# SNOW CORNICE DISTRIBUTION OBTAINED BY AIRBORNE LASER SCANNING

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ABSTRACT: Airborne laser scanning was carried out on Mt. Niseko-Annupuri in Hokkaido, Japan, during the winter season to obtain detailed snow cover distributions, including snow cornices and snow-drifts. Close observation of the snow cornice distribution revealed that there were two distinct areas on a continuous ridge where snow cornices were developed and non-developed. In order to understand the differences in snow cornice development, the topographic conditions near the ridges were analysed. The results showed that the slope angle was higher on the windward side of the ridge where snow cornices were not developed. This suggests that the wind flow may change in a way that makes it difficult for snow cornices to develop.

KEYWORDS: Snow cornice, Airborne laser scanning, Distribution

## 1. INTRODUCTION

In mountainous terrain, winds are accelerated or decelerated by topographical changes. Where winds accelerate, the accumulated snow is blown away, whereas where winds decelerate, the blown snow deposits and the snow depth increases. This is particularly noticeable around ridges, where it appears as snow cornices on ridges and snowdrifts on leeward slopes. Snow cornices are sometimes unstable and can collapse, leading to the formation of avalanches.

It is considered that snow cornices develop where change in slope angle is sharp (McLung and Schaerer, 2022). In reality, however, snow cornices sometimes develop locally rather than uniformly on a ridge with similar topography. To obtain detailed information on the distribution of snow cornices, airborne laser scanning was carried out in mountainous areas during the winter season. To understand the factors that determine the development of snow cornices, we analysed the differences between areas with and without snow cornice development in terms of topographic conditions.

## 2. METHODS

Airborne laser scanning was carried out over an area of 20.4 km$^2$ (4.0 × 5.1 km) centred on Mt. Niseko-Annupuri (1308 m a.s.l.) in Hokkaido, Japan. Measurements were taken on the following three occasions during 2021-2023:

No. 1: 9 December 2021,
No. 2: 10 March 2022,
No. 3: 5 March 2023.

The first measurement in December 2021 was taken when snow had started to accumulate and undergrowth such as bamboo had fallen down, thus it can be considered an elevation value when there was almost no snow. On the other hand, the measurements in March were taken just before the snow started to melt, which can be considered as the time when the snow depth was at its maximum. The differences between the measurements in March and December provide information on the distribution of snowpack over the entire mountain area.

On all measurement days there was no cloud cover and measurements could be taken over the entire area. During each measurement, several reference points were established on the snow-free ground surface and the difference between the measured and field surveyed reference point elevations was calculated. The total elevation values were adjusted so that the mean of the calibration approached 0 m. This resulted in data within a standard deviation of 5 cm. Finally digital elevation model were obtained at 1 m grid intervals.

## 3. RESULTS AND DISCUSSION

The snow depth distributions obtained by airborne laser scanning are shown in Figures 1 (difference between March 2022 and December 2021) and 2 (difference between March 2023 and December 2021). Snow cornices can be seen where the snow depth has increased in stripes near the ridge. In general, the snow depth was lower in the winter of 2023 due to less snowfall.

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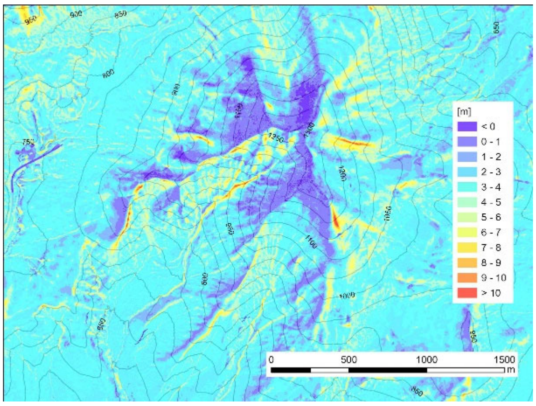


Figure 1: Snow depth distribution in 2022 winter (March 2022 − December 2021).

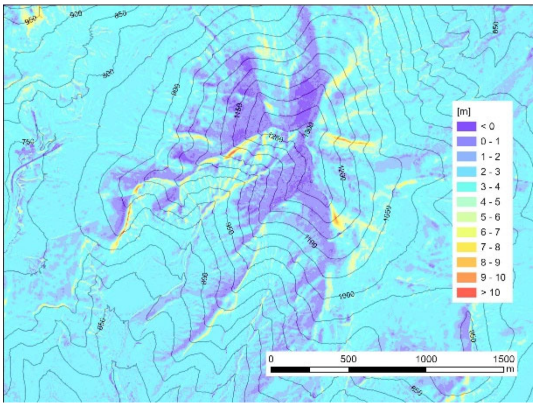


Figure 2: Snow depth distribution in 2023 winter (March 2023 − December 2021).

However, the height of the snow cornices remained almost the same levels. This is because snow cornices can form when there is a certain amount of snowpack and strong winds.

