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Wind and snow particle distribution in powder snow cloud

Yoichi Ito[1,*], Kouichi Nishimura[1], Florence Naaim-Bouvet[2], Hervé Bellot[2], Xavier Ravanat[2] and Emmanuel Thibert[2]
[1] Nagoya University, Nagoya, Japan
[2] UR ETNA, IRSTEA, Saint-Martin d'Hères, France

ABSTRACT: An ultrasonic anemometer and a snow particle counter were newly installed in the avalanche test site locating at the Col du Lautaret pass, France. Simultaneous measurements of both wind and snow particles in the powder snow cloud were made to investigate the powder part of the avalanche in 2013 winter. The particle speed and diameter were calculated from the high-frequency recording of direct SPC output. The particle speed showed lower values than the wind speed. Relatively large particles were observed around the avalanche front and the size of the particles was slightly decreased in the following flow. The particle size distribution was well estimated by the aerodynamic theory except around the avalanche front.

KEYWORDS: Avalanche, Powder snow cloud, wind speed, particle size

1 INTRODUCTION

Generally snow avalanches consist a dense-flow layer at bottom and a powder snow cloud on top. The powder cloud sometimes shows large development and longer runout distance than the dense part (Gruber and Margreth, 2001). Field observation (Vallet et al., 2004) and model studies (Ancey, 2004; Louge et al., 2012) were carried out to survey the development of the powder snow cloud, however, the internal structure of the powder cloud is still not well known due to the lack of suitable measuring devices.

Only a few attempts have so far been made on direct measurements of the powder cloud; the velocity distribution was obtained using an ultrasonic anemometer (Nishimura et al., 1995) and a pressure difference sensor connected to the inside and outside of the avalanche (Nishimura and Ito, 1997). The size distribution of the snow particles suspended in the powder part was measured by means of a particle capturing technique (Rastello et al., 2011) and the result was compared to the theoretical estimation by Clément-Rastello (2001).

However, both the velocity and particle size distribution have not been measured simultaneously although the interaction between the wind and particles is a key factor for the development of the powder cloud. Therefore we started new powder snow avalanche observation adopting an ultrasonic anemometer for wind speed measurement and a snow particle counter (SPC), which is usually used for blowing snow survey, for particle measurement. Both the sensors were newly installed in the French avalanche test site.

2 METHOD

Avalanche experiments were carried out at the Col du Lautaret Pass, France (Ravanat and Ousset, 2010). Two avalanche paths (No.1 and No.2) are located in the southeast facing slope; the longer No.2 path was used in the experiments. The avalanche is triggered by GAZEX from the starting zone around 2400 m a.s.l., then the flow hits 3.5 m high measurement tower set in the lower part of the avalanche path (2238 m a.s.l.). On the tower, Load cells and velocity sensors using a set of optical sensors (Dent et al., 1998) were installed (Figure 1).

Recently the ultrasonic anemometer (Kaijo, TR-61B and DA-600) and SPC (Niigata Electric, SPC-S7) were set on top of the tower (Figure 2). The ultrasonic anemometer directly shows the three-dimensional wind direction and speed in

Figure 1. View of the avalanche test site. The measurement tower is located in a circle below.

Corresponding author address: Yoichi Ito;
Nagoya University, Nagoya, Japan;
tel: +81 52 789 3481; fax: +81 52 789 3481;
email: slayer@nagoya-u.jp

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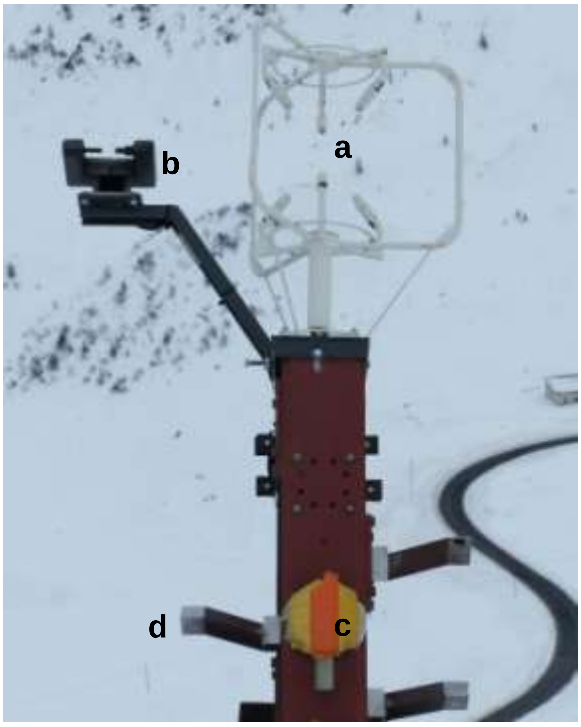

Figure 2. (a) Ultrasonic anemometer and (b) SPC set on the tower. The center of the sensors is about 40 cm above the top of the tower and 40 cm apart each other. (c) Load cell for the impact pressure and (d) optical velocity sensor.

the powder cloud. The SPC consists a set of laser diode and photodiode; a pulse signal proportional to its diameter is generated when a snow particle passes through the sensing volume (Sato et al., 1993). Usually the SPC output shows the number of particles and its diameter at each 1 second for mass flux calculation. However, not only the diameter but also the velocity of each particle can also be calculated by high-frequency recording of the direct SPC output since the amplitude and width of the each pulse signal are proportional to the diameter and speed of the each particle, respectively. Detailed procedure is described in Nishimura et al. (2013).

