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# THE INCORPORATION OF AN OCEAN TEMPERATURE PROFILE INTO AN EXISTING ICEBERG DETERIORATION MODEL

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## ABSTRACT

Analytical modelling of iceberg drift forms an essential part of management strategies and scientific investigations. The rate of iceberg deterioration is an important component of iceberg drift models because it affects the life expectancy of the icebergs, and their size, which influences drift speed and direction. Coded models of iceberg deterioration typically use sea surface temperature to characterize the far field temperature of the full water column to which an iceberg becomes exposed. In this work the authors speculate whether the characterization of water temperatures may be improved by considering more closely the ocean temperature profile, both spatially and temporally, but in a manner still conducive to operational modeling.

The work is comprised of two parts, the first is an analysis and modelling of monthly water column data available for a discrete location, the second, an example of how the profile "effect" may be used to modify input for an existing deterioration model. The location considered in this study is DFO Station 27, 5 km offshore from St. John's, Newfoundland. The deterioration model used for the analysis is the CIS operational iceberg deterioration model (2007) coded in Matlab.

The results (for Station 27) indicate that the modification of water temperature to account for the profile "effect" can result is significant differences in predicted iceberg deterioration rates. In particular the revised input temperature reduces the melting influence of extreme or anomalous SST values for a given month. However, incorporating ocean temperature profile data into the CIS melt model requires considerably more analyses and computational effort. The scarcity of historic ocean temperature profile data in the vast oceanic range of interest is also a considerable stumbling block for routine implementation in operational modeling.

## INTRODUCTION

The seasonal presence of arctic icebergs in the Western North Atlantic presents a considerable hazard to commercial activities at sea. The timing and severity of the iceberg season is important as it affects costly decision-making in both the transportation and oil and gas industries. An understanding of the natural causality would help establish predictive indicators that can improve management efficiencies and shed light on the potential effects of longer-term climatic shift. Presently, continuous tracking of all potential iceberg threats in the vast zone of interest (Figure 1) is not feasible and only discrete intermittent surveillance is available. As a result theoretical and empirical modelling of iceberg drift forms an essential part of management strategies and scientific investigations. The rate of iceberg deterioration is an important component of iceberg drift models because it affects the life expectancy of the icebergs, and their size, which influences drift speed and direction.

Figure 1. Region of interest and Station 27.

An iceberg deterioration model intended for the operational use by the Canadian Ice Services (CIS) is described by Kubat et al (2007). The paper provides the formulation used to account for iceberg deterioration via solar radiation, melting due to buoyant convection and forced convection, as well as wave erosion and calving.

The CIS model utilizes a far field water temperature, $T_\infty$, for quantifying melt rates due to buoyant convection, forced convection and wave erosion. It is implicit that this far field temperature is the sea surface temperature (SST). This can be obtained from historical data, measured by satellite as a part of ongoing meteorological monitoring, from numerical ocean models, or via very occasional direct measurement. As this measure of sea temperature is available over the entire region of interest at sufficient resolutions, it is the obvious choice for use in an iceberg drift model that must operate effectively on a daily basis. The work of Kubat et al (2007) demonstrated that as a first-order approximation of water temperature, SST can be effective in semi-empirical formulations. As effective as it is, the authors of this paper speculate whether the characterization of water temperatures may be improved in by considering more closely the ocean temperature profile, both spatially and temporally, but in a manner still conducive to operational modeling.

According to the National Oceanic and Atmospheric Administration (NOAA) the general definition of sea surface temperature is the temperature of water at 1m below the surface. It seems, however, that a variety of measurement techniques exist and each can potentially yield different results. For instance, while buoys may accurately measure temperature at depths of 1m, satellite detection measures surface-emitted infrared radiation which is representative of the surface "skin" considerably less 1mm in depth (NOAA, 2008). This skin temperature may not represent the bulk temperature of the upper meter of ocean due to the effects of solar surface heating in the daytime vs. night surface evaporation, sensible heat loss and reflected radiation.

Notwithstanding the limitations of remote STT inference, there is still a shortcoming with this measure as seasonal variations in the upper strata (0-30m) of the ocean surface temperatures may not be felt at depths into which icebergs extend. Iceberg keels may reach well below 100m with the maximum width of the ice mass occurring at more than 1/3 of the depth iceberg. Barker et al (2004) developed a few generic iceberg shapes and sizes that were subsequently used in calibration trials for the CIS model. One such berg has been reproduced at accurate depth scale (and 4x reduced width scale) in Figure 2.

