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REPORT

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Title:
Method for the susceptibility mapping of snow avalanches in Norway, Technical report

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Summary:
This technical report describes the method used to draw the susceptibility maps for snow avalanches in Norway. In order to cover the entire territory of Norway, a fully-automatic GIS-based solution was developed and applied. The gridded digital elevation model of Norway at 25 meter cell size is the only input dataset. The potential release areas are detected applying a slope angle threshold. The potential propagation zones are delimited coupling a 2D extension of the alpha-beta method with a cone propagation model. In the final product, (1) potential release areas and (2) potential propagation zones are mapped. Finally limitations and issues related to the use of these maps are discussed in the last chapter.

Keywords:	Susceptibility mapping	National coverage
Snow avalanches	Release areas	Propagation zones
Alpha-beta method	GIS	Cone propagation

IGAR | University of Lausanne

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1 Introduction

1.1 Context and goals

In 2007, in the frame of the project "National Susceptibility Mapping of Geohazards" at NGU, it was decided to draw maps of susceptibility for snow avalanches for the whole Norwegian territory. These maps aim to provide a first overview (screening) of the entire country, in a relatively short time, at reduced costs, and with an automatic procedure applied homogeneously to the whole country. The main requirements for these maps are:

- To cover the entire Norwegian territory (385'000 km^2)
- To assess in a simple way the susceptibility of an area of being affected by a snow avalanche, without any distinction of the type of avalanche
- To provide maps at an indicative scale of around 1:50'000 within a short time frame (around 2 years)
- To use only data already available for the entire area

A large part of this work was achieved within the cooperation between the Geological Survey of Norway (NGU) and the Institute of Geomatics and Risk Analysis (IGAR) of the University of Lausanne, including the development of new methods and softwares.

This report describes the method used to draw these susceptibility maps. It explains the reasons of some scientific or technical choices, presents the main advantages and drawbacks of the method used, and pays a particular attention to make clear that the final maps delivered with this work have limitations that must be respected.

1.2 Some definitions

The definitions used in this report are conform to those of Fell et al (2008):

Danger: The natural phenomenon that could lead to damage, described in terms of its geometry, mechanical and other characteristics. The characterisation of a danger does not include any forecasting.

Hazard: A condition with the potential for causing an undesirable consequence. The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material, and the probability of their occurrence within a given period of time.

Susceptibility: A quantitative or qualitative assessment of the classification, volume (or area) and spatial distribution of a danger which exists or potentially may occur in an area. <u>The susceptibility does not provide any information about the probability that an event occurs (hazard), nor about the consequences of an event (risk).</u>

Risk: A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability × consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.

2 Description of the method

2.1 Principles

The method used to draw these susceptibility maps is an extension to 2D (maps) of the alpha-beta method designed initially to work along profiles (Lied & Bakkehøi 1980 , Bakkehøi et al 1983). The main principle of the alpha-beta method are shortly reminded here (Figure 1):

1) A release point, A in Figure 1, is selected
2) The avalanche path starting from A is manually selected and its topographical profile is drawn
3) This profile is then smoothed according to a polynomial fitting (2nd or 4th degree)
4) The point B is then located on the smoothed profile where the slope angle =10°
5) The angle beta is measured as the angle between the line AB and the horizontal
6) The angle alpha is then estimated using a statistical relationship between alpha and beta. The simplest relationships are of the type: alpha = m*beta -n, where m and n are empirical coefficients
7) Finally the potential propagation of the avalanche is estimated using the angle alpha as a shadow angle from A.

