Measuring ice thickness with EISFlow™, a fixed-mounted helicopter electromagnetic-laser system

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ABSTRACT

A helicopter-borne ice thickness sensor, mounted on the nose of an MBB B0105 helicopter, was developed for the Canadian Coast Guard in support of its ice breaking operations. The sensor utilises low-frequency electromagnetic induction measurements, coupled with a precise laser altimeter, to measure snow plus ice thickness over seawater to centimetre-level accuracy with the helicopter skids on the ice. The system can also be operated in a profiling mode, yielding similar mean ice thickness accuracy over the sensor's footprint. For 1 m thick ice the footprint's diameter increases from 6 m for soft-landing to 12 m for profiling mode of operations. Soft-landing mode of observations are made with the helicopter's skids on the ice but not with the helicopter's weight on the ice.

KEYWORDS: Ice thickness; helicopter sensor; electromagnetic induction; laser; EISFlow™

INTRODUCTION

Helicopter Electromagnetic (HEM) technology has been a standard method of airborne geophysics (Palacky and West, 1991) to locate and characterise geoelectric features such as conductive ore bodies. Advances have been made in specialised data acquisition techniques and in subsequent 1D interpretation for layered structures. Towed HEM sensors typically consist of a set of transmitter and receiver coil sets that are mounted in a rigid cylindrical boom, known as a "bird" and slung beneath a helicopter on a "tow cable". One such system was developed for the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory for pack ice studies off the northern coast of Alaska (Kovacs and Holladay, 1989). More advanced systems have been used by the Canadian Coast Guard to measure ice thickness distributions along icebreaking routes (Holladay et al., 1997) and to validate ice features seen in RADARSAT imagery (Peterson et al., 1999). Bird pitch and roll, derived from a GPS attitude sensor within the bird, corrects the laser altitude used in the inverse data processing software. These systems both use towed-bird airborne electromagnetic technology, in which a sensitive, precisely calibrated transmitter/receiver package is carried approximately 30 m below a helicopter over the sea ice, at a bird altitude of approximately 15 m.

Fig. 1 "EISFlow™" Electromagnetic Induction sensor mounted on a Canadian Coast Guard B0105 helicopter onboard the CCG icebreaker *Edward Cornwallis*.

Towed-bird operations inevitably involve significant weight and aerodynamic drag, and require significant levels of training, support, and logistics. They have also proven unpopular with icebreaker captains, owing to the difficulty of controlling the bird during its landing on the flight deck and the subsequent complexities of moving the bird after the landing, while safeguarding its tow cable. Based on these considerations, it was decided to revisit the option of hard mounting the sensor on the helicopter. This paper describes the new fixed-mounted ice thickness sensor EISFlow™, collegially known as the "*Ice Pic*", tested during February and March of 2001 over the pack ice in the southern Gulf of St. Lawrence, Canada.

INSTRUMENTATION

Figure 1 shows the ice thickness sensor mounted to the front of a Canadian Coast Guard MBB BO105 helicopter onboard the CCG icebreaker *Edward Cornwallis* in the southern Gulf of the St. Lawrence. The sensor utilises electromagnetic induction measurements and precise laser altimeter readings to measure snow

Fig. 2 The hand-held operator's control unit on the front passenger seat with power and GPS input connectors to the helicopter shown in the background.

plus ice thicknesses over seawater. The electromagnetic induction system uses 1.7, 5.0, 11.7, and 35.1 kHz transmitter frequencies; has a coil separation of 1.2 m; and a footprint of approximately 2.5 times the sensor altitude above the seawater surface. The sensor altitude above the pack ice surface is 1.1 m with the helicopter skids on the surface, and the system's overall weight is 44 kg. Its real-time outputs include snow and ice thickness, ice conductivity, and laser altitude at a sample rate of 10 Hz. A small system console, strapped into the back seat of the helicopter, logs the data and controls the operation of the sensor by means of an operator control box from the front passenger seat of the helicopter (Fig.2).

