VEÐURSTOFA ÍSLANDS

Report
07006

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Calibration of the samosAT 2D avalanche model for large Icelandic dry-snow avalanches

VÍ-VS-04
Reykjavík
March 2007

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Introduction

The SAMOS model was developed for the Austrian Avalanche and Torrent Research Institute in Innsbruck by AVL and has been taken into operational use in some district offices of the Austrian Foresttechnical Service in Avalanche and Torrent Control. The model has been used to simulate recorded avalanches in Iceland and it has been utilised in hazard zoning by the IMO. The first version of the model used in Iceland was based on a Lagrangian integration scheme but the most recent version of the model has been reimplemented using a shock-capturing Eulerian scheme in addition to several other modifications and improvements. The underlying system of dynamical equations is the same for both model versions. This report describes testing of the new model version for two recorded Icelandic avalanches and at two locations where the earlier model version had been run in connection with hazard zoning. The purpose of the testing is to compare the results of the new model with earlier results in Iceland and establish a recommended set of model parameters for the new model to be used in Iceland.

The model is based on assumptions regarding avalanche dynamics similar to other depth-integrated 2D avalanche models that have been developed in Switzerland and France. Friction in the dense flow part of the model is assumed to be composed of a bed friction term proportional to the friction angle, δ [°], and a velocity dependent friction term which may be represented by a non-dimensional coefficient C_D [-]. The friction angle, δ, which is widely used in dynamic descriptions of granular materials, relates to the more typical bed friction coefficient, μ [-], by:

$$\mu = \tan\delta \,. \tag{1}$$

The developers of SAMOS have chosen to model the dynamics of a flowing avalanche so that the velocity dependent friction is expressed in a similar manner as the Coulomb friction by multiplying a dynamic pressure $C_D \rho_0 u^2$ with the bed friction coefficient. The traditional friction coefficient for velocity dependent friction, ξ [-], in traditional Voellmy-type avalanche models may be written in terms of the above-mentioned C_D and μ as follows:

$$\xi = \frac{g}{\mu C_D} \,. \tag{2}$$

By assuming simple yielding to occur in the granular pile, the relation between the normal stress, σ, and the internal shear stress, τ, within the bulk of the avalanche is described by:

$$\tau = \pm\sigma \cdot \tan\varphi \,, \tag{3}$$

where φ [°] is the internal friction angle (Sampl and Zwinger, 1999). The default parameter values for the current release of the model for large dry-snow avalanches are: δ = 15.0°, φ = 35.0° and C_D = 0.02.

Rather than adding the two friction components as is done in the Swiss and French 2D avalanche models, the SAMOS model uses the maximum of the two friction terms and ignores the smaller term. This leads to slightly higher modelled velocities than for the Swiss and

a. b.

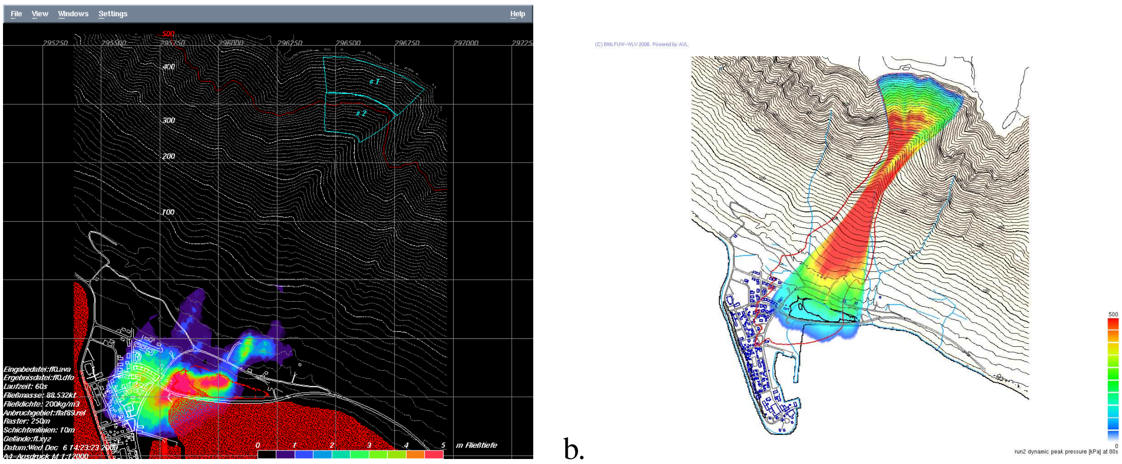


Figure 1: a. SAMOS simulation of the avalanche on 26.10.1995 at Flateyri with the earlier model version displayed as final snow depth in meters and b. a simulation using the latest SAMOS version with the default set of parameters, displayed as peak pressure in kPa and the outline of the catastrophic avalanche in 1995 is shown with a red curve.

French 2D models for avalanches with similar run-out. The velocities are, also, somewhat higher than corresponding velocities in the same path from the Swiss AVAL-1D model or the PCM model.

The model runs are, furthermore, based on an assumed value for the density of flowing snow, ρ_0 [kg m^{-3}]. The default model value for the density, $\rho_0 = 200\,\mathrm{kg\,m^{-3}}$, was used in earlier SAMOS simulations in Iceland. Observations in Icelandic starting zones indicate that density of the snow cover is often in the range 300–400 kg m^{-3}. Based on this, it was decided to adopt a higher value for the density, $\rho_0 = 300\,\mathrm{kg\,m^{-3}}$, in the calibration reported here for the new model version.

