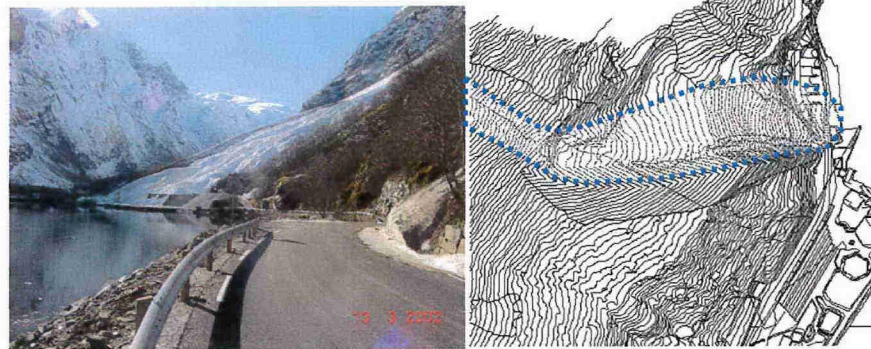


SIP8–Offshore Geohazards and SIP6–Snøskredforskning

3D-Visualization of slides and the NIS slide model

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Summary

Numerical models are important tools for hazard assessment, and visualization is an important tool for pre-processing the input to those models and presenting results from the model runs. Visualization results address external clients, project responsible and his/her co-workers as well as model developer.

Visualization is a powerful tool, which helps to gain in-depth understanding and to give sophisticated answers to our problems. Efficient tools for visualization help to simplify the analysis, to improve the interpretation and to keep the time schedule.

The report presents possibilities on how visualization can be used at NGI

- to present results from slide models to a client,
- to ease the pre-processing needed to initialise numerical models in house,
- and in the developing phase of models.

The report also gives an overview of visualizations already made using the available tools at NGI.

A high degree of standardization can help to make the interpretation simpler, e.g., using standardized colour codes for representing hazard zones. However, no standardized representation for hazard maps exists. Hence, standardization for presenting different hazards in similar ways should be further discussed. Also future visualization has to be discussed.

In addition the report summarizes some developments of NIS, a numerical tool used in slide hazard assessment, and also future plans with respect to coupling the model with visualization tools.

Visualization has connections to projects like

- SKRED-database,
- Best-practise.

Visualization should be followed up in those projects as they progress.



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1 INTRODUCTION

1.1 Why visualization

Imagine, you have spent some time building a numerical slide model and getting the initial and the boundary conditions reasonable correct. Then running the program, do a brief post-processing and move to the next task. What's wrong with that picture? The problem is that we often don't spend enough time reviewing the results from our model runs and gaining insight into the problem to offer an enlightened interpretation of what the results really mean.

Visualization is a powerful tool, which helps to gain in-depth understanding and to give sophisticated answers to our problem. However, one usually has to keep tight schedules and most often one has only one chance to analyse the results. At this stage, efficient tools for visualization help to simplify the analysis, to improve the interpretation, and to keep the time schedule.

1.2 Who is the end-user of the visualization

The requirements for the visualization depend largely on who are the end-users of the visualization results are. Here, one can distinguish between:

- External clients.
At this stage, the presentation of final results is most important. The visualization should help to show findings easily. A high degree of standardization can help to make the interpretation simpler, e.g., using standardized colour codes for representing hazard zones. A smooth presentation has a high marketing value.
- Project responsible (NGI groups)
The focus at this stage is to simplify the procedures needed to obtain intermediate results, e.g., slope angle maps, extraction of profile lines from topographic maps or the presentation of pressure maps. Here, to a certain degree standard routines are feasible; however, some special applications might be needed too.
- Model developer.
The model developer needs a highly flexible tool, which allows him to investigate different fields at individual time steps during debugging of a new or modified model. Such investigations are also important for increased physical understanding.

1.3 What shall be the outcome

The outcome of the visualization depends on the end-user and might be:

- Hazard maps.
This is an end product to the client.

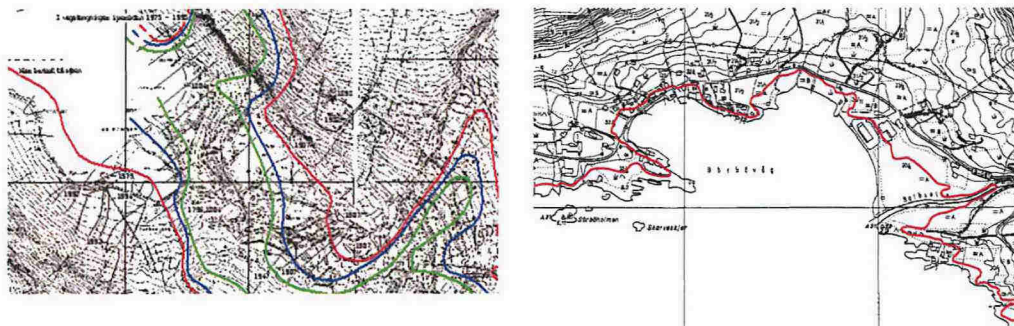


Figure 1.1 Left panel: avalanche hazard map with historic events and lines indicating estimated return periods corresponding to the Norwegian legislation for Geiranger village. Right panel: hazard map indicating wave run-up resulting from a potential rock slide of a specified volume.

- Topography maps and profile lines.
Typical tasks during the process of model initialisation require 3-dimensional visualization of the topography and the evaluation of topographic data with respect to, e.g. critical slope angles for slide release or extraction of profile lines for numerical models.

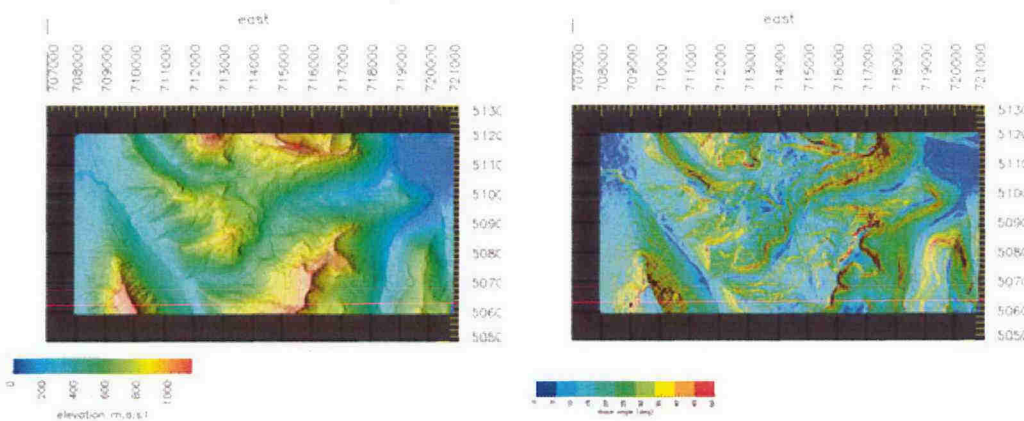


Figure 1.2 Topography (left) and the corresponding slope angle (right) from an evaluation of starting zones for possible landslides in risk assessment (Iceland).

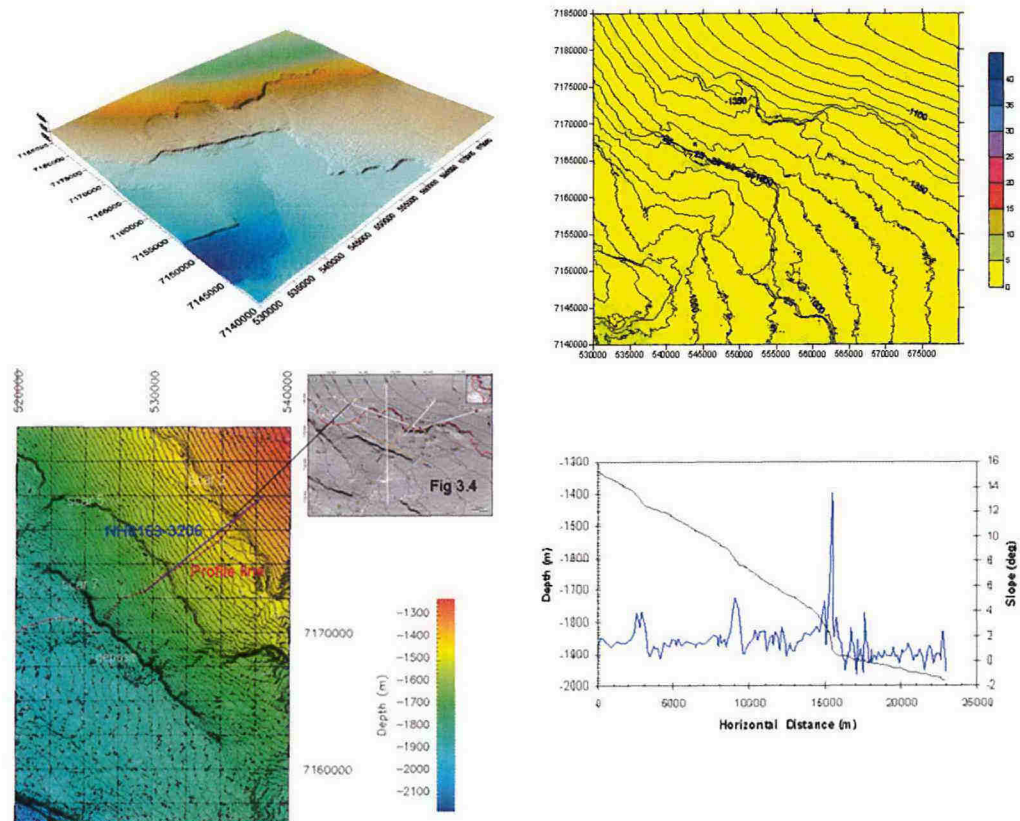


Figure 1.3 *Plastic presentation of a digital topographic map (DTM) (upper left) and slope angle presentation (upper right). Lower row shows the topography of an area of interest and an extracted profile line. Left: overview with a close up. The close up shows also the location of a seismic line and the location of the extracted profile line. Right: an extracted topographical profile based on a steepest gradient approach (black line is the topography, blue line the corresponding slope angle). The profile line is used as input for numerical models. (North-Flank of the submarine Storregga slide)*

- Maps of dynamic fields.
This type of visualization shows critical locations and what forces can be expected. Based on such maps and additional information hazard mapping and risk assessment can be performed.

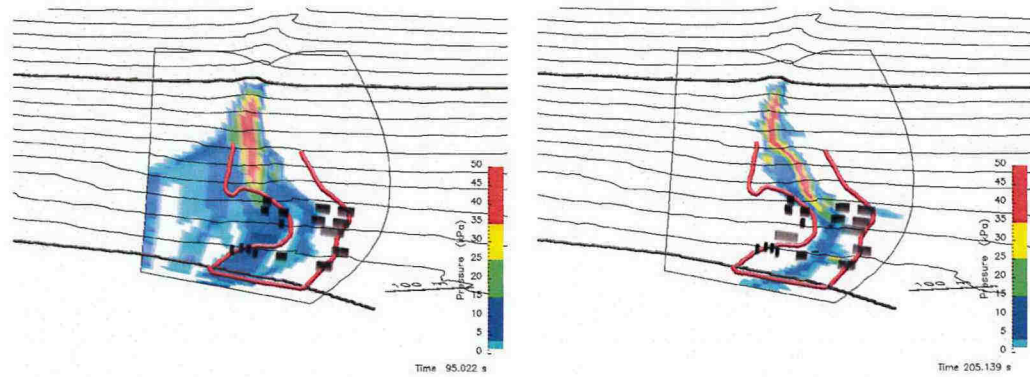


Figure 1.4 Simulated maximum dynamic pressure; slushflow simulation with CFX4 (a commercial flow solver using user-defined subroutines). Left panel: disregarding the interaction with the snowpack; right panel: including interaction with the snowpack.

- Animation or time series.
Animation or time series help to gain in-depth process understanding. They are also a marketing tool.

