COMPARSION of POWDER SNOW AVALANCHE SIMULATION MODELS (**RAMMS** and **SamosAT**) BASED on REFERENCE EVENTS in SWITZERLAND

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ABSTRACT: In this paper, we compare two advanced avalanche dynamics simulation tools: **SamosAT** and **RAMMS**. Both tools apply similar depth-averaged approaches to model the avalanche core, including cohesive extensions to the classical Voellmy flow rheology. However, they apply vastly different approaches to model the formation and motion of the powder cloud. The extended **RAMMS** model considers streamwise variations of avalanche flow density that are coupled to the statistical configuration of the snow particles. Expansions and contractions of the particle configurations define the mass and energy fluxes driving the formation of the powder cloud. **SamosAT** assumes mass transfer into the powder cloud proportional to the shear stress acting on the dense flow surface and models the powder cloud as a three-dimensional, two-phase flow of ice-particles and air. **RAMMS** adopts a two-phase depth-average approach for the powder cloud leading to dramatic reduction in calculation times. However, information over the height of the cloud is lost. In **RAMMS** snow entrainment is considered as a collisional-thermomechanical process that amplifies random mechanical energy fluxes that enhance the configurational energy of the core and therefore the formation and strength of the powder cloud. Also in **SamosAT** entrainment can be included in various ways through the dense flow layer, or directly into the powder cloud, taking into account threshold values of particle-Froude numbers. However, in the standard operational setting entrainment is currently not activated. We apply both simulation tools to three well-documented reference events from Switzerland. We compare not only the predicted process area, but also peak velocities and impact pressures. Both simularities and differences in the simulation results exist.

Keywords: powder snow avalanche, **SamosAT**, **RAMMS**, snowcover, entrainment, case studies..

1. INTRODUCTION

Simulations are a standard tool for hazard and risk assessment of snow avalanches. One way to test the applicability of advanced avalanche simulations is to use and compare different tools to simulate the same set of avalanche case studies. At present, avalanche simulation tools differ in three important areas: (1) the underlying flow model that describes the friction of the dense flowing avalanche up to the formation of the powder cloud (2) the interaction with the snowcover and respective entrainment model and (3)if implemented, the model to describe the motion of the powder cloud. Avalanche simulation tools strongly deviate in their theoretical assumptions and further differences come into effect when transferring the theory into efficient computer algorithms, i.e. the numerical implementation.

In this paper we compare the simulation results of two advanced simulation programs on three reference avalanches in Switzerland: the extended **RAMMS** model (Christen et al., 2010; Buser and Bartelt, 2015; Bartelt et al., 2016) and **SamosAT** (Sampl and Zwinger, 2004; Sampl and Granig, 2009). Both models are able to predict the motion of the avalanche core and powder cloud. Hence, they can be applied in practice to address the destructive power of powder snow avalanches. In some respect there are significant differences between the two models that have important implications in an operational setting. **SamosAT** is calibrated for extreme events (return period of 150 years), which can lead to an overestimation of powder impact pressures for smaller and more frequent avalanches. Furthermore, in standard operational use, snow entrainment is not explicitly considered. Snow entrainment is implicitly accounted for by using model parameters (e.g. friction coefficients) for extreme events. This approach is similar to the operational **RAMMS**

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model where entrainment is not explicitly included in the calculations. Like SamosAT, calibrated parameters are applied. This approach is not adopted by the extended RAMMS model. The extended **RAMMS** model does not apply calibrated parameters for a certain return period. Specific snowcover information, such as the snow density, temperature and erodibility, need to be specified. The properties of the snowcover have a strong influence on the fluidization of the avalanche core and therefore the formation and intensity of the powder cloud. Thus, the two models can only be compared if they are modelling the "same" extreme avalanche. To test the models we use the same set of initial and boundary conditions (location, dimension and density of release zone, digital elevation model, entrainment conditions). Each model uses its own calibrated parameters to predict powder cloud inundation areas with the corresponding velocities and impact pressures.

2. CASE STUDIES

The three case study areas are the (1) San Gian, Canton Grisons, (2) Zermatt, Canton Wallis and (3) All'Aqua, Canton Tessin. The terrain and initial conditions of the three case studies are report in the overview Table 1.

In 1916 a large powder avalanche reached the river Inn, inundating a field near the village of St. Moritz (Fig. 1). The powder avalanche destroyed forests approaching the field, and on the other side of the river. This avalanche event became of interest when it was not possible to recalculate the primary flow direction of the 1916 event with the standard **RAMMS** model. Subsequently, the extended **RAMMS** model was applied.

