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Airborne Electromagnetic Sea Ice Sounding Measurements During 1998 Gulf of St. Lawrence Field Program

by

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Abstract

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The 1998 Gulf of St. Lawrence airborne ice monitoring program was active between February 21 and March 24. Field operations were based at the Canadian Coast Guard Helicopters facility at Charlottetown Airport in PEI. Approximately 1520 line kilometres of airborne Electromagnetic Ice Sounder data were obtained during this period, including long data acquisition traverses over the Gulf and Northumberland Strait as well as calibration confirmation lines over marked and augered sites.

The real-time data snow-plus-ice thickness data acquired by the system during the first half of the field program were contaminated by spikes generated by poor signal returns during laser altimeter operation over open water. A post-processing procedure removed the spikes from affected datasets for presentation in this report, while improvements to the system software installed on March 18 eliminated spiking in the real-time output of the system.

The system's calibration had changed since the 1997 field season owing to the removal of a snow radar transceiver unit from the sensor bird. A new "field" calibration was calculated, tested and installed on February 22, based on data obtained on February 21 over a marked and augered test line. An independent opportunity to verify system calibration occurred on 18 March, using a marked and augered ice floe floating in the Northumberland Strait. This yielded good agreement between EIS and surface measurements on average despite strong lateral changes in ice thickness along the surveyed line. Over a thin flat floe at this site, the results agreed at the 1 centimetre level. The system calibration was re-calculated using an advanced calibration utility during the preparation of this report and found to be consistent with the field calibration to within 0.4% in amplitude, corresponding to negligible systematic error at the normal bird height of 15 m.

Résumé

Holladay, J.S. and S.J. Prinsenberg, 1999. Airborne Electromagnetic Sea Ice Sounding Measurements During 1998 Gulf of St. Lawrence Field Program. Can. Contract. Rep. Hydrogr. Ocean Sci. 53: vi + 118p.

Le programme d'observation aéroporté des glaces du golfe du Saint-Laurent 1998 a eu lieu du 21 février au 24 mars. Les opérations sur le terrain ont été menées à partir de l'installation des hélicoptères de la Garde côtière canadienne à l'aéroport de Charlottetown, à l'Île-du-Prince-Édouard. On a recueilli des données de sondage électromagnétique aéroporté sur environ 1 520 kilomètres de lignes au cours de cette période, y compris de longs trajets d'acquisition de données effectués au-dessus du golfe du Saint-Laurent et du détroit de Northumberland, ainsi que des lignes de confirmation de l'étalonnage effectuées au-dessus de sites marqués et forés.

Les données en temps réel sur l'épaisseur de la neige et de la glace saisies par le système au cours de la première moitié des programmes sur le terrain étaient contaminées par des pics engendrés par de mauvais retours de signaux au cours des opérations à l'altimètre laser effectuées au-dessus des eaux libres. Une procédure post-traitement a permis d'enlever les pics des ensembles de données contaminés afin qu'ils puissent être présentés dans ce rapport. De plus, des améliorations apportées au logiciel installé le 18 mars a permis d'éliminer les pics dans les extrants en temps réel du système.

L'étalonnage du système avait été modifié après les opérations sur le terrain de 1997, puisqu'on avait enlevé un émetteur-récepteur radar à neige de la torpille de détection. Un nouvel étalonnage « sur le terrain » a été calculé, mis à l'essai et installé le 22 février à partir des données saisies le 21 février au-dessus d'une ligne d'essai marquée et forée. Une nouvelle occasion de vérifier l'étalonnage du système s'est présentée le 18 mars. Cette vérification a été effectuée au-dessus d'une banquise marquée et forée dans le détroit de Northumberland. Il y avait, en moyenne, une bonne concordance entre les données de sondage électromagnétique aéroporté et les mesures à la surface, malgré d'importants changements latéraux au niveau de l'épaisseur de la glace le long de la ligne observée. L'écart entre les données recueillies pour une banquise plate et mince à ce site était inférieur à 1 centimètre. L'étalonnage du système a été recalculé au moyen d'un programme d'étalonnage perfectionné pendant la préparation de ce rapport. On a conclu que l'étalonnage était fidèle à l'étalonnage sur le terrain à moins de 0,4 % d'amplitude, ce qui constitue une erreur systématique négligeable étant donnée l'altitude moyenne des torpilles de détection, soit 15 m.

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1. Introduction

The 1998 Gulf of St. Lawrence pack ice field measurement program began on February 17 and continued to March 24. Airborne Electromagnetic Ice Sounder (EIS) measurements were obtained over the Northumberland Strait and southern Gulf during a series of flights by CCG helicopter CG353. Surface activities, including Argos beacon emplacement and retrieval, preparation of marked lines for test and calibration purposes, and sampling for ice salinity were conducted using other CCG helicopters.

The methodology used during this program was based on procedures developed during field work and data analysis for programs in 1994, 1995 and 1996, as described in Holladay and Moucha, (1998), Holladay *et al*, (1998), and Moucha *et al*, (1998).

The Canadian Coast Guard airborne Electromagnetic Ice Sounder used during this field program was described in Holladay *et al*, (1998). It was towed by a Coast Guard MBB B0105 helicopter #CG353 that was piloted by Ron Moores.

This report begins with a summary of field personnel and operations, describes the 1998 EIS dataset, and concludes with an assessment of system performance and calibration.

The processed results are presented in flight statistics table form in Appendix B and as profile plots in Appendix D. Flight path plots are provided in Appendix C. "Standard Plots" of the data have not been included in this report, as they would fill hundreds of pages. They are however available as Postscript file archives which are indexed relative to the statistics tables and the flight path and profile plots in the Appendices. Surface measurements obtained during the field program are listed in Appendix A.

2. 1998 Field Program

Objectives

The 1998 field program for the EIS had the following objectives:

1. Evaluate and improve modifications made to the laser hardware and software so that improved high-frequency laser data could be acquired and stored,
2. Deliver real-time and processed EIS data and plots to the Canadian Ice Service, and
3. Collect EIS data to validate ice signatures seen in RADARSAT imagery.

Personnel:

Bedford Institute of Oceanography

- SP Simon Prinsenberg (Principal Investigator)
- GF George Fowler
- IP Ingrid Peterson (remote support)

Vanguard Geophysics Inc.

- JSH Scott Holladay (EIS support lead)
- RZM Robert Z. Moucha (contractor to Vanguard)
- JL James Lee (EIS remote support)

Canadian Coast Guard

- AM André Maillet (Ice Operations chief)
- RM Ronald Moores (pilot)
- PM Paul Mosher (pilot)
- IH Ian Henderson (Charlottetown helicopter engineer)

Canadian Ice Centre

- ST Syd Thompson (Ice Services Specialist)
- CS Colin Stock (Ice Services Specialist)
- DF Dan Fequet (Ice Services Specialist)

Daily Field Activity Summary:

Tuesday, 17 February

Weather: clear, cold –10 °C. Winds light NW

On arrival JSH and RZM, initiated diagnostics on Ice Probe bird. Identified and repaired problem with analogue input for EM: input amplifiers damaged. Cause uncertain, but static discharge through the tag line is a possibility. Added some protection for the inputs to the analog board. Tested bird outside in evening: EM signals good, but no GPS data.

Wednesday, 18 February

Weather: fair, -2 °C, turning poor in evening. Winds light NE

Troubleshooting GPS problem began with cable continuity checks: all cables were OK but an incipient problem with a signal line from preamplifier was noted and repaired. An oscilloscope was requested from CG base to assist in trouble shooting the GPS problem. Oscilloscope arrived in afternoon. Testing confirmed that the interface chips on both channels of the RS422-232 interface board were damaged. No spares for the chip were present in the CG spares kit.

Thursday, 19 February

Weather: rain, low ceiling all day.

A workaround for the blown interface chip for Channel A (the only one in use) was fabricated from discrete components. This was tested and found to be operational. The bird was tested outside. Pitch and roll data were found to be correct. The rest of the system was set up and tested as well as possible on the ground for a flight test on Friday.

Friday, 20 February

Weather: rain, slight clearing in late afternoon (ceiling still low).

EM Flight Files: 001-003

Test flight #1. On takeoff, bird shut down. On disassembly, found fuse blown on 5V-power supply input. Symptoms suggest low power supply voltage at bird. Inspected and rebuilt the helicopter power supply cable: located a possible high-resistance point at helicopter end during rebuild. Note that this cable is not the same one as was used earlier (apparently lost). Present cable was assembled from the cable designed for 206L installation, and had been modified by the addition of a plug to its helicopter end. It was in this modification that the apparent high-resistance point was located. Ground tests completed. Installed DVM to monitor 28V output of rack-mount power supply.

Saturday, 21 February

Weather: overcast in am, clearing toward noon.

EM Flight Files: 004-007

Flew test flight #2. Noted that Navlink transmissions seemed to interfere with the GPS interface. RM turned Navlink off. File FLT004 measured over Hillsborough Bay calibration line. All systems appear to be operational. Calibration is slightly low (20 cm over line which should read 35 cm ice thickness). Flight #3: short flight over Strait, ended with ceiling deteriorating. Files FLT005, 007 included good data. FLT006, 008-009 were tests. Halted analogue chart recording after these flights due to chart paper shortage. System operating normally without chart printing.

Sunday, 22 February

Weather: clear, -2° to 0°C, winds 10 km/hr W

EM Flight Files: 010-013

Flight #4: JSH operated over test line and Strait for extended test of EM and new calibration, FLT10-012, set up using FLT004 data over marked line.

Old calibration factors:

(+1.0315 0.0194),(0.9806 0.3300),(1.3076 0.5778)

New calibration factors computed in field from FLT004, Line 20:

(+0.9953 0.0034),(0.9560 0.3104) (1.2994 0.5733)

Ratios (new/old): (0.9646 - 0.0148i), (0.9714 - 0.0104i), (0.9935 - 0.0006i)

Calibration appeared to be good. Noted many spikes in laser altimeter caused by melt water on ice.

Flight #4: Re-fueled at Summerside. System problem appeared during FLT013, just after start of profiling. Restarted immediately, received error messages from bird, so returned to base. Determined that bird was operational after landing. The error messages seen were due to startup too soon after bird turnoff. A 2 minute wait between shutdown and startup under this circumstance (hot shutdown without “halt” being issued) is advisable to avoid this problem.

Flight #5: Trained ST (ISS) in use of system over Hillsborough Bay, files FLT014 –015. JSH evaluated new post-processing software with RZM in evening.

Monday, 23 February

Weather: Clear, -1 °C, winds light W

EM Flight Files: 016-021

Flight #6: Flight file FLT016 for training purposes over Hillsborough Bay test line and out over Strait, including run north along the western side of the Confederation Bridge.

Flight #7-8: Flight files FLT017-018, 019 – 021 with ST operating solo.   021 aborted. JSH continued to check through new post-processing software with RZM during ST solo flights. RZM departed 1400 for Toronto. ST departing on Tuesday, to be replaced by Colin Stock (CS)

Plotted portions of FLT017 and provided them to SP. Laser-generated spikes made it difficult to use profile plots. Colour plots will serve a short-term solution until the laser spike problem can be corrected.

Tuesday, 24 February

Weather: clear, high cirrus, degrading as storm approaches from S.

EM Flight Files: 022-024

Flight #9: Flight file FLT022 to north of PEI, then west over North Cape and down over ice to Summerside.

Flight #10: After refuelling at Summerside, flew east along strait to a point east of Hillsborough Bay. Strong winds were encountered toward the end of this track.

System “froze” twice during eastbound acquisition. Real-time data were recovered, but raw data files 023-024 were not. Reasons for these infrequent freeze-ups unknown. [Later determined likely due to Ethernet intermittency.]

Wednesday, 25 February

Weather: rain, windy (40 kts)

EM Flight Files: none. JSH worked on field report and processing.

Thursday, 26 February

Weather: rain, low ceiling.

EM Flight Files: none. JSH worked on field report and processing. Plotted up colour bar plots of FLT010, 011, (012 already plotted), 014, (017 already plotted), 018, 019, 020. Plotted 024 from real-time results.

Friday, 27 February

Weather: poor, no flying, bad forecast for weekend.

EM Flight Files: none. Met with SP, discussed profile plots prepared during field work and further plans for processing and field work. JSH returned to Toronto.

Monday, 9 March

Weather: poor, no flying. EM Flight Files: none

Problems encountered with tow cable: Ethernet failure. Turned out to be due to the Ethernet’s socket pins at bottom of tow cable being pulled back into the rubber insert (remote diagnosis.) Temporarily solved by Andre, helicopter engineer from Laurentian Region, working with RM, by pulling socket pins down into play using pliers.

Tuesday, 10 March

Weather: poor, no flying. EM Flight Files: none

Complete bird shutdown during takeoff, would not restart. Attempted to run TST on ground, no response. Turned out to be due to 3A fuse F1 on Receiver Power Supply board in slow blow failure again. This fuse is evidently slightly underrated and should be replaced by a larger one.

Thursday, 12 March

EM Flight Files: 039, 040 (high altitude ferry)

Flight #11: CS operated. System operated nominally for FLT039 and high altitude ferry during 040 for return to base.

Friday, 13 March

Weather: snow showers

EM Flight Files: 041-043 (all aborts). Ground testing with TST prior to flight indicated that EM was operational. CS flew FLT041 to 043 (through snow shower on way out). No EM responses measured, indicating that EM had failed. JSH during phone support call requested that copies of chart records be faxed so that he could assess operational status.

Saturday, 14 March

Weather: clear, -10°C, winds 10km/hr W.

EM Flight Files: none

Chart records not available for faxing at time of call to JSH by RM in morning. Evidence from TST check by RM strongly suggested failure of EM receiver. SP authorized RM to request that JSH travel to PEI to service system by this time.

JSH travelled to Charlottetown. On inspection of analog chart plots, it was determined that a receiver or transmitter failure had occurred after the successful flight on March 12.Further troubleshooting with the bird opened up indicated that the problem lay in the input amplifiers on the analog/digital board. All three were replaced, and the anti-static protection at this end of the board improved. Testing indicated that the system was operating normally.

3A fuse F1 was replaced with a 5A fuse to prevent future slow-blow failures. Extra loading (not visible at DC) due to high pulsed load from Vicor DC-DC converters may account for these marginal overloads. During testing, it was observed that the socket pins at the bottom of the tow cable were improperly seated. These carry the Ethernet signal, and intermittence in this connection could have caused some of the problems observed.

Sunday, 15 March

Weather: poor and deterioriating, with snow and low ceilings.

EM Flight Files: none

The connector at the bottom of the tow cable was partially rebuilt to permit proper seating of the Ethernet socket pins. The Molex connectors used in this system should be replaced with a more robust type of connector as soon as is practical.

Monday, 16 March

Weather: clear in morning, snow showers developing

EM Flight Files: 044-055

Flight #12: JSH flew with system FLT044-52, Charlottetown to Cape Egmont, returning via Strait after fueling. System operated nominally. Arrived at Charlottetown in light snow shower in late morning. Laser, GPS shut down during approach, perhaps due to a static discharge. The system was restarted to ensure that laser was available for pilot, as no ground crew was available.

Flight #13: CS scheduled to fly out over Gulf on long mission with SP. Many snow showers were present, due to instability in advance of a high pressure system. First test line (FLT055) with system started properly, but failed in snow shower and could not be restarted. Helicopter returned to base.

Determined that either receiver or transmitter were damaged, based on initial examination of chart record. Receiver subsequently found to be operational. Transmitter was inspected. Damage was found in the driver portion of the unit, which was disassembled. After replacement of damaged parts, the transmitter was reasssembled and tested. Steps were also taken to reduce static buildup on the transmitter heat sink and to repair mechanical damage (chafe on digital signal lines) observed at this time. After reassembly, the system was found to be fully operational.

Tuesday, 17 March

Weather: Clear, -6oC, wind light NW

EM Flight Files: 056-073

Flight #14: CS flew a long mission with system, refueling in Moncton. One survey line per flight file was recorded. Operation was essentially nominal.

Wednesday, 18 March

Weather: clear, -6 °C in morning. Winds calm.

EM Flight Files: 074-076

Installed revised bird program intended to prevent laser spikes from reaching the real-time processing and logging system.

Flight #15: During test FLT074, the revised software worked very well. The laser display was steady over open water and no spikes were noted at any time.

Flight #16: During the afternoon, flew out to a floe (FLT075) in Egmont Bay to test system calibration where a Granada TV crew was filming.

Flight #17: FLT076: Flew numerous passes along line and perpendicular to line. Lack of video recording on the ice sensor helicopter make it hard to tie the results back to the marked ice, as the floe was drifting. However, real-time results were in close agreement with drilling results, particularly over the small, thin pan at the north end of the line where thicknesses were quite uniform. Main floe thickness was found (both from airborne and surface measurements) to be highly variable.

Thursday, 19 March

Weather: clear, cold in morning, winds light E

EM Flight Files: 077-081

Flight #18-19: JSH flew long tandem mission with SP and LL over Strait and Gulf. System operation was nominal, data quality very good for all five flight files.

Weather: forecast to be poor for Friday and through weekend. Backed up remaining data onto Zip disk. Returned to Toronto in afternoon.

Tuesday, 24 March

Weather: Clear, -2^{o}C, winds light NW.

EM Flight Files: 082-086

Flight #20: CS flew last mission of season, FLT082-086 (O84 aborted). System performed nominally.

3. Flight Summary

1998 flights are summarised in Table 3.1 below. They are listed by their FLT number and date, with a brief description for each flight file. Also included is operator identification by initials for the flight (see Sect. 3). Files which were aborted or which could not be used for profile and map preparation are not listed. Statistical summary files for these files may be found in Appendix B.

Table 3.1: 1998 Flight Summary

FLT Number	Date	Comments	Operator
4	21-Feb-98	Test flight over marked line: Recalibrate	JSH
5	21-Feb-98	Test flight over Strait: Recalibrate	JSH
7	21-Feb-98	Test run over Strait: Recalibrate	JSH
10	22-Feb-98	Test flight over marked line--verify new RT calib.	JSH
11	22-Feb-98	Hillsborough Bay: marked lines	JSH
12	22-Feb-98	N. Strait, Hillsb. Bay to Bedeque Bay	JSH
15	22-Feb-98	Training flight for S. Thompson, Hillsb. Bay	ST
16	23-Feb-98	S. Thompson solo check over Hillsb. Bay	ST
17	23-Feb-98	Gulf N. of Charlottetown: NW, then SE	ST
18	23-Feb-98	East through Strait after refuel at S'side	ST
19	23-Feb-98	West from Hillsb. Bay to Egmont Bay	ST
20	23-Feb-98	Egmont Bay, West Point, North Cape	ST
22	24-Feb-98	Radarsat validation, leg 1 in Gulf	JSH
47	16-Mar-98	E Side, W Side of Confederation Bridge	JSH
48	16-Mar-98	Continue to Egmont Bay	JSH
51	16-Mar-98	Cape Egmont and eastward	JSH
52	16-Mar-98	Strait E from Bridge to open water	JSH
56	17-Mar-98	File 1: long flight to Moncton and return	CS
62	17-Mar-98	Recce leg #1 N. of Tracadie (short line)	CS
63	17-Mar-98	Recce leg #2 N. of Tracadie to North Cape	CS
64	17-Mar-98	Recce leg #3: Cape North course WNW	CS
65	17-Mar-98	Recce leg #4: Course SSW to 46.80 N	CS
66	17-Mar-98	Recce leg #5: Course SSW, end SW West Point	CS
69	17-Mar-98	Recce leg #6: E in Strait	CS
70	17-Mar-98	Recce leg #7: E in Strait, end S of Bedeque Bay	CS
71	17-Mar-98	Recce leg #8: NE along Confederation Bridge	CS
72	17-Mar-98	Recce leg #9: SW along Confederation Bridge	CS
74	18-Mar-98	Test after Bird Program patch for spikes	JSH
75	18-Mar-98	Egmont Bay marked line: approach, 1 pass	JSH
76	18-Mar-98	Egmont Bay marked line: multiple passes	JSH
77	19-Mar-98	Strait to Bridge	JSH
78	19-Mar-98	Bridge, E and W sides	JSH
79	19-Mar-98	Bridge to Egmont waypoint, then refuel	JSH
80	19-Mar-98	Egmont waypoint to Cape North waypoint	JSH
81	19-Mar-98	Cape North waypoint to Pearkes, S. to Tracadie	JSH
82	24-Mar-98	Reconnaissance flight	CS
83	24-Mar-98	Reconnaissance flight	CS
85	24-Mar-98	Reconnaissance flight	CS
86	24-Mar-98	Reconnaissance flight	CS

4. Processing

Introduction:

The plan at the outset of this project was to process the airborne data overnight in order to provide processed and plotted data to the Canadian Ice Service on a daily basis. Some processing was in fact carried out during the program and the results provided to S. Prinsenberg and I. Peterson on an overnight basis.

The task was complicated by the abundance of spikes in the ice thickness output caused by laser altimeter glitches where the bird flew over open water. The spikes arose from changes made to the laser altimeter filtering software and to the installation of a different model of laser altimeter. Field priorities were therefore amended as follows:

1. Keeping the system operational and correcting problems as they occurred,
2. Gaining a detailed understanding of the source of the altimeter glitches,
3. Devising means of removing these glitches from the processed data, and
4. Considering techniques for preventing such glitches from generating spikes during real-time processing.

By the end of the February phase, the laser altimeter glitches were well understood and a technique for removing them from existing data had been formulated and initially tested. The real-time elimination of laser spikes was successfully tested on March 18. Laser data obtained after this time were essentially spike-free and unfiltered.

Data gathered prior to this time required de-spiking in post-processing. A preliminary "cumulant" procedure for removing spikes using the observed statistical behaviour of the laser altimeter data to distinguish laser-generated spikes from genuine ice thickness changes was implemented as an m-file and Fortran program by R. Moucha.

After testing and analysis, it was determined that this statistical approach was unsatisfactory. A new method based on searching for indicators in the "fast" laser altimeter data embedded in the .RAW output files was implemented as a Matlab script and found to be very effective in removing laser spikes.

Flight files 004 – 073 were de-spiked using this new method during post-processing for this report. The profile map results presented in Appendix C thus show no evidence of such contamination. Flights after this time did not require de-spiking in post-processing.

Processing Procedure:

The first step in processing of the 1998 field dataset was to adjust for incorrect system calibrations, as discussed in the next section.

When this had been completed, the files were conditioned and re-inverted using the standard utilities. Except for FLT files 51, 63 and 71, the drift corrections were not altered, as the real-time drift corrections were of acceptable quality. Where corrections were necessary, new baseline drift correction points were selected and the data re-baselined using utility program DRIFT32.

The data were then inverted using the same frequencies and model set-up used for post-processing inversion of the 1996 and 1997 data, *i.e.*

- Frequencies used were 30 kHz, 90 kHz, inphase and quadrature;
- Ice conductivity initial value 0.02 S/m, with range 0.001 to 0.1 S/m;
- Seawater conductivity 2.5 S/m (fixed);
- Ice thickness initial value 0.35 m, with range 0.01 and 10 m;

While some of these model and inversion control parameters may eventually benefit from adjustment, it was considered preferable for the purposes of this report to maintain consistency in the model parameters from year to year to prevent the introduction of spurious systematic changes into this series of ice thickness datasets.

When inversion was complete, the flight files were processed in Matlab to remove spikes due to laser dropouts using the raw laser data. The de-spiked data were then used to generate standard plot profiles and map output using the Matlab mapping utilities. The statistical summaries, flight paths and profile maps for each flight are listed in Appendices B, C and D. Appendix A lists the surface measurements obtained during this field program.

5. Calibration

The 1998 system calibration was prepared on February 22 using data from FLT004, line 20. The required surface measurements are summarised in Table 5.1. There was no snow present on the ice (it had melted during a thaw) so that only ice thicknesses are provided.

Table 5.1: Surface measurements for Hillsborough Bay calibration line

Distance	Site #	Thickness	Distance	Site #	Thickness
0	1*	36	100	21*	36
5	2	36	105	22	38
10	3	37	110	23	40
15	4	37	115	24	36
20	5*	38	120	25*	36
25	6	35	125	26	39
30	7	37	130	27	36
35	8	38	135	28	36
40	9*	37	140	29*	37
45	10	39	145	30	38
50	11	35	150	31	39
55	12	36	155	32	38
60	13*	38	160	33*	36
65	14	36	165	34	39
70	15	38	170	35	36
75	16	40	175	36	39
80	17*	35	180	37*	38
85	18	35	185	38	38
90	19	37	190	39	38
95	20	35	195	40	38
			200	41**	40

* indicates a marker bag placed at the site

The EM system component of EIS uses calibration coefficients which are expressed as three complex numbers, one each for the 30, 90 and 150 kHz operating frequencies. The use of complex coefficients is an efficient way to scaling changes in amplitude and changes in system phase. The results of the calibration calculations performed in the field were:

Old calibration factors (pre-98):

(+1.0315 0.0194),(0.9806 0.3300),(1.3076 0.5778)

New calibration factors computed on Feb. 22, 1998 from FLT004, Line 20:

(+0.9953 0.0034),(0.9560 0.3104) (1.2994 0.5733)

Ratios (new/old):

(0.9646 - 0.0148i), (0.9714 - 0.0104i), (0.9935 - 0.0006i)

The above field calibration was checked after reprocessing of the dataset using the program PCCalQW on two passes from this flight, lines 20 and 50:

The mean and SD of the incremental calibration factors computed using PCCalQW for Line 020 were

(0.99546, -0.00071) (0.99787, -0.00167) (1.00206, 0.00069)

(0.00115, 0.00014) (0.00109, 0.00038) (0.00123, 0.00037)

These incremental changes are consistent with those generated in the field (a perfect match would consist of (1.0, 0.0) for each frequency). These values differ in amplitude by less than 0.5% from the field calibration in all cases.

As a consistency check, the mean and SD of Incremental Calibration Factors computed using PCCalQW for Line 050 are:

(0.99969, 0.00192) (0.99318, 0.00807) (0.98146, -0.00425)

(0.00066, 0.00007) (0.00066, 0.00025) (0.00088, 0.00028)

Again, these results match the field calibration very well, to within 0.1% at 30 kHz, .7% for 90 kHz, and 1.9% at 150 kHz.

These two sets of incremental factors match well (to better than 0.5% in amplitude) between Line 20 and Line 50 at 30 and 90 kHz but differ at the 2% level at 150 kHz. The reasons for the differences are not known, but are consistent with typical noise levels for the three frequencies. The results from the first pass will be used for later comparisons. To put these differences into perspective, at 15 m altitude over 1 m ice, an difference of 1% in the amplitude of the calibration factors at both frequencies being used for inversion (30 and 90 kH) corresponds to a difference of about 0.6 cm in snow plus ice thickness and 0.12 mS/m in ice conductivity. The 0.5% differences observed in this case yields a systematic difference of about 0.3 cm in ice thickness and 0.06 mS/m in ice conductivity. These differences are certainly negligible compared to errors in surface measurements and laser altitude.

Using PCCalQW to combine the pre-98 calibration factors with the observed incremental factors yielded the following mean bird calibration factors:

(0.99157, 0.00383) (0.95579, 0.30762) (1.30359, 0.57886)

The differences between the factors determined using PCCalQW to those prepared on February 22 and used in real time are approximately 0.4% 0.2% and 0.2% in amplitude for the three frequencies. As a further check, tests were performed to evaluate the differences in inverted data corrected with these two calibrations. The differences were found to be negligible, as expected.

This analysis indicated that it was not necessary to recalibrate FLT010-086 before re-inversion for this report. FLT004-007 were re-calibrated using the field-generated incremental factors

(0.9646 -0.0148), (0.9714 -0.0104), (0.9935 -0.0006)

for the 30, 90 and 150 kHz data to make them consistent with the rest of the dataset.

Confirmation of calibration over marked line:

Figure 5.1 and Figure 5.2 below show the EIS result on which the February 22 calibration was based (Line 20) and a subsequent pass (Line 50). Laser altimeter spikes are present near –100 and +230 m during the second pass, generated by specular reflection of the laser beam from the surface of small melt pools on the ice and the consequent loss of reflected signal. These artifacts were left in to illustrate the large amplitude of the laser spikes, which were eliminated in real-time data by a bird software change on March 18. Spikes were removed during post-processing from data files gathered prior to this date.

The correspondence between the mean airborne and surface measurements was good, to within 2.5 cm for both passes. Registration to the surface measurement line was accomplished through manual "fiducial" marks placed on the system's hardcopy chart output during data acquisition. This procedure is not as precise as registration from video imagery, but over flat ice surfaces it is the best approach available, in the absence of differentially corrected GPS positions.

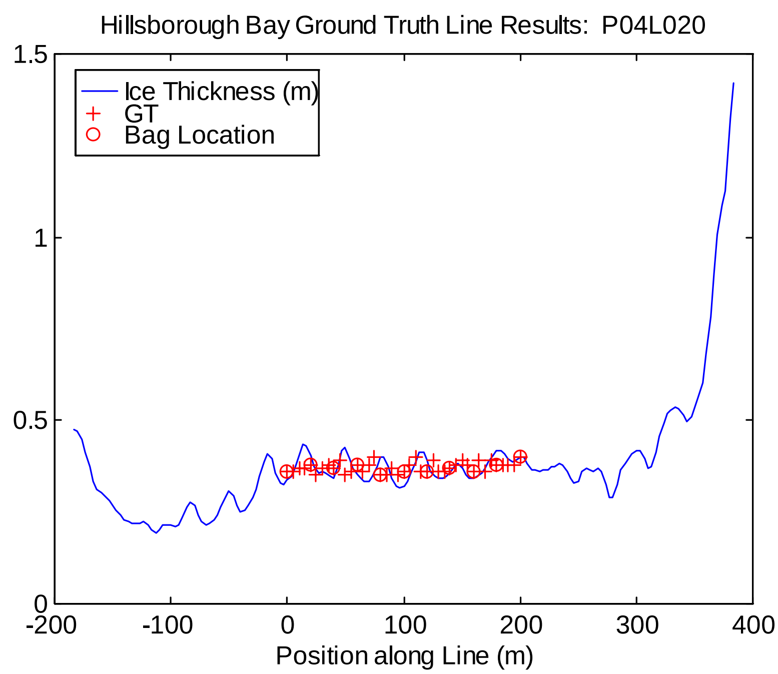

Figure 5.1: Plot of EIS-observed ice thickness over Hillsborough Bay calibration line. Surface measurements are presented as crosses. Circles mark bag locations or other known features.

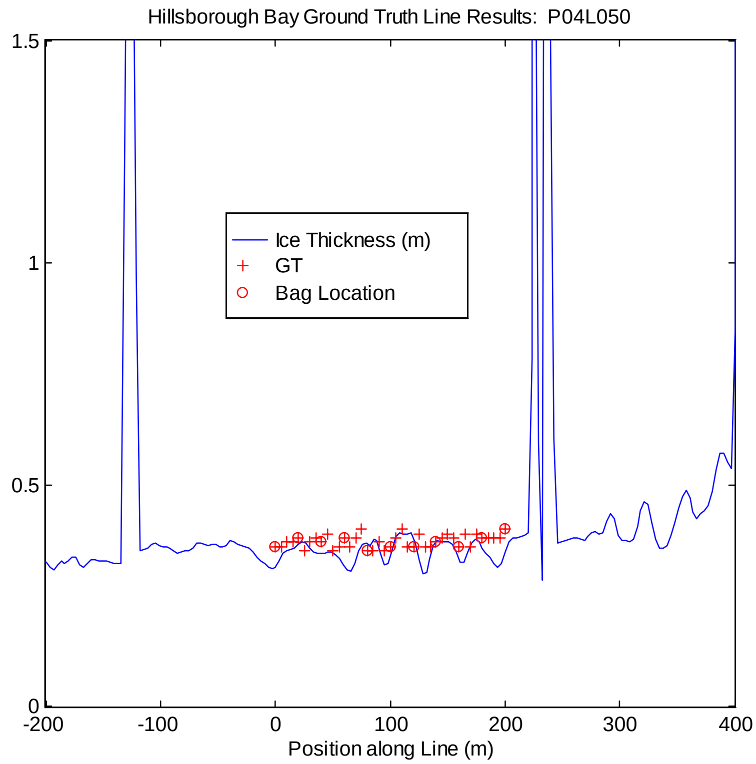

Figure 5.2: A subsequent pass over the calibration line. Surface measurements are presented as crosses. Circles mark bag locations or other known features. Laser-altimeter generated spikes may be seen near the –100 and 230 metre positions.

Comparison to pre-1998 Calibration:

The change required between the 1998 calibration factors and those from the previous year were the result of two factors:

1. The calibration calculation during the 1997 field work was erroneous due to a mistaken snow plus ice thickness estimate along the calibration line of 0.35 m (this was the average ice-only thickness), when in fact the average snow plus ice thickness along the line was 0.50 m. This error was not detected until recent reprocessing for reporting purposes. The actual bird calibration factors (A_{30},A_{90} and A_{150}), computed during this reprocessing, were approximately:

   (0.9865 + 0.0187i) (0.9471 + 0.3171i) (1.2690 + 0.5438i)

2. The snow thickness radar was installed in the bird throughout the 1997 field season. Its presence was expected to alter the system's calibration slightly. The actual differences between the 1998 field calibration and the corrected 1997 calibration stated in item 1 above were:

   (-0.0255 – 0.0330i) (0.0233 – 0.3299i) (-0.2713 – 0.5420i)

This suggests shifts in both amplitude and phase calibration due to the presence of the radar transceiver: the differences in amplitude are on the order of 3-5% at 30 and 90 kHz, and the phase difference increases rapidly with frequency. These differences are large enough to generate ice thickness errors on the order of 0.03 m at normal operating altitudes, as well as more serious ice conductivity errors.

Test of Open-Water Calibration:

Another system calibration test was performed using four patches of open water encountered during FLT074, after the laser spike rejection software had been installed in the bird. This yielded the following set of incremental calibration factors (relative to FLT004 Line 20 calibration):

A	(0.99433, -0.00254)	(0.98211, 0.00683)	(0.96753, -0.00413)
B	(1.00285, 0.00098)	(0.98974, 0.00731)	(0.97507, -0.00527)
C	(1.00116, -0.00067)	(0.98818, 0.00700)	(0.97678, -0.00557)
D	(0.99765, -0.00017)	(0.98359, 0.00833)	(0.97369, -0.00480)

Differences from FLT004, L20 were:

A (	0.0019	+0.0030i)	(0.0169	-0.0094i)	(0.0366	+0.0064i)
B (	-0.0066	-0.0005i)	(0.0092	-0.0099i)	(0.0291	+0.0076i)
C (	-0.0049	+0.0011i)	(0.0108	-0.0095i)	(0.0274	+0.0079i)
D (	-0.0014	+0.0006i)	(0.0154	-0.0109i)	(0.0305	+0.0071i)

These differences had percentage means and SD's (in amplitude) of

mean	(-0.28	+0.10i)	(1.31	-0.99i)	(3.09	+0.73i)
sd	0.41		.037		0.41	

which are considerably larger than the differences between the L20 and L50 on the Hillsborough Bay calibration line, as well as the difference between the February 22 field calibration and the PCCalQW calibration, both of which were based on FLT004, Line 20.

