EXPERIMENTS OF DEPTH HOAR FORMATION UNDER EXTREMELY LOW TEMPERATURE

Y.Kamata*, and A.Sato*

ABSTRACT: To investigate the growth of depth hoar crystals in a very cold region, an experiment was carried out for three days with temperature gradients of 200 K/m.

After three days of fixed conditions, snow samples were divided into three layers. Photographs of the snow grains were taken using a microscope for each layer. The mean cross-sectional area of the digitized grains was determined as a diameter of a circle with an equivalent area. Snow crystals of these layers were also classified into three types. Growth direction of depth hoar crystal was also observed by vertical thin section for each layer.

From these experiments, the texture of original fine snow was considerably changed into sharply edged hoar grains. They were solid and skeleton types due to dry metamorphism. And the crystals grew toward warmer part. Depth hoar crystals developed where temperature was high and temperature gradient was low more than where temperature was low and the gradient was high. This indicates that the growth of depth hoar crystals is controlled by temperature itself rather than temperature gradient under extremely low temperature.

KEYWORDS: depth hoar, extremely low temperature, saturated water vapor concentration

1. INTRODUCTION

Snow cover in polar regions, like Alaska, Canada, Siberia, is very important as cold source for water cycle and global climate change. Very low air temperatures in winter are common, and soil temperatures at the base of snow cover are near the melting point in these regions. Snow depth in the plain is also mostly several tens of centimeters. So these condition produce extreme strong temperature gradients across the snow.

The snow mostly consists of depth hoar crystals that are highly-developed to over 10 mm in size. The structure of the snow pack affects strongly its thermal and mechanical properties. We have started to observe snow characteristics of these regions and to conduct basic laboratory experiments.

Akitaya(1964, 1967, 1974) studied growth conditions of depth hoar in connection with the snow temperature, magnitude of temperature gradient, and size of an air space in snow by field observation and experiments. He reported that depth hoar crystal grew in snow when the snow was subjected to a consistent negative temperature gradient for a considerably long period. Fukuzawa and Akitaya(1991, 1992) investigated growth of depth hoar crystals under strong temperature gradient, which appeared in the surface layer of snow cover on nights with clear skies. Their results indicated that the larger the temperature gradient was, the larger the growth rate of the average size. Temperature range of these experiments was within -12 to -4℃.

Sturm and Johnson(1991) studied

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observationally in the subarctic snow cover in Fairbanks, Alaska and measured temperature field using an array of thermistors to detect air convection in snow. At the same time the relationships between grain growth and vapor flux were observed and calculated (Sturm and Benson, 1997). They concluded that air convection in snow caused the highly-developed depth hoar crystals because of increasing vapor fluxes.

Many such previous experimental and observational studies (Marbouty, 1980; Adams and Sato, 1993; Palm and Tveitereid, 1979; Brown et al., 1994; Yoshida, 1950) were reported. However, there are few experiments which reproduce highly-developed depth hoar crystals in the laboratory under extremely low temperatures. In this study an experiment was carried out for three days with strong temperature gradients of 200 K/m. The growth of depth hoar crystals under the conditions of below -20℃ were investigated.

2. EXPERIMENTAL METHOD

2.1 *Snow sample*

We used lightly compacted snow initially (Figure 1), which was made in the Cryospheric Environment Simulator (CES) in Shinjo Branch, NIED and kept in a cold room (-15℃) for a month. The snow was sifted into the experimental box made from 10 cm heat insulators, of size 25 cm×25 cm×10 cm. Density of initial snow was 0.25 g/cm³.

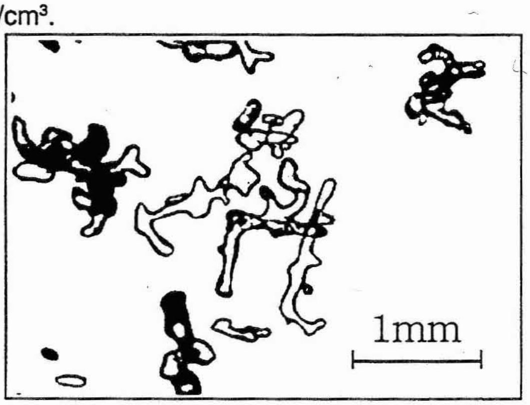


Figure 1. Initial Snow 0.25 g/cm³

2.2 *Apparatus*

A schematic experimental apparatus is shown in Figure 2. This apparatus was put in a cold room. And the inside temperature of the isothermal box was kept at -10±1℃ by a heater and fan with a thermo regulator. The snow sample in the insulated box was placed in this box.

The bottom end of the snow sample was covered with an iron plate, so the temperature of the bottom was kept within ±0.2℃. A cold plate of circulating thermostat was put on the top end and we could control its temperature with accuracy of ±0.05℃. In this way the sample was subjected to an accurate temperature gradient.

To measure temperature distribution in the sample we set six copper-constantan thermocouples about 2 cm apart.

