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Iceberg Calving Frequency from Field Observations

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One of the primary mechanisms of iceberg deterioration is calving. Calving in this context is an event in which a piece or pieces of ice abruptly break free of a parent iceberg. These events occur regularly though the interval and quantities calved are observed to vary considerably depending upon ambient environmental conditions. Scarcity of field data supporting analytical modeling of this phenomenon has led to an ongoing program of iceberg observation. This paper describes the program methodology and the results of the most recent dataset collected from St. John's Newfoundland in June 2007.

1. Introduction

Understanding the nature and rate of various iceberg mass-reducing mechanisms is important for accurate forecasting of iceberg position and size. Forecasts which are based on drift and deterioration models are required because it is not presently feasible to continuously monitor all bergs entering waters where they may be a risk to commercial activities (Kubat et al, 2007).

It is observed that icebergs loose mass through the action of melting and calving and that these mechanisms are highly correlated. Owing to the discrete and visible nature of calving events specifically, it has been determined that relatively low cost field work provides indicative data of this phenomenon. Experiments by the author in 1998 and later analyzed by Crocker (Ballicater, 2005) demonstrated the viability of using shore-based time lapse recordings for obtaining this data. Icebergs trapped on the coast of Newfoundland, and in particular in an exposed location near Signal Hill, St. John’s, could be observed for extended periods of time and provide near-ideal circumstances for recording calving rates and quantities under conditions approximating open sea.

In the 1998 test program a time lapse VHS machine was used in conjunction with a personal Hi8 video camera. In subsequent years various other camera and recorder arrangements were used. In 2004 a similar video camera and web-cameras were used with a laptop providing image capture and storage functions. Specialized software for gathering and post-processing high numbers of still frames was employed in that work. As an experiment that year, a digital still camera with time lapse capabilities was packaged with auxiliary batteries and memory to provide an alternate means of data acquisition at remote sites. This work met with mixed success as conditions were less than ideal for iceberg work in 2004. In 2005 the Canadian Ice Services provided funding for some new equipment – two laptop/video camera packages. These were to be deployed with the older gear in an attempt to substantially increase data collection. The year proved to be a rare near-zero iceberg season around Newfoundland and so a one-week excursion to Greenland was alternately planned and executed. That program proved to be most interesting and useful information resulted though the applicability of results to lower latitudes remains questionable. In 2006 another very low iceberg season did not permit convenient field research and no data was obtained. Icebergs arrived around St. John’s in June of 2007 and equipment was again deployed on Signal Hill. This paper describes that fieldwork and includes a discussion of observed deterioration mechanisms in general.

2. Field Observations of Iceberg Deterioration

Melting can be observed by inference only as it must be interpreted from the transition and evolution of iceberg shape, size and texture over time. From numerous hours of first hand observation it has been inferred that melting results primarily from multi-directional complex fluid flows over the submerged ice surface. The rate is accelerated at the waterline as a result of wave action and higher surface water temperatures. Swell and wind-waves increase fluid flow/replacement rates and thus available heat from the surrounding ocean is more readily available. Wave run-up, diffraction, reflection, refraction and interference are observed to contribute overall to an impossibly chaotic fluid flow regime around the waterline of icebergs under most conditions. Below the wave zone it is postulated that a continuum of current speeds and directions result from berg translation, wind shear, prevailing oceanic and tidal actions and vortex shedding as they interact with berg shape. These combine with near-berg convective actions driven by buoyant melt-water, heavy chilled seawater, and ascending bubble flows to create a flow regime best described as complex.

At times, surface melting above water is visible through the presence of running and dripping water and a glistening appearance – though the latter is not always the case when rapid evaporation "dries" the surface. The melting above water accelerates in warm temperatures, high winds and direct sunlight, but occurs over a much smaller surface and does not appear to match the surface retreat rate observed for the below water portion when revealed, and is thus, likely to be a relatively small component of iceberg deterioration overall.

