Proc. NIPR Symp. Polar Meteorol. Glaciol., 2, 111-116, 1989

TEMPERATURE MEASUREMENTS OF FIRST-YEAR SEA ICE IN THE SEA OF OKHOTSK USING AN AIRBORNE INFRARED RADIOMETER

Masaaki AOTA[1], Kunio SHIRASAWA[1], Masao ISHIKAWA[1],
Shun-ichi IKEDA[2]* and Kohkichi SUEHIRO[2]**

[1]*Sea Ice Research Laboratory, Hokkaido University, 4-10, Minamigaoka 6-chome, Mombetsu 094*
[2]*Hydrographic Department, The 1st Regional Maritime Safety Headquarters, 5-3, Minato-cho, Otaru 047*

Abstract: Brightness temperature of the Okhotsk coastal sea was measured by an airborne infrared radiometer off Hokkaido, Japan on February 16, 1984. The infrared brightness temperatures were around 270 K for open water, 264 to 266 K for level fast ice and 268 K for thin level ice and young gray ice, when the helicopter was 10 m above sea level. Temperature increased after snow removal from 45 cm thick sea ice. Measurements at different altitudes between 20 and 150 m indicated that the atmosphere did not affect the brightness temperature within these altitudes.

1. Introduction

Ice thickness and ice concentration are important components of a heat exchange model as well as of a dynamic model for the coastal Sea of Okhotsk off Hokkaido, Japan (44°-45°30′N), in the marginal ice zone. The flat landfast ice is 40-50 cm thick on the average. In coastal regions there are unstable ice packs, some consisting of drift ice from the north and others of locally frozen fast ice, and packs of double or triple rafted ice several meters thick with pressure ridges 1-2 m in sail height and 3-5 m in keel depth.

The movements and distributions of ice along the Okhotsk Sea coast have been monitored by radar since 1967. AOTA *et al.* (1985) discussed the possibility of estimating ice thickness by using surface temperatures obtained with an airborne infrared radiometer. They presented a relation between surface temperature and ice thickness for a simple case without snow cover on the ice. Further investigation into the relationships between brightness temperature and ice thickness and surface conditions and altitudes is attempted in the present study, which will provide guidelines for future experiments and discussion.

Present address:
* Hydrographic Department, Maritime Safety Agency, 3-1, Tsukiji 5-chome, Chuo-ku, Tokyo 104.
** Hydrographic Department, The 2nd Regional Maritime Safety Headquarters, 4-1, Teizandori 3-chome, Shiogama 985.

2. Observations

The experiments took place on February 16, 1984. A helicopter equipped with the infrared radiometer flew from the coast to 30 nautical miles off Mombetsu (Fig. 1) at 60 km/h on average, 10 m above sea level with a target area 0.35 m in diameter. The sky was clear and the air temperature at 10 m was about -7 to -8°C. At a site 30 nautical miles offshore, the helicopter was moved vertically to measure temperatures from various altitudes. The surface conditions were only visually observed from the helicopter in the two cases mentioned above. Another experiment was carried out on snow-covered Lake Komuke to investigate the effect of snow on the brightness temperature of sea ice.

The specifications of the infrared radiometer (Matsushita Model ER-2007 SA1) are 8.5 to 12.5 μm spectral bandpass, 0.2°C resolution, $\pm$3.0°C accuracy and 2° field-of-view. The brightness temperature T_b as measured by a radiometer satisfies $\varepsilon = T_b/T_s$ where ε is the average emissivity of the surface in the spectral range used, and T_s is the surface temperature (HALL and MARTINEC, 1985). From the author's *in situ* measurements for nilas and thin first-year ice (3 to 20 cm thick) in the coastal Okhotsk Sea, the infrared emissivities obtained were approximately 0.99 (M. AOTA and K. SHIRASAWA, unpublished data, 1988), while the emissivity of sea ice here can be reasonably taken to be unity.

