—研究ノート—
Scientific Note

Construction of Ice Domes at Asuka Station in Antarctica

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南極あすか観測拠点におけるアイスドームの製作

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要旨: アイスドームの製作技術と時間によるその変形を研究するために，アイスドームの建設が試みられた．直径 10 m の膜を送風機で膨らませ，水と雪をこの上にかけた．約 13 t の水を使って厚さ 7 cm，高さ 3 m のものができあがった．

天井はクリープにより，徐々に変形が進み，中央部は 99 日間で 55 mm 沈下した．また，夏にはアイスドームの厚さが昇華により急速に薄くなったため，ロータリ除雪車で時々雪掛けを行った．このアイスドームは倉庫あるいは作業場として有効に使用できた．

もうひとつのアイスドームは，このために持ち込んだ造水装置を使用して実施したが，強風と低温で大変な作業だった．また，水を使わない雪だけのスノードームの製作も試みたが，固まらなかった．

Abstract: An attempt was made to construct an ice dome in order to study the construction technique and to examine its deformation by creep and sublimation of ice in the Antarctic. A 10-m diameter membrane was inflated by a ventilator. Stored water was sprayed on it, and sometimes milled snow was blown by a small snow miller. About 13 t of water was consumed for making an ice dome 7 cm thick, 3 m high.

The deformation of the ceiling grew with time due to creep. The sinkage of the center reached 55 mm after 99 days. The wall thickness rapidly decreased due to sublimation in summer time; consequently, snow was occasionally added with a rotary snowplow. The ice dome was effectively used as storehouse and workshop.

Though it was attmpted to make water outside by using a snow melter with an oil burner for another ice dome, the work was hard. A snow dome without water was also attempted, but the snow did not harden.

1. Introduction

A great deal of material is needed when we construct a wide covered space such as a workshop and/or storehouse on a snow surface at an inland station in Antarctica. An ice dome may be an efficient structure because it can be made easily with water and snow. It is good for the environment because construction material is not left when the station closes.

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Stanley and Glockner (1975a, b) proposed a reinforced ice dome and carried out an experimental creep study on an ice dome of 2 m diameter for the first time. Kokawa (1985) developed a construction method for an ice dome. The construction technique consists of: (1) inflating a membrane bag covered with rope, (2) spraying the bag with water and snow, (3) solidifying the snow-ice sherbet on it, and (4) removing the bag and ropes. While experimental construction of a snow dome has once been tested in the polar region (Mellor, 1969), ours seems to be the first attempt to build an ice dome using water in the Antarctic. Hannuki *et al.* (1992) carried out a laboratory test on the construction and load-carrying capacity with an about 1/22 scale model. It was confirmed experimentally that ice domes can be made at temperature below −18 ℃. In the Antarctic experiment we aimed at studying the construction feasibility on a snow surface, and measuring the deformation of the ice dome in the cold.

2. Climatic Condition at Asuka Station

Asuka Station is located in the northern part of the Sør Rondane Mountains in Queen Maud Land (Fig. 1) . The location is at 71°31′34″S, 24°08′17″E, 930.45 m above sea level, about 150 km south of Breid Bay on the Princess Ragnhild Coast. The climatic condition is shown in Table 1. The air temperature is ideal for construction of an ice dome except in January and December because the desirable air temperature for construction is below −10 ℃ (Kokawa, 1985). But the strong wind that blows over much of the year is unfavorable for construction work.

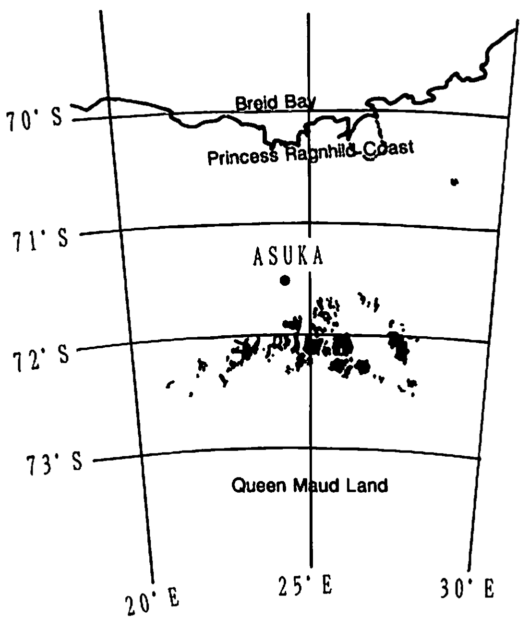

Fig. 1. Location of Asuka Station.