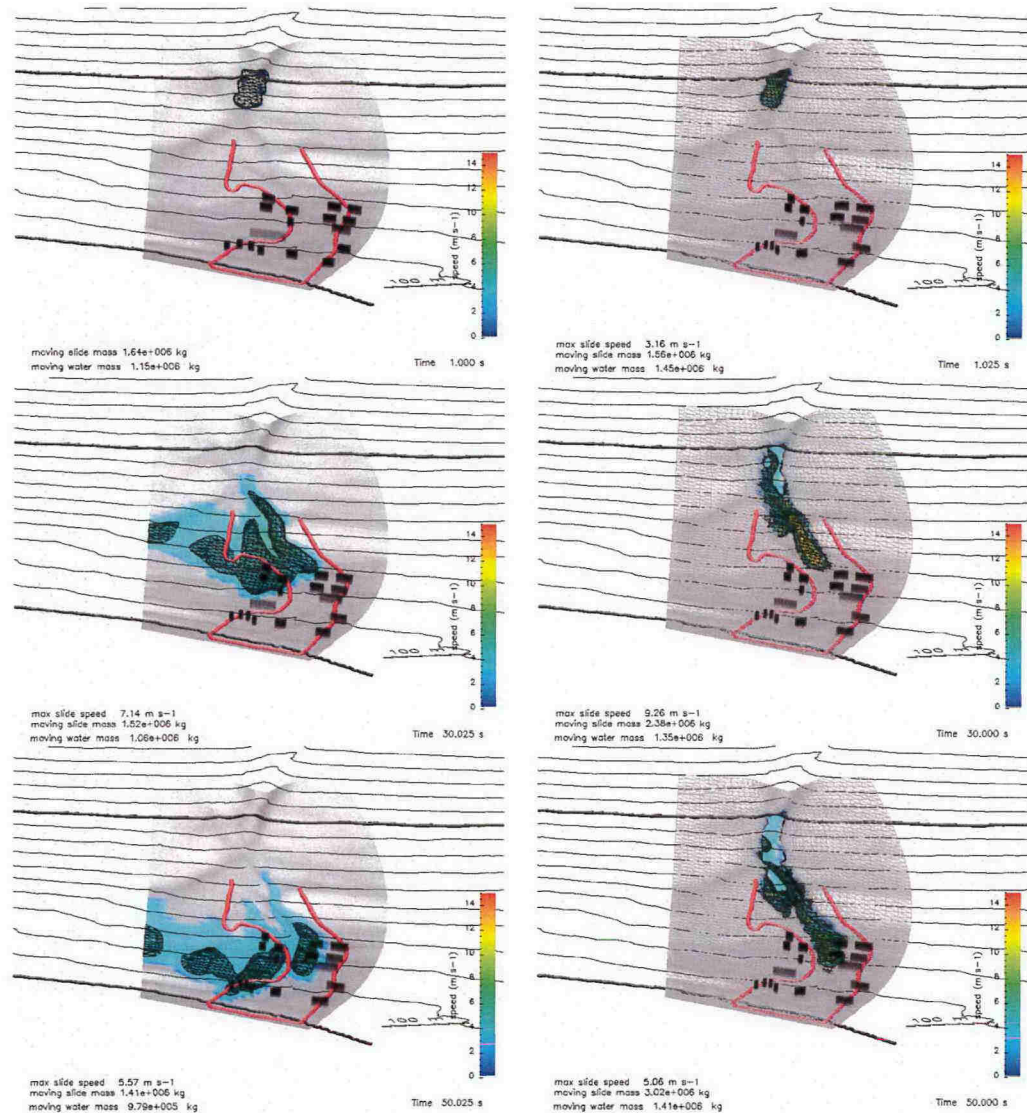


Figure 1.5 Time series of a slushflow simulation with CFX4. Left panel: disregarding the interaction with the surrounding snowpack; right panel: including interaction. Shown is the 100 kg m^{-3} -isosurface of the density and the speed mapped onto. The red line indicates the boundary of an observed slushflow. The calculation domain is within the slightly darker area.

- Special representation.
During debugging of models or for research purposes it might be desirable to combine presentations of different fields.

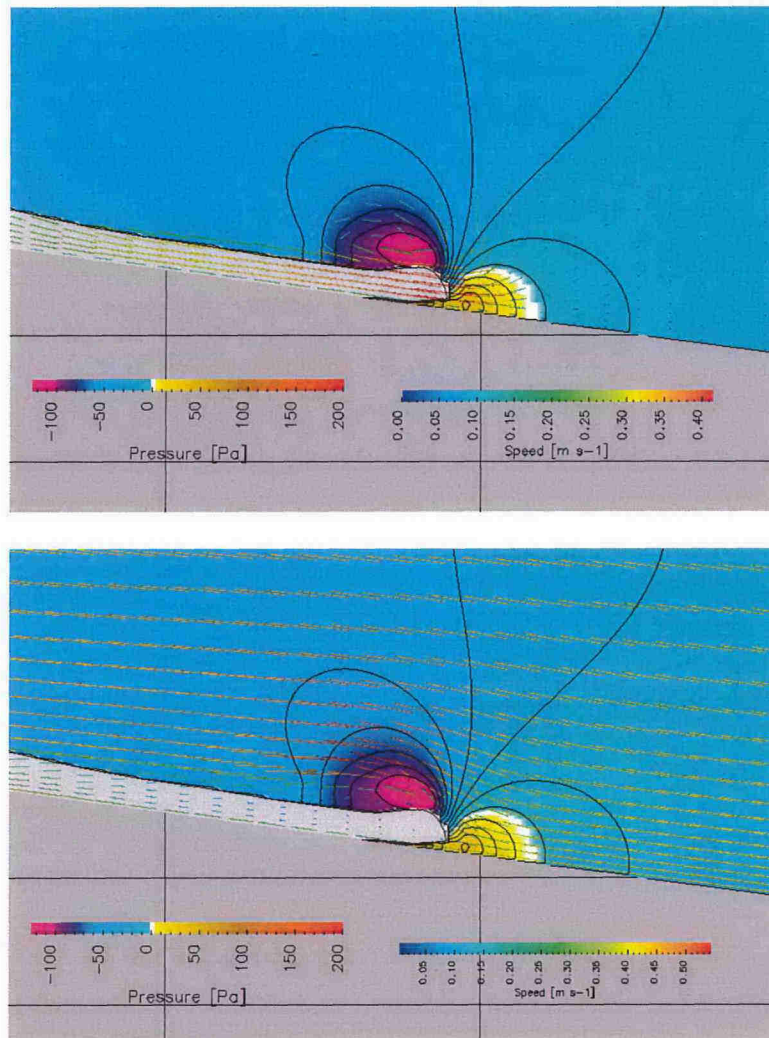


Figure 1.6 Pressure field (colour shading), isobars (black lines) and velocity field (coloured arrows) around the head of a submarine slide. Back-calculation of laboratory experiments. Upper panel, velocity relative to the fixed frame and, lower panel, velocity relative to the stagnation point at the head.

1.4 Numerical slide models at NGI that require visualization

In general, one has to distinguish between the dimensionality of a visualization of results from numerical models and the dimensionality of the numerical model itself. It might be possible to show the result from one-dimensional model on a three dimensional terrain. However, this does not change the limitations of the one-dimensional model. Hence, to extend the quality of slide modelling with respect to a real topography, multi-dimensional models are needed. At the time, only CFX4 can be used for fully 3-dimensional simulations for restricted (small) domains at NGI. The size of the domain



depends on the required resolution. All other presently available models are more or less one-dimensional. With these limitations in mind, the following models can be regarded for

- Submarine slides: CFX based model and statistical model
- Turbidity current: CFX based model
- Avalanches: NIS, PCM, α/β statistical model
- Rock fall: Rockfall

1.5 Visualization tools at NGI

At NGI the following tools are available to present model results or intermediate steps in multi-dimensional settings (the list might not be complete):

- Geographical information systems (GIS) and tools
 - ArcGIS,
 - GeoMedia,
 - Global Mapper,
- Grapher, Surfer
- OpenDX
- MatLab (used for example as visualization tool for the tsunami model at NGI)

1.6 Who are the users of visualization tools

One major question with respect to the available visualization tools is, Who shall be the user?

- Project responsible?
- Model developer?
- GIS experts?

With increasing requirements on the visualization, the complexity to produce them increases. This limits the user-group as not everybody can sufficiently use every visualization tool and not every tool is meant to be used by every one. However, a model developer needs a tool, which he can handle by himself and he needs a high degree of familiarity to use it sufficiently when debugging a new model. The preparation/pre-processing of model runs, i.e., choice of area of interest or extraction of profile lines, presentation of final results in a standardized format, on the other side, might be tasks, in which a project responsible works together with a GIS expert.

1.7 Connections to other projects

Visualization has also connection to other R&D projects at NGI, e.g., to:

- SKRED
SKRED is a graphical user interface (GUI) for the computational models

most frequently used at NGI for run-out distance and velocity analyses of snow avalanches (developed under R&D Snow avalanche project 20021067). In 2004 it was decided to upgrade the user-friendliness, the model stability, and the possibilities for installation of the existing version on different PCs (network, laptop, etc.), rather than changing the platform of SKRED into, e.g., a GIS system. As a first developing step, new installation procedures are developed, the reading and storing of input and results are significantly improved by enabling a higher degree of path- and file specification, and some re-factoring is completed. A new version is ready for release and will be installed by the new procedures these days.

As part of a long-term planning of the further development of SKRED, modifications required for three-dimensional visualisation of results from the computational models have been discussed. This was done in collaboration with the 'SIP8 offshore geohazards-3D visualization' project.

- SKRED data bank.
The coupling to this project is the visualization of avalanche (topographic) information stored in the data bank, e.g., the figure below shows the historic records for Geiranger village.

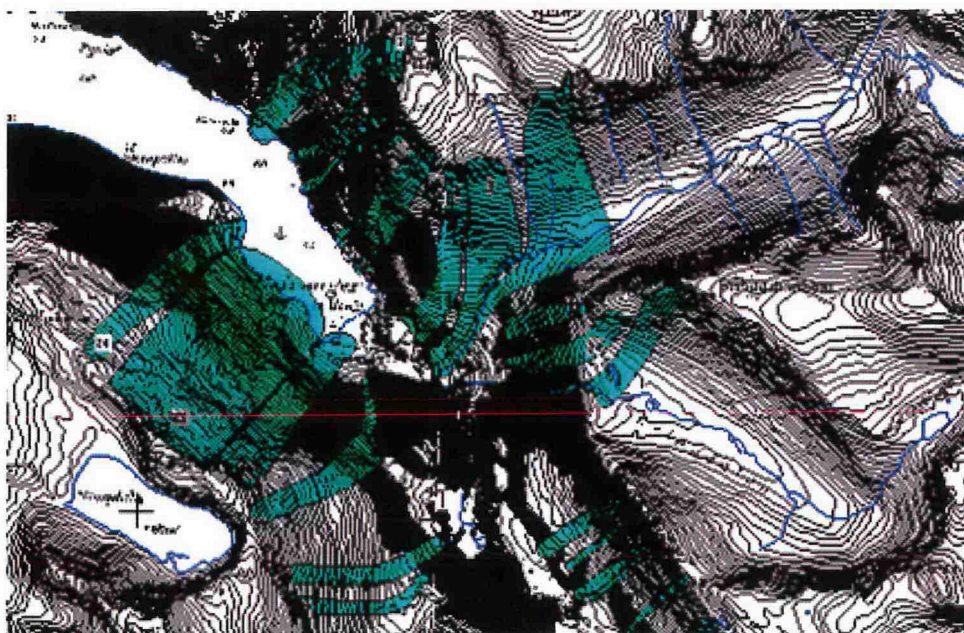


Figure 1.7 Map showing historic avalanches close to the Geiranger village.

- Best practice/ Risk analysis.
Visualization is an important tool in risk assessment and planning of mitigation measures. Combining results from different stages/contributions in the evaluation phase eases the final decision making process.

