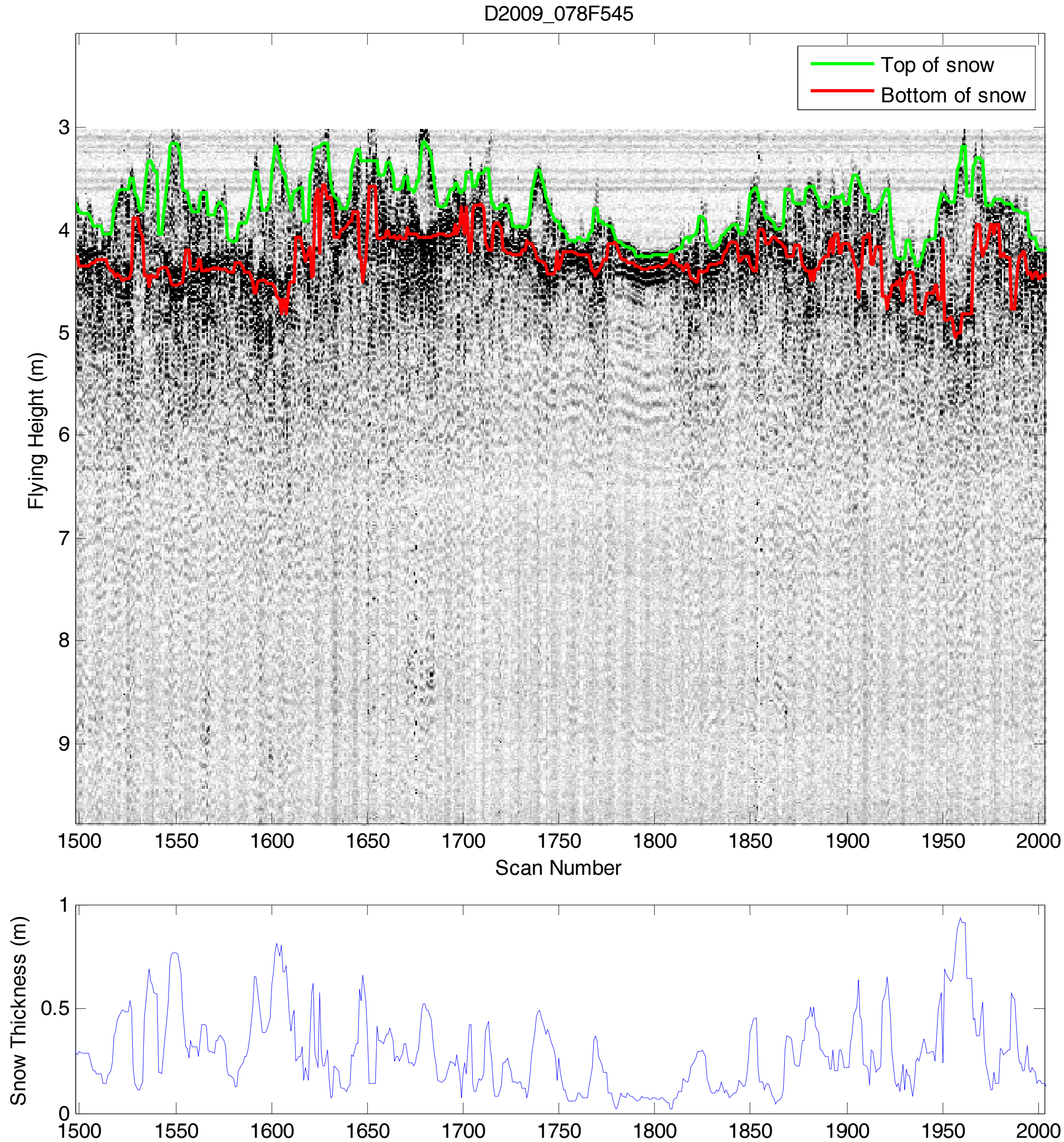
File 545: 500-1000



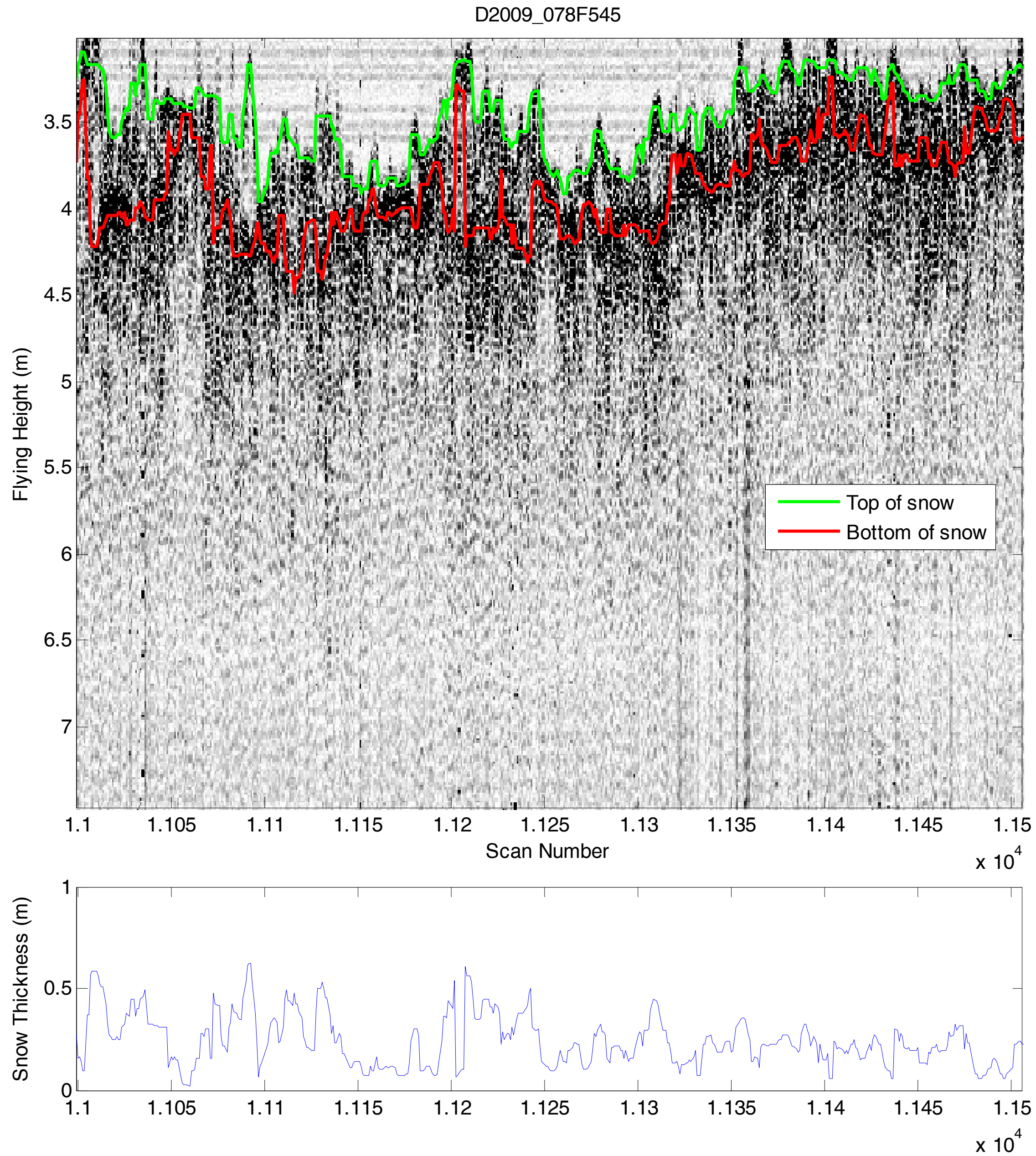
File 545: 1000-1500



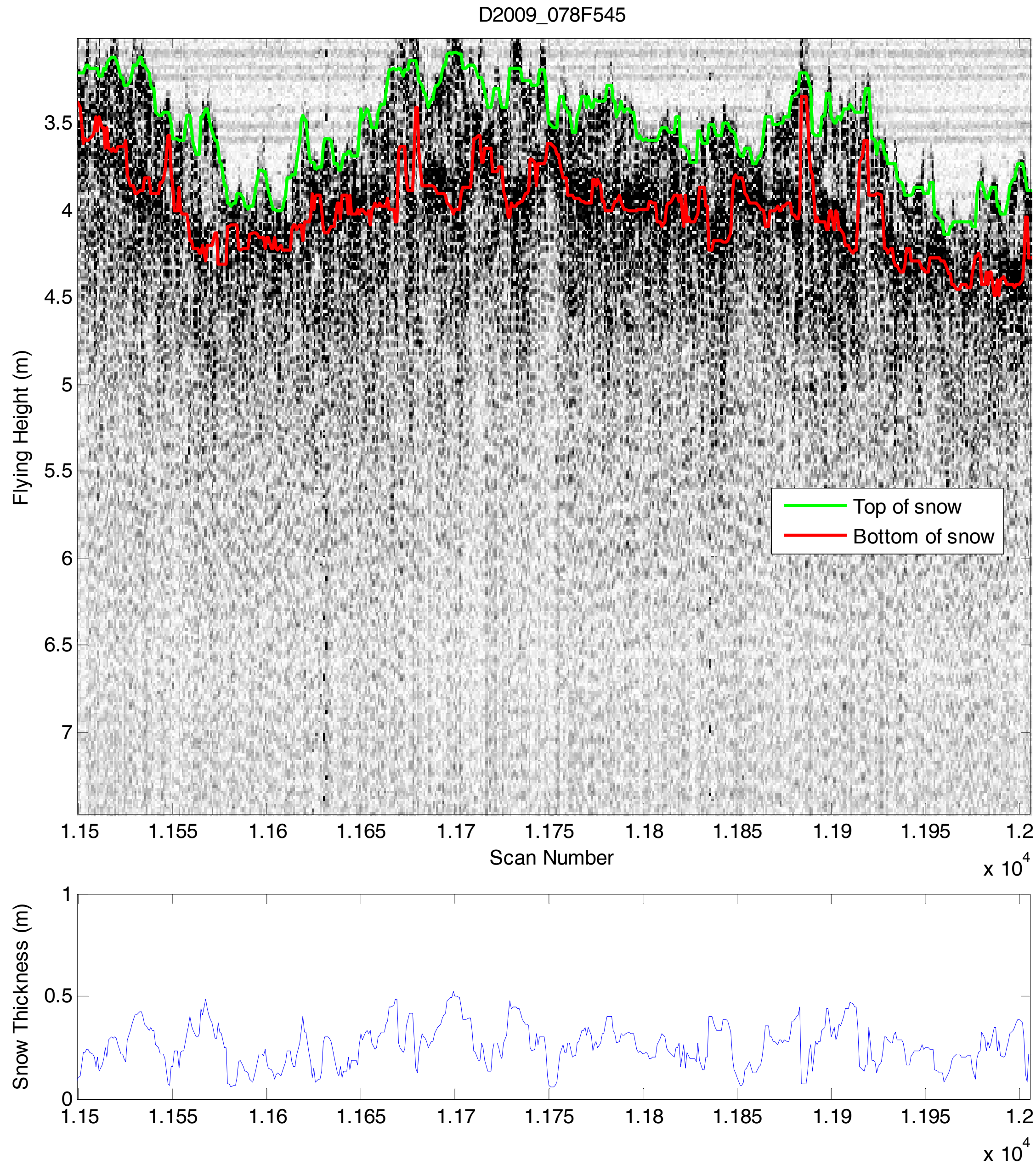