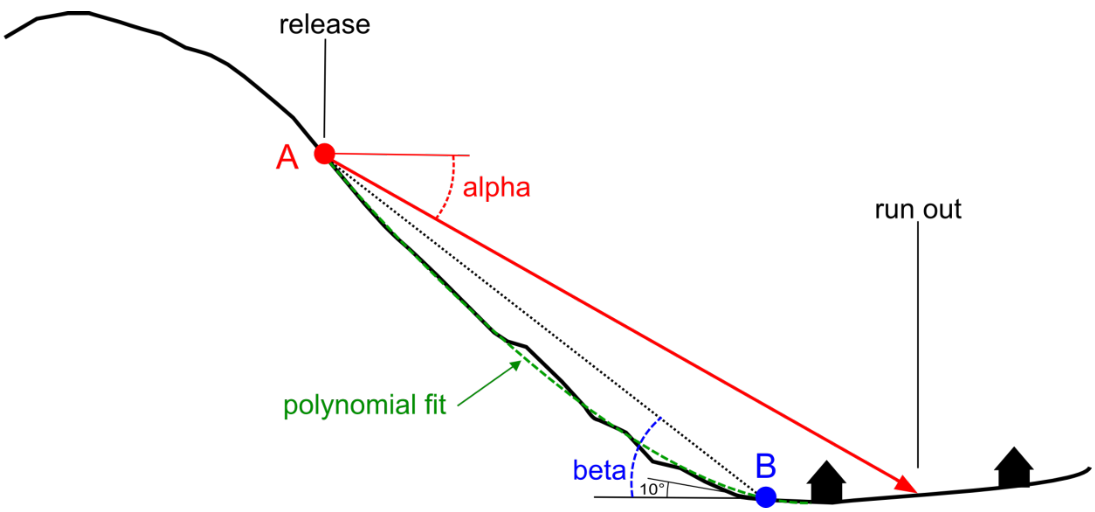

Figure 1 : Basics of the alpha-beta method (Lied & Bakkehøi 1980, Bakkehøi et al 1983)

The classical alpha-beta method requires to define manually the possible avalanche corridors. But for the purpose of this project, to cover the entire Norway, the processing had to be fully automatized, without requiring any human interaction or interpreting.

Practically the amount of data to be processed makes it very difficult to use common GIS softwares like ArcGIS. For example, the raw digital elevation model (DEM) of Norway at 25 meters resolution is 3.5 Gigabytes, and it is distributed over three geographical UTM zones. Moreover, several required functionalities are not available in common GIS packages. Therefore an independent code was developed at NGU and IGAR specifically for this project.

In outline, the processing used for this project has two main steps: (1) the determination of release areas, i.e. the areas from which an avalanche can initiate, and (2) the estimation of the propagation zone for this avalanche.

2.2 Datasets

Input data: The only dataset used is the digital elevation model (DEM) provided by Statens Kartverk to the partners of the Norge Digitalt program. This DEM is an elevation grid of 25 m cell size, projected and georeferenced in UTM/WGS84 - zones 32, 33 and 35 N.

No other dataset or avalanche inventory were used.

Output data: All the processing is done in raster mode and the results of the computations are raster files (geotiff format) in the same projection and coordinate systems than the input data (UTM 32, 33, 35 N / WGS84). At the end of the processing, all the cells of the initial DEM were classified according to three categories: 1) cell included in a release area, 2) cell included in a propagation zone, 3) cell not included in a release or propagation area. In order to make the results easier to handle in GIS environment, the release areas and propagation zones were finally vectorized in polygons (without any smoothing).

2.3 Determination of release areas

2.3.1 Slope thresholding

The method to define if a cell in included in a release area is a simple thresholding of its slope angle value. A cell of the DEM is in a release area if:

$$30° <= \text{slope angle} <= 55°$$

The lower and upper limit values were selected according to McClung & Schaerer (1993) and Lied & Kristensen (2003) showing that almost all the avalanches are released from areas with slope from 30° to 55°.

The slope angle is estimated with a 3x3 moving filter, with the algorithm of Horn (1981), exactly in the same way than for example in ArcGis.

The potential release areas for snow avalanches were extracted for the entire country. Examples of release areas are presented in Figure 2.

