FIRST ATTEMPT AT PREDICTION OF AVALANCHES RESULTING FROM NO RIMED FALLING SNOW CRYSTALS IN JAPAN

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ABSTRACT: Predicting avalanches resulting from the fall of unrimed snow crystals is key to mitigating the impacts of avalanche accidents in Japan. However, we do not yet have a sufficient understanding of this type of avalanche. Based on previous studies that assert that the fall of unrimed snow crystals occasionally form at the front of a low-pressure system (cyclone), we attempted to predict unrimed snow crystal avalanches using meteorological conditions. Three meteorological elements, precipitation amount, air temperature, and wind direction, were simulated in this study using a numerical meteorological forecasting model. Using simulated air temperatures and precipitation amounts, the system forecasts the snowfall while classifying whether the simulated synoptic precipitation conditions represent cyclones using the simulated wind direction. By setting up an appropriate threshold for these meteorological elements, the system could successfully predict previous avalanches resulting from the fall of unrimed snow crystal resulting from cyclones. This prediction system is capable of impacts of these types of avalanches in Japan.

KEYWORDS: unrimed snow crystal avalanche, avalanche forecasting, fall of unrimed snow crystal, low-pressure systems (cyclone)

1. INTRODUCTION

In the recent years, many serious accidents involving avalanches induced by the fall of unrimed snow crystals have occurred in Japan. For example, eight people, including seven high school students, were killed in an avalanche during an extracurricular outing in March 2017. In January 2015, several avalanches occurred simultaneously and killed four backcountry skiers. Moreover, hundreds of avalanches occurred simultaneously in the Kanto region in February 2014, an area that typically receives limited snow fall during the winter. Many villages, with a total of more than nine-thousand residents, were cut off from roads and service due to avalanche risk.

The prediction of avalanches resulting from the fall of unrimed snow crystals is key to mitigating the impacts of avalanche accidents. However, we do not yet have a sufficient understanding of this type of avalanche. In fact, the difficulties associated with avalanche prediction using snow-cover models (e.g., SNOWPACK) can be attributed to the lack of knowledge regarding the physical properties of snow consisting of the fall of unrimed snow crystals, such as density and strength.

Kamiishi et al. (2016) observed that the repose angles with the unrimed snow crystals resulting from the low-pressure system (cyclone) were 35 - 45° in a temperature of -5 °C. These values are smaller than those of rich rimed snow crystals (> 90°) (Narita and Takeuchi, 2009). Therefore, the unrimed snow crystals are easily broken because of the crystal form that gives them of small repose angle.

In this study, we report our first attempt at farecasting avalanches resulting from the fall of unrimed snow crystals using characteristic meteorological conditions.

2. THE CHARACTERISTICS METEOROLOGICAL CONDITIONS THAT PRODUCE A WEAK LAYER DUE TO THE FALL OF UNRIMED SNOW CRYSTALS

Colle et al. (2014) reported the consistent spatial patterns of habit and riming intensity relative to the cyclone structure at Stony Brook, New York. In Japan, Nakamura et al. (2013) and Akitaya and Nakamura (2013) analyzed three cases of avalanche accidents in Japan caused by weak layers of the fall of unrimed snow crystals. According to the results of their studies, which utilized meteorological conditions, unrimed snow crystal fell at the warm front of the

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cyclone and subsequently led to avalanches. These previous studies corroborate each other.

To investigate the detailed characteristics of meteorological conditions that produce a weak layer due to the fall of unrimed snow crystals, we analyzed six avalanche cases that represent this scenario based on the simulation results from a Mesoscale numerical weather prediction model (Meso Scale Model: MSM) (Saito et al., 2006; Saito, 2012) developed by the Japan Meteorological Agency. Figure 1 shows an example of the simulation results, which was a surface avalanche that occurred at 07:00 on Feb. 9, 2014, on the National Route 112 in Nishikawa, Yamagata Prefecture. During the period between the start of the snowfall and the avalanche occurrence (SA period), the zone of high relative humidity (> 80 %) reached the area with a height above 500 hPa. This simulation indicates the presence of thick clouds that resulted from the passage of the warm front and the approach of cyclone; the falling snow crystals that caused the weak layer were produced by these clouds. The wind direction in the lower area (< 850 hPa height) had an eastward component. These characteristics are common across all cases. Therefore, we classified a falling snow event with an eastward component in the area of lower altitude (< 850 hPa height) as a cyclone type.

