Annual Report of the Research Institute for Hazards
in Snowy Areas, Niigata University, №12, 1990

Characteristics of Icing Observed at the Høghetta Ice Dome in Northern Spitsbergen*

Kaoru IZUMI**

Abstract

From May to June 1987, ice core drilling was performed at the top of an ice dome in northern Spitsbergen to study climatic and environmental change during last few centuries. Meteorological observations were carried out at the drilling site. In the cloudy period we observed occasional icing of soft rime on vertical obstacles with low temperature and high humidity. When soft rime developed, air temperature ranged from −8℃ to −10℃ and wind speed was less than 5 m/s. Density of soft rime ranged from 0.13 to 0.47 g/cm³ and increased with an increase in the mass rate of icing. The calculated value of liquid water content in the air ranged from 0.1 to 0.5 g/m³. The pH of melt-water of soft rime had a low value, which is presumed to be caused by the pollutant transported from middle latitudes to the Arctic.

Key words : density of soft rime, liquid water content in the air, pH of melt-water

I . Introduction

A shallow ice coring was carried out on the ice dome called Høghetta, at the top of the glacier called Åsgårdfonna, in the northern part of Spitsbergen by the Japanese Arctic Glaciological Expedition 1987 (JAGE'87) to study climatic and environmental changes during last few centuries (Watanabe and Fujii, 1988). Some meteorological observations were carried out at the site from May 26 to June 13, 1987, together with ice coring. In the cloudy days during the observation period, we occasionally observed a rapid icing on vertical obstacles with low temperature and high humidity. This paper describes characteristics of icing in the Arctic region in early summer.

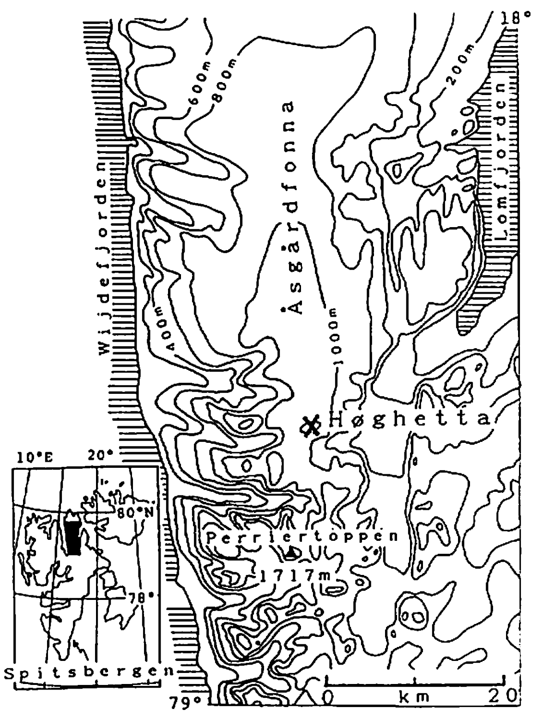

Fig.1 Location of observation site (×) at Høghetta ice dome in northern Spitsbergen.

---

* This paper was presented at the 5th International Workshop on Atmospheric Icing of structures, Oct. 29 − Nov. 1, 1990, Tokyo, Japan

** Research Institute for Hazards in Snowy Areas, Niigata University, Niigata, 950-21 Japan

II. Meteorological conditions at the site

The location and altitude of the observation site are 79°16′N, 16°52′E and 1200 m a.s.l. (Fig. 1). The surface condition around the site is characterized by a flat snowfield.

Variations in meteorological elements measured during 19 days are shown in Fig. 2 (Izumi et al., 1988). Air temperature and relative humidity were measured at a height of 1.0 m in a ventilated shelter. Wind speed was measured at a height of 1.9 m. Vertical profiles of wind speed were occasionally measured. Precipitation was measured at 08^h as a daily total value. Wind direction and cloud amount were measured three times a day (08^h, 012^h and 20^h).

