OBJECTIVE COMPARISON OF TWO NUMERICAL AVALANCHE DYNAMICS MODELS

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ABSTRACT: Numerical avalanche dynamics models are nowadays used by engineers all around the world as an integral part in risk assessment studies. Especially in areas like the European Alps with limited space suitable for settlements the demand for high quality hazard zoning is present and models have become increasingly important. Two of the leading software tools are SamosAT (AT) and RAMMS (CH). The underlying flow models deviate in their numerical implementation and in their physical assumptions. Both software tools provide results on the time and spatial evolution of avalanche flow dynamical parameters such as flow depth and velocity. The complexity and huge amount of result data makes an objective comparison of a high number of simulations challenging and difficult to interpret by decision makers. In this paper we objectively compare the two software tools, using a new approach called AIMEC (Automated Indicator based Model Evaluation and Comparison) approach (see also Fischer et al. (2012a)). Avalanche scenarios, based on observations at the avalanche test site Ryggfjonn (Norway), serve as input for the comparison. This approach allows a direct and objective comparison of: (1) variations in the model output due to input changes, (2) different models or (3) field measurements. Two dimensional peak pressure distributions serve as main input and are used to automatically calculate indicators like run out distances and other flow dynamical variables. The objectively analyzed and visualized results show how an avalanche engineer can easily compare the main results for different initial scenarios and models.

1. INTRODUCTION

Snow avalanche models and simulation software are becoming more important and are commonly used in engineering and risk assessment studies. For decision makers the important questions are how far and how fast does an avalanching mass move. To answer these questions, the available tools range from topographical statistical models (Lied and Bakkehøi, 1980; McClung and Lied, 1987), block models (Voellmy, 1955; Salm, 1993), one dimensional numerical models (Bartelt et al., 1999; Christen et al., 2002) up to modern simulation software based on multidimensional flow models coupled to a geographic information system (GIS) interface (Sampl and Granig, 2009; Mancarella and Hungr, 2010; Christen et al., 2010b).

The complexity and amount of the resulting data increases from simple point data to one dimensional data along a mountain profile up to two or three dimen-
sional data in natural terrain. In the last case the methods of interpreting and analyzing the model results in a comprehensive, reproducible way are limited. For this purpose the new AIMEC (Automated Indicator based Model Evaluation and Comparison) approach was developed (Fischer, 2012).

In the present study we use the AIMEC approach to compare results of two different snow avalanche simulation software tools. SamosVO, an adapted version of the Austrian software SamosAT (Snow Avalanche MOdelling and Simulation - Advanced Technology, Zwinger et al. (2003); Sampl and Zwinger (2004); Sampl and Granig (2009)) that applies a Voellmy friction relation, and the Swiss software RAMMS (RApid Mass MovementS, Christen et al. (2010b)) are used to conduct snow avalanche simulations. The software tools differ in their numerical implementation but require the same kind of input data: digital elevation model, release area, release depth and specification of friction parameters.

We investigate how the two simulation software tools perform under the condition of same input data and setup with respect to runout and flow velocity. A release volume variation for an avalanche scenario at Ryggfonn is applied. A brief description of the AIMEC approach and the analysis indicators (runout and AMV (averaged maximum velocity)) is provided. Finally the two software tools are compared by interpreting simulation results in a classical way and using the AIMEC approach.

2. METHODS

2.1. Simulation software

To perform a simulation run a digital representation of the mountain topography (digital elevation model - DEM), an assigned area of potential avalanche release, the release depth and the physical model parameters have to be provided.

The main simulation results are the flow depth \( h(x, y, t) \) and slope parallel velocities \( v(x, y, t) \) at a constant density \( \rho \). \( x, y \) denote the two dimensional Cartesian coordinates. The maximum over time of the two dimensional velocity and depth field

\[
  v_{\text{peak}}(x, y) = \max_t \{ ||v(x, y, t)|| \},
\]

\[
  h_{\text{peak}}(x, y) = \max_t \{ h(x, y, t) \},
\]

and the according peak pressure is

\[
  P(x, y) = \rho v_{\text{peak}}^2(x, y).
\]

However, the avalanche path may generally not be aligned with the Cartesian \( x \)- or \( y \)-axis. For this reason quantitative statements about the two dimensional results are challenging.

Generally both simulation softwares are based on a depth averaged shallow flow model coupled to a GIS environment to handle data in- and output. In both models the flow dynamics are predominately influenced by the net force \( F \) which is given by a superposition of gravitational acceleration and frictional resistance

\[
  F = h \mathbf{g} - \frac{\mathbf{v}}{||\mathbf{v}||} \left( h \mu (g_n + \kappa \mathbf{v}^2) + \frac{||\mathbf{g}||}{\xi} \mathbf{v}^2 \right),
\]

with the friction parameters \( \mu, \xi \), the gravitational acceleration \( g \) and its surface normal component \( g_n \). \( \kappa \) accounts for the terrain curvature, in the case of RAMMS \( \kappa = 0 \), for more details we refer to Fischer et al. (2012b).

Throughout this study a snow density of \( \rho = 300 \text{ kg/m}^3 \) and constant friction parameters \( \mu = 0.2, \xi = 0.5 \) are assumed.
\( \xi = 2000 \text{ m} \cdot \text{s}^{-2} \) are used for both models according to the calibration Guidelines (Salm et al., 1990; Salm, 1993).