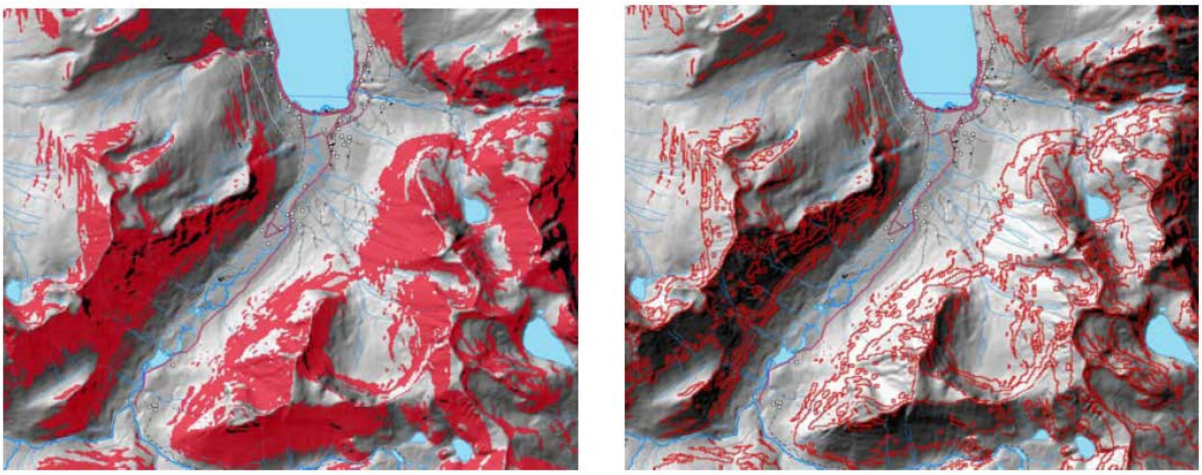

Figure 2: Left: release areas (red) based on the slope angle thresholding (30°-55°) , Right: edges of the release areas.

Comment: A similar criterion was used for the *forsvarets snøskredkart* from NGI, except that in our case it was decided to keep the forested areas included in the release areas.

2.3.2 Reduction to edges

Later we will have to estimate the propagation from each of the 25x25 meters cell included in the release areas. But the surface to cover is huge and then it is judicious to consider a reduction of the number of release cells. Some tests have shows that it is equivalent to take only the outer edges of the release areas (Figure 2 right) in order to get the maximum extent of the propagation. This reduction of the number of release cells is done by removing all the cells whose eight direct neighbouring cells are “release cells”. Technically, this is done very efficiently with a 3x3 convolution filtering.

2.4 Propagation zones estimation

As mentioned earlier, the estimation of avalanche propagation is based on a adaptation of the alpha-beta method (Figure 1). For the present project, two aspects have to be improved compared to the initial alpha-beta method: (1) the new method must produce propagation maps and not only profiles, (2) the processing has to avoid any manual selection and be entirely automatic to be able to cover very large regions.

The steps of the processing used to estimate the propagation zones are illustrated in the flow chart of Figure 3:

