HOW TO EXPLAIN AVALANCHE DYNAMICS TO CHILDREN AND …THEIR PARENTS

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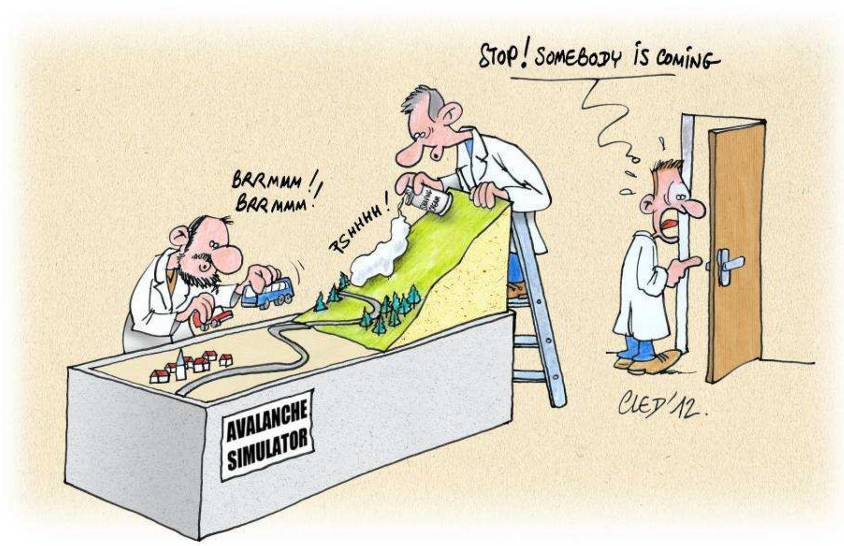
ABSTRACT: Snow avalanches threaten mountain communities worldwide: avalanches affect not only snow sport tourists but people can also be caught in inhabited areas and on roads, as reminded by the extraordinary winter of 1998/99 in the Alps. It means that we have to increase local population awareness of avalanche hazard, risk assessment and mitigation. In this case, it is interesting to focus not only on avalanche release, as it is generally done for snow sport tourists but also on avalanche dynamics and interaction with structures. In the laboratory, powder avalanches are often modeled by density currents (salt water in pure water) and dense avalanches are modeled by granular avalanches. Similitude requirements are fulfilled to estimate real pressure, velocity, run-out distance from the small-scale model.
But even if small-scale models are used in the laboratory, their dimensions are too large to be removed from the lab to exhibition halls, schools or meeting rooms. With water, salt, grains, aquarium and wood panels it is still possible to reproduce laboratory experiments physically based at a smaller scale to explain qualitatively the dynamics of powder and dense avalanches and to show the effectiveness or ineffectiveness of protective measures such as dams and retarding mounds. Examples of such experiments and devices, which can be reproduced everywhere, will be described in this paper, offering the children a unique opportunity to release the avalanche by their own and to play with grains and water. Such an initiative is thus always a success.

KEYWORDS: avalanche, dynamics, small-scale model, education, general public,



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1. INTRODUCTION

Snow avalanches are natural phenomena, as rockfalls and debris-flows, which have concerned mountainous areas for a very long time. The 20th century witnessed the increase of the human presence on mountains, as the urbanization process started and the interaction between man and mountains changed. Areas which were previously considered as rough and hostile turned out to have a very high potential for human activities, with tourism benefiting the most. The boom of winter activities led to the construction of communication ties to mountain valleys, infrastructures to host people, burgeoning ski resort and economic activities. Natural phenomena then became natural risks. A growing need of protecting goods, life and activities arose. Prior to urbanization boom of the 20th century man had always tried to protect himself. And the spread of human activity throughout mountain slope has generally been associated with an increase of scientific knowledge and protection effectiveness. Nevertheless, dramatic accidents such as those in Val d'Isère (France, 1970), Montroc (France, 1999), Evolène (Switzerland, 1999) and Galtur (Austria, 1999) remind us the further need for deeper knowledge of this complex phenomena. But at the same time, in terms of prevention, we have also to increase local population awareness of avalanche hazard, risk assessment and mitigation. One way is to explain qualitatively the dynamics of avalanches and to show the effectiveness or ineffectiveness of protective measures. And the use of small physical experiments to illustrate explanations is always more demonstrative!