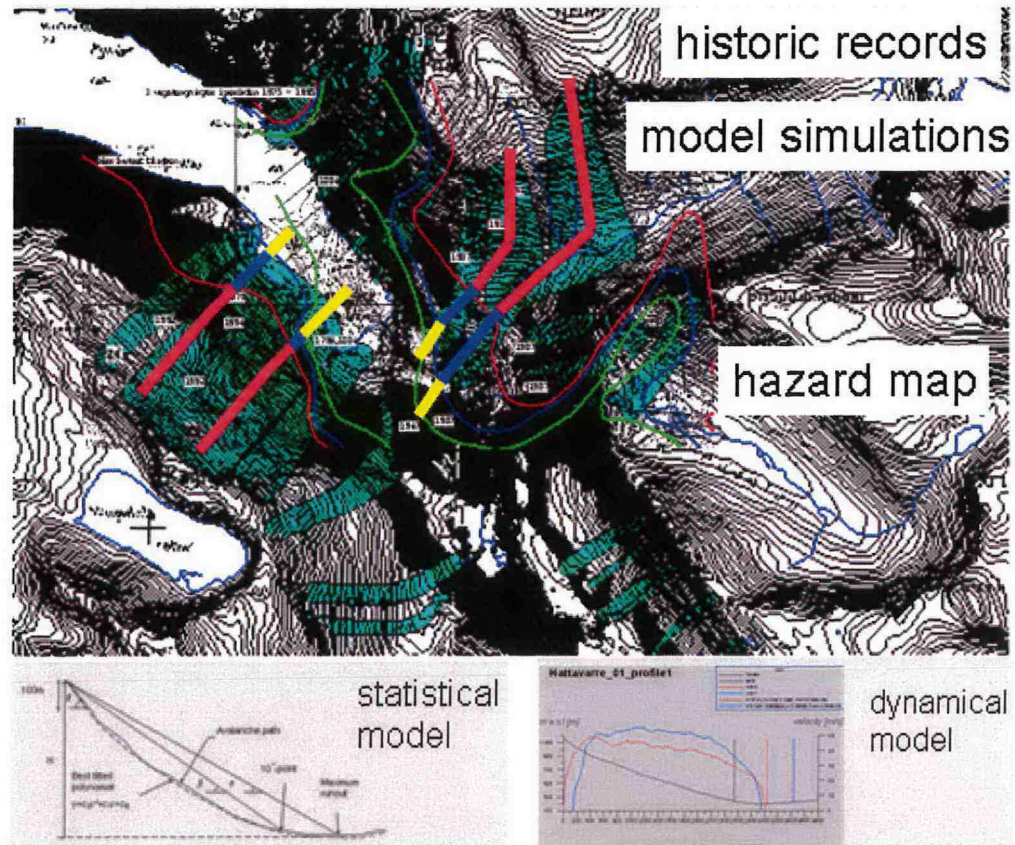


Figure 1.8 Example for the combined presentation of data bank information (shaded areas), model results (thick coloured lines) and final zonation (thin coloured lines) map, upper panel. Today, model results are presented along the profile line (lower panel).

2 GIS BASED VISUALISATION

There are now many GIS systems convenient for simple to advanced visualization, analysis, etc. regarding slides.

In this project we have tried to show examples of how to connect numerical models and GIS systems for visualization of the model results. The examples show how results from slide models can be visualized on a 3D-terrain.

2.1 A few advantages of using GIS in avalanche work

Avalanches represent spatial processes and illustrate clearly the influence of topography. GIS are designed to analyse and model spatial data; they are an efficient tool for present (and to a certain degree also to model) processes such as the spreading of an avalanche, velocity and pressure fields, and also to put the results into a geographical and cartographical (visual) context. By combining existing data and models, new information can be gained. Heterogeneous data (scaled, different thematic layers, measurements, etc.) may be overlaid and integrated to a common data set. One of the great advantages and also GIS-research topics are interpolation and extrapolation procedures for areas between measuring points. Moreover GIS produce cartographic products, which need not go through time consuming (analogue) map production processes. The result of an analysis can be shown on the computer screen or printed immediately. Such "instant maps" may have the character of hypothesis and can be recalculated again and again until they fit their purpose.

The examples below were programmed and tested on ESRI's ArcGIS as GIS software. Most spatial modelling is done with the raster module "Spatial Analyst" and TIN module "3D Analyst". Some programs were written in Python (an *interpreted, interactive, object-oriented* programming language, often compared to Tcl, Perl, Scheme or Java), using some of the geo-processing tools in ArcGIS 9.0, and some programs in Visual Basic using the ArcObjects components of ArcGIS (a truly huge collection of components).

The analysis and visualization were done semi-automatically, but this can be programmed to become a more automatic and user-friendly system in the future. The most important part of these tests was to show possible ways to integrate models with the emphasis on visualization.

2.2 Snow avalanche mapping for civil and military use

At the moment, NGI produces avalanche hazard maps on a 1:50 000 map scale for most of the avalanche-endangered areas in Norway. The maps are produced using a specialized GIS tool with an integrated simple statistical/topographical run-out calculation model (α/β -model, description in (Harbitz, 1998)). The maps in Figure 2.1 show two different visualisations produced by this method.

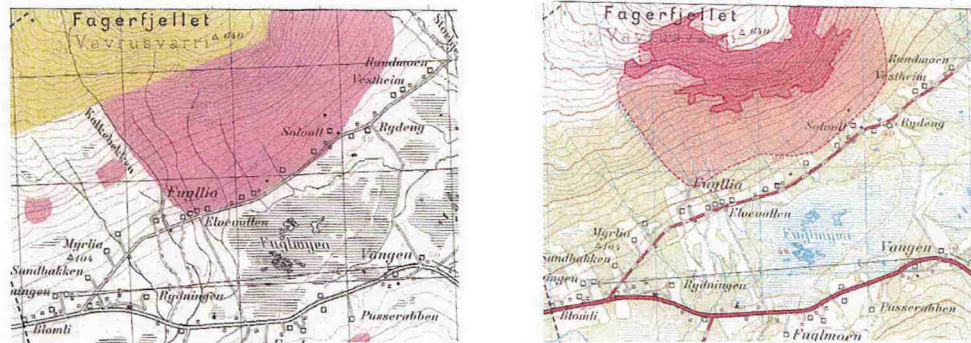


Figure 2.1 Two avalanche map examples based on GIS analysis. Nominal annual probability less than 10^{-3} (left) and less than 10^{-2} with release zone and run-out zone explicitly shown (right).

2.3 3D visualization for interpretation of topography

A typical task in hazard assessment is the evaluation of possible slide paths. In this task visualization of 3D terrain can be very useful. To ease the interpretation, a possible way to go is to use a digital topographic map that is superposed on 3D terrain. This in turn is calculated based on a DTM grid or a vectorized contour line map. In suitable software programs this 3D terrain map may be studied for avalanche hazard assessments, optimal positioning of housing areas and physical mitigations. The 3D terrain may be superposed by air or satellite photos or other thematic maps to improve the evaluations.

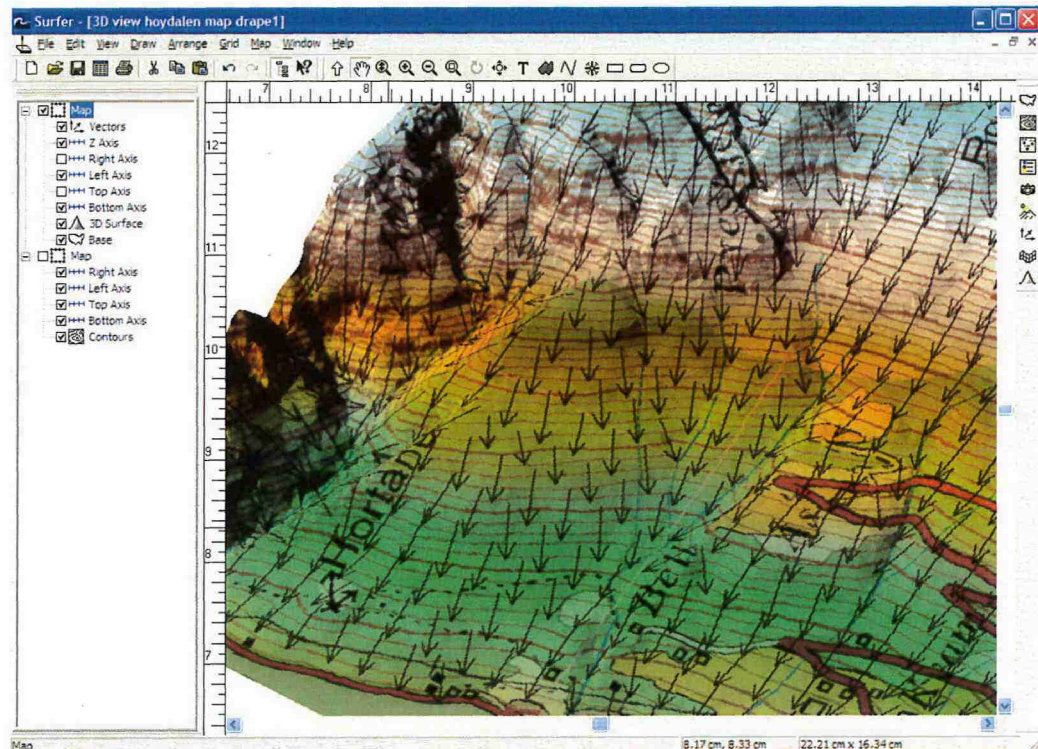


Figure 2.25 3D terrain based on a digital elevation map (DEM) superposed by a topographic bitmap and vectorized contour line maps. Calculated down slope vectors normal to the contour lines indicate fall lines.

2.4 Use of GIS in dynamical slide modelling

The next example presents a possible use of GIS in connection with a dynamical slide model. Here, the PCM (Perla, Cheng & McClung, see description in Harbitz, 1998) model is used. The figure below shows the work flow from capturing the avalanche path in the GIS system, then giving this data to the NGI SKRED application, which computes velocity (pressure) values, and then exports these values back to ArcGIS for visualization in both 2D and 3D.

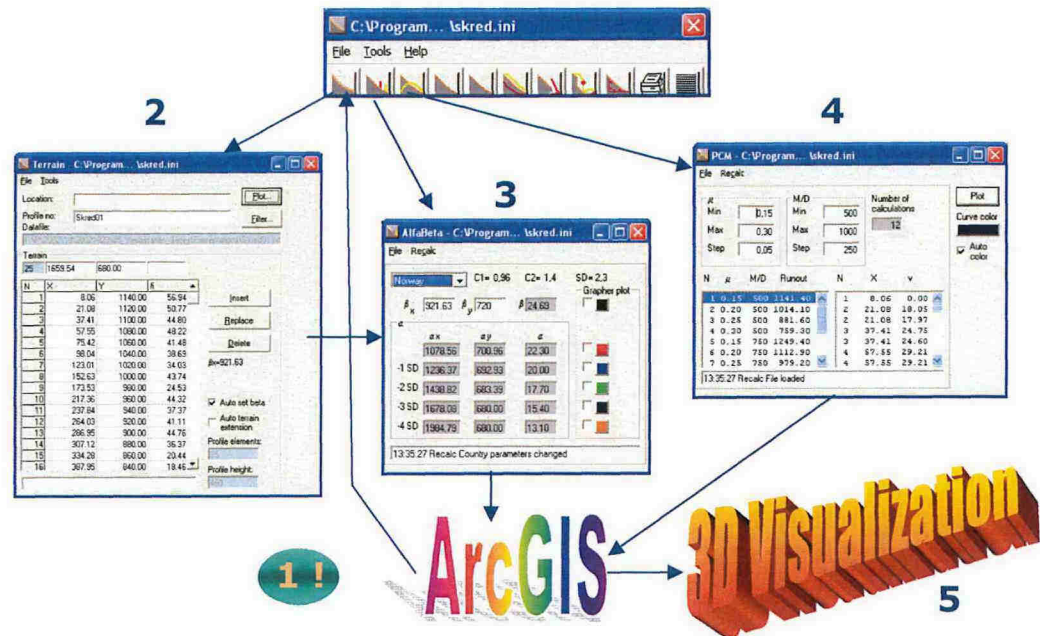


Figure 2.3 The terrain profile is extracted from a DTM using a GIS system and transferred to the dynamical avalanche model. After the model calculation the results are stored as a text file and combined with the topographic data for further use in GIS. For an example see Figure 1.8. This model may be integrated directly in a GIS-system.