Table 1. Monthly summary of meteorological data at Asuka Station from 1987 to 1991 after YAMANOUCHI et al. (1988), AOKI (1989), MESHIDA et al. (1991), IWASAKI et al. (1992) and JAPAN METEOROLOGICAL AGENCY (1993).

	Jan.	Feb.	Mar.	Apr.	May	June	Annual
Mean air temperature (℃)	−8.3	−11.9	−16.1	−20.6	−23.7	−22.3	
Extreme of maximum air temperature (℃)	0.5	0.0	−1.7	−8.8	−7.0	−7.8	
Extreme of minimum air temperature (℃)	−18.8	−24.4	−33.8	−38.1	−42.9	−44.6	
Mean wind speed (m/s)	10.8	13.4	13.7	12.1	11.4	13.9	
Maximum instantaneous wind speed (Gust) (m/s)	36.1	40.4	38.5	32.7	39.1	45.2	
	July	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**	**Annual**
Mean air temperature (℃)	−23.3	−25.6	−25.7	−20.2	−14.0	−8.5	−18.3
Extreme of maximum air temperature (℃)	−9.2	−12.9	−12.3	−6.6	−2.8	0.3	
Extreme of minimum air temperature (℃)	−42.0	−48.7	−45.7	−37.0	−32.9	−19.0	
Mean wind speed (m/s)	14.4	13.7	12.9	12.7	12.5	9.6	12.6
Maximum instantaneous wind speed (Gust) (m/s)	37.1	39.5	38.1	42.8	32.1	27.8	

3. Construction Procedure of Ice Dome

Construction of an ice dome was attempted at a site about 15 m from the main buildings of the station, leeward of the buildings (Fig. 2). At first the construction site was leveled and smoothed by a crawler shovel, and wooden anchors for supporting guy ropes were buried 50 cm deep in the snow.

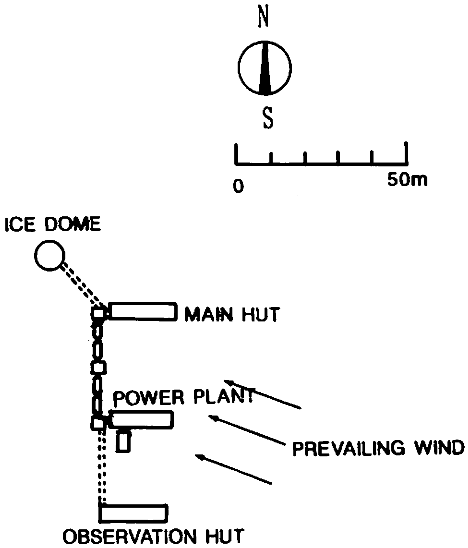

Fig. 2. Buildings of Asuka Station and position of ice dome.

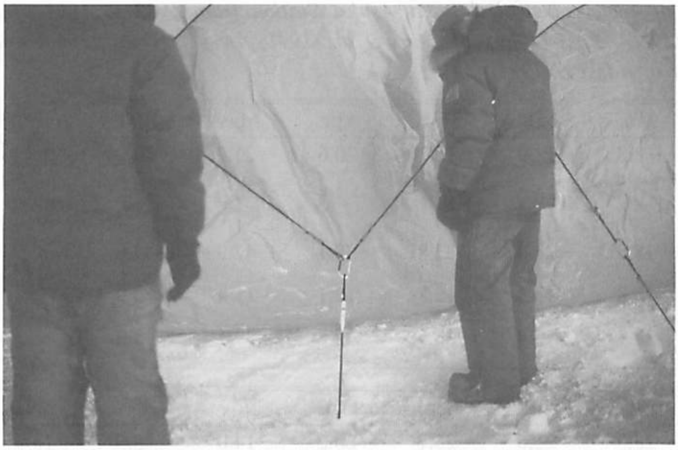

Fig. 3. Buried anchors with ropes. The guy ropes connected to the anchor ropes with carabiners keep the shape of the dome.