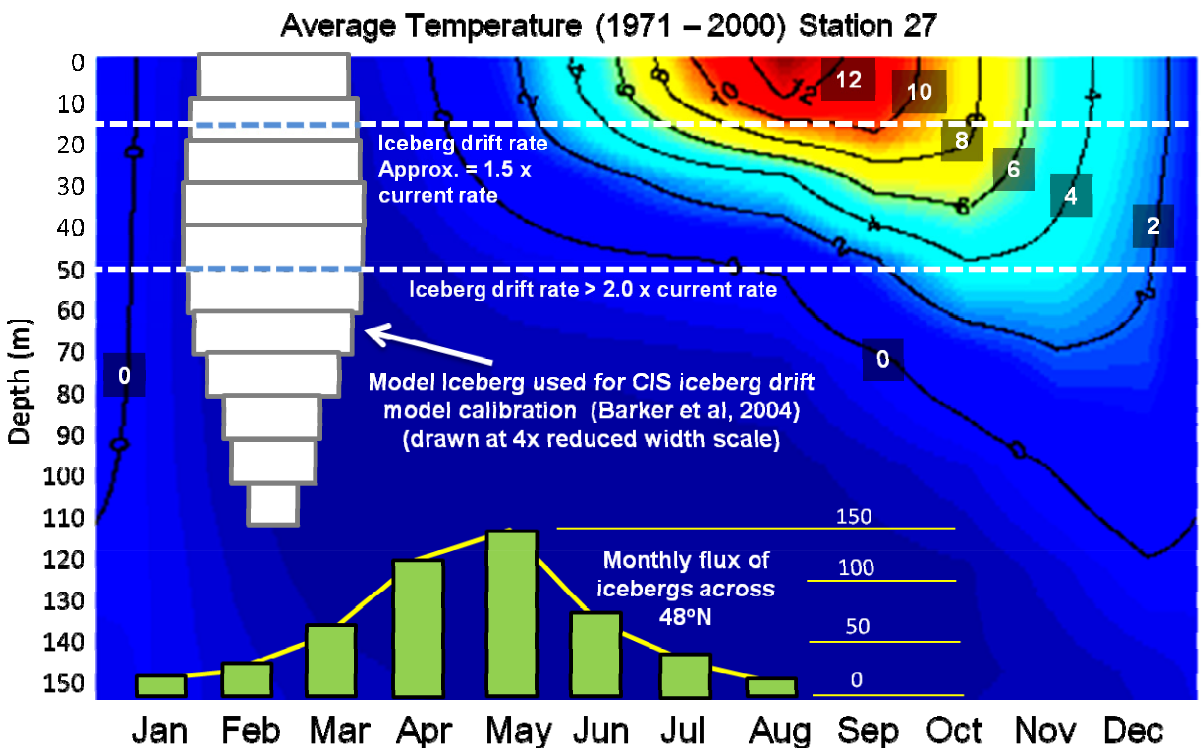



Figure 2. Illustration of water temperature vs iceberg size and flux.

The image of the iceberg shown as a stack of 10m thick plates is superimposed on a contour plot of water temperature versus depth, for each month of the year for Station 27 outside St. John's Newfoundland (Atlantic Zone Management Program (AZMP), Department of Fisheries and Oceans Canada). The rationale for this assemblage is to illustrate the non-uniformity of temperature to which a single iceberg may be exposed, and, how this non-uniformity becomes acute in the late spring and early summer months when iceberg frequency intensifies (see flux histogram overlay). Two horizontal lines are also shown, one at 15 m and the other at 50m depth.

These lines indicate the depths at which relative fluid velocities have been determined for icebergs drifting in ocean currents on the East Coast of Canada (El Tahan et al 1984). At the 15m depth mark research indicates that iceberg drift rates exceed current rate by a factor of 1.5 and that this factor increases to over 2 times at the 50 m depth interval. The substance of this information is that the water in which an iceberg is positioned is moving at different rates relative to each depth interval of the iceberg and that the water temperature at each interval varies uniquely through the seasons.

The observation that the shape of temperature profile varies monthly gives rise to speculation whether the performance of iceberg deterioration models may be improved if sea temperature profile information were somehow taken into consideration. Thus this paper considers two questions: can the ocean temperature profile be reasonably modeled for a specific time and place in the region of interest, and if so, how might this information be used in operational deterioration models. The approach here has been to find source data that may be used to develop representative formulas for temperature distributions for specific locations, to develop those formulas so that the data can be used in the existing operational models, and to look at how the new input data influences the outcomes, specifically iceberg melt rates. It is understood that profile data will be available for only a limited number of sites and therefore, the implementation of this approach and associated code development remains open to consideration.