The use of open water for calibration purposes, if it could be accomplished without generating systematic errors in estimated ice thickness and conductivity, would be useful for Coast Guard operational surveys in Gulf and Labrador Sea waters as it would reduce the amount of laborious ground truth data acquisition required. A few conductivity-temperature-depth (CTD) casts in the immediate vicinity of the site and at the approximate time of EM data acquisition would probably provide sufficiently accurate ground truth for such calibrations. The logistics of obtaining good CTD data in open water may make optimal experimental design difficult, but performing a number of CTD casts in close proximity to the ice edge should provide sufficient constraints on the water conductivity profile for calibration purposes.

Although open-water calibration may be a desirable alternative in an operational CCG mode to the present method, the above results do raise some questions.

They suggest that some systematic errors may be generated during the procedure, particularly at high frequencies, or that a systematic bias is present in the existing calibration procedure. Further experimental work including simultaneous acquisition of CTD data, ice-based calibration and adjacent open-water-based calibration appear to be required to further test this approach.

Before data acquisition activities are resumed in 1999, an accurate assessment of the system calibration should be obtained by the standard method, including if possible airborne imagery to verify registration of the airborne dataset to the on-ice calibration line. This will facilitate the assessment of system calibration changes as a function of time. This can be followed, if desired, with a careful assessment of open-water calibration.

6. Egmont Bay Validation Line

A drifting floe in Egmont Bay was marked and drilled, then profiled with EIS on March 18, FLT075-076. The surface measurements for this line are given in Table 6.1:

Table 6.1: Surface measurements on Egmont Bay marked floe

Distance	Snow	Thickness	Distance	Snow	Thickness
-100	15	125	200*	10	34
-80	5	146	220	10	39
-60	0	160	235*	--	--
-40	26	50	240	10	38
-20	0	136	260	0	125
0***	12	34	270*	--	--
10	20	37	350	12	42
20	1	40	370	0	35
30	20	48	390	0	120+
40*	18	75	410	13	120+
50	17	68	430	0	120+
60	9	64	450	0	52
70	8	50	470	0	120+
80*	1	36	490	10	46
90	15	32	510	0	58
110	12	40	530	7	34
130*	15	32	550	0	36
140*	15	30	570	15	32
160	15	30	590	10	32
180	15	32	650		rubble starts

where

* denotes a surface mark position
+ denotes that ice is greater than the stated thickness

FLT075 ended with an initial pass over the floe from E-W before it had been marked. FLT076 included five N-S and S-N passes. The first three airborne passes flew directly over the line, while the last two were displaced approximately 40 m to the W owing to the presence of a film crew near the line. These profiles are presented as a composite in Figure 6.1.

The lack of flight path imagery makes direct registration of the ground truth to the airborne data difficult. However, this was accomplished to first order by the following procedure:

1. Identify common features (*e.g.* a ridge with a particular shape in profile)
2. Use these features to register the different airborne passes together
3. Register the ground truth data to the airborne passes using stretching (effectively just velocity changes) and translation of the airborne data.

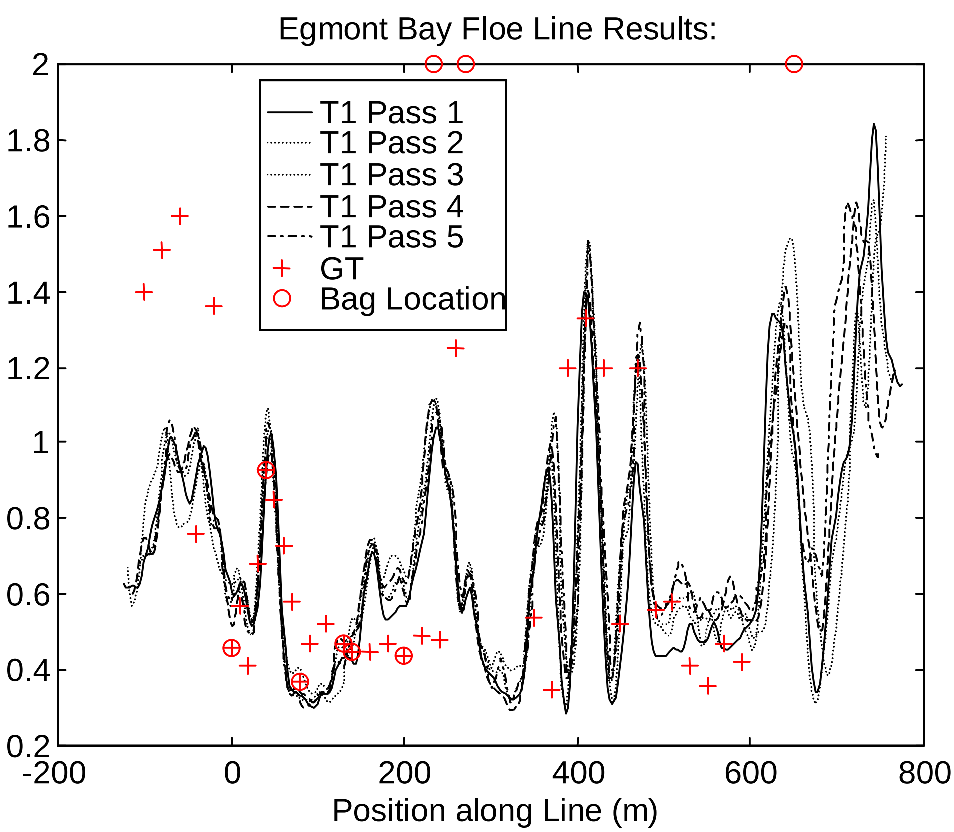

Figure 6.1: Composite of five airborne thickness profiles over the Egmont Bay floe line. Surface measurements are presented as crosses. Circles mark bag locations or other known features.

Figure 6.1 is of particular interest in that it shows the strong coherency and repeatability of the airborne measurements over the complex floe structure, as well as the degree of correspondence between surface and airborne measurements expected for such a structure. There are zones of disagreement between surface and airborne measurements, such as the section between –100 and –40 m along the line. It is likely that the feature responsible for these thickness disparities was a narrow ridge of total thickness 1.2-1.4 m, aligned with the survey line. This is supported by the small snow thickness observed at several of the auger sites and by the much lower average thickness of the floe. A feature having this geometry would not have been accurately captured by the airborne measurements unless its width was greater than 10-30 m. A less likely explanation is that, since these auger measurements were obtained at unmarked points on the lead-up to the marked portion of the line, they may have been systematically excluded by curvature in the flight path as the bird was lined up with the marks.

Another point of systematic difference between the airborne and ground measurements occurs near +200 m. The ground truth indicates a consistent 0.45 to 0.5 m snow plus ice thickness, while the airborne data suggests at least 10 cm greater thickness and considerably more variability. It is possible that a large rafted block exists beneath this section of the floe which was not detected in the auger holes but which does increase the EM-estimated thickness.

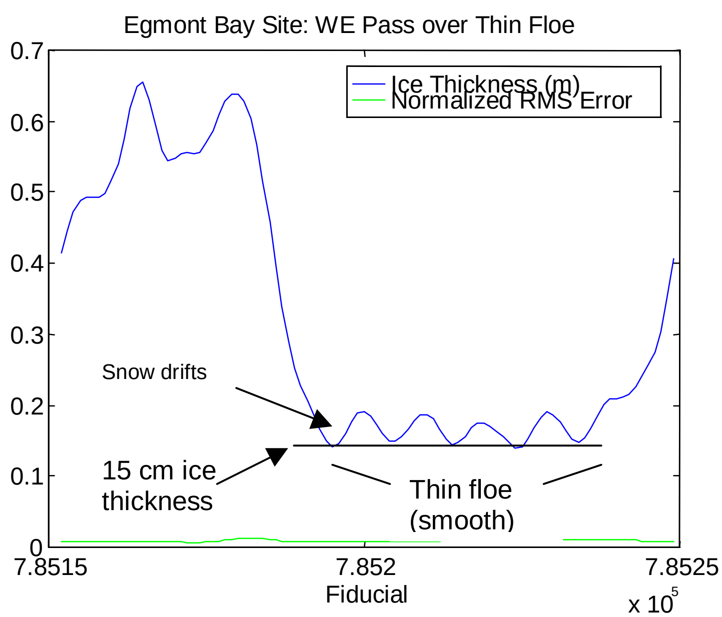

Figure 6.2: Pass from W to E over thin floe to north of main Egmont Bay floe. The auger-measured 0.15 m ice thickness and snow drifts are clearly visible due to the smooth surface and uniform thickness of the floe.

An airborne pass crossed the thin (15 cm ice plus 10 cm snow drifts) floe to the north of the main floe from W to E (Figure 6.2). This example provides an opportunity to examine the snow-plus-ice thickness resolution of the under good operating conditions. The auger-measured thickness of the ice of this floe was 0.15 m, with snow drifts of up to 0.1 m observed and drift-to-drift separations of about 20 m. The real-time airborne data (here plotted with respect to time in tenths of a second) are in agreement with these observations. They show a 0.15 m minimum thickness matching the surface measurements within 0.01 m), corresponding to bare ice, and undulations with an amplitude of 0.05 m and a period of 1 second, corresponding to 30 m at a speed of 30 m/s. The greater apparent separation of the drifts appears to correspond to the effect of crossing the linearly oriented drifts at an oblique angle.

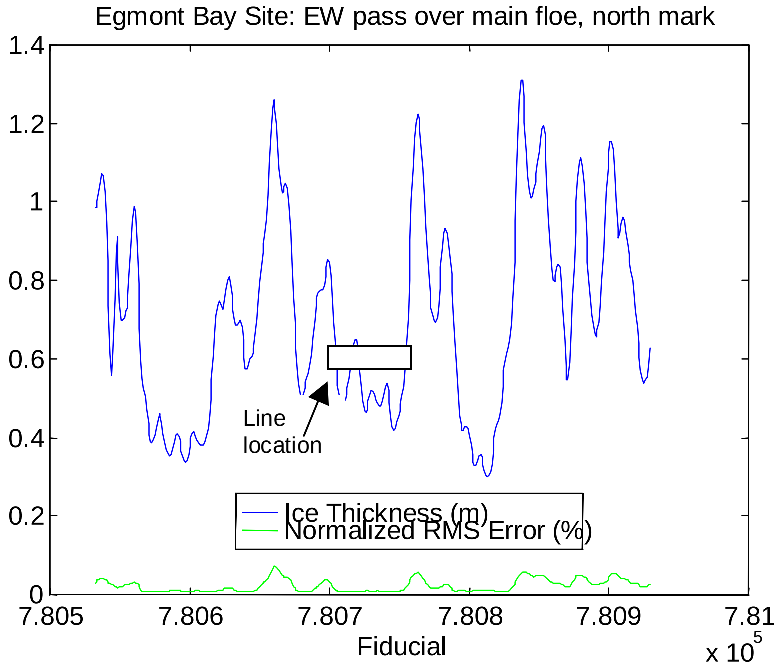

Figure 6.3: Line crossing northern end of marked line from W to E. Box marks estimated location of ground truth line.

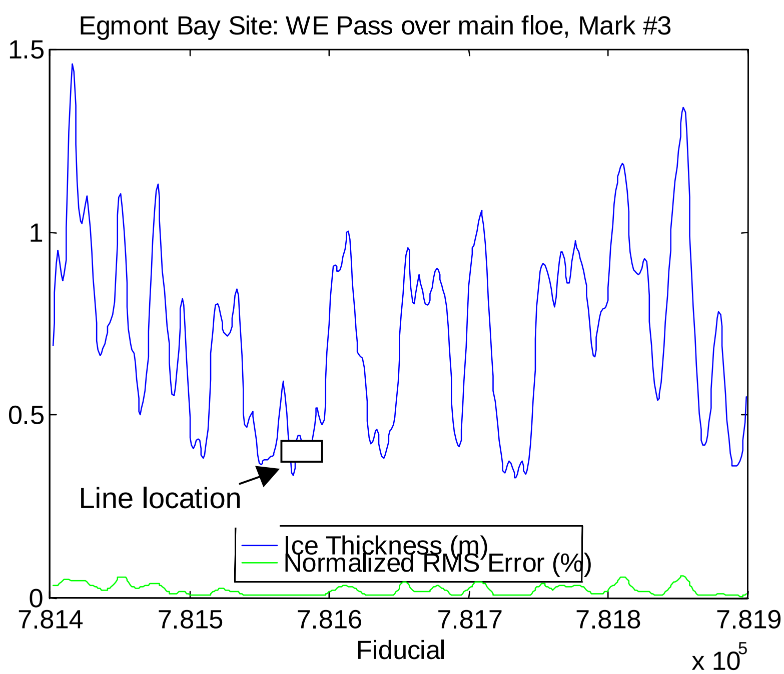

Figure 6.4: Line crossing over third mark on line, passing from E to W. Box marks estimated location of ground truth line.

Two more passes crossed the marked line itself, the first run from E to W passing over the northernmost mark, and the second from W to E passing over the third mark (Figs 6.3 and 6.4). In the absence of airborne imagery it was difficult to precisely locate the point where the profile crossed the ground truth line. The best estimates for the locations of these crossings are indicated on the figures.

The principal point of interest in these two profiles is that they extend knowledge of the highly variable character of the ice thickness observed along the marked line into the third dimension. Despite its gentle surface relief, this floe was clearly a complex structure formed from smaller floes that were rafted and sutured together, then smoothed by weathering.

7. Summary

The 1998 EIS field program was executed between February 21 and March 24. The principal objectives were:

1. to test and correct modifications made to the laser hardware and software in 1997 so that improved high-frequency laser data could be acquired and stored; and
2. to deliver real-time and processed EIS data and plots to the Canadian Ice Service; and to collect EIS data to validate ice signatures seen in RADARSAT imagery.

The EIS system was calibrated and tested on February 22. Spikes in ice thickness generated by laser altimeter signal dropouts over open water were analysed and a post-processing spike rejection method was tested. Ten missions were executed, including calibration and training flights. Survey flights continued after the departure of one of the authors (Holladay).

On Friday, March 13, the system was damaged by a static discharge during a snow shower. This problem was too serious for correction by DFO personnel on site. One of the authors (Holladay) returned to PEI on Saturday, 14 March and remained until Thursday, 19 March. By the end of this time, the sensor's transmitter had been partially rebuilt, the real-time laser spike elimination software was in place, system operation was essentially optimal, and a considerable amount of profiling had been completed during 8 missions.

System problems encountered in 1998 fell into three categories:

1. the first generated by static discharge,
2. the second by problems in the power and tow cables, and
3. the third by a change in the character of the Optech Alpha (new in 1997) laser altimeter output over open water compared to the previous IBEO PS100E unit. The altimeter problem was exacerbated by an error in the bird 1997 software when the radar snow sensor was installed into the system.

Cabling problems often had to be solved by locating and correcting faults as they occurred. In a few cases, it was possible to identify and correct incipient cabling problems before they caused system failures. Static discharge issues were also addressed on a case-by-case basis. A long series of flights with nominal operation following the last static-damage repair suggests that the most troublesome cabling and static-discharge weaknesses of the system have been corrected.

The laser altimeter glitches were addressed by a change to the bird computer software, which now inspects the laser data and passes it on to the helicopter computer only when it is valid. Post-processing correction software for data recorded prior to the bird software change was prepared and demonstrated to eliminate virtually all spikes in ice thickness.

The field calibration, prepared on February 22, is consistent with calibration checks performed during post-processing and with surface measurements made on the Egmont Bay marked floe. For this reason, it was not necessary to recalibrate any data (FLT010-086) acquired after the real-time calibration was updated on February 22. Flight files FLT004-007 were re-calibrated in post-processing to utilise the same February 22 calibration factors.

Approximately 1520 line kilometres of data were acquired during this field program. These data were post-processed using the same inversion control parameters as were used for the 1996 and 1997 datasets in order to maintain year-to-year consistency in the results. A spike rejection filter was used to correct data files that were affected by laser spikes. The flight data files have been presented as statistical summaries (Appendix B) and as flight path and profile maps (Appendices C and D). Detailed “standard plot” profiles have been archived digitally.

Recommended maintenance for the EIS system before the 1999 field season includes the following:

1. Replace serial interface chip (used for GPS–to-bird computer traffic), replace spare parts used during the1998 field program and provide spares for the serial interface chip.
2. Replace the Molex tow cable connectors with more robust ones (lower priority).

Prior to routine flying of the system, and before any modifications to the bird’s EM subsystems, a careful calibration over a marked line on level land-fast ice should be performed in order to determine whether the system’s calibration has changed significantly. This should assist with assessment of changes in system calibration with time.

It would be useful to reconsider the possibility of performing system calibrations over open water. This has been problematic in the past, owing to frequent problems with signal return in the laser altimeter. The relatively high quality of laser altitudes obtained during this year’s field suggests that the procedure might be able to yield good results for Coast Guard operational purposes over water that is fairly smooth (though not flat and glassy). However, an initial test performed using this year’s data identified systematic differences between ice-based and water-surface-based calibrations that should be thoroughly investigated before changing the calibration methodology.

At a lower level of priority, it would be useful to equip the system with a flight-path monitoring camera and recording system. This is primarily used for registering airborne data to features such as marked lines on the ice surface, particularly those located on drifting ice. It is useful during analysis of long survey traverses as well. If integrating a digital “Video-GPS” package into the EIS system were to prove impractical for some reason, the same video camera mounted in a pod and recorded on the existing CG S-VHS VCR would be sufficient. Suitable cabling would have to be procured to interface with the video annotation board in the system computer.

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Appendix A: Surface Measurements

Gulf of St. Lawrence 1998 Ice Station Data

Station 17.1 — Clear, -10^{o}C
Light NW winds

Land-fast ice off Point Gage
-46 53.85^{o}N, 64 14.87^{o}W
-Ice thickness 60, 45 and 59cm.
-no snow
Ice Salinities (depth/ppt):
5cm/3ppt, 15cm/4ppt, 20cm/5ppt and 35cm/ 8ppt.

Station 18.2 — Clear, -2^{o}C
Light NE winds

Pack ice off Point Gage
-46 57.71^{o}N, 64 21.99^{o}W
-Ice thickness 50, 44 and 44cm.
-no snow
Ice Salinities (depth/ppt):
5cm/7ppt, 15cm/3ppt, 25cm/5ppt and 35cm/7ppt.

Station 18.3 — Clear, -2^{o}C
Light NE winds

Pack ice off Point Gage
-46 57.39^{o}N, 64 24.63^{o}W
-Ice thickness 30 and 30cm.
-rough snow covered floe 4cm of snow
Ice Salinities (depth/ppt):
snow/1ppt, 5cm/1ppt, 15cm/0ppt and 25cm/1ppt.

Station 18.4 — Clear, -2^{o}C
Light NE winds

Pack ice Northumberland Strait, northwest of bridge
-46 17.10^{o}N, 63 50.14^{o}W
-Ice thickness 2+m, 500mx500m rafted floe
-3cm snow
-GPS beacon #2755 (15:20)
-Ice Salinities (depth/ppt):
5cm/3ppt, 15cm/4ppt, 20cm/5ppt and 35cm/ 8ppt.

Station 18.5 Clear, -2^{o}C
Light NE winds

Pack ice Northumberland Strait, southwest of bridge
-46 14.5^{o}N, 63 53.00^{o}W (guess!)
-Ice thickness 39cm, 500mx500m smooth floe
-no snow
-GPS beacon #2756 (15:35)
-Ice Salinities (depth/ppt):
5cm/9ppt, 15cm/7ppt and 25cm/8ppt

Station 18.6 Clear, -2^{o}C
Light NE winds

Pack ice Northumberland Strait, southeast of bridge
-46 07.44^{o}N, 63 41.03^{o}W
-Ice thickness 2+m, 150mx250m rafted floe
-no snow
-GPS beacon #2754 (15:45)
no ice Salinities

Station 18.7 Clear, -2^{o}C
Light NE winds

Pack ice Northumberland Strait, northeast of bridge
-46 10.54^{o}N, 63 38.77^{o}W
-Ice thickness 2+m, 150mx150m rafted floe
-3cm snow
-GPS beacon #2757 (16:10)
-Ice Salinities (depth/ppt):
5cm/1ppt and 15cm/4ppt

Station 20-1

Cloudy, 0°C
Light w winds

Calibration Line in Hillsborough Bay
-46 05.1°N, 63 02.9°W in 13.8 to 14.2 m of water.
-200m line with bags and holes at 20 and 5m intervals.
-Ridge to the NE at ~200m from end of the line (two bags).
-Water 2-3cm on surface of ice.

Distance	Site #	Thickness	Distance	Site #	Thickness
0	1*	36	100	21*	36
5	2	36	105	22	38
10	3	37	110	23	40
15	4	37	115	24	36
20	5*	38	120	25*	36
25	6	35	125	26	39
30	7	37	130	27	36
35	8	38	135	28	36
40	9*	37	140	29*	37
45	10	39	145	30	38
50	11	35	150	31	39
55	12	36	155	32	38
60	13*	38	160	33*	36
65	14	36	165	34	39
70	15	38	170	35	36
75	16	40	175	36	39
80	17*	35	180	37*	38
85	18	35	185	38	38
90	19	37	190	39	38
95	20	35	195	40	38
			200	41**	40

* indicates a marker bag place at the site

Station 22.1

Clear, -4°C
20km/hr westerly winds

Calibration line (10:30).
-Surface water frozen, trace of snow.
-Checked ice thickness at every 40m site.
-0m/36cm; 40m/40cm; 80m/38cm; 120m/39cm; 160m/36cm; 200m/35cm.

Station 22.6

Clear, -4^{o}C
10km/hr westerly winds

Calibration line (16:00)
-measured distance to ridge (200m) from double end bags.
-depths/ice thickness at every 50m from end of the line to ridge.
50m/ 13.2m/ 41cm; 100m/ 13.1m/ 45cm; 150m/ 12.8m/ 52cm; 180m/x/52cm
-no sounding at ridge or ice thickness but several freeboards:
distance from and before the ridge 10m/35cm; 15m/23cm and 20m/10cm
-ice thickness behind ridge: 20m/50cm and 40m/50cm

Station 20.2

Cloudy, 0^{o}C
Light W winds

Pack ice Northumberland Strait, northeast of bridge
-46 07.95^{o}N, 63 35.04^{o}W
-Ice thickness 2+m, 100mx150m rafted floe
- Rough floe, no snow
-GPS beacon #4459 (15:15)

Station 20.3

Cloudy, 0^{o}C
Light W winds

Pack ice Northumberland Strait, southeast of bridge
-46 05.27^{o}N, 63 37.34^{o}W
-Ice thickness 2+m, 50mx50m rafted floe
-Very rough floe, no snow
-GPS beacon #4458 (15:30)

Station 21-1

Clear, -1^{o}C
Light W winds

Pack ice off Cape Gage
-46 59.14^{o}N, 64 36.53^{o}W
-Ice thickness: 38, 44 and 52cm
-Rough 200mx200m floe, spots of hard snow mostly flat slippery ice.
-Deployed GPS beacon #26381 (11:30)

Station 21-2

Overcast, 0^{o}C
Light W winds

Pack ice off northern cost of PEI (temporary land-fast ice)
-46 27.5^{o}N, 62 56.4^{o}W.
-Bright area on Radarsat image.
-Rough wind generated rubble pile 1km wide.
-Blocks 20cm thick have sharp edges.
-2+m thick rafted pans.

Station 22.2

Clear -2 to 0^{o}C
10km/hr westerly winds

Ice pressure station #1 (11:45)
-round floe 300mx300m made of mostly flat ice with some snow patches.
-Ice thickness 50cm/ 52cm/ 53cm and 50cm.
-Lat. 46 41.47^{o}N , Long 64 30.92^{o}W .
-GPS beacon #3124, 3d pressure beacon #1055 and 1d pressure beacon #22191.
-Salinities depth/ppt:
2cm/0ppt; 10cm/2ppt; 20cm/6ppt.
-Salinities from ice at pressure sensors; #22191/ 4ppt and 1155/ 4ppt.

Station 22.3

Clear -2 to 0^{o}C
10km/hr westerly winds

GPS beacon at ice pressure station #1 (13:00)
-North corner of triangle, GPS beacon #3123.
-Round floe 500mx500m made of mostly flat ice with some snow patches
-Ice thickness 58cm and 60cm
-Lat. 46 43.76^{o}N , Long 64 32.49^{o}W

Station 22.4

Clear -2 to 0^{o}C
10km/hr westerly winds

GPS beacon at ice pressure station #1 (13:00)
-Southeast corner of triangle, GPS beacon #3121.
-Round floe 400mx400m made of rough ice with some snow patches
-Ice thickness 34cm and 38cm
-Lat. 46 40.18^{o}N , Long 64 26.79^{o}W

Station 22.5

Clear -2 to 0^{o}C
10km/hr westerly winds

GPS beacon at ice pressure station #1 (13:00)
-Southeast corner of triangle, GPS beacon #3122.
-Round floe 500mx500m made of mostly flat ice with some snow patches.
-Ice thickness 76cm and 80cm.
-Lat. 46 38.57^{o}N , Long 64 33.93^{o}W

Station 23.1

Clear -1^{o}C
Light westerly winds

Ice pressure station #2 (11:07)
-Oval 100mx200m floe; beacons on thicker top segment
-Ice thickness 55cm/ 65cm and 65cm, no snow.
-Lat. 46 29.46^{o}N , Long 64 23.13^{o}W.
-GPS beacon #8541, 3d pressure beacon #2364 and 1d pressure beacon #1053.
-Pressure beacon 30m from edge facing 200^{o}.
-Salinities depth/ppt:
2cm/0ppt; 15cm/6ppt; 30cm/10ppt.

Beacons recovered on March 24 after one month.
-Beacons on a temporary land-fast ice along the NB shore.
-Ice rafted over 2m thick with some wet layers.
-Beacons along with 8542 still together on 5x7m pan in between rubble field.
-Beacons all tilted as if rain melted ice surface around before frozen in again
-Both beacons were very lose in the surface ice and could be pulled out.
-3d pressure beacon sensor top 7cm and bottom 17cm from ice surface.
-1d pressure beacon sensor top 5cm and bottom 15cm from ice surface.
-Ice surface rough covered with snow up to 20cm deep

Station 23.2

Clear -1^{o}C
Light westerly winds

GPS beacon at ice pressure station #2 (11:15).
-North corner of triangle, GPS beacon #8543.
-Rough floe 200mx200m with some snow patches.
-Ice thickness 35cm and 40cm.
-Lat. 46 32.06^{o}N , Long 64 23.59^{o}W.

Station 23.3

Clear -1^{o}C
Light westerly winds

GPS beacon at ice pressure station #2 (11:29).
-Southwest corner of triangle, GPS beacon #8542.
-Large round floe 500mx500m made of rough ice with some snow patches
-Ice thickness 50cm and 50cm, snow patches.
-Lat. 46 26.31^{o}N , Long 64 25.39^{o}W.

Station 23.4

Clear -1^{o}C
Light westerly winds

GPS beacon at ice pressure Station #2 (14:44).
-Southeast corner of triangle, GPS beacon #4457.
-Round floe 500mx500m made of mostly flat ice with some snow patches.
-Ice thickness 50cm and 50cm.
-Lat. 46 29.31^{o}N , Long 64 19.06^{o}W

Station 11.1 and 11.2

Cloudy, -1^{o}C
15km/hr westerly winds

Seal herd locations north of Cape North
-GPS beacons placed out by A. Maillet in afternoon Feb. 11, 1998.
-beacons #26368 centre and #26378 southeastern end.

Station 11.3

Cloudy, -1^{o}C
15km/hr westerly winds

Hooded seal herd location north of Summerside.
-GPS beacon #26382 placed out by M. Hamel and G. Stenson.

Station 14.1

Clear, -10^{o}C
10km/hr Westerly winds

Pancake ice rubble north of Cape North.
-Placed Seimac beacon on pancake ice, beacon #26380.
-Largest floe 3m, mostly smaller. Ice thickness 1.5m at floes 40cm between floes.
-Composite floes 2kmx2km, other similar floes in area.
-50% water in area, old ice 20% and pancake ice 30%.

Station 18-1 Clear, -6^{o}C
Calm

Calibration Line SE of Point Egmont at 46 19.91^{o}N, 64 04.5^{o}W
-First visit in morning landed on rafted section of floe
-Ice thickness 64/75/75cm south of three end bags, floe 1.03kn mile wide.
-Thin floe to NW: ice thickness 15/15/15cm with 10cm of snow drifts
-Ship track in between at edge of old floe.
-Second visit in afternoon with film crew.
-Old floe has snow drifts to 26cm approximately 20m wide.
-End bags (three) at SE end approximately 300m from edge
-NW end of line ends in wide rubble field 200-300m wide.

Distance	Snow	Thickness	Distance	Snow	Thickness
-100	15	125	200*	10	34
-80	5	146	220	10	39
-60	0	160	235*	--	--
-40	26	50	240	10	38
-20	0	136	260	0	125
0***	12	34	270*	--	--
10	20	37	350	12	42
20	1	40	370	0	35
30	20	48	390	0	120+
40*	18	75	410	13	120+
50	17	68	430	0	120+
60	9	64	450	0	52
70	8	50	470	0	120+
80*	1	36	490	10	46
90	15	32	510	0	58
110	12	40	530	7	34
130*	15	32	550	0	36
140*	15	30	570	15	32
160	15	30	590	10	32
180	15	32	650	rubble starts	

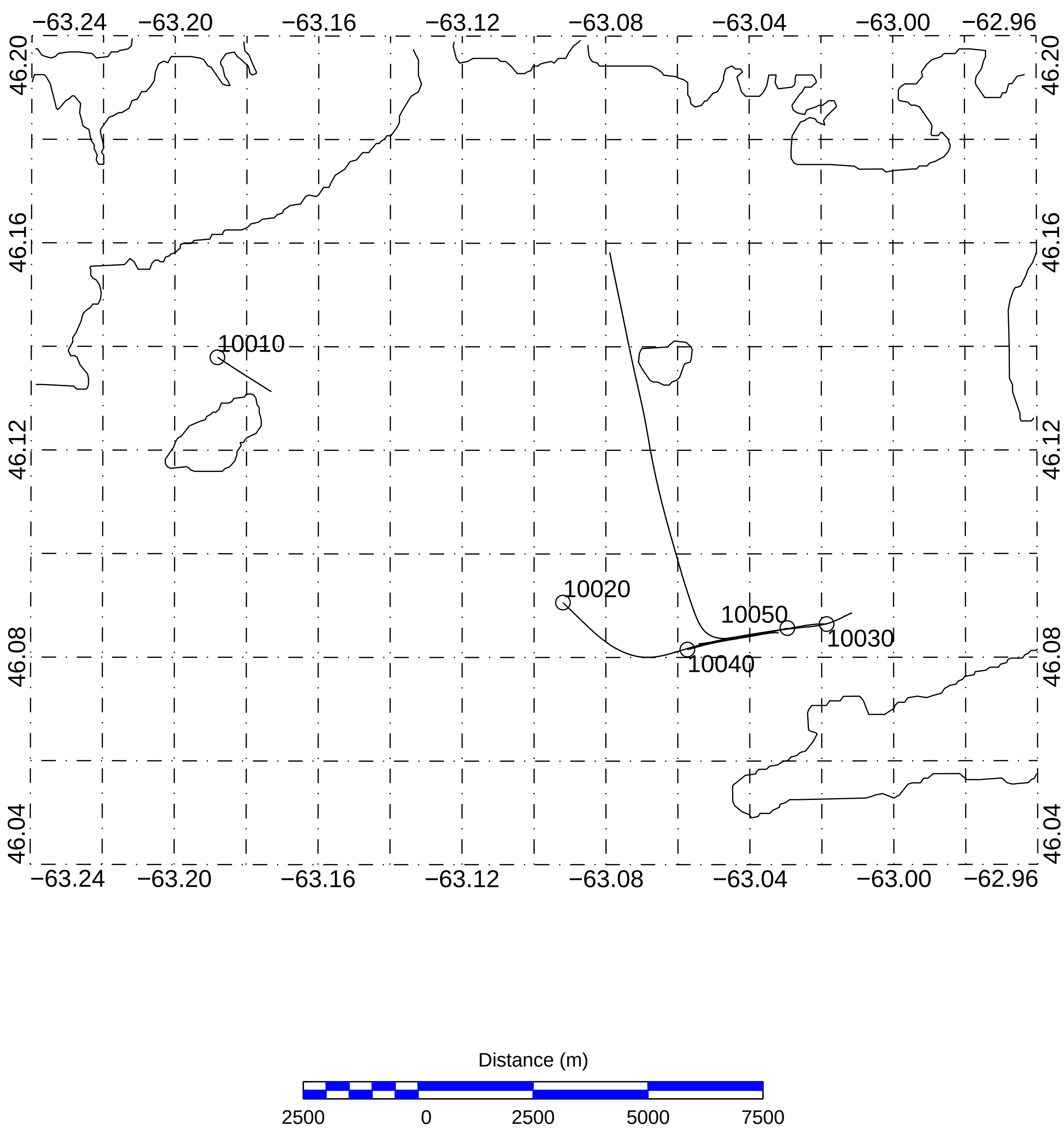
Appendix B: Statistical Summary Tables

Appendix C: Flight Path Maps

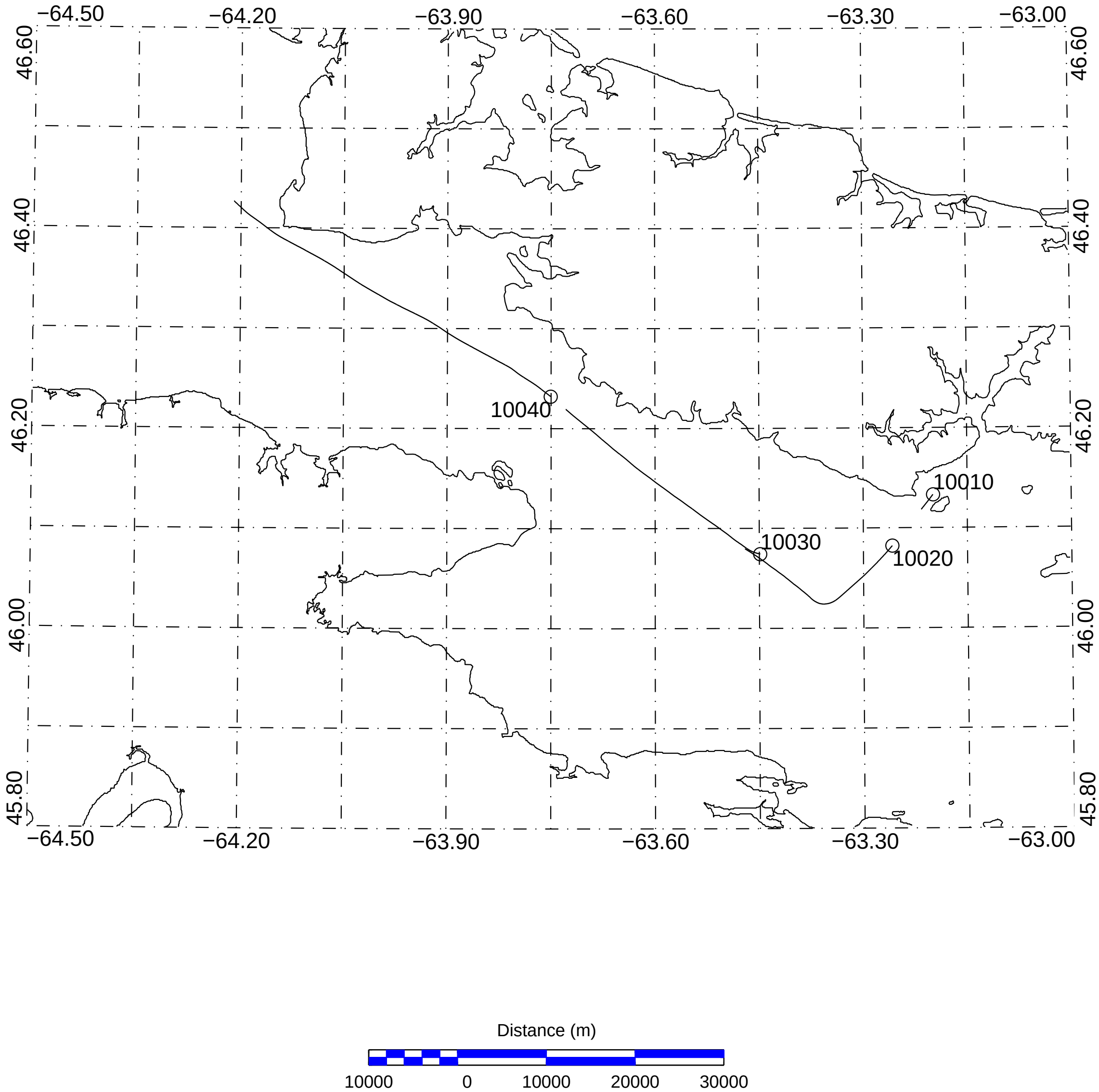
This appendix presents flight path maps generated from the airborne EIS dataset.   Although the legends on these maps identify a nominal scale for each map, they have been resized to fit into this document and so are no longer to scale.   Distances may be estimated using the scale bar or the latitude/longitude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

FLT files 052 and 062-072 have been combined into a single map.