File 545: 1500-2000



File 545: 11000-11500

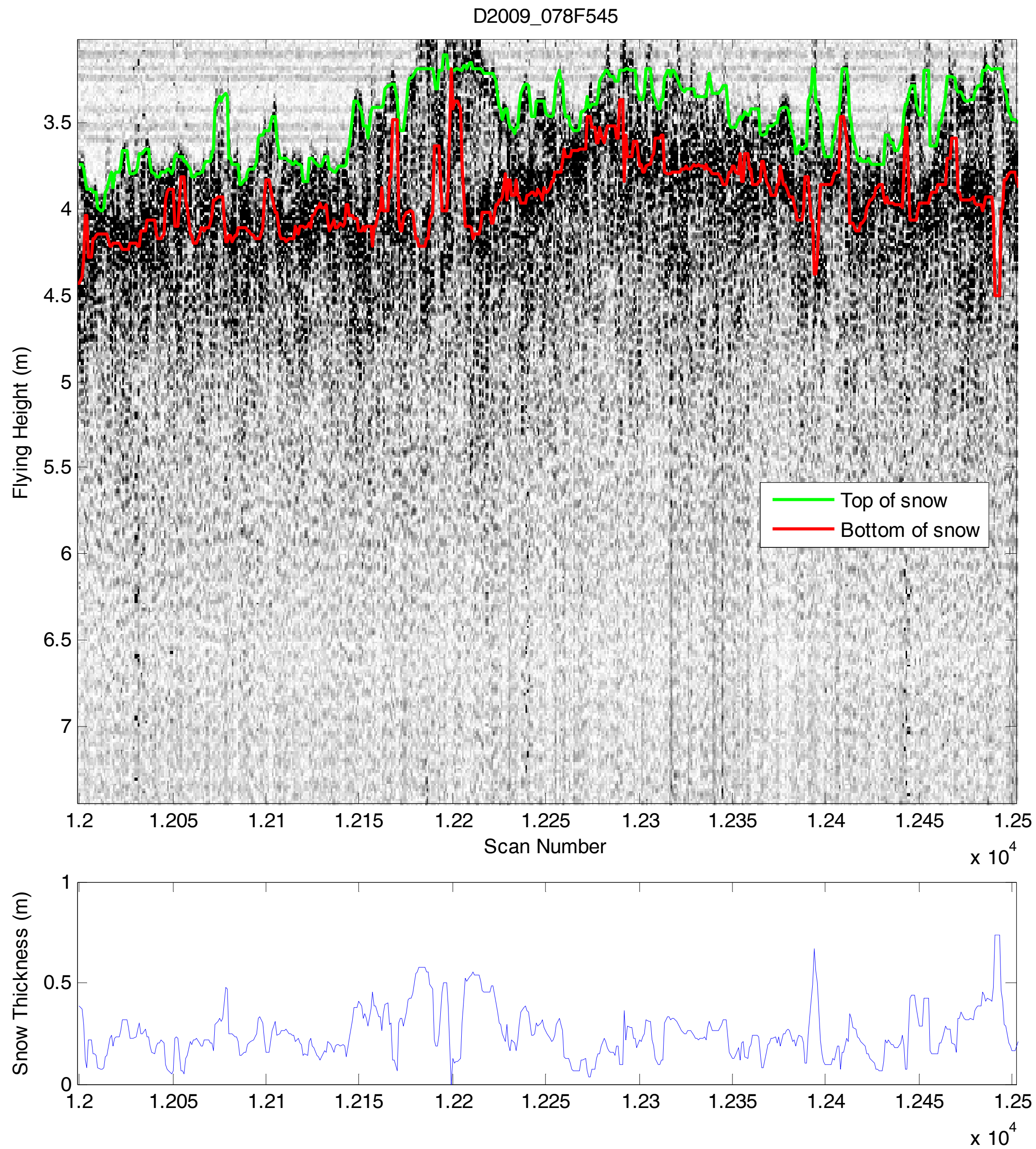


File 545: 11500-12000

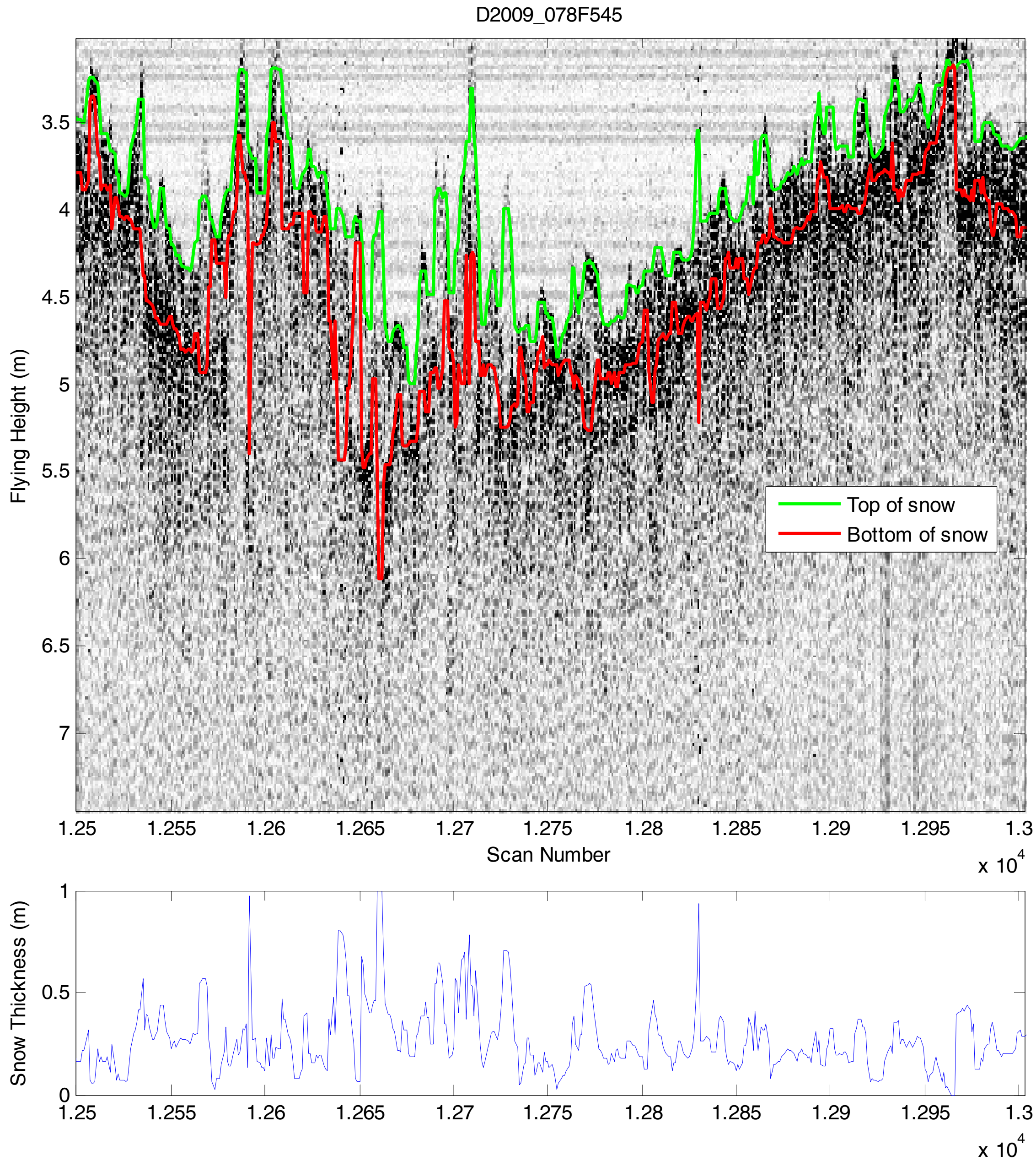