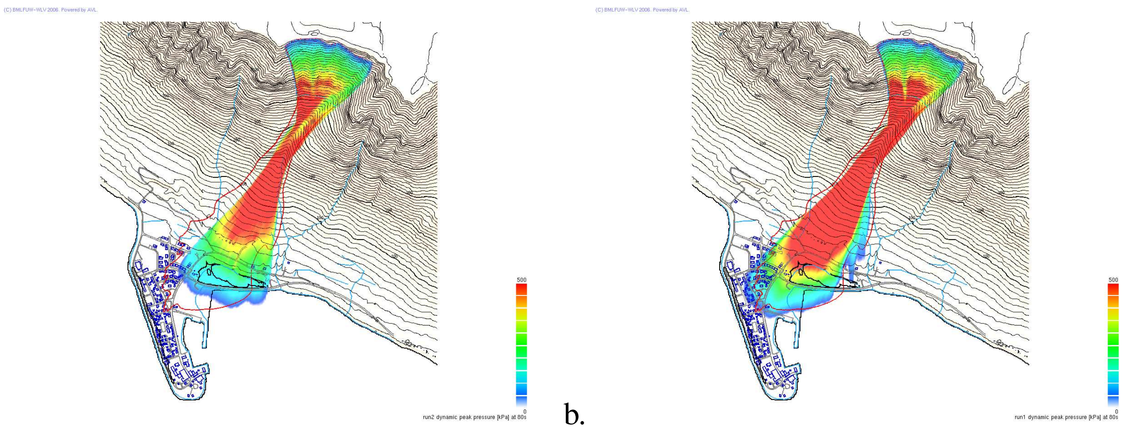
The avalanche at Flateyri 26.10.1995

The earlier version of the SAMOS avalanche model was initially tested for Icelandic conditions by simulating the catastrophic avalanche that hit Flateyri in NW Iceland on 26.10.1995. This initial simulation reproduced the 1995 avalanche quite well with the default model parameters, with a main direction in good agreement with the observed outline of the avalanche and a realistic location for the eastern/left margin of the avalanche where it is known to have just passed a house. Therefore, it was somewhat of a surprise when it was discovered that the revised release of the model with the recommended set of parameters failed to simulate the 1995 event equally well. The results of the initial simulation together with a simulation with the new model version using the default parameter set are displayed in Figure 1. Both simulations are started with the same mass of snow in the starting area, $\approx 98 \cdot 10^3$ tonnes. The figure shows that the new simulation produces an avalanche with a somewhat shorter run-out and the tongue is located too far to the east with respect to the outline of the avalanche from 1995. The run-out may easily be adjusted by increasing the released mass slightly, but the placement of the tongue indicates that the default parameter values lead to lower velocity in the track, which results in a wrong direction of the avalanche as it flows out of the opening of the gully. The shape of the tongue in the new simulation is also different from the observed outline (and the older simulation) in that the tongue form is less convex. This is also found in other paths where the new model version has been tested. The default model parameters lead to deposit shapes which are comparatively wide all the way to the maximum run-out location.

As the default parameter set did not lead to a good simulation with the new model version, an attempt was made to find a different parameter combination for the new model, which could be adopted as a default parameterisation for simulations of large Icelandic dry-snow avalanches. The Flateyri avalanche, which was released in the Skollahvilft path, was strongly channelised in an undulating path geometry. Therefore, it is expected that the direction of the main tongue is sensitive to the simulated speed as the avalanche flows out of the gully at about 200 m a.s.l. The two friction terms, governed by δ and C_D, respectively, determine in combination the run-out length of a simulated avalanche in such a way that a given run-out length can be reached with different pairs of δ and C_D. However, such different model runs, having the same run-out length, are not identical. Different velocity profiles which result from different δ, C_D pairs are of special interest in a channeled path like the one from Skollahvilft. The outline of the avalanche contains in this case implicit information about the speed of the avalanche, which is in general not the case for unconfined paths where simulations produced with different δ, C_D pairs with the same run-out are seemingly equally good.

Internal friction

As stated in Equation (3) the internal friction angle, φ, influences the dynamics of the model. There is very little observational evidence for any particular choice of the internal friction angle and some avalanche researchers have expressed the view that different values of active and passive pressure, which is a consequence of a non-zero internal friction angle, are not appropriate for snow avalanches. A simulation with the lowest admissible value of φ in the model, which is equal to the friction angle, δ, is compared with the default simulation in Figure 2. It is clear from the figure that the lower value of φ leads to much improved results. Lowering the internal friction angle leads to a more round shape of the tongue, in agreement with the observed outline. The run-out distance is also slightly increased, which leads to a stopping position closer to the observed avalanche. The run-out of the simulation with the default parameter values can be made more realistic by increasing the mass of the avalanche slightly as mentioned above. The shape and placement of the tongue are, however, not improved so that it is clear that a reduced value for the internal friction leads to a marked improvement in the simulation of the Flateyri avalanche.



a. b.

Figure 2: results obtained using a reduced internal friction angle, φ. Both images display peak pressure in kPa and the outline of the catastrophic avalanche in 1995 as a red curve.

