WHAT CAN AVALANCHE BURIALS HEAR?

ACOUSTIC CHARACTERISTICS OF SNOW PACKS AND THEIR RELATION TO INPUT SOUNDS

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ABSTRACT: In this paper, acoustic characteristic of sound insulation of two different snow packs: (1) a natural snow pack; and (2) a compressed snow by stomping, were measured. Acoustic characteristics of a compressed snow pack directly vibrated by stomping on surface and sticking with ski poles were also measured.

As a result, a natural snow pack shows varied insulation characteristics depending on its inner snow layer structure. In a less dense layer, high-frequency domain was insulated more than lower-frequency domain, and in a dense layer, all frequency domain was uniformally insulated. In a compressed snow, insulation reached to more than $40\,\mathrm{dB}$ uniformally in all frequency domain. On the other hands, in a method directly vibrating a snow pack, such as ski-pole sticking and stomping, sound pressure level measured at $30\,\mathrm{cm}$ depth was about $20\,\mathrm{dB}$ greater than the MAF (minimum audible field) in wide frequency domain. Furthermore, even if a vibrating point was horizontally $1\,\mathrm{m}$ far from the position of a microphone, sound pressure level at $60\,\mathrm{cm}$ was $10\,\mathrm{dB}$ greater than the MAF at $1000\,\mathrm{Hz}$. The results suggest that sticking with ski poles is effective to send sounds to a burial, and much better than voice call.

1 Introduction

Recent development in searching technique with avalanche transceivers has increased survival rate of avalanche burials. However, in some cases, such as for burials without avalanche transceivers, it leaves some room for consideration of searching methods other than using avalanche transceivers. In such cases, acoustic cues are sometimes effective for both a burial and rescuer to localize a position of each other.

According to the data of avalanche accidents in Canada 1984–1996, eight completely buried victims were found alive by a method of localization with sounds (Jamieson et al., 1996). In Japan, to search a burial without a avalanche transceiver, a method by calling and listening was proposed and has been taught in the training course for avalanche rescue (Nitta, 2000). However, it is unclear that a burial can hear rescuers' voices from the snow surface.

Acoustic characteristics of a snow layer was widely reported in the literature: characteristics of sound absorption of snow (Oura, 1953; Ishida et al., 1954; Ogaki et al., 1990; Iwase et al., 2001, 2008), acoustic impedance of a homogeneous snow sample (Takada et al., 1954; Ishida, 1964, 1965), propagation above snow cover (Albert 2000; Albert et al., 1990), and sound absorption and insulation of homogeneous snow in an actual field (Iwase et al., 2001; Iwase et al., 2008). However, in reality, a snow pack has layered structure which consists of various types of snow with various densities, hardness, and thus, acoustic impedances. Therefore, to clarify realistic acoustics characteristics of a snow pack, an experimental investigation on acoustic characteristics of a natural snow pack in an actual field and compressed snow found in the debris of the avalanche.

In this paper, we measured acoustic characteristic of sound attenuation of two different snow packs: (1) a natural snow pack; and (2) a compressed snow by stomping and jumping on. The latter was to simulate the debris of the avalanche. We also measured acoustic characteristics of a compressed snow pack directly vibrated by stomping on surface and sticking with ski poles.

2 Methods

2.1 Field and Instruments for measurements

Field measurements on snow packs were carried out on February 22 and 23, 2012, at a wide and flat field located at the side of the road which has been closed in winter season, in Ishikari-gun, Hokkaido, Japan. The coordinates and altitude of the field measured by GPS were $(\mathrm{N}43°28.013', \mathrm{E}141°34.960')$ and $122\ \mathrm{m}$, respectively.

A snow pit with $\mathrm{Width} \times \mathrm{Length} \times \mathrm{Depth} = 1.5\,\mathrm{m} \times 2.5\,\mathrm{m} \times 1.3\,\mathrm{m}$ was dug, and a vertical face for profiling a snow layer and inserting a microphone was made. The cotangent vector of the vertical face was directed to $\mathrm{W}270$ (Fig. 1).

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For recording sounds, a condenser microphone with $16\,\mathrm{mm}$ capsule diameter (DPA, 4006C) was employed. The microphone was set at the tip of a polyvinyl chloride cylindrical pipe with $70\,\mathrm{mm}$ inside diameter. The pipe was used for protecting cable and an amplifier, and its inside was filled with semi-hard polyurethane foam for sufficient insulation of sounds propagated inside the pipe.