File 545: 12000-12500

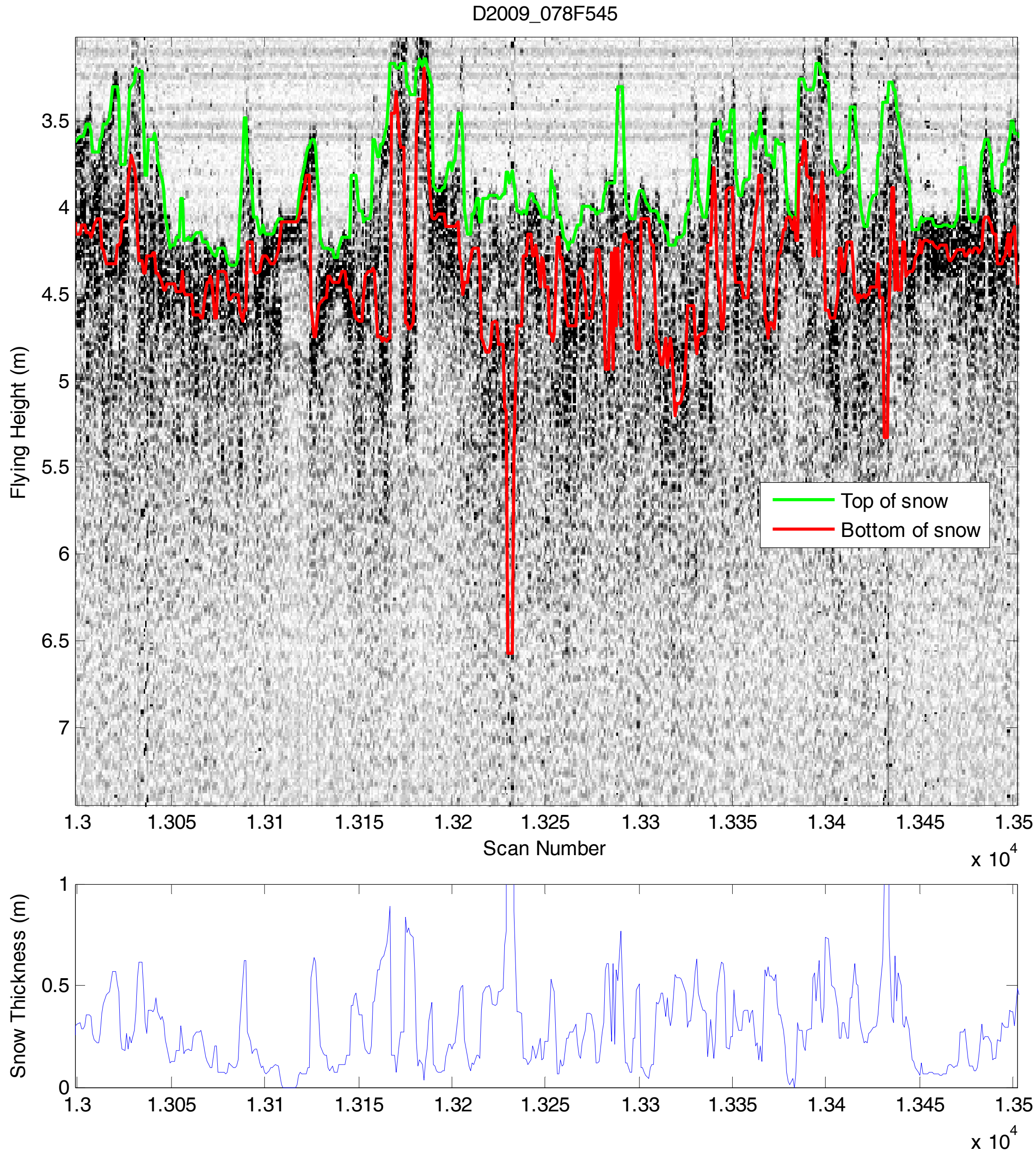
Notice how the snow thickness is clipped (reduced) where the top echo is too soon for the GPR window.