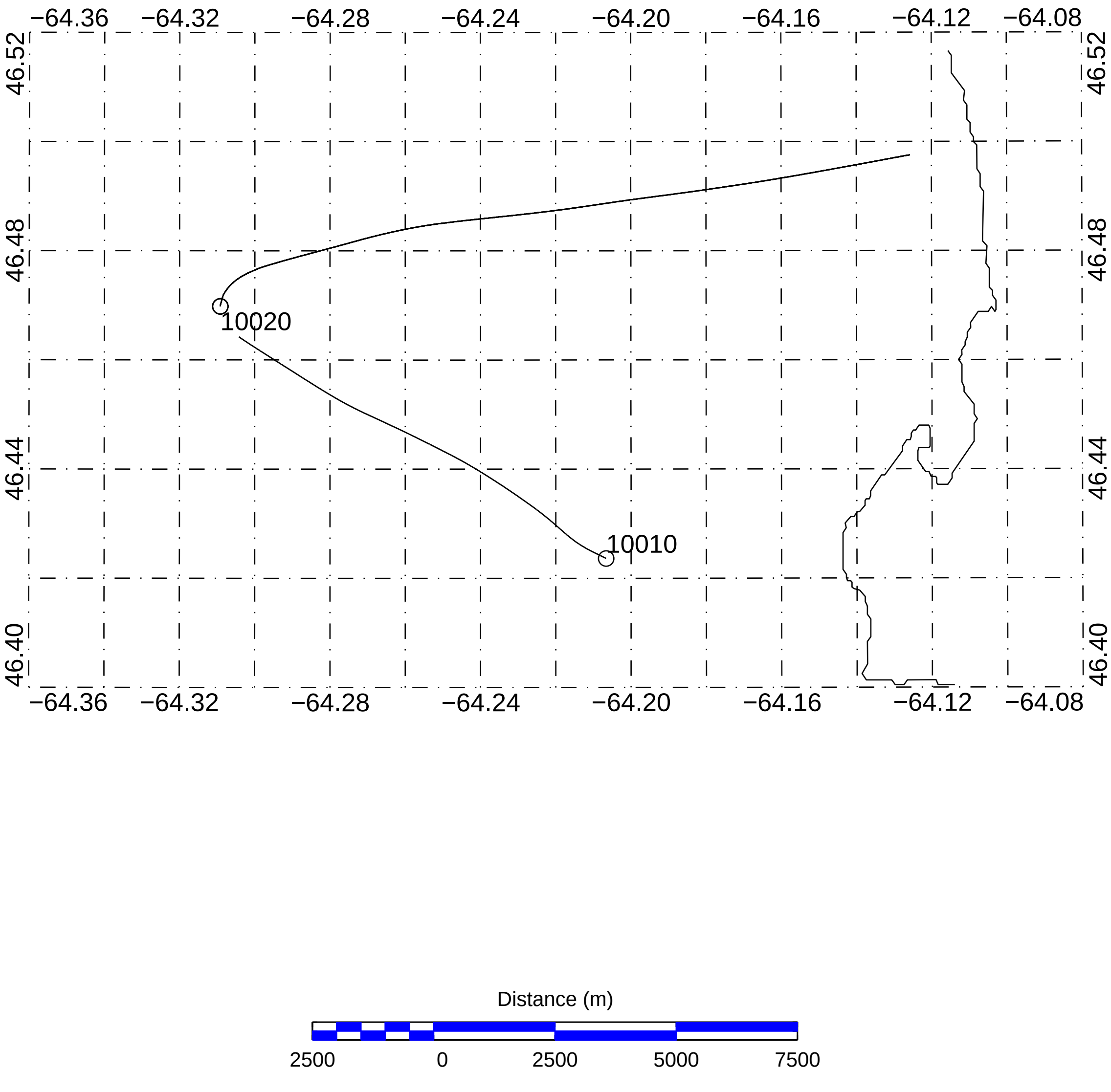
FEBRUARY 21, 1998 FLIGHT 4
Lambert Conic Proj., Center Long.: −63.10, Lat1 49.00, Lat2 77.00
Map Scale 1:150000



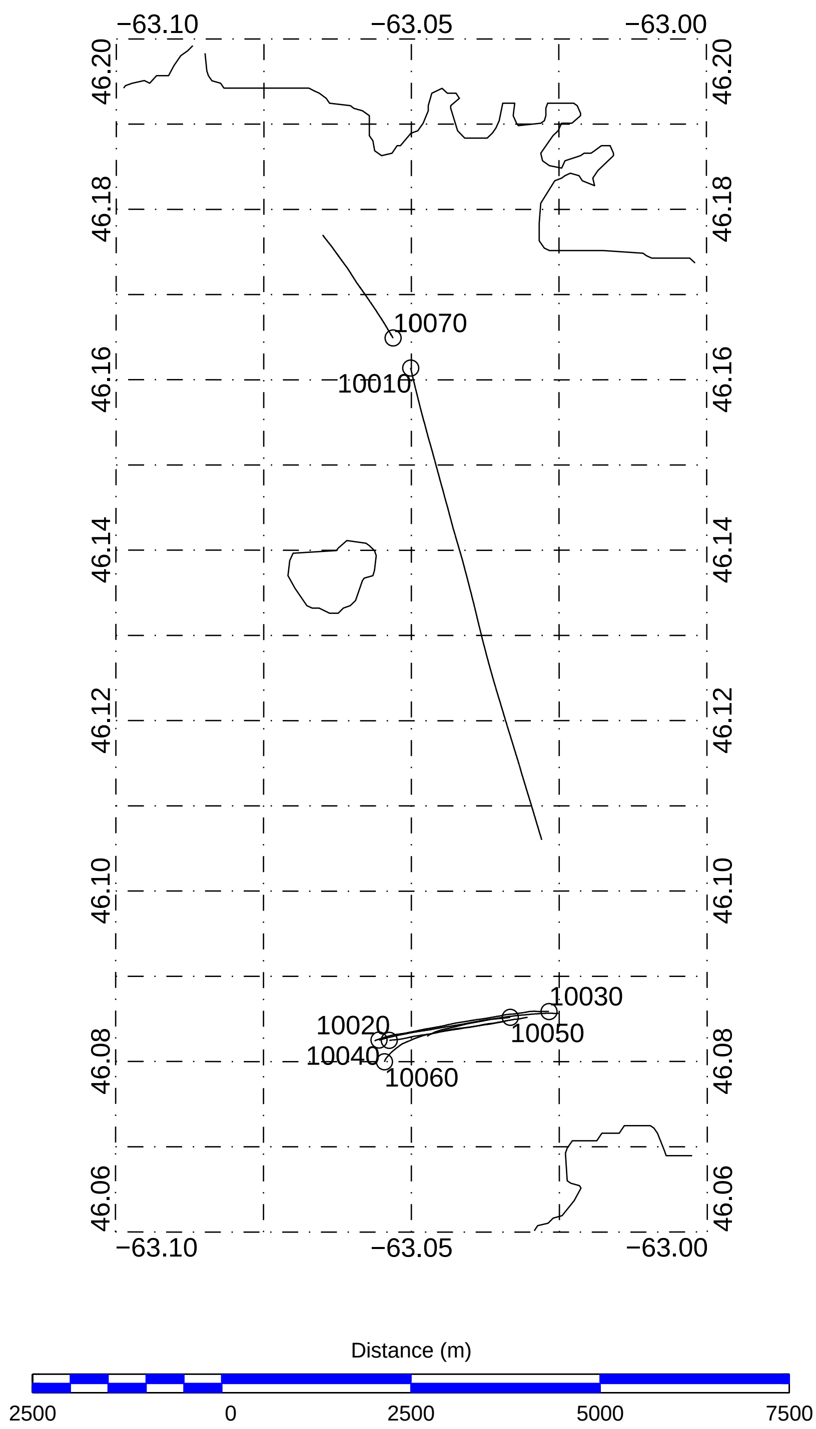
FEBRUARY 21, 1998 FLIGHT 5
Lambert Conic Proj., Center Long.: −63.70, Lat1 49.00, Lat2 77.00
Map Scale 1:700000



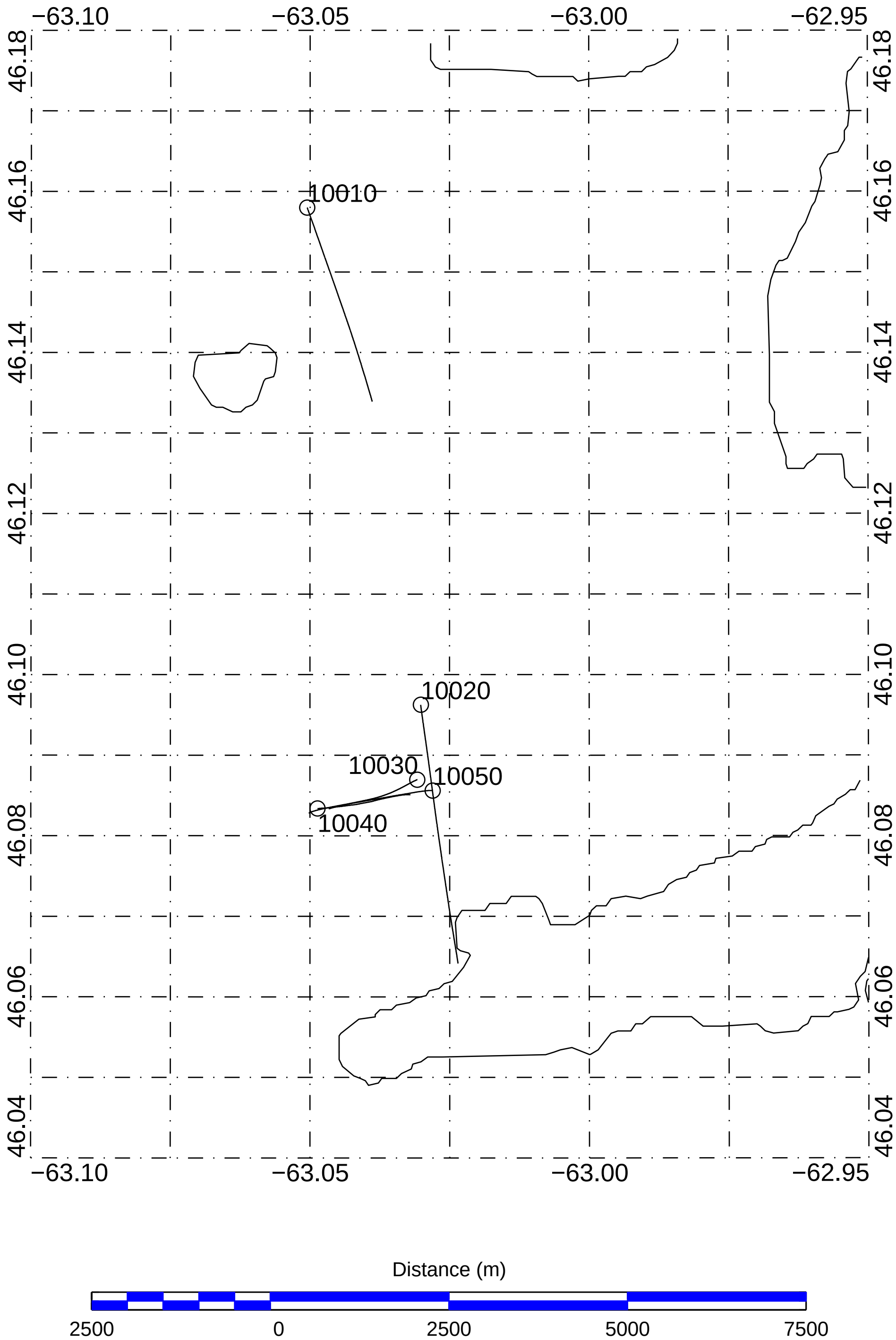
FEBRUARY 21, 1998 FLIGHT 7
Lambert Conic Proj., Center Long.: −64.26, Lat1 49.00, Lat2 77.00
Map Scale 1:150000



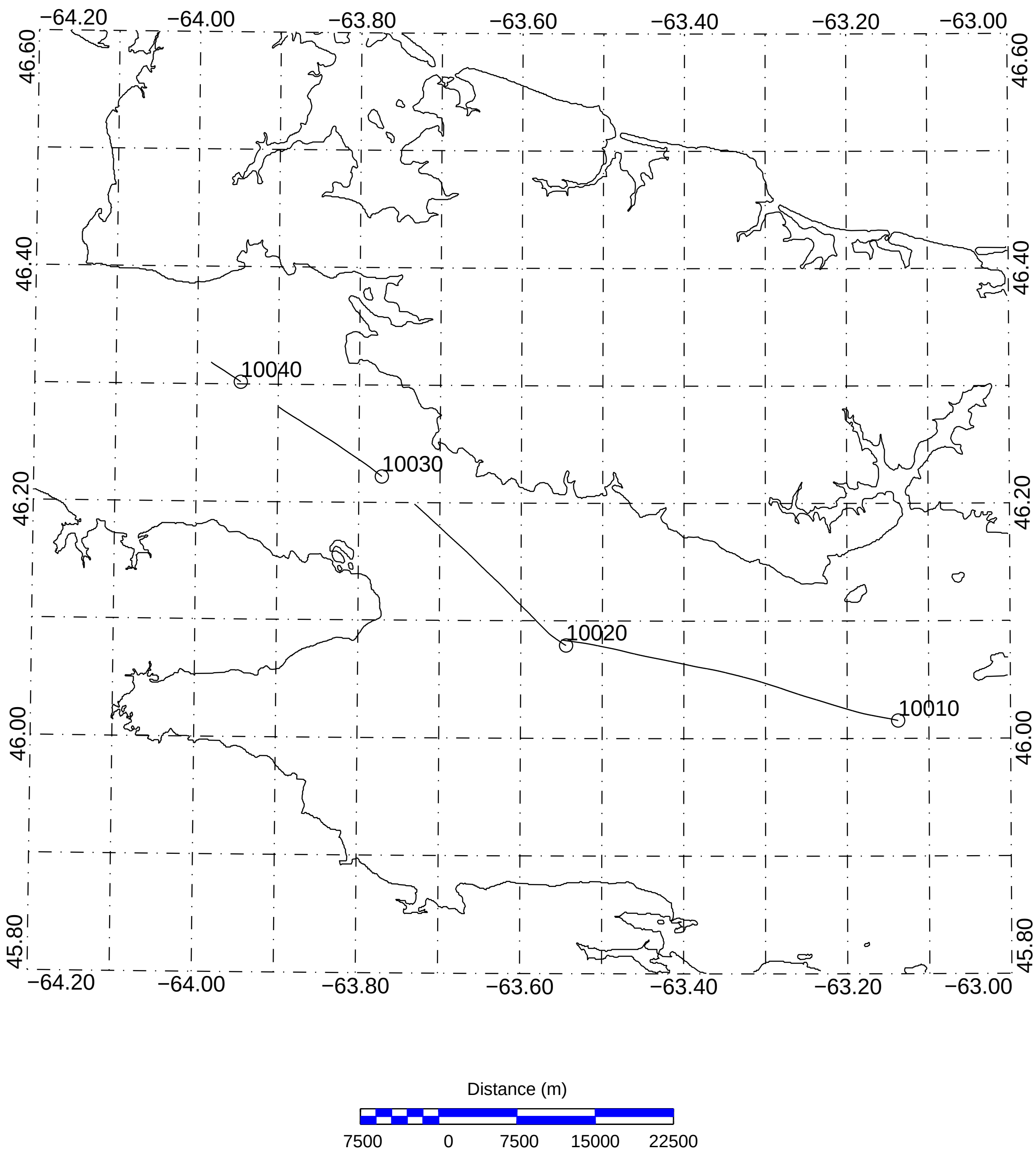
FEBRUARY 22, 1998 FLIGHT 10
Lambert Conic Proj., Center Long.: −63.05, Lat1 49.00, Lat2 77.00
Map Scale 1:100000



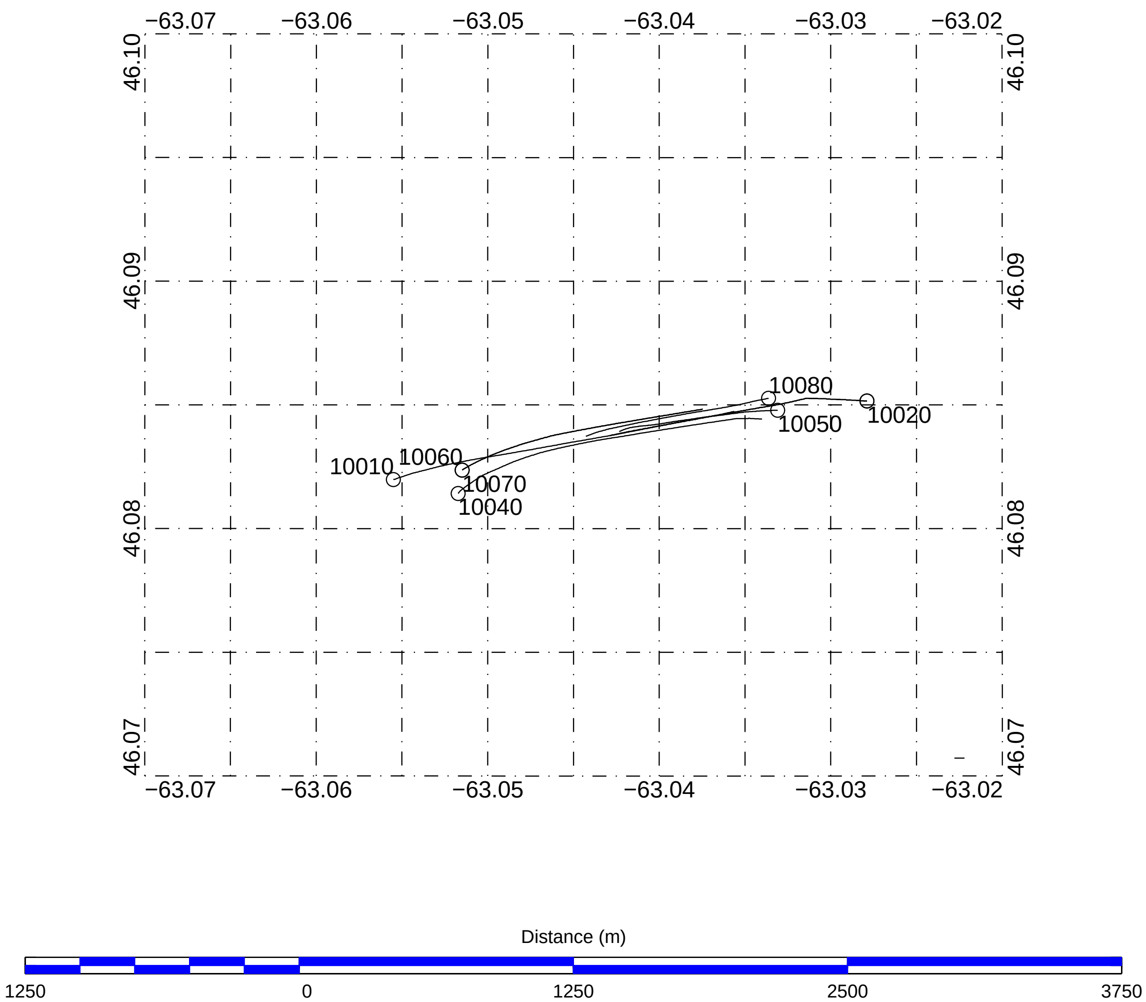
FEBRUARY 22, 1998 FLIGHT 11
Lambert Conic Proj., Center Long.: −63.04, Lat1 49.00, Lat2 77.00
Map Scale 1:100000



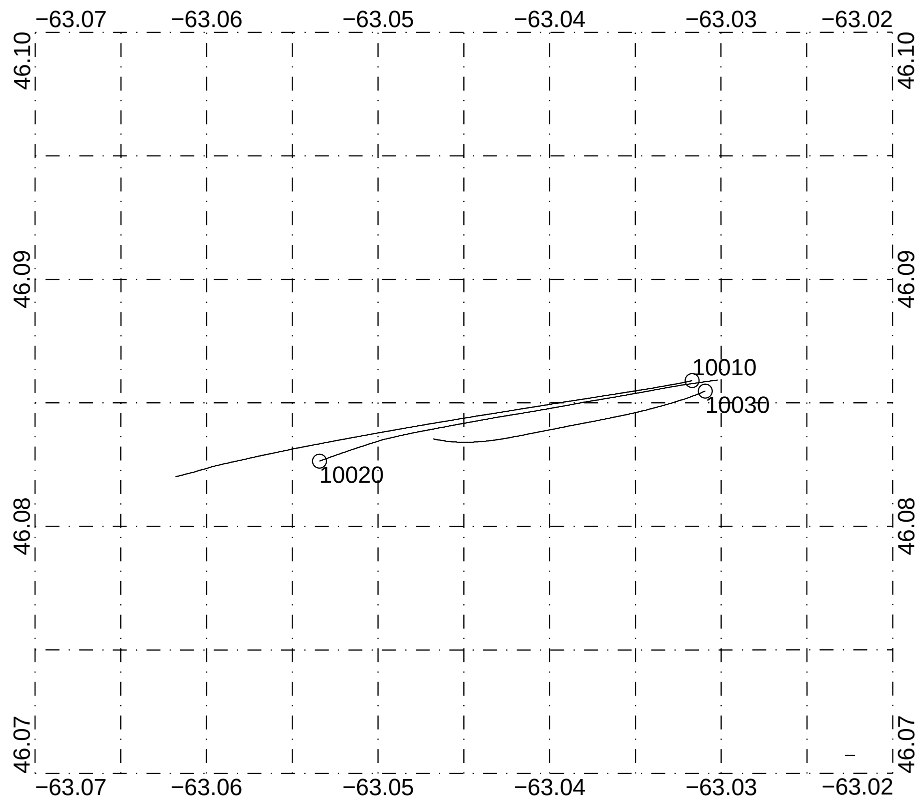
FEBRUARY 22, 1998 FLIGHT 12
Lambert Conic Proj., Center Long.: −63.34, Lat1 49.00, Lat2 77.00
Map Scale 1:600000

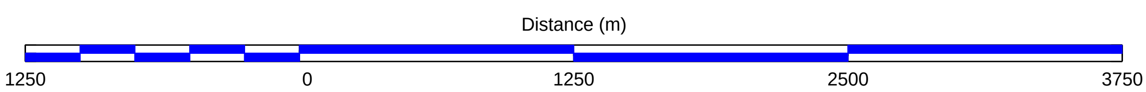


FEBRUARY 22, 1998 FLIGHT 15
Lambert Conic Proj., Center Long.: −63.04, Lat1 49.00, Lat2 77.00
Map Scale 1:30000

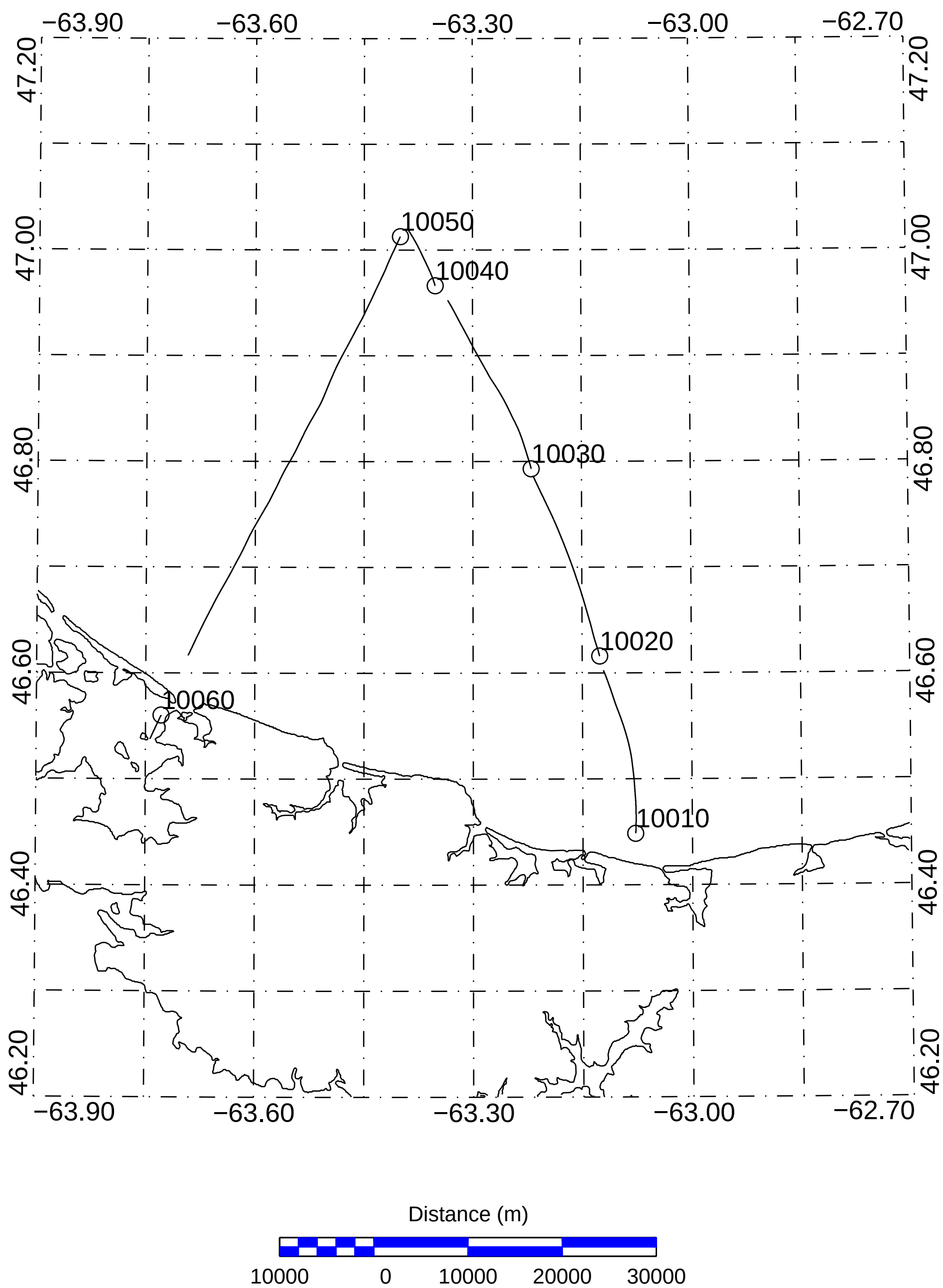


FEBRUARY 23, 1998 FLIGHT 16
Lambert Conic Proj., Center Long.: −63.05, Lat1 49.00, Lat2 77.00
Map Scale 1:30000

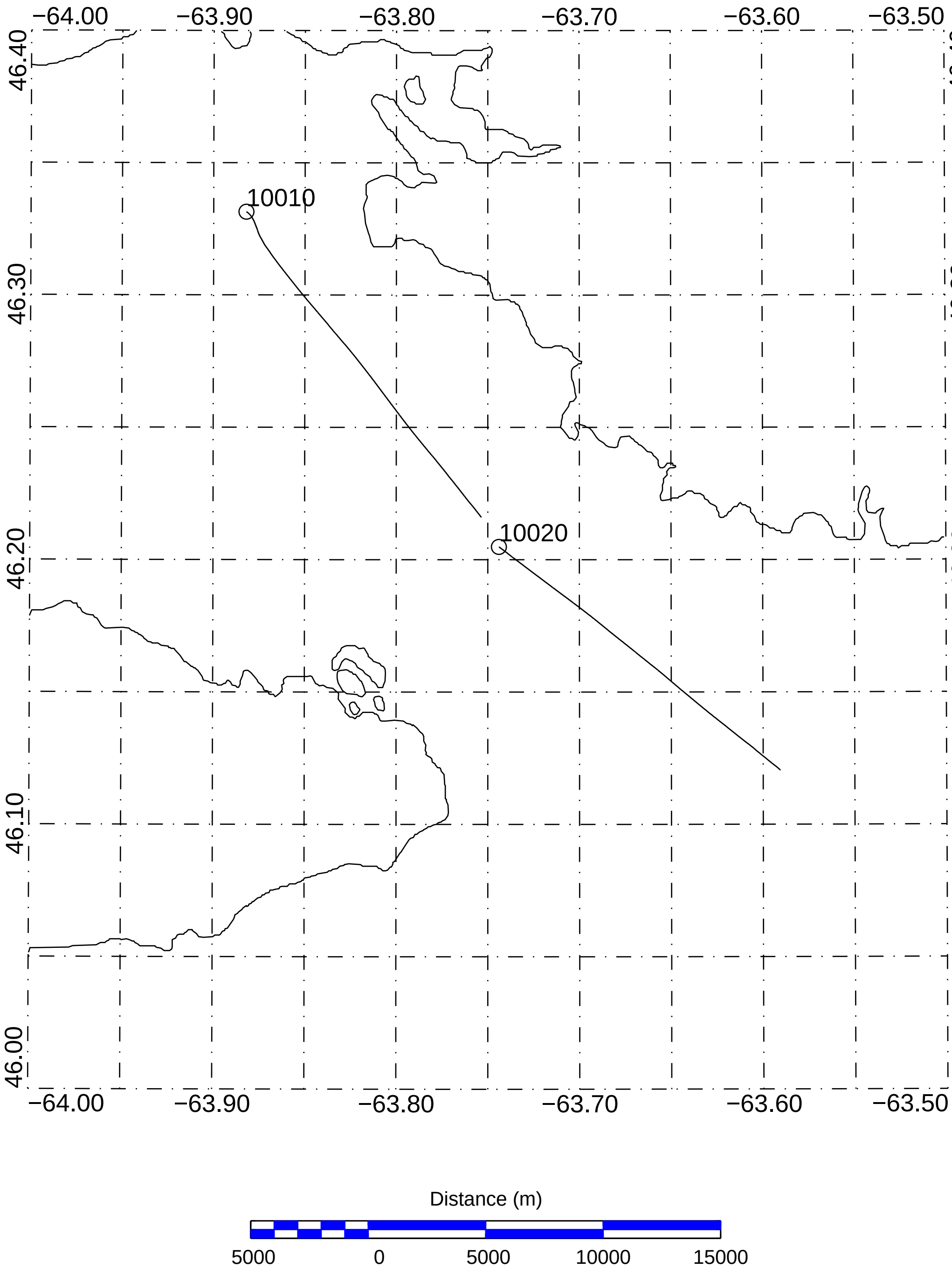




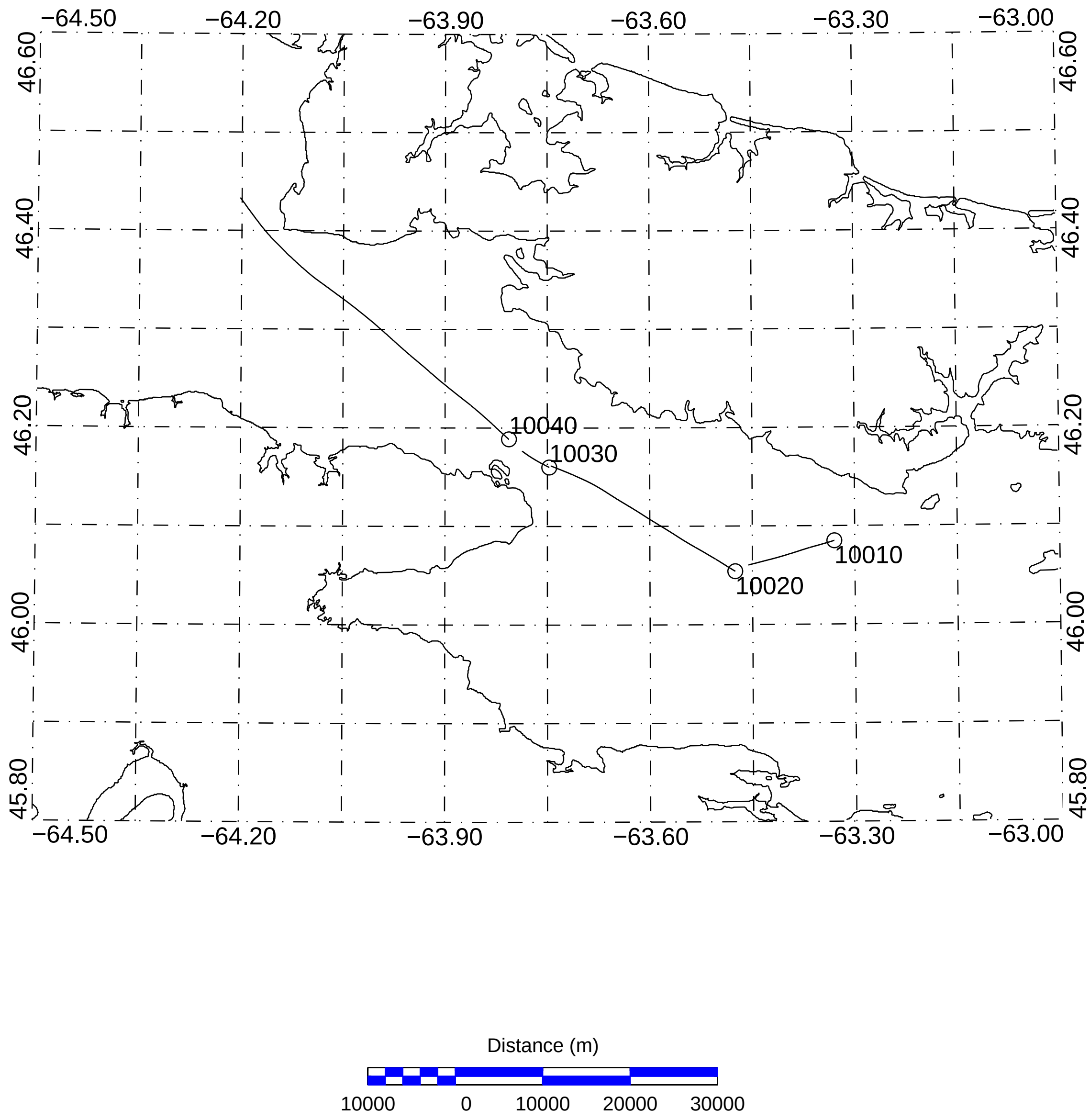
FEBRUARY 23, 1998 FLIGHT 17
Lambert Conic Proj., Center Long.: −63.40, Lat1 49.00, Lat2 77.00
Map Scale 1:800000



