NUMERICAL MODELLING OF ICE AVALANCHES FROM THE PLANPINCIEUX GLACIER (ITALY)

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Ice avalanches are common processes in glacierized high-mountain areas in a changing climate.

They are particularly relevant where glaciers retreat over steep rock cliffs. The glacier terminus becomes unstable and releases a mass of ice which evolves into an **avalanching flow**.

Anticipation of ice avalanche dynamics is important to inform **risk management**.

The application of **computer models** is thereby necessary to devise travel distances, impact areas, travel times, flow pressures, or flow kinetic energies of future events.

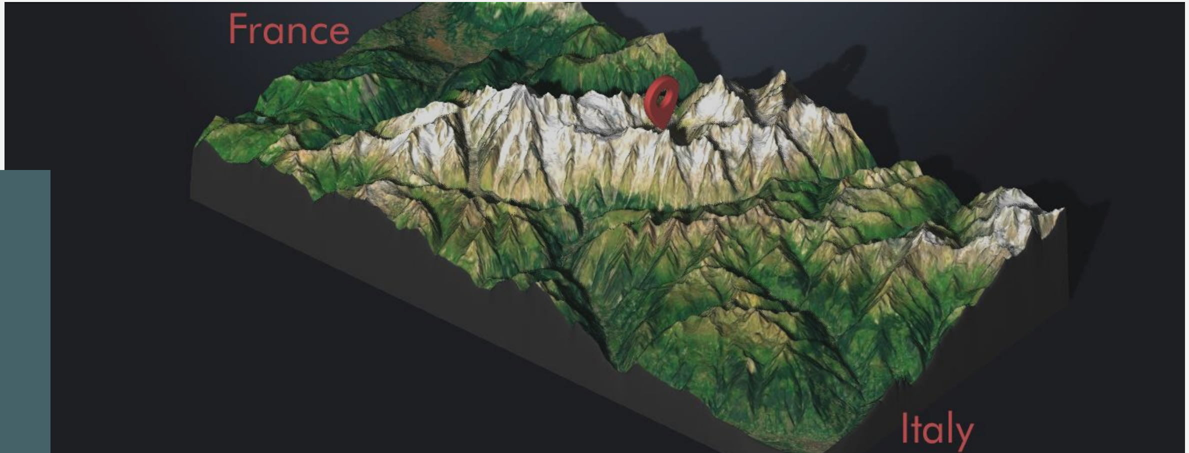
Parameterization of such models remains a challenge.

Model parameters can be optimized, based on the **back-calculation** of documented events in the past.

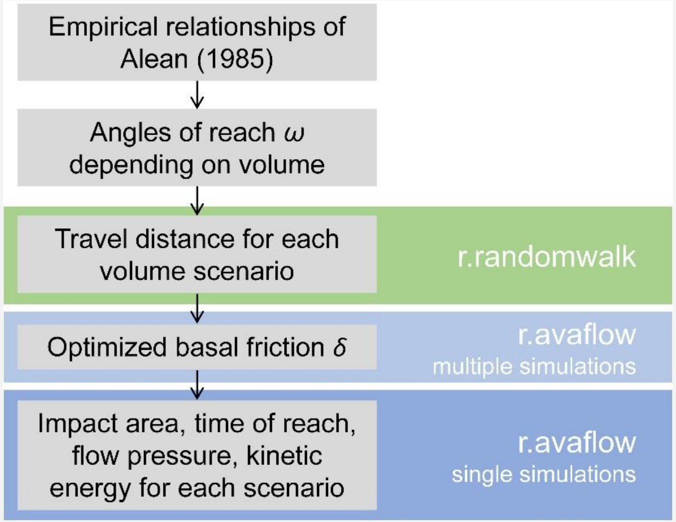
It is a common scenario that only **smaller events** have occurred in the past, while risk management should account for worst-case scenarios of **larger events** yet unaccounted for in a given area.

A **major challenge** in this respect consists in the appropriate adaptation of model parameterization to larger events.

