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FRACTURES IN ARCTIC WINTER PACK ICE
(NORTH WATER, NORTHERN BAFFIN BAY)

by

K. Steffen

(Department of Geography, Swiss Federal Institute of Technology, Zürich, Switzerland)

ABSTRACT

Profiles of the ice cover in the North Water area were obtained in the winter of 1980/81 by using low-level infrared thermometry. The flight measurements were carried out from December to March. The statistical analysis of the sea ice surface temperature was carried out to yield distributions, frequencies and widths of fractures. Ice-free as well as ice-covered fractures with a maximum ice thickness of 0.4 m were analysed. Typical fracture frequencies were 0.25 per km for Lancaster Sound and 0.14 per km for Baffin Bay and the North Water area, with 90% of fractures being less than 0.6 km wide. From December to March, the fractures occupied 8.8% of the ice cover in the North Water area, 8.7% along the Baffin Bay profile and 10% in the Lancaster Sound. In the North Water area the distance (y) between fractures for different fracture widths (x) is an exponential function of the form y=Aexp(ax) (A,a are constants), for fractures between 50 and 800 m wide. In the North Water area during winter, fractures of all widths occur 5 times more frequently than in M'Clure Strait and about 7 times more frequently than in southern Beaufort Sea. The heat loss in Lancaster Sound at the ice–air interface was found to be 40 to 100% larger due to the fractures compared to a fast ice situation in the same winter.

INTRODUCTION

The occurrence of fractures in pack ice is of major geophysical interest. In sea ice mechanics, the knowledge of, for example, fracture distribution, is important, since each fracture is a potential pressure ridge, and the distribution of fractures is a measure of the capacity of the ice cover to sustain deformation through convergence and shear. A direct application of fracture statistics deals with the openings in Arctic and Antarctic pack ice which are a natural environment for sea mammals during winter and spring. A drastic change in the number of fractures between the years can be fatal for large sea mammals (e.g. whales). In climatology, information on fracture occurrence is vital for energy exchange calculations at the ice–air interface. At this boundary layer the heat flux for ice-free fractures and those covered with young ice is about ten times larger than over first year ice. Other applications are of more practical use – fractures may for instance serve as surfacing sites for submarines, or as landing sites for aircraft, now widely used in support of ice research.

So far, little is known about the number of fractures, their width and their distribution in Arctic winter pack ice. Fracture patterns from infrared satellite imagery (Ackley and Hibler 1974) have been available for some time, but not until recently was infrared satellite imagery suitable for the detection of fractures less than 1 km wide. The best suited instrument platforms for high resolution fracture analysis in winter are submarines or low-flying aircraft. Measurements obtained from low-flying aircraft will be discussed in more detail.

The study was carried out as part of the North Water Project (Müller and others 1973). North Water, well-known for its young ice and open water areas during winter, caused by the existence of polynyas (Steffen 1985[a]), is situated between Greenland and the Canadian islands, Ellesmere and Devon Island (Fig.1). The objective of the present paper is (1) to report on the number of fractures, as well as their width and distribution in winter pack ice of the North Water region, and (2) to give some estimates of the energy loss through fractures during the winter months.

METHODS AND MEASUREMENTS

In winter 1980/81, six low level remote sensing flights were carried out over the North Water area. The sea surface temperature (SST) was measured from a flight altitude of 300 m with an infrared sensor (Barnes PRT-5) along profiles in Lancaster Sound and the northern Baffin Bay (Fig.1). The radiation temperature measured with the PRT-5 intrument in the spectral range 9.5 to 11.5 μm was corrected by taking into account the emissivity of water (ϵ=0.991), snow (ϵ=0.997) and ice (ϵ=0.987); the absorption and emission by atmospheric water vapour as well as the multiple reflection between the cloud base and the ground. The temperature dependence of the emissivity for dry snow was neglected. Young ice surfaces remain wet due to the high brine content in the thin ice. Consequently, brightness temperature measurements of sea ice up to 0.25 m thick were corrected by using the emissivity of water. A detailed account of this correction procedure is presented in Steffen (1985[b]). After having applied the corrections, the accuracy of the PRT-5 temperature was estimated at ±0.15°C at a flight altitude of 300 m.