2. AN AVALANCHE CAN HIDE ANOTHER

The word avalanche could derive from the Latin term labi which means to slip. Avalanches (Caccamo, 2012) generally consist of snow flow which, once released by the snow pack rupture, rapidly flows downward driven by gravity. After the release, along its flowing path, an avalanche grows, accelerates and then slows down and stops. A typical avalanche path can be separated in three main parts, as stated in the UNESCO Avalanche atlas:

- the release zone, is the area where the snow pack rupture occurs and the snow starts flowing;
- the flowing zone, generally canalized and steep, is the section where the avalanche can erode or depose relevant amount of snow, increasing its size and velocity;
- the run-out zone, where the slope decreases, the flow slows down and stops generating the final avalanche deposit.

The Avalanche atlas, which is an international avalanche classification edited by UNESCO (1981), proposes several criteria which allow to describe an avalanche :

A- Manner of starting / B-Position of sliding surface / C- Liquid water in snow at fracture, D-Form of path / E-Form of movement / F-Surface roughness of deposit / G-Liquid water in snow debris / H. Contamination of deposit

Not all of them are of interest for a given problem. Schematically, the engineer or the expert in charge of avalanche zoning and avalanche protection in run-out zone will focus on the dynamics.

2.1 *Dense avalanche*

The dense family includes wet and dry-snow avalanches (depending on the water content) and is characterized by high densities (200 kg/m^{-3}- 500 $kg.m^{-3}$). The typical flow velocity ranges between 1 and 30 $m.s^{-1}$, the mean flow depth is a few meters (in canalized conditions this value can increase significantly) but can nevertheless exert very high pressures upon impact with obstacles (up to 1000 kPa). Wet-snow avalanches occur in high air temperatures, when solar radiations are intense or when the rain brings to the water percolation through the snow pack. Melted snow (or the rain) increases the water content and the avalanche reacts like liquid flow descending at low velocities because of the high friction rate at the sliding surface. Dry dense flows follow relatively well the terrain morphology.

2.2 *Powder-snow avalanche*

Powder-snow (or aerosol) avalanches consist of turbulent suspensions of snow particles in the air. Their density is very low (1-10 $kg.m^{-3}$), but the flow depth velocity can reach up to 100 m. They can exert pressure upon 50 kPa. They don't follow topography and are able to cross the valley and to flow up the opposite slope. They generally appear, but not only, under cold and dry snow with low cohesion conditions. Pure powder avalanches are very rare at Alps latitudes. After the release, an avalanche generally starts flowing only composed by the dense part. The suspension layers can develop later. In this case we speak about mixed avalanches.

2.3 *Mixed avalanche*

Mixed avalanches are composed by a dry-dense layer flowing at the bottom, combined with a powder snow cloud on top. Between the dense layer and the powder cloud on top, a third layer represents an intermediate phase between the dense core and the aerosol outer layer. Current understanding on this layer remains limited as scientists are divided over either a saltation or fluidized layer interpretation.

Photos 1, 2, 3, 4, 5, 6 : Mixed avalanche – Abries – France – January 2004 (by courtesy of Maurice Chave)

We can first identify a powder-snow avalanche on the following and successive photos. The snow cloud height rapidly increases by incorporating air along the path. Then the cloud crosses the valley and flows up the opposite slope. The avalanche loses energy and snow particles settle, hence the impression of fog. Then avalanche deposit appears (10 meter high, you can see some people at the top of the deposit). This deposit is due to the dense part which stops in the valley. The dense flow was hidden by the powder part: it was a mixed avalanche.