It alerts the operator of system malfunctions, lets the operator control the start and end times of the system's operations and survey lines, and allows the operator to copy the resulting data files to a removable Zip^{TM} disk.

Validation

The system can be used to "spot" sample by soft-landing and averaging the incoming 10 Hz data, or to profile floes by flying slowly at low altitude over the floe. Sensor-measured ice thicknesses were compared to ice thicknesses made through ice-auger holes along a calibration line on land-fast ice. The ice-auger hole locations were 50 m apart and marked by black plastic bags filled with snow. At each bag, three snow depths and three ice thicknesses through separate ice holes were measured. Their averages along with the spot sensor data are shown in Table 1. Also shown are the mean and standard deviation for data at eight bag locations (#1 to #8) where sensor data was collected. Considering the variability in snow depths, there appears to be no difference between the spot sensor and the ice-auger hole measurements. This was also observed along a second calibration line on a thin refrozen lead with an average thickness of 24 cm.

Next, the sensor was tested and calibrated for low-level profiling over the same calibration lines. Figure 3 shows three profiles with the sensor at 1.6 m, 3.3 m, and 6.0 m above the ice surface. The calibration line ended at a ridge (-70 m) where a spot sample showed a thickness of 3.3 m; the ridge was not drilled (Table 1).

Table 1. Comparison of snow-plus-ice thickness data from ice-auger hole and sensor measurements.

Position (m)	Bag #	Snow (m)	Ice (m)	Holes (m)	Sensor (m)
-70	---	---	---	---	3.03
-60	---	0.16	0.64	0.80	---
0	1	0.10	0.45	0.55	0.56
50	2	0.15	0.48	0.63	0.65
100	3	0.10	0.45	0.55	0.53
150	4	0.09	0.52	0.61	0.61
200	5	0.15	0.62	0.77	0.73
250	6	0.14	0.52	0.66	0.63
300	7	0.06	0.52	0.58	0.55
350	8	0.11	0.48	0.59	0.59
400	9	0.17	0.46	0.63	
		Mean	1 to 8	0.62	0.61
		STD	1 to 8	0.07	0.06

The ice hole thicknesses measured at multiple points perpendicular to the line were used to compute mean ice thickness and error bars. The mean values are plotted as Xs and the top and bottom error bars by Δs. In addition, the spot samples of the sensor along the line are shown by circular symbols.

The ice-auger and spot samples compare well with the profile data. The profiles show good repeatability of the data regardless of the sensor height, which ranged from 1.6 m to 6.0 m, and would increase the sensor's footprint from 6.0 m to 17.0 m. This indicates that, at least along the calibration line, no rafts were present beneath this part of the land-fast ice.

Operational Use

Both the spot sample and the profiling modes were used during February and March of 2001 in the southern Gulf of St. Lawrence to support icebreaking operations and ice chart production. The real-time ice thickness data shown on the operator control box were used to quantify "ice types" reported by the "Ice Observer" of the Canadian Ice Service on his field sheets. Data from the surveys were also copied by the helicopter console to a Zip^{TM} disk which was then used to quickly quality check the data, produce plots, and e-mail plots and data files from the helicopter base to the Canadian Coast Guard and Canadian Ice Service forecasters.