Fractures in the pack ice could be detected due to the SST-difference between open water and ice surfaces. However, only fractures wider than 50 m could be classified because of the ground resolution of the instrument. Fractures covered with young ice (<0.4 m thick) still have a large conductive heat flux at the ice–air interface (Fig.2). Therefore, not only ice-free fractures are of importance for energy flux calculations over pack ice regions. The conductive heat flux, the only energy source over Arctic winter pack ice, amounts to 840 W m^{-2} in ice-free fractures and to approximately 125 W m^{-2} for fractures covered with young ice (Maykut 1978: January situation, air temperature -30°C). The conductive heat flux decreases to about 20 W m^{-2} for ice 2 m thick.

Both sensible and latent heat fluxes are dependent on surface temperatures, which in turn are influenced by the ice thickness. From the SST-measurements, the ice thickness can be calculated by the parametrisation of the energy balance equation (Steffen 1986). The following ice types could be classified: dark nilas, light nilas, grey ice and grey-white ice. Therefore, the occurrence frequency and distribution of ice-free and ice-covered fractures (maximum ice thickness: 0.4 m) could be calculated from the SST-measurements. The analysis was carried out for six flight dates from December to March for the following areas: Lancaster Sound (Fig.1, point 5 to 7), Baffin Bay

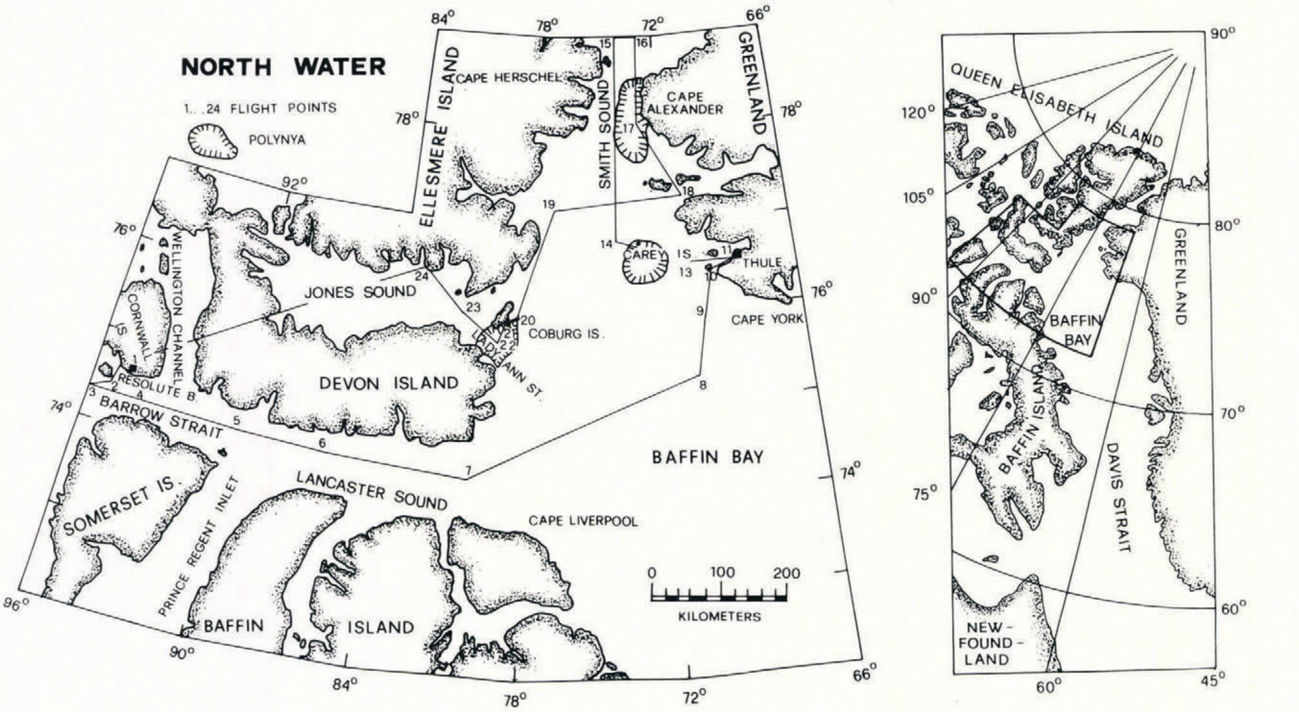

Fig.1. Map of North Water region and profile of remote sensing. Note position and average extension of the polynyas in Smith Sound, around the Carey Islands and in Lady Ann Strait during winter 1980/81.

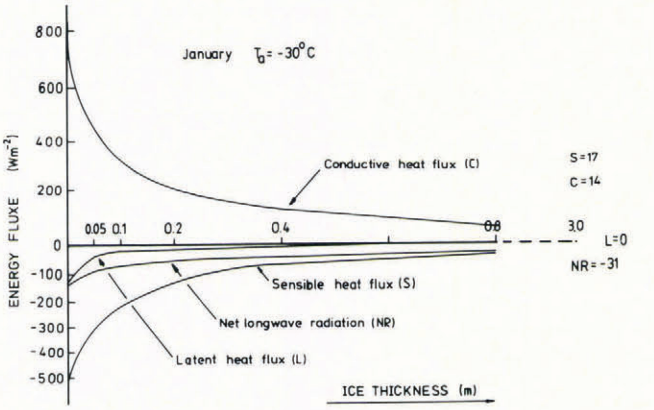

Fig.2. Energy fluxes and ice thicknesses at the ice–air interface in January for an air temperature of −30°C (after Maykut 1978).

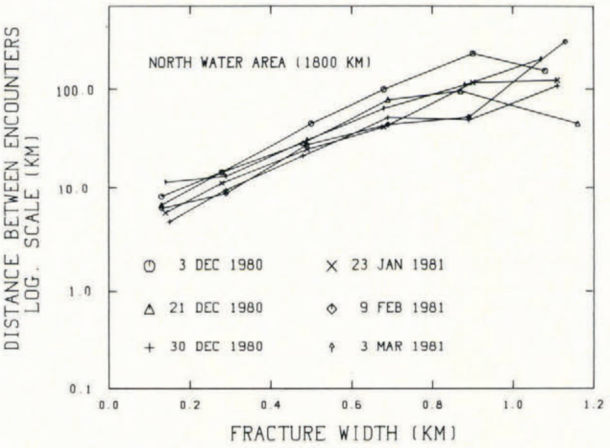

Fig.3. Relation between encounters with fractures and fracture widths in the North Water area during winter 1980/81.

(point 7 to 9), and North Water area (point 13 to 23). The polynyas in Smith Sound, Lady Ann Strait and around the Carey Islands, all located between the flight points 13 to 23 (Fig.1), were excluded from the fracture analysis. The fractures were classified according to their width: (1) 50 – 200 m, (2) 200 – 400 m; (3) 400 – 600 m; (4) 600 – 800 m, (5) 800 – 1000 m, (6) 1000 – 1200 m. Fractures in class (1) are called small fractures, those in class (2) medium fractures and those in the classes (3) to (6) large fractures, according to the ice classification (WMO 1970).

