AVALANCHE FORECASTING AND COMMUNICATION : EXPERIENCES IN AVALANCHE HAZARD SCALES

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ABSTRACT

Avalanche hazard scales can express a gradation in the severity of situations but, avalanche danger being multi-dimensional,it implies a partly subjective classification. Considering hazard scale as a code, evaluation of entropy gives guidelines to improve communication efficiency.From experiences of alpine countries, a new scale is proposed.

THE NEED TO CODIFY AND QUANTIFY AVALANCHE WARNINGS

The avalanche forecasting task tákes place in a whole information processing chain with, at one end, field snow and weather data collection , and at the other end a safety related decision by final users, public authorities or individual skiers. Every link of this chain is involved in final quality, and namely the questions related to diffusion and interpretation by the user.

To be taken into account as an operational help for safety decisions, avalanche warnings should avoid any kind of expression allowing subjective interpretation, even if it means loosing some slight details in its technical content. Moreover they should give a quantitative as well as qualitative description of risk.

Most countries concerned by avalanche warning did feel the need to codify and quantify this concept, which lead to the definition of more or less complicated "avalanche hazard scales" in the last ten years. The scattering observed between the main features of those scales illustrates the complexity of such a definition, which was the matter of thorough discussions held among the alpine countries in München (1983), Davos (1985) and Grenoble (1986).

The topic of this paper is to spread the light on the difficulties inherent in defining any avalanche hazard scale, to formulate some guidelines and propose a new scale inspired of the experiences of european alpine countries.

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AVALANCHE RISK AS A MULTIDIMENSIONAL VARIABLE

Applying to the specific case of avalanches the definitions of some concepts related to risk due to a natural phenomenon [1] , distinction should first be made between :

* "avalanche hazard", meaning the probability of occurence , within a specific period of time in a given area, of potentially damaging avalanches .

* "vulnerability" meaning the degree of loss to a given element at risk (people, buildings, etc) resulting from the occurence of avalanches, and expressed on a scale from 0 (no damage) to 1 (total loss).

* "avalanche risk" meaning the probability of loss (expected number of persons injured, buildings damaged, disruption of economic activity,etc) due to an avalanche situation , and which is the product of avalanche hazard, elements at risk, and vulnerability.

The "user" is sometimes expecting an information about the avalanche risk level for his own case, but this is much depending on how he is exposed at risk, according to his own activity. The same avalanche situation may imply at the same moment quite different risk evaluations for a road safety authority or for backcountry skiers. A "general purpose" avalanche warning should therefore be limited to the accurate description and evaluation of avalanche hazard , regardless of the individual cases of vulnerability and exposition at risk .

But how can we compare on one hand a critical instability involving only some specific parts of the area, and on the other hand a widely extended moderate instability ? or a given probability of spontaneous avalanches, and that of triggered unstable slabs ? or the probability of numerous surface sluffs and that of a few very large avalanches ?

As those elements are not strictly correlated , and in order to give more than a very poor (danger/no danger) information , avalanche hazard has to be considered as a multidimensional object.

Every individual interpretation of a given hazard situation is a kind of projection of this multidimensional object on the relevant "risk axis" corresponding to the own exposition at risk.

Any classification of avalanche hazard situations is therefore criticable, for it is also a projection, involving a somehow arbitrary choice about the rank of intermediate situations.

SCALES IN USE IN FRANCE AND OTHER ALPINE COUNTRIES

During winter 1979-1980, french Snow Research Center initiated the daily use of an eight-level avalanche hazard scale based on two criteria : first the intensity of "natural hazard" (spontaneous release probability) , then the spatial extension of "accidental hazard" (aptitude of slopes to be triggered).

The first level is "minimum" hazard , the next three levels are all "low natural hazard" situations with increasing "accidental hazard", then comes "moderate" and "high" natural hazard, then "avalanche situation" and "extreme avalanche situation".

1	**MINIMUM HAZARD**	Very low hazard. But always keep in mind safety rules, for hazard is inherent in mountain
2	**LOW HAZARD**	Snowpack generally stable. Low hazard related to local and/or temporary weak instability.
3	**LOCAL ACCIDENTAL HAZARD**	Low probab. of natural release. Local accidental hazard due to marked local latent instability
4	**GENERAL ACCIDENTAL HAZARD**	Still low natural hazard. Very marked accidental hazard due to widespread latent instability
5	**MODERATE NATURAL HAZARD**	Likely natural release of limited avalanches.All the more so accidental hazard is high.
6	**HIGH NATURAL HAZARD**	Unstable snowpack. Natural release of avalanches will occur .
7	**AVALANCHE SITUATION**	High instability. Large local accumulations. Numerous and sometimes large avalanches .
8	**EXTREME AVALANCHE SITUATION**	Numerous avalanches.Due to huge accumulations,exceptional large avalanches are expected .

TABLE 1 : French avalanche hazard scale in use since 1979

In practice, the various levels are often associated to well defined typical snow situations . "Local accidental hazard" is mentionned when local surface slabs are observed although the snowpack is mainly stable. "General accidental hazard" is corresponding to very specific winter conditions when widespread depth-hoar layers cause an unusual extension of slab instability, like during winter 1984-1985 in western Alps . "Moderate natural hazard" is related either to a noticeable amount of recent snow , or to moist snow instability in springtime sunny days. "High natural hazard" is mostly used after heavy precipitation, with or without warming weather and rain at high elevations. "Avalanche situation" is referred to in the case of real snow storm with large amounts of fresh snow, usually associated with high wind of changing direction, and quick temperature changes.