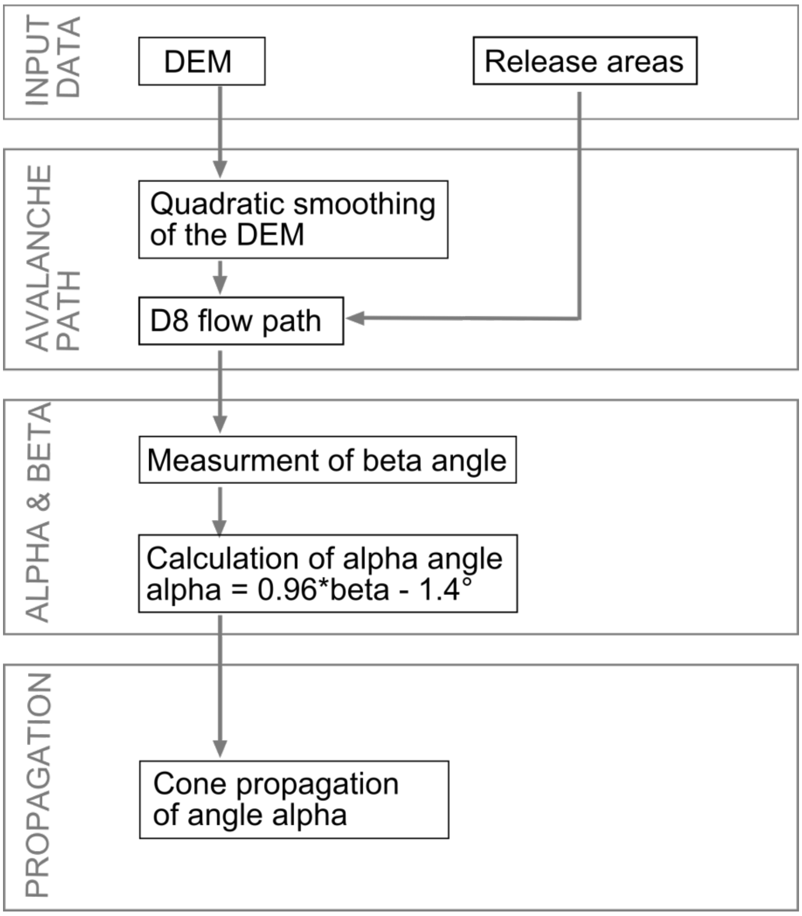

Figure 3 : Flow chart of the snow avalanche propagation calculation

2.4.1 Input data

The input data for the propagation estimation are: (1) the 25 m grid cells DEM and (2) the edges of the release areas defined previously. Both datasets are rasters (geotiff format) projected and georeferenced in UTM/WGS84.

2.4.2 Avalanche path determination

In the classical alpha-beta method, the topographical profile is first smoothed, from the release area to the bottom of the valley, using a polynomial fitting. This has for effect to consider only major morphological features (valley side) and to remove small local pits and flats. In order to keep in 2D the idea of the smoothing by a polynomial function, a local quadratic fitting of the digital elevation model is achieved (quadratic function: z=ax2+by2+cxy+dx+ey+f; Wood 1996). This function is the surface equivalent of the parabolic function (2^{nd} degree polynomial) used on profiles.

Practically a kernel of 35 cells (= 875x875 m) is used for the quadratic fitting. That means that for each cell (xi,yi) of the DEM, the best fitting quadratic surface on the 35x35 cells area with (xi,yi) as center is calculated. Then the value of the elevation at (xi,yi) is replaced by its quadratic estimation. The smoothing effect of the quadratic fitting on the DEM is displayed in Figure 4.