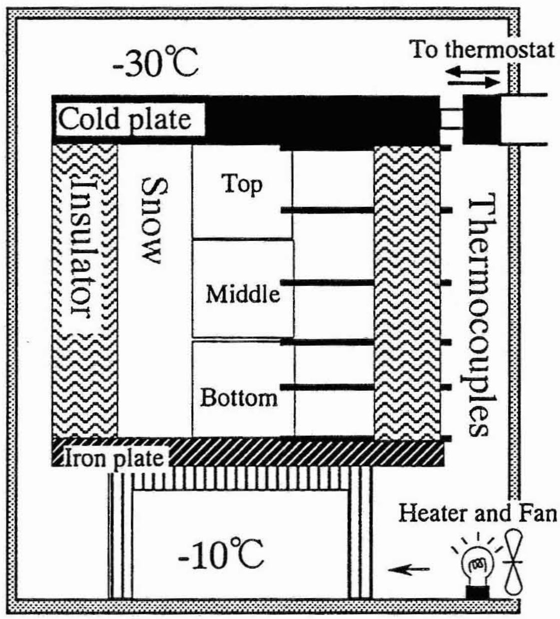


Figure 2. A schema of apparatus

2.3 *Method*

The whole sample was kept at -10℃ as an

initial condition. Then we changed the temperature of the cold plate to -30℃ so that the sample was subjected to strong temperature gradient of 200 K/m. The temperature distribution in the sample was measured continuously.

After three days of the fixed thermal conditions, as shown in Figure 2, the snow sample whose thickness was 0.1 m was divided into three layers : Top (0.1~0.068 m), Middle (0.068~0.033 m), and Bottom (0.033~0 m).

Photographs of the snow grains for each layer were taken using a microscope. The mean cross-sectional area of the digitized grains was determined as a diameter of a circle with an equivalent area. And we calculated the average diameter of each layer. Snow crystals were also classified into three types: original type, solid type, and skeleton type. The growth direction of depth hoar crystals was observed by vertical thin section for each layer. The relationships between diameters, snow types, temperatures, and temperature gradients were investigated.

3. RESULTS

Figure 3 shows quasi-steady state temperature and calculated temperature gradients of each position. We can see temperature distribution was not linear, but convex curve. Consequently temperature gradients were not constant and decreased with increases in temperature as witness Figure 3.

Now let's see about depth hoar formation. From this experiment it became clear that the texture of initial lightly compacted snow was considerably changed into sharply edged depth hoar. The top layer was near the cold plate and consisted mostly of solid type depth hoar, the Middle layer was solid + skeleton type, and the Bottom layer was mostly skeleton type due to dry metamorphism. The ratio of skeleton type depth hoar increased with approaching warmer part, that is, increases in temperature (Figure 4). In addition, the average diameter of crystals of each layer increased Top(0.33 mm), Middle(0.34 mm), Bottom(0.41 mm) in order (Figure 5).

From thin section observations, depth hoar crystals grew toward the warmer part.

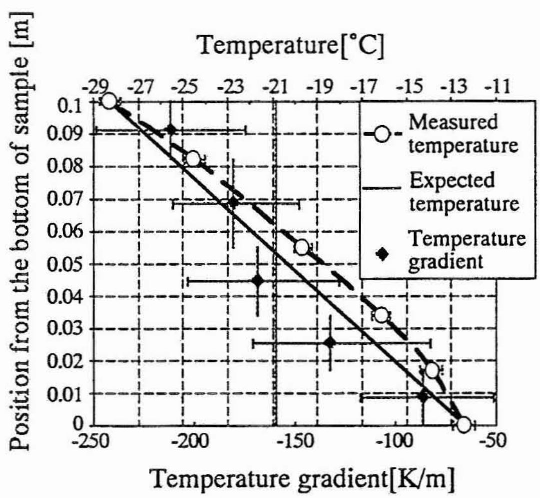
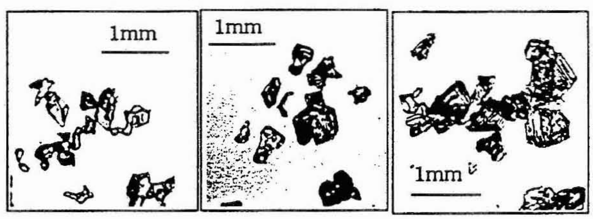


Figure 3. Temperature distribution and temperature gradients in snow sample



(a) (b) (c)

