Visualization and Analysis of the Swiss Avalanche Bulletin using GPS

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ABSTRACT

For the visualization of the (verbal) Swiss avalanche bulletin a GIS prototype was developed which aims at the prediction of the local avalanche hazard in a scale of 1:25'000. For this purpose weight factors are derived from the actual bulletin concerning the bulletin hazard level, the critical values for altitude, slope and aspect. Main input data is a high resolution digital terrain model (25 x 25 meters). As GIS-Software ARC/INFO 7.04 was used and in particular its raster data module GRID. The prototype is based on AML-scripts and is completely menu driven. Whenever a new bulletin appears the GIS-based calculations can be performed within a few minutes and be used to adjust the accuracy of the bulletin before its release. The evaluation of the prototype will take place during winter 1996/97; it includes the comparison of the predicted avalanche hazard and observed avalanches as well as statistical tests.

INTRODUCTION

Swiss avalanche forecast has been performed for over 50 years by the Swiss Federal Institute for Snow and Avalanche Research Weissfluhjoch Davos (SFISAR). The bulletin covers the whole Swiss Alps or approximately 25'000 km^2. It refers to the European avalanche hazard scale (Pahaut 1994, SFISAR 1994), differs among five hazard levels and indicates the actual hazardous conditions thus helping the user where to look for the areas of potential danger. So far the bulletin is a plain text and offers only very general visualization facilities for the spatial dimension to the user. In order to accurately interpret the bulletin specialised knowledge and good map reading capabilities are required. Professionals however, manage perfectly well but skitouring and off-piste skiing become more and more popular. Therefore an increasing number of people with less knowledge and skills attempt to travel the backcountry. Reliable and easy to understand forecasting systems – not only for avalanches – are hence of growing interest and importance.

TOPICS

This growing demand for "visual and easy to interpret data" encouraged the authors to develop the GIS-prototype LAWIPROG for the visualization of the Swiss avalanche bulletin. Special emphasis was put on the transformation of the global to the local hazard prediction and its cartographic representation in a scale of 1:25'000.

The authors are well aware of the fact that the original bulletin is designed for large-scale statements where prediction as well as judgement of the actual local risk must be left to the user. However, a tool for testing the forecast's accuracy was anticipated which enables the Avalanche Warning Service to judge the forecast results.

LAWIPROG does not calculate a new bulletin or even the hazard level from the original measuring data. The avalanche bulletin is still produced traditionally by the experts. Only then LAWIPROG translates the derived hazard conditions into a spatial and cartographic language thus pointing out the "green or red spots" (see Fig. 5 and 6), as indicated in the text of the bulletin.

For the modeling of the local hazard maps special weight factors were assigned to the various input parameters (slope, aspect, etc.). The basic idea behind this is, that LAWIPROG "simulates a skilled skitourist" who judges snow and avalanche conditions by consulting the bulletin, reading maps, taking into account weather conditions, etc.

USE OF A GEOGRAPHICAL INFORMATION SYSTEM (GIS)

Avalanches represent spatial processes and illustrate very clearly what impact topographical structures may have. GIS are designed to analyse and model spatial data; they are an efficient tool for modeling dynamic processes such as the spread of an avalanche and to put the results into a geographical as well as cartographical context. By combining existing data and models new informations and models can be gained. Heterogenous data (scale, thematic layers, measuring regime, etc.) may be overlayed 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" (Allgöwer 1995) may have the character of hypothesis and can be recalculated again and again until they fit their purpose.

LAWIPROG was programmed using ESRI's[1] ARC/INFO as GIS-Software. All spatial modeling is done with the raster module GRID and all programs are written in Arc Macro Language (AML). LAWIPROG is an interactive application and has a user interface which requires no special GIS-knowledge from the end-user.

THE SWISS AVALANCHE BULLETIN

The Swiss avalanche bulletin is designed as a forecast tool and published about one hundred times during wintertime by the Avalanche Warning Service, a small group of five experts at SFISAR. The input data are assembled through four main country-wide networks, gathered in the Snow and Avalanche Information System (Meister 1994):

- Daily conventional snow and avalanche observations since the beginning of the Avalanche Warning Service in Switzerland (80 observers)
- Every fortnight detailed snow profiles and Rutschblocks from the observers
- Hourly readings from 30 automatic weather stations (ANETZ) above 2500 m
- Personal informations and reports about snow cover conditions, etc. by professionals (mountain guides, alpine lodge keepers, etc.)

