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ICE ISLAND OCCURRENCE ON THE CANADIAN EAST COAST

Ingrid Peterson[1]

[1]Bedford Institute of Oceanography, Dartmouth, CANADA

ABSTRACT

Ice islands are a major hazard for offshore structures and shipping on the Canadian East Coast. Calving rates and drift rates of ice islands for the two main sources of ice islands in Canadian waters, the Ellesmere Island Ice Shelves and the Petermann Glacier, are described using values from the literature and from satellite imagery.

The Petermann Glacier, is of more importance as a hazard for the Canadian East Coast. Until recently, the position of the Petermann calving front fluctuated over time, with no significant trend. However in the year or two prior to the calving event of 2010, the calving front was unusually far into the fjord along the northeast side, and since the calving event, the calving front as a whole appears to be at a new minimum position.

The Ellesmere Island Ice Shelves are of less importance as a hazard for the Canadian East Coast, since they produce ice islands that usually drift in the Arctic Ocean, but occasionally enter Nares Strait or the Canadian Archipelago. For the Ellesmere Ice Shelf between 66 and 79°W, the calved ice area per unit time has been relatively constant over the last 100 years, although the frequency of calving has varied over time.

Fragments of ice islands from both areas that reach Nares Strait (80.8°N), can later reach Davis Strait in 4-5 months and the Grand Banks area in 9-10 months. However, most fragments are delayed or lost before reaching the Grand Banks, due to entrapment in coastal inlets or slow current regions, grounding or melting. Thus, ice island occurrence on the Labrador and Newfoundland coast is partly determined by the length of the iceberg season. The iceberg season length since 1900 shows a strong multidecadal variation, and is consistent with air temperature changes in the Labrador Sea area.

INTRODUCTION

An ice island is defined by the World Meteorological Organization (WMO) as "A large piece of floating ice protruding about 5 m above sea level, which has broken away from an Arctic ice shelf. They have a thickness of 30 to 50 m and an area of a few thousand square metres to 500