The melting surface of the submerged portion of an iceberg is characterized globally by long (10s of meters) sweeping curved surfaces devoid of the flat multifaceted and angular fracture surfaces often seen above water after calving events. It is not uncommon to see crevasses and sometimes narrowly supported globular and wing-like appendages below water or revealed above after berg repositioning. On a medium and small scale the surface is dominated by two distinct shapes: *furrows* and *cusps*. Parallel furrows are carved by ascending bubble flows which scour the ice with accelerated heat transfer on vertical and downward facing surfaces. These may be small (approx 1 meter length) if the surface is small and the berg has not been in a stable equilibrium for long; or quite pronounced (many meters long, 10's cm deep and wide) where melting is fast, the berg is stable, water is relatively calm and the berg is large enough to have expansive surfaces below its (vertically tangential) waistline. Most remarkable is the formation of a complete cuspate surface of striking uniformity, akin to the surface of a golf ball. The individual cusp-like depressions are of the scale of 1-50cm and are of smooth parabolic or spherical dimple shape. It appears that this complexion describes the entire wetted surface of an iceberg though this is only surmised from observing bergs after rollover and from various subsurface photos.

It is believed that this cuspate surface is an artifact of fluid flow structures which may be initiated by some surface irregularity and then evolve due to characteristic vortex sizes depending upon fluid flow rates. Indications of this type of phenomenon occur elsewhere in nature as described by Leighly (1948) and Villien et al (2001). In this case, the gouge-like action results from accelerated melting in regions of heightened flow rates and on incoming/convergent zones within each cusp. The spatial distribution of these cusps appears independent of berg orientation and are approximately uniform in size over any one observed surface – though they are not necessarily of the same size over the entire berg. It is also noteworthy that the cusp size appears to vary between icebergs or bobbing ice fragment observed in different locations and under different sea state conditions. It is surmised that the cusp size is controlled by sea state (relative surface flow rate) and duration of action and that water temperature controls the rate at which the "scalloped" surface evolves and develops to maturity. The presence of bubbles in the ice which create a tiny surface void when overtaken by the melting surface may be the catalyst for cusp formation in the first instance. But it is not necessary for bubbles to be present for cusps to exist as is the case where the scalloped appearance is uninterrupted over bubble-free re-frozen crevasse features (clear blue streaks) in icebergs. Whether salinity, density, core ice temperature, crystal shape and size, or some other material or fluid parameter plays a role in the development of these surface structures is not known. But understanding and describing this phenomenon may be important for analytical modeling as it may indicate true convective action and significantly (20% estimated) increase iceberg surface area.

Mass loss due to **calving** is observed to occur over a wide range of scales. Melting furrows and wave wash continuously cut channels which eventually cause the isolation and parting of small fragments above and below water. This is common and regularly observed at close range under warm water conditions – but may not be significant due to the relative quantities involved (under 100 Kg each typically). Spalling of vertical surfaces and overhanging slabs occurs presumably as a result of reduced support conditions due to wave-induced notching or undercutting at the waterline. Weakening of ice near the surface due to warming and thermal stress cracks likely precipitates calving of vulnerable sections. The quantity of ice calved varies widely in these events.

Major calving events usually occur as a result of a shift in the equilibrium position of an actively melting berg. The shift usually creates overhanging conditions on one side where once only steep or vertical surfaces prevailed. Avalanches of ice are observed to take place in these cases and this is then followed by a reversal of orientation to compensate for the new loss – often resulting in a similar large-scale calving event on the opposite side. This breakup is common and is observed locally as the death nell – because the remaining pieces often depart in various directions and appear to melt away rapidly. Grounded bergs sometimes undergo global failure presumably due to tide-induced buoyant flexural stresses in which the berg parts into two smaller bergs, the smaller of which may be considered the calved portion. The nature of underwater calving events is not known and has not been observed directly by this author, however, instances of ice chipping and erosion due to seabed grinding and bumping is common in rough seas as observed when viewing at close range is possible.

3. Field Program, Signal Hill, St. John’s, June 2007

On the morning of June 3rd 2007 an iceberg was observed in the distance from Signal Hill St. John’s as it drifted a general course to the South West. There were approximately two other bergs within sight at that time. Fortuitously, the author photographed this distant iceberg and returned the next day to find that it had drifted in to shore and apparently grounded in the general vicinity referred to as Quidi Vidi. The berg was again photographed in the same area the following few days confirming it had grounded and that it may be a suitable candidate for extended study. It may be useful to note that it was assumed it would remain somewhat stationary because it had drifted into place in a tabular form. These, is has been observed in the past will remain in place through a considerable period of deterioration owing to the fact that the flat-top and bottom geometry results in a minimum draught and thus subsequent melting or calving events which may cause imbalances serve to increase the downward reach of one side or another of the ice mass – further anchoring the berg in place.

