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Verification of avalanche danger with respect to avalanche forecasting - *Verification du danger d'avalanche par rapport aux prévisions du risque d'avalanche*

Paul M.B. FÖHN and Jürg SCHWEIZER[1]

ABSTRACT

The ambitious goal of any avalanche forecasting group is to foresee the daily avalanche danger. In the last years it became obvious that good input data, computer modelling help, personal experience and expressive avalanche output variables are mandatory. Here another ***must*** *in avalanche forecasting will be presented, namely the continuous and realistic* ***verification*** *of the output variables (degree of avalanche danger, endangered altitude zones and aspects).*
The principal difficulties and possible solutions of verifying the local or regional avalanche danger are analyzed. It is shown that not only the areal observation problem is of prime importance but also the fact that, e.g. the two lowest danger degrees of the European danger scale may often only be verified by snow profile inspection and Rutschblock tests, whereas the upper degrees can mostly be verified by an intensive, areal observation of avalanche occurrences. Several transformation procedures and some verification examples are described. Any improvement of an avalanche forecasting system and finally also the credibility of avalanche warnings are based on appropriate verification procedures.

RÉSUMÉ

Le but de la prévision journalière des avalanches à l'échelle régionale est de prévoir le degré et les lieux de danger correctement. Dans les années passées diverses analyses ont montré que des données appropriées, le soutien par des modèles, l'expérience personnelle et une variable de sortie représentant au mieux la situation avalancheuse sont indispensables. D'autre part, la vérification journalière des variables de sortie (degrés de danger, altitudes et expositions dangereuses) est également de prime importance.
Nous présentons les principales difficultés rencontrées lors de la vérification du danger local ou régional ainsi que quelques possibilités de solution du problème. On montre que non seulement le problème de l'observation des avalanches est important, mais que par exemple les deux degrés de danger les plus bas de l'échelle européenne ne peuvent souvent être vérifiés qu'avec des profils de neige et des tests de glissement. Des procédures de transformation de telles informations en degrès de danger sont présentées à partir de quelques exemples. Il est clair qu'une bonne vérification des résultats est à la base de chaque amélioration des prévisions en augmentent la crédibilité.

INTRODUCTION

In the late seventies/early eighties several research groups developed avalanche forecasting models, which raised more than before - having only traditional, synoptic methods to forecast ava-

[1]Swiss Federal Institute for Snow and Avalanche Research, CH-7260 Weissfluhjoch/Davos, Switzerland

lanches - the demand of quantified verification of the avalanche danger or activity. Föhn et al. (1977), Williams (1979), Judson and King (1983), Buser (1983), Giraud et al. (1987) and finally Elder and Armstrong (1987) described some verification problems and made the first trials with verification procedures. At that time avalanche danger ratings were almost exclusively compared with various kinds of observed avalanche activity indices, i.e. pears were compared with apples. After adoption of the new European avalanche danger scale (1993) this handicap has been eliminated and here a new approach and some new and improved procedures for verification will be presented.

BRIEF REVIEW ON RECENT VERIFICATION RESULTS

Despite the fact that avalanche forecasting is going on since decades, the number of published verification results, describing methodological details and yielding longer verification series, are surprisingly small. The most informative ones are the ones of Elder and Armstrong (1987), Giraud et al. (1987), Remund (1993) and McClung and Tweedy (1994). Elder and Armstrong (1987) present forecast series from Colorado for one winter using the number of avalanches as verification base. They applied contingency tables for the verification. They describe 134 days using the 4 degree U.S. hazard scale and report a success score of 64%. The ratio of days rated too high to the ones rated too low was 6 to 1. Giraud et al. (1987) describe forecast results for the French ski area of Vanoise for three winters. The verification has been done by an avalanche activity index, whereby artificially triggered avalanches got a weight of 0.5. Discriminating between 8 hazard degrees (old French scale!) they still reached a success score of 56%. The ratio of days rated too high to the ones rated too low was 2 to 1. Remund (1993) reports a mean success rate of 69% for two regions of the Swiss Alps considering 5 danger degrees and a ratio of days rated too high to the ones rated too low of 1.3 to 1. Finally McClung and Tweedy (1994) describe forecast results for a highway in western Canada. They used the number and sizes of avalanches on highways for verification calculating a magnitude-frequency index for subcategories of "dry", "moist" and "wet" avalanches. Discriminating between avalanche and non-avalanche time periods and setting various warning levels between 0.5 and 0.7 for dry and moist/wet avalanches they achieved a success score between 73% and 79%.

