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Marie Rastello, Fabrice Rastello, Hervé Bellot, Frédéric Ousset, François Dufour

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M. Rastello[‡*] F. Rastello[†] H. Bellot[‡] F. Ousset[‡] F. Dufour[§]

The size of the snow particles involved in a powder-snow avalanche is a key parameter of the local dynamic of the flow. An experimental device has been realized to collect snow particles within powder-snow avalanches. Snow particles have been captured in the powder-snow part of an avalanche triggered artificially on the experimental test site of the vallée de la Sionne. The collected particles have been photographed and the pictures digitized. An image analysis tool to evaluate the size of the collected particles have been developed for the purpose of this study. The obtained order of magnitude is $0.2\,\mathrm{mm}$.

[*] Laboratoire de Mécanique des Fluides et d'Acoustique, Université de Lyon, Ecole Centrale de Lyon, CNRS, UCBL, INSA Lyon, 36 avenue Guy de Collongue, 69134 Ecully cedex, France.

[†] INRIA - Laboratoire de l'Informatique du Parallélisme, Université de Lyon, ENS Lyon, CNRS, INRIA, UCBL, 46 allée d'Italie, 69364 Lyon cedex 07, France.

[‡] Cemagref - UR ETNA, 2 rue de la papeterie, BP 76, 38402 Saint Martin d'Hères cedex, France

[§] SLF, Section Snow and Avalanches, Flüelastrasse 11, CH-7260 DAVOS Dorf, Switzerland

1 Introduction

Snow avalanches can be very powerful and very destructive phenomena, especially large powder-snow avalanches that have very impressive characteristics. Their height can reach $100\,\mathrm{m}$, while their velocity is sometimes larger than $100\,\mathrm{m.s}^{-1}$. An example of powder snow avalanche is given in figure 1. Large powder-

Figure 1: Picture of the avalanche artificially triggered on the experimental test site of the vallée de la Sionne (Switzerland) the 31^{th} of January 2003

snow avalanches are huge, highly turbulent dilute suspensions of snow. Heavier than air they behave like a non-boussinesq cloud running very fast down the slope. Because of their power and because their natural trigger is unpredictable, only a few field studies exist restricted to macroscopic characteristics such as thickness or front velocity [2, 10]. Many research efforts concentrate on modeling. Some deal with physical modeling coupled with laboratory experiments [1, 16, 21, 22]. Some other use numerical modelings [18, 23, 12]. Both modeling must take into account at best the real characteristics of the avalanche. Among other ill-known quantities, the size of snow particles involved in a powder-snow avalanche is very important. Indeed, the behavior of a turbulent dilute suspension highly depends on the sedimentation velocity of the particles. As an example, for a powder-snow avalanche an error of a factor 10 on the size of the snow particles implies an error of a factor 100 on the sedimentation velocity of the particles. This can lead to a completely different behavior. For this purpose, Rastello [6] made a theoretical study that provides an order of magnitude of snow particles in a powder-snow avalanche. It focused on the mechanisms present in a powder-snow avalanche and on how particle size selection ensues from them. This paper tackles the problem from the experimental point of view: snow particles were captures inside an avalanche, stored and transferred to the laboratory were there size could be measured. The paper is organized as follows. Section 2 presents the experimental setup. Section 3 details the realization of the experiments from the capture of the particles to their digitization. Then Section 4 describes the image processing to obtain particles size. Finally, Section 5 deals with the presentation and discussion of the results.

2 Experimental setup

The design of an experimental setup that captures snow particles in the body of a powder-snow avalanche faces several difficulties:

- Velocities for a powder-snow avalanche is easily of the order of $60\,\mathrm{m.s}^{-1}$ and can reach more than $100\,\mathrm{m.s}^{-1}$. A particular care is necessary to ensure that snow particles are not damaged while captured.
- A 5 minutes upper limit is set up for standing in the running zone of the avalanche before its artificial triggering. The disposal located in the running zone must be set in operation within those time constraints.
- After the avalanche has run down the slope, 20 minutes to 1 hour is the approximate laps of time necessary to secure the avalanche pathway area. During this time the captured snow particles must undergo no metamorphism.
- The disposal must be cheap because of the high avalanche damaging probability.

According to these specifications, the experimental device was built as follows (see figure 2 and figure 3).