Figure 1. provides the reader with an impression of the changing shape of the iceberg over time. Note that the images are not scaled equally and so size is not to be gleaned from these.

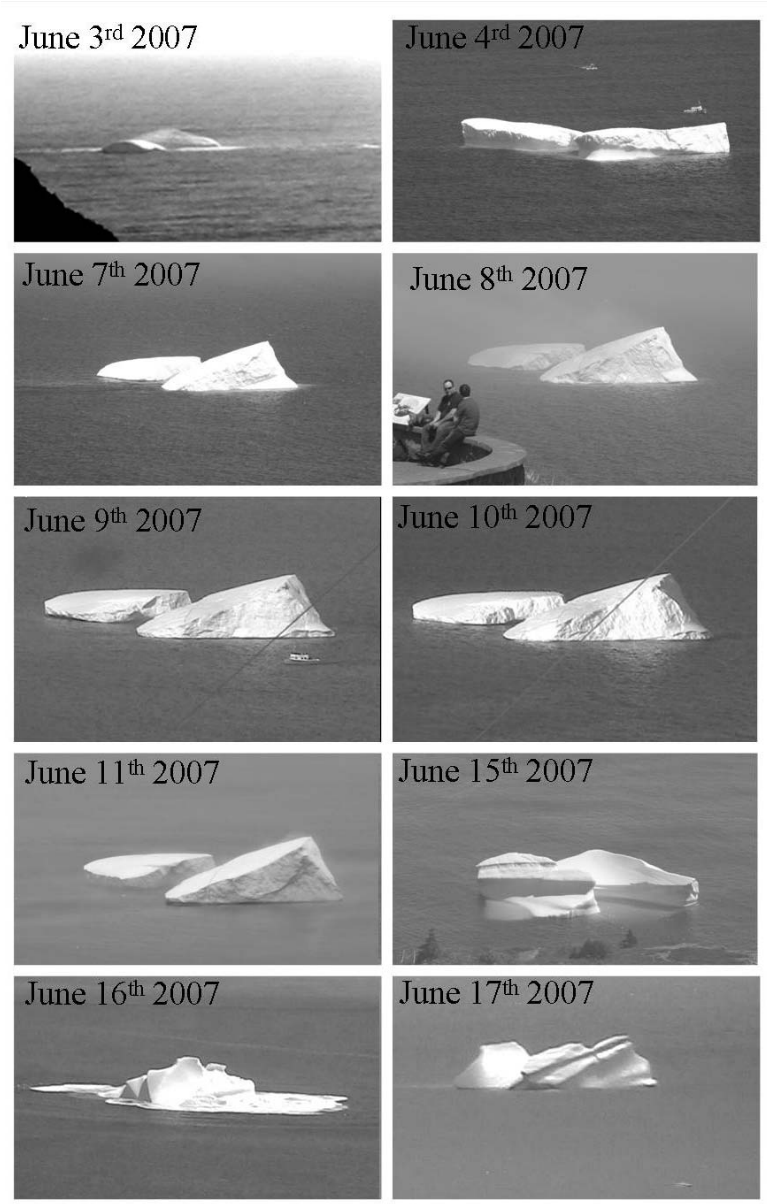

Figure 1. Images of the iceberg subject throughout the observation period – not to scale.

