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Airborne Electromagnetic Sea Ice Sounder Measurements of RADARSAT Validation Project 1996

by

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ABSTRACT

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An airborne EM-laser altimeter sensor system was used to measure snow-plus-ice thickness and surface ice cover roughness for comparison with, and validation of, sea ice signatures seen in RADARSAT images as part of the 1996 RADARSAT Validation Project (RVP). Approximately 760km of airborne electromagnetic ice sounder (EIS) data was acquired over the ice cover of the Gulf of St. Lawrence and over the southern Labrador Shelf during late February and early March of 1996. Much of the profiling was performed at times close to RADARSAT overpasses.

Extensive surface measurements were collected in both areas before, during and after the airborne program. The EIS data were validated using these surface measurements: system performance was found to be nominal, yielding snow plus ice thickness accuracies better than the system's 0.05 m accuracy system specification over level ice.

RÉSUMÉ

Moucha R.Z., J.S. Holladay and S.J. Prinsenberg. 1998. Airborne Electromagnetic Sea Ice Sounder Measurements of RADARSAT Validation Project 1996. Can. Contract. Rep. Hydrogr. Ocean Sci. 51: vii + 349.

Un système de capteurs aéroportés composé d'un altimète laser et d'un dispositif électromagnétique a servi à mesurer l'épaisseur de la neige et de la glace, et la rugosité de de la couverture de glace en surface, en vue de l'établissement de comparaisons et de la validation des signatures de glaces de mer vues sur des images RADARSAT, dans le cadre du projet de validation RADARSAT de 1996. Les données du sondage électromagnétique aéroporté d'environ 760 km de glaces ont été saisies au-dessus de la couverture de glace du golfe Saint-Laurent et du plateau du sud du Labrador, à la fin de février et au début de mars 1996. La majorité du profilage a été fait presque en même temps que les survols RADARSAT.

Un grande quantité de mesures de surface ont été recueillies dans les deux secteurs avant, pendant et après le programme aéroporté. Les données de sondage électromagnétique des glaces ont été validées au moyen de ces mesures de surface : on a conclu que la performance du système était nominale, et que ce dernier produisait des mesures de l'épaisseur de la neige et de la glace meilleures que les spécifications indiquées quant à la précision du système, soit 0,05 m au-dessus d'une glace uniforme.

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1. INTRODUCTION

Seasonal ice cover over Maritimes waters poses a threat to safe operation of marine shipping, fishing activity and hydrocarbon exploration. The ability to map and classify ice types is of particular value to the Canadian Coast Guard and ice forecasters of the Canadian Ice Centre (CICE) who provide icebreaking services and ice information to mariners and offshore operators. Ice imagery from RADARSAT, a Canadian Space Agency (CSA) satellite, will be used for daily development of ice charts for the Maritimes and the Arctic regions. RADARSAT is equipped with a Synthetic Aperture Radar (SAR) giving it the ability to acquire ice imagery independent of lighting and weather conditions.

The sea ice programs of the DFO, funded primarily by the Federal Panel of Energy and Resource Development, are investigating the seasonal variability of pack ice properties such as southern ice extent, ice drift, ice concentration and ice thickness. One of these programs explores the use of the Electromagnetic (EM) Induction technique for measuring the thickness of pack ice as an operational tool in support of the Canadian Coast Guard (CCG) icebreaking service. The Airborne EM Induction technique has provided the most promising results to date. A series of prototype systems were built at Geotech Ltd. of Markham, Ontario in the mid-80's and Aerodat Inc. of Mississauga, Ontario in the late 1980's and early 1990's. The Geological Survey of Finland has also performed experimental ice surveys in the Baltic Sea using a Twin Otter-mounted airborne EM system. The last of the Aerodat systems, known as the *Ice Probe*™ [1] "production prototype" and here referred to as the "airborne Electromagnetic Ice Sounder" or EIS, was delivered to CCG in 1995. It was successfully used during the SIMMS'95 field experiment near Resolute, NWT in April-May, 1995 (Holladay *et al*., 1998). This EIS system is now being supported and maintained by Vanguard Geophysics Inc. of Toronto.

The RADARSAT Validation Project (RVP) was initiated to assist with the initial evaluation of RADARSAT sea ice data products. The EIS was used to provide surface roughness and ice thickness ground truth information for the RVP. Data acquisition took place between February 27th and March 12th, 1996. The data collected were of high quality and much of the profiling was executed to coincide with a series of RADARSAT overpasses.

This report documents the 1996 EIS data set and the results of post-processing. Tables describing the processed data are given in Appendix A. Post-processing software was used to present data in both *profile map* format and in *standard plot* format along with *statistics tables*. The *profile map* consists of data presented in profile form superimposed on a map of the area in a Lambert Conic Conformal projection (Appendix C). The *standard plot* presents ice thickness and high-pass filtered laser altimeter histograms along with profile plots of ice thickness, laser altimeter and high-pass filtered laser altimeter (Appendix E for March 6, 10 and 11 only). Each *standard plot* corresponds to a 2km segment of the flight traverse. The statistics for each segment are presented in the *statistics tables* (Appendix D). Surface measurement data gathered by Dr. Prinsenberg and assistants, and consisting of ice thickness measurements from augered ice holes, snow depths and ice salinity data, are presented in Appendix B.

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[1] Non-registered trademark of Aerodat Inc.

2. STUDY AREA AND FIELD WORK

2.1 Study Area

The RADARSAT Validation Project acquired surface pack ice data from two areas. The first area consisted of the pack ice of the southern Gulf of St. Lawrence around Prince Edward Island (PEI) including the Northumberland Strait, while the second area included the pack ice off the southern Labrador Shelf, using Cartwright, Nfld., as the base camp. The ice conditions in both areas were less severe than the norm as surface air temperatures for the areas had been warmer than in previous winters, when severe ice conditions occurred.

In the southern Gulf of St. Lawrence, the ice drifts from west to east under the predominant westerly winds, causing ice divergence north of PEI and ice convergence west of the Magdalen Islands. Open water and new thin ice is thus present north of PEI and thickens as the Magdalen Islands are approached. Pack ice emerging from the upper St. Lawrence normally reaches a thickness of 80cm and is compressed against the western shore of the Islands forming pressure ridges. Although the main pack ice of the southern Gulf only reached an average thickness of 55cm in 1996, it did include a wide variety of ice types, facilitating the validation of different ice signatures present in the RADARSAT SAR images of the area.

The pack ice off the southern Labrador coast moves parallel to and southwards along the coast under the predominant NW winds and southward setting ocean currents. Warmer winter air temperatures and stronger than usual offshore winds along the Labrador coast caused the pack ice to be thinner than normal. Level ice thickness values measured through augered ice holes at several sites of the inshore pack ice reached by helicopters did not exceed ¾m. The offshore wind conditions did provide conditions conducive to the formation of thin young ice along the land-fast pack ice margin, thus providing a variety of ice types for validation of SAR image ice signatures.

2.2 Field Work

Two Coast Guard helicopters, CG303 (a Bell 212) and CG353 (an MBB BO105) were used for the Gulf of St. Lawrence field work. CG353 was used for EM surveying, while CG303 was used for on-ice work.

In Labrador, two Bell 206L helicopters (C-CJBC and C-GLSH) from Universal Helicopters Ltd. were used. JBC was oriented toward on-ice work and was equipped with fixed floats, while LSH carried the EM sensor and was equipped with pop-out floats.

The remainder of this section contains an abbreviated daily summary of activities. The first portion of the program, covering the Gulf of St. Lawrence, was based in Charlottetown, PEI and extended from 27 February to March 8. The CCG helicopter base at the Charlottetown airport served as the operations centre for this phase.

On March 8, the equipment was loaded into a LabAir Shorts Skyvan aircraft and flown to Goose Bay, Labrador. The EM system was installed into a Universal Helicopters 206L, designated here as LSH, and flown to Cartwright, Labrador on March 10 to begin operations.

Personnel involved in the project included:

Initials	**Name**	**Organization**
JL	James Lee	Aerodat Inc.[2]
JSH	Scott Holladay	Aerodat Inc.[2]
GF	George Fowler	BIO
IP	Ingrid Peterson	BIO
SP	Simon Prinsenberg	BIO
AM	Andre Maillet	CCG
CS	Clifford Sadler	CCG helicopters
IH	Ian Henderson	CCG helicopters
TH	Tony Heacock	CCRS
DF	Dan Fequet	CIS
RH	Ralph Hilchie	CIS

2.2.1 Daily Summary of Activities: Gulf of St. Lawrence

Tuesday, 27 February (Weather: clear, approx. 1°C)
EM Flights Number: 26
CG303 (Bell 212) flew out to perform a visual reconnaissance to the W of the Magdalen Islands.

Ice sensor equipment was reinstalled in "scientific" in CG353 (MBB B0105). New weight and balance calculations and flight approvals were required from Ottawa (1600) for this installation. A short test flight (FLT026) was started at about 1630, with JSH and IP aboard, over Hillsborough Bay. Ice thickness results from this flight were plotted immediately after the flight.

Wednesday, 28 February (Weather: cloudy, -2°C)
EM Flight Number: 27
SP, AM and others prepared a 160 m surface measurement line (Station #3, Calibration Floe #1) on a medium-size floe in Northumberland Strait. RH flew the system over this line. 5 passes (Lines 10060-10100) were flown [the final two passes appear to have been off to one side of the line.], as well as the fixed link corridor (10130). These results were checked on the chart record

[2] Now employed by Vanguard Geophysics Inc.

and agreed well with SP's auger results (Appendix B) [airborne mean of 0.62 ± .3 (2σ) vs. .63 ± .24 GT. for 1995 Resolute calibration data]

Thursday, 29 February **(**Weather: snow flurries, clear by 0900. Temp -11°C.)

EM Flight Number: 29 - 31.

The long-range fuel tank was installed in CG353 before takeoff. CG303 flew out to set up beacon sites and perform surface measurements, while CG353 waited 45 minutes to meet them at Grindstone. IH flew in CG303 to Grindstone to help "land" the bird for the outbound and homebound trips, then returned in CG303. RH operated the system: three large files (FLT029-031) were then acquired, separated by refuelling stops at Grindstone: 029 was an outbound run almost due N of PEI, then due E to Grindstone. 030 covered four sides of a square defined by an array of ARGOS-GPS beacons W of Grindstone, then a short track SE to another ARGOS-GPS beacon location. 031 ran SSW back toward Charlottetown.

The data were plotted up in the afternoon, then faxed off to Ice Centre (Tom Carrieres) in the early evening. JSH noted increased EM noise despite modest winds. Noise pulses from the NAVLINK HF radio transmitter had also appeared, possibly a result of the installation of a new HF transceiver unit on CG353.

Friday, 1 March (Weather clear, temp -17°C)

EM Flight numbers: 35 (small), 36

CG303 left for surface activities at 9:45. CG353 left at 1200. Before CG353's departure, JL removed the camera pod window, checked the aperture and inspected the EM bird.

JSH plotted FP for the marked line (MLA027F) and post-processed data files. A data glitch was observed during processing of FLT031.

After the return of CG353, JL cleaned the VCR heads to improve image quality.

JSH picked ground truth marks from the FLT027 video imagery.

Data acquisition for 036 centred on the area W of Magdalens again. The large and small squares were profiled again in 036, as in Flight Number 030. Problems were encountered during the flight: RH found that the laptop "froze" on him several times. [This problem was caused by "display repaint" problems on the laptop and corrected by shortening the period of data displayed.] One small data file (035) was lost due to rebooting of the system during acquisition.

Saturday, 2 March (Weather clear, temp -6°C)

EM Flight Number: 37 - 41.

RH in CG353 flew again over the test area W of the Magdalens. SP and AM took off in CG303 seeking a ridge suitable for drilling and profiling. The ice sensor first profiled the large square area's perimeter (as in Flight 030) again. RH then profiled the ridge area several times successfully, refuelled at Grindstone, and collected more data at the ridge site. The same problem occurred on these flights as on 1 March, so JSH flew the next mission for diagnostic purposes. Files 037-038 and 40-41 were aborted, but 039 recorded good data.

Calibration test lines from FLT027 were plotted up using the MATLAB ground-truth profile tools. It was determined that the system lag was 1.8 rather than the 2.0 seconds determined for the 206L installation, probably due to camera-bird geometry differences. All lines agreed well with ground truth at the N end of the line, where the bird often flew right over the line. At the S end, differences were substantial with respect to ground truth, but were consistent in the airborne profiling results. The bird generally flew W of the line, especially at the S end. Agreement with ground truth at the N end indicates that the system's calibration is good. It appeared likely that:

1. There was substantial lateral variation at the S end of the line, and the auger measurements along the line did not sample the thicker ice to the W, or
2. There was rafting underneath the Southern end that was not detected during drilling. This is supported by the narrow ridge-like structure crossing the floe perpendicular to the line, which shows itself as an isolated high point at the 60m station.

Further measurements on the floe were recommended to resolve this issue.

Sunday, 3 March (Weather in morning: windy, mild, overcast, improving in afternoon)

EM Flight numbers: 042 - 043

Reprocessed previous days' flights from .RAW file (for real-time data).

In the afternoon, JSH and RH flew the Fixed Link corridor (FLT042), then a heavily ridged floe and Station #14 (Calibration Floe 2) site, on which SP, AM and others had initiated a 160 m auger line (FLT043). Observed an error similar to those reported by RH during final ferry flight back to Charlottetown during this flight, but was able to save the data files.

Summary plots of FLT043 were produced, as well as a map with smoothed navigation. The floe was evidently drifting, so that each line should be shifted to compensate before trying to compare the ice thickness map with the video imagery. JL reviewed the log to date and made additions.

Monday, 4 March, 1996 (Weather in morning: snow, clearing in afternoon)

EM Flight Number: 44 in afternoon.

Reviewed video quality on flight path tapes, observing problems with horizontal hold at top of image during bright lighting conditions.

JL added a protection circuit to the transmitter, intended to reduce the risk of static-discharge-generated transmitter failure while not generating EM noise. A short flight (FLT044) was executed to test the system's noise performance.

Chuck Livingston arrived with the CCRS Convair 580 SAR system in afternoon, performing a SAR pass along the Northumberland Strait while surface measurements were being made.

Tuesday, 5 March, 1996 (Weather clear, -8°C, very windy)

EM Flight Numbers: 5, 46 Fixed Link, 47 Magdalen Islands

JSH and RH flew Fixed Link in morning. Flew out to ground-truth floe NW of Grindstone, profiled this. Refuelled in Grindstone. GPS failure noted at takeoff from Grindstone.

GPS problem repaired in evening, bird reassembled.

Wednesday, 6 March, 1996 (Clear, -8°C in morning)

EM Flight numbers: 49 Fixed Link, 53 - 54 Magdalen Islands

RH flew Fixed Link corridor in morning, assisted on-ice work in afternoon. JSH flew with system for 053-054. Long traverse during FLT053 resulted in a good data set.

Thursday, 7 March, 1996 (Weather high thin overcast, -8°C. Snow forecast for evening)

EM Flight numbers: 55 North of PEI

Planned long traverse to/from Magdelans area to support on-ice work. However, encountered a bird connector problem after takeoff from Charlottetown. Tow cable was immediately replaced and RH flew first two target areas (FLT055) before returning.

JSH post-processed March 6 flights, made 5 km summary plots for FLT053.

Friday, 8 March, 1996

FLT055 was plotted, then all data and working files were backed up onto tape. Log and flight databases were printed and backed up. System was packed and shipped to Goose Bay, Labrador via Labrador Airways Skyvan, arriving in evening.

2.2.2 Daily Summary of Activities: Labrador Shelf

Saturday, 9 March, 1996

Weather overcast in morning, clearing in afternoon. Temperature -8°C. Cartwright weather reported as high winds, low visibility.

The ice sensor system was installed into Universal Helicopters' Bell 206L C-GLSH during the morning. A short test flight was performed in the afternoon: system performance nominal. Since Cartwright's weather had not improved, plans were to start early on Sunday morning.

Sunday, 10 March, 1996 (Weather: -15° C, clear)

EM Flight numbers: 56 (marked line, start of traverse), 57 rest of traverse to E.

GF off early (0600) for Cartwright in C-CJBC with JSH and JL in LSH at about 0900.

SP, GF and IP marked a line for ground truth checking of system (no auger holes yet).

SP, IP and GF flew SE to establish a pressure sensor site in the offshore ice pack.

JSH and JL flew with the system to the check line at 53°57.67'N, 56° 59.55'W via the channel N of Huntingdon Island. Two passes, S-N and N-S, were made.

A traverse to the E was begun, then broken at Grady Island before resuming run (FLT057) to offshore rendezvous point and return. Ice conditions were monotonous, large pans of thin (.2 m) ice separated by smaller, somewhat thicker (.75 m) ice rubble regions. On the return trip, a large area of grease ice was traversed with good (~zero thickness) results. Temperatures were cold, so the thicknesses along the check line were considered likely to be noticeably different on Monday.

The real-time results for MAR10F56 and MAR10F57 were plotted and provided to SP.

Video picks for the marked line were performed and the flight database updated.

The video camera was operated with an infrared filter, in an attempt to improve the image quality over ice. One problem which occurred was that the camera's internal settings were changed during the power-up after landing on Grady Island, with the result that the rest of the day's video recording was very dark.

Monday, 11 March, 1996

Weather: Clear, -6°C, winds strong NW, decreasing in late afternoon, temperature -1°C. Fog encountered SW of Roundhill Is. in early afternoon.

EM Flight numbers: 58 test line, 59 inshore due to fog offshore, 60, 61 search for new check line

JL flew short flight 058 to run line CART1 (7 passes). No further flying due to high winds.

In the afternoon, JL flew 059 SE along land-fast ice in Table Bay and Stony Arm. Could not fly offshore due to fog. Returned mainly to seaward of the earlier line.

Flight 060 was undertaken to locate a suitable site for a secondary auger line to SE of Cartwright. The goal was to locate a series of descending ice thickness zones such as exist at CART1. This was found in the channel S of Huntingdon Island. Two passes, SW-NE and NE-SW, then the system was hovered over the location of the first thickness step (from .9 to .7 m) before landing.

After marking two points, one approx. 100 m W. of the step and one near the step, aligned with a line passing the SE. tip of Huntingdon Isl., another pair of passes were flown over the line (061) to verify its location and that of the steps in ice thickness relative to the marks.

Tuesday, March 12, 1996

Weather: overcast (9000’) with breaks appearing 0830, -4°C. Winds light from N or NE.

EM Flight numbers: 62, 64 offshore traverse.

JL started a long flight offshore in tandem with JBC: Murray Scotney of BIO was scheduled to perform a series of CTD casts starting about 60 miles offshore.

JSH prepared profile data plots for FLT056 and FLT058 along line CART1.

