Surface Hoar Growing for Several Days

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ABSTRACT

Surface hoar growing for several clear and humid days were observed. In the daytime, the air and the snow surface temperature increased and the relative humidity decreased, hence evaporation (sublimation) occurred at the snow surface. The amount of evaporation calculated with a bulk method was enough to evaporate out the surface hoar crystals which grew previous night, but they were observed to survive on the snow surface even in the daytime. In the following nights new hoar crystals formed on the old ones and developed largely. This result suggested that the surface hoar crystals were cooled by outgoing radiation even in the daytime and kept their size, while snow grains underneath the surface were warmed by solar radiation and evaporated. The layer composed of the surface hoar and the depth hoar crystals showed a very weak shear strength.

INTRODUCTION

Surface hoar crystals are formed by the deposition of water vapor onto the snow surface during the clear night. They have long been of interest to avalanche researchers (*e.g.* Perla and Martinelli, 1976), because after being buried by a subsequent snowfall, they often form a weak layer due to their lack of intercrystalline bonding and weak attachment to the original snow surface. Besides, a layer composed of larger hoar crystals is hard to metamorphose. Lang et al. (1984) reported that the shear strength remained too low to measure for extended periods of time. In this paper we report the surface hoar crystals survived on the snow surface even in the daytime and developed largely for several days.

OBSERVATION SITE AND OBSERVED ITEMS

Observations were carried out in the winter of 1994- 95 in the Teshio Experimental Forest of Hokkaido University located in Toikanbetsu, northern Hokkaido, Japan. The station (45∞N, 142∞E) is close to the Japan Sea (about 20km in distance), and the southwest is the predominant wind direction in winter. Air temperature, humidity, wind speed, snow surface temperature and vapor condensation were measured. Observation methods and the instrumentation used were same as Hachikubo *et al.* (1995) and described in detail by Hachikubo and Akitaya (1997). The latent heat flux at the surface, which corresponds to the vapor condensation rate or evaporation rate, was obtained with the weighting- type evaporimeter in nighttime, while it was estimated with a bulk method (Takeuchi and Kondo, 1981) in daytime using the data of air temperature, surface temperature, humidity and wind speed. In the calculation, the value of 2.9 ¥ 10^{-3} obtained from field observations (Hachikubo and Akitaya, 1997) was used as the bulk transfer coefficient of water vapor.

OBSERVATION RESULTS

The following two cases of surface hoar growth are described.

Case one on December 26 to 28, 1994

It was almost clear during this period except for the morning Dec. 27 and the midnight Dec. 27-28, and the surface hoar was formed in the two nights. Figure 1 shows the time variations of the air temperature T_a at 1m high and the snow surface temperature T_s. T_s was always lower than T_a and the difference between T_a and T_s became larger during two nights. T_s increased in the cloudy conditions due to the decrease in the radiative cooling. Figure 2 shows the time variation of the latent heat flux. From 18:30, Dec. 26 to 3:00, Dec. 27 the total condensation of surface hoar was 74 g/m², while the total evaporation from 3:30 to 15:00 on Dec. 27 was 62 g/m². Therefore, the surface hoar crystals formed in the first night were expected to be eliminated mostly. However, they were survived on the snow surface and the new hoar crystals developed on them in the second night. Figure 3a shows a microscopic photograph of surface hoar crystals formed on a snow particle at the surface in the first night. Their size was less than 1mm in diameter. Figure 3b shows the "survived" crystal even in the daytime though it was rounded by the evaporation. New crystals in the second night developed on the old ones and reached to 3mm in diameter (Fig. 3c- e).

Case two on February 23 to 26, 1995

The surface hoar growth was observed for three clear and humid nights of Feb. 23 to 26. The time variations of T_a and T_s are shown in Fig. 4. T_s was 5 to 10∞C lower than T_a at each midnight due to the radiative cooling. Figure 5 shows the time variation of the latent heat flux. Large amount of