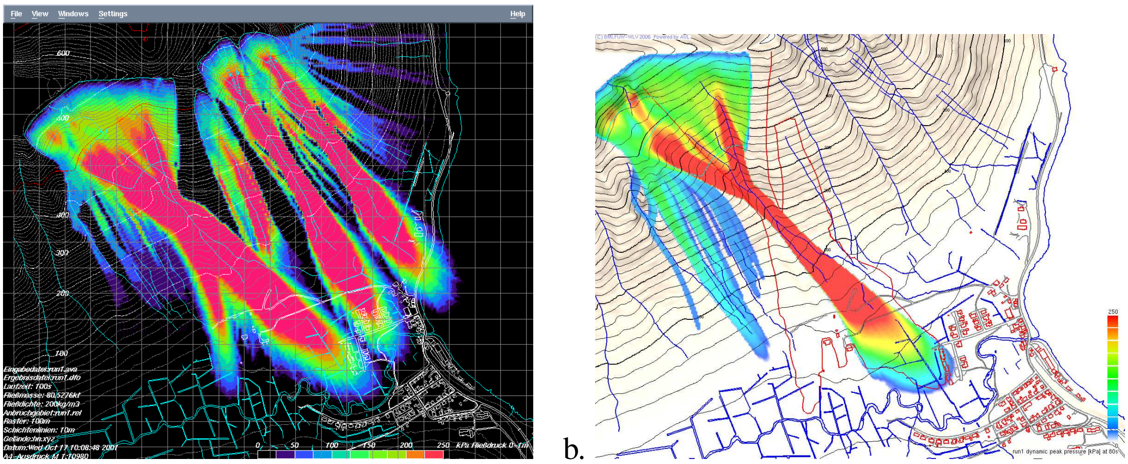
Systematic calibration of δ and C_D

As described earlier, different combinations of δ and C_D can result in essentially equivalent run-out and such different combinations could give precisely the same run-out in a one-dimensional flow line model. In a 2D model, the quality of simulations with similar run-out may, however, be slightly different since these two parameters affect the velocity profile of the avalanche and one might expect the selection of δ and C_D to influence the direction of the main stream and the shape of the tongue. Figure 8 at the end of the report displays the results of six simulations corresponding to different δ, C_D pairs, which all give similar run-out. δ is in the range 12–17.5° and C_D in the range 0.005–0.05. From these results, it is obvious that these different δ, C_D pairs indeed have an effect on the shape of the front of the avalanche and reproduce the observed outline with different realism. The effect on the flow direction is not as obvious but it seems that the avalanche tends to head further westward when C_D is increased and δ decreased.

The results shown in Figure 8 do not pinpoint a single δ, C_D pair as the most appropriate but they suggest that the two simulations with the most extreme parameter pairs are less realistic then the other four.

The avalanche in Hnífsdalur 25.1.2005

Another event of special interest is the avalanche from Hraunsgil in Hnífsdalur on 25.1.2005. The path is somewhat comparable to Skollahvilft, Flateyri, since it forces the avalanche into a narrow stream before it reaches the opening of the gully where it spreads out over an unconfined debris cone. This avalanche is interesting for the following reasons: The avalanche splits in two separate streams before coming to rest. Quite good data was collected about the



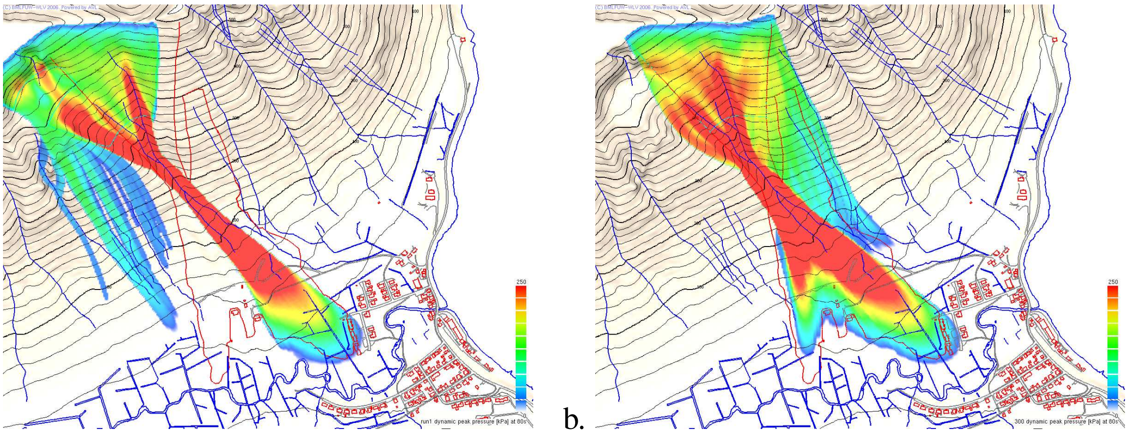
a. b.

Figure 3: a. SAMOS simulation of the avalanche in Hnífsdalur on 25.1.2005 with the earlier model version together with the outline of the avalanche in 2005 which is shown with a red curve and b. a simulation using the latest samosAT version with the default set of parameters. These results are obtained using same release snow mass. The images display the peak pressure field in kPa.

extent and total volume of the deposit. Before the event in 2005, an effort had been made to simulate a large avalanche in this path with the earlier version of the SAMOS model. As can be seen in Figure 3a the simulated outline is in good agreement with the observed outline but again the newer samosAT version with the default parameters and the same released snow mass fails to produce an equally good result. The simulated avalanche with the new model is not split on the ridge in the middle of the run-out area and forms a single tongue rather than the observed two-tongue shape.

