# 1 r.avaflow & r.randomwalk: two complementary and com-
# 2 prehensive open source GIS simulation tools for the propa-
# 3 gation of rapid geophysical mass flows

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## 13 Abstract

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

## 21 Introduction

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

## 29 The computational tools r.avaflow & r.randomwalk

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

38  ons of flow height, change of basal topography, flow velocities, pressure and kinetic energy for the

39  solid and fluid phases are the key output. Output hydrographs can be provided for user-defined

40  profiles.

41  r.randomwalk (Mergili et al., 2015) uses simple conceptual models, targeting at susceptibility map-

42  ping at broader scales, but also at quick first-order analyses of the impact areas of foreseen events.

43  Starting from one or more user-defined release points or zones, a series of constrained random

44  walks – governed by a set of parameters determining lateral spreading – is routed through the ter-

45  rain until a defined break criterion is reached. Break criteria may (i) consist in empirical-statistical

46  rules for the angle of reach or related parameters; (ii) build on the two-parameter friction model of

47  Perla et al. (1980). The output consists in a binary impact/no impact map, but various rules can be

48  combined in order to derive an impact indicator score. Alternatively, an impact probability may

49  be assigned to each pixel, based on the probability density function of the angles of reach back-

50  calculated from the analysis of observed events.

51  The core functionalities of r.avaflow and r.randomwalk are implemented as C codes. Both tools are

52  available in two versions, differing in the way how the C code is embedded. The structure how

53  each of the versions is designed is identical for both tools:

54  (i) Version intended for research, targeting at scientists performing parameter studies or other

55  types of complex computational experiments. This version is available for UNIX systems. r.avaflow

56  and r.randomwalk are implemented as raster modules of the GRASS GIS software. Python scripts

57  for pre- and post-processing are wrappped around the C codes. R scripts are employed for built-in,

58  automatized validation and visualization functions. Further, the model runs may be repeated with

59  varying combinations of uncertain input parameter. This results in an impact indicator index (III)

60  map in the range 0–1, corresponding to the fraction of parameter combinations resulting in an

61  impact on a given pixel. III therefore builds on parameter ranges or spaces instead of definite valu-

62  es, reflecting uncertainty. The same feature allows to perform parameter optimization and sensiti-

63  vity analyses in a convenient way (Krenn et al., 2016). The tools are most efficiently operated in a

64  non-interactive way on the shell script level. For this purpose, the codes are parallelized at the

65  python level in order to speed up computation, a useful feature when exploiting high-performance

66  computational environments.

67  (ii) Stand-alone version intended for use by practitioners. The C code is implemented in a multi-

68  platform GUI system building on C++ and python. Parameters are entered in an interactive way,

69  and also the resulting maps may be displayed and queried interactively. The validation and para-

70  meter testing functionalities are not available as built-in functions, but the results may be vali-

71  dated by an additional R script.

## Simulation experiments

73  We focus on the case of the 6.4 million cubic m Acheron rock avalanche in Canterbury, New Ze-

74  aland, for demonstrating the functionalities of the two simulation tools. Due to its mobility (travel

75  distance of 3.5 km and angle of reach of 11.6 degree) and a sharp bend in the flow path, this exa-

76    mple is particularly challenging in terms of modelling. Applying an ad-hoc parameter optimizati-
77    on to r.avaflow already leads to a reasonable correspondence between the observed deposition
78    areas of the rock avalanche and the flow depth distribution at a final stage (after 80 seconds;
79    Fig. 1A). We use the GRASS version of r.randomwalk to demonstrate a more systematic optimiza-
80    tion strategy, employing the two-parameter friction model for this purpose. Instead of definite
81    parameter values (Fischer et al., 2015), we prefer to optimize value ranges (parameter spaces).
82    Thereby, the III values yielded with various parameter sub-spaces are validated against the obser-
83    ved impact area in terms of the area under the ROC curve (AUROC) and the ratio between the
84    average III and the fraction of observed impact pixels, compared to all pixels in the study area
85    (conservativeness measure CIII). Values of AUROC and CIII close to 1 indicate a good simulation
86    performance. We arrive at optimzed ranges of 0.1–0.4 for the bed friction coefficient and of 2150–
87    4650 for the mass-to-drag ratio, yielding values of AUROC = 0.93 and CIII = 1.01 (Fig. 1B). An
88    analogous procedure is supported by the GRASS version of r.avaflow.
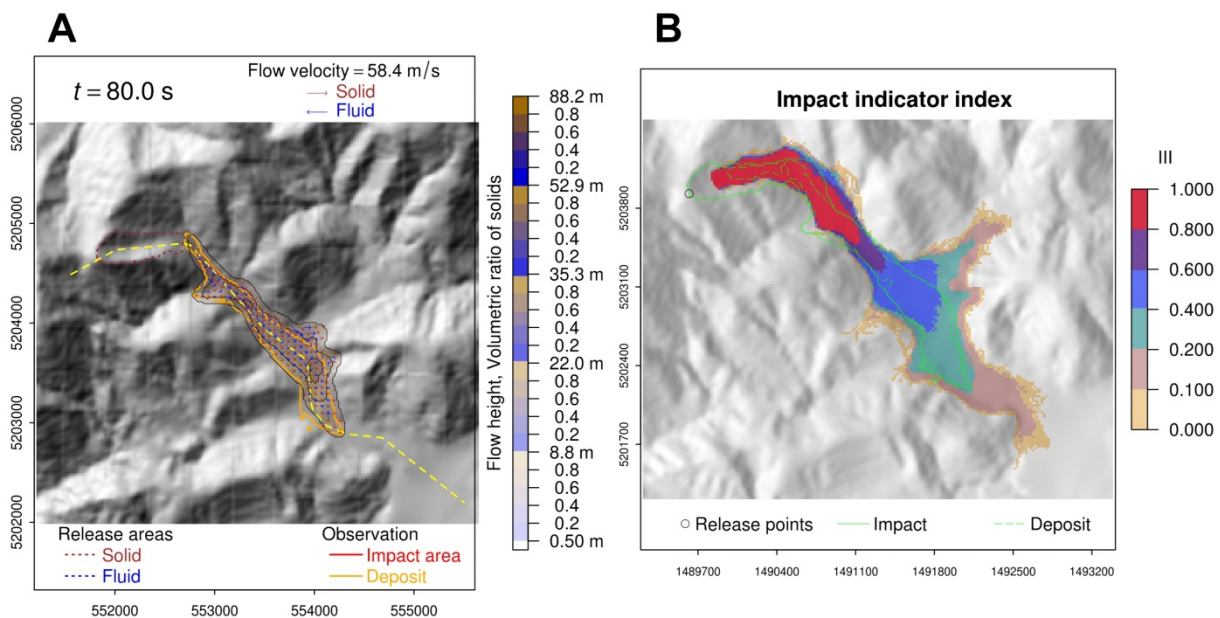


90    Fig. 1. Results yielded for the Acheron rock avalanche, New Zealand. A: Flow depth after
91    80 seconds derived with r.avaflow. B: Impact indicator index (III) yielded with r.randomwalk,
92    applying the optimized parameter sub-space.

93    **Conclusions and outlook**

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

99    From October 2016 onwards, the latest source codes and installation scripts (GRASS version) and
100   the binaries for various platforms (stand-alone version) along with the corresponding manuals and

101 selected test data sets are available through the software web sites http://www.avaflow.org and
102 http://www.randomwalk.org.

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