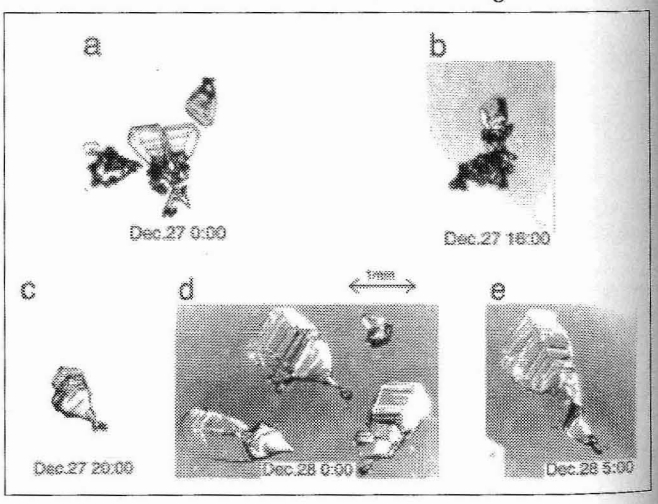

Fig. 3 Microscopic photographs of surface hoar crystals formed on December 26 to 28, 1994. (a) surface hoar crystals formed in the first night. (b) a surface hoar crystal survived in the daytime and rounded by the evaporation. (c)- (e) new crystals in the second night developed on the old ones.

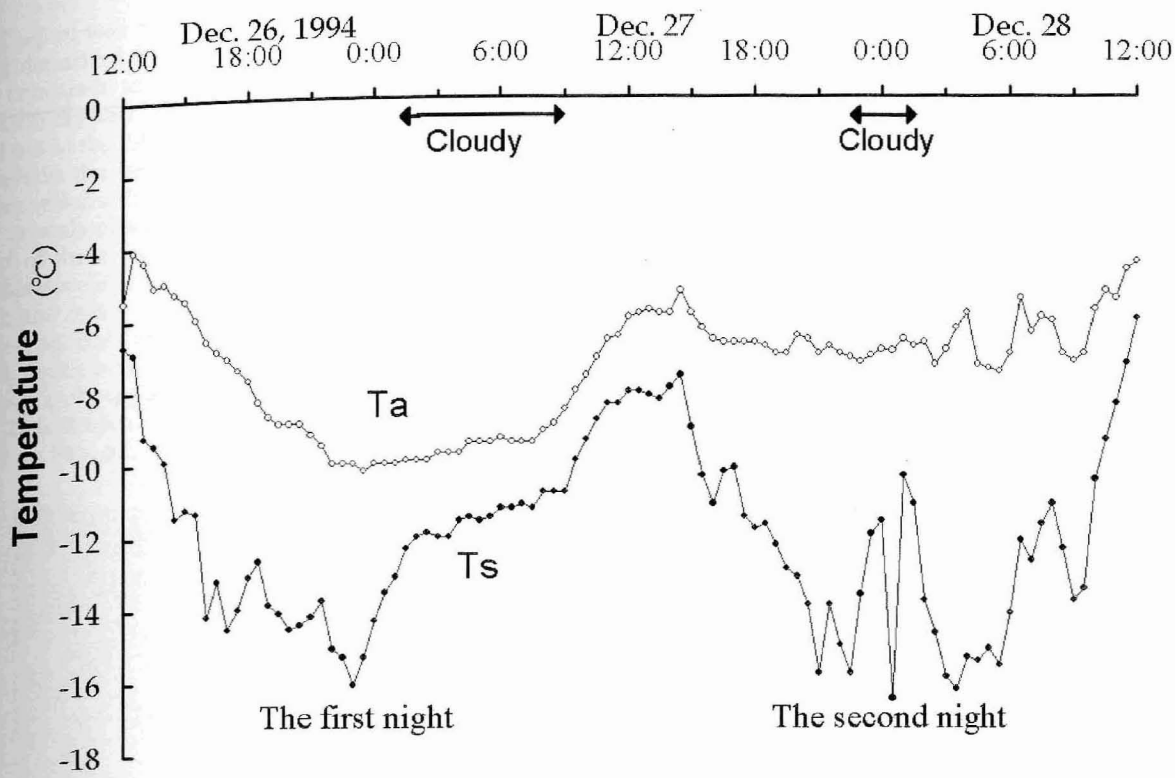

Fig. 1 The time variations of the air temperature T_a at 1m high and the snow surface temperature T_s on December 26 to 28, 1994.