3. WATER, SALT AND GRAINS TO MODEL AVALANCHES

The scientific study of avalanches is a recent subject: most of this work dates back to 40-50 years ago, the knowledge within this field remains limited and today represents a growing research area. They are three main approaches to tackle this phenomenon: (i) direct in situ information, (ii) physical simulation using small-scale models and (iii) numerical simulation. In situ measurements are the most reliable because they deal with real snow avalanches but are difficult to handle, weather dependent, most of the starting parameters cannot be controlled and they can potentially be destructive and dangerous for operators. Physical and numerical simulations were therefore developed simultaneously.

We will focus here on physical simulations because such experiments are often educational, sometimes spectacular and can be directed at a wide audience.

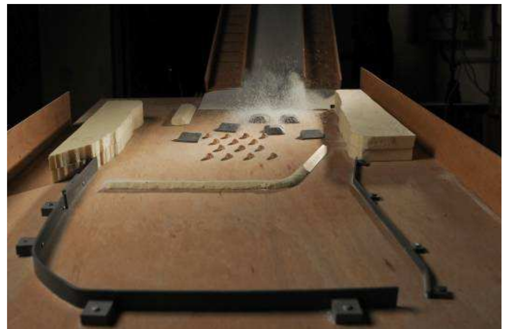
Physical modeling allows the study of avalanches in small-scale laboratory models. The full-scale predictions are obtained from small-scale experiments by using similarity criteria. Often the large number of modeling parameters cannot be satisfied.

As aforesaid, avalanches can be classified as dense-flow avalanches or powder snow avalanches depending on their flow behavior. That's why physical experiments conducted to reproduce avalanches primarily depend on avalanches type.

3.1 <u>*Dense avalanche*</u>

Dense avalanches are modeled thanks to granular materials (Faug et al., 2008). When looking at an avalanche deposit it is obvious that snow has a natural aptitude to aggregate and create larger particles. These aggregates can be approximated to grains with diameter varying from centimeters to meters. But this visual consideration is not the only similarity existing between snow flows and granular flows. A dimensionless analysis of the depth-averaged equations highlights three similarity criteria: (1) the geometry ratio, (2) the Froude number $U / \sqrt{gH}$ and (3) the difference between the slope angle and the basal friction angle (tanθ-µ). U is the down slope velocity, H is the flow height.

The model is fed with granular flows using an inclined channel with an adjustable slope, equipped at its top with a reservoir where the avalanche volume is initially stored. The adjustable slope of the channel allows the desired velocity and Froude number to be fixed at the entry to the runout zone. The granular material used is chosen after several calibration tests. In this case, we test different proportions of PVC beads of diameter 0.1mm to glass beads of diameter 1 mm to fulfill the third criteria.