Adjustment of the release area

Since the original release area used in the simulation carried out in 2001 is not properly located with respect to the actual release area of the 2005 avalanche, the first attempt to improve the results was to adjust the release area to better reflect the actual release area of the avalanche in 2005. The upper and lower edges were retained but the release area was shifted eastward to match the outline of the avalanche. The adjustment of the release area obviously leads to a marked improvement and the simulated outline closely matches the observed geometry of the 2005 avalanche. This good results is achieved with the default value of the internal friction parameter φ which did not lead to a realistic simulation of the Flateyri 1995 avalanche. It is unusual that the location of the starting zone has this much influence on simulations results as observed here. The reason is that the momentum of the easternmost part of the released snow mass gives the avalanche a “push” to the right in the narrow gully where the amount of snow which is able to overflow the ridge seems to be very sensitive to the location of the



a. b.

Figure 4: SamosAT simulations of the avalanche in Hnífsdalur on 25.1.2005 using the default set of parameters. a. The original release area b. A modified release area corresponding to the 2005 avalanche. The images display the peak pressure field in kPa. The outline of the avalanche in 2005 is shown with a red curve on the maps.

main stream of the flowing avalanche. The avalanche simulated with the earlier version of the model seems to split in a realistic manner in the gully in spite of a wrong delineation of the starting snow mass. It is not clear why this is so, but it appears that the good quality of the earlier simulation when it is compared with the 2005 event, is partly due to a coincidence.

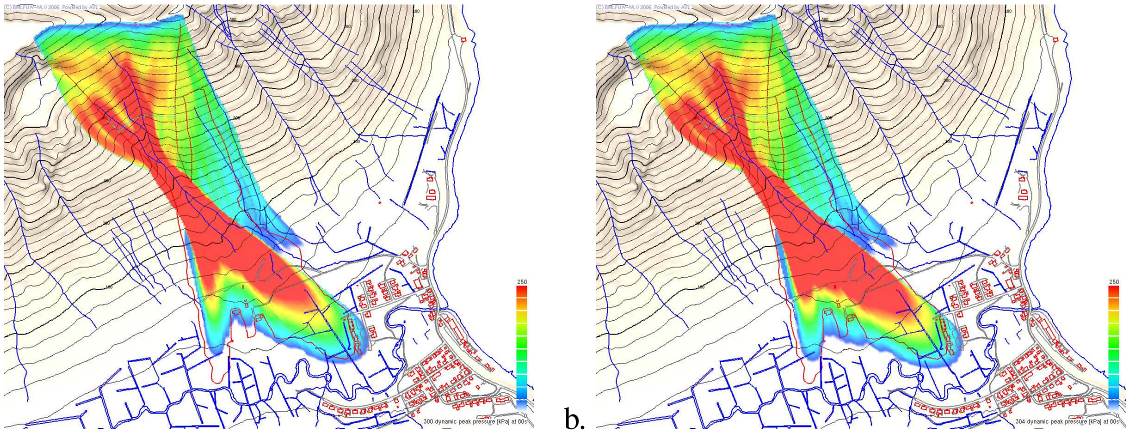
Internal friction

The effect of the value of the internal friction angle was examined by carrying out a simulation with $\varphi = \delta$ as for the Flateyri 1995 avalanche. In contrast to what was experienced at Flateyri, the internal friction does not seem to have a significant effect on the behaviour of the avalanche in the Hraunsgil path as Figure 5 implies. Both runs result in similar overall shape of the avalanche although the reduced internal friction results in longer run-out as was also observed at Flateyri.

Results with different δ, C_D pairs

In order to further study different combinations of δ and C_D, six simulations were performed for Hraunsgil with different δ, C_D pairs, which are identical to those that resulted in similar run-out at Flateyri and were described previously. Since the release mass for this avalanche is not known some backcalculations are used to determine the release snow depth of 0.8 m which gives run-out length comparable to that of the 2005 avalanche.

As Figure 9 at the end of the report shows, the nature of the simulated avalanche is quite dependent on the choice of the δ, C_D combination, even though the maximum run-out length



a. b.

Figure 5: a. SamosAT simulations of the avalanche in Hnífsdalur on 25.1.2005 with the default set of parameters and b. results obtained using reduced internal friction angle, φ. The images display the peak pressure field in kPa. The outline of the avalanche in 2005 is shown with a red curve on the maps.

is comparable. For the lower values of the bed friction and higher values for the velocity dependent friction, the flowing mass tends to form a single well defined stream. When the the bed friction is increased and the velocity dependent friction decreased at the same time, the flowing mass tends to spread more out. For this particular site only two of the six δ, C_D pairs give reasonable results, that is c. (16.5°, 0.013) and (15°, 0.02) whereof (15°, 0.02) is noticeably better.

Hazard zoning simulations

Following the catastrophic avalanches in Súðavík and Flateyri in 1995, the methodology for assessing avalanche danger in Iceland was completely revised. After a new procedure for the delineation of hazard zones had been developed, hazard zoning for settlements around Iceland that are exposed to avalanche danger commenced. Two-dimensional simulations with the SAMOS model were utilised in the hazard zoning work following an initial verification and calibration process which established a certain routine for these simulations. Therefore, it is of interest to compare simulations with the more recent samosAT model with the earlier SAMOS results, in particular to identify parameter combinations and release snow depth for the new model version that correspond to the standard runs that were carried out in the hazard zoning with the older model version. The following subsections describe a comparison of samosAT results with earlier results at two different locations, Neskaupstaður and Siglufjörður, which span a considerable range in path geometries so that a reasonably complete comparison of the two model version is obtained.

