Adaption and further development of the numerical solution in the avalanche simulation model SamosAT

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ABSTRACT

The avalanche simulation model SamosAT is in practical application for the assessment of potential avalanche hazards since 2008. Step by step the tool has been further developed. The current software release 2015 of SamosAT contains new improvements, especially to optimize the modeling of the dense flow part. The new release focuses on enhancements in the numerical solution as well as on the modeling of avalanches by implementing new boundary conditions. Additional features are optimizing the handling of the program. This paper gives an overview of the main new features and procedures of the SamosAT update including first work experiences and recommendations for the practical application.

KEYWORDS

avalanche modelling, SamosAT, avalanche simulation, model improvements

INTRODUCTION

The avalanche simulation software SamosAT (Snow Avalanche MOdelling and Simulation - Advanced Technology) is an approved tool for the assessment of potential avalanche hazards for many years. The SamosAT modeling recommendations were updated according to the actual findings (see Granig, Sauermoser, 2009; Joerg et al., 2010). The program release of SamosAT in March 2015 gives new possibilities in the simulation. In this paper we concentrate on the major enhancements of the model. Therefore we explain the newly implemented Smoothed Particle Hydrodynamics (SPH) function in more detail. So far the SamosAT model worked with a predefined end time criterion. Now a stop criterion based on the flow energy has been introduced to optimise the simulation time and to avoid premature simulation cut offs. Furthermore the mountain snow cover (MSC) approach (Fischer, 2013), that provides a continuous initial snow distribution, which can be used as boundary condition for avalanche release and entrainment is implemented in the SamosAT software. This feature allows an easy application and quick comparisons with the standard avalanche release for the analysis of the results.

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METHODS

The lateral pressure forces within the SamosAT dense flow avalanche (DFA), acting tangentially to the terrain surface and in direction against the flow depth gradient, have been calculated in a simplified way in SamosAT. Under certain circumstances this has resulted in artificial "fingers" in the predicted DFA deposition. Figure 1 shows an example of such a finger on the orographic left side of the simulation. This problematic behaviour has been corrected by an improved calculation of these forces. The improved result is shown in figure 2. Also the overrun of the ridge in the avalanche runout on the orographic right side is reduced in the SPH mode.

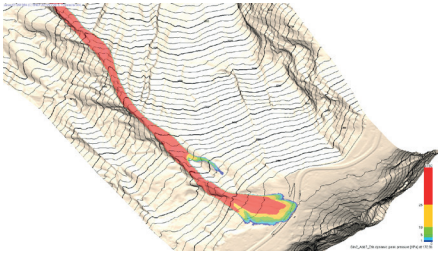

Figure 1: SamosAT DFA standard simulation with lateral spreading

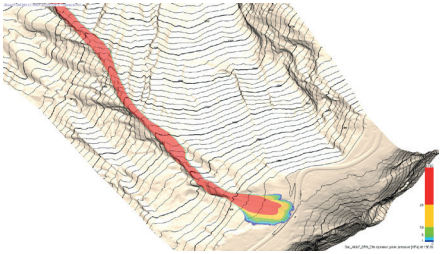

Figure 2: SamosAT DFA simulation with SPH mode

In order to explain what has been changed, some background information on the SamosAT simulation needs to be given.