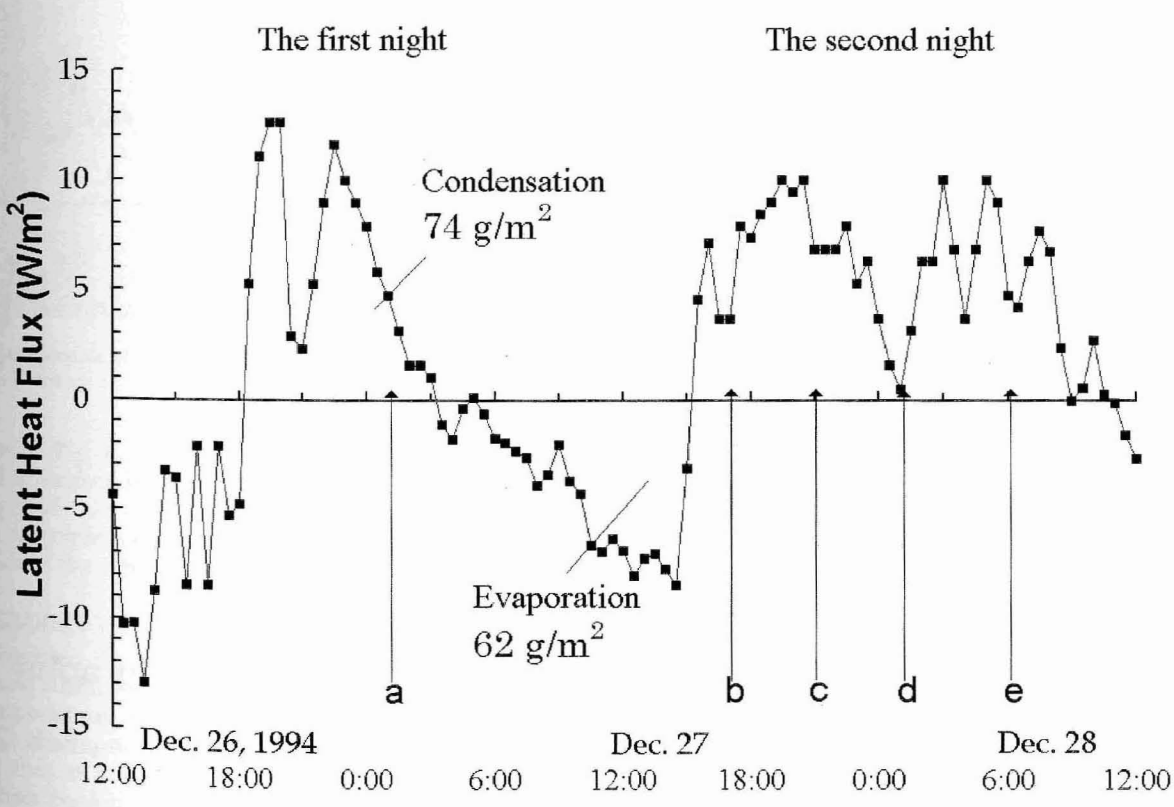

Fig. 2 The time variation of the latent heat flux on December 26 to 28, 1994.