File 545: 12500-13000



File 545: 13000-13500



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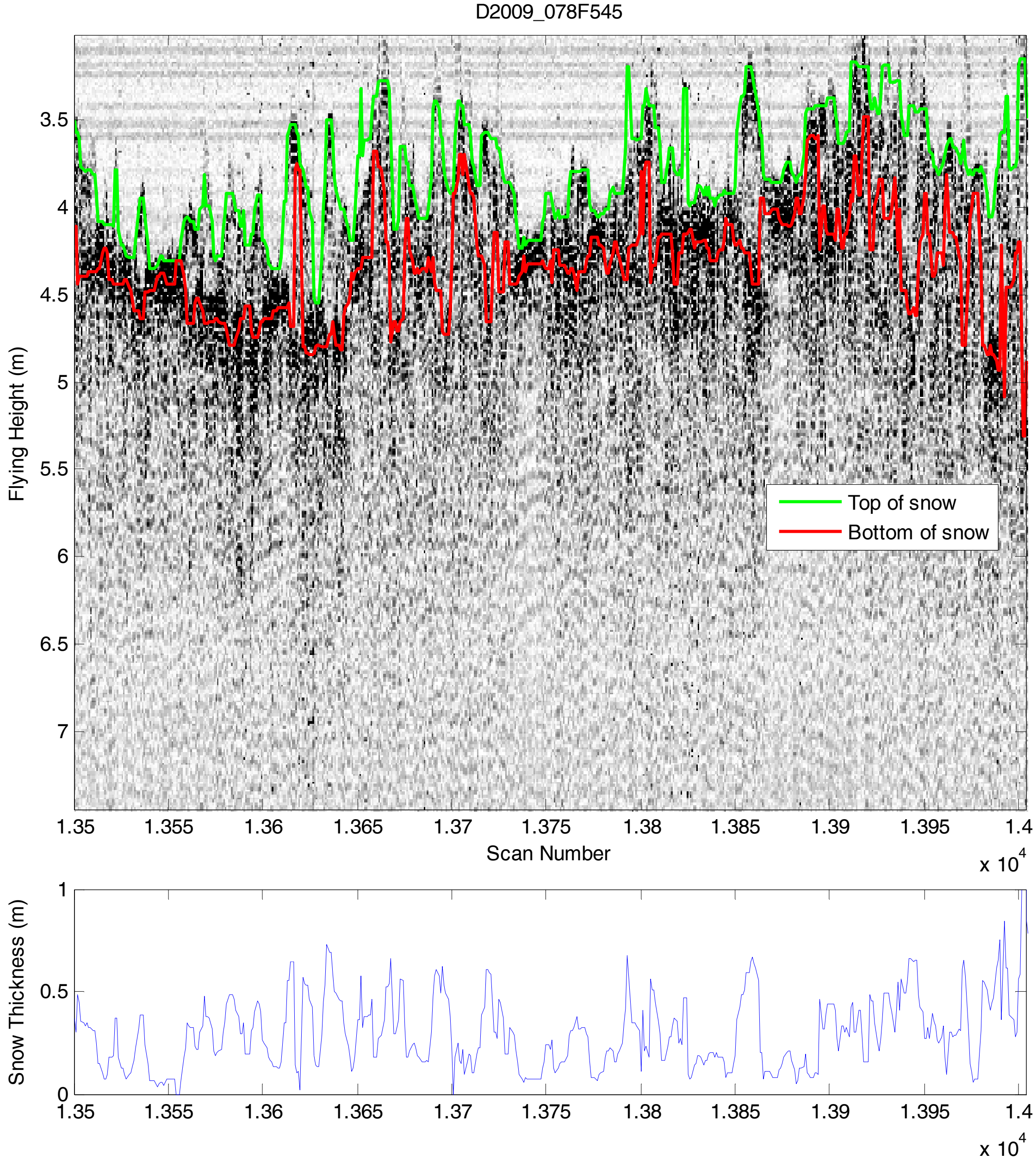

