SEASONAL CHANGE IN CONDITIONS FOR OCCURRENCE OF WET SNOW AVALANCHES IN HOKKAIDO

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ABSTRACT: To clarify the meteorological conditions for occurrence of wet snow avalanches in Hokkaido, located in the northern part of Japan, data analysis have been carried out using wet snow avalanche examples occurred on roadside slopes in the past 11 years. The 100 wet snow avalanche cases, including of 53 full-depth avalanches and 47 surface avalanches, were used in this study. The hourly observation data of precipitation, air temperature and snow depth were obtained from the nearest observational station at avalanche site. The results revealed that the conditions supporting wet snow avalanches varied by periods of earlier and later winter seasons. In January, air temperature is commonly subfreezing and snow depth is not yet its maximum, wet snow avalanche tends to be accompanied with rainfall but increase in air temperature was not remarkable. In March, snowpack will start to be melted, most of wet snow avalanches were associated with the increasing air temperature above 0°C and occurred as full-depth avalanches. In February, commonly the minimum of air temperature and the maximum of snow depth in the winter, wet snow avalanches occurred due to the influences of both the rainfall and temperature rise.

1. INTRODUCTION

Wet snow avalanches occur mainly when snow on slope becomes unstable due to snow strength reductions caused by the presence of water from rainfall and thawing and/or increased vertical loads caused by weight of rainfall amount (McClung and Schaerer, 2006; Tremper, 2008; Jones, 2004). The occurrence of such avalanches also depends on the morphological snow grain shape and the layer structure of snow cover in relation to effects on the water infiltration process and associated in metamorphism of snow (Conway and Raymond, 1993; Tremper, 2008; Conway et al., 2009).

The ability to describe the conditions for wet snow avalanches involving these complex processes using readily available meteorological data to distinguish those caused by rainfall from those related to air temperature is considered highly useful in avalanche prediction. For example, studies have been conducted to identify meteorological and snow factors strongly related to the occurrence of wet snow avalanches through statistical analysis (e.g., Baggi and Schweizer, 2009; Peitzsch et al., 2012). However, as the causes and forms of avalanches are affected by regional climatic characteristics (e.g., Jones, 2004), it is necessary to consider the local characteristics of wet snow avalanches when evaluating their occurrence using meteorological data.

Accordingly, the authors conducted studies to clarify meteorological conditions supporting the occurrence of wet snow avalanches in Japan and to enable the use of such data in avalanche risk evaluation. In this paper, simple analysis using meteorological data was conducted to find the characteristics of meteorological conditions when wet snow avalanches occurred in the Hokkaido region of Japan.

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2. DATA and METHOD

2.1 *Target area*

As shown in Fig. 1, the target area of this study was Hokkaido, northernmost island in Japan. Figures 2 and 3 show seasonal changes in the snow depth and air temperature in Shumarinai and Kucchan, which are heavy snowfall areas in the region. The snow depths peak in February and March at over 200 cm, and the mean air temperature drops to below 0°C between December and March.

2.2 <u>Data</u>

Avalanche cases studied in this research are those occurring in the past 11 years (November 2000 - April

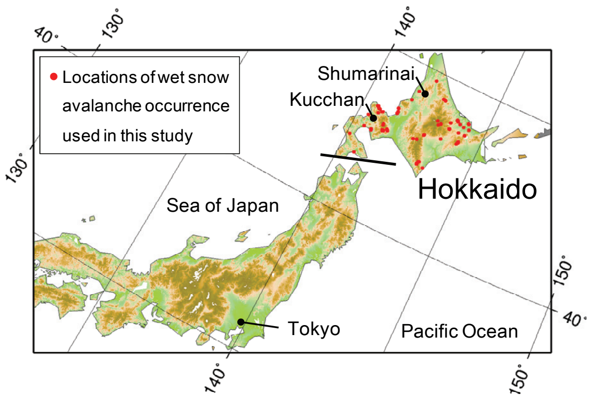

Figure 1: Distribution of wet snow avalanche occurrence in Hokkaido for the past 11 years (November 2000 – April 2011) used in this study.

2011) on national highways under the management ofthe Hokkaido Regional Development Bureau. Wet snow avalanches for which the distinction between surface and full-depth types was recorded were selected and were used in following analysis (Fig. 1).

