Decay of first year sea ice: a second season of field measurements: interim report

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DECAY OF FIRST-YEAR SEA ICE: A SECOND SEASON OF FIELD MEASUREMENTS, 2001

Interim Report

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August 2001

CHC CANADIAN HYDRAULICS CENTRE

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A SECOND SEASON OF FIELD MEASUREMENTS

Interim Report

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ABSTRACT

This report describes a field program that was undertaken to characterize the seasonal ice decay process using a second year of measurements. Ice property measurements were made and a borehole jack assembly was used to measure the *in situ* confined compressive strength (borehole strength) of the ice. The project was conducted from 14 May to 28 June 2001 during which time the ice thickness ranged from 1.45 to 1.30 m. More than one hundred borehole jack tests were conducted at depths 0.3, 0.6, 0.9 and 1.2 m. No significant ice ablation occurred during the time that the borehole jack tests were conducted. Over the period mid-May to early June, the ice strength decreased by 50% in the top 0.50 m of ice. Measurements showed that the surface layer of ice decreased from a strength of 22 MPa to 10 MPa between mid May and early June. In comparison, the strength in the bottom layer of ice (depth 1.20 m) remained relatively constant (10 to 13 MPa) during that time.

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DECAY OF FIRST-YEAR SEA ICE: A SECOND SEASON OF FIELD MEASUREMENTS

1. INTRODUCTION

Last year, Canadian Hydraulics Centre (CHC) of the National Research Council of Canada undertook a study to monitor the decay of first-year sea ice from mid-May to early July 2000 (Johnston and Frederking, 2001). This year, the same program was conducted for a second season. The two-month measurement program extended from mid-May to late June 2001 and was conducted by personnel from Canadian Hydraulics Centre with assistance from Canadian Ice Service and the University of Manitoba. The physical properties of the snow and ice were recorded over a seven-week period, extending from 14 May to 28 June 2001. Depth profiles of the ice strength were obtained with a borehole jack from 14 May to 11 June. The acquired data were forwarded to Canadian Hydraulics Centre for analyses.

This report serves as an interim report, requested for incorporation into the Collaborative-Interdisciplinary Cryospheric Experiment (C-ICE'00) 2001 field report, issued by the University of Manitoba. This report includes some preliminary results obtained during the 2001 season. A complete discussion of the final results will be presented in a later report.

2. BACKGROUND

Generally, physical property measurements of first-year sea ice are conducted before mid-May, when the ice is still several degrees below freezing. This study was conducted to provide data on the properties of first year sea ice throughout the ice decay process. The surface properties and the bulk properties of the ice were measured over a seven-week period, from mid-May to late June 2001. Property measurements that do not require direct physical contact with the ice are defined as *extrinsic* properties. Of relevance here are extrinsic properties that include air temperature, snow thickness and snow density (Table 1). The bulk physical properties of the ice, or so-called *intrinsic* properties, include the temperature, salinity and density of the full thickness of the ice, ice microstructure and measurements of the ice borehole strength (*in situ* confined compressive strength).

Table 1 Factors Influencing Ice Decay

Measured Properties		Derived Parameters
Extrinsic Properties: Ice Surface	**Intrinsic Properties: Bulk Ice Cover**	
Air temperature Snow depth	Ice temperature Ice thickness	Ice density Brine volume

Snow density Ice surface temperature	Ice salinity Ice freeboard Ice borehole strength Ice microstructure	Total porosity Flexural strength Compressive strength

Measurements obtained during this program would enable the stages of ice ablation identified in Barber et al. (1997) to be more clearly defined. In particular, the stages of ablation could be related to both the *in situ* ice strength and the calculated ice strength. Most of the extrinsic and intrinsic properties listed in Table 1 will be used to calculate the ice density, brine volume and total porosity of the ice (sum of brine volume and air porosity). The total porosity is needed for calculating the compressive strength of the ice (Timco and Frederking, 1990) and flexural strength of the ice (Timco and O'Brien, 1994).