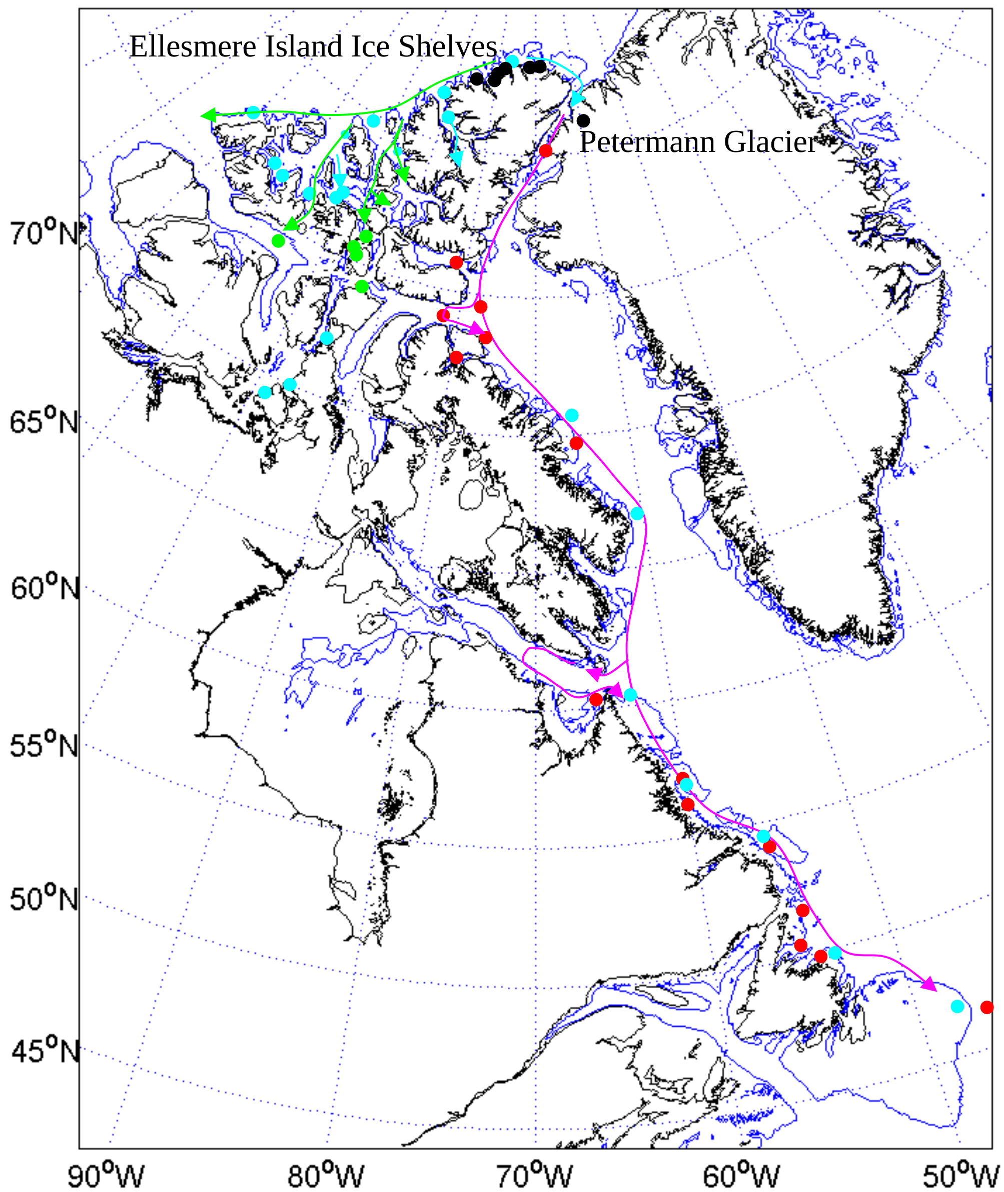

Figure 1. Map showing representative locations of ice islands and drift patterns, from various data sources. The black dots show the major places of origin: the Ellesmere Ice Shelves and the Petermann Glacier. The cyan dots and arrows represent ice island data from Koenig et al. (1952) and Nutt (1966). The green dots and arrows represent recent ice island data from CIS ice charts, Johnston et al. (2003) and Johnston (2004). The red dots and arrows are believed to be from the Petermann Glacier, and are from Peterson (2005), Peterson et al. (2009), Zentilli et al., (2003), CIS ice charts and other information provided by the Canadian Ice Service. The magenta lines represent iceberg drift patterns shown in Newell (1993).

square km or more. They are usually characterized by a regularly undulating surface giving a ribbed appearance from the air" (Environment Canada, 2005, page 1-7). Like icebergs, which are greater than 5 m above sea-level, ice islands are defined as "calved ice of land origin". While ice islands are relatively flat-topped, icebergs can either be tabular (flat-topped), or non-tabular (domed, pinnacled, wedged or dry-docked). Ice islands are generally larger in area (but lower in height) than icebergs, with medium icebergs having a length of 61-120m and height of 16-45m above sea-level.

Ice islands are a major hazard for offshore structures and shipping on the Canadian East Coast. Calving rates and drift rates of ice islands for the two main sources of ice islands in Canadian waters, The Ellesmere Island Ice Shelves and the Petermann Glacier, are described in this paper using values from the literature and from satellite imagery.

ICE ISLAND SOURCES

The two main sources of ice islands on the Canadian East Coast are the Ellesmere Island Ice Shelves and the Petermann Glacier (Figure 1).

The Ellesmere Island Ice Shelves are located in embayments along the north coast of Ellesmere Island, and are remnants of a continuous ice shelf stretching along the coast at the beginning of the 20th century (Jeffries, 2002). The shelves are composed of multiyear landfast sea ice, glacier ice or a mixture of both. Following the 2008 breakup, the total area of the ice shelves was 720 km^2 (Mueller et al., 2008).