The bulletin text is structured in four subsequent paragraphs:

- General informations: weather and snow situation
- Snow cover conditions: structure, layering and stability of the snowpack
- Hazard level: 1 – 5, according to the European Avalanche Hazard Scale
- Trends: covering the next 24 to 48 hours

The original language of the avalanche bulletin is German, translations into French and Italian are performed before distributing the bulletin via phone, telex, fax, teletext and the World Wide Web. Additionally, two general maps on the average snow depth and the distribution of the hazard levels in the different bulletin regions can be obtained by GIS (scale 1:1'000'000) (Schöning 1992).

THE LAWIPROG-MODEL

The Swiss avalanche bulletin uses topographical and morphological features to describe the hazard areas: altitude, slope, aspect and morphological elements like ridges, gullies and basins. Depending on how those features are expressed and how they recombine for a given location the resulting hazard levels may vary considerably. For example: If the terrain is steep and the aspect considered hazardous but the location situated below the critical altitude, the avalanche hazard may be lower because of the eventual higher snowpack stability at lower altitudes. On the other hand backcountry skier will be save even under hazardous conditions and in high altidudes if the inclination of the terrain does not get close to the critical values.

Hence a simple multiplicative model for avalanche hazard map modeling was implemented on ARC/INFO in a first approach.

The main input data for LAWIPROG is a high resolution digital terrain model (DTM) with a cellsize of 25 meters (Swiss coordinate system, scale 1:25'000). Each mesh point in this net represents a different altitude above sealevel, looking like a fishnet, folded in the form of the terrain's surface (see Fig. 1). From this raster data set (grid) the data for slope, aspect and altitude are derived and saved as separate data layers. To further process these data the map algebra language of the raster module GRID is used (Tomlin 1990). Any mathematical operation or function can be applied to either a single or various grids in order to derive a result grid (see Fig. 1).

To calibrate the input data for the LAWIPROG-model according to their significance for the hazard prediction, weight factors were developed (see Fig. 2 – 4). A semantic analysis showed, that the main part of the bulletin-text is structured in hazard levels and explanatory sentences about the critical terrain features altitude, slope and aspect.

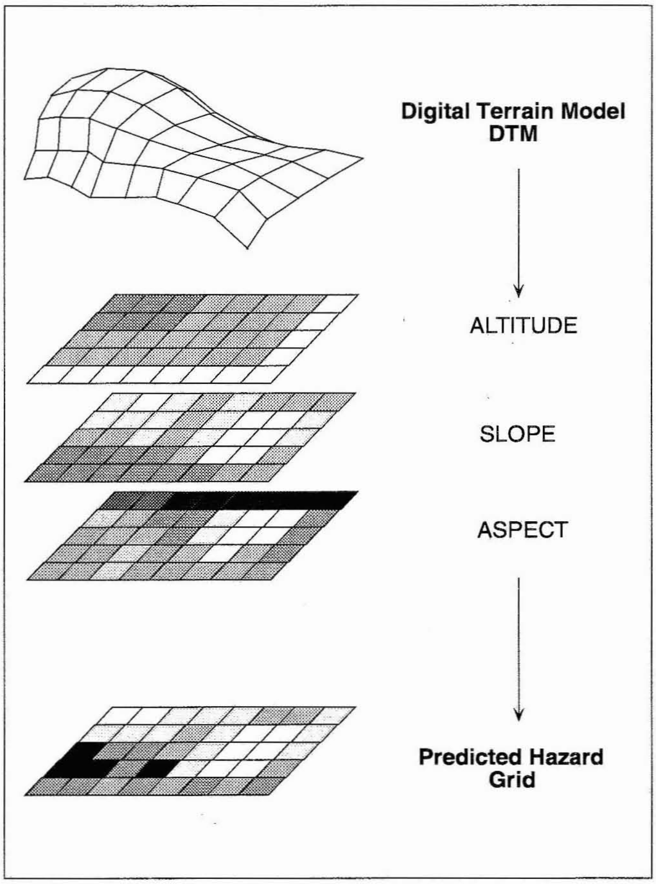


Fig 1: Derivation and multiplication of the three weight grids

Data Calibration

- Hazard Level P_{HL}

As the hazard level represents the main result of the bulletin - snowpack stability - it weighs a priori twice as much as the other input data. Values between 2 and 10 are possible. In present prototype the regions are not yet differentiated. All cells in the resulting hazard grid (PHG) get the same weight factor for the hazard level.
The following data are weighed according to their significance in the actual bulletin, using a scale from 1 to 5.