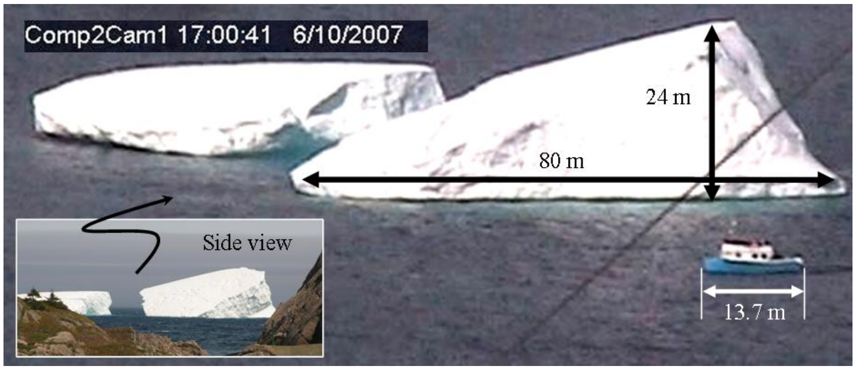

Figure 2. Approximate size of iceberg subject scaled from a known tour boat.

The berg mass likely exceeded one million tones when it was first sighted. Figure 2. illustrates the manner in which approximate scaling was determined throughout the field program. A vessel of known size in close proximity is photographed near the berg allowing direct scaling to take place. Viewing the berg from various approach angles facilitates the volumetric calculation. In the figure, the near portion of the berg is a wedge shape for which a triangle of base 80m and height 25m is an approximation. The side view indicates a wedge width of approximately twice the height, or 50m. The volume above waterline is thus approximately 0.5x80x25x50 or 50,000 m^3. If the glacial ice density is 900 kg/m^3 and the seawater is 1029kg/m^3 then the total ice volume would be 8 times the above water portion, or, 400,000 m^3 equal to 360,000 tones.

On June 9th, through a prior agreement with Parks Canada, Historic sites, two independent recording stations (laptop, tripod, video camera . . .) were configured and triggered from within the Marconi room in Cabot Tower on Signal Hill. Approximately Parallel camera records for 9 days were managed through twice-daily visits to the Tower. As is often the case, fog, darkness and iceberg repositioning out sight meant that a cumulative total of only 72.25 hours of unambiguous eligible records were obtained. In all instances the better of the two views from the camera setups was selected for any particular recording interval. (The strategy with two cameras being a near field view with good resolution and high risk of iceberg departure from the viewfinder, and, a wide angle with poorer resolution but a fighting chance of keeping the berg within sight during unmanned periods.)

In a manner similar to that described in some detail in previous work (Ballicater 2005) the time lapse data were reduced and scrutinized for calving events. The observed events are listed in Table 1. according to the following size classifications: 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 1. Summary of Calving Events at Signal Hill June 2007

Date/Time	Calving event size
6/09/10:04	Small
6/09/13:55	Small
6/09/15:22	Small
6/09/16:23	Medium
6/09/17:01	Small
6/09/21:28	Small
6/10/10:21	Small
6/10/11:06	Medium
6/10/17:11	Large
6/10/18:13	Small
6/11/4:41	Small
6/11/7:45	Small
6/11/14:36	Small
6/11/16:31	Large
6/11/17:07	Small
6/12/9:01	Medium
6/12/10:38	Small
6/12/11:31	Medium
6/12/12:58	Small
6/15/9:34	Small
6/15/11:42	Large
6/16/8:00	Medium
6/16/11:30	Large

These results have been graphically represented below (Figure 3.) on a timeline whereby periods of valid data are differentiated from lost time.

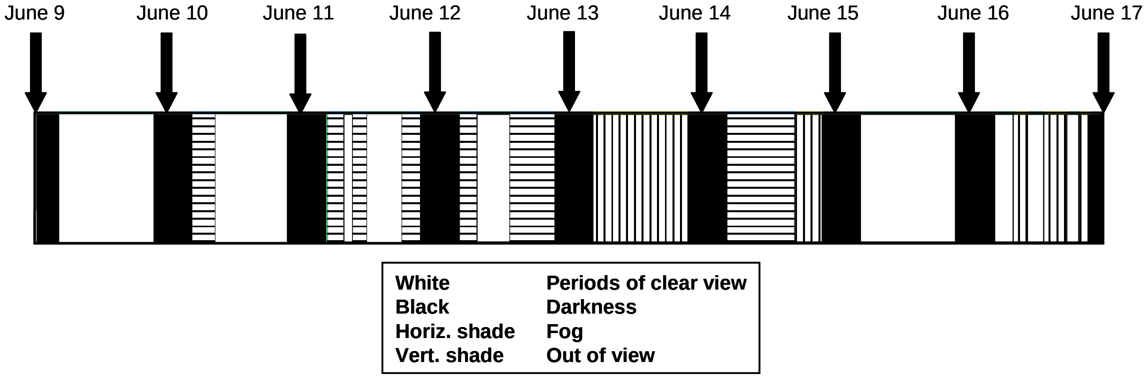

Figure 3. Field program timeline including lost time and clear viewing.