The Zermatt example problem arose when a local engineering office wanted to check the existing yellow (powder) avalanche zone. The existing zone was delineated using historical observations as well as one-dimensional avalanche dynamics calculations with **AVAL-1D** (Christen et al., 2002).

The powder cloud of the 1999 All'Aqua avalanche event destroyed forest and overturned a power transmission pylon (Schaer, 1999). The observed avalanche release zone was relatively small. Snowcover entrainment or secondary releases therefore played an important role in growth and the final destructive potential of the event. Calculation of the event with the extended **RAMMS** model is presented in Stoffel et al. (2016).

3. MODEL COMPARISON AND CONCLUSIONS

Maximum calculated velocities for the avalanche core and powder cloud impact pressures are presented in Figs. 1 and 2 for San Gian, Figs. 3 and 4 for Zermatt and Figs. 5 and 6 for All'Aqua. Powder avalanche velocities and impact pressures are also compared along selected profiles for all three events. The profiles are along the calculated path of maximum powder avalanche velocity of the respective model, hence there is a slight difference in their spatial location.

The most apparent difference in the calculations is the calculation of the avalanche core. In all three case studies the **RAMMS** calculated runout distances and peak core velocities are higher than predicted by **SamosAT**. **RAMMS** applies model parameters for cold, weakly bonded snow. This leads to high entrainment rates and fluidization of the avalanche (necessary for the powder cloud to form). The consequence of this modelling approach is that the **RAMMS** avalanches do not follow the terrain as closely as the **SamoAT** simulations. The avalanche cores penetrate deeper into the runout zone. For example, in San Gian case study, the **SamoAT** avalanche is deflected towards the village of St. Moritz by a gully, whereas the **RAMMS** avalanche follows a strait path to the road and open field (Fig. 1). In Zermatt the **RAMMS** avalanche accelerates strongly on the steep slopes above the village, leading to higher core flow velocities (Fig. 3). In San Gian and Zermatt this leads to higher powder cloud velocities (compare profiles).

Another obvious difference between the calculation results is the degree of lateral spreading of the powder cloud. In all three case studies **SamosAT** predicts a larger spread of powder cloud impact pressures. **RAMMS** predicts these areas would be overrun by the cloud, but the impact pressures attenuate strongly. Interestingly, the **RAMMS** impact pressures are higher, because of the higher cloud velocities, *but only in the direction of the core*. It appears that the **RAMMS** core and cloud movements are more strongly coupled. It should be pointed out that in two case studies, San Gian and All'Aqua, the observed damage from the powder cloud was not widespread, but concentrated in the runout direction of the core. In the All'Aqua case study, **SamosAT** predicts the flowing avalanche will stop before reaching the steep gully above the settlement. This is a plausible result, which can be easily obtained with the **RAMMS** model by assuming more strongly bonded snowcovers. However, in such a situation the calculated **RAMMS** powder cloud would certainly stop well above the settlement of All'Aqua. We arrive again at the conclusion that the motion of the core and cloud are more strongly coupled. The powder cloud calculations of **SamosAT** appear to be optimized for extreme avalanches and are independent of the actual core movement. Both approaches have advantages and disadvantages in a practical setting.

At present the pressure calculation in **RAMMS**

Table 1: Overview of release and entrainment conditions for the three avalanche case studies: San Gian (GR), Zermatt (VS) and All'aqua (TI). The growth index is the calculated ratio of final mass to the inital avalanche mass. The suspension ratio is the calculated mass of the powder cloud in relation to the total mass.

							RAMMS		SamosAT	
Event	Release volume (m^3)	Release height d_0 m	Release density (kg/m3)	Release elevation (masl)	Runout elevation (masl)	Final volume (m^3)	Growth index (-)	Susp. ratio (%)	Growth index (-)	Susp. ratio (%)
San Gian (GR)	177,670	1.10	200	2400-2550	1770	266,000	3.7	9.8	no Entr.	7.17
Zermatt (VS)	82,350	1.40	200	2500-2600	1650	184,380	4.7	4.9	no Entr.	2.52
All'Aqua (TI)	37,800	1.50	200	2400-2550	1600	88,970	5.3	10.7	no Entr.	5.35