We suggest a reliable, straightforward and practically applicable **work flow for forward simulation of ice avalaches** for the purpose of risk management with regard to the **Planpincieux Glacier** in northern Italy (Mont Blanc massif).



The strategy of the present work builds on the combination of the empirical relationships for the reach of ice avalanches *(Alean, 1985)* applied with the tool **r.randomwalk** *(Mergili et al., 2015; Mergili, 2021)* and the physically-based model **r.avaflow** *(Mergili et al., 2017; Pudasaini and Mergili, 2019).*



r.randomwalk represents a multi-functional tool for backward- and forward-analyses of landslide propagation. Mass points are routed from defined release pixels down a DTM as long as the pre-defined break criterion has not been reached.

r.avaflow represents a comprehensive GIS-based framework for the simulation of geomorphic mass flows. This software utilizes a multi-phase-flow model describing the dynamics of the mixture of solid particles and viscous fluid and the strong interactions between these phases.

Mergili, M., Krenn, J., Chu, H.-J. (2015): *r.randomwalk v1, a multi-functional conceptual tool for mass movement routing*. Geoscientific Model Development.

Mergili, M., Fischer, J.-T., Krenn, J., Pudasaini, S.P. (2017): *r.avaflow v1, an advanced open source computational framework for the propagation and interaction of two-phase mass flows.* Geoscientific Model Development 10: 553-569.

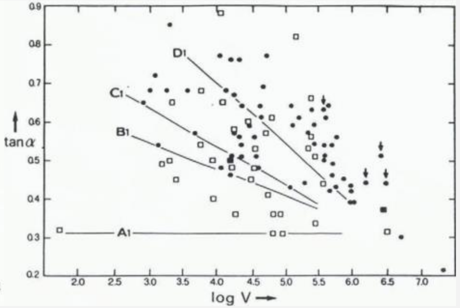
1) Simulation of ice avalanches of different initial volumes with **r.randomwalk** based on the empirical relationships for the **angle of reach (ω)** from *Alean (1985).*

	Volume V (m^3)	Criteria	ω (A)	ω (B)	ω (C)	ω (D)
0	3,000	Observed on 9 May 2020, travel times derived from automatic camera	30.2	**38.0**	27.0	17.2
1	6,000	Observed on 14 July 2020, travel times derived from automatic camera, deposition area mapped	28.9	**36.3**	26.0	17.2
2	10,000	Observed on 25 May 2020, deposition area mapped	28.0	**35.0**	25.3	17.2
3	50,000	Observed in summer 2017, deposition area mapped	24.8	**30.5**	23.0	17.2
4	200,000	Future scenarios based on drone photos and interferometric radar	21.8	**26.3**	20.9	17.2
5	450,000		20.1	**23.7**	19.6	17.2
6	960,000		18.4	**21.2**	18..4	17.2

Alean, J. (1985): *Ice avalanches: some empirical information about their formation and reach*. J. Glaciol., 31(109):324-333.

	Criteria	Volume range of validity V in m^3	Equation of line in Figure 9 V in m^3
A1	$\log V > 6$		$\tan \alpha = 0.31$
B1	More than 60% of path over firn, with few or or no crevasses; $B < 1100$ m; $Q < 70$ m	$3.0 < \log V < 5.0$	$\tan \alpha = 0.754 - 0.0703 \log V$
C1	$R < 1100$ m; $Q < 100$ m	$3.0 < \log V < 5.0$	$\tan \alpha = 0.930 - 0.0998 \log V$
D1	$R < 1500$ m; $Q < 250$ m	$3.7 < \log V < 5.7$	$\tan \alpha = 1.327 - 0.157 \log V$
E1	Large terraces, also in the uppermost third of the path		