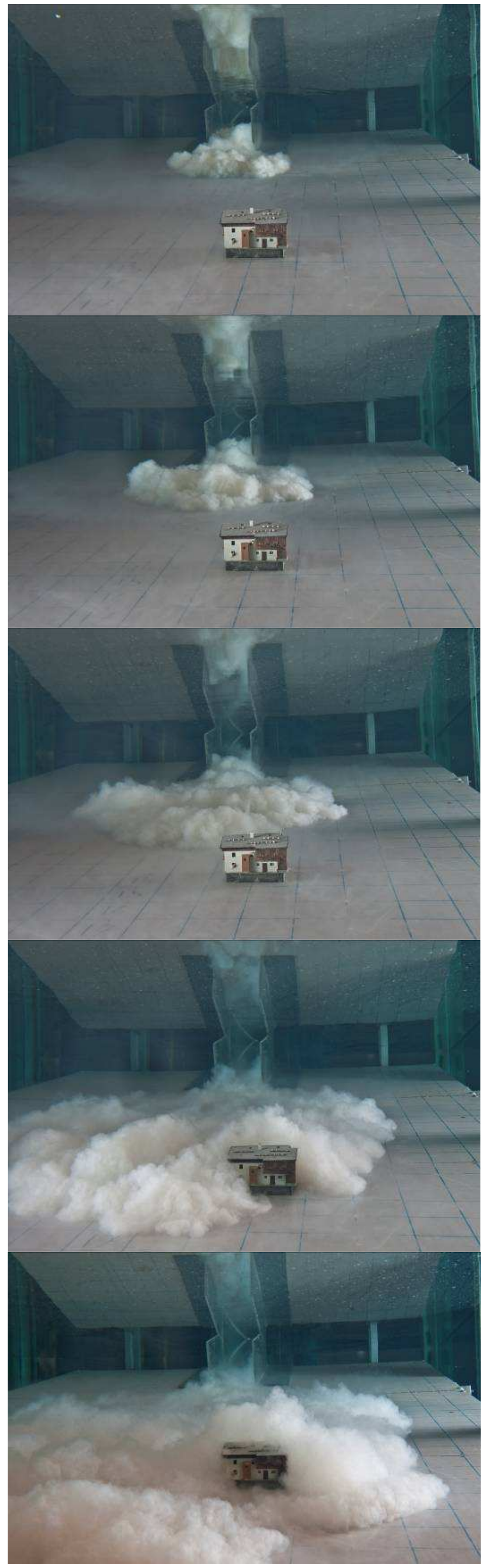


Photos 7, 8, 9, 10, 11: Small-scale modeling of dense avalanche using granular material – IRSTEA (by courtesy of Hubert Raguet)

These pictures represent some part of real experiments done at IRSTEA in order to design the most effective passive structure able to contain the reference avalanche in the Taconnaz avalanches path (Naaim et al., 2001). This is a simplified small-scale model (scale 1: 500) of the run out zone. This run out zone inclined at 13° (in the foreground) fe d with granular flows from a channel of adjustable slope (in the background) and equipped with a reservoir at the top to store material before the granular avalanche release. The incoming flow hits first mounds. The purpose of these mounds is to dissipate the energy and spread out the flow

3.2 *Powder snow avalanche*

In France, we developed a physical model of a powder avalanche using the gravity or turbidity concept, in which the powder-snow avalanche consists of a heavy fluid dispersing in a lighter one. When the Reynolds number (4) is sufficiently high, similarity is respected if the densimetric Froude number (5) $\frac{U^2}{gH\frac{\Delta\rho}{\rho}}$ and the density ratio of the current to the ambient fluid (6) $\frac{\Delta\rho}{\rho}$ are respected (where U is the down slope velocity, H is the flow height, and $\frac{\Delta\rho}{\rho}$ is the relative density difference). The experimental set-up consists of a water tank with dimensions of 4m*2m*4.5m with glass walls. Powder avalanches are simulated by salt water (density of 1.2) dispersing in pure water. The gravity current in the water tank could be made visible by adding kaolin to salt water. Buoyant clouds flow along an inclined plane from a small immersed tank with a release gate. So, contrary to what occurs in Nature, the avalanches in the laboratory simulation start as powder avalanches. Furthermore, the entrainment of particles is not simulated (Naaim-Bouvet et al., 2002).



Photos 12, 13, 14, 15, 16: Powder snow simulation in the water tank – IRSTEA (by courtesy of Hubert Raguet)

The release gate is in the background. The incoming stream flows down and growths incorporating pure water. Its turbulent structure develops into a series of characteristic eddies. Then the flow hits the house and bursts. The impact with the house makes the cloud incorporate the ambient fluid and its volume increases. This series of experiments was made specifically for journalists who like these pictures because the experiments really look like a powder avalanche. Even if it is not the most highly specialized experiment in the laboratory, we can see more or less the same images on TV report year by year.

4. RESEARCH LABORATORIES GO TO MEET GENERAL PUBLIC

Small-scale models are also great educational tools to explain the dynamics of powder and dense avalanches and to show the effectiveness or ineffectiveness of protective measures such as dams and retarding mounds. That's why an open day is held annually for 10 years at IRSTEA (previously Cemagref).
But even if they are "small-scale" models, their dimensions are too large to be removed from the lab to exhibition halls, schools or meeting rooms. Nevertheless with water, salt, grains, aquarium and wood panels it is still possible to reproduce laboratory experiments physically based at a smaller scale.