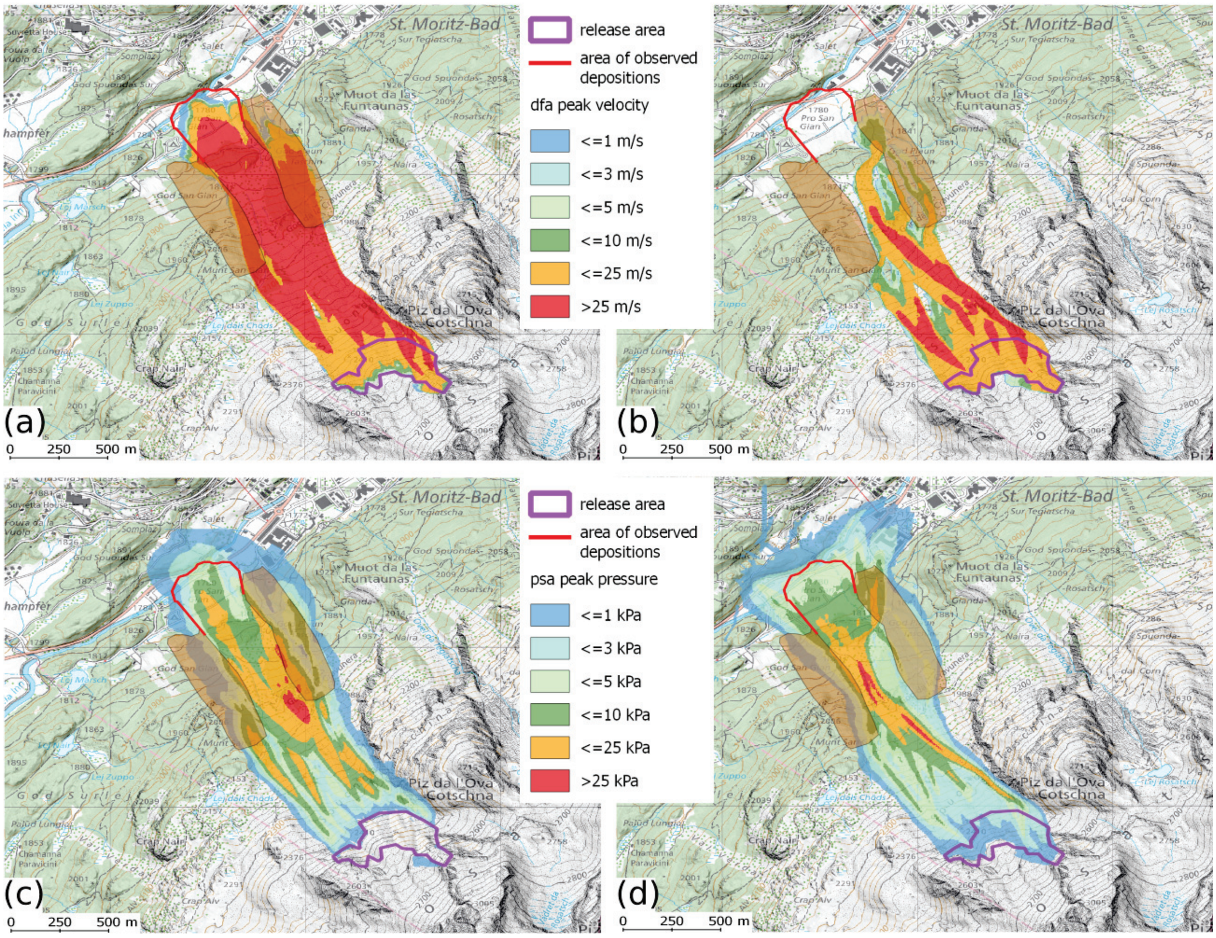

Figure 1: **SamosAT** and **RAMMS** calculations of the San Gian (St. Moritz) avalanche event. a) Max flowing velocity core **RAMMS**, b) Max flowing velocity core **SamosAT**, c) Max powder pressure **RAMMS**, d) Max powder pressure **SamosAT**. The primary difference is simulation of the avalanche core. The **SamosAT** simulation follows the terrain, while the **RAMMS** simulation covers the valley bottom.