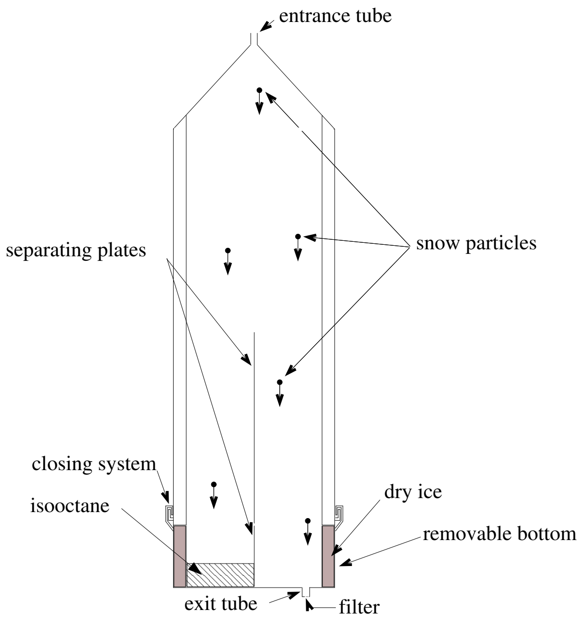

Figure 2: Sketch of the disposal - section view.

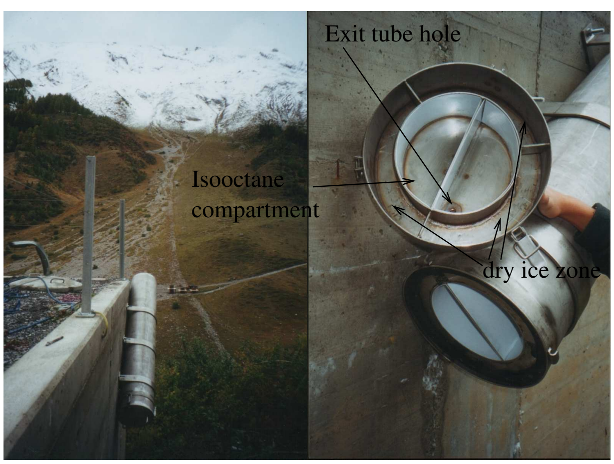

Figure 3: Left: the experimental device fixed on the bunker of the experimental test site of vallée de la Sionne (Switzerland). Right: the removable bottom.

Air and snow particles enter the device by a small tube (Ø $= 2\,\mathrm{cm}$). The tube is then diverging to reach a $40\,\mathrm{cm}$ diameter. This has the effect of slowing down the moving air by a factor of 400. An air velocity at the entrance of $60\,\mathrm{m.s}^{-1}$, is thus reduced to $15\,\mathrm{cm.s}^{-1}$. This enables to slow down snow particles by friction and to avoid breaking collisions. For particles which sizes are supposed to be a few tenth of a millimeter a tube of 1 meter long is enough to reduce particles speed to a very low velocity. The exit is made with a convergence of the tube back to a $2\,\mathrm{cm}$ diameter. To avoid snow particles to fill in the whole device and to compact and agglomerate in it, a ceramic filter has been adapted to the exit tube. This filter lets air pass but not snow. Hence, as soon as enough snow particles have filled the filter, air cannot flow across anymore and no more air nor particle circulation is possible in the device.

A prototype has been realized in PVC. A Plexiglas window, located on the side of the tube allowed to look at what was occurring in it. The avalanche was modeled with compressed air and sand particles of different sizes. The slow down of the sand particles and their gentle deposition have been observed to work very well. So does the filling of the filter and the blocking of air and particles circulation.

Snow particles can be conserved without any occurring metamorphism for many months if they are immersed in isooctane at temperatures lower than $0°C$. [3]. The bottom of the device has then been equipped with a removable piece (see figure 3-right). This piece has three compartments, two on the center and one on the periphery. One contains the exit tube and the filter. Another one, where isooctane is poured, is where snow particles are gathered. The third one, on the periphery, contains dry ice. The dry ice cools isooctane below $0°C$. This avoids snow particles from suffering any metamorphism before one can come and collect them.

The final disposal has been realized in stainless steel. The inner part is partially covered with Teflon to avoid snow particles from being stuck on the cold metal. An angle of $45°$ has been chosen between the disposal and the horizontal so as gravity can help to the deposition process, and isooctane can remain in its compartment.