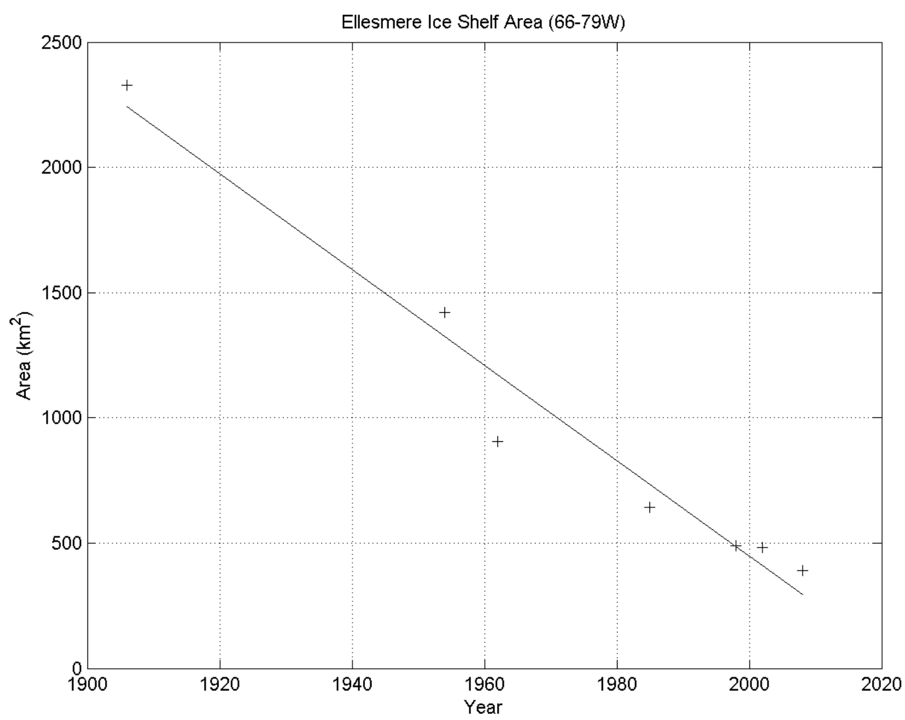

Figure 2. Ellesmere Ice Shelf area from 79-66°W (east of Ayles Ice Shelf) from Vincent et al. (2001), updated to 2008.

Figure 2 shows changes in the area of the Ellesmere Island ice shelf between 79 and 66°W (east of the Ayles Ice Shelf) from values given in Vincent et al. (2001) from 1906 to 1998, and updated using losses of 6 km^2 in 2002 from the Ward Hunt Ice Shelf (Copland et al., 2007), and losses of 42 and 50 km^2 from the Ward Hunt and Markham Ice Shelves in 2008 (Mueller et al., 2008). Losses from the Ayles and Serson Ice Shelves in 2005 and 2008 are not included. Although it has been suggested that the timing of individual calving events may have been caused by local atmospheric changes (Copland et al., 2007), the long-term areal rate of loss has been relatively constant (Figure 2). This suggests that the areal rate of loss may be related to long-term changes in air or water temperatures, which have been increasing globally since the beginning of the 20th century.

The Petermann Glacier is located in northwest Greenland, and flows into a fjord where it consists of a floating ice tongue 70 km long and 20 km wide. The thickness decreases from about 600m at the grounding line (Rignot and Steffen, 2007) to less than 100 m at the calving front (Higgins, 1991). Until recently, the position of the calving front appeared to be stable (Peterson, 2005; Johannessen et al., 2010), A stable position corresponds to a calving rate of 0.59 km^3/yr, and a retreat of 1 km/yr corresponds to an additional calving rate of 0.69 km^3/yr, using glacier thickness values from Higgins (1991). Following the calving event in August 2010, the front had retreated ~15 km beyond the envelope of previous observations extending back to 1953 (Johannessen et al., 2010). Figure 3 shows the position of the calving front in 2008 obtained with MODIS imagery (heavy black line) compared to previous years (Peterson, 2005). The grounding line is about 70 km into the fjord from the calving front (Rignot and Steffen, 2008). While the overall position of the front was within historical limits, it appears to be unusually far into the fjord on the northeast side (B), as well as near the centre of the fjord (A), making it more prone to melting, and to fracturing farther into the fjord.