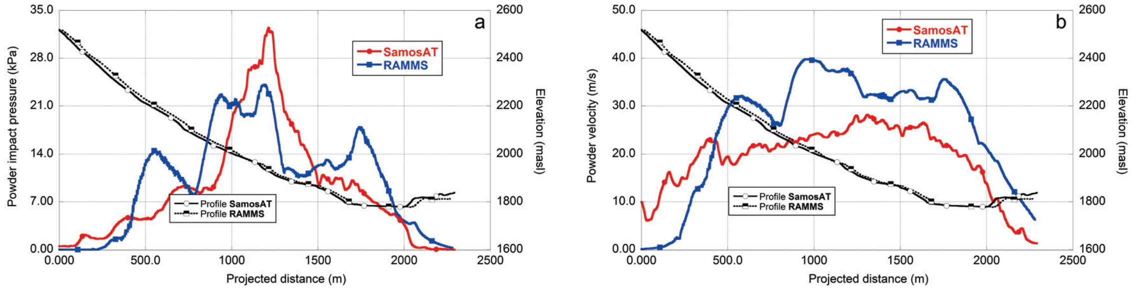

Figure 2: Profile comparison San Gian case study. a) Powder cloud impact pressure. b) Powder cloud velocity. **RAMMS** predicts higher mean velocities; impact pressures are slightly larger in the runout zone.

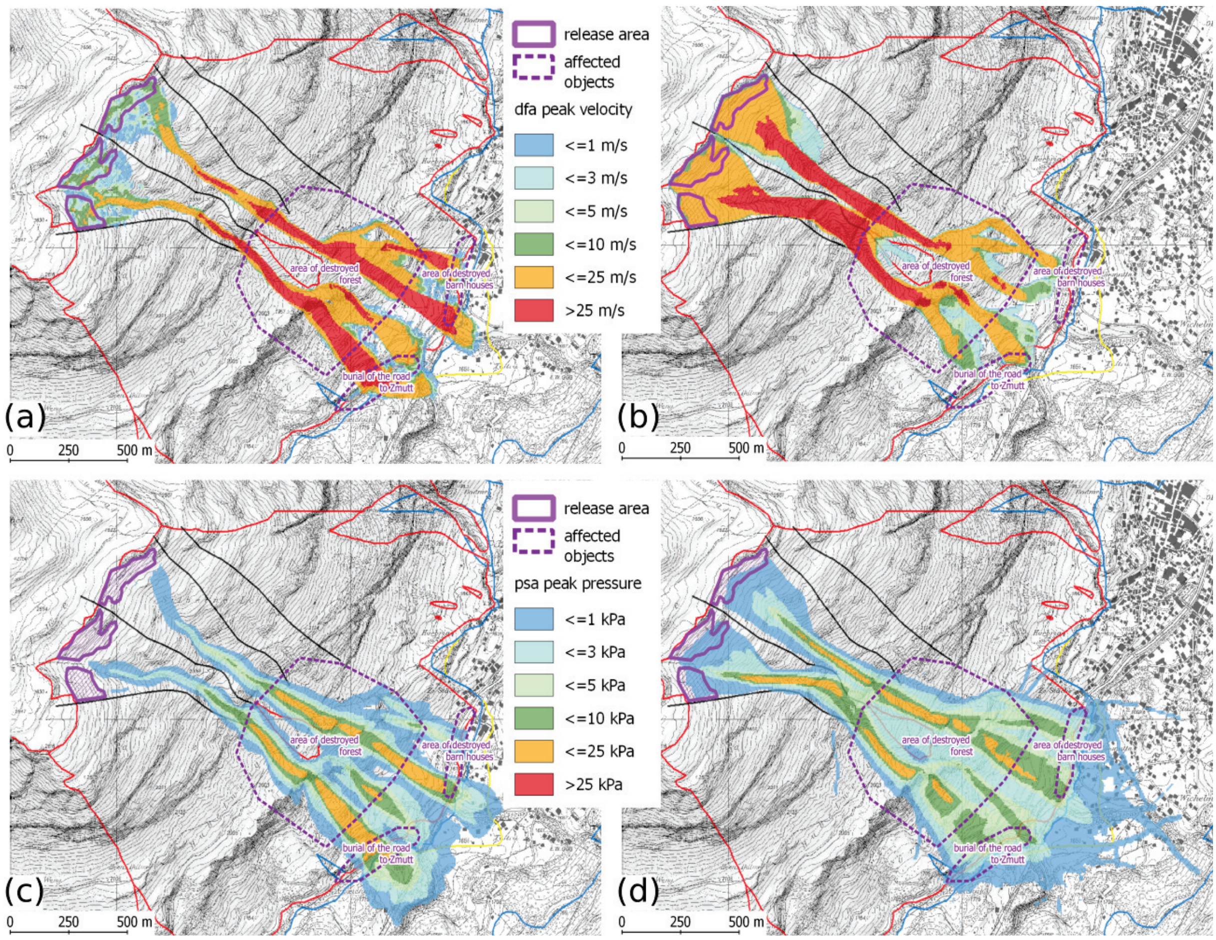

Figure 3: **SamosAT** and **RAMMS** calculations of the Zermatt case study. a) Max flowing velocity core **RAMMS**, b) Max flowing velocity core **SamosAT**, c) Max powder pressure **RAMMS**, d) Max powder pressure **SamosAT**.

