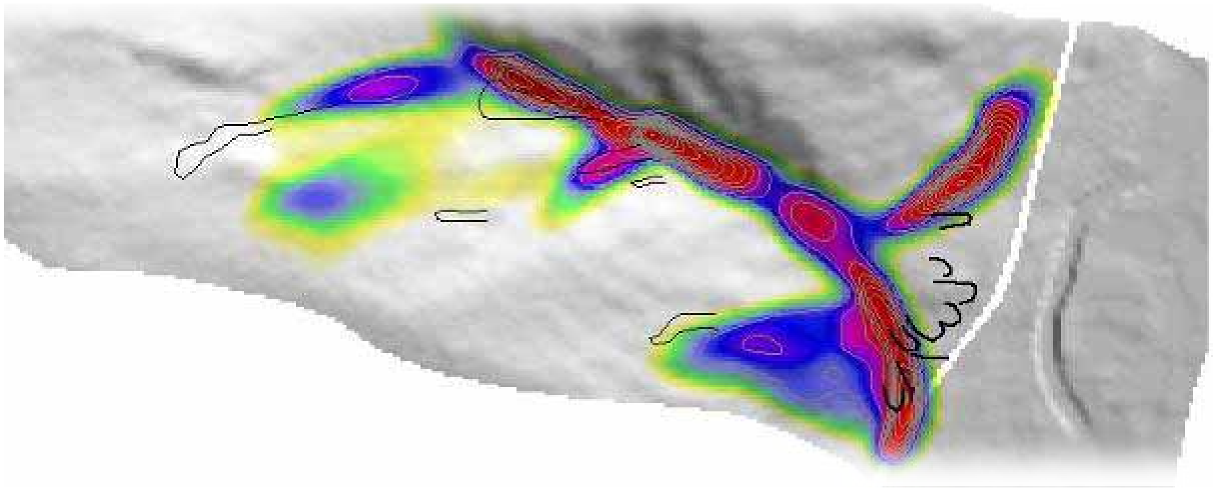
An Open Source model for the simulation of granular flows

First results with GRASS GIS and needs for further investigations



Martin Mergili
Institute of Geography, University of Innsbruck

Katharina Schratz
Dept. of Mathematics
Univ. of Innsbruck

Mechthild Thalhammer
Dept. of Mathematics
Univ. of Innsbruck

Wolfgang Fellin
Unit of Geotechnical Engineering
Univ. of Innsbruck

Alexander Ostermann
Dept. of Mathematics
Univ. of Innsbruck

Chile

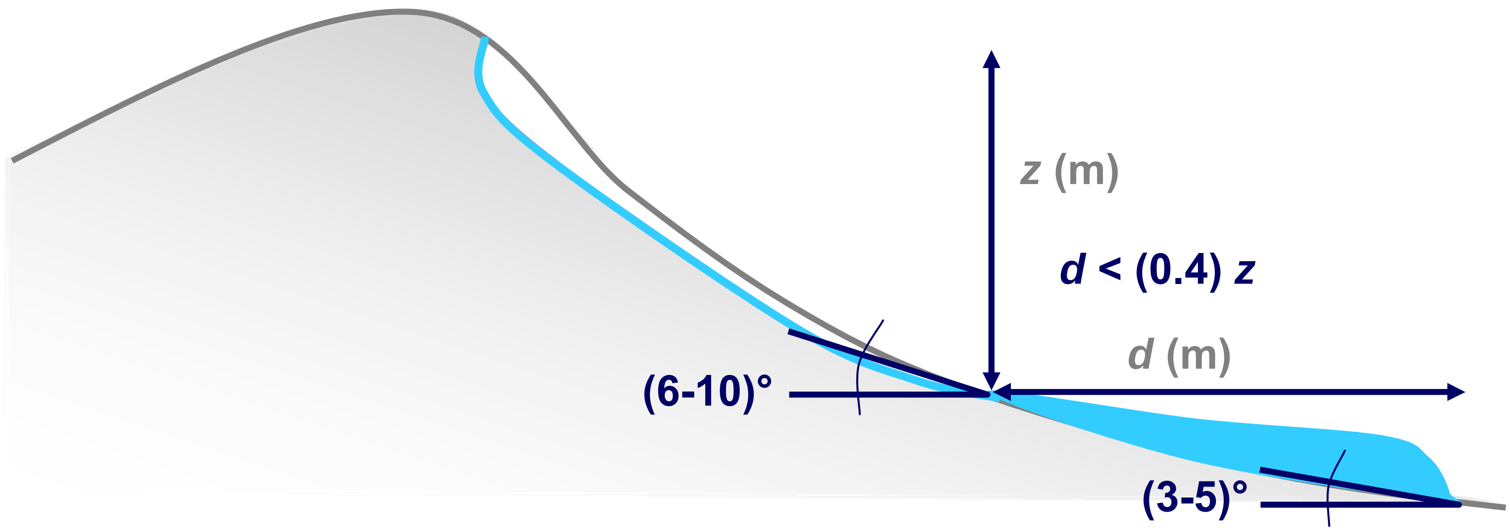
Ecuador

debris flows

Argentine Andes

empirical and semi-deterministic models

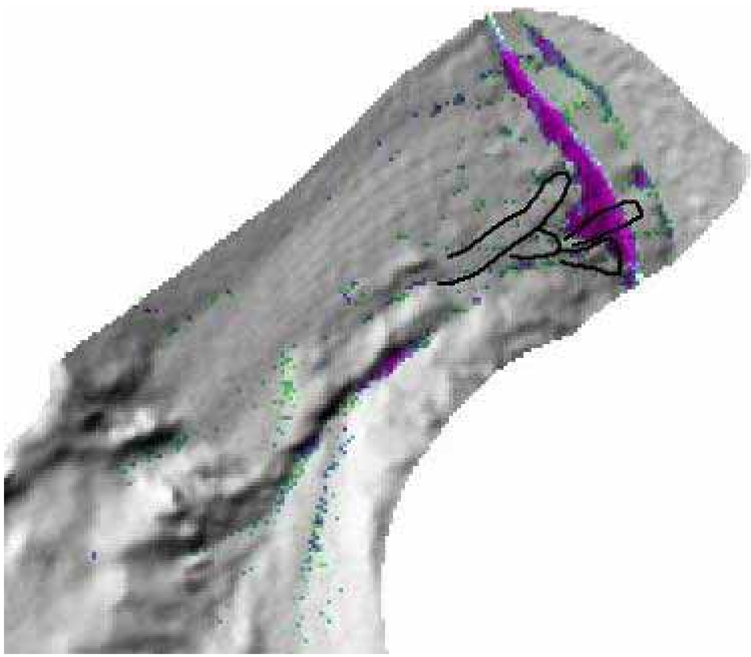
Corominas **et al. (1999)**
Rickenmann **(1999)**
Vandre **(1985)**
Perla **et al. (1980)**



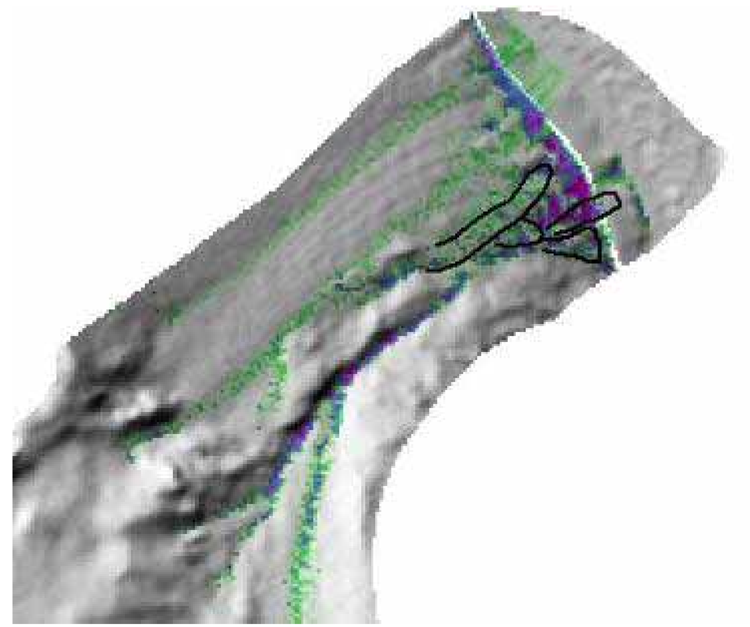
- **runout with random walk, weighted for local slope angle**

GRASS GIS implementation
r.debrisflow

Perla et al. (1980)



with parameters from the literature



with calibrated parameters

implications

- models can be used for computing debris flow events in the past
- but they have no capability for the prediction of future events characteristics different from those in the past
- **models usable without a calibration are required for class A predictions**

- only fully physically-based (deterministic) models fulfil this requirement
- they do exist, but are often difficult to handle or expensive and are therefore not widely applied
- Savage-Hutter (**SH**) model is one of the most advanced models

objectives

to develop a ...

- ► fully deterministic
- ► easy to use
- ► freely accessible

... model for predicting the runout and deposition of debris flows

- ► GRASS GIS
- ► SH model

GRASS GIS implementation
r.avalanche

basics of the Savage-Hutter model

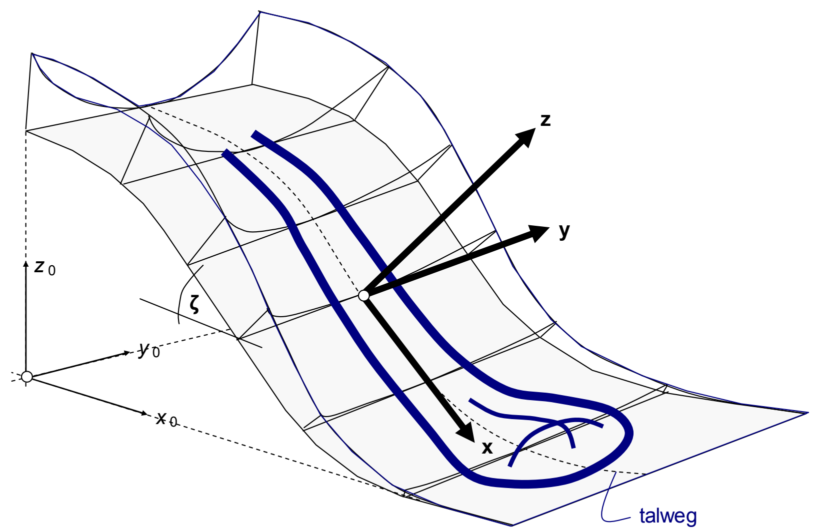
- continuum theory for description of motion of finite mass avalanche over a rough inclined slope
- based on system of partial differential equations of mass and momentum balances

major parameters:
- slope angle
- slope curvature
- angle of internal friction
- bed friction angle

- solutions do exist for several topographic situations, but are rather complex for arbitrary topographies

basics of the Savage-Hutter theory

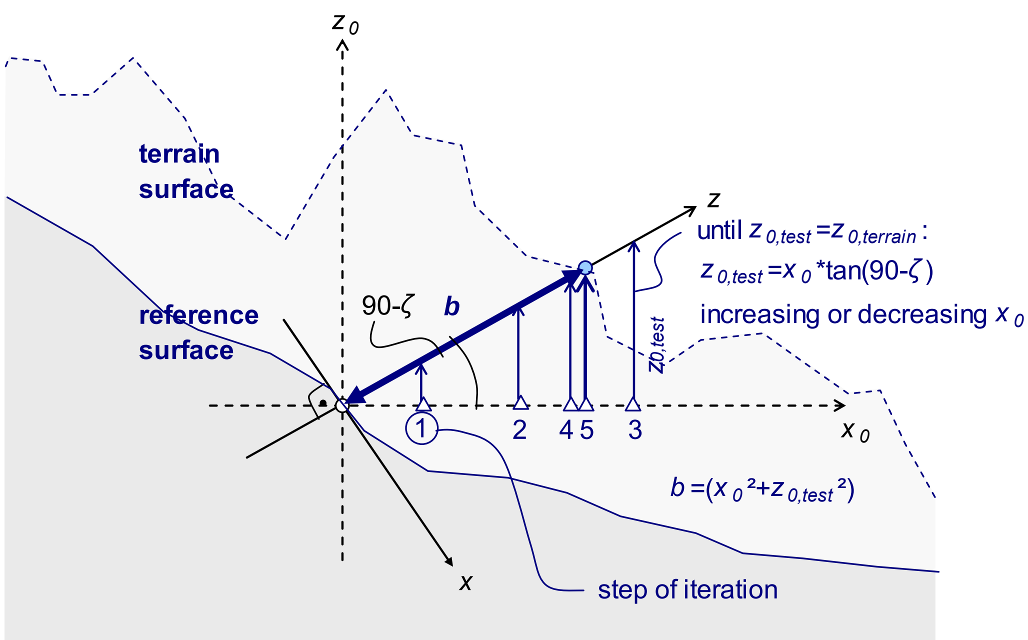
- solutions do exist for several topographic situations, but are rather complex for arbitrary topographies
- solution for simple concave valley with "talweg" in *x* direction



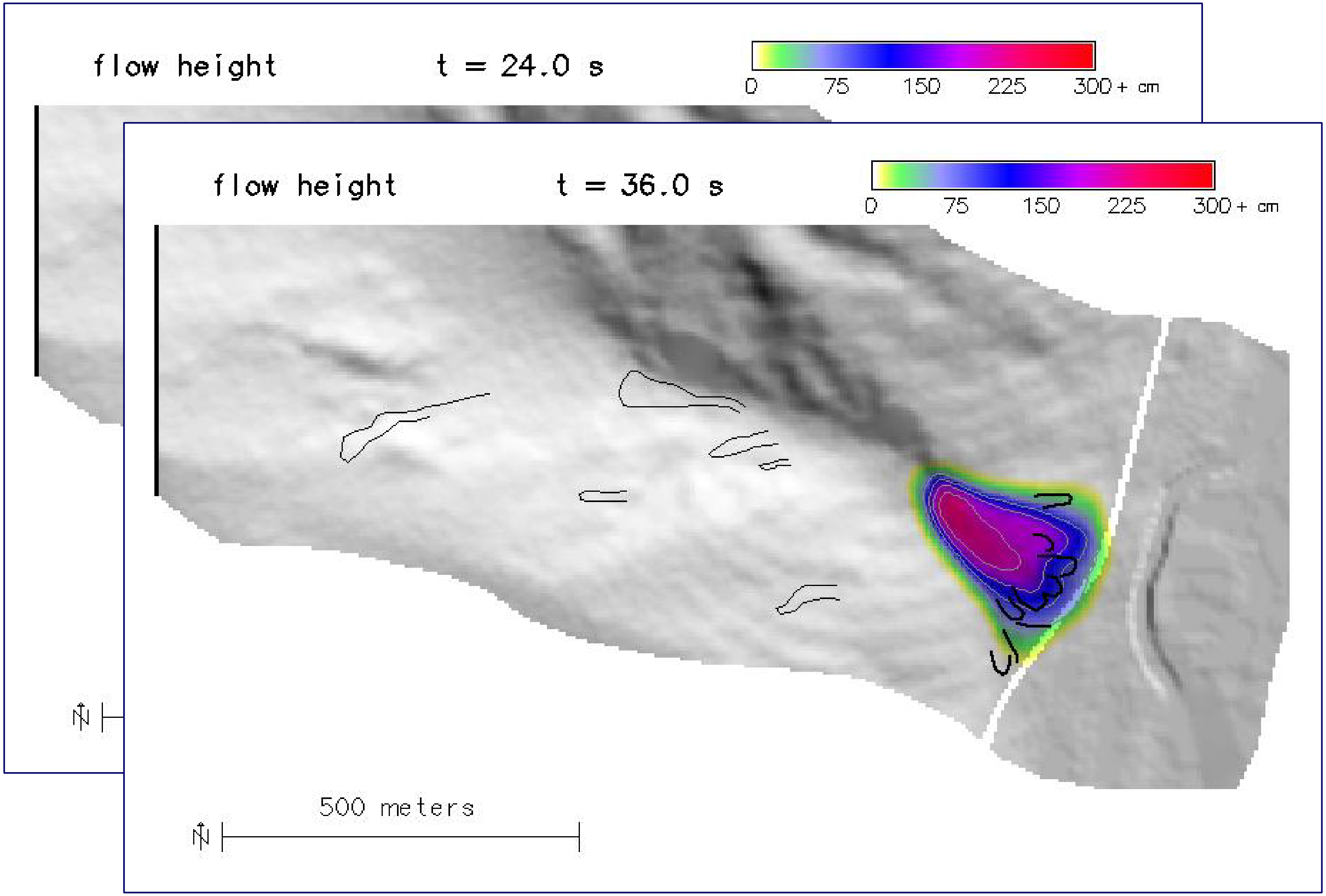
- numerical scheme ready to be implemented into GIS
- maximum time step length limited by Courant-Friedrichs-Levy condition

problems with implementation

- SH theory not designed for GIS:
- dimensionless values are used
- coordinate system follows topography so that transformation is required



