SIMULATION OF DENSE SNOW AVALANCHES WITH OPEN-SOURCE SOFTWARE

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ABSTRACT: In this contribution, we apply the recently published open-source model *faSavageHutterFOAM 1.0* to back-calculating a documented avalanche event. *faSavageHutterFOAM 1.0* is a simulation tool for dense snow avalanches, which is based on a depth-integrated model and implemented in the open-source framework OpenFOAM®. In this study, we focus on (i) pre- and post-processing input data and model results with complementary open-source tools and (ii) reconstructing a well-documented avalanche event using the presented modeling approach. We aim to demonstrate the practical applicability of a modeling work flow, which solely utilizes openly available software tools and want to encourage future extensions of the presented framework.

Keywords: open-source, avalanche simulation, openFOAM, faSAavageHutterFOAM 1.0

1. INTRODUCTION

Numerical models for dense snow avalanches are commonly used tools in applications such as hazard zone mapping and planning of mitigation measures. Several commercial and free applications implement such models. Recently Rauter and Tukoviĉ (2018) and Rauter et al. (2018) presented a software-tool based on the open-source toolkit OpenFOAM® as an alternative to existing solutions. OpenFOAM allows assembling of custom physical models with build-in primitives and implements the numerical solution at a high level. It also supports an extendable solver structure, which renders the tool well-suited for future developments and rapid prototyping (Rauter et al., 2018). A detailed description of the model principles can be found in Rauter and Tukoviĉ (2018), the integration of the model in an open-source modeling tool-chain, especially focusing on data transfer with GIS software is described in Rauter et al. (2018). Instructions on how to obtain the model code, model documentation and data on test-cases are also available via Rauter et al. (2018). In this contribution we show an application of *faSavageHutterFOAM 1.0* to a documented avalanche event at the Arzler-Alm avalanche track. The main focus is on presenting a practical open-source workflow.

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2. AVALANCHE EVENT - 21 JANUARY 2018

The avalanche event in question recently occurred in the Arzler-Alm catchment, near the city Innsbruck in Tyrol, Austria. Due to its visibility from and proximity to the urbanized area, the avalanche path is well observed, with documented events dating back as far as 1859 (Fischer et al., 2013). On 21 January 2018, a size 3 to 4 avalanche released in the upper part of the catchment, depositing approximately $70000\,\mathrm{m}^3$ of snow and debris in the runout zone. Detailed documentation data of this event was recorded on 24 January 2018: The release areas were surveyed by means of aerial photographs taken during a manned helicopter reconnaissance flight; the lower part of the avalanche track and the runout zone were mapped using UAV-based photogrammetry and ground-based GPS measurements (for details see: Adams et al., 2018).

3. MODEL APPLICATION

Necessary input-files and model parameters for *faSavageHutterFOAM 1.0* include: (i) information on the base-topography in the form of a mesh, (ii) definition of the spatial extent of release areas and respective release snow-depths and (iii) choice and parametrization of a process model describing the basal friction and erosion behavior of the modeled avalanche. Preparation of release areas is done in QGIS, while meshing and definition of friction parameters is accomplished via supplementary scripts and parameter files available through *faSavageHutterFOAM 1.0*.

3.1. Meshing

As the basis for meshing we use a summer digital elevation model of the avalanche path with 1 m grid resolution. We then utilize the `txt2mesh.py` script provided along with *faSavageHutterFOAM 1.0* to produce the mesh for computation. We define a mesh with 200x400 elements in x,y direction, which results in roughly 80000 mesh elements with an average resolution of 6.7 m in y and 4.4 m in x direction.

3.2. Defining inital and boundary conditions

Shapefiles of release areas were defined in QGIS. Here we utilize the release areas as defined by Kofler et al. (2018). In accordance with Kofler et al. (2018) we define two release areas with an area of 4.5 ha and 4.1 ha and assume an average release snow-depth of 0.9 m resulting in approx. 75000 m^3 of release mass. Boundary conditions at the edge of the mesh are assumed as open, so any mass that reaches the border of the mesh flows out of the computational domain.

3.3. Process model and numerical settings

faSavageHutterFOAM 1.0 offers a range of different process models which describe basal friction relations and entrainment approaches (Rauter et al., 2018). In this application we chose the well known Voellmy friction relation. The parameters are defined via the `transportProperties` file. While an approach for erosion modeling is implemented in *faSavageHutterFOAM 1.0* (Rauter et al., 2018) we do not take advantage of this possibility in this example. Using a simple incremental ad-hoc parametrization, fitting observed to modeled deposition patterns, resulted in a parameter set of $\mu = 0.4$, $\xi = 10000$; density of the flowing mass was assumed with $\rho = 200\,\mathrm{kg/m^3}$. Numerical Parameters (time-step, computational time, etc.) are defined via the `controlDict` file in *faSavageHutterFOAM 1.0*. Here we use 200 s simulation time with automatically adjusted time steps (`adjustTimeStep = true` in the `controlDict` file); model outputs are saved every 5 s.