RESULTS AND DISCUSSIONS

For pack ice in the North Water area, the distances between fractures for different fracture widths are plotted in Fig.3. The analysed profile, which excluded polynyas in Smith Sound and around Carey Islands, has a total length of 1800 km. Only fractures between 50 m and 1.2 km in width were analysed; those below 50 m could not be detected due to the instrument resolution; fractures wider than 1.2 km were rare. For fractures of 50 to 200 m wide, the distance between encounters varies from 5 to 11 km. There was no systematic change observed in fracture distribution during winter. The relation between distance of encounters between fractures (y) and fracture widths (x) was an exponential of the form y=Aexp(ax) (a=1.786, A=3.899) for fracture widths of up to 0.8 km as a mean of six flights in winter 1980/81. Fractures between 1 and 1.2 km in width were found with spacings varying from 50 to 280 km. For a statistically relevant statement on fractures wider than 800 m, the profile length should be much longer. There is no reason to expect an exponential law or any other simple analytical form to be valid for all fracture width classes. Rothrock and Thorndike (1984) have shown that the floe size distribution (mean caliper diameter and number of floes per unit area) can be approximated by a power law for certain Arctic pack ice regions. Further, they showed other possible distribution laws which are of some interest for this work as floe size and fractures are somehow related to each other. However, for a detailed discussion more data on fracture-width frequency from different regions and years are needed. Fig.4 depicts the situation for Lancaster Sound, Baffin Bay and the North Water profile as a mean for the six flights between December and March. Lancaster Sound is 300 km long, borders with Barrow Strait in the west and leads into Baffin Bay in the east. As the narrow channel is only

60 km wide, pack ice movement is limited by its coastal boundaries. Pack ice in Baffin Bay by contrast has more freedom to move around due to the polynyas in Smith Sound and around the Carey Islands. However, shortest spacings between fractures were found in Lancaster Sound. Fractures along Baffin Bay and the North Water profile had an almost identical spacing for fracture widths of up to 0.5 km.

Typical fracture frequencies were 0.25 per km for Lancaster Sound and 0.14 km for the Baffin Bay and the North Water area. For the three areas in discussion about 55% of all fractures were between 50 m and 200 m wide, about 25% between 0.2 and 0.4 km, and 10% between 0.4 and 0.6 km (Fig.5). The occurrence frequency of fractures 0.6 to 1.2 km wide was less than 10%.

During the AIDJEX pilot study in April 1972 high resolution aerial photographs were taken along profiles of 600 km in length in the Beaufort Sea. The visible interpretation of the photographs showed that on the average every 4 km a fracture occurred which was less than 200 m wide (Hall 1980). This fracture-width frequency measured in the Beaufort Sea in April is similar to the one found for the North Water region during winter 1980/81. However, the AIDJEX study includes fractures less than 50 m in width and therefore the two data sets can not be compared directly. Further, it is not clear which fracture ice types (age of fracture) were included in the AIDJEX study.

The fracture distribution along Lancaster Sound, Baffin Bay and the North Water profile is comparable to the results published for M'Clure Strait (Wadhams and Horne 1980) and the Beaufort Sea (McLaren and others 1983). M'Clure Strait is located at the west end of the North West Passage, whereas Lancaster Sound is at its eastern end. M'Clure Strait leads into the Beaufort Sea, which is part of the Arctic Ocean. The fracture analysis from the western part of the Canadian Arctic was obtained from submarine vessels by using a narrow-beam upward-looking sonar. For the sonar measurements a fracture was defined as a continuous sequence of depth points in which no point exceeds 1 m in draft (McLaren and others 1984). The results of Wadhams and Horne (1980) and McLaren and others (1984) include fractures with an ice cover of up to 1 m compared to our analysis, which includes a maximum ice thickness of 0.4 m.

Fig.4 shows the difference between the fracture distribution in winter and summer in M'Clure Strait (including the neighbouring Beaufort Sea shelf) as well as the winter situation for the southern Beaufort Sea, the North Water area, Lancaster Sound and the northern Baffin Bay. In M'Clure Strait, fractures of all widths occur almost ten times more frequently in summer than in winter. Compared to the North Water area, the fracture distribution in M'Clure Strait is about 4 to 5 times less frequent in winter. It is surprising that in M'Clure Strait there are only twice as many fractures in summer as in the North Water in winter. For the southern Beaufort Sea, the fracture distribution in spring is even 7 times smaller compared to the North Water in winter. This can be explained by the influence the polynyas (Smith Sound, Carey Islands, Lady Ann Strait) have on the pack ice cover in northern Baffin Bay and Lancaster Sound. The polynyas are ice-free or covered by young ice throughout winter (Steffen 1985[b]; 1986), which has a direct influence on the surrounding pack ice regions.