3 Realization of the experiments

3.1 Pick-up of particles

The device has been fixed on the side of the bunker of the experimental test site of the vallée de la Sionne (Switzerland). Large avalanches are artificially triggered on this experimental test site. On the 31^{th} of January 2003 a large avalanche (see figure 1) was triggered. Some of its characteristics are described in [2, 27]. The snow layer break was $80\,\mathrm{cm}$ thick on a length of $450\,\mathrm{m}$. The avalanche ran down the $1200\,\mathrm{m}$ of difference of height between the top of the mountain and the valley. Its width was of the order of $300\,\mathrm{m}$ to $450\,\mathrm{m}$ during its way down. Front velocities of the order of 50 to $60\,\mathrm{m.s}^{-1}$ have been measured[1]. It was a mixed avalanche. Snow particles have been collected in the powder-snow part of this avalanche: its dense part stopped down in the valley while only the powder snow part reached the bunker located $100\,\mathrm{m}$ above on the opposite slope. Around 20 minutes after the avalanche has reached the bunker the particles collected in the device were transferred in small boxes filled with isooctane and cooled with dry ice. All these boxes were then always kept below $0°C$ before the imaging process.

3.2 Images of the snow particles

The snow particles imaging process has been realized in a cold chamber of the LGGE french glaciology laboratory. Air temperature was far below zero Celsius degrees (of the order of -20 to -30°C). No metamorphism of the particles occurred during the whole process. Snow particles have been laid out of the boxes onto pieces of colored paper. Pictures were taken only after the thin isooctane film, initially present, completely volatilized. A numeric camera was used equipped with a zoom and fixed on a rack. Together with the particles, a ruler was on each picture to allow to determine the ratio between pixels and millimeters.

4 Image and data processing

The goal is to measure the size of particles from the digital pictures. When doing the processing, different difficulties arise. One comes from the fact that pictures are inherently, only, two-dimensional. Thus, the third dimension of the particle is not accessible to us. Another one comes from isooctane capillarity that makes it difficult to separate small particles. Performing the distinction between really stuck particles and adjacent particles was then really hard. This task was complicated by the fact that the typical minimal precision (one pixel) of a picture corresponds to 0.02 millimeters while many particles have size around 0.1 millimeter.

Image processing falls into the following steps:

- *Particle regions* (pixels of the picture considered as part of a particle) are separated from the background of the picture using dynamic thresholding: the particle region grows iteratively starting from an initial point selected by hand; each point adjacent and with a similar color to a point already in the particle region is put (if not already) in the particle region also. The notion of similarity of colors is a simple threshold [19] on the distance between color vectors. The designed tool allows, for each particle region to tune the value of the threshold depending on a visual check of the result.

- Particle regions are separated by hand into atomic *sub-particles*: a particle will be considered as an aggregate of sub-particles where a sub-particle has an ellipsoid shape. This process of aggregation allows us to distinguish three cases:

  1. a *lower* bound for particle sizes is obtained by considering that each particle is composed of only one sub-particle.
  2. an *upper* bound for particle sizes is obtained by considering that each particle is composed of all adjacent sub-particles.
  3. an *intermediate* value (more realistic) for particle sizes is obtained by choosing the aggregates manually.

- The volume of a particle is the sum of the volume of its composing sub-particles. The volume of each sub-particle is evaluated as the volume of a three dimensional ellipsoid of axis lengths (A, a, a): A is the major axis and a the minor axis of an ellipse that has

[1] peronnal communication from B. Sovilla

the same normalized second central moments as the two dimensional image of the sub-particle.

An example of the different particles and sub-particles can be found on figures (4), (5), (6), and (7).

Colbeck et al. in [8] performed a classification of particles. The one we are concerned with are ”highly broken particles” (packed, shards or rounded fragments of precipitation particles; saltation layer). The size of a particle is defined as the greatest extension (while the authors noticed that it could be defined differently). The two different methods cited for measuring size of particles are stereology and sieving. The authors outline the fact that the two methods provide different results. For this classification, the obtained particles in our study are said to be “very-fine” and “fine”.

Gay et al. [15] have proposed a methodology to measure size of particles using image processing. A Sobel operator (gradient) is used to separate particles from the background. For each particle, a so called “skeleton” is built. The methodology provides the ”mean convex radius” which is the average of the radii (the radius associated to each end-point of the skeleton). The problem is that end-points highly depends on the resolution of the image. Most obtained size are between 0.1mm and 0.3mm.