AVALANCHE OUTPUT VARIABLE AND VERIFICATION PROCEDURES

"Any avalanche prediction method, whether of conventional, statistical, or even of physical nature, needs an appropriate avalanche variable in order to establish and to verify the method" (Föhn, 1977). This statement may be viewed as a point of departure for the new European avalanche hazard scale (degree 1-5), which has been adopted by the European working group of avalanche warning services. The main guidelines of this scale have been described by Föhn (1985) and by Giraud et al. (1987). It comprises now a simple scale of the ordinal level (1 to 5) which expresses the probability of certain states of snow cover instability, described by main terms of increasing avalanche hazard: *low, moderate, considerable, high, very high.*
The avalanche hazard may be approximated by the release probability A and by the avalanche volume V:

$$D \propto A V \propto \frac{1}{S} V \qquad (1)$$

where S is snow cover stability and V the total avalanche snow volume.

It is obvious that the larger the released snow volume and the smaller the snow cover stability are, the larger the avalanche hazard. The ratio of the snow cover stability index S' including additional loads to the natural snow cover stability index S may be approximated as (Föhn, 1981):

$$S' = \frac{S\,\tau_{xz}}{\tau_{xz} + \Delta\tau_{xz}} \qquad (2)$$

where τ_{xz} = shear stress due to the weight of the snow cover
$\Delta\tau_{xz}$ = shear stress due to additional load as skiers, explosions etc.

The following Table 1 yields the specific stress relations of eq. (2). In order to approximate the verification for an individual forecasted day, it is simply assumed that in eq. (2) S' equals 1. According to the release conditions (type of triggering) S may be calculated. Thus the release probability A and hence the danger index D may be approximated.
If for a given day no avalanches were observed, nor triggering methods were in operation, one still can try to verify the lower part of the avalanche danger degree scale (1-3) by analysing snow profiles and Rutschblock tests. According to these lines (Remund, 1993) verified the forecasted degree of avalanche danger for two regions of the Swiss Alps during 4 winters (1987/88 - 1990/91). Calculating the daily danger values as percentage of the maximum, regionally possible danger totals an appropriate standardization has been achieved. The final summation of the daily scores gave a mean success score of 68 % for one and 70 % for the other region. It is obvious that the verification work for specific cases shall not be done obstinate, but integrating additionally the common sense interpreting the European danger scale, most cases (days) may be verified successfully.

Table 1: Various avalanche release sources described by the Swiss avalanche observation code and the proportion of the natural stress to the sum of the natural and the artificial shear stress (eq. 2).

Swiss avalanche observation code (1989)	**Release by**	$\frac{\tau_{xz}}{\tau_{xz} + \Delta\tau_{xz}}$
1 ... 3	no release despite various triggering sources	0.1 - 0.5
4	snow mobile	0.1
5	explosion, 1-2 kg	0.2
6	skier	0.5
7	natural and artificial	1
8	only natural	1
9	not known	0.8

VERIFICATION EXAMPLES

Summarizing the thoughts and facts presented up to now, we may conclude that verification success depends on the type of output variable which also decides if an expressive and hopefully objective verification method may be found. We believe that the European danger scale fulfils the above mentioned demands and is a good compromise of various earlier scales used in

Europe. It is simple and nevertheless contains the most important components of the avalanche danger (release probability and avalanche volume). So a successful verification is in the reach of every organisation applying this scale.
As we in the last years developed and continuously verified different so-called expert systems to forecast the degree of avalanche danger (Schweizer and Föhn, 1995), some verification examples are presented in Fig. 1. With the aim to visualize not the final success score of the presented methods but the daily course of forecast and verification results we want to draw the attention on verification problems.