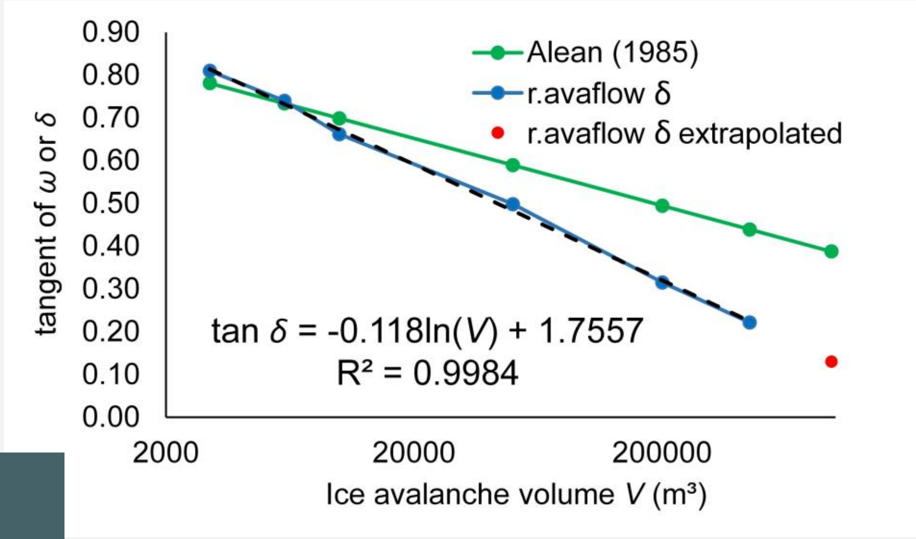
V Avalanche volume.
R Reach of avalanche.
Q Maximum distance of avalanche path from an oblique line (slope 0.5) drawn from the top of the starting zone and above the avalanche path (cf. Fig. 5). Large Q-values are assumed to indicate high avalanche velocity.



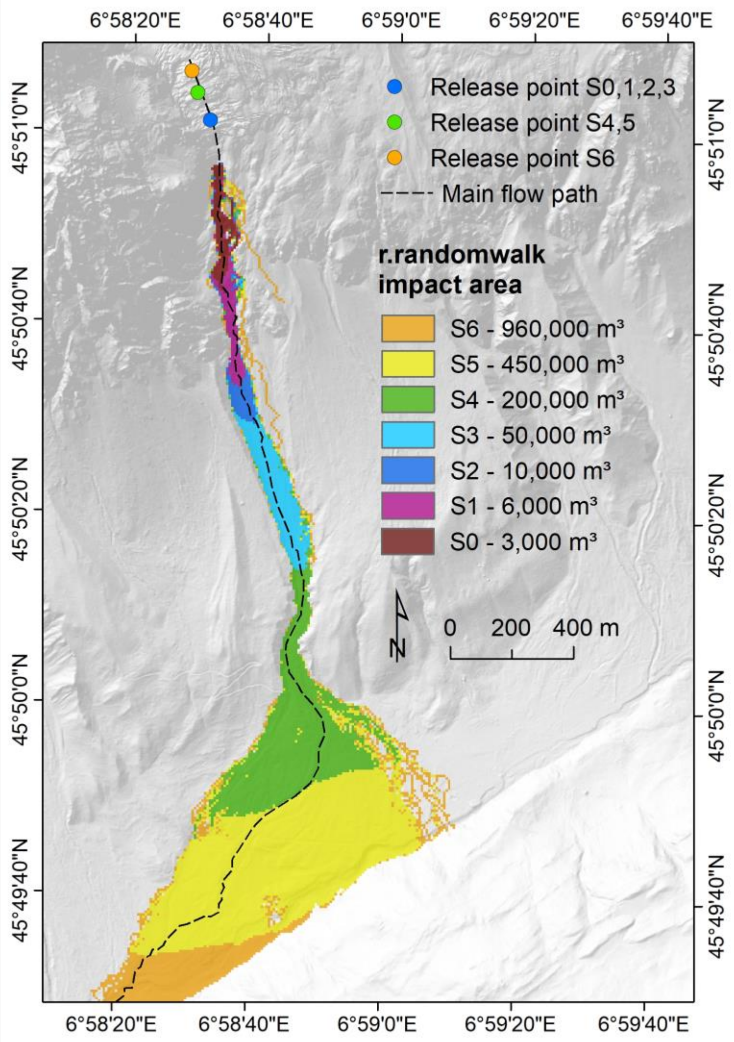
These simulations provide estimates of the **travel distance** and **impact areas**, but not of the travel times, flow pressures, or kinetic energies.