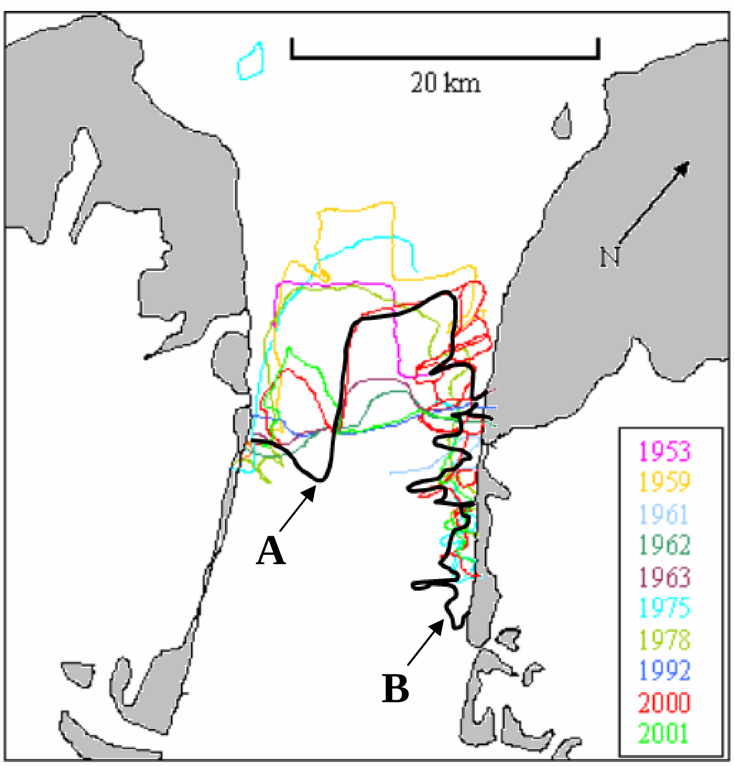

Figure 3. Position of calving front in 2008 (black line), compared with previous years.

ICE ISLAND EXAMPLES

Figure 4 shows an ice island observed in Barrow Strait in August 2010 during the deployment of a mooring array by personnel at the Bedford Institute of Oceanography. It is thought to have originated from the Ayles Ice Shelf which calved in 2005, or possibly from one of the other ice shelves that calved in 2008. Marine sediments visible at the surface in areas of the Ward Hunt Ice Shelf have been brought there due to basal freezing when the sediments are incorporated into the sea ice, and surface ablation when they accumulate at the surface (Vincent et al., 2004). Sediments have also been observed on areas of the Ayles Ice Shelf (Copland et al., 2007).

Figure 5 shows an ice island observed in Ungava Bay in July 2005. The freeboard was 4-12 m, consistent with the altitude of the calving front of the Petermann Glacer (Higgins, 1991), and with the surface appearance of the Petermann Glacier (Peterson, 2005). Based on the general iceberg drift in the area (Newell, 1993), the ice island likely drifted into the Bay from the east in the Labrador Sea. From MODIS imagery, the ice island drifted eastward toward Cape Chidley between 14 July and 13 August, broke up by 21 August, and drifted out of the bay.

Figure 4. Ice island in Barrow Strait from Ellesmere Ice Shelves, 14 August 2010, about 910 m x 730 m. Photo courtesy of Brian Beanlands, Fisheries and Oceans Canada.

ICE ISLAND DRIFT PATTERNS AND RATES

The ice islands that calved from the Ellesmere Island Ice Shelves in the 1940s and 50s were described as falling into 2 groups: one group that drifted in the Arctic Ocean and a second group that drifted into the Arctic Archipelago (Koenig et al., 1952). Of the five ice islands that calved from the Ward Hunt Ice Shelf in 1961-2, four drifted westward, and one drifted eastward and then southward through Nares Strait and the Labrador Sea (Nutt, 1966). The drift of ice islands from the Ellesmere Ice Shelves into the Arctic Archipelago can be seen in sequential ice charts from the Canadian Ice Service in recent years (Figure 1). As shown by the example in Figure 4, the ice islands can take several years to reach Lancaster Sound, because for much of the year they are immobilized in the channels of the Arctic Archipelago by consolidated sea ice (sea ice with a concentration of 100%). The melt duration has been increasing, and more multiyear ice has been drifting into the Arctic Archipelago from the Arctic Ocean since the mid 1990s (Howell et al., 2009). This would have the effect of increasing the likelihood of ice islands drifting into the Arctic Archipelago, rather than remaining in the Arctic Ocean.

In 1963-64, ice islands from the Ward Hunt Ice Shelf on Ellesmere Island drifted from Nares Strait (80.8°N) to north of Cape Dyer (68°N) in 4 ½ months, between 24 July and 05 December 1963, and fragments reached the Grand Banks in late April 1964, 9-10 months after drifting south of 80.8°N (Nutt, 1966).