3. FIELD MEASUREMENTS

The C-ICE'01 base camp was located on the southern tip of Truro Island (75°14.7 N, 97°09.2 W) in the Canadian Eastern Arctic Archipelago. The ice measurement site was located in McDougall Sound, about 5 km from base operations. The selected area of first year sea ice had a moderately thick snow cover and did not have any signs of roughness or pressure ridging.

(a) ice measurement site **(b) assembled test equipment**

Figure 1 Measurement site on first-year ice in McDougall Sound

The snow depth and ice properties were measured from 14 May to 28 June over a 900 m² area of ice. Three different teams of people conducted measurements over the two-month period. Measurements during the first two weeks (13 to 22 May) were conducted by one person from Canadian Hydraulics Centre (CHC) and an assistant (from the C-ICE'01 camp). During the first phase of the field project (13 to 22 May) measurements were conducted on daily basis, weather permitting.

CHC personnel left the camp on 22 May. After 22 May there was a data gap of about ten days. From 01 June to 11 June personnel from Canadian Ice Service (CIS) made ice property measurements and conducted borehole jack tests on alternate days.

Although no borehole jack measurements were acquired after 11 June, personnel from University of Manitoba provided sporadic snow and ice property measurements until 28 June. Camp was decommissioned during the last week of June.

3.1 Measured Properties

Each test day, a station was selected (near the previous test stations) for conducting the borehole jack tests. The borehole jack tests were conducted in a triangular pattern with about 1.5 to 2.0 m separating the individual holes. This arrangement was decided upon to minimize damage introduced to the ice by the coring process and nearby borehole strength tests.

After the station had been selected, the snow depth was recorded over the location of the first borehole jack test. The ice surface was exposed by shoveling a circular area of snow from around the individual borehole station. Immediately after the ice surface had been exposed, the temperature of the ice surface was measured by inserting a thermal probe into a small hole that was drilled in the ice.

After the ice surface temperature had been recorded, a motor driven, fibre glass corer was used to make a 150 mm diameter, smooth walled, vertical borehole in the ice. The fibre glass corer provided a 100 mm diameter full-thickness core of ice. The core was processed immediately to obtain ice property measurements that were representative of *in situ* ice conditions (discussed subsequently). After the core was processed, the ice thickness and freeboard at the borehole were measured. Freeboard was measured by placing a straight edge across the core hole and measuring the depth from the ice surface to the water with a set of calipers (Figure 2).

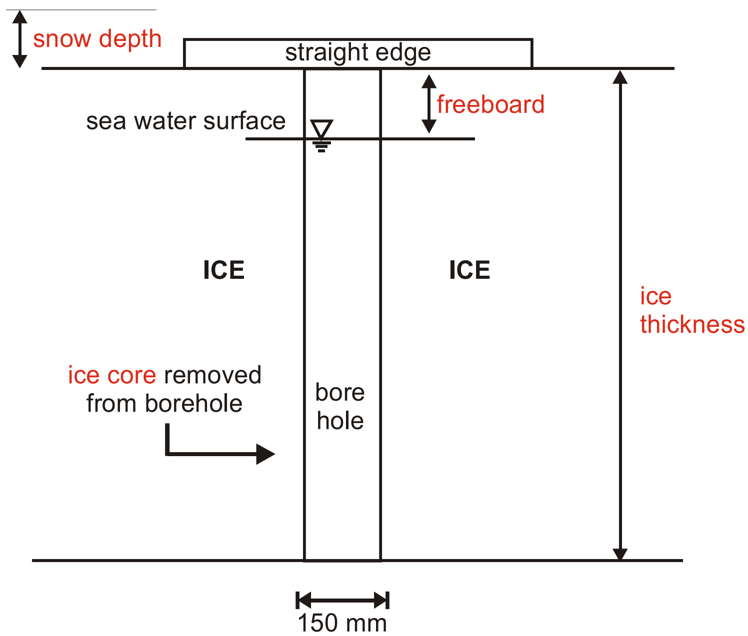


Figure 2 Measurements of ice thickness, freeboard and snow depth

3.2 Ice Core Measurements

The first ice core was used to obtain a profile of ice temperature. The ice temperature was measured immediately after the core had been extracted from the ice. The contents of the core barrel were emptied into a wooden holder that was marked at 150 mm intervals (Figure 3). If more than one attempt was required to extract a full-thickness ice core, temperature measurements were made as soon as the core pieces had been obtained. After the temperature of the first core piece had been measured, the corer was fitted with an extension rod to obtain the rest of the full thickness core.