Underscoring the challenging nature of this work is the fact that this iceberg broke into two pieces of roughly equivalent size, and both pieces remained in very close proximity for some time. It was judged that the calving events coming from the two adjacent pieces would continue to be recognized as coming from a single berg until one or the other of the halves moved off by a distance at least equal to one berg length. This judgment became moot as under the cover of fog both pieces drifted off site and only the larger of the two was seen again.

Fisheries and Oceans Canada catalog sea surface temperatures in the oceans surrounding the country. The temperatures are recorded by satellite and weekly and monthly composite means are produced for various regions. Though resolution at the precise location of observation is somewhat vague, the composite for June 3 – 9th indicates a temperature in the range of 6 - 8°C, as did the composite for the period of June 10 – 16th (Figure 4.).

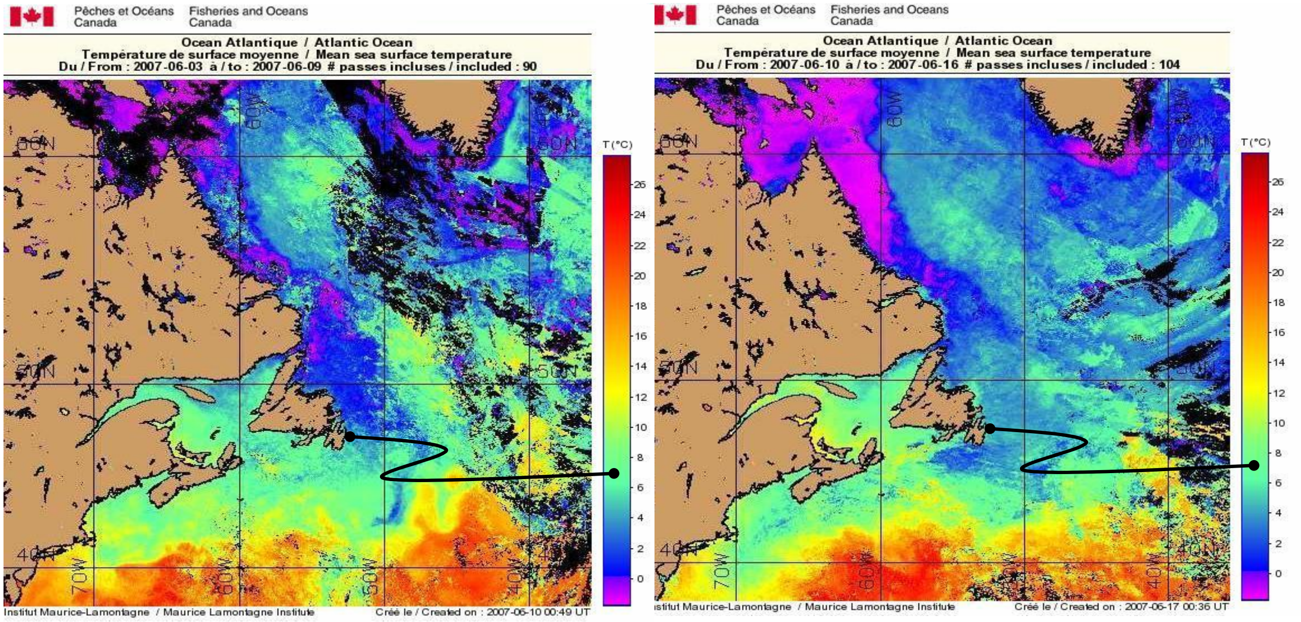

Figure 4. Weekly Mean Surface Temperatures June 3-9 & June 10-16 from DFO, 2007

The Marine Environmental Data Service of DFO also provides hydrographic information for many specific sites, and significantly this includes data from a station not four kilometers from the berg grounding site. On June 15th, 2007 at 47.55°N and 52.59°W a STD profile was obtained as shown in Figure 5. for the vicinity indicated.