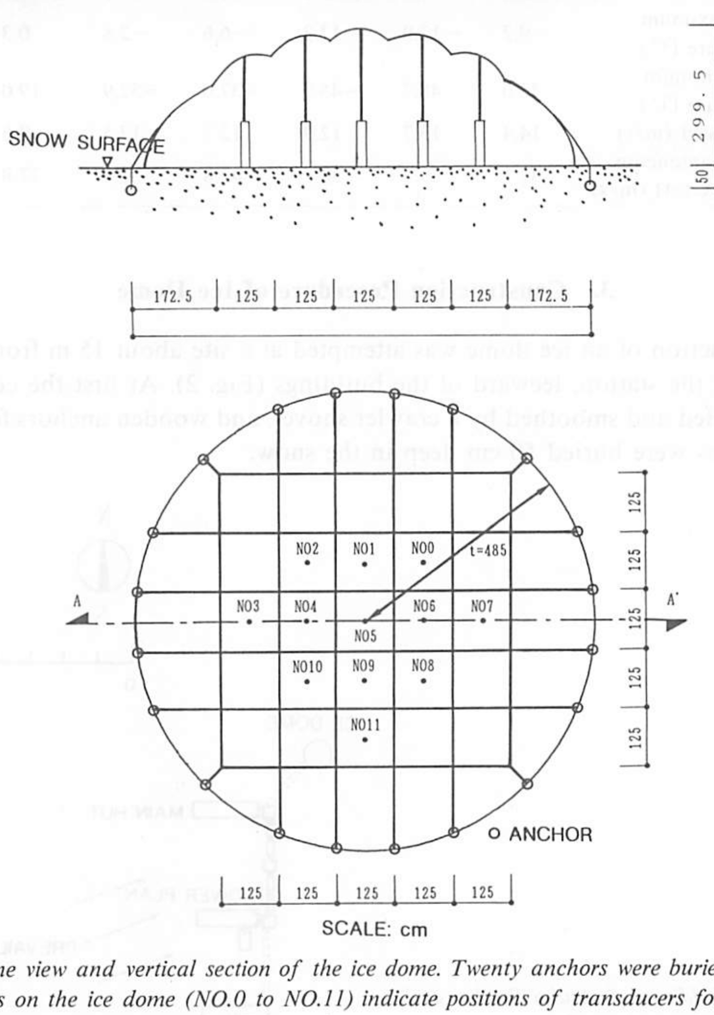

Fig. 4. Plane view and vertical section of the ice dome. Twenty anchors were buried in the snow. Dots on the ice dome (NO.0 to NO.11) indicate positions of transducers for displacement between the snow floor and the ceiling.

A 10-m diameter membrane bag made of polyester fibers with polyvinyl chloride coating was set on the snow surface. The thickness and weight of the membrane were 0.65 mm and 125 kg respectively. Polyethylene guy ropes 9 mm in diameter were

Fig. 5. Spread membrane bag with ventilator.

Table 2. Apparatus used for the dome construction.

