2D modelling of Icelandic snow avalanches for hazard zoning

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ABSTRACT: The methodology for snow avalanche hazard zoning in Iceland is based on a statistical run-out analysis of a data-set of historical avalanches. The method makes use of the one-dimensional PCM snow avalanche model to define a quantitative measure of run-out which is termed *run-out index*. The data-set is being revised and expanded to include recent events. The samosAT two-dimensional model was used to simulate some of the avalanches in the data-set. The run-out index concept has been expanded to two dimensions and a new statistical run-out distribution was derived based on the two-dimensional indices. Simulation results verify that the two-dimensional model is able to take into account the effect of various geometrical features of avalanche paths that cannot be represented by one-dimensional avalanche models. Thus, the effect of lateral geometry to form tongues of long run-out below gullies in the mountainside is taken into account. The 2D model results show a distinct difference in relative run-out lengths compared with more conventional one-dimensional avalanche modelling along longitudinal profiles. Geometrical features of the avalanche path can thus be used to explain a part of the difference in return periods between paths. This leads to more consistent return period estimates. The two-dimensional run-out index concept and the revised run-out distribution have the potential to make the hazard zoning procedure more objective and provide quantitative arguments for the shape of tongues in hazard zones. This reduces the reliance on subjective judgment of the avalanche expert in the hazard zoning process compared to the previous methodology.

KEYWORDS: Avalanche modelling, two-dimensional run-out index, hazard zoning.

1 INTRODUCTION

Following two catastrophic avalanches in NW Iceland in 1995 the methodology for snow avalanche hazard zoning in Iceland was revised and a new risk-based approach was developed. This methodology is based on a statistical run-out analysis of a data-set of historical avalanches. To allow data from different slopes to be included in a unified manner and to facilitate the estimate of run-out distance distribution, Jónasson and others (1999) introduced the so-called *run-out index,* a slope-independent measuring scale for run-out distance based on physical modelling of avalanches in a *standard path*.

Topographical features such as gorges, gullies and ridges frequently stretch along avalanche paths. These features, which tend to channelize or spread the flow of the avalanche can either magnify or reduce the run-out distance depending on lateral position within the run-out area. Two-dimensional models do not rely on a single longitudinal profile, but simulate the flow on a two-dimensional surface representing the actual landscape. A two-dimensional model can, thus, be used to compute a two-dimensional run-out index, which describes the effect of various landscape features on run-out characteristics. This provides a potential for further development of the hazard zoning method.

2 OBJECTIVES

The goal of this study is to verify fundamental elements of the present hazard zoning procedure in Iceland. Furthermore, to utilize recent developments in avalanche simulation to make the procedure more objective and reduce the reliance on subjective judgement of avalanche experts.

3 DATA

The original data-set includes 196 avalanches recorded in the proximity of eight Icelandic towns and villages. The avalanches fell from 81 different paths in about 50 different mountainsides, of which 34 avalanches fell into the sea. The data-set spans just over 100 years,

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although some paths have a shorter observation history. The average observation period was estimated to be ~80 years. As a part of this work several recent avalanches of interest were studied and added to the data-set. The data-set is based on avalanche reports and geographical information collected and stored by the Icelandic Meteorological Office (IMO).

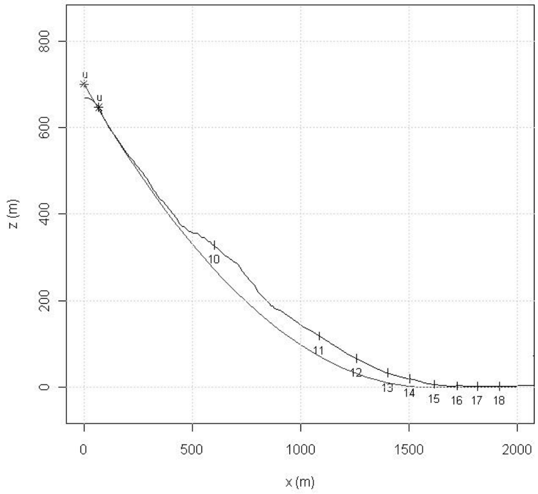

Figure 1. Path profile along a single flowline in Skollahvilft above Flateyri, NW Iceland (see figure 2), together with the specified standard path. Run-out indices (10-18) are marked along the path. The run-out index is the vertical run-out length of an avalanche that has been transferred to the standard path.

4 METHODS

The original data-set is revised to verify that all entries are in agreement with available avalanche reports and geographical information. Longitudinal profiles for one-dimensional modelling are checked and verified with respect to the behaviour of known avalanches and the 1D run-out index is recalculated with the PCM model using updated elevation data, where applicable.

Systematic two-dimensional simulations are performed with the samosAT with simulation parameters that yield 2D run-out indices in the range from 10 to 18 for all paths. Avalanches are given a 2D run-out index value by a visual comparison of simulation results and the avalanche outline.

