Short user manual for the Cemagref dense snow avalanche model based on Shallow water equations

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Le Cemagref

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Requirement : Excel software and the file sv.xls, November 26, 2003

1 Installation

All files should be copied to c:\cemagref\cm. The paths have been hard coded. The “usual” US ‘.’ decimal separator should be set in “Menu démarrer, paramètres, options régionales”.

2 About this model of snow avalanches

A model is a simplified representation of reality (That is what makes them useful). The present model, and others built on the same principles by NGI or SLF are used to estimate run out distances, and sometimes velocity and pressures occasioned by dense snow avalanches.

In all cases, adjusting part of the parameters on observed events secures the predictions that can be extrapolated from a model.

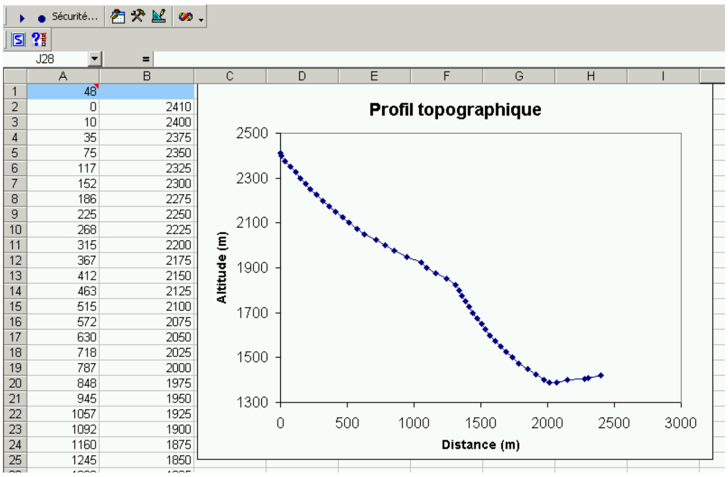
A dense snow avalanche is considered here as the free surface flow of an incompressible fluid moving under a gravity field. We have adopted shallow water hypotheses, which hold only when the flow thickness is small, compared to its length. They are classically used for hydraulic river modeling.

1.1 Topography in one dimension

The data format is:

- n (points in the profile)
- x1, z1
- …
- xn, zn.

The data should be derived form a source at least as precise as a 1:25000 topographic map (IGN map in France), with further control according to a terrain observation that no feature that might be significant to the avalanche is left over.



	A	B
1	48	
2	0	2410
3	10	2400
4	35	2375
5	75	2350
6	117	2325
7	152	2300
8	186	2275
9	225	2250
10	268	2225
11	315	2200
12	367	2175
13	412	2150
14	463	2125
15	515	2100
16	572	2075
17	630	2050
18	718	2025
19	787	2000
20	848	1975
21	945	1950
22	1057	1925
23	1092	1900
24	1160	1875
25	1245	1850

Figure 1: Topography profile

The release area is a segment along the profile, provided by the user. So is the height of snow that can be triggered into movement, all along the avalanche path (i.e., on each point of the topographic profile).

Two parameters characterize the avalanche on each point of the topographic profile reached by the flow:

- its thickness h;
- its velocity u.

This snow moves either on the ground or on a certain thickness of still snow.

Equations of mass and momentum conservation, of friction and erosion-deposition as implemented in the code determine acceleration (positive or negative), snow erosion and deposition at each space step. Time steps, velocity, thickness of flow and deposition as well as induced pressure result from numerical resolution of these equations.

Second order effects of slope variations are not accounted for.

More precisely, around each topographical point is a cell spanning 5m when projected on the x axis, with a given slope, and given thicknesses (positive or null) of still or moving snow. These conditions determine a specific time step, so there is no global clock for the computations over all cells. At each iteration, the shortest time step is taken from the most constraining cell, and used for all the others to insure non divergence of calculations. 10*dt*umax<(dx=5m) has proved convenient.

In fact, as suggested in figure 2, the layer does not move as a solid. Velocity within the layer u_z is described as a function $u_z = uf(\frac{z}{h})$. This expression is used in the model through parameter α as shown in the equations below.