Figure 4. Changes of type and diameter by development of depth hoar

(a) *Top : solid type*

(b) *Middle :solid+skeleton type*

(c) *Bottom : skeleton type*

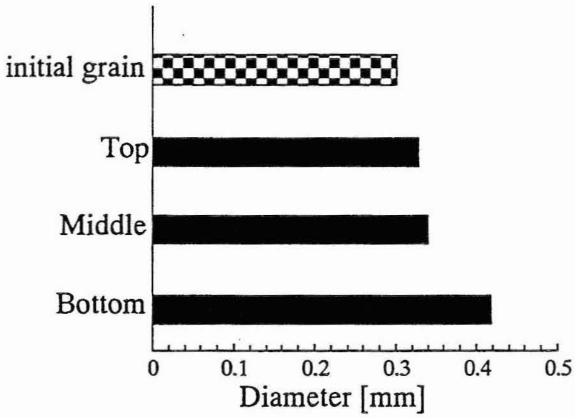


Figure 5. Average diameter of initial and each layer crystals

4. DISCUSSION

As temperature increased, depth hoar crystals grew into skeleton type and its diameter increased. As shown in Figure 3, the central temperature and temperature gradient of the Top layer were about -26℃ and -210 K/m, Middle layer were about -21℃ and -160 K/m, Bottom layer were about -14℃ and -85 K/m. We can see that temperature gradient decreases with increases in temperature. The experiment indicated depth hoar crystals highly developed at the Bottom layer where temperature was high and temperature gradient was low. While the crystal growth of the Top layer was smallest, where temperature was low and temperature gradient was high.

Previous studies reported that the larger the temperature gradient, the larger the growth rate of the average size (Fukuzawa and Akitaya, 1992). Akitaya (1964) reported that the top surface of the warmer snow grain evaporated sublimatically, then condensed sublimatically on the bottom surface of the colder snow grain. However, our results of very cold temperature showed a tendency contrary to that reported in previous studies. Such under extremely cold temperature, depth hoar crystals were mainly affected by temperature itself rather than the magnitude of temperature gradient.

One reason for this is the following. Figure 6 shows the relationship between temperature and saturated water vapor concentration. Under extremely low temperature, saturated water vapor concentrations are very small. For example, at -30℃ it is about ten times as small as the value of -10℃. This is why depth hoar crystals hardly developed at the Top layer under cold temperatures even if the magnitude of temperature gradients were large, and the crystals of the Bottom layer developed greatly in spite of relatively small temperature gradient.

Figure 7 shows the relationships between calculated water vapor concentration gradients and average diameter of each layer. We can see the diameter increases with increases in magnitude of the gradients. The factors of accelerating depth hoar crystal growth is firstly the amount of water vapor concentration, which depends on temperature, and secondly by transportation due to temperature gradient.

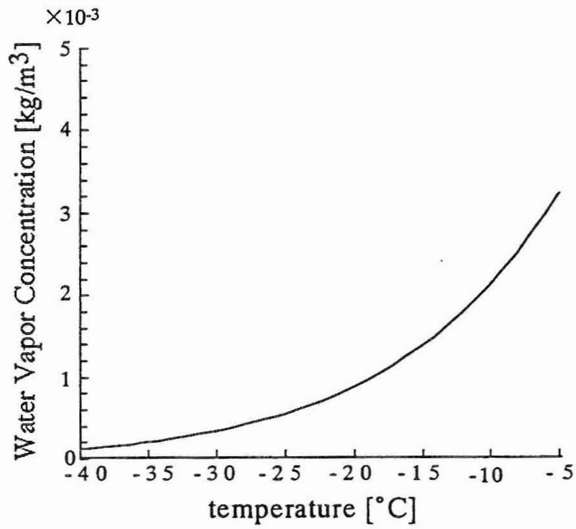


Figure 6. Changes of saturated water vapor concentration with temperature

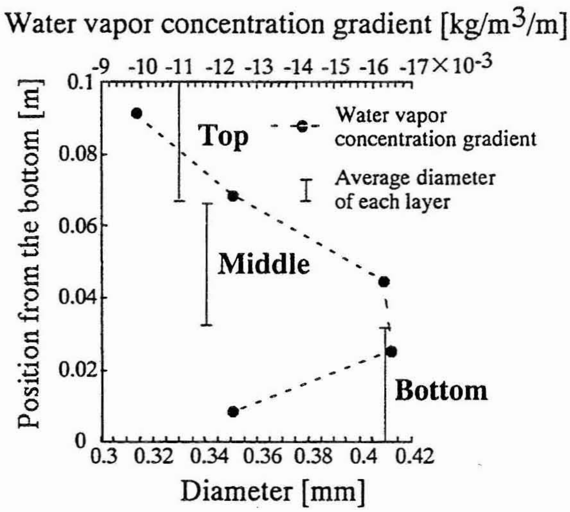


Figure 7. Relationships between diameter and the saturated water vapor concentration gradient for each position

5. CONCLUSION

To investigate the growth of depth hoar crystals in polar region like Alaska, experiments were carried out for three days with strong temperature gradient of 200 K/m under the conditions below -20℃.

Initial lightly compacted snow were metamorphosed into solid and skeleton type depth hoar. The crystals of the Bottom layer, where temperature was high and temperature gradient was low, developed more than those of the Top layer, where temperature was low and temperature gradient was high. These results indicated a tendency contrary to previous reports. But when we consider the saturated water vapor flux, our results were not contradictory to other reports. Our results can be understood in the following way. Since under extremely low temperature the saturated water vapor concentration is very small, the growth of depth hoar crystals is controlled by temperature itself rather than temperature gradient.

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