2) Optimization of the **basal friction angle (δ)** used with r.avaflow.

Assuming that δ is a function of the flow kinetic energy – and therefore the flow volume – **different values of δ apply to different volumes**.

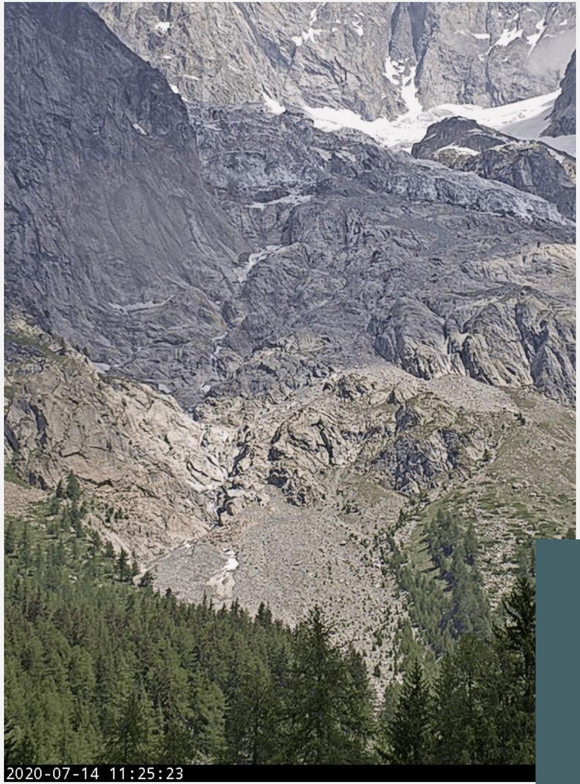


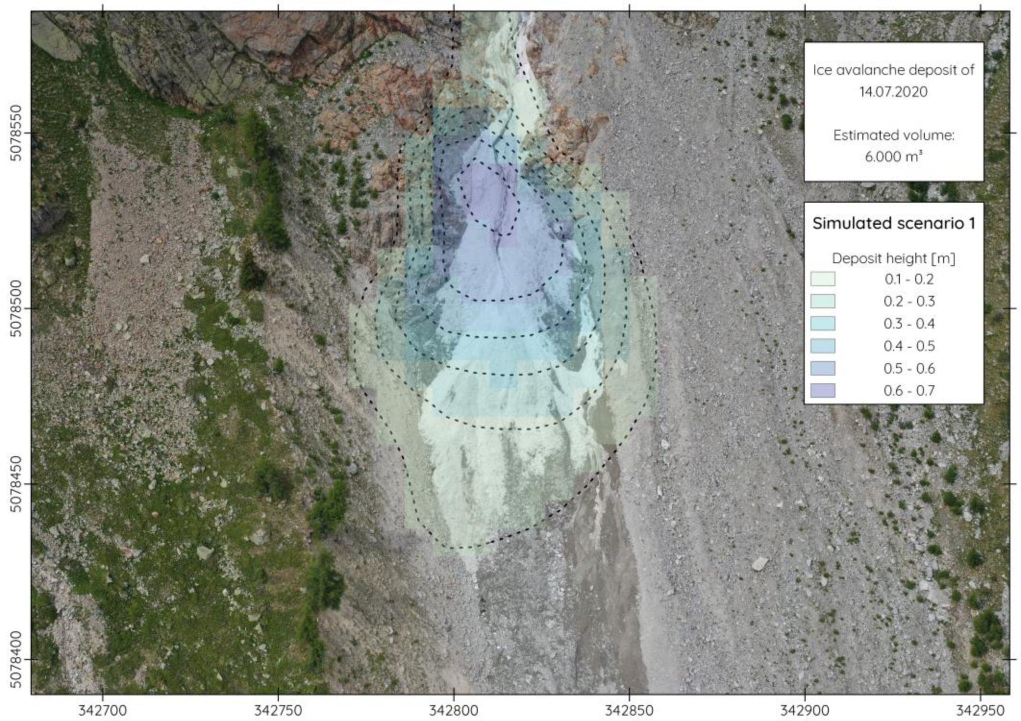
Optimization builds on the **travel distances** predicted with **r.randomwalk** for each tested volume.