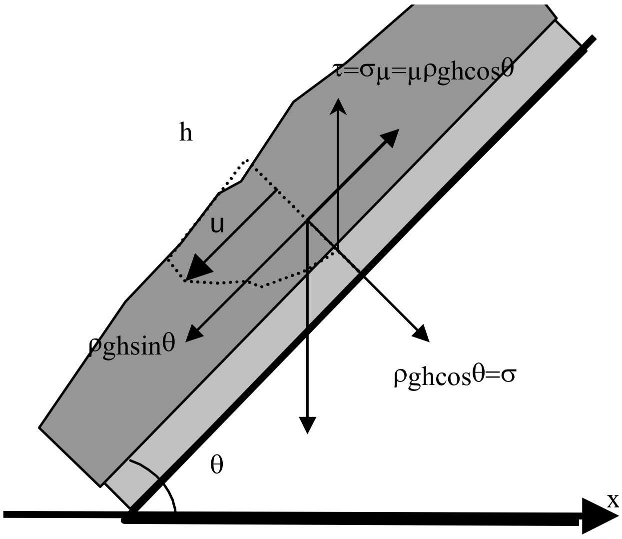


Figure 2: the main model parameters

1.2 Friction and erosion model

Following the so-called Coulomb representation, the friction modulus at the bottom of the flow is proportional to the normal component of weight.

The balance of forces applied to still snow being positive, some snow is entrained and the avalanche gains mass. Otherwise, the avalanche deposits snow and less mass is involved in the movement.

The resulting tangent force is:

$$\tau = \left[\mu + \frac{u|u|}{h\xi} \right] \rho g h \cos(\theta) \qquad (1)$$

μ is a dry friction coefficient, ξ is the inertial friction coefficient, the slope angle, is the mean the velocity obtained by integrating the velocity profile.

Mass and momentum equations are integrated on a vertical axis; t being the current time step.

$$\frac{\partial h}{\partial t} + \frac{\partial hu}{\partial x} = \phi_{e/d} \qquad (2)$$

$$\frac{\partial (hu)}{\partial t} + \frac{\partial}{\partial x}\left(\alpha h u^2 + g\frac{h^2}{2}\right) = gh\sin\theta - \left[\mu + \frac{u|u|}{h\xi} \right] gh\cos\theta \frac{u}{|u|} \qquad (3)$$

$$\frac{dz}{dt} = \varphi_{e/d} \qquad (4)$$

$$u_z = uf\left(\frac{z}{h}\right) \; and \; \alpha = \frac{\int_0^h f^2\left(\frac{z}{h}\right)dz}{\left[\int_0^h f\left(\frac{z}{h}\right)dz\right]^2}$$