To examine the characteristics of the meteorological conditions seen upon the occurrence of wet snow avalanches, meteorological data from the observation stations closest to the selected avalanche locations were used. Hourly observation data for precipitation, air temperature and snow depth were obtained from the telemetering equipment for road maintenance of the Hokkaido Regional Development Bureau and the Automated Meteorological Data Acquisition System (AMeDAS) of the Japan Meteorological Agency.

Meteorological conditions may not be represented well for avalanches occurring far from observation stations. Accordingly, this study focused on cases in which the horizontal distance and elevation difference between avalanche locations and observation stations were within 20 km and 200 m, respectively.

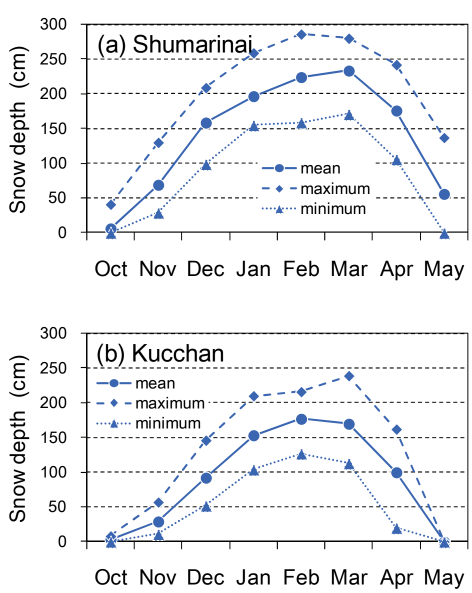

Figure 2: Seasonal variation of snow depth in (a) Shumarinai and (b) Kucchan. Solid, broken and dotted lines indicate the mean, maximum and minimum of monthly maximum snow depth for the past 11 years (October 2000 – May 2011), respectively.

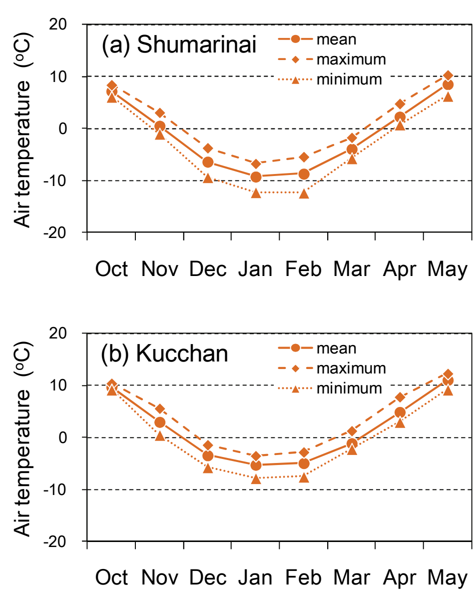

Figure 3: Seasonal variation of air temperature in (a) Shumarinai and (b) Kucchan. Solid, broken and dotted lines indicate the mean, maximum and minimum of daily mean air temperature for the past 11 years (October 2000 – May 2011), respectively.

2.3 *Method*

From the metrological data collected in Section 2.2, precipitation and the cumulative air temperature above 0°C seen before the occurrence of wet snow avalanches were obtained. As a meteorological condition for the occurrence of wet snow avalanches, it was assumed that precipitation amounts were related to avalanches caused by rainfall and that cumulative air temperatures were related to avalanches caused by continued high-temperature conditions.

As wet snow avalanches caused by rain tend to occur within 24 hours of the onset of rainfall (Conway and Raymond, 1993; Clarke and McClung, 1999), cumulative precipitation values for the 24-hour period before avalanche occurrence were found in this study. As wet snow avalanches caused by high air temperatures are affected by such conditions for several days before their occurrence (Baggi and Schweizer, 2009; Peitzsch et al., 2012), cumulative air temperature values were calculated by sum of hourly air temperature above 0°C for the 24-hour, 48-hour and 7-day periods beforehand.

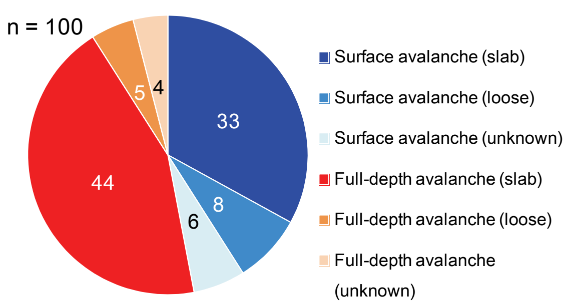

Figure 4: Ratio of types of wet snow avalanche.