5 Results and discussion

The previously described image processing on the whole set of images give us the size distribution for the sub-particles, the intermediate case and the upper-bound. The interest of the results for the upper-bound are principally to give a maximum value for the size of the snow particles present in the sample. Indeed as can be seen on figure (7), the automatic aggregation of the adjacent sub-particles can give sometimes unrealistic particles (see for instance particle 1 of figure (7)). The interest of the procedure is that no larger particle can exist that the ones given by this process. The distribution of sub-particles represents particles before clustering. The clustering should have occurred before or during the avalanche, but not during the gathering. This provides a pessimistic lower-bound of particles size. The obtained distribution for the intermediate size of particles (corresponding radius given in millimeters) is similar to a log-normal distribution (see figure 9). (μ, σ) for the normal distribution of

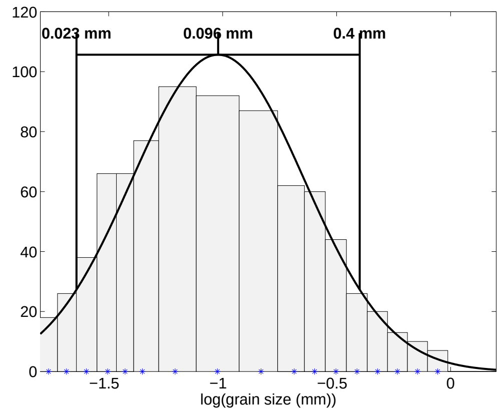

Figure 8: Log-normal distribution of sub-particles

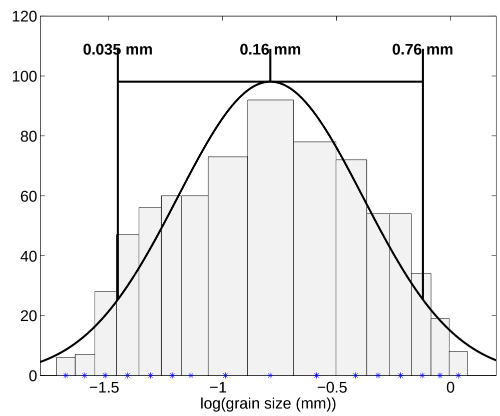

Figure 9: Log-normal distribution of particles

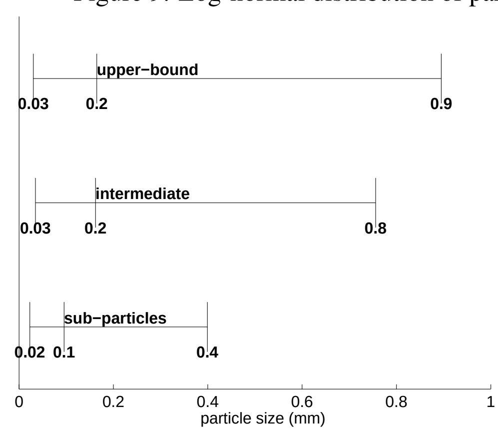

Figure 10: Size of particles

$\log 10(radius)$ are equal to $(-0.79, 0.41)$. This gives a particle radius between $0.03mm$ and $0.8mm$, with a mean radius of $0.2mm$. The upper-bound gives similar values with particle radius between $0.03mm$ and $0.9mm$, and a mean radius of $0.2mm$. The obtained distribution for sub-particles is also log-normal with $(\mu, \sigma) = (-1.02, 0.38)$ (see figure 8). This gives a pessimistic lower bound of particle radius between $0.02mm$ and $0.4mm$, with a mean radius of $0.1mm$.

Log-normal distribution has been frequently used for rain drops [13], and snow particles [20]. Rounded/wet snow particles [24, 11, 7] follow a log-normal distribution while airborne grains can be fitted using a two-parameter gamma distribution [5]. We are not aware of any results concerning size distribution of precipitation snow particles; while Colbeck [24] did not manage to show any log-normal distribution it may reasonably behave as rain drops. Notice that the particle's size probably change during the avalanche carriage: local shear due to turbulence, collisions, and energy dissipation may lead to fragmentation, melting, or fusion. But, log-normal distribution is classical when dealing with splitting [26, 4], coalescing, or crushing [14].

Size of particles in snow cover have been widely measured in different contexts (e.g. [9, 25, 17, 15]). Most measured mean sizes are between $0.1mm$ and $0.8mm$. The largest snow particles can reach several millimeters.