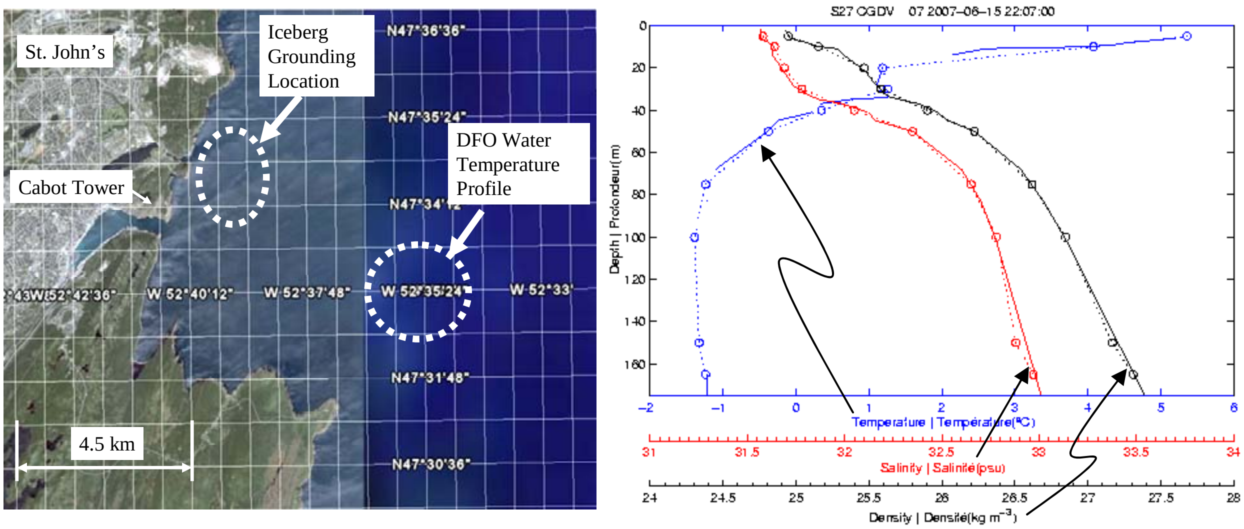

Figure 5. Relative location of iceberg subject and DFO-MEDS station and STD measurements.

The STD profile plotted below indicates a near surface (10 m or less) temperature between 5 and 6 degrees C though the resolution at this depth is vague, and it appears readings above 5 meters are non-existent. Extrapolation suggests the surface temperature tending towards 6 or 8 C which fits well with the remote sensing data. Based on this information the sea surface temperature at the location of the berg closer to land than the DFO station was assumed to be 8 C for the period of investigation. Future work on iceberg melting may be carried out to better account for the distribution of temperature with depth on the bases of the available data.

4. Analysis and Discussion

During the 72.25 hours of observation time 14 small, 5 medium and 4 large events were recorded. The average calving interval during this time period for both medium and large events combined was 8.0 hours. The plot below indicates the relative goodness-of-fit of the present data with past work. Previous investigations resulting in calving interval data have been undertaken from both air and on land. The calving intervals from 2000 to 2003 were obtained from CFR flights and the data in 1998 and 2004 were obtained from video observations much like the present 2007 data (Ballicater 2005). The round markers on the graph represent the calving intervals for medium and large events. Only the medium and large events were used because it is unlikely that the smaller events were able to be seen during the observations from the air. Upper and lower limits have been added to the 2007 data to represent the range of the actual calving interval. The upper limit is developed by recording the large calving events. During the 2007 observations there were 4 large events leading to a calving interval of 18.1 hours. The lower limit is developed by recording all (small, medium and large) calving events, this leads to a calving interval of 3.1 hours. The upper and lower limits have been displayed on Figure 6 for the 1998, 2000 and 2004 data points as well.