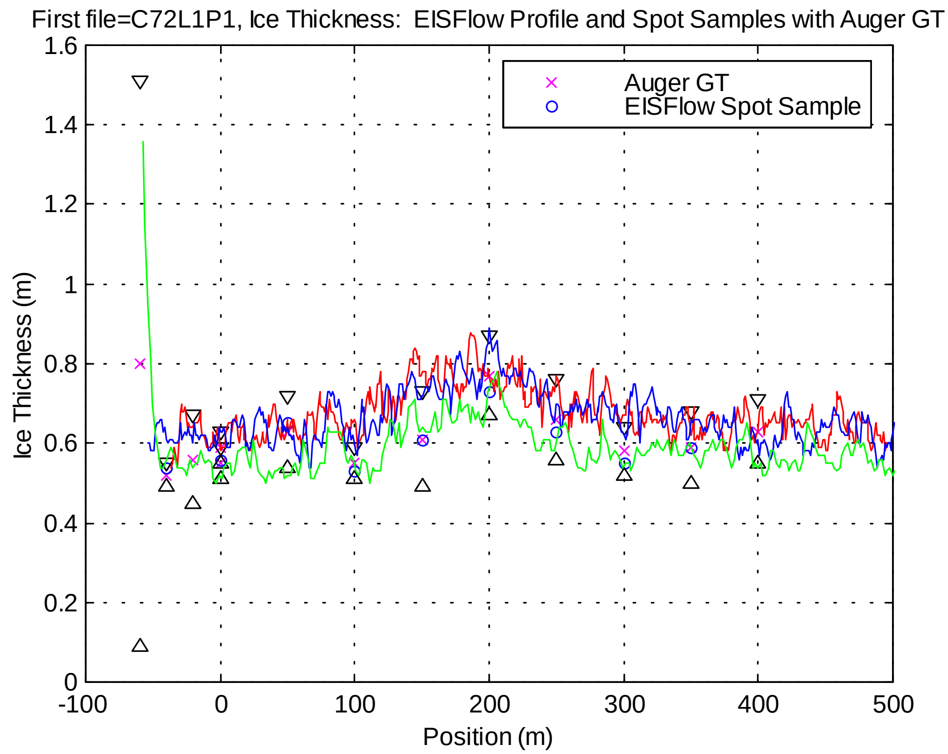

Fig. 3 Low-level flying ice thickness profiles (three heights) over marked calibration line. Ice-auger average ice thickness data (x) and error bars (Δ) shown along the line. The large variability in ice auger hole data is shown at the start of the ridge at -60 m.

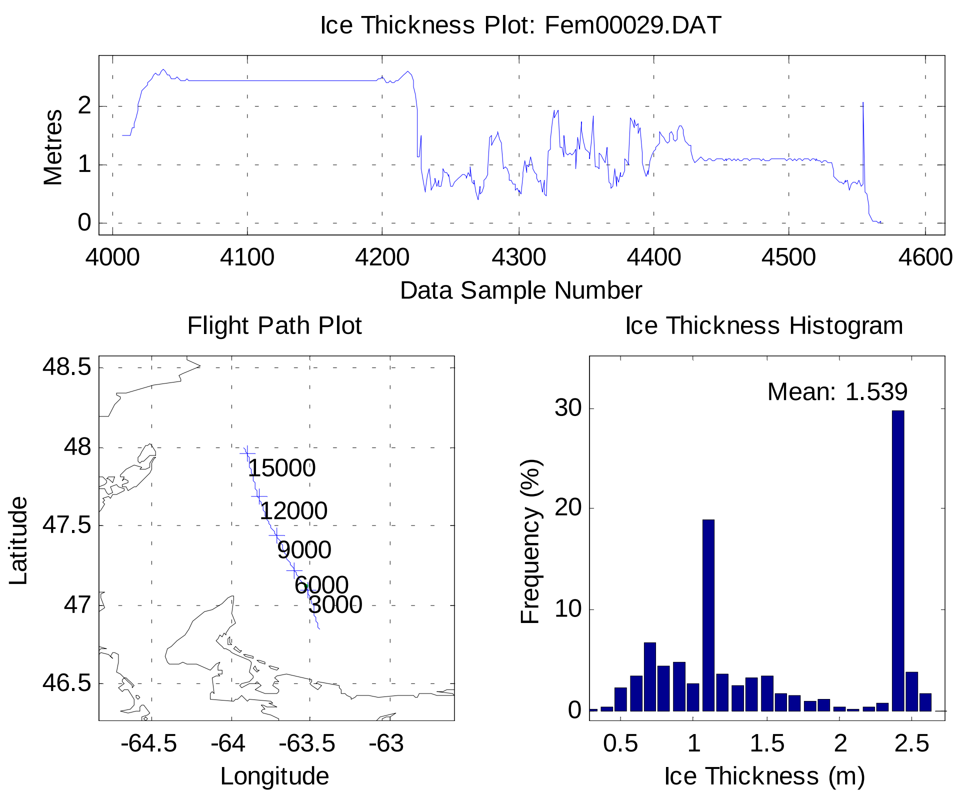

Fig. 4 Ice thickness profile and histogram covering two spot samples and area traversed between the two spot sample sites.