The full thickness core from the second hole was used to profile the ice salinity. As the core barrel was emptied, the core pieces were sectioned as quickly as possible to minimize brine drainage. Discs of ice, about 20 mm thick, were cut from the core at intervals of 150 mm. The ice discs were melted and used subsequently to measure the ice salinity with a calibrated digital conductivity meter.

The third core was sectioned into 100 mm discs for density measurements. Alternate discs were bagged immediately, to minimize the effect of brine drainage on the sample weight. The samples were first weighed and the sample dimensions were measured. The ice density was only measured during the first two weeks of the program, when the air temperatures were sufficiently cold and when personnel from CHC were available to perform the measurements. After that, the third core was discarded, since it was not required for property measurements.

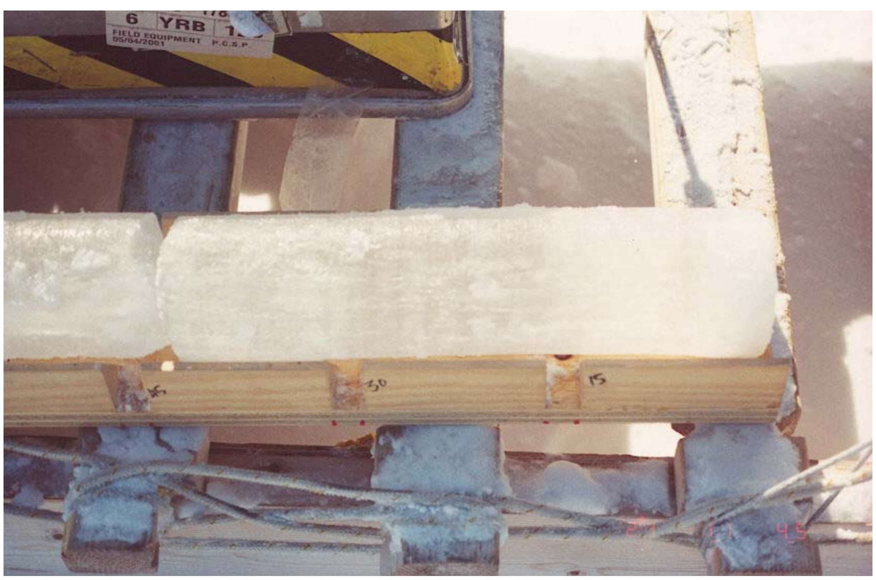


Figure 3 Fragments of ice core used for property measurements

3.3 Borehole Jack Tests

After the ice core had been processed, the borehole jack tests were conducted in the hole from which core was extracted. Details of the borehole jack system can be found in Johnston and Frederking (2000). The borehole jack indentor was lowered into each borehole made by the fibre glass corer (Figure 4). Once positioned at the specified test depth, the borehole jack indentor plates were extended and the data were output to a Campbell Scientific data logger. The test was continued at a specified depth until the gauge showed that the external oil pressure had stabilized or decreased. The plates were then fully retracted, the jack was rotated 90° and was lowered to the next test depth. Tests were conducted at depth intervals of 0.30 m until the bottom of the ice was reached. Typically, borehole jack tests were conducted at four levels to an ice depth of 1.2 m. Frequently, the orientation of the jack (north-south or east-west) was noted for each depth, so that any dependence of the ice strength on directionality. could be later assessed.

