Growth and Decay of Landfast, First-Year Ice near Nain, Labrador.
Johnston, Michelle
GROWTH AND DECAY OF LANDFAST, FIRST-YEAR ICE NEAR NAIN, LABRADOR

M.E. Johnston

Canadian Hydraulics Centre, National Research Council Canada
Ottawa, Ontario, Canada

ABSTRACT

Property measurements made in level landfast first-year ice from six sites within a 20 km radius of Nain are presented. Measurements were made during four site visits, from early February to mid-May, 2004. Three of the examined sites were located along the proposed shipping route to Voisey’s Bay Mine, in Edwards Cove. Rapid changes in air temperature were noted to have a visible effect on the ice conditions. Ice thickness ranged from 0.41 to 0.65 m in February and had increased to 0.95 to 1.28 m by May. By May, the ice showed clear signs of seasonal decay. The ice desalinated throughout its full thickness, it became isothermal at near-melting temperatures, and it showed a 20 to 60% reduction in its in situ strength.

INTRODUCTION

In the year 2000, the Canadian Hydraulics Centre (CHC) of the National Research Council Canada (NRC) began conducting measurements on decaying Arctic first-year sea ice. The measurements were undertaken to provide much needed information about the properties of the ice during summer, which was then used as input for the Arctic Ice Regime Shipping System (AIRSS), in terms of how that system accounts for ice decay (Timco et al., 2004). To date, three seasons of measurements have been conducted on Arctic first-year ice (Johnston et al., 2001; 2002 and 2003). One direct outcome from that work has been the Ice Strength Charts that the Canadian Ice Service issues for level, landfast first-year ice in the Arctic (Gauthier et al., 2002; Langlois et al., 2003).
FIRST-YEAR ICE IN THE SUB-ARCTIC

The past three years of fieldwork provided much needed information about the changes that occur in ice during summer, and how those changes relate to the in situ strength of the ice. Relating those measurements to ice in more temperate regions below the Arctic Circle is more difficult, however. That is because relatively few measurements have been conducted on sub-Arctic ice, as indicated in Johnston and Timco (2004).

Realizing there was a paucity of information about the properties of sub-Arctic ice, the focus of the measurement program shifted from Arctic ice to level, landfast first-year ice near Nain, Labrador (56.53°N, 61.68°W). That area of the sub-Arctic was selected for three reasons. Transport Canada wanted to determine the affect that temperate ice had on shipping, the Canadian Ice Service (CIS) wanted to extend the scope of their Ice Strength Charts to include level, landfast first-year ice in the sub-Arctic, and developments in Voisey’s Bay would result in increased shipping to that area.

Site Location

Property measurements were made of landfast first-year ice near Nain from February to May 2004. Sites were sampled along the two transects shown in Figure 1. The first transect was in Strathcona Run, along the ‘traditional’ shipping route to Nain. The second transect was made about 15 km south, on the approach to Anaktalak Bay, which is the proposed shipping route to Voisey’s Bay Mine site (Rowell and Metcalf, 2005). A transect of ten sites, spaced at 1 km intervals, was mapped in the level, landfast first-year sea ice of Strathcona Run and Anaktalak Run. Johnston (2005-a) provides a record of the coordinates for each site. Six of the sampling sites are discussed in this paper: S2, S6, S10 and A2, A6 and A10.

![Figure 1 Site locations in Strathcona Run and Anaktalak Run](image-url)
Sampling Methodology

At each site, a motor driven, fibreglass corer was used to make three boreholes in the ice (0.15 m diameter), each at least 2.0 m apart. The ice thickness, freeboard and snow depths were measured at each borehole. The core from the first hole was used to measure the ice temperature profile using a calibrated Fluke 73 multimeter with an attached 80T-150U temperature probe. The probe was inserted into small holes made in the core at depth intervals of 200 mm (100 mm for the thinner ice in February). The Fluke temperature probe has limited accuracy (+/- 2°C) when the temperature of the ice approaches its melting point.

The ice temperature was also measured from temperature chains that were installed in the ice at S7 and A1. The chains measured the in situ temperature of the air, snow and ice at 30 minute intervals, from 1 February to 14 May, when the chains were removed (Johnston, 2005-a). The temperature chain at S7 measured the temperature of the ice at depth intervals of 200 mm, to a depth of 1.4 m. The chain at A1, which was initially intended for ridged ice, measured the ice temperature at 100 mm depth intervals to an ice depth of 0.30 m, and at 200 mm intervals below that depth. Temperature chains were installed at two locations to enable a regional and temporal comparison of ice temperatures.