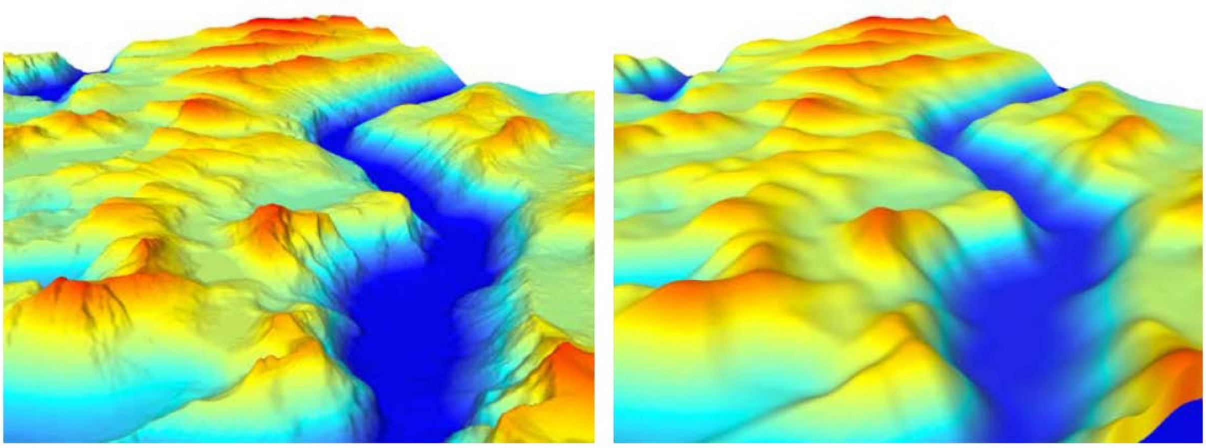

Figure 4 : view of the original DEM (left) and its quadratic fitting with a kernel of 35x35 cells (right)

Then a flow path is computed from each release cell on the smoothed DEM with the algorithm D8(Jenson & Domingue 1988): the flow passes from one cell to the lowest of its 8 neighbouring cells. The flow path is stopped when the path reaches a cell where the slope of the smoothed DEM is less than 10° (point B in Figure 1 and Figure 5). Finally, one cell B is associated to each release cell A.

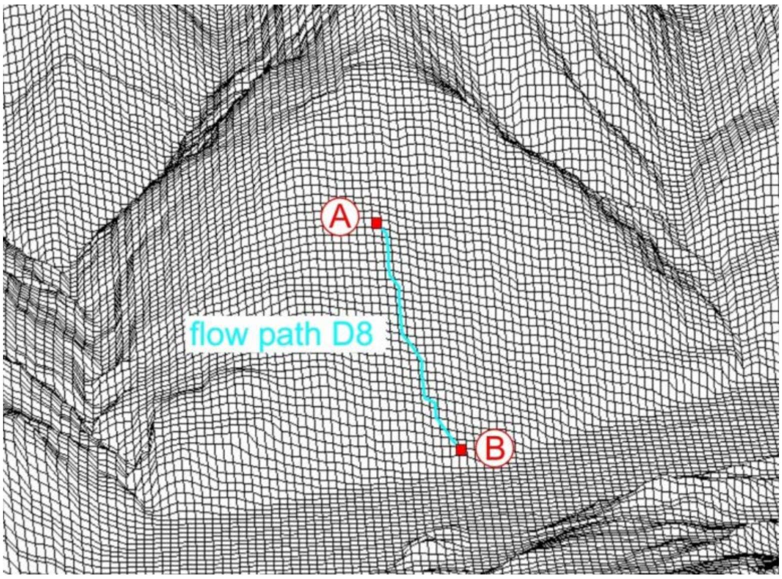

Figure 5 : Flow path determination from the release area (A) to the point B where the slope angle on the smoothed DEM is less than 10°.

2.4.3 Estimation of alpha and beta angles

For each couple of points AB, the angle beta is measured like on the Figure 1: beta is the angle between the line AB and the horizontal. Then alpha angle is calculated with the relationship:

$$\alpha = 0.96*\beta - 1.4^{\circ}$$

This relationship is from Bakkehøi et al (1983) who used an inventory of about 200 snow avalanches in Norway (standard deviation = 2.3°, correlation coefficient = 0.92).

A value of alpha is then attributed to each release cell A. In U−shape valleys the path AB are quite simple, flowing straight down the valley flanks. But in other contexts they can be tortuous and get through a long distance before to reach a locations with a slope < 10º. In these cases, beta angles can be very low. That is why the value of alpha is limited to a minimum of 18º.

$$\alpha = 0.96*\beta - 1.4º \quad \geq 18°$$

2.4.4 Cone of propagation

The cone propagation technique was developed first for rockfalls (Jaboyedoff & Labiouse 2003). Once a value of alpha angle is attributed to a release cell, a vertical cone can be drawn (Figure 6A), with its apex located in the release cell. The zone of potential propagation for a release cell is delimited by the intersection of the cone with the DEM (Figure 6B).