JBC returned at about 1300, carrying crews and passengers from both helicopters. LSH had experienced engine failure just SE of Huntingdon I at an altitude of 250 feet. RM managed to land the helicopter safely on relatively stable ice, but had to release the bird at 50 feet bird altitude to prevent complications during his auto-rotation. There were no injuries to personnel. The EM bird was severely damaged on impact.

LSH was retrieved from the ice using a Bell 212 to pick it up and carry it to Cartwright airport.

Wednesday, 13 March, 1996

The damaged bird was recovered in the morning, inspected and packed for shipping.

Processing continued and the flights database was brought up to date. Processing concentrated on FLT059, roughly coincident in time with the Tuesday afternoon RADARSAT pass. Summary plots were prepared and printed, and XYZ files including filtered lat-long data were generated.

Thursday, 14 March, 1996

Completed printing of summary plots for FLT057 and FLT059.

Post-processed and printed profile plots for FLT062-064 (final series of files obtained before the engine failure.) Automatic post-processing had some problems with the latter part of FLT062.

Assessed the processing status for all flight files. Few had been finalised, although a higher proportion of the Cartwright files was brought through the complete process than for the Gulf.

Provided IP with data plots from FLT057, 059 and 062-064 for copying and reference, and backed up and delivered all .XYZ files on hand.

3. INSTRUMENTATION

3.1 Sensors In The Bird

The EM induction sensor package is towed in a bird about 30 m beneath the helicopter at altitudes of 10 to 25 m above the ice surface. The distance of the bird to the water/ice interface can be determined by measuring the amplitude and phase of the secondary field relative to the transmitted field. The frequencies in the EM sensor were 30 and 90 kHz. The antenna configuration was the horizontal coplanar mode, which has a larger footprint than the coaxial mode (3.75 times the bird altitude at the 90% level) but a much better signal/noise ratio for ice thickness measurement. The transmitter and receiver antennas were separated by 3.5 m. The overall length of the bird is approximately 4.2 m and its weight is about 100 kg. The bird is slung from the helicopter's cargo hook on a 30-meter tow cable that carries power and digital control signals down to the bird and digital data up to the helicopter.

An IBEO PS100E laser profilometer mounted in the sensor bird was used to measure the distance from the bird to the snow/air interface. Its beam has a radius of less than .05 m when flying the sensor at an altitude of 15 to 20 m. A Trimble Navigation TANS Vector attitude monitoring system was also mounted in the bird. It measures the orientation of the bird in pitch, roll and yaw to an accuracy of approximately 0.1°, and also provides a bird position estimate. Finally, a radar altimeter operating at about 2 GHz was mounted in the helicopter to assist the pilot in maintaining a steady survey attitude. Data from all of these ancillary sensors was logged by the helicopter computer along with the EM results.

3.2 Helicopter Instrumentation

The system console was mounted on a rack in the back seat area of the helicopter such that the operator could monitor the master computer/data logger while viewing the annotated imagery from the video camera on the CRT. A Panasonic AG-7400 S-VHS video recorder made an analogue recording of this imagery for later use in assessing ice conditions below the helicopter. This camera was mounted in front of the forward passenger's seat, pointing downwards through the “chin bubble” of the helicopter, and observed the ice conditions and bird flight behaviour.

The master computer collated, reduced and logged EM and other incoming data onto magnetic media. It also controlled an auxiliary processor which inverted incoming data to ice thickness and other parameters, plotted the data on the GR33 graphic recorder, and generated a text overlay on the video flight path imagery including time, position and ice parameters. Positioning was carried out using the TANS Vector’s position output, which was logged on the EM computer in WGS84 co-ordinates, displayed on the CRT, and recorded on the video flight path tape.

3.3 RADARSAT

RADARSAT satellite is equipped with a Synthetic Aperture Radar (SAR) which can provide coverage regardless of lighting and weather conditions. The RADARSAT SAR has the unique ability to shape and steer its radar beam over a 500 kilometre range providing image swaths from

35 kilometres to 500 kilometres with resolutions from 10 metres to 100 metres respectively. Incidence angles range from less than 20 degrees to more than 50 degrees" (CSA 1995). (see **Figure 3.3.1**) RADARSAT has a planned lifetime of five years.

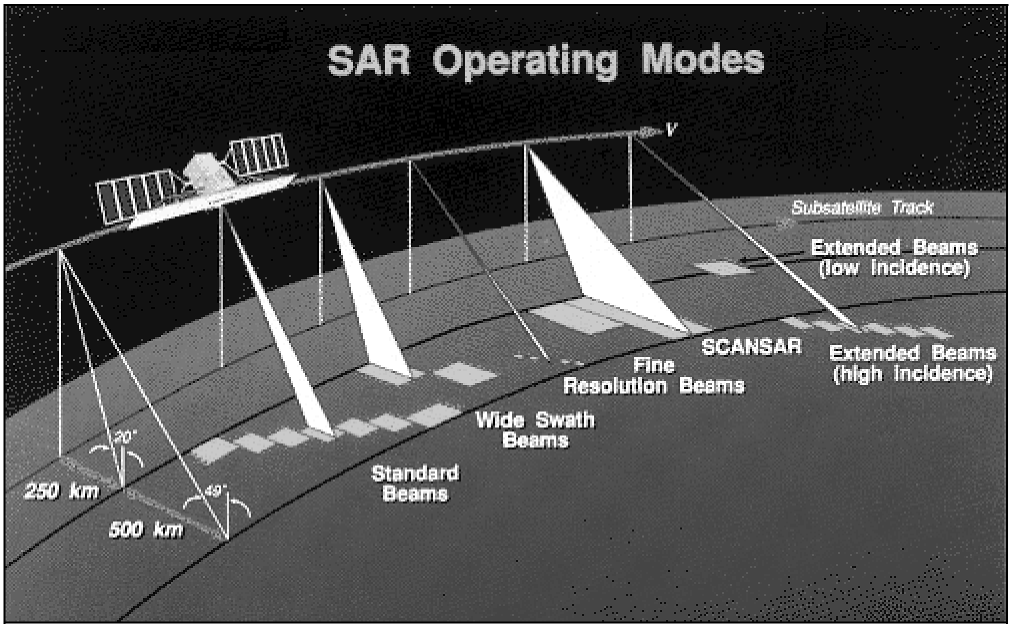

Figure 3.3.1: RADARSAT SAR scan geometry.

ScanSAR Narrow RADARSAT images during the pre-operational phase of RADARSAT were made available to the project through the Canadian Centre for Remote Sensing (CCRS) in order to ground truth ice signatures seen in the RADARSAT images after the locations of the data was co-registered with ice drift data from the ice beacons. The long flight north of PEI on March 6 has been used to identify some of the variation seen in the ScanSAR March 6 image of the southern Gulf taken (Peterson et al., 1997).

3.4 Other Instrumentation

A second helicopter was available to collect on-ice surface data and to deploy satellite-tracked ice beacons for related ice projects. The ice beacons were deployed to provide:

- the data required to study the effect of ice divergence and convergence on the pack ice pressure and ice acoustics and,
- ice drift data throughout the area for co-registration of the ice sensor and RADARSAT data to a common time.

The second helicopter was also used to set out ice thickness calibration lines in order to check the performance of the EIS. Ice thickness data was collected using hand-augered ice holes marked by snow-filled garbage bags. Ice chips and snow samples were collected at various sites and their salinity determined with a hand-held refractometer. The on-ice calibration data is listed in Appendix B.

4. DATA COLLECTION AND ANALYSIS

4.1 Airborne Data Collection

Weather conditions during late February and early March of 1996 were favourable for airborne data acquisition. However, temperatures were unusually warm and hence the ice was below average thickness for that time of the year (Table 4.1 and Table 4.2). Long-range data collection missions over pack ice and land-fast ice were undertaken during which large quantities of airborne and surface ice thickness data were collected. Of these flights a total of 613km of EM data was collected, 313 km over pack ice and 301 km over land-fast ice. A summary of ice types according to date and flight number is provided in Table 4.3. A detailed summary of EM data collected for each date, flight and survey line number can be found in Appendix A. A coastal map of the areas surveyed with superimposed survey line flight paths is shown in Figure 4.1.1-Figure 4.1.3. More detailed coastal maps of the areas surveyed for each flight with survey line flight paths superimposed, are given in Figure 4.1.4-Figure 4.1.27.

Date	Temperature (^oC)	Clouds/Precip.	Wind
27/2/96	-2	ice pellets/rain	light NW
28/2/96	-5	cloudy	light NW
29/2/96	-6	flurries, p.c.	20 km/h NW
1/3/96	-8	clear	6 km/h NW
2/3/96	-6	clear	6 km/h SW
3/3/96	0	clear	18 km/h W to SW
4/3/96	-6	snow	50 km/h W to SW
5/3/96	-8	clear	25 km/h W
6/3/96	-8	clear	5 km/h E
7/3/96	-8	clear	5 km/h NE

Table 4.1: Gulf of St. Lawrence weather conditions summary.

Date	Temperature (^oC)	Sky/Precipitation	Wind
9/3/96	-8	snow	15 km/h NW
10/3/96	-15	clear	35 km/h NW
11/3/96	-8	clear	30 km/h NW
12/3/96	-4	clear, snow squalls	10 km/h NW

Table 4.2: Labrador Shelf weather conditions summary.

Flight	Pack Ice	Land-fast Ice
Flt27	10052 10060 10070 10080 10090 10100 10110	the rest
Flt29	all lines	
Flt30	all lines	
Flt31	10030 10040 10050 10060 10070	
Flt36	all lines	
Flt39	all lines	
Flt43	all lines	
Flt44	10020	the rest
Flt45	all lines	
Flt46	all lines	
Flt47	all lines	
Flt49	the rest	10010
Flt53	all lines	
Flt54	all lines	
Flt55	all lines	
Flt56	10050	the rest
Flt57	the rest	10060
Flt58		all lines
Flt59	10121	the rest
Flt60		all lines
Flt61		all lines
Flt62	the rest	10010
Flt63	all lines	
Flt64	all lines	

Table 4.3: Flight summary over pack and land-fast ice floes.

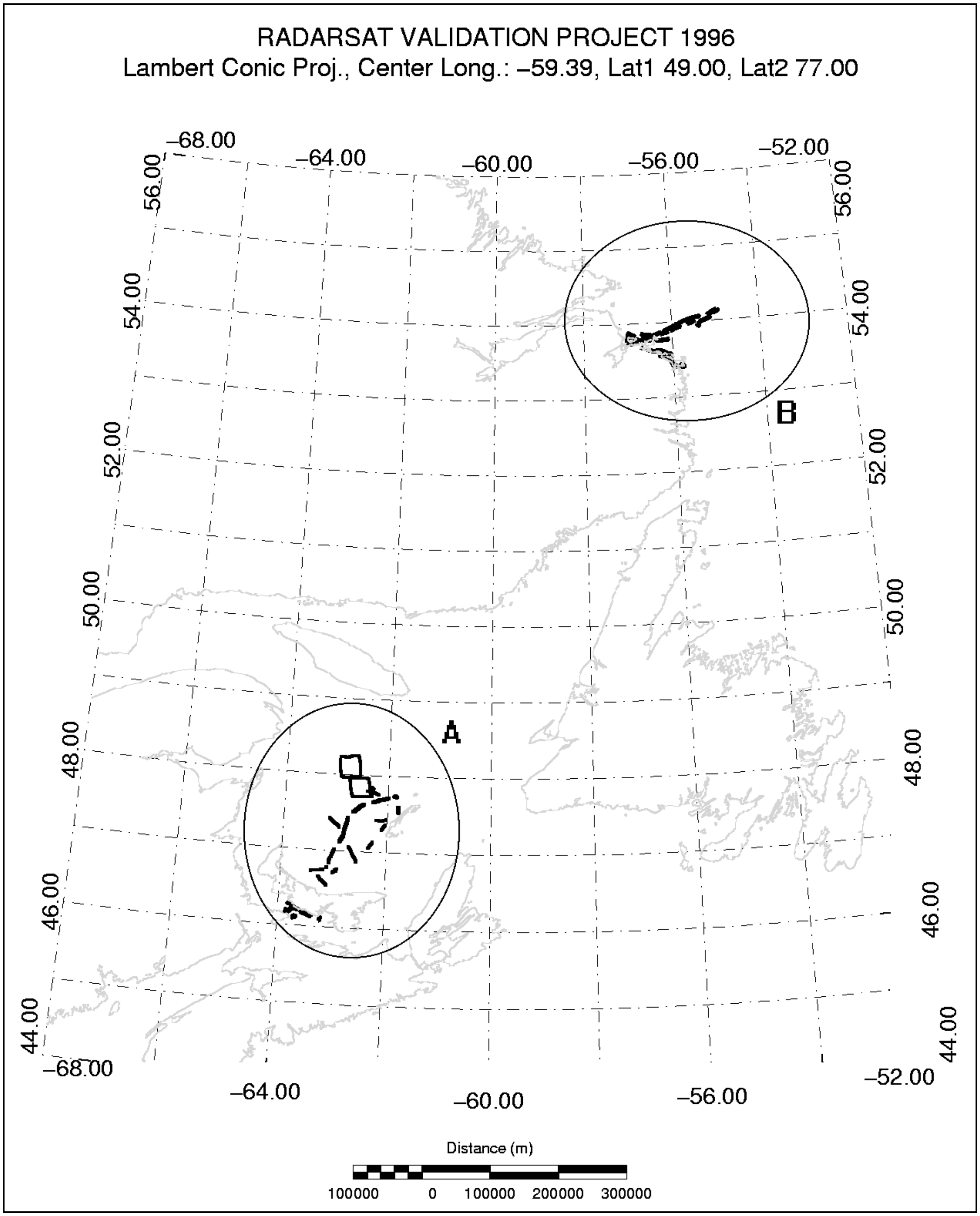

Figure 4.1.1: Areas selected for the RVP, A) Southern Gulf of St. Lawrence and B) Labrador Shelf.

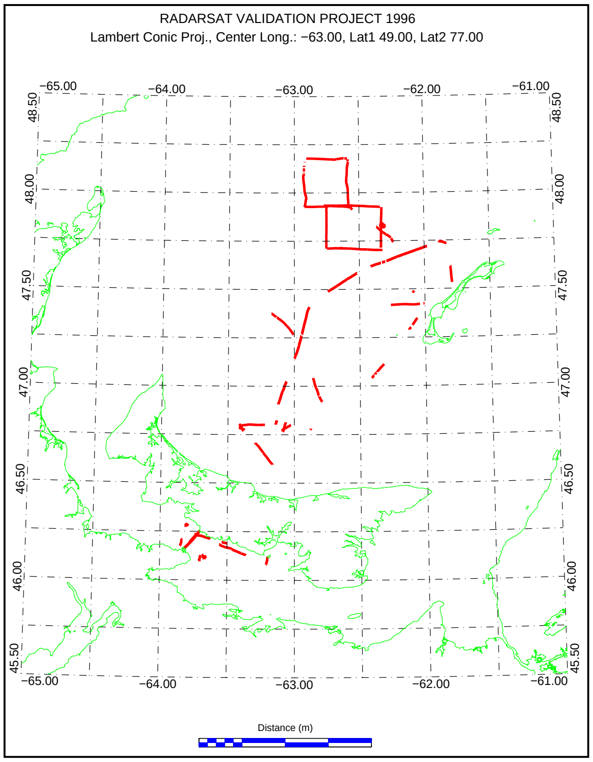

Figure 4.1.2: RVP survey area A, southern Gulf of St. Lawrence.

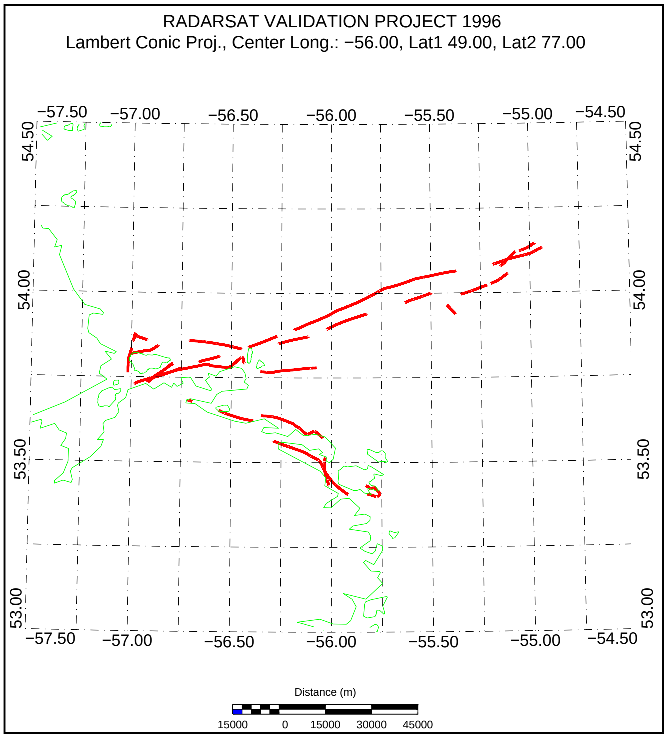

Figure 4.1.3: RVP survey area B, Labrador Shelf.