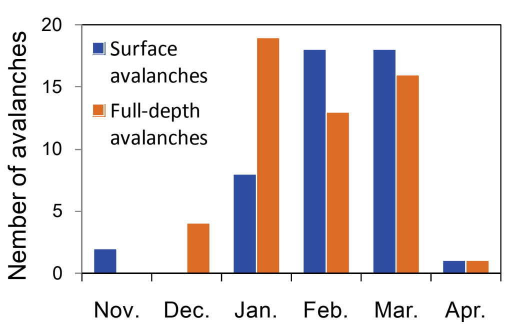

Figure 5: Monthly numbers of wet snow avalanche occurrence in Hokkaido for the past 11 years.

In addition, the characteristics of the meteorological conditions upon avalanche occurrence were also examined to be related with snow depths at times of avalanche occurrences.

3. RESULTS

3.1 *Tendency of wet snow avalanche occurrence*

Among 100 cases of wet snow avalanches selected as described in Section 2.2, 47 were surface wet snow avalanches and 53 were full-depth wet snow avalanches (Fig. 4). Most were slab avalanches, while eight of the surface ones and five of the full-depth ones were loose-snow avalanches.

Figure 5 shows the monthly number of wet snow avalanches observed in this study. The number of surface avalanches was large in February and March, and the number of full-depth avalanches was large in January and March.

3.2 *Characteristics of meteorological conditions upon wet snow avalanche occurrence by month*

Figure 6 shows the relationship between precipitation and cumulative air temperature values in the 24-hour period before avalanches by month. In January (Fig. 6a), the precipitation was observed in many cases, although the cumulative air temperature were 20°C or lower. Conversely, many avalanches in March (Fig. 6c) occurred when the d cumulative air temperature was higher than in January and the precipitation was 10 mm or less. It can be said that wet snow avalanches in January were caused mainly by rainfall and those in March were caused mainly by air temperatures above 0°C. Avalanches in February (Fig. 6b) are considered to have been affected both by rainfall and by air temperature. In February, surface avalanches tended to occur especially when precipitation was observed, and full-depth avalanches tended to occur when the cumulative air temperature was high.

3.3 *Characteristics of precipitation and snow depth upon wet snow avalanche occurrence*

To clarify the characteristics of the snow depth seen

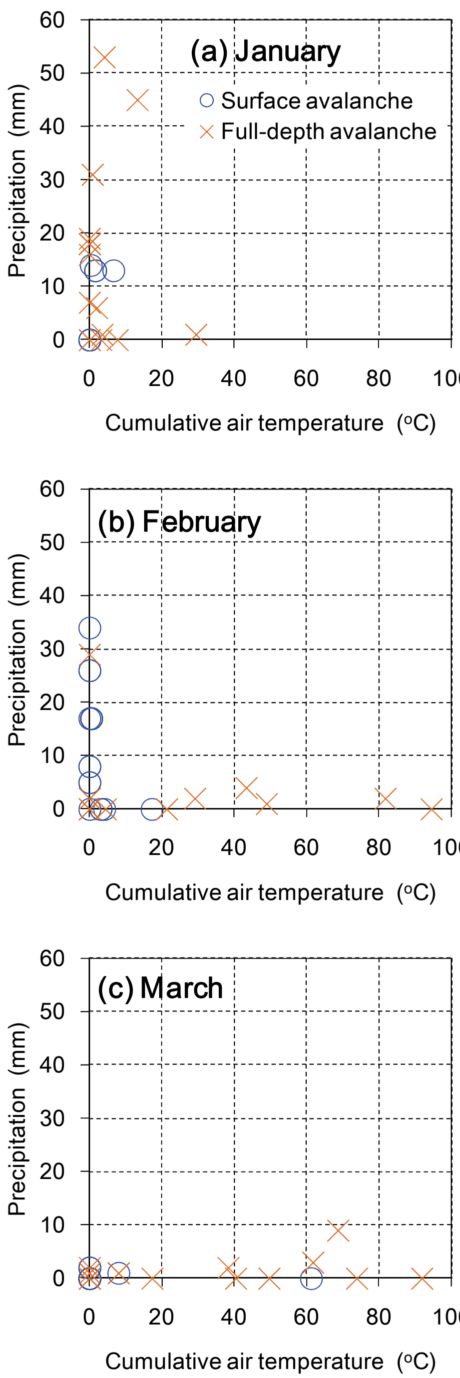

Figure 6: Relationship between precipitation and cumulative air temperature in the 24-hour period before avalanches in (a) January, (b) February and (c) March. Cumulative air temperature were calculated by sum of hourly air temperature above 0°C. Circle and cross indicate surface and full-depth avalanches, respectively.