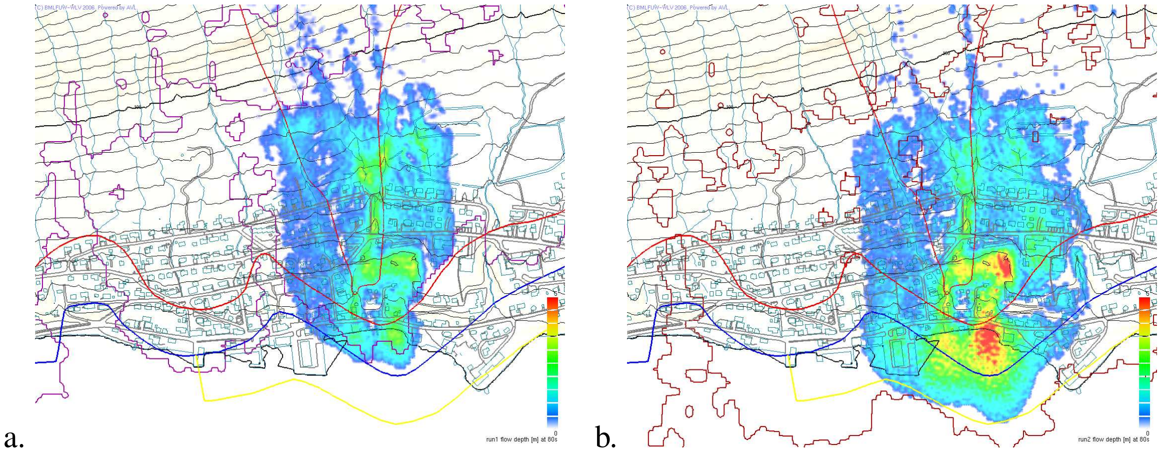


Figure 6: Drangagil in Neskaupstaður. Final deposit depth for samosAT simulations (colour images), iso-risklines of the hazard zoning below Drangagil (yellow, blue, and red curves), and the outline of the final snow deposit simulated by the earlier SAMOS model from 2001 with the same release snow mass. a. run1, and b. run2.

Hazard zoning simulations at Drangagil in Neskaupstaður

The avalanche path of Drangagil is well confined above the run-out zone. The starting zone is bowl shaped and the track is a deep, cliffy, and narrow gully from 400 to 280 m a.s.l. Three different model runs were carried out in 2001 that included the Drangagil starting zone (id = 18 in Jóhannesson and others, 2001a) and surrounding starting areas. Two runs are considered here, run1 and run2. These two runs were started with 1.25 m and 2.5 m release snow depth with density $\rho_0 = 200\,\mathrm{kg\,m^{-3}}$ in run1 and run2, respectively. Similar SAMOS runs were carried out for other locations in Iceland threatened by paths with large, bowl shaped starting areas. According to these earlier results, which are displayed as outlines of the final snow deposit in Figure 6, the smaller model run coincides approximately with the blue iso-riskline of $1 : 1 \cdot 10^5$ /year in Neskaupstaður, which defines hazard zone B in Iceland, while the larger run coincides approximately with the yellow iso-riskline of $0.3 : 1 \cdot 10^5$ /year.

The final deposit depth for two samosAT simulations with the same release mass as in the 2001 runs are shown in Figure 6. The friction parameters are the same at obtained above for Flateyri, $\delta = 15^\circ$, $C_D = 0.02$, the internal friction, ϕ, is put equal to the bed friction, δ, and the snow density is specified as $\rho_0 = 300\,\mathrm{kg\,m^{-3}}$ (the earlier release snow depth from 2001 is scaled with 2/3 to obtain the same mass). The simulated run-out with the old and new model versions is similar, the run-out simulated with the new model is somewhat longer for the smaller snow depth and somewhat shorter for the larger snow depth, but considering the crude approximations that underly the model physics and parameterisations, the new and old runs may be considered essentially equivalent.

Hazard zoning simulations for two avalanche paths in Siglufjörður

The starting zones of Jörundarskál, Syðra- and Ytra-Strengsgil and Fífladalir in Siglufjörður (id = 1, 2, 4 and 9 in Jóhannesson and others, 2001b) are typical for the situation in various Icelandic costal settlements. Jörundarskál and Ytra-Strengsgil have a well known history of large avalanches but in spite of this the residential area expanded into the run-out zone of these paths in the latter half of the twentieth century. Soon it became obvious that the avalanche risk in this area was not acceptable and deflecting dams have been built to protect this part of the settlement. Avalanches in the Fífladalir path are not as frequent but it has a potential for causing a devastating accident if a large avalanche were to be released from this large starting zone.

Two-dimensional SAMOS simulations with the earlier model version were carried out in 2001 not only to assess the avalanche danger in Siglufjörður, but also to verify the functionality of the deflecting dams below Jörundarskál and Strengsgil. For this purpose, four model runs that involved the abovementioned starting zones were made using a terrain geometry including the deflecting dams.

The final deposit depth for the samosAT simulations with the same release mass as in the 2001 runs are shown in Figure 7. The friction parameters and snow density are again the same at obtained above for Flateyri and described in the previous subsection for Drangagil, and the release snow depth from 2001 was scaled with 2/3 to obtain the same mass as in the earlier runs (the release snow depth in the two Strengsgil starting zones was twice that in Drangagil, Jörundarskál and Fífladalir because of very heavy accumulation of drift snow in these gully shaped starting zones). As for Drangagil, the simulated run-out with the old and new model versions is similar, except that the deposit tongues are somewhat narrower for the new model and the new model simulates considerably less overflow over the dams than the old model. Less overflow over the dams is probably cause by the shock capturing numerics of the new model, which is able to capture the interaction of the avalanche with the deflecting dams more realistically.