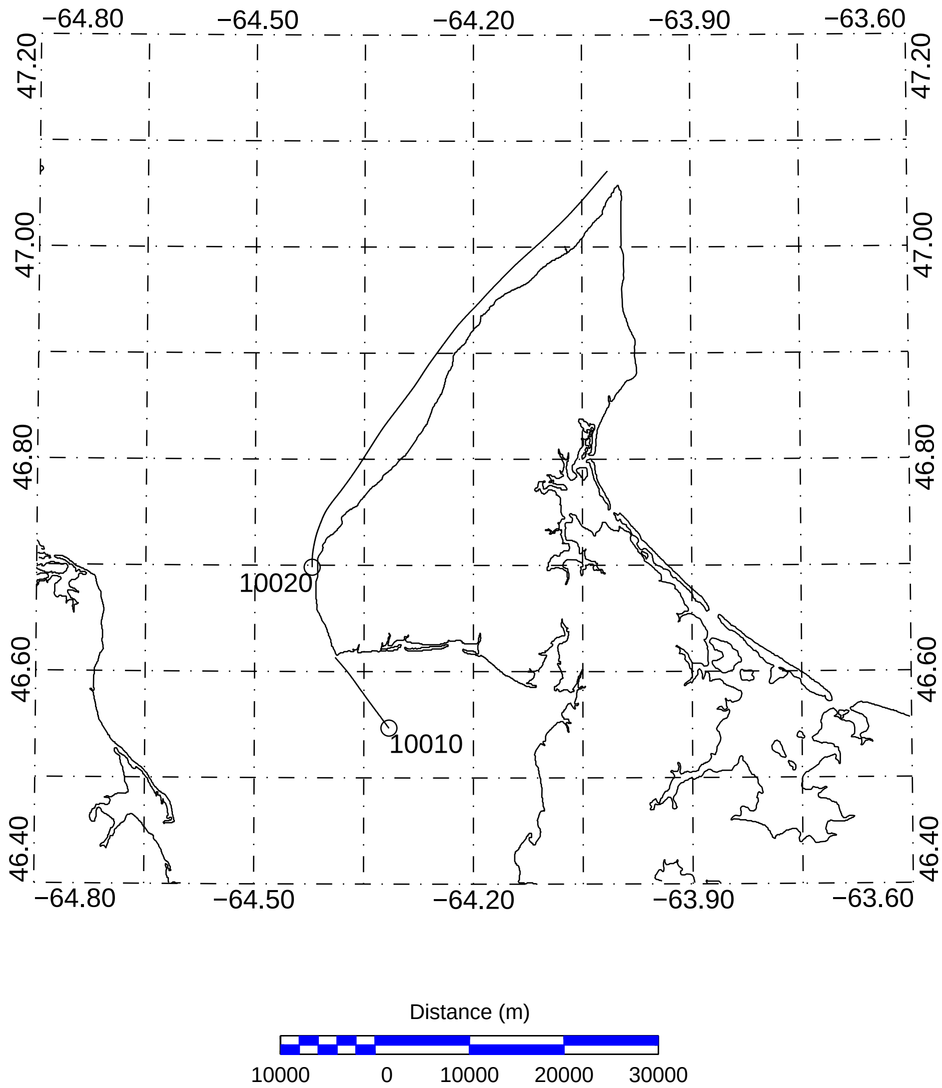
FEBRUARY 23, 1998 FLIGHT 18
Lambert Conic Proj., Center Long.: −63.75, Lat1 49.00, Lat2 77.00
Map Scale 1:300000



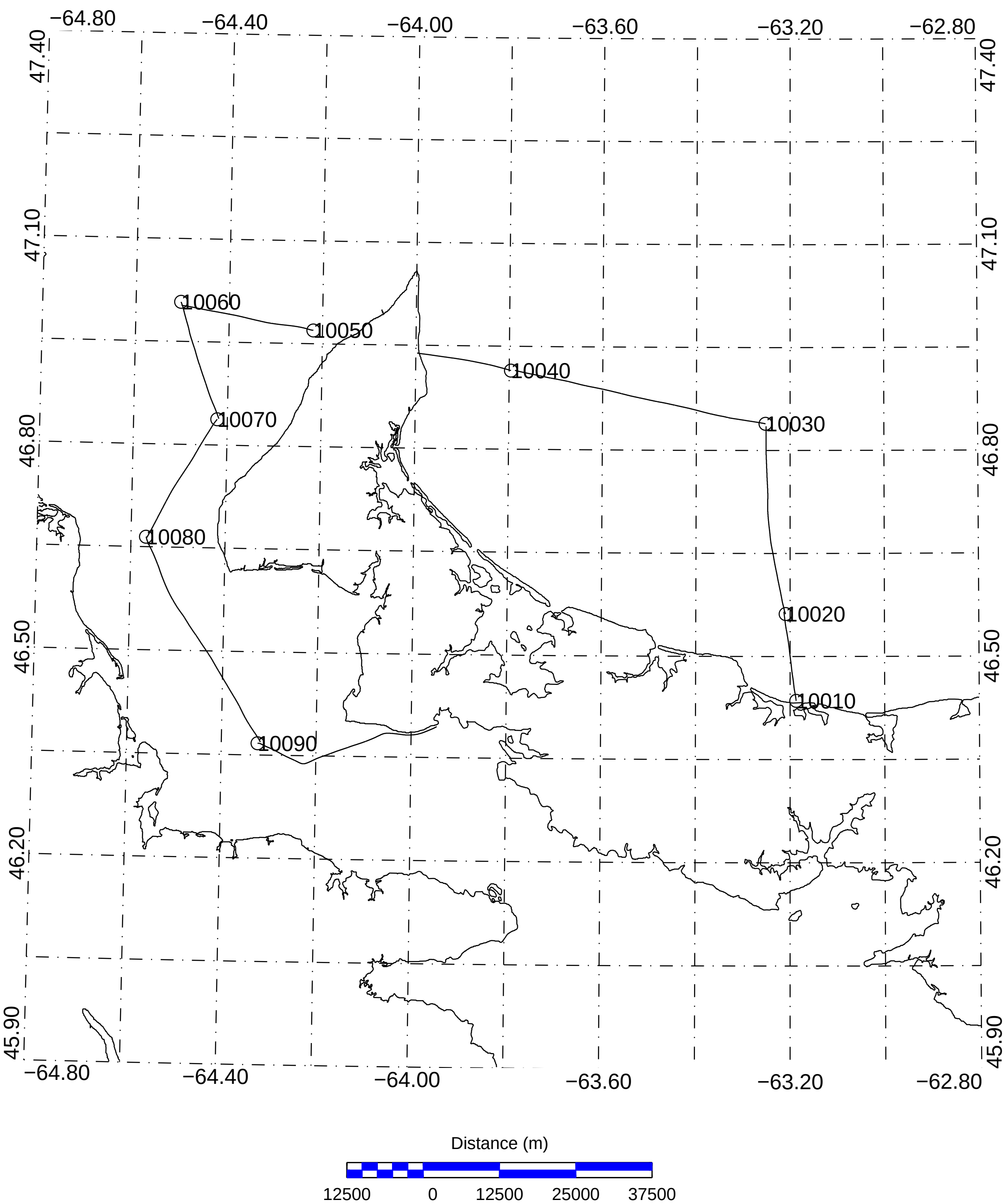
FEBRUARY 23, 1998 FLIGHT 19
Lambert Conic Proj., Center Long.: −63.80, Lat1 49.00, Lat2 77.00
Map Scale 1:800000



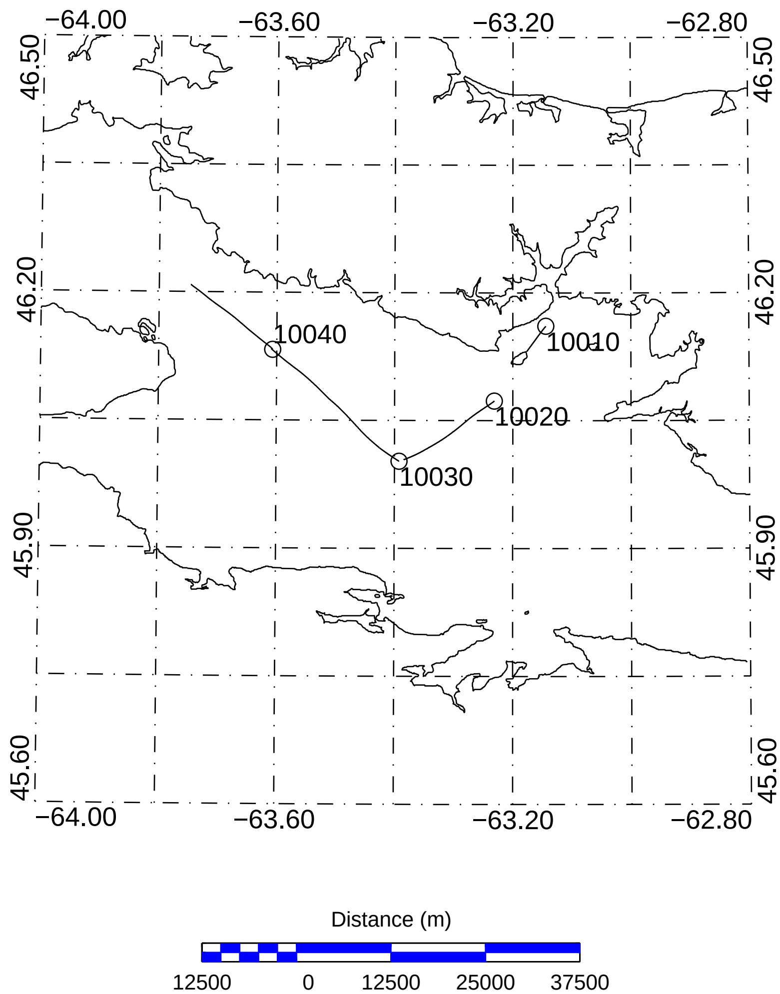
FEBRUARY 23, 1998 FLIGHT 20
Lambert Conic Proj., Center Long.: −64.20, Lat1 49.00, Lat2 77.00
Map Scale 1:800000



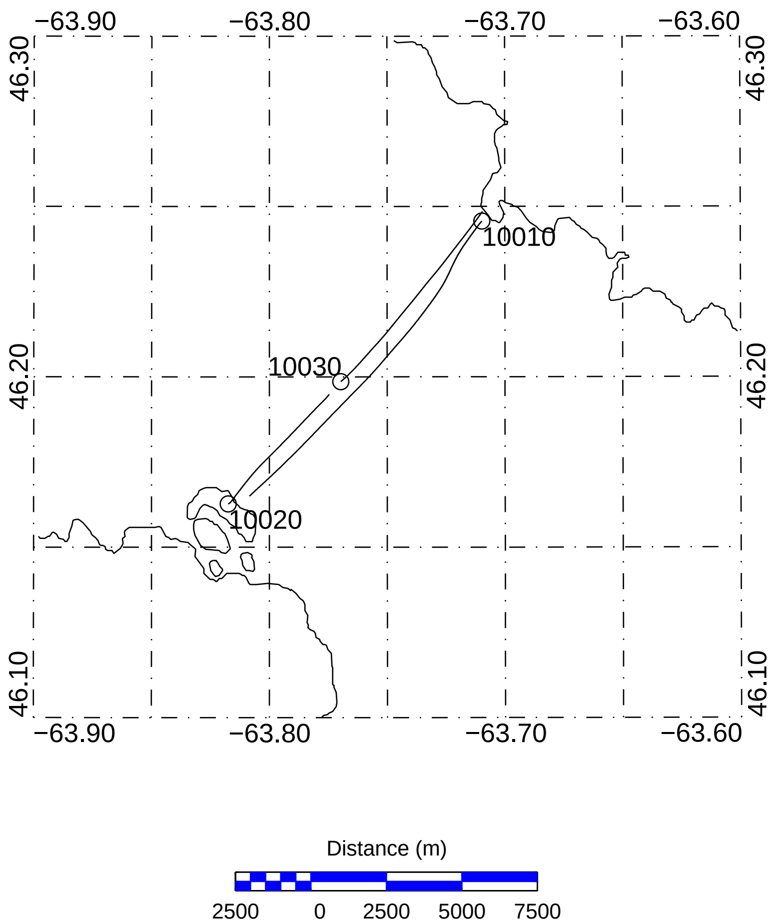
FEBRUARY 24, 1998 FLIGHT 22
Lambert Conic Proj., Center Long.: −63.20, Lat1 49.00, Lat2 77.00
Map Scale 1:1000000



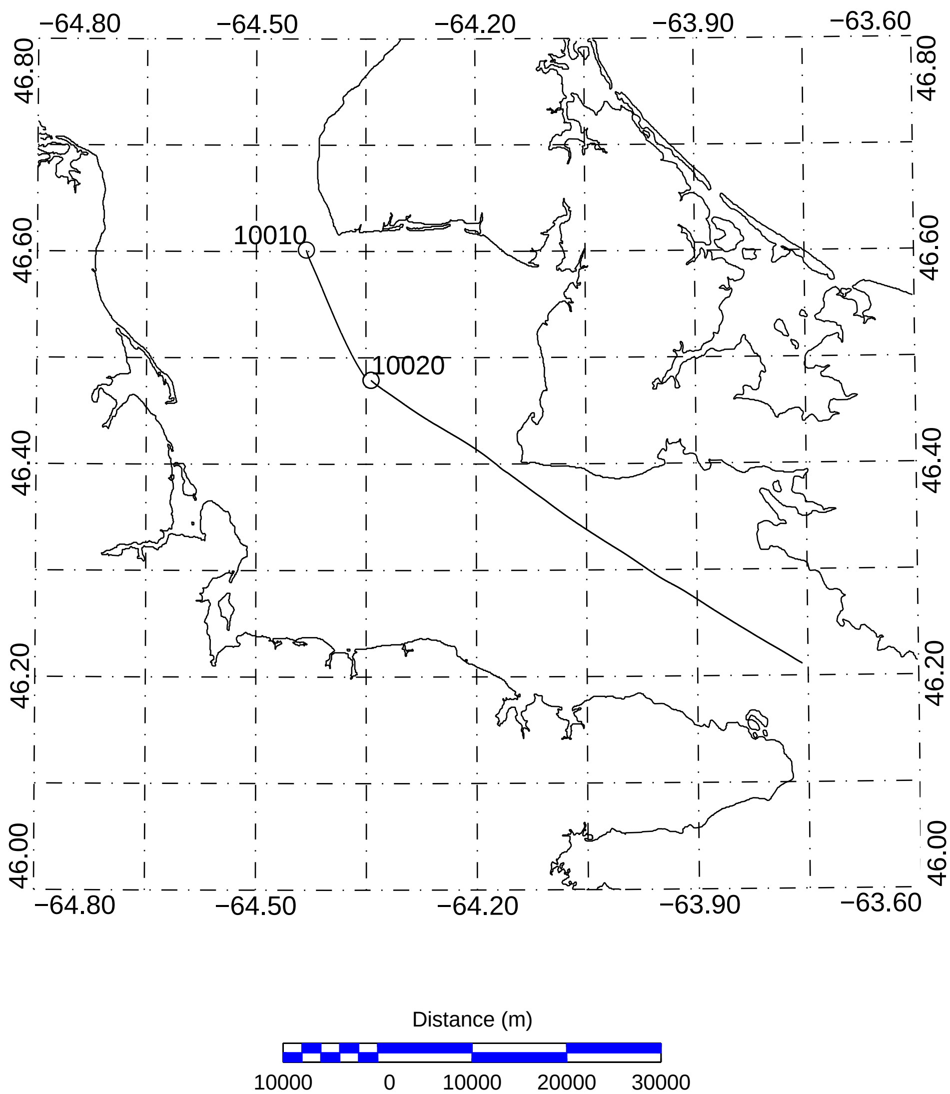
MARCH 16, 1998 FLIGHT 47
Lambert Conic Proj., Center Long.: −63.16, Lat1 49.00, Lat2 77.00
Map Scale 1:1000000



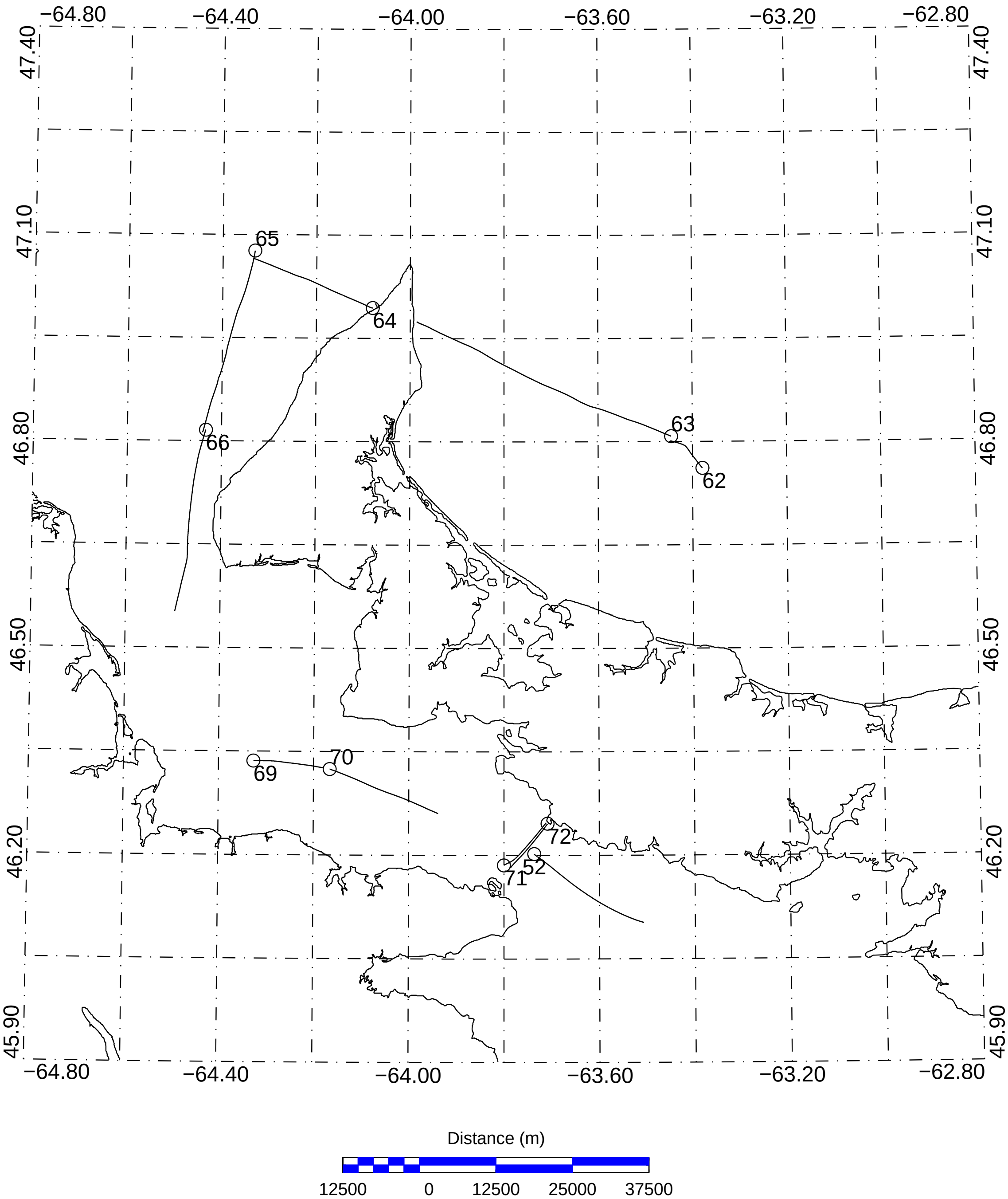
MARCH 16, 1998 FLIGHT 48
Lambert Conic Proj., Center Long.: −63.80, Lat1 49.00, Lat2 77.00
Map Scale 1:250000



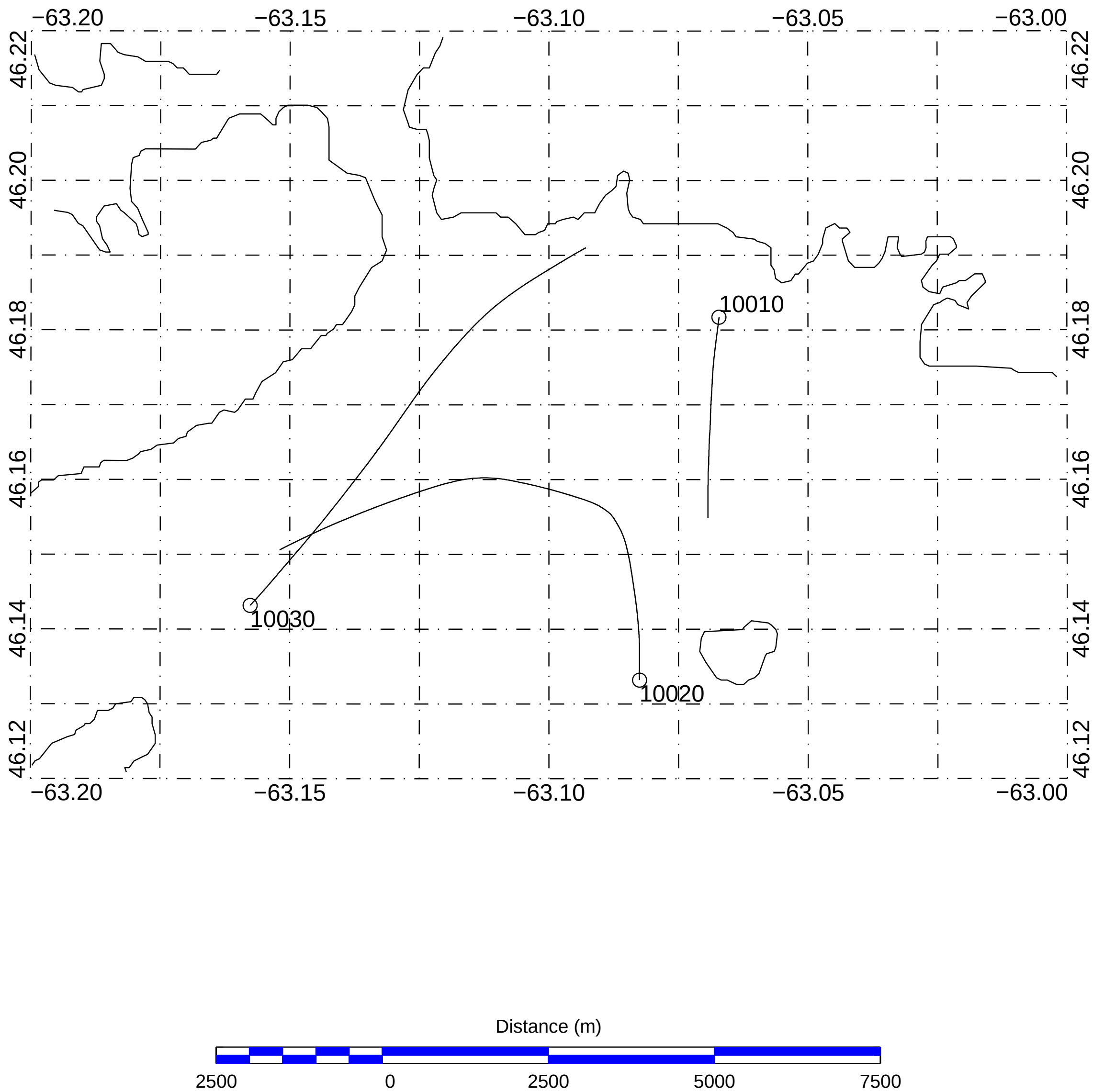
MARCH 16, 1998 FLIGHT 51
Lambert Conic Proj., Center Long.: −64.39, Lat1 49.00, Lat2 77.00
Map Scale 1:800000



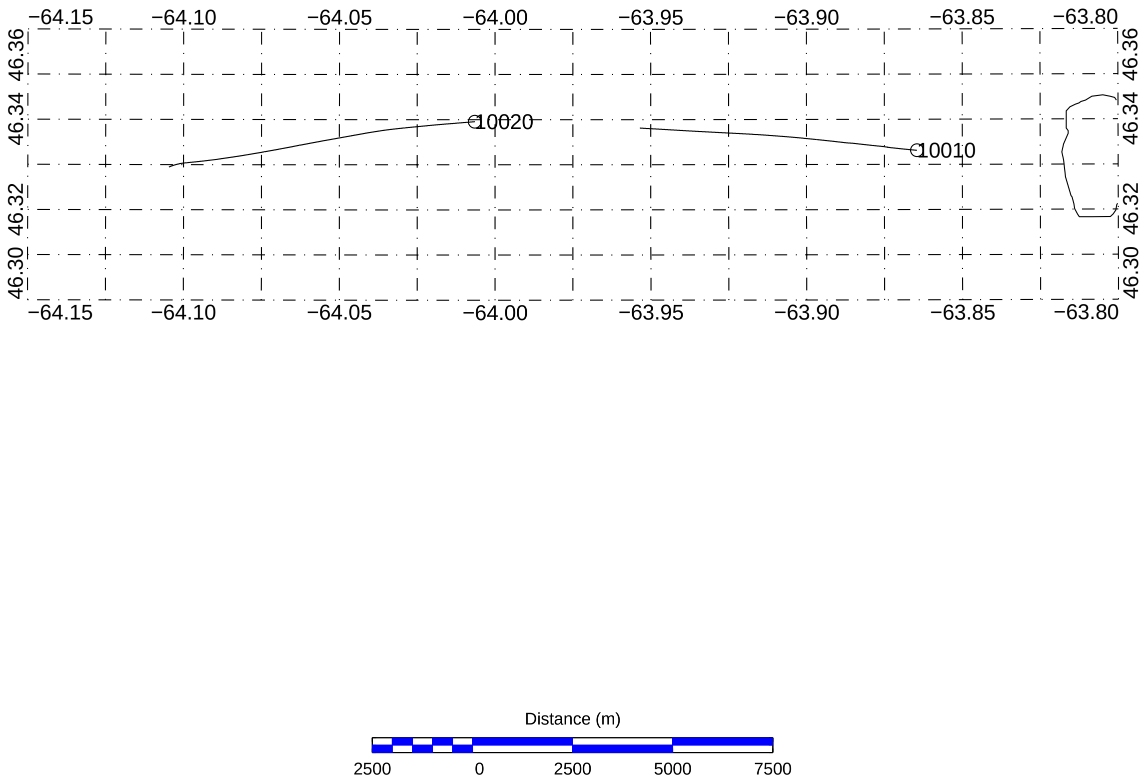
MARCH 16−17, 1998 SINGLE LINE FLIGHTS
Lambert Conic Proj., Center Long.: −63.80, Lat1 49.00, Lat2 77.00
Map Scale 1:1000000



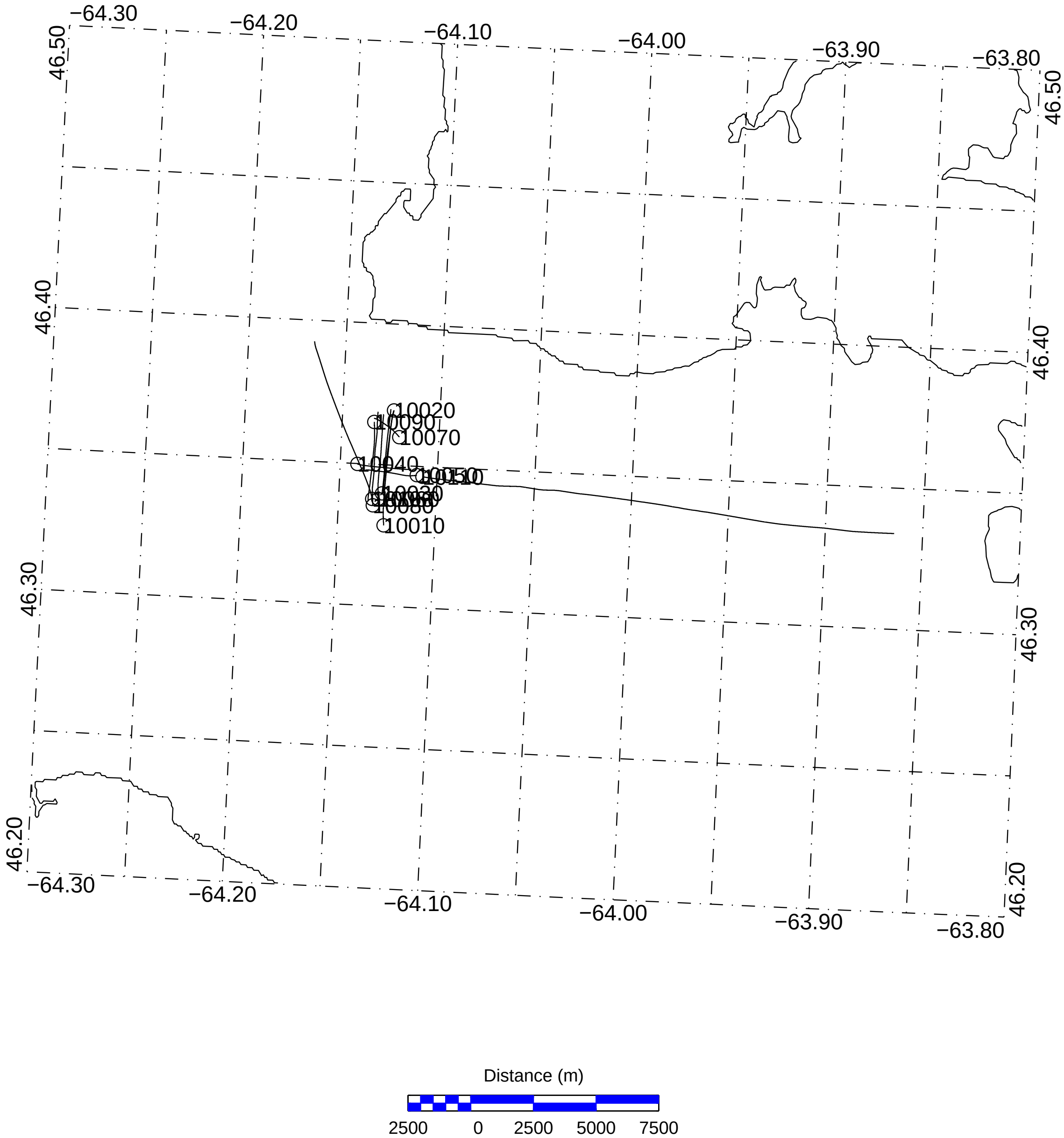
MARCH 18, 1998 FLIGHT 74
Lambert Conic Proj., Center Long.: −63.10, Lat1 49.00, Lat2 77.00
Map Scale 1:100000