Focusing on the ridge extending south-southwest from the summit (ridges a and b in Figure 3), it can be seen that snow cornices develop along the entire ridge below 1100 m asl, whereas there is no increase in snow depth and no snow cornice development above 1100 m asl. This is consistent with Figures 1 and 2 and is unlikely to be influenced by annual variations in the prevailing wind direction. Other possible reasons are:

- lack of snow accumulation due to the high wind speed in high altitude zone,
- the direction of the ridge is not directly aligned with the prevailing wind direction.

However, these reasons do not seem to apply, as snow cornices have developed on ridges at the same altitude and in the same azimuth extending westwards from the summit (ridge c in Figure 3). Therefore, we analysed the topographic conditions, considering that the topography of the mountain could prevent the development of snow cornices.

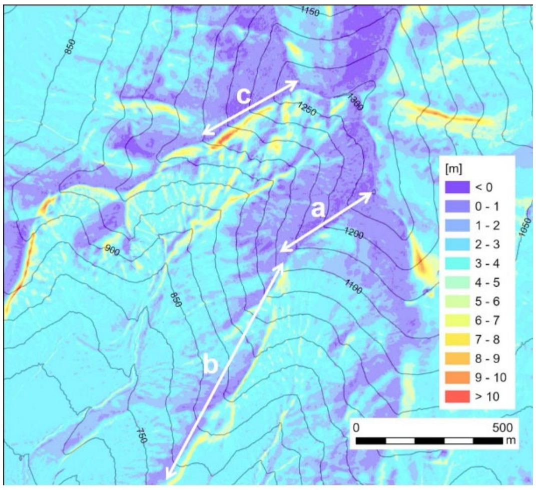


Figure 3: Close-up of the snow depth distribution in 2022 winter. a: ridge without snow cornice, b: ridge with snow cornice, c: ridge with snow cornice, similar in elevation and azimuth to ridge a.

We first compared the topographic cross sections in the direction perpendicular to the ridge (Fig. 4). Data from December 2021 were used for the topographic analysis. In areas where snow cornices did not develop, the slope angle in the windward direction was large and the ridge was sharply convex. On the other hand, where snow cornices develop, the terrain is generally gentle and the change in slope angle between the windward and leeward sides is small.

To get a more detailed view of the topographic conditions, the distribution of slope angles was calculated. Figure 5 shows the distribution of slope angles near the ridge. It can be seen that the slope angle is generally large on the windward side at high altitudes where snow cornices do not develop. It is assumed that the vertical component is greater than the horizontal component because the wind blows up the slope due to the steep topography on the windward side. This may also result in snow particles being blown vertically and not reaching the direction of horizontal growth of the snow cornice.

Figure 3 shows that the difference in snow depth is partly negative on the windward side,

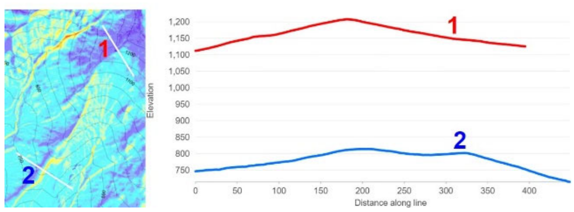


Figure 4: left: Lines where the cross-section was created; right: Cross-sectional view across ridge.

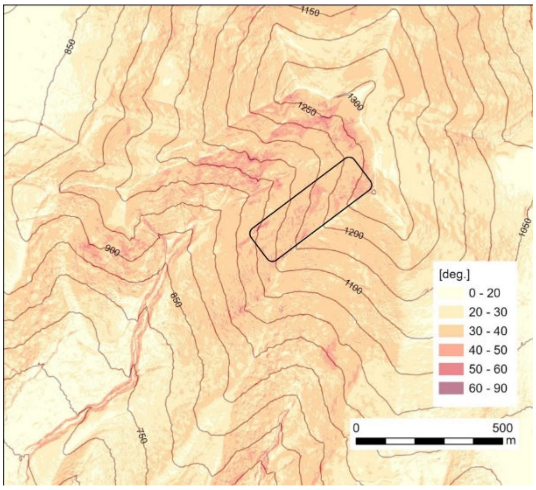


Figure 5: Distribution of slope inclination angles. Black box indicates areas where the slope angle is large on the windward side of the ridge a in Figure 3.

where no snow cornices develop, indicating that the snow depth in March is less than that in December. This suggests that the snow cover is continuously scraped off during the winter season. The topography remains the same on the windward side even after snowfall, indicating that the conditions that prevent the development of snow cornices also remain the same.

## 4. SUMMARY

Investigation of the precise snow depth distribution in mountainous areas obtained by airborne laser scanning indicates that snow cornices do not develop uniformly on the ridges. Analysis of the topographic conditions where snow cornices developed/non-developed areas showed a significant difference in the slope angle on the windward side. This suggests that snow cornice development depends on the topography. The effect of topography may influence the strength and direction of the winds near the ground, hence further investigations should be carried out using computational fluid dynamics simulations.

## ACKNOWLEDGEMENT

This work was supported by JSPS KAKENHI Grant Number 21H04601.

## REFERENCES

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