Salinity measurements were made by cutting small pie-shaped discs, about 20 mm thick, from the core at 200 mm intervals (100 mm intervals in February). The sections were cut and bagged as quickly as possible to minimize brine drainage. After the bagged samples had melted, at room temperature, an Orion model 105A portable conductivity meter (accuracy 0.5%) was used to measure the salinity of the melt water.

The NRCC borehole indentor was used to measure the in situ borehole strength of the ice. The NRCC borehole indentor consists of a high-strength stainless steel hydraulic cylinder with a laterally acting piston and two indentor plates, both of which are curved to match the wall of the borehole (Sinha, 2005). A 10,000 psi electro-hydraulic pump, with an average flow rate of 20 in³/min, was used to activate the two pistons inside the body of the indentor and extend both indentor plates. An external digital data acquisition system is used to record the displacement of each indentor plate and the oil pressure during the test. The pressure and indentor displacement were also monitored throughout the test with a handheld keypad to ensure that the 10,000 psi capacity of the system was not exceeded, and that the 50 mm total diametrical displacement (the limit of the stroke ram) was approached, but not exceeded. After each test, the indentor plates were fully retracted, the borehole indentor was rotated 90° and the test unit was lowered to the next depth. Strength tests were conducted at depth intervals of 0.30 m, until the bottom of the ice was reached.
The ice borehole strengths reported in this paper used a conversion factor of 0.56 to convert the measured oil pressure to an ice pressure. The conversion factor was determined from the ratio of the area on which the hydraulic fluid acts (3768 mm²) to the surface area of the indentor plate (6692 mm²). All ice borehole strengths in this paper are given for an indentor penetration of 3 mm (Johnston et al., 2001) and are compensated for the stress-rate effect using the procedure outlined in Johnston et al. (2003). Studies have shown that the ice borehole strength is almost twice that of the confined compressive strength of the ice measured in the laboratory (Sinha, 1986) and three to four times greater than the ice strength measured in unconfined tests (Masterson, 1996; Sinha, 1986).

SEASONAL CHANGES IN ICE CONDITIONS

The photographs in Figure 2 show the very different ice conditions that characterized the ice in Anaktalak Run from February and May. Similar conditions were observed in Strathcona Run, as illustrated in the following discussion.

February

The morning of 1 February (Julian Day JD32) was spent freezing a temperature chain into the ice at S7, which was located far enough from the community to avoid interfering with snowmobile traffic (Figure 1). The next day, a temperature chain was installed in the ice in Anaktalak Run, 35 km south of Nain (at site A1, Figure 1).

Figure 2  Evolution of ice surface conditions in Anaktalak Run from February to May
The ice at S8, S9 and S10 was sampled on the afternoon of JD32, when air temperatures ranged from -2.6 to -3.5°C. The ice at S1 to S6 was sampled the following afternoon, on 2 February (JD33) at air temperatures ranged of -5.5 to -6.8°C. In February, the ice thickness at the ten sites in Strathcona Run ranged from 0.47 to 0.65 m, and snow thicknesses ranged from 0 to 80 mm. Figure 3-a plots the three-hole average of the ice thickness measured at S2, S6 and S10.

On February 3 (JD34) the properties 10 sites in Anaktalak Run were measured. Air temperatures were from -8.5 to -11.5°C during sampling. Although the snow and ice thicknesses were measured at all ten sites, the temperature and salinity profiles were measured at only the even-numbered sites (due to the limited amount of daylight that is available that time of year). Ice thickness in Anaktalak Run varied from 0.41 to 0.55 m, with snow thicknesses from 0 to 100 mm. Figure 3-b shows measured snow and ice thickness at sites A2, A6 and A10.

![Figure 3](image)

Figure 3  Snow and ice thickness in (a) Strathcona Run and (b) Anaktalak Run

**March**

Strathcona Run was next visited on 25 March (JD85), when strength tests were added to the suite of property measurements. On 25 March, the strength tests in the third hole at S2 were abruptly terminated when the rented generator failed to power the system. Strength tests were completed at S6, S8 and S10 the following day. Air temperatures ranged from -1.8 to +8.5°C during those two days. Ice thickness at the ten sites in Strathcona Run ranged from 0.74 to 0.95 m, with snow depths from 80 to 410 mm. Figure 3-a shows the three-hole average of snow and ice thickness for sites S2, S6 and S10.
On 27 March (JD87), the ice in Anaktalak Run was sampled. Air temperatures ranged from -5.1 to -8.6°C during sampling. In March, the ice thickness in Anaktalak Run ranged from 0.71 to 0.90 m, and snow depths were from 0 to 360 mm. No strength tests were conducted that day because, once again, generator problems plagued the test program. Borehole strength tests were conducted successfully at A2, A6 and A10 the following day (JD88), using a different generator. Figure 2-b shows measurements being made at A6. The photograph shows the chunk of snow (with a hole in it) that was dislodged during the coring process. The nicely sculpted snow illustrates how densely packed the snow cover was in March.