Figure 4 Borehole jack indentor inserted in ice borehole (courtesy of D. Bradley)

4. ACQUIRED DATA: PRELIMINARY ANALYSIS

Figure 5 shows the daily mean air temperatures for Resolute Bay during the sampling period. Borehole jack tests were conducted on 14 days between 14 May (Julian Day 134) and 11 June (JD162). The circular markers in Figure 5 indicate the days on which borehole jack tests were conducted. The first borehole jack tests of the season were conducted on May 14 (JD134) at which point the mean daily air temperature was −10°C.

The air temperature continued to rise during the sampling period, with the exception of the 10°C decrease that occurred between 26 May (JD146) and 28 May (JD148). The first above freezing air temperature that season (+1.4°C) was experienced on 7 June (JD158).

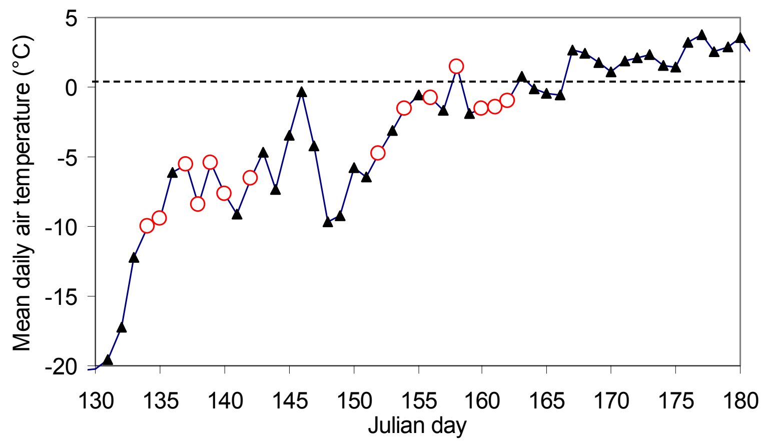


Figure 5 Daily mean air temperatures for Resolute during sampling period

4.1 Snow and Ice Thickness Measurements

Initially, the snow cover was about 0.30 m thick and remained quite thick until 13 June (JD164), as shown in Figure 6. The ice thickness continued to increase until 3 June (JD154), after which time the ice remained about 1.5 m thick until 21 June (JD172). Note that after 15 June (JD166) the above zero air temperatures were maintained, causing the snow cover to rapidly melt and the ice cover to ablate substantially. The ice was 1.20 m thick when it was last measured on 28 June (JD179). Once the snow cover melted, the ice thickness decreased from 1.5 m to 1.2 m, which amounted to a loss of 0.30 m of ice in one week. Recall that the last ice strength measurements were conducted on 11 June (JD162), which was before the snow cover melted and the ice began to ablate.