The microphone was horizontally inserted into the position with $1\,\mathrm{m}$ from the face. An active loudspeaker (Behringer C50A) was set at $90\,\mathrm{cm}$ above the snow surface and a sound was propagated to right under (Fig. 2).

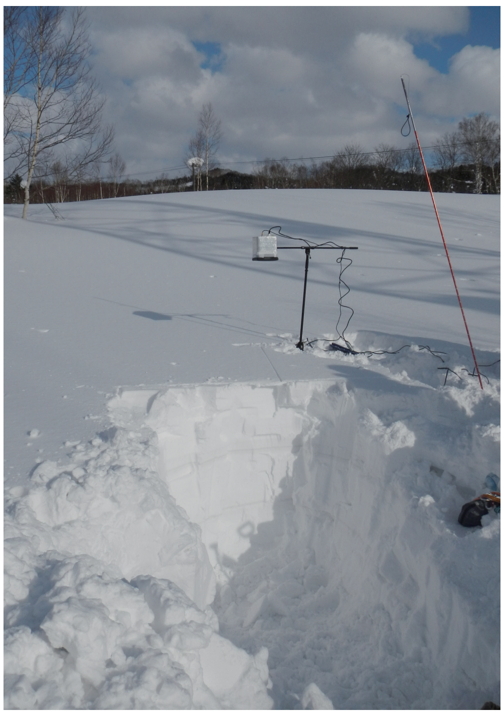

Fig. 1: A snow pit in a field.

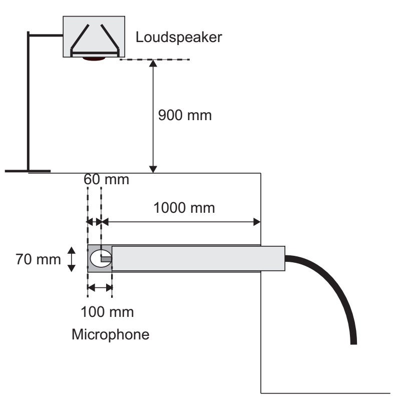

Fig. 2: Configuration of instruments for field measurement.

As a sound source for acoustic measurement of a snow pack, a TSP (Suzuki et al., 1995) was used, and was played by a linear PCM recorder (Tascam DR-100 MKII). A signal from the microphone was recorded into a linear PCM recorder (Tascam DR-100 MKII). As other sound sources than a TSP, two different whistles: ACM, Tornad No. 636 (denoted by type A, here) and FIN-345 (denoted by type B, here) were used. Stomping sounds were generated by two subjects: a male subject *M* weighed $70\,\mathrm{kg}$ and a female subject *F* weighed $50\,\mathrm{kg}$.

2.2 Profiles of snow packs

Profiles of snow packs were obtained in two different conditions at the same field. On the first day of our experiments, February 22, 2012, a profile of a natural snow pack was obtained. After experiments, we jumped and stomped on the snow surface, and set a compressed snow condition, which simulated a condition of the debris of the avalanche. On the second day, February 23, 2012, compacted snow was formed and a profile of a compressed snow was obtained.

To profile snow layers, a push-pull force gauge (Aikoh, PX50 with $15\,\mathrm{mm}$ diameter disc-shaped attachment) for hardness, a snow sampler (Climate Engineering, $100\,\mathrm{cm}^3$, depth $= 5.6\,\mathrm{cm}$) and a digital hanging spring scale (WeiHeng, rated load: $5\,\mathrm{kg}$, accuracy: $1\,\mathrm{g}$) for density, and a digital thermometer (Andokeiki, AND-5625) for temperature were employed.

Natural snow

Total snow depth of a natural snow pack in an experimental field was $270\,\mathrm{cm}$, and temperature at $120\,\mathrm{cm}$ beneath the snow surface was $0.9\,\mathrm{C}°$. According to the AMeDAS weather data during the experiment, 13:00 – 16:00, the temperature of the area around the field was from -1.4 to $0.3\,\mathrm{C}°$, and the wind speed and direction was from 3 to $5\,\mathrm{m/s}$ and from W to WNW. The weather is fin, occasionally cloudy.