Item	Manufacture	Specification
Submersible pump	Tsurumi Manufacturing Co. Ltd.	Type: 4 NC Power: 0.4 kW Drainage: 180 l/min Head: 6 m
Line pump	Hitachi Manufacturing Co. Ltd	Type: JL VEFOVP-K 40R2-52.2 Power: 2.2 kW Drainage: 200 l/min Head: 31 m
Sprayer		Worked pipe with holes of 2 or 3 mm in diameter
Membrane bag	Koushin Rubber Co. Ltd.	10 mϕ, 0.65 mm thick Type: KR6300 (sheet) Polyester coated by polyvinyl chloride
Guy lope	Tokyo Seiko Sen-i Co. Ltd.	9 mmϕ, polyethylene
Rotary snowplow	Fujii Corporation	Type: FSR1100DTA-2 Cutting width: 1100 mm Throwing distance: 15-20 m Ability: 150 t/h Engine: 22PS diesel
Ventilator	Suiden Co. Ltd.	Type: SJF-304-1V, 320 mmϕ, 55 m^3 /min, 400 W, 2850 rpm
Voltex blower	Hitachi Manufacturing Co. Ltd.	Type: VB-002S-E

covered on the membrane and the ends were connected to the anchor ropes buried in the snow with carabiners (Fig. 3). A top view and schematic section of the membrane and ropes are shown in Fig. 4. The membrane was inflated by a portable ventilator (maximum air flow 55 m^3/min) in 30 min (Fig. 5). The mean air temperature of the day (September 4, 1991) was −29.9 ℃. After inflating the membrane, the inner air pressure was held at about 343 Pa (35 mm water head) by a vortex blower. The pressure was measured by reading a scale on a U-type pipe gage attached to the membrane.

The spraying started by using two sprayers developed for this work. Big holes 2 or 3 mm in diameter were drilled at one end of an iron pipe to prevent water from freezing. The nozzles were insulated by glass wool. Tap water stored in a 16-kl tank was used for the spraying. The water was pumped up by a 0.4-kW submersible suction pump and a 2.2-kW booster pump from the tank to the nozzle through a rubber hose 32.4 mm in outer diameter. Water pressure of 470.9 kPa was obtained in the spraying. The apparatus used in the construction is shown in Table 2. The construction procedure and climatic condition are shown in Table 3 and Fig. 6 respectively. The construction was started on September 3 and completed on September 10. The spraying was carried out for 4 hours and 45 min on September 6 (Fig. 7). In the spraying, snow was blown onto the membrane by a rotary snowplow with

Table 3. Construction process of the ice dome.

Date (1991)	Description
September 3	Grading of the snow surface by a crawler shovel
4	Surveying, laying anchors and inflating the membrane
5	Freeze of pump and nozzle
6	Spraying
10	Removal of the membrane

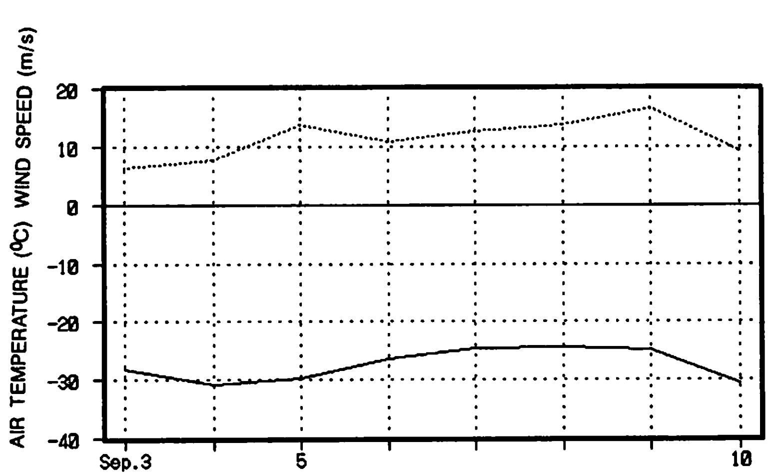

Fig. 6. Climatic condition for the ice dome construction period.