Date	Estimated Volume V (m^3)	Observed travel times to C1, C2, C3 (s)	Simulated travel times to C1, C2, C3 (s)
04.04.2020 (HS)	1,500	35, 42, 67	Not simulated
09.05.2020 (HS)	3,000	36, 45, 73	50-60, 100-110, not reached
25.05.2020 (SS)	10,000	Insufficient data	Not analyzed
30.05.2020 (SS)	8,000	31, 52, 123	Not simulated
27.06.2020 (LS)	Multiple	Not analyzed	Not simulated
14.07.2020 (LS)	**6,000**	**23, 34, 143**	**20-30, 40-50, 120-130**

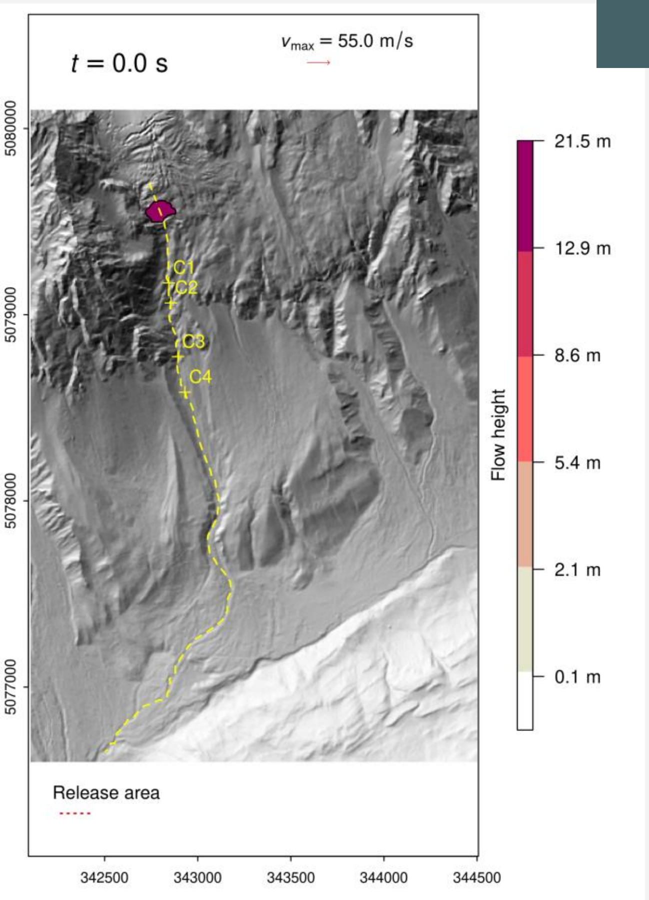
HS = heavy snow
SS = some snow
LS = little snow