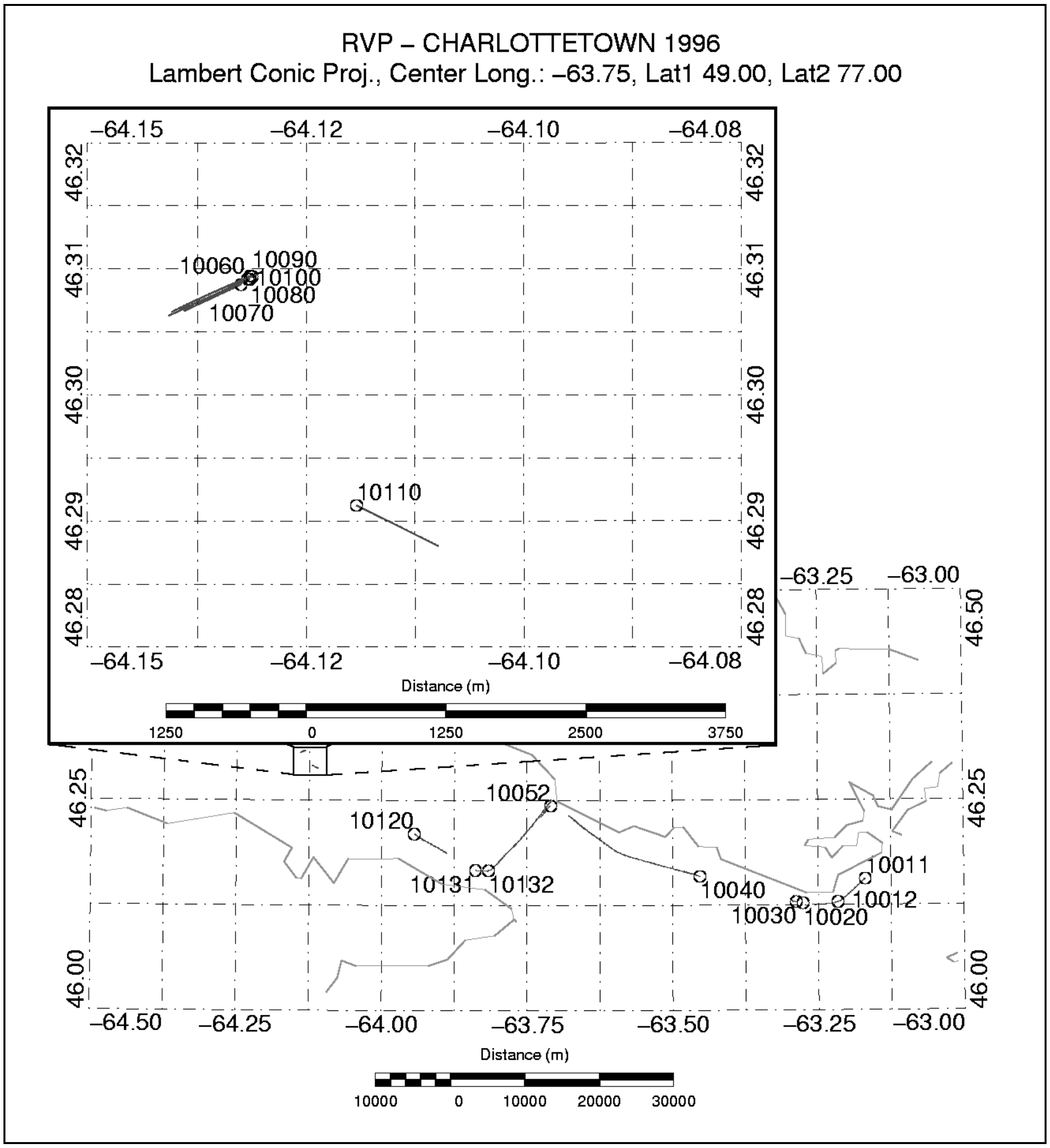

Figure 4.1.4: February 28, 1996 survey line flight path, flight #27.

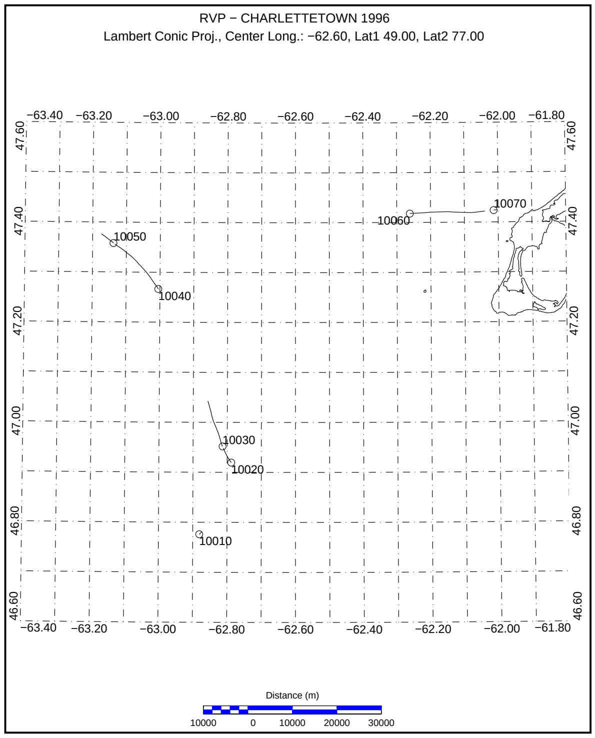

Figure 4.1.5: February 29, 1996 survey line flight path, flight #29.

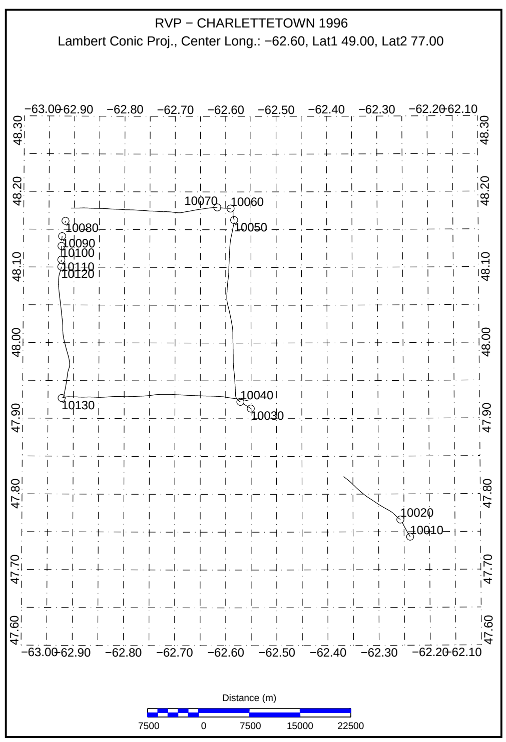

Figure 4.1.6: February 29, 1996 survey line flight path, flight #30.

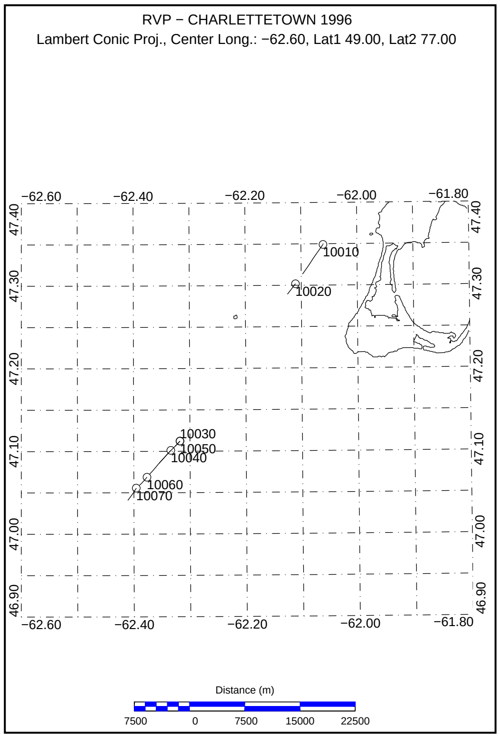

Figure 4.1.7: February 29, 1996 survey line flight path, flight #31.

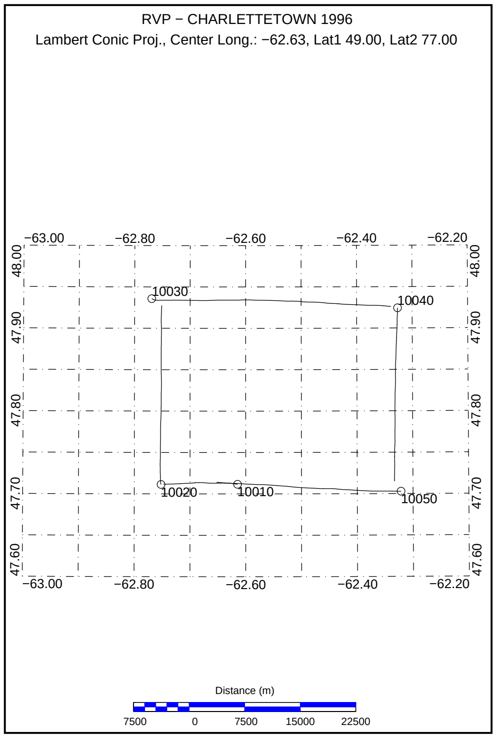

Figure 4.1.8: March 1, 1996 survey line flight path, flight #36.

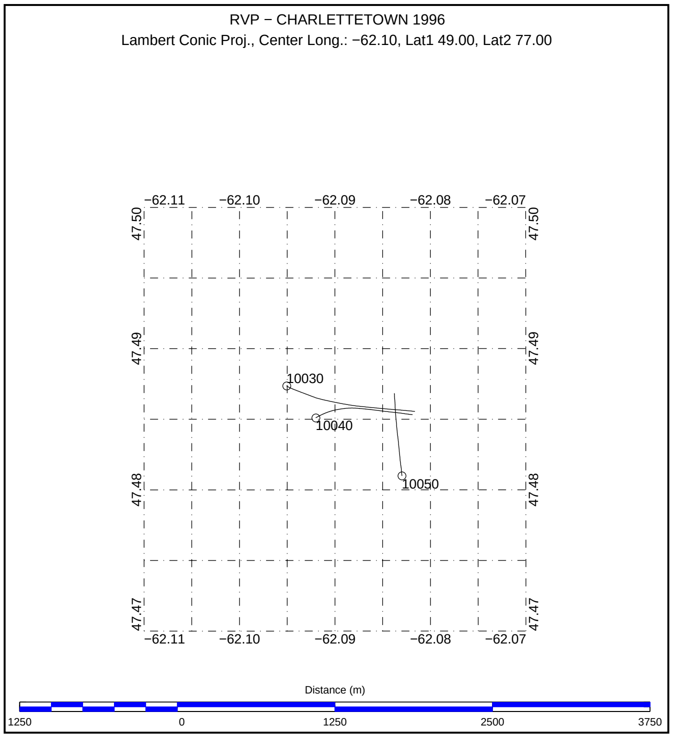

Figure 4.1.9: March 2, 1996 survey line flight path, flight #39.

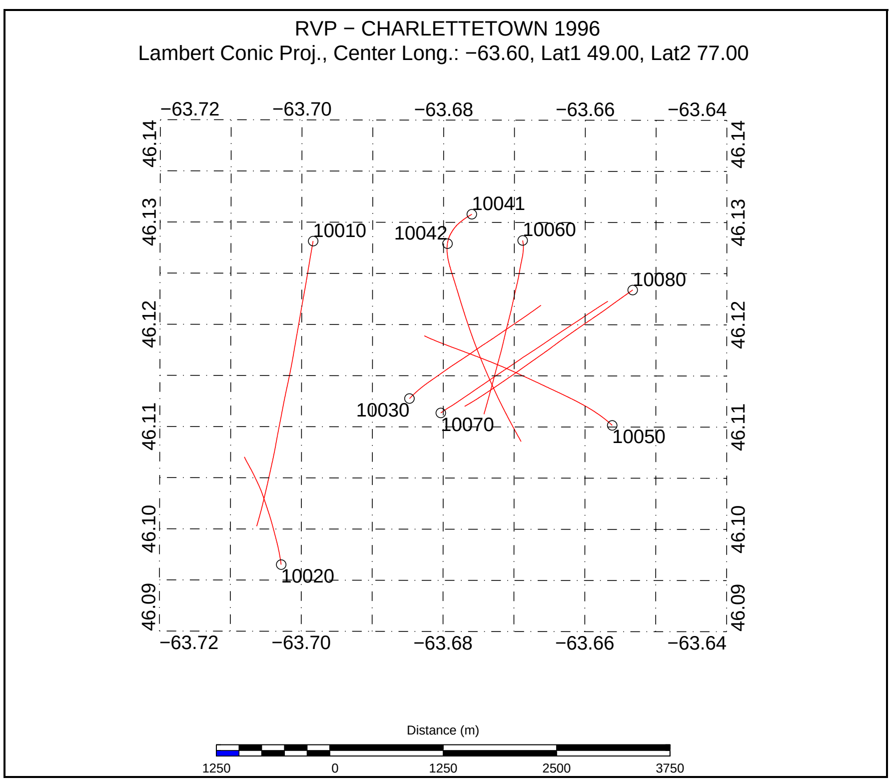

Figure 4.1.10: March 3, 1996 survey line flight path, flight #43.

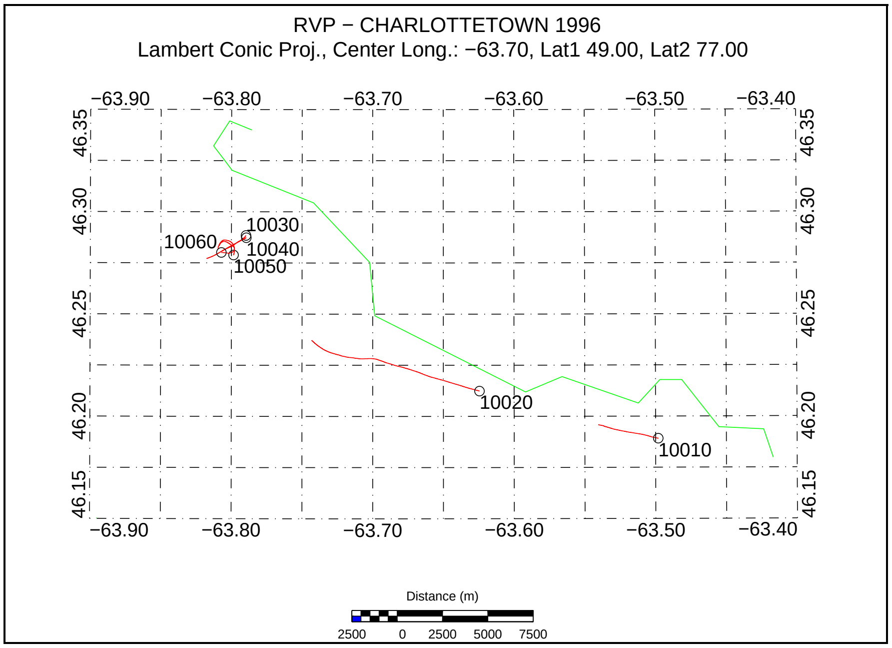

Figure 4.1.11: March 5, 1996 survey line flight path, flight #44.

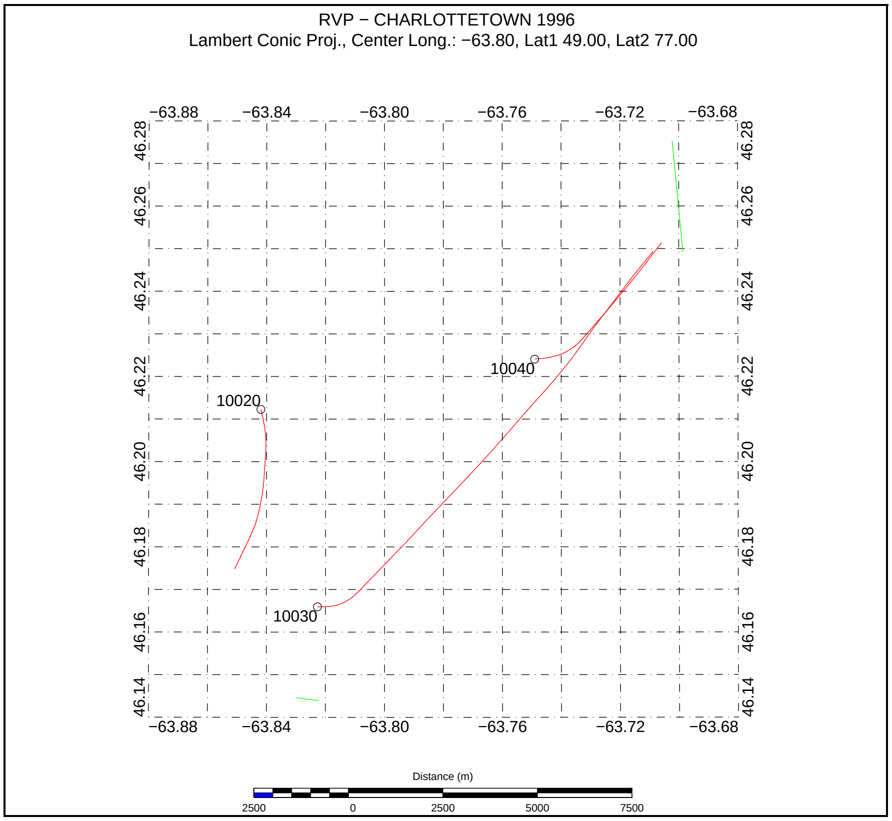

Figure 4.1.12: March 5, 1996 survey line flight path, flight #45.

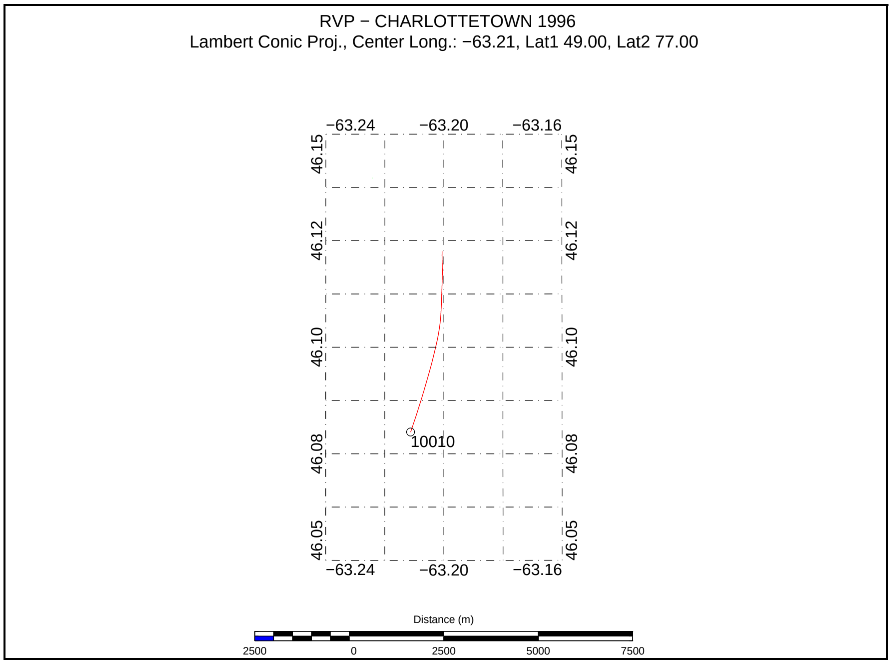

Figure 4.1.13: March 5, 1996 survey line flight path, flight #46.

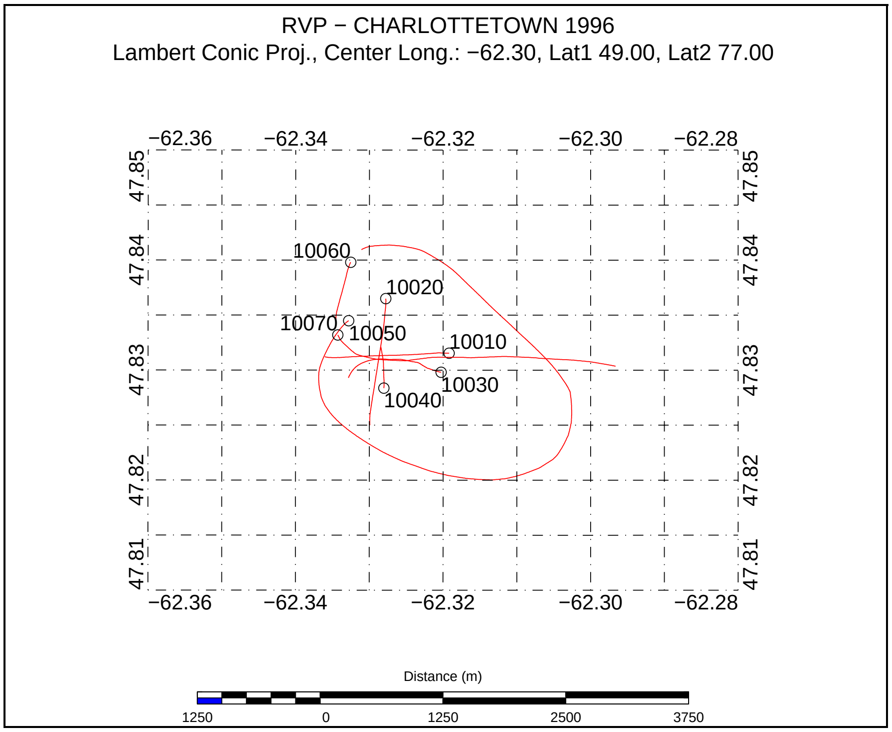

Figure 4.1.14: March 5, 1996 survey line flight path, flight #47.

