On the Relation between Sea Ice Growth and Freezing Index at Syowa Station, Antarctica

Renji NARUSE*, Tamotsu ISHIDA*, Yasoichi ENDO* and Yutaka AGETA**

南極昭和基地における海氷の成長と積算寒度の関係について

成瀬廉二*・石田完*・遠藤八十一*・上田豊**

要旨：1967～69年に測定された，昭和基地周辺の一冬氷の氷厚と積算寒度（結氷日からの日平均気温の和）との関係から，海氷の成長に関する次の二つの経験式を導いた．

北の浦：　$I=2.4\sqrt{\sum\theta}$

オングル海峡：　$I=2.0\sqrt{\sum\theta}$

ただし，I は氷厚 (cm)，$\sum\theta$ は積算寒度 (°C・day)．

Empirical equations for the relationship between the thickness of sea ice and freezing index (accumulated degree-days below 0°C) were derived from the observations at Syowa Station carried out by the wintering members of the 8 th (1967), 9th (1968) and 10th (1969) Japanese Antarctic Research Expeditions (JARE).

Thickness of winter ice was measured about once a week at various points of the Kita-no-ura Cove and the Ongul Strait near Syowa Station (see Fig. 1). The results of observations on the growth and decay of sea ice in 1967～1970 were summarized in the previous paper (NARUSE *et al.*, 1971).

According to STEFAN's theory of ice formation due to heat conductivity, ice thickness I (cm) is proportional to the square root of freezing index $\sum\theta$ (°C・day) as follows:

$$I=K\sqrt{\sum\theta} \qquad (1)$$

where $$K^2=\frac{2\cdot k}{L\cdot\rho}\cdot 86400$$

and k is the heat conductivity of ice (cal/cm・s・°C), L is the latent heat of crystallization (cal/g), ρ is the density of ice (g/cm^3) and 86400 is the number of seconds

* 北海道大学低温科学研究所. The Institute of Low Temperature Science, Hokkaido University, Sapporo, Hokkaido.

** 名古屋大学理学部水質科学研究施設. Water Research Laboratory, Nagoya University, Chikusa-ku, Nagoya.

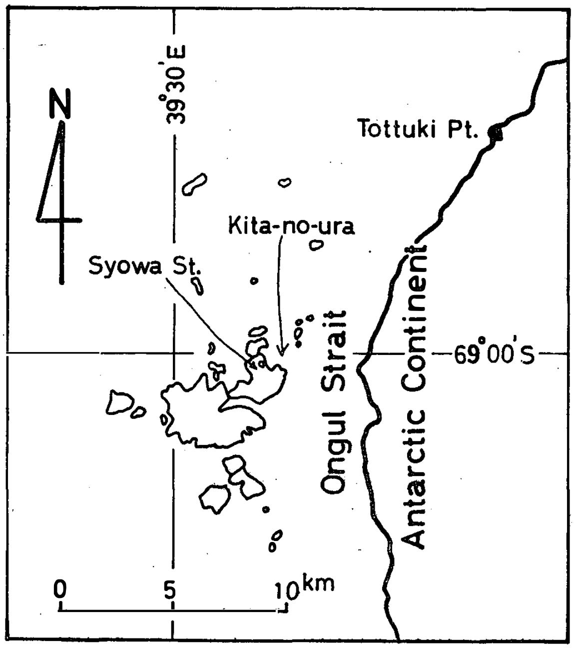

Fig. 1. Locations of the Kita-no-ura Cove and the Ongul Strait.

in a day. For pure (fresh water) ice, substituting the values of k (5.5×10^{-3}), L (80) and ρ (0.9) for eq. (1), the following equation is given.

$$I=3.6\sqrt{\sum\theta} \qquad (2)$$

Although eq. (1) is derived theoretically for pure ice, this relation may be applied also to sea ice as a first approximation.

Relations between the thickness of sea ice and the freezing index (°C·day) observed at the Kita-no-ura Cove and the Ongul Strait are shown in Fig. 2. The freezing index is calculated by summing up the mean daily air temperatures at Syowa Station since the new ice has formed. From the relations represented by the straight lines in Fig. 2, two empirical formulas were derived respectively as follows:

In the Kita-no-ura Cove;　$I=2.4\sqrt{\sum\theta}$　(3)

In the Ongul Strait;　$I=2.0\sqrt{\sum\theta}$　(4)

where I is the thickness of winter ice (cm) and $\sum\theta$ is the freezing index (°C·day).

In Fig. 2, the maximum and the minimum values of ice thickness related to the freezing index are also shown by the broken lines. From these relations, the above formulas are expressed as follows:

In the Kita-no-ura Cove;　$I=2.0\sim3.0\sqrt{\sum\theta}$　(5)

In the Ongul Strait;　$I=1.5\sim2.4\sqrt{\sum\theta}$　(6)

