Observation and Analysis of Iceberg Calving - June/July 2004

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EXECUTIVE SUMMARY

The Canadian Ice Service (CIS) provides sea ice and iceberg information to governmental and industrial users on Canada's east coast and in the Canadian Arctic. Hydrocarbon exploration and development activities on the Grand Banks of Newfoundland have resulted in an increased demand for iceberg information in this region. In response to this user requirement, and to further meet its mandate of environmental protection and the safety of lives at sea, the CIS is actively developing improved iceberg products and services.

Field observations of iceberg properties and processes are required for validation and calibration of new iceberg drift and deterioration models. Calving is one of the principal mechanisms by which icebergs deteriorate, but relatively few measurements or observations are available on which to base a calving model. Ballicater Consulting Ltd. *estimated* calving rates from observations made during iceberg reconnaissance flights, and measured the mass calved during specific events using aerial photography. Additional aircraft observations are not possible at the present time. Ballicater Consulting Ltd. also derived information on calving rates from time-lapse video observations of icebergs of a single iceberg near St. John's in 1998. The analysis provided unambiguous measurement of the frequency and approximate size of calving events for a specific iceberg.

This report describes the collection and analysis and new time-lapse video observations of 2 icebergs along the northeast coast of Newfoundland. The water temperature at the observation sites was about 10°C, and 42.9 hours of useable video imagery was recorded. Four small, 4 medium, and 1 large calving event were observed. The average calving interval for medium and large events was 8.6 hours. This fits very well with the calving interval versus water temperature trends derived from previous observations programs. The sea state at the time of the observations was nearly calm, which may have had an effect on the calving rate. It is recommended that further analyses be carried out to incorporate sea state in the empirical predictive model. The success of the video

observation program (despite the late start data) indicates that it is a viable and relatively cost-effective data collection technique, and should be refined and expanded for the 2005 iceberg season.

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1. BACKGROUND

The Canadian Ice Service (CIS) provides sea ice and iceberg information to governmental and industrial users on Canada's east coast and in the Canadian Arctic. Hydrocarbon exploration and development activities on the Grand Banks of Newfoundland have resulted in an increased demand for iceberg information in this region. In response to this user requirement, and to further meet its mandate of environmental protection and the safety of lives at sea, the CIS is actively developing improved iceberg products and services.

Field observations of iceberg properties and processes are required for validation and calibration of new iceberg drift and deterioration models. Calving is one of the principal mechanisms by which icebergs deteriorate, but relatively few measurements or observations are available on which to base a calving model. Ballicater Consulting Ltd. *estimated* calving rates from observations made during iceberg reconnaissance flights, and measured the mass calved during specific events using aerial photography. Additional aircraft observations are not possible at the present time. Ballicater Consulting Ltd. also derived information on calving rates from time-lapse video observations of a single iceberg near St. John's in 1998. This analysis provided unambiguous measurement of the frequency and approximate size of calving events for a specific iceberg.

Additional iceberg calving data were collected during June and July of 2004. Several short time-lapse image sequences of grounded icebergs were collected along the north east coast of Newfoundland during the period June 29 to July 3. A total of 42.9 hours of observations on 2 different icebergs was obtained.

This report describes the data acquisition program, the imagery collected, the approaches used to extract the required data from the imagery, and the results of the analysis. The new data are compared to previously derived information on calving rates of icebergs on the east coast.

2. METHODOLOGY AND DATA COLLECTED

2.1 Project Planning

This project was initiated late in the iceberg season for the East Coast of Newfoundland. Therefore, the dominating control factor for site selection and execution was the availability of suitable icebergs for viewing from shore. A telephone survey of boat operators and tourism proprietors along the Northeast coast of the Island was required to identify the location of remaining icebergs. The phone survey resulted in the confirmed sightings of two grounded icebergs, the first near Catalina, Trinity Bay, and the second in Merritt's Harbour, near Twillingate. Both icebergs were reported to be stationary and of medium size.

