AN OBSERVATION OF DEPTH HOAR IN THE MARITIME

S. Ikeda* and M. Ryan
ARGOS INC. Niigata, Japan
Graduate School of Agriculture, Gifu University Gifu, Japan

ABSTRACT: Generally speaking, in continental climates thick depth hoar layer may develop near at or near the ground, where in maritime climates a compacted snow or wet-grain layer tend to develop at or near the ground. However, it is common knowledge that even in maritime climates where wind erosion of shallow areas of the snow-pack is seen, a depth hoar layer often develops. In some cases this phenomenon can be linked to the cause of serious avalanche accidents. Observations of this particular development of depth hoar were made in the maritime climate in Japan during 04-06 winters for which results follow.

Rainfall has a strong influence of deterring the development of depth hoar.
-Even if the total snow-pack becomes saturated / become wet grains from rainfall, transformation back into depth hoar is possible.
-To estimate the development of such depth hoar layer(s), one must consider the timing and frequency of rainfall events.

KEYWORDS: depth hoar, maritime climate, wind erosion, rainfall

1. INTRODUCTION

An avalanche accident occurred in Garagara-sawa (Garagara Valley) Hakuba-mura (Town of Hakuba), Nagano on February 19, 2000. Three snow boarders were killed in this accident. Hakuba area is located near the Sea of Japan, and maximum snow depth is around 3 m, which is typical maritime climate area. Because the accident occurred just after a three day storm, it was thought that the accident caused by storm instability. However, the start point of the avalanche was a shallow area which had where had seen wind erosion. In other studies, it has been demonstrated that the avalanche occurred due to instability of a faceted snow layer which had developed at a shallow point of the snow-pack (Ikeda, 2002).

Generally, in continental climates, in continental climates thick depth hoar layer may develop near at or near the ground, where in maritime climates a compacted snow or wet-grain layer tend to develop at or near the ground. However, it is common knowledge that even in maritime climates where wind erosion of shallow areas of the snow-pack is seen, a depth hoar layer often develops. In some cases this phenomenon can be linked to the cause of serious avalanche accidents. (McClung and Schaerer, 1993; Daffern, 1992; Jamieson and McDonald, 1999; Tremper, 2000). In this paper we report the results of the observation of the snowpack in the maritime climate where wind erosion of shallow areas of the snow-pack occurs.

2. SITE & METHOD

Observations were carried out at Happou-one (Happou Ridge) Ridge Hakuba-mura, Nagano. Happou-one is located about 40km Northwest of the Sea of Japan, maximum snow depth reaches around 3m, and sees 2 to 3 considerable rainfall events each high winter period. The study site was a north-facing slope of 30° at 1850m a.s.l., where wind erosion of shallow areas occurs.

The snow layer structure, snow grain shape, grain size, snow density, hardness (hand hardness) and snow temperature (every 0.1m) were measured. Observations were carried out at a fixed location (Study Plot A) and along an "Observation Line" which consisted a series of 4 other snow pits dug in a straight line containing Study Plot A. Observations at Study Plot A were carried out during the winter seasons of 2004, 2005 and 2006 in the end of December to the end of February of, with a frequency of one time each two to three weeks. Observations along the Observation Line were carried out in the end of February in each of 2005 and 2006 in an effort to establish the depth at which depth hoar occurs or predominates. Observation values are shown in Fig1 c.

Snow temperatures were measured at Study Plot A using a thermistor sensor at a height of 0 m, 0.1 m, 0.2 m, and 0.4 m from the ground at one hour intervals. Measurements were carried out in the end of
January to the end of February of 2005 and 2006.

Data sets of air temperatures values were sourced from the Japan Meteorological Agency AMDAS (Automated Meteorological Data Acquisition System by Japan Meteorological Agency) Hakuba (703m a.s.l.) which is located 5km to the East of the study, and adjusted for study site air temperatures using lapse rate of 5.5°C/1000m. Snow depth and rainfall event data was collected from the Hakuba 47 Ski Area (1100m a.s.l.) which is situated 2km SW of the Study Area.