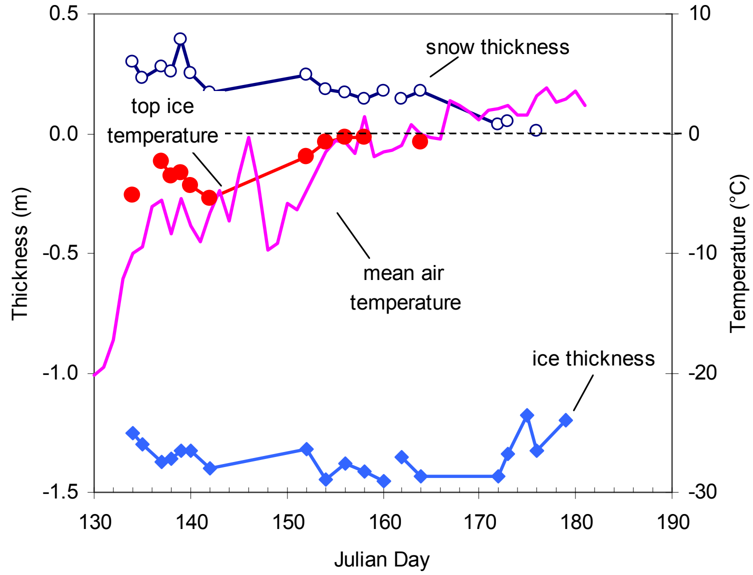


Figure 6 Average measurements made at sampled boreholes

4.2 Ice Salinity

Figure 7 shows the ice salinity profiles that were obtained during the sampling period. The salinity of the bulk layer of ice remained relatively constant at about 5‰ between the beginning of the field studies on 15 May (JD135) until 11 June (JD162). By 22 June, the ice was nearly devoid of salt, as shown by the salinity of les than 1‰. Since no salinity measurements were conducted between JD162 and JD173, there is little information about the temporal evolution of the salinity profile during the latter stages of ice decay.

Elevated air (and ice) temperatures accelerated brine drainage from the cores while they were being extracted from the ice and as measurements were being taken. Although attempts were made to section the core as quickly as possible, brine drainage became increasingly problematic as the season advanced. As a result, the reported ice salinity profiles are less than would be representative of the *in situ* ice conditions.