2.2 Equipment Selection and Preparation

To make definitive observations of iceberg calving frequency and quantity it was necessary to consider the capture rate and resolution of recorded images. Prior experience (Ballicater, 2001) indicated that standard television format frame sizes were adequate for iceberg calving observations, provided the field of view was not wider than 1 km at the distance of the iceberg. Television screen and VHS resolution is low at around 280 x 320 pixels, therefore, this was identified as a lower bound for frame sizes in this work.

The average rate of calving is known from prior work to be much less than one event per hour with individual events lasting up to a few minutes in cases where an iceberg rolls, breaks and rolls again etc. In addition, it was assumed that calved material is not likely to translate away from the parent iceberg at rates greater than 0.5 m/s. A frame interval of 10 minutes would provide for event tracking by capturing either "before and after" or "during and after" images with calved materials still present in the field of view. Longer intervals could result in material disappearing from view prior to being seen and therefore going unrecorded. Shorter intervals would provide the same calving rate information but may enhance the accuracy or resolution of other observations. The factors competing against high frame rates and higher image resolutions are the data handling/storage requirements of the equipment, battery consumption and equipment limitations.

The emergence of digital imaging as an alternative to analogue VHS and the availability of equipment on short notice were important factors in equipment selection and preparation. Prior work (Ballicater, 2001) had been executed using a time-lapse VCR machine enclosed in a secure box inside a building with security and a 110 AC power supply. VHS tapes were exchanged every three days. For the present work, given the scarcity of icebergs, it was necessary to consider that observations may have to be made in the absence shelter, power and security. In the event that a well-positioned structure with a willing owner was available then a simplified system may also be considered.

A time-lapse VCR could not be obtained by any means within the few days of preparation time for the present field work. Therefore, two digital recording systems were assembled, one for independent remote recording, the other for power and shelter-assisted scenarios.

Remote System (Kodak unit):

The camera selected for the remote system was a Kodak DC290 digital camera with 3X optical zoom and time-lapse capabilities. The internal battery system for the camera utilized four AA batteries and did not have the stamina to power the camera over the extended capture periods expected. Options considered for auxiliary power included external batteries, a gas generator or a solar assisted system. Both solar and generator options were ruled out due to visibility, cost and risk of theft. A battery system was selected whereby a 12 volt power pack with an internal 300watt AC inverter was used as the primary external power source (Figure 2.1). The battery pack and camera were fitted into a weatherproof utility box and a 6 volt inverter linked the two. The box had an open aperture in one end through which the camera could be positioned to view an iceberg unobstructed. The top of the box was fixed with a window for additional viewing options, while the bottom was supported by an aluminium frame that allowed for various stable orientations depending on the field conditions and circumstances. The entire assembly was compact and easily managed by a single person, and could be readily hidden from view for theft prevention.

Figure 2.1 Remote camera system with Kodak DC290.

Sheltered System (Hi8 Unit):

In the event that shelter and power were available a second recording system was developed. The arrangement used a Hi-8 video camera, unprotected on a tripod (Figure 2.2 and Figure 2.3). The zoom capabilities of this camera exceeded that of the still camera but resolution was limited to VHS standards. This camera was linked to a laptop PC that had the following features installed for this project:

- external 40 GB hard drive for image storage
- external USB analogue/digital video interface card
- Capturemax Pro software for time-lapse image capture and storage.

The laptop with auxiliary equipment was placed in a plastic storage box with all power connections consolidated into a single extension cord for external power connection.

Figure 2.2 Hi-8 video camera set up.

Figure 2.3 Hi-8 video camera location in shed near Catalina.

2.3 Temperature Measurement

To obtain temperature readings in the water near each of the iceberg observation sites a standard indoor/outdoor remote operated thermometer was employed. At each site the wire probe containing the outdoor thermocouple was lowered into the water to a depth of 20 cm and readings were taken after one minute. The accuracy of the temperature sensor was ±1°C. Two measurements at Catalina averaged 10°C, while a single measurement at Merritt's Harbour gave a temperature of 11°C.

