

STUDIES ON THE SNOW AVALANCHE DYNAMICS BY THE FULL-SCALE EXPERIMENTS

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ABSTRACT: Systematic full-scale but small avalanche experiments have been started since 2016 in Niseko, a ski resort in Hokkaido, Japan. Although the vertical drop in the test sites are 100 to 200 m, they have advantages that we are able to access relatively easy and can expect both dry avalanches in February and wet ones in March. On top of that, it has a potential that we can look at the phenomena closer and investigate the detailed structures and mechanism of avalanches.

Although the artificial releases and measurements were not always successful so far, data for three wet snow avalanches were obtained and they revealed that the combination of different data is effective measures to characterize their structures.

KEYWORDS: Small full-scale snow avalanche experiment, Drone, Inertial Measurements Units (IMU)

1. INTRODUCTION

Numerous experiments have been carried out in order to investigate the dynamics and the structures of large snow avalanches for a long period, such as, at the Vallee de la Sionne in Switzerland, Lautaret pass in France, and Ryggfonn in Norway (Sovilla et al., 2018, Gauer et al., 2016, Thibert et al., 2015). Similar trial was also conducted in the Shiai-dani, Kurobe Canyon in Japan and the outcome contributed to increase our knowledge (Nishimura and Ito, 1997). However, the scale of the avalanches which broke out and caused the disasters in Japan were, in usual, much less. Thus, the data sets for such small scale avalanches are of importance for the avalanche risk management, for instance, validation of dynamical models, hazard mapping, a proper design of structural protections and development of early warning systems.

Based on these background, we have started systematic full-scale but small avalanche experiments since 2016 in Niseko, a ski resort in Hokkaido, Japan in order to deepen our understanding of the snow avalanches.

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In advance of the project, we organized "International Symposium on snow and avalanche in Niseko" on December 9 to 12, 2015. Following the public symposium on the first day (Figure 1), workshops on "Micro-structures of snow" and "Avalanche dynamics" were held for three days. Not only ten participants from abroad but more than fifty Japanese, who are working at glaciology, meteorology, volcanology, seismology and mathematical science, came together and active discussions were conducted.



Figure 1: "International Symposium on snow and avalanche in Niseko" on December, 2015.

Although the measurements for last three winters were not always successful, data for three wet snow avalanches were acquired and they revealed that the combination of different data is effective measures to characterize their structures.

2. MEASUREMENTS

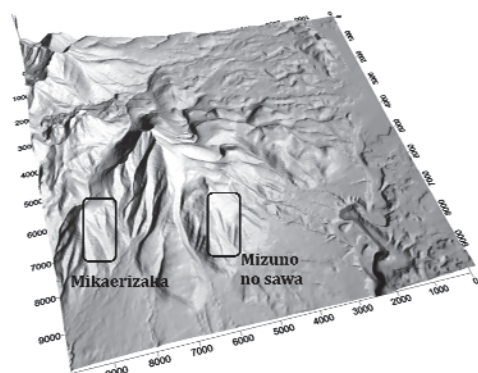
2.1 Observation site

Large amount of dry snow accumulates in Niseko in winter. Although the altitude of the resort's summit (Mt. Annupuri) is only about 1300 m a. s. l., the snow in the area is completely dry in winter and, thus, it is quite popular among skiers and snow boarders from not only Japan but also foreign countries. In fact, several snow avalanche disasters occurred in the past (Nishimura et al., 2005).

Our observation sites of "Mikaerizaka" and "Mizuno-no-sawa" are shown in Figure 2. Although the vertical drops of the both test sites are less than 300 m, they have advantages that we are able to access relatively easy and can expect both dry avalanches in February and wet ones in March. On top of that, it has a potential that we can look at the phenomena closer and investigate the detailed structures and mechanism of avalanches.

Avalanches at Mikaerizaka were triggered with the snowcat. On the other hand, at Mizuno-no-sawa, avalanches were released by the explosives.

Figure 2: Two snow avalanche observation sites in



Niseko

2.2 Instruments

Drones are used to record the entire avalanche behavior, map the avalanche path and produce precise digital elevation models (DEM) before and after an avalanche event. From the difference of two DEMs, the spatial distributions of erosion and deposition are extracted.

Seismic and infrasound sensors are installed near the avalanche path to record the ground and air vibrations generated by snow avalanches. They can be useful to monitor the spontaneous avalanche release as well as the artificially triggered ones. Obtained recordings will be useful to elucidate the internal structures of the avalanches and be helpful to understand the probability of avalanche release under different topographic and weather conditions.

Temperature of the avalanche flow was recorded continuously with the Infrared thermography camera. It may give us the information of heat production in the flow and the entrainment of snowpack with low/high temperature profile along the truck.