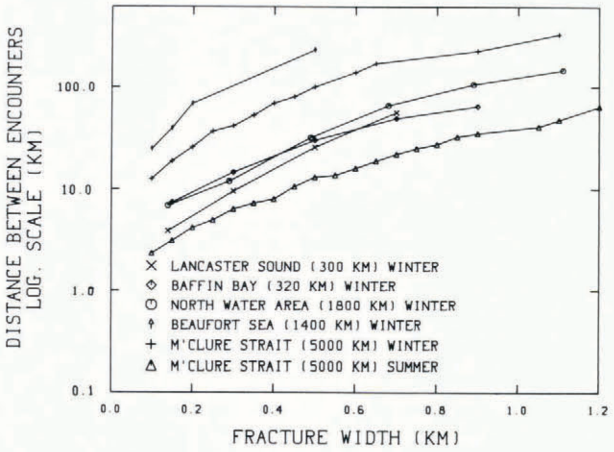

Fig.4. Relation between encounters with fractures and fracture widths in North Water area (point 13-23, Fig.1), Lancaster Sound (point 5-7), northern Baffin Bay (point 7-9), M'Clure Strait (after McLaren and others 1984) and Beaufort Sea (after Wadhams and Horne 1980)

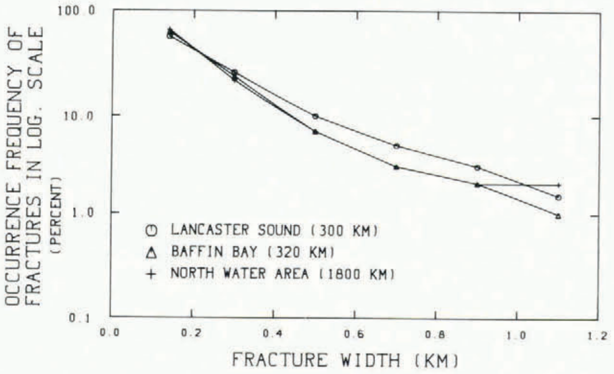

Fig.5. Occurrence frequency of fractures for fracture width between 50 m and 1.2 km in Lancaster Sound, northern Baffin Bay and the North Water area during winter 1980/81 (mean of six measurements).

The energy loss caused by open water and the thin ice covering the fractures was calculated for the Lancaster Sound (profile points 5 to 7, Fig.1) and on the basis of the heat flux rates for different ice types (Maykut 1978) and the fracture analysis along the flight profile. From December to March, the calculated heat loss on the ice–air interface due to fractures is 40 to 100% larger than for a fast-ice situation. The mean heat loss over the fractures in Lancaster Sound was 240 W m^{-2} for the six flight dates in winter 1980/81.

SUMMARY AND CONCLUSIONS

The distribution of fracture frequency and widths has been found to fit an exponential function $y=A\exp(ax)$, with y as distance between fractures of the same width in km, x as fracture width in km and A,a empirical constants ($a=1.786$, $A=3.899$) for $0.05<x<0.8$. This function is valid for the North Water area and northern Baffin Bay. For Lancaster Sound, the constants are: $a=2.036$ and $A=2.065$. This parametrisation of the fracture distribution might be useful for energy flux modelling in pack ice regions which are influenced by the existence of recurring polynyas. The analysis of the fracture distribution showed that during winter (December to March), fractures occupied 8.8% of the surface in the North Water area, 8.7% along the Baffin Bay profile and 10% in Lancaster Sound. In the North Water area in winter, fractures of all widths occur 5 times more frequently than in M'Clure Strait and about 7 times more frequently than in southern Beaufort Sea in winter. The fracture occurrence of the North Water region in winter is almost the same as in M'Clure Strait in summer.

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