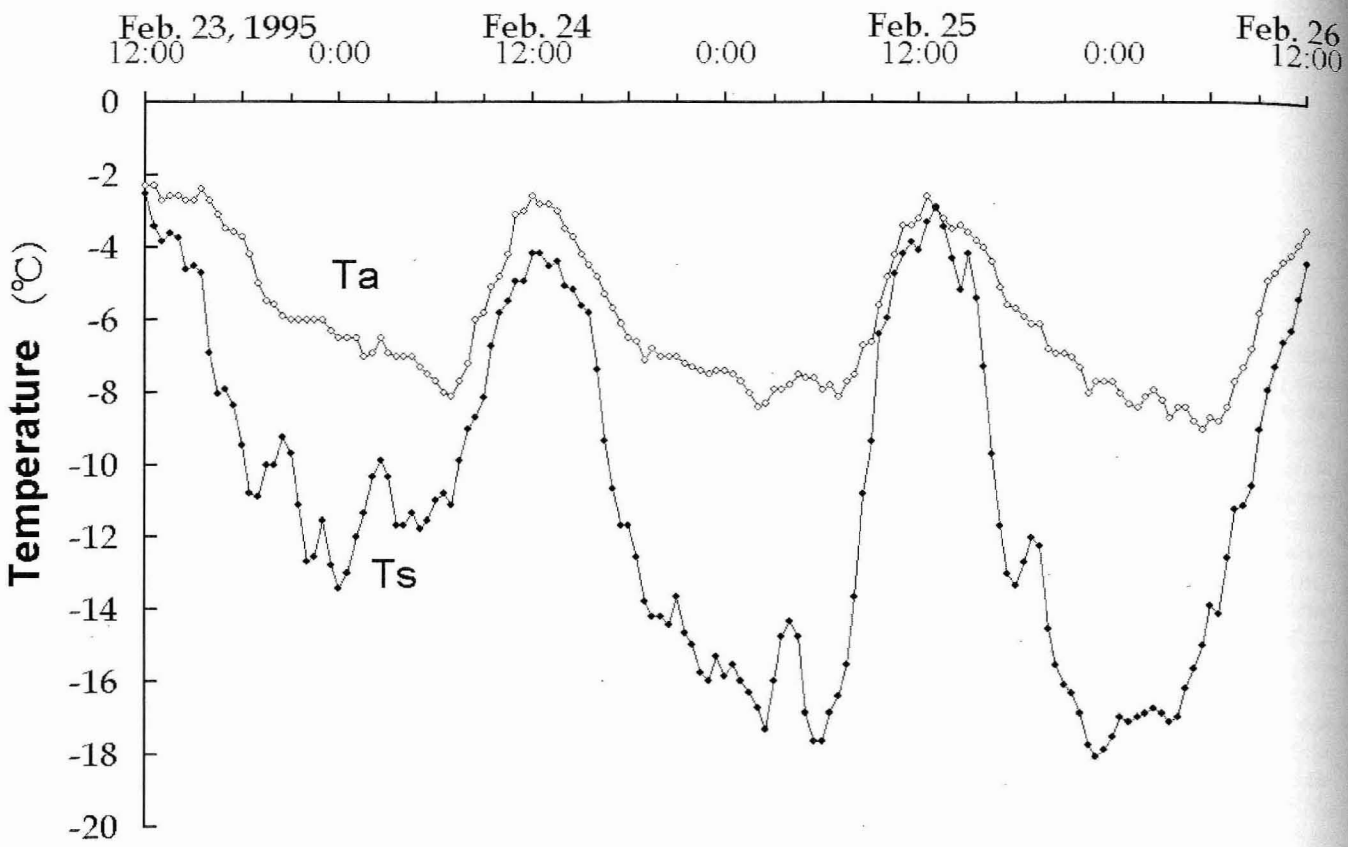

Fig. 4 The time variations of T_a and T_s on February 23 to 26, 1995.