upon wet snow avalanche occurrence when precipitation was observed, Figure 7 shows the relationship between snow depths seen at the times of avalanche occurrences and precipitation amounts in the 24-hour period before the occurrence in January and February. In February (Fig. 7b), only surface avalanches occurred when the snow depth was 150 cm or more, and full-depth avalanches mainly occurred when the snow depth was less than this. However, no characteristics dividing surface and full-depth avalanches as observed in February were seen for January (Fig. 7a).

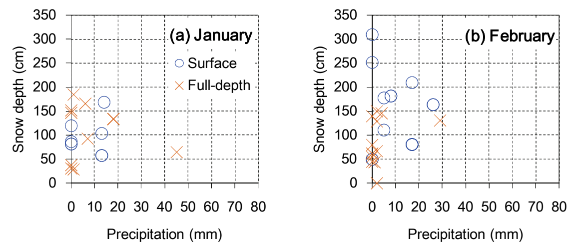

Figure 7: Relationship between snow depth at time of avalanche occurrence and precipitation in the 24-hour period before avalanches in (a) January and (b) February.

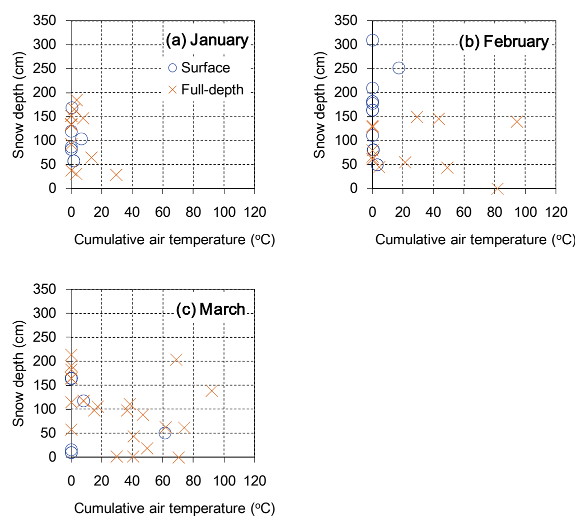

Figure 8: Relationship between snow depth at time of avalanche occurrence and cumulative air temperature in the 24-hour period before avalanches in (a) January, (b) February and (c) March.

3.4 *Characteristics of cumulative air temperature and snow depth upon wet snow avalanche occurrence*

Figure 8 shows the relationship between cumulative air temperatures in the 24-hour period before and snow depths seen at the times of avalanches. Only full-depth avalanches occurred when the cumulative air temperature exceeded 20°C except for one case in March. Snow depths in cases where cumulative air temperatures were 20°C or higher and full-depth avalanches occurred were 50 cm or less in January and 150 cm or less in February. In March, full-depth avalanches occurred even when snow depths exceeded 200 cm.

Figure 9 shows the relationship between cumulative air temperatures in the 24- and 48-hour periods before and that between cumulative air temperatures in the 48-hour and 7-day periods before avalanches. In February (Figs. 9a, b), there was no significant difference between cumulative air temperatures in the 24-hour period before and that in the 48-hour or 7-day periods before avalanches. It is therefore presumed that the air temperature rose above 0°C within the 24-hour period before the occurrence of wet snow avalanches. However, in March (Figs. 9c, d), there were cases in which cumulative air temperatures in

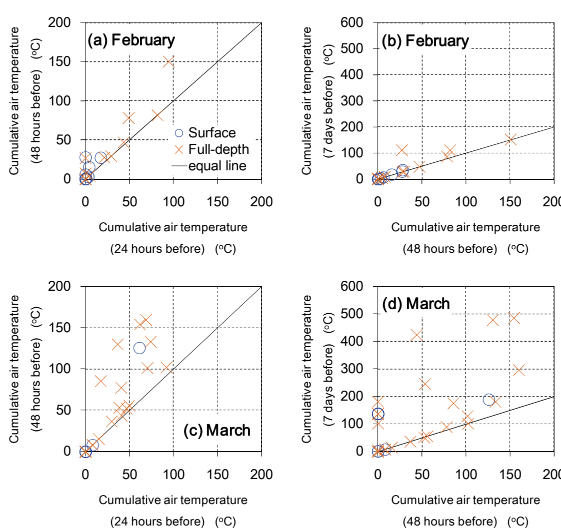

Figure 9: Relationship between cumulative air temperatures in the 24- and 48- hour periods before avalanches and that between cumulative air temperatures in 48-hour and 7-day periods before avalanches in February (a, b) and March (c, d).