Z_s is the terrain elevation

$\phi_{e/d}$ is the algebraic term of flux of erosion or deposition

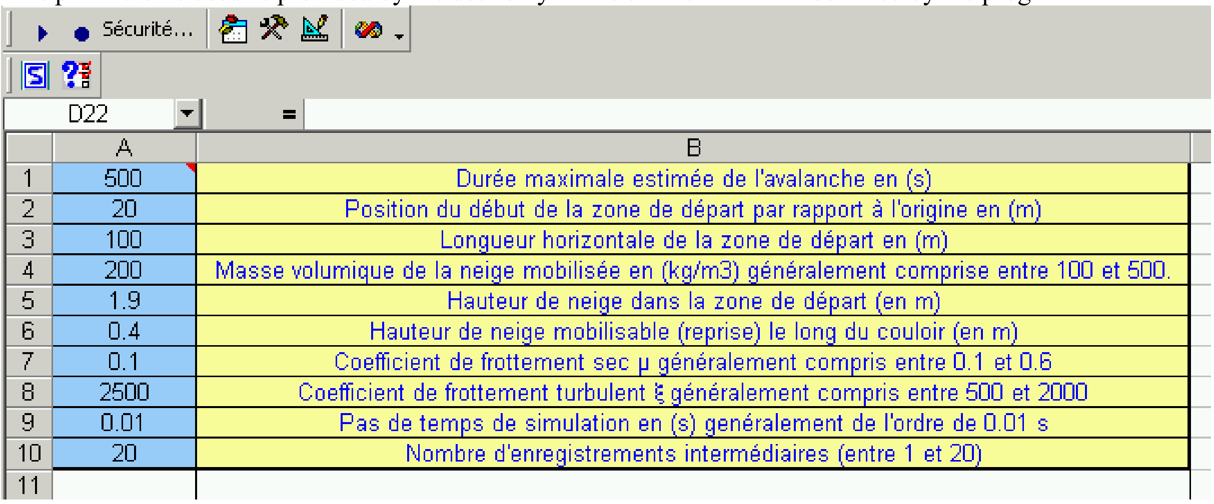
3 A simulation run

The following parameters are demanded:

T : estimated maximum duration of the whole avalanche flow. T varies in practical situations from 30 to 300s. It has no effect, except that the calculations could stop while some snow is still moving. This allows you to get the state at any precise time duration.
Release area, given by D, beginning of starting zone, along x axis (in metres) and L, its length
ρ density of moving snow (in the range100 to 500 kg/m^3). ρ has no effect on simulation, it can be used to obtain a pressure from the velocity: $p = \rho(gh + \frac{1}{2}u^2)$
(6)
hi : snow thickness in the release area
hr : still snow, along the path
μ : is a dry friction coefficient, should be in the range 0.1 to 0.6
ξ is the inertial friction coefficient , in the range 500 to 2000
dt : simulation time step, generally 0.01s is OK.
N The simulation is divided into N equal periods, and for each the final parameters values are recorded for ulterior displaying. For practical reasons, 0<N<20, after what the curves superimpose.
That's the friction coefficient at low speed between the sliding and the still snow. It influences all the avalanche flow, especially the stopping phase.
Many experiments have aimed at determining value for μ between snow and other materials. Cassassa (1992) has published values for μ at different velocities and temperatures for snow sliding onto itself. They range from 0.22 at –25°C to 0.45 at –5°C. Adjustment of the parameters of the present model on observed avalanches suggest a range from 0.1 to 0.6.
The global friction is decomposed into two terms, μ is the first, ξ being indexed on velocity. The larger ξ, the faster the avalanche can run on a given cell. Cross-experiments suggest a reasonable value for ξ between 500 and 2000.
One can take advantage of this coefficient to account for characteristics such as narrowing, widening of the avalanche path, presence of rocks, forest, etc. that are not represented otherwise in the model. Obstacles would slow the avalanche down and therefore call for more friction, and lower values of ξ.

3.1 The initial time step

This parameter is used as provided by the user only if it is smaller than that obtained by the program.



	A	B
1	500	Durée maximale estimée de l'avalanche en (s)
2	20	Position du début de la zone de départ par rapport à l'origine en (m)
3	100	Longueur horizontale de la zone de départ en (m)
4	200	Masse volumique de la neige mobilisée en (kg/m3) généralement comprise entre 100 et 500.
5	1.9	Hauteur de neige dans la zone de départ (en m)
6	0.4	Hauteur de neige mobilisable (reprise) le long du couloir (en m)
7	0.1	Coefficient de frottement sec μ généralement compris entre 0.1 et 0.6
8	2500	Coefficient de frottement turbulent ξ généralement compris entre 500 et 2000
9	0.01	Pas de temps de simulation en (s) généralement de l'ordre de 0.01 s
10	20	Nombre d'enregistrements intermédiaires (entre 1 et 20)
11		

The parameters on sv.xls
The SaintVenant macro calls the simulation code. For each of the N records, thickness, velocity, pressure are given on each topographical point in the *Resuh*, *Resuu* and *Resup* sheets, and drawn in the *Graphe-hauteur*, *Graphe-vitesse* and *Graphe-pressio* sheets. A non-null velocity at the last recorded step should prompt to rerun the simulation with an augmented T.