Note that NOAA composite, two-week average, Sea Surface Temperature images (2km resolution) available at:

http://www.mar.dfo-mpo.gc.ca/science/ocean/ias/seawifs/seawifs_3.html

show values of about 9°C at both Catalina and Merritt's Harbour over the June 15-30, 2004 period, and about 10°C at Catalina and 11°C at Merritt's Harbour over the July 1-15 2004 period. Therefore, a temperature of 10°C is considered representative of the sea surface at the time of the calving observations.

2.4 Selection of Sites

A reconnaissance trip was initiated June 29th to the Bonavista Peninsula with the intention (hope) of spotting previously unknown icebergs prior to reaching Catalina - the location of the only confirmed sighting in the region. The West coast of the peninsula, the Cape and the North East coast yielded two other sightings both of which were small, distant and drifting iceberg fragments. The iceberg near Catalina was positioned as shown on the map in Figure 2.4. Local citizens explained that it had been there for at least four to six weeks and was now only a shadow of its former bulk. None-the-less the iceberg was approximately 20m high, 40m long and likely in excess of 40,000 tons (Figure 2.5). There were many paths, meadows and roads to explore in order to find the optimal location for long term camera surveillance. Ultimately, a shed in the nearby community of Melrose had the clearest view of all accessible locations with structures. The owners were quite accommodating and understanding of the task at hand. This site was chosen for the sheltered equipment. Table 2.1 provides a summary of Iceberg 1 (T_w is the surface water temperature).

Table 2.1 Summary of information on Iceberg 1.