implementation of the SH model

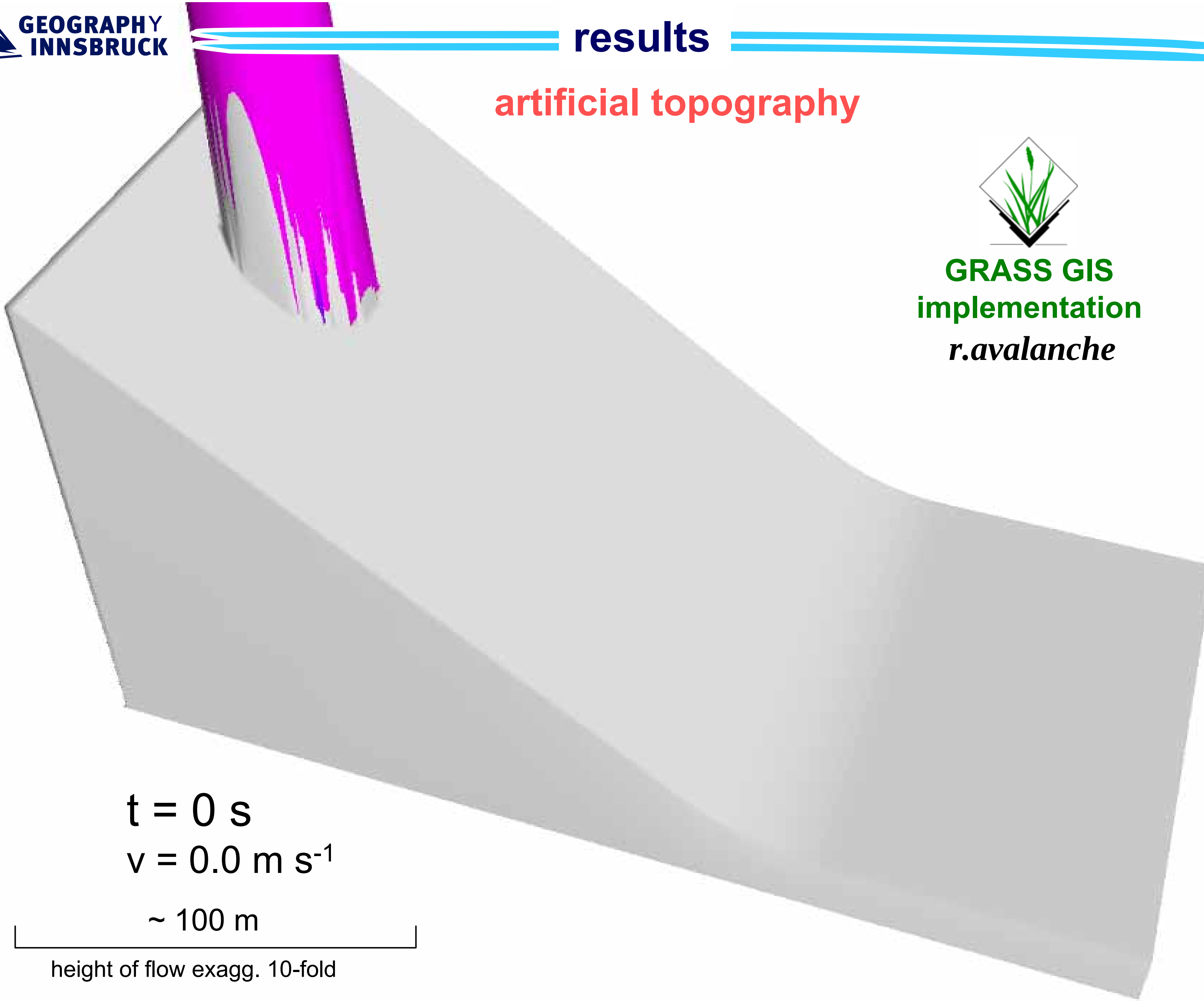


results

artificial topography

GRASS GIS implementation

r.avalanche

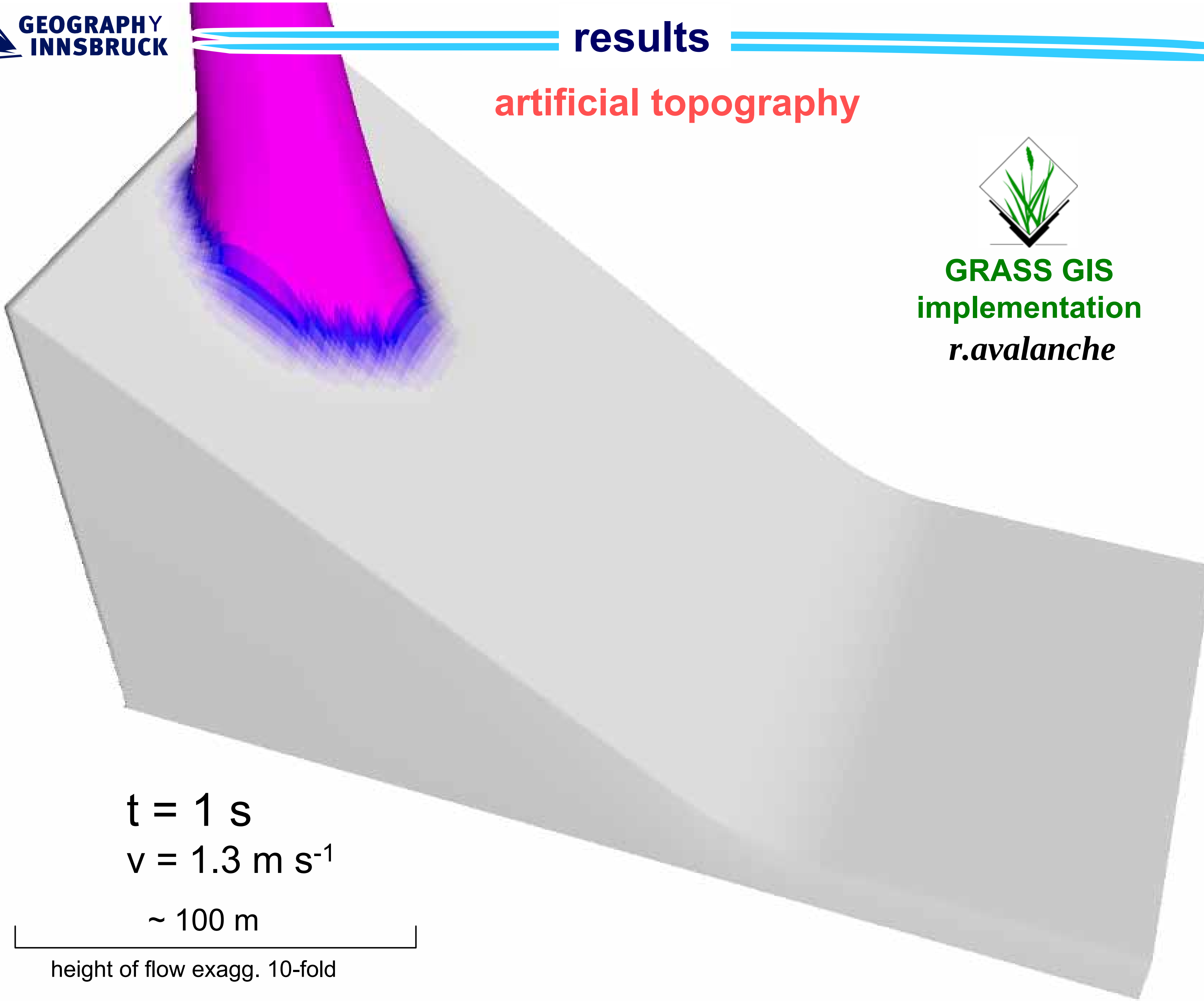


results

artificial topography

GRASS GIS implementation

r.avalanche



t = 1 s

v = 1.3 m s^{-1}

~ 100 m

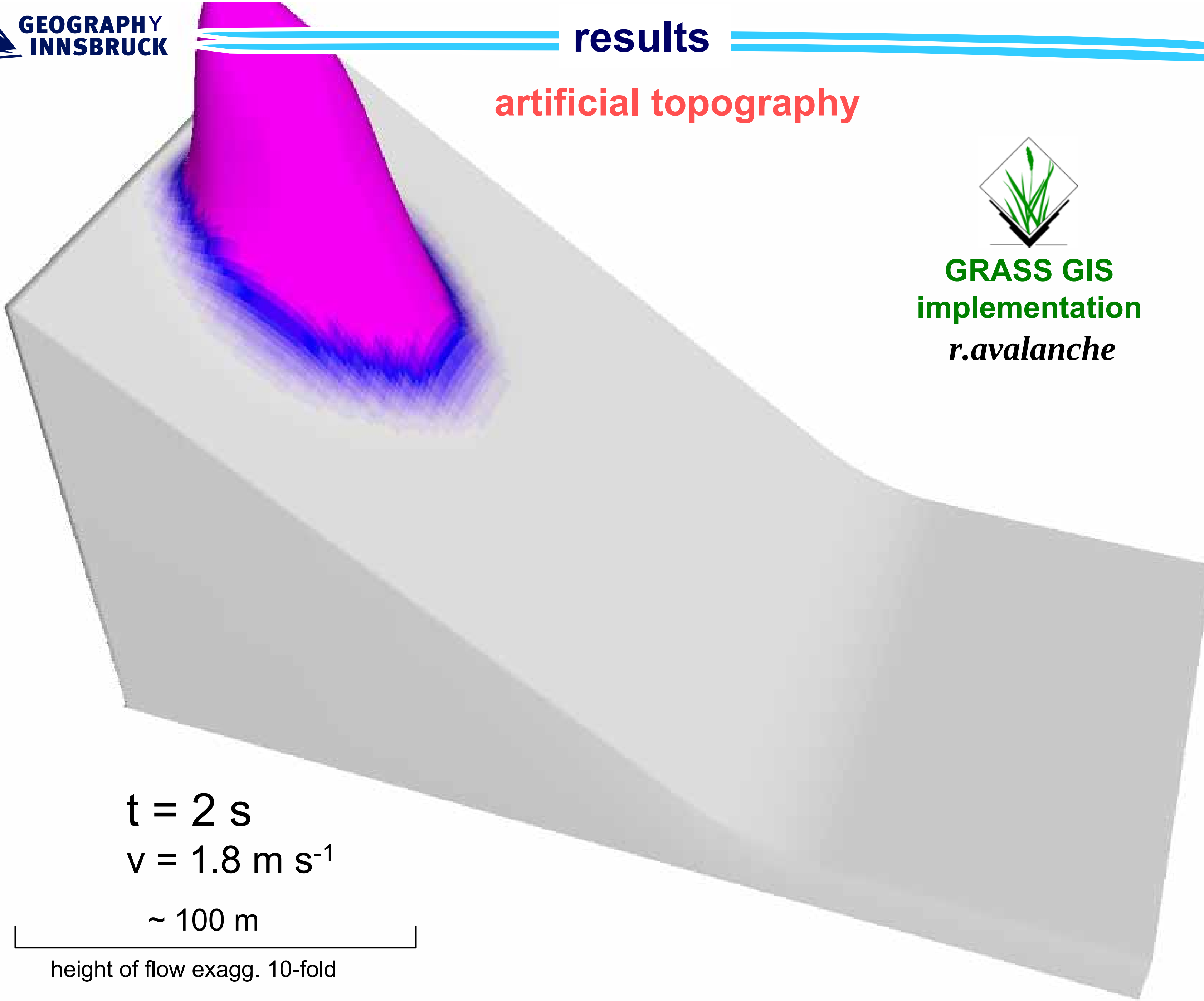
height of flow exagg. 10-fold

results

artificial topography

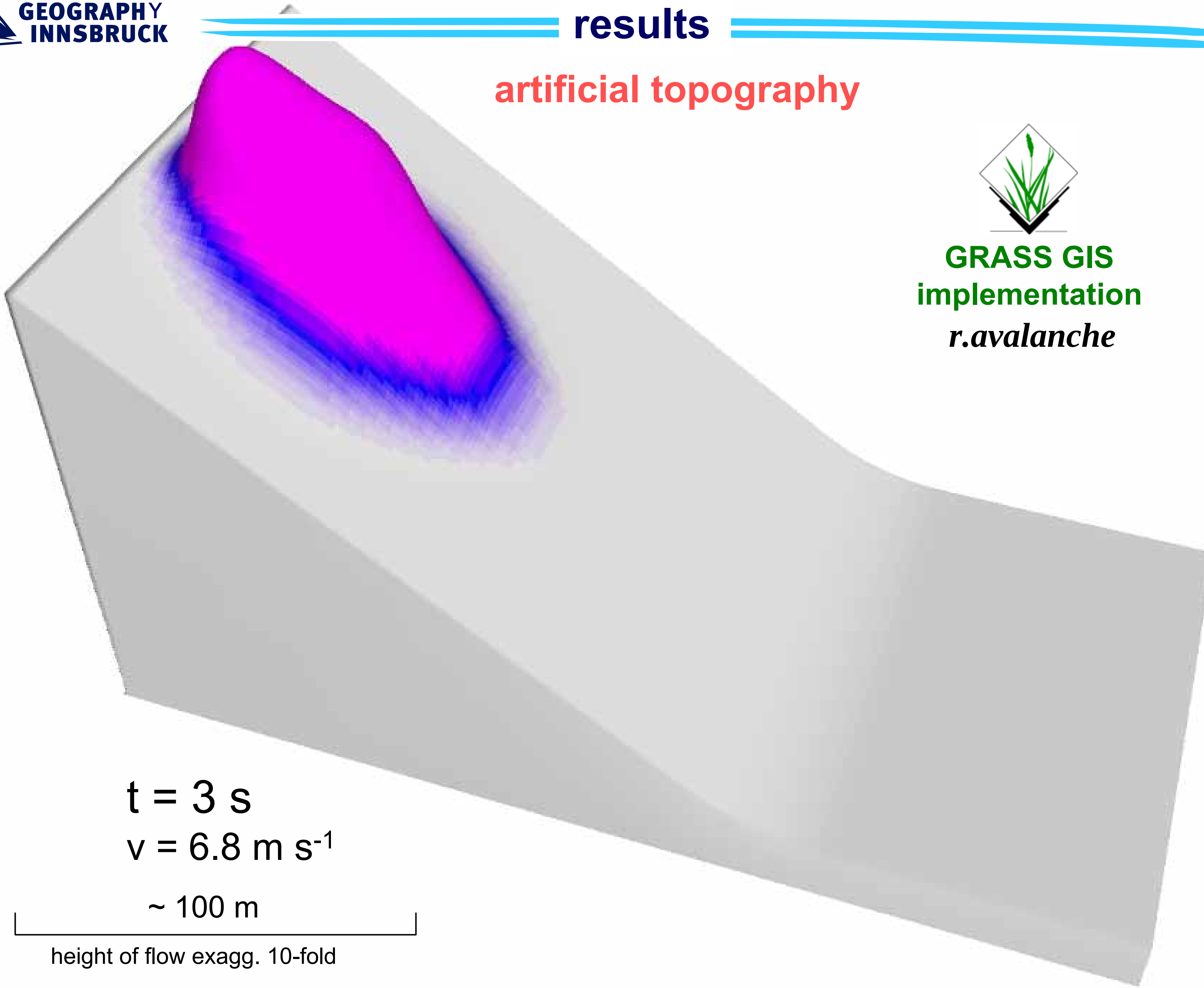
GRASS GIS implementation

r.avalanche



results

artificial topography



GRASS GIS implementation

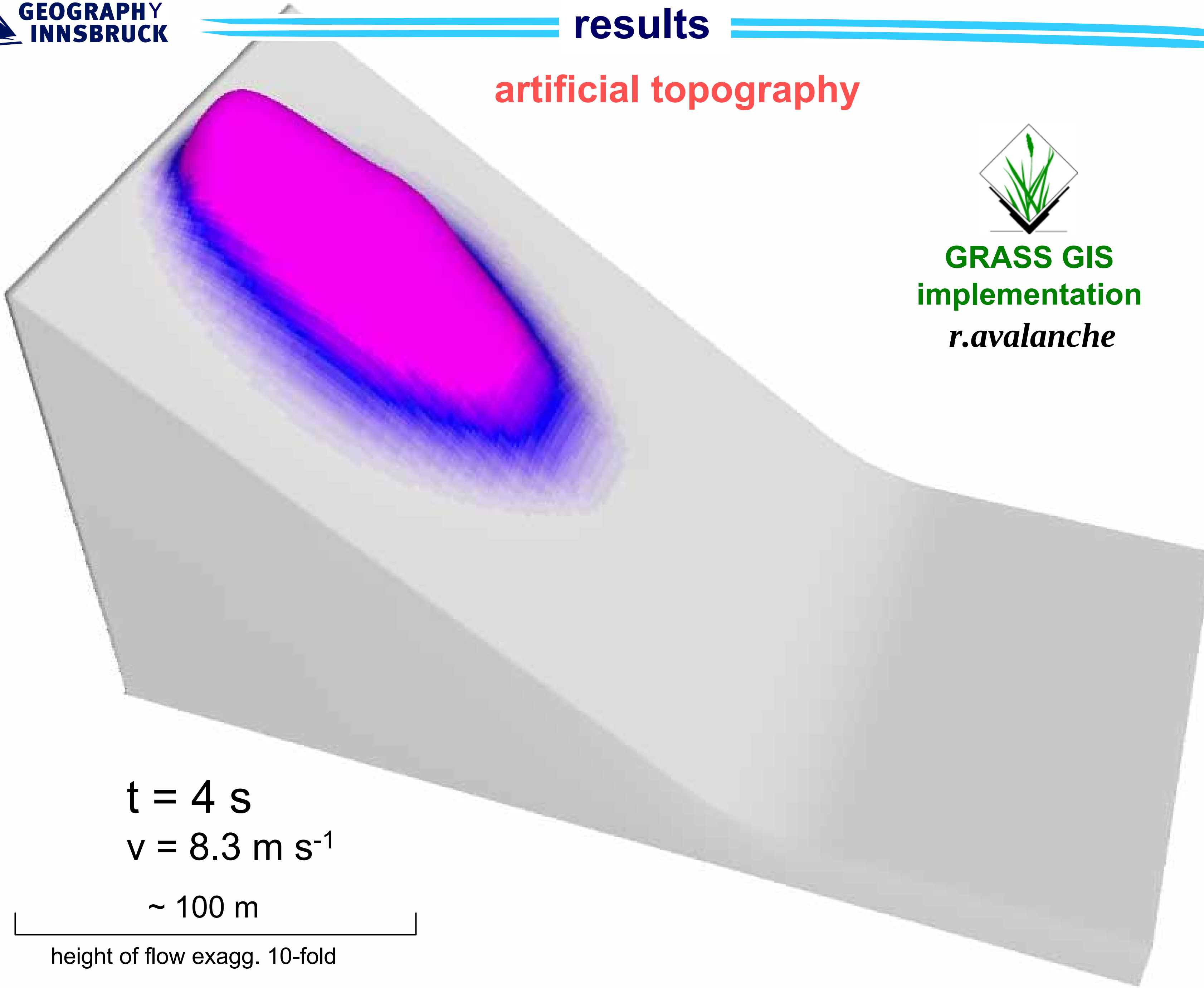
r.avalanche

results

artificial topography

GRASS GIS implementation

r.avalanche

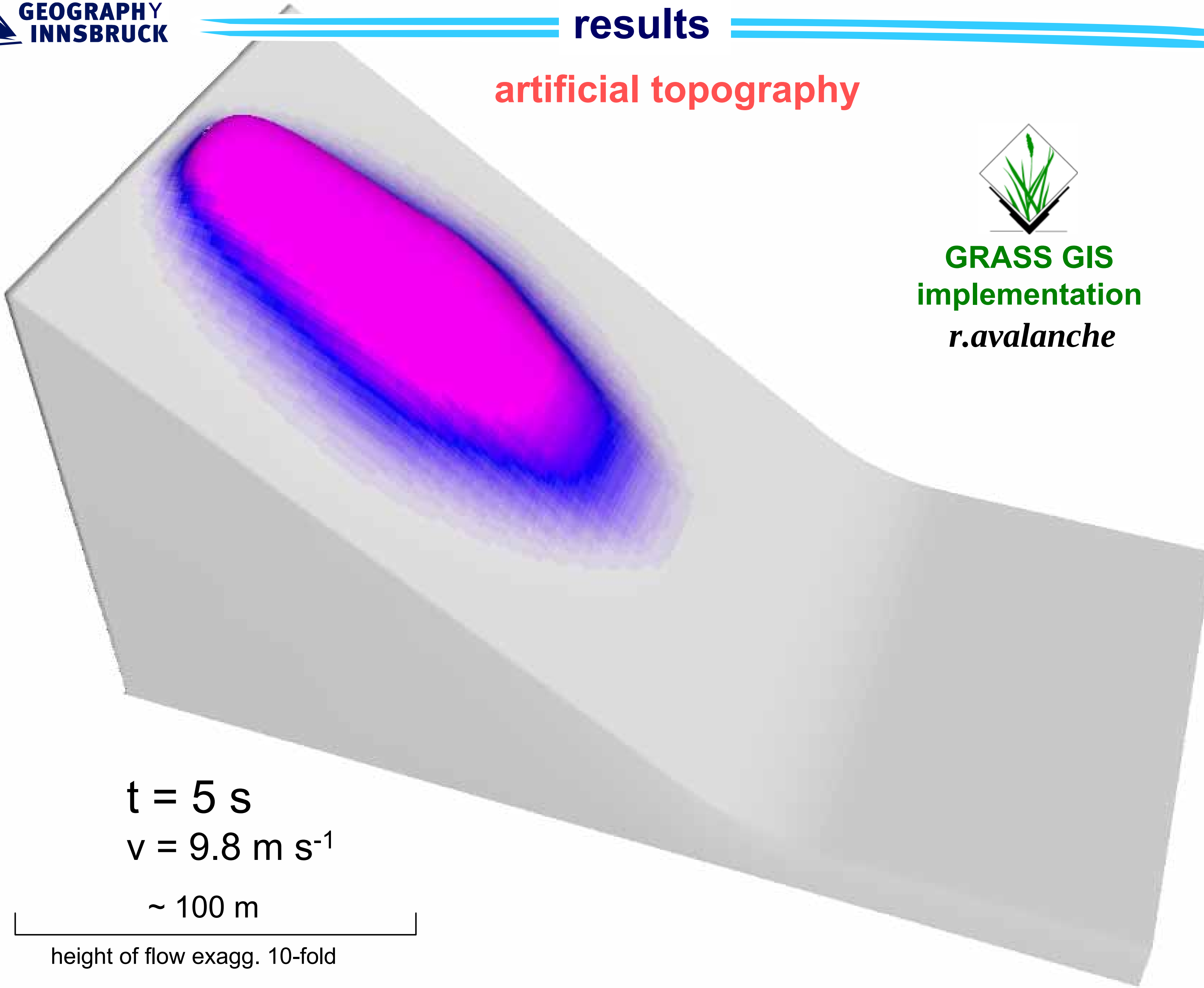


results

artificial topography

GRASS GIS implementation

r.avalanche



t = 5 s

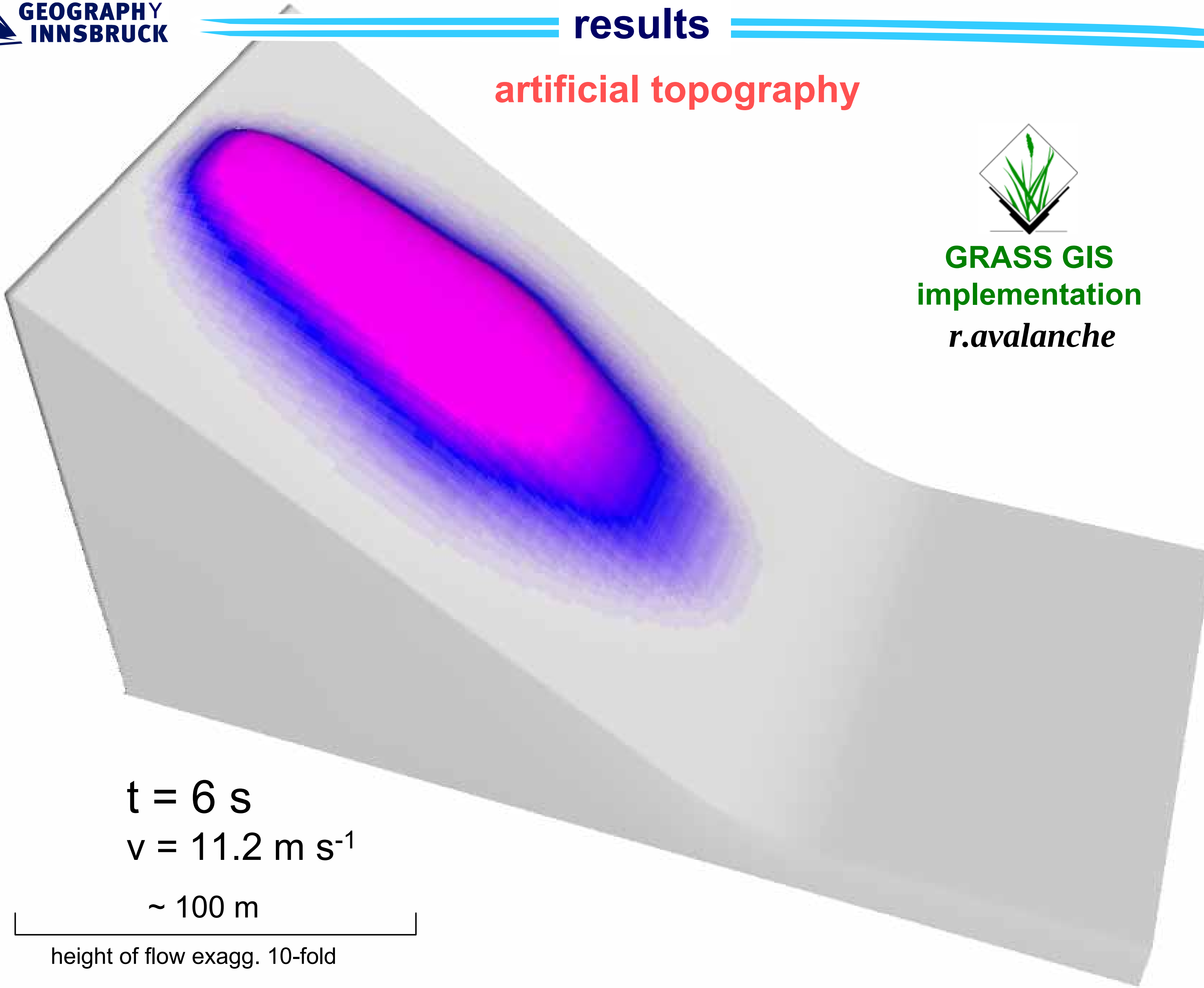
v = 9.8 m s^{-1}

~ 100 m

height of flow exagg. 10-fold

results

artificial topography



GRASS GIS implementation
r.avalanche

t = 6 s
v = 11.2 m s^{-1}

~ 100 m

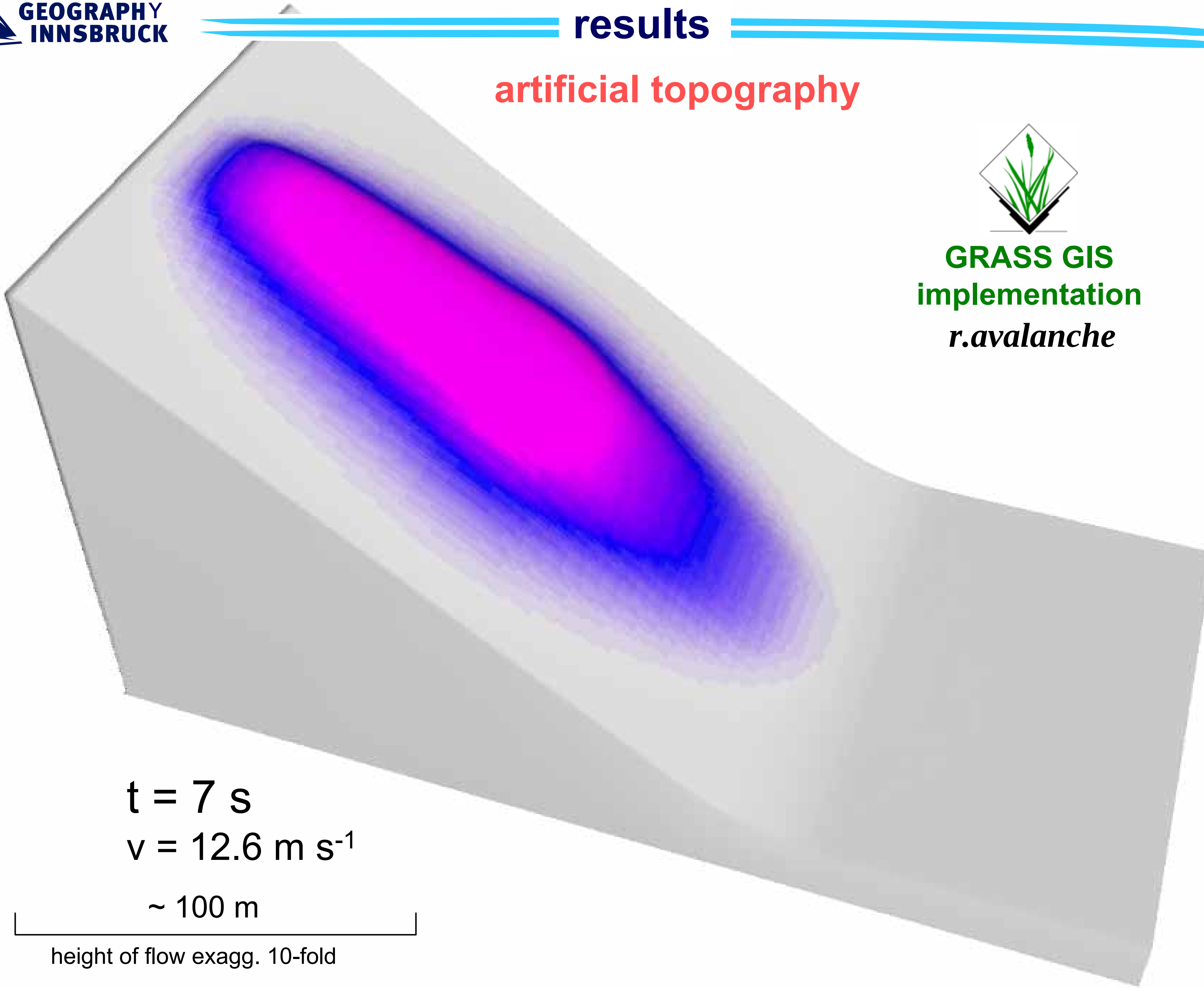
height of flow exagg. 10-fold

results

artificial topography

GRASS GIS implementation

r.avalanche

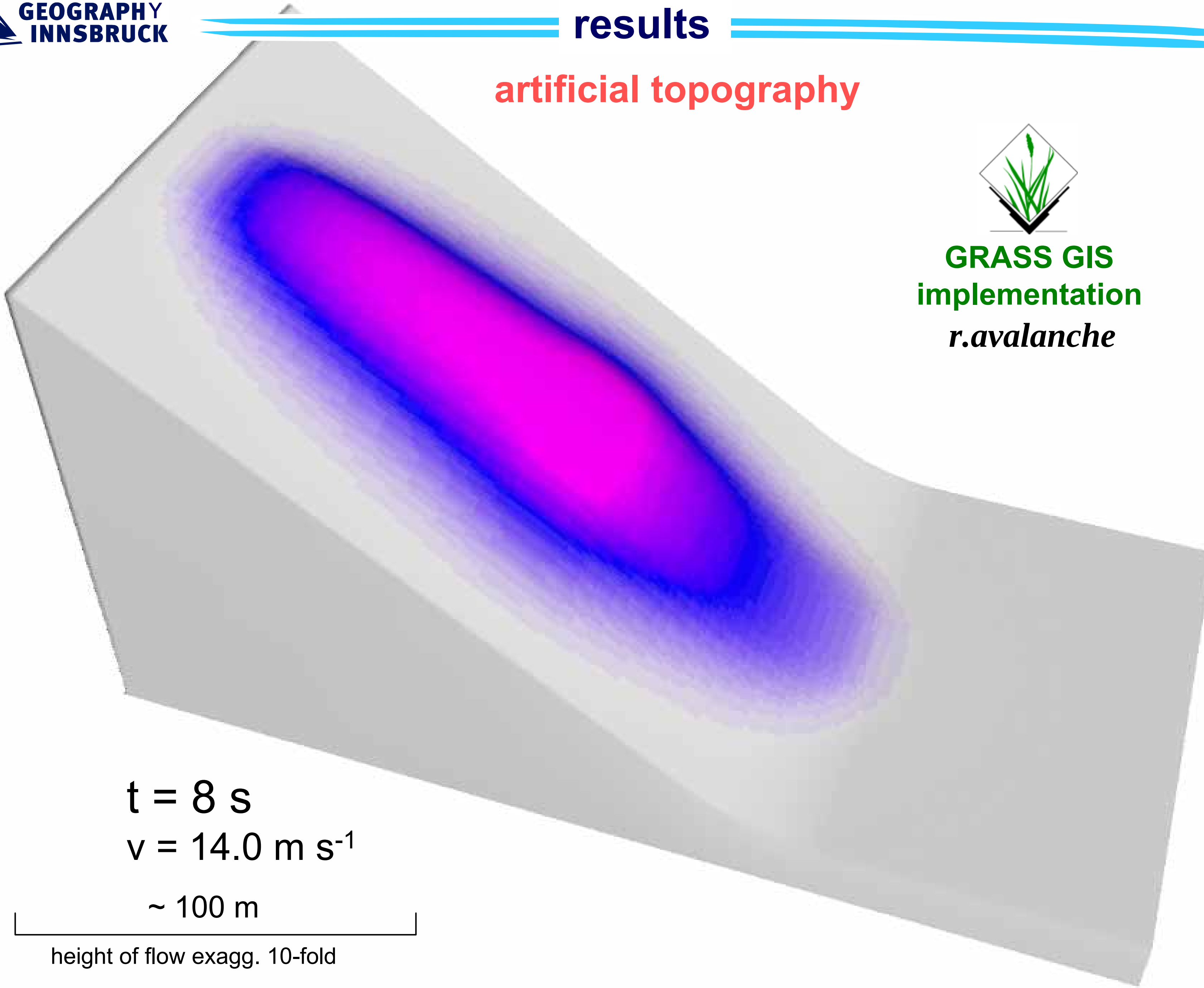


results

artificial topography

GRASS GIS implementation

r.avalanche

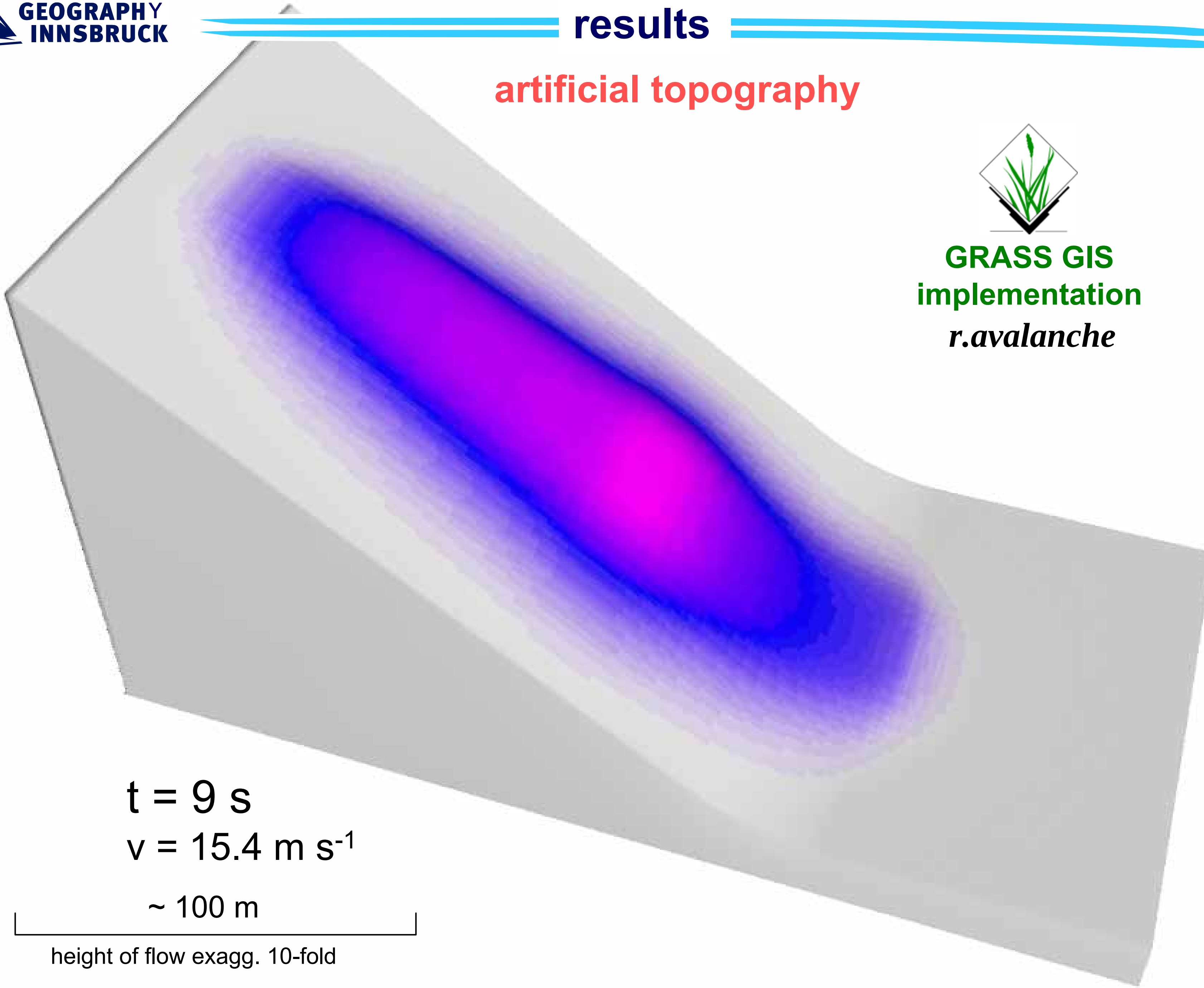


results

artificial topography

GRASS GIS implementation

r.avalanche

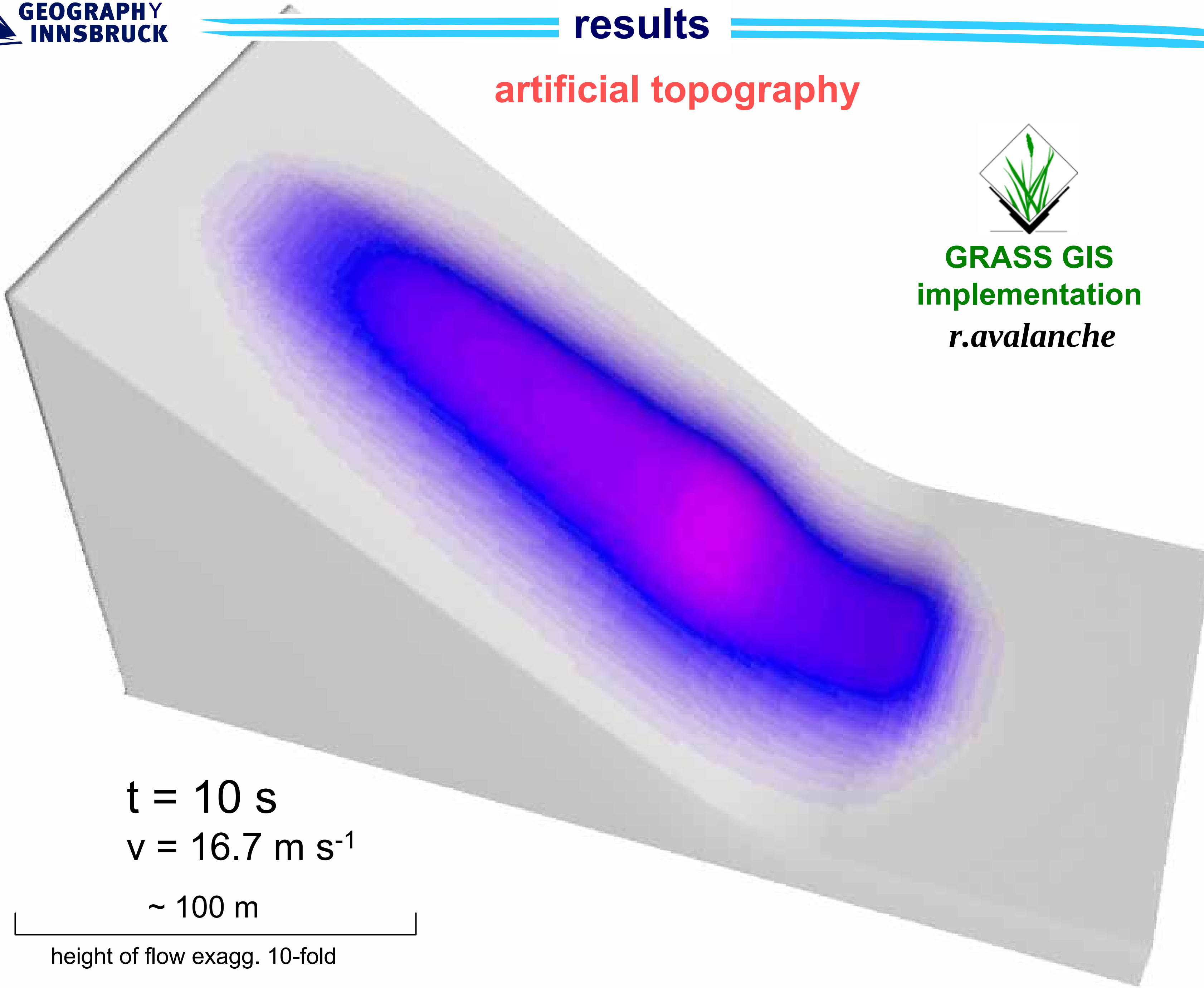


results

artificial topography

GRASS GIS implementation

r.avalanche

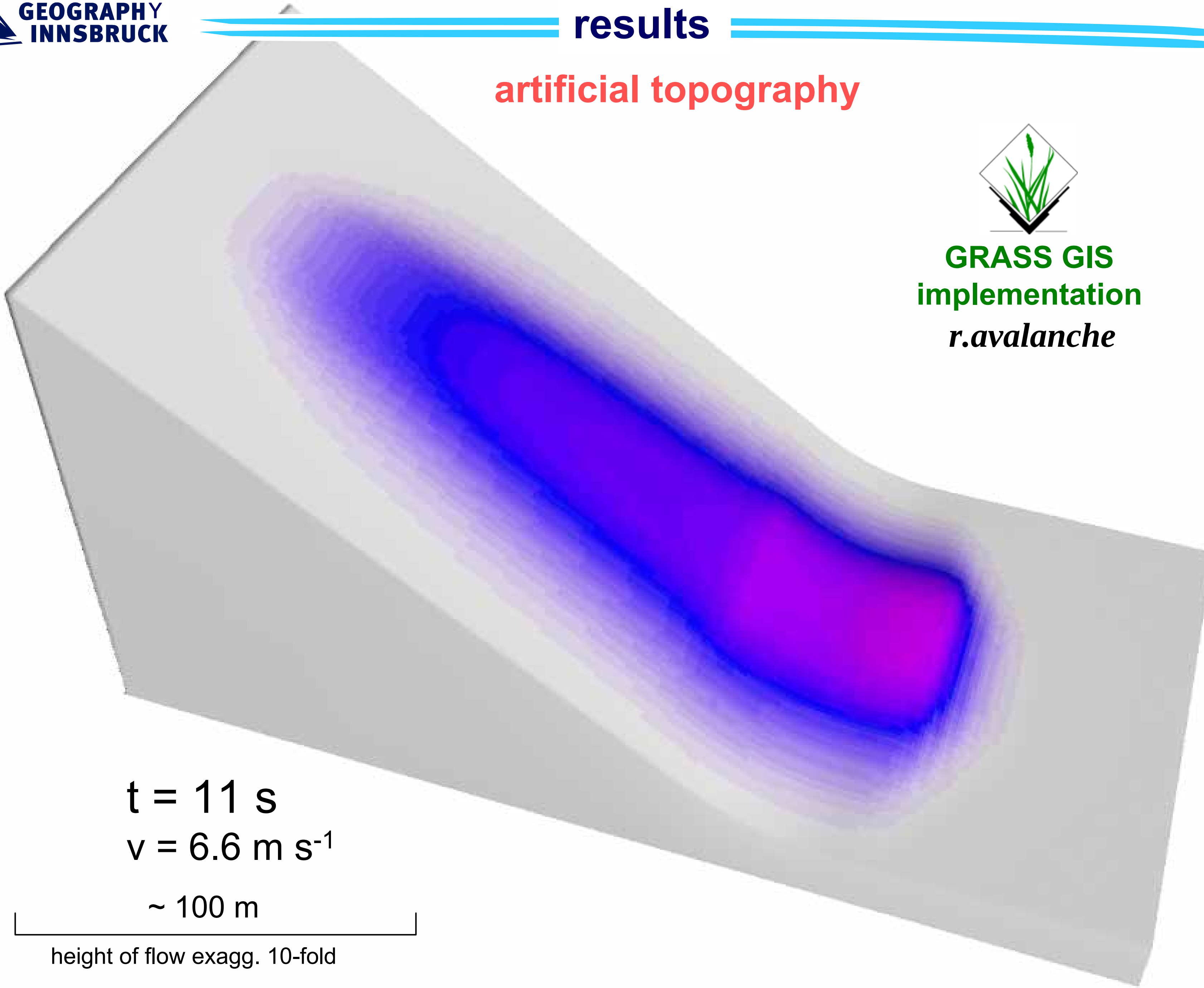