Conclusion

Backcalculation of two large, Icelandic, dry-snow avalanches with the new samosAT 2D avalanche model indicates that the parameter combination $\delta = \phi = 15^{\circ}$, $C_D = 0.02$, $\rho_0 = 300\,\mathrm{kg\,m^{-3}}$ is able to reproduce the run-out distance and deposit shape of the avalanches if the released mass is chosen appropriately and in rough agreement with available information about the actual mass of snow released from the starting zones. Comparison of simulations with the new model version with the earlier version of SAMOS, which has been used in Iceland for several years, shows that the results of the two versions are comparable for the above choice of parameters in the new model if the same release mass of snow is used in both cases. The new model may thus be used for hazard zoning purposes at new locations to produce

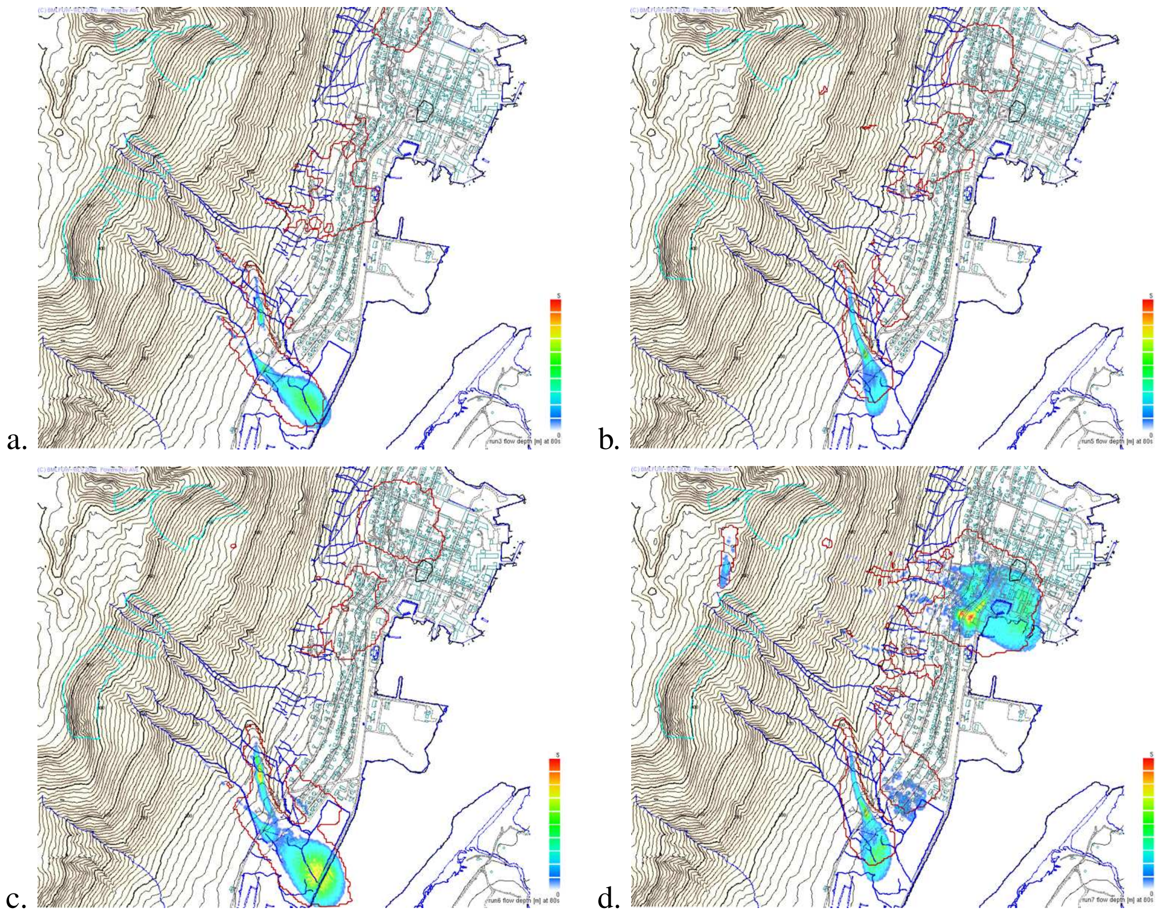


Figure 7: Jörundarskál, Strengsgil and Fífladalir in Siglufjörður. Final deposit depth for samosAT simulations (colour images), and the outline of the final snow deposit simulated by the earlier SAMOS model from 2001 with the same release snow mass. a. run3, b. run5, c. run6, d. run7.

comparable results to the old model.

Some differences between the two model versions were observed. The new model tends to produce narrower tongues which appear more realistic in the cases where this occurs. This tendency results in notable differences between the model versions in certain topographies. The new model also simulates less overflow over deflecting dams than the earlier model version, presumably because of a better physical and numerical representation of momentum loss in shocks formed in the impact with dams. This process is not well described in the earlier model version, so we assume that the new model is more realistic in this regard, although we do not have direct observations to substantiate this conclusions.