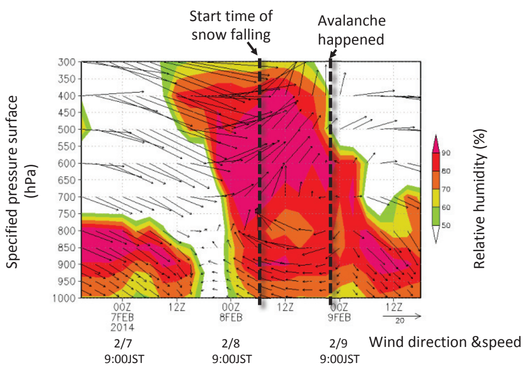

Fig. 1 Simulation result of the avalanche in Nishikawa, Yamagata Prefecture on Feb. 9, 2014, using MSM.

We analyzed other meteorological elements (e.g., air temperature and precipitation amount) and obtained the following conditions that represent the common characteristics found across six avalanche cases.

1) A maximum air temperature during the SA period lower than 0 °C.

2) A precipitation total during the SA period larger than 20.0 mm.

3) A snow height increase during the SA period larger than 28 cm.

4) Wind direction in the lower area (< 850 hPa height) with an eastward component.

5) All avalanches occurred during the fall of unrimed snow crystals that resulted from the cyclones, or just after the snowfall had stopped.

3. THE DEVELOPMENT OF A FERECSTING SYSTEM FOR AVALANCHES CAUSED BY THE FALL OF UNRIMED SNOW CRYSTAL DUE TO CYCLONES

Based on the analyses conducted in Section 2, we developed a forecasting system for avalanches caused by the fall of unrimed snow crystals due to cyclones (Fig. 2). The detailed description is as follows:

1） Temperature and precipitation conditions

Although all avalanches occurred at a temperature lower than 0 °C, we adopted the threshold of 2 °C for the ground temperature based on the consideration of the designing a system that could account for intrinsic uncertainly of weather forecast information obtained from numerical models. We also consider any precipitation under 2 °C to be falling snow.

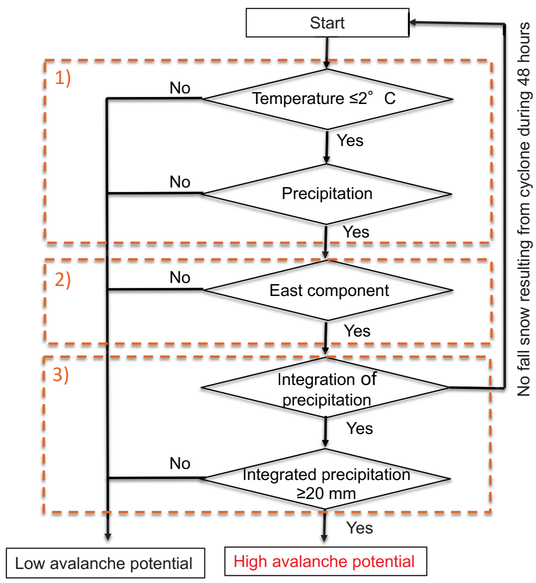

Fig. 2 Flowchart of the forecasting system for avalanches resulting from the fall of unrimed snow crystal due to cyclones.

2) Abstraction of the precipitation events resulting from cyclones

We considered any precipitation events possessing wind on eastward component direction in the lower area (< 850 hPa height) as a precipitation event resulting from a cyclone.

3) Calculation of integrated precipitation amount

When weather forecast information showed precipitation of more than 0.1 mm in 1 h, we integrated the precipitation amount. Moreover, if the precipitation resulting from a cyclone did not occur within 48 hours, we reset the integrated precipitation to 0 mm.