results

artificial topography

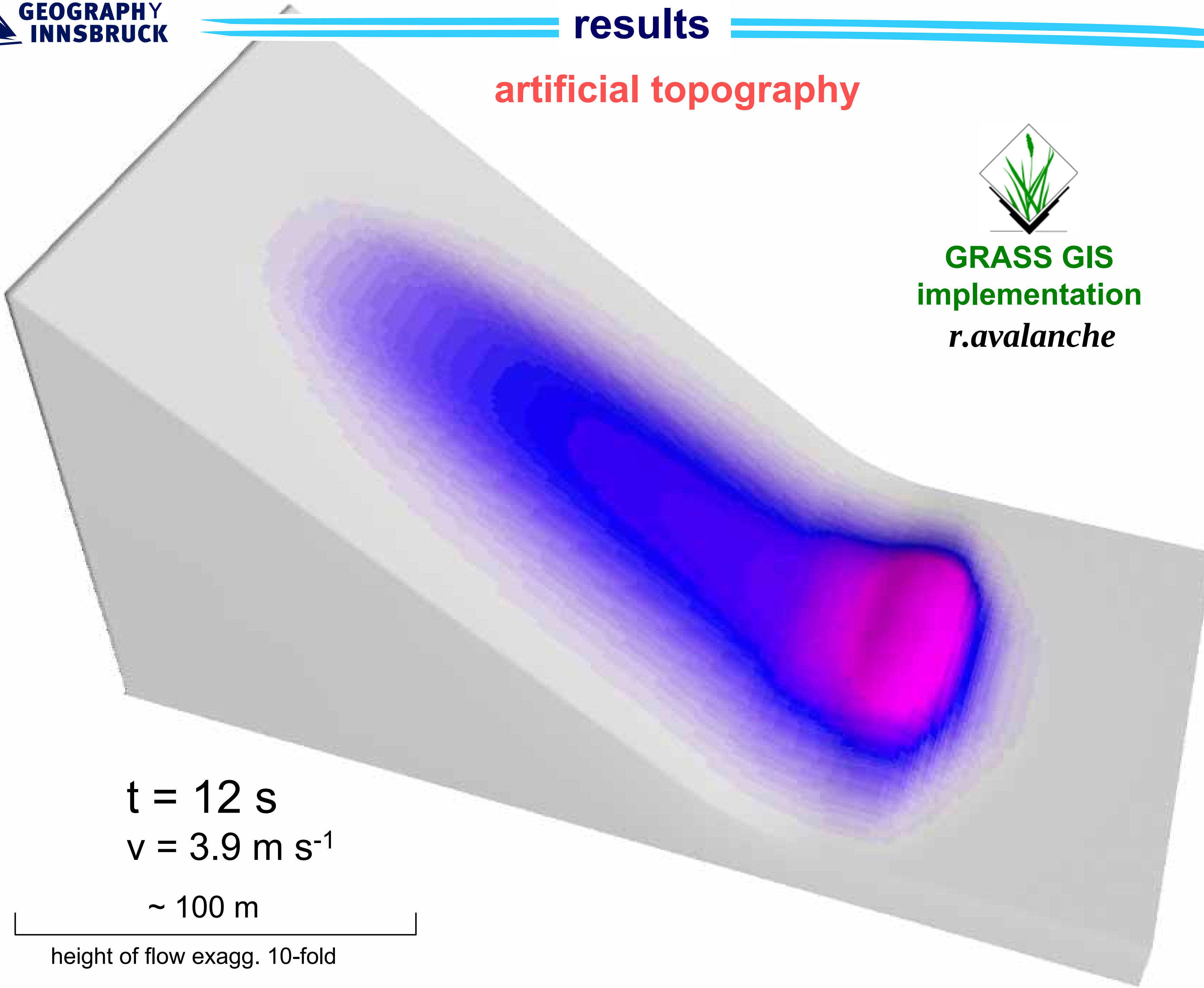
GRASS GIS implementation

r.avalanche



results

artificial topography



GRASS GIS implementation

r.avalanche

t = 12 s

v = 3.9 m s^{-1}

~ 100 m

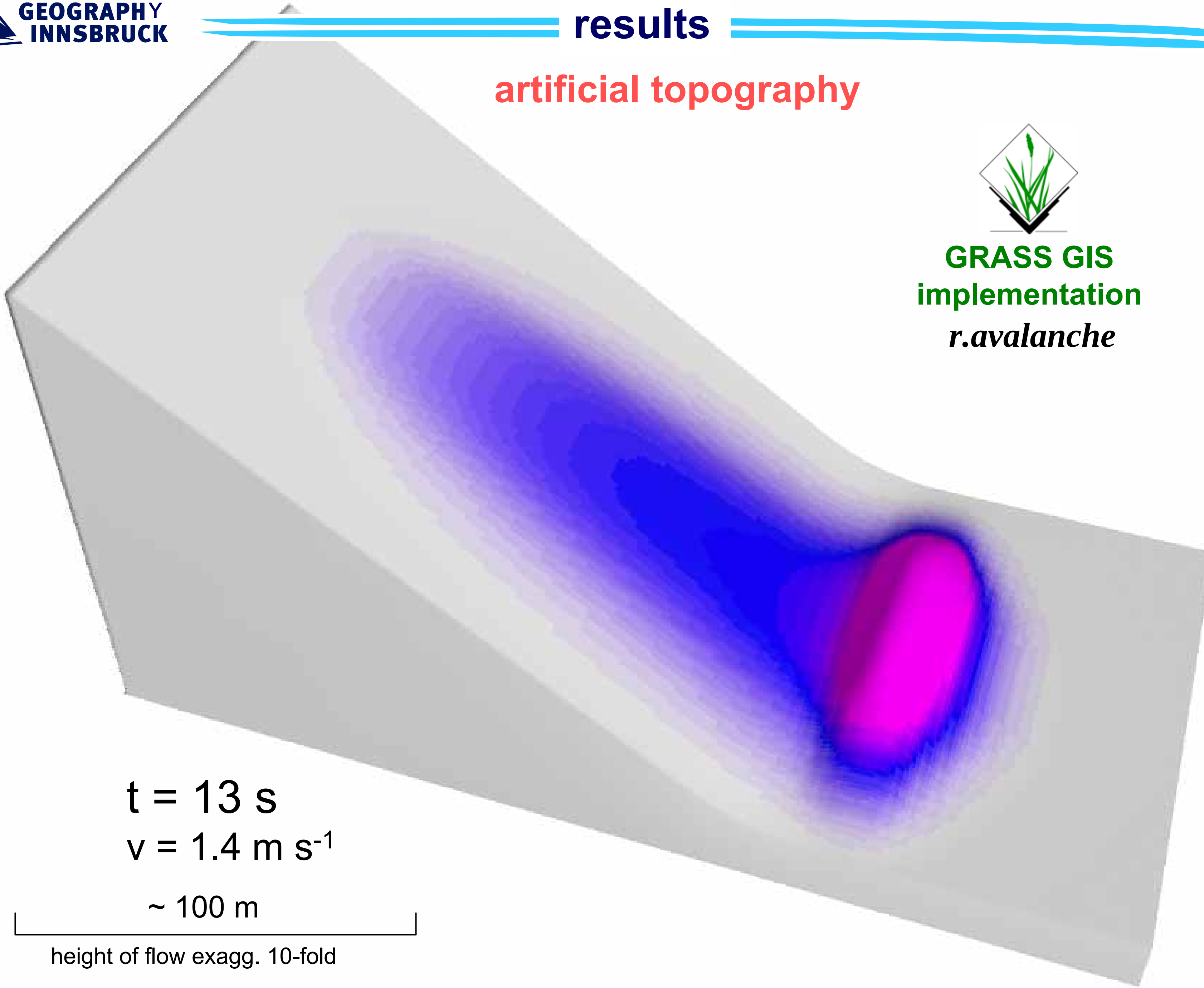
height of flow exagg. 10-fold

results

artificial topography

GRASS GIS implementation

r.avalanche

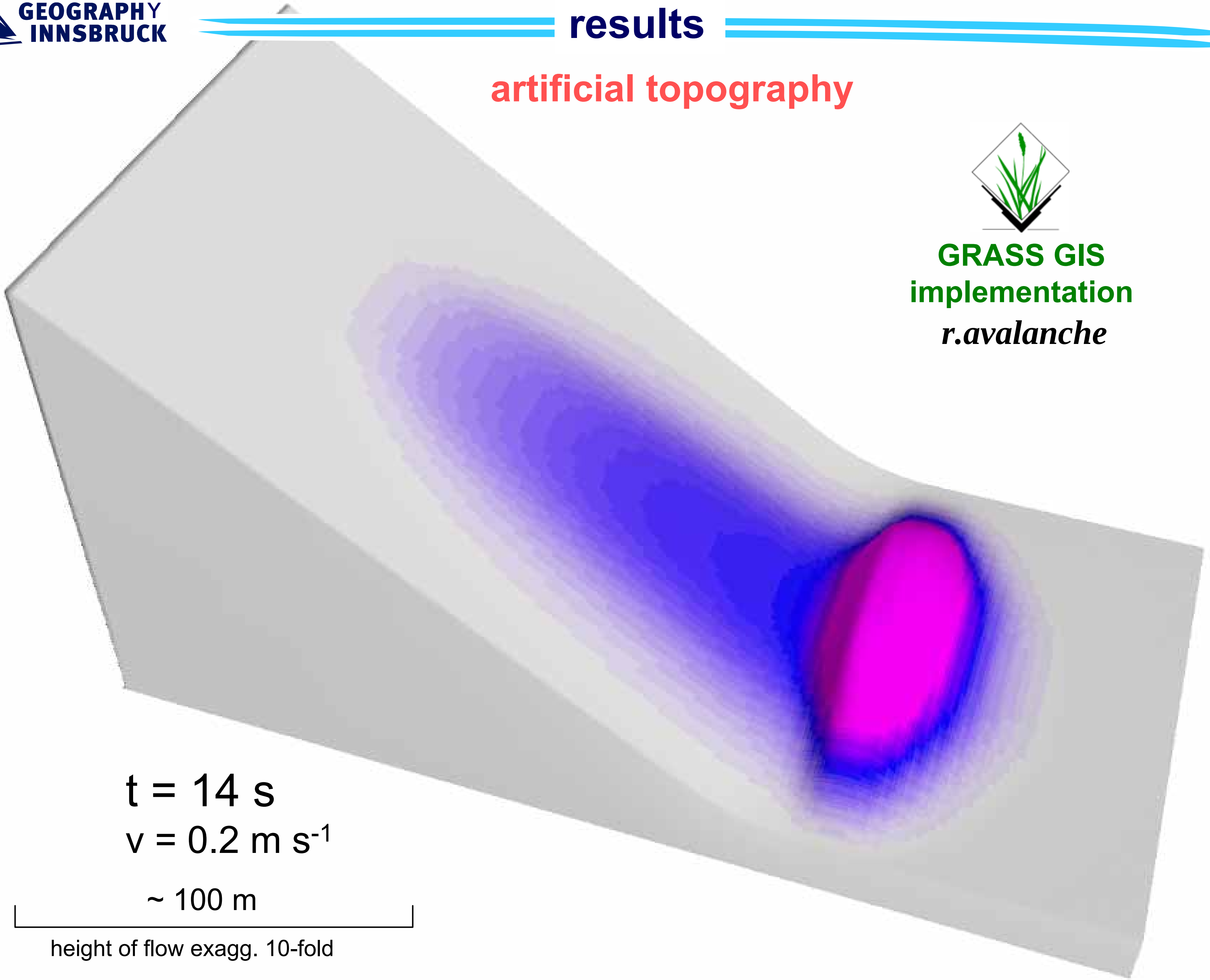


results

artificial topography

GRASS GIS implementation

r.avalanche

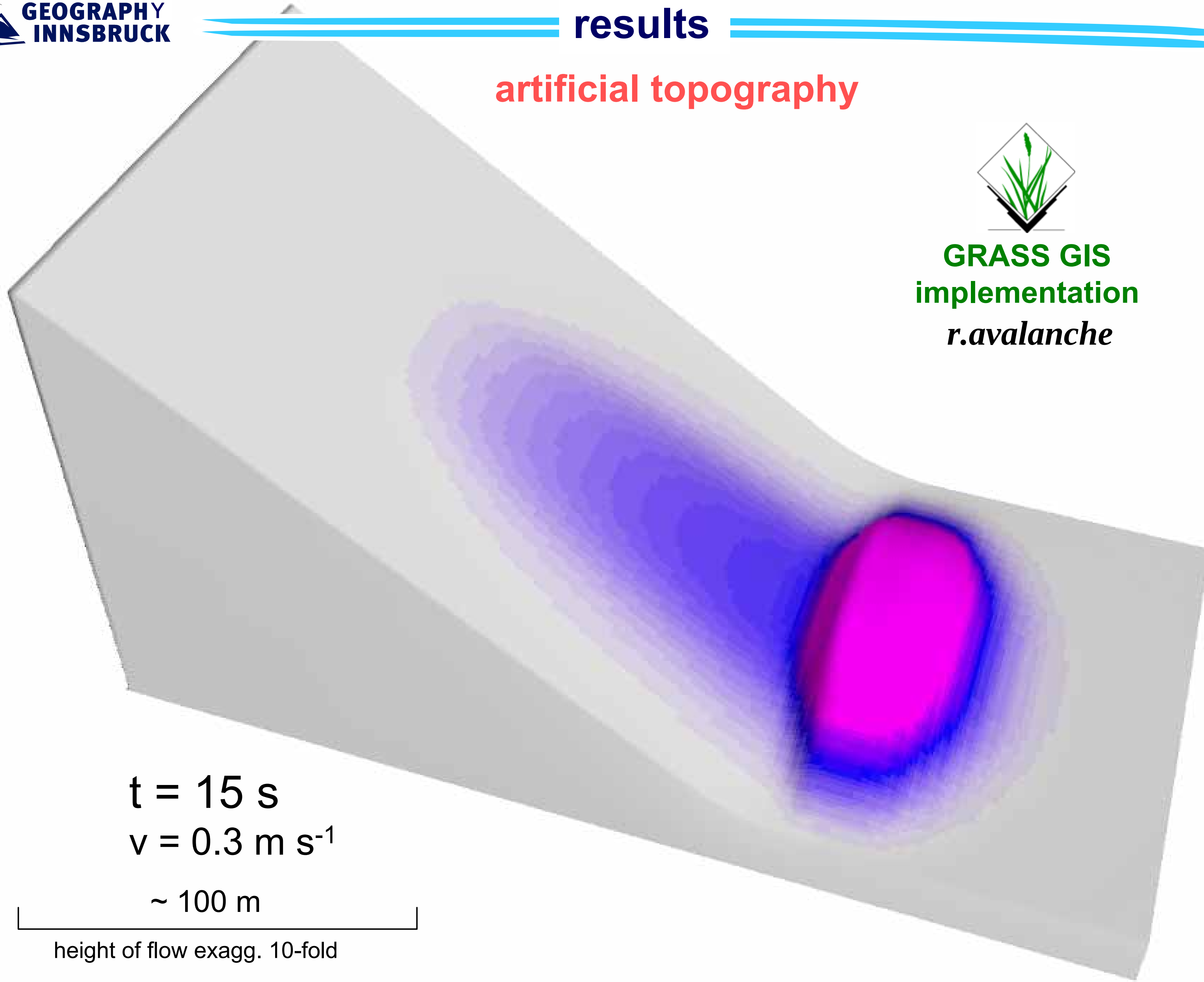


results

artificial topography

GRASS GIS implementation

r.avalanche



t = 15 s

$v = 0.3\ \mathrm{m\ s^{-1}}$

~ 100 m

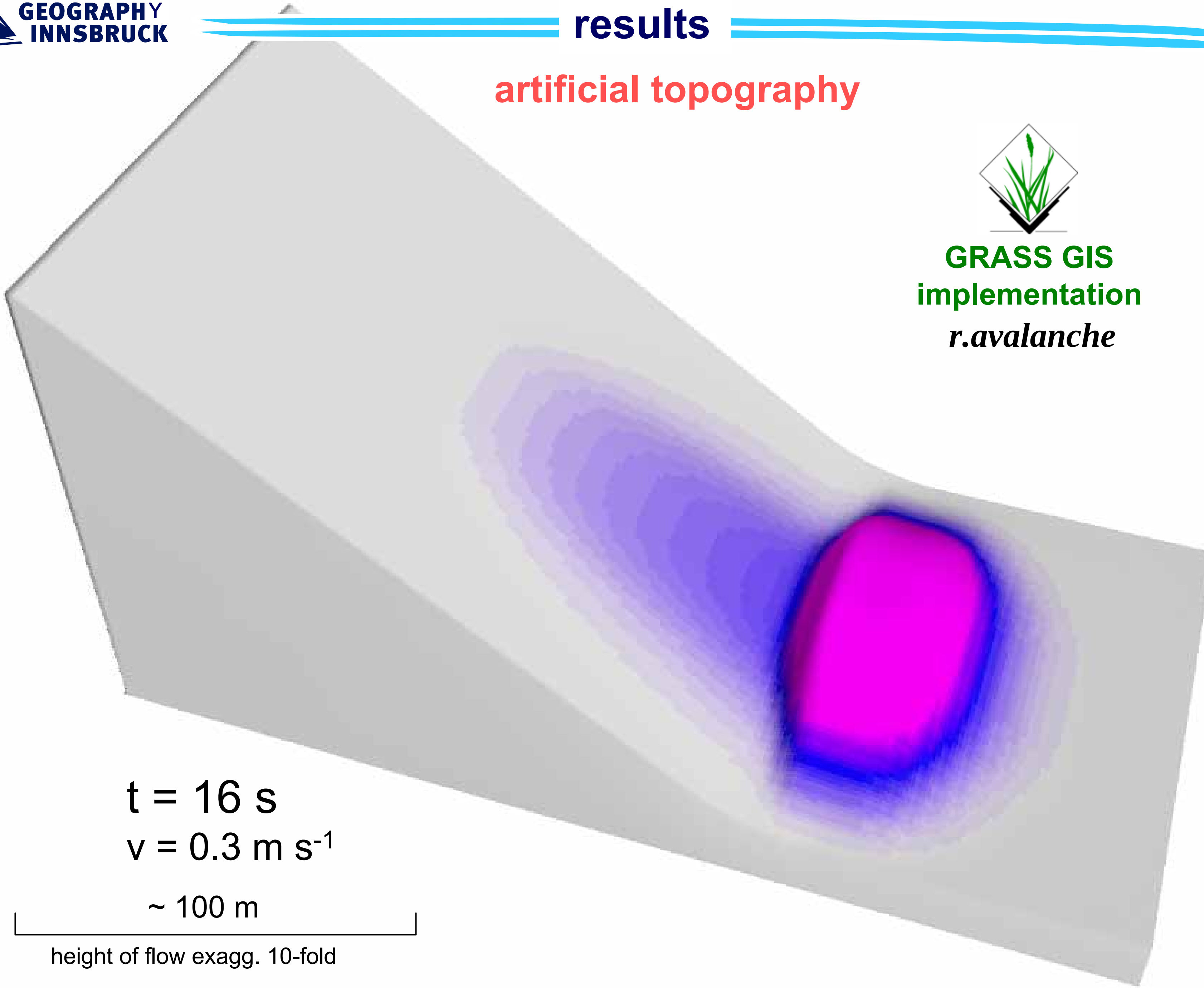
height of flow exagg. 10-fold

results

artificial topography

GRASS GIS implementation

r.avalanche



t = 16 s

v = 0.3 m s^{-1}

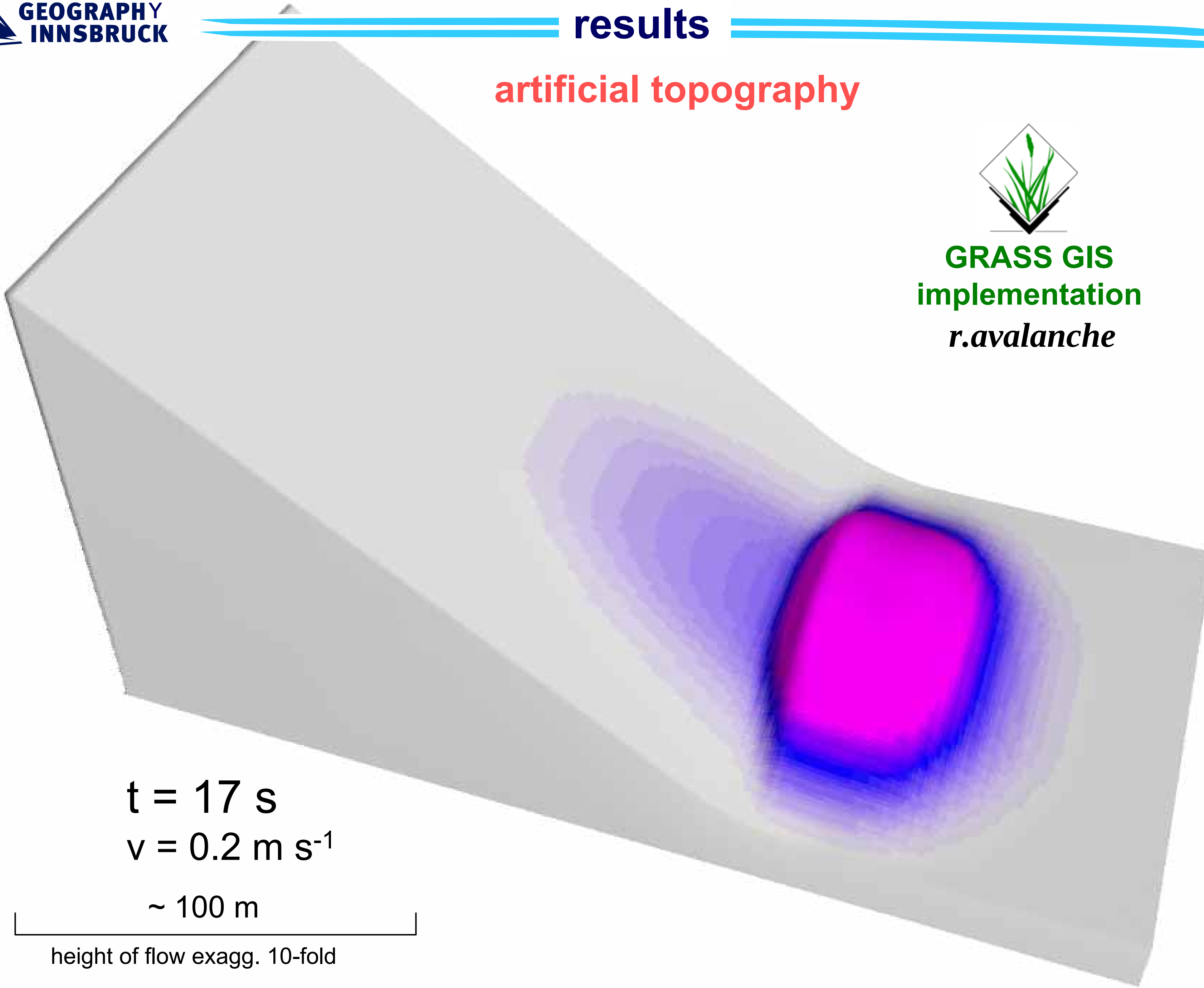
~ 100 m

height of flow exagg. 10-fold

results

artificial topography

GRASS GIS implementation
r.avalanche



t = 17 s
$v = 0.2\ m\ s^{-1}$

~ 100 m

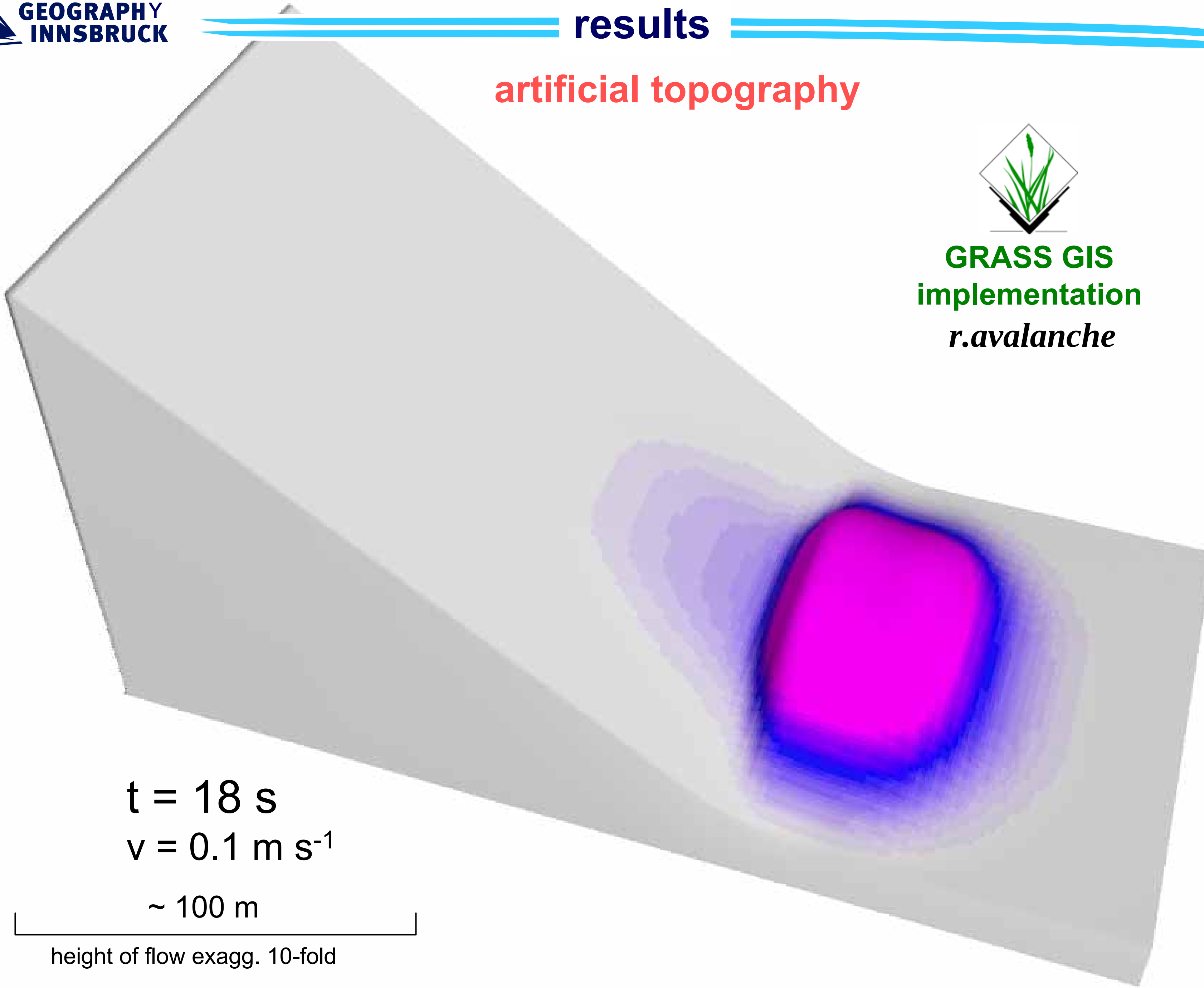
height of flow exagg. 10-fold

results

artificial topography

GRASS GIS implementation

r.avalanche



t = 18 s

v = 0.1 m s^{-1}

~ 100 m

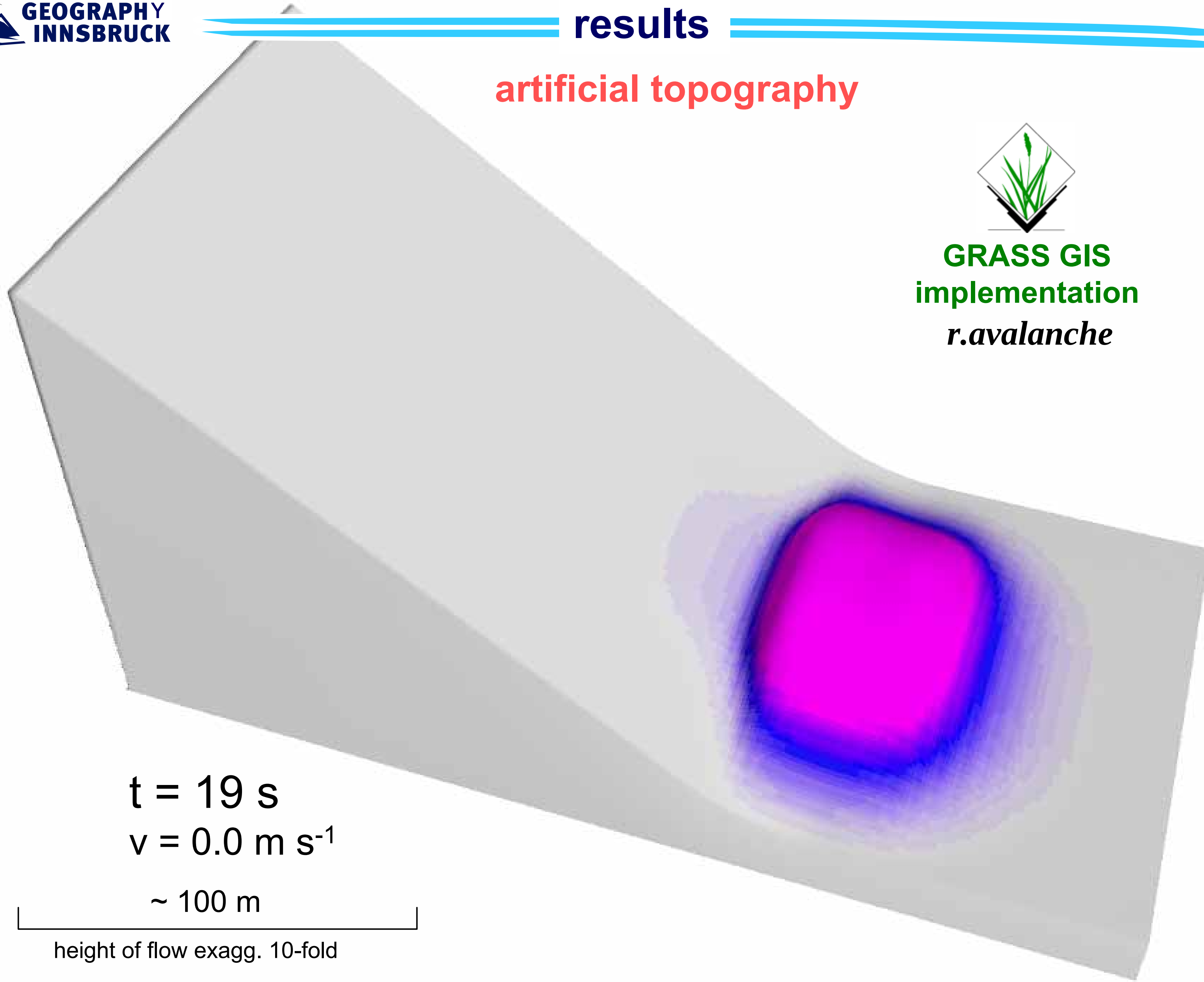
height of flow exagg. 10-fold

results

artificial topography

GRASS GIS implementation

r.avalanche

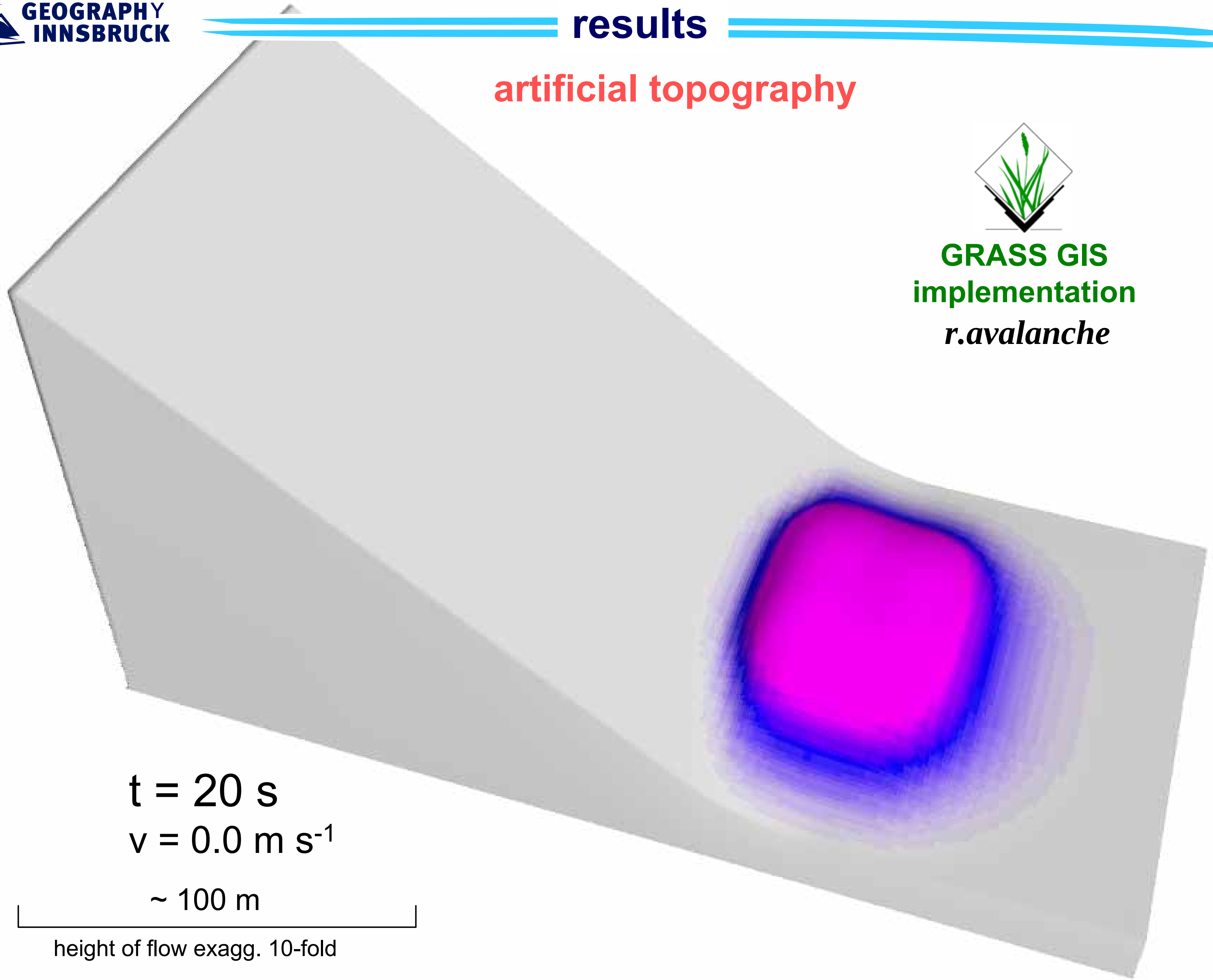


results

artificial topography

GRASS GIS implementation

r.avalanche

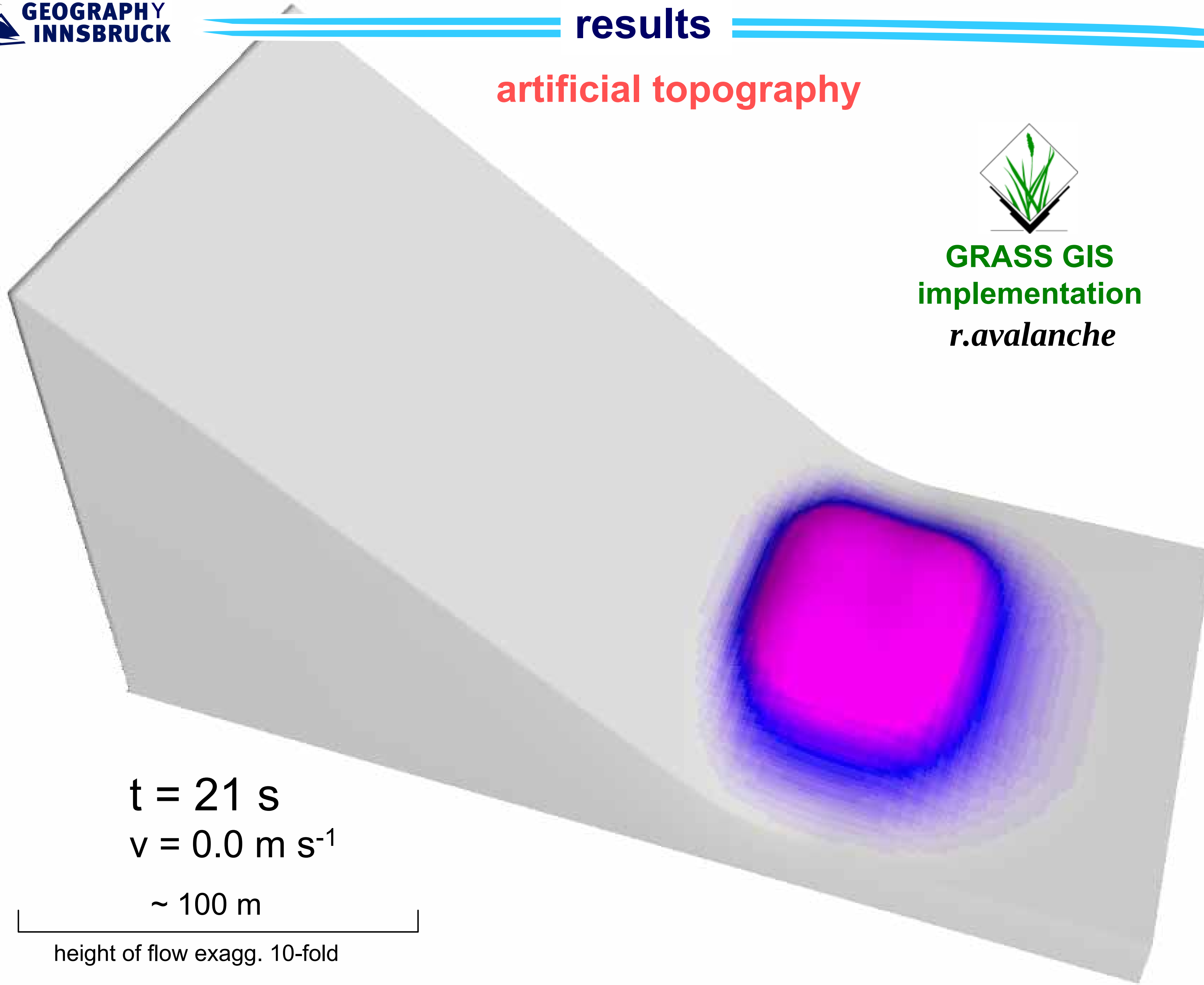