- Altitude P_{ALT}
- Slope P_{SLP}
- Aspect P_{ASP}

Once all data are ready, the predicted hazard map (grid) can be calculated according to the following formula:

$$PHG = P_{HL} * P_{ALT} * P_{SLP} * P_{ASP}$$

The result is an integer value between 0 and 1250 for each grid cell; it represents realistic sentences of the bulletin such as: "considerable hazard above about 2200 m on steep slopes facing NW to E". – In the following the weight factors are described; at present they depend from expert knoweledge only.

HAZARD LEVEL P_{HL}

In this model P_{HL} ranges from 2 to 10. "Low hazard" is equal to 2, "moderate hazard" = 4, "considerable hazard" = 6, "high hazard" = 8 and "very high hazard" = 10. As mentioned P_{HL} is purely numeric since no regional differentiation is made yet.

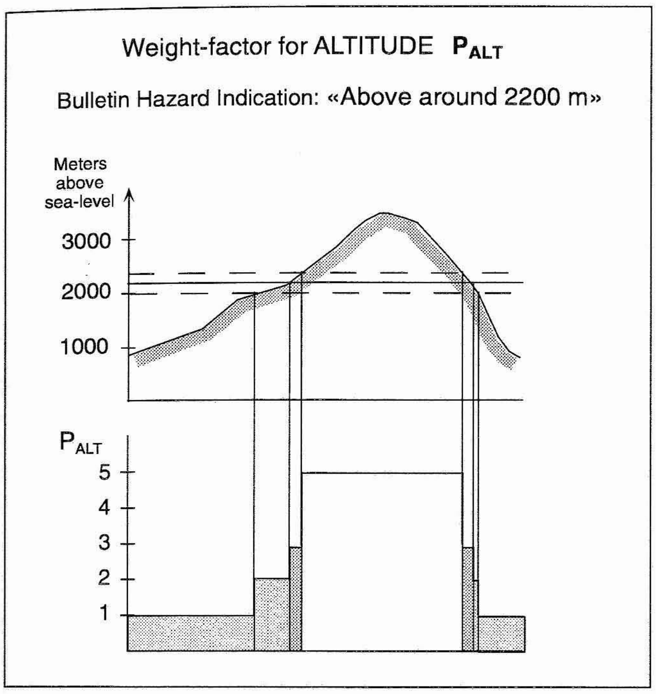


Fig. 2: Calculation of weight-factor for ALTITUDE

Altitude P_{ALT}

The Altitude is weighed as follows:

Altitude ≥ 2200m —> P_{ALT} = 5

2200 ≤ Alt. ≥ 1800 m —> P_{ALT} = 3

2000 ≤ Alt. ≥ 1800 m —> P_{ALT} = 2

Altitude ≤ 1800 m —> P_{ALT} = 1

The adjective "about" causes the differentiation between 1800 m and 2200, a ribbon which cannot be set to the lowest level. Similar converting rules exist for terms as "below about", "in altitudes from...to..." or "in all altitudes".

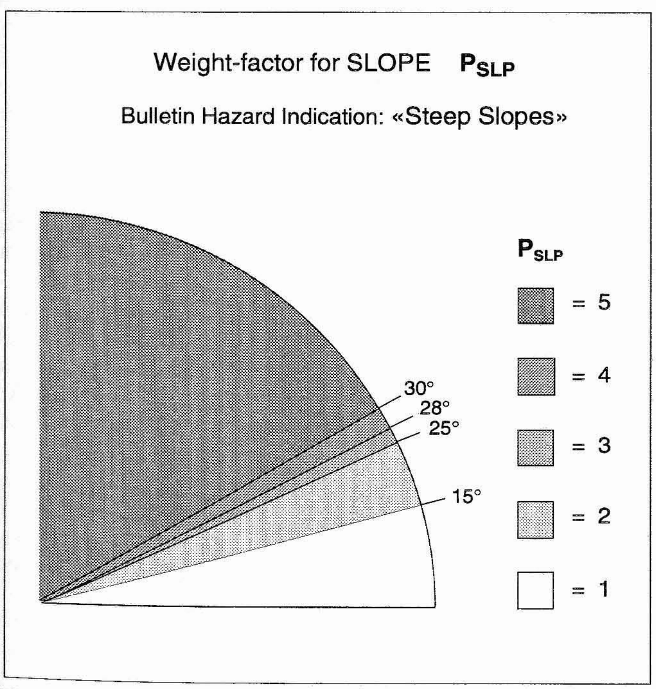


Fig. 3: Calculation of weight-factor for SLOPE

Slope P_{SLP}

The weight factor for the slope angle is defined as follows:

slope angle ≥30° —> P =5

between 28° and 30° —> P = 4

between 25° and 28° —> P = 3

between 15° and 28° —> P = 2

slope angle≤ 15° —> PP =1

Similar converting rules as for the altitude exist for expressions like "extreme steep" or "moderate steep".