April

The third trip to Labrador was made in April, with a new 2600 W generator in tow. Because the clear and cold conditions on April 16 (JD107) made excellent travelling weather, the more distant sites in Anaktalak Run were sampled first. While attempting to take the second core at A2, the recoil mechanism for the corer motor broke. Realizing that a motor would be needed for the tests planned in the considerably thicker hummocked ice (Johnston, 2005-b), the field party returned to camp to see what could be done. Although parts were not available in that remote location, fortunately a resident of Nain had a motor that fit the core barrel. Measurements continued the next day.

Sites S2, S6 and S10 were sampled on the morning of 17 April (JD108). The skies were clear and the air temperature was -9.7°C when sampling began at about 09:00 hrs. By the time measurements at S10 had been completed (13:00 hrs), the air temperature had increased to +4.9°C. Ice thickness at the three sites in Strathcona Run ranged from 0.85 to 0.98 m, with snow depths of 90 to 290 mm (Figure 3-a). That afternoon, a trip to Anaktalak Run was made, to continue the work that had been interrupted on the previous day. Warm air temperatures persisted into the afternoon, with temperatures of +6.0°C at A10 (14:00) and temperatures of +5.3°C at A6 (16:00 hrs). Ice thickness at A2, A6 and A10 ranged from 0.85 to 1.04 m, with snow depths from 110 to 290 mm (Figure 3-b).

May

The fourth and final trip to Labrador was made in mid-May, by which time the snow cover had melted almost completely and the ice surface had a considerable amount of surface ponding (Figure 2-d). Because the surface conditions made traveling by snowmobile extremely difficult, the ice in Strathcona Run and Anaktalak Run was sampled on one of the few days that the ice could be accessed: 14 May (JD135). Evidently, the ice had been covered with up to 0.30 m of standing water the day before (R.Webb, personal communication). Much of that surface water had drained through the ice when the sites were visited on 14 May.
Sites A2, A6 and A10 were sampled on the morning of 14 May (JD135), under sunny skies, no wind and air temperatures from +1.2 to +5.2°C. Ice thickness at A2, A6 and A10 was from 0.97 to 1.22 m, and snow depths were from 0 to 90 mm. The three sites in Strathcona Run were sampled on the afternoon of 14 May, when the air temperature was about +3°C. By that time, the clear skies of the morning had clouded over, the wind was increasing, and it was threatening to rain. The ice thickness at S2, S6 and S10 ranged from 0.89 to 0.99 m, with snow depths from 0 to 60 mm.

**DEPTH PROFILES OF ICE TEMPERATURE**

Figure 4 shows the *in situ* ice temperatures measured by the temperature chains at S7 and A1 on 3 February (JD34), 25 March (JD85), 17 April (JD108) and 13 May (JD134). Measurements from the temperature chains were used, rather than from the extracted ice cores, because the *in situ* measurements are believed more accurate. The temperatures in Figure 4 are reported for 06:00 hrs, a time when the ice temperature was considered to be more stable (than later in the day).

![Figure 4 In situ ice temperatures at (a) site S7 and (b) site A1](image_url)

On JD34 the top surface of ice at S7 was several degrees colder (-11.9°C) than the top ice at A1 (-5.2°C). Snow and ice thicknesses were respectively 50 mm and 0.50 m at S7, and 40 mm and 0.44 m at A1. By March (JD85), the top ice surface at S7 was -6.5°C and the top ice at A1 was -6.3°C. Both sites had a snow thickness of 175 mm, however the ice at A1 was about 100 mm thicker than the ice at S7. In April (JD108), the ice at both S7 and A1 had warmed throughout their full thickness. The top ice surface at S7 was -2.5°C and the top ice at A1 was -2.3°C. Snow and ice thicknesses were 176 mm and 0.87 m at S7, and 260 mm and 0.88 m at A1 on JD108.
When the temperature chain was removed from S7 on the afternoon of 13 May (JD134), the overlying snow cover had completely melted, leaving the ice surface exposed (as shown by the above-zero temperatures). The in situ temperature measurements in Figure 4-a showed that the full thickness of ice had isothermal, near-melting temperatures. The full thickness of ice at A1 also had isothermal, near-melting temperatures on JD134, despite the presence of a 140 mm thick snow cover.