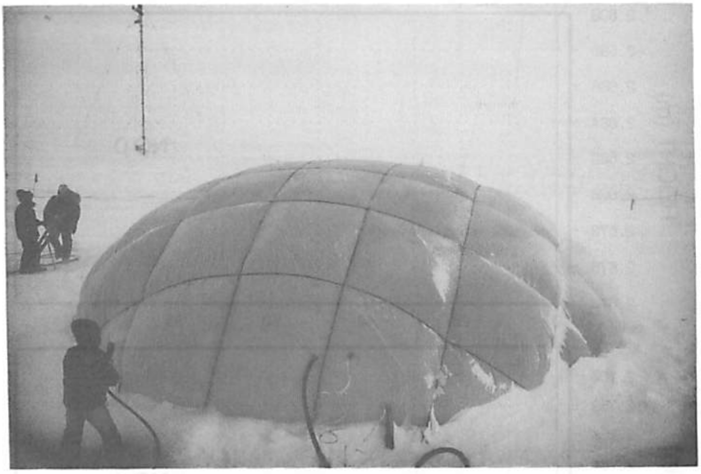

Fig. 7. Spraying to make the ice dome.

maximum throwing distance of 20 m. The thickness of the ice dome was 6-7 cm and the water comsumption was about 13 t. The membrane was deflated and removed on September 10, 3 days after spraying.

4. Deformation of the Ice Dome

A snow tunnel was excavated between the main hut and the ice dome in order to use the dome as a doorway of the station (Fig. 2). The opening (1.8 m height, 1.5 m width) was excavated in the wall on September 18, 8 days after removal of the membrane. The length between the ceiling and the floor was measured at twelve points by wire-rolled type transducers as shown in Fig. 4. The data obtained are shown in Fig. 8. The heights of the ceiling at all points except No. 0 and No. 1 decreased with time. Furthermore, the speed of shrinkage increased according to the air temperature shown in Fig. 9. Figure 10 shows accumulative shrinkages over the measurement period. The shrinkage of the center (No. 5) reached 55 mm for 99 days. The average was calculated as 0.55 mm per day. The shrinkage would reach 20 cm in a year if that average value were used. This value suggests that it will be possible to use an ice dome used as a wide covered space in one or two years in the Antarctic.

5. Advantages and Problems

The ice dome was used as workshop, storehouse and doorway of the station. The door was attached to the wall at a right angle to the prevailing wind direction. The door was very accessible because snow drift did not accumulate in front of it, while an old doorway on the lee of the building had to be cleared of snow drift almost every day. The wind is sometimes accelerated at a right angle to the prevailing wind direction when it strikes the ice dome. The snow drift developed only on the leeward