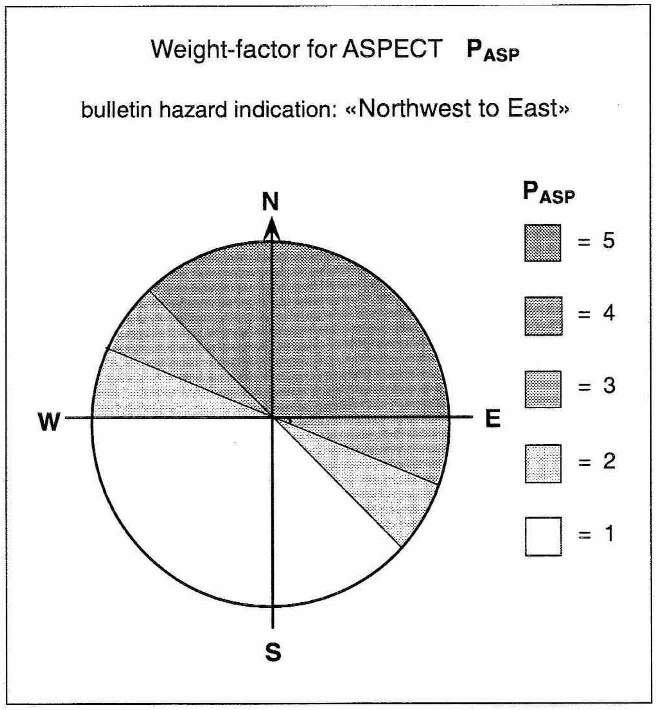


Fig. 4: Calculation of weight-factor for ASPECT

Again flexible rules for expressions like "all aspects", "facing north" or "shady slopes" exist.

In our (fictive) example, a 38 degree steep, northeast facing slope at an altitude of 3000 m would be estimated with PHG_{max} = 8 * 5 * 5 * 5 = 1000 (see Fig. 5).

RESULTS AND VERIFICATION OF LAWIPROG

The output of the LAWIPROG-model is a raster data set of continous "hazard values" for each cell. These values can now be transformed into a colorramp for cartographic purpose showing all transitions from non-dangerous (non-hazardous) to dangerous (hazardous) areas for a given bulletin. According to the European hazard standard a colorramp from green to red over yellow was choosen. In the present paper dark grey/black indicates high danger, light gray low danger (see Fig. 5).

With LAWIPROG's interactive user interface the PHG can now be analysed. For each cells all values can be interrogated, areas of equal values can be selected, altitude, slope and aspect of a selected cell will appear on the screen etc. Moreover input parameters can be changed and new maps be calculated immediately. Thanks to modern data storage technologies computational operations perfomed by the GRID module require only little computing time and new PHGs may be obtained within moments. This is a great advantage for the experts who want to evaluate the accuracy of their forecast before its release.

The multiplicative modell is but an initial approach. LAWIPROG was developed during winter 1995/96. The weight-factors were defined by avalanche experts, but not yet empirically tested under field conditions. The first method to do so is to compare the predicted hazard with observed events. Released avalanches – spontaneous and man-made ones – can be mapped, digitized and finally

Aspect P_{ASP}

The weight factor for aspect changes from situation to situation (and bulletin resoectively) according to what aspects are considered to be dangerous. In this example aspects from the weights are distributed as follows

P_{ASP} = 5: NW yo R (315 – 90°)

P_{ASP} = 3: E to ESE (90 - 112.5°) and WNW to NW (292.5 - 315°)

P_{ASP} = 2: ESE to SE (112.5 - 315°) and W to WNW (270 - 292.5°)

P_{ASP} = 1: SE to W (135 -270°)