FID	Shape	Id	x	y	z	Dist
0	Point	0	491725.391793	7415976.33929	1140	8.059881
1	Point	1	491737.339652	7415969.3561	1120	21.079864
2	Point	2	491751.570697	7415961.95116	1100	37.407772
3	Point	3	491769.125129	7415952.07679	1080	57.548806
4	Point	4	491784.70297	7415943.31426	1060	75.422002
5	Point	5	491804.418252	7415932.22439	1040	98.042327
6	Point	6	491826.179452	7415919.98374	1020	123.009940
7	Point	7	491851.999606	7415905.4559	1000	152.634628
8	Point	8	491870.215415	7415895.21351	980	173.534491
9	Point	9	491911.002315	7415886.23746	960	217.364952
10	Point	10	491931.360536	7415888.38043	940	237.835650
11	Point	11	491957.405971	7415891.12205	920	264.024983
12	Point	12	491980.208592	7415893.52233	900	286.953987
13	Point	13	492000.266079	7415895.63364	880	307.121899
14	Point	14	492027.279195	7415898.47713	860	334.284250
15	Point	15	492080.647351	7415904.08484	840	367.947300
16	Point	16	492140.478533	7415903.90376	820	447.896840
17	Point	17	492271.424508	7415899.67959	800	578.896332
18	Point	18	492330.913318	7415897.7604	780	638.412689
19	Point	19	492384.70165	7415896.02549	760	692.222996
20	Point	20	492508.135604	7415912.08463	740	817.466336
21	Point	21	492610.10982	7415933.32946	720	921.630029
22	Point	22	492757.485787	7415999.86515	700	1086.439402
23	Point	23	493103.094749	7416245.67351	680	1510.659903
24	Point	24	493222.19673	7416335	680	1659.537379

Figure 2.4 Example of an extracted terrain profile, based on a steepest path line on a DTM (digital terrain model) and/or the contour lines in the GIS system. This type of file is provided as input to a slide model.

The elevation values were taken from the intersection of the steepest path line with the contour lines through a specially written program module in ArcGIS. Below is an example showing this approach.

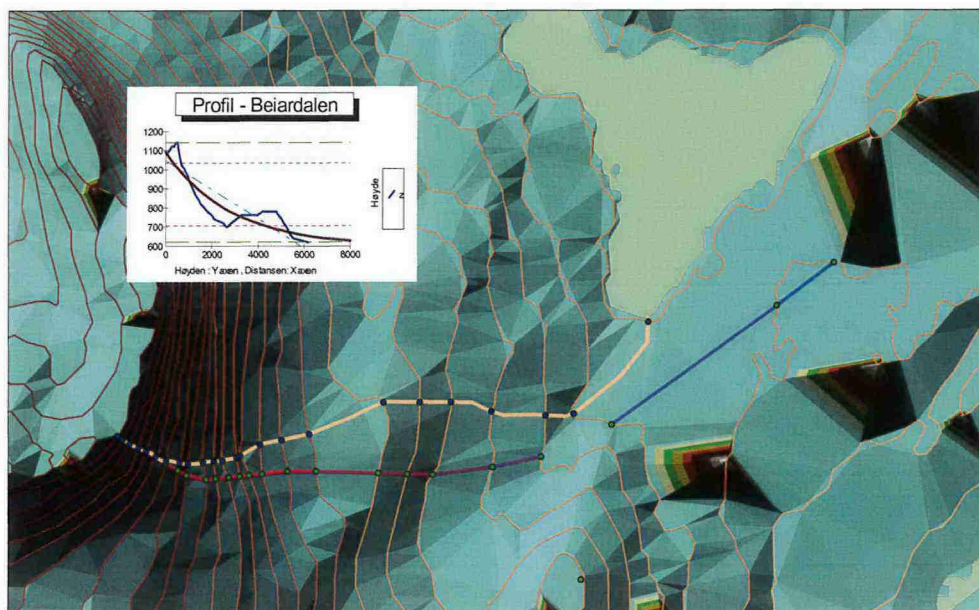


Figure 2.5 Yellow line shows the steepest path according to ArcGIS "Steepest path tool" described in appendix. The red-blue line was based on visual interpretation by an expert.

However, one could also take height values from a triangulated irregular network (TIN) or grid through interpolation.

A goal for further hazard evaluations is to automatically evaluate run-out distances for large areas. The model should calculate steep areas and initiate the "Steepest path function" for all these areas, and combine the run-out calculations on all profile lines associated with each steep area in several run-out zone polygons.

An alternative or complementary way to find the steepest path, in comparison to the method we used in this report, both semi-automatic and automatic is described by B. Romstad in a separate report (ICG, 2004).

A few interesting points in the method B. Romstad has used are:

- His method (referring to the COSTPATH/FLOWDIRECTION-method) for finding the slide paths in comparison with our "steepest path" function has advantages of being able to "run" both up and down the slope/terrain and can also show several alternative routes.
- He restricts the area of analysis to areas less than 2 km away from the "starting point" (a specified distance a slide could run), partly for making the computations effective/quick since he was going to analyse the whole Norway on a 25 m x 25 m "high resolution" grid from the Norwegian Mapping Authorities.

- He did not make calculations for height and length (H/L) for each step (segment) down the slope path as we did due to processing time. This is maybe necessary for computing the whole Norway, but not for small areas as we usually analyse at NGI for Norwegian local authorities.
- The way he defined the starting point for rock slides should be changed/adjusted for other kinds of slides.
- One might get better digital elevation models (DEMs) than the one which were used for generating TINs by interpolating to a grid using the TOPOGRID method in GIS. The “Topo” to “Raster” (TopoGrid in Map Algebra) command is an interpolation method specifically designed for the creation of hydrologically correct DEMs.

As previously mentioned, one of the great advantages and also GIS-research topics are interpolation and extrapolation procedures for areas between measuring points. Below is an example of an interpolation of points based a TIN (lower line) versus points extracted using “only” the contour lines (upper line).

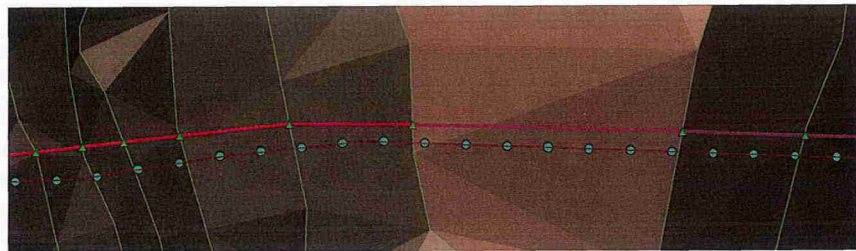


Figure 2.6 *TIN* interpolation (lower line) compared to the contour line intersections (upper line).

Various interpolation methods exist to produce grids by using different kinds of “expert systems”, for example the TOPOGRID method in ArcGIS, which attempts to make a hydrologically correct terrain model.

The figure below shows the avalanche velocity imported in ArcGIS. The velocities are calculated as average speed between each point along the line and given graded colours. Choosing a good colour ramp can often be a challenge and the next picture shows another example (yellow to red).

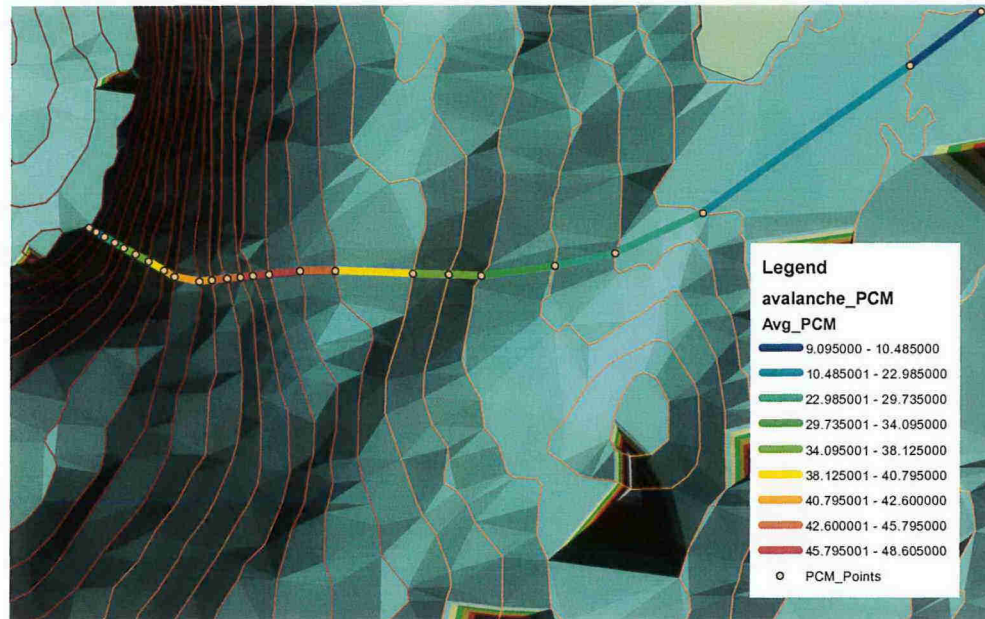


Figure 2.7 Colour ramp with several different algorithmic colours where blue is the lowest speed and red is the highest speed. Velocity ranges in m/s.

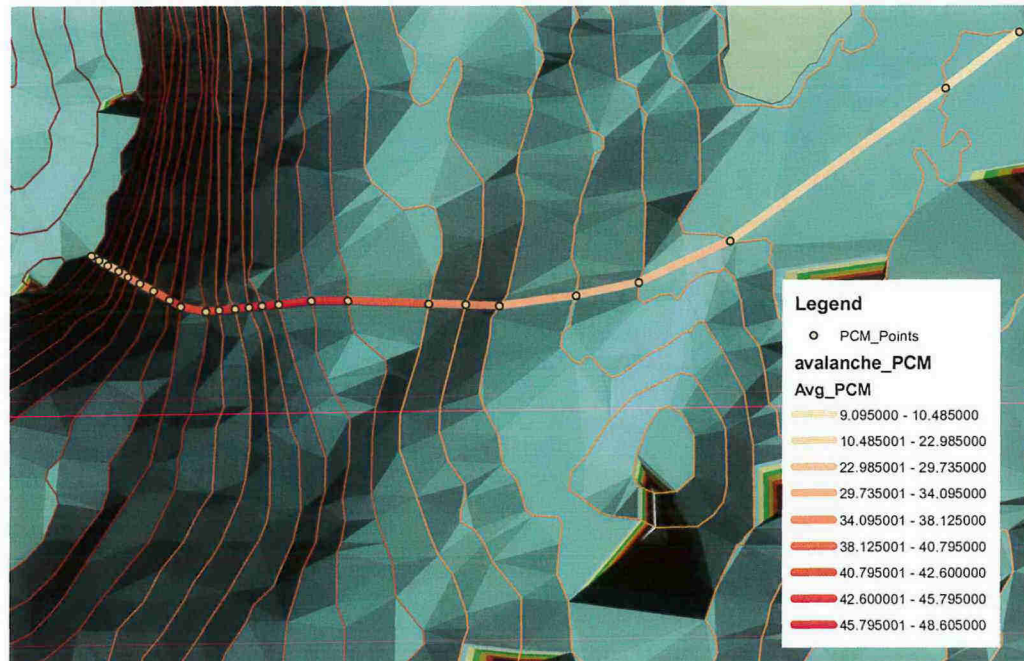


Figure 2.8 Yellow to red colour ramp where red represents the highest speed. Velocity ranges in m/s.

Based on the map in Figure 2.9 an interactive 3D model was made in ArcScene (part of ArcGIS) where you can move around in the 3D scenery and evaluate the topography along the profile path. One can take a close look at the release area from all angles and re-evaluate the starting position and the path of the avalanche track. This may also be helpful in evaluating the size of the release area, and hence, the avalanche release volume. Further down the avalanche

path it is important to understand the potential for snow entrainment. In addition to properties of the snowpack, the steepness and topography of the path is critical for snow accumulation for example. The topography in the run-out zone can give information about expected avalanche snow deposition pattern.