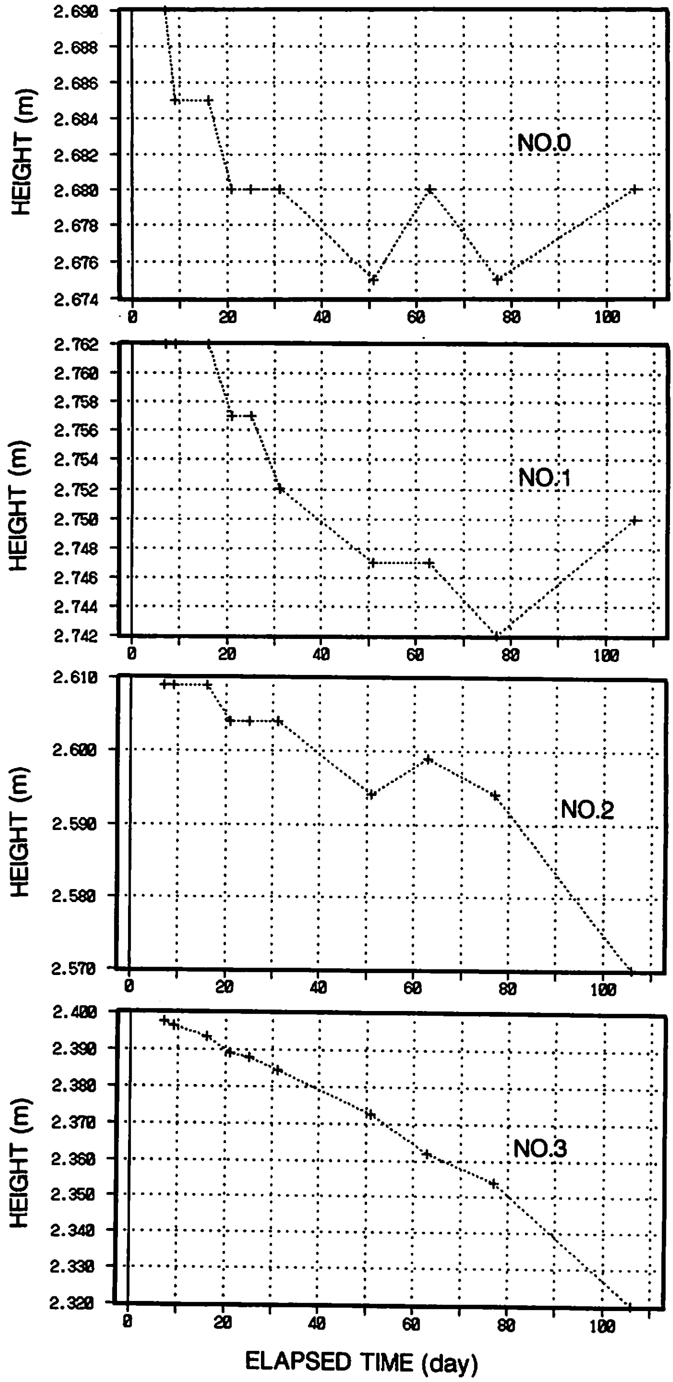

Fig. 8. Height changes at twelve points of the ceiling. The numbers coincide with those in Fig. 4.