6 Conclusion

We have designed a disposal to capture snow particles in the body of a powder-snow avalanche. The device is able to collect some particles from the powder-snow avalanche. A slow down avoids breaking collisions. Compaction and agglomeration of particles is avoided thanks to a ceramic filter positioned at the exit of the tube. Particles are protected from any metamorphism until the experimenter can come and pick them thanks to the use of isooctane and dry ice. Snow particles have been collected in the powder-snow part of a mixed avalanche triggered on the experimental test site of the vallée de la Sionne (Switzerland). Images of snow particles have been taken in a cold chamber. They have been studied using an image processing developed for the purpose. Each particle is decomposed into sub-particles, and its volume is the sum up. A sub-particle is represented as a three dimensional ellipsoid (A, a, a) where A is the major axis and a the minor axis of an ellipse that has the same normalized second central moment as the sub-particle two dimensional image. Image processing was also used to separate particles that were adjacent on the picture. The obtained distribution of particle size (corresponding radius given in millimeters) is similar to a log-normal distribution. (μ, σ) for the normal distribution of $\log 10(radius)$ are equal to $(-0.7902, 0.4065)$. This gives particle radius between $0.03mm$ and $0.8mm$, with a mean radius of $0.2mm$.

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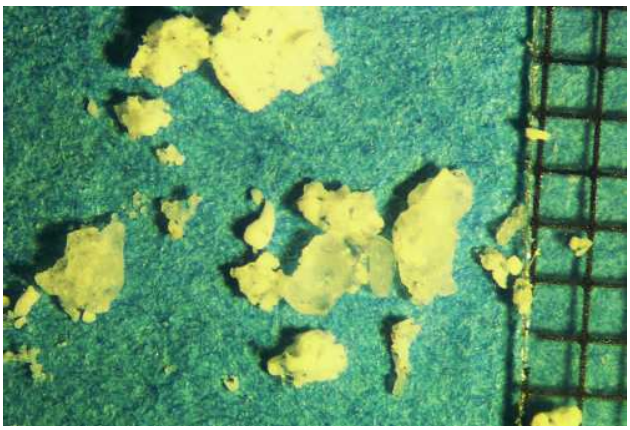

Figure 4: Initial picture

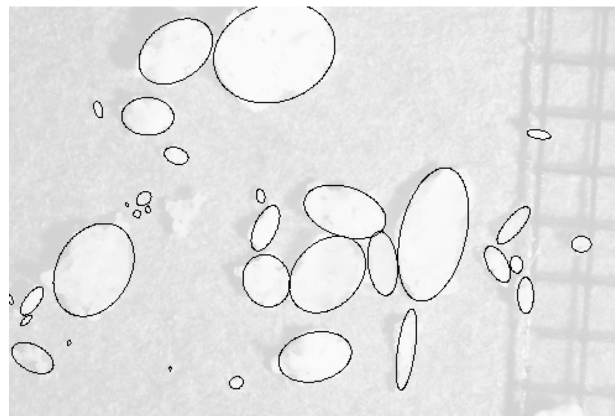

Figure 5: Particles delimited by hand and their corresponding ellipses

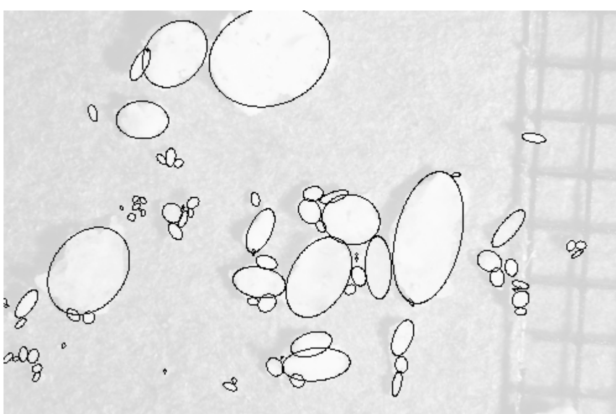

Figure 6: Sub-particles and their corresponding ellipses

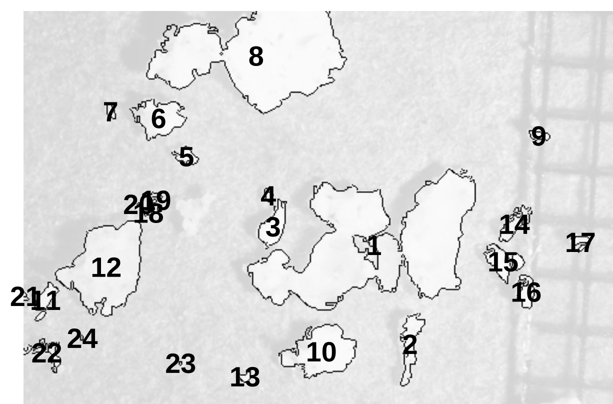

Figure 7: Upper-bound: all adjacent particles aggregated all together