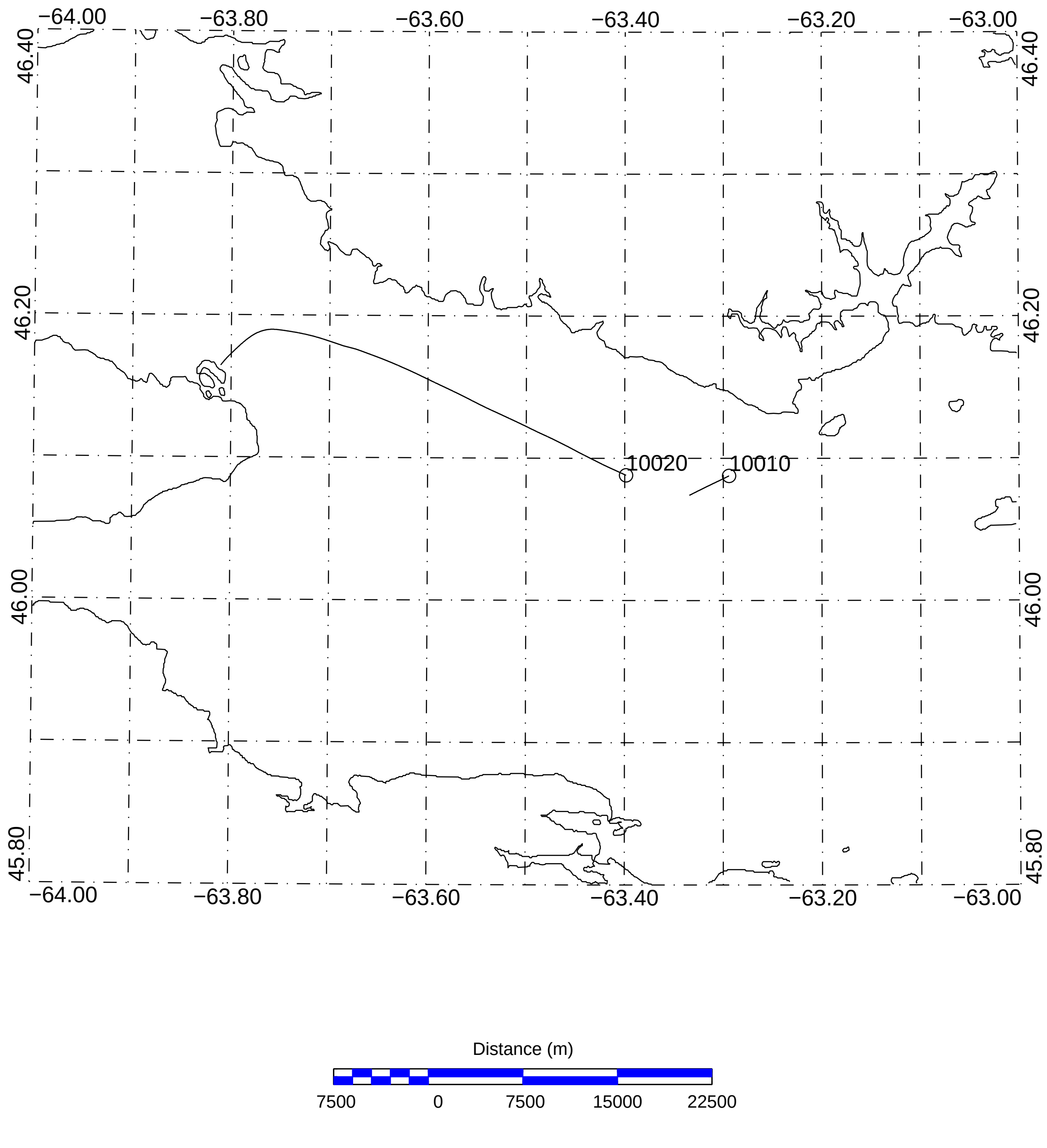
MARCH 18, 1998 FLIGHT 75
Lambert Conic Proj., Center Long.: −64.00, Lat1 49.00, Lat2 77.00
Map Scale 1:150000



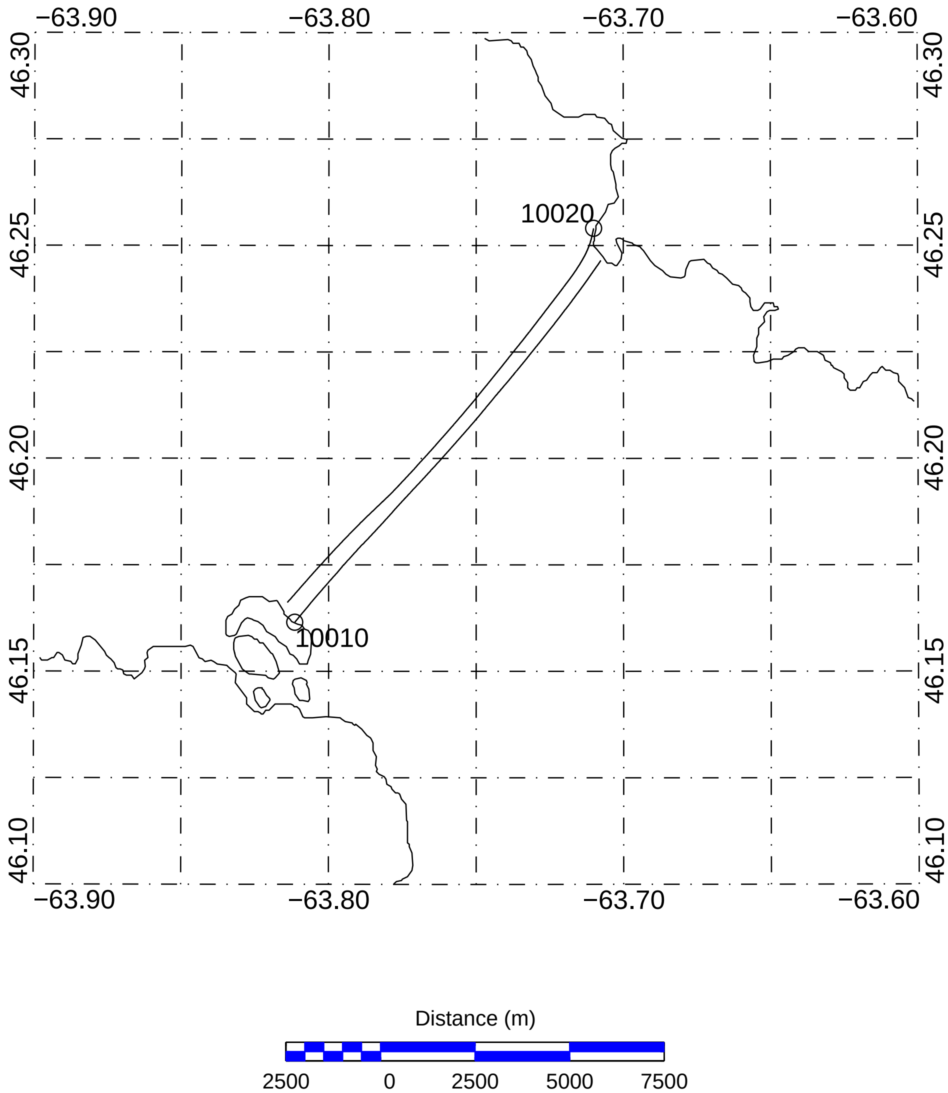
MARCH 18, 1998 FLIGHT 76
Lambert Conic Proj., Center Long.: −61.10, Lat1 49.00, Lat2 77.00
Map Scale 1:250000



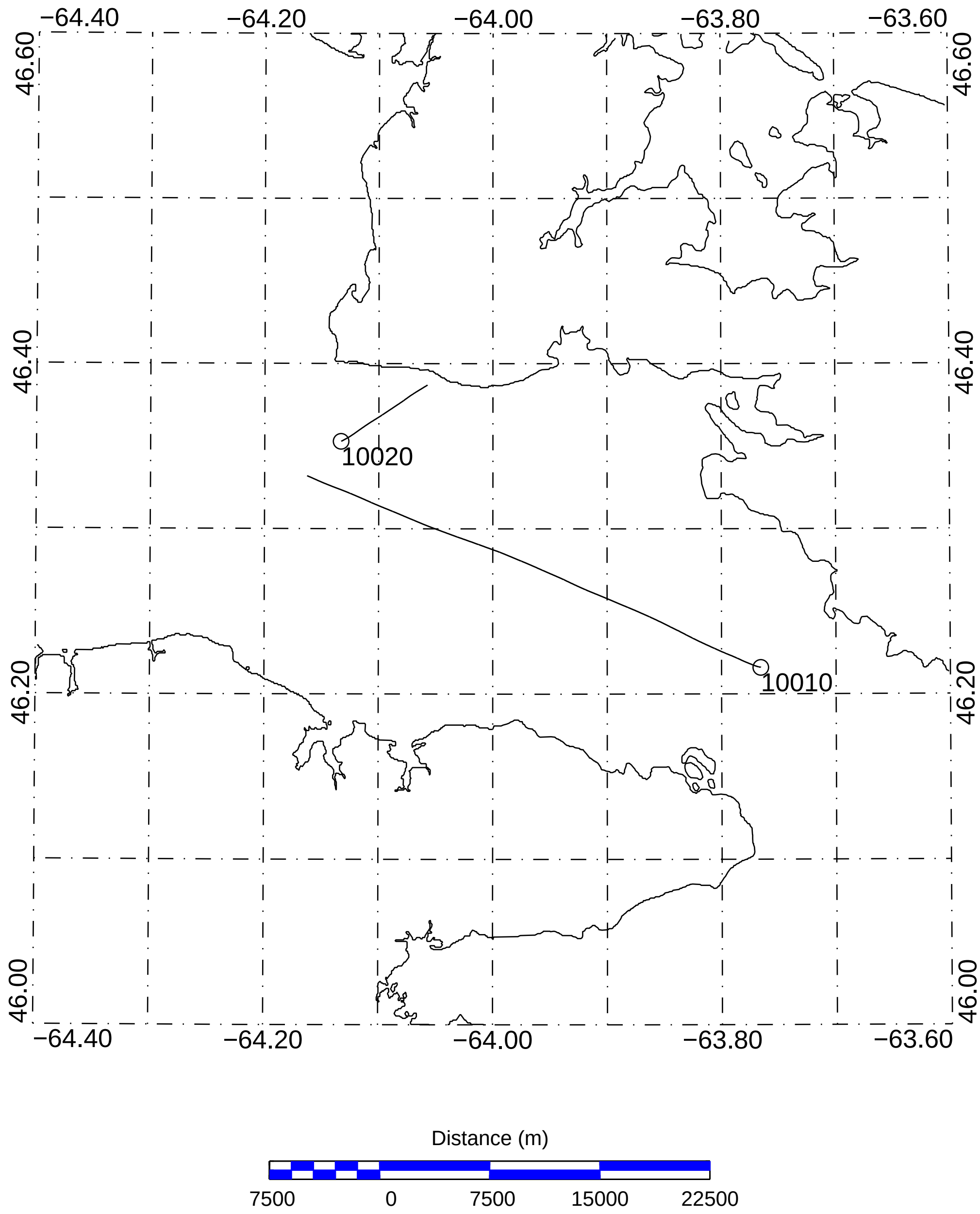
MARCH 19, 1998 FLIGHT 77
Lambert Conic Proj., Center Long.: −63.31, Lat1 49.00, Lat2 77.00
Map Scale 1:500000



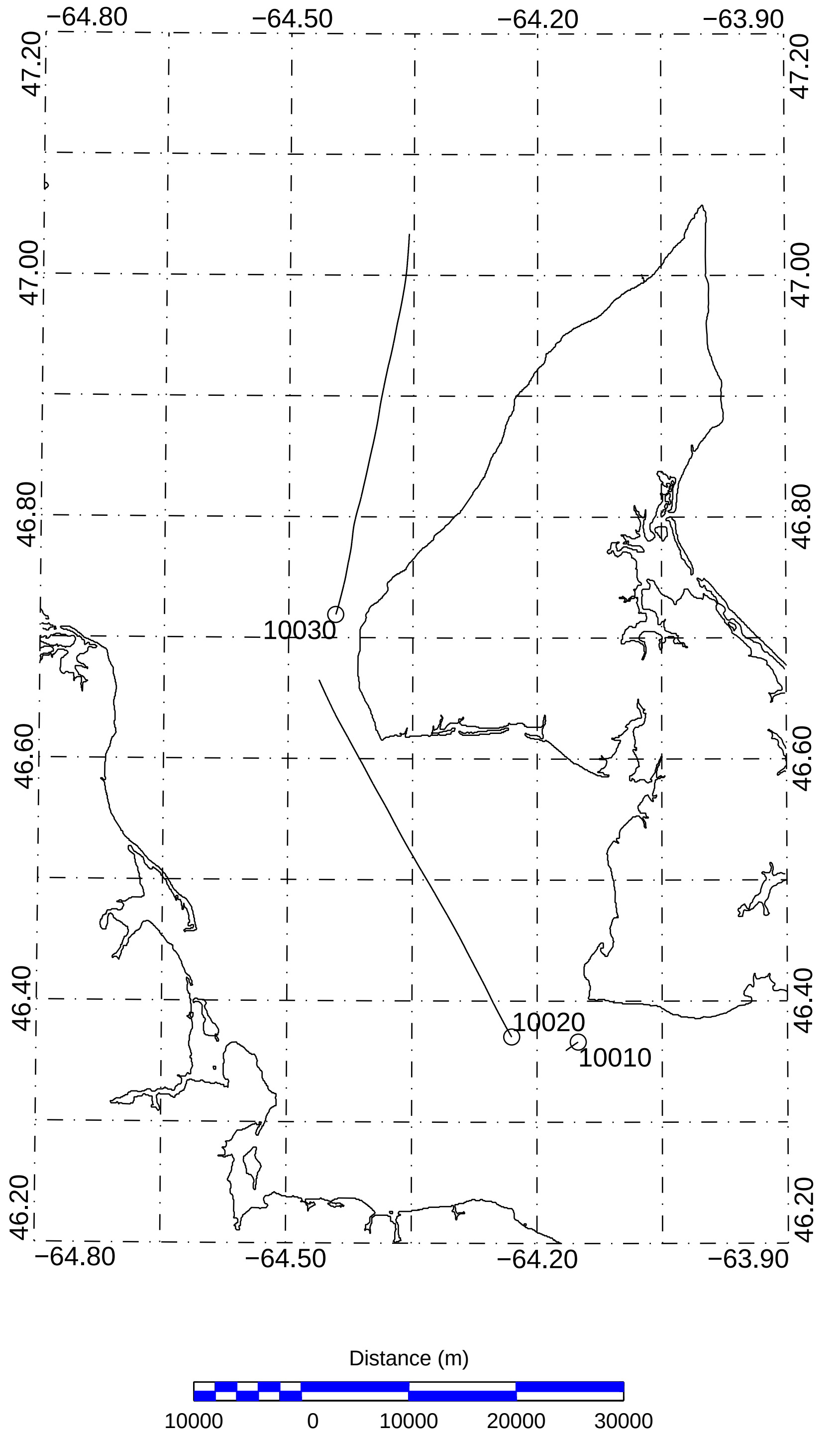
MARCH 19, 1998 FLIGHT 78
Lambert Conic Proj., Center Long.: −63.75, Lat1 49.00, Lat2 77.00
Map Scale 1:200000



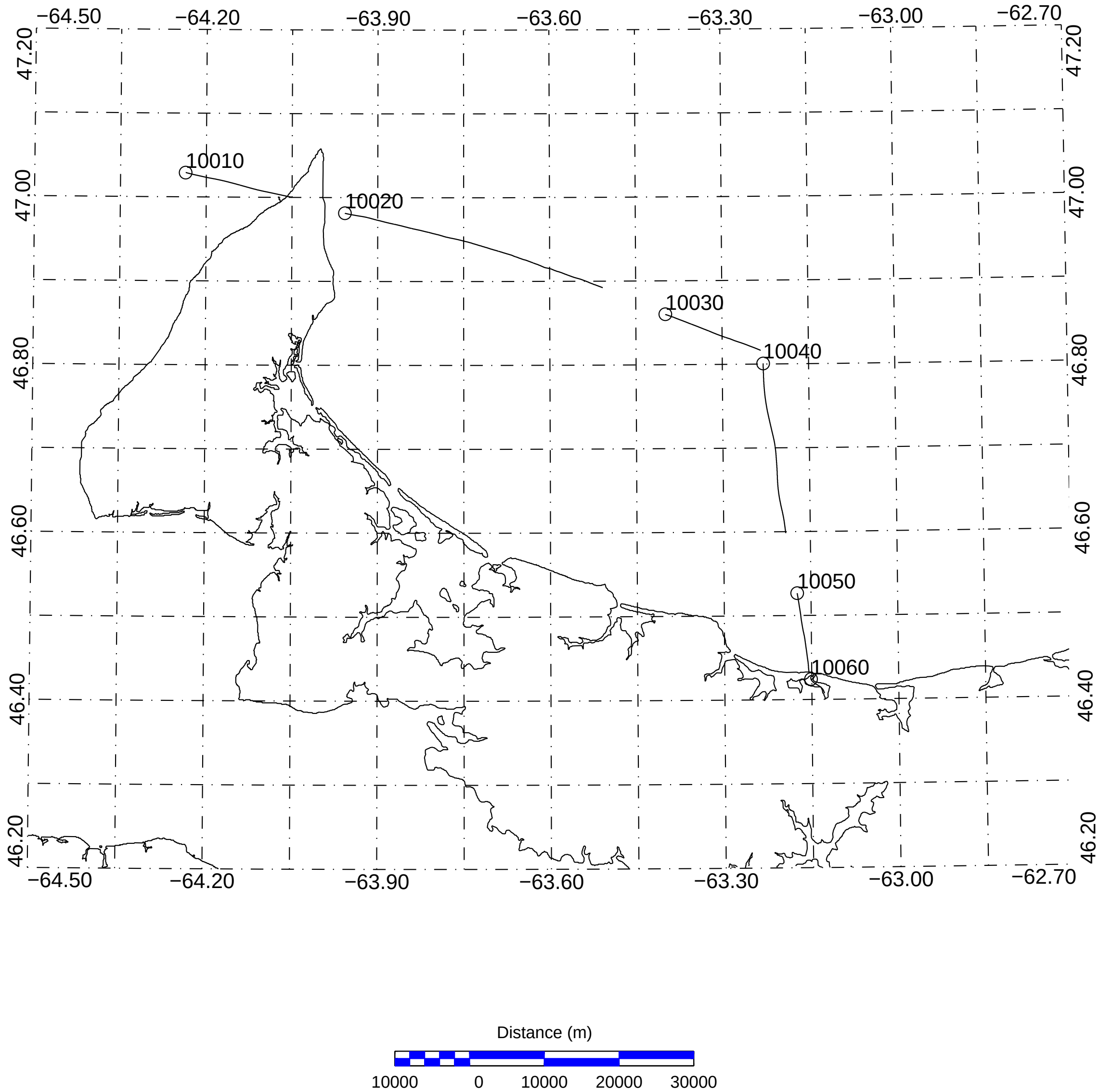
MARCH 19, 1998 FLIGHT 79
Lambert Conic Proj., Center Long.: −63.96, Lat1 49.00, Lat2 77.00
Map Scale 1:500000



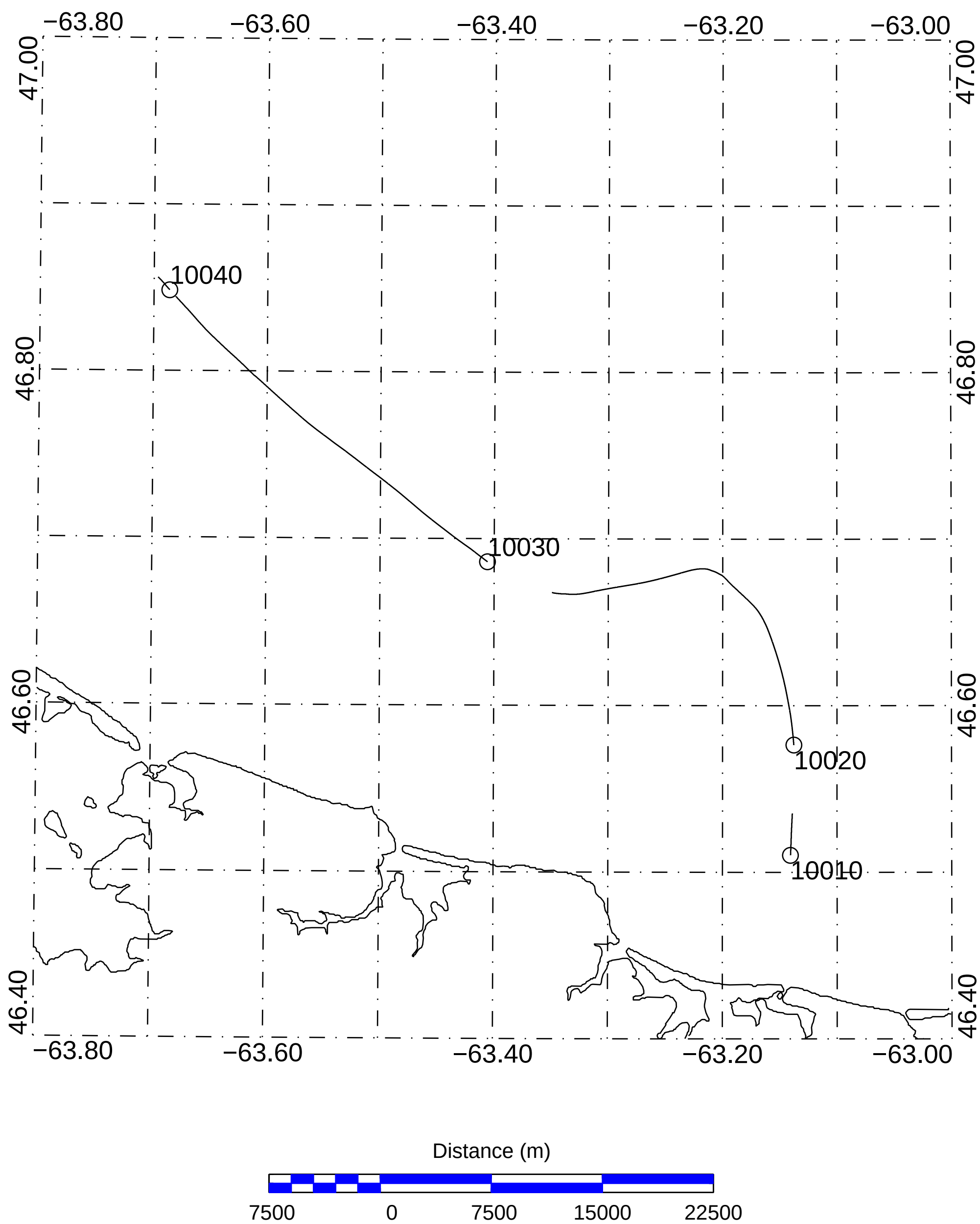
MARCH 19, 1998 FLIGHT 80
Lambert Conic Proj., Center Long.: −64.16, Lat1 49.00, Lat2 77.00
Map Scale 1:700000



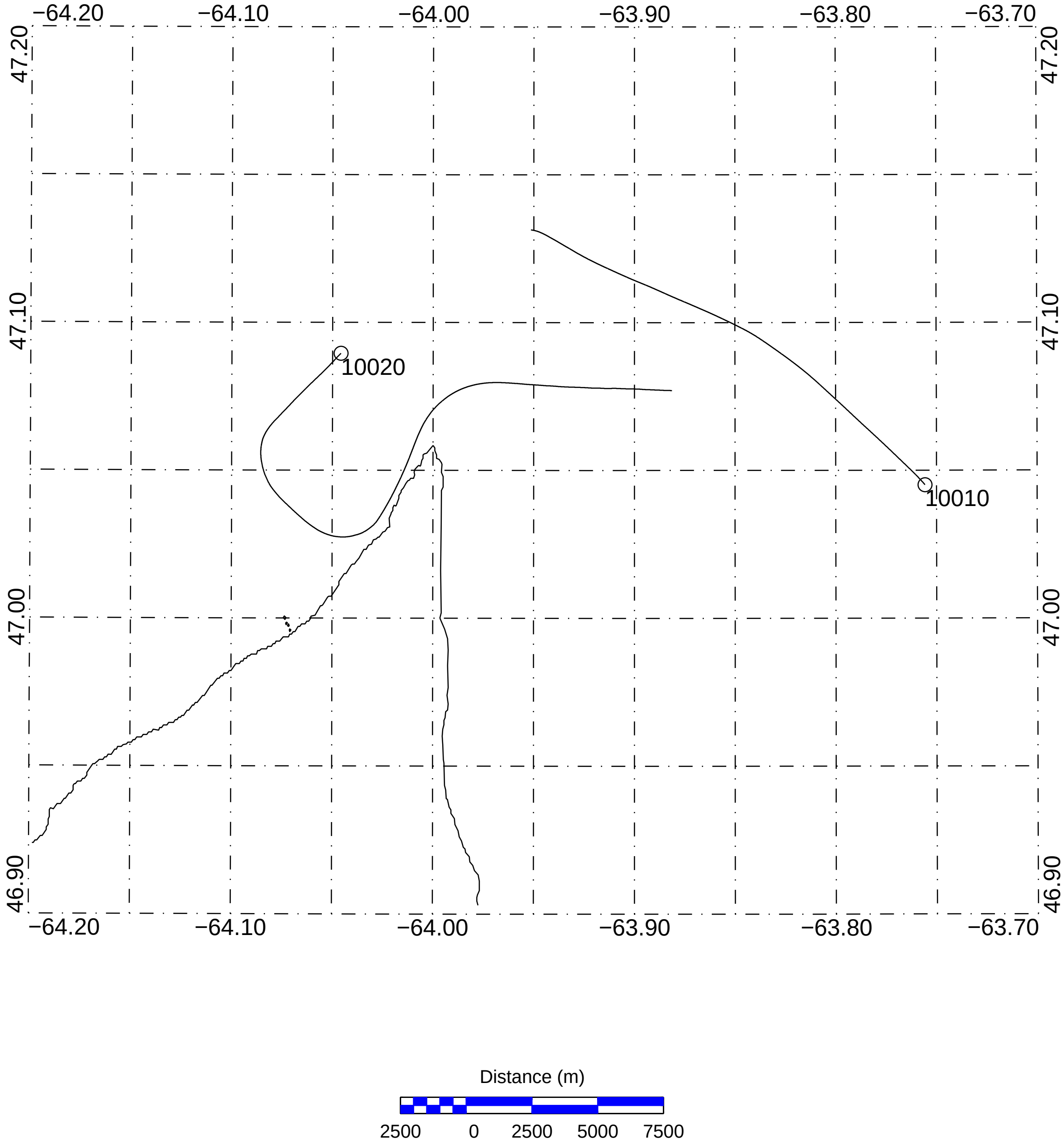
MARCH 19, 1998 FLIGHT 81
Lambert Conic Proj., Center Long.: −63.80, Lat1 49.00, Lat2 77.00
Map Scale 1:800000



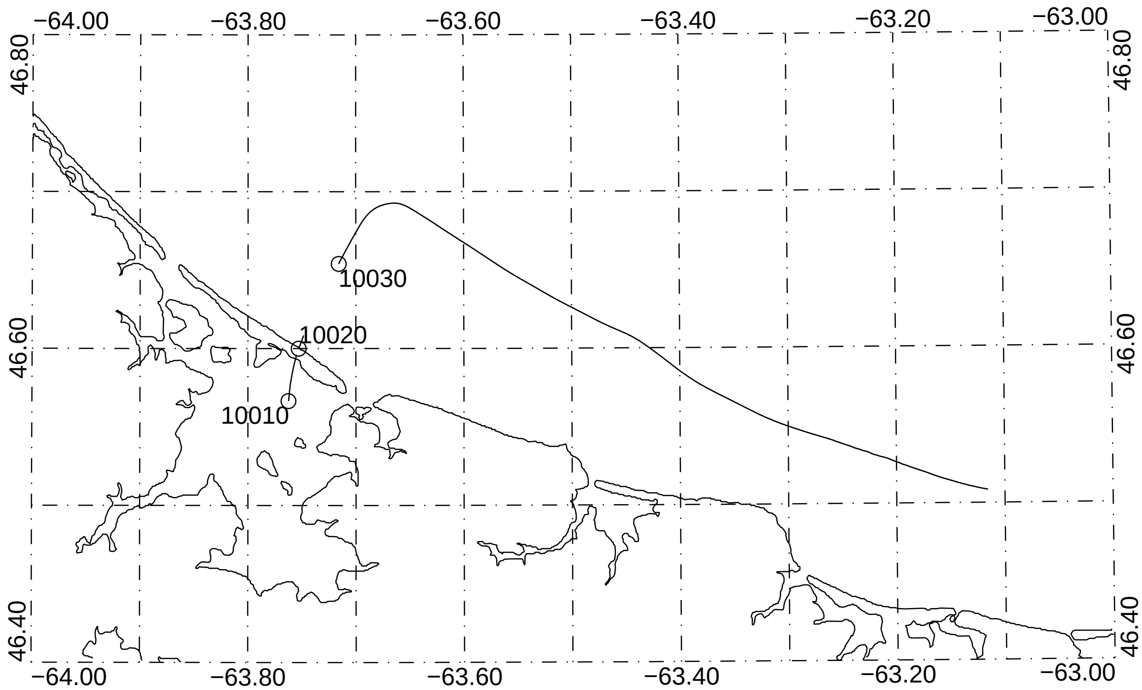
MARCH 24, 1998 FLIGHT 82
Lambert Conic Proj., Center Long.: −63.14, Lat1 49.00, Lat2 77.00
Map Scale 1:500000

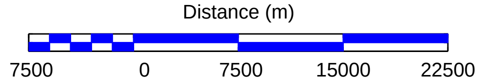


MARCH 24, 1998 FLIGHT 83
Lambert Conic Proj., Center Long.: −63.90, Lat1 49.00, Lat2 77.00
Map Scale 1:250000



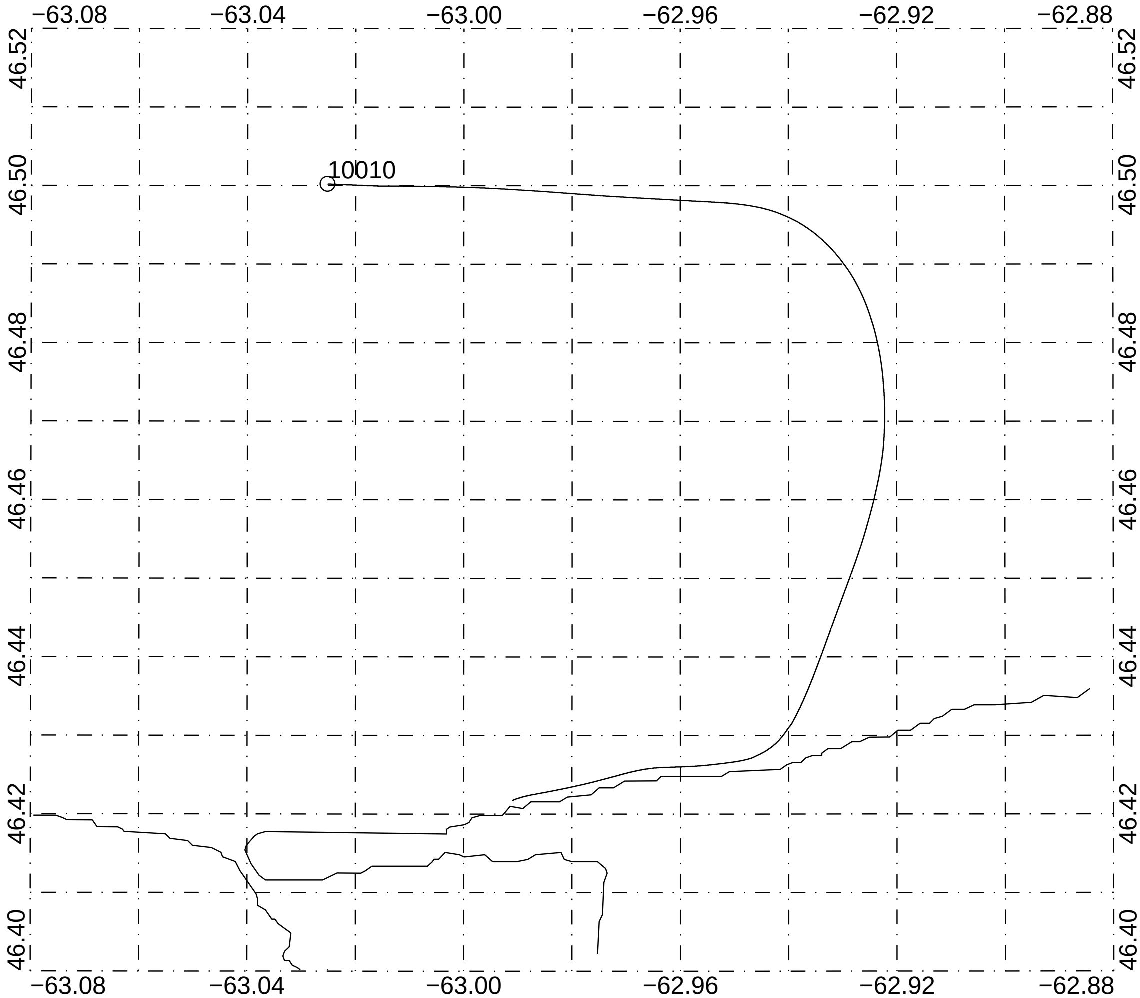
MARCH 24, 1998 FLIGHT 85
Lambert Conic Proj., Center Long.: −63.76, Lat1 49.00, Lat2 77.00
Map Scale 1:500000

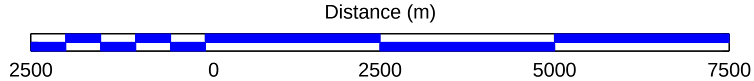




C-30

MARCH 24, 1998 FLIGHT 86
Lambert Conic Proj., Center Long.: −62.97, Lat1 49.00, Lat2 77.00
Map Scale 1:100000





Appendix D: Profile Maps

This appendix presents snow plus ice thickness profile maps generated from the airborne EIS dataset. 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.