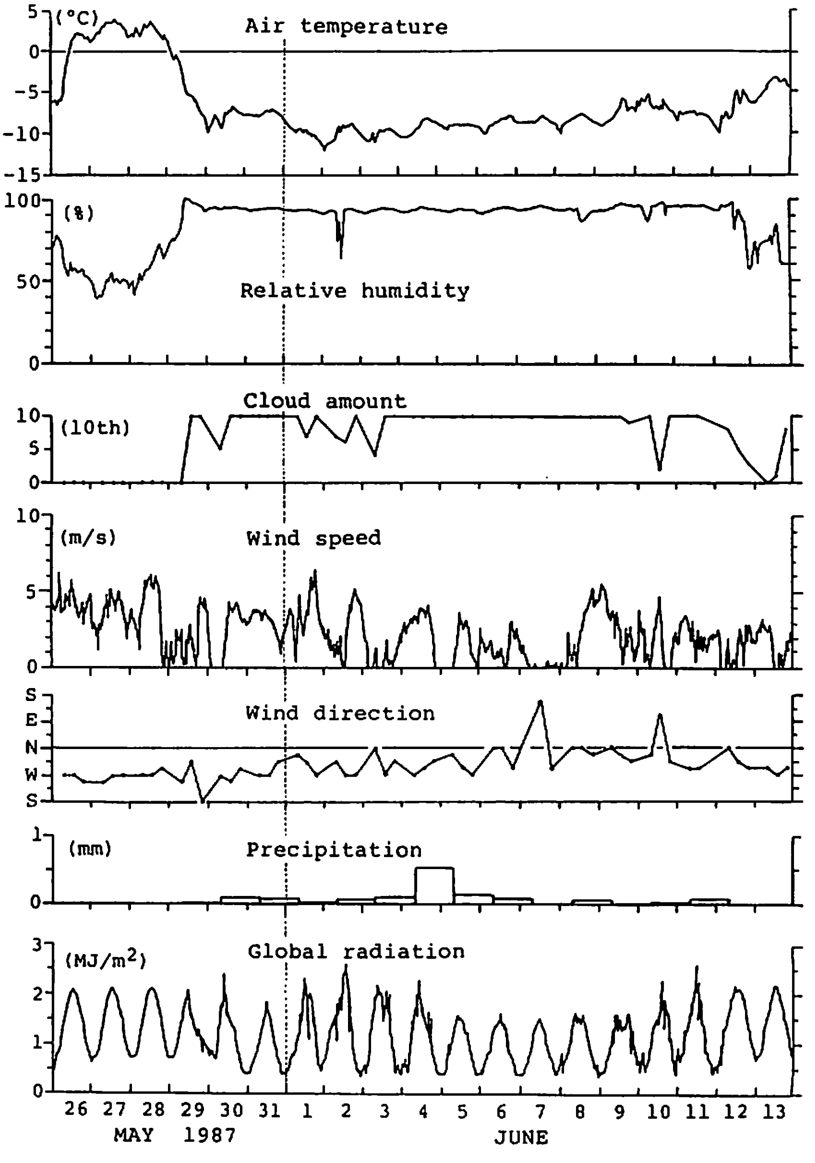

Fig. 2 Meteorological conditions at observation site from May 26 to June 13, 1987 (Izumi et al., 1988)

As seen from Fig. 2, there was remarkable contrast of weather conditions between warm/sunny period at the beginning of the observation and cold/cloudy period after that. In the latter period, air temperature maintained low values of about −8℃ with high relative humidity of more than 90%, and we occasionally observed a rapid icing on vertical obstacles.

Ⅲ. Observation of icing

At the site, we used bamboo stakes about 10 mm in diameter and 2 m high for a boundary mark. In the cold period, icing was occasionally observed also on the stakes. Ice began to accrete on the stake in the evening when solar radiation decreased to about 1.4 MJ/m^2, and fell off from the stake in the morning when solar radiation increased to about 0.9 MJ/m^2. Figure 3 shows a vertical profile of the thickness of ice accretion in the growth direction which developed on a bamboo stake of 9 mm in diameter for a half a day on June 5. It is found that this diagram is similar to the logarithmic vertical profile of wind speed, which is an important factor controlling the icing.

Thickness of ice accretion for specific stakes was measured at intervals, at a height of 1.3 m above the snow surface. An example of the development of icing and ice-forming conditions is shown in Fig. 4. In this case, soft rime began to accrete on the stake at about 18^h and fell off by solar radiation immediately after the thickness had reached 49 mm by 08^h.