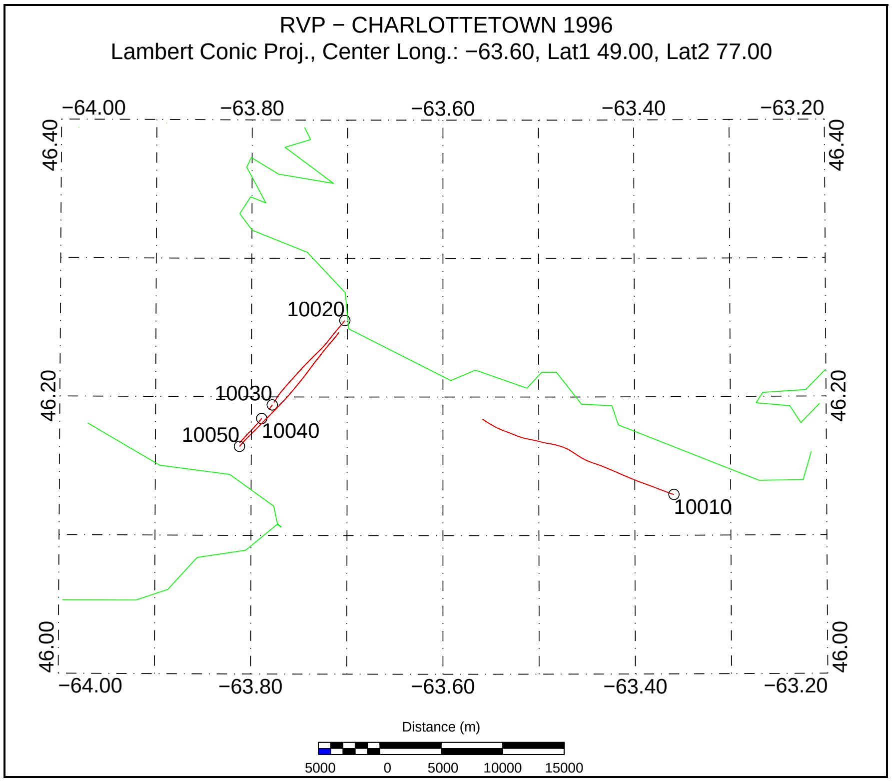

Figure 4.1.15: March 6, 1996 survey line flight path, flight #49.

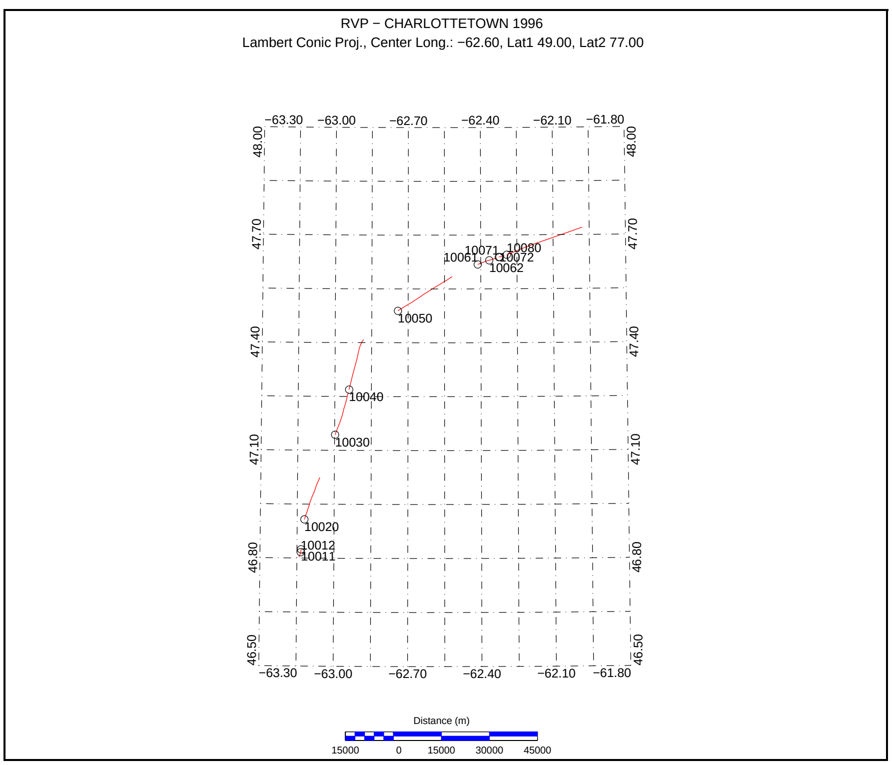

Figure 4.1.16: March 6, 1996 survey line flight path, flight #53.

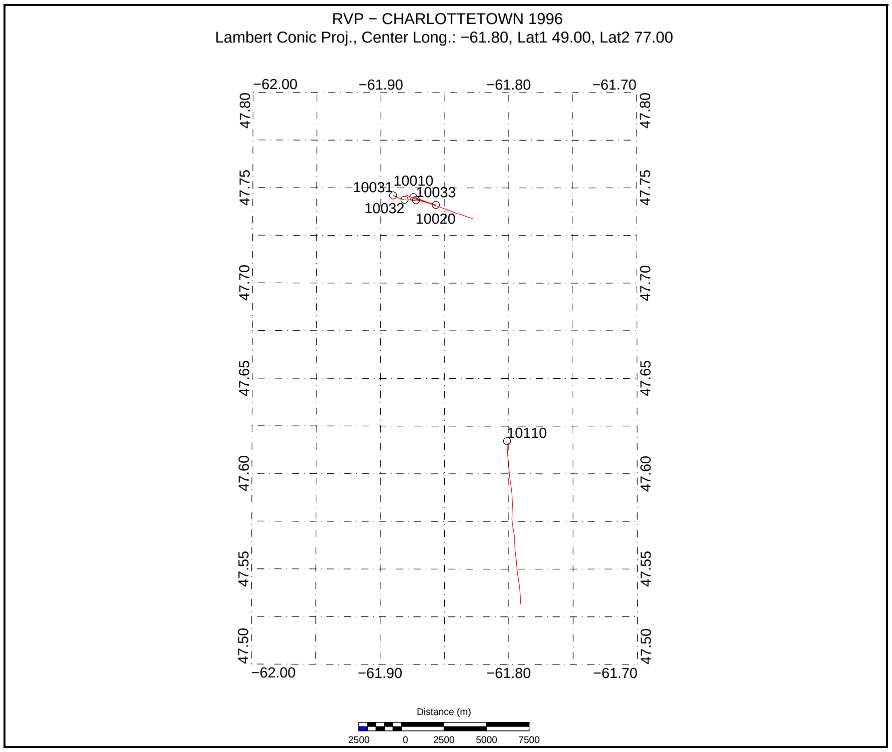

Figure 4.1.17: March 6, 1996 survey line flight path, flight #54.

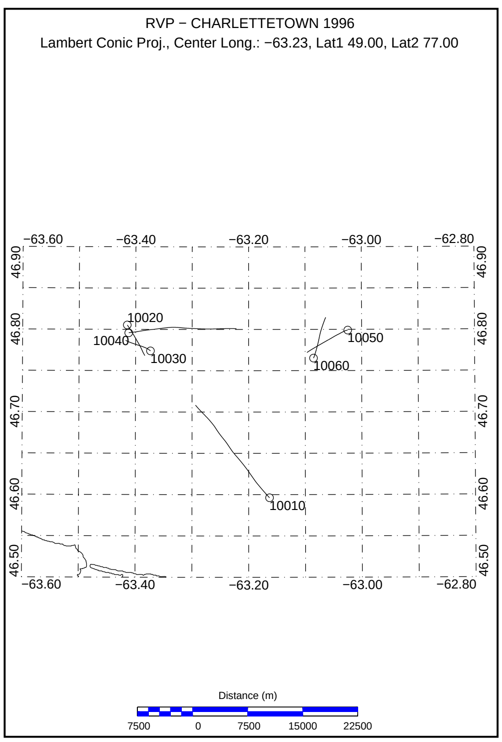

Figure 4.1.18: March 7, 1996 survey line flight path, flight #55.

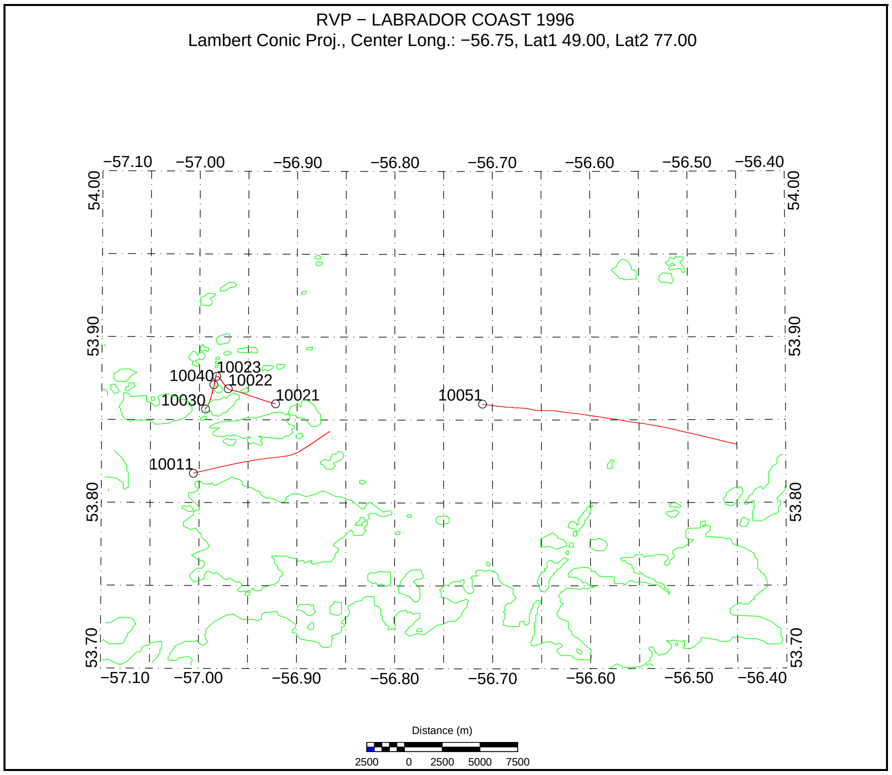

Figure 4.1.19: March 10, 1996 survey line flight path, flight #56.

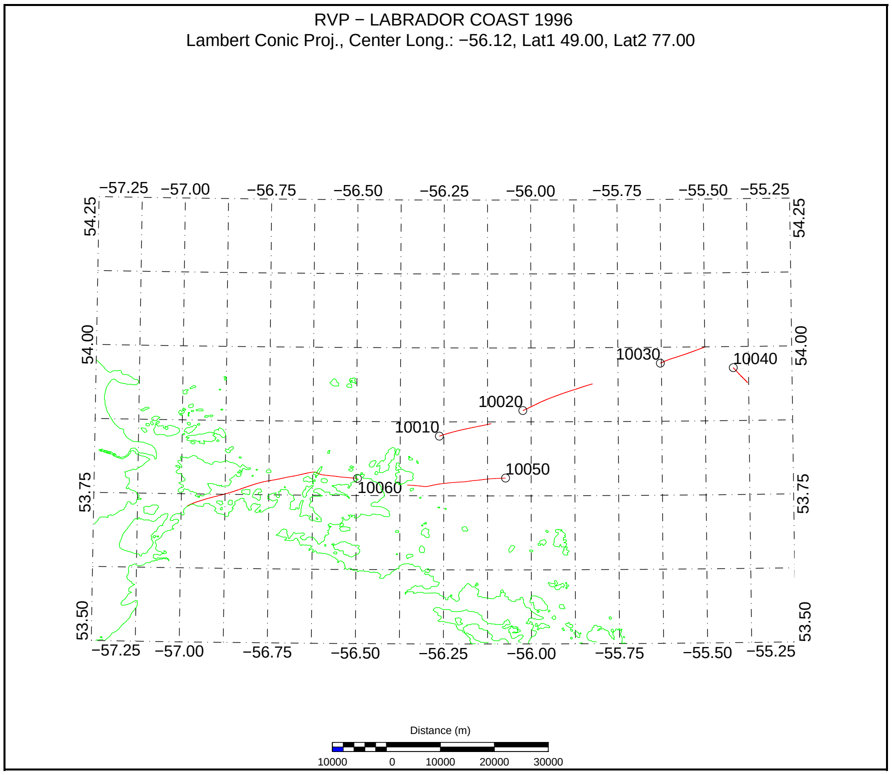

Figure 4.1.20: March 10, 1996 survey line flight path, flight #57.

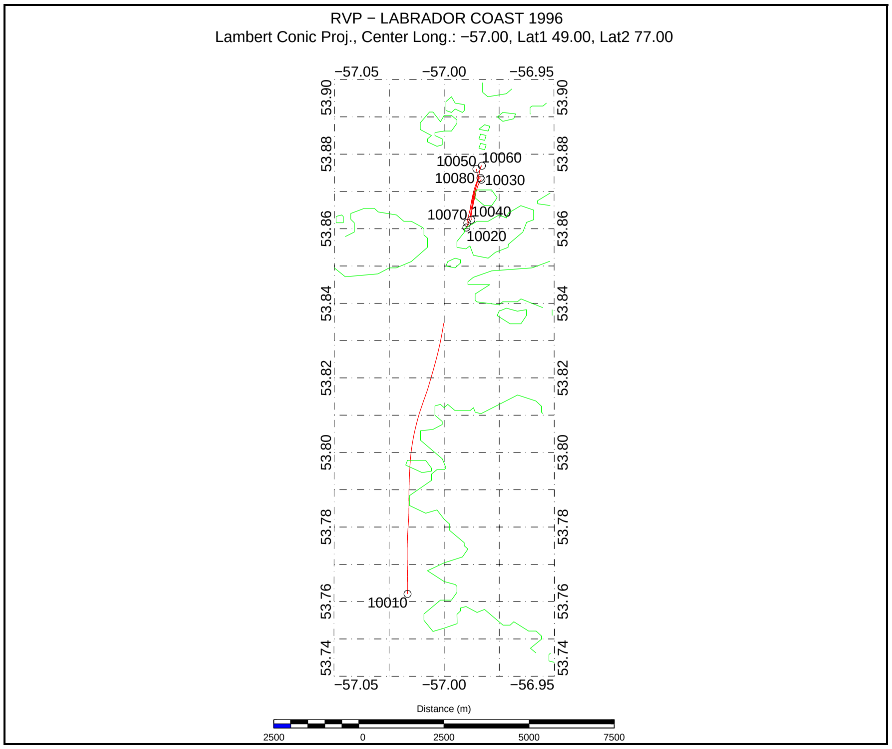

Figure 4.1.21: March 11, 1996 survey line flight path, flight #58.

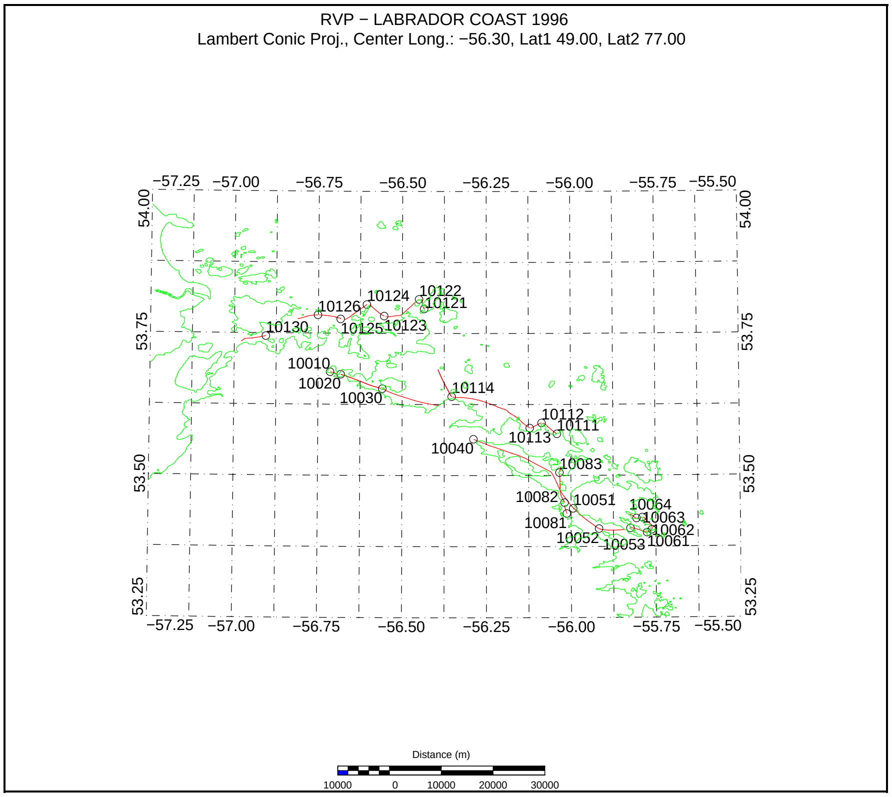

Figure 4.1.22: March 11, 1996 survey line flight path, flight #59.

