—研究ノート—
Scientific Notes

Variation of the Vertical Distribution of the Sea Ice Temperature near Syowa Station, Antarctica from September 1984 to January 1985[1]

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昭和基地付近における海氷温度鉛直分布の 1984 年 9 月から 1985 年 1 月にかけての変動[1]

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要旨： 第25次南極地域観測隊の海洋生物環境調査の一環として，昭和基地付近の定着氷上の一定点において海氷温度の鉛直分布を観測した．観測は1984年9月より1985年1月まで毎月1回実施し，この間の氷厚は 139 cm から 155 cm であった．海氷内の温度は表層（5 cm 部位）と最下層でそれぞれ −15.2～−0.3°C，−2.0～−0.3°C の間で変化し，鉛直的には深度に対しほぼ直線的な変化を示した．最低温度は9月から1月にかけて次第に上昇した．

***Abstract*:** Observation on the vertical distribution of the sea ice temperature was carried out at a station near Syowa Station. During the monthly observation from September 1984 to January 1985, the thickness of ice varied between 139 cm and 155 cm. Since the bottom ice temperature resembled the underlying seawater temperature, while the surface ice approached the air temperature, distribution of temperature generally showed a steep gradient across ice. The sea ice temperature at the surface and the bottom varied from −15.2 to −0.3°C and from −2.0 to −0.3°C, decreasing with depth. The minimum temperature of sea ice rose from September to January.

1. Introduction

Sea ice is a habitat of ice algae (or ice algal assemblages) which are an important primary producer as well as phytoplankton in the Antarctic ecosystem (HORNER, 1985a). As ice algae inhabit not only undersurface of ice but also brine pockets entrapped in sea ice as micro-habitat (WATANABE and SATOH, 1987), physical and chemical conditions of sea ice are important factors affecting the growth of ice algae. However, studies

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done so far on ice algae paid little attention to the effect of sea ice temperature on the physiological condition of ice algae, although the temperature when it is extremely low may influence the growth of ice algae (HORNER, 1985b).

The surface temperature of the Antarctic sea ice approaches the air temperature, which may be as low as $-40 \sim -50$°C in winter, whereas the bottom ice temperature resembles the underlying seawater temperature which is almost the freezing point of seawater. Since the freezing point of seawater is a function of salinity, the seawater temperature under ice is generally higher than -1.9°C provided that salinity is lower than 34.3‰ and supercooling does not occur. Therefore, steep temperature gradients generally exist across sea ice regardless of the thickness of ice.

According to Stefan's law, the thickness of sea ice is expressed as follows;

$$h = A \cdot \sqrt{Et},$$

where h is the thickness of sea ice, A is the constant and Et is the freezing index (degree·day). NARUSE *et al.* (1971) estimated the thickness of annual sea ice near Syowa Station at approximately 140 cm by using an empirical formula based on Stefan's formula. Their result agreed quite well with the result of this study in which we observed thickness of around 150 cm and with other observations (*e.g.* WATANABE *et al.*, 1990). These values of ice thickness indicate the integrated coldness of the area.

In order to have basic data on the sea ice temperature, we observed the variation of the vertical distribution of temperature in fast ice near Syowa Station during the 25th Japanese Antarctic Research Expedition (JARE-25) as part of the marine biological study of JARE-25 whithin the framework of the Biological Investigations of Marine Antarctic Systems and Stocks (BIOMASS) program. The effect of the sea ice temperature on the growth of ice algae is also discussed based on the result of the sea ice temperature observation.

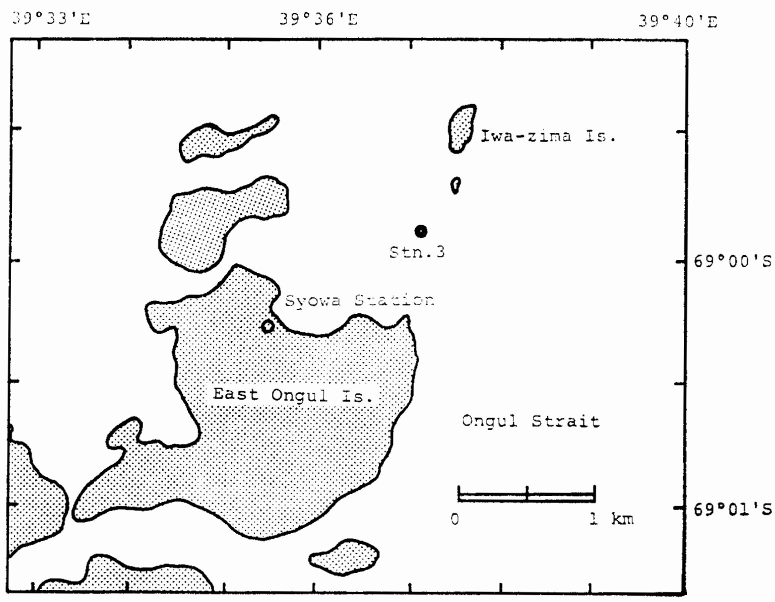

Fig. 1. Location of ice core sampling (Stn. 3) near Syowa Station.