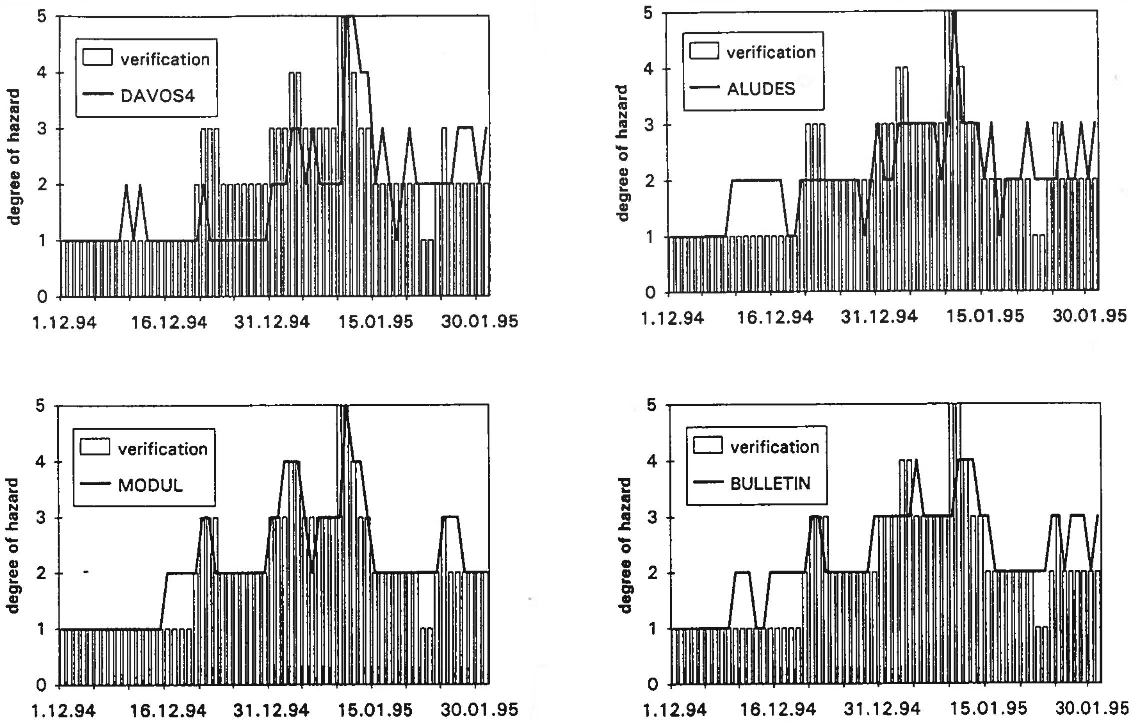
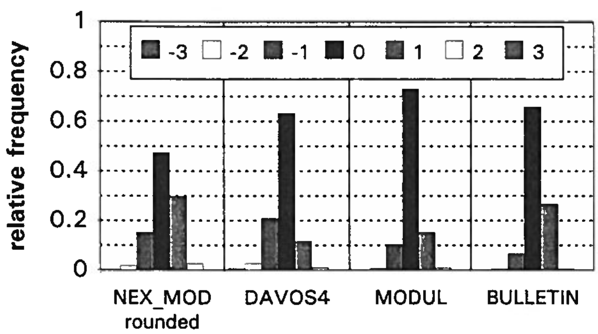


Fig. 1 Daily forecasts of degree of danger (European danger scale: 1 to 5) for a two month period in the region of Davos, Switzerland. The vertical columns indicate the "a posteriori" verified degree of danger per day; the fat lines indicate the forecasted degree of danger of three expert systems and of the avalanche bulletin that is mainly based on the conventional synoptical method.