the 48-hour and 7-day periods before were higher than that in the 24-hour period before avalanches. It was therefore a characteristic of meteorological conditions in March that wet snow avalanches sometimes occurred after air temperatures remained above 0°C for several days.

4. DISCUSSION

Meteorological conditions supporting the occurrence of wet snow avalanches in Hokkaido were found to differ by month between January and March. Such avalanches were caused by rainfall especially frequently in January and February, but were more likely to occur due to high temperatures in the snow melting season of March. In the following section, monthly differences in meteorological characteristics seen upon wet snow avalanche occurrence are discussed.

4.1 *Wet snow avalanches associated with rainfall*

Figures 6a and 6b show that many wet snow avalanches were caused by rainfall in January and February. According to Conway and Raymond (1993), if rain falls on new snow with a medium grain size and very low hardness, avalanches often occur immediately after the onset of rainfall. In addition, Clarke and McClung (1999) indicated also that wet snow avalanches happen suddenly due to rainfall especially in the cold season. In Hokkaido, snow cover is usually sub-zero in temperature (as shown in Figs. 2 and 3) and dry in January and February. It was assumed that wet snow avalanches occurred even with relatively small amounts of rain, as rainwater infiltrates such snow.

Rainfall tended to cause full-depth avalanches in January and surface avalanches in February (Figs. 6a and 6b). In February, snow depth is at its deepest in many parts of Hokkaido, and diverse layers (e.g., coarse-grained granular snow, ice layers) are known to form within snow cover. It was therefore presumed that rainwater accumulates at the boundary of snow layers with different grain sizes or on ice layers before infiltrating the ground, causing surface avalanches in February (Conway and Raymond, 1993; Tremper, 2008).

In March, precipitation amounts seen upon the occurrence of wet snow avalanches were 10 mm or less (Fig. 6c). In Hokkaido, snow in March has a high content of coarse-grained granular snow, and rain falling on such snow with large particles infiltrates relatively quickly and flows through it (Tremper, 2008; Conway et al., 2009). This was thought to be the reason for the low number of wet snow avalanches caused by rainfall during this month.

4.2 *Wet snow avalanches caused by high air temperatures*

Full-depth avalanches occurring when the air temperature was high (i.e., cumulative air temperature was 0°C or more) were observed in February and March. Baggi and Schweizer (2009) reported that the first few days of the isothermal state when the snow temperature is 0°C carry the highest risk of wet snow avalanche, and that a rapid increase in temperature or the presence of a liquid water can trigger wet snow avalanches if snow cover is already in an isothermal state of 0°C. Based on Figs. 9a and 9b, it was presumed that wet snow avalanches in February were affected by temperature rises in the 24-hour period before their occurrence. Those in February therefore probably occurred when an isothermal state of 0°C was reached for the first time in snow cover. Conversely, above-zero temperatures continued for several days before wet snow avalanches in March (Figs. 9c, d). It was therefore assumed that an isothermal state of 0°C had already been reached and sufficient accumulation of snowmelt water on the bottom of the snow cover caused full-depth avalanches.

5. CONCLUSION

The characteristics of meteorological conditions upon the occurrence of wet snow avalanches were examined using meteorological data related to wet snow avalanches in Hokkaido region, Japan. The results indicated that conditions supporting wet snow avalanches varied by month. It was found that full-depth avalanches were often caused by rainfall in January, and tended to occur due to continued high temperatures in March. In February, wet snow avalanches occurred due to the influences of rainfall and temperature rise. More surface avalanches tended to occur when snow was deeper, and more full-depth avalanches occurred when it was shallower.

The authors plan further studies incorporating consideration of snow grain type and other snow conditions. In order to provide additional data for future analysis, research is also planned to enable the evaluation of snow dryness or wetness based on meteorological data for cases in which it is unclear whether avalanches were dry or wet.

6. REFERENCES

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