3. RESULT
3.1 2004 winter
Snow pit observations were carried out Dec. 17th, Jan. 10th, Jan. 18th, Feb. 8th and Feb. 28th. Weather conditions of 2004 winter, snow depth at Study Plot A, Predominant snow grain shape are shown in Fig. 2. Snow pit observation results of late December, late January, late February are shown Fig 3.

Snow depth at Study Plot A hovered around 0.3m, with the following exception.

Fig. 2 Weather conditions of the season and snow depth at the study plot: symbols show the predominant snow type in the snow-pack. □:facets and depth hoar, ●:compacted snow, ○:wet grain.

Fig. 3 Winter 2003-2004 snow profile results.
As a result of a snowfall with during SW winds (which is not the prevailing wind direction and is generally a result of passing of a low-pressure front over the Sea of Japan) in the early February, and snow depth increased temporarily. This increase in total snow pack depth was eroded immediately afterward the storm event by NW wind (which is the prevailing wind direction). A rainfall event occurred early Dec. (Dec.6th). With the exception of early February, depth hoar layers predominate in the snow pack from late December to late February.

3.2 2005 winter

Snow pit observations were carried out on Dec. 24th, Jan.18th, Jan. 24th, Feb. 7th and Feb. 27th. Weather conditions of 2005 winter and snow depth of Study Plot A and predominant snow grain shape are shown in Fig. 4 and the snow pit observation results of late December, late January, late February are shown in Fig. 5. Snow depth of Study Plot A changed at around 0.5m. From late December to late February, depth hoar layers were predominate in the snow pack. Rainfall events were seen Dec. 5th, Dec. 11th, and Feb. 16th.

The results from the Observation Line carried out late February (Feb.27th) showed that depth hoar and faceted crystals were predominant ranging from -5m (snow depth: 0.27m) to 5m (snow depth: 0.98m) from Study Plot A. Wet grains were predominant further than 15m (snow depth: 1.35m) from Study Plot A. Fig. 6 shows the results of snow temperature (day average) and temperature gradient (day average) at Study Plot A. Because snow temperature at 0cm ranges from 0 ℃ to -1.5 ℃, the surface of the ground is around the melting point and also falls slightly below freezing point. The temperature gradient changes ranges from 0 ℃/m to 35 ℃/m, and shows that there was both the time necessary to promote temperature gradient metamorphism and the time to promote an equitemperature condition. In addition, because snow temperature at each sensor reached 0 ℃, it is thought that all layers also reach 0 ℃, and that all layers got wet in just a due to the Feb.16th rainfall. We consider this is enough (moisture) to promote all layers to become wet grains.
3.3 2006 winter

The snow pit observations were carried out on Jan. 2\textsuperscript{nd}, Jan. 9\textsuperscript{th}, Jan. 21\textsuperscript{st} and Feb. 19\textsuperscript{th} of 2006. Weather conditions, snow depth of Study Plot A and predominant snow grain shape at sampling are shown in Fig. 7. Snow pit observation results of late December, early January, late January, and late February are shown in Fig. 8. Snow depth at Study Plot A changed from around 0.5m to 0.7m. In early January depth hoar layers were predominant in the snow pack and after late January wet grain layers were predominant. Rainfall events occurred Jan. 14\textsuperscript{th}, Feb. 14\textsuperscript{th} and Feb. 16\textsuperscript{th}.

Sampling on the Observation Line was carried out late February (Feb. 19\textsuperscript{th}) and wet grain predominance was identified in all at pit locations immediately adjacent (within 5m) from Study Plot A (snow depth were: 0.4m).

Fig. 9 shows the measurement results of snow temperature (day average) and a temperature gradient (day average) at Study Plot A. Because snow temperature of 0cm from the ground changes from 0 °C in a range of -1 °C, surface of the ground is around melting point and slightly fall below freezing point. Temperature gradient changes greatly in a range from 0 °C/m to 47 °C/m, and it show that there was both in the time promote temperature gradient metamorphism and the time promote equitemperature metamorphism. In addition, because snow temperature of all sensor reach 0 °C, it is thought that all layers become 0 °C, and all layers got wet by Feb. 14\textsuperscript{th} and Feb. 16\textsuperscript{th} rainfall.
4. DISCUSSION
4.1 Influence of the rainfall in the depth hoar development.