The model DAVOS4 (upper left) that is a prototype expert system (based on the commercial software CYBERTEK-COGENSYS™), estimates the degree of avalanche danger on the base of 13 weather, snow and snow cover parameters. Even though this simple principally statistically based model had in the last three years an average performance of 63%, it has tremendous problems to reach equilibrium in the early winter period (December 1994). A further faintness period is visible from January 10 to 15, 1995, when suddenly with heavy snowfall and strong winds (about 80cm of dry new snow within 24 hours) a very high danger (5) developed. However, the model at least realized the very high danger.
During the first mentioned period (December 1994) the danger was mainly verified by analysing snow profiles and Rutschblock tests, which showed a latent avalanche danger for single skiers and groups of skiers, even so no avalanche could be observed. During the second period the danger was mainly verified by avalanches: whereas on January 10 and 11, 1995 everywhere large, dry avalanches could be observed, on the following days the number and size of avalanches decreased drastically and from January 14, 1995 on no spontaneously released avalanches were observed. From January 15, 1995 Rutschblock tests performed in various avalanche slopes yielded Rutschblock degrees of 5 (second or third jump) rather than 4 (first jump). This short excursion into the details of the verification procedure shall give an example of the applied

type of reasoning.
All other methods presented in Fig. 1 demonstrate similar problems, although the more rule based model MODUL (below left) that includes detailed snow cover profile analysis does not much deviate from the verification during December 1994 and proceeds quite nicely in January. The avalanche bulletin shows a certain deficiency during the intensive snowfall and wind period (10. to 15. January 1995) probably due to a avalanche data lack during that exceptional period of snowfall, fog and adverse observation conditions. The model ALUDES that is a hybrid expert system integrating neural networks and rules (Schweizer et al., 1994) shows an impressive behaviour during the intensive snowfall/wind period indicating high or very high danger.
A complete representation of the performance of the two models (DAVOS4 and MODUL) based on the CYBERTEK-COGENSYS™ software, the nearest neighbour model NEX_MOD (operationally used by the avalanche warning service) and for comparison the avalanche bulletin is given in Fig. 2.

Fig. 2. Performance of different forecast models and of the avalanche bulletin. The average deviation from the verification during three winter periods (1991/92 to 1993/94) is given for the Davos region in the eastern Swiss Alps. The model NEX_MOD (an adjusted version of nearest neighbour method) delivers average values of danger degrees, which are rounded for representation reasons.



CONCLUSIONS

Verification of avalanche danger, i.e. verifying daily forecasted danger degrees is a difficult task, anyway much more difficult than to verify an avalanche activity index or an "avalanche day". For this there are three main reasons:

1) Avalanche danger is not a directly measurable quantity, not even "a posteriori".
2) The main danger factors, the "avalanches" can often not be observed due to fog, snowfall or snow drifting.
3) Even if avalanches could be observed continuously in time and space, the potentially dangerous situations *low* or *moderate* danger (European scale 1 or 2) are often not traceable by avalanches. This is especially true when skier presence for triggering is low and/or when avalanche triggering by explosives is not operational.

Avalanche danger verification is a deductive process which integrates all the above mentioned principles and limitations. It is not possible to base one of the most important steps in avalanche forecasting, namely the verification solely on observed avalanches. Therefore we may conclude that every forecasting group should dispose of at least one test region where on one side optimal avalanche observations are guaranteed, on the other side where snowpack testing, test skiing and artificial triggering is also possible in multiple repetition on all aspects and in various altitude zones. Finally we would like to mention that despite of improved verification procedures and possibly ideal avalanche observations the verification of avalanche danger will always contain an error between 10 and 20 %.

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