results

artificial topography

GRASS GIS implementation

r.avalanche

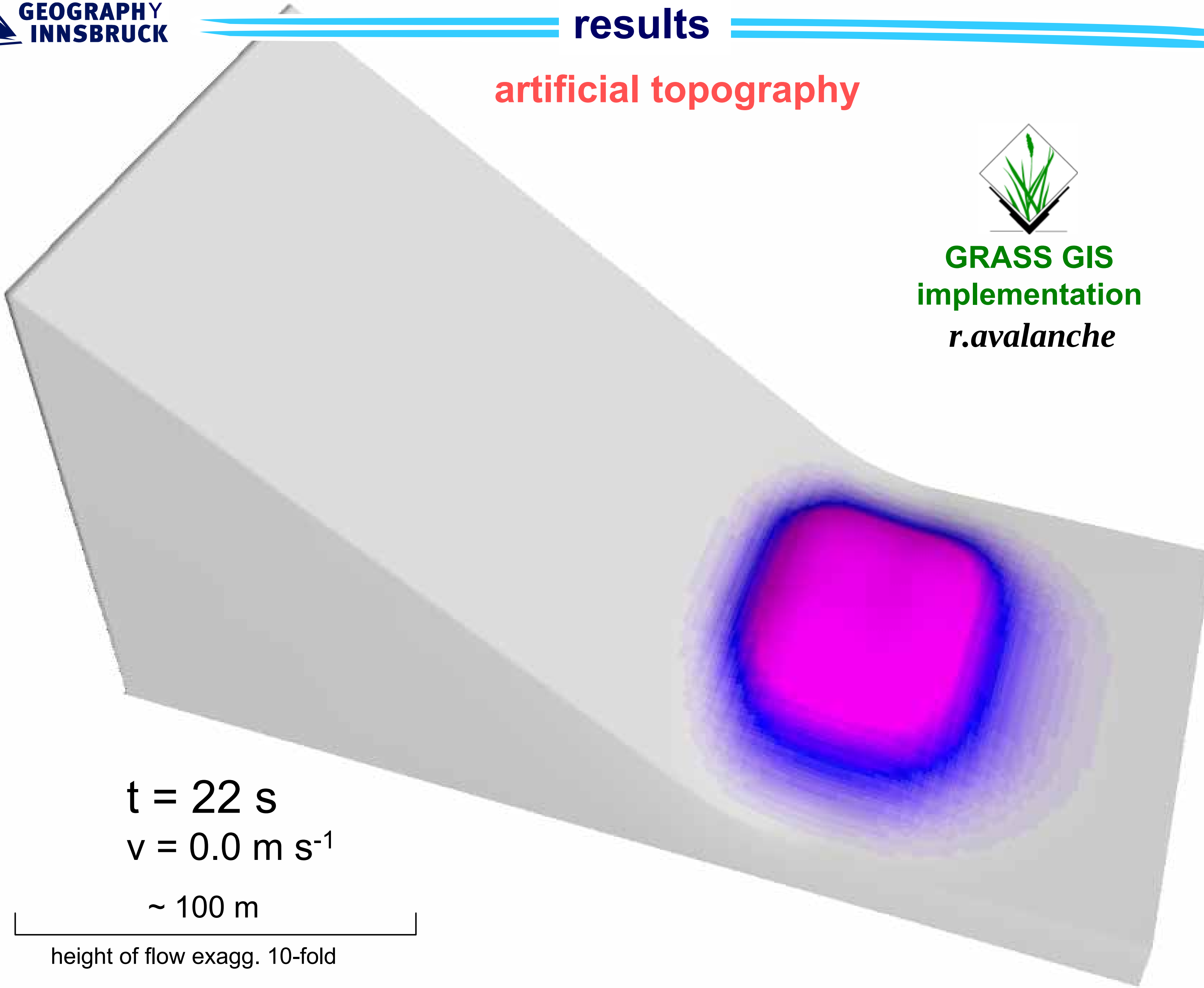


results

artificial topography

GRASS GIS implementation

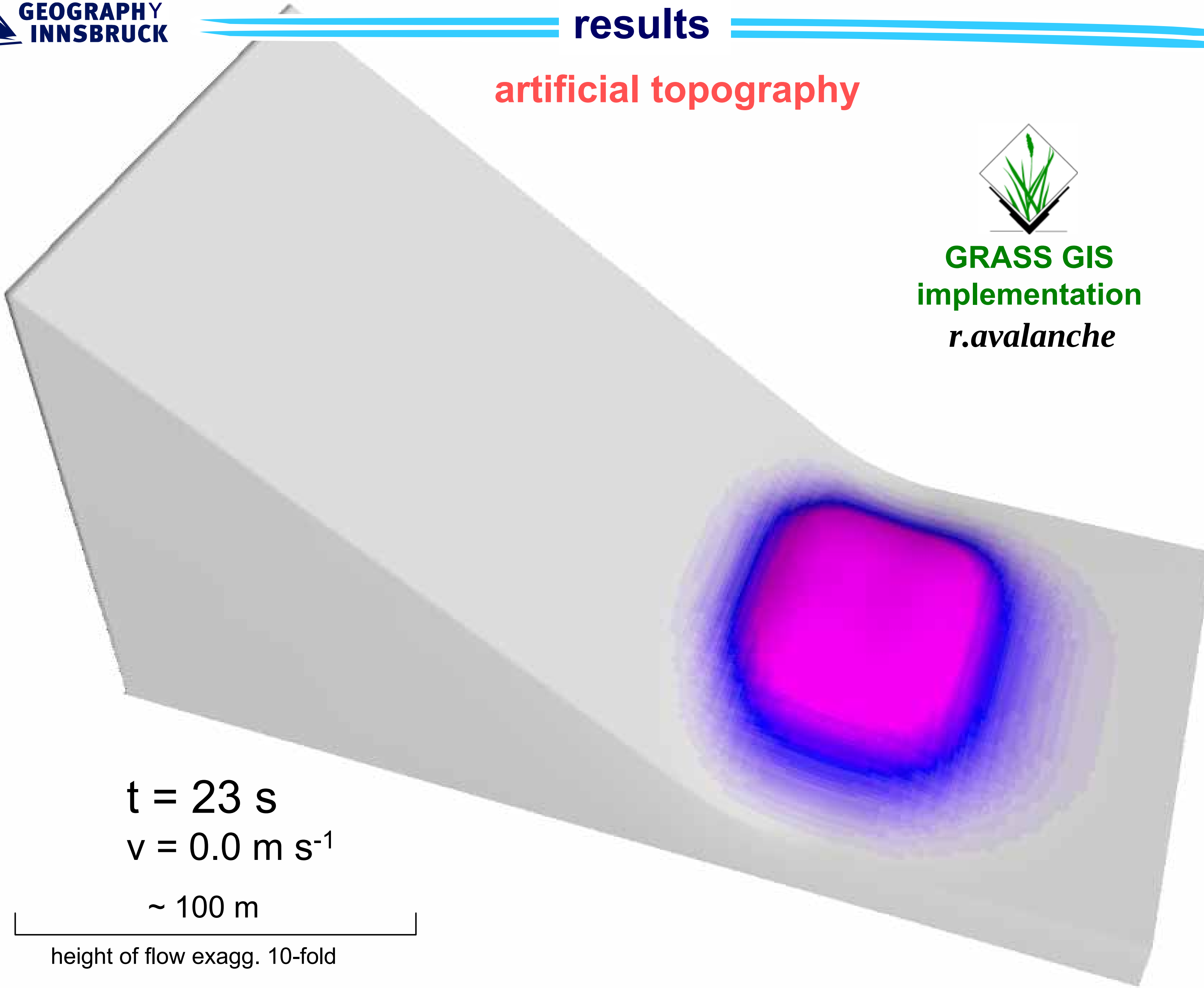
r.avalanche



artificial topography

GRASS GIS implementation

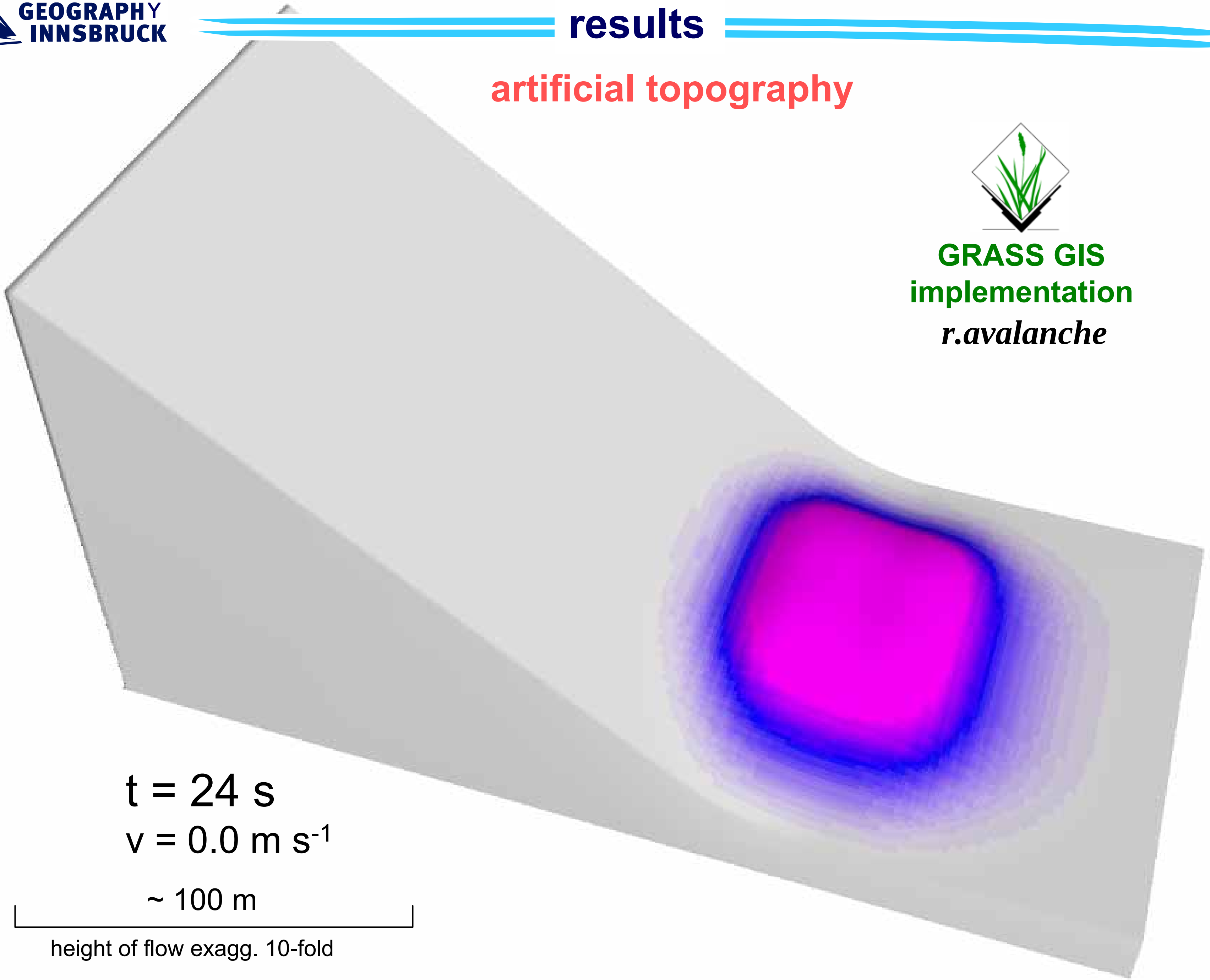
r.avalanche



results

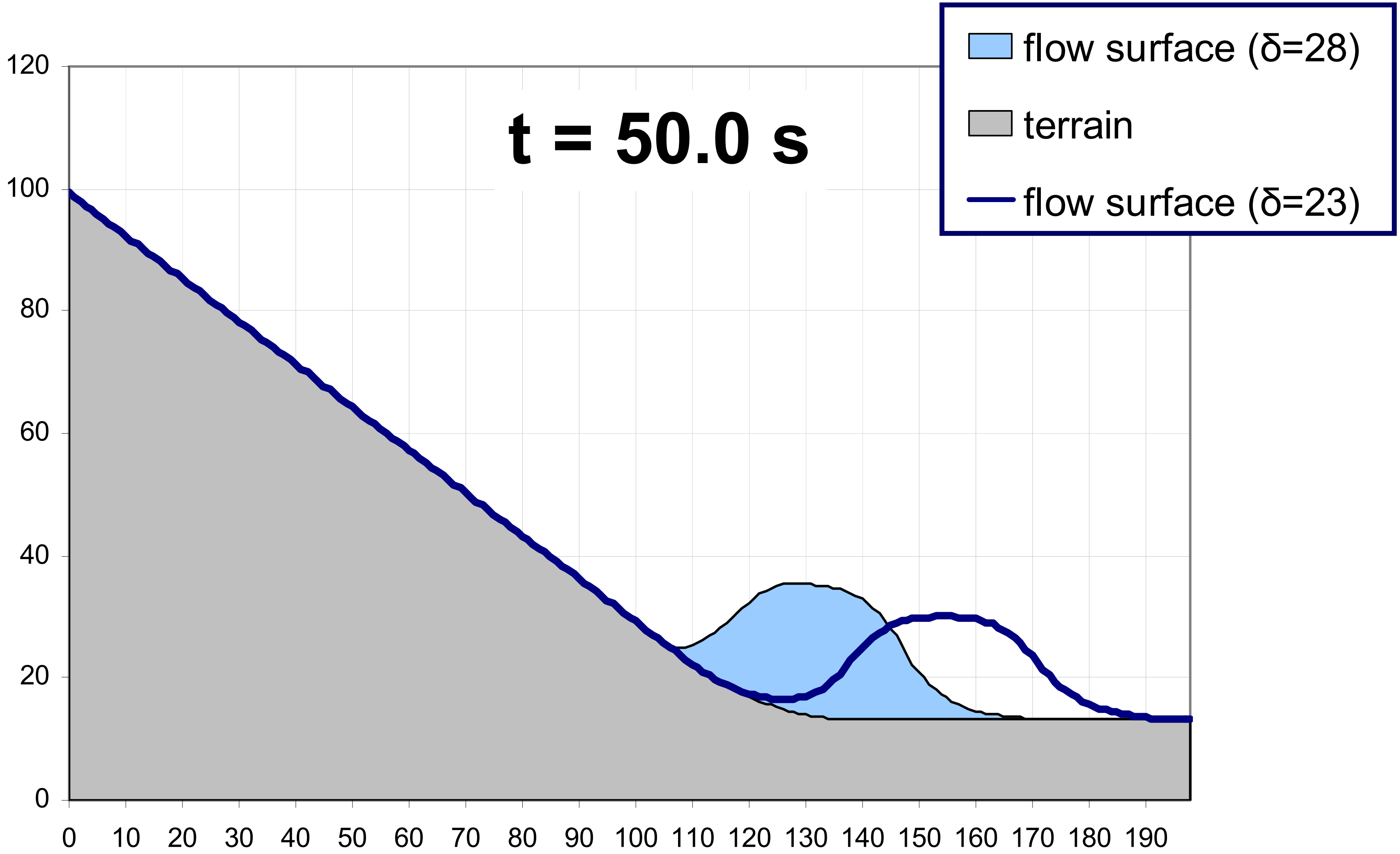
artificial topography

GRASS GIS implementation
r.avalanche



results

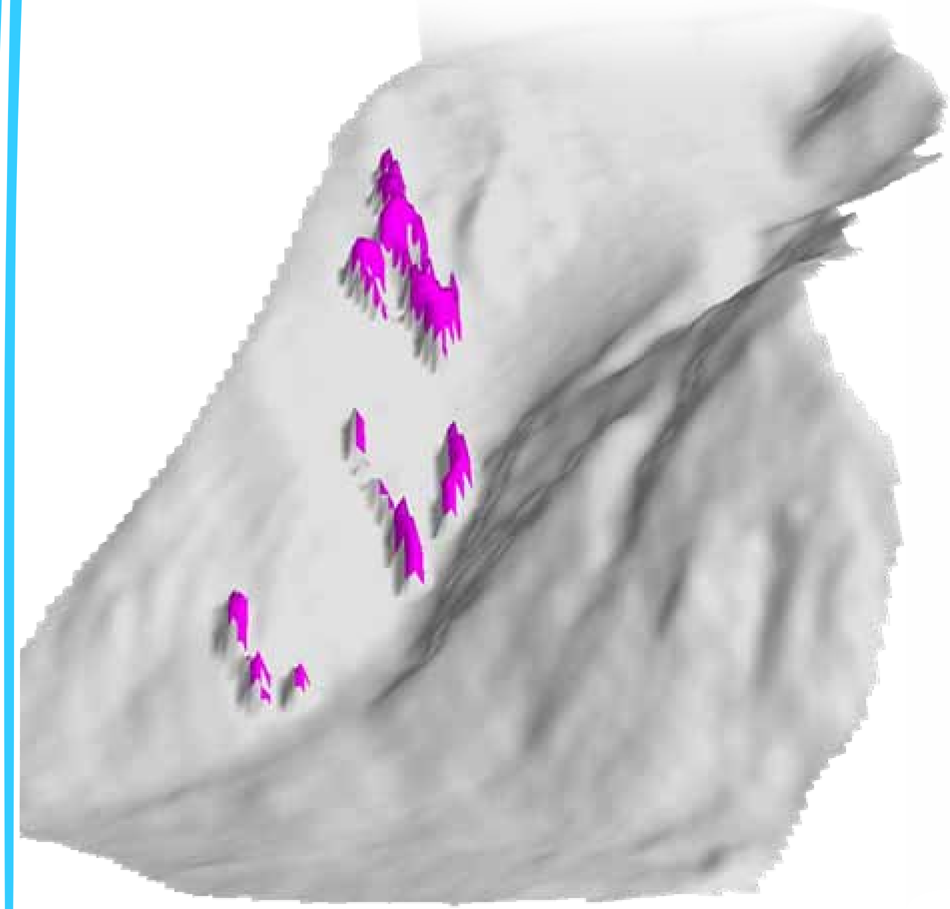
artificial topography



results

arbitrary topographies

GRASS GIS implementation
r.avalanche



t = 0 s   v = 0.0 m s^{-1}

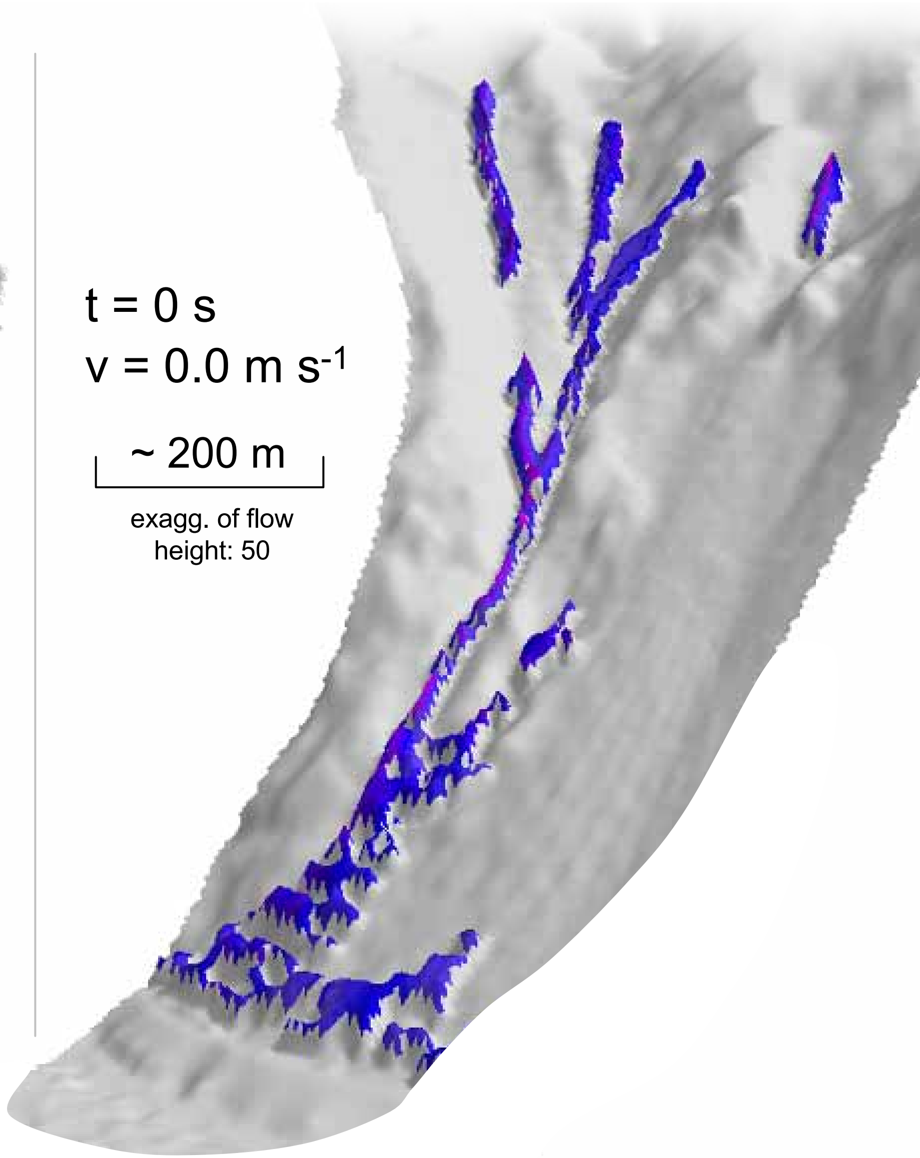
~ 300 m

exagg. of flow height: 50

t = 0 s
v = 0.0 m s^{-1}

~ 200 m

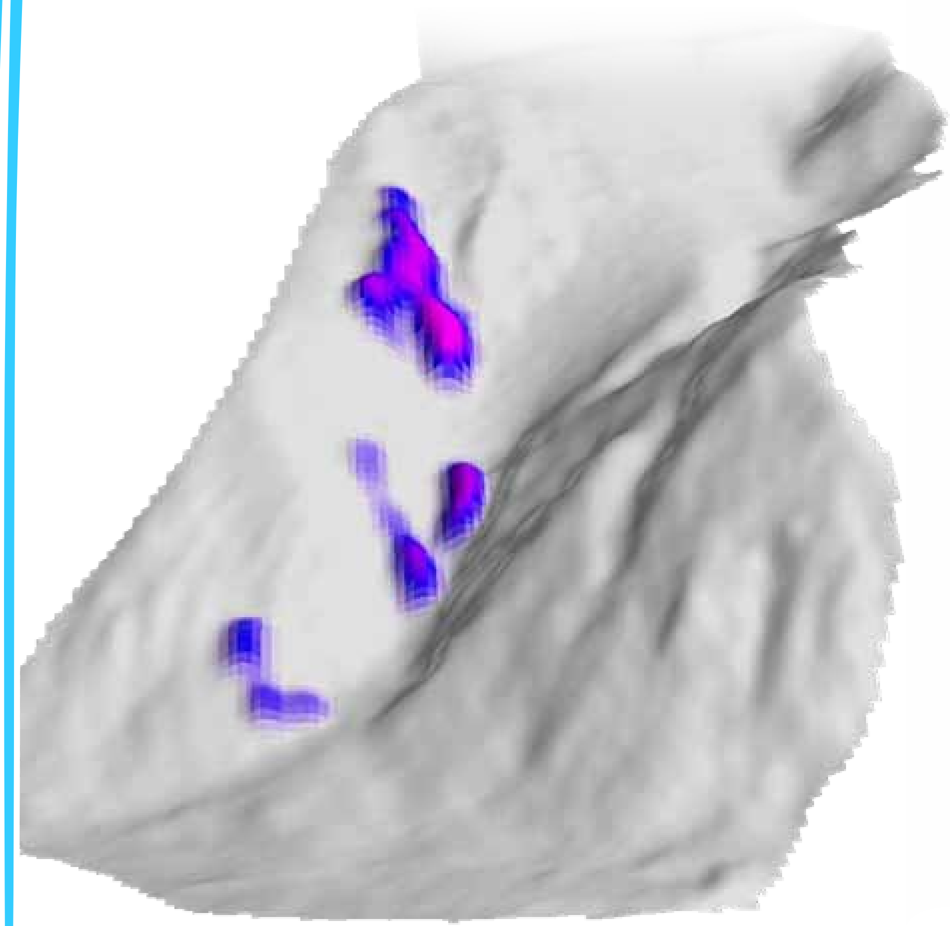
exagg. of flow height: 50



arbitrary topographies

GRASS GIS implementation

r.avalanche



t = 2 s   v = 4.8 m s^{-1}

~ 300 m

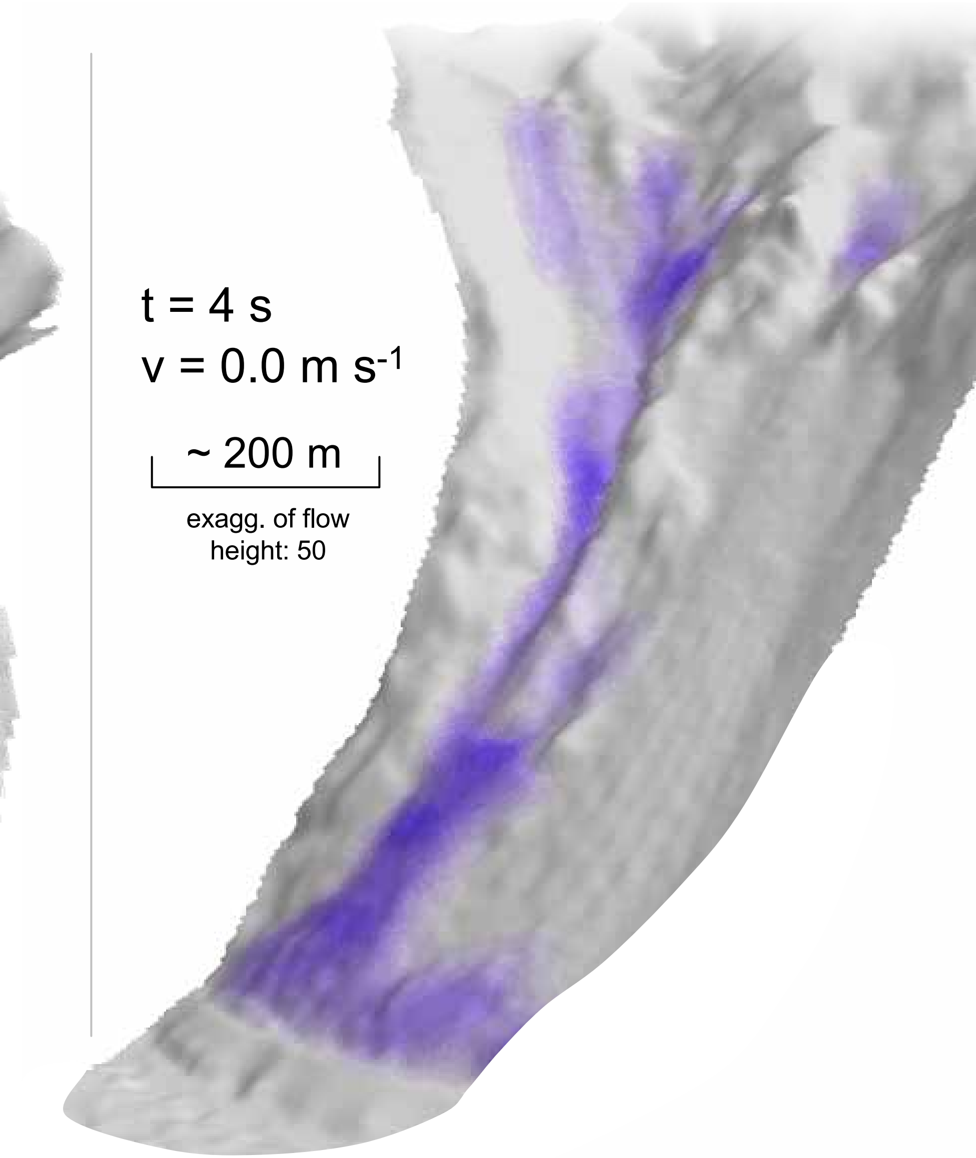
exagg. of flow height: 50

t = 4 s

v = 0.0 m s^{-1}

~ 200 m

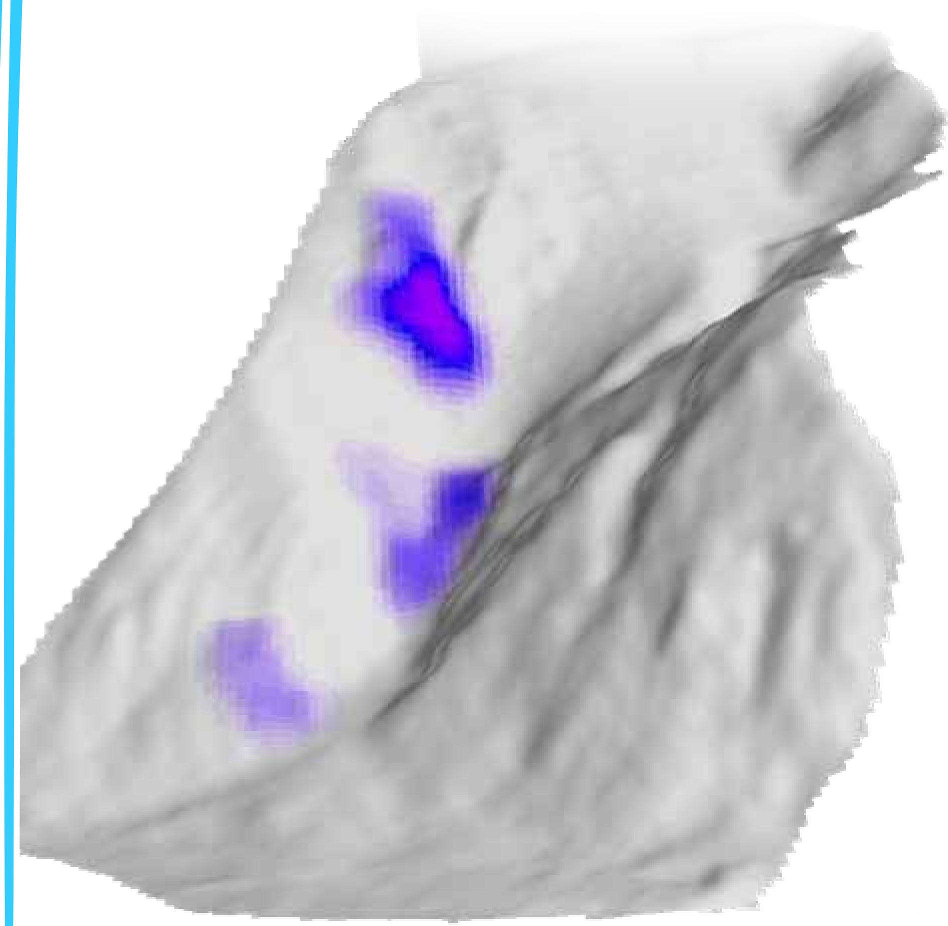
exagg. of flow height: 50



arbitrary topographies

GRASS GIS implementation

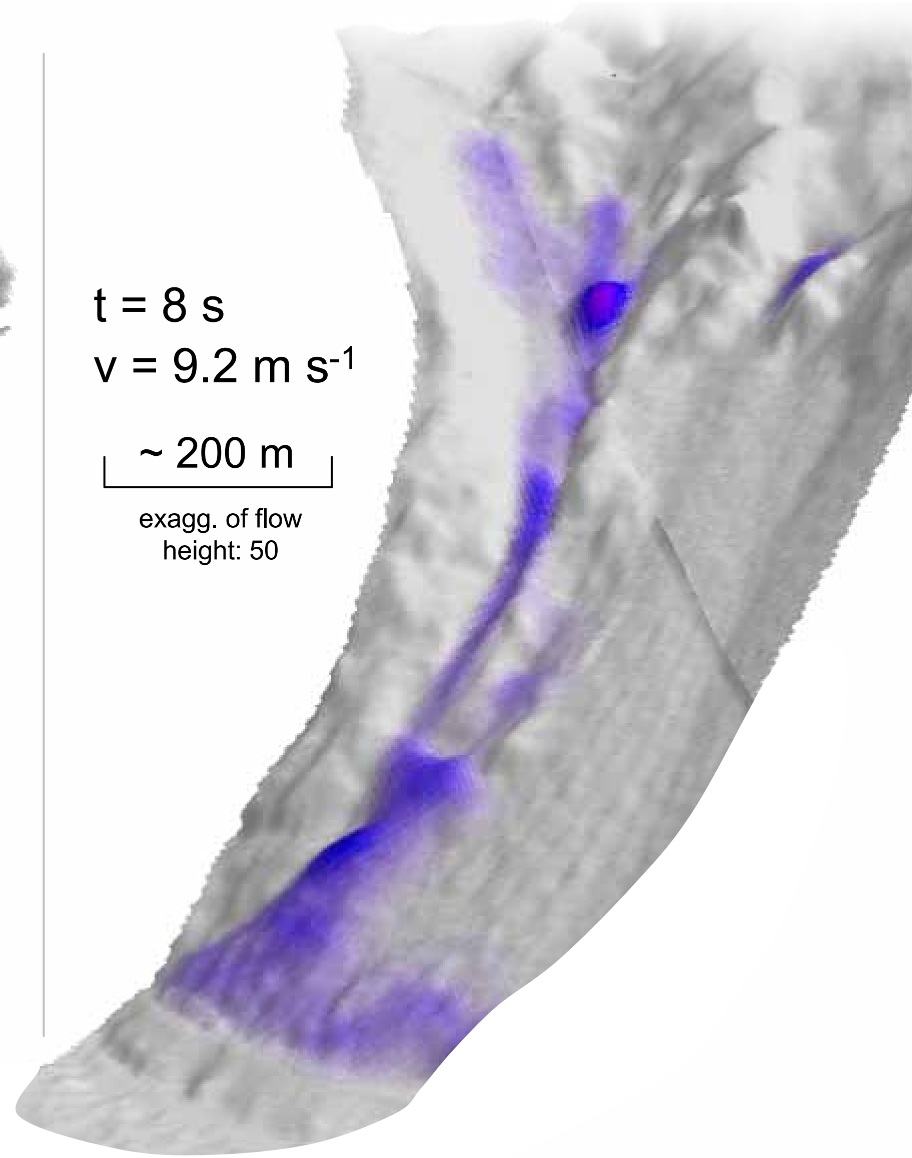
r.avalanche



t = 4 s v = 10.0 m s^{-1}

~ 300 m

exagg. of flow height: 50



t = 8 s

v = 9.2 m s^{-1}

~ 200 m

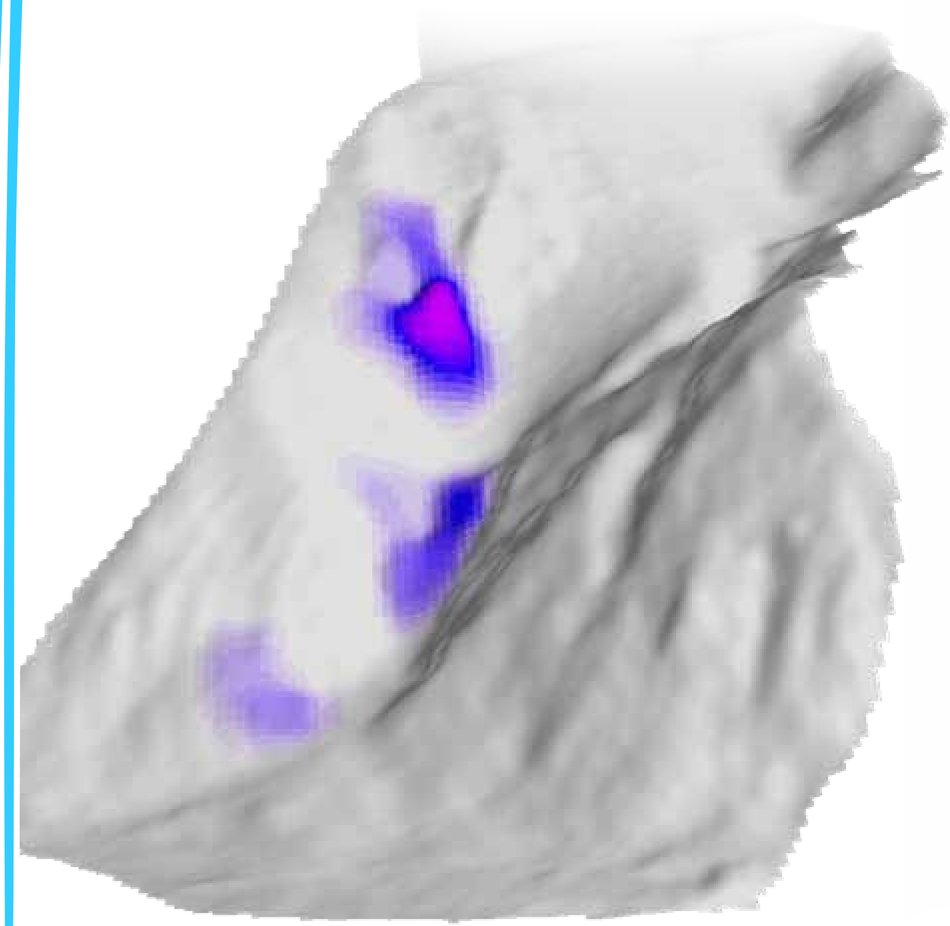
exagg. of flow height: 50

results

arbitrary topographies

GRASS GIS implementation

r.avalanche



t = 6 s   v = 16.7 m s^{-1}

~ 300 m

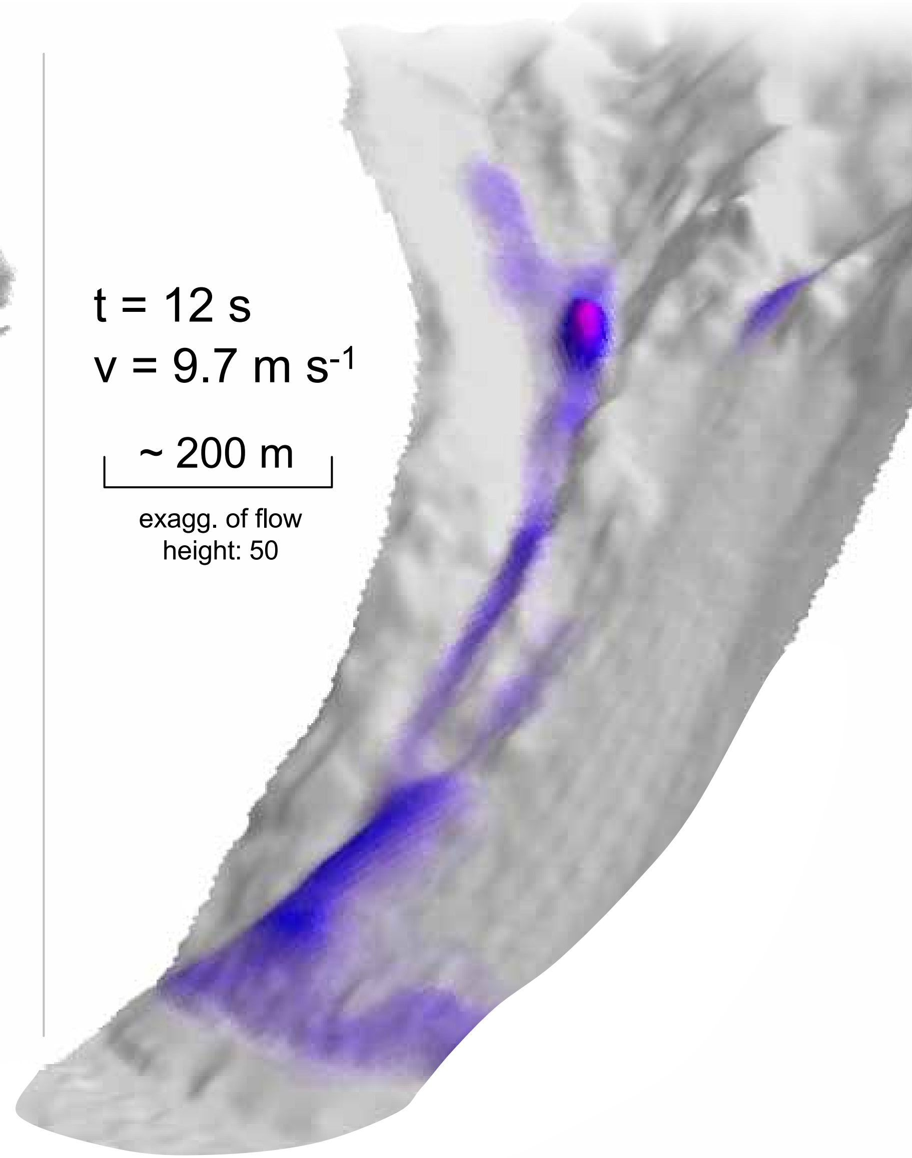