During an ice reconnaissance flight on February 16, 2001 north west of Prince Edward Island, the helicopter soft-landed twice to sample two adjacent floes characteristic of some of the thicker pack ice conditions in the area (Fig. 4). The total flight track is shown in the flight path map with sample numbers listed along the path. Only when the helicopter was below 9 m altitude were reliable data collected and logged. For this example data were logged between samples #4010 and #4560 and took only 55 seconds to complete at the 10 kHz sampling rate. Observed ice thicknesses are shown as a time series profile plot (top panel). With a horizontal time axis, the spot samples are shown as flat steps in contrast to the variable ice thickness conditions between the two floes (samples #4225 to #4425) when the helicopter was moving. At the first floe, the sensor sampled 150 times and provided a "sample average" ice thickness of 2.4 m. The second spot sample showed thinner ice (1.07 m) and was sampled 80 times in 8 sec. The ice thickness histogram, using all the data, is biased to the two spot samples.

On March 7, 2001 ice thickness distributions were collected along several long lines north of PEI over rough, rafted pack ice compressed against the coast (Fig. 5).

Fig. 5 Ice conditions as seen from helicopter at 2.5 m altitude along line shown in Fig. 6.

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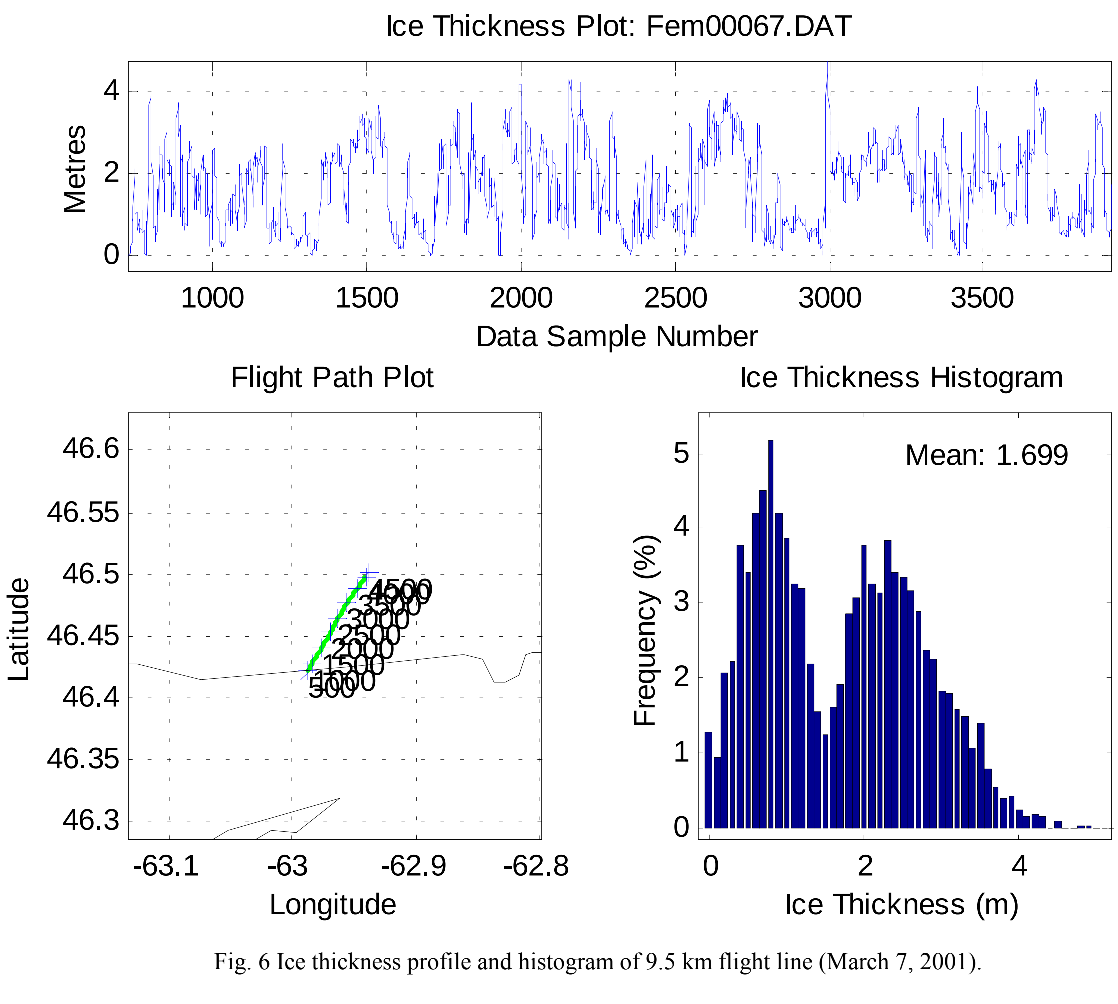