In the experiment, the data were sampled at 60060 Hz for the ultrasonic anemometer and the SPC, on the other hand, the impact pressure measured by the load cell was recorded at 3000 Hz. Additionally the side view of the flow was recorded by a high speed video at 200 frame rates per second.

3 RESULTS

The avalanche experiment was made and data were obtained successfully on April 10, 2013. In the experiment nearly two-thirds of the measurement tower was buried in the snow and about 1.1 m of the upper part was exposed over the snow surface. Hence the ultrasonic anemometer and SPC were located at about 1.5 m high from the snow surface.

Figure 3 shows the wind speed obtained by the ultrasonic anemometer, direct output of the SPC, impact pressures and flow velocities. The impact pressures indicate the avalanche main body hit the tower at about 15.9 s. Before 15.9 s, saltating snowballs can be found in the pressure record as spike-shaped signals. The high speed video record also indicates the existence of snowballs around the avalanche front. Note that the SPC record started around 15.3 s; this suggests the snow particles were suspended in the air before the avalanche front arrival. The flow velocity reached about 20 ms^{-1} at the maximum near the avalanche front, although the downslope component of the wind speed was lower than 10 ms^{-1}. This difference caused by the avalanche front was not enough high to cover the ultrasonic anemometer. Then the flow height became larger and the wind and flow velocity reached almost the same magnitude of 15 ms^{-1} around 17 s. However, the SPC output suddenly disappeared at 16.9-17.6 s, where the maximum wind speed period. This is probably due to the SPC output saturated in the highly

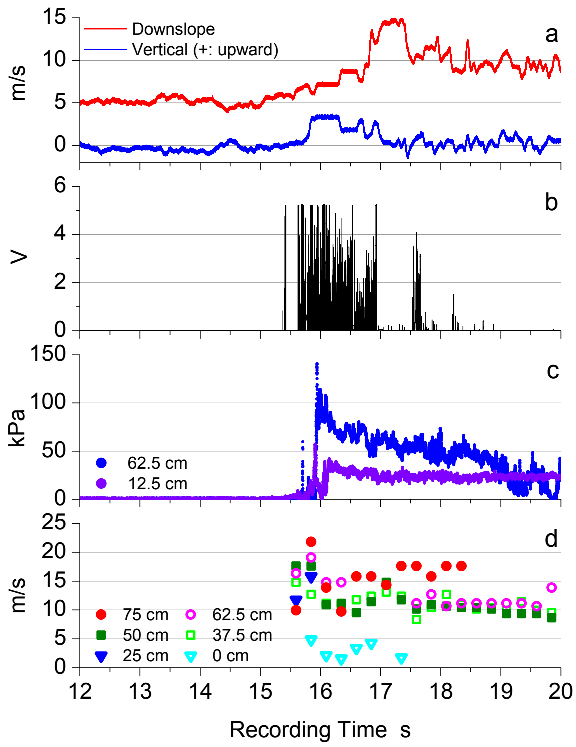

Figure 3. Data obtained in the experiment on April 10. (a) Wind speed obtained by the ultrasonic anemometer, (b) direct output of the SPC, (c) impact pressures, (d) velocity distributions in the flow at 0.25 s interval. The approximate heights of the sensor from the snow surface are indicated in (c) and (d).

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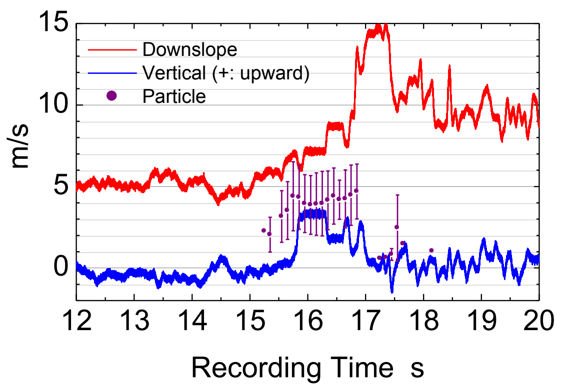

Figure 4. Wind and particle speed distributions in the avalanche.

dense powder part, since the SPC is designed to cut the continuous (saturated) signals to eliminate ambient light disturbance.

In the SPC record, over 3000 pulses were recognized. In the analyzing procedure, almost the half of the pulses described below were eliminated: i) pulses in the noise level (corresponding to < 20 µm in diameter), ii) very wide pulses induced by multiple particles in the sensing volume (corresponding to < 0.5 ms^{-1}), iii) very narrow pulses induced by noise and sampling error. The analyzing result of the particle speed is displayed in Figure 4 with the wind speed data. The particle speeds were kept almost constant at about 4 ms^{-1} while the wind speed showed the larger value from 6 to 9 ms^{-1}.