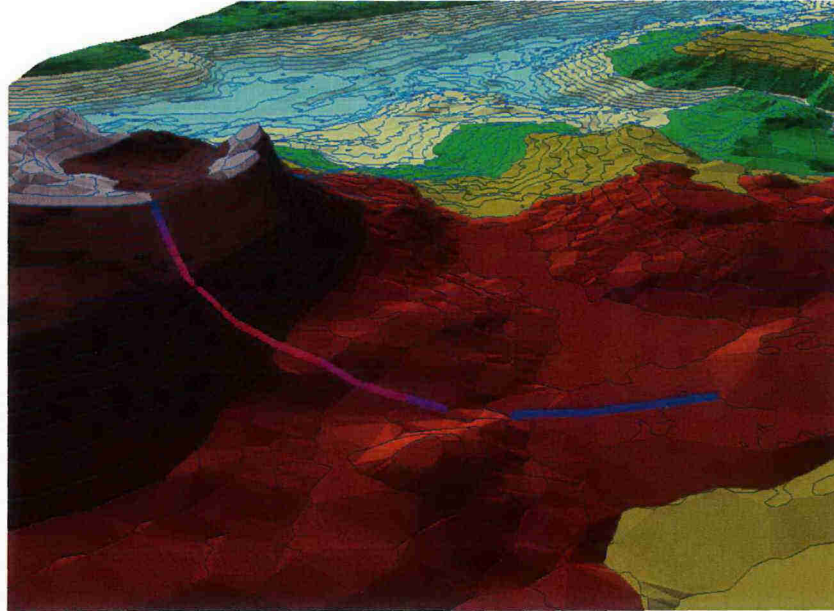


Figure 2.9 The avalanche velocity as lines in 3D terrain with visualization by means of ArcScene in ArcGIS

2.5 Further examples and possibilities for the use of GIS in connection with slide models

2.5.1 Combining DEM with ortho-photo

The 3D visualization can be improved by for example draping an ortho-photo on top of the DEM as the example below shows.



Figure 2.10 Ortho-photo draped on top of the DEM with profile lines.



2.5.2 Global and Regional Hotspot Landslide hazard zonation

This example presents the use of GIS for visualization of landslide hazard on a global and regional scale using grids in 2D (see Figure 2.11). The visualisation is based on an empirical formulation of the hazard risk level (Nadim & Lacasse, 2004; NGI, 2004):

$$H_{\text{landslide}} = (S_r \cdot S_l \cdot S_h) \cdot (T_s + T_p)$$

where S_r is the slope factor, S_l is the lithological factor, S_h is the relative soil moisture factor, T_s is the seismic trigger indicator, and T_p is the precipitation (rainfall) trigger indicator. The model is fully embedded in the GIS system and uses the strength of GIS systems. The decision tree for the model is shown in Figure 2.12. In Figure 2.13, the predicted hazard level is compared with number of fatalities due to landslides. The combination of several thematic layers with cartographic variables is one of the mean strengths using GIS systems.

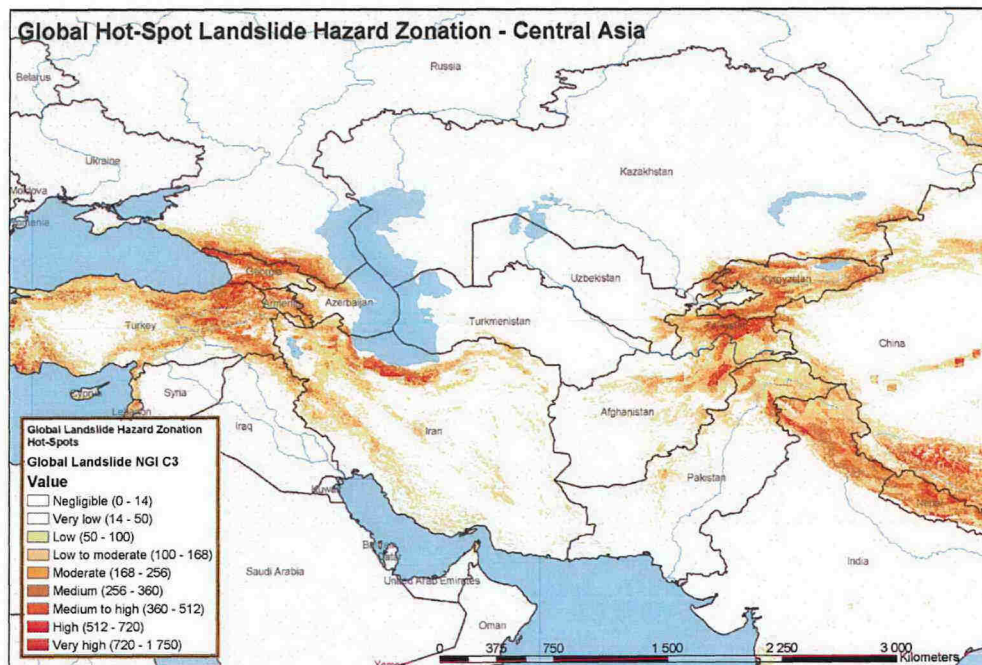
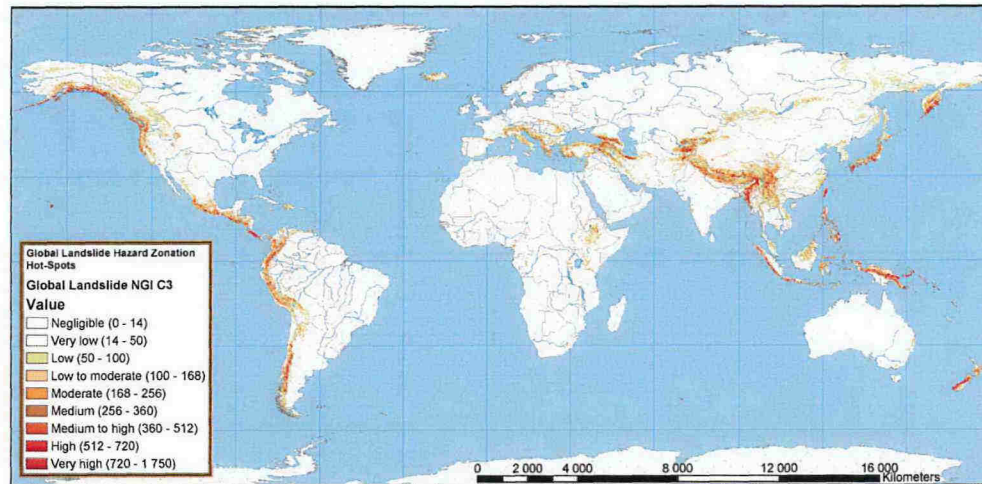


Figure 2.11 Global Hotspot Landslide hazard zonation for the whole world, upper panel; and for the region central Asia, lower panel (NGI, 2004).

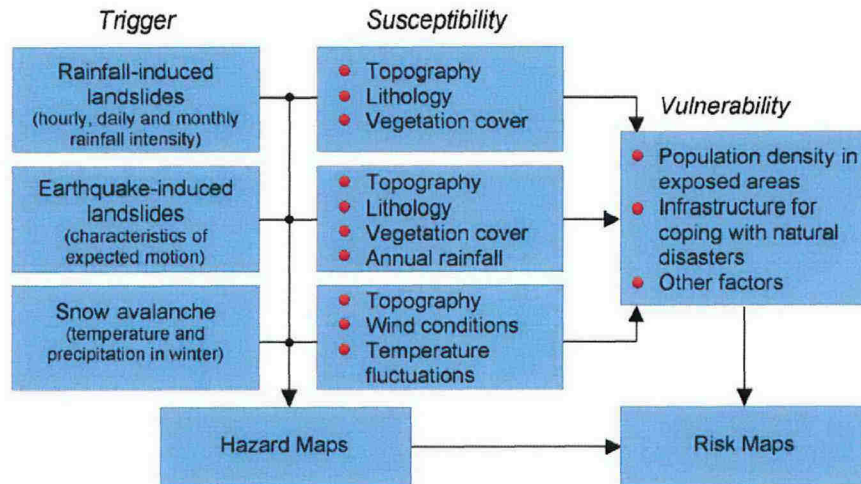


Figure 2.12 Decision tree for the global landslide model.

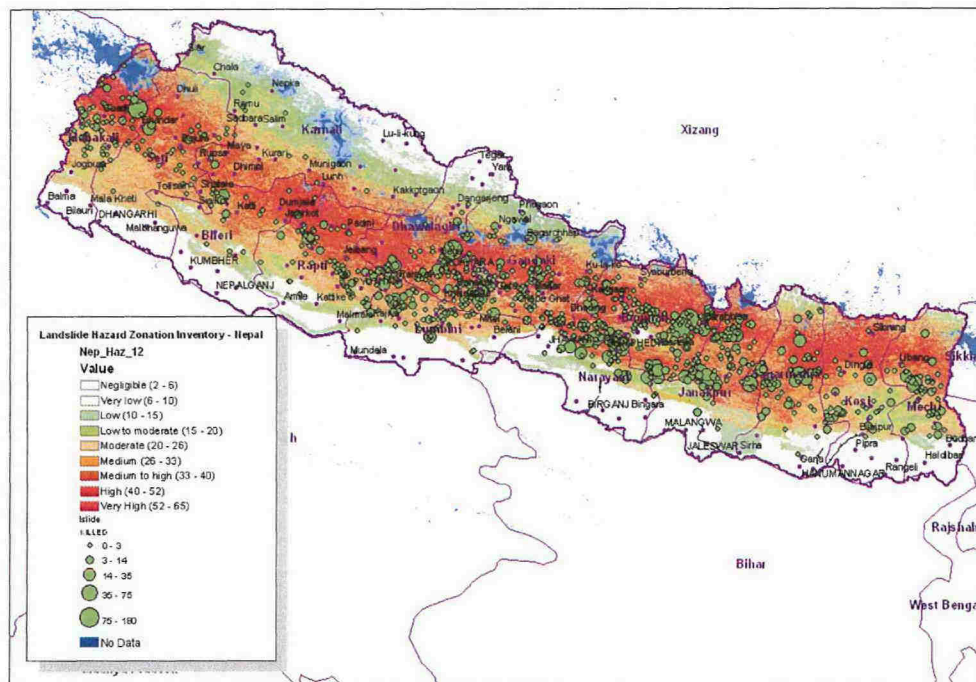


Figure 2.13 Landslide hazard map. Green circles indicate accidents reported by N. R. Khanel. (NGI 2004).

2.5.3 Regional avalanche hazard zonation

Figure 2.14 illustrates a visualization of the snow avalanche hazard in Norway. Snow avalanches are frequent in Western Norway, especially in the mountains close to the fjords. Looking at the map in Figure 2.14, there is a very good correlation between the predicted Avalanche Hazard Classes 7 (moderate to high) to 9 (very high) and the areas where frequent occurrence of snow avalanches in Norway are observed.

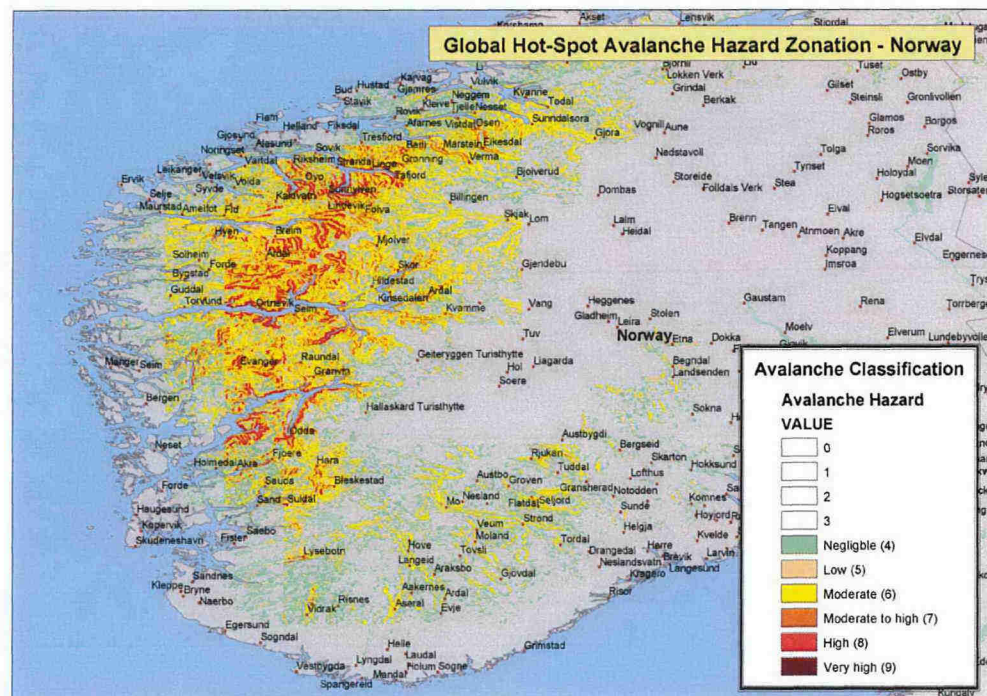


Figure 2.14 *Snow avalanche hazard zones for Norway based on NGI's hazard model.*

3 DYNAMIC AVALANCHE MODELS IN 3D TERRAIN

A “snap shot” image from a computer animation of an avalanche simulation is shown below (ELBA model, Volk & Kleemayr, 1999). The avalanche is shown on a DEM, which has ortho-photos draped on top of it. The physics involved are simple. The animation shows how an avalanche may proceed down the mountain side and the deposition in the run-out zone is reasonable.