DEPTH PROFILES OF ICE SALINITY

Figure 5 shows the ice salinity profiles for S2 and A2 from February to May. In February (JD33), the interior regions of ice at S2 had a salinity of 4.2 to 4.4 ‰, with a slightly lower salinity at the top ice surface, and a higher salinity at the bottom ice surface (Figure 5-a). By mid-May (JD108), ice at S2 had a salinity of 8.8 ‰ at a depth of 1.0 m, yet the uppermost 0.20 m of ice had little or no salinity. The ice at A2 showed a less clear trend of seasonal desalination, compared to ice at S2. Only in mid-March (JD85/87) did the ice at S2 and A2 show the classic ‘C-shaped’ salinity profile that is so characteristic of first-year ice in the high Arctic (Sinha and Nakawo, 1981).

![Figure 5 Salinity of ice at (a) site S2 and (b) site A2](depth of zero indicates top surface of ice cores)

DEPTH PROFILES OF ICE BOREHOLE STRENGTH

Figure 6 shows results from the borehole strength tests conducted at S2 and A2 in March, April and May. The number adjacent to the data point was used to note the number borehole tests conducted at each test depth (in different holes). The strengths reported in the figure are the average of the strength measured in each borehole, at a particular depth.
On 25 March (JD85), ice at S2 had a borehole strength of 15.6 MPa and 13.0 MPa at depths of 0.30 m and 0.60 m respectively. The ice strength at a depth of 0.90 m was considerably lower (4.7 MPa) because the ice thickness was 0.93 m. By mid-April (JD108), the ice at S2 had increased in thickness to 0.97 m, but its strength had decreased to 5.5, 7.8 and 4.3 MPa at depths 0.30, 0.60 and 0.90 m, respectively. When the ice at S2 was sampled on 14 May (JD135), it had decreased in thickness to 0.93 m, and its strength had decreased to 3.3, 4.8 and 2.7 MPa at depths 0.30, 0.60 and 0.90 m respectively.

Figure 6  Strength of ice at (a) site S2 and (b) site A2
(bars show standard deviation, number of tested boreholes shown next to data point)

In March, the ice at A2 (at depths 0.30 and 0.60 m) had a strength that was about 3.3 MPa lower than at S2. That is to be expected, since the ice at A2 was considerably thinner and had a slightly thicker snow cover (0.78 m and 17 mm) than the ice at S2 (0.93 m and 9 mm). In mid-April (JD107), ice at A2 was 0.88 m thick, had a 19 mm snow cover, and strengths of 5.7 and 8.3 MPa at depths 0.30 and 0.60 m respectively. It is interesting to note that on JD107, the strengths at both test depths at A2 were higher than at S2, even though the ice was thinner (0.88 m at A2 vs. 0.97 m at S2). By mid-May (JD135), the ice at A2 had decreased in strength, compared to March. Whereas the ice at S2 had begun to decrease in thickness when the last measurements were made in May, the ice at A2 had not. Similarly, the ice at A2 had a higher strength throughout its full thickness, than the ice at S2. The ice at A2 tended to retain its strength longer than the ice at site S2, which is likely due to the protective effects of the overlying snow cover (90 mm at A2 and 0 mm at S2) and different ice thicknesses (1.08 m at A2 and 0.89 m at S2).
CONCLUSIONS

Ice property measurements were made, from early February to mid-May, at various sites along two transects in landfast, first-year ice near Nain, Labrador. The two transects were about 15 km apart. Ice conditions changed dramatically from February to May, which can be attributed, in part, to the rapidly changing air temperatures that characterize the region. Ice thicknesses in February ranged from 0.41 to 0.65 m and snow thickness from 0 to 100 mm. In May, ice thickness ranged from 0.89 to 1.20 m, and the snow thickness from 0 to 70 mm. Ice along both transects showed clear signs of decay as the season advanced. Salinity decreased throughout the full thickness of ice, the ice became isothermal at near-melting temperatures, and it experienced a measurable reduction in strength. The highest strengths were measured in March, when the ice was coldest. From March to mid-May, ice along the two transects experienced a reduction in strength from 20 to 60%.

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