3. Results

3.1. *Brightness temperatures for various ice types*

Shown in Fig. 2 is the brightness temperature distribution observed by the in-

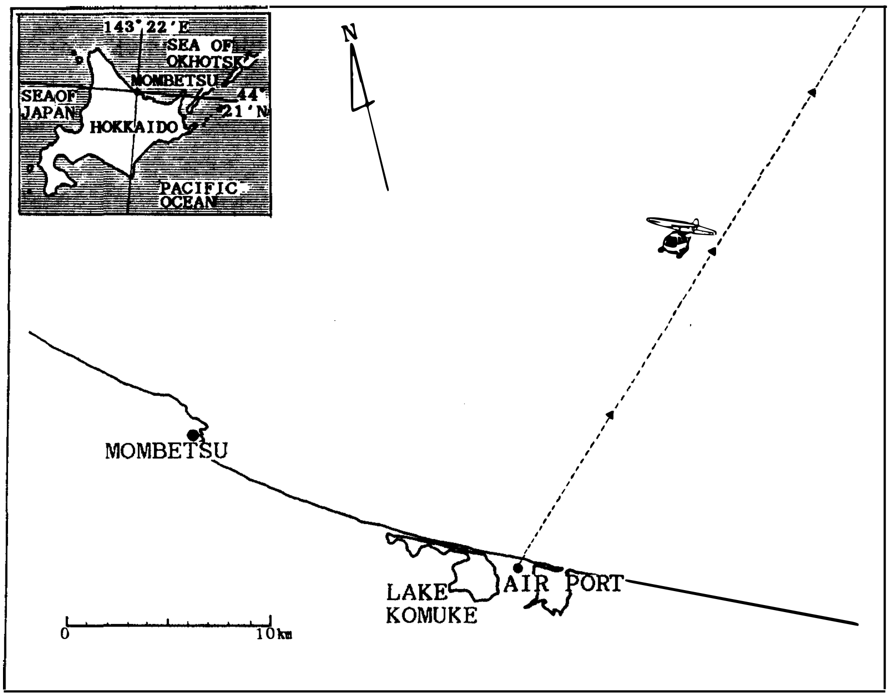

Fig. 1. Area of brightness temperature observation by infrared radiometer mounted in a helicopter from 1400 to 1500 LST on February 16, 1984.

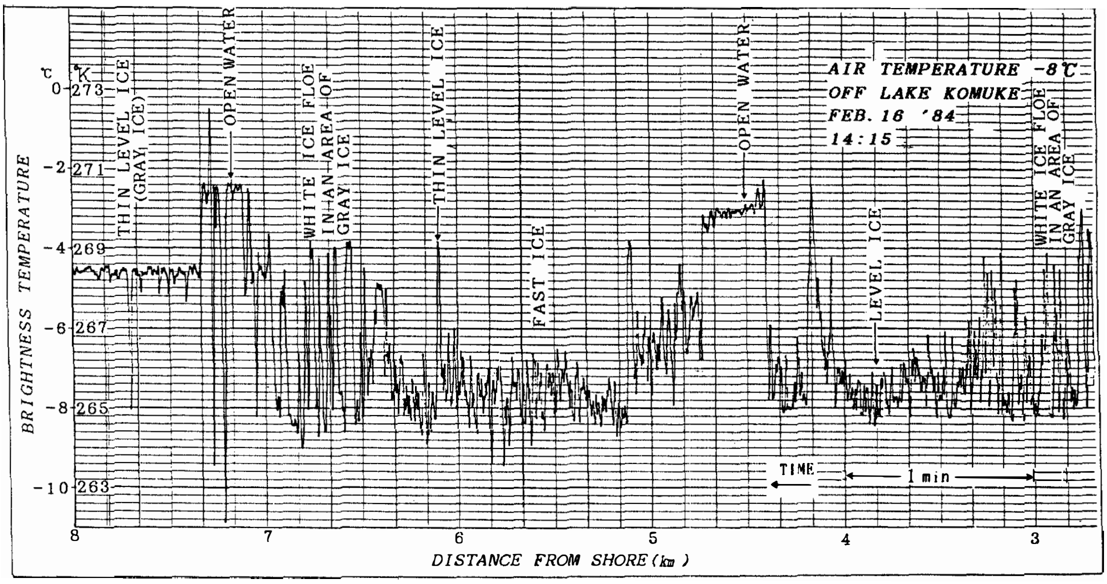

Fig. 2. Brightness temperature distribution observed by the infrared radiometer 3 to 8 km northeast of Mombetsu Airport.