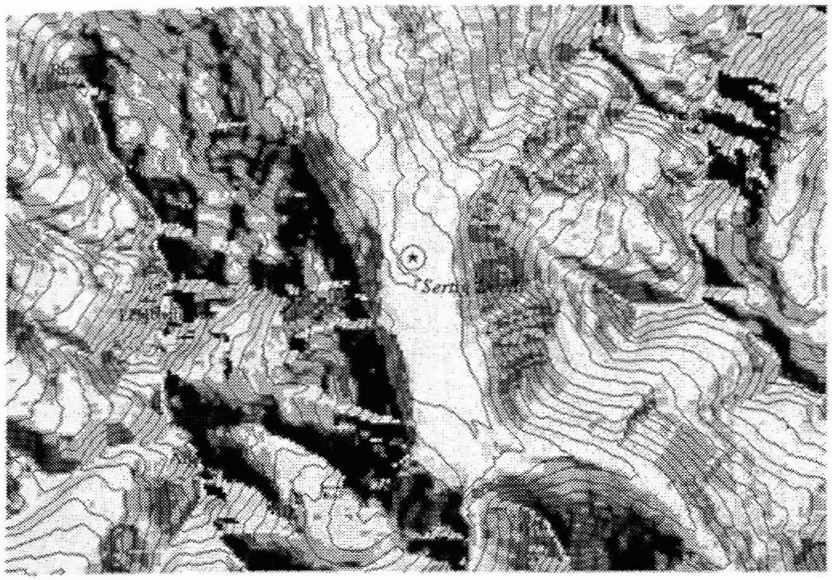
superimposed to the map of the predicted hazard. Fig. 6 shows an example from a very extreme situation. On march 23, 1996 most of the possible avalanches departed. All of them started in the dark aerea: PHG_{max} = 6 * 5 * 5 * 5 = 750.For reliable validation experimental avalanches should be performed (Bolognesi 1996). Spontaneous or accidental avalanches have the disadvantage that they are not always reconstructable. Very often they were not observed and many of the connected parameters remain unknown. Moreover it is difficult to localize the release areas of potential avalanches. They manifest themselfes only by external influences such as skitourists, animals or explosives. Since such avalanches are rare (fortunatly) and not always predictable, it is difficult to gather a big enough sample for statistical testing – a fact which complicates the work of all avalanche experts.

CONCLUSIONS AND OUTLOOK

The visualization of the Swiss avalanche bulletin using GIS is an attempt to hand more detailed information to the public: mountain professionals as well as people with little avalanche training and expert knowledge. All these people expect and eventually depend on detailed information concerning the snowcover and avalanche situation.

As shown, it is possible to "pin down" the avalanche hazard and to reproduce it in a scale in which the individual skitourist moves to and fro as well. Setting up a model like LAWIPROG and producing such maps is possible as soon as the underlaying data like a high resolution digital terrain model are available. It would even be possible to model optimal skiroutes (between departure and arrival point) on top of predicted hazard maps by using so called "cross country movement" algorithms (Xu and Lathrop, 1995). However, the critical question must be asked, if such maps should be produced at all. To most forecast systems a great many sources of uncertainties are inherent. Very often simple models are used, which can only be justified if they are applied by experts. In the wrong hands such maps may be disastrous. On the other hand with modern computing facilities it will not take long until such maps will be produced and spread by the mass media. Most obviously not much expert knowledge will then be involved. Therefore it is planed to further develop LAWIPROG at the SFISAR. LAWIPROG will be tested in-

PREDICTED AVALANCHE HAZARD AREAS (FICTIVE BULLETIN)



Hazard Indication

- high hazard
- above and around 2000 meters
- steep slopes
- aspects from NW to E

very dangerous

dangerous

critical

less critical

very low risk

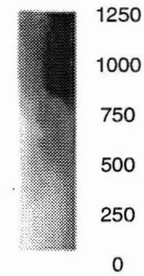
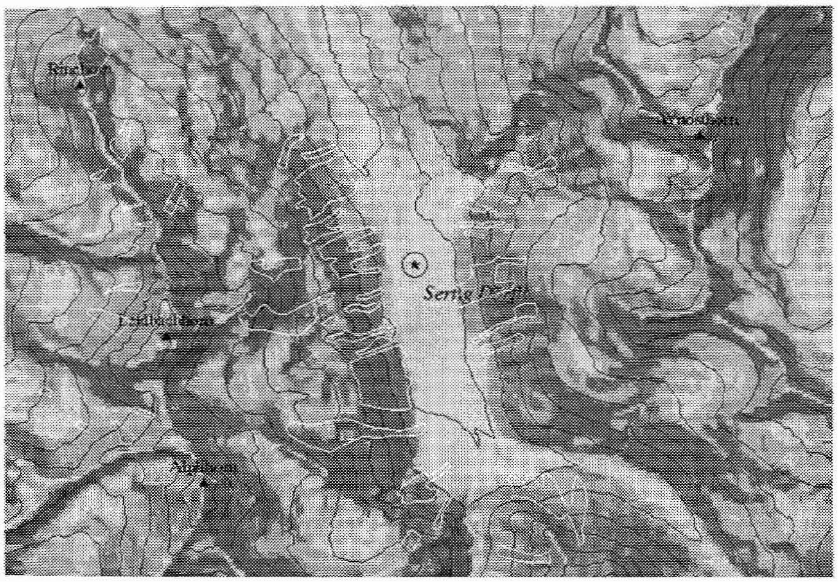