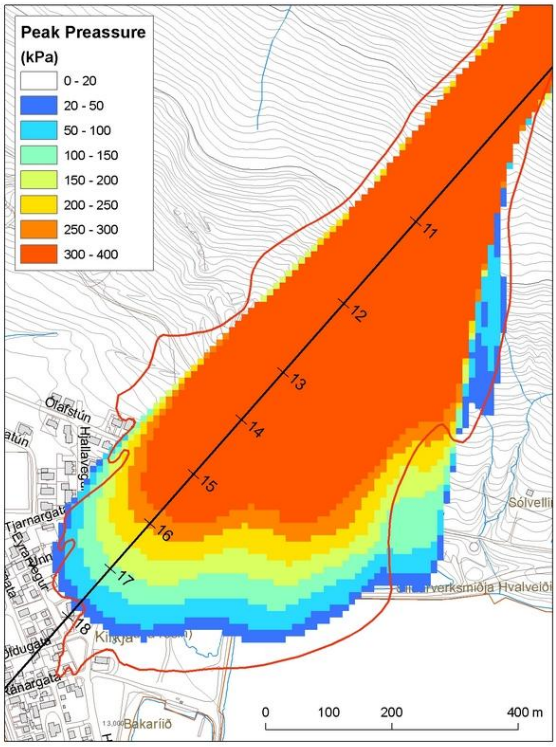

Figure 2. Peak pressure field (kPa) of a samosAT simulation in Skollahvilft above Flateyri, NW Iceland together with a flowline used for modeling in one dimension. Model parameters yield 2D run-out index 16. The outline of the catastrophic avalanche in 1995 is shown with a curve.

5 MODEL RHEOLOGY AND CALIBRATION

Since early 2006, the dense-flow version of the samosAT snow avalanche model has been used for two-dimensional modeling at IMO. The mild costal climate in Iceland, which is a North Atlantic island, differs from the climate of higher and drier continental mountain areas. Snowfall is usually accompanied by wind and thus the snowdrift is very important in the formation of the snow pack. Measurements indicate that the density of released snow mass is rather high, frequently greater than 300 kg/m^3. As a consequence of this high density and the relatively high winter temperatures, it is likely that a smaller part of the flowing mass will become suspended to form a powder cloud accompanying the flowing dense core of avalanches in Iceland compared with Alpine regions. The dense-flow-only version of the model has, furthermore, proved to be able to simulate Icelandic avalanches with reasonable accuracy for several test cases. Thus, simulations of the powder cloud are considered to be of secondary importance for the analysis described here.