Table 1 summarizes such observation results. It is found from Table 1 that ice accretion during the observation period developed at the rate of 1 to 5 mm per hour under meteorological

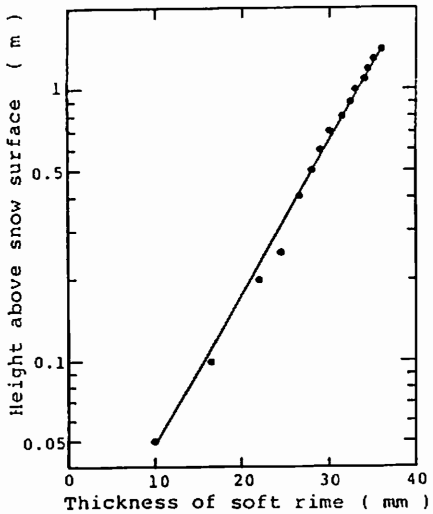

Fig. 3 Vertical profile of thickness of ice accretion developed on a bamboo stake for a half a day on June 5.

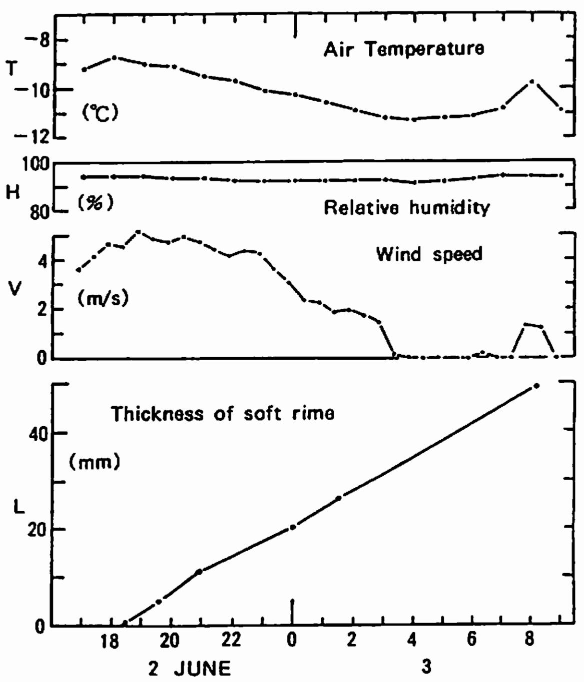

Fig. 4 Development of icing and ice-forming conditions.

conditions of: west wind, wind speed under 5 m/s, air temperature range -8℃ to −10℃, relative humidity over 92%. The type of ice accretion observed is concluded to have been soft rime from these conditions according to the results obtained by Kuroiwa (1958). Figure 5 shows a close-up photograph of soft rime released from a stake.

Table 1 Summary of ice-forming conditions and soft rime properties.

No	Period	Wind direction	Wind speed V(m/s)	Air temperature T (℃)	Relative humidity H (%)	Soft rime Growth rate (mm/h)	Soft rime Density (g/cm³)
I	18^h − 24^h,May 29	SE	3.9	− 8.3	94	3.6	0.47
II	20^h,May 30 − 9^h,May 31	W	3.3	− 7.8	94	1.6	0.13
III	18^h,May 31 − 8^h,June 1	NW	2.3	− 8.6	93	1.1	0.21
IV	9^h − 11^h,June 1	N	2.8	− 9.5	94	3.0	
V	20^h,June 1 − 8^h,June 2	W	3.0	−11.3	92	5.4	
VI	18^h,June 2 − 8^h,June 3	W	2.4	−10.2	93	3.5	0.23
VII	10^h,June 3 − 1^h,June 4	W	0.8	−10.0	94	0.9	
VIII	19^h,June 4 − 10^h,June 5	W	0.5	− 9.1	93	1.1	0.28
IX	10^h − 24^h,June 5	W	1.8	− 9.1	93	2.5	0.19
X	0^h − 8^h,June 7	W	0.6	− 8.7	93	1.2	
XI	0^h − 8^h,June 9	N	4.4	− 8.9	93	1.2	
XII	23^h,June 10 − 8^h,June 11	NW	2.5	−7.6	95	2.0	0.35

Density of some samples of soft rime was obtained by measuring the mass and volume. The density of soft rime ranging from 0.2 to 0.4 g/cm³ agrees with the previous data of 0.2 to 0.4 g/cm³ (Suzuki, 1987) and under 0.6 g/cm³ (Kuroiwa, 1958). Average mass rate of the ice accretion at the height of 1.3 m on the stake (per unit length) can be obtained from the mass of soft rime and icing time. Relation between the average mass rate (dM/dt) and density of soft rime indicates that the density increa-ses in an increase of dM/dt (Fig. 6).