SamosAT, like for instance the model of Savage and Hutter (1989) or Hungr (in Harbitz et al. 1998), employs a Lagrangian method to compute the DFA movement instead of the more common Eulerian method, as used for instance in RAMMS (Christen et al. 2008). The essence of the Lagrangian method is that the control volumes (CVs), used to apply the fundamental equations of conservation of mass and momentum, are attached to the fluid mass and move with the fluid, while in the Eulerian method the CVs are grid cells attached to the terrain model and hence have a fixed position. Since the avalanche typically covers a small part of the terrain only at a given time, the Eulerian method wastes storage and computational effort by filling the entire terrain with CVs. The Lagrangian CVs are always concentrated in the avalanche, effectively rendering a higher numerical resolution with the same number of CVs. Furthermore, the Lagrangian method is simpler to implement since there is no mass transfer between the CVs. With the Euler method, the mass flow between the CVs has to be computed for each time step. The disadvantage of the Lagrangian method, however, is that the momentum transfer between the CVs due to lateral friction and pressure is much harder to compute, since neither the shapes of the CVs nor their boundary surfaces are actually known precisely, only the centres of gravity of the CVs are. Fortunately, for shallow flows like the DFA, it can be shown (see Savage & Hutter 1991) that lateral friction and pressure forces are much smaller than the main forces, which are gravitational acceleration, bottom pressure and bottom friction. Indeed lateral friction is so small that it is ignored by most of the avalanche models altogether (see Harbitz et al. 1998), and lateral pressure

needs not be calculated with full accuracy. This fact finally makes the Lagrangian method very attractive for DFA simulations.
In the momentum balance for a CV, the pressure force ***Fp*** may be formulated as

$$F_p = -mg\nabla h$$

with ***m*** the mass of the CV, ***g*** the gravitational acceleration and ∇***h*** the gradient (vector) of the flow depth. SamosAT used a simple and fast method to compute the depth gradient. First, the masses of all CVs were assigned to points of an auxiliary uniform grid according to an inverse bilinear interpolation. Then the flow depth was computed from the summed masses at each grid point and finally the depth gradient was computed from a bilinear interpolation from the depths at the grid points. This works fine as long as the flow depth is not too small or the main forces are large compared to the lateral pressure. But for a single CV in the runout zone, where the main forces tend to zero, this method always gives a depth gradient and pressure force which drives the CV towards the centre of the containing auxiliary grid cell. The gradient is zero at the cell centre only, which is clearly unphysical. It should be zero everywhere for an isolated single CV. In presence of shallow channels in the runout which are aligned with the grid lines, this computation method even leads to the formation of "chains" of CVs. To resolve this problem, the depth gradient is now computed according to the Smoothed Particle Hydrodynamics (SPH), a Lagrangian method, which is well known in fluid dynamics (Monaghan 1992). According to SPH, the flow depth h at any terrain point x may be computed as the sum over all CVs,

$$h(x)=\sum m_p \rho^{-1} w(r_{xp})$$

with m_p the mass of the p-th CV, ρ the flow density and w a "kernel function" dependent on the distance r_{xp} between x and the centre of the CV. The kernel function (figure 3, left) has the dimension m^{-2} and is chosen such that it drops to zero for distances larger than a smoothing length r_k, which is determined to be identical to the grid size of the terrain model in SamosAT (usually 5 m). Only CVs within this distance need to be considered in the sum (figure 3, right).
Taking the gradient of this depth function yields

$$\nabla h(x)=\sum m_p \rho^{-1} \nabla w(r_{xp})$$

This relation is used in SamosAT to compute the depth gradient at each CV-centre and the pressure force acting on it. This method avoids any auxiliary grid and the formation of grid-aligned "chains" and gives a zero depth gradient for a single CV with no other CVs closer than the smoothing length. It generally leads to a more homogenous distribution of the CVs. The method is slower than the original one, because all CVs closer than the smoothing radius have to be determined for each CV at each time step. Using fast searching algorithms this