exagg. of flow height: 50

t = 12 s

v = 9.7 m s^{-1}

~ 200 m

exagg. of flow height: 50

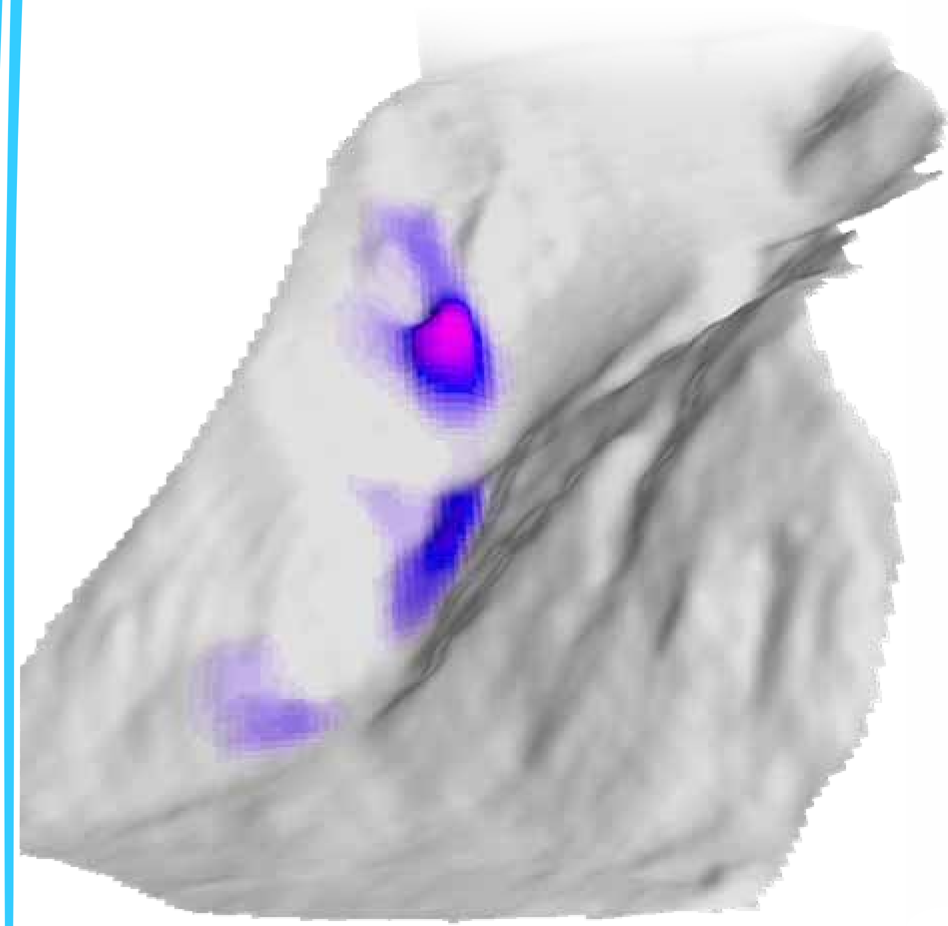


results

arbitrary topographies

GRASS GIS implementation

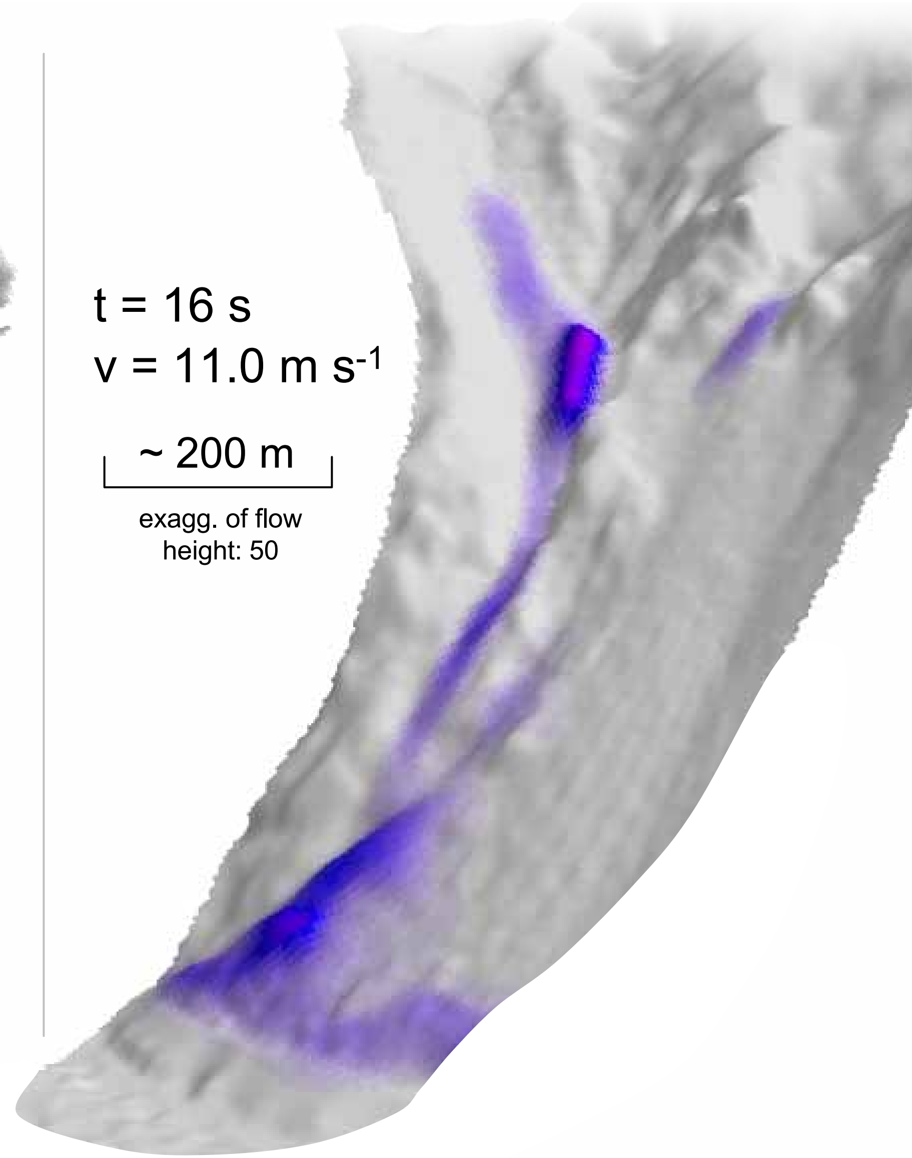
r.avalanche



t = 8 s   v = 22.0 m s^{-1}

~ 300 m

exagg. of flow height: 50



t = 16 s

v = 11.0 m s^{-1}

~ 200 m

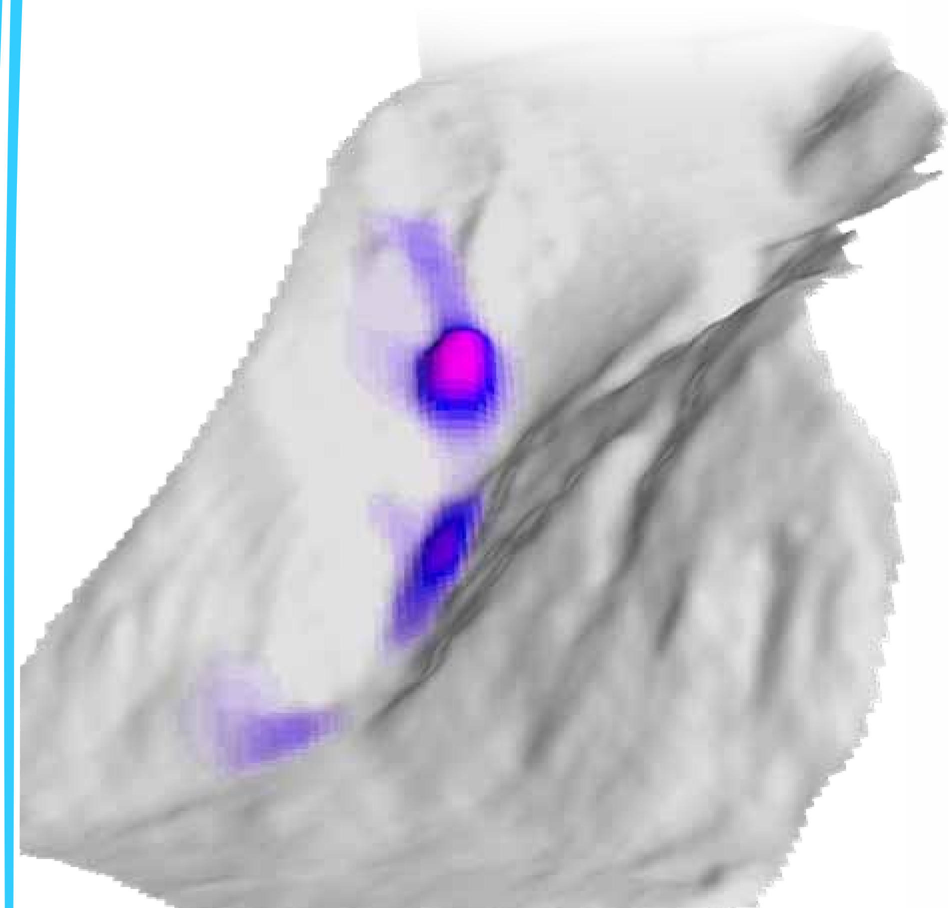
exagg. of flow height: 50

results

arbitrary topographies

GRASS GIS implementation

r.avalanche



t = 10 s v = 25.5 m s^{-1}

~ 300 m

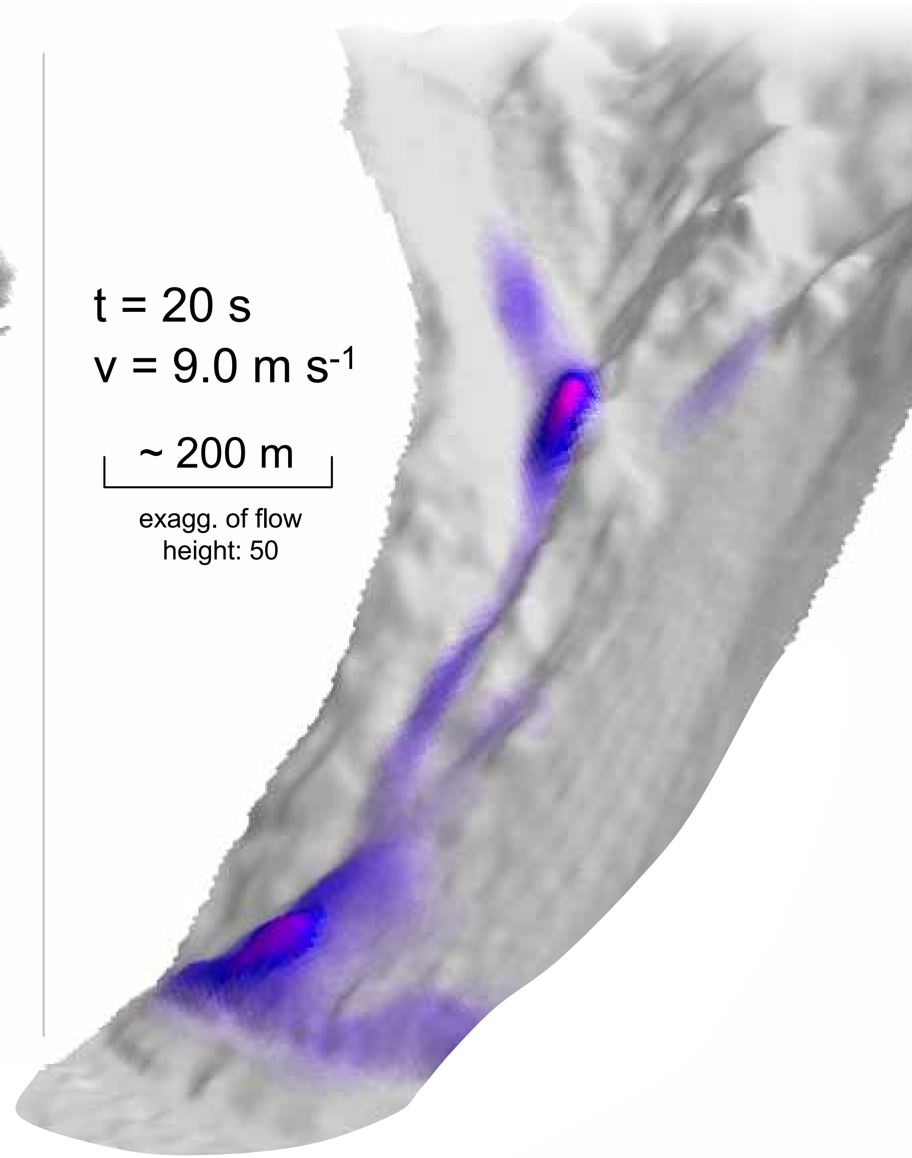
exagg. of flow height: 50

t = 20 s

v = 9.0 m s^{-1}

~ 200 m

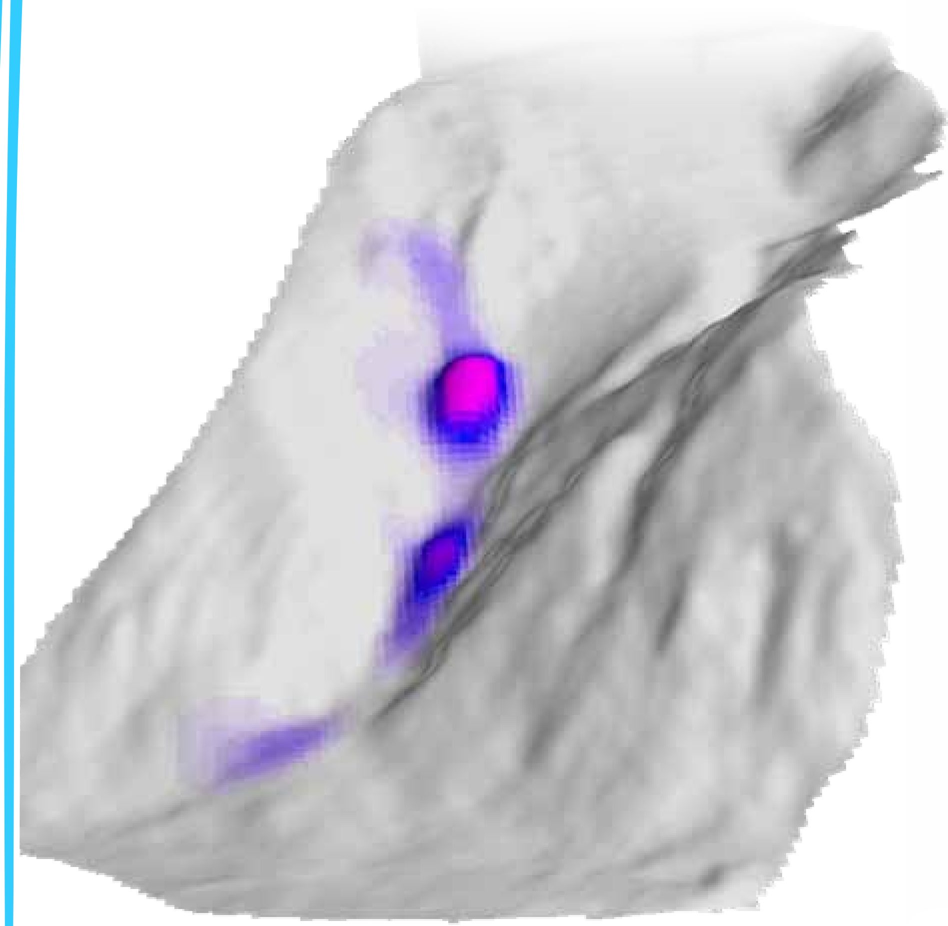
exagg. of flow height: 50



arbitrary topographies

GRASS GIS implementation

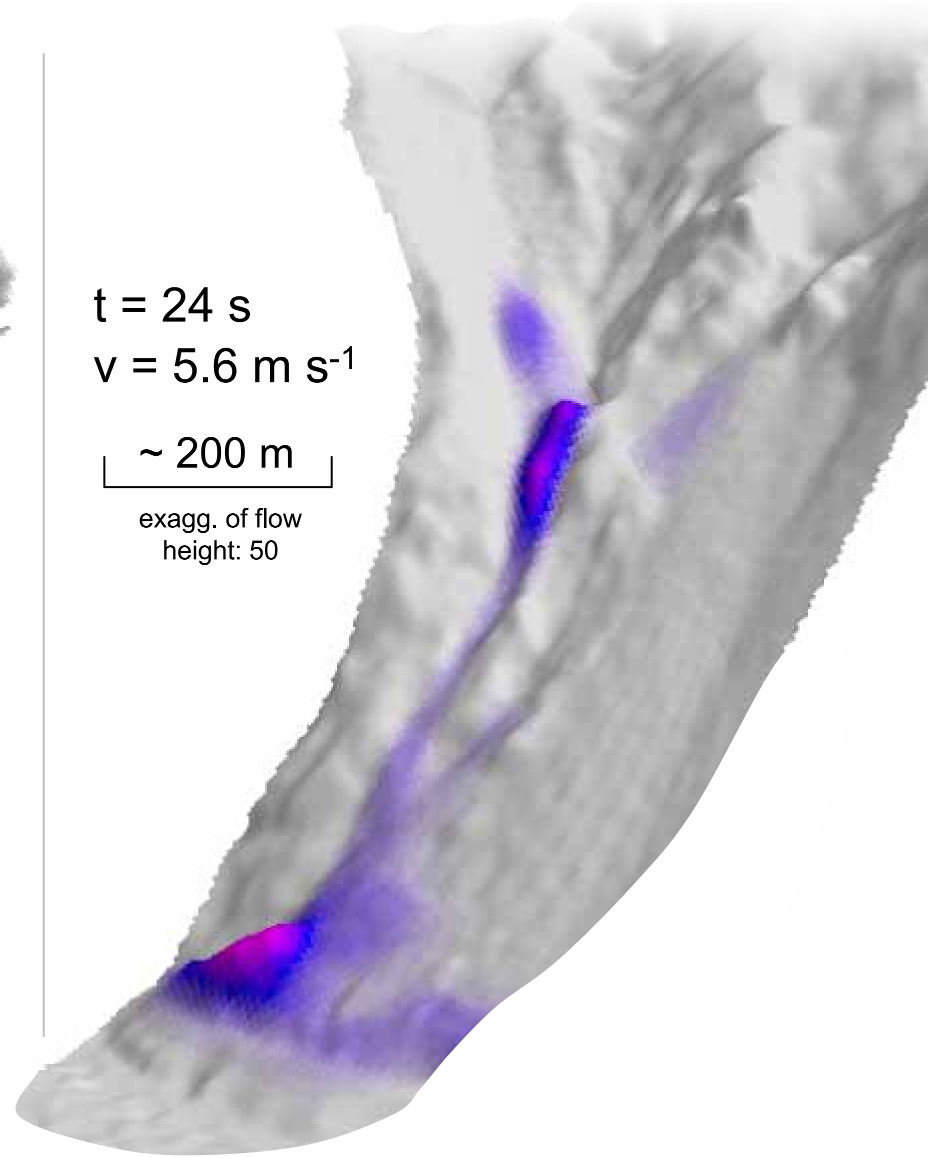
r.avalanche



t = 12 s v = 29.0 m s^{-1}

~ 300 m

exagg. of flow height: 50



t = 24 s

v = 5.6 m s^{-1}

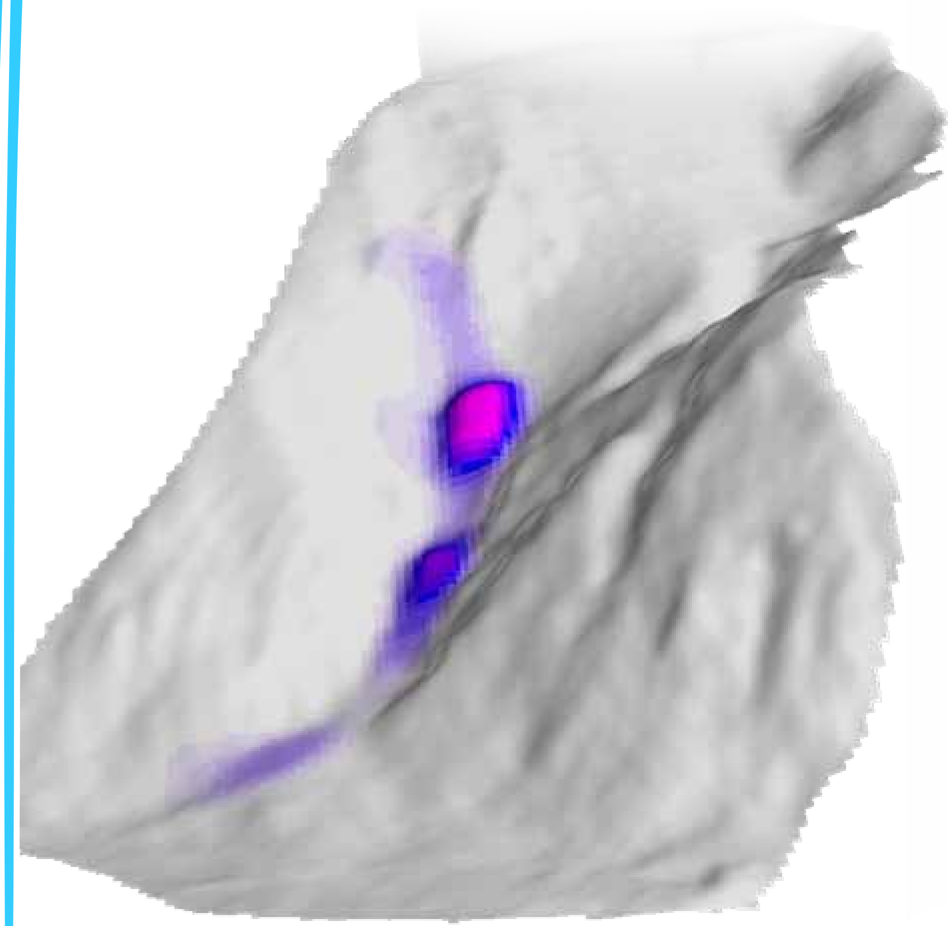
~ 200 m

exagg. of flow height: 50

arbitrary topographies

GRASS GIS implementation

r.avalanche



t = 14 s v = 31.8 m s^{-1}

~ 300 m

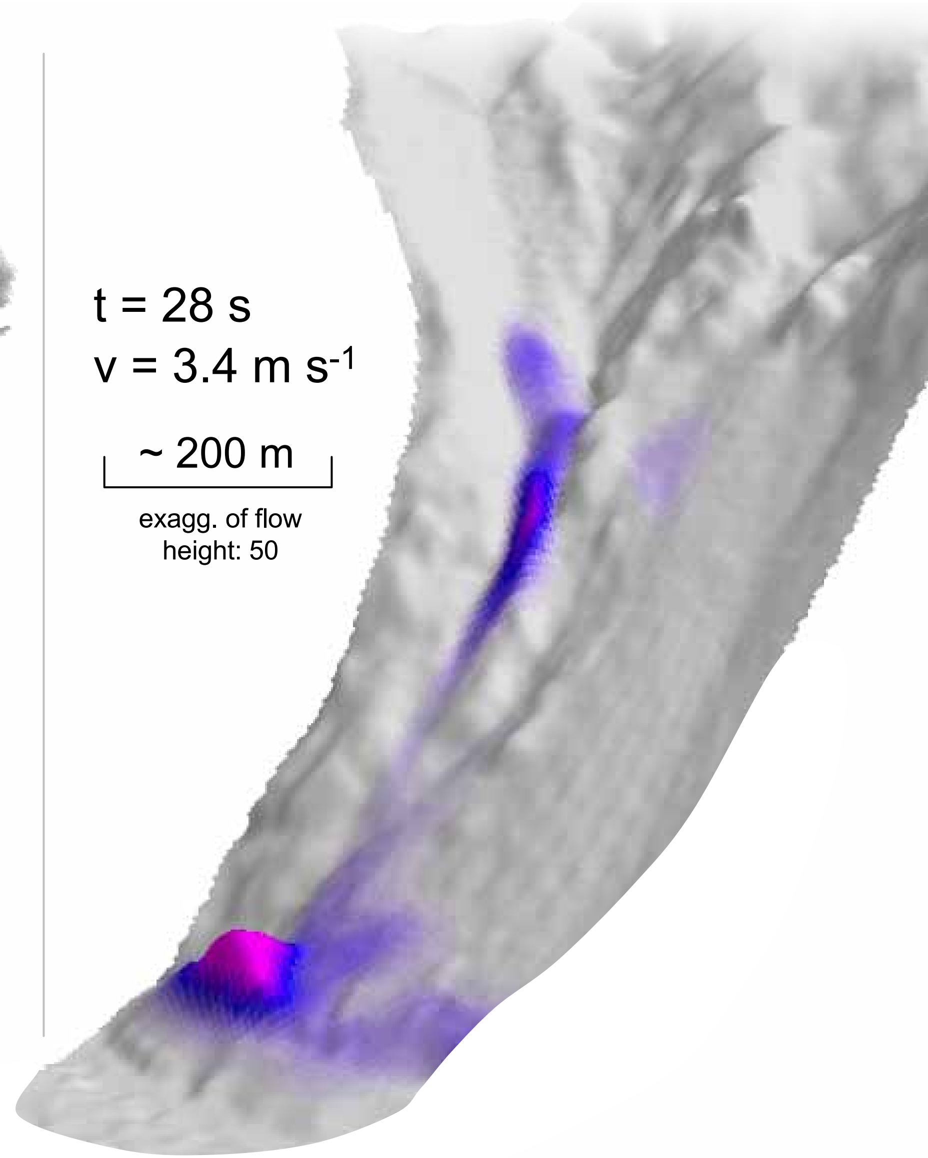
exagg. of flow height: 50

t = 28 s

v = 3.4 m s^{-1}

~ 200 m

exagg. of flow height: 50

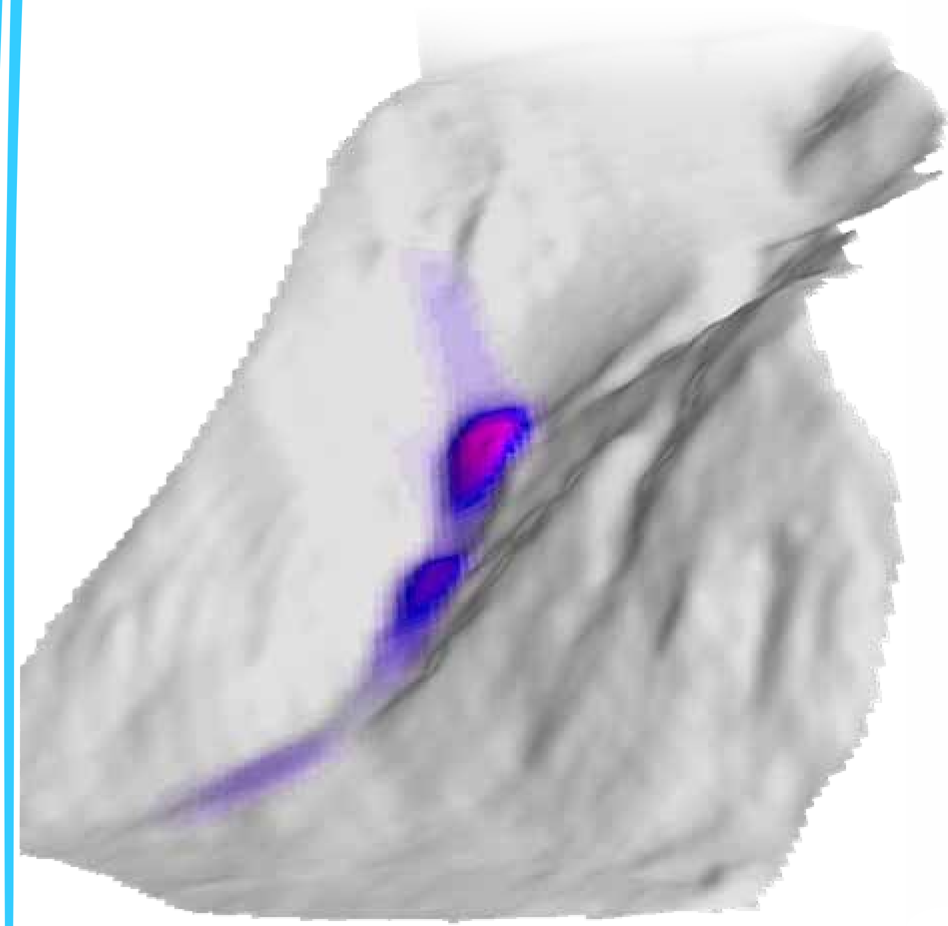


results

arbitrary topographies

GRASS GIS implementation

r.avalanche



t = 16 s v = 35.7 m s^{-1}

~ 300 m

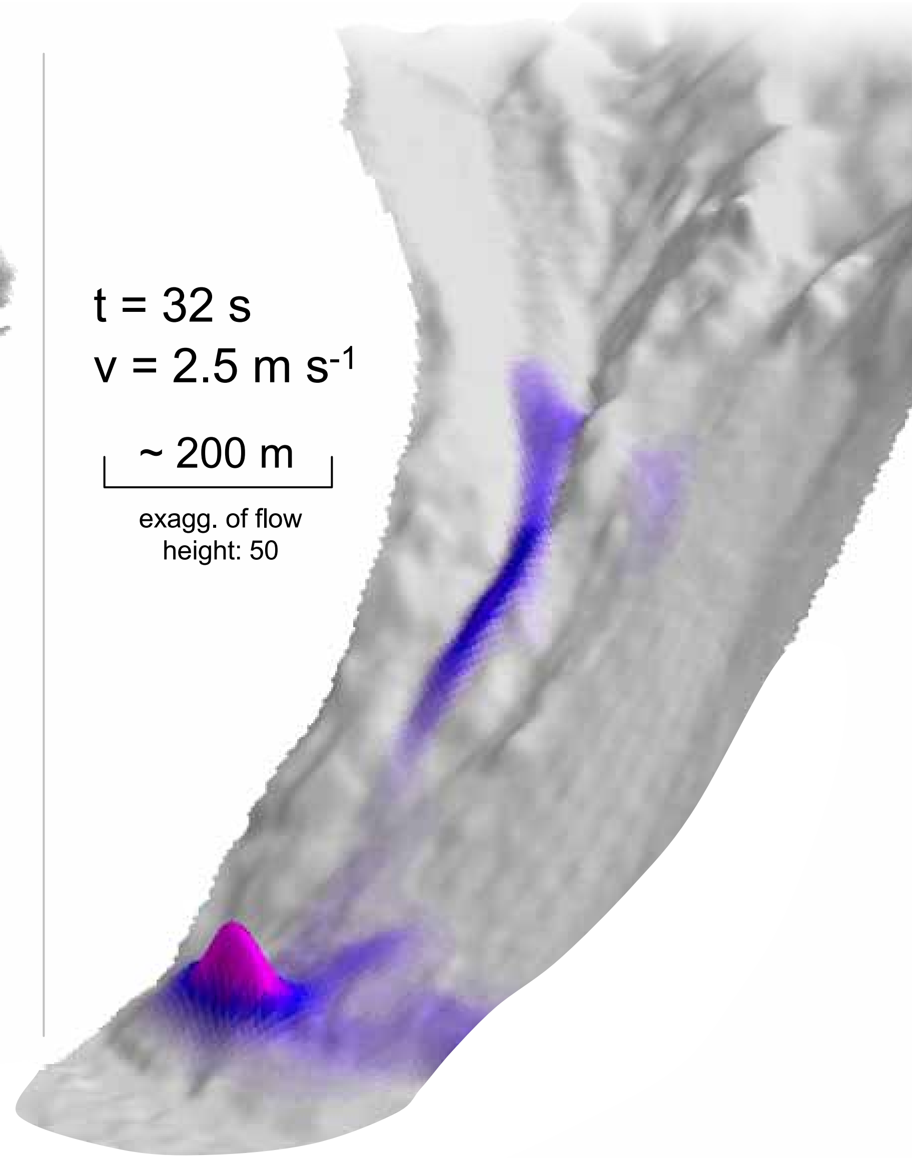
exagg. of flow height: 50

t = 32 s

v = 2.5 m s^{-1}

~ 200 m

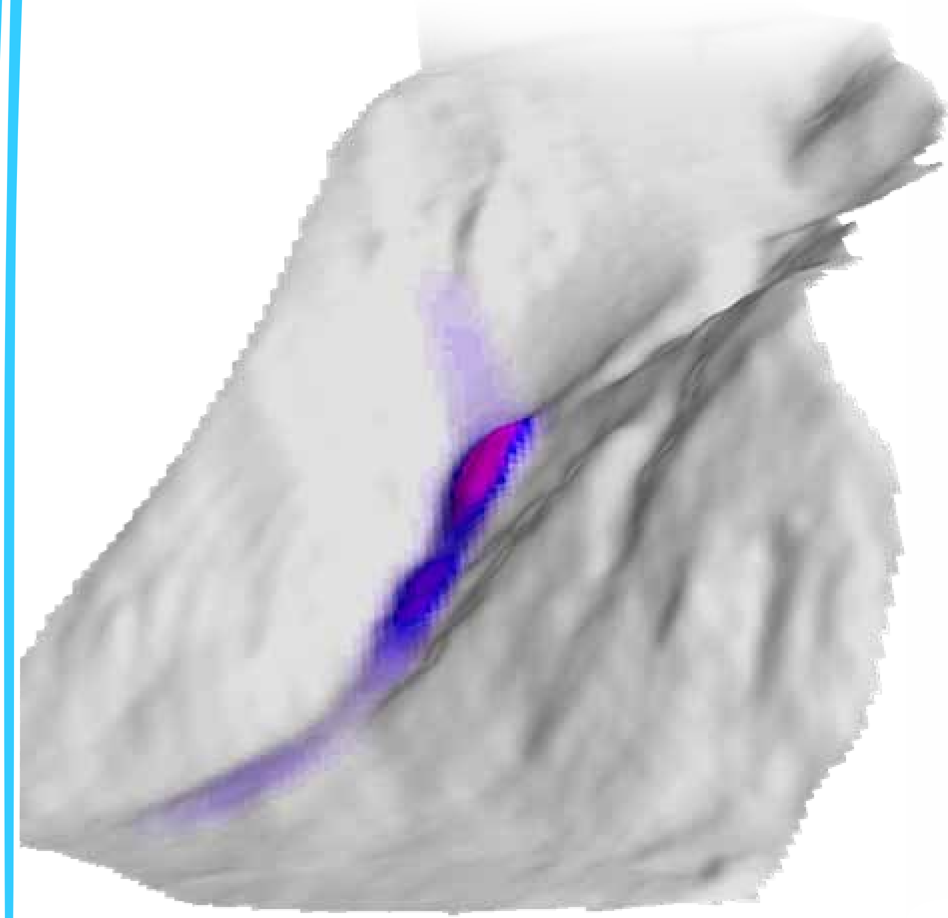