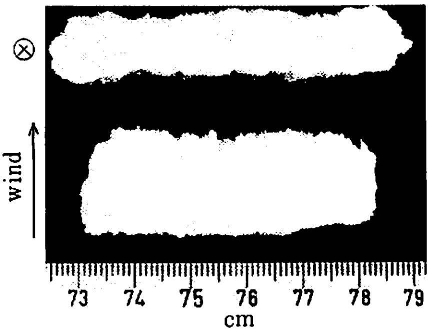

Fig. 5 Close-up photograph of soft rime. (up : front view, down : side view)

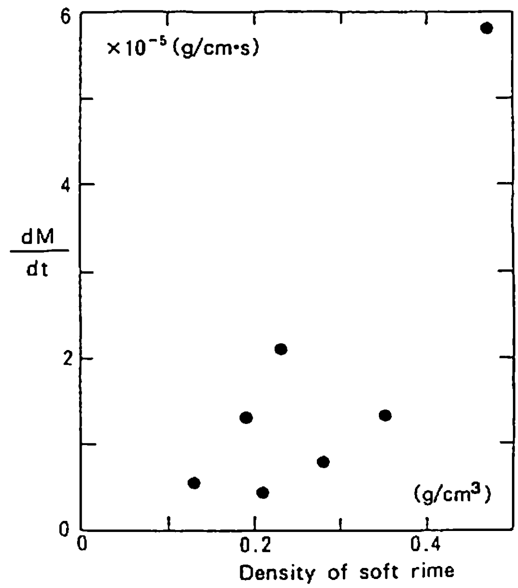

Fig. 6 Relation between mass rate (dM/dt) and density of soft rime.

Ⅳ. Development of accretion and liquid water content

The mass rate of supercooled water droplets arriving perpendicular to a circular cylinder (perunit length) can be written as:

$$dM/dt = 2R \cdot E \cdot V \cdot W \qquad (1)$$

where 2R is the diameter of the cylinder, V the wind speed, W the liquid water content and E the collection efficiency. Langmuir and Blodgett (1946) presented curves showing the collection efficiency, E, as a function of two dimensionless parameters, each depending on V, R and the droplet radius.

Since the type of icing was soft rime for this observation, all of the impinging water droplets are consider to have been frozen (dry growth regime). Average mass rate can be calculated for the soft rime whose density was measured as mentioned above. Average liquid water content in the air, W, therefore can be calculated from the meteorological conditions using equation (1) above, if the radius of the supercooled water droplet is known.

The diameter of the supercooled droplet ranges from 5 to 20μ under the growth condition of soft rime (Kuroiwa, 1958). Here, by assuming the droplet diameter to be 15μ, the collection efficiency and liquid water content in the air were obtained as shown in Table 2. Since the width of the soft rime was nearly as same as the size of the stake diameter, the initial value of the collection efficiency prior to icing was assumed to be costant during the growth of soft rime. The wind speed measured at a height of 1.9 m was directly used without collection, because there was no significant difference of wind speed between at heights of 1.3 m and 1.9 m.

The liquid water content is generally considered to be in the range 0.3 to 0.6 g/m^3 as ice accretes (Kuroiwa, 1958), which nearly agrees with the obtained range 0.1 to 0.5 g/cm^3 as shown in Table 2.

Table 2 Calculation of collection efficiency (E) of bamboo stake and liquid water content (W) in air.
R : radius of bamboo stake, dM/dt : mass rate of soft rime

No.	Growth time (h)	2R (cm)	E	dM/dt (g/cm·s)	W (g/m^3)
Ⅰ	6.5	0.9	0.31	5.8×10^{-5}	0.5
Ⅱ	13.5	0.7	0.34	5.3×10^{-6}	0.1
Ⅲ	15	0.7	0.25	4.2×10^{-6}	0.1
Ⅵ	14	0.9	0.20	2.1×10^{-5}	0.5
Ⅸ	11.5	1.0	0.15	1.3×10^{-5}	0.4
Ⅻ	11	0.85	0.22	1.3×10^{-5}	0.3

Ⅴ. Electrical conductivity and pH of soft rime

The values of electrical conductivity (EC) and pH of the liquid phase of precipitation would represent the local environment. Soft rime and new snow samples were, therefore, melted *in situ* and transported to Japan for measurements of EC, pH and major ion in the laboratory. New snow samples, which were collected on the snow measuring plate once a day, often contained hoar frost and soft rime besides snowfall. Measurements of EC at 25℃ and pH were carried out with an electrical conductivity meter (C-172, HORIBA Ltd) and an ion meter (IM-20E, TOA Electrics Ltd), respectively.