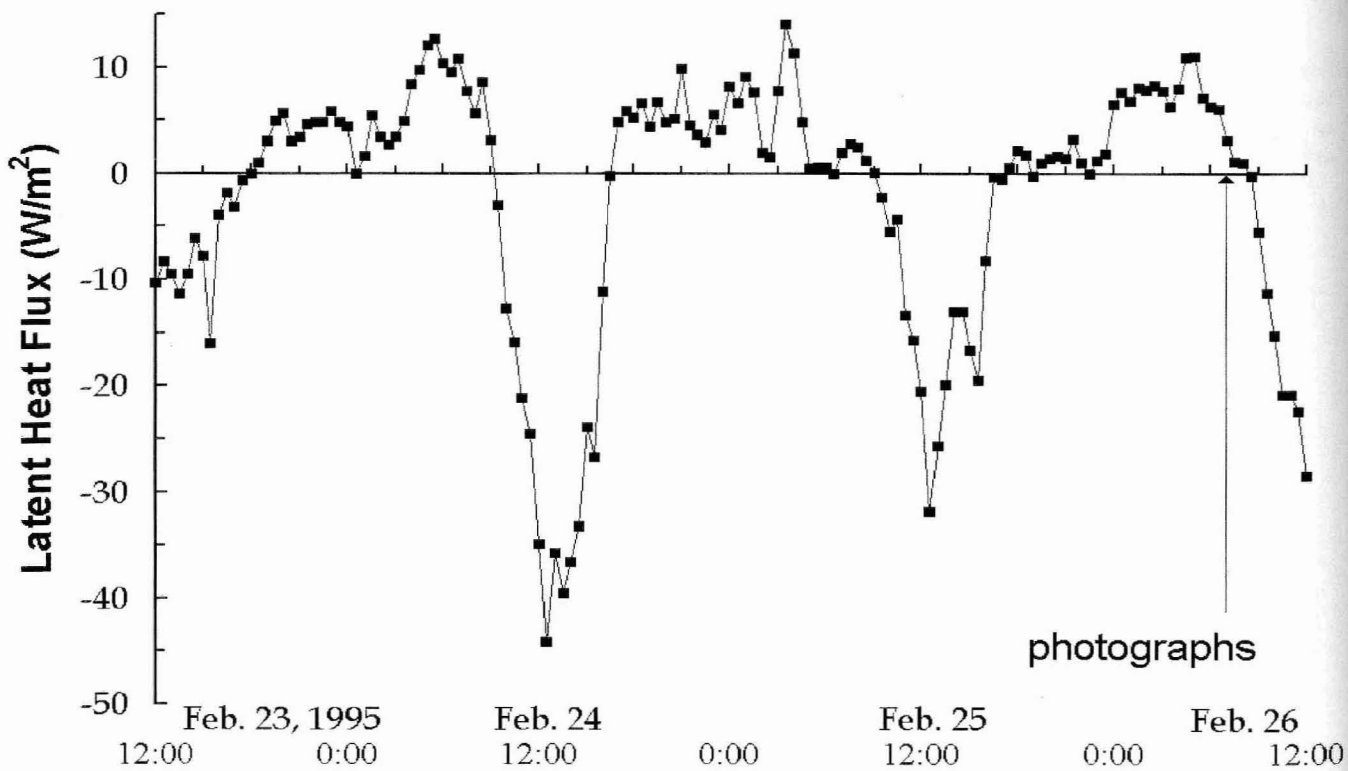

Fig. 5 The time variation of the latent heat flux on February 23 to 26, 1995.

evaporation was calculated in the daytime, whereas water vapor deposited onto the snow surface and formed surface hoar crystals in the nighttime. We can expect that the surface hoar crystals which grew in the first two nights evaporated out in the following daytime. Therefore, surface hoar crystals in the morning on Feb. 26 should be due to the vapor condensation only in the last night. However, surface hoar crystals observed at 7:00 on Feb. 26 had a form consisted of three parts (Fig. 6), which suggested that these crystals developed step by step during the three nights.

On the other hand, since large temperature gradients formed not only above but also below the snow surface at night, depth hoar crystals grew beneath the surface. Microscopic photograph of the depth hoar crystals taken on Feb. 27 is shown in Fig. 7. They began to form in the new snow on Feb. 22, and developed in the layer of 20 mm as

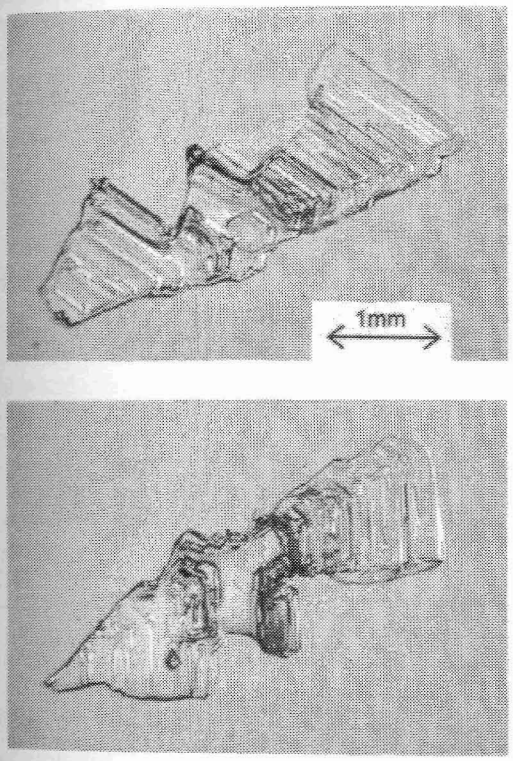

Fig. 6 Microscopic photographs of surface hoar crystals observed at 7:00 on February 26. They had a form consisting of three parts.

shown in Fig. 8. The upper region of 10 mm was composed of surface hoar and depth hoar crystals. The shear strength of this layer was less than 100 Pa on Feb. 27. Since subsequent drifting snow eroded this layer, we could not obtain the time variation of the shear strength.