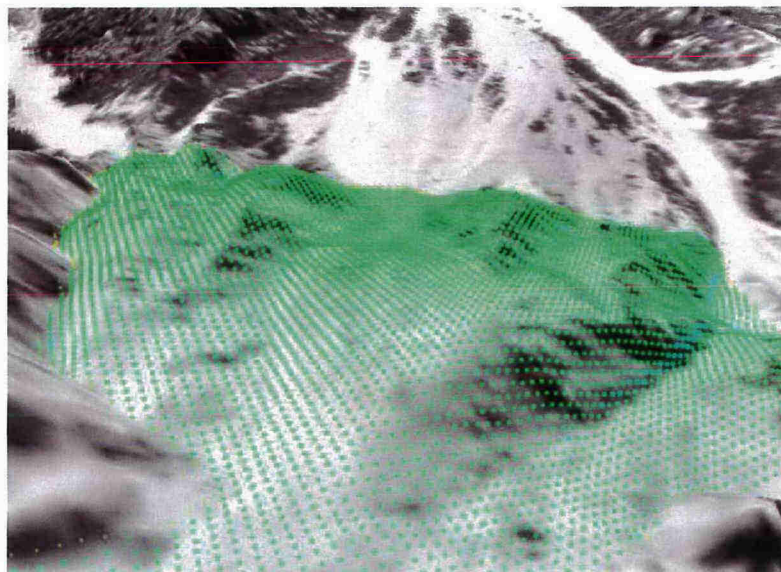


Figure 3.1 *The ELBA model simulates avalanches on digital 3D terrain (Volk & Kleemayr, 1999).*

In the winter of 1999, a large mixed avalanche started near the Tacconnaz glacier in France and mobilised up to 800 000 m³ of dry snow. The dense part interacted with the defence structures. The major part of the dense flow was retained by the protection system but a significant part of the avalanche overflowed it. The dam situated on the right side of the flow and the frontal dam was overtopped. Topography measurements were undertaken before and after the event to accurately determine the depth distribution (at points of a 5m x 5m grid) inside the protective system.

Based on the digital terrain model and a two-layer avalanche model N2L (Naaim and others, 2004), the avalanche was simulated by CEMAGREF. The model analysed three different results: global characteristics of the flows, structure of the deposits and overflow localisations.

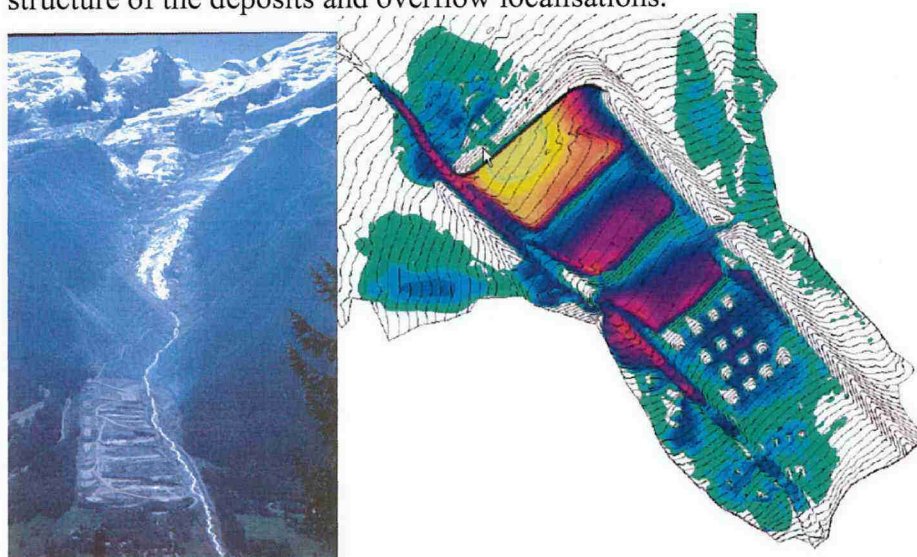


Figure 3.2 Visualisation of results from a dynamic avalanche model N2L (Naaim and others, 2004). The picture is a snap shot capture from an animation of the calculated propagation of the avalanche.

The complete SAMOS model combines a depth averaged dense flow avalanche model with a fully resolved 3-D powder snow avalanche model (Sampl and others 1999; Zwinger and other 2003). The model provides velocities and pressure fields.

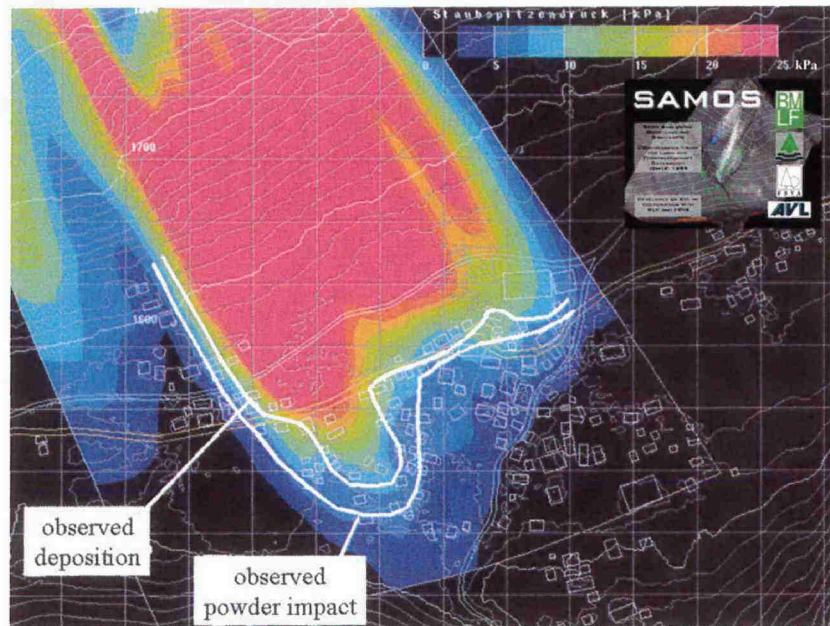


Figure 3.3 Presentation of a simulation with SAMOS model (Sampl and others 1999; Zwinger and other 2003)

The CFX4 powder snow avalanche model is similar to the powder snow avalanche part of the SAMOS model. The model is based on a simple mixture theory. It includes erosion of the snow pack and snow deposition. Velocities and pressure fields can be provided.

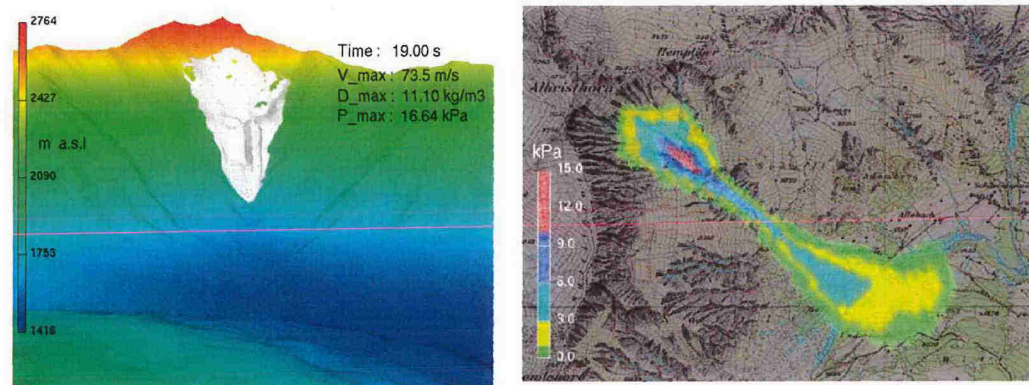


Figure 3.4 Snap shot from simulation of a powder snow avalanche in Adelboden/CH in 1995 (left side), and right final pressure map (Simulation with CFX4 by Gauer)

4 OPENDX

OpenDX originated as a software product known as IBM Visualization System's "Visualization Data Explorer" (Thompson, et al., 2001). It provides general-purpose, yet specialized, software to support data visualization and analysis. OpenDX is conceptually based on an underlying abstract data model, supported by visual programming components:

- A graphical program editor which allows a user to create a visual program (network)
- A set of OpenDX modules which allows specific data manipulations. The modules build a basis for program networks.

Figure 4.1 shows an example of a simple visualization network consisting of six connected modules. In this form complex networks can be constructed to post-process and to visualize data.

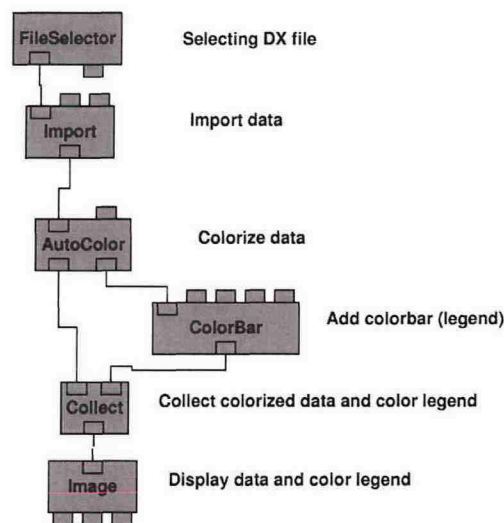


Figure 4.1 Example of a simple OpenDX program network

OpenDX.nets exist for various (CFX based) slide models at NGI providing basic functions for post-processing. If required, these net-files can be further adapted to visualize special tasks. Examples of parts of OpenDX.net-files are given in the appendix. The typical output of OpenDX is a TIFF-image. However, it is possible to generate a time series in MIFF-format, which can then be converted into an animated GIF-format (movie), for example. For this purpose, a continuous MIFF-file (a series of pictures in one MIFF file) can be produced of the OpenDX image viewer. It has proven that the resolution should be set to 800×600 to gain a good quality in subsequent steps. The conversion from MIFF-file into a GIF-file can be done with 'convert' from ImageMagick (<http://www.imagemagick.org>) (using the command: `convert MIFF:filename.mif GIF:filename.gif`).



The animated GIF-file can then be post processed using Movie GIF Gear, for example (<http://www.gamani.com>). Finally, the GIF-file can be converted into AVI-format for compression. The last step has the disadvantage that the quality of the animation decreases during compression; however the file size decreases.



5 NIS-SLIDE MODEL

The NIS slide models are based on the rheology proposed by Norem, Irgens and Schieldrop for avalanches and submarine slides (see description in Harbitz, 1998).

The present project includes supervision of one PhD student. He has been developing further the NIS rheological model and the numerical code of the NIS2 model. The code is meant to be included in the graphical user interface SKRED (project no. 20021067, see Section 1.7). The collaboration with the University of Manchester for development of the "SATSIE numerical next-generation model" (below) is also established.