Further, in this research, we introduced IMU (Inertial Measurement Unit) shown in Figure 3. This unit records accelerations, magnetic field of the Earth, and angular velocities with high sampling frequency of 1000 Hz. A Global Positioning System (GPS) is also integrated and records the position. Thus, when the sensor was thrown into the avalanche, we can expect to reveal the flow behavior inside the avalanche.



Figure 3: IMU (inertial measurement unit) unit that can sense accelerations, magnetic field of the Earth, and angular velocities. (48mm x 85mm x 15 mm)

Pulsed Doppler radar was also prepared in 2017/2018 winter. It measures the velocity distribution inside the avalanche (which is highly characteristic of its internal dynamics) in different range gates as well as the position and speed of the avalanche front.

Schematic picture of the measurement system can be found in Figure 3.

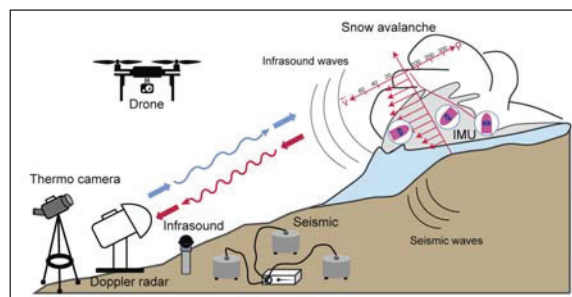


Figure 3: Schematic picture of the full-scale experiments conducted at Mt. Niseko Annupuri. Seismic and infrasound sensors are used to record the waves generated by snow avalanches. The Doppler radar measures the avalanche velocity and position. The drone and the thermal camera record the whole avalanche motion. IMU sensors travel inside the avalanche to track their inner position, rotation and acceleration.

In addition to the sensors introduced above, one 1.5 m high measuring structure was installed on the avalanche path as shown in Figure 4. Here, video camera, several impact pressure sensors and optical sensors to acquire

the velocity profile were equipped.

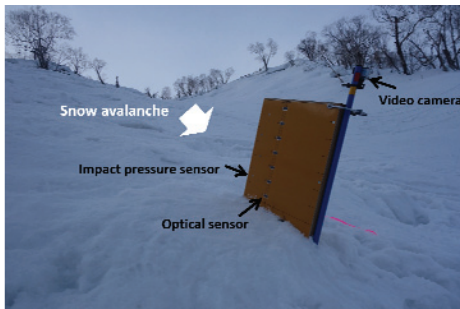


Figure 4: Measuring structure of 1.5 m high. A video camera, several impact pressure sensors and optical sensors were equipped.

3. RESULTS

3.1 *Snow avalanche on March 28, 2016*

One wet snow avalanche was released by the explosion at Mizuno-no-sawa on March 28, 2016.

Figure 5 displays the picture of the avalanche taken by the drone (top right), and the front positions are indicated every one second (top left). It ran down nearly for 200 m distance at the maximum speed of 14 m/s. Since this was the first trail no other measurements were carried out.

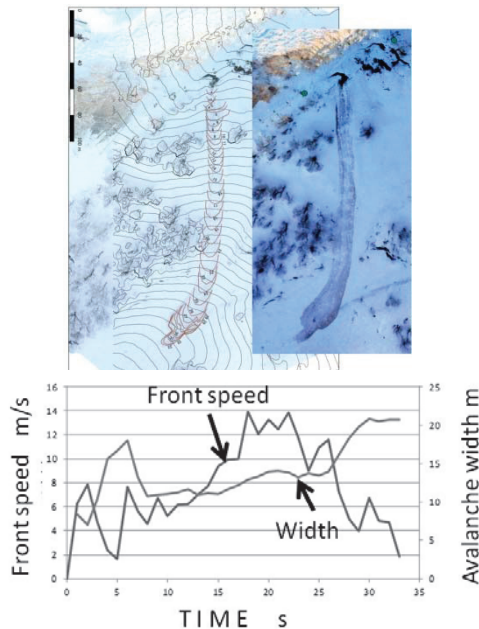


Figure 5: Wet snow avalanche released at Mizuno-no-sawa on March 28, 2016. Top: Entire flow by drone and front position every one second. Bottom: Estimated front speed and width.

3.2 *Snow avalanche on March 25, 2017*

On March 25, 2017, artificial release with the

explosion at the Mizuno-no-sawa was conducted at the same position in 2016 and again one wet snow avalanches flew down along the same track. Observations with the IMU unit, one set of seismic and infrasound sensor, one infrared camera and video recordings including drone were carried out.