Lat.	Lon.	Length	Height	Mass	T_w
48° 30.5 N	53° 01.0 W	40m	20m	40,000	10°C

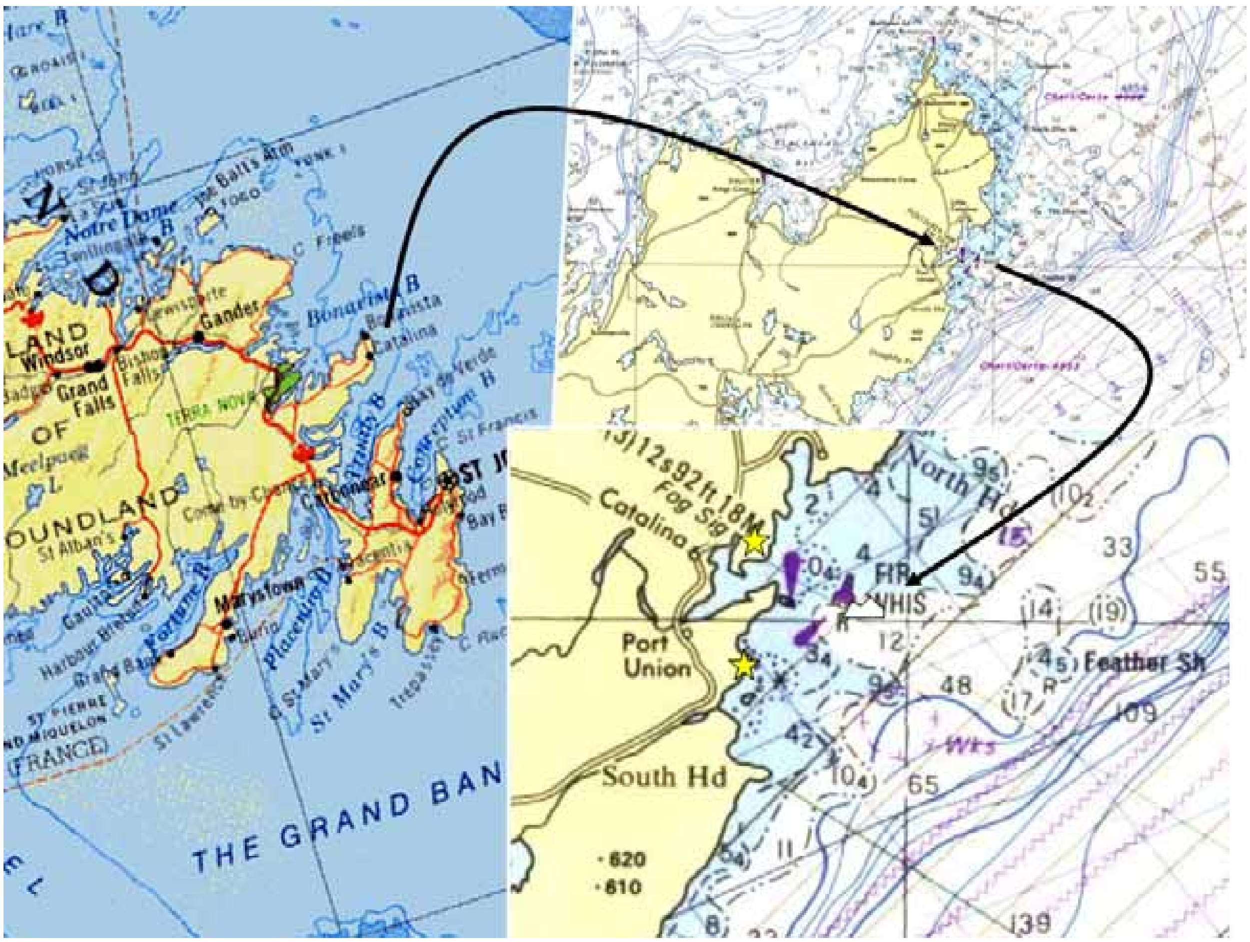

Figure 2.4 Maps showing location of Iceberg 1 near Catalina.

Figure 2.5 Photograph of Iceberg 1.

Another reconnaissance trip was carried out two days later as recording was proceeding at Catalina. The target area this time was Twillingate Island, traditionally one of the best locations in Newfoundland for viewing icebergs from land and the only other location where an iceberg sighting was confirmed. A lengthy tour of the various arms and headlands in the Twillingate area verified that the only iceberg in the region was in the Main Tickle behind Merritt's Harbour – just as the local contacts had described (Figure 2.6). The iceberg was a three–pinnacled, drydock type approximately 30m high and 80 m long, and nearing 150,000 tons (Figure 2.7). It was said to have been in the bay for several weeks.

Selecting a site for viewing this iceberg was a great challenge as none of the communities in the area had a view of the tickle where the iceberg was grounded. It was necessary to climb several hills and break trails to find an optimal location combining proximity to the iceberg, a clear field of view and security. A hilltop overlooking the tickle near Merritt's Harbour was identified for this purpose. Table 2.2 provides summary information on Iceberg 2.

Table 2.2 Summary of information on Iceberg 2.

Lat.	Lon.	Length	Height	Mass	T_w
49° 38.5 N	54° 40.0 W	80m	30m	150,000	10°C

Figure 2.6 Maps showing location of Iceberg 2 near Merritt's Harbour.

Figure 2.7 Photograph of Iceberg 2.

2.5 Equipment Deployment and Monitoring June 29th – July 7th

Prior to setting up the sheltered recording system in the shed near Catalina it was decided to experiment for the first evening with a simplified arrangement using a digital still camera (Canon S-45) with intervelometer or time lapse capabilities. The camera was positioned on a window ledge and set to take 4 mega-pixel photos of the grounded iceberg at 10 minute intervals. Recording began at 6:00PM June 29th. The following day, June 30th the site was revisited and the camera was *missing* from the shed. It was later discovered that a relative of the property owner had removed it early in the morning mistaking it for his own. He returned it later that day after discovering the truth and all was settled. The Video camera and laptop system were then deployed and settings were adjusted to allow for six days of uninterrupted time lapse recording. The system was triggered at 3:20 PM June 30th and was not revisited until July 3rd.

On July 2nd at around 4:30 PM the remote system was deployed at Merritt's Harbour, Twillingate. Time lapse images (4 Mpxl @ 1 min int.) were taken during setup using the Canon stand alone camera. The Kodak system was triggered at 6:00 PM and the site was vacated.

Returning the next day July 3rd, it was discovered that the iceberg had moved from the field of view and was now freely floating further out in the bay. The equipment was collected and a new site was chosen a few kilometres further down the tickle near Salt Harbour. After recording the icebergs movements (with the Canon time lapse) for a few hours from this new vantage point it was determined that further attempts at long term data collection using this iceberg would be futile. All equipment was then gathered after which the site was abandoned permanently.