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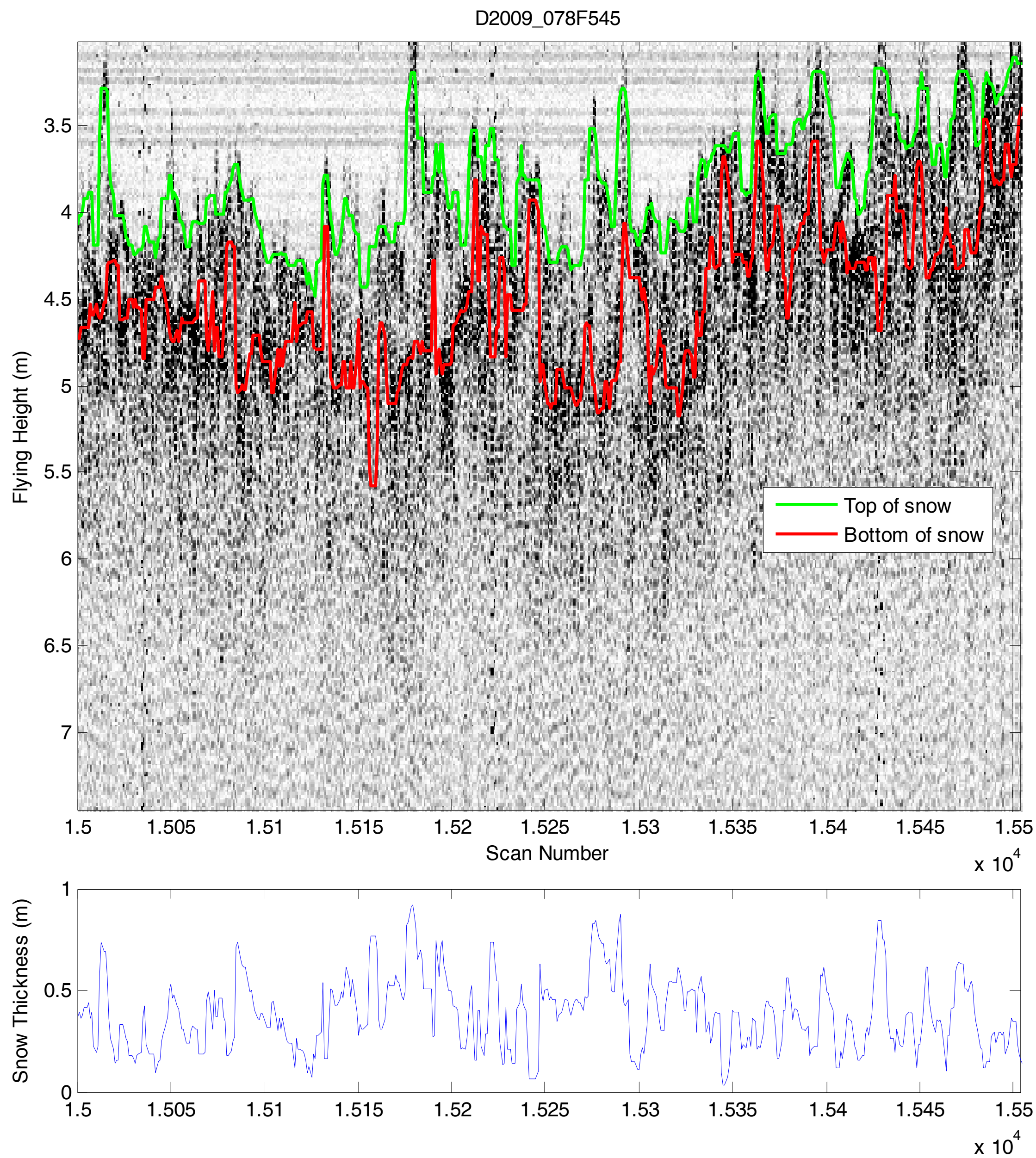

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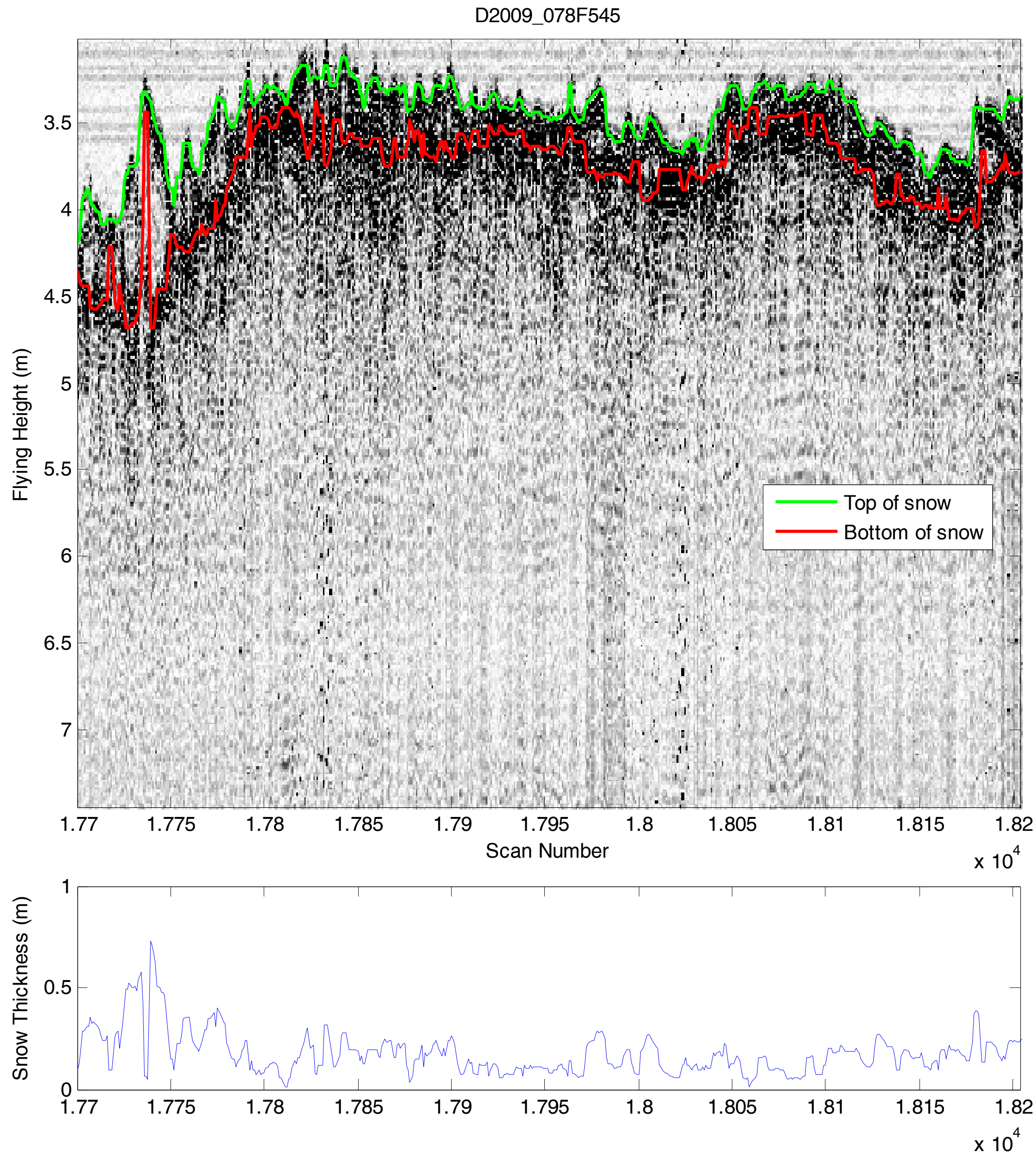