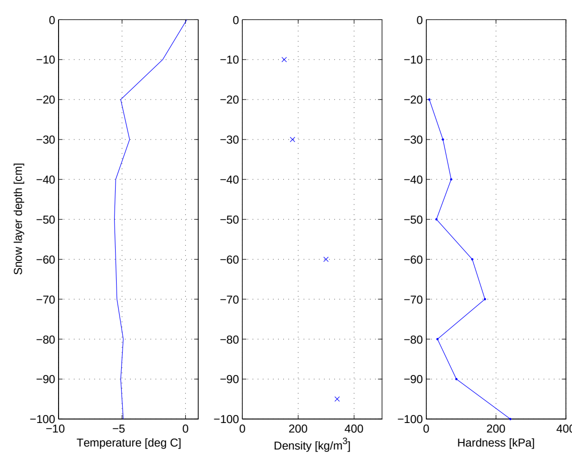

Fig.3: Temperature, deinsity, and hardness of a natural snow pack.

Fig.3 shows temperature, density, and hardness of the snow pack. Table 1 shows type of snow, grain size, and hand hardness of the snow layer. From the temperature inside the snow pack and observation of snow grain, the snow pack was considered to be dry.

Table 1: Type of snow, grain size, and hand hardness of a natural snow pack.

Depth from the surface [cm]	Type of snow	Grain size [mm]	Hand harness
$- -20$	PP	0.3	F
$-20 - -50$	DF	0.5–0.7	$4f$
$-50 - -85$	RG	0.5–1.0	f
$-85 - -90$	DF	0.5	$4f$
$-90 - -110$	RG	1.0	f

Compressed snow

Total snow depth of a natural snow pack in an experimental field was $270\,\mathrm{cm}$, and temperature at $120\,\mathrm{cm}$ beneath the snow surface was $5.0\,\mathrm{C}^{\circ}$. According to the AMeDAS weather data during the experiment, 11:00 – 14:00. the temperature of the area around the field was from 0.7 to $1.5\,\mathrm{C}^{\circ}$, and the wind speed and direction was from 2 to $3\,\mathrm{m/s}$ and from E to ESE. In latest 24 hours, according to the AMeDAS weather data, no snow has been fallen and the lowest temperature was $-5.4\,\mathrm{C}^{\circ}$ at 3:00 in the night. The weather of the day was fine.

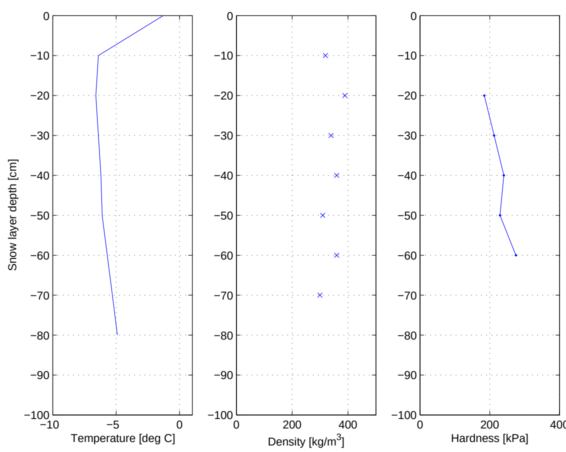

Fig. 4: Temperature, deinsity, and hardness of a compressed snow pack.

Table 2: Type of snow, grain size, and hand hardness of a compressed snow pack.

Depth from the surface [cm]	Type of snow	Hand harness
$- -10$	RG	f
$-10 - -18$	RG	$4f$
$-18 - -58$	RG	f
$-58 - 62$	RG	$4f$
$-62 - 70$	RG	f
$-70 - 80$	il	p

Fig.4 shows temperature, density, and hardness of the snow pack. Table 2 shows type of snow, grain size, and hand hardness of the snow layer. From the temperature inside the snow pack and observation of snow grain, the snow pack was considered to be dry.

2.3 Acoustic analysis

The sounds were recorded in $48\,\mathrm{kHz}$ sampling frequency and 16 bits, and for spectral analysis, a Hamming window with 16384 points length and Fast Fourier Transformation 32768 points were employed. In addition, to remove fine spectral components which were not resolved in human auditory peripheral system, the power spectrum obtained was smoothed by a rectangular window with $10\log_{10} B = 8.3\log_{10} f_0 - 2.3$, where B, f_0 is the band width and the center frequency of the window, respectively (Patterson, 1974).