2.1.1. RAMMS::Avalanche

The avalanche simulation software RAMMS::Avalanche was specifically designed to provide snow avalanche engineers with a tool that can be applied to analyze problems that cannot be solved with existing one-dimensional models (Christen et al., 2010a). RAMMS solves the two-dimensional depth-averaged equations governing avalanche flow in complex three-dimensional terrain with accurate second-order numerical solution schemes. The model allows the specification of multiple release zones and predicts avalanche run out, flow velocities and flow depths (Christen et al., 2010b). RAMMS employs the well-calibrated Voellmy friction model (Voellmy, 1955) containing two parameters: the Coulomb friction (\( \mu \)) and the velocity squared dependent turbulent friction (\( \xi \)). Swiss guideline suggestions for friction parameters are available (Salm et al., 1990). These values correspond to extreme, fast moving, dry-flowing avalanches. Simulation runs are performed manually and the results are exported in raster format.

2.1.2. SamosVO

SamosVO, based on SamosAT, is extended with a Voellmy friction relation. SamosAT itself consists of two basic models, a dense flow (DFA) avalanche model and a powder snow (PSA) avalanche model in order to describe the flow of dry snow avalanches (Zwinger et al., 2003; Sampl and Zwinger, 2004; Sampl and Granig, 2009). For the comparison to RAMMS the SamosAT DFA model with a Voellmy friction relation (SamosVO) is used. The DFA is modeled as a shallow flow in two dimensions above the mountain surface. The depth averaged model equations for shallow flow include a Voellmy fluid friction relation. In the DFA model the released volume is discretized in a large number of mass elements. The model equations are solved following a Lagrangian approach us-
ing a smoothed particle hydrodynamics (SPH) scheme (Monaghan, 1992).

Simulation runs are performed in automatization mode (see (Fischer, 2012)). The results are exported in raster format.

2.2. Avalanche scenario at Ryggfonn

The instrumented Norwegian avalanche test site Ryggfonn is operated since the 1980ies. The release zone is located at about 1530 m a.s.l. The slightly channelized avalanche path with an average slope of 28° passes into the run out zone at about 650 m a.s.l where a 100 m long and 16 m high retaining dam was constructed. Typical avalanche size varies between 20000 – 100000 m³ (Norem et al., 1985; Gauer et al., 2007).

In this study an area of about 55000 m² in the typical release zone is chosen as input for the avalanche scenario, compare figure 1.

A release volume variation scenario is performed to not only compare one single event, but the response of the software for varying input conditions (without changing the model parameters). 35 simulation runs with increasing release volume (constant release area, increasing release depth 0.1 – 3.5 m) are performed with each simulation software.

2.3. AIMEC analysis

The simulation results of both models provide the input for the independent comparison approach AIMEC. For a detailed AIMEC description we refer to Fischer (2012).

The AIMEC approach is based on indicators representing how far and how fast the avalanche was moving downslope. An avalanche path dependent coordinate system is introduced. In this coordinate system a pressure based runout length can be defined based on the peak pressure field and a certain pressure limit (e.g. \( P_{\text{limit}} = 1 \text{kPa} \)). Additionally to the runout we introduce the flow velocity indicator \( AMV \) (averaged maximum flow velocity). It is a measure to evaluate the peak flow velocities of the avalanche along the path and represents the lateral maximum of the peak velocity for each point along the path, averaged from release to runout.

3. COMPARISON and CONCLUSIONS

In figure 1 the 1 kPa peak pressure outlines are shown for two Ryggfonn avalanche simulations with a release depth of 1 m and 3 m, respectively. The overall extent shows good agreement between the two models and for both release depth scenarios. Differences can be observed in the runout area where both models over-flow the dam. In both cases RAMMS (green) shows slightly longer runout distances than SamosVO (blue, dashed). In the case of 3 m release depth (figure 1, right) RAMMS follows the topography downstream after it hits the counter slope whereas SamosVO tends to extend in lateral direction. Similar investigations were conducted for other release depths (not shown), however, this approach quickly reaches the limitations of a manually performed comparison of multiple simulation runs.

To compare a high number of simulation runs in a comprehensive and objective way the AIMEC approach is used. The results of the two avalanche simulation software tools RAMMS and SamosVO have been compared with respect to runout and velocity indicators applying an avalanche scenario at Ryggfonn. The release depth was varied between 0.1 – 3.5 m while constant friction parameters were used. Figure 2 direct comparison of the velocity \( AMV \) and runout indicator
Figure 2: Velocity and runout indicators (AMV vs runout) for the Ryggfonn scenario. Every point corresponds to one of 35 simulation runs with increasing release depth from 0.1 to 3.5 m (SamosVO: dark blue to light blue, RAMMS: green to yellow). Simulation runs with 1, 2 and 3 m release depth are highlighted with ○, □ and ▲.

for 35 simulation runs with increasing release depth (0.1 – 3.5 m) is displayed.

The overall agreement of the simulation results is good. Although both software tools are based on a similar flow model and the same input conditions are applied, differences in the results are observed for individual release scenarios (figure 2). With the 1 m release depth scenario the runout and velocity indicator are almost the same for SamosVO and RAMMS. At 2 m release depth differences in runout and velocity indicator appear, which further increase at 3 m release depth. Generally SamosVO seems to produce slightly higher velocity indicators for low release depths while RAMMS produces higher velocity indicators for higher release depths. Beside single exceptions the RAMMS runout indicator is higher. Observed deviations in the results are associated to different numerical implementations. The difference in the terrain curvature treatment in both flow models could be a further reason for lower runout indicators with SamosVO, which is in accordance to observations of Fischer et al. (2012b).

Overall the AlMEC approach proves to be a useful tool when interpreting a large amount of simulation results and comparing different software tools.

Acknowledgement: We want to thank Peter Gauer (NGI) for providing the Ryggfonn input data and Perry Bartelt (SLF) for fruitful discussions.

References