exagg. of flow height: 50



arbitrary topographies

GRASS GIS implementation

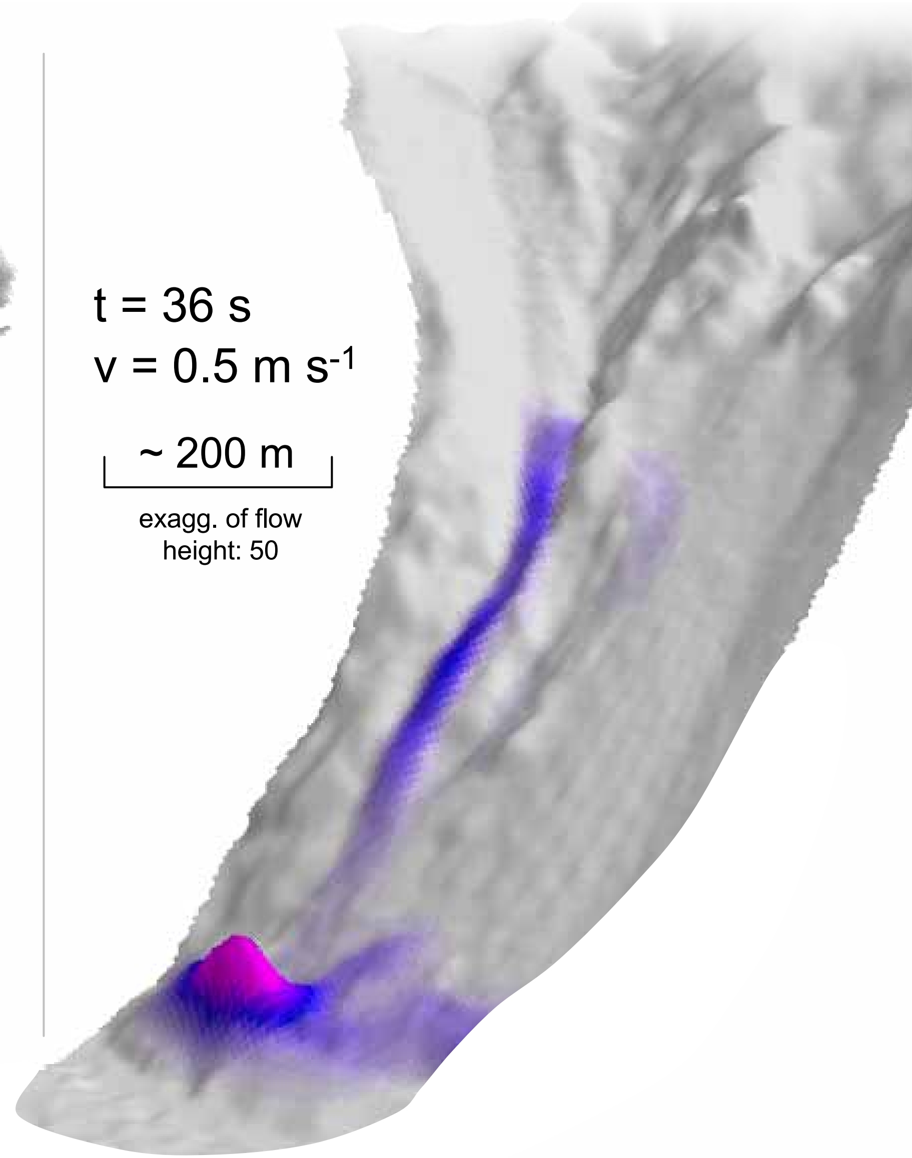
r.avalanche



t = 18 s v = 35.5 m s^{-1}

~ 300 m

exagg. of flow height: 50



t = 36 s

v = 0.5 m s^{-1}

~ 200 m

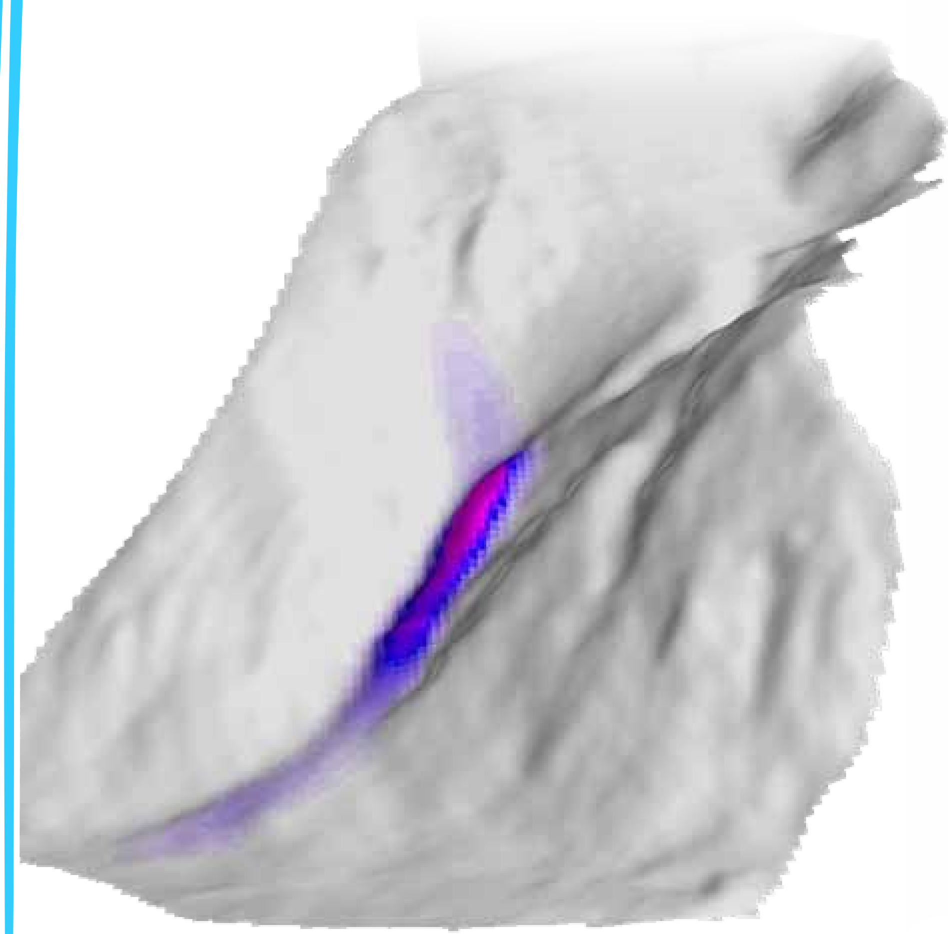
exagg. of flow height: 50

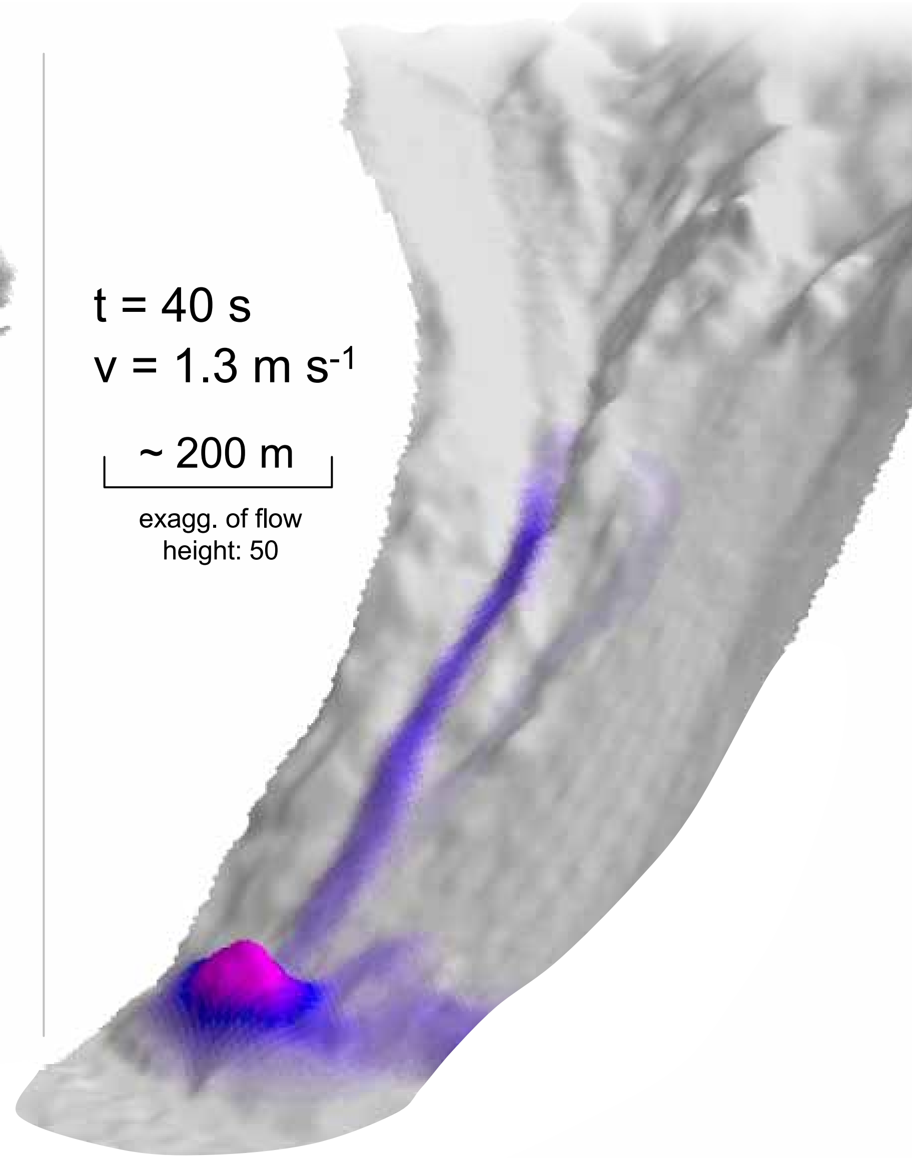
results

arbitrary topographies

GRASS GIS implementation

r.avalanche



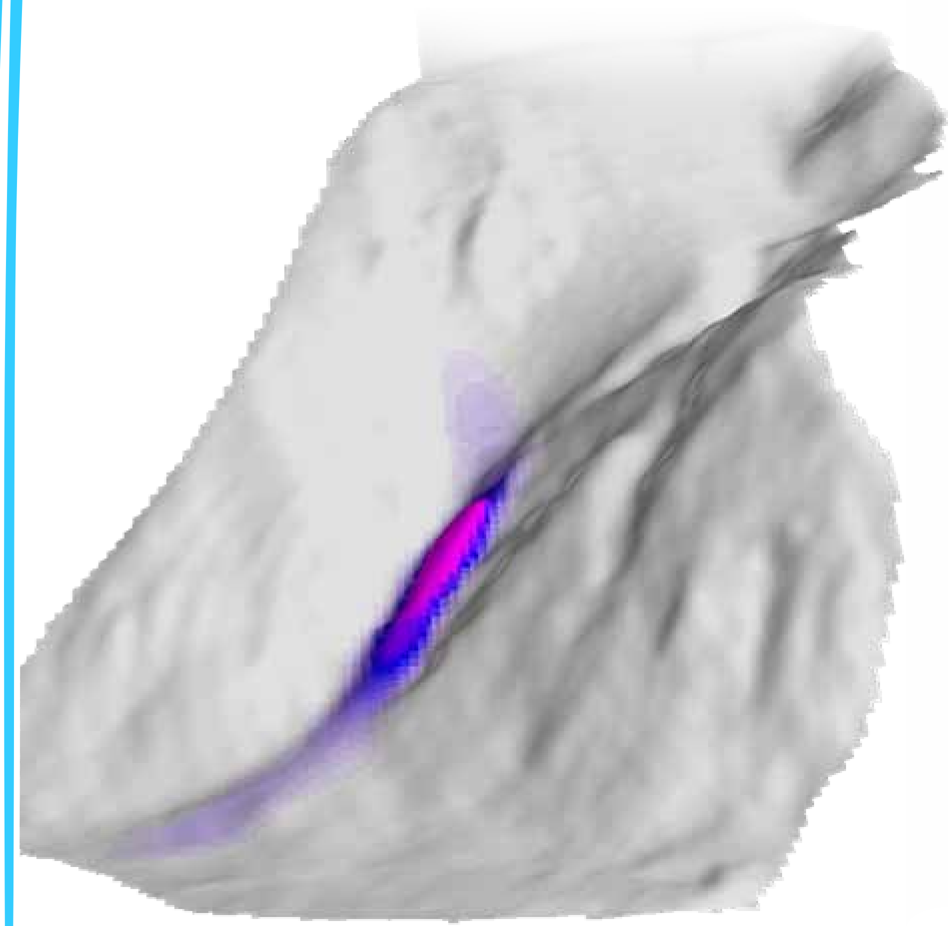


results

arbitrary topographies

GRASS GIS implementation

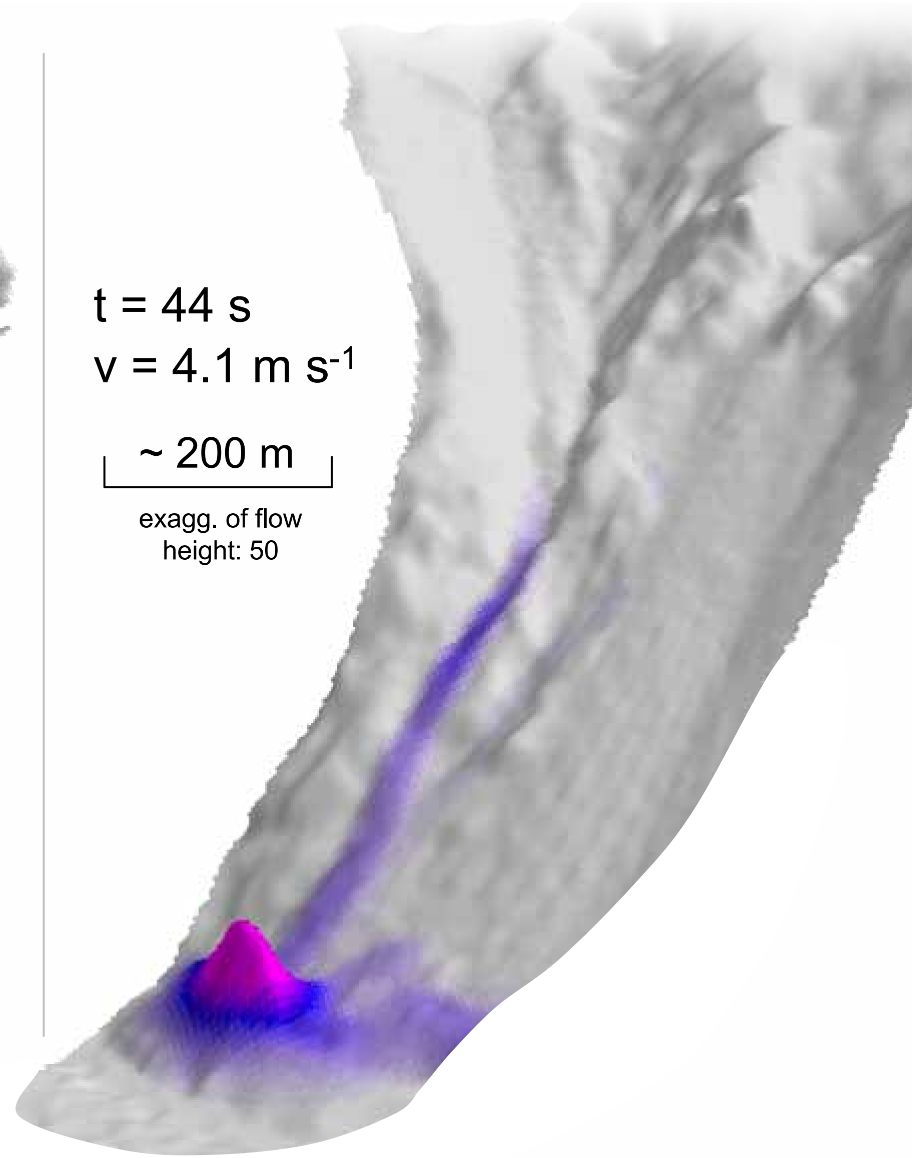
r.avalanche



t = 22 s v = 34.7 m s^{-1}

~ 300 m

exagg. of flow height: 50



t = 44 s

v = 4.1 m s^{-1}

~ 200 m

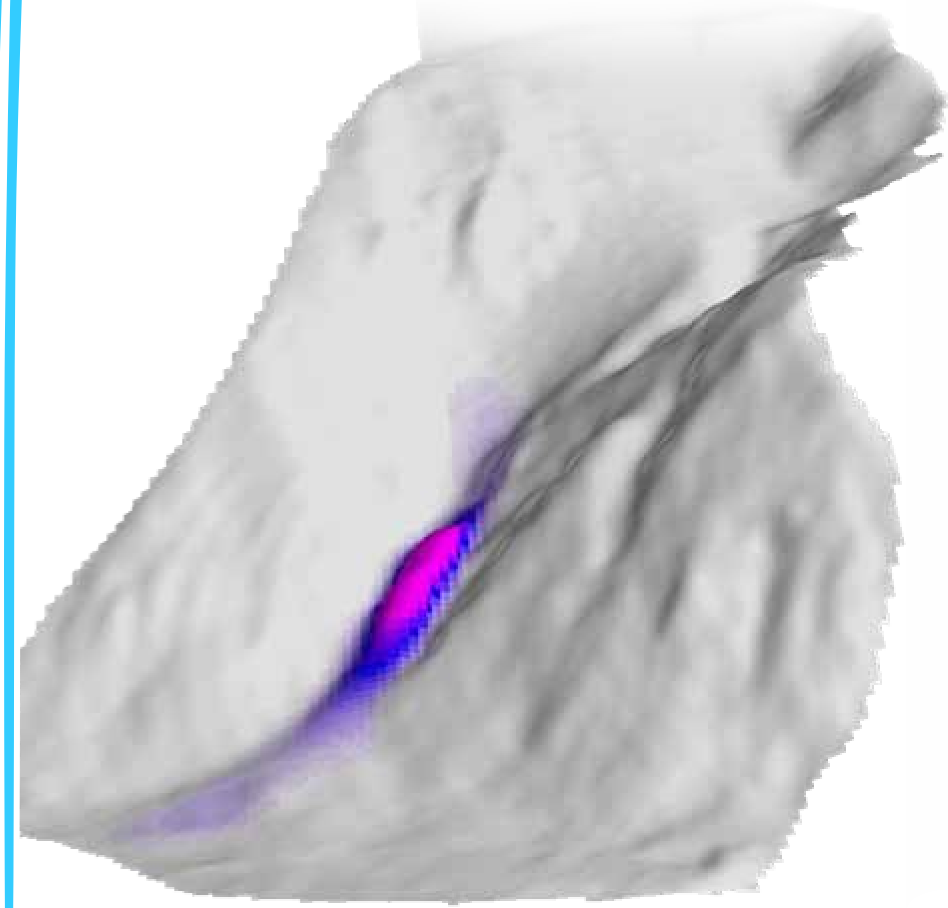
exagg. of flow height: 50

results

arbitrary topographies

GRASS GIS implementation

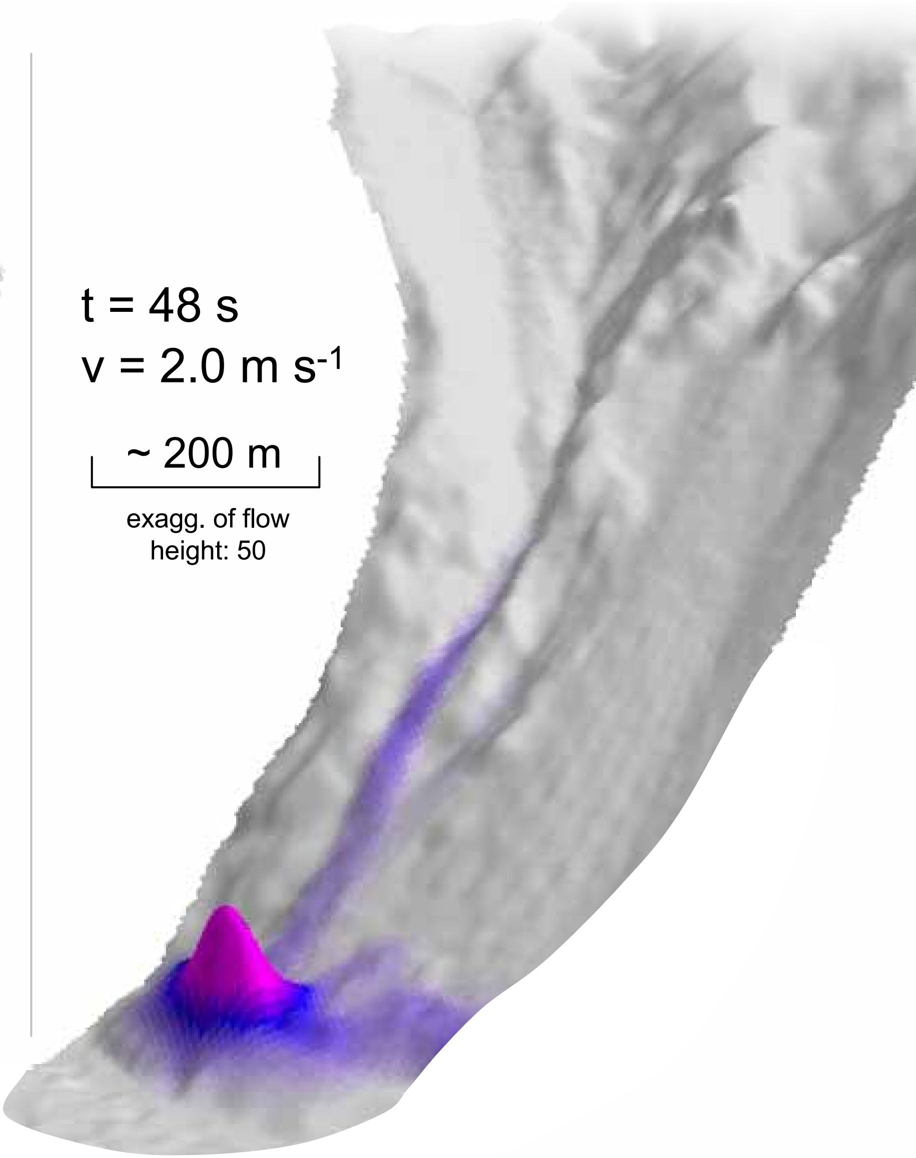
r.avalanche



t = 24 s   v = 34.2 m s^{-1}

~ 300 m

exagg. of flow height: 50



t = 48 s

v = 2.0 m s^{-1}

~ 200 m

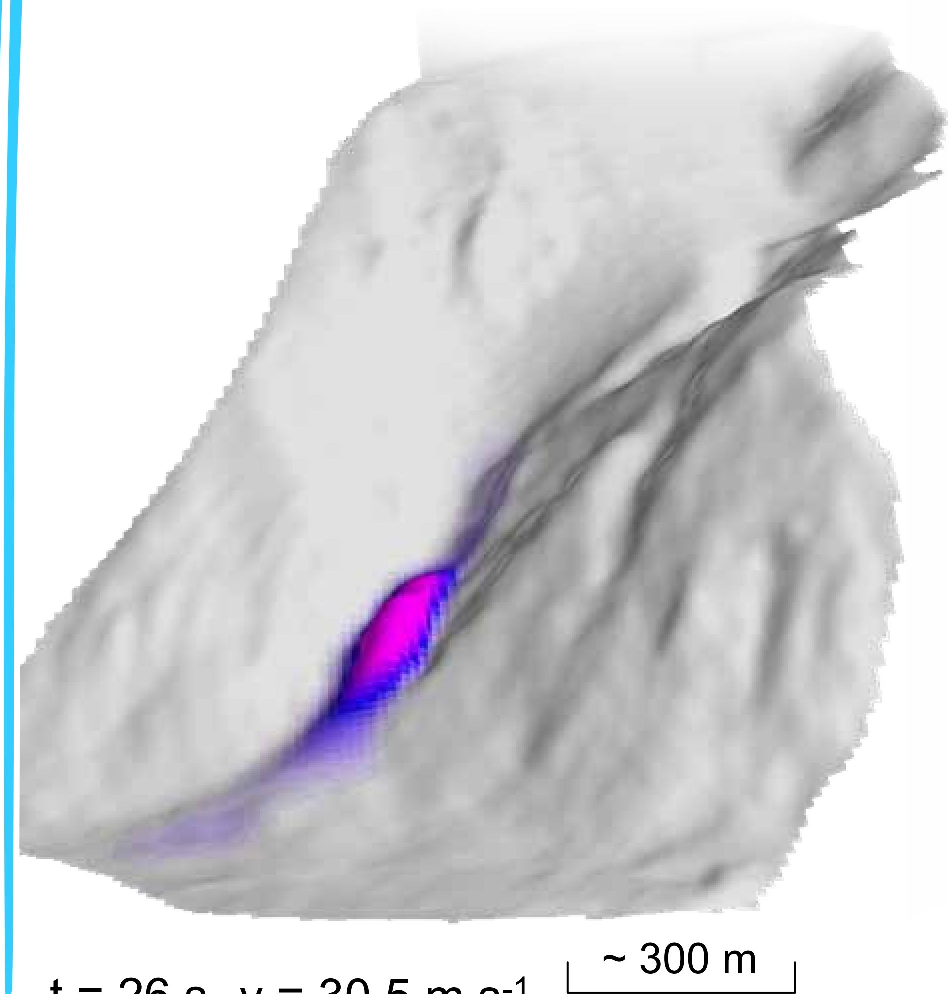
exagg. of flow height: 50

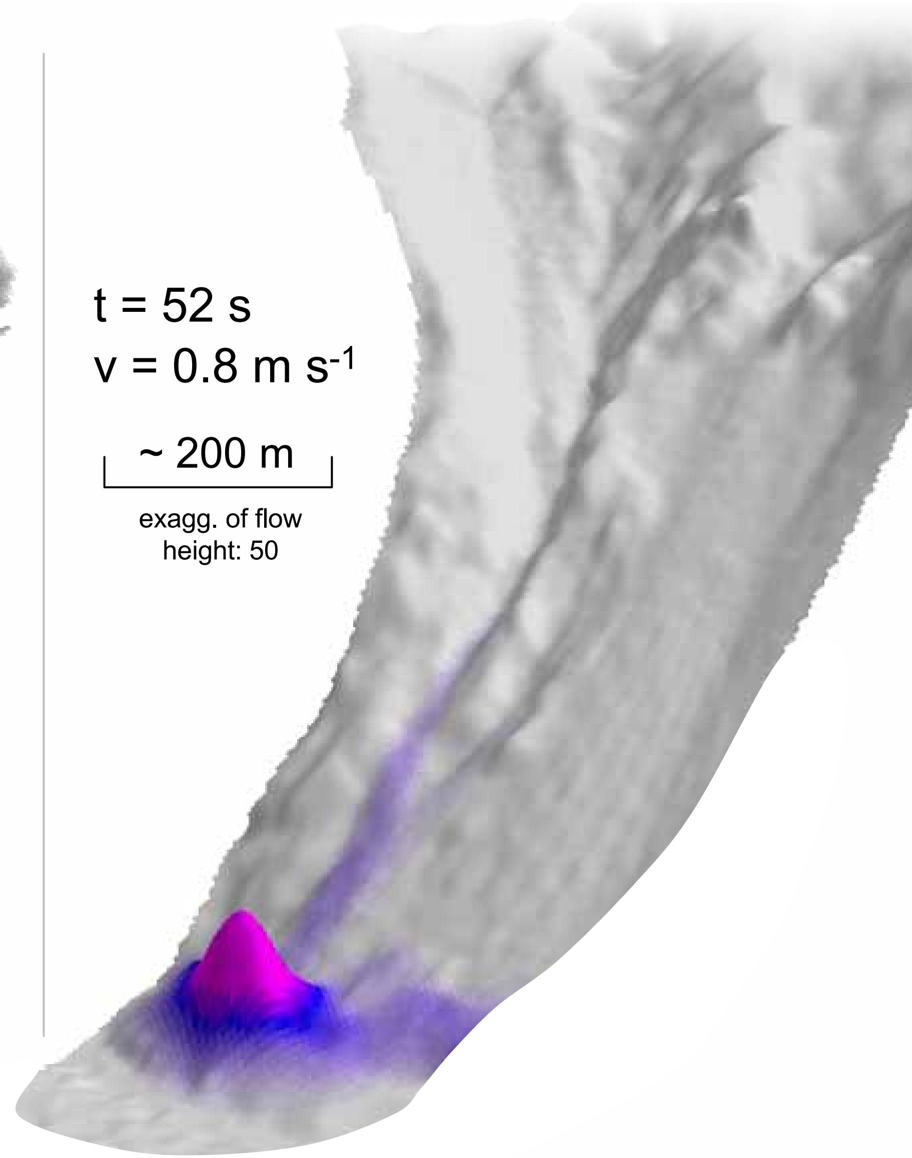
results

arbitrary topographies

GRASS GIS implementation

r.avalanche



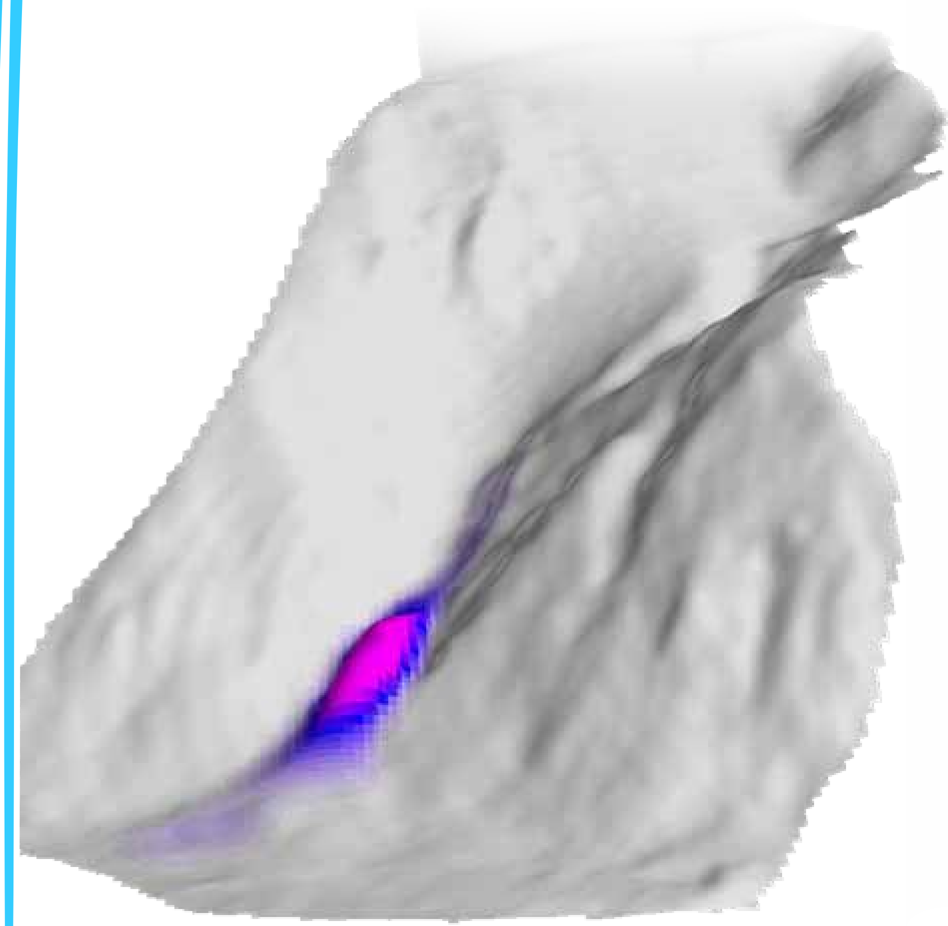


results

arbitrary topographies

GRASS GIS implementation

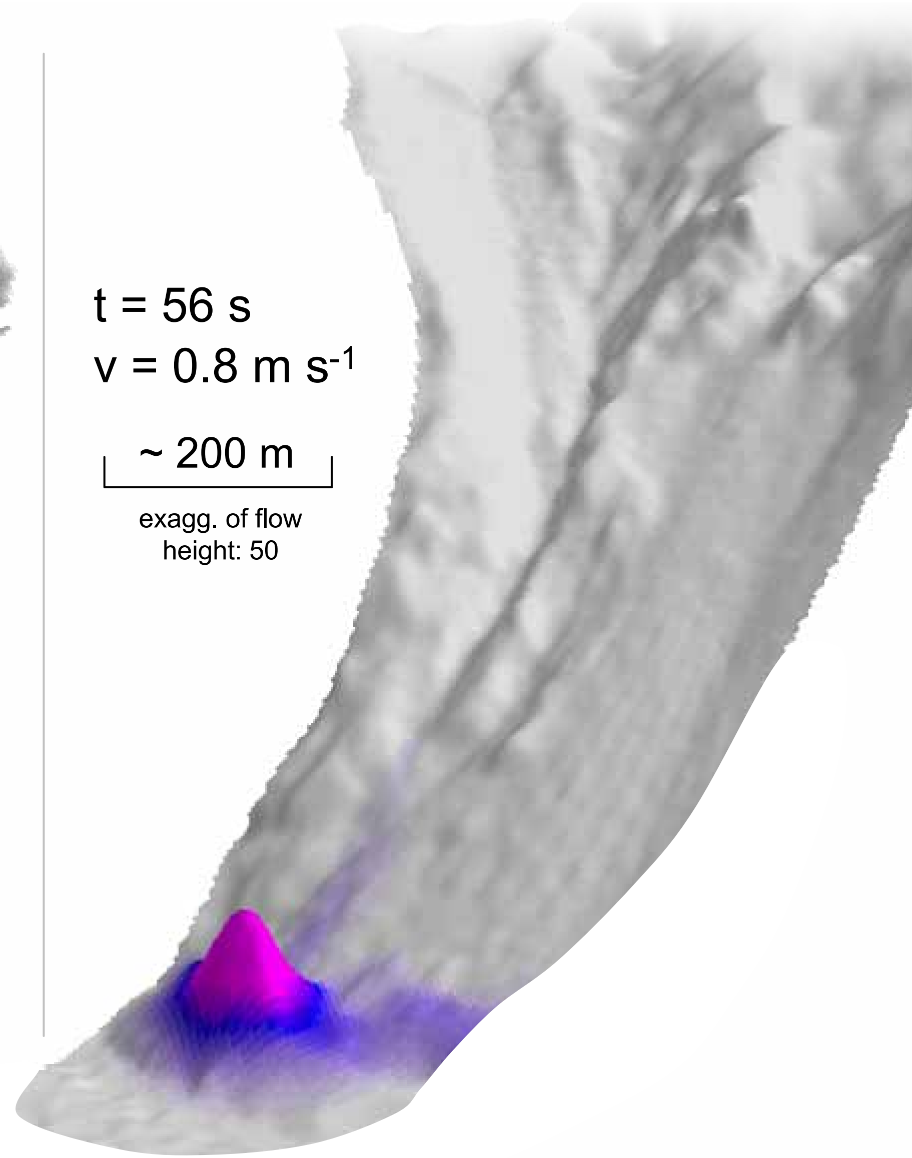
r.avalanche



t = 28 s v = 33.9 m s^{-1}

~ 300 m

exagg. of flow height: 50



t = 56 s

v = 0.8 m s^{-1}

~ 200 m

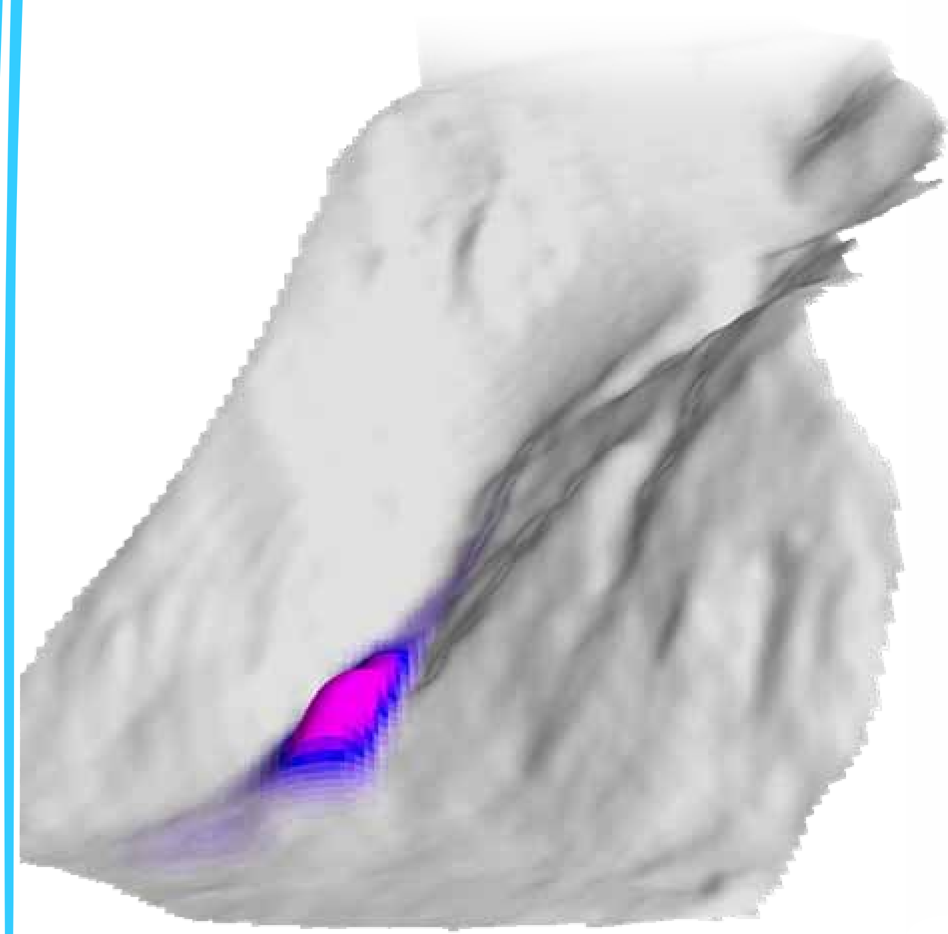
exagg. of flow height: 50

results