3 Results

3.1 Attenuation characteristics

Natural snow pack

Acoustic characteristics of the sound propagation of a natural snow pack was analyzed. Fig. 5 shows attenuation characteristic of the sound propagation from the reference point ($4\,\mathrm{cm}$ above the surface) to the points for measurement in different depths.

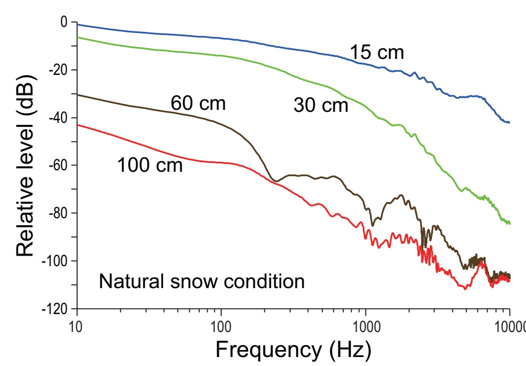

Fig. 5: attenuation characteristics of sound propagation in a natural snow pack

The level of attenuation trivially increases as a point of measurement is deepened. For example, at $1\,\mathrm{kHz}$, $18\,\mathrm{dB}$ at $15\,\mathrm{cm}$, $35\,\mathrm{dB}$ at $30\,\mathrm{cm}$, $78\,\mathrm{dB}$ at $60\,\mathrm{cm}$, and $90\,\mathrm{dB}$ at $100\,\mathrm{cm}$.

The level of attenuation increases as a frequency increases. For example, at $60\,\mathrm{cm}$, $30\,\mathrm{dB}$ at $10\,\mathrm{Hz}$ and $100\,\mathrm{dB}$ at $10\,\mathrm{Hz}$.

Compressed snow pack

Acoustic characteristics of the sound propagation of a compressed snow pack was analyzed. Fig. 6 shows attenuation characteristic of the sound propagation from the reference point ($4\,\mathrm{cm}$ above the surface) to the points for measurement in different depths.

Level of attenuation does not strongly depend on frequency. This tendency is especially clear in the higher frequency region. For example, in the frequency range greater than $100\,\mathrm{Hz}$, the level of attenuation is almost equal to $60\,\mathrm{dB}$.

In the compressed snow pack, the difference of the level of attenuation among different depths is smaller than that in the case of a natural snow pack. In fact, the difference of the level of attenuation between $30\,\mathrm{cm}$ and $60\,\mathrm{cm}$ is $5\,\mathrm{dB}$ in a compressed snow pack. The difference is much smaller than $20\,\mathrm{dB}$ in the case of a natural snow pack.

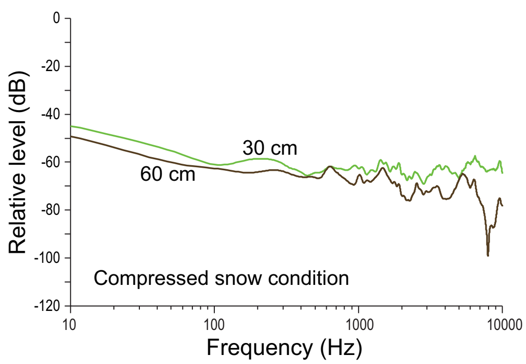

Fig. 6: Attenuation characteristics of sound propagation in a compressed snow pack

Various sound sources for a compressed snow pack

To evaluate levels of attenuation of actual sound sources, such as whistle, footsteps, and sticking ski poles, possibly used in the avalanche rescue, levels of attenuation of those sound sources in the compressed snow pack were measured at $30\,\mathrm{cm}$ and $60\,\mathrm{cm}$. Sounds by whistle, stomping, and sticking a snow surface by a ski pole were generated right beneath the microphone.

Fig. 7 shows time-domain sound waveforms of stomping on the snow surface and sticking the snow surface with a ski pole. Both waveforms reveal pulse-like shapes.