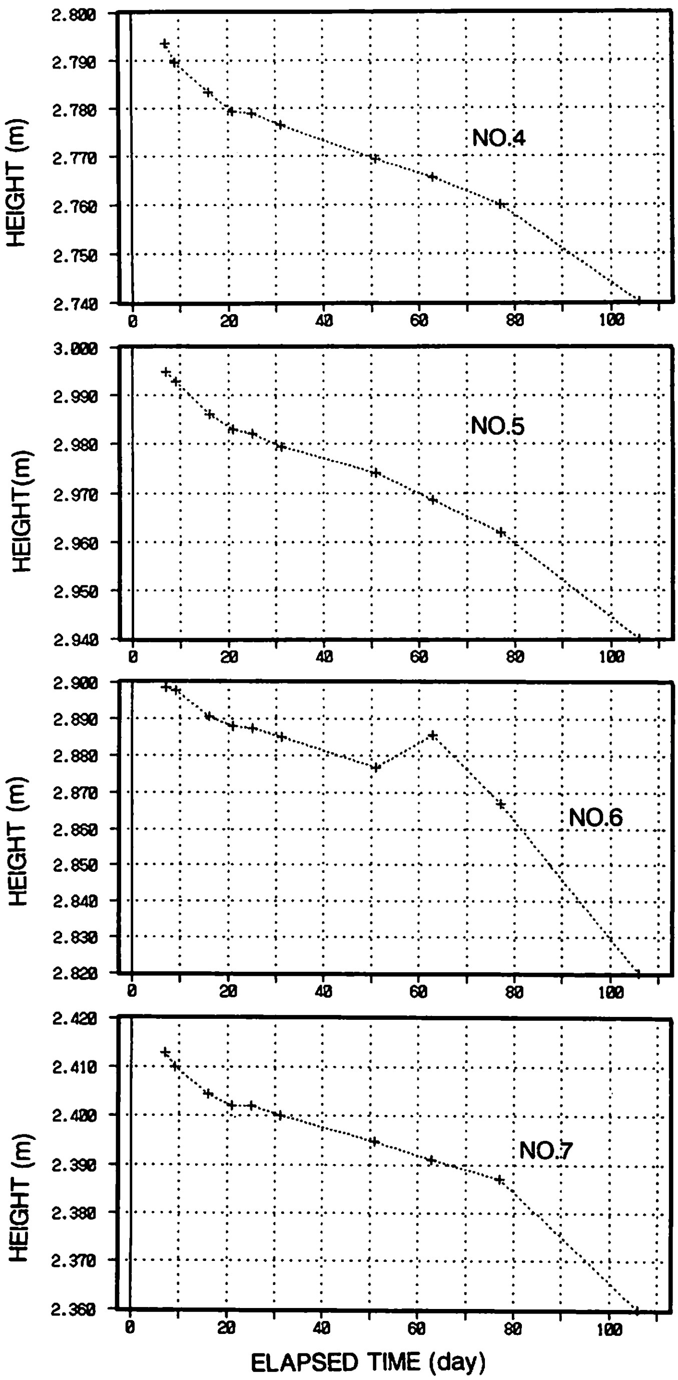

Fig. 8. (Continued)

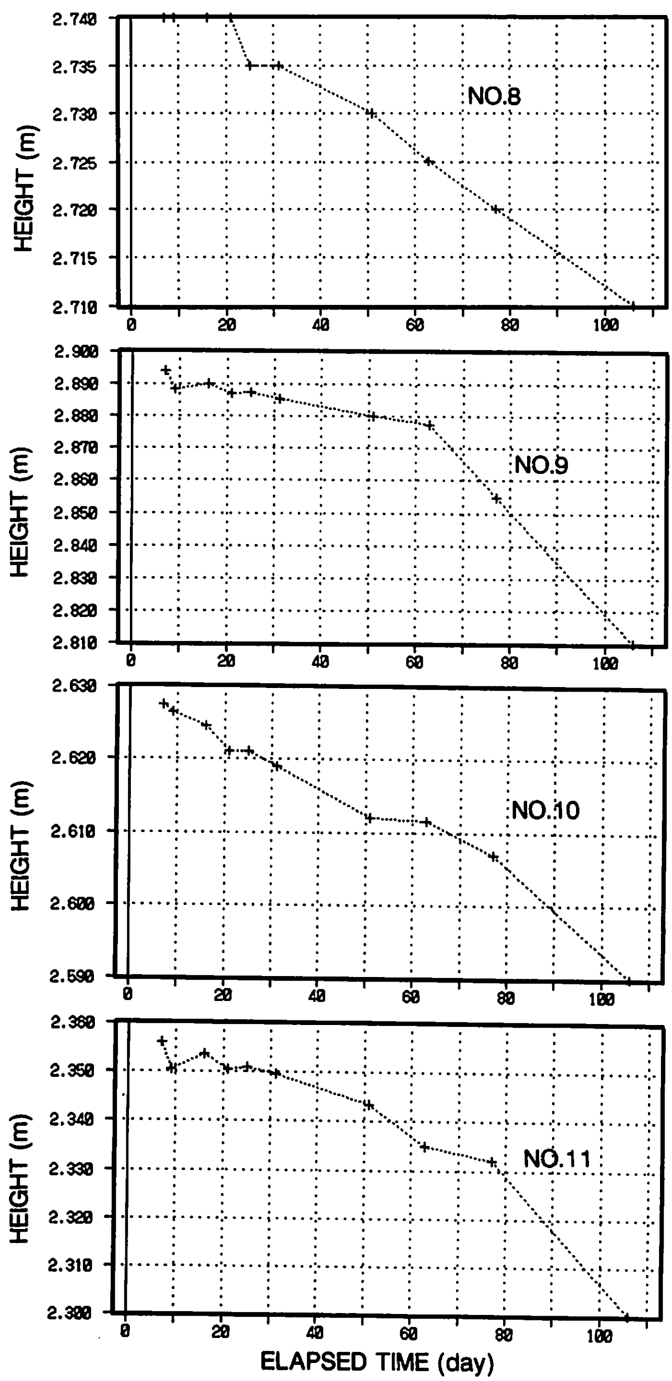

Fig. 8. (Continued)