Later on July 3rd the equipment near Catalina was revisited. It was discovered that the equipment had worked flawlessly, however, the iceberg had moved closer to shore and out of sight the previous day. Subsequently, an alternate site was selected for viewing the same iceberg, this time a hilltop antenna site near the port entry in Catalina was chosen. There were no shelters or homes in the area and so the re-acquired remote Kodak system was deployed. Again the Canon was temporarily activated for monitoring while the stand alone equipment was prepared for long –term recording. During this period a significant rolling and calving event was witnessed and many close up photos were taken. Later, at 7:00 PM, July 3rd the Kodak unit was activated and left hidden in bushes. The system was not revisited until July 7th, 3:00PM.

Returning to the site on July 7th the equipment was still in place, however, the iceberg was gone and the battery pack had expired. Equipment was gathered and the field work concluded. The timeline of observations is show graphically in Figure 2.8. The hashed bars indicate periods of successful image acquisition. The dark bars indicate the periods of darkness. The remaining bars indicate periods of data loss due to the 'missing' camera, fog, or when the iceberg had drifted out of the field of view.

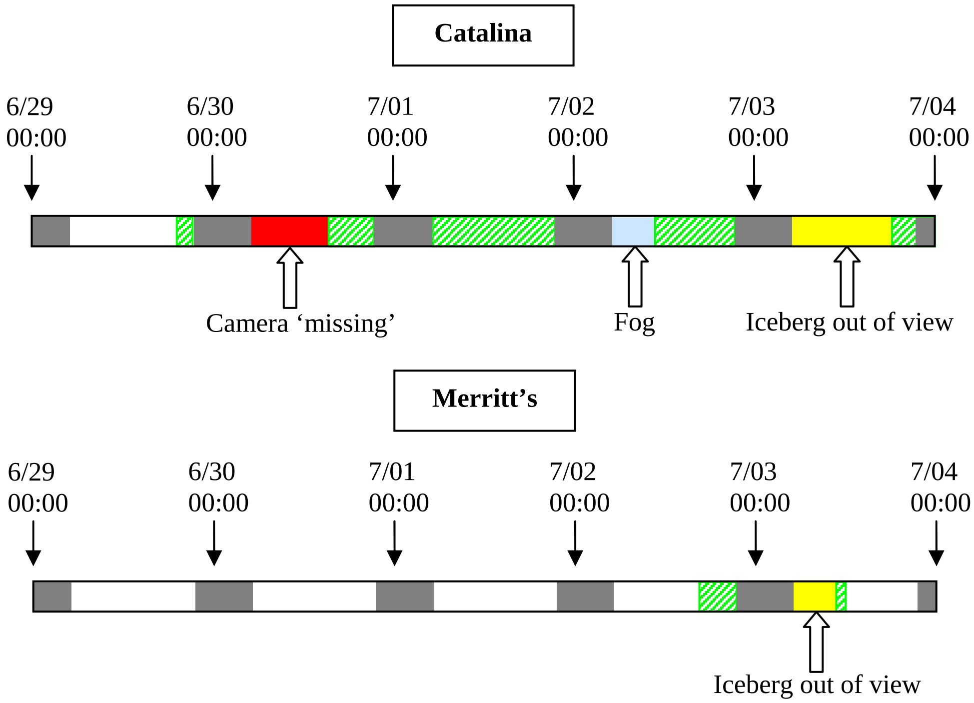

Figure 2.8 Timeline of video observations.

3. DATA ANALYSES

A total of 42.9 hours of iceberg imagery were collected. As indicated above the water temperature was about 10°C. Each of the time series was screened frame by frame for images that could not serve the objective of positive identification of any calving events that may have occurred. Therefore, many frames taken during darkness, during fog and while the iceberg had moved out of the field of view, were eliminated. The remaining time series were then screened carefully for calving events. The guidelines for ranking the quantities of calved materials were established as follows:

Small: single growler, few bits of brash,

Medium: a few large pieces, several smaller and a noticeable halo of brash in the surrounding water,

Large: Noticeable change in berg shape and orientation, large quantities of floating ice rubble of all sizes, some sintered piles of brash noticeable.