Fig. 8 shows power spectrum of different sound sources, such as stomping by male and female, two types of whistles, and a ski-pole sticking by male, recorded at $30\,\mathrm{cm}$ in the compressed snow pack. All spectrum were average spectrum of repetitions more than ten times, and smoothed by a rectangular window simulated the human auditory filter. Sound pressure level was calibrated using a sound level meter (RION, NL-27) in indoor situation. A dotted line represents the MAF (Minimum Auditory Field). Background noise includes both acoustic and electrical noises

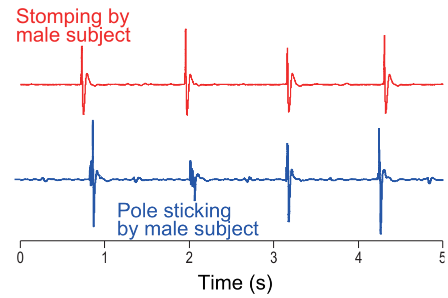

Fig. 7:Time-domain sound waveforms of stomping (at the top) and sticking by a ski pole (at the bottom) recorded at $30\,\mathrm{cm}$ in a compressed snow pack.

Sounds of stomping (red line) and ski-pole sticking (blue line) by male reveal similar features that sound pressure levels monotonously decrease as frequency increase. However, in the frequency range greater than $3\,\mathrm{Hz}$, the level of the ski-pole sticking sound is $10\,\mathrm{dB}$ or more greater than that of the stomping sound.

The sounds of both stomping and ski-pole sticking by male are $40\,\mathrm{dB}$ greater than the MAF in the wide frequency range. The sound of stomping by female (orange line) is $20\,\mathrm{dB}$ greater than the MAF.

On the other hand, the sounds of whistles (type A and B) have frequential components only in the range from 3 to $5\,\mathrm{kHz}$ with its peak at about $4\,\mathrm{kHz}$. The level of the sound of type A whistle is $20\,\mathrm{dB}$ greater than the MAF, however, the level of the sound of type B whistle is only a little bit greater than the MAF.

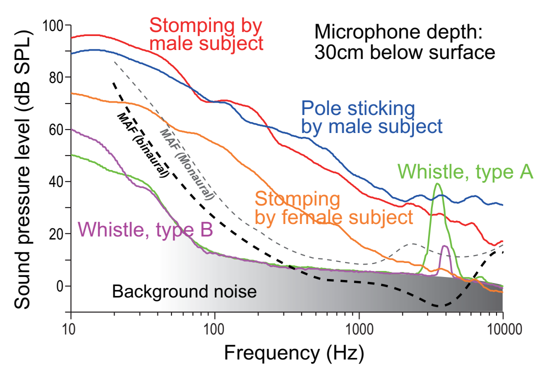

Fig. 8: Power spectrum of different sound sources, such as stomping by male and female, two types of whistles, and a ski-pole sticking by male, recorded at $30\,\mathrm{cm}$ in a compressed snow pack. A dotted line represents MAF (Minimum Auditory Field). Background noise includes both acoustic and electrical noises.

To evaluate horizontal propagation in a snow pack of stomping sound, sound pressure levels were measured in the conditions with different distances from the point just beneath the microphone.

Fig. 9 shows the sound pressure levels measured at $30\,\mathrm{cm}$ depth for stomping sounds by male with different horizontal distances. Fig. 10 shows sound pressure levels of the point at $60\,\mathrm{cm}$ below the surface for stomping sounds by male in different distances from the point right just above the microphone.

In the case of stomping by male, the sound pressure level is from 10 to $30\,\mathrm{dB}$ greater than the MAF. In the case that the microphone was set at $60\,\mathrm{cm}$ depth even in the case that the distance is $180\,\mathrm{cm}$.

Here, we do not show the detailed results for male stomping sounds in the case that the microphone was set at $60\,\mathrm{cm}$ depth, and, in such case, the sound pressure levels were slightly smaller than that of the case of the microphone at $30\,\mathrm{cm}$ and was also sufficiently greater than the MAF.

On the other hand, for stomping by female, the sound pressure level measured at $60\,\mathrm{cm}$ is sufficiently greater than the MAF if the distance is $100\,\mathrm{cm}$, however, if the distance is $180\,\mathrm{cm}$, the sound pressure level measured is just $10\,\mathrm{dB}$ greater than the MAF.