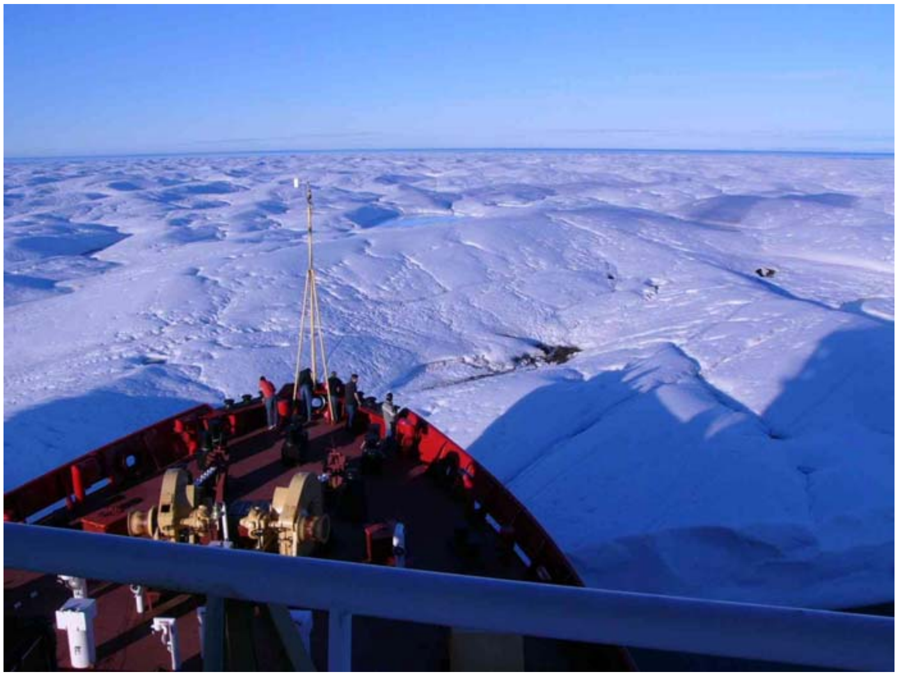

Figure 5. Ice island in Ungava Bay, 25 July 2005, about 2.2 km x 1.5 km, 4-12 m freeboard. Photo courtesy of the Canadian Ice Service.

A tabular iceberg observed off Labrador in 1976 was believed to be from the Petermann Glacier (Dunbar, 1978). In 2002, ice islands from the Petermann Glacier reached the Grand Banks in late May (Stoermer and Rudkin, 2003), 9 ½ months after a large ice island drifted out of the fjord on 09 Aug 2001. In 2003, ice islands reached the Grand Banks in early May, and were likely from an ice island sighted at 69.5°N on 26 Oct 2002, 7 ½ months previously. In comparison, ice islands in 1963-64 drifted this distance between about 19 November and late April, 5 ½ months (Nutt, 1966). In 2008-2009, an ice island reached 68°N on 22 January, 4 months after crossing 80.8°N. This drift rate is similar to the maximum drift rate in 1963-64 (Peterson et al., 2009).

Many fragments become entrapped in coastal inlets or embayments such as Eclipse Sound in 2002-2003 (Peterson, 2005), Ungava Bay in 2005, and Jones Sound in 2008 (Figure 1). The ice island in 2008-2009 (Peterson et al., 2009) passed through Davis Strait, then drifted into a slow current region south of Baffin Island where it eventually melted.

ICEBERG SEASON LENGTH

The occurrence of ice islands south of 48°N is not well known. However the survival rate of any ice islands reaching temperate latitudes would be related to the length of the iceberg season for all icebergs (Figure 6). This is defined simply as the total number of months with icebergs drifting south of 48°N from October to September of each year, using the International Ice Patrol monthly iceberg numbers dataset. The iceberg season length shows a strong multidecadal cycle, with high values in the early 20th century and 1970s to early 1990s, as well as a trend toward a shorter iceberg season. Similarly mean annual air temperatures were low in the early 20th century and 1970s to early 1990s, with an upward trend in air temperature at St. John's. This multidecadal pattern corresponds to that of the Atlantic Multidecadal Oscillation (AMO), defined as the detrended mean sea surface temperature in the North Atlantic Ocean from 0 to 70°N.