The observations revealed that there was no distinct difference in the amount

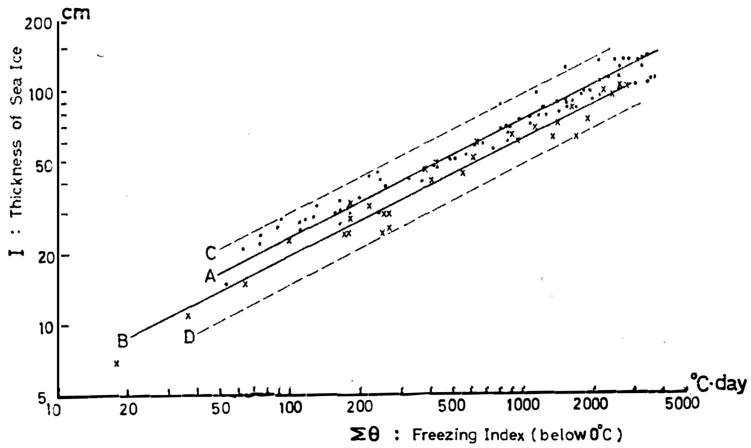

Fig. 2. Relations between the thickness of sea ice (cm) and the freezing index (°C·day). Solid circles are the observed values in the Kita-no-ura Cove, and crosses are those in the Ongul Strait. Straight line (A) indicates eq. (3) for the Kita-no-ura Cove, (B) indicates eq. (4) for the Ongul Strait. Broken line (C) indicates the upper boundary of observed values, expressed by $I=3.0\sqrt{\sum\theta}$, (D) indicates the lower boundary, expressed by $I=1.5\sqrt{\sum\theta}$.

of snow cover between the region of the Kita-no-ura Cove and that of the Ongul Strait, the snow depth being less than 30 cm in both regions. However, the numerical value of the coefficient in eq. (4) is smaller than that in eq. (3). It may be attributed mostly to the presence of sea current in the Ongul Strait. The depth of sea water is 19～49 m in the Kita-no-ura Cove and 360～660 m in the Ongul Strait.

Many investigators hitherto have obtained various forms of empirical formulas on the ice formation. STEFAN (1890) (FUKUTOMI *et al.*, 1947) derived the following formula from the observations in the Arctic Ocean.

$$I=3.18\sqrt{\sum\theta} \tag{7}$$

LEVEDEV (1938) (BILELLO, 1960) found the accretion of sea ice related to the sum of negative mean daily air temperature from the observations in the Soviet Arctic as follow:

$$I=1.33\ (\sum\theta)^{0.58} \tag{8}$$

BILELLO (1960) obtained an equation of the same form, from the observations by Graystone in Canada, when the snow cover was negligible as follows:

$$I=1.53\ (\sum\theta)^{0.59} \tag{9}$$

DRALKIN, KARELIN, BECKER, and BARNES obtained the following formulas (PESCHANSKIY, 1963; BARNES, 1928).

A. G. DRALKIN; $I^{2.5}=5.6\sum\theta$ (10)

D. B. KARELIN; $I^{2}=2.15\ (\sum\theta)^{0.15}$ (11)

G. T. BECKER (1908); $I^2+2I=13.4\sum\theta$ (12)

H. T. BARNES (1906); $I^2+2I=11.7\sum\theta$ (13)

N. N. ZUBOV (1945) derived the following formula for the average conditions in the Soviet Arctic:

$$I^2+50I=8\sum\theta \tag{14}$$

FUKUTOMI and others (1947) derived the following formula for Nemuro, Japan within the small freezing index ($\sum\theta<350$°C·day):

$$I=2.72\sqrt{\sum\theta} \quad \text{(below } -1.8°\text{C)} \tag{15}$$

BILELLO (1960) derived the following formula for the Canadian Arctic under the conditions free of snow cover:

$$I=3.55\sqrt{\sum\theta} \quad \text{(below } -1.8°\text{C)} \tag{16}$$

Some of the above equations are shown in Fig. 3.

For practical use in the Kita-no-ura Cove or in the Ongul Strait, eq. (3) or eq. (4) may be applicable to predict approximately the thickness of sea ice by the mean daily air temperature.

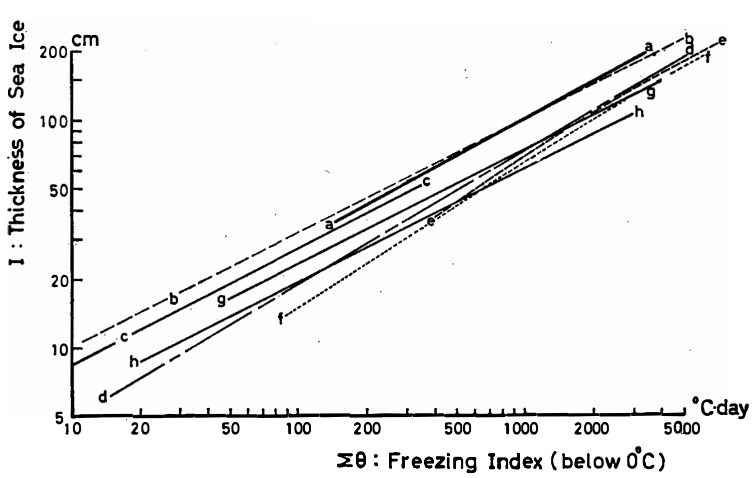

Fig. 3. Comparison of various empirical formulas relating the thickness of sea ice (cm) to the freezing index (°C·day).

a) BILELLO (Canadian Arctic): Free of snow cover. Transformed eq. (16) for a case with a base of 0°C.

b) STEFAN (Arctic): Eq. (7).

c) FUKUTOMI (Nemuro, Japan): Eq. (15), below −1.8°C.

d) LEVEDEV (Soviet Arctic): Eq. (8).

e) ZUBOV (Soviet Arctic): Eq. (14).

f) BILELLO: Composite of 5 Canadian arctic stations.

g) NARUSE (Kita-no-ura Cove, Antarctica): Eq. (3).

h) NARUSE (Ongul Strait, Antarctica): Eq. (4).

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