We have here used a single set of frictional parameters to represent large, dry-snow avalanches. The release snow depth is the only variable parameter used to represent avalanches of different sizes with different run-out distances. Further experimentation of the model with both large and small avalanches, which is not described further here, indicates that it is not feasible to describe a wide range of avalanche sizes by varying only the release snow depth for the same set of frictional parameters. It appears that a somewhat smaller friction is needed to capture the geometry and run-out distance of the longest avalanches and that a larger friction is needed for smaller avalanches. This indicates that a systematic covariation of release snow depth and friction parameters is needed to obtain realistic avalanche simulations over a wide range of sizes or run-out distances. Here, we restrict our attention to a comparatively narrow range of avalanche size/run-out, for which the above recommended parameter combination seems to give reasonable results, which is importantly in agreement with earlier SAMOS simulations in Iceland. Further testing of the model is underway to define more appropriate parameter combinations for hazard zoning and backcalculation of historical avalanches where a wider range of avalanche sizes is needed. More realistic treatment of entrainment/deposition may also be important to obtain realistic simulations of avalanches spanning a wide size range without needing to resort to artificial variations in friction parameters to compensate for lack of physical realism in the model assumptions. This question will also be addressed in further testing of the model that is planned at IMO.

References

Ólafur Jónsson, Sigurjón Rist and Jóhannes Sigvaldason. 1992. *Skriðuföll og snjóflóð. III. Snjóflóðaannáll.* Reykjavík, Bókaútgáfan Skjaldborg.

Icelandic Meteorological Office. 2005. *Snjóflóðahrina á Vestfjörðum 1.-6. janúar 2005* Reykjavík, IMO, report 05010.

Tómas Jóhannesson, Þorsteinn Arnalds and Leah Tracy. 2001a. *Results of the 2D avalanche model SAMOS for Bolungarvík and Neskaupstaður.* IMO, report 01011.

Tómas Jóhannesson, Þorsteinn Arnalds and Leah Tracy. 2001b. *Results of the 2D avalanche model SAMOS for Siglufjörður.* IMO, report 01019.

Tómas Jóhannesson and Oddur Pétursson. 2004. *Snjóflóð á varnargarðinn við sorpbrennsluna Funa í Engidal við Skutulsfjörð þann 14. janúar 2004.* Reykjavík, IMO, memo TóJ-2004-02.

Icelandic Meteorological Office. 2003. *Snjóflóð á Ísafirði og í Hnífsdal.* IMO, internal report 03011.

Zwinger, T., A. Kluwick og P. Sampl. 2003. Numerical simulation of dry snow avalanche flow over natural terrain. *In:* Hutter, K. og N. Kirchner, *eds.*, *Response of granular and porous materials under large and catastrophic deformations.* Lecture notes in applied and computational mechanics, **11**, 160–194. Berlin, Springer.

Þorsteinn Arnalds, Siegfried Sauermoser, Tómas Jóhannesson og Harpa Grímsdóttir. 2002. *Hazard zoning for Ísafjörður and Hnífsdalur. Technical report [Hættumat fyrir Ísafjörð og Hnífsdal. Tæknileg skýrsla].* IMO, report 02020.