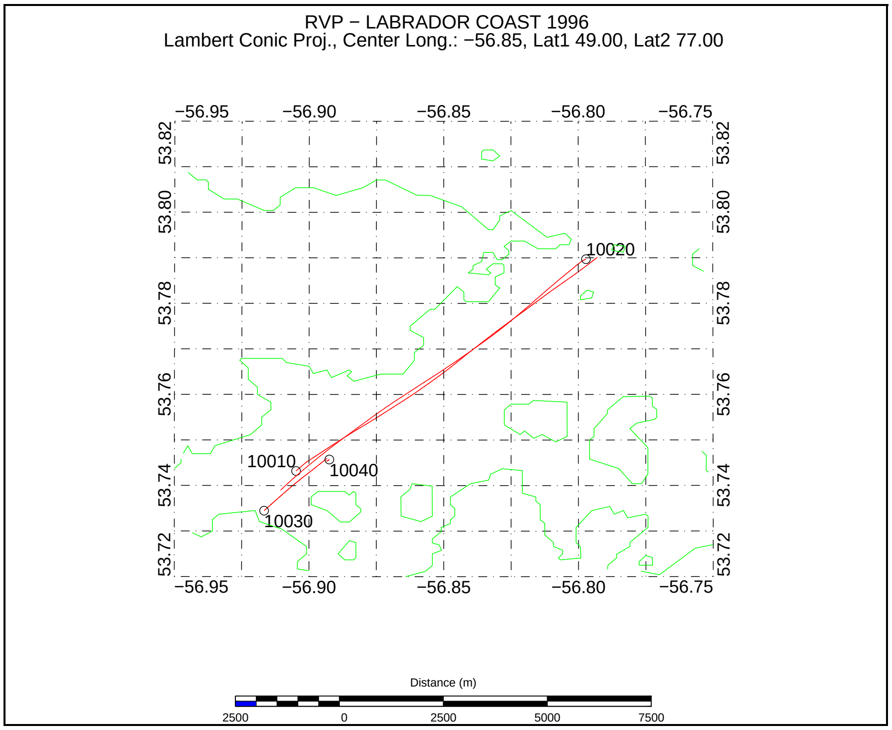

Figure 4.1.23: March 11, 1996 survey line flight path, flight #60.

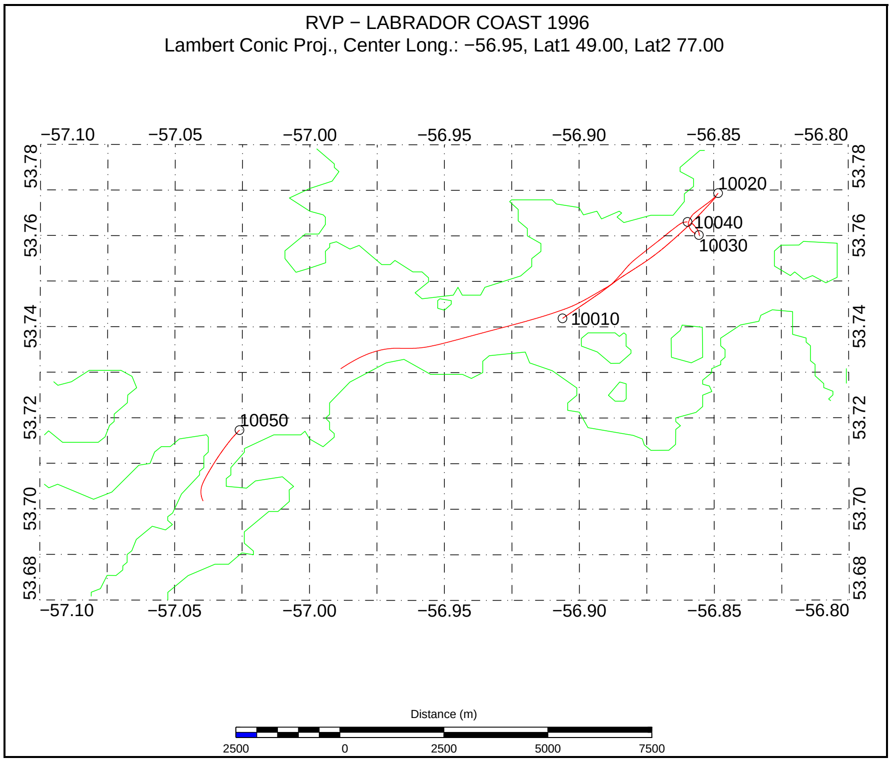

Figure 4.1.24: March 12, 1996 survey line flight path, flight #61.

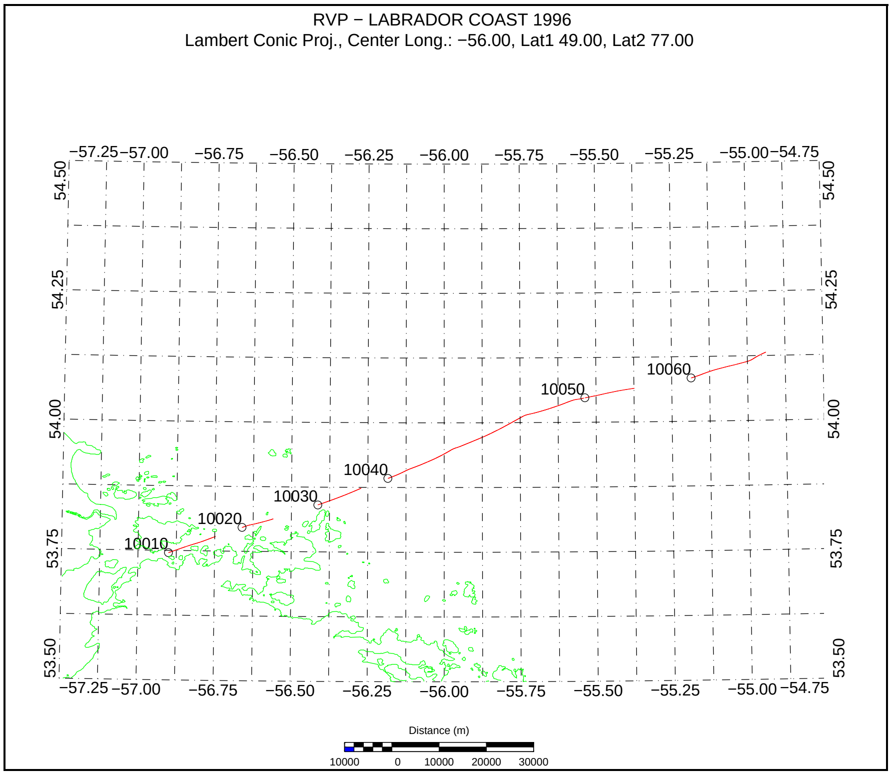

Figure 4.1.25: March 12, 1996 survey line flight path, flight #62.

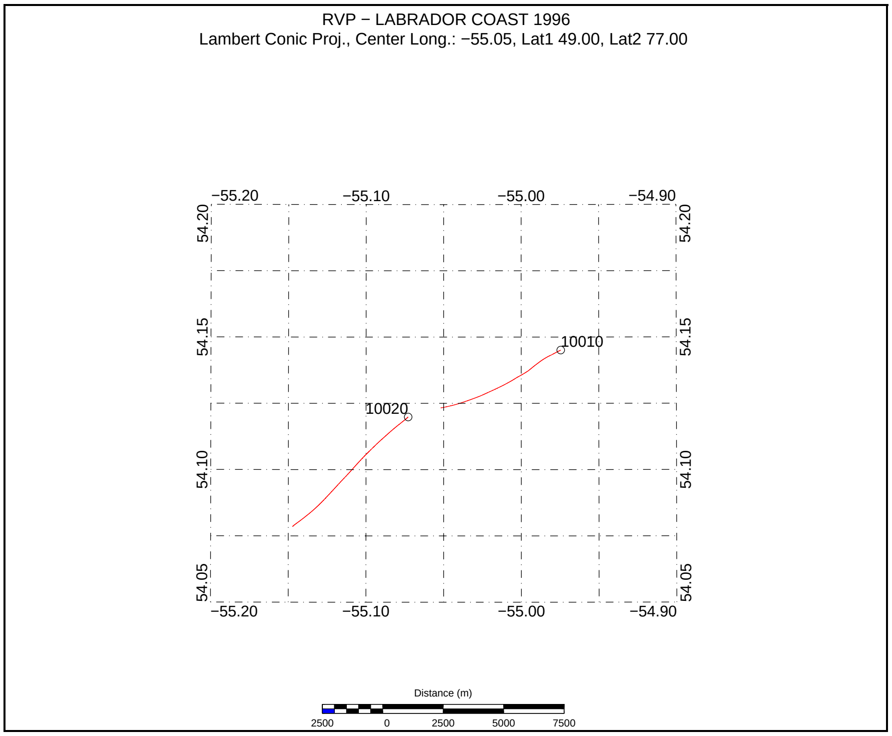

Figure 4.1.26: March 12, 1996 survey line flight path, flight #63.

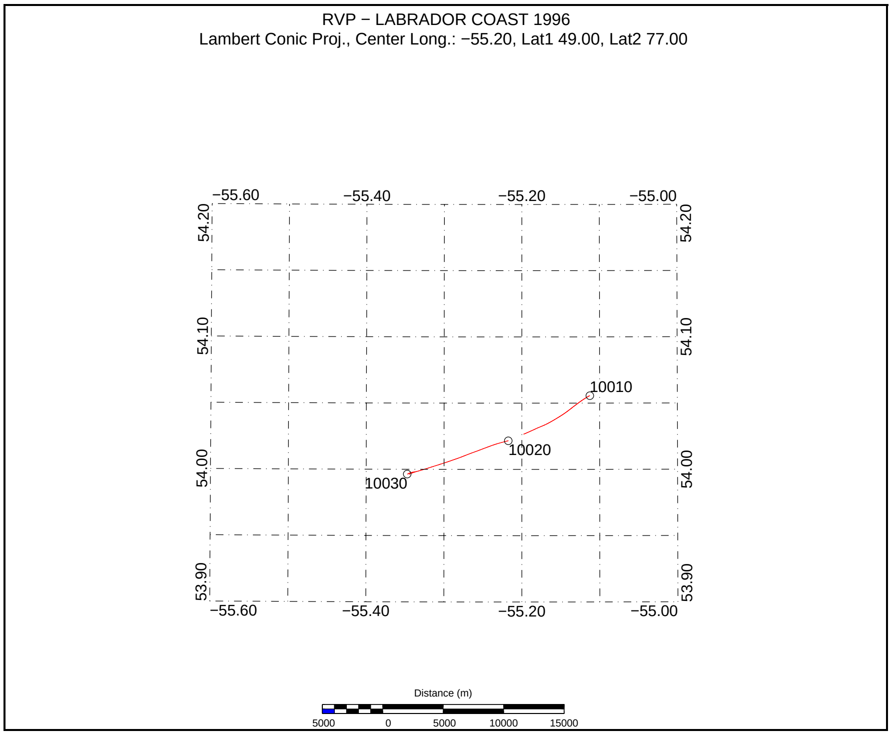

Figure 4.1.27: March 12, 1996 survey line flight path, flight #64.

4.2 Data Analysis

4.2.1 Real time processing

The snow plus ice thickness is effectively measured by estimating the bird-to-water distance, then subtracting the bird-snow distance measured with the laser altimeter, although in fact the calculations are combined as a joint inversion of the EM and laser altimeter measurements. This inversion operation is numerically intensive and is therefore performed on a secondary computer within the helicopter computer package.

The amplitude and phase of the measured EM signals depend not only on the bird's altitude above the ice surface, but also on the operating frequency, the ice conductivity and the sea water conductivity. The response can be numerically estimated for undeformed, level ice and water layers of known thickness and conductivity (1D models). Approximations to more complex ice features such as ridges are more difficult and time-consuming to model and interpret. Using these models, the measured EM signals can be inverted to yield estimates of distances from the bird to the sea water surface on a point-by-point basis (1D model) or as a profile or grid data (2D and 3D models). The 1D inversion technique remains the standard approach for ice thickness calculations, and provides excellent accuracy over relatively smooth ice conditions.

4.2.2 Post-processing

Post-processing comprises the extraction of data from binary files to XYZ format (geolocated, columnar ASCII files), smoothing and resampling of GPS data, high-pass filtering of the laser altimeter, and manual editing of data. Data extraction from binary to XYZ files introduces repetition of GPS values since the GPS data are sampled at .5 to 1Hz whereas the EM data are sampled at 10Hz. Software was developed to process the GPS data stream, specifically to despike, filter and resample it to match the sample rate for the ice thickness, conductivity and other data series derived from the EM data.

First, the GPS data series is prepared (latitudes and longitudes) by removing anomalies (significant gaps and/or spikes in data) and adding synthesised or "contrived" data to minimise edge effects associated with filtering. The procedure also keeps track of where these anomalies occur to keep the user up to date. Secondly, the GPS data series is filtered by using a weighted average filter. The filter is advanced in time through the GPS data at the desired output sampling rate. Data points within the filter window are weighted, summed and output with a time stamp corresponding to the centre point of the filter window. The filtered GPS data stream is free of repeating values, spikes and large gaps. The associated data (ice thickness, laser altimeter, etc…) are then linearly interpolated to match the sampling rate of the filtered GPS data.

Ice and snow surface roughness can be estimated by removing the helicopter motion (altitude variations of the helicopter) from the laser altimeter (Dierking 1995). An automated three step filtering technique (referred to here as the *maximum technique)* was used to separate the different signals following the GPS filtering. The laser altimeter data are filtered via a Butterworth low pass filter (LPF) with a spatial cut off frequency of 0.01 m^{-1} and a Nyquist frequency equal to the spatial sampling rate divided by 2. The high-pass filtered laser altimeter data series (HPFL) is then obtained by subtracting the LPF laser altimeter result from the laser data.

Maxima in the HPFL are then located by numerical differentiation. The first derivative of the HPFL changes from positive to negative on each side of a peak (maximum). These changes in the slope are used to detected these peaks. The sequence of the maxima are then linearly interpolated to match the common sampling rate of the data series to give the estimated helicopter motion. The unfiltered laser altimeter is then subtracted from the estimated helicopter motion. The result is a generally positive laser profile of the surface roughness (surface topography). Small negative values in the surface roughness profile are due to the combination of the linear interpolation and the points of inflection. The laser profile of the surface roughness is referred to as the HPF laser altimeter throughout this report. A more complete description of HPF laser altimeter profile generation is given in Holladay and Moucha (1998).

One of the formats for presenting the data is the *standard plot* format (Figure 4.2.1). The *standard plot* contains ice thickness and HPF laser altimeter histograms along with profile plots of ice thickness, laser altimeter and HPF laser altimeter. The software that creates the *standard plot* excludes data corresponding to laser altimeter readings of 5 m or less and 25 m or greater from statistical calculations when the system is too low or high, respectively, to provide accurate measurements. In addition, data points that imply high apparent system velocities (over 83 m/s) ordinates of each segment are displayed in the subtitle of the *standard plot*. Figure 4.2.1 shows the *standard plot* format. Tables of profile statistics (Table 4.4) are also created by the post-processing software. These tables contain useful line and line segment information, and are listed in Appendix D. The post-processing software also has the ability to overlay profiles onto a geo-referenced map, as in the example in Figure 4.22.

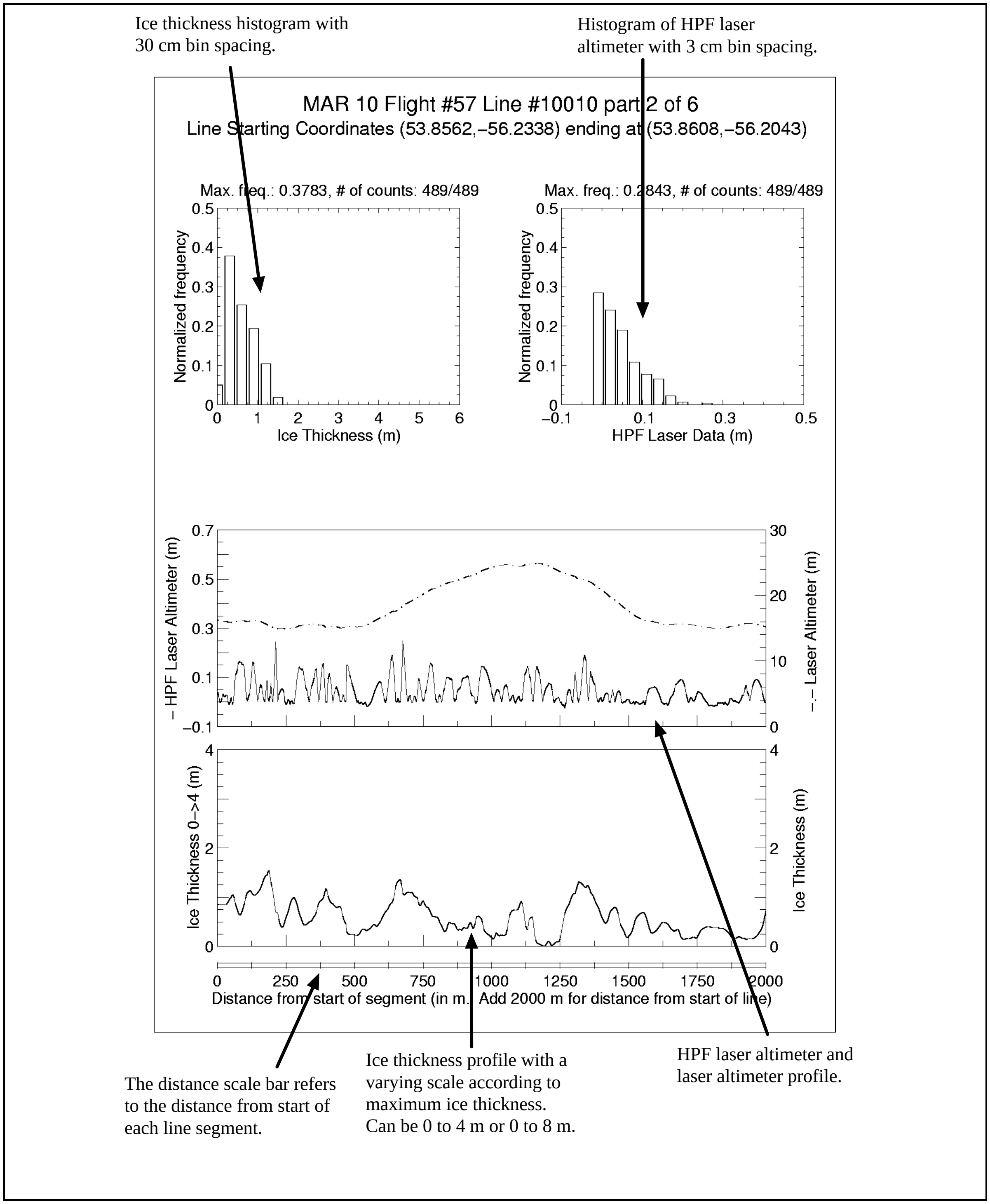

Figure 4.2.1: The *standard plot* format.

