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r.avaflow & r.randomwalk: two complementary and comprehensive open source GIS simulation tools for the propagation of rapid geophysical mass flows

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Abstract

We present two GIS model applications for simulating the propagation of rapid geophysical mass flows: r.avaflow employs an advanced physically-based two phase flow model intended for in-detail case studies, r.randomwalk a conceptual model suitable for studies at various scales. Both tools are implemented in open source software environments serving for the needs of both research and practice. They offer a range of visualization, validation, parameter sensitivity analysis and parameter optimization functions. Some of the key functionalities of both tools are demonstrated for the Acheron rock avalanche in New Zealand.

Introduction

Rapid geophysical mass flows such as snow avalanches, rock avalanches or debris flows are potentially dangerous phenomena in mountain areas worldwide. Anticipation of such events at different stages of the risk management cycle, and at various spatial scales, assists in reducing the associated risks. All up-to-date efforts in this direction rely on physical-mathematical and computer models. The present work focuses on open source GIS model applications simulating the propagation of rapid mass flows. Thereby we present two tools, r.avaflow and r.randomwalk, and selected results obtained with these tools.

The computational tools r.avaflow & r.randomwalk

r.avaflow employs an advanced two-phase flow model (Pudasaini, 2012) and targets at the detailed analysis of observed or expected mass flow events. This tool is suitable for the simulation of more or less complex process chains (e.g., the impact of a flow-like landslide into a lake and the resulting flood wave) and includes functionalities to compute entrainment and deposition. Starting from one or more aggregations of release pixels, or one or more release hydrographs, the motion of the flow is described by mass and momentum conservation laws and numerically solved on a high-resolution NOC central differencing scheme. Propagation ends as soon as all material has met a certain stopping criterion or moved out of the investigation area. The spatio-temporal distributi-

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ons of flow height, change of basal topography, flow velocities, pressure and kinetic energy for the solid and fluid phases are the key output. Output hydrographs can be provided for user-defined profiles.

r.randomwalk (Mergili et al., 2015) uses simple conceptual models, targeting at susceptibility mapping at broader scales, but also at quick first-order analyses of the impact areas of foreseen events. Starting from one or more user-defined release points or zones, a series of constrained random walks – governed by a set of parameters determining lateral spreading – is routed through the terrain until a defined break criterion is reached. Break criteria may (i) consist in empirical-statistical rules for the angle of reach or related parameters; (ii) build on the two-parameter friction model of Perla et al. (1980). The output consists in a binary impact/no impact map, but various rules can be combined in order to derive an impact indicator score. Alternatively, an impact probability may be assigned to each pixel, based on the probability density function of the angles of reach back-calculated from the analysis of observed events.

The core functionalities of r.avaflow and r.randomwalk are implemented as C codes. Both tools are available in two versions, differing in the way how the C code is embedded. The structure how each of the versions is designed is identical for both tools:

(i) Version intended for research, targeting at scientists performing parameter studies or other types of complex computational experiments. This version is available for UNIX systems. r.avaflow and r.randomwalk are implemented as raster modules of the GRASS GIS software. Python scripts for pre- and post-processing are wrappped around the C codes. R scripts are employed for built-in, automatized validation and visualization functions. Further, the model runs may be repeated with varying combinations of uncertain input parameter. This results in an impact indicator index (III) map in the range 0–1, corresponding to the fraction of parameter combinations resulting in an impact on a given pixel. III therefore builds on parameter ranges or spaces instead of definite values, reflecting uncertainty. The same feature allows to perform parameter optimization and sensitivity analyses in a convenient way (Krenn et al., 2016). The tools are most efficiently operated in a non-interactive way on the shell script level. For this purpose, the codes are parallelized at the python level in order to speed up computation, a useful feature when exploiting high-performance computational environments.

(ii) Stand-alone version intended for use by practitioners. The C code is implemented in a multi-platform GUI system building on C++ and python. Parameters are entered in an interactive way, and also the resulting maps may be displayed and queried interactively. The validation and parameter testing functionalities are not available as built-in functions, but the results may be validated by an additional R script.