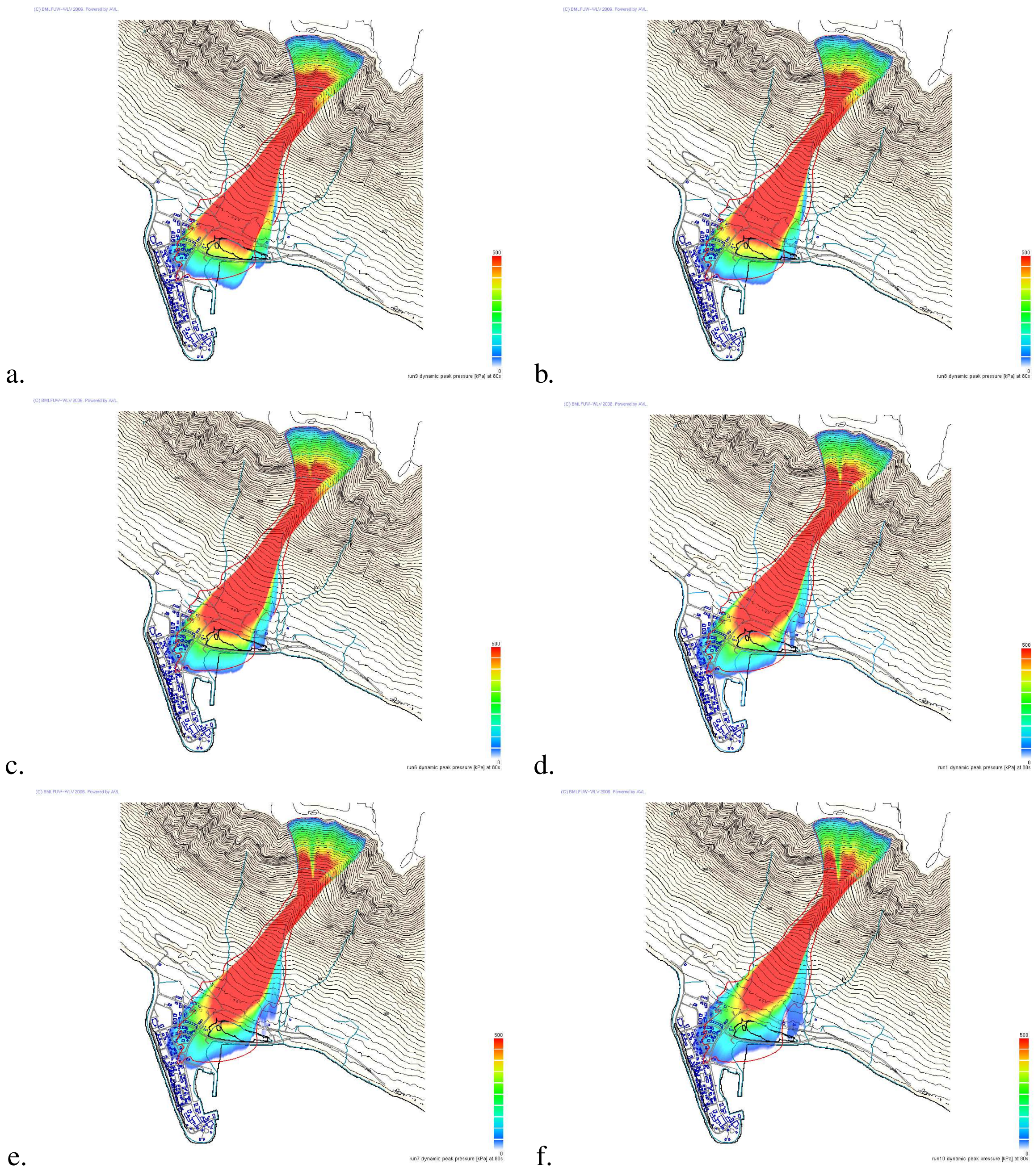
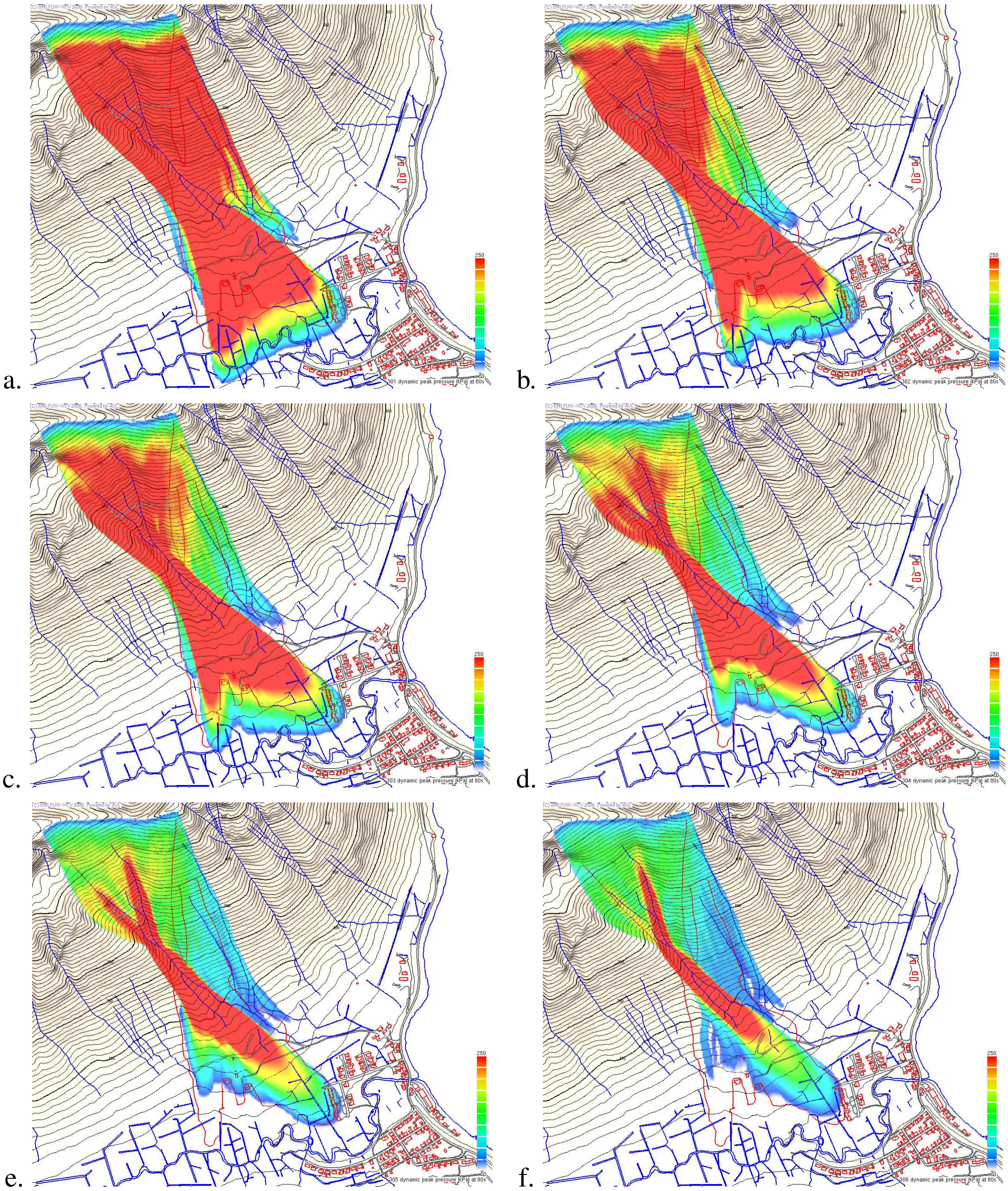


Figure 8: Six runs using different (δ, C_D) pairs which result in similar run-out length: a. (17.5°, 0.005) b. (17,0°, 0.01) c. (16.5°, 0.013) d. (15°, 0.02) e. (13.5°, 0.03) and f. (12°, 0.05). The images show the peak pressure field for each simulation in kPa.



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