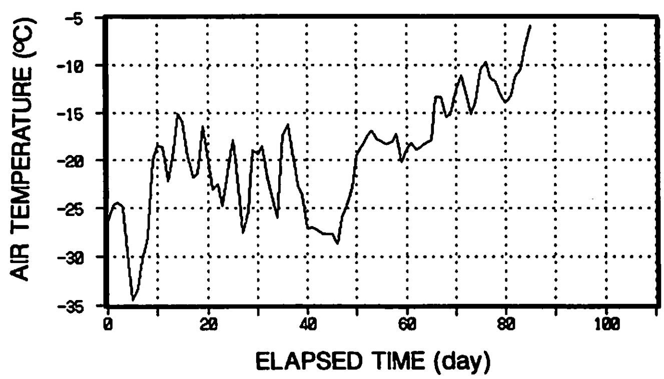

Fig. 9. Change of air temperature for the period of the displacement measurement.

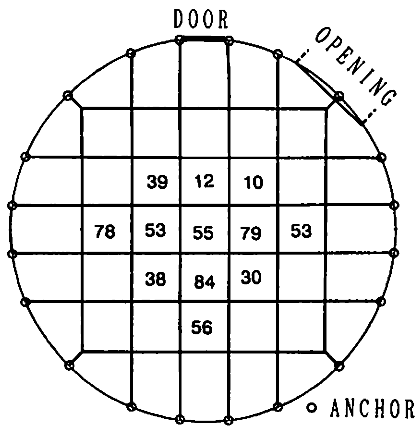

Fig. 10. Accumulated displacement of the ceiling in the ice dome.

side of the ice dome.

The thickness of the ice dome rapidly decreased due to sublimation in summer; consequently, small holes appeared, especially on top of the ceiling and on the north side of the ice dome. Figure 11 shows typical holes due to sublimation on another ice dome. An air pressure difference between inside and outside of the ice dome occurs on windy days; consequently, a draft mainly drained into the outside through the holes formed by sublimation. That may accelerate the development of the holes. Snow was sometimes added to the ice dome to prevent sublimation.

An attempt was made to construct a snow dome without using water. The construction was carried out from October 22 to November 28. Snow was blown onto the membrane bag by the rotary snowplow. The lower part of the membrane was covered with snow, but it was impossible to cover the upper part. The snow did not harden. One reason is believed to be that the diameters of the snow lumps blown from the rotary snowplow were too large.

Water making was also attempted outside using a snow melter with an oil burner

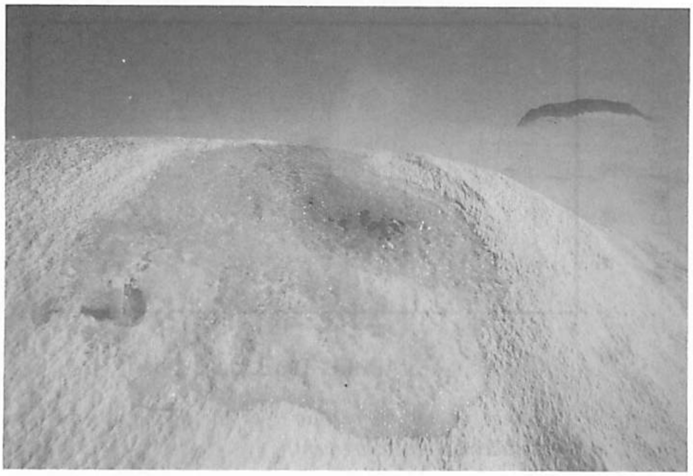

Fig. 11. Holes of the ice dome developed by sublimation in summer.

of 335 MJ/h and a sectional water tank. But this was not successful owing to the strong wind and low temperature.

6. Conclusion

The ice dome was very convenient as a temporary wide covered space for a workshop, storehouse and doorway at an inland station in the Antarctic, but it was difficult to make water outside in the cold condition. Therefore, it is advised to use tap water stored in a station. It is worth making a large supply pool when construction of several ice domes is planned at once.

An ice dome is good for the environment because nothing remains but the door if it is demolished.

Adding snow was useful in order to prevent ice thickness from decreasing owing to sublimation.

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