4. RESULTS AND POSTPROCESSING

Simulation results are written to hard disk in the usual OpenFOAM file format for post-processing, evaluation and simulation restart (see Rauter et al., 2018). For the presented case, simulation results are written to harddisk in 5 s intervals. *faSavageHutterFOAM 1.0* provides a number of scripts to export OpenFOAM result files to GIS format (see Rauter et al., 2018). Here we export the maximum simulated flow depths for every cell of the computational mesh to a POINT shapefile (see fig. 1). The location of the points represents the center of mass of the elements of the computational mesh. A different representation of the same results can be reached by interpolating the Points to a regular grid with common GIS algorithms (here we use `gdal_rasterize`). The corresponding result for a regular 5 m raster is presented in fig. 2. The model results show a reasonable agreement with observed deposition patterns.

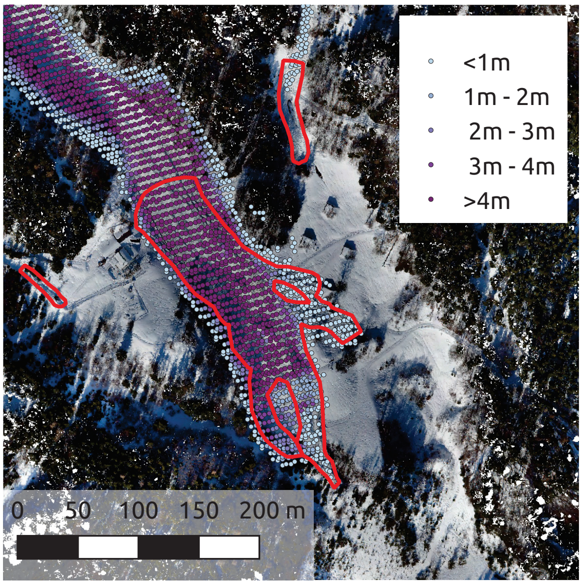

Figure 1: Maximum simulated flow heights (cell centers of computational mesh) and documented deposition (red outline). Background: UAV-based orthophoto captured three days after the event (Adams et al., 2018).

Besides export of results to GIS formats visualization and animation of results is also possible in ParaView (Rauter et al., 2018). The open source-code of *faSavageHutterFOAM 1.0* and the existing interfaces to the different file-formats also present a good base for the development of additional post-processing tools and/or integration with open-source GIS software packages (e.g. QGIS).

5. DISCUSSION & OUTLOOK

We demonstrated the practical applicability of *faSavageHutterFOAM 1.0* by using the model to back-calculate a documented avalanche event in the Arzler-Alm catchment. Only open-source software has been used throughout the modeling workflow. We believe that the major advantage of *faSavageHutterFOAM 1.0* is its object-oriented open-source code, which can be extended with reasonable effort. The code structure allows the implementation and application of different models to real case examples and the provided scripts allow an exchange of the model inputs and outputs with other

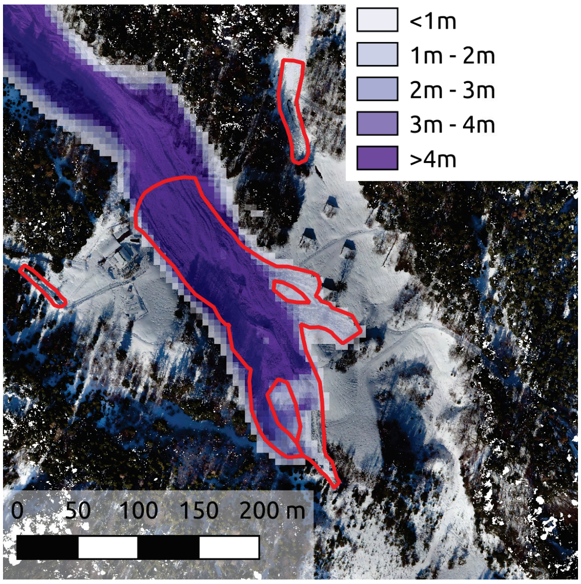

Figure 2: Maximum simulated flow heights (interpolated to 5 m raster) and documented deposition (red outline). Background: UAV-based orthophoto captured three days after the event (Adams et al., 2018).

open-source software such as QGIS, ParaView and others. This especially qualifies *faSavageHutterFOAM 1.0* for model development and academic purposes. The community-based development of additional pre- and post-processing scripts or user-interfaces for interaction with the model might further increase the accessibility and practical applicability of *faSavageHutterFOAM 1.0* and is highly encouraged.

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