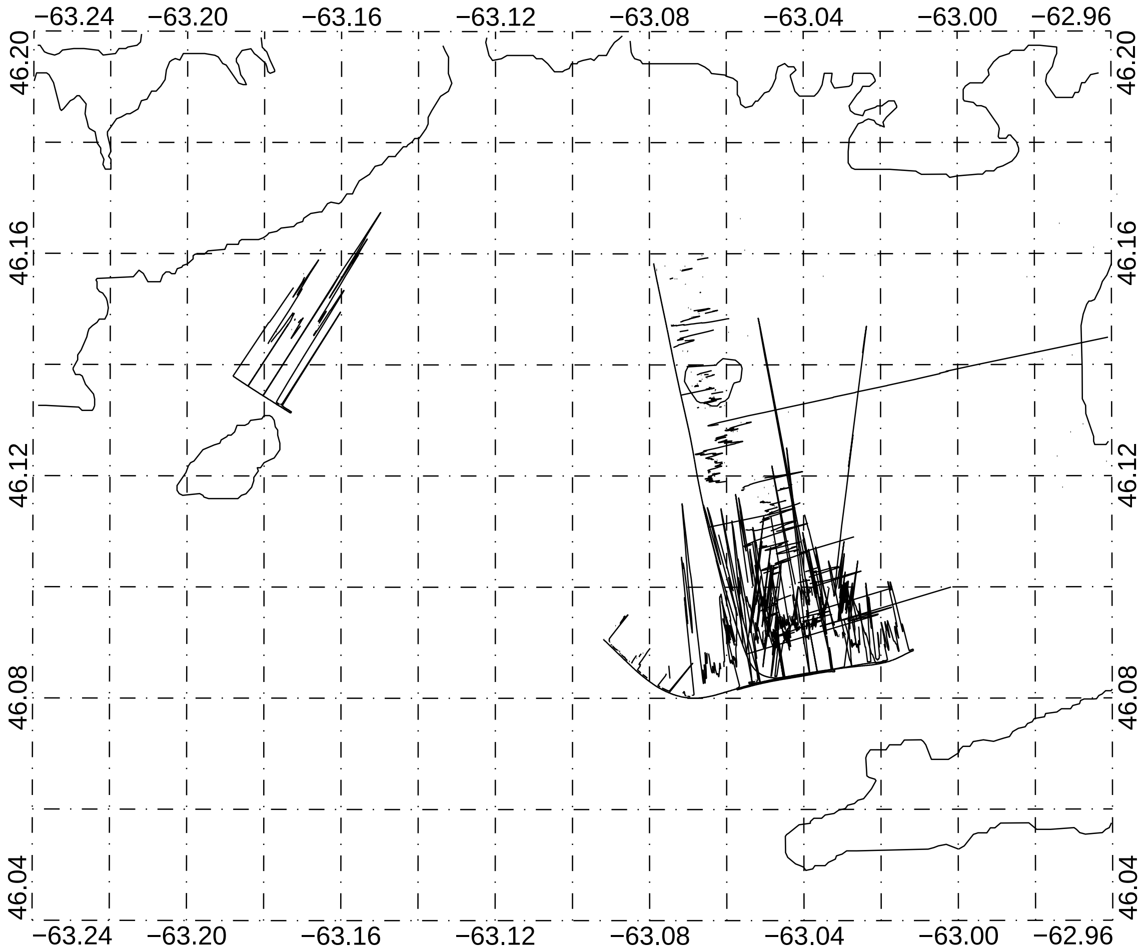
FLT files 052 and 062-072 have been combined into a single map.

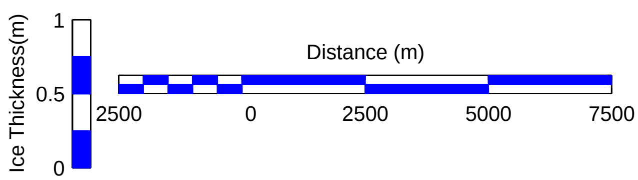
D-2

FEBRUARY 21, 1998 FLIGHT 4

Lambert Conic Proj., Center Long.: −63.10, Lat1 49.00, Lat2 77.00

Ice Thickness 1 cm/0.5 m,Map Scale 1:150000



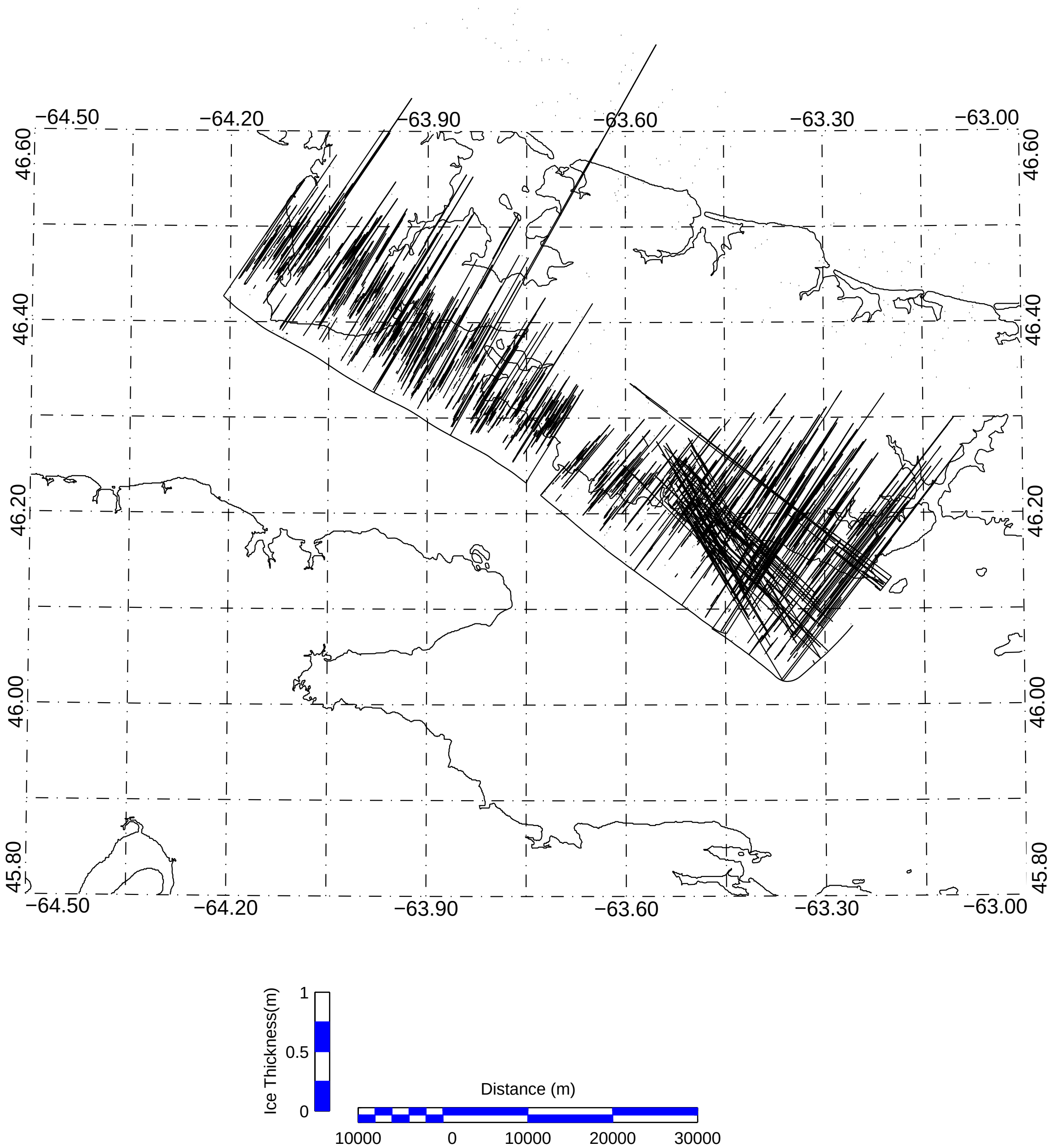


D-3

FEBRUARY 21, 1998 FLIGHT 5

Lambert Conic Proj., Center Long.: −63.70, Lat1 49.00, Lat2 77.00

Ice Thickness 1 cm/0.5 m,Map Scale 1:700000

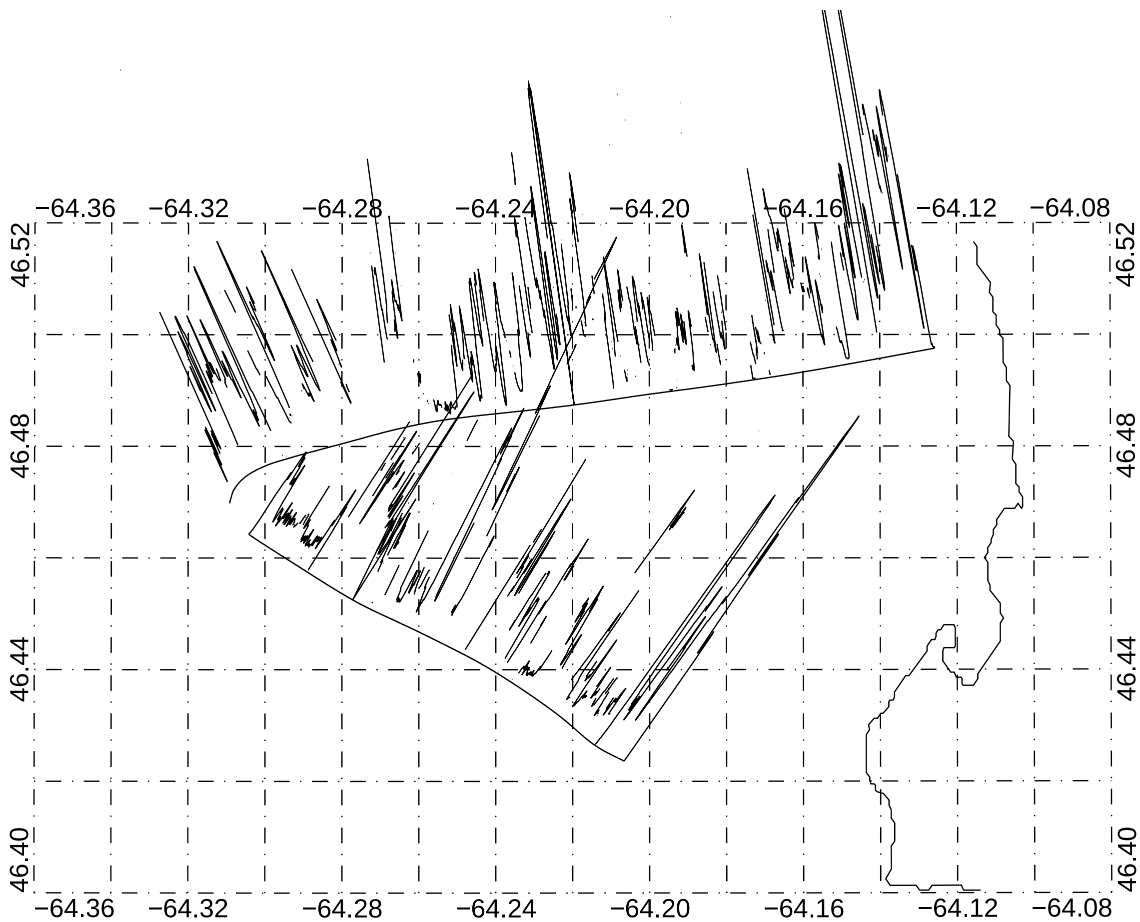


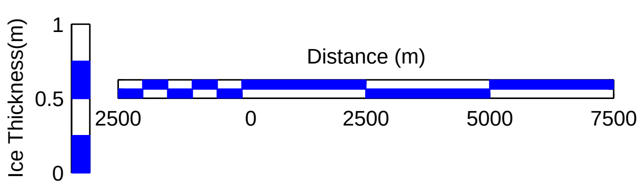
D-4

FEBRUARY 21, 1998 FLIGHT 7

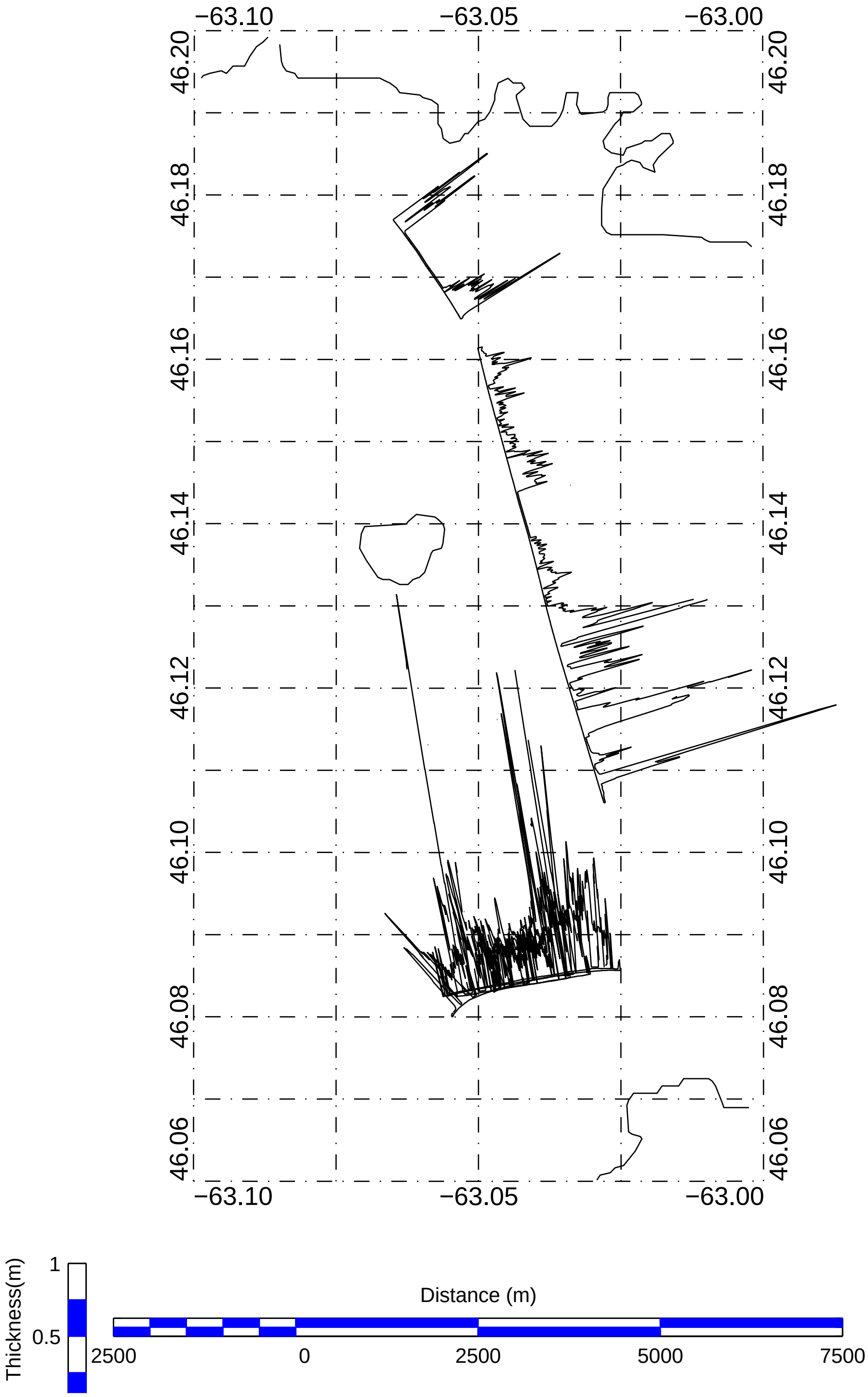
Lambert Conic Proj., Center Long.: −64.26, Lat1 49.00, Lat2 77.00

Ice Thickness 1 cm/0.5 m,Map Scale 1:150000

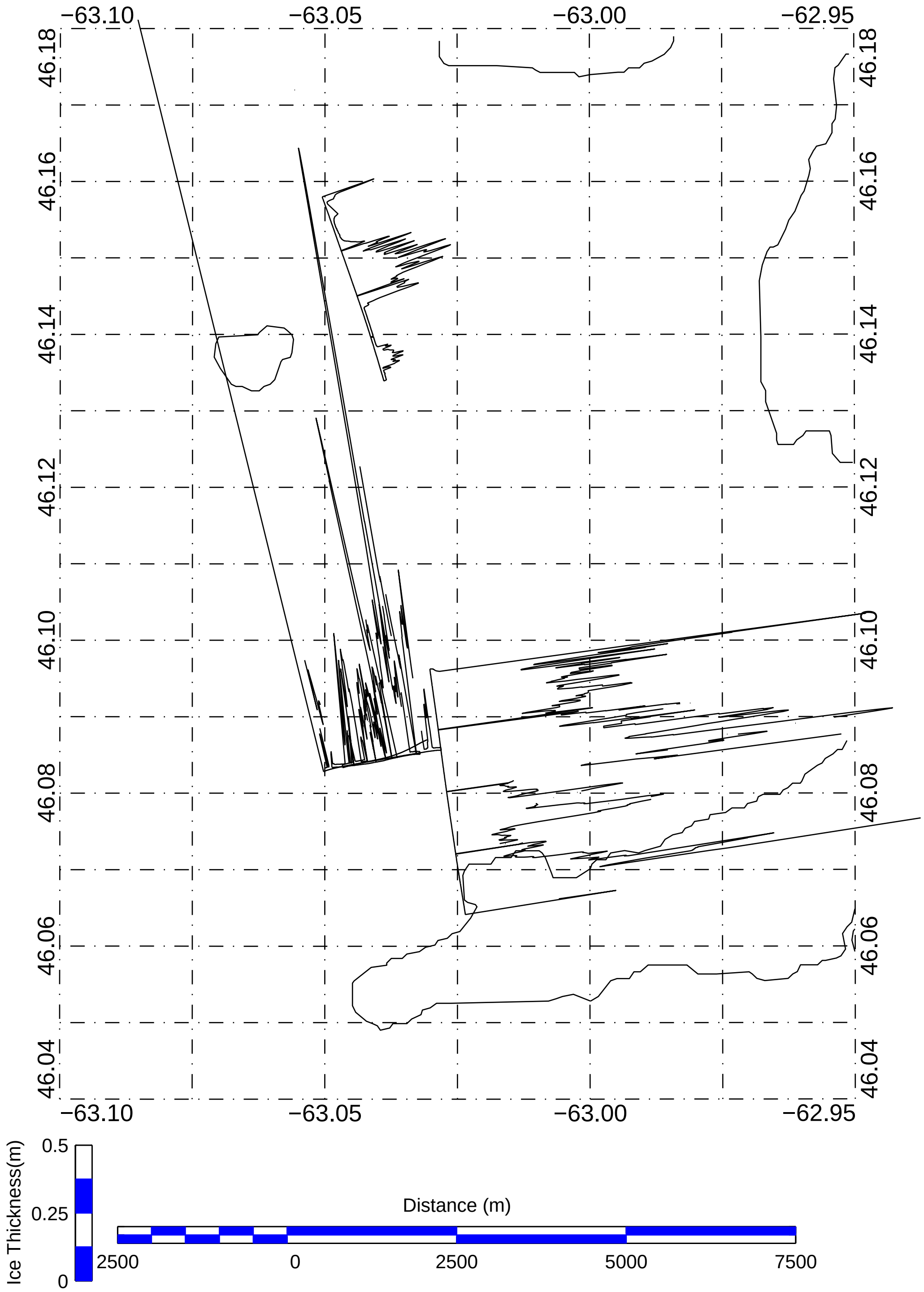




FEBRUARY 22, 1998 FLIGHT 10
Lambert Conic Proj., Center Long.: −63.05, Lat1 49.00, Lat2 77.00
Ice Thickness 1 cm/0.5 m,Map Scale 1:100000



FEBRUARY 22, 1998 FLIGHT 11
Lambert Conic Proj., Center Long.: −63.04, Lat1 49.00, Lat2 77.00
Ice Thickness 1 cm/0.25 m,Map Scale 1:100000

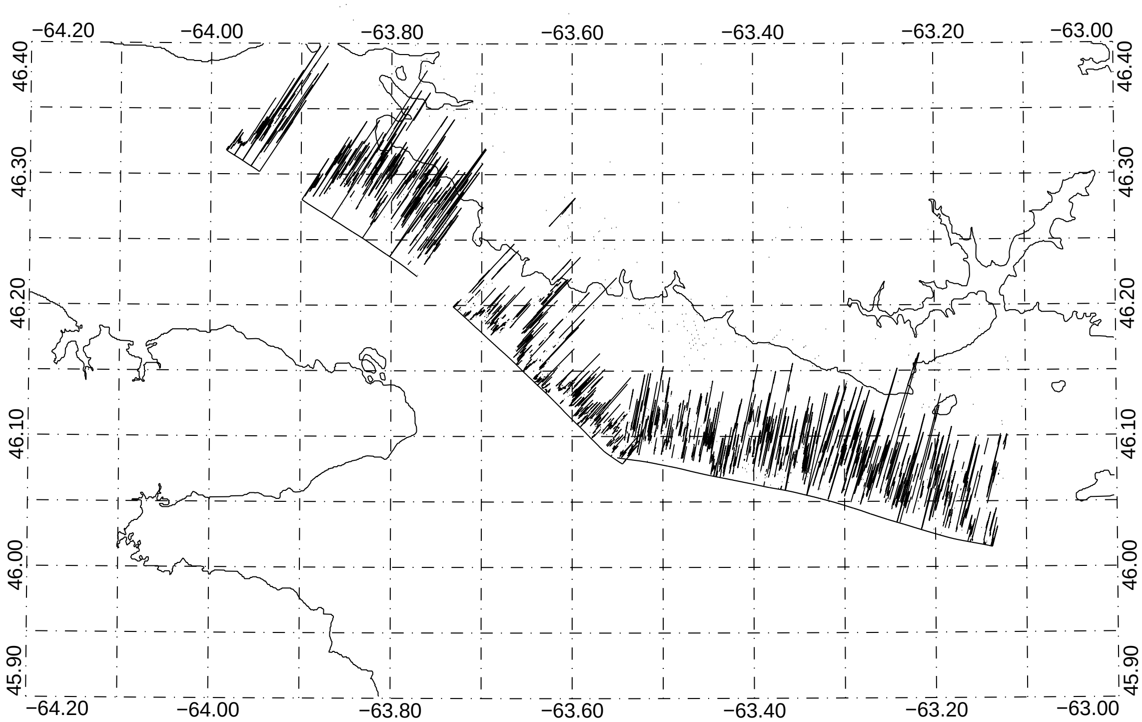


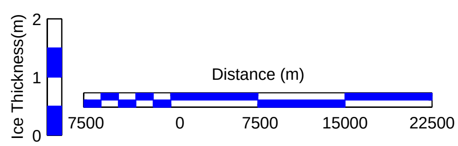
D-7

FEBRUARY 22, 1998 FLIGHT 12

Lambert Conic Proj., Center Long.: −63.60, Lat1 49.00, Lat2 77.00

Ice Thickness 1 cm/1 m,Map Scale 1:500000



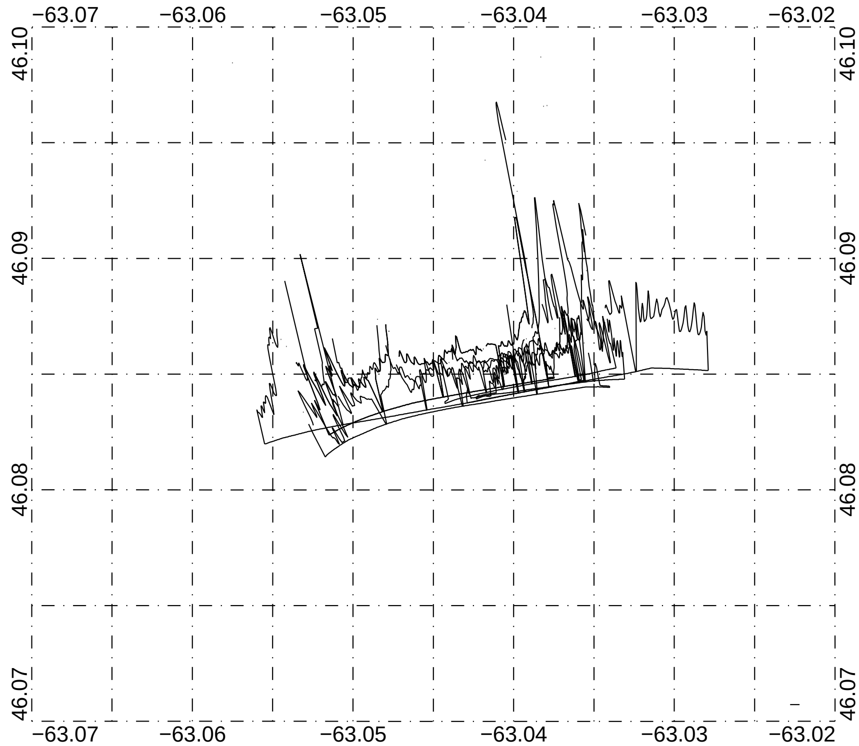


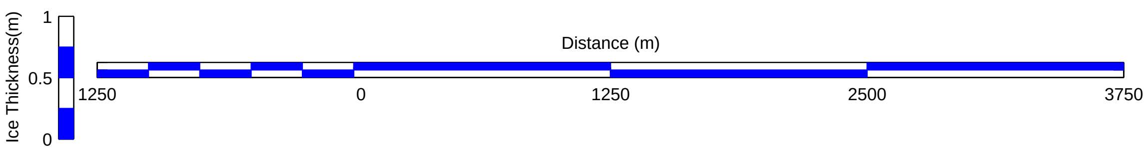
D-8

FEBRUARY 22, 1998 FLIGHT 15

Lambert Conic Proj., Center Long.: −63.04, Lat1 49.00, Lat2 77.00

Ice Thickness 1 cm/0.5 m,Map Scale 1:30000



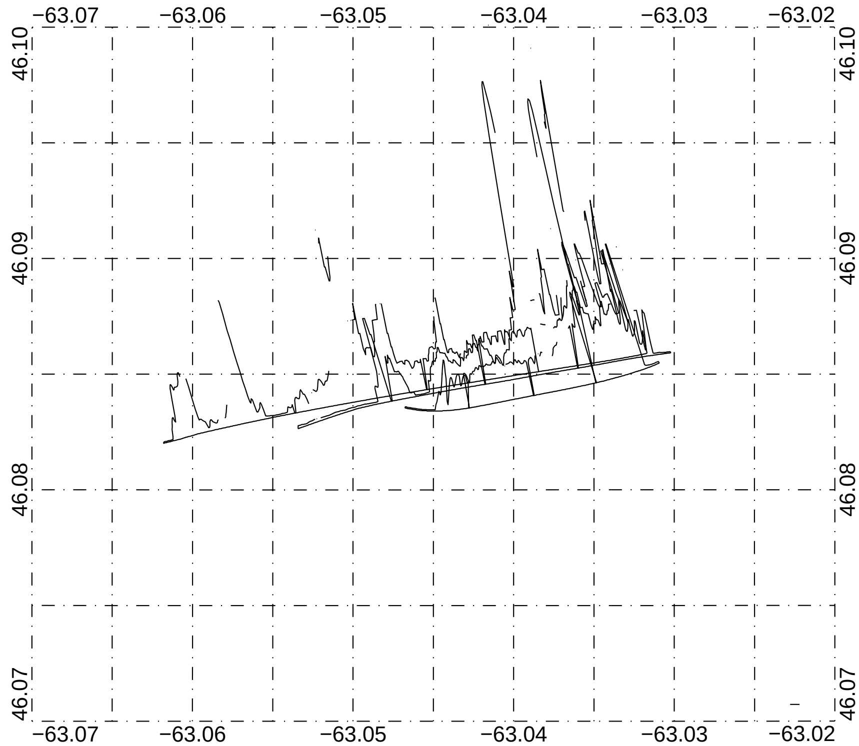


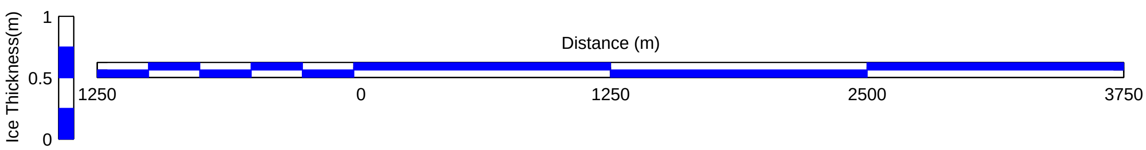
D-9

FEBRUARY 23, 1998 FLIGHT 16

Lambert Conic Proj., Center Long.: −63.05, Lat1 49.00, Lat2 77.00

Ice Thickness 1 cm/0.5 m,Map Scale 1:30000



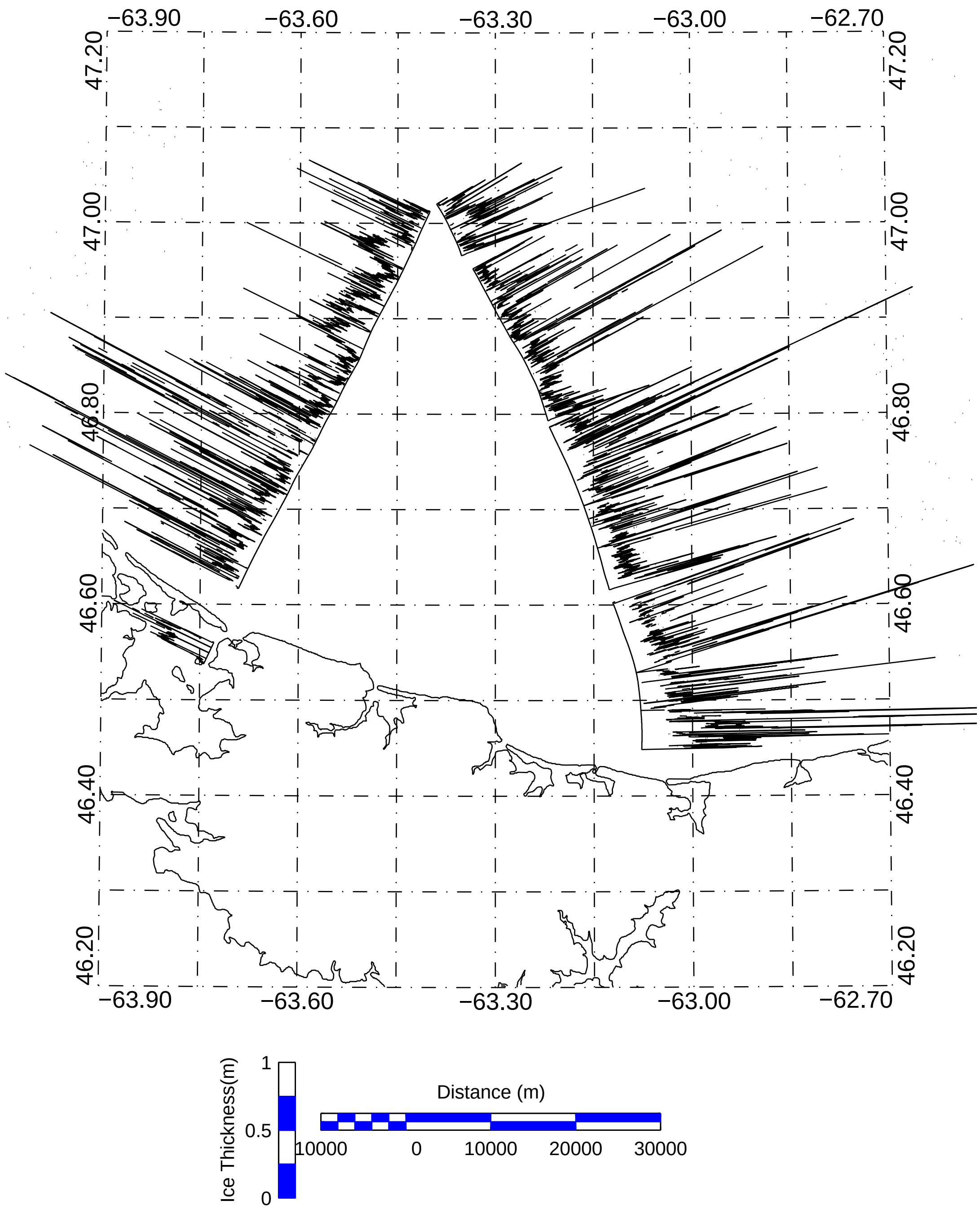


D-10

FEBRUARY 23, 1998 FLIGHT 17

Lambert Conic Proj., Center Long.: −63.30, Lat1 49.00, Lat2 77.00

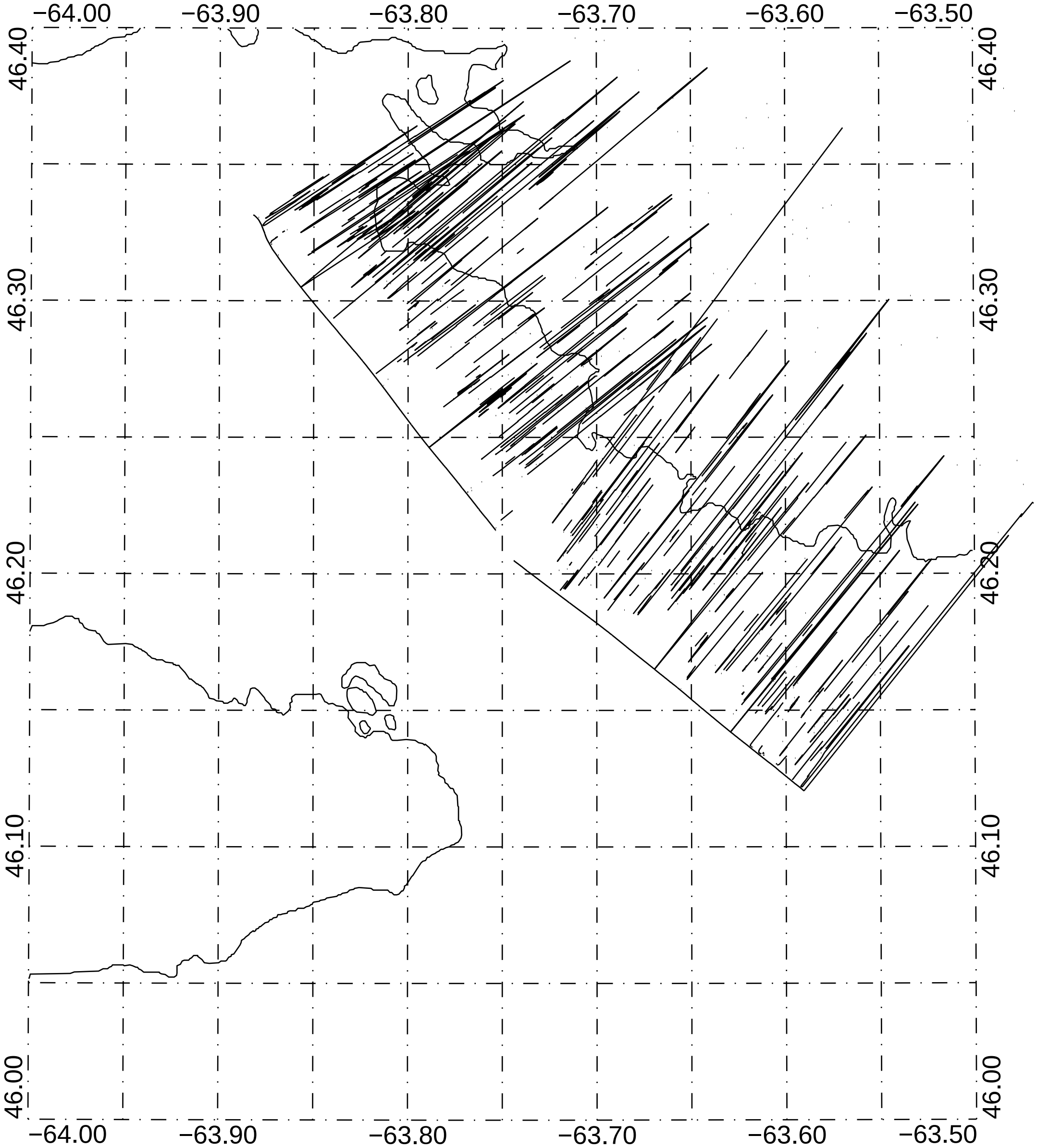
Ice Thickness 1 cm/0.5 m,Map Scale 1:800000