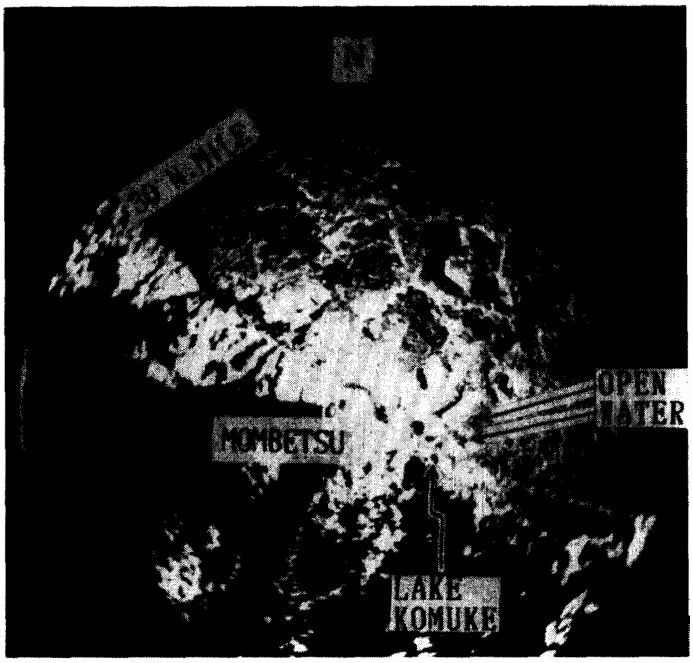

Fig. 3. Ice distribution off Mombetsu at 1503 LST on February 16, 1984, obtained by ice monitoring radar (operated at 5.54 GHz) in Mombetsu.

frared radiometer 3 to 8 km northeast of Mombetsu Airport. The brightness temperatures are around 270 K for open water regions, 264 to 266 K for level fast ice and around 268 K for thin level ice and young gray ice, which are still growing. The repeated fluctuations between 264 and 269 K reflect the effect of white ice floes in young gray ice areas.

Shown in Fig. 3 is the ice distribution off Mombetsu at 1503 LST on February

16, 1984, obtained by ice monitoring radar (operated at 5.54 GHz) in Mombetsu. The white and the arrow-indicated darker/black parts in the picture (Fig. 3) correspond to level/fast ice and open water areas (Fig. 2), respectively.

MÜLLER *et al.* (1975) also reported that their infrared-radiometer-measured ice and water surface temperatures differed significantly for ice types over the North Water polynya from late winter to early summer. There, the surface temperatures varied from -2.6°C for black nilas to -28°C for multiyear ice at the mean air temperatures of -12 to -20°C at the North Water research stations, while the fast ice was 90 to 158 cm thick at the end of March.

ISHIKAWA and KOBAYASHI (1982, 1984) observed variations in ice thickness together with air and ice surface temperatures at artificial pools opened in frozen saline Lake Saroma. AOTA *et al.* (1985) discussed the relation between surface temperature and ice thickness for a simple case without snow cover on the ice using results from the experiments by ISHIKAWA and KOBAYASHI (1982). Given emissivity, radiation, latent heat, winds, currents, snow cover and characteristics of ice structure from *in situ* measurements, the quantitative relation can be discussed for more realistic models.

3.2. Effect of radiometer height on brightness temperature

At 30 nautical miles northeast of Mombetsu Airport, a measuring site was chosen where ice flowers were seen to cover the surface of thin level ice. Shown in Fig. 4 is the brightness temperature obtained during vertical flight between 20 and 150 m with target areas between 0.7 and 5.2 m, respectively, in diameter. The brightness temperature was nearly constant with changing radiometer altitude, except from 40 to 70 m, where the helicopter's ascent appeared to be unsteady. On the whole, the atmosphere does not appear to influence the brightness temperature within the altitudes from 20 to 150 m.

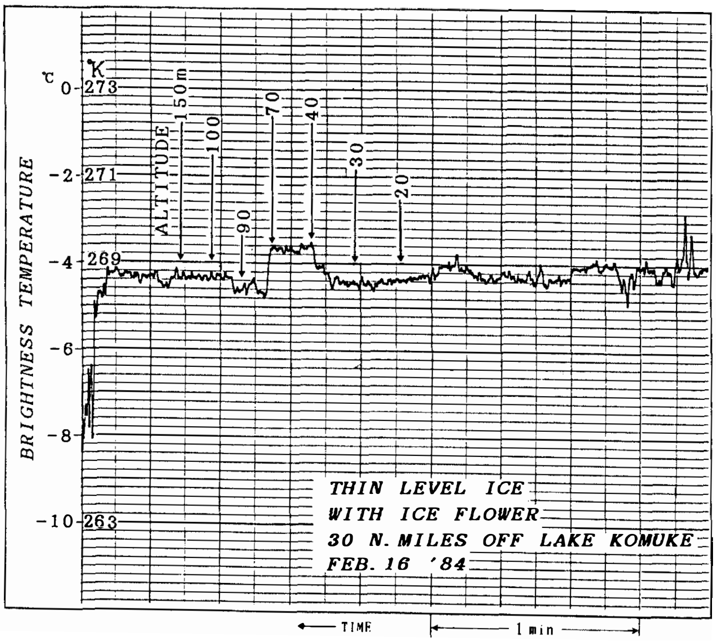

Fig. 4. Brightness temperature obtained 30 nautical miles northeast of Mombetsu Airport.