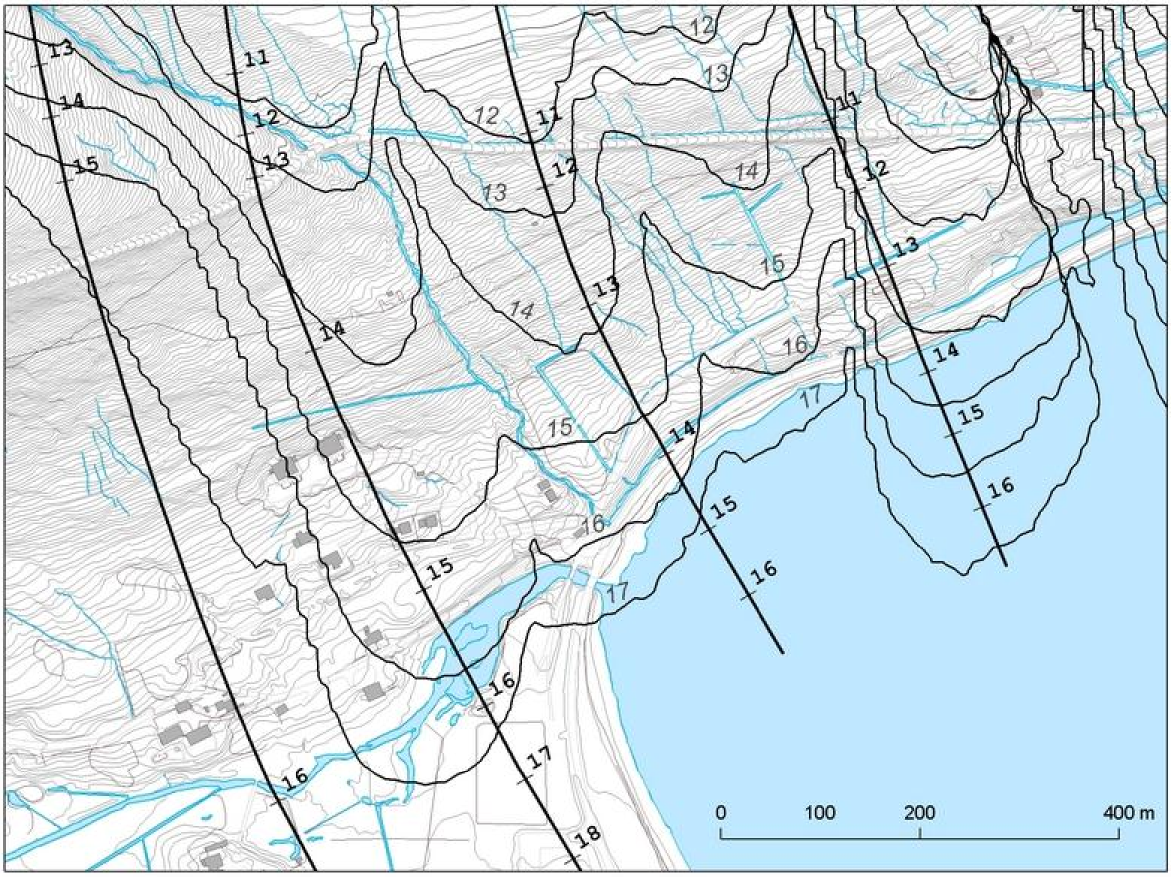

Figure 3. Comparison of 1D and 2D run-out indices based on simulations with a flow-line model and samosAT, respectively. The 2D run-out lines provide quantitative arguments for the shape of tongues in hazard zones.

Previously, the model had been calibrated by exploratory simulations of important and well-recorded avalanches in Iceland to provide in-house guidelines for two-dimensional avalanche modelling at IMO. The primary result of this work was to use the SAMOS classic friction law with velocity dependent friction, C_D = 0.02, and release density, ρ = 300 kg/m^3. The internal friction angle, ϕ, was set equal to the bed-friction angle, δ (Jóhannesson and others, 2007). The bed-friction angle, δ, and the released depth, d, are varied in combination in order to simulate avalanches that vary in size. A set of (d,δ) pairs that shall be used to simulate avalanches with run-out indices in the range 10-20, and which thereby defines the 2D run-out index scale, was developed by Gíslason (2007).

6 RUN-OUT DISTRIBUTION

Avalanche paths in the proximity of Flateyri NW-Iceland are of great importance for avalanche studies in Iceland, both in the past and at present. Figure 4 shows a simple comparison of the run-out of 22 avalanches at Flateyri. The plot shows the run-out of each of the avalanches as measured by the conventional run-out index scale and the 2D run-out index, respectively. The paths at Flateyri are characterized by topological features such as gullies and ridges that channelize the flow in a well-defined stream and therefore tend to increase run-out.

It is apparent from Figure 4 that the 2D run-out indices of the Flateyri avalanches span a smaller range and are in general about two units lower than the 1D run-out index. This suggests that a contributing factor to the high frequency of avalanches with long run-out at Flateyri is the topography of the path rather than adverse meteorological conditions, extreme snow depths or physical properties of the flowing snow mass favoring long run-our. Furthermore, this means that in terms of this new run-out scale the frequency of avalanche run-out in Flateyri is quantitatively comparable to avalanche frequency in other avalanche-prone Icelandic villages, rather than being 10-100 times higher as must be concluded from an analysis based on the older 1D run-out scale.

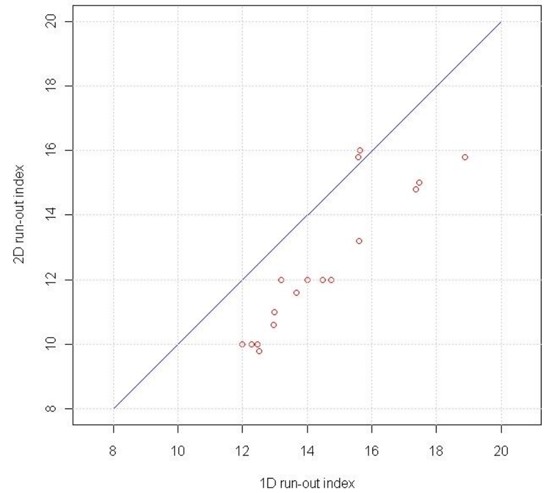

Figure 4. Simple comparison of run-out distribution of a subset of 22 avalanches from the original data-set recorded in Flateyri NW Iceland. The diagonal reference line indicates equal run-out measured by the two scales.

7 RESULTS AND CONCLUSIONS

By applying two-dimensional avalanche simulations the extreme run-out of avalanches can, under certain circumstances, be explained largely by the topography of the avalanche path while the only way to reproduce these avalanches by flowline model is to assume that the released snow mass was very large or that the physical properties were in some way very favorable for the run-out of an avalanche. By introducing a path-independent scale, the 2D avalanche run-out index, it is possible to compile a single run-out series based on real avalanches recorded in different paths. Such data is valuable for decision making in hazard zoning work and could in some cases reason withdrawal of hazard lines under unconfined mountainsides.

Incorporating the results of two dimensional modelling, in the way described above, has the potential to make the hazard zoning procedure more objective and, thus, enhance safety while minimising development restrictions in avalanche-prone regions.

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