## DATA SOURCE AND DESCRIPTION

The data used in this work was collected and published by the Atlantic Zone Management Program (AZMP), Department of Fisheries and Oceans Canada. Station 27, located 5km off the coast of St. John's, Newfoundland and Labrador, at the co-ordinates 47.55°N, 52.59°W, has been visited monthly by coast guard vessels since 1999. The data available for this report span 1999 to 2007. STD values were measured at fixed depth intervals 5m, 10m, 20m, 30m, 40m, 50m, 75m, 100m, 125m, 150m, and 155+m (the deepest measurements were recorded at depths ranging from 156 to 175m). This data, now published on the Fisheries and Oceans Canada website, provided a total of 2729 discrete temperature values for use in this study.

## ANALYSIS OF TEMPERATURE PROFILE VARIABILITY

Table 1 lists the average water temperature at discrete depths per month for Station 27 for the years 1999-2007. As the objective of this study was to determine how temperature profiles might be modeled and subsequently used in existing iceberg deterioration models it was proposed to carry out an ordinary least squares regression analysis on the monthly data sets with SST and depth as the input variables. Before doing so, it was observed that for a given month and at a given depth approximately one-half of data series for 1999-2007 exhibited little variability at from year to year (the maximum range of temperature was less than 2.5°C). For these depth/month pairs the mean values are a good approximation of overall conditions. In addition, the variation that was observed in those squares did not correlate to the near-surface temperature (at 5m) in any meaningful way. Thus these data (highlighted in yellow and bounded by the darker line on Table 1) were fixed at constant values and used as a look-up table. In other cases the annual temperature values varied to a larger extent and exhibited some correlation with the near surface temperature. For these an embedded ordinary least squares regression method was used to relate the temperature at each depth increment to the near surface (5m) value.

Table 1. Station 27 mean water temperature 1999-2007 (variation<2.5°C values highlighted).

| **DEPTH** | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5m | 0.9 | -0.4 | -1.1 | -0.2 | 1.7 | 5.7 | 10.8 | 14.7 | 12.8 | 9.4 | 5.6 | 3.3 |
| 10m | 0.9 | -0.5 | -1.1 | -0.3 | 1.6 | 5.2 | 9.8 | 13.7 | 12.8 | 9.3 | 5.6 | 3.3 |
| 20m | 0.8 | -0.5 | -1.1 | -0.4 | 1.2 | 3.8 | 5.2 | 6.6 | 11.2 | 8.9 | 5.6 | 3.2 |
| 30m | 0.7 | -0.4 | -0.8 | -0.6 | 0.6 | 2.1 | 1.9 | 2.9 | 8.5 | 8.3 | 5.3 | 3.0 |
| 40m | 0.5 | -0.5 | -1.1 | -0.7 | 0.0 | 0.8 | 0.1 | 0.9 | 5.4 | 6.7 | 5.0 | 2.9 |
| 50m | 0.5 | -0.6 | -1.1 | -0.8 | -0.4 | -0.1 | -0.5 | -0.1 | 2.8 | 4.8 | 4.2 | 2.7 |
| 75m | 0.4 | -0.6 | -1.2 | -1.1 | -1.0 | -1.0 | -1.1 | -1.1 | 0.1 | 1.0 | 1.8 | 1.9 |
| 100m | 0.3 | -0.5 | -1.2 | -1.2 | -1.2 | -1.2 | -1.2 | -1.3 | -0.9 | -0.6 | 0.1 | 0.9 |
| 125m | -0.1 | -0.7 | -1.1 | -1.3 | -1.3 | -1.3 | -1.2 | -1.4 | -1.2 | -1.2 | -1.0 | -0.6 |
| 150m | 0.1 | -0.1 | -0.7 | -1.0 | -1.2 | -1.0 | -1.1 | -1.0 | -1.1 | -0.8 | -0.9 | -0.4 |
| >155m | 0.0 | 0.1 | -0.3 | -0.8 | -1.0 | -0.7 | -0.9 | -0.6 | -0.9 | -0.5 | -0.7 | -0.6 |

The general form of the equation derived for each month is as follows:

$$T_{m,d} = a_m + b_m \cdot SST + c_{m,d} \qquad (1)$$

where:

$T_{m,d}$ = temperature in month m at depth d
$a_m$ = monthly constant for all depths
$b_m$ = monthly coefficient
$c_{m,d}$ = depth-dependant constant
$SST$ = sea surface temperature

The coefficient and constant for each month are given provided in row 1 and 2 of Table 2, and the depth dependant constant is listed in the remainder. For example to calculate the 50m temperature for June if the surface temperature was 5°C,

$$T_{June,50m} = -3.022 + 0.340 \cdot 5 + 1.118 = -0.204\ ^{o}C$$

Table 2. Empirical values for temperature equation.