2. Methods

Five observations were carried out at one fixed station (Stn. 3) at Kita-no-ura Cove near Syowa Station (Fig. 1) in Lützow-Holm Bay, Antarctica monthly from September 27, 1984 to January 6, 1985 when the growth of ice algae was reported to be generally high (HOSHIAI, 1981). Core samples of sea ice were taken with a SIPRE ice corer, *ca.* 7.5 cm in diameter, and then the length of the core, namely the thickness of ice, was measured. Immediately after sampling, holes were electrically drilled in the core sample at every 10 cm. Temperature of ice core was promptly measured by inserting a temperature probe of electrical-thermometer (Yokogawa Model 2541) into the drilled holes. Then a core was divided into 10 cm long subsamples and was kept frozen in plastic bags for chemical analysis.

3. Results and Discussion

Results of the observation and sampling data are shown in Table 1 and Fig. 2. Since the period of observation ranged from austral spring to midsummer, increase of ice temperature was noticeable near the surface showing almost 15°C rise from −15.2°C to −0.3°C. On the other hand, the sea ice temperature at the bottom was around −2°C except in January when it was −0.3°C.

Based on our observation, the sea ice temperature increased from September

Table 1. Sampling data and results of observation at Stn. 3.

Date	Sep. 27, 1984	Oct. 26	Nov. 20	Dec. 4	Jan. 6, 1985
Time (local time)	1120	1400	1640	1545	1530
Snow thickness (cm)	13	24	23	22	13
Air temperature (°C)	−17.7	−11.3	−4.8	−0.9	−0.1
Snow temperature (°C)	—	−11.1	−4.7	−1.8	+0.1
Core length (cm)	139	146	141	155	143
Ice temperature (°C) at depth of:					
5 (cm)	−15.2	−9.3	−6.2	−4.8	−0.3
15	−14.1	−8.9	−6.0	−4.9	−0.5
25	−13.0	−8.5	−5.7	−4.6	−0.6
35	−12.0	−8.1	−5.4	−4.5	−0.7
45	−11.4	−7.8	−5.0	−4.2	−0.8
55	−10.3	−7.5	−4.7	−4.0	−0.9
65	−10.3	−6.8	−4.5	−3.9	−1.0
75	−5.7*	−6.4	−3.7*	−3.7	−0.8
85	−5.6*	−4.8*	−3.4*	−3.5	−0.8
95	−4.9*	−4.4*	−3.3*	−3.0*	−0.7
105	−4.4*	−3.9*	−3.0*	−3.2*	−0.6
115	−4.1*	−3.4*	−2.7*	−2.7*	−0.4
125	−3.0*	−3.0*	−2.4*	−2.5*	−0.3
135	−2.0*	−2.5*	−2.0*	−2.3*	−0.3
145		−1.6*		−2.0*	

* Temperature more or less influenced by seawater temperature at the time of sampling (see text).