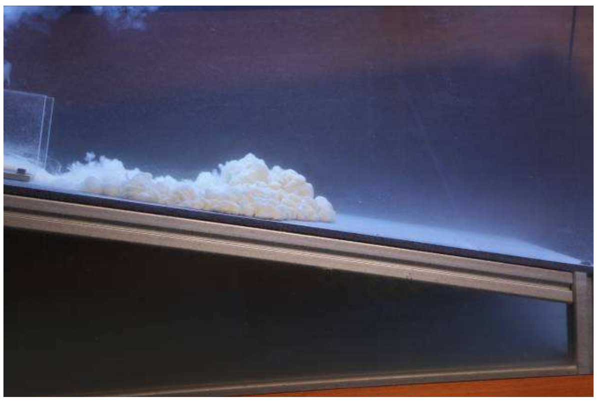
With wood panels it is possible to build a small run out zone divided in two parts with an adjustable slope, equipped at its top with a reservoir and a release gate. A small scale model of house is put on one path (on the left). The same small scale model is put on the other path (on the right) but protected by rows of mounds fixed on the floor. After the release of granular material (generally several trials are necessary before the demonstration in order to choose the right slope, released volume and proportions of PVC and glass beads), the house which is not protected by mounds is swept away by avalanche.

Photos 17, 18, 19, 20 : "Very" small-scale modeling of dense avalanche using granular material (by courtesy of Isabelle Ousset)

Other setups and experiments could be considered with the same device. By changing the proportion of glass beads and PVC beads, it is possible to show the influence of particles characteristics (ie snow characteristics) on run-out distance: the same volumes of released particles (but with different proportion of PVC and glass beads!) lead to different run-out distances.

The design of defence structures against snow avalanches typically takes into account only the dense part, which represents the greatest threat in terms of potential damage due to its high density.
Effectiveness of such devices can be explained thanks to previous experiments. But in most cases, the aerosol layer is supposed to overflow the defence structure and is considered to be the residual risk that avalanche still represents further downhill. It is also possible to increase public awareness of this issue thanks to experiments. In that case, the large water tank with dimensions of 4m*2m*4.5m could replaced by an aquarium with reasonable size. In such case it can be carried everywhere. As previously, the powder avalanches are simulated by salt water (with kaolin or talc) which is introduced into the aquarium release tank thanks to a funnel and a hose (photos 21 and 22).

The children have the opportunity to release the avalanche and to play with grains and water. That's why such initiatives are always a success.



Photos 21, 22: “Very” small-scale modeling of powder avalanche (by courtesy of Isabelle Ousset)

5. CONCLUSION

Since several years, researchers from Irstea export science from the lab to the street (Science festival, public conference, school, Comenius Regio INSTINCT (Inspiring New Scientists Through Investigations, Challenge and Teamwork)), lend material to associations which ask for, or welcome groups of children or students in the lab. It is also a nice opportunity to meet people, to explain them all other research activities dealing with snow avalanches, to share a passion and also to appeal new generations to science.

Photo 23: Public conference (Vaulnaveys-2009) (by courtesy of Isabelle Ousset)

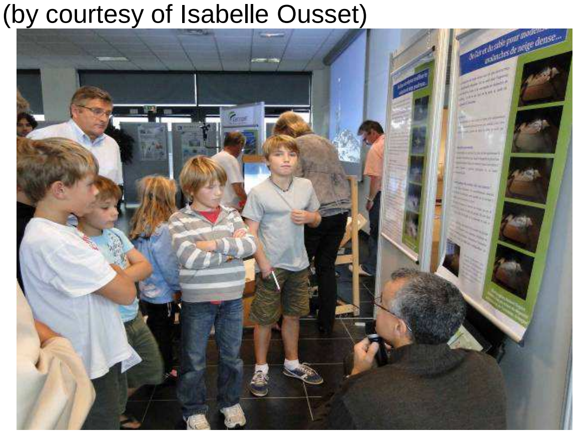


Photo 24: 40 years of ANENA (Grenoble 2012) (by courtesy of Dominique Letang)

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