The EC value rapidly increases with a decrease of the pH value as seen from Fig. 7. Since all of the pH values are under 5.65, soft rime and new snow samples collected at the site can be called acid precipitation. The acidity is closely related with SO_4^{2-} as seen from Fig. 8. The pollutant, which causes acid precipitation, is presumed to be transported from middle latitudes as indicated by measurements of SO_4^{2-} at Ny Ålesund in Spitsbergen (Iversen and Joranger, 1985).

The pH value of melt-water of ice core drilled in the site gradually decreases from about 30 m depth to the surface. This decrease is due to the increase in acidity of precipitation in this region since the Industrial Revolution (Fujii et al., 1990).

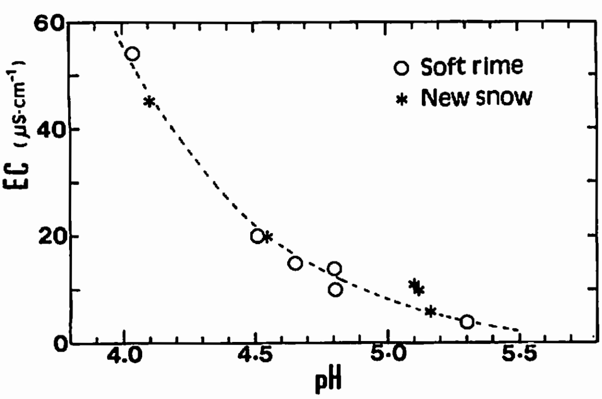

Fig. 7 Electrical conductivity (EC) versus pH for melt-water of soft rime and new snow.

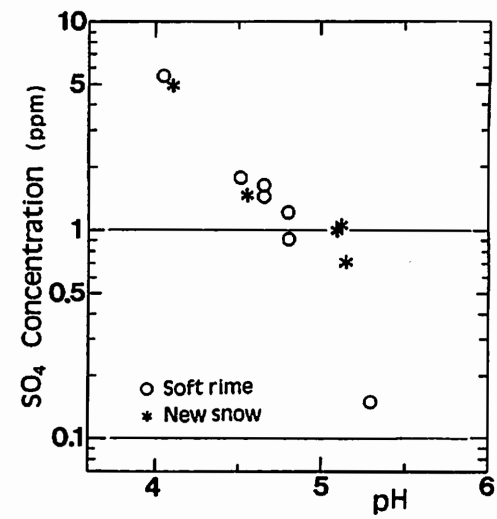

Fig. 8 SO_4 concentration versus pH for melt-water of soft rime and new snow.

VI. Conclusion

The present study shows physical and chemical characterristics of icing in the Arctic region in early summer. The type of icing observed at the site was soft rime. The physical characteristics of icing were consistent with those reported previously. By chemical analyses, it was revealed that ice accretion in this region was considerably polluted.

Ackowledgments

The author expresses sincere gratitude to the members of JAGE'87, especially to Mr. K. Satow of Nagaoka College of Technology, for their cooperation in the field work.

Reference

Fujii, Y. et al. (1990): 6000 Year Climate Records in an Ice Dome from the Høghetta Ice Dome in Northern Spitsbergen. Annals of Glaciology, **14**, 85−89.

Iversen, T. and E. Joranger (1985): Arctic Air Pollution and Large Scale Atmospheric Flows. Atmos. Environ., **19** (12), 2099−2108.

Izumi, K., K. Satow, Y. Fujii and S. Kawaguchi (1988): Meteorological Observations at Åsgårdfonna, Spitsbergen, 1987. Bulletin of Glacier Research, **6**, 51−54.

Kuroiwa, D.(1958): Icing and Snow Accretion. Microwave propagation in snow district [ed. Asami, Y], Monograph Ser. of the Res. Inst. of Applied Electricity, Hokkaido Univ., **6**, 1−30.

Langmuir, I. and K. B. Blodgett (1946): A Mathematical Investigation of Water Droplet Trajectories. G. E. Res. Lab. Rep., RL225, 65pp.

Suzuki, M.(1987): Radio-Optical Engineering with Snow and Ice. Showkowdo Inc., 163pp.

Watanabe, O. and Y. Fujii (1988): Outlines of Japanese Arctic Glaciological Expedition 1987. Bulletin of Glacier Research, **6**, 47−50.