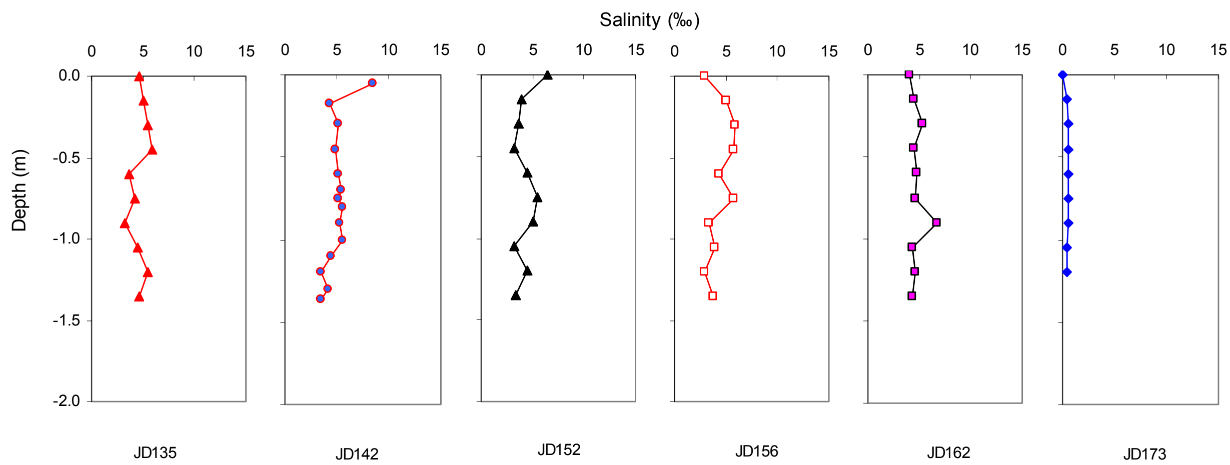


Figure 7 Salinity Profiles during Sampling Program

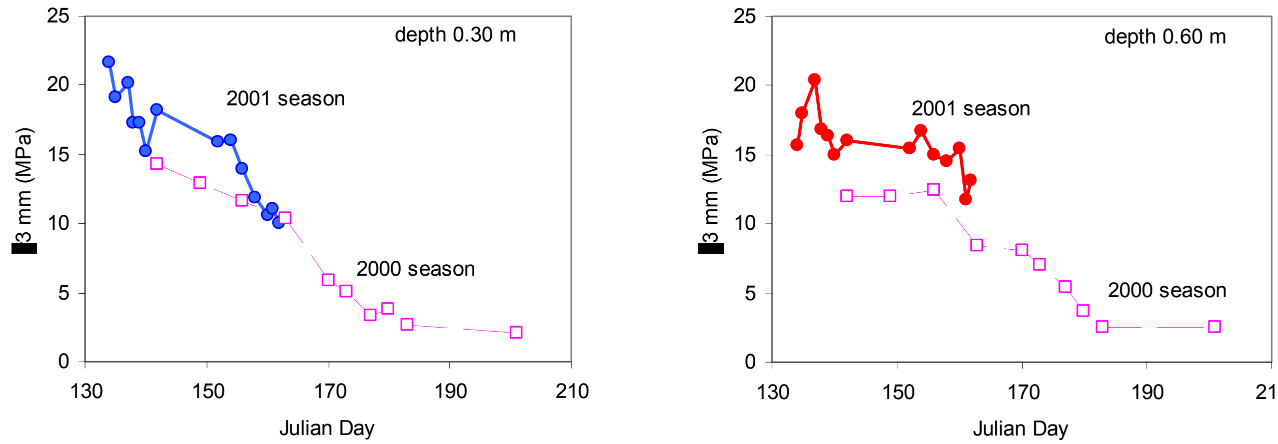
4.3 Ice Borehole Strength

A total of 36 boreholes were drilled (three, on average, each test day) between 14 May (JD134) and 11 June (JD162). As a result, more than 100 borehole jack tests were conducted at different ice depths. The pressure at which the indentor penetrated into the ice a distance of 3 mm was used to compare results from the different borehole jack tests. The reader is referred to Johnston and Frederking (2000) for a discussion of the technique used to compare test pressures. Note that the following discussion focuses upon the *average* borehole strengths (for a specific depth) of the number holes (typically three) tested at that particular station.

4.3.1 Ice Depth 0.30 m

Figure 8-a shows the decrease in the *in situ*, confined compressive strength of the ice (ice borehole strength) that occurred at a depth of 0.30 m during the 2001 season. For comparison, the results obtained during the 2000 season are also shown at a depth of 0.30 m. Although the ice measurements began about one week earlier during the 2001 season, they did not extend as far into the melt season as last year. The ice borehole strength was in excess of 20 MPa when measurements were first acquired on 14 May (JD134). Those initial strength measurements are in good agreement with borehole jack strength measurements conducted in cold, first year sea ice by Masterson et al. (1997) and Sinha (1997). Measurements during the 2001 decay season showed that the ice strength in the surface layer decreased by about 50%, or from 21.7 MPa to 10.0 MPa.

Since borehole jack tests were conducted on a near-daily basis during the 2001 decay season, the data show small-scale variations in ice strength. The small-scale perturbations were not observed during the 2000 decay season. That is to be expected, since borehole jack tests were conducted less frequently last year. The general trend of decreasing ice strength for the two years is similar from JD134 to JD140. On JD140 however, the strength of the surface layer of ice increased. By JD 158 there is, once again, good agreement between the two years of data.



(a) depth 0.30 m **(b) depth 0.60 m**

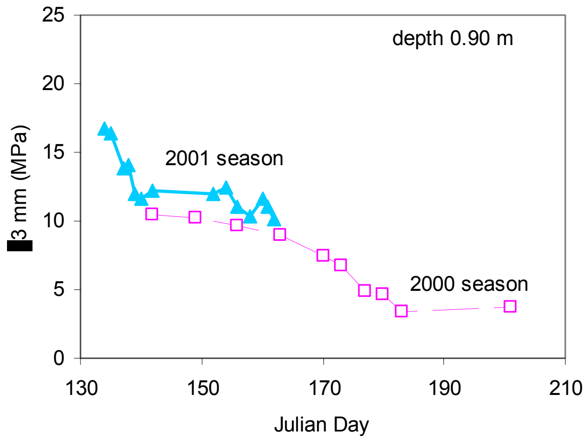
Figure 8 Deterioration of borehole strength of uppermost layer of ice