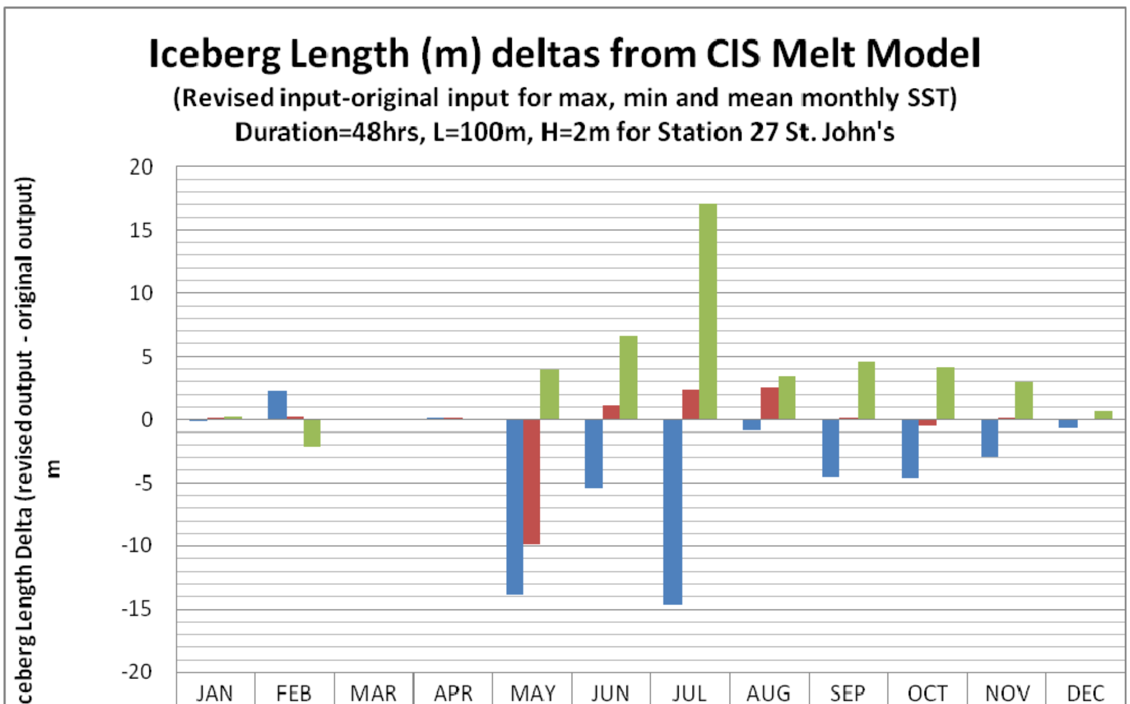
| Variable | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| a | -0.208 | n/a | n/a | -0.061 | 5.607 | -3.022 | -3.445 | -5.959 | 1.121 | -1.825 | -3.256 | -0.125 |
| b | 0.929 | n/a | n/a | 0.959 | 0.003 | 0.340 | 0.205 | 0.397 | -0.086 | 0.273 | 0.596 | 0.873 |
| c(5m) | 0.270 | n/a | n/a | 0.055 | 0.004 | 6.756 | 12.067 | 14.835 | 12.765 | 8.864 | 5.538 | 0.538 |
| c(10m) | 0.243 | n/a | n/a | n/a | 0.004 | 6.316 | 11.078 | 13.873 | 12.760 | 8.834 | 5.496 | 0.544 |
| c(20m) | 0.184 | n/a | n/a | n/a | 0.002 | 4.990 | 6.427 | 6.715 | 11.194 | 8.382 | 5.411 | 0.429 |
| c(30m) | 0.168 | n/a | n/a | n/a | n/a | 3.285 | 3.129 | 3.042 | 8.476 | 7.679 | 5.211 | 0.280 |
| c(40m) | 0.132 | n/a | n/a | n/a | n/a | 1.984 | 1.358 | 0.982 | 5.412 | 5.911 | 4.822 | 0.151 |
| c(50m) | 0.116 | n/a | n/a | n/a | n/a | 1.118 | 0.767 | n/a | 2.656 | 3.872 | 3.987 | n/a |
| c(75m) | n/a | n/a | n/a | n/a | n/a | 0.217 | 0.148 | n/a | n/a | n/a | 1.690 | n/a |
| c(100m) | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| >100m | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |