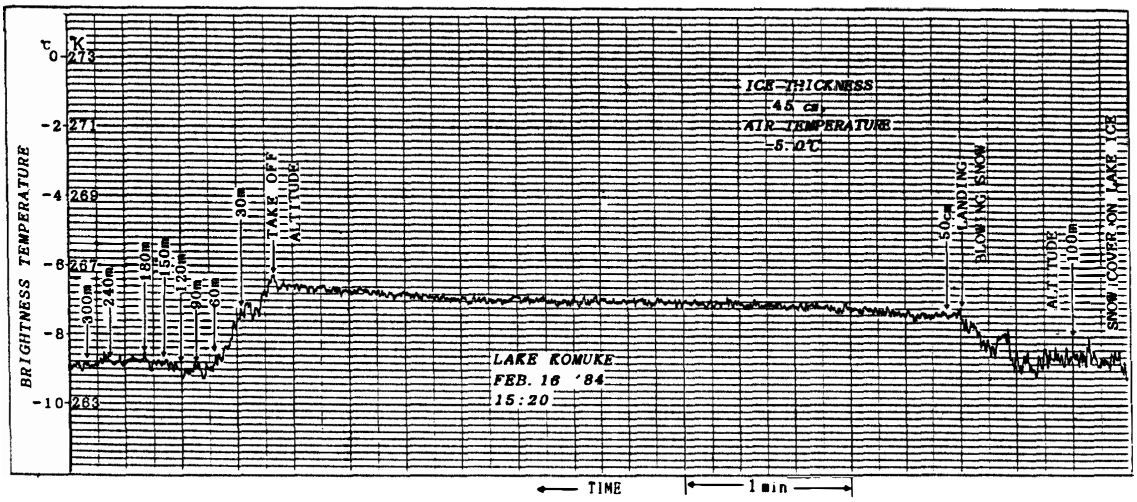

Fig. 5. Brightness temperature for various surface conditions, obtained at Lake Komuke near Mombetsu Airport.

3.3. *Effect of snow cover on brightness temperature*

Shown in Fig. 5 is brightness temperature for various surface conditions, obtained at Lake Komuke (a saline lake) near Mombetsu Airport. As the helicopter descended from 100 m, 10 cm-deep snow cover was blown off, exposing the ice surface. The ice thickness was 45 cm and the air temperature was −5°C. After about a 4 min pause on the bare ice surface with the radiometer 50 cm above it, the helicopter took off, ascending diagonally to 300 m. The brightness temperature of snow cover (about 264 K) increased rapidly to 265.6 K as soon as the snow was blown off. During the pause, it continued to rise gradually, reflecting heat transfer through the surface, until it reached 266.5 K, which can plausibly be taken as or as almost the ice temperature. The temperature decrease after takeoff is explained by the fact that the helicopter flew diagonally from the snow-dispersed area toward an undisturbed snow-covered area.

4. Conclusion

We found that 1) brightness temperature of ice surface significantly reflects the ice type; 2) difference in altitude between 20 and 150 m does not affect brightness temperature; 3) brightness temperature increased after snow removal from sea ice. It is hoped that these results will be applied to future development of experiments and models of the coastal Okhotsk Sea.

Acknowledgments

This experiment was supported by the Ministry of Education, Science and Culture of Japan. The authors are indebted to the anonymous reviewers for their valuable com ments to help improve this paper.

References

AOTA, M., OI, M., ISHIKAWA, M. and FUKUSHI, H. (1985): Detection of an ice-forming area by radar and satellite. Ann. Glaciol., **6**, 252–253.

HALL, D. K. and MARTINEC, J. (1985): Remote Sensing of Ice and Snow. New York, Chapman and Hall, 189 p.

ISHIKAWA, N. and KOBAYASHI, S. (1982): Kaihyô no seichô ni tomonau hyômen-netsushûshi no henka I—Saroma-ko ni okeru touki no hyômen-netsushûshi (Short-term variations in heat budget with the growth of sea ice. I). Teion Kagagu, Butsuri-hen (Low Temp. Sci., Ser. A), **41**, 179–189.

ISHIKAWA, N. and KOBAYASHI, S. (1984): Usui kaihyô jô ni okeru netsushûshi no tokusei (Experimental studies of heat budget of very thin sea ice). Seppyo (J. Jpn. Soc. Snow Ice), **46,** 109–119.

MÜLLER, F., BLATTER, H. and KAPPENBERGER, G. (1975): Temperature measurement of ice and water surfaces in the North Water area using an airborne radiation thermometer. J. Glaciol., **15**, 241–250.

(Received April 7, 1988; Revised manuscript received December 15, 1988)