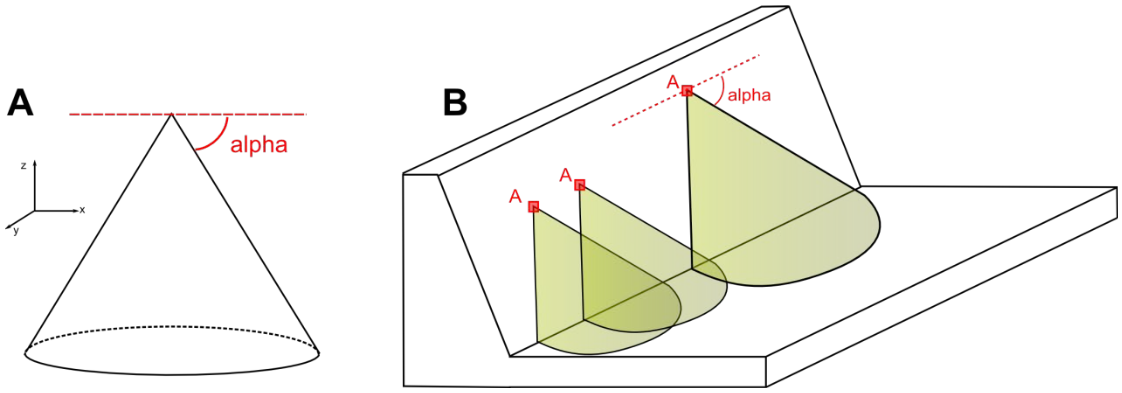

Figure 6 : A : cone of propagation with an angle of propagation alpha; B: intersection of some propagation cones on a simplified topography.

The propagation can also be constrained laterally by an opening angle δ (or dispersion angle), whereas the actual opening is 2*δ (Figure 7). The angle δ defines how far the avalanche can deviate from its steepest flow path (path AB). For granular material avalanches, γ increases with the slope angle (Daerr & Douady 1999) but stays quite narrow, most of the material flowing straight down close to the steepest path. A very conservative value δ = 30º was selected for the final maps. Tests have shown that this parameter is by far not critical and that the results are only very slightly sensitive to its value.

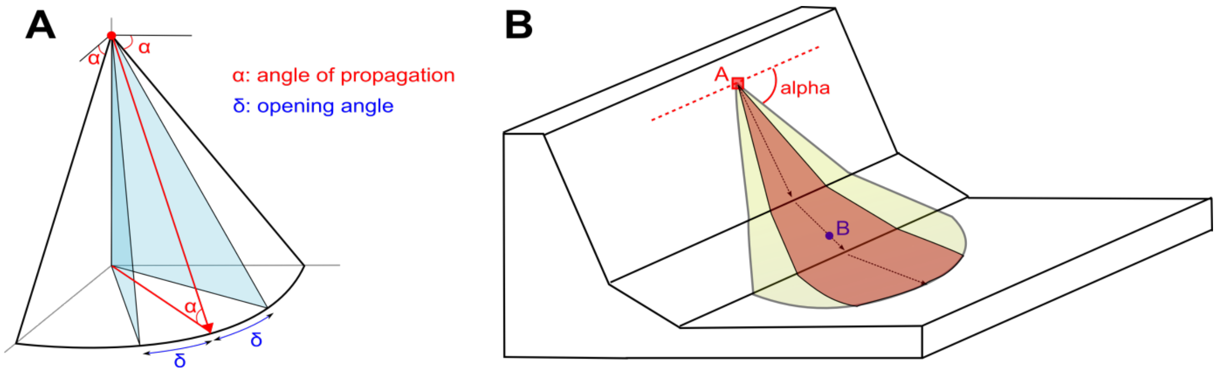

Figure 7 : A:Principle of the limiting opening angle.used to reduce the possible dispersion of an avalanche away from its main path. B: Application of the opening angle on a simplified topography (yellow: full cone propagation, red: propagation reduced laterally to the opening angle).