## APPLICATION

As a preliminary analysis of the effect of the proposed temperature input, the iceberg deterioration model described in Kubat et al. (2007), was coded in MATLAB© with the revised parameterization and executed over a 48 hour time period for each month at maximum, minimum, and mean sea surface temperatures observed at Station 27 with all other input parameters held constant. (100m original waterline length, 77m draft, 2m wave height). Then, as a first-order approach to implementing profile data, the sea surface temperature input value was replaced with an average ocean temperature across the instantaneous depth of the iceberg. The draft (D) of the iceberg was derived from the input waterline length (L) as proposed by Barker et al. (1994) in which:

$$D = 2.91 \cdot L^{0.71} \qquad (2)$$

The results have been summarized in Figure 3 below, with the values plotted and listed defined as the difference between the resultant iceberg length using revised far field (input) temperatures, versus iceberg length derived from far field temperatures equal to SST. Bars below the zero line indicate deterioration was greater using the temperature profile method.




| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MINIMUM | -0.1 | 2.3 | 0 | 0.1 | -13.9 | -5.4 | -14.7 | -0.9 | -4.5 | -4.6 | -3 | -0.7 |
| MEAN | 0.1 | 0.2 | 0 | 0.1 | -9.9 | 1.1 | 2.4 | 2.5 | 0.1 | -0.5 | 0.1 | 0 |
| MAXIMUM | 0.2 | -2.1 | 0 | 0 | 4 | 6.6 | 17.1 | 3.4 | 4.6 | 4.1 | 3 | 0.7 |

Figure 3. Results of modifying the melt model input to account for the profile "effect"

Results indicate the greatest anomaly for mean SST occurs in May, an important month for iceberg management. The revised water temperature value has resulted in more rapid deterioration in the late spring and slower deterioration in summer. A significant observation is that the revised data provides a clearer expression of the range of potential melt rates. The minimum and maximum SSTs for a given month if used unaltered result in significantly slower melting in circumstances where SST is lower than average in a particular month, and significantly faster when SST is higher than average in a given month. In other words the revised input temperature reduces the melting influence of extreme SST values for a given month. It does this as a result of the knowledge that instantaneous SST readings are not fully representative of the water column temperature profile in a given month.

## CONCLUSIONS AND RECOMMENDATIONS

The above work has shown that during the months of high iceberg concentrations on the East Coast of Canada, temperatures in the water column can vary significantly from the sea surface temperature. Utilization of water temperature profile data in place of unqualified sea surface temperature can result is significant differences in predicted iceberg deterioration rates. Incorporating ocean temperature profile data into the CIS melt model requires considerably more analyses and computational effort. The scarcity of historic ocean temperature profile data in the vast oceanic range of interest is also a considerable stumbling block for routine implementation of the profile "effect". None the less, the present study has demonstrated that for a specified location with data available, the concept can be implemented and has shown that the effects may be significant enough to warrant continued research in this area.

## REFERENCES

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El-Tahan, M, El-Tahan, HW, and Venkatesh, S (1983). Forecast of iceberg ensemble drift *Proc Offshore Tech Conf,* OTC Paper No. 4460, Houston, Texas, USA, 1983, pp 151-158.

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White, F. M., M. L. Spaulding, and L. Gominho, 1980. Theoretical Estimates of the Various Mechanisms involved in Iceberg Deterioration in the Open Ocean Environment. Report CG-D-62-80 to U. S. Coast Guard Research and Development Center, 126 p.

## DATA SOURCES

National Oceanic and Atmospheric Administration (NOAA)
Satellite and Information Service: http://www.osdpd.noaa.gov/ml/ocean/sst/

Fisheries and Ocean Canada (DFO)
www.dfo-mpo.gc.ca> Science>Data and Products>AZMP>Hydrographic Data>Station Yearly Data>Station 27 http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/azmp-pmza/hydro/station/