Line Number	Start		End		Number of Samples ICE	Length of Line/Seg. (km)	Ice Thickness (m)		Average Spacing (s) ICE	Average Spacing (m) ICE
	Lat. (deg. N)	Long. (deg. W)	Lat. (deg. N)	Long. (deg. W)			Mean	Std.		
10010	53.7428	-56.1099	53.7280	-56.0544	222	4.012	3.53	1.385		
	53.7280	-56.0544	53.7130	-55.9993	219	3.993	3.31	1.793		
	53.7130	-55.9993	53.6972	-55.9446	225	4.011	5.00	1.937		
	53.6972	-55.9446	53.6937	-55.9324	56	0.896	6.66	1.252		
Total	53.7428	-56.1099	53.6937	-55.9324	719	12.911	4.16	1.971	0.4	17.96
10020	53.6547	-55.9566	53.6344	-55.9065	223	4.008	0.31	0.662		
	53.6344	-55.9065	53.6172	-55.8534	216	4.000	2.12	1.436		
	53.6172	-55.8534	53.6124	-55.8369	72	1.207	2.92	1.076		
Total	53.6547	-55.9566	53.6124	-55.8369	509	9.215	1.44	1.513	0.4	18.10
10030	53.6158	-55.7112	53.6060	-55.6747	160	2.646	1.69	0.658		
Total	53.6158	-55.7112	53.6060	-55.6747	160	2.646	1.69	0.658	0.4	16.54

Table 4.4: Sample statistics table created by the post-processing software.

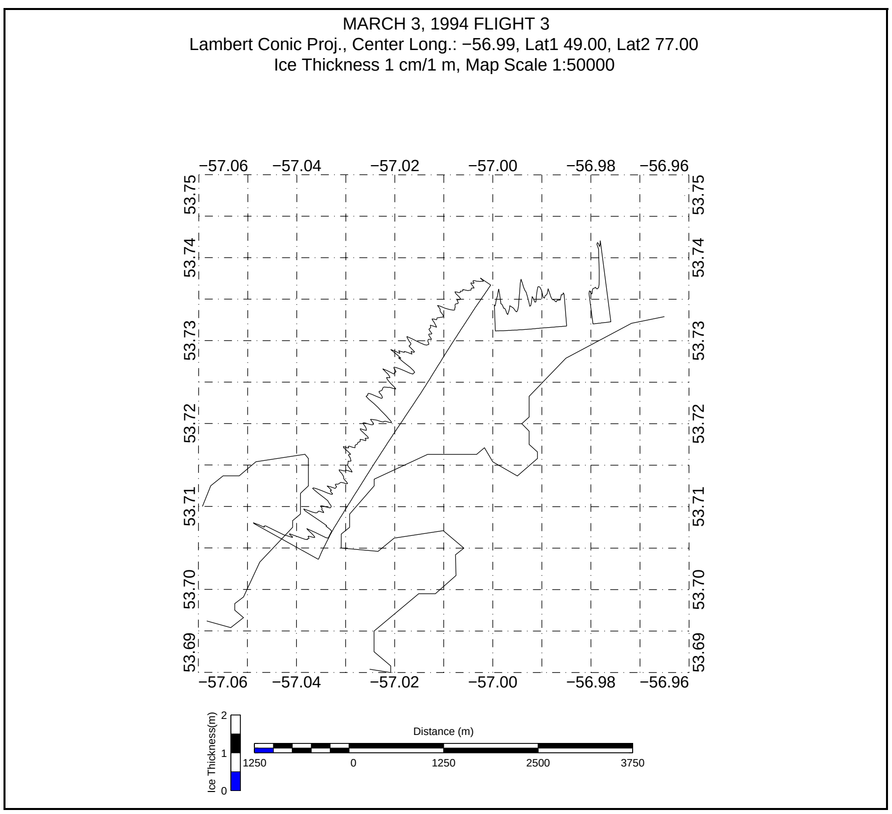

Figure 4.2.2: An ice thickness profile map (not to scale).

5. RESULTS

5.1 General Observations

The principal factors governing data quality for an airborne sea ice sensor are EM performance, laser altimeter accuracy and survey altitude. The quality of the EM data stream is a function of noise and baseline drift in the system, which are minimised first by careful design and implementation, then by application of suitable data acquisition methodologies. The laser altimeter data are affected by gaps in the data stream, caused by a lack of reflected laser signal from the surface (a common problem over open water), and by bird orientation effects, which magnify the measured bird height relative to the true height (Holladay *et al* 1997). The EM-measured bird height above sea water is also increased by orientation effects, but the increase is not large enough to cancel out the laser altimeter effect. This orientation error leads to underestimation of the snow plus ice thickness. A pilot experienced with flying EM systems can reduce the amount of bird swing considerably by careful flight practices, but this is difficult under windy conditions, particularly with cross winds. The CCG EIS corrects for the effects of bird swing through the use of an accurate GPS-based bird orientation sensor, which does not rely on gravity as its vertical reference. Data quality and accuracy improved substantially when using the GPS orientation sensor, compared to a gravity-actuated device (Holladay *et al*, 1997.*)*

Weather conditions in February were not ideal, resulting in significant thinning of the ice cover in the southern Gulf of St. Lawrence and the appearance of large areas of open water. Results from the first few days of the Gulf field program were also negatively affected by a series of instrument and methodology problems, most of them minor. These had been largely solved by March 3, and a series of data sets were gathered in the Gulf between March 3 and March 8, at which time the system was moved to Goose Bay, Labrador.

EIS operations began near Cartwright, Labrador on March 10, and included data acquisition from two marked test lines and many near-shore and offshore survey flights. The Labrador survey flights ended abruptly on March 12, when the engine of the Bell 206L carrying the EIS sensor failed near Huntingdon Island. Fortunately, the helicopter was landed safely on a land-fast ice pan, and the pilot and equipment operator were immediately picked up by the companion helicopter. However, the EIS bird was badly damaged, which ended EM survey for the season.

The main survey areas in the Gulf were W of the Magdalen Islands, with some coverage in the Northumberland Strait. Ice conditions were thinner than normal, but included a wide range of ice types ranging from grease ice to moderately ridged and rafted first year ice. These data are depicted in profile plot format in Appendix C, and in a more detailed presentation as *Standard Plots* in Appendix E for March 6 (Gulf) and March 10 and 11 (Labrador).

Ice conditions in the Labrador Sea had been affected by a series of storms, which had generated offshore large areas of ice rubble. These were profiled on March 10 and 12, in flight files 57 and 62 to 64. The inshore ice cover was mainly profiled on March 10 and 11, in flight files 56 and 59, with files 58, 60 and 61 devoted to profiling over marked lines for calibration purposes. Ice thickness observed along the coast was strongly dependent on the type and location of ice. Land-fast snow plus ice thickness ranged from 90 cm in protected areas down to 10 cm or less in more exposed areas. Discrete steps in ice thickness indicated the extent to which storms had broken up the land-fast ice. Ice in the outer reaches of larger bays such as Table Bay was typically very thin, often less than 10 cm.

The system's calibration factors were not changed at the beginning of the 1996 ice season. These factors had been installed in the bird after the conclusion of the 1995 Resolute field survey and were based on the best calibration data obtained during that survey. They were used throughout the 1996 field survey. Their continuing validity was investigated through comparison of the airborne results to surface measurements at a number of sites during the field program.

5.2 Northumberland Strait Surface Measurement Line

A drifting floe was marked and drilled in deep water in the Northumberland Strait on February 28. It was profiled using the EIS in the afternoon, as part of FLT027. The surface measurements obtained by auger measurements are listed in Appendix B. The mean snow plus ice thickness along the marked line was 0.63 ± .22 (2σ), with mean ice thickness 0.51 ± .13.

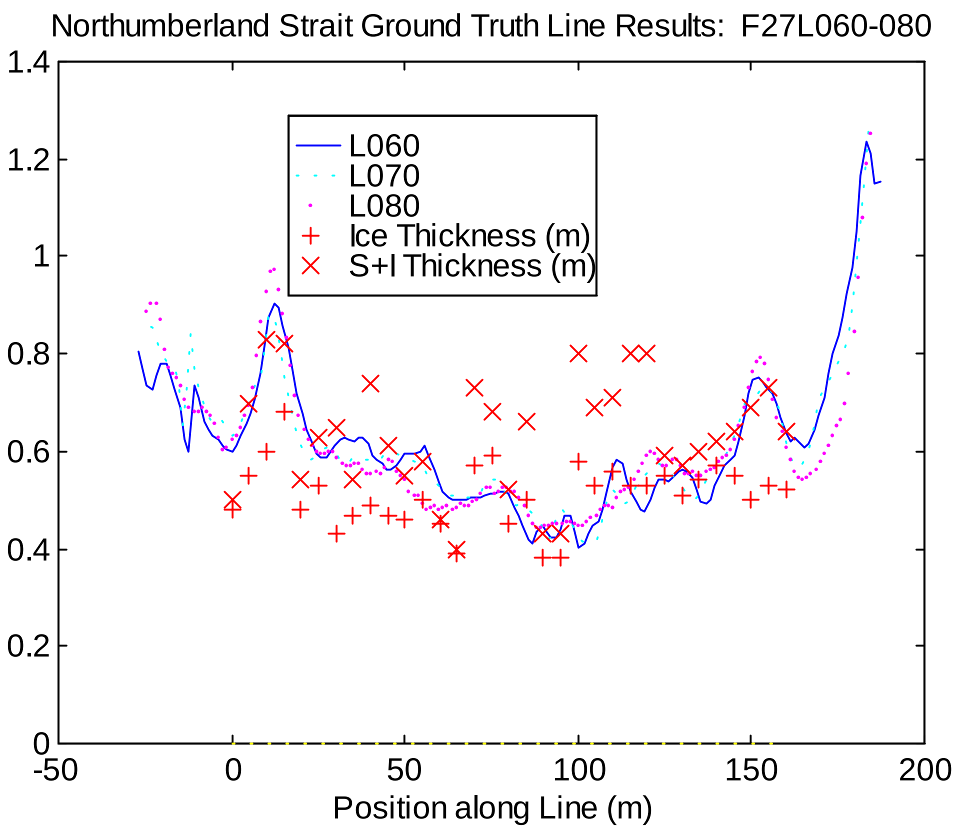

Figure 5.2.1: February 28 marked line surface measurements with airborne results.

The mean snow plus ice thickness for the three passes are 0.63 ± .32 m, 0.62 ± .28m and 0.61 ± .28m (2σ), for an overall average thickness of 0.62 ± .17m. The standard deviation of the mean EIS thickness is 0.01m, reflecting the high degree of repeatability of the EIS results. While there is a substantial amount of scatter in the surface measurements relative to the airborne results, the mean thickness match remarkably well. The scatter is likely due to the relatively rough character of the floe and the substantial contribution of snow drifts to the total thickness.

5.3 Cartwright Surface Measurement Line #1

The first surface measurement line set up during the Labrador field survey, CART#1, was located northwest of Huntingdon Island in deep water. The line was profiled with EIS on March 10 and 11. The surface measurements were made on March 10 during the airborne data acquisition.

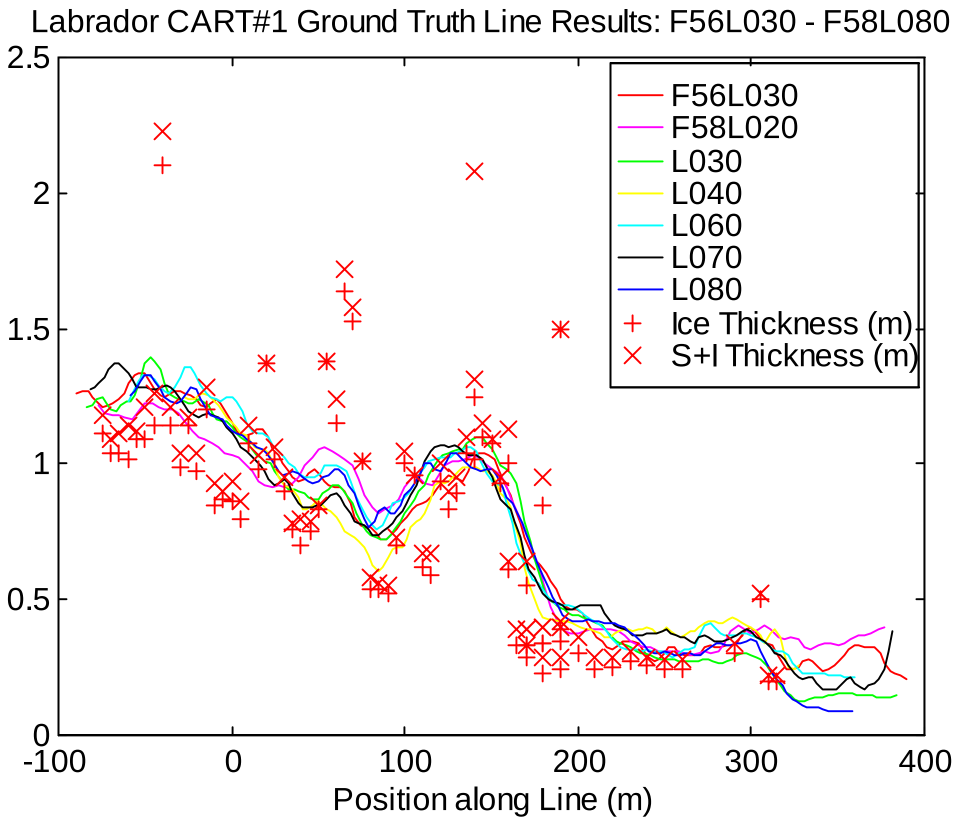

Figure 5.3.1: Surface measurements on CART#1 line with EIS results.

The EIS results, as expected, smooth out short-wavelength variations in snow plus ice thickness such as the ridges near 60 and 140 m. These variations are associated with the edge of the land-fast ice, which was presumably deformed by the storm activity that broke up much of the land-fast ice in the area. However, ice features which are broader than the EIS footprint of approximately 30 m are reflected in the EIS results, which are highly repeatable from pass to pass. The system's footprint effect is particularly visible at the steep margin near 160 m.

The average snow plus ice thickness along this line as estimated by surface measurements is 0.86 ± .83 (2σ), while the EIS averages ranged from 0.69 to 0.72 ± .7. The mean thickness for all passes was 0.71 m, with a standard deviation in the mean of .015, reflecting the repeatable nature of the EIS profiles. The systematic difference of 0.11 m between the surface measurements and the EIS results is unexplained, but could be a result of conductivity effects in the deformed ice.

5.4 Cartwright Surface Measurement Line #2

The CART#2 surface measurement line was set up south of Huntingdon Island on ice that was less deformed than at CART#1. Two marks were set up initially to provide a sight line for the pilot on March 11. The line was measured off and augered on March 15 after flying had ended.

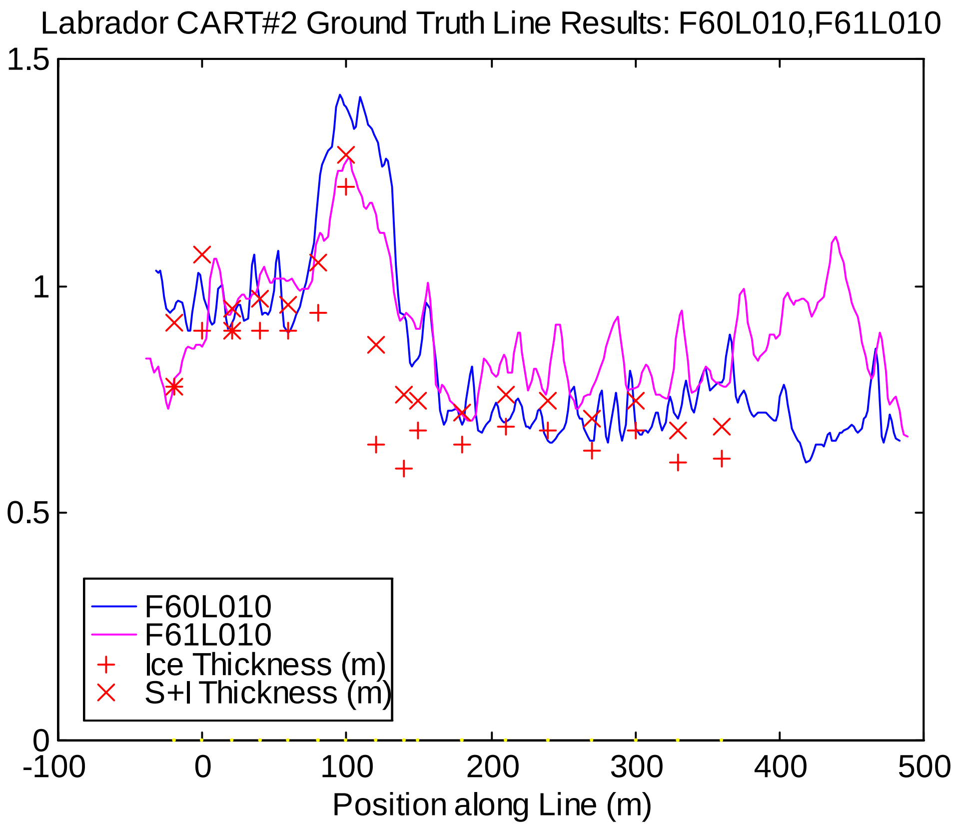

Figure 5.4.1: Surface measurements on CART#2 line with EIS results.

The surface measurements indicate that the ice thickness is relatively level on the thicker side of the ridge but is more variable on the thinner side. Snow drifts are thickest on the older ice and near the ridge. The average snow plus ice thickness in the surface measurements over the line is 0.86 ± .32 m (2σ), while the two EIS passes yielded 0.85 ± .4 and 0.90 ± .26 m. The surface and airborne results thus agree to better than the system's nominal 0.05m accuracy for level ice.

Footprint effects are again visible, spreading the sharp transition in ice thickness at the margin by an additional 30 m. The rapid variation of snow plus ice thickness over the flat portions of the line is most likely due to snow drifting. The mismatch observed at the right end of the line is probably the result of flight path deviations from the surface measurements as this portion of the line was not marked when the airborne passes were executed. It is interesting to note that the second profile matches the ice-only thickness very well at the left side of the figure. The flight path for this pass deviated from the extension of the line while lining up (compare Figure 4.1.22 with Figure 4.1.13), bypassing the snow drift observed along the extension of the marked line.

6. CONCLUSIONS

A series of ice thickness profiling data sets were gathered over land-fast and pack ice in the Gulf of St. Lawrence and over the southern Labrador Shelf in support of the 1996 RADARSAT Validation Program.

In the Gulf, profiling was concentrated over pack ice located west of the Magdalen Islands. Some profiles were acquired in the Northumberland Strait and between PEI and the Magdalens.

The system's calibration factors had been finalised and installed after the completion of the Resolute field survey. They were not changed at the beginning of the 1996 field survey. The validity of these factors was verified using multiple passes over marked lines on ice floes and land-fast ice for which surface measurements had been obtained. The results were typically accurate to better than 0.05 m in snow plus ice thickness over level ice, as shown by comparisons of the mean surface-measured and airborne thickness estimates over the Northumberland Strait floe and the CART#2 line. The thickness of narrow features such as ridges in deformed ice were underestimated, as expected, owing to the footprint of the EM system. Enhanced local ice conductivity effects may also slightly bias ice thickness estimates downward in deformed ice, as appears to be the case for the CART#1 line.