Simulation experiments

We focus on the case of the 6.4 million cubic m Acheron rock avalanche in Canterbury, New Zealand, for demonstrating the functionalities of the two simulation tools. Due to its mobility (travel distance of 3.5 km and angle of reach of 11.6 degree) and a sharp bend in the flow path, this example is particularly challenging in terms of modelling. Applying an ad-hoc parameter optimization to r.avaflow already leads to a reasonable correspondence between the observed deposition areas of the rock avalanche and the flow depth distribution at a final stage (after 80 seconds; Fig. 1A). We use the GRASS version of r.randomwalk to demonstrate a more systematic optimization strategy, employing the two-parameter friction model for this purpose. Instead of definite parameter values (Fischer et al., 2015), we prefer to optimize value ranges (parameter spaces). Thereby, the III values yielded with various parameter sub-spaces are validated against the observed impact area in terms of the area under the ROC curve (AUROC) and the ratio between the average III and the fraction of observed impact pixels, compared to all pixels in the study area (conservativeness measure CIII). Values of AUROC and CIII close to 1 indicate a good simulation performance. We arrive at optimzed ranges of 0.1–0.4 for the bed friction coefficient and of 2150–4650 for the mass-to-drag ratio, yielding values of AUROC = 0.93 and CIII = 1.01 (Fig. 1B). An analogous procedure is supported by the GRASS version of r.avaflow.

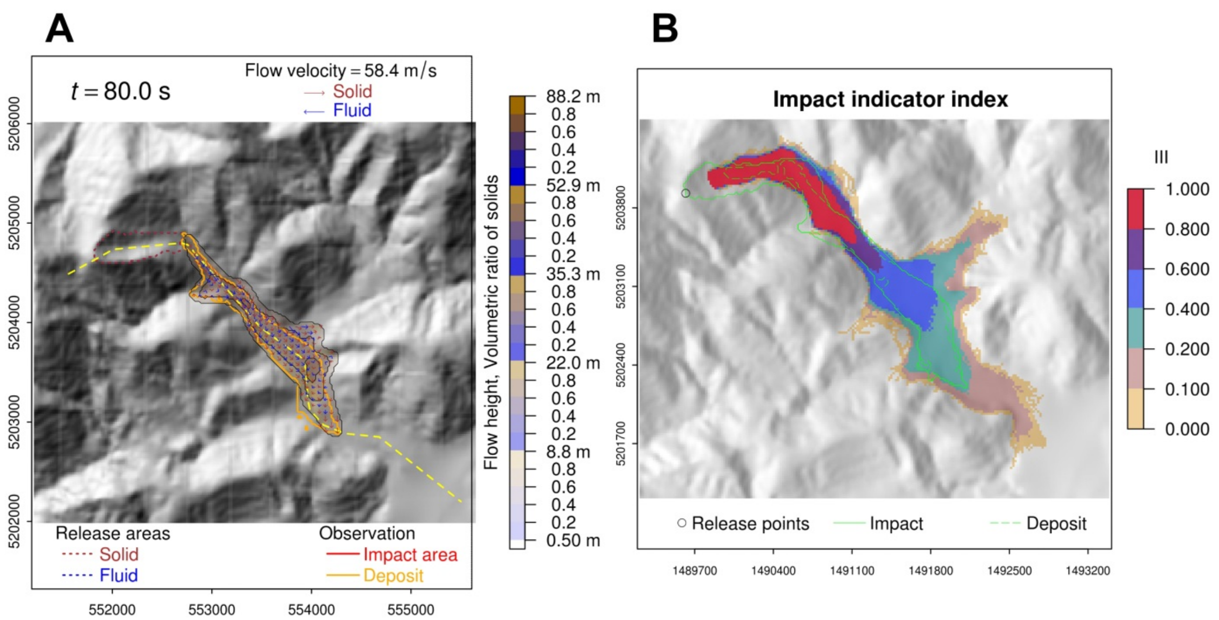

Fig. 1. Results yielded for the Acheron rock avalanche, New Zealand. A: Flow depth after 80 seconds derived with r.avaflow. B: Impact indicator index (III) yielded with r.randomwalk, applying the optimized parameter sub-space.

Conclusions and outlook

We note that the back-calculation of a larger number of documented events of different process types and magnitudes may result in guiding values – or ranges of guiding values – of parameters that can be used for the forward calculation of possible future events. In this way we intend to implement open source guiding parameter databases for both r.avaflow and r.randomwalk directly in the stand-alone tools in order to facilitate forward modelling for risk management practitioners.

From October 2016 onwards, the latest source codes and installation scripts (GRASS version) and the binaries for various platforms (stand-alone version) along with the corresponding manuals and selected test data sets are available through the software web sites http://www.avaflow.org and http://www.randomwalk.org.

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