The particle size distribution was also calculated and shown in Figure 5. At 15.5-16 s around the avalanche front, relatively large size of particles (up to 300 µm in average) was found. Then the particle size slightly decreased around 200 µm in the avalanche flow. It is noteworthy that the wind speed was smaller where the larger particles were observed, although the particles can be suspended in the air generally when the acceleration of the particle due to turbulence is higher than the gravity.

4 DISCUSSION

The particle speeds in the powder cloud showed lower value and less time variation than the wind speed recording. One explanation for these results may be that the diffusivity of snow particles is lower than the turbulent diffusivity of the air. In Figure 5, the smaller particle speeds were found for the larger particles around 15.5 s; hence the particles in the powder cloud may not be enough small to follow the turbulent eddy. The lower speed of particles than the wind is also observed in the blowing snow observation using the same SPC measuring technique (Nishimura et al., 2013). Another possible explanation is that the sampling frequency of the

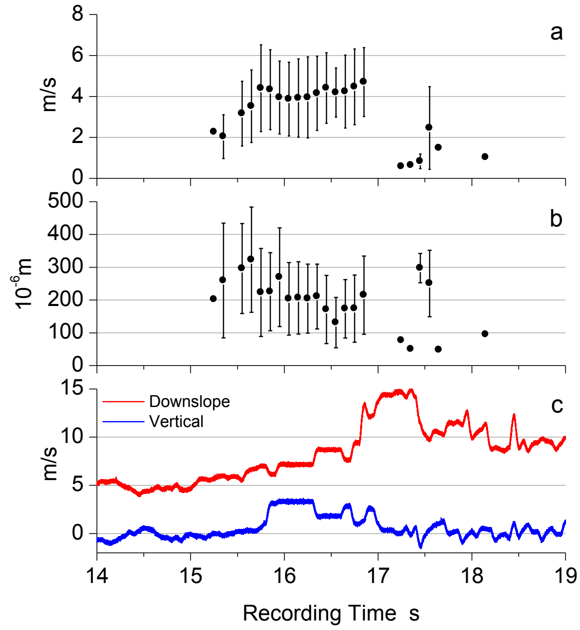

Figure 5. Time variation of (a) particle speed, (b) particle size and (c) wind speeds.

SPC (60060 Hz) in this study also may affect the particle speed measurement. The thickness of the sampling volume of the SPC is 0.5 mm, hence the particles faster than 15 ms^{-1} cannot be correctly sampled; the increased sampling frequency would allow more reliable result.

The observed particle size was in the range of 200-300 µm approximately. This value is almost consistent with the theoretical prediction by Clément-Rastello (2001) and previous measurement by Rastello et al. (2011) although the avalanche velocity and the sensor height were different from their observation.

However, as we noted in Figure 5, the larger particles were observed in ahead of the avalanche front where the wind speed was relatively small Thus, we calculated turbulent condition in the avalanche. Nalpanis (1985) indicated the particle suspension criterion can be expressed as:

$$18\rho_a v u_* / \rho_p g d^2 > 1 \qquad (1)$$

Where ρ_a and ρ_p are the density of air and particle, respectively, v is kinematic viscosity of air, u_* is friction velocity, g is gravity acceleration and d is particle diameter. The friction velocity, u_*, can be calculated from the downslope velocity, U and vertical velocity, W:

$$U = \overline{U} + u' \qquad (2)$$

$$W = \overline{W} + w' \qquad (3)$$

$$u_* = (|\overline{u'w'}|)^{1/2} \qquad (4)$$

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Table 1. Friction velocity, the observed and estimated particle size before and after 15.9 s.

Time	u_*	Particle size observed	Particle size estimated
	[ms^{-1}]	[μm]	[μm]
14.9-15.9 s	0.53	255	138
15.9-16.9 s	0.96	196	185

where $\overline{U}$ and $\overline{W}$ are the mean value and u' and w' are the fluctuation value of the U and W, respectively.

The u_* and the particle size estimated from Eq.(1) was calculated for 1 second before and after 15.9 s (the time of the avalanche front arrival) and shown in Table 1. Before 15.9 s, the observed particle size is almost twice the theoretically estimated size. The large suspended particles in ahead of the avalanche front would not be produced by the turbulent force but by splash of the saltating snowballs. On the other hand, both the observed and estimated size are almost equal after the 15.9 s. This result suggests that the particle size distribution observed in the avalanche body can be reasonably explained by the aerodynamic theory.

5 CONCLUSIONS

The snow avalanche experiments were made using the ultrasonic anemometer and SPC to investigate the powder part of the avalanche. The particle speeds showed lower values than the wind speed in the powder cloud. This result may suggest the low diffusivity of snow particles in the turbulent air, although the sampling frequency needed to be higher to measure the fast particles precisely. The particle diameter slightly decreased from ahead of the avalanche to the following flow. The calculation of turbulent condition revealed that the large particles around the avalanche front seem not to be lifted by turbulent forces. On the other hand, the particle size distribution in the avalanche body agreed fairly well with the aerodynamic theory.

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