Fig. 6 Ice thickness profile and histogram of 9.5 km flight line (March 7, 2001).

Figure 6 shows the ice thickness data from the 9.5 km long centre line, collected with an average sensor altitude of 2.4 m above the pack ice surface. Some level, undeformed young ice, 35-40 cm thick and level, rafted older first year ice, 75-100 cm thick is present in between the thicker ice rubble (1.5 m – 4.5 m). The histogram in this case clearly shows the separation between the relatively level undeformed ice and the ice rubble even with the approximate 9 m footprint for ice 1.0 m to 1.5 m thick

The system in its present configuration can acquire representative thicknesses for all floating sea ice types, including first year, multi-year, and deformed ice such as ridges. It has not been ground-truthed over brash ice, which presents special challenges for this type of measurement, owing to its low electrical conductivity contrast with seawater and the transitional nature of the water-brash ice contact. The system will not measure the thickness of freshwater ice unless that ice is floating on seawater.

The maximum thicknesses that are measured over high-salinity ice or ice-water mixtures will be smaller than those for low-salinity ice such as second or multi-year. But this should only affect unconsolidated, heavily rubbled ice or brash, where the average conductivity of the ice-water mixture is a substantial fraction of the seawater conductivity.

Ridges are better defined by this instrument than they are for a towed bird, owing to the lower achievable sensor altitude and correspondingly smaller measurement footprint; the footprint diameter in this context is approximately 2.5 times the sum of ice thickness plus sensor height above the ice. In principal, the system should be able to measure 10 m ice thicknesses with 10% accuracy or better, although this has not yet been tested in the field.

CONCLUSIONS

The new helicopter fixed-mounted sensor proved to be an easy system to operate. Using DFO display and data transmission software, the data was distributed to clients within one hour upon landing at the helicopter base. Real time ice thickness values are also available to the operator during the survey flight for inclusion into ice chart field sheets. Ice thicknesses were measured to centimetre-level accuracy with the helicopter skids on the ice, compared to observations made through ice-auger holes. In profiling mode, observations yielded similar mean ice thickness accuracy at profiling heights of 1 m to 6 m. Its low weight and negligible impact on helicopter performance renders the new fixed-mounted sensor much more suitable than towed-sensor systems for operation from icebreakers and remote bases.

ACKNOWLEDGEMENTS

The authors thank the Canadian Coast Guard personnel, R. Moores and I. Henderson stationed at the CCG base in Charlottetown, PEI, for the mounting, testing, and operation of the new sensor. The project was supported with funds and logistic support by Canadian Coast Guard and with funds from Panel of Energy Research and Development.

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