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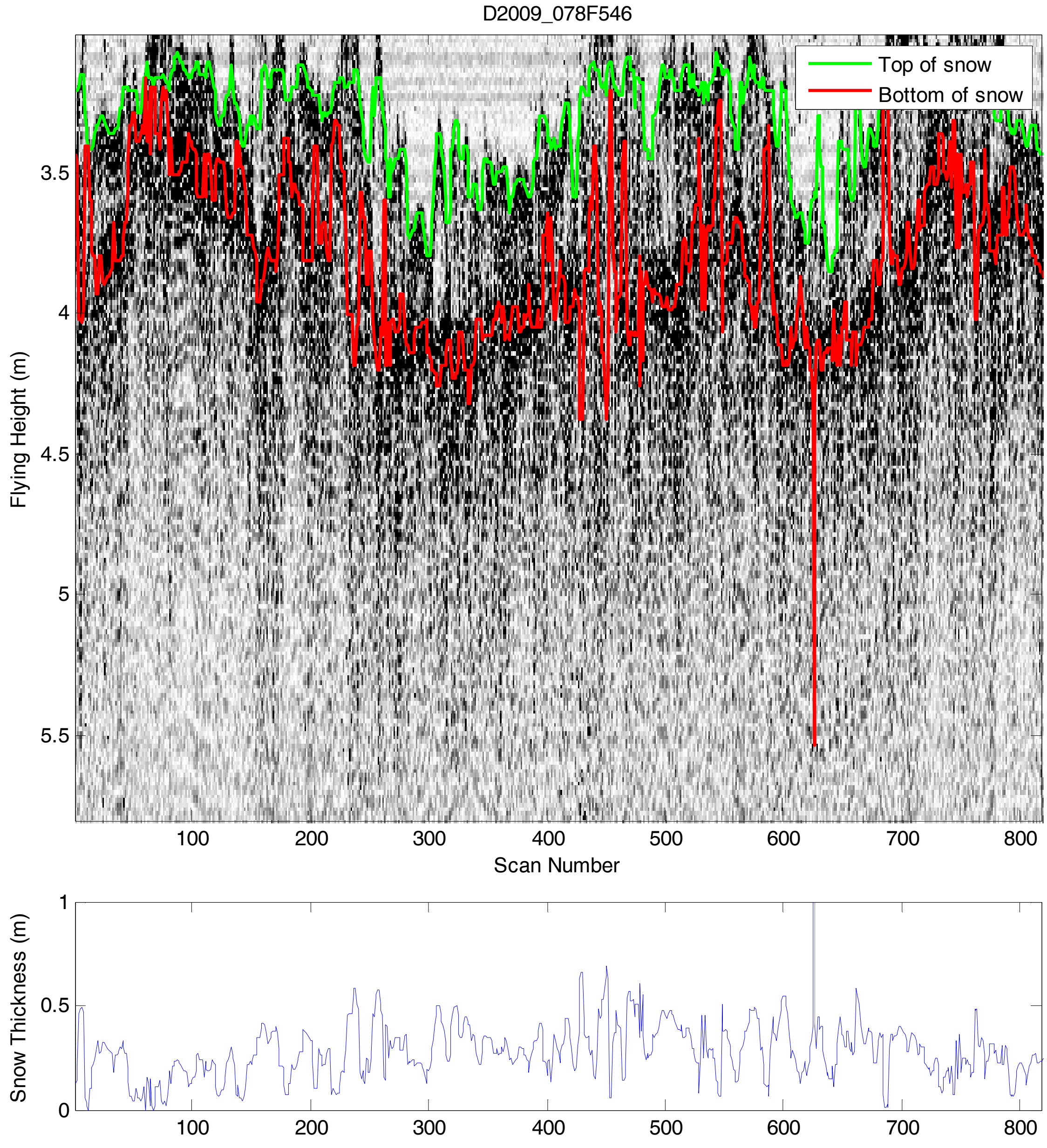

Appendix 3 – Lake Melville On-ice Station and GPR Snow Data

On Saturday March 21, 2009 three stations were sampled on way back from Makkovik to Goose Bay with both EM and GPR with an E-W and S-N line centered at locations where on-ice station data was collected. CTD profiles were collected to shallow depths, later deeper profiles were collected on March 23. (Note CTD still on daylight saving time for the three profiles taken on March 21). Data is also listed in Appendix #1:

<u>First Site (21-1):</u> FEM 221 54.038N and 58.5776W.

Just north of the polynya off Rigolet: CTD done to just 4m (20090002), up and down profile at 12:28:33 + 1hr. A second profile (#23-4) on March 23 went to 25m, surface water of 4ppt to 3.5m overlaid a saltier water of up to 20-25ppt to 25m. GPR 570 to North and GPR 569 to E. Sampling at station done at 13:34 and going to Station #2 passing through Narrows at 13:53 (GPR 571 and 572).

On-ice data: ice 79cm with 45cm snow at hole.
Snow at 2m intervals S-N line: 35, 33, 35, (45), 19, 15, 20.
Snow at 2m intervals W-E line: 30, 29, 18, (45), 21, 20, 23

Salinity ice chips:	Surface	bag 9	8ppt
	At 29cm	bag 1	6ppt
	At 45cm	bag 8	9ppt

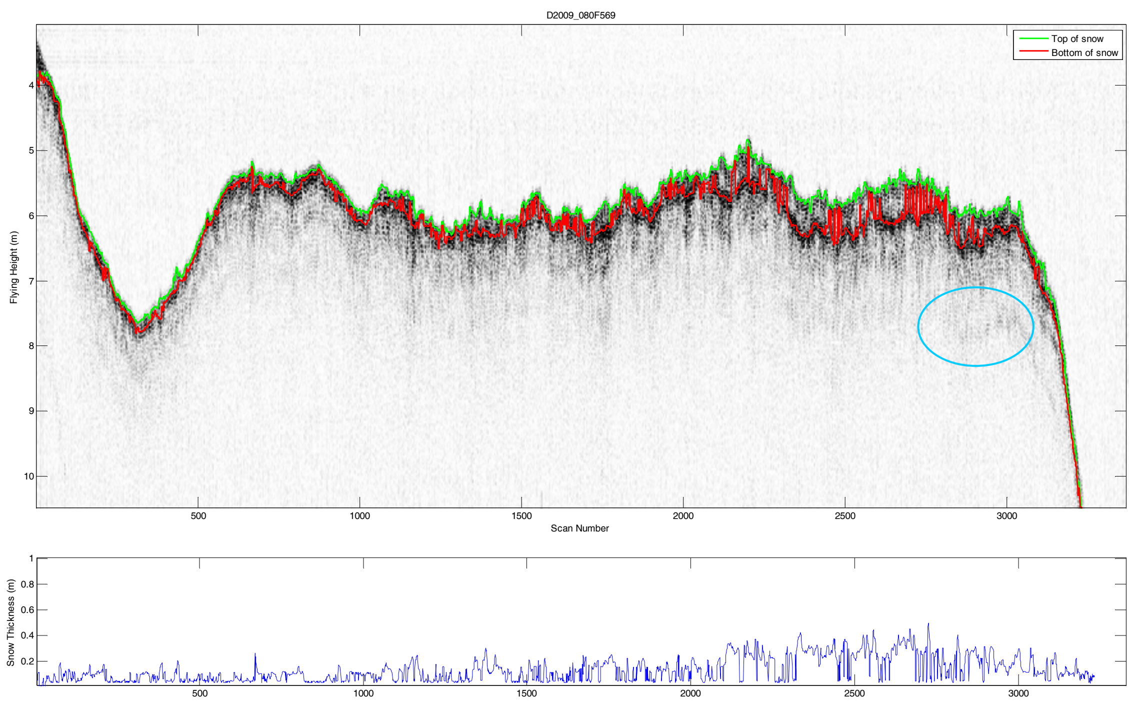

Fig. A1 GPR line plot and snow thickness of First Site 21-1 GPR 570 line flown South to North. This site (Fig. A1 and A2) has less snow than the other two sites within Lake Melville.