Table 3.1 summarizes the calving observations at each site.

Table 3.1 Summary of calving events.

Location	**Calving Events**	
	Date/Time	**Size**
Catalina	6/30/16:00	Medium
	6/30/18:57	Small
	6/30/19:22	Small
	6/30/19:32	Large (iceberg rolled)
	7/1/08:35	Small
	7/1/10:37	Small
	7/2/17:41	Medium
	7/3/18:30	Medium
Merritt’s Harbour	7/2/20:00	Medium

In all there were 4 small, 4 medium, and 1 large event during 42.9 hour observation period. The average calving interval (the time between calving events) for medium and large events (combined) was 8.6 hours. This parameter can be compared to the calving intervals calculated from the air during CFR flights in 2000, 2001, 2002 and 2003 (Ballicater, 2003). The medium and large calving events are used because it is thought that events of this size would have been seen and counted during the CFR flights, whereas the small calving events would not have been visible.

Figure 3.1 shows all calving interval observations made to date. For the 2004 data, the large round dot indicates the calving interval for medium and large events combined. The upper and lower limits show the calving intervals for large events only (42.9 hours), and for all events combined (small, medium and large, average interval = 4.8 hours). The bars around the 1998 data point, which was derived from video observations near St. John's, indicate calving intervals for large only, and for all events, in a similar manner. The bars around the 2000 data point indicate an approximate range of values for observed events (medium and large). These have been added because the 2000 calving interval is an estimate only, and could fall anywhere between the upper and lower bound.

The diagonal dashed line is a linear best fit through the 4 points derived from CFR observations. The equation of the line is:

$$t_c = 55.3 - 5.3 \times T_w,$$

where t_c is the calving interval in hours and T_w is the surface water temperature. Although this line fits the 4 data points from CFR quite well, it is inappropriate in the extremes. It is not reasonable to expect the calving interval to go to zero (constant calving) at any finite water temperature. As an alternative, the curved solid line is a non-linear fit to the CFR data points of the form,

$$t_c = 62 \times \exp[-0.20 \times T_w].$$

The formulation allows the calving interval to approach small values when the water temperature is high, but never go to zero. The new data point from 2004 falls much closer to this line, providing further evidence that it is more appropriate than a linear function.

The very high upper value for large calving events from the 2004 observations is probably an artefact of the limited duration of the observations. It was noted during the data collection process that the iceberg at Catalina rolled twice during the periods of darkness. These events, if witnessed, would probably have been accompanied by large calving events, and would have reduced the calving interval for large events considerably.

The 2004 data point fits the general trend toward lower calving intervals at higher temperatures, but the sea state in 2004 was essentially calm for the entire observation period, while the other observations were made in a range of sea states. Since calving is strongly influenced by wave erosion, it is reasonable to assume that the observed calving intervals from 2004 would have been different if there had been higher sea states. In the new CIS iceberg model (see Savage, 1999) the calving interval is calculated from,

$$t_c = \frac{0.33 \cdot (37.5 \cdot H + h^2)^{1/2}}{T_w \cdot 0.000146 \cdot (R/H)^{0.2} \cdot (H/p)},$$

where,

H = Wave height (m)
h = Height of the over-hanging ice slab (m)
R = Ice surface roughness (m)
p = Wave period (s).

In this formulation the calving interval (t_c) is proportional to $H^{-0.3}$, and $p^{1.0}$. For example, if the water temperature is 10°C and the iceberg height is 20m, a change in sea state from H = 0.25, p = 1 (nearly calm), to H = 1.5, p = 6 (more typical values) *increases* the predicted calving interval from 9.7 hours to 14.6 hours. This is because the increase in wave period (p) has a greater effect than the increase in wave height.