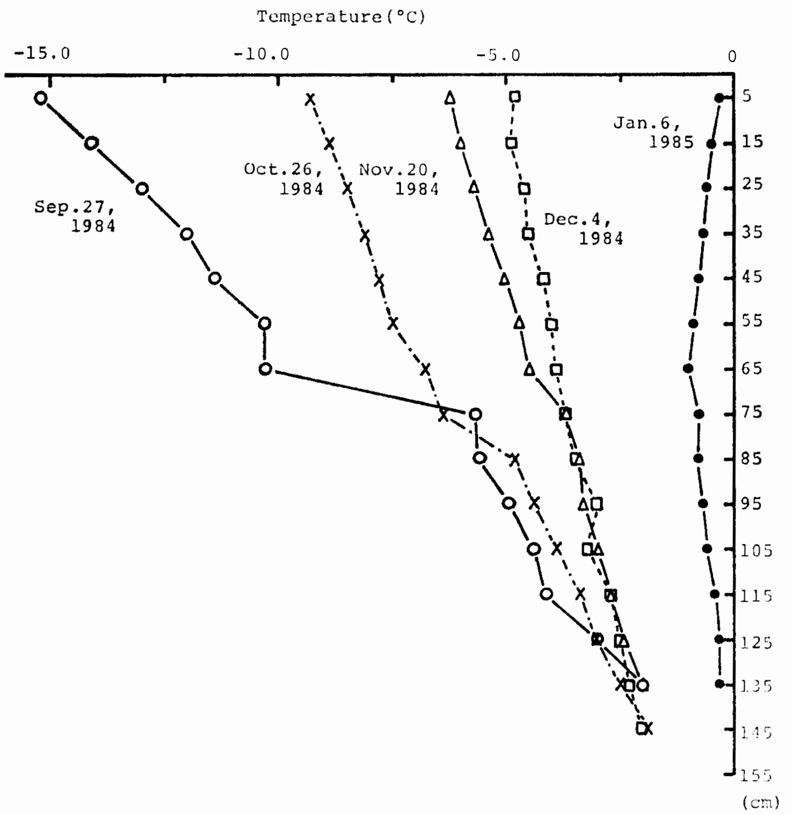

Fig. 2. Vertical distribution of sea ice temperature observed at Stn. 3.

to January although the vertical gradient of temperature varied from September to January. It is concluded from the results of both our observations and meteorological observations (YAMAMOTO *et al.*, 1988) that increase in the air temperature raised the ice temperature especially in the upper part.

The vertical distribution of the sea ice temperature showed a linear decrease with depth. In September, however, a relatively wide temperature difference was observed between 65 cm and 75 cm depths which was due to samplings artifact caused by the core sampling. In order to obtain a core sample of sea ice, we had to make two successive core samplings because the length of the core barrel was not sufficient to reach the bottom of sea ice. During our sampling in September, an approximately 70 cm depth of the upper part of sea ice was initially taken. And then the rest of ice was collected by the second coring, when the seawater seeped into the space between the core barrel and the sample ice inside it. The seepage of the seawater possibly raised the temperature of the lower part of the ice core because the temperature of the underlying seawater was higher than the sea ice temperature. That is why the observed temperatures below 75 cm for this month are higher than correct values. In the case of October, November and December, the observed ice temperature values in the lower part of sample cores marked with asterisk in Table 1 were also influenced more or less by the same cause though the influence was not appreciable as in the case of September.

The vertical distribution of the sea ice temperature measured on January 6 showed that the lowest temperature was at the depth of 65 cm while those at the surface and the bottom were slightly higher. Judging from both the seawater temperature (MATSUDA *et al.*, 1987) and the fact that the air temperature and the temperature of overlying snow were −0.1°C and 0.1°C, respectively at the time (Table 1), the vertical distribution of the sea ice temperature of the month is mainly due to the temporal increase of the air temperature.

Linearity of ice temperature with depth is high, for example, the regression coefficients obtained in September, October, November and December were higher than 0.98 ($P<0.01$), so that we could estimate the ice temperature at a given depth from the surface and bottom temperatures of sea ice. Since the surface temperature of ice is approximately equivalent to the average air temperature (YAMAMOTO *et al.*, 1988) it was possible to estimate the sea ice temperature at a given depth from the air temperature data and the freezing point of seawater. Because few data on sea ice temperature are available compared with the observed data on air and seawater temperatures, this convenient method of estimating sea ice temperature can help us to understand sea ice conditions.

As factors affecting the variation of ice algal standing stocks, solar radiation, nutrient concentration and salinity have been discussed by HORNER (1985b), WATANABE and SATOH (1987) and HOSHIAI (1981), while only vary few works have been made on the effect of sea ice temperature on the growth of ice algae. SATOH and WATANABE (1986) experimentally studied the effect of water temperature on the rate of photosynthesis and respiration of ice algae. They found that the rate of photosynthesis and respiration decreased with decreasing temperature from 8°C to −1.7°C. Although there are no available data on the rates of photosynthesis and respiration below −1.7°C, both rates are supposed to be almost diminished at the lower temperature range.

Thus, the temperature of sea ice has some effects on the growth of ice algae. So the distribution and seasonal variation of ice algae (*e.g.* HOSHIAI, 1981; WATANABE and SATOH, 1987) might be influenced by the temperature of ice. Judging from the dependence of algal growth on temperature (PALMISANO and SULLIVAN, 1985), algae in sea ice grow possibly only where the ice is warmer than the critical temperature of their growth. Seasonal variation of solar radiation in the Antarctic area is so extreme that photosynthesis of ice algae is supposed to take place only in the restricted season and depth. Combining temperature and light condition, sufficient conditions of temperature and solar energy for algal growth are supposed to be available only in a limited season at a limited depth of ice. It is obvious that further study is needed to elucidate the effect of the sea ice temperature on the algal growth. The result of observation of the present study seems to provide the basic information for such studies.

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