2.4.5 Final propagation zones

The final propagation zones is defined by the union of all the cone propagation areas. If a cell of the DEM is in <u>at least one cone of propagation</u>, then this cell is considered as "susceptible" and then included in a final propagation zone. A cell in a propagation zone can be included in only one cone or be at the intersection of several propagation cones. There is no distinction of the number of release cells that may reach a propagation cell in the final product. The final map is then a binary map: inside/outside an area susceptible to be reached by a snow avalanche (Figure 8).

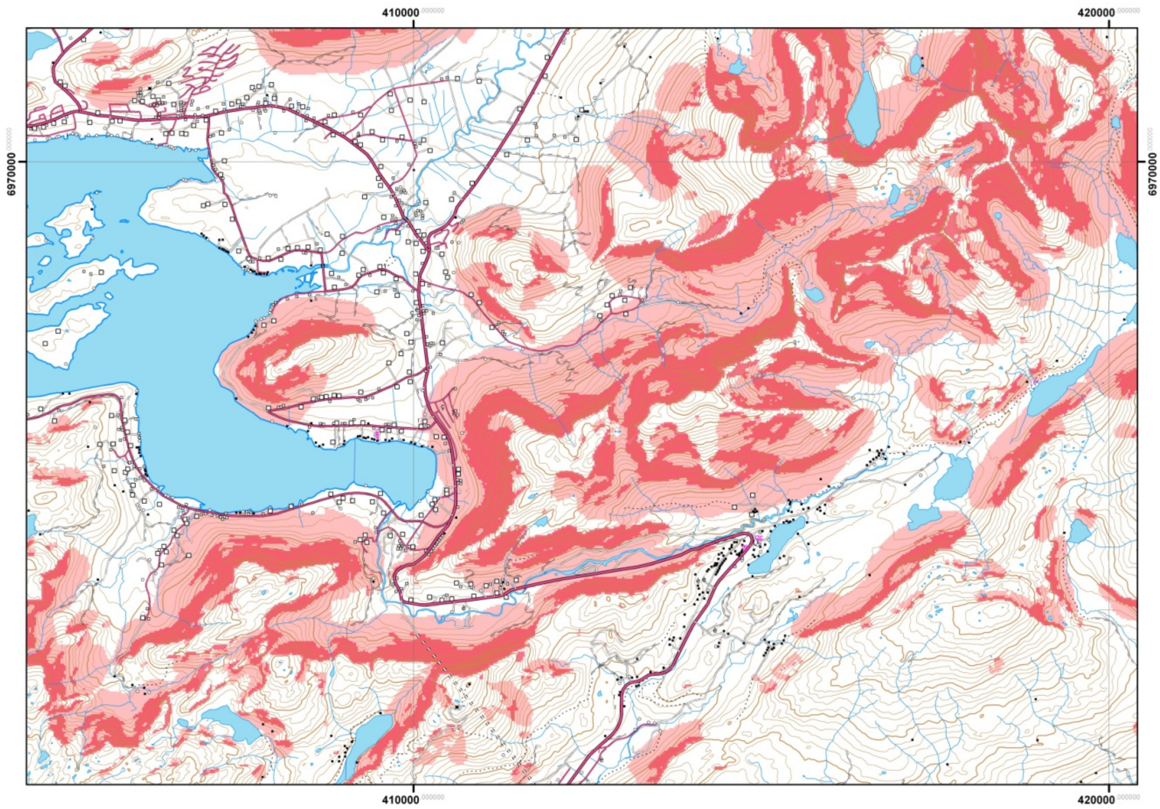

Figure 8 : Detail of the final susceptibility map for snow avalanches. Red: release areas, pink: propagation zones

3 Discussion

The technical description of the procedure used to draw these susceptibility maps is provided in the previous chapter. It is now important to discuss some issues related to the use of these maps. Modelling a complex phenomena such as snow avalanche implies strong simplifications, technical and strategic choices. All these factors will influence the final product and define its potential field of applications.