4.3.2 Ice Depth 0.60 m

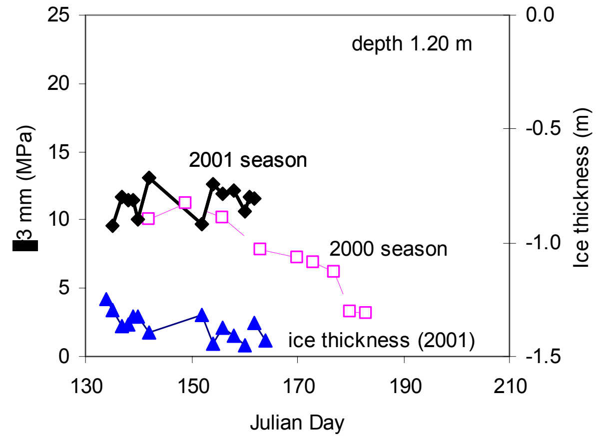
Figure 8-b shows that, during the first three days of testing the ice at a depth of 0.60 m showed a clearly defined increase (and subsequent decrease) in the ice strength. In about one week the ice strength had increased from 15.7 to 20.4 MPa and then returned to 15.0 MPa (JD140). Although no measurements were made from JD142 to JD152, the ice strength at a depth of 0.60 m most likely remained stable during that time. After JD152, the ice strength again started to decrease from 15.0 MPa (JD156) to 11.8 MPa (JD161). The ice strengths at a depth of 0.60 m were somewhat higher this season than last season, however the overall trend of the two data sets is similar.

4.3.3 Ice Depth 0.90 m

Figure 9-a shows that strength of the ice at a depth of 0.90 m decreased from JD135 to JD140. Measurements acquired from JD142 to JD154 indicate that the ice strength stabilized and then began to decrease after JD154. Strength measurements from a depth of 0.90 m do not show the small-scale perturbations in strength that the upper layers of ice showed (Figure 8). The incremental temperature fluctuations did not have time to penetrate to a depth of 0.90 m.



(a) depth 0.90 m



(b) depth 1.20 m

Figure 9 Deterioration of borehole strength in lower layers of ice

4.3.4 Depth 1.20 m

Figure 9-b shows that the borehole ice strength at a depth of 1.20 m varied by about 3 MPa between mid-May and early June. Although no decreasing trend in strength was observed during the 2001 season, measurements showed more variation than last year. This is due to the fact that consecutive tests were conducted on a near-daily basis. Given that the maximum ice thickness attained during the 2001 season was 1.44 m, many of the borehole jack tests at the 1.20 m depth were conducted within 10 to 20 cm of the ice bottom (Figure 9-b). Examination of pressure and ice thickness data from two seasons of decay data indicate that a clearance of about 10 cm (from the ice bottom) was sufficient for conducting tests, i.e. trends were not masked by free surface effects. The ice bottom did not show a decrease in ice strength during the 2001 season because no significant ice ablation had occurred by 11 June (JD 162), which was the last day in which borehole jack tests were conducted.

5. CONCLUSIONS

This report described the second season of a field program in which ice decay was characterized from mid-May to late June. Last year, the same measurement program was also conducted on the first year ice in McDougall Sound. This year, the measurement program began about one week earlier. As a result, the initial decrease in ice strength was characterized more completely. Measurements included temperature (air and ice), ice freeboard, snow and ice thickness, ice salinity and the ice borehole strength. Due to complications, borehole jack tests were conducted for only three weeks during the 2001 season (from mid-May to early June). The last strength measurements were made before the snow cover melted and the ice began to ablate.

Time series of ice strengths obtained from the borehole jack tests showed that the overall decreasing trend in ice strength included small-scale perturbations. The upper layers of ice showed that the ice strength decayed from 22 MPa to 10 MPa, a trend that was comparable to observations made last year. Over the period 14 May to 11 June 2001, mean daily temperatures increased from −10°C to 0°C and the ice surface temperature increased from −5°C to 0°C. The *in situ* confined compressive strength at a depth of 0.30 m decreased by 60%, ice strength at 0.60 m decreased by 20% and the ice strength at 0.90 m decreased by 30%. Ice strength in the bottom layer of ice (depth 1.20 m) remained constant while the ice thickness increased slightly.

6. ACKNOWLEDGEMENTS

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