arbitrary topographies

GRASS GIS implementation

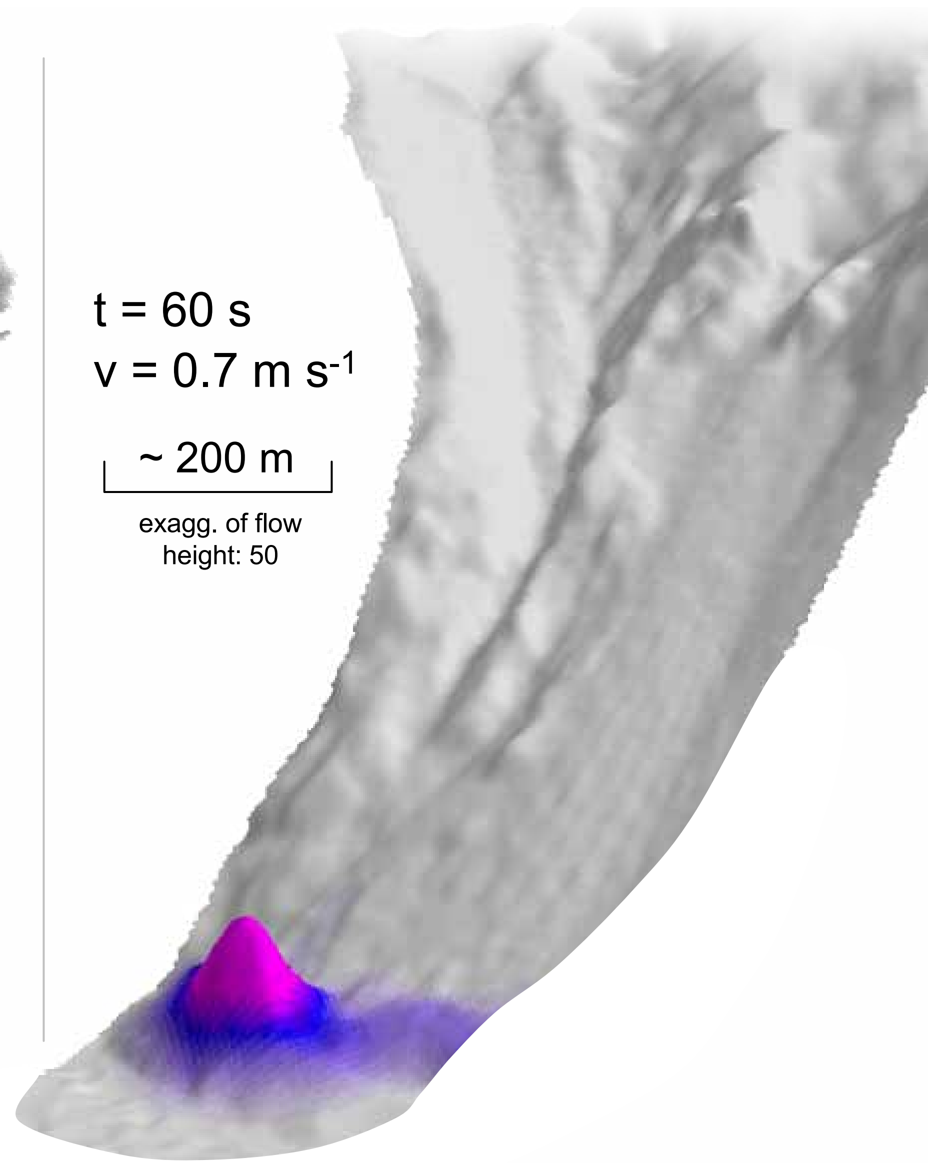
r.avalanche



t = 30 s v = 34.2 m s^{-1}

~ 300 m

exagg. of flow height: 50



t = 60 s

v = 0.7 m s^{-1}

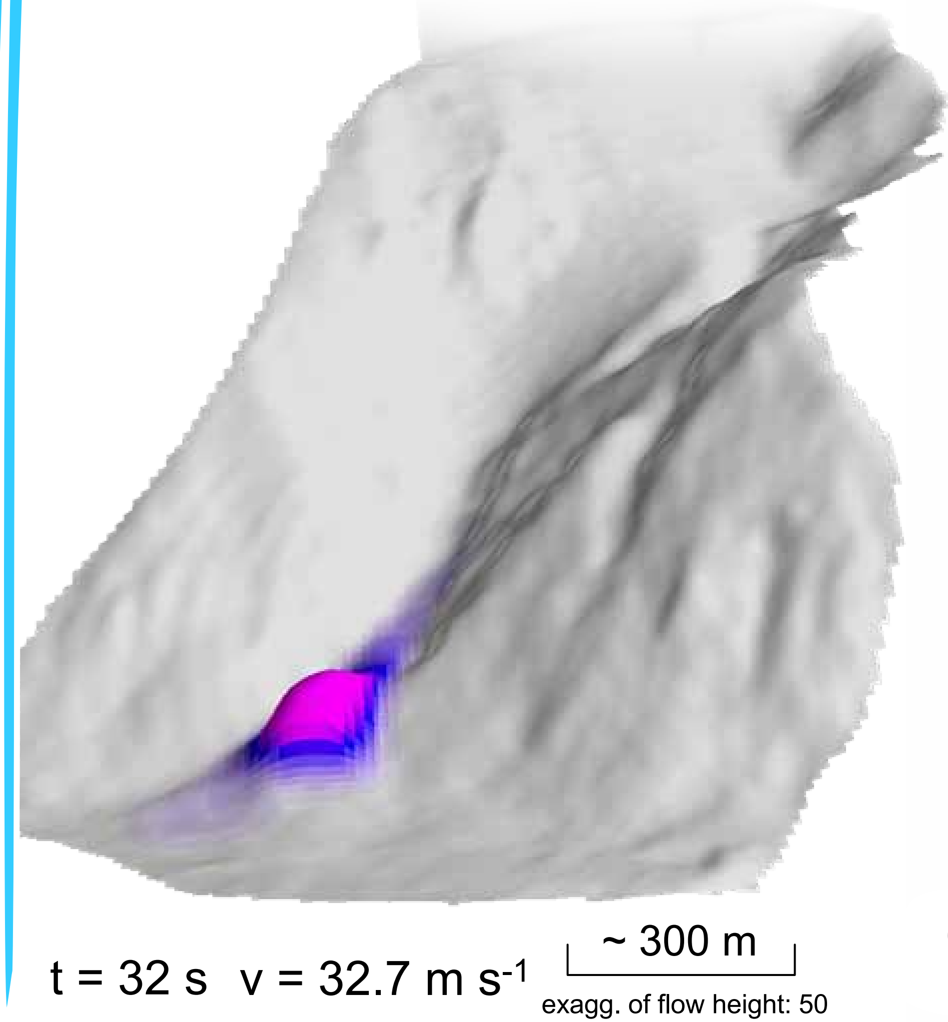
~ 200 m

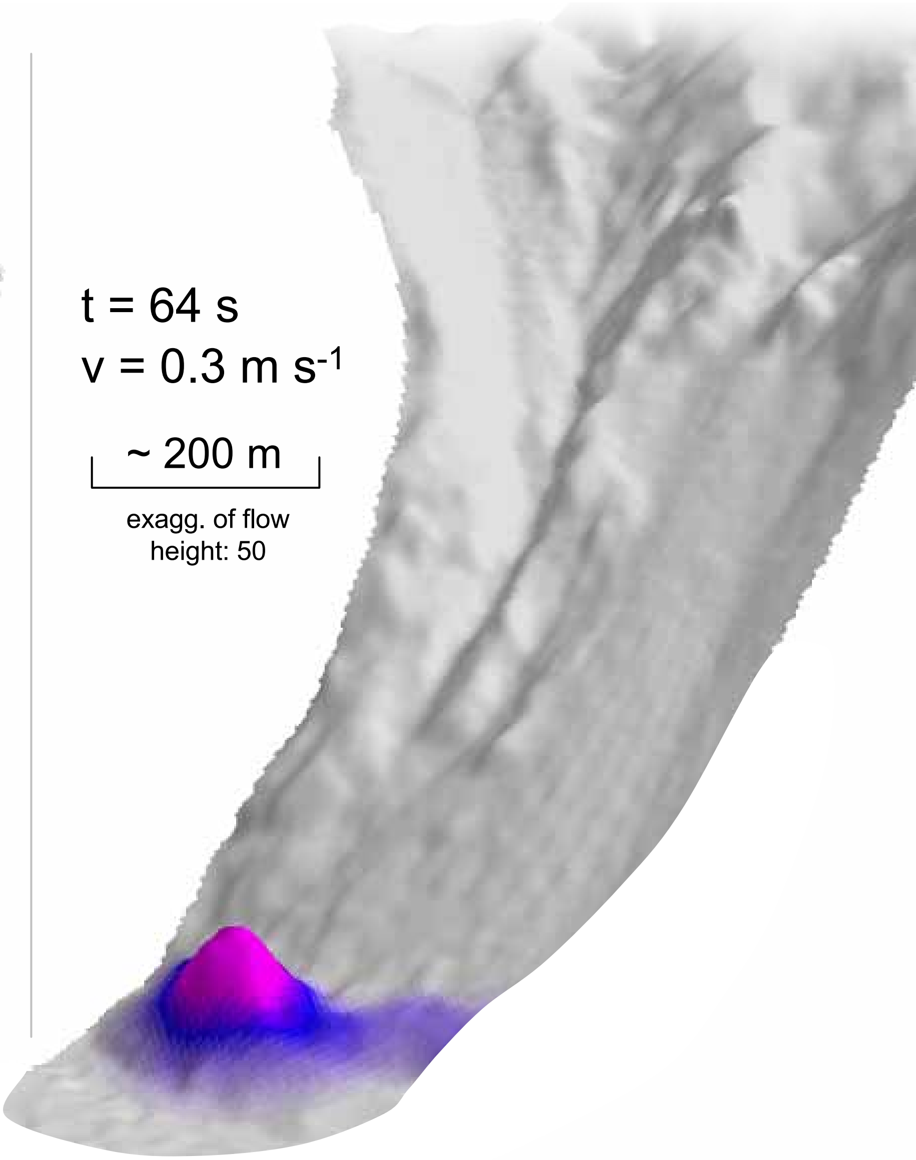
exagg. of flow height: 50

arbitrary topographies

GRASS GIS implementation

r.avalanche



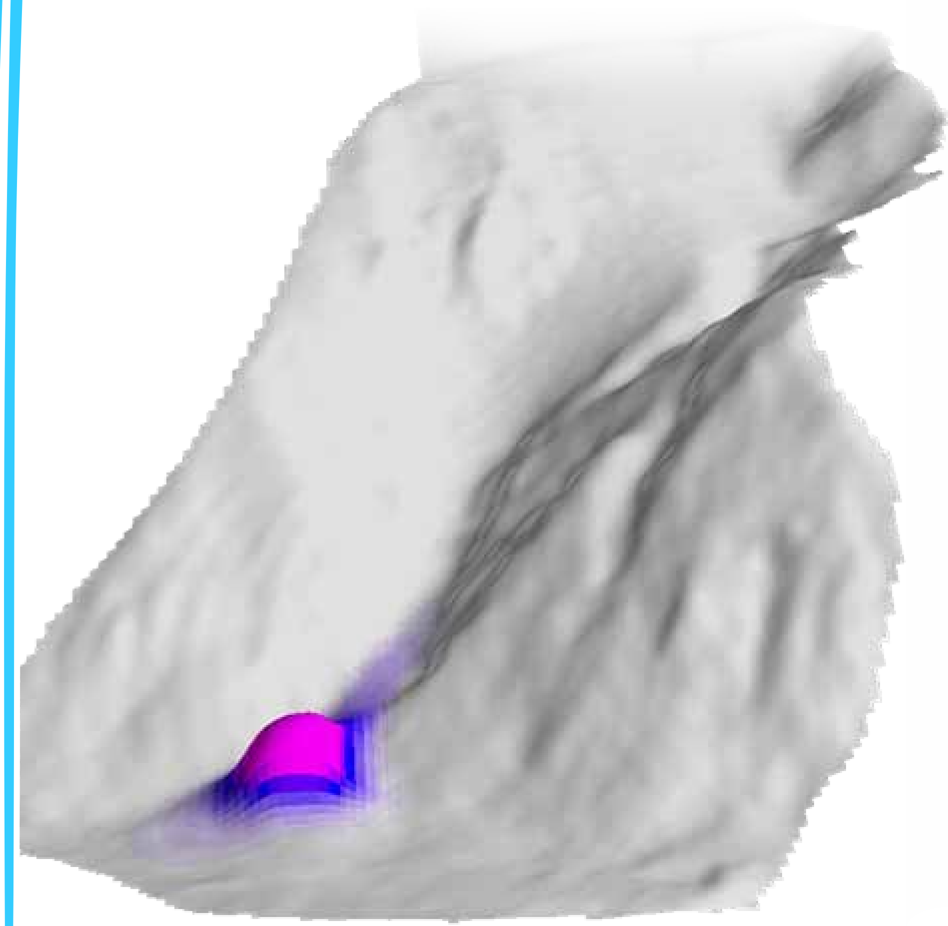


results

arbitrary topographies

GRASS GIS implementation

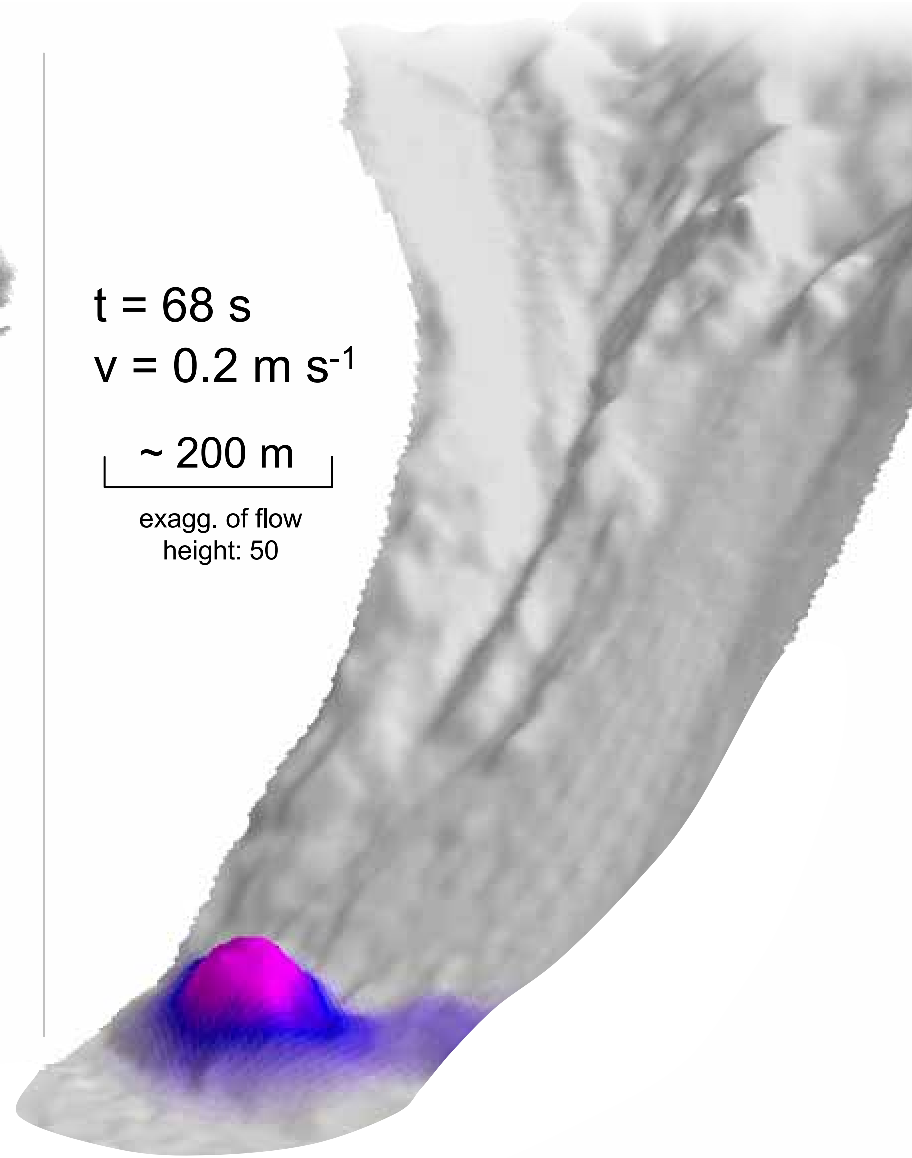
r.avalanche



t = 34 s v = 30.3 m s^{-1}

~ 300 m

exagg. of flow height: 50



t = 68 s

v = 0.2 m s^{-1}

~ 200 m

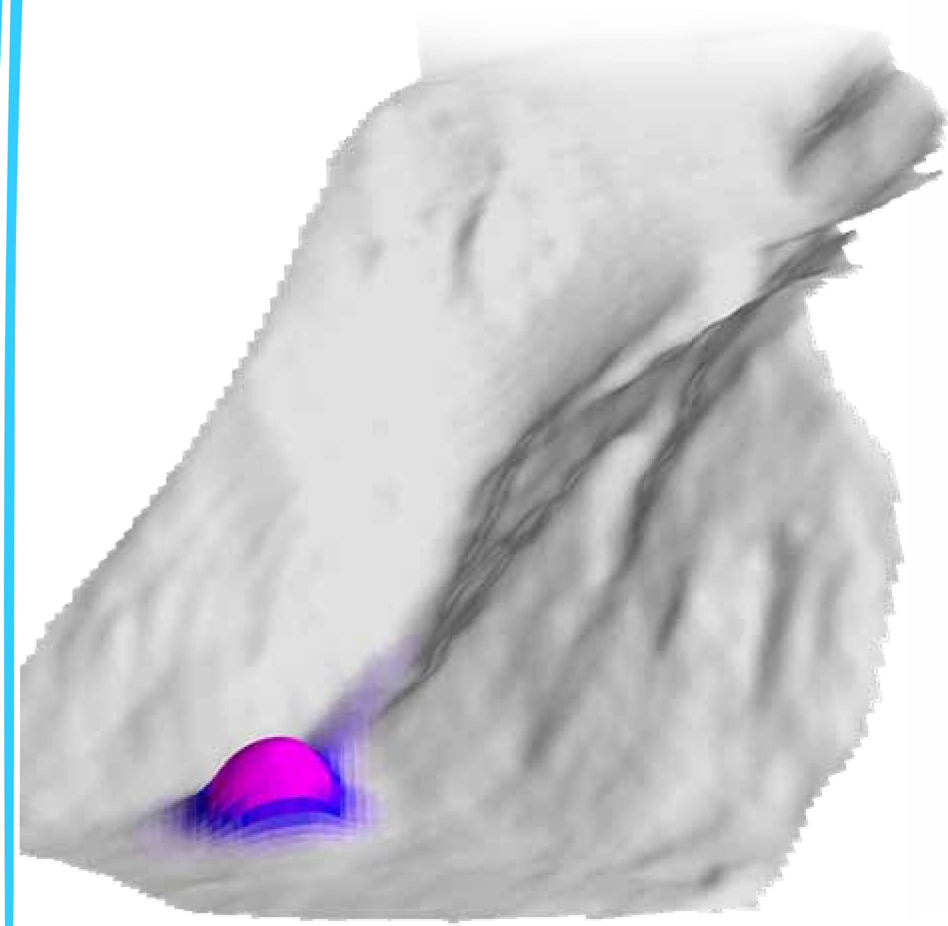
exagg. of flow height: 50

results

arbitrary topographies

GRASS GIS implementation

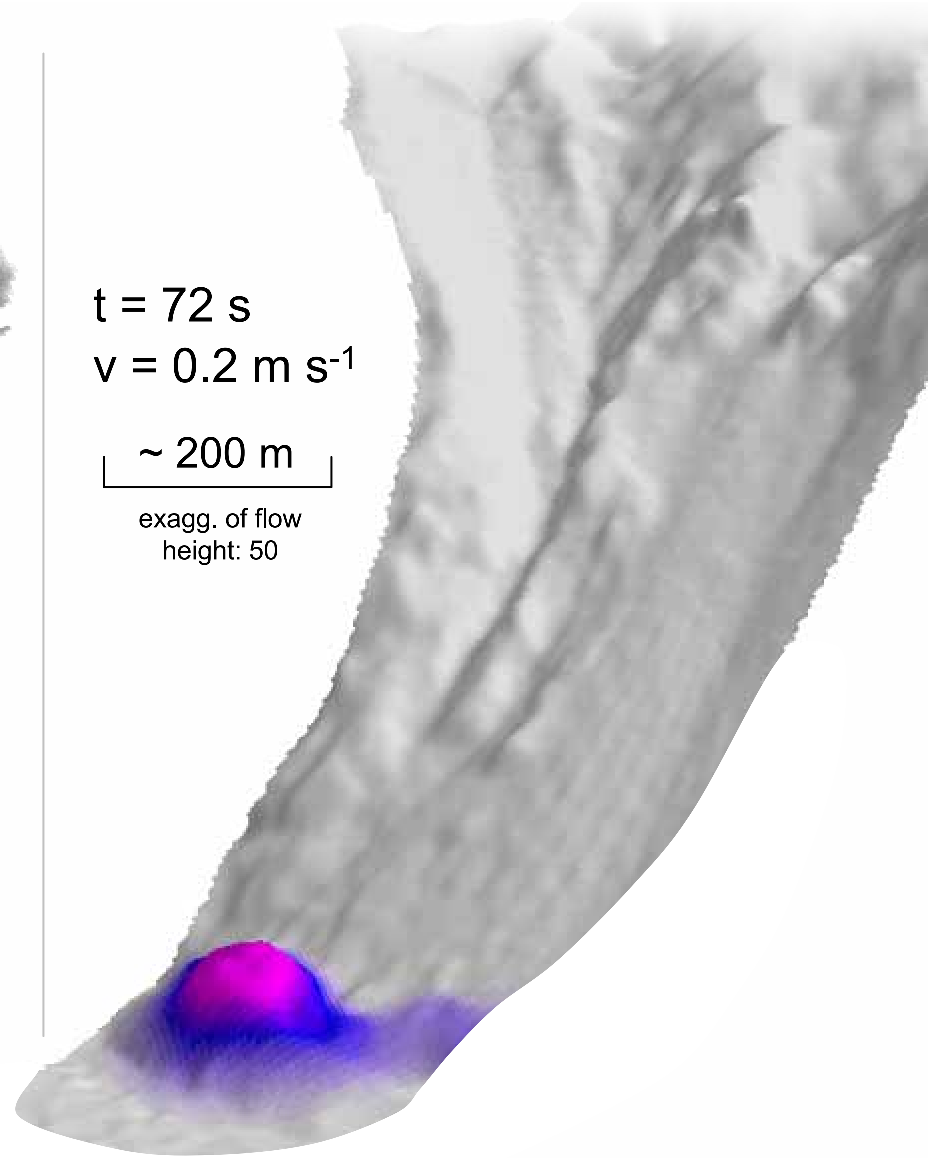
r.avalanche



t = 36 s   v = 28.3 m s^{-1}

~ 300 m

exagg. of flow height: 50



t = 72 s

v = 0.2 m s^{-1}

~ 200 m

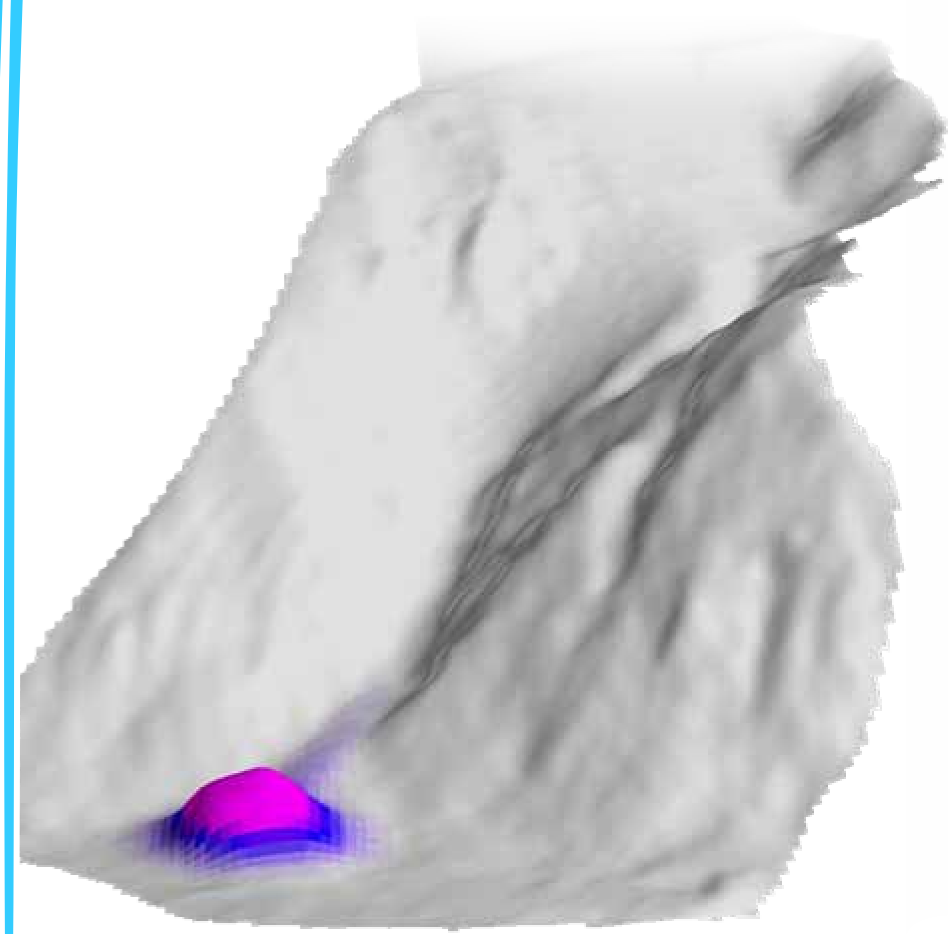
exagg. of flow height: 50

results

arbitrary topographies

GRASS GIS implementation

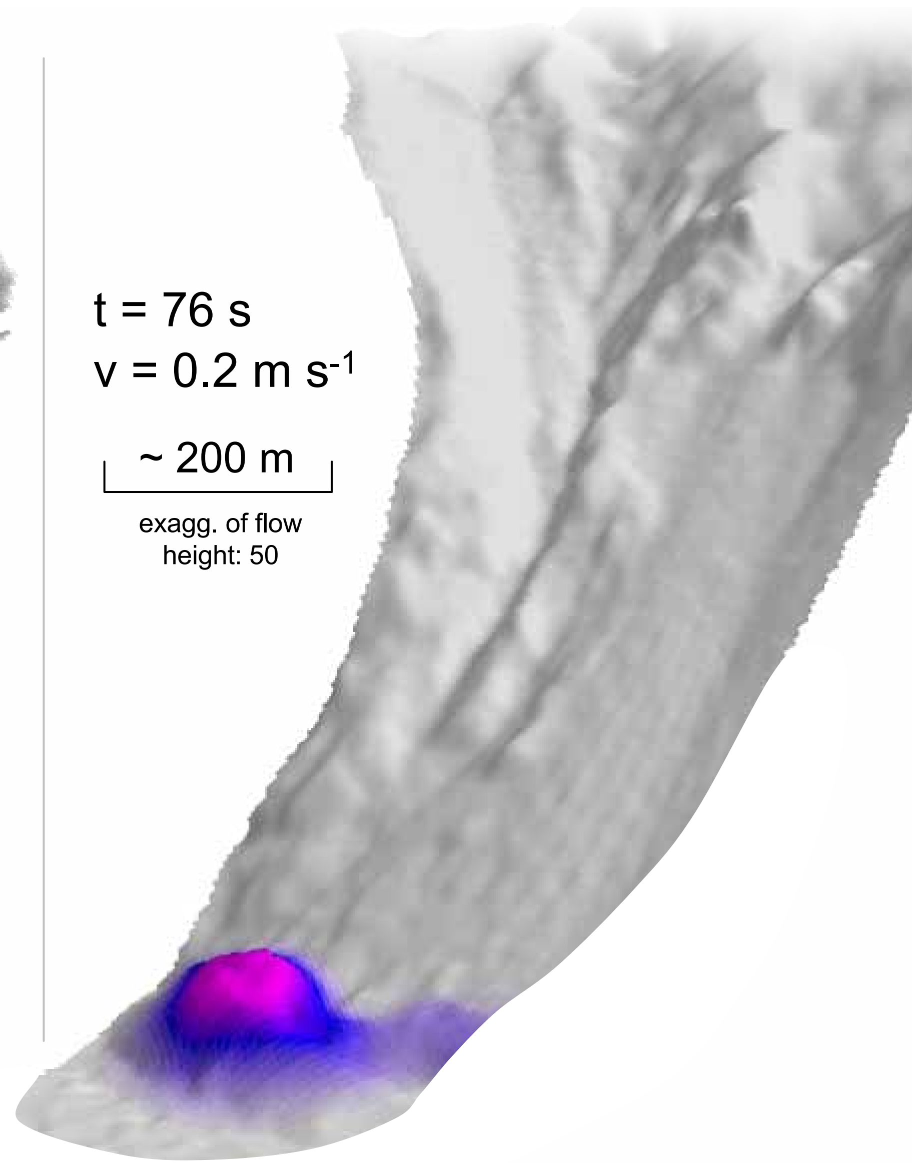
r.avalanche



t = 38 s v = 26.8 m s^{-1}

~ 300 m

exagg. of flow height: 50



t = 76 s

v = 0.2 m s^{-1}

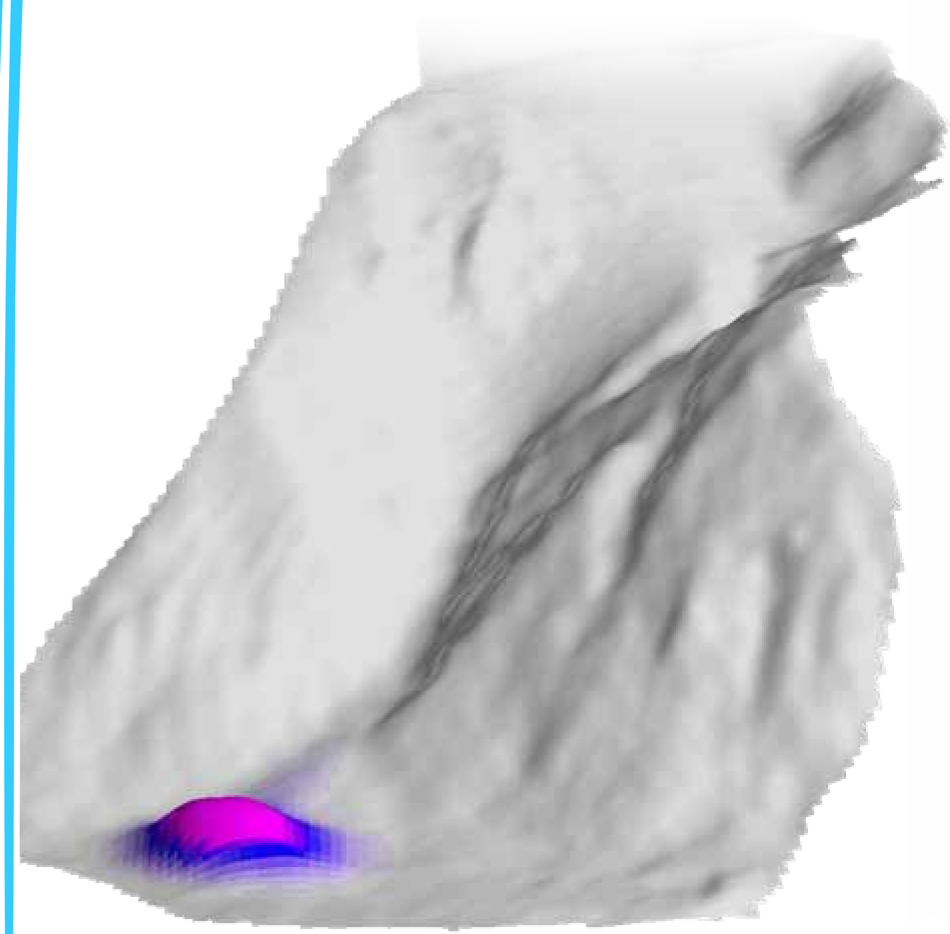
~ 200 m

exagg. of flow height: 50

arbitrary topographies

GRASS GIS implementation

r.avalanche



$t = 40$ s $v = 19.9$ m s^{-1}

~ 300 m

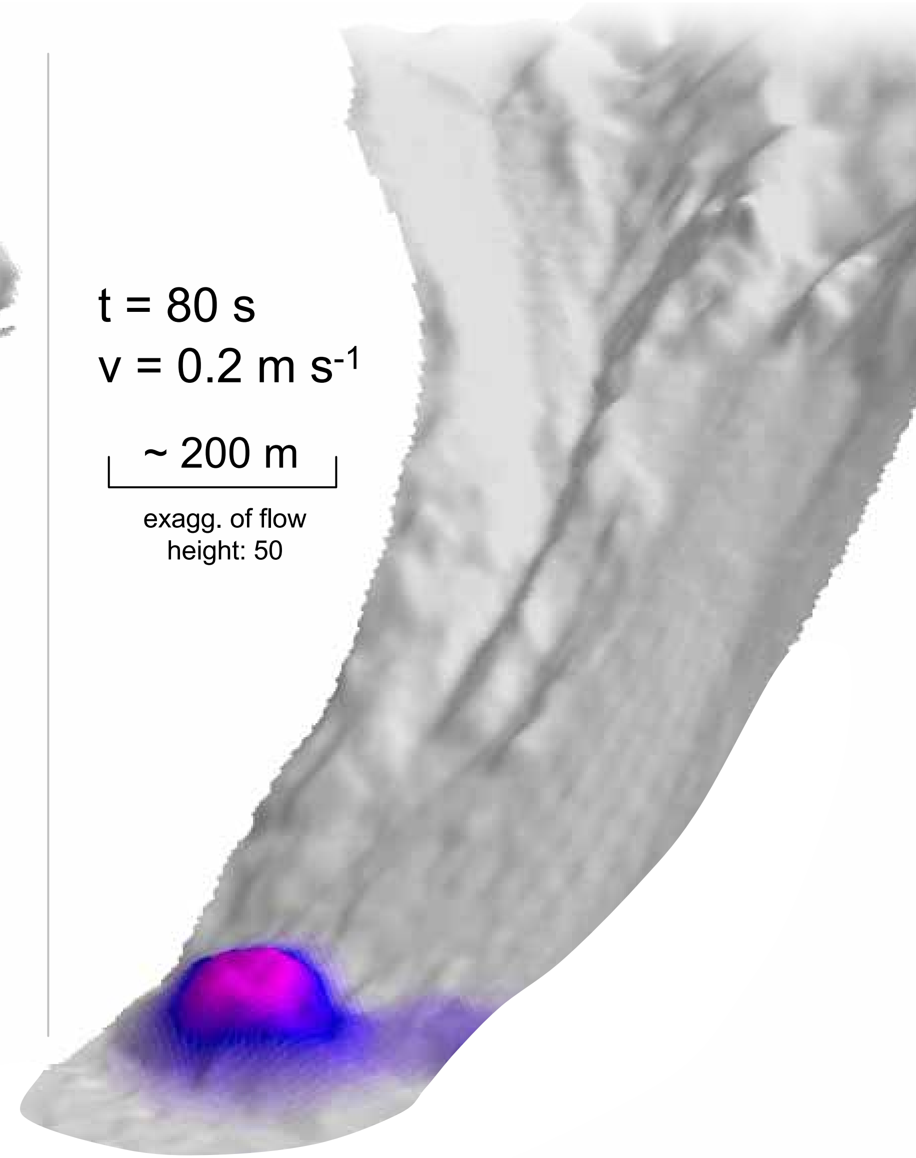
exagg. of flow height: 50

$t = 80$ s

$v = 0.2$ m s^{-1}

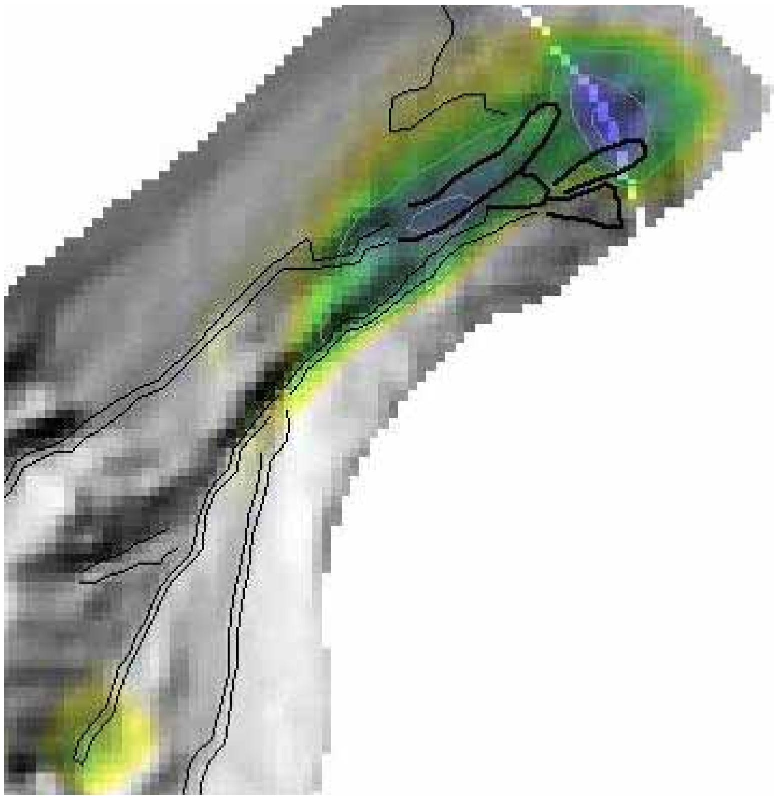