Finally, we classified the avalanche potential into three categories based on the above process.

a) High avalanche potential

An integrated precipitation amount of more than 20 mm due to snow fall resulting from a cyclone.

b) Relatively high avalanche potential

An integrated precipitation amount of more than 10 mm due to snow fall resulting from a cyclone.

c) Low avalanche potential

An integrated precipitation amount of less than 5 mm due to snow fall resulting from a cyclone.

4. PERFORMANCE TESTS OF THE DEVELOPED SYSTEM

We tested our system using six cases of avalanches resulting from the fall of unrimed snow crystals during cyclones. In the test, successive meteorological data consisting of predictions 3 hours ahead of the event using the MSM model, were used for input.

Figure 3 shows an example from simulation; the surface avalanche that occurred at 07:00 on Feb. 9, 2014, on the National Route 112 in Nishikawa, Yamagata Prefecture. In the figure, an orange alert showing a relatively high avalanche potential appeared at 19:00 on Feb. 8, and then, a red alert showing high avalanche potential appeared at 09:00 on Feb. 9. The actual avalanche occurred at 07:00 on Feb. 9. Therefore, the high avalanche potential warming in our system occurred two hours after the actual avalanche. To investigate the cause of this delay, we checked the integrated precipitation amount at 07:00, 08:00, and 09:00. Each value shows almost the same value of thread (20.0 mm): 19.69 mm at 7:00, 19.97 mm at 8:00, and 20.08 mm at 9:00. Therefore, we should adopt a little bit smaller value to the threshold for the alert with the consideration of intrinsic uncertainly of weather forecast information.

The results of the other five case studies results indicated that our system could effectively signal high avalanche potential before, or the

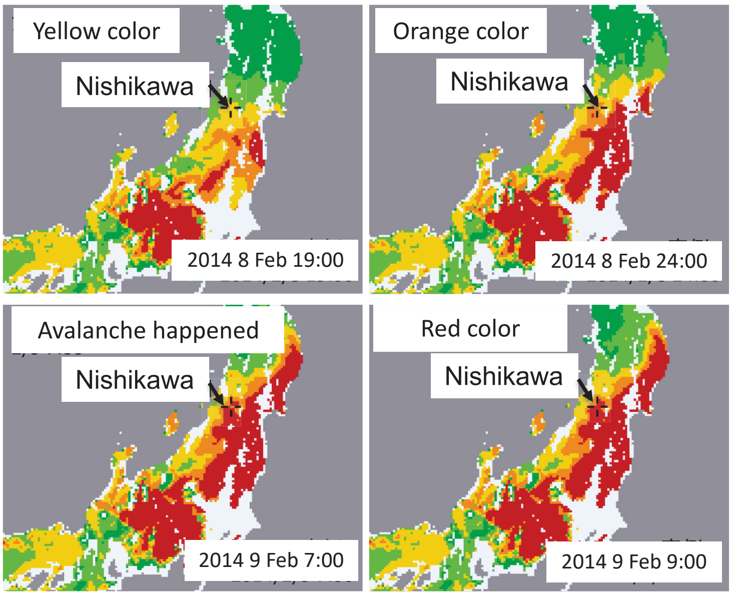

Fig. 3 Simulation result of the avalanche potential at Nishikawa, Yamagata Prefecture with input data using the MSM (Feb. 8 to Feb. 9, 2014).

same time of, the actual occurrence. Using these results, we concluded that our system can provide useful information for the forecasting of avalanches resulting from the fall of unrimed snow crystal due to cyclones. However, better thread values are needed to improve the efficacy of the system.

5. SUMMARY

Although avalanches resulting from the fall of unrimed snow crystals are a critical problem in Japan, we do not yet have a sufficient understanding of them. To forecast this type of avalanche, we analyzed the characteristics of meteorological conditions that produce a weak layer resulting from the fall of unrimed snow crystals. Based on these analyses, we developed a system for farecasting unrimed snow crystal avalanches due to cyclones. The strong results of the performance tests using six cases of the same type of avalanche indicated that our system has the potential to provide useful information for the mitigation of avalanches resulting from the fall of unrimed snow crystals due to cyclones.

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