The real-time data quality from the system was excellent, yielding rapid turnaround of ice thickness profiles in hard-copy form after a flight. Post-processing of the data was used to remove small systematic errors caused by inaccurate real-time drift prediction in a few cases. Most of the post-processing of the data was completed in the field.

As a postscript, it should be noted that the sea ice sensor bird, which was damaged on February 12, 1996, had been insured for this project. It was rebuilt by Aerodat Inc. and returned to service during the 1997 Gulf ice season. EIS operations continued during the 1998 ice season.

ACKNOWLEDGMENTS

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The high degree of skill and professionalism exhibited by Universal Helicopters pilots Jim Myra and Ron Moores were vital to the execution of the Labrador program and to its successful conclusion under difficult circumstances.

Finally, many thanks are due to James Lee and Ingrid Peterson for their many efforts before, during and since the field programs.

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APPENDICES

A. Flight Line Ice Type Summary

It is important to note that the line numbers that do not end with 0 are the result of manual editing. These lines were split into numerous parts. For example, the line 10010 on May 1st, Flight 9 was split into three parts, therefore the line numbers 10011, 10012, and 10013. Also note, that lines shorter than 400 meters were omitted from the table (*e.g.* 10011 of Flight 9 was shorter than 400 m).

Date	Flight #	Pack Ice				Land-fast Ice			
		Line #	Length (km)	Ave. Ice Thickness (m)	Subtotal Length (km)	Line #	Length (km)	Ave. Ice Thickness (m)	Subtotal Length (km)
28-Feb	27					10011	4.751	0.23	
						10012	3.435	0.74	
						10020	0.231	1.08	
						10030	0.616	0.99	
						10040	19.511	0.93	
						10051	0.544	0.01	
		10052	1.931	0.44					
		10060	0.774	0.56					
		10070	0.556	0.59					
		10080	0.675	0.61					
		10090	0.688	0.62					
		10100	0.779	0.61					
		10110	0.805	0.38					
						10120	4.993	0.09	
						10131	1.753	0.30	
						10132	12.431	0.43	
					6.208				48.265
29-Feb	29	10010	0.852	0.11					
		10020	3.678	0.75					
		10030	10.638	0.27					
		10040	14.080	0.18					

Date	Flight #	Pack Ice				Land-fast Ice			
		Line #	Length (km)	Ave. Ice Thickness (m)	Subtotal Length (km)	Line #	Length (km)	Ave. Ice Thickness (m)	Subtotal Length (km)
		10050	3.386	0.25					
		10060	16.746	0.60					
		10070	0.739	1.52					
					50.119				
	30	10010	2.461	0.76					
		10020	10.485	0.55					
		10030	1.38	0.22					
		10040	26.877	0.51					
		10050	1.270	0.49					
		10060	1.534	0.63					
		10070	21.626	0.76					
		10080	0.263	1.04					
		10090	0.719	0.61					
		10100	1.623	0.71					
		10110	0.340	0.67					
		10120	19.445	0.63					
		10130	27.570	0.61					
					115.593				
	31	10010	4.871	0.55					
		10020	1.789	0.30					
		10030	0.987	0.27					
		10040	2.368	0.30					
		10050	6.076	0.25					
		10060	1.490	0.26					
		10070	2.018	0.20					
					19.599				

Date	Flight #	Pack Ice				Land-fast Ice			
		Line #	Length (km)	Ave. Ice Thickness (m)	Subtotal Length (km)	Line #	Length (km)	Ave. Ice Thickness (m)	Subtotal Length (km)
1-Mar	36	10010	2.792	0.58					
		10020	24.080	0.66					
		10030	32.208	0.69					
		10040	23.340	0.52					
		10050	31.993	0.45					
					114.418				
2-Mar	39	10030	1.039	0.35					
		10040	0.780	0.40					
		10050	0.655	0.61					
					2.474				
3-Mar	43	10010	3.166	1.03					
		10020	1.246	1.70					
		10030	1.759	0.62					
		10041	0.430	0.67					
		10042	2.316	0.63					
		10050	2.750	0.59					
		10060	1.943	0.56					
		10070	2.189	0.65					
		10080	2.227	0.65					
					18.026				
5-Mar	44	10010	3.371	0.57					
		10020	9.668	1.21					
						10030	1.565		
						10040	2.437		
						10050	1.786		
						10060	1.999		

Date	Flight #	Pack Ice				Land-fast Ice			
		Line #	Length (km)	Ave. Ice Thickness (m)	Subtotal Length (km)	Line #	Length (km)	Ave. Ice Thickness (m)	Subtotal Length (km)
					13.039			7.79	
	45	10010	0.331	0.02					
		10020	4.560	0.07					
		10030	12.964	0.41					
		10040	4.655	0.92					
					22.510				
	46	10010	4.837	0.97					
					4.837				
	47	10010	1.263	0.65					
		10020	1.292	0.62					
		10030	1.040	0.52					
		10040	0.422	0.42					
		10050	6.982	1.05					
		10060	0.596	0.71					
		10070	2.916	0.56					
					14.511				
6-Mar	49					10010	16.632	1.33	
		10020	8.716	0.32					
		10030	0.459	0.02					
		10040	2.655	0.44					
		10050	12.166	0.25					
					23.996				1.330
	53	10011	0.880	0.22					
		10012	1.572	0.41					
		10020	13.896	0.16					
		10030	13.730	0.22					

Date	Flight #	Pack Ice Line #	Pack Ice Length (km)	Pack Ice Ave. Ice Thickness (m)	Pack Ice Subtotal Length (km)	Land-fast Ice Line #	Land-fast Ice Length (km)	Land-fast Ice Ave. Ice Thickness (m)	Land-fast Ice Subtotal Length (km)
		10040	16.215	0.33					
		10050	19.869	0.56					
		10061	3.851	0.73					
		10062	2.363	0.64					
		10071	0.246	0.98					
		10072	1.561	0.75					
		10080	24.876	0.77					
					99.059				
	54	10010	0.880	0.66					
		10020	1.825	0.65					
		10031	0.712	0.43					
		10032	0.674	0.47					
		10033	3.491	0.81					
		10110	9.564	0.68					
					17.146				
10-Mar	55	10010	16.004	0.50					
		10020	4.761	0.60					
		10030	3.672	0.47					
		10040	14.586	0.53					
		10050	6.284	0.63					
		10060	5.752	0.56					
					51.059				
10-Mar	56					10011	9.742	0.43	
						10021	3.337	0.17	
						10022	1.136	0.15	
						10023	1.223	0.44	

Date	Flight #	Pack Ice				Land-fast Ice			
		Line #	Length (km)	Ave. Ice Thickness (m)	Subtotal Length (km)	Line #	Length (km)	Ave. Ice Thickness (m)	Subtotal Length (km)
						10030	1.602	0.97	
						10040	0.771	0.17	
		10051	17.340	0.80					
					17.340				17.811
	57	10010	10.033	0.40					
		10020	14.033	0.33					
		10030	9.002	0.34					
		10040	3.958	0.30					
		10050	18.616	0.38					
						10060	33.100	0.71	
					55.642				33.100
11-Mar	58					10010	8.217	1.27	
						10020	1.037	0.85	
						10030	0.942	0.65	
						10040	0.798	0.83	
						10050	1.009	0.46	
						10060	1.508	0.54	
						10070	1.007	0.81	
						10080	1.072	0.57	
									15.590
	59					10010	1.157	0.90	
						10020	8.266	0.81	
						10030	11.566	0.87	
						10040	25.051	1.16	
						10051	6.430	0.90	
						10052	5.076	0.48	

Date	Flight #	Pack Ice				Land-fast Ice			
		Line #	Length (km)	Ave. Ice Thickness (m)	Subtotal Length (km)	Line #	Length (km)	Ave. Ice Thickness (m)	Subtotal Length (km)
						10053	3.186	0.22	
						10061	0.883	0.21	
						10062	3.190	0.12	
						10063	1.065	0.18	
						10064	1.652	0.51	
						10081	1.705	2.41	
						10082	5.868	0.99	
						10083	1.145	1.91	
						10111	3.451	0.82	
						10112	2.317	0.91	
						10113	16.612	0.66	
						10114	5.990	0.19	
		10121	2.054	0.77					
						10122	7.685	0.93	
						10123	3.684	0.84	
						10124	5.333	0.68	
						10125	4.361	0.68	
						10126	4.051	0.47	
						10130	4.975	0.72	
					0.770				134.699
	60					10010	9.036	0.48	
						10020	9.378	0.55	
						10030	2.002	1.19	
						10040	0.087	2.04	
									20.503
12-Mar	61					10010	4.808	0.63	

Date	Flight #	Pack Ice				Land-fast Ice			
		Line #	Length (km)	Ave. Ice Thickness (m)	Subtotal Length (km)	Line #	Length (km)	Ave. Ice Thickness (m)	Subtotal Length (km)
						10020	1.386	0.33	
						10030	0.373	0.29	
						10040	9.439	0.74	
						10050	2.033	0.48	
									18.039
	62					10010	10.740	0.51	
		10020	6.993	0.92					
		10030	10.005	0.67					
		10040	45.71	0.71					
		10050	10.859	1.56					
		10060	17.078	2.47					
					90.645				10.740
	63	10010	5.649	0.65					
		10020	6.709	0.76					
					12.358				
	64	10010	6.475	0.61					
		10020	8.280	0.46					
		10030	0.809	0.50					
					15.564				
Total				0.59	764.913			0.813	300.077

B. Surface Measurement Data

<u>Gulf of St. Lawrence, Winter 1996 Surface Ice Data</u>

Station #1	-Thick Ice floe.	February 27, 1996
	-West Northumberland Strait.	Clearing, Light NW
	-Lat: 45 22.52	2°C, 14:40
	-Long: 64 14.37	

-500mx500m rafted ice floe.
-Four ice holes >130cm.
-20cm of freeboard, 2nd raft started at 180cm.
-5th hole in melt pond was 45cm with -10cm freeboard.
-Ice soft and wet: snow 0.0ppt, surface ice 0.0ppt.

Station #2	-Floe covered with slush (15cm).	February 27, 1996
	-150km north of PEI.	Clear, Light NW
	-Lat: 47 53:401	2°C, 16:25
	-Long: 63 22.856	

-500mx500m floe. First white floe (thick).
-Two ice holes, ice >120cm thick.
-Third ice hole 85cm and 4th hole 95cm thick ice.
-Beacon #966 deployed on thick rafted ice (16:25).
-Snow is 0.0ppt.

Station #3

-Calibration Floe (1st).
-West Northumberland Str.
-Lat: 46 18.452
-Long: 64 08.234

February 28, 1996
Cloudy, light NW
-2°C, 10:30

-500mx500m floe.
-17 ice holes along single line at 10m spacing.
-9 bags, every other ice hole plus two lead-up bags at 50m.
-Ends of line: SW end 2bags, NE end 3 bags.
-EM passes were from NE to SW.
-Snow 0.0ppt, surface ice 0.0ppt, surface water 30ppt.
-Beacon #969 deployed at 10:30 on ice >120cm.

Site #	distance (m)	Ice (cm)	Fboard (cm)	Snow (cm)	Snow+Ice (cm)	
1	0	45	4	2	47	SW /2 bags
2	10	46	4	1	47	
3	20	44	5	1	45	
4	30	51	4	1	52	
5	40	57	5	1	58	
6	50	45	4	1	46	
7	60	120	10	2	122	beacon 969
8	70	60	5	2	62	
9	80	54	5	1	55	
10	90	51	4	1	52	
11	100	55	5	1	56	
12	110	61	4	2	62	
13	120	52	4	2	54	
14	130	59	5	1	60	
15	140	54	4	1	55	
16	150	59	3	2	61	
17	160	51	3	1	52	NE /3 bags
	Mean*	52.8	4.25	1.4	53.2	

*excluding site #7 (EM sampled from site #17 to site #1)

Station #4	-Large 2kmx2km floe. -SE corner of large square. -Lat: 47 43.28 -Long: 62 15.21	February 29, 1996 Flurries, -6°C 20 km/h NW, 11:50

-Ice holes: 35, 33 and 43cm thick ice and 2cm of freeboard.
-Beacon #11249 reported at 11:50.
-Surface ice 0.0ppt, 10cm ice 0.0ppt.
-Hard surface ice with some snow patches.

Station #5	-Large 2kmx2km floe. -SE corner of middle square. -Lat: 47 53.98 -Long: 62 35.05	February 29, 1996 Flurries, -6°C 20 km/h NW, 12:10

-Ice holes: 37 and 42cm thick ice and 2cm of freeboard.
-Beacon #26382 reported at 12:10.
-Surface ice 1.0ppt, 10cm ice 1.0ppt.
-Hard surface ice with some snow patches.

Station #6	-Large 2kmx2km floe. -SW corner of middle square. -Lat: 47 54.71 -Long: 62 51.45	February 29, 1996 Flurries, -2°C 5 km/h NW, 12:30

-Ice holes: 39 and 42cm thick ice and 2.5cm of freeboard.
-Beacon #26385 reported at 12:30.
-Surface ice 0.0ppt, 10cm ice 2.0ppt.
-Hard surface ice with some snow patches.

Station #7	-Large 1kmx1km floe. -NW corner of middle square. -Lat: 48 09.0 -Long: 62 54.0	February 29, 1996 Flurries, -6°C 20 km/h NW, 15:35

-Ice holes: 35, 60 and 60cm thick ice and 3cm of freeboard.
-Beacon #326387 reported at 15:35.
-Surface ice 0.0ppt, 10cm ice 0.0ppt.
-Hard surface ice with some snow drifts.

Station #8	-Large 1kmx1km floe.	February 29, 1996
	-NE corner of middle square.	Flurries, -6°C
	-Lat: 48 09.0	20 km/h NW, 16:00
	-Long: 62 35.0	

-Ice holes: 48 and 52cm thick ice and 3cm of freeboard.
-Beacon #26386 reported at 16:00.
-Surface ice 1.0ppt, 10cm ice 0.0ppt.
-Hard surface ice with some snow patches.

Station #9	-Small 1kmx1km floe.	March 1, 1996
	-NE corner of small square.	Clear, -6°C
	-Lat: 47 54.0	6 km/h NW, 10:55
	-Long: 62 30.0	

-Ice holes: 47, 46 and 49cm thick ice and 2.5cm of freeboard.
-Beacon #26381 reported at 10:55.
-Surface ice 0.0ppt, 10cm ice 2.0ppt.
-Hard surface ice with some snow patches.

Station #10	-Small 1kmx1km floe.	March 1, 1996
	-NW corner of small square.	Clear, -6°C
	-Lat: 47 53.0	6 km/h NW, 11:14
	-Long: 62 36.0	

-Ice holes: 32, 30 and 35cm thick ice and 2cm freeboard.
-Beacon #26384 reported at 11:14.
-Surface ice 0.0ppt, 10cm ice 2.0ppt.
-Hard surface ice with some snow patches.

Station #11	-Small 1kmx1km floe.	March 1, 1996
	-SE corner of small square.	Clear, -6°C
	-Lat: 47 50.0	6 km/h NW, 11:29
	-Long: 62 31.0	

-Ice holes: 34, 35 and 37cmthick ice and 2cm freeboard.
-Beacon #26377 reported at 11:29.
-Surface ice 0.0ppt, 10cm ice 0.0ppt.
-Hard surface ice with some snow patches.

Station #12

-Small 1kmx1km floe.
-SW corner of small square.
-Lat: 47 48.0
-Long: 62 35.0

March 1, 1996
Clear, -6°C
6 km/h NW, 15:38

-Ice holes: 44, 42 and 32cm thick ice and 2cm freeboard.
-Beacon #26383 reported at 15:38.
-Surface ice 0.0ppt, 10cm ice 1.0ppt.
-Hard surface ice with some snow patches.

Station #13

-Small S-N ridge.
-20km west of Magdalen Islands.
-Lat: 47 28.0
-Long: 62 05.0

March 2, 1996
Clear, -4°C
6 km/h SW, 12:00

-Ridge ice holes: 277, 340, 420 and 410m thick ice.
-Surface and 10cm ice 0.0ppt both sides of ridge.
-Drainage water in 30cm ice hole was 42ppt.
-Hard surface ice with very few snow patches.
-Distances below from ridge (* number bags)
-** double bags at 40m west perpendicular to line.
-** double Bags at 50m east parallel to line.

	Distance west (m)	Ice (cm)		Distance east (m)	Ice (cm)
	5	191		5	>120
*	10	115	*	10	>120
	15	75		15	20
*	20	74	*	20	40
	25	74		25	41
*	30	73	*	30	49
	35	72		35	47
**	40	51	*	40	48
	45	55		45	18
	50	33	**	50	29
	55	30		60	30
	60	28		70	30
	65	30	*	80	28
*	70	30			

Station #14

-Calibration Floe #2 (Fixed Link).
- Lat: 46 06.0
- Long: 63 39.0

March 3, 1996
Clear, light SW
0°C, 14:30

-500mx500m floe; 32 ice holes 5m apart along a 160m line.
-Surface ice 0.0ppt, 10cm ice 2.0ppt.

Site #	distance (m)	Ice (cm)	Fboard (cm)	Snow (cm)	Snow+Ice (cm)	# of bags
1	0	48	2	2	50	(SW)**
2	5	55	2	15	70	
3	10	60	3	23	83	
4	15	68	3	14	82	
5	20	48	0	6	54	*
6	25	53	2	10	63	
7	30	43	0	22	65	
8	35	47	0	7	54	
9	40	49	2	25	74	*
10	45	47	2	14	61	
11	50	46	1	9	55	
12	55	50	1	8	58	
13	60	45	2	1	46	*
14	65	39	2	1	40	
15	70	57	3	16	73	
16	75	59	4	9	68	
17	80	45	1	7	52	*
18	85	50	2	16	66	
19	90	38	0	5	43	
20	95	38	0	5	43	
21	100	58	2	22	80	*
22	105	53	0	16	69	
23	110	56	1	15	71	
24	115	53	-1	27	80	
25	120	53	2	27	80	*
26	125	55	2	4	59	
27	130	51	1	6	57	
28	135	54	1	6	60	
29	140	57	1	5	62	*
30	145	55	1	9	64	
31	150	50	1	19	69	
32	155	53	-1	20	73	
33	160	52	-3	12	64	(NE)***
	Means	51.1	-1.2	12.2	63.3	

Station #15

-Floe west of Fixed Link.
-Camera crew on board.

March 5, 1996
Clear, -8°C
28 km/h W, 09:30

-Lat: 46 16.0
-Long: 63 48.0
-Five bags along 75m.
-Beacon #2362 out at 09:30.
-Drainage water in 30cm ice hole was 42ppt.