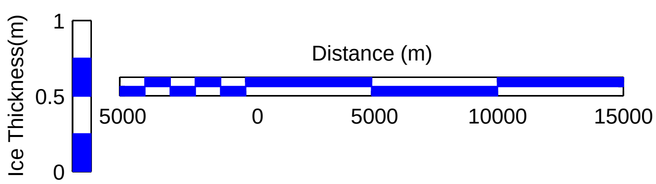


FEBRUARY 23, 1998 FLIGHT 18

Lambert Conic Proj., Center Long.: −63.75, Lat1 49.00, Lat2 77.00

Ice Thickness 1 cm/0.5 m,Map Scale 1:300000



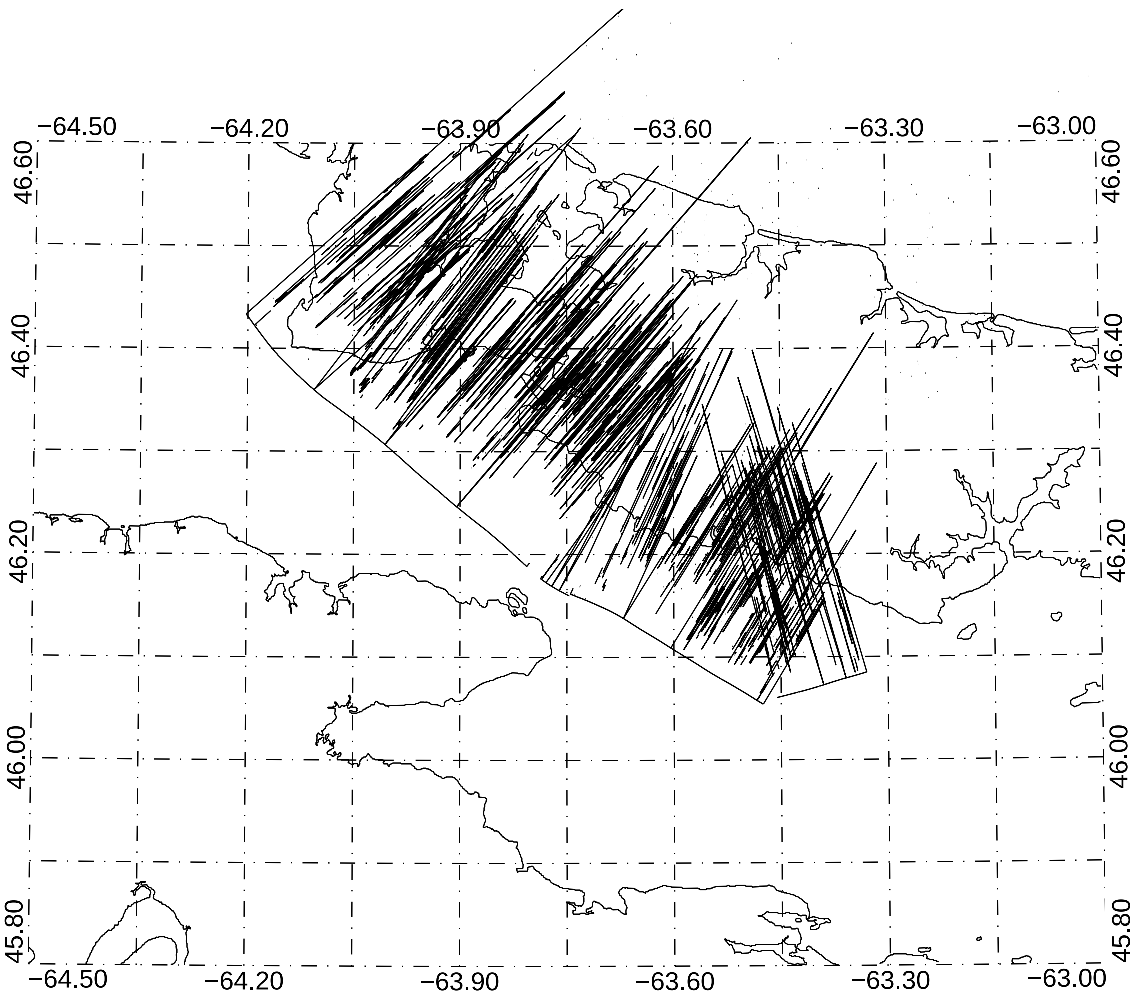


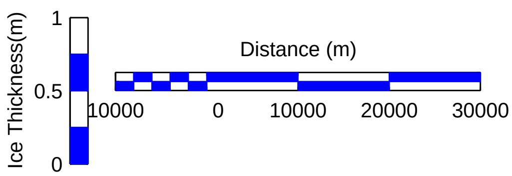
D-12

FEBRUARY 23, 1998 FLIGHT 19

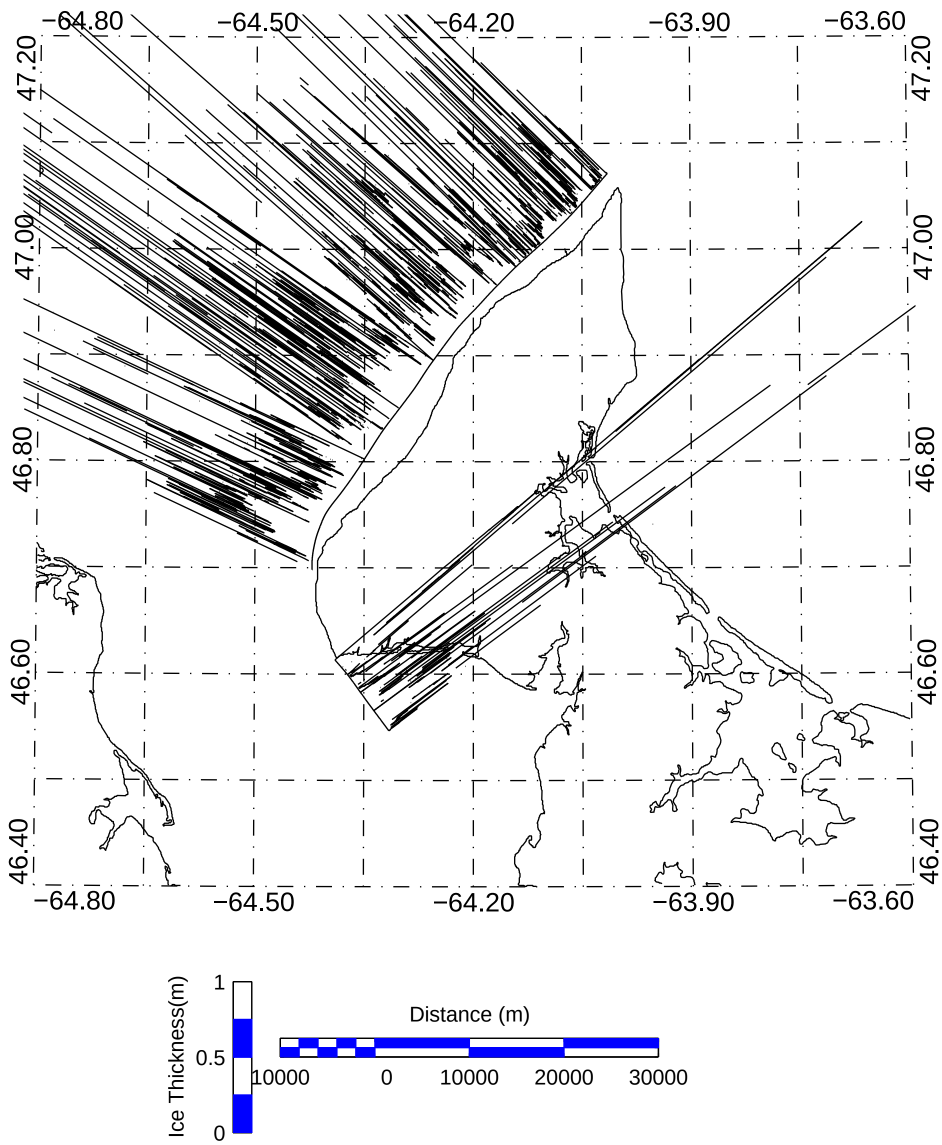
Lambert Conic Proj., Center Long.: −63.80, Lat1 49.00, Lat2 77.00

Ice Thickness 1 cm/0.5 m,Map Scale 1:800000





FEBRUARY 23, 1998 FLIGHT 20
Lambert Conic Proj., Center Long.: −64.20, Lat1 49.00, Lat2 77.00
Ice Thickness 1 cm/0.5 m,Map Scale 1:800000

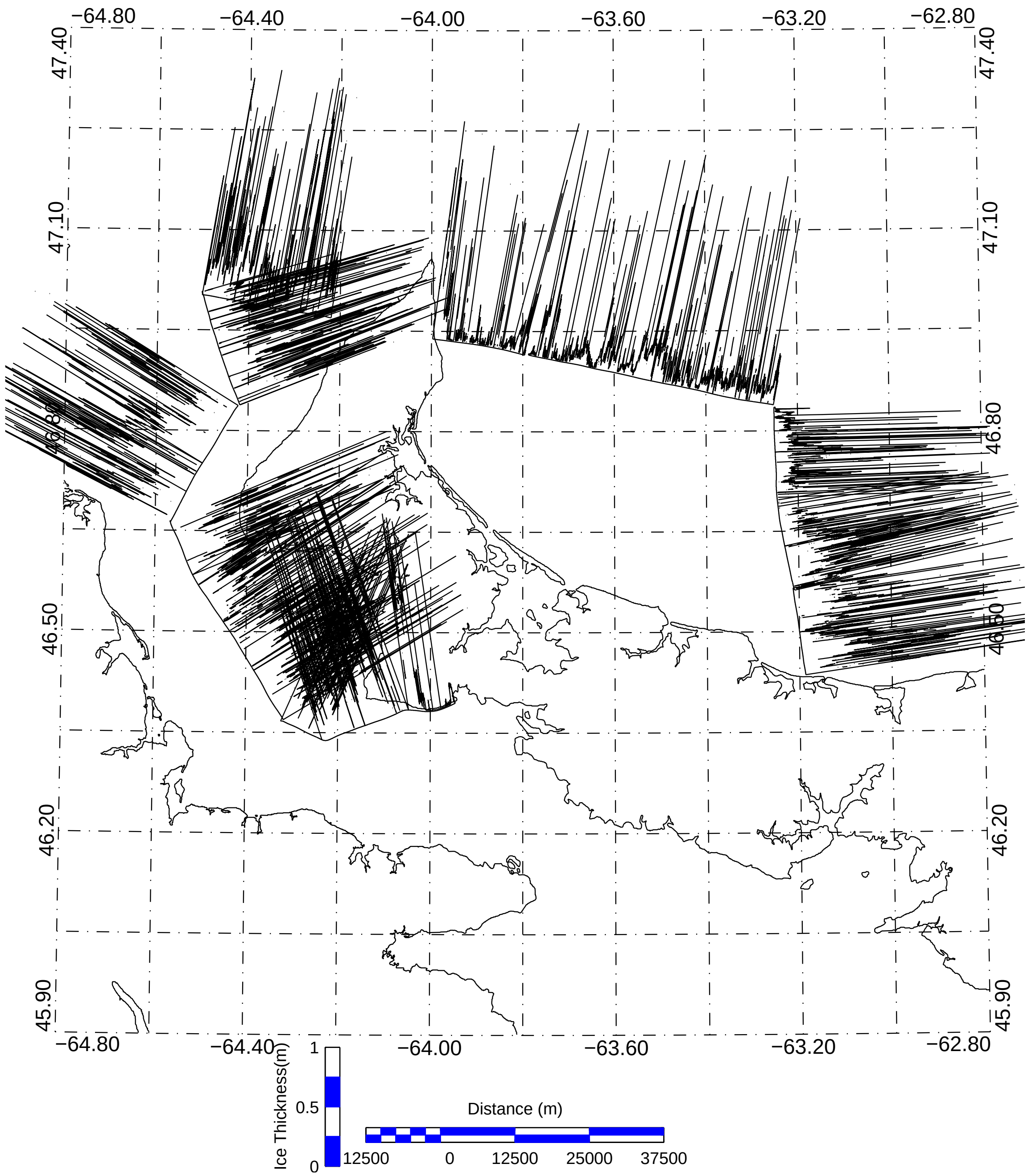


D-14

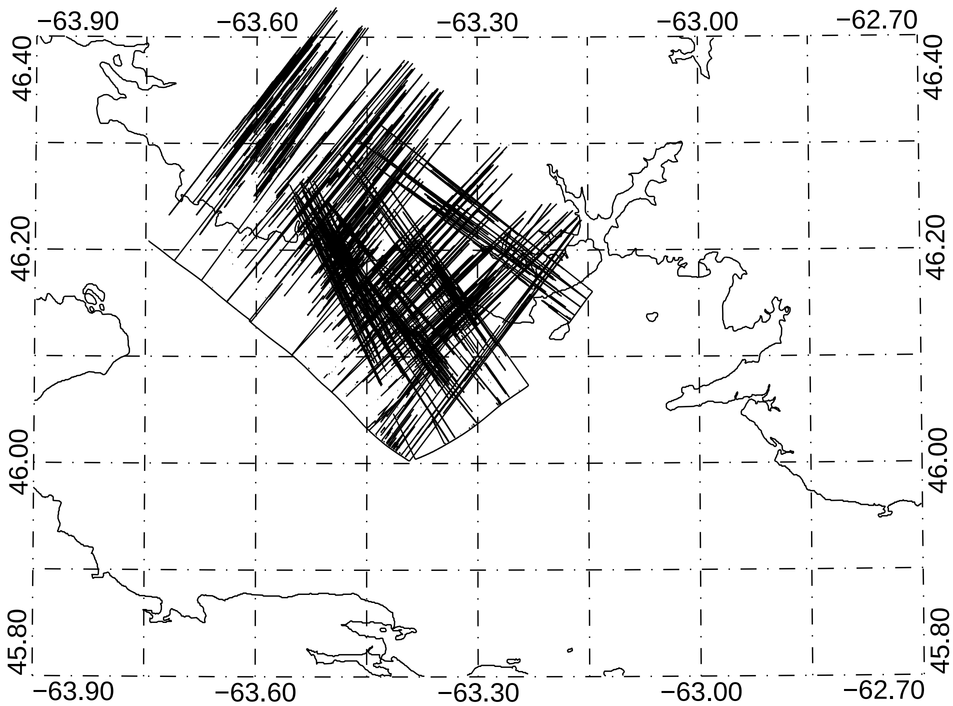
FEBRUARY 24, 1998 FLIGHT 22

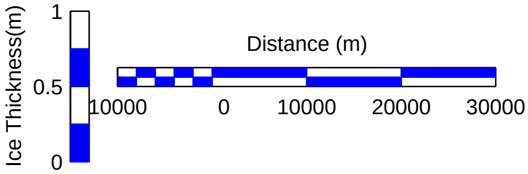
Lambert Conic Proj., Center Long.: −63.80, Lat1 49.00, Lat2 77.00

Ice Thickness 1 cm/0.5 m,Map Scale 1:1000000



MARCH 16, 1998 FLIGHT 47
Lambert Conic Proj., Center Long.: −63.40, Lat1 49.00, Lat2 77.00
Ice Thickness 1 cm/0.5 m,Map Scale 1:800000

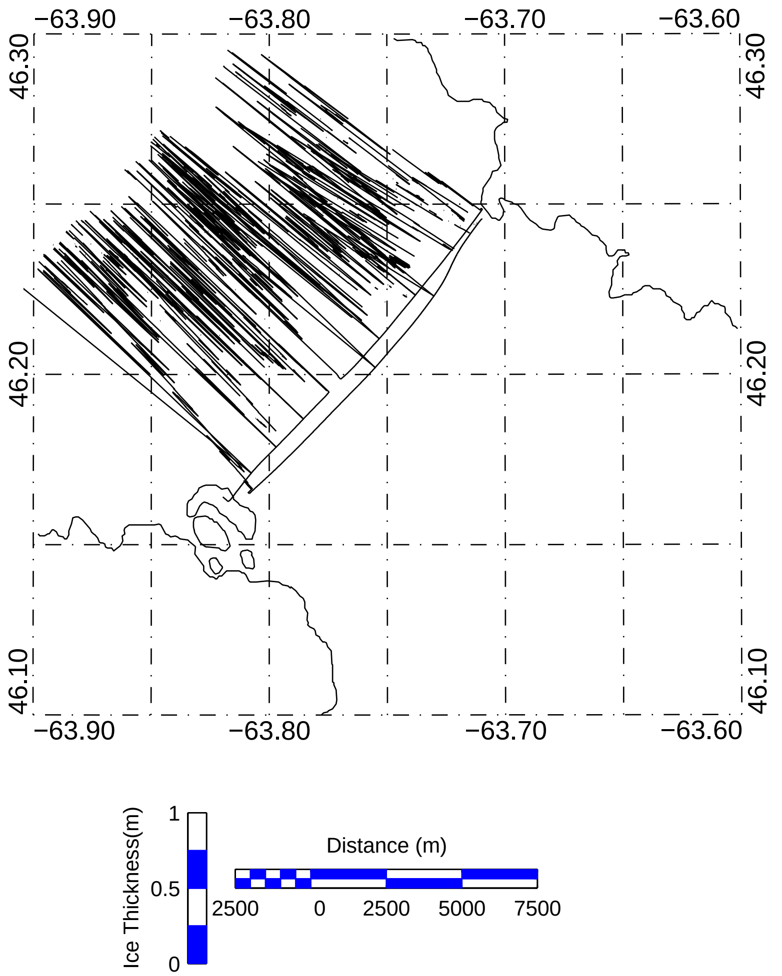




MARCH 16, 1998 FLIGHT 48

Lambert Conic Proj., Center Long.: −63.80, Lat1 49.00, Lat2 77.00

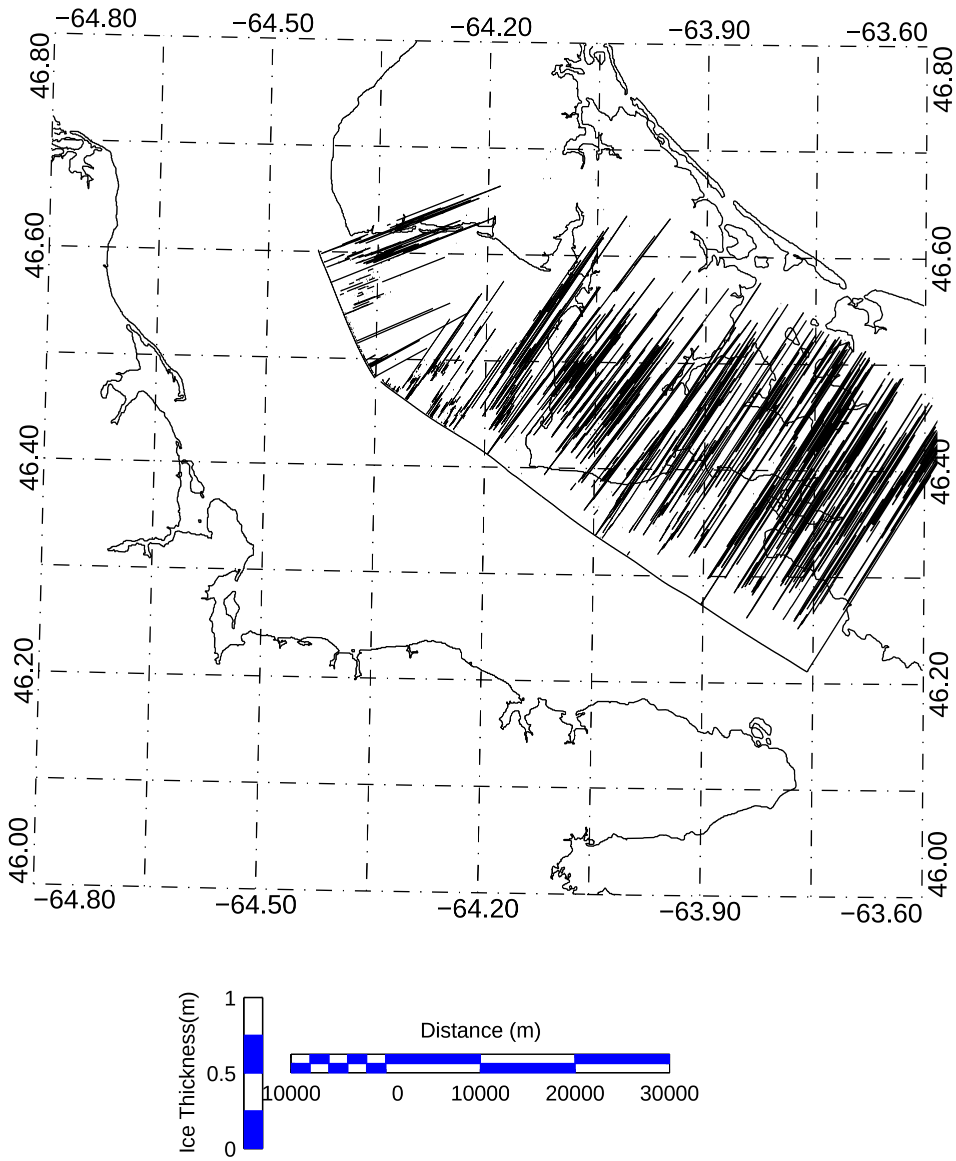
Ice Thickness 1 cm/0.5 m,Map Scale 1:250000