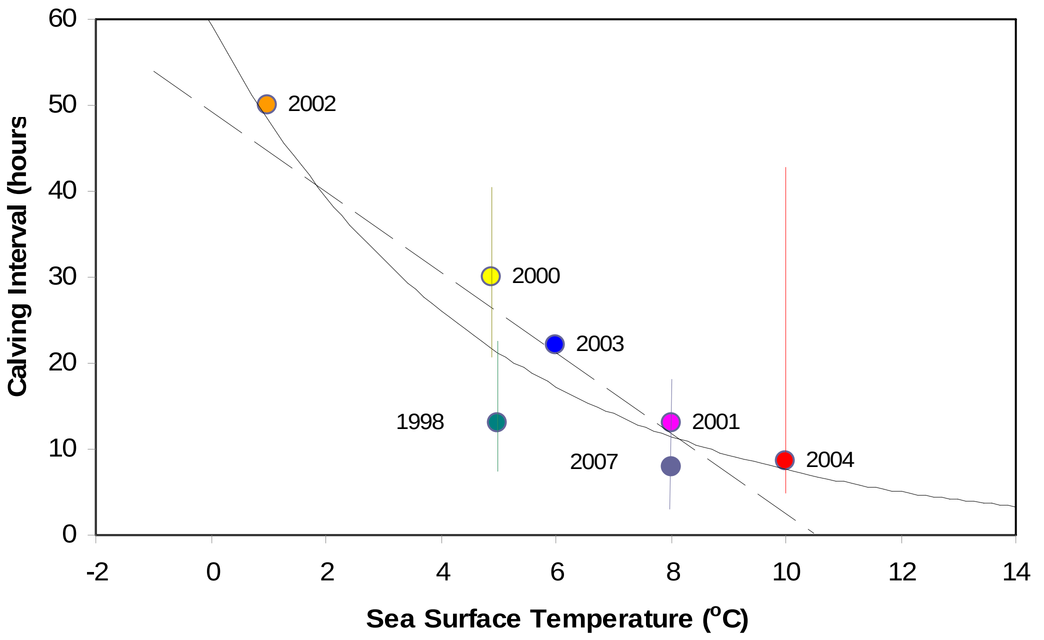

Figure 6. Iceberg calving interval from present (2007), and prior work (from Ballicater, 2005).

The straight dashed line on the graph represents the best linear fit through all data points. The equation of the line is given by:

$t_c = 49.2 – 4.66T_w$

Where t_c is the calving interval in hours and T_w is the surface water temperature.

Reasonable agreement results from the linear model ($R^2 = 0.8084$) but it poses problems reconciling with natural tendencies towards the extremes. To avoid a calving interval tending towards zero as temperatures rise past 10°C, and, appreciable calving rates in waters well below zero, a declining exponential best fit was applied with the resulting curve formulation:

$t_c = 59.4 * e^{(- 0.205T_w)}$

Whether this fit is better or not within the context of CIS iceberg modeling is unknown. By comparison, in Ballicater (2005) similarly derived empirical formulas from the 4 CFR data points were expressed as:

$t_c = 55.3 – 5.3T_w$ $t_c = 62 * e^{(- 0.20T_w)}$

Note that subtle changes in coefficients and exponents have resulted from the addition of new data to the analysis.

Conclusions and Recommendations

Observations of iceberg deterioration have been made and a range of complex mechanisms have been described. Calving events are one of the least difficult mechanisms to quantify owing to the discrete and visible nature of them. Calving frequency is also proportional to melt rate and so modeling of the calving phenomenon presents an opportunity to capture overall iceberg ablation rates. This work analyzed time lapse recording of an iceberg grounded near St. John's in 2007. Calving intervals were determined for periods of uninterrupted viewing and the results were plotted against previous work. The calving frequency appears to agree generally with the body of data presented, however, a trend towards higher frequencies (lower intervals) from this and other shore-based monitoring programs is noted. This discrepancy may be a result of observer differences in the cataloging of event significance, the difficulty with capturing all events with repeat flight data, or perhaps the actual tendency towards higher calving rates for bergs in grounded situations near the coast – perhaps through higher sea states, higher temperatures of greater stresses and impact accelerations.

It is proposed to carry out further investigations of this nature with better equipment and to begin to correlate overall ablation rates to calving frequencies. Considerable data have been collected in this year (2008) to date and more is likely as this iceberg season appears higher than average and somewhat early.

Acknowledgments

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