3.1 Information content

The maps produced in this project provide a qualitative assessment of the susceptibility for a location to be affected by a snow avalanche (in/out). They do not include any information about: the probability of occurrence of an event, its return period, its intensity or the consequences of an event on the elements at risk (population and infrastructures).

3.2 DEM resolution and error

All the procedure is based on one dataset: the 25 m gridded digital elevation model (DEM) provided by Statens Kartverk. Some limitations are inherent to the quality of this DEM: (1) some few errors were detected in the original DEM (unrealistic pits) and corrected, (2) the relatively low resolution of the DEM (one point each 25 m) is a more important limiting factor. As the DEM surface is a simplified representation of the real topography, some morphological features may be missing. In particular, small potential release areas with slope >30° may not be detected during the procedure of release areas detection.

3.3 Forest cover

It was decided in this project not to take into account the forest cover. The main reason for this choice are:

- No dataset of the forest cover and suitable for our purpose is available for the whole country. In addition such a dataset should be periodically updated to take into consideration land-use changes.
- Even if such a dataset was available, then the impact of forest cover on release and propagation should have been defined. Then choices about the type of avalanches (slab or powder) should have been done. This is beyond the scope of this project, as it was decided to always consider the worst case scenario.

3.4 Parameters choice

Such small scale (= large area, few details) susceptibility assessment are made to be conservative: we prefer to overestimate than underestimate the hazardous zones. All the parameters used during the processing were selected along this conservative line. Then the final result aims to represent the worst case possible scenario, and not the “usual avalanche” occurring every couple of years. It means too that some propagation areas may be overestimated.

3.5 Operational use

A particular caution must be taken not to over-interpret these susceptibility maps. This maps aim to provide a first overview, a screening over the entire country, of the regions that may be exposed to avalanches. They can be used to identify risk hotspots at regional scale and to help prioritizing future more detailed hazard assessment. Even if in a digital format, they must not be used at scale more detailed than 1:50'000. They do not replace in any way, fieldwork, detailed mapping and specific site investigations. In particular, these maps cannot be used for detailed planning such as house or road implementation

4 References

Bakkehøi S, Domaas U, Lied K, 1983: Calculation of snow avalanche run-out distances. Annals of Glaciology, 4, 24-30.

Daerr A, Douady S, 1999: Two types of avalanche behaviour in granular media. Nature, 399, 241-243.

Fell R, Corominas J, Bonnard C, Cascini L, Leroi E; Savage W, 2008: Guidelines for landslide susceptibility, hazard and risk zoning for land use planning. Engineering Geology. 102; 3-4, 85-98.

Horn B, 1981: Hill shading and reflectance map. Proc. IEEE, 69, 1, 14-47.

Jaboyedoff M, Labiouse V, 2003: Preliminary assessment of rockfall hazard based on GIS data. ISRM 2003–Technology roadmap for rock mechanics, South African Institute of Mining and Metallurgy, 575-578.

Jenson S, Domingue J, 1988: Extracting topographic structures from digital elevation data for geographic information system analysis. Photogrammetric engineering and remote sensing, 1593-1600.

Lied K, Bakkehøi S, 1980: Empirical calculations of snow avalanche run-out distances based on topographic parameters. Journal of Glaciology, 26, 165-177.

Lied K; Kristensen K, 2003: Snøskred, Håndbok om snøskred. Vett & Vitten AS, 200 pp.

Mc Clung DM, Schaerer PA, 1993: The avalanche handbook. The Mountaineers, Seattle. 271 pp.

Wood J, 1996: The geomorphological characterisation of digital elevation models PhD Thesis, University of Leicester, UK, http://www.soi.city.ac.uk/~jwo/phd.

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