This experiment proved the feasibility of IMU sensor as a tracer of the avalanche internal flow. Specifically, GPS tracking (Figure 6) worked well when the sensor traveled on the avalanche surface. Maximum values of the internal velocities estimated with GPS data were around 10 m/s and the accelerations were in the order of 20 m/s^2 . These are in accordance with the velocities deduced from the drone images. The accelerometer, magnetometer and gyroscope are supposed to illustrate the orientation of the sensor and thus, the internal acceleration, velocity and position of each sensor. However, they were very sensitive to impacts and vibrations. More data processing including the noise reduction with the filtering is needed to obtain more accurate results. Calibration of IMU sensors with the shaking table was also carried out and analysis are under way.

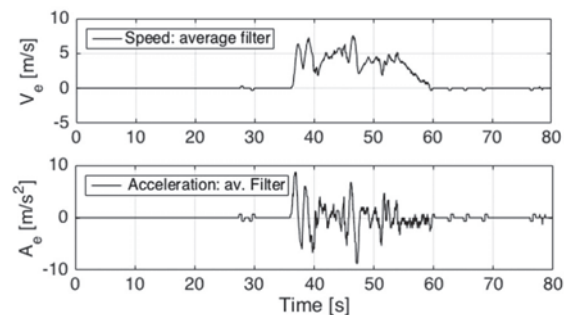


Figure 6: Internal snow avalanche speed and accelerations obtained with a IMU sensor.

Figure 7 shows the recording of the seismic and the infrasound data. Amplitudes of the former decreased with time as the avalanche is moving away from the sensor. On the other hand, amplitudes of the latter were in the order of the background noise. Thus, it looks infrasound sensor is not adequate to detect small and wet avalanche. The seismic sensor, however, recorded the entire avalanche motion with the maximum amplitudes of 10^{-6} m/s which corresponds to the order of small avalanches in general (Pérez-Guillén et al., 2016).

3.3 *Snow avalanche on March, 2018*

Three sets of seismic sensors and infrasound sensors are equipped from February to March. In particular, for the experiment on March 23, 2018, five IMU units, one infrared camera, and

three drones were prepared. Further, as stated before, one Doppler radar was newly introduced and a construction on which a video camera, impact presser sensors and the optical sensors were installed was set on the avalanche track. However, the explosion in the late afternoon did not succeed to release the avalanches.

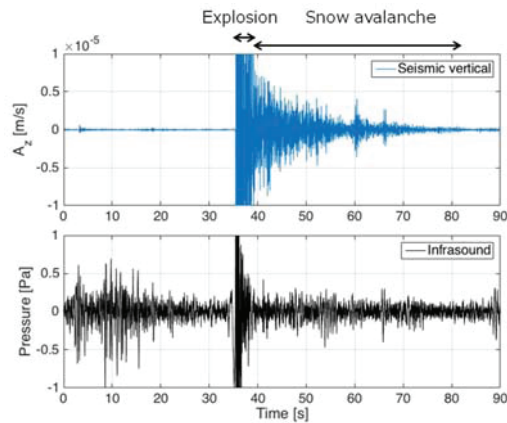


Figure 7: Recording of seismic and infrasound data on March 25, 2017.

On the other hand, a medium size wet-snow avalanche was spontaneously released on March 24, 2018 very close to the explosion point on March 23 and it ran down along the path. Pictures taken before and after the avalanche release by the drone allow us to derive the erosion and deposition map as shown in Figure 8.

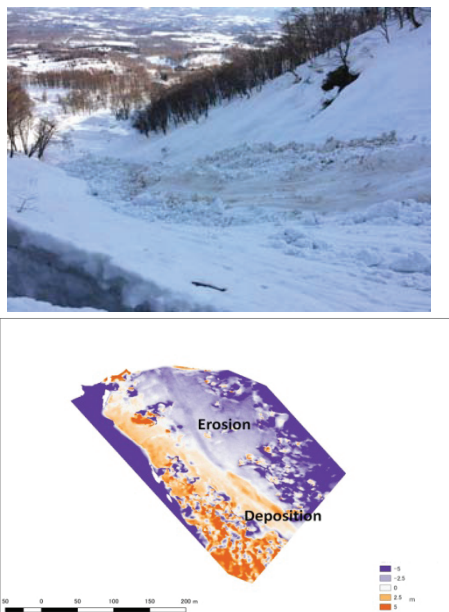


Figure 8: Wet snow avalanche on March 24, 2018. Upper: picture taken just after the release, Lower: erosion and deposition map obtained with drone pictures taken before and after the incident

OUTLOOK

As is stated above, the measurements for last three winters were not always successful. However, the data obtained so far were quite useful to develop our understanding of the small-scale avalanches. In particular, the erosion and deposition map in Figure 8 will be valuable to construct and evaluate the avalanche kinetic model. Further, it is attested that IMU sensor can be a strong tool to reveal the internal structures. This project keeps going on 2018/2019 winter as well.

In addition, "2nd International Symposium on snow and avalanche in Niseko" is also planned in December, 2018. We hope that it will bear fruitful results owing to your cooperation.

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