5.1 The NIS1 model

The NIS1 model describes the avalanche as a deformable body model of which velocity and flow height are a function of both space and time. The snow is described as a visco-plastic material with dispersive pressure (i.e. the normal stresses depend on the shear rate), forming a shear flow with or without a basal slip velocity. Varying slope inclination produces centrifugal forces. The model is one-dimensional as the equations are depth-averaged for a velocity profile assumed to be identical in form to the steady shear flow profile. The resulting equations for balance of mass and linear momentum are solved by an Eulerian finite difference mid-point scheme in space and a fourth-order Runge-Kutta procedure in time.

5.2 The NIS2 model

The NIS2 model is an extension of the NIS1 model. The same one-dimensional equations as for the NIS1 model are applied, but motion in a three-dimensional terrain is considered. The avalanche is assumed to flow in a depression approximated by a set of volume elements with varying widths, compensating for converging and diverging effects in a real avalanche flow. Furthermore, horizontal centrifugal effects due to the curvature of the horizontal projection of the path are taken into account. A circular segment approximates the cross section (perpendicular to the bed) of the flowing material. Owing to centrifugal forces the free surface in the cross section will be inclined with respect to the horizontal plane. The main feature of the model is the fact that the centre line of the avalanche is a space curve, which is determined by the terrain and also by the dynamics of the flowing material itself.

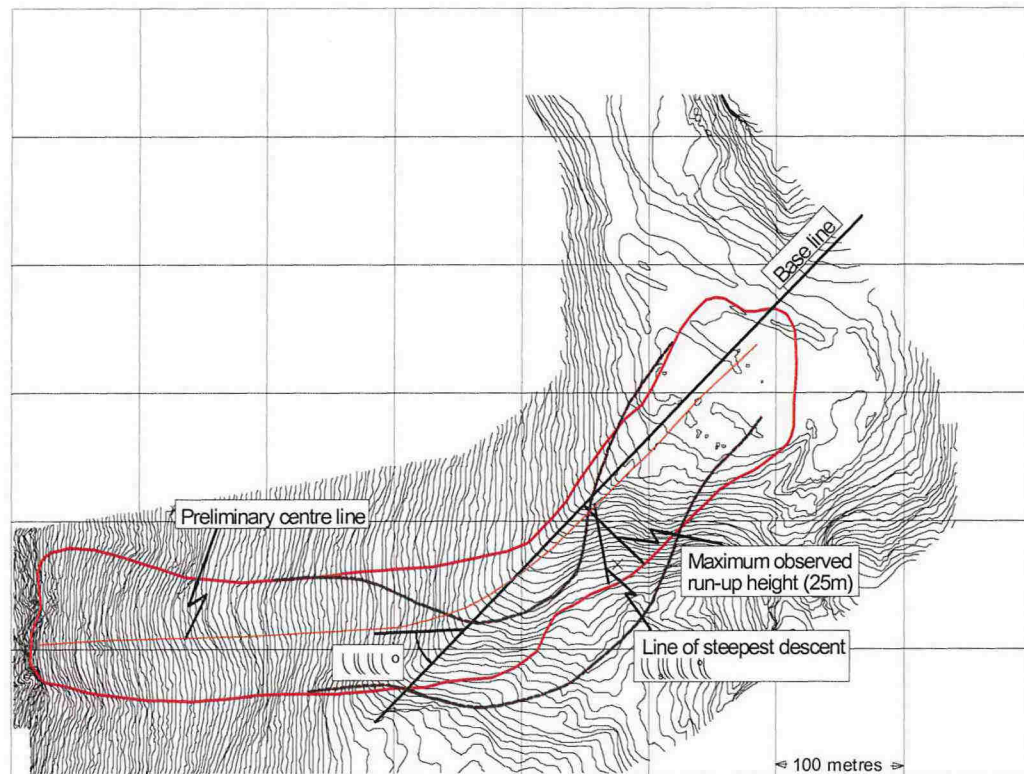


Figure 5.1 Distribution of the 1986 Vassdalen avalanche back-calculated by the NIS2-model (purple line) and compared to observations (red line). Contour line interval: 2 m.

5.3 Next generation NIS simulation tool

Presently, a new simulation tool based on the NIS physics is being developed within the EU project SATSIE. The equations of motion are depth-averaged and two-dimensional, and they are evaluated on a fully three-dimensional terrain. The flow height varies in time and space.

Shock fronts that occur around obstacles and irregularities in the avalanche path are taken into account, giving very high pressure, flow height and velocity gradients.

The numerics are tentatively adapted to include entrainment and deposition of avalanching material, but the physical mechanisms that control the mass balance are not understood well enough to be implemented in this model at present.

5.4 Use visualisation for design of avalanche deflecting dams

Design and analysis of deflecting dams are significantly eased by mapping and visualisation tools. Back-calculations of deflected avalanches by computational/empirical centre-of-mass model for avalanche flow along a

plane deflecting dam wall show that curved deflecting dams cause much lower run-up heights than comparable straight deflecting dams (see Figure 5.2). The possibility and importance of placing the deflecting dams in steep terrain to avoid accumulation is emphasised.

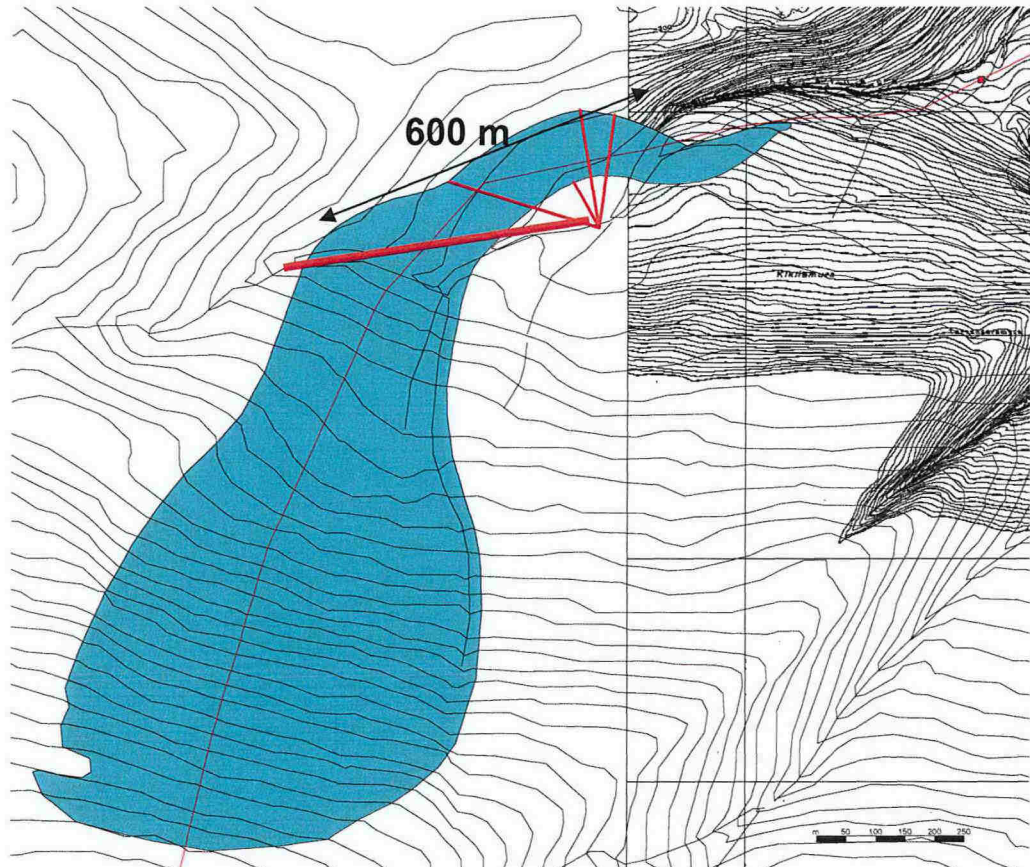


Figure 5.2 Observed distribution and deflection of the Lienden avalanche, Beirn (between 1987 and 1990). Maximum run-up height is 47 m. Calculations for an artificial straight deflecting dam with its foot along the red line reveal 4-5 times higher run-up.



6 OUTLOOK

Visualization is a powerful tool that helps to gain in-depth understanding and to present sophisticated answers to our problems. Efficient tools for visualization help to simplify the analysis, to improve the interpretation and help to keep the time schedule.

Visualization has connections to projects like

- SKRED-database,
- Best-practise.

Visualization should be followed up in those projects as they progress.

The presentation of final results to clients is most important. The visualization should help to show findings easily. A high degree of standardization can help to make the interpretation simpler, e.g., using standardized colour codes for representing hazard zones. However, no standardized representation for hazard maps exists, e.g., colour coding?

Hence, standardization for presenting different hazards in similar ways should be further discussed. Also what kinds of visualization to be used in the future has to be discussed.

Visualization is one task that heavily depends on the input. At present, NGI has the following models available, which can provide input to visualization tools:

- Submarine slides: CFX based model, statistical model, Bing model
- Turbidity current: CFX based model
- Avalanches: NIS, PCM, α/β -model
- Rock fall: Rockfall model

The CFX-based models are the only fully 3-dimesional models available at NGI. However, they are computationally demanding and thus restricted in their applicability. The other models are only at most 1-dimsional. Hence, NGI is lacking a model, which is multidimensional, e.g. 2-dimesional depth averaged, and is applicable for various slides in large terrain settings.

A goal for further hazard evaluations is also to automatically evaluate run-out distances for large domains. The model should calculate steep areas from topographic data and extract profile lines, then do run-out calculations for the extracted profile lines, and finally present computational results on a topographic map.



7 REFERENCES

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Baard_Romstad_Methods.doc

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APPENDIX A

GIS

Description of the Steepest Path used in ArcGIS and extension of this tool by NGI

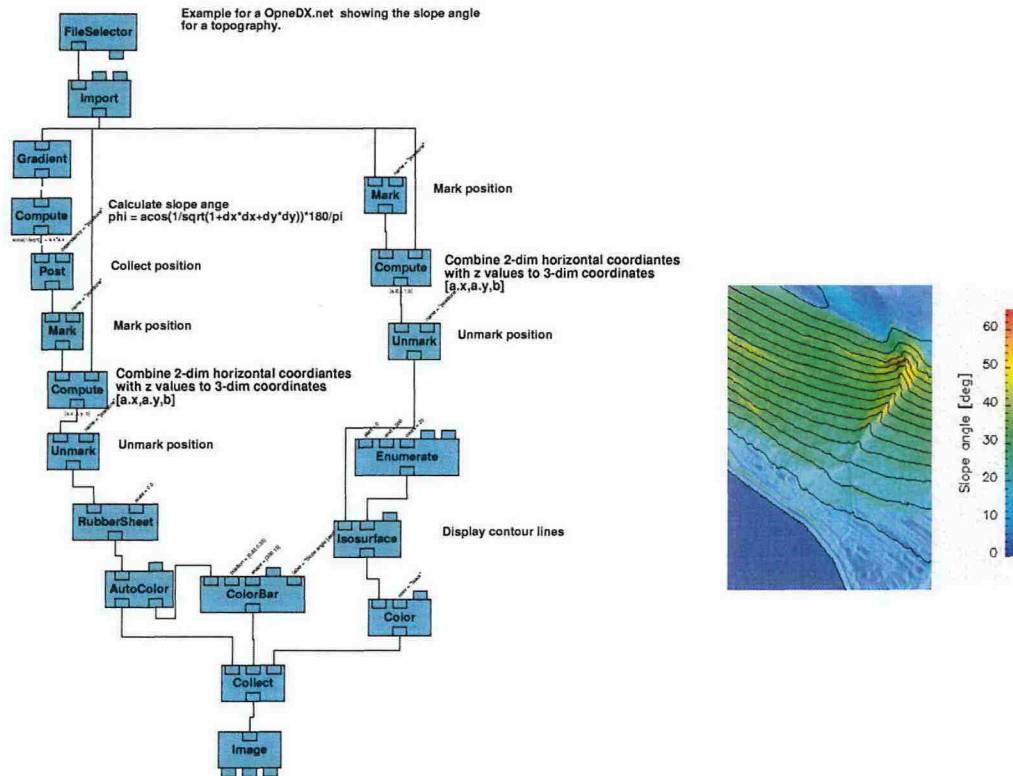
- One can evaluate runoff patterns on a TIN- or grid surface model by using the 'Create Steepest Path' tool in ArcGIS 3D-Analyst module. The 'Create Steepest Path' tool calculates the direction a ball would take (neglecting centrifugal effects) if released at a given point on the surface. The ball will take the steepest path downhill until it reaches the perimeter/boundary of the surface model or it reaches a pit—a point that all surrounding areas flow into. The result is a 3D graphic line added to the map or scene (which can be converted to 3D polyline and/or 3D points.).
- One can also use the 'Create Steepest Path' tool to evaluate the integrity of a TIN surface model, for example, to find paths that end unaccountably or meander off in a direction different from assumed runoff on the actual site. If one is going to use the model for runoff studies, one needs to correct such anomalies. At NGI the steepest path tool was extended such that the path continues in the direction of motion if it hits a pit or hits a small reverse slope.
- One question is if one should always use a TIN produced from ArcGIS for runoff evaluations and if the TIN produced in ArcGIS is good enough for such purposes. Alternatives are TIN creation in other systems (for example Surfer) and advanced grid methods like TOPOGRID. "Topo To Raster" is the ArcGIS 9.x implementation of TopoGrid from ArcInfo Workstation 7.x briefly described below.