Similar approaches to distinguish areas of depth hoar predominance from areas of compacted snow predominance through analysis of meteorological condition. For example, Akitaya and Endo (1977) found that depth hoar was predominant when the mean temperature gradient (divided mean air temperature of January by mean snow depth of January) was greater than 13°C/m in Hokkaido Japan. In addition, Kawashima suggested that depth hoar was predominant when TG-index shown in equation (1) was greater than 9°C/m.

\[ TG\text{-index} = \frac{|Ta|}{Hs} \]  
(1)

Ta: Mean air temperature from the beginning of snow deposition to the day when index is calculated.
Hs: Mean snow depth during the above period.

On the other hand, a value of 10°C/m is suggested in North America by Armstrong and Armstrong1987 or McClung and Schaere1993.

Fig.10 shows TG-index in study site. The maximum TG-index is 43°C/m and minimum is 17.1°C/m. All of calculated values exceed existent critical values (9~13°C/m), but wet grains were predominant in late January (Jan.21th, TG=17.1°C/m) in late February (Feb.19th, TG=21.6°C/m) in 2006 winter. It is clear that these cause was rainfall, melt-freeze metamorphism was proceeded by all layers were wet by rainfall, and depth hoar change to wet grains. On the other hand, it had rainfall and all layers got wet in almost a day in Feb.16th 2005 winter, but depth hoar were predominant in late February. It was consider that all layers wet in almost a day enough to promote all layer become wet grain. It was regard that these wet grains were changed by 16.7°C/m average temperature gradient between from Feb.16th to Feb.19th.

Fig.11 shows results of the Observation Line in late February in 2005, 2006 and TG' (equation (2)).

\[ TG' = \frac{|Ta|}{H_{Feb}} \]  
(2)
Ta: Mean air temperature from the beginning of snow deposition to the end of the February.
H_{Feb}: Snow depth of late February when observations were carried out.

H_{Feb} is not so different from Hs, because study site is a wind eroded point and snow depth of there does not change greatly throughout the winter season (it is thought that H_{Feb} is slightly deep).

The results of 2005 winter shows that depth hoar was predominant when TG' was greater than 8.0°C/m. On the other hands the results of 2006 winter show that wet grain was predominant even if TG' =24.0°C/m. As mentioned above, it is influence by rainfall.

Rainfall has a strong influence to deter development of depth hoar, because it is not unusual for it to rain in the high winter period in maritime climate area. However, it is Even if the total snow-pack becomes saturated / become wet grains from rainfall, transformation back into depth hoar is possible. For that reasons to estimate the development of such depth hoar layer(s), one must consider the timing and frequency of rainfall events.
4.2 Snow stability of wind eroded points in maritime climate
As expressed in 4.1, wind eroded point in maritime climate, snow pack change greatly between 3 states: a melting state, a freezing state and a faceting state (Fig.12). Accordingly, snow stability will change at the same time. On the other hand, upper layers of wind eroded locations change greatly according to shifting of the wind direction, like an example of early February 2004 (fig.13). The combinations of these two effects determine the snow stability in that site.

5. CONCLUSION
Rainfall has a strong influence on the deterrence of development of depth hoar in wind eroded points of the snowpack in maritime climates, but even if the total snowpack has once become has saturated / become wet grains as a result of rainfall, transformation back into depth hoar is possible. Therefore, to estimate the development of such depth hoar layer(s), one must consider the timing and frequency of rainfall events. In addition, mechanical strength of snow pack will change greatly when bottom layer state is changed (melting state, freezing state and faceting state), and it is bring to change snow stability greatly. From now it should be a concern of forecasters and others to work to devise a method to estimate snow pack condition which takes into consideration these factors in determining the mechanical strength of the snow pack.

References