The calving interval formula closely approximates the observed interval when reasonable input values are used. However, the equation is quite sensitive to some of the parameters, and a different set of 'reasonable' values can yield results that are not nearly as good. Given the theoretical importance of sea state on the calving interval, it is possible that a better empirical formulation for t_c could be derived if some wave parameters were included in the analysis of the data. This is beyond the scope of the present analysis, but should be considered in future.

Including sea state in the algorithm may eliminate some of the concerns about how representative observations of grounded near-shore icebergs are of freely drifting offshore icebergs of primary interest. One of the main differences between near-shore and off-shore icebergs is the wave conditions which tend to be more severe in the offshore where the icebergs are more exposed.

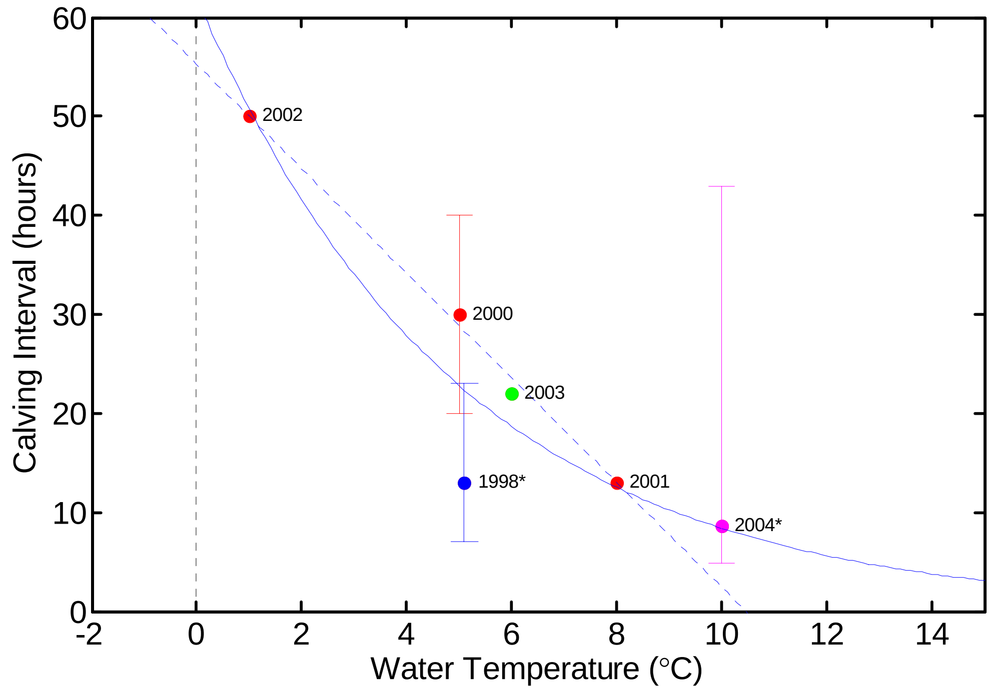

Figure 3.1 Calving interval as a function of water temperature – all data.

4. SUMMARY AND RECOMMENDATIONS

Shore-based video observations of iceberg calving rates have been demonstrated on 2 occasions (1998 and 2004) to be a viable data collection method. The 2004 observations fit very closely to the trend derived from previous observations. The empirical model for the average calving interval,

$$t_c = 62 \times \exp[-0.20 \times T_w],$$

is theoretically attractive and fits the data fairly well. The primarily limitation of the 2004 observations was the limited duration of observation due to the very late project start-up date. It is recommended that a similar program be conducted in the spring of 2005. The observations should commence in early May, and continue through the iceberg season in order to maximize the amount of information collected and to provide a range of environmental conditions, particularly water temperature. The use of night vision technology, either infrared or ultra low-light cameras, would increase the quantity of usable imagery by about 50% and should be considered.

In the CIS iceberg model the calving interval is used in conjunction with the mass calved per event, to estimate the total mass loss due to calving. Therefore, any information that could be obtained on the mass calved would be very beneficial for model verification. This will likely prove to be very difficult from shore, but the potential benefit warrants some brainstorming and investigation of potential techniques.

As mentioned above, a better empirical model may be possible if some sort of sea state parameter is included. This is recommended, and could be performed using the existing data set.

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