How Topo To Raster works

Topo To Raster is an interpolation method specifically designed for the creation of hydrologically correct digital elevation models (DEMs). "Topo to Raster" is the only ArcGIS interpolator specifically designed to work intelligently with contour inputs. It is based upon the ANUDEM program developed by Michael Hutchinson (1988, 1989). See Hutchinson and Dowling (1991) for an example of a substantial application of ANUDEM and for additional associated references. A brief summary of ANUDEM and some applications are given in Hutchinson (1993). The version of ANUDEM used is 4.6.3.

APPENDIX B

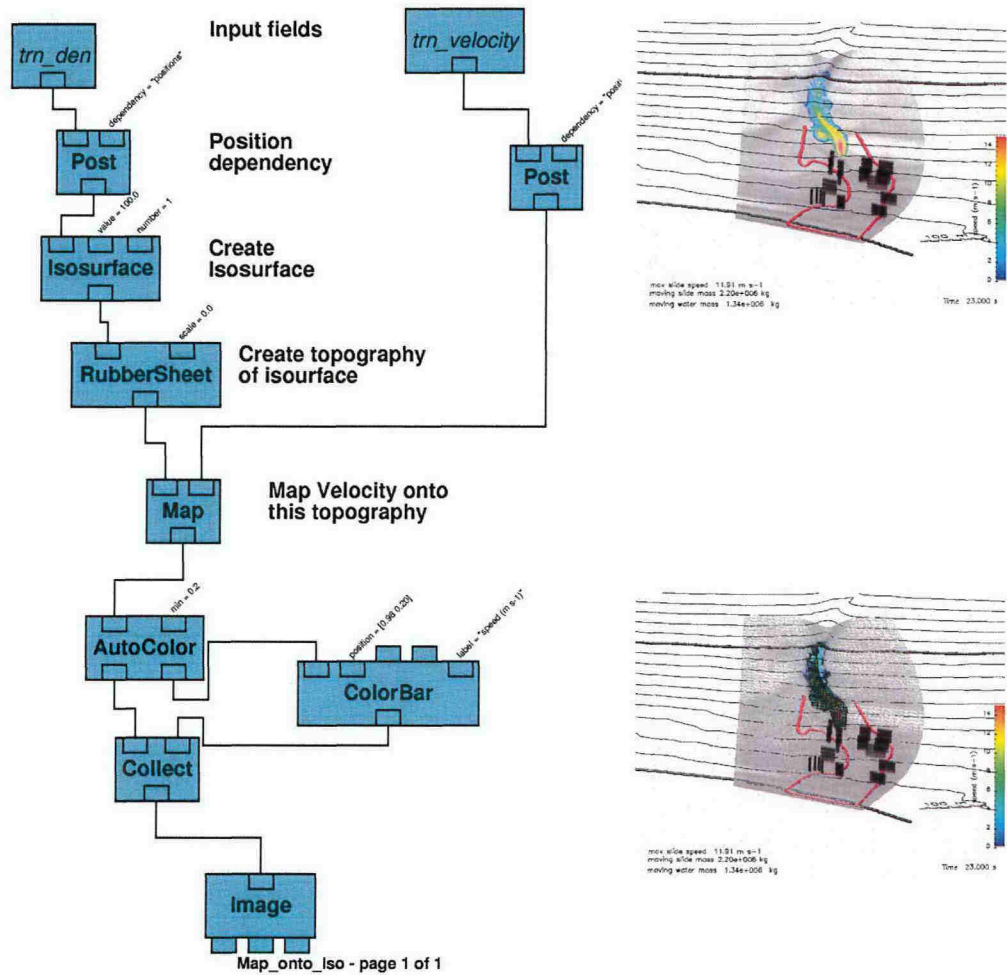
OpenDX



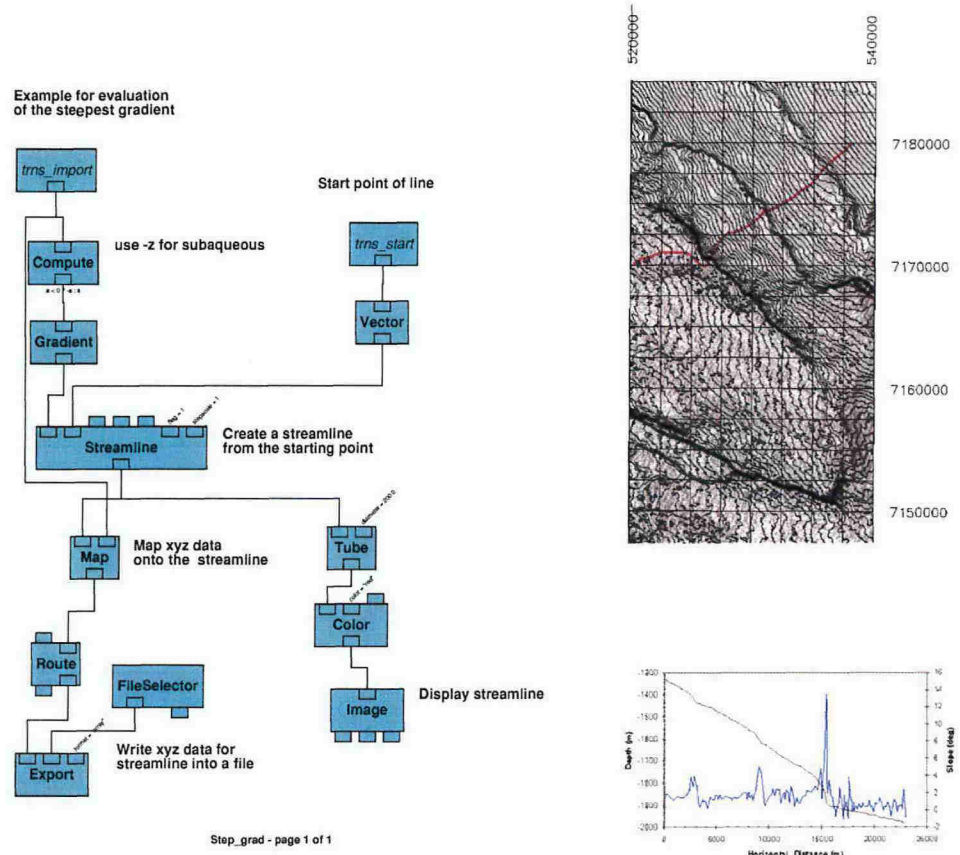
Slope_angle - page 1 of 1

OpenDX.net for slope angle evaluation, left panel; and an example, right panel.

Example for mapping a field onto an isosurface



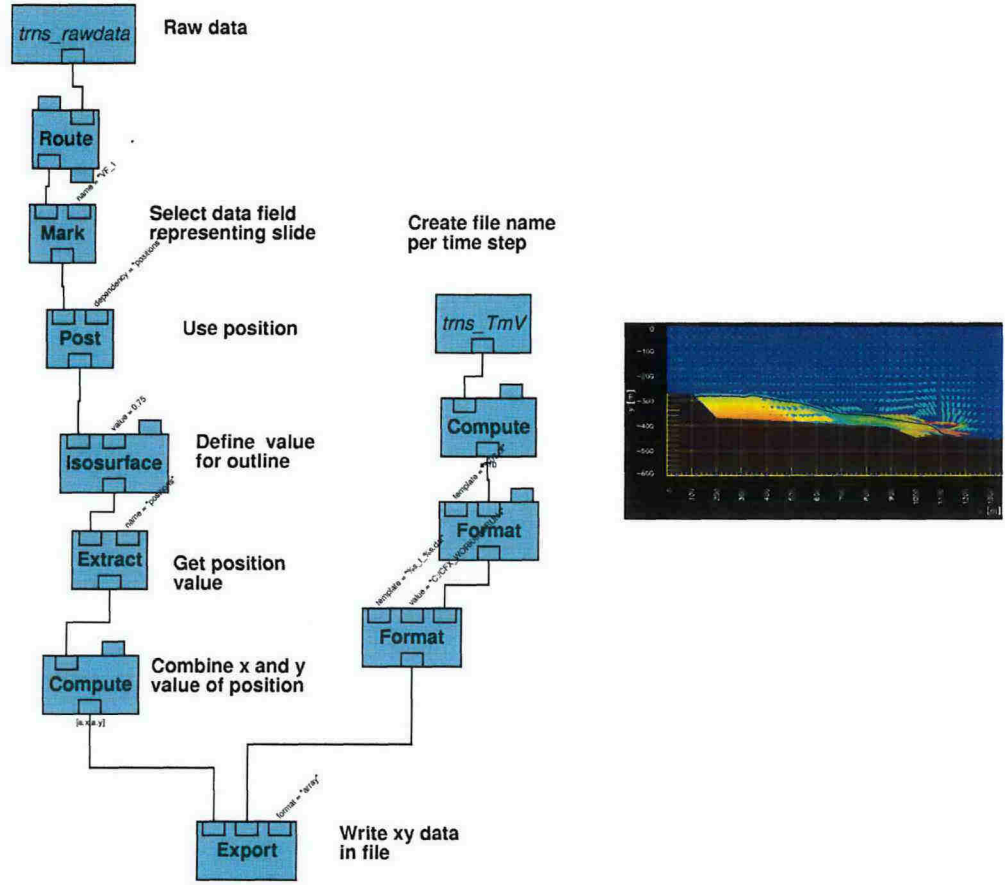
Part of an OpenDX.net for mapping the velocity field onto an iso-surface of the density, left panel; and two examples, right panels. One of those shows in addition the connections (black raster) of the iso-surface.



Part of an OpenDX.net used to construct a profile line based on steepest gradient approach, left panel; example of a profile line extracted this way, right panels.



Example for extraction of slide geometry



Ext_slid_otl - page 1 of 1

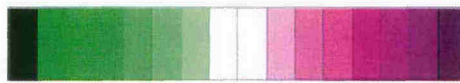
Part of an OpenDX.net used to extract slide geometry as input for tsunami simulations, left panel; example of geometry, right panel.

APPENDIX C

Colours for Colour-deficient persons

Approximately 8 percent of the population is colour-deficient. This should maybe be considered when developing colour schemes. Below is an example of this challenge:

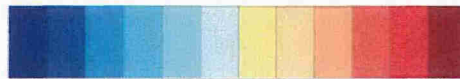
Green-to-Magenta, 16 Steps



Useful for generic diverging data.

Colours can be differentiated by colour-deficient viewers.

Blue-to-Dark Red, 12 Steps



Useful for temperature-like data, with a subjective interpretation (blue=cold, red=hot)

More about this can be found for example here:

http://geography.uoregon.edu/datagraphics/color_scales.htm

http://www.internettg.org/newsletter/mar99/accessibility_color_challenged.html

Kontroll- og referanseside/ Review and reference page



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Kontraksreferanse/ Contract reference 140353/420	Dato/Date 31 March 2005
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Emneord/Keywords slide, visualization, GIS	
Land, fylke/Country, County Kommune/Municipality Sted/Location Kartblad/Map UTM-koordinater/UTM-coordinates	Havområde/Offshore area Feltnavn/Field name Sted/Location Felt, blokknr./Field, Block No.

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