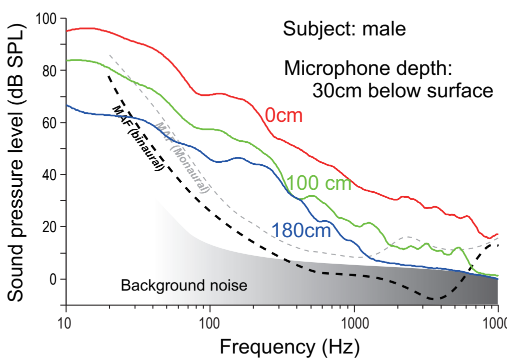

Fig. 9: Sound pressure levels of the point at $30\,\mathrm{cm}$ below the surface for stomping sounds by male in different distances.

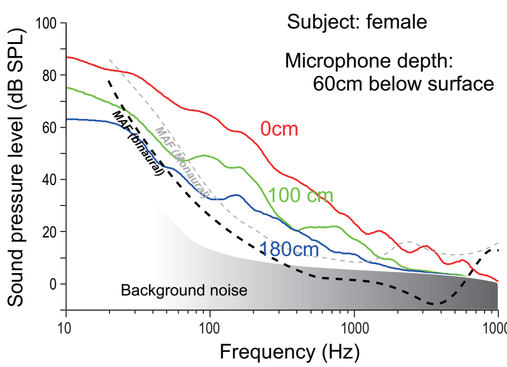

Fig. 10: Sound pressure levels of the point at $60\,\mathrm{cm}$ below the surface for stomping sounds by female in different distances.

4 Discussions

In the case of a natural snow pack, our results show that the level of attenuation increases as the depth increases, and also as frequency increases. This result shows good agreement with the results in the literature. However, physical properties of the snow pack here was indispensably different from that in (Iwase et al. 2001), and the level of attenuation in our result is greater than that in (Iwase et al. 2001).

In this study, to simulate the snow pack in the debris of the avalanche, the compressed snow pack was made by stomping and jumping, and its density was 350 – $400\,\mathrm{kg/m^3}$ (Fig. 4). The density is slightly smaller than the reported density $400 < \rho < 600\mathrm{kg/m^3}$ of the snow in the debris (Maeno et al., 1986). However, it might be considered to simulate a snow pack in the debris of the avalanche.

In our study, the level of attenuation of the sounds at $30\,\mathrm{cm}$ in the compressed snow pack show was greater than $50\,\mathrm{dB}$, and therefore, it may be very difficult for burials to hear voices by rescuers.

On the other hand, the sounds by stomping and ski-pole sticking have high possibility to reach avalanche burials. However, the sounds by stomping and ski-pole sticking are very pulsive and its duration is vey short, and therefore, to reach avalanche burials, it is necessary to repeat stomping and sticking several times. Furthermore, sticking the snow surface by ski poles is easy and with less physical efforts and, hence, it may be good method to generate sounds for burials. The sound of stomping by a rescuer is audible by burials if a rescuer reach at $2\,\mathrm{m}$ (male rescuer) $1\,\mathrm{m}$ (female rescuer) horizontally far from a burial.

The whistle (type A) is also audible by a burial, otherwhile the whistle (type B) is not. However, a whistle is much more effective than voice.

5 Conclusion

To evaluate effectiveness of actual sounds, such as footstep, voice, ski-pole sticking, and whistle, for burial hearing, acoustic characteristics of sound propagation in a compressed snow pack which simulates the debris of the avalanche. As a result, the level of attenuation at $30\,\mathrm{cm}$ depth in the snow was $50\,\mathrm{dB}$ in wide frequency range. This result suggests that rescuers' voices might be not audible by a burial. On the other hand, the sound pressure levels of the sounds of stomping and ski-pole sticking by rescuers were much greater than the MAF even at $60\,\mathrm{cm}$ depth in the snow.

This suggests that stomping and ski-pole sticking by rescuers are more effective than calling by rescuers in avalanche rescue of a burial without an avalanche transceiver.

Acknowledgement

We would like to thank Eiji Akitaya, Takayuki Matsuura, and Toshihio Ozeki for their helpful advices about snow profiling and discussions. We also would like to thank Mika Ito and Mitsunori Mizumachi for their helpful comments. The first author would like to thank all members of the research group of avalanche in Hokkaido. This work was supported by JSPS KAKENHI Grant Number 23651182.

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