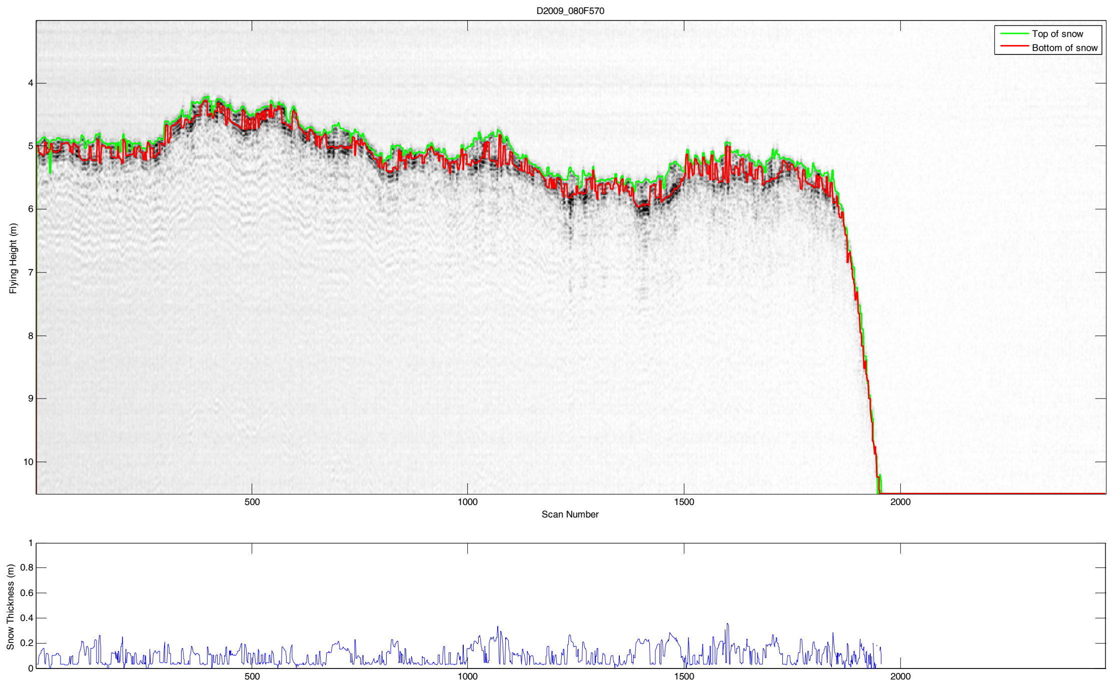

Fig. A2 GPR line plot and snow thickness of First Site 21-1 GPR 569 line flown West to East. This site (Fig. A1 and A2) has less snow than the other two sites within Lake Melville.

Second Site (21-2): at end of FEM222 53.919N and 59.041W.

13:58 GPR 574 South to North and GPR 575 East to West. Deeper snow at this station. CTD 20090005, one up and down profile to 4.5m at 13:27:27 +1hr. Sampling done by 14:33.

At hole: snow was 48cm, ice 98cm and –1cm freeboard.
Snow going East to West at 2m intervals: 89, 60, 53, (48), 50, 48, 51.
Snow going South to North at 2m intervals: 54, 59, 69, (48), 55, 55, 65.

Salinity ice chips:	Surface	bag 4	10ppt
	At 35cm	bag 10	12ppt
	At 42cm	bag 2	9ppt

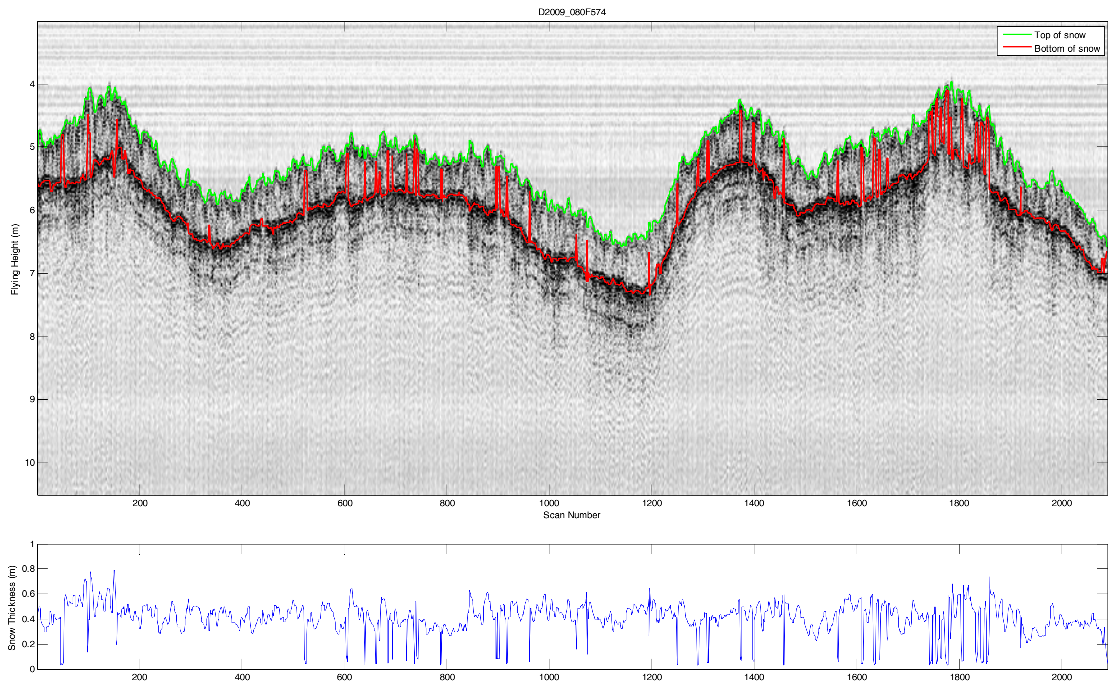

Fig. A3 GPR line plot and snow thickness of second Site 21-2 GPR 574 line flown South to North. This site (Fig. A3 and A4) has more snow than site 21-1.

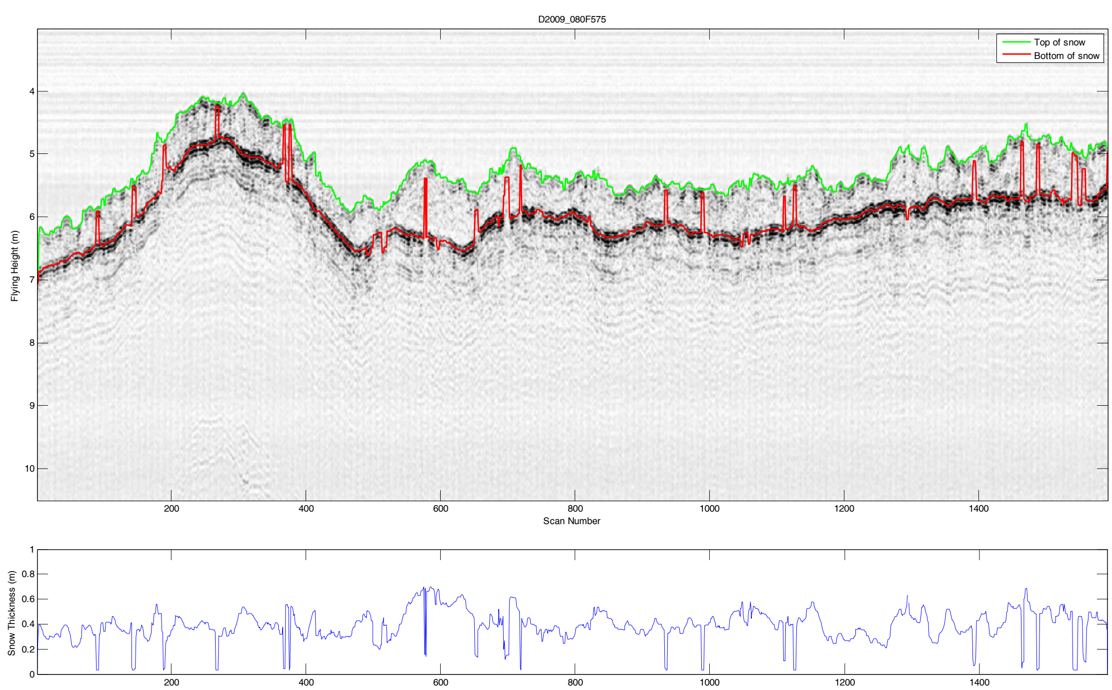

Fig. A4 GPR line plot and snow thickness of Second Site 21-2 GPR 575 line flown East to West. This site (Fig. A3 and A4) has more snow than site 21-1.