Distance west (m)	Ice (cm)	Snow (cm)	Snow+Ice (cm)	# of bags
0	142	0	142	(W)*
10	178	0	178	
25	53	7	60	*
35	57	0	57	
45	57	0	57	
55	124	0	124	*
65	>300	10	>300	
80	48	0	48	***
90	36	0	36	
100	29	2	31	(E)*
110	31	0	31	
120	47	0	47	
130	42	0	42	
140	46	0	46	
150	50	0	50	Marker Bag

Station #16

-Calibration Floe.
-Fixed Link area.
-Lat: 47 49.0
-Long: 62 20.0

March 5, 1996
Clear, 20 km/h W
-6°C, 12:00

-Large 2kmx5km floe.
-16 ice holes 5m apart along 80m long line.
-5 location bags plus two lead-up bags.
-W end 1 bag, E end 3 bags (down wind).
-EM passed over and circled the floe.
-Four ice samples:
-0cm (0ppt), 5cm (1ppt), 15cm (4ppt) and 25cm (6ppt).
-GPS/ARGOS beacon # 26388 on at 12:00.

Site #	distance (m)	Ice (cm)	Fboard (cm)	Snow (cm)	Snow+Ice (cm)	# of bags
1	0	39	2	6	45	(W)**
2	5	34	2	6	40	
3	10	34	3	5	39	
4	15	34	0	5	39	
5	20	32	0	6	38	*
6	27	34	-1	9	43	
7	34	43	-1	8	51	
8	40	35	1	9	44	*
9	45	33	2	2	35	
10	50	37	3	0	37	
11	55	33	3	0	33	*
12	60	35	4	0	35	
13	65	38	2	0	38	
14	70	42	3	0	42	
15	75	60	6	6	66	***
16	80	55	0	10	65	
	Means	37.8	1.7	4.5	42.3	

Station #17	-Calibration Floe.	March 6, 1996
	-Fixed link area.	Clear, 5 km/h E
	-Lat: 47 44.0	-6°C, 13:15
	-Long: 61 52.0	

-Large 3kmx5km floe.
-17 ice holes, 5m apart along 80m long line.
-5 bags location plus two lead-up bags.
-W end 2 bags, E end 3 bags, ridge at 100m due East.
-EM passed over and circled the floe.
-Four ice plus drainage water samples.
-0cm (0ppt), 5cm (1ppt), 15cm (2ppt) .nd 25cm (3ppt).
-Drainage water in ice hole 25cm deep was 32ppt.

Site #	distance (m)	Ice (cm)	Fboard (cm)	Snow (cm)	Snow+Ice (cm)	# of bags
1	0	32	4	0	32	(W)**
2	5	29	2	0	29	
3	10	32	2	0	32	
4	15	32	2	0	32	
5	20	30	2	2	32	*
6	25	32	1	6	38	
7	30	33	1	6	39	
8	35	32	0	8	40	
9	40	32	-1	18	50	*
10	45	29	-4	20	49	
11	50	31	-4	25	56	
12	55	32	-8	30	62	
13	60	39	0	20	59	*
14	65	38	-2	10	48	
15	70	38	0	2	40	
16	75	34	0	0	34	
17	80	46	1	0	46	(E)***
	Means	35.6	-0.3	8.1	43.7	

Station #18	-Floe north of PEI. -Target #1 on Thursday. -Lat: 46 46.9 -Long: 63 22.9	March 7, 1996 Clear, 5 km/h NE -8°C, 10:35

-Large 3kmx3km floe.
-3 ice holes: 38, 32, 35cm thick ice and 8, 8, 10cm of snow.
-EM passed over and circled the floe.
-Deployed beacon #2364 at 10:35.
-Four ice salinity samples:
-0cm (0ppt), 5cm (2ppt), 20cm (5ppt) and 30cm (6ppt).

Station #19	-Ridge offshore Magdalen Islands. -Lat: 47 28 -Long: 61 54	March 7, 1996 Clear, 5 km/h NE -8°C, 14:05

-Young blue coloured ridge with a 2.2 m sail height.
-Ridge over 30m wide with 45 to 50cm thick blocks.
-Block surface and interior salinity were 0.0ppt.

Labrador Shelf March 1996 Surface Ice Data

Sunday: March 10, 1996

Clear, 35km/h NW
-15°C, 11:00.

-Stn. 10.1: (Land-fast calibration line; EM Stn.: CART#1)
-Position of calibration line: 53 51.67N, 56 59.55W.
-Packs Harbour north of Huntingdon Island.
-Put out 14 bags, 20m apart along 260m line.
-SW end (Cartwright) 3 bags, NE end (thin ice) 2 bags.
-Obtained ice thickness and snow depths (March 11).

-March 11 (morning): Salinities along the line at positions in meters.
-Salinities (70m): Top snow 0ppt, Bottom snow 6ppt, 4cm 3ppt, 20cm 6ppt and 35cm 4ppt.
-Salinities (140m): Top snow 0ppt, bottom snow 0ppt, 3cm 0ppt, 10cm 3ppt, 20cm 5ppt, 35cm 4ppt, 45cm 4ppt and 60cm 5ppt.
-Salinity (180m): snow (wet) 43ppt.
-Salinities (310m): snow 62ppt and 5cm ice 6ppt.

-March 11 (afternoon): beacons deployed at 140m position.
-At beacons: ice 102, 110cm, snow 7cm and freeboard 12 cm.
-GPS: 26373 (14:00), Pressure #1055 and # 26373 (14:45) and Temp Staff # 2347.

-March 12 (morning): Ice thicknesses and ice cores.

-March 14 (afternoon): ice thicknesses south of line.
-Removed the bags.

-March 15 (afternoon): Salinity sample at 180m.
-Salinities: wet snow 18ppt, 5cm ice 22ppt.
-Note more snow since March 11 due to storm on March 12.

-March 17 (afternoon): Bottom depths, ridge ice thicknesses.
-Line direction is 25°(offshore) and 205° (inshore).

-March 19 (11:00): At 140m recover ice beacons, ice 122cm.
-In ice staff hole ice 144cm, freeboard 12cm, distance from bottom of ice to bottom flange of ice staff was 128cm.

Stn. 10.1: (Land-fast calibration line; EM Stn.: CART#1)

# Bags	distance m	snow cm	ice cm	fboard cm	Snow+ice cm	depth m
*	-75	7	111	10	118	31.6
	-70	5	104	7	109	
	-65	7	104	8	111	
	-60	12	102	6	114	
	-55	3	109	7	112	
	-50	12	109	8	121	
	-45	12	114	12	126	
	-40	13	210	9	223	
	-35	7	114	8	121	
	-30	5	99	8	104	
	-25	3	114	9	117	
	-20	7	97	9	104	
	-15	8	120	7	128	
	-10	8	85	8	93	
	-5	3	87	7	90	
***	0	8	86	5	94	30.2
	5	6	80		86	
	10	6	108	5	114	
	15	5	98	7	103	
*	20	0	137	11	137	
	25	4	102	12	106	
	30	5	90	9	95	
	35	2	76		78	
*	40	3	70	9	80	
	45	4	75		79	30.3
	50	2	83	10	85	
	55	0	138		138	
*	60	9	115	7	124	
	65	8	164		172	
	70	5	153	12	158	
	75	0	101		101	30.5
*	80	4	54	3	58	
	85	2	54		56	
	90	3	52	4	55	
	95	3	70		70	
*	100	5	100	9	105	
	105	0	96		96	
	110	5	62	5	67	
	115	8	59		68	
*	120	6	94	9	100	
	125	6	83		83	
	130	6	89	7	95	
	135	6	104		110	
*	140	6	115	12	127	Beacons
	145	5	110		110	31.0
	150	1	108	9	109	
	155	2	93	5	95	
*	160	3-13	83	8	91	Ridge

Stn. 10.1: (Land-fast calibration line; EM Stn.: CART#1)

# Bags	distance m	snow cm	ice cm	fboard cm	Snow+ice cm	depth m
*	160	3-13	83	8	91	Ridge
	165	6	33	1	39	
	170	4-6	29-33	1	36	
	175	4				
*	180	6	23-34	-3	34	
	185	6				
	190	5	24	-3	29	
	195	5				
*	200	6	30	0	36	
	205	5				
	210	5	24	-2	29	
	215	4				
*	220	4	25	0	29	
	225	4				
	230	4	27	0	31	
	235	3				
*	240	3	26	0	29	
	245	4				
	250	4	24	0	28	
	255	6				
**	260	4	24	0	28	
	290	4	30	1	34	
	305	2	50	4	52	small ridge
	310	2	20	0	22	
	315	2	20	0	22	
10mE	170	6	33		39	
15mE	170	9	55		64	
10mE	180	6	34		40	
15mE	180	10	85		95	
10mE	190	5	35		41	
15mE	190	3	39		42	
20mE	190	0	150		150	

Note: Extra ridge ice thicknesses (160m): 92, 83, 78 and 100cm.
Ridge (160m) was 61cm. Average of five = 83cm.
Ice thicknesses at 140m besides 125cm: 102, 110, 122 and 114.
Average of five at 140m (beacons) = 115cm.

Sunday: March 10, 1996 Clear, 35km/h NW
-15°C, 15:08.

-Stn. 10.2: 54 03.42N, 55 27.27W.
-GPS/ARGOS beacon #26379 (15:08).
-SW corner of triangle #1.
-Ice thickness: 75, 61, 35cm. Snow 6-12cm.
-Ice salinities: 0cm 0ppt, 10cm 3ppt, 20cm 5ppt and 30cm 5ppt.

Sunday: March 10, 1996 Clear, 35km/h NW
-15°C, 15:45.

-Stn. 10:3: 54 03.58N, 55 27.24W.
-GPS/ARGOS beacon #26378 (15:45).
-Ice pressure beacons #1054 and #22195 (15:45).
-Centre of triangle #1.
-Ice thickness: 48, 45, 47cm. Snow 5, 6 and 8cm.
-Snow and ice salinities: bottom snow 13ppt, 0cm ice 2ppt, 10cm 2ppt, 20cm 6ppt and 30cm 5ppt.

Sunday: March 10, 1996 Clear, 35km/h NW
-15°C, 16:05.

-Stn. 10.4: 54 04.18N, 55 28.88W.
-GPS/ARGOS beacon #21598 (16:05).
-N corner of triangle #1.
-Ice thickness: 37, 37, 36cm and 1cm of snow.

Sunday: March 10, 1996 Clear, 35km/h NW
-15°C, 16:30.

-Stn. 10.5: 54 04.32N, 55 22.63W.
-GPS/ARGOS beacon #26376 (16:30).
-SE corner of triangle #1.
-Ice thickness: 47, 49, 49cm. Snow 5, 5 and 6cm.

Wednesday: March 13, 1996 Clear, 5km/h NW
-6°C, 15:30.

-Stn. 13.1 (#6): 54 40.33N, 56 20.04W.
-GPS/ARGOS beacon #26374.
-Ice pressure beacons #1052 and #22196 (15:30).
-Centre of triangle #2.
-Ice thickness: 33, 33, 33cm, Snow 1, 1 and 1cm.
-Snow/ice salinities: snow 15ppt, 0cm ice 8ppt, 10cm 7ppt, 20cm 5ppt and 30cm 6ppt.

Wednesday: March 13, 1996 Clear, 5km/h NW
-6°C, 15:40.

-Stn. 13.2: 54 42.97N, 56 22.30W.
-GPS/ARGOS beacon #26366.
-North corner of triangle #2.
-Ice thickness: 84, 97, 82cm. Snow 25, 22 and 23cm.

Wednesday: March 13, 1996 Clear, 5km/h NW
-6°C, 16:29.

-Stn. 13.3: 54 39.54N, 56 12.66W.
-GPS/ARGOS beacon #26370.
-Southeast corner of triangle #2.
-Ice thickness: 38, 38, 43cm. Snow 1, 1 and 2cm.

Wednesday: March 13, 1996 Clear, 5km/h NW
-6°C, 16:45.

-Stn. 13.4: 54 37.27N, 56 23.31W.
-GPS/ARGOS beacon #26368.
-Southeast corner of triangle #2.
-Ice thickness: 34, 35, 34cm. Snow 2, 2 and 2cm.

Thursday, March 14, 1996. Cloudy, +2°C
5 km/h W, 10:20.

-Table Bay Stn. 14.4: 28.5 m depth.
-Black land-fast ice: 53 38.24N, 56 25.40W.
-Ice, snow depths and salinity samples.
-Ice: 75, 82 and 92cm: Snow: 3, 3, and 3cm.
-Top snow 0ppt, bottom snow 0ppt, 3cm ice 0ppt, 10cm 1ppt, 20cm 3ppt, 30cm 5ppt and 45cm 4ppt.

Thursday, March 14, 1996. Cloudy, +2°C
5 km/h W, 10:50.

-Table Bay, Stn. 14.5: bright thin land-fast ice.
-100m NE of 53 38.24N, 56 25.40W.
-Ice, snow thicknesses and salinity samples.
-Ice: 20, 21 and 20cm; Snow bumps 1m apart 4-5cm high.
-Top snow 25ppt, bottom snow 25ppt and 5cm ice 7ppt.

Thursday, March 14, 1996. Cloudy, +2°C
5 km/h W, 11:20.

-11:20: Table Bay.
-Stn. 14.6: 5km NE of Stn. #14.5. Black land-fast ice.
-Ice, snow thicknesses and salinity samples.
-Ice: 37, 39 and 38cm; snow 10, 11 and 10cm.
-Top of snow 14ppt, bottom of snow 22ppt and 5cm ice 14ppt.

Thursday, March 14, 1996. Cloudy, +2°C
5 km/h W, 11:45.

-11:45: Table Bay, Stn. 14.7: 5km NE of Stn. 14.5.
-Black thin land-fast ice (snow saw tooth pattern).
-Ice, snow thicknesses and salinity samples.
-Ice: 14, 14 and 14cm; snow tooth 10cm apart.
-Top of snow 27ppt, bottom of snow 20ppt and surface ice 24ppt.

Friday, March 15, 1996. Cloudy, +2°C
5 km/h SE, 10:10.

-Stn. 15.8: Lat. 53 52.68, Long. 56 59.51.
-North of calibration line, bright area on image.
-Depth 28m. Ice thicknesses: 26, 26 and 26cm.
-Same ice as 310m calibration line.
-Salinities: snow slush 7ppt, 5cm ice 6ppt.

Friday, March 15, 1996. Cloudy, +2°C
5 km/h SE, 10:25.

-Stn. 15.9: Inland from Lat. 53 52.68, Long. 56 59.51.
-NW of calibration line, not-so-bright area on image.
-Ice thicknesses: 39, 42 and 55cm.
-Inland from Stn. #15.8.
-Slush snow cover with white snow bumps 2m apart.
-Salinities: snow tops (dry) 5ppt, wet snow 8ppt, 5cm ice 16ppt and 10cm ice 13ppt.

Friday, March 15, 1996. Cloudy, +2°C
5 km/h SE, 10:45.

-Stn. 15.10: Lat. 53 53.33, Long. 56 09.85.
-Strand station, dull land-fast area on image.
-Ice thicknesses: 65, 65 and 64cm.
-Snow depths: 8, 10 and 10cm.
-Salinities: snow top 0ppt, snow bottom 8ppt, 3cm ice 2ppt, 0cm 2ppt, 20cm 5ppt and 30cm 6ppt.

Friday, March 15, 1996. Cloudy, +2°C
5 km/h SE, 11:05.

-Stn. 15.11: Lat. 53 45.75, Long. 56 51.28.
-Inside break from thick to thin ice.
-East of Huntingdon Island, dull land-fast area on image.
-Ice thicknesses: 58, 59 and 60cm.
-Snow depths: 5, 4, and 3cm.
-Salinities: snow top 0ppt, snow bottom 3ppt, 3cm ice 0ppt, 5cm 4ppt and 15cm 5ppt.

Friday, March 15, 1996. Cloudy, +2°C
5 km/h SE, 11:15.

-Stn. 15.12: Lat. 53 45.75, Long. 56 51.28.
-Outside break from thick to thin ice.
-East of Huntingdon Island, bright band against thick ice.
-Ice thicknesses: 14, 15 and 16cm; snow depths: 2, 2, and 2cm.
-Salinities: snow wet 16ppt, surface ice 9ppt.

Friday, March 15, 1996. Cloudy, +2°C
5 km/h SE, 13:30.

-Stn. 15.13: Second calibration line
-Lat. 53 44.72N, 56 53.74W; (150-360m done on March 17).
-East of Huntingdon Island, dull land-fast area on image.
-In line but south of Stns. 15.11 and 15.12.
-Nine ice thicknesses and snow depths.
-Salinities: top snow 2ppt, bottom snow 0ppt, 3cm ice 0ppt, 10cm 7ppt, 20cm 6ppt and 35 cm 8ppt.

# Bags	distance m	snow cm	ice cm	fboard cm	Snow+ice cm
	-20	0-14	78	5	85
*	0	17	90	8	107
	20	0-5	90	8	95
	40	7	90	9	97
	60	6	90	6	96
	80	11	94	6	105
	100	7	122	9	129
*	120	22	65	0	87
	140	16	60	2	76
	150	7	68		75
	180	7	65		72
	210	7	69		76
	240	7	68		75
	270	7	64		71
	300	7	68		75
	330	7	61		68
	360	7	62		69

Snow thicknesses for 150 - 350 were taken as an average of the previous thicker ice -20m - 100m.
Note: Old holes were not found, but thicknesses were very consistent as EM data indicated.

Monday, March 18, 1996. Cloudy, +2°C
10 km/h SE, 10:00.

-Stn. 18.01: Lat. 53 36.14, Long. 55 33.84.
-Small thick but soft ice floe off Spotted Island.
-ARGOS beacon # 975 deployed at about 10:00.
-Ice 117 cm, 10mx10m floe.

Tuesday, March 19, 1996. Clear, -4°C
15 km/h SW, 09:15.

-CTD Stn. #4: Lat. 53 56.30, Long. 55 36.97.
-Small thick ice floe 60km of Grady Island.
-175 m depth, thick ice on both sides of floe,
-thin 30cm in middle.

Tuesday, March 19, 1996. Clear, -4°C
15 km/h SW, 09:50.

-CTD Stn. #5: Lat. 53 53.03, Long. 55 55.31.
-Small thick ice floe 40km of Grady Island.
-150m depth, thick (>200cm) floe,
-CTD done from edge.
-ARGOS beacon # 2365 deployed.

Tuesday, March 19, 1996. Clear, -4°C
15 km/h SW, 10:30.

-CTD Stn. #6: Lat. 53 50.44, Long. 56 08.27.
-Small thin ice floe 20km of Grady Island.
-92m depth, ice 39cm thick.

C. Ice Thickness Profile Maps

This appendix presents snow plus ice thickness profile maps generated from the airborne EIS data set. Although the legends on these maps identify a nominal scale for each map, they have been resized to fit into this document and so are no longer to scale. Distances may be estimated using the scale bar or the latitude/longitude grid.

D. Profile Plot Segment Statistics Tables

E. Standard Plots (March 6, 10 and 11 only)