MARCH 16, 1998 FLIGHT 51

Lambert Conic Proj., Center Long.: −63.20, Lat1 49.00, Lat2 77.00

Ice Thickness 1 cm/0.5 m,Map Scale 1:800000

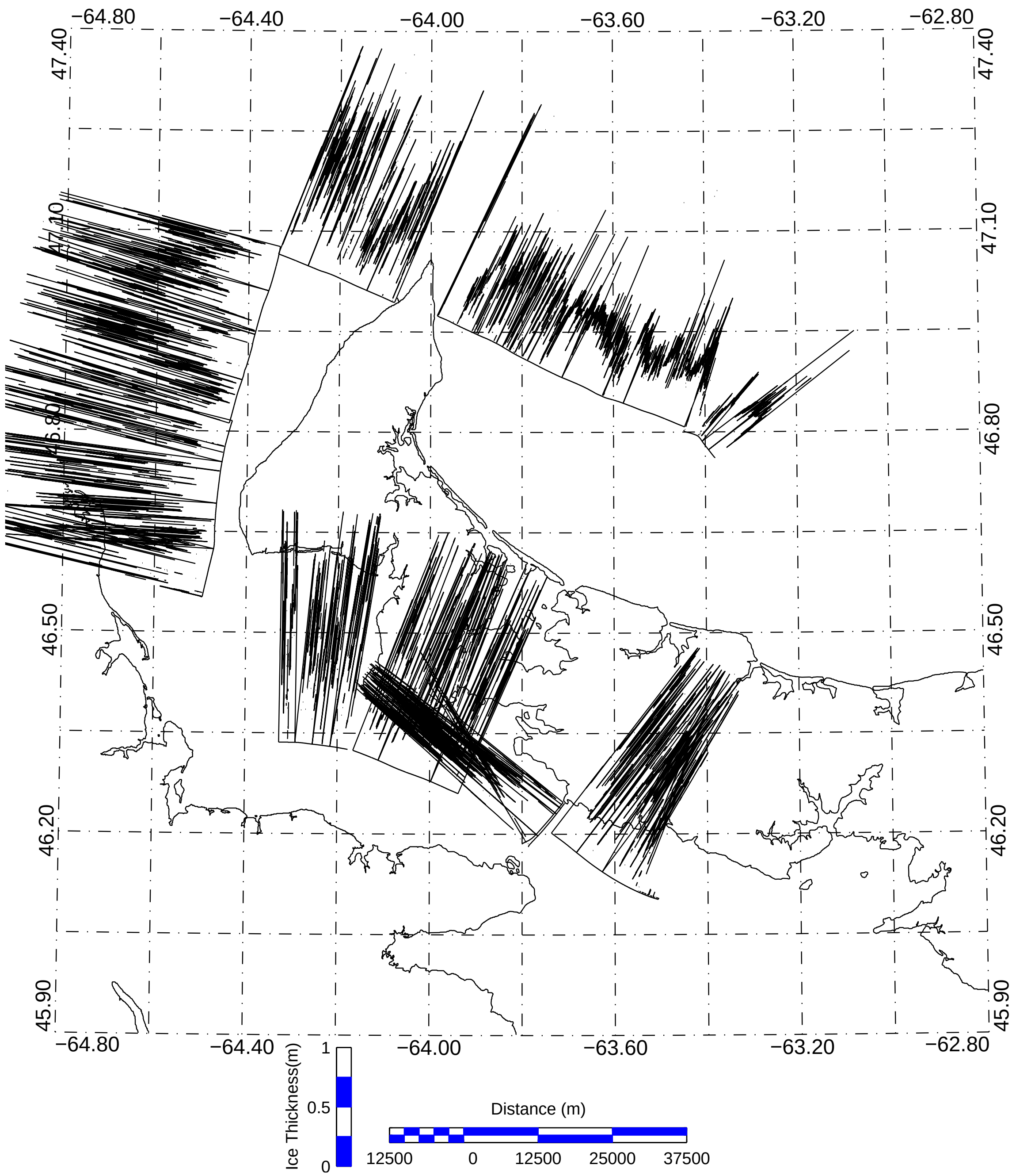


D-18

MARCH 16−17, 1998 SINGLE LINE FLIGHTS

Lambert Conic Proj., Center Long.: −63.80, Lat1 49.00, Lat2 77.00

Ice Thickness 1 cm/0.5 m,Map Scale 1:1000000

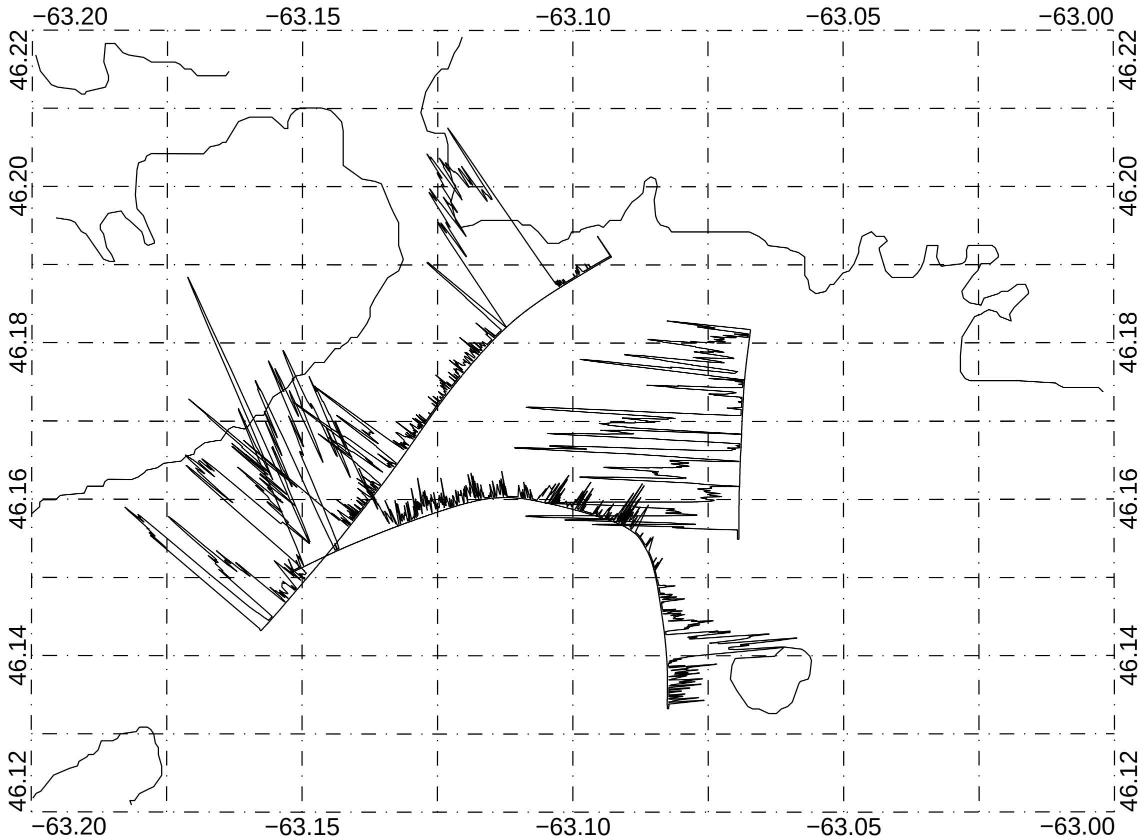


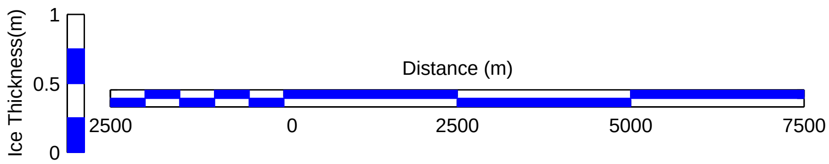
D-19

MARCH 18, 1998 FLIGHT 74

Lambert Conic Proj., Center Long.: −63.10, Lat1 49.00, Lat2 77.00

Ice Thickness 1 cm/0.5 m,Map Scale 1:100000



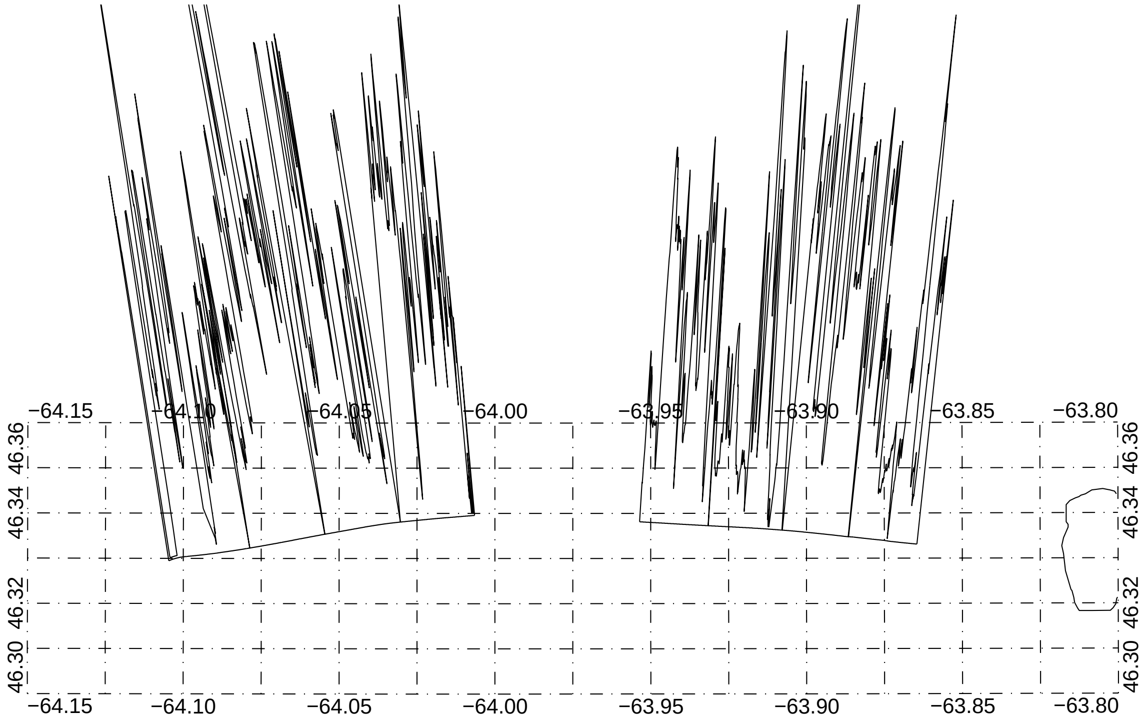


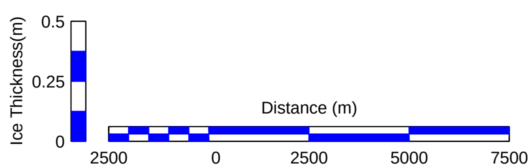
D-20

MARCH 18, 1998 FLIGHT 75

Lambert Conic Proj., Center Long.: −64.00, Lat1 49.00, Lat2 77.00

Ice Thickness 1 cm/0.25 m,Map Scale 1:150000



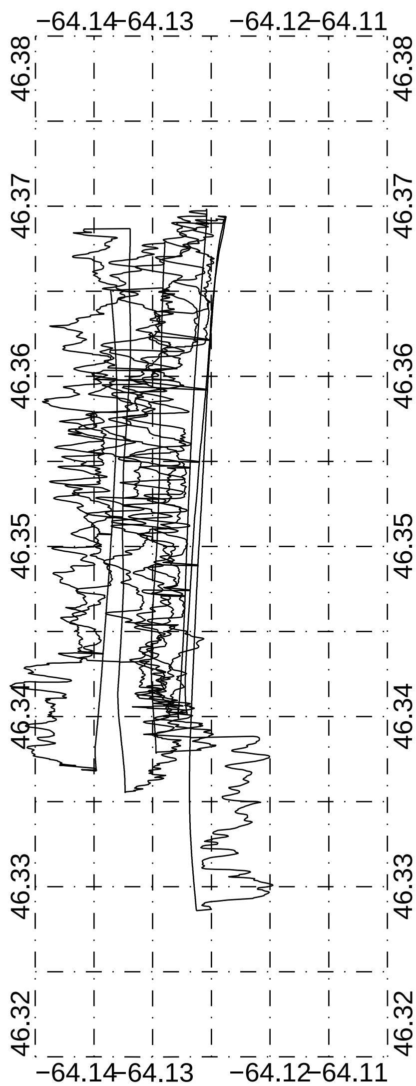


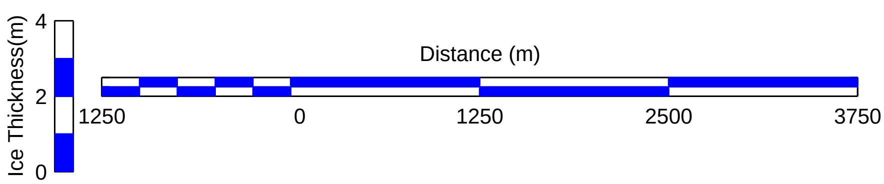
D-21

MARCH 18, 1998 FLIGHT 76

Lambert Conic Proj., Center Long.: −64.13, Lat1 49.00, Lat2 77.00

Ice Thickness 1 cm/2 m,Map Scale 1:50000



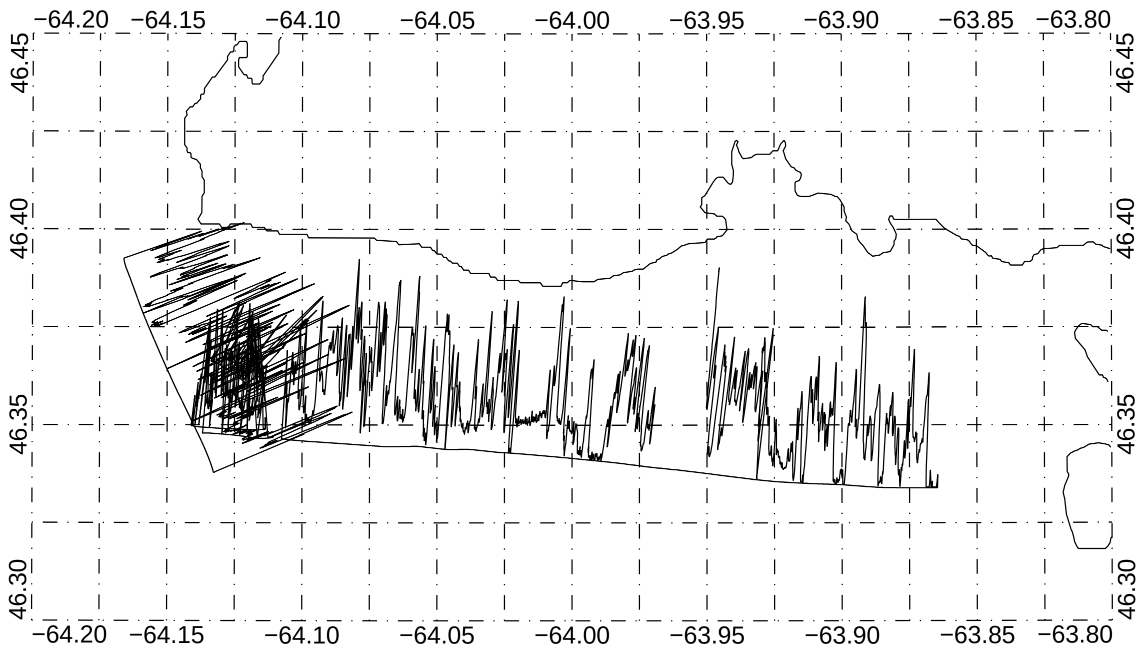


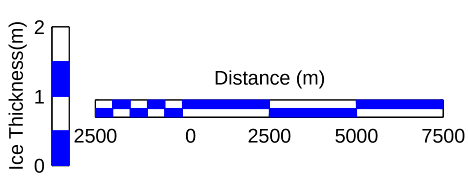
D-22

MARCH 18, 1998 FLIGHT 76

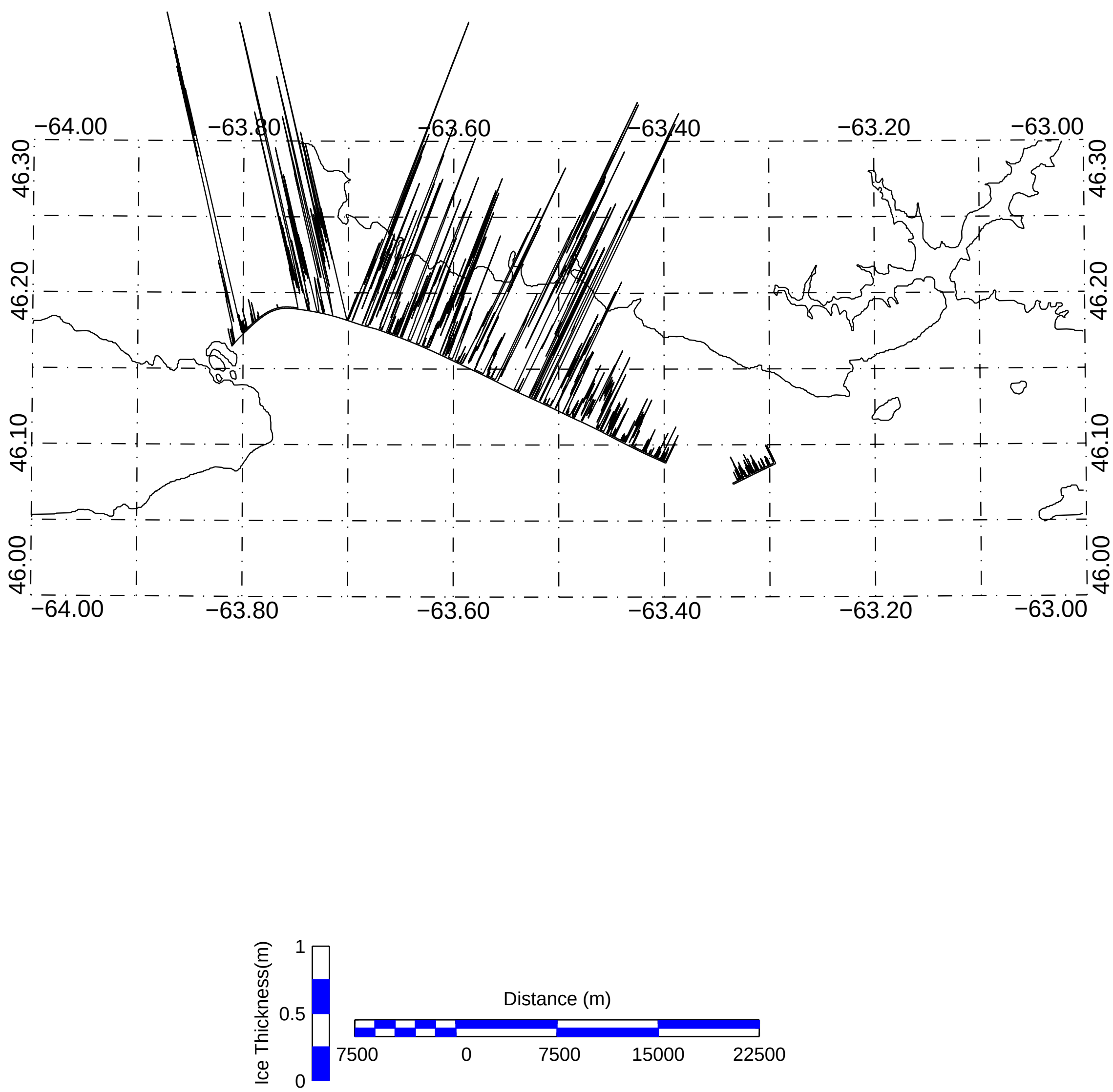
Lambert Conic Proj., Center Long.: −64.00, Lat1 49.00, Lat2 77.00

Ice Thickness 1 cm/1 m,Map Scale 1:200000

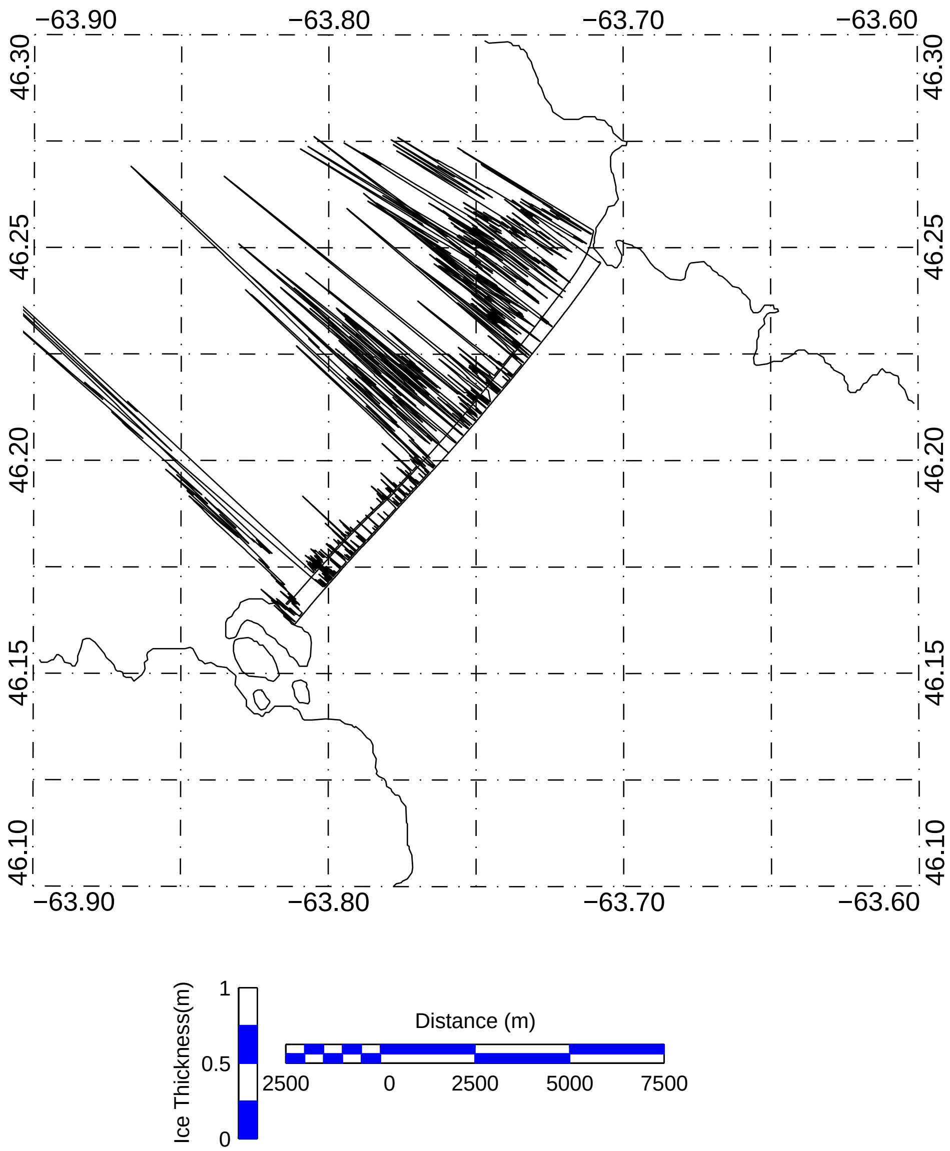




MARCH 19, 1998 FLIGHT 77
Lambert Conic Proj., Center Long.: −63.50, Lat1 49.00, Lat2 77.00
Ice Thickness 1 cm/0.5 m,Map Scale 1:500000



MARCH 19, 1998 FLIGHT 78
Lambert Conic Proj., Center Long.: −63.75, Lat1 49.00, Lat2 77.00
Ice Thickness 1 cm/0.5 m,Map Scale 1:200000

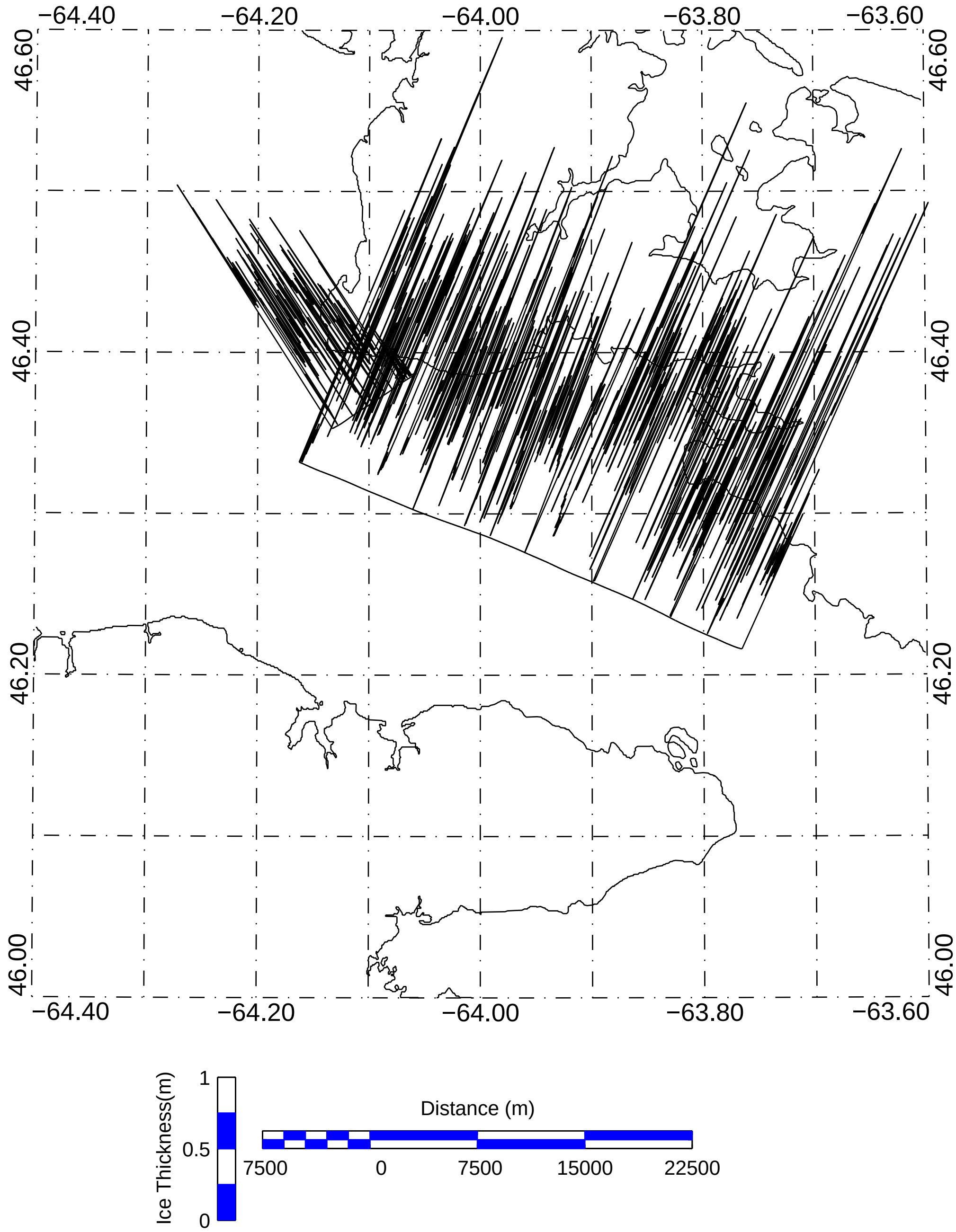


D-25

MARCH 19, 1998 FLIGHT 79

Lambert Conic Proj., Center Long.: −64.00, Lat1 49.00, Lat2 77.00

Ice Thickness 1 cm/0.5 m,Map Scale 1:500000

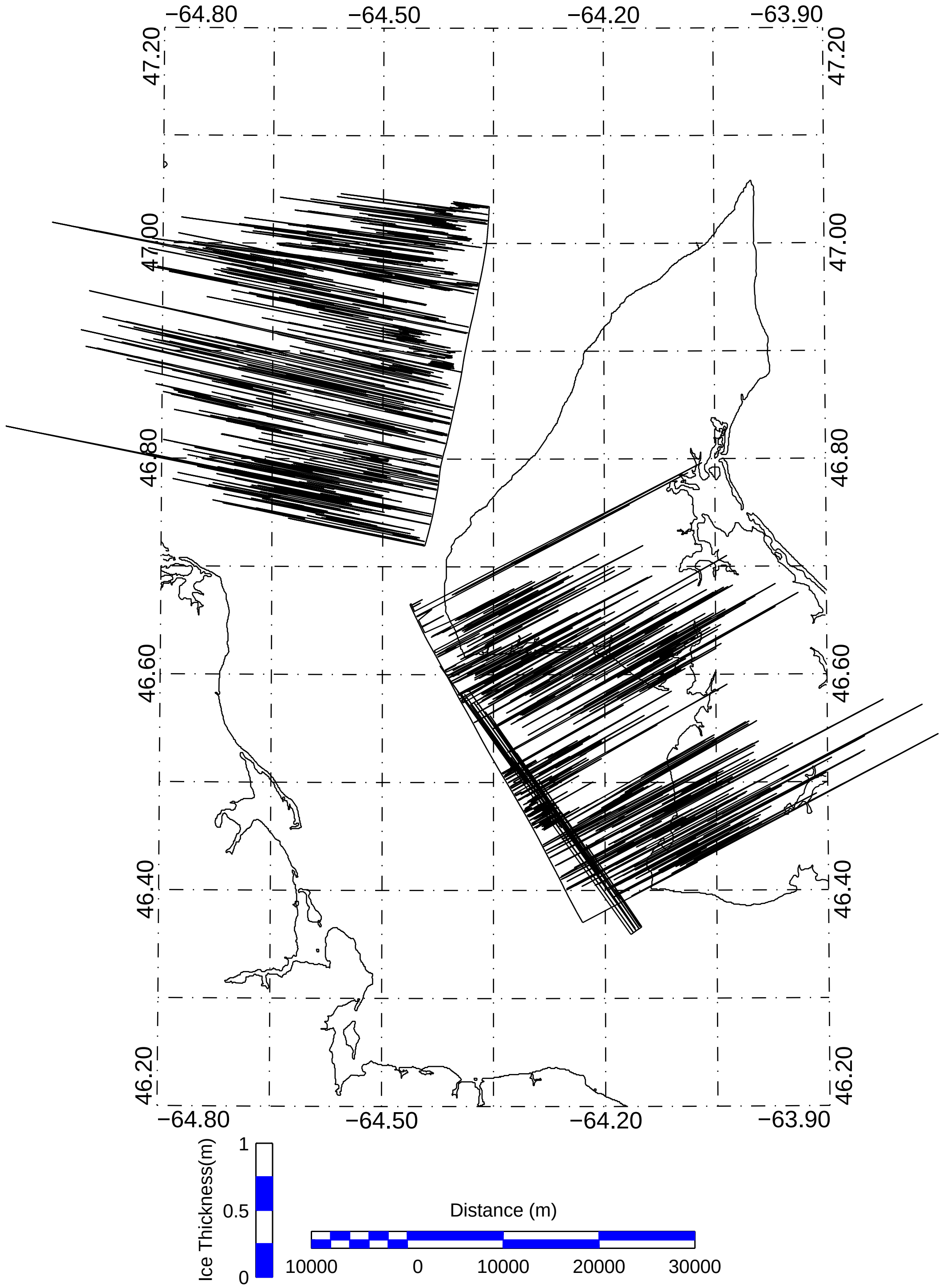


D-26

MARCH 19, 1998 FLIGHT 80

Lambert Conic Proj., Center Long.: −64.35, Lat1 49.00, Lat2 77.00

Ice Thickness 1 cm/0.5 m,Map Scale 1:700000

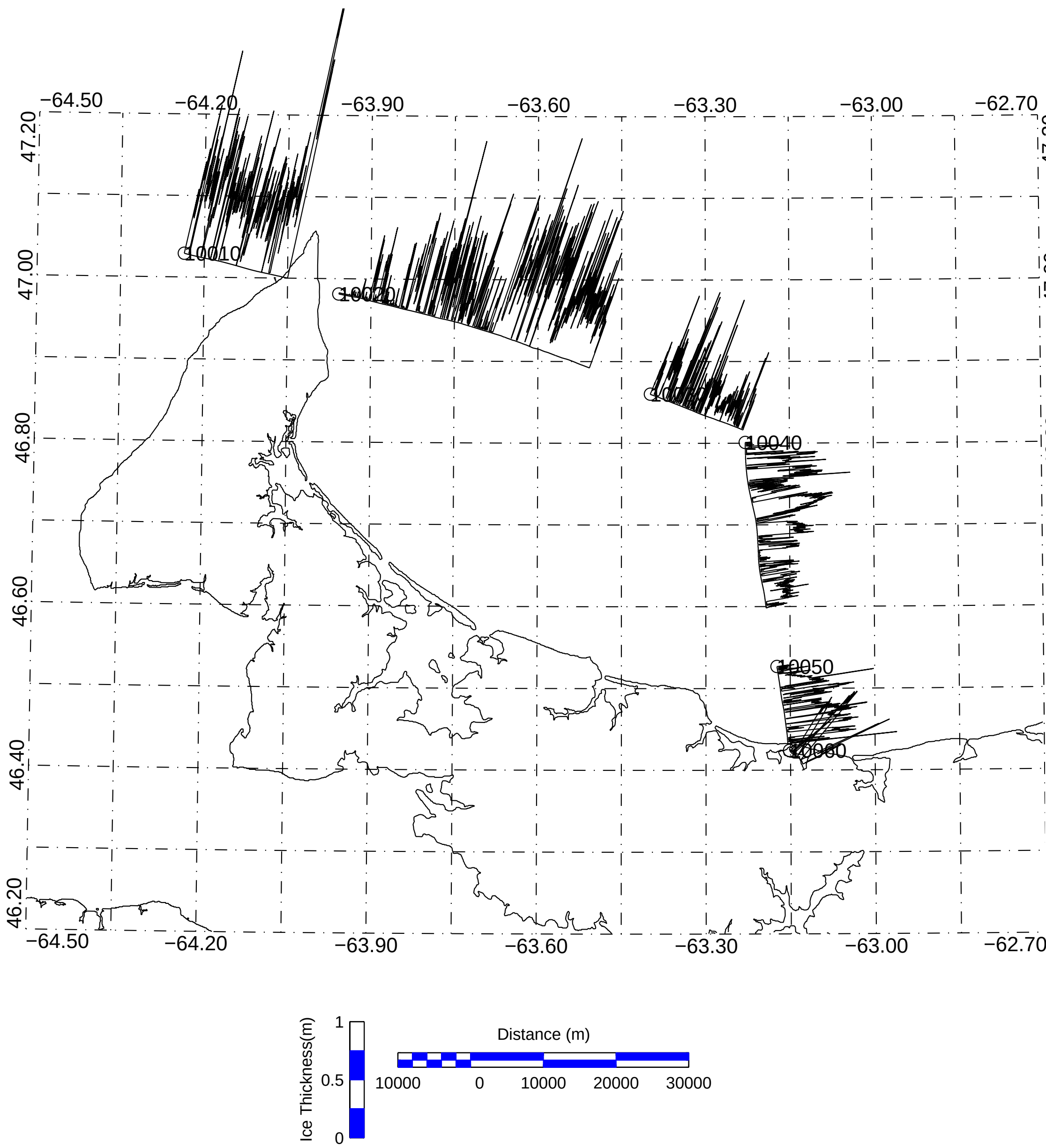


D-27

MARCH 19, 1998 FLIGHT 81

Lambert Conic Proj., Center Long.: −63.40, Lat1 49.00, Lat2 77.00

Ice Thickness 1 cm/0.5 m,Map Scale 1:800000

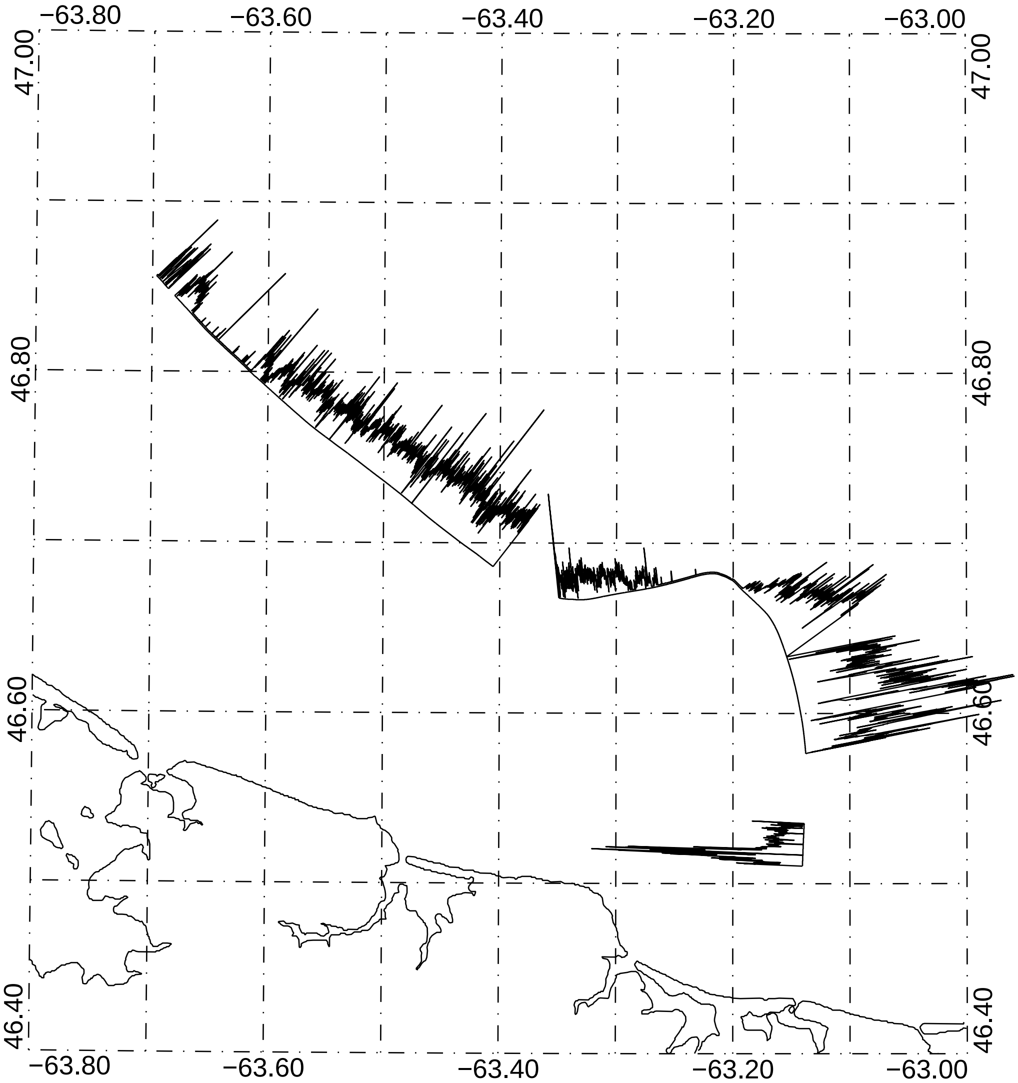


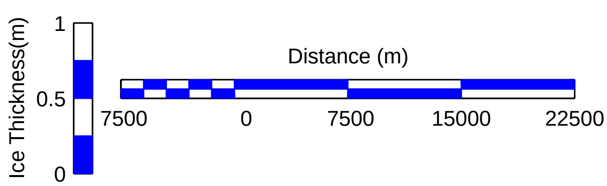
D-28

MARCH 24, 1998 FLIGHT 82

Lambert Conic Proj., Center Long.: −63.14, Lat1 49.00, Lat2 77.00

Ice Thickness 1 cm/0.5 m,Map Scale 1:500000



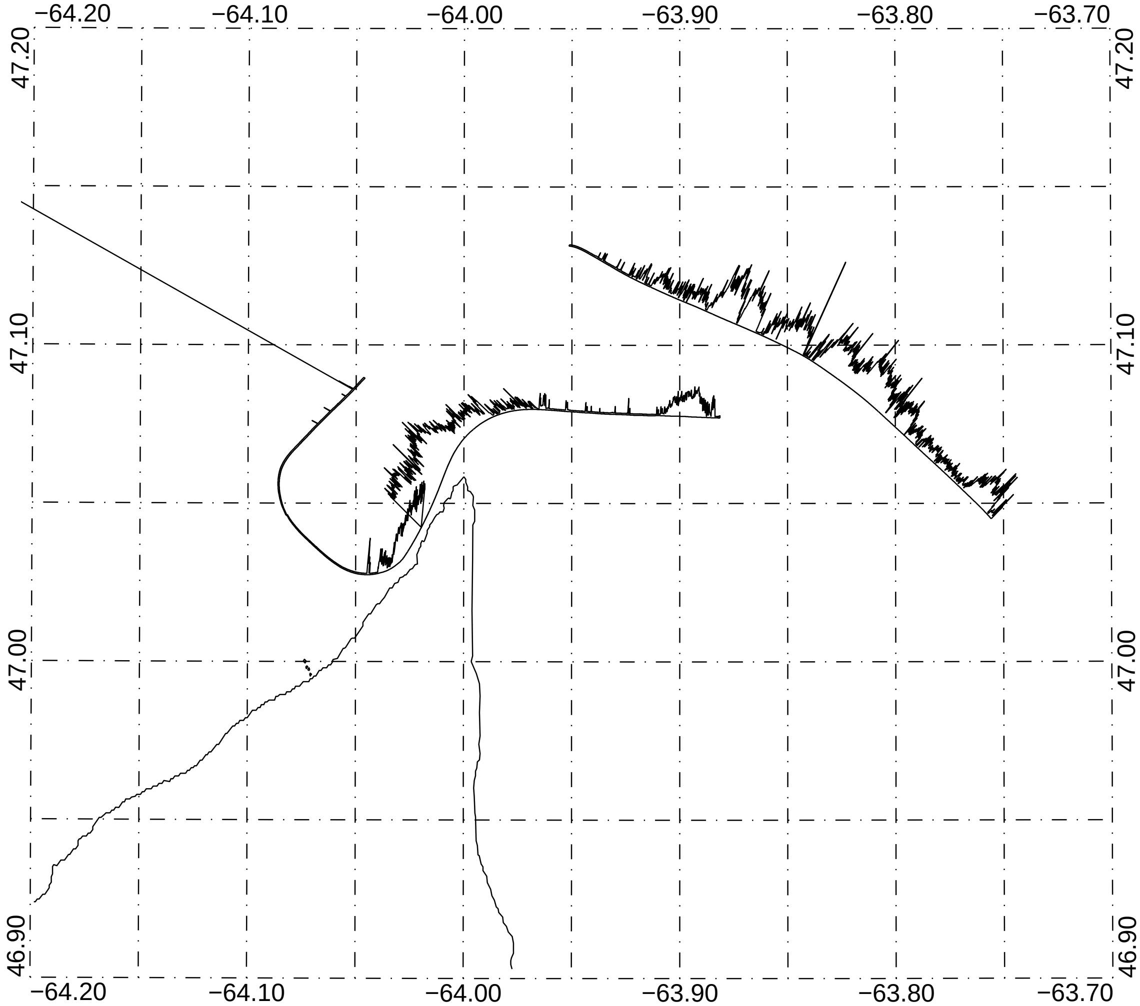


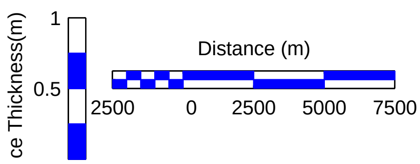
D-29

MARCH 24, 1998 FLIGHT 83

Lambert Conic Proj., Center Long.: −63.90, Lat1 49.00, Lat2 77.00

Ice Thickness 1 cm/0.5 m,Map Scale 1:250000



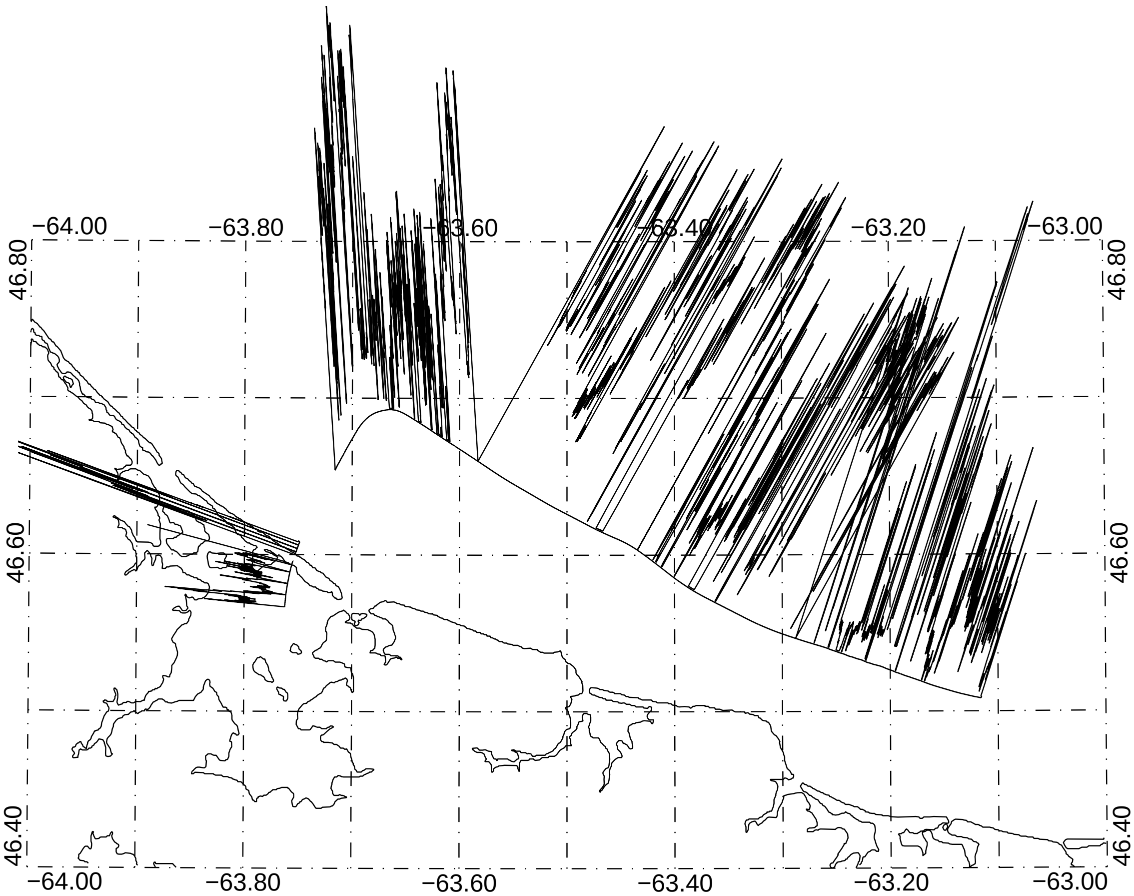


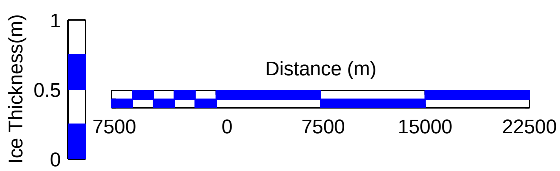
D-30

MARCH 24, 1998 FLIGHT 85

Lambert Conic Proj., Center Long.: −63.50, Lat1 49.00, Lat2 77.00

Ice Thickness 1 cm/0.5 m,Map Scale 1:500000





D-31

MARCH 24, 1998 FLIGHT 86

Lambert Conic Proj., Center Long.: −62.97, Lat1 49.00, Lat2 77.00

Ice Thickness 1 cm/0.5 m,Map Scale 1:100000