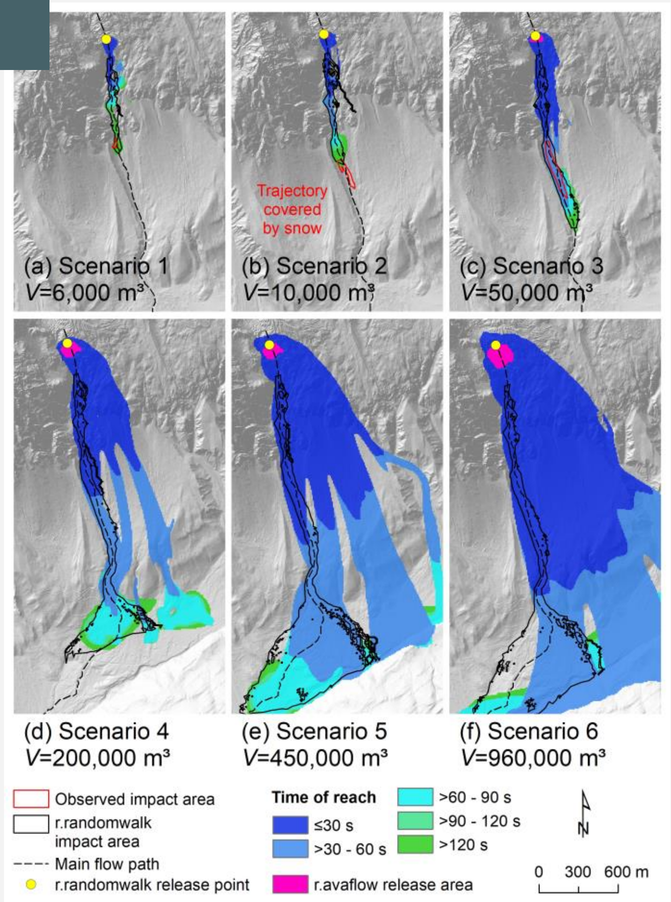




3) The travel distances and travel times are **checked for plausibility** against well-documented events.

RESULTS – PLAUSIBILITY TEST





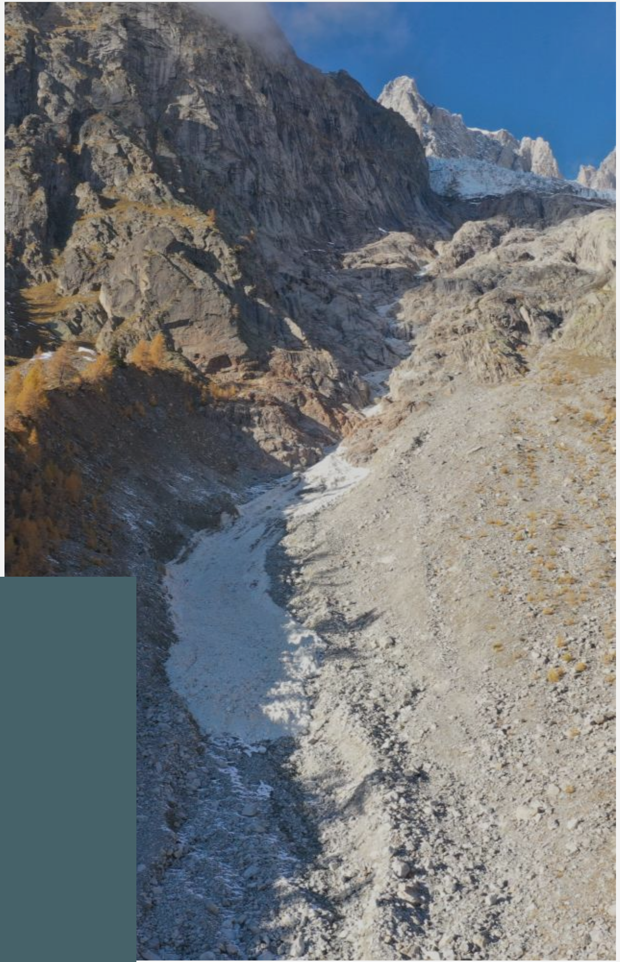
4) **Forward simulations** of scenarios of ice avalanches of different volumes with **r.avaflow**, resulting in estimates of **travel time** and **flow pressure** for each scenario.

Interpretation of the results has to take into account that:

A) For some scenarios, the **empirical relationships had to be extended** beyond their known range of validity, introducing additional uncertainty.

B) The relationships **do not work for snow-covered trajectories**.

As a result, the outcomes can be considered as **worst-case assumptions for ice avalanches in summer**, but are not valid for ice avalanches during the other seasons.



THANKS FOR THE ATTENTION

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