CONCLUDING REMARKS

We observed that the surface hoar crystals survived on the snow surface even in the daytime, whereas the amount of evaporation calculated with the bulk method was enough to evaporate them out. Ozeki and Akitaya (1996) noted that at a sun crust formation, outgoing longwave radiation cooled the snow surface, while shortwave radiation was absorbed beneath the snow surface and caused

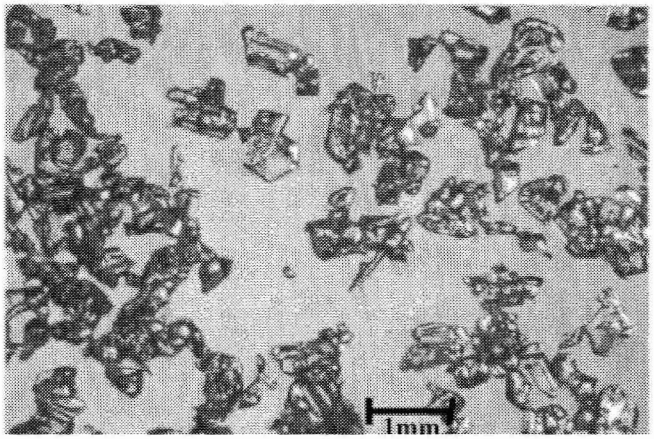

Fig. 7 Microscopic photograph of the depth hoar crystals on February 27, 1995.

internal melting of the surface layer. So, we may say in the same manner that the surface hoar crystals were cooled by outgoing radiation even in the daytime and kept their size, while snow grains underneath the surface were warmed by solar radiation and evaporated.

Hachikubo *et al.* (1995) found a linear relationship between the condensation rate and vapor pressure difference multiplied by wind speed, thus the surface hoar condensation could be estimated with the bulk method from meteorological data; air temperature, snow surface temperature, humidity and wind speed. However, this method may underestimate the vapor condensation, because it cannot evaluate the preservation of surface hoar in the daytime. We need further quantitative investigation how surface hoar crystals are protected from evaporation during the day time.

Fukuzawa and Akitaya (1993) observed the quick growth of depth hoar crystals just below the snow surface under radiative cooling; the meteorological condition of depth hoar formation is similar to the one of surface hoar. Under the several clear and humid nights the layer near the surface may change into the mixture of surface hoar and depth hoar crystals as observed in this study. Since the depth hoar is well known to be a cause of weak layer as well, a layer composed of both surface hoar and depth hoar crystals has a potential to create a rather thick one.

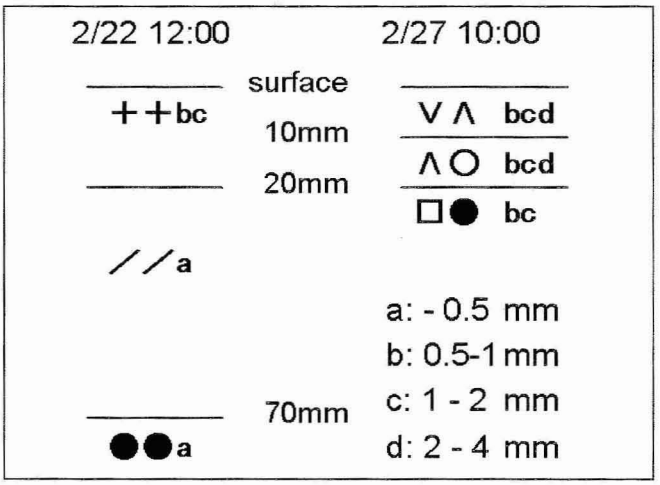

Fig. 8 Profiles of the snow surface layer at 12:00 on February 22 and at 10:00 on February 27, 1995.

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