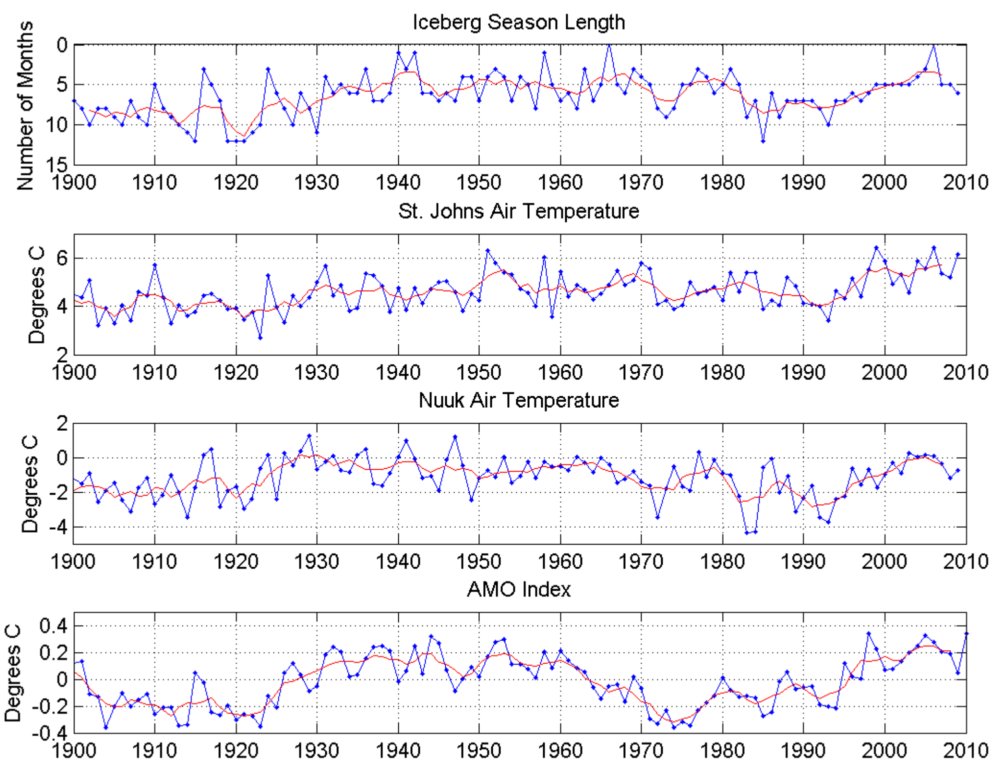

Figure 6. Iceberg season length south of 48°N, with the vertical axis direction reversed (top panel), annual mean air temperatures at St. John's, Newfoundland (second panel), and Nuuk, Greenland (third panel), and the Atlantic Multidecadal Oscillation Index (bottom panel), October to September. For each time series, the red line represents the 5-year running mean.

The correlation coefficients of iceberg season length with St. John's air temperature, Nuuk air temperature, and the undetrended AMO index are -0.54, -0.46 and -0.51 respectively, and -0.46,

-0.47 and -0.40 after detrending. Because of autocorrelation, the effective number of points (Chelton, 1983) for the 109 years is reduced to 51, 28 and 19 for the 3 time series. Thus the correlations are significant at the 5% level for St. John's and Nuuk air temperature ($p<0.05$), but only at the 10% level for the AMO index ($p<0.10$). Since the AMO index is dominated by a cycle of about 60-70 years, and there are less than 2 cycles in the time series, the high p-value for the AMO index is not surprising.

CONCLUSIONS

The sources and occurrence of ice islands was reviewed using information from the literature, from the Canadian Ice Service, and from satellite imagery. The Ellesmere Island Ice Shelves originally formed via in situ thickening and are now retreating, with no evidence for regrowth in the near future. The Petermann floating glacier tongue is constantly replenished by the Greenland Ice Sheet, but the calving rate and thus the position of the calving front vary from year to year, with a major calving event occurring in 2010.

Although the frequency of calving from the Ellesmere Ice Shelves has varied over time, the areal rate of decrease has been relatively constant. There is one documented case of ice islands reaching the Labrador coast and the Grand Banks from the Ellesmere Ice Shelves in 1963-64 via Nares Strait. A few have been sighted in Parry Channel (Northwest Passage), but are not known to have reached the East Coast through the Canadian Archipelago.

In 2008, prior to the calving event of the Petermann Glacier in 2010, the calving front was unusually far into the fjord along the northeast side. Ice islands are known to have reached the Grand Banks from the Petermann Glacier in 2002 and 2003, Labrador in 1976, and Baffin Island in 2009.

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