Third Site (21-3): at end of FEM223 53.7745N and 59.422W

GPR 579 flown East to West and GPR 580 flown South to North. Ice thickness 158cm and snow 28cm. Freeboard -4cm, some of bottom snow was actual snow-ice but loose from the original ice. CTD two up and down profiles – 20090006. 14:17:50 + 1hr. A second profile (#23-3) on March 23 went to 25m., a surface water of 1.5ppt to 4.5m overlaid a saltier water of up to 20-25ppt to 25m.

Snow thicknesses at 2m intervals to West: 56, 51, 38, (28), 40, 54, 40.
Snow thicknesses at 2m intervals to North: 70, 49, 60, (28), 41, 50, 46.

Salinity ice chips: very wet ice needed to drill second hole.

Surface	bag 6	8ppt
At 48	bag 3	7ppt
Ice block	bag 7	2ppt

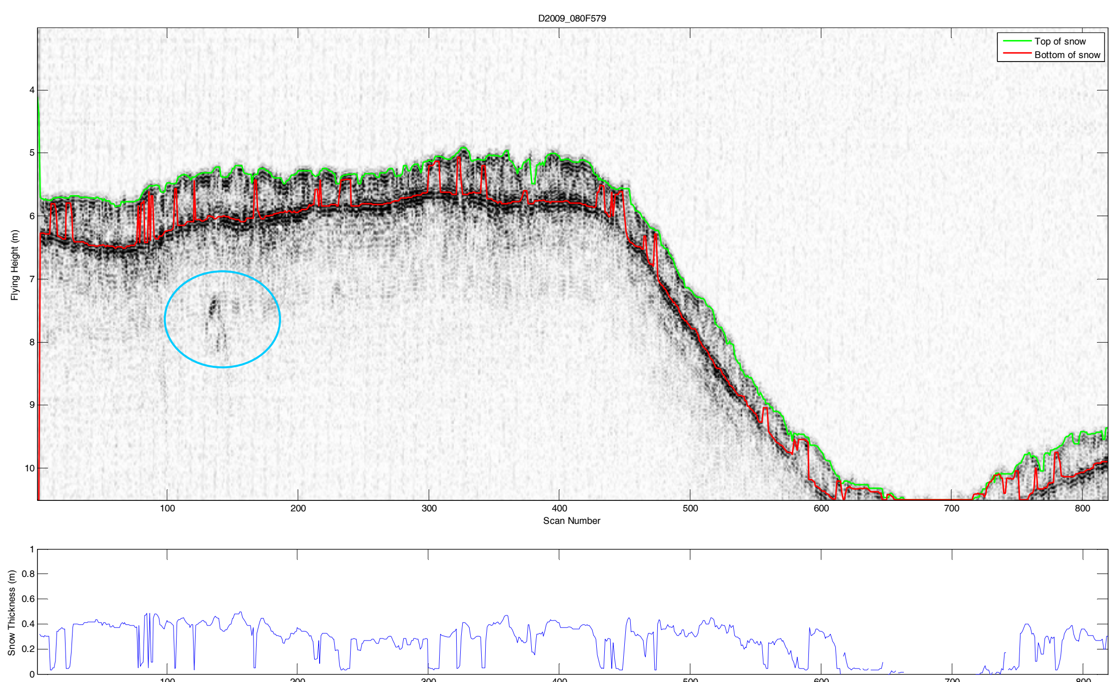

Fig. A5 GPR line plot and snow thickness of third Site 21-3 GPR 579 line flown East to West. This site (Fig. A5 and A6) has a thick snow layer like Site 21-2.

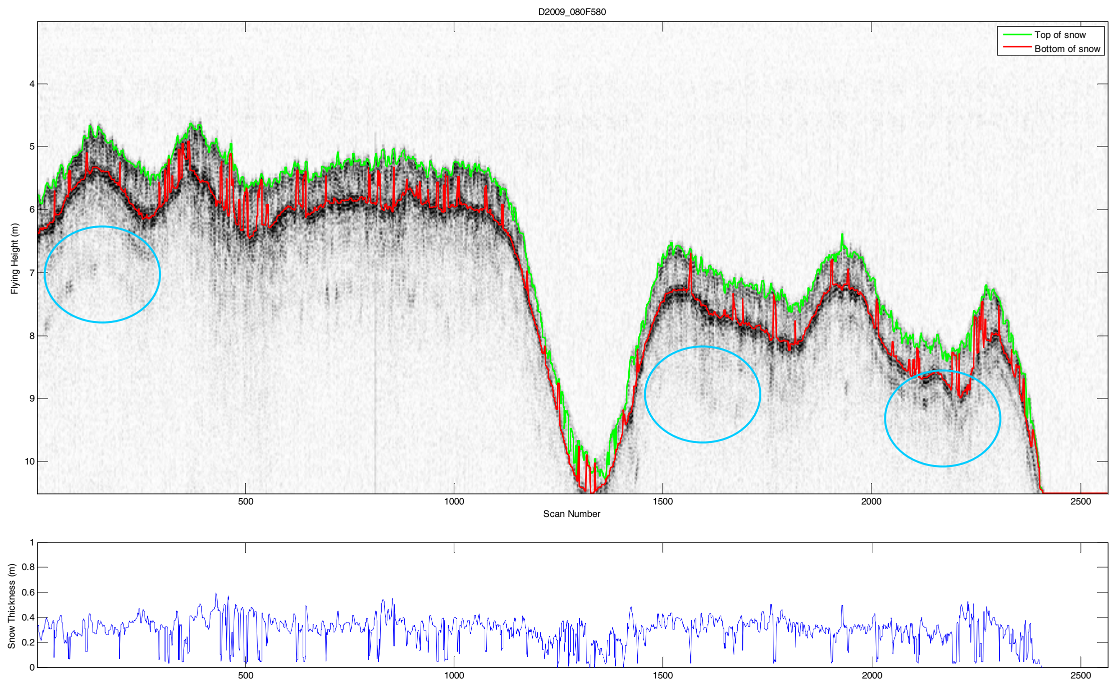

Fig. A6 GPR line plot and snow thickness of third Site 21-3 GPR 580 line flown South to North. This site (Fig. A5 and A6) has a thick snow layer like Site 21-2.