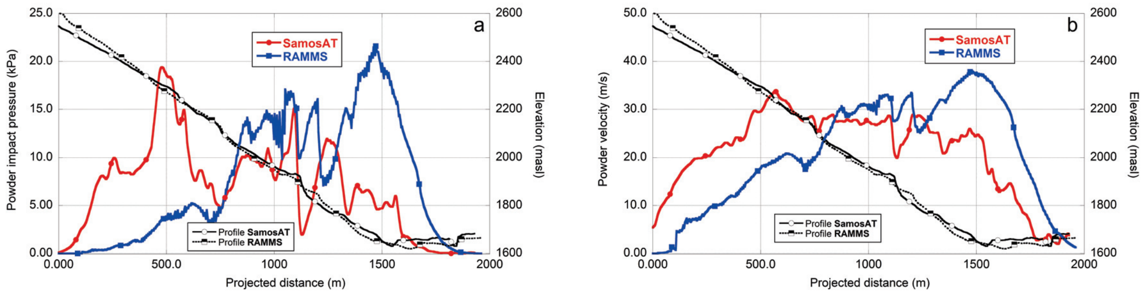

Figure 4: Profile comparison Zermatt case study. a) Powder cloud impact pressure. b) Powder cloud velocity. **RAMMS** predicts higher mean velocities; impact pressures are slightly larger in the runout zone.