~ 200 m

exagg. of flow height: 50

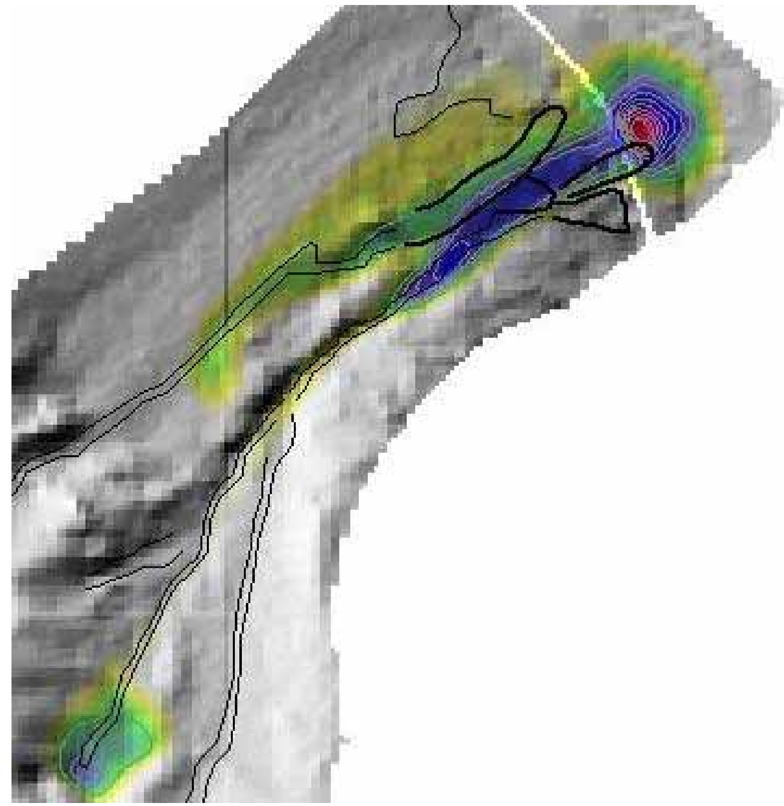


GRASS GIS implementation
r.avalanche

effects of spatial resolution



resolution: 10 m



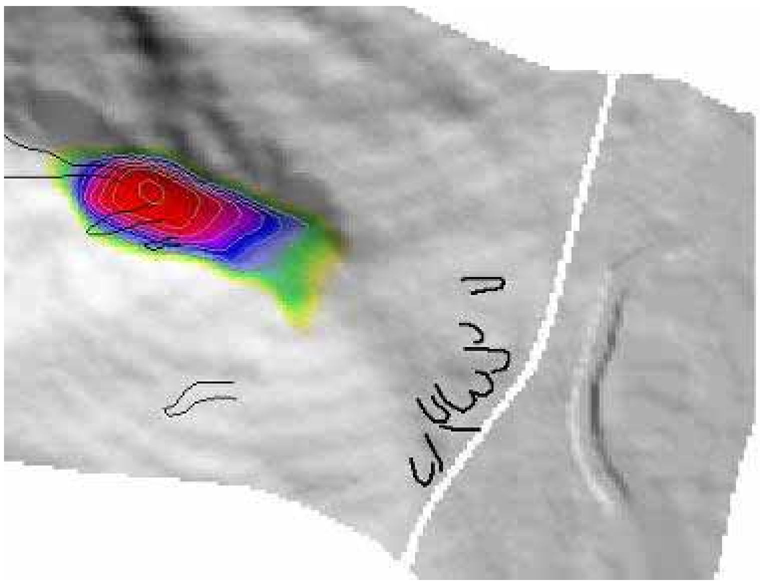
resolution: 5m

exagg. of flow height: 50

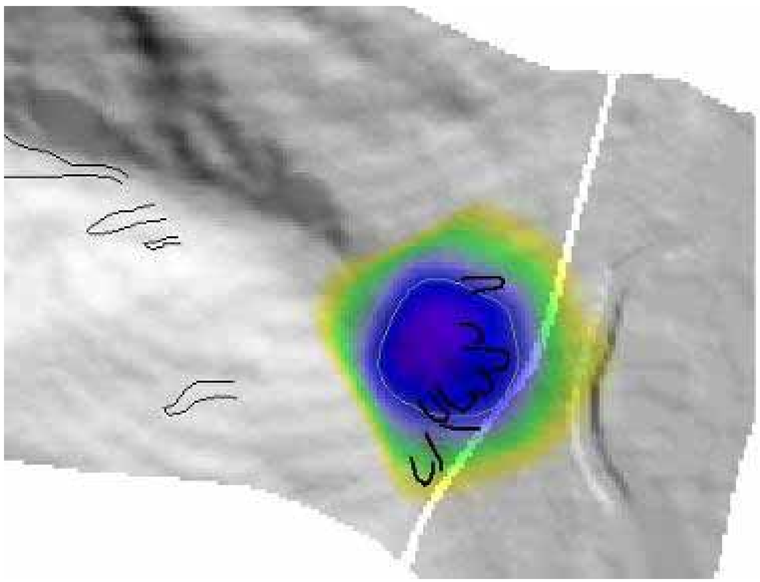
GRASS GIS implementation

r.avalanche

effect of bed friction angle



bed friction angle: 33°



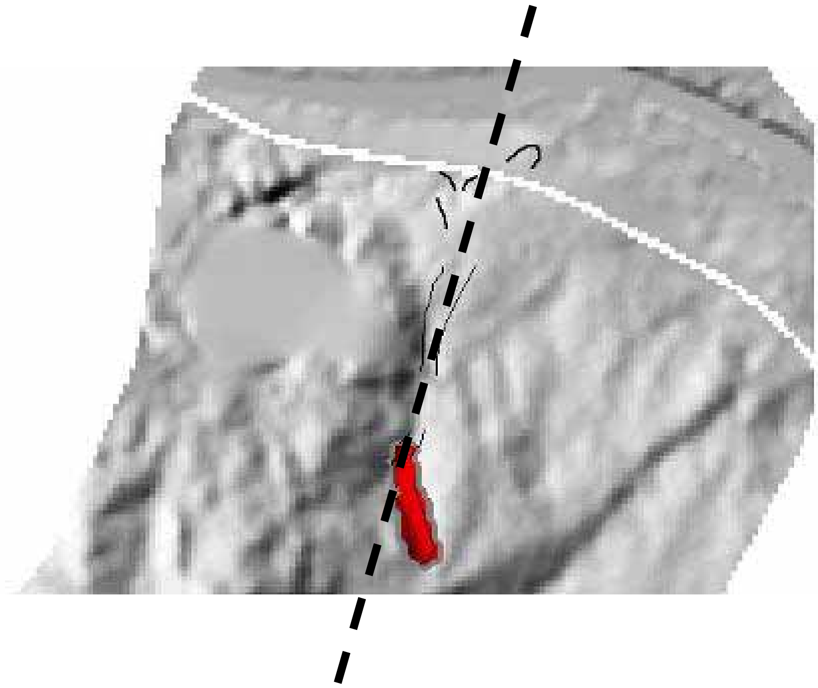
bed friction angle: 27°

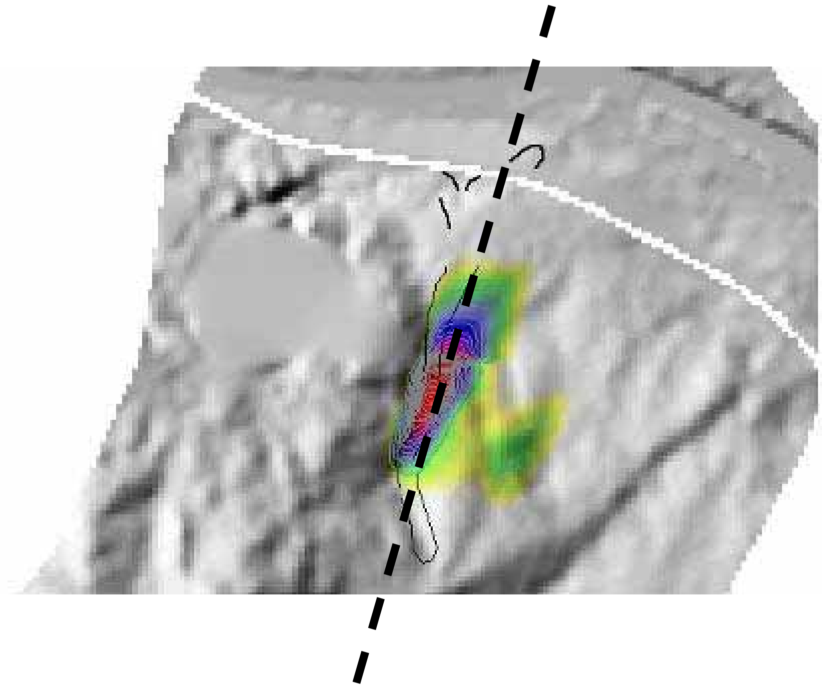
exagg. of flow height: 50

GRASS GIS implementation

r.avalanche

problems with curved flow channels





capabilities and limitations

- in general, *r.avalanche* worked fine for simple topographies, but:
  - **calibration of bed friction angle was necessary, limiting the capability for class A predictions**
  - **some numerical oscillations occurred**
  - **spreading of flow was too pronounced, compared to observations**
- problems occurred with more complex topographies and with curved channels

needs for further investigations

- extension of the SH theory with particle entrainment and two-phase flow (solid-fluid)
- development of a numerical scheme for flow over arbitrary topography
- testing with further study areas
- improvement of data management during simulation (enabling finer resolution)
- elaboration of a Graphical User Interface
- finding characteristic bed friction angles for different types of surfaces

- download: www.uibk.ac.at/geographie/personal/mergili/scripts