Fig 5: Example of a map, showing the predicted danger of avalanche release



Hazard Indication

- considerable hazard
- above and around 2000 meters
- steep slopes
- all aspects

very dangerous

dangerous

critical

less critical

very low risk

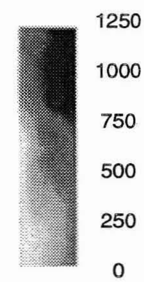


Fig. 6: Map of predicted danger: bulletin march 23, 1996 with registered avalanches of the same day

DTM25: reproduced with the permission of the Swiss Federal Office of Topography, September 6, 1996. Map: Department of Geography, University of Zurich, Heiri Leuthold

tensely during the winter 1996/97 to improve the underlaying model and it's reliability; statistical uncertainty analysis (e.g. Monte Carlo Simulation) will be of great importance. So far, the weight factors are based on a simple a priori multiplicative model, which has to be validated thoroughly under field conditions, taking into account the actual hazard situation observed in the field. In other words: it is still a long way to go until such maps may be handed to the public and until their distribution over internet e.g. could be encouraged.

To improve the country-wide Avalanche Warning Service, SFISAR works since a long time on different modules such as snow cover modeling (Fierz et al. 1996), improvements of the expert systems for avalanche warning (Schweizer and Föhn 1996), operational databases, regional bulletins and validation of the hazard levels (Bolognesi 1996). LAWIPROG is but a completion to this research program which is devoted to the improvement of the operational avalanche warning and prophylaxis.

REFERENCES

Allgöwer, B., 1995. Geographical Information Systems – toys or useful tools? Original title: Geographische Informationssysteme – Spielzeug oder brauchbares Arbeitsinstrument? In: Schweizer Umwelt-Jahrbuch 95 für Unternehmen und Betrieb, Ed. Chr. Erdin und W. Obrist, WEKA-Verlag AG, Zürich, pp. 144 – 152.

Bolognesi, R., 1996. Validation des Systèmes de Prèvision des Avalanches, Neige et Avalanches No. 73, ISSN 1247-5327, pp. 9-14.

Fierz, Ch., Plüss, Ch. and Martin, E., 1996. Modelling the Snow Cover in a Complex Alpine Topography, Submitted to Annals of Glaciology, Vol 25.

Meister, R., 1995. Country-wide Avalanche Warning in Switzerlandì, Proceedings of the ISSW 94, Snowbird, UT, pp. 58-71.

Pahaut, E., 1994. L'Echelle Européenne de Risque d'Avalanches, Neige et Avalanche No. 68, ISSN 1247-5327, pp. 26-27.

Schöning, R. 1992, GIS-Prototype for Operational Avalanche Warning at SFISAR Weissfluhjoch Davos, Original title: GIS-Prototyp für die operationelle Lawinenwarnung im SLF Weissfluhjoch Davos, Department of Geography, University of Zurich, unpublished.

Schweizer, J. and Föhn, P.M.B., 1996. Avalanche Forecasting - an Expert System Approach, Journal of Glaciology (in press).

SFISAR, 1994. Interpretationshilfe zum Lawinenbulletin des Eidgenössischen Institutes für Schnee und Lawinenforschung Weissfluhjoch Davos, Mittg. Nr. 50, Ed. W.Ammann.

Tomlin, C. D., 1990. Geographic Information Systems and Cartographic Modelling, Prentice Hall, Englewood Cliffs, New Jersey.

Xu, J. and Lanthrop, R. G., 1995. Improving simulation accuracy of spread phenomena in a raster-based Geographic Infromation System, Int. J. of Geographical Information Systems 9 (2), pp. 153 – 168.