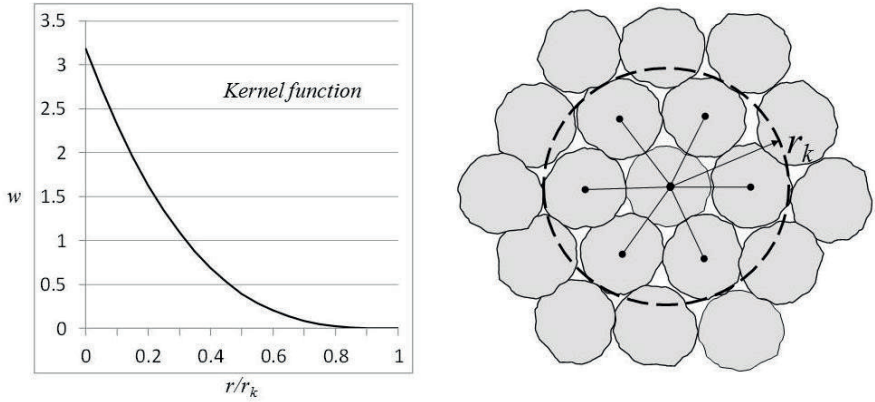

Figure 3: SPH kernel function used in SamosAT and CVs contributing to the flow depth

overhead can be reduced such that DFA simulation times increases by about 20% to 50%. The SPH method gives a substantially more homogeneous distribution which is numerically desirable.

Another improvement in SamosAT is the implemented stop criterion, such that the simulation is automatically terminated as soon as the avalanche comes to a rest. The model optionally stops as soon as the kinetic energy of the entire avalanche drops below a user defined fraction (typically 2-3%) of the maximal kinetic energy that occurred in the running simulation up to this point. Using the running maximum as reference ensures that the simulation is neither stopped prematurely in the release phase nor continued too long due to trailing avalanche parts still slowly moving when the main part has already stopped. The criterion is checked separately for the DFA-part and the powder-snow-part (if active), and the stop is performed only if the condition holds for both parts at the same time. The energy threshold values are derived pragmatically to ensure sufficient calculation steps and to save calculation time. A 2 % threshold value is good to be on the rather safe side, especially for smaller avalanches with a lower energy maximum to avoid early cut offs. In the previous versions it was necessary to predefine an end time (usually 200 sec.). Consequently after the simulation it was required to check, whether the assumed end time was sufficient. This procedure was time consuming and led in some cases to too short avalanche runout simulations.

The mountain snow cover (MSC) approach was implemented in SamosAT as an additional feature to provide an alternative boundary condition for the snow mass input. This approach assumes a smooth snow cover distribution (hMSC) over the whole digital terrain model. It has the advantage that the definition of especially the lower end of an avalanche release area has less importance, because the potential snow entrainment provides similar snow heights along the avalanche path. Though the concept works properly it needs careful handling as a

consequence of the shift of release mass to rather more snow entrainment. With the new implementation of this concept it can be easily tested and studied as an alternative simulation result. More details about the idea and the simulation of MSC can be derived from Fischer (2013) and Fischer et al. (2014).

RESULTS AND CONCLUSIONS

The tests with the SPH mode in SamosAT displayed a compact runout behavior as shown in figure 1 also for avalanches in complex terrain. This is in some cases resulting in slightly shorter avalanche (DFA) runout calculations. In a next step the avalanche simulation with SPH needs a comparison with the reference avalanche data pool for systematic verification. Therefore we recommend the practical application of the SPH mode as an additional scenario to the standard simulations in conjunction with a careful plausibility check to use the simulation for further assessments.

So far the MSC approach usually calculates a rather big avalanche runout behavior in comparison to the documented avalanche events. A possibility is to combine the mountain snow cover approach with the SPH module. The first step is done to introduce the feature of the mountain snow cover simulation in the SamosAT program. Now further analysis can be done to verify and to develop a practical application procedure also for the standard simulation routine.

The stop criterion is working as planned and can already be used in the practical application. We recommend a defined fraction of the kinetic energy of 2% for both dense flow and powder flow avalanches. Hence premature runout cut offs can be minimized with the stopping criterion. The computational time benefit is though smaller as expected. Still for computing powder snow avalanches which takes several hours the time saving is in order of 10-15% of the total simulation time. Now with this new feature early cut offs can be avoided. Furthermore it reduces a potential source of error.

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