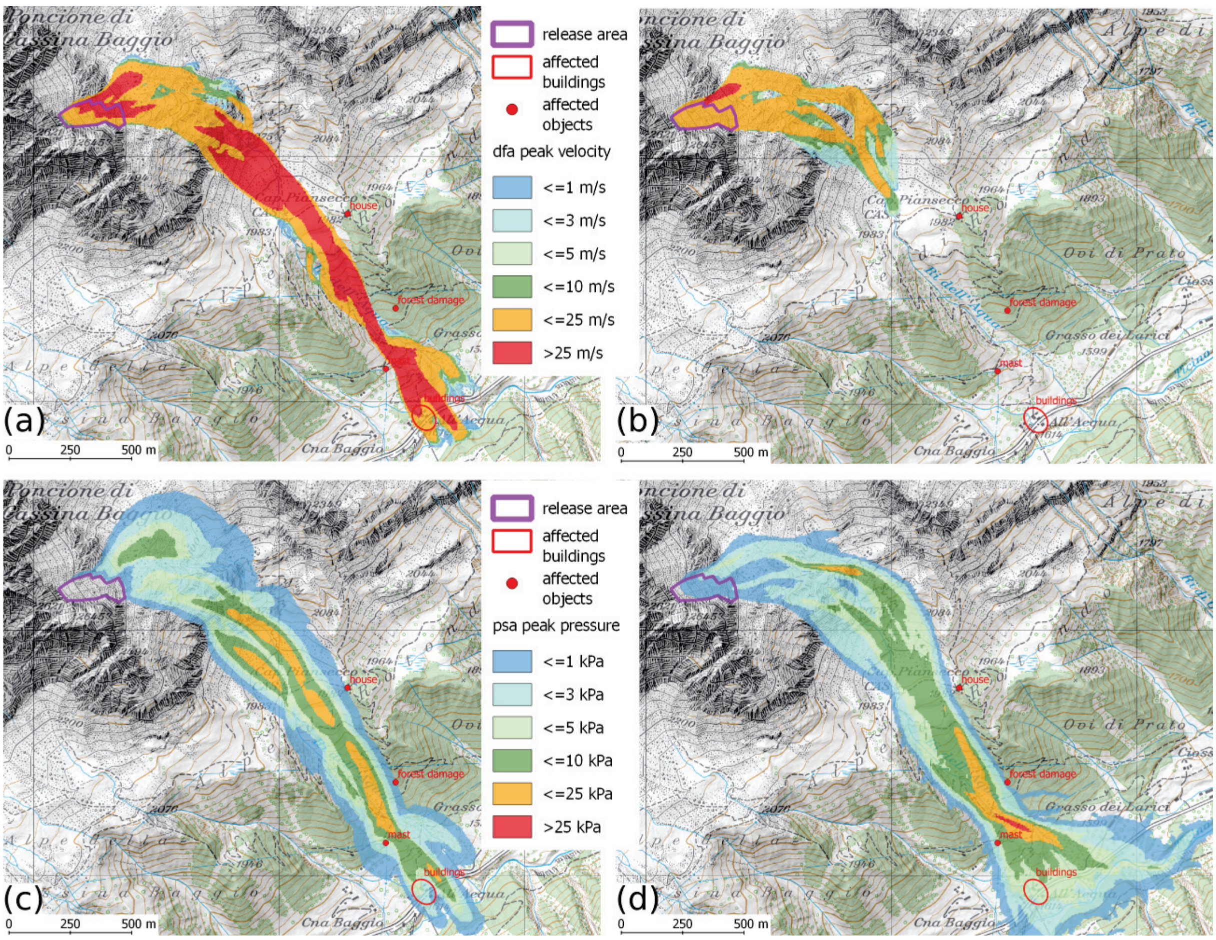

Figure 5: **SamosAT** and **RAMMS** calculations of the All'Aqua case study. a) Max flowing velocity core **RAMMS**, b) Max flowing velocity core **SamosAT**, c) Max powder pressure **RAMMS**, d) Max powder pressure **SamosAT**.

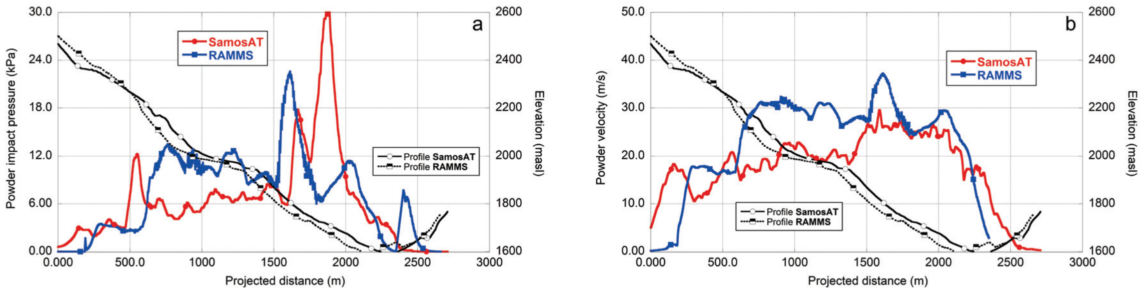

Figure 6: Profile comparison All'Aqua case study. a) Powder cloud impact pressure. b) Powder cloud velocity. **RAMMS** predicts higher mean velocities; impact pressures are slightly larger in the runout zone.

assumes a triangular velocity distribution (zero velocity at the top of the cloud and double the mean velocity at the bottom) and a constant density over the height of the cloud. The comparison between **RAMMS** and **SamosAT** indicates when this assumption might break down, but appears for a first analysis to be reasonable. It is remarkable that **RAMMS** and **SamosAT** predict similar powder avalanche velocites. In respect to the practical application there are two different model strategies are pursued. For **RAMMS** detailed information on the physical state of the snow cover are needed in order to predict plausible avalanche magnitudes. If no measurements of these quantities are available, they have to be chosen based on assumptions or back calculations. **SamosAT** is calibrated for a specific extreme event, whereby a differentiated treatment of dense flowing and powder snow avalanches is in operation. To predict extreme dense flowing avalanches, in **SamosAT** a pure dense flow simulation is performed. For the prediction of a powder snow avalanches a coupled simulation is performed. In the latter case the calibration is focused on the powder cloud neglecting the extreme representation of the dense flowing counterpart.

The powder version of **RAMMS** is now being extended to include a fully three-dimensional treatment of the powder cloud. The treatment of the interfacial mass and momentum fluxes between the core and cloud will however remain the same. The three-dimensional treatment will allow a better analysis of height effects important in many practical applications, such as the evaluation of power transmission lines. In future the combination of computationally robust depth-averaged approaches such as **RAMMS**, and three-dimensional approaches, such as **SamosAT** would be a helpful contribution to improve avalanche engineering.

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