This avalanche hazard scale has been used for seven years in all daily avalanche reports for french Alps and Pyrenees , and later also in Italy .

Meanwhile , other hazard classifications were proposed and set in use in Austria , Germany , Switzerland , the United States, and perhaps still other cases unknown to the author. The austrian-german group proposed a double six-level scale , one number giving avalanche risk for roads and villages, the other describing avalanche risk for backcountry skiers in high mountain area.

A seven level scale was proposed by P. Föhn [2] and is used in swiss avalanche reports. It is based on two criteria : first the local or general spatial extension of instability , and second the intensity of instability. The size of avalanches is assumed to be correlated with instability. In this scale , the first 4 levels are "very low", moderate", "marked" and "high" local hazard , while the last 3 levels are "marked" , "high" , and "very high" general hazard respectively.

IMPROVING COMMUNICATION EFFICIENCY

Whatever the choices made regarding the relative order of snow and avalanche situations , the minimum benefit to expect when defining an avalanche hazard scale is to improve communication efficiency by using the "codification" constituted by a limited set of keywords .

In practice , an extensive information campaign is absolutely needed to get sure that everyone understands the conventional meaning of those keywords , which implies a minimum knowledge of snow and avalanches . From this point of view , a total number of 6 to 8 levels allows a detailed enough classification to describe the main features of situations , without exceeding what the public can easily understand and remember .

For every hazard scale , a special attention must be paid to the relative frequencies of use of the various levels of the scale over a long period . According to classical communication theory [3] the expected mean value of information quantity transmitted by a code taking n possible values is the entropy expressed as :

$$H = \sum_{i=1}^{n} p_i \operatorname{Log}_2(1/p_i)$$

$$\text{with} : p_1 + \dots + p_i + \dots + p_n = 1$$

where p_i is the relative frequency of use of the i^{th} level .

H is expressed in Binary Information Unit (bit) , which means that :
H = 1 bit in the case where : n=2 and : $p_1=p_2=1/2$

It can be easily shown that for any value of n , the maximum value of H is reached for : $p_1 = ... = p_i = ... = p_n = 1/n$
and this maximum is : $H_{max} = Log_2(n)$

The entropy was calculated for the french avalanche hazard scale taking into account the empirical frequency distribution of the 8 levels among the total sample of around 3.000 daily avalanche reports published over the last 6 years for 4 major forecasting areas : Vanoise, Oisans, Queyras, central Pyrenees .

FREQUENCY DISTRIBUTION (%)								ENTROPY (Bit)	COMMENT
1	2	3	4	5	6	7	8		
1	**10**	**32**	**6**	**34**	**12**	**4**	**1**	**2.3**	**REAL CASE**
50	50	0	0	0	0	0	0	1	EXAMPLE
44	44	2	2	2	2	2	2	1.7	EXAMPLE
12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	3	EXAMPLE (Hmax for 8 levels)

TABLE 2 . Empirical frequency distribution (in %) of the 8 levels of french avalanche hazard scale ("real case") , and its entropy , compared to three arbitrary "extreme" distributions.

In Table 2 , this is compared with 3 theoretical examples in order to show the range of variation of entropy. The entropy value of 2.3 is significantly lower than the theoretical maximum of 3 (for a 8-level scale) . As 2.3 is close to Log_2 (5) , we notice that information quantity transmitted here on eight levels is about what could be transmitted by a 5 level scale with ideal uniform frequency distribution. This can be accounted for by the very low frequency (1%) of the two extreme levels (1 and 8) which are not efficiently used to transmit information , thus reducing the number of effective levels .

On this basis , some modifications are expected to increase the informative efficiency .

PROPOSAL FOR A NEW INTERNATIONAL SCALE

Several reasons lead us to consider a revised version of the initial hazard scale :

* The need to increase information efficiency as presented above through a better spreading of the frequencies over the various levels .

* The concern for bringing the different existing hazard scales to a convergent form, at least within the Alps.

* The statement that one of the levels, namely "MODERATE NATURAL HAZARD" was actually used in two kinds of situations, with somewhat different meanings.

As it was told above, "MODERATE NATURAL HAZARD" is the most frequent case but may describe typically two different kinds of well identified situations : either a general surface instability, often due to recent snowfall, or well localized instability due to surface warming of sun-facing slopes in springtime. In both cases, natural release is likely, but does not involve the severe conditions meant by "HIGH NATURAL HAZARD".

A revised version of hazard scale is then proposed, in which "MODERATE NATURAL HAZARD" is split into two levels . Classical springtime situations with many natural releases occuring in the afternoon would be referred to as "LOCAL NATURAL HAZARD" , while widespread surface instability after a snowfall would be described as "NATURAL HAZARD".

In this proposed version, inspired of both the french scale and the swiss one, all "LOCAL" hazards are listed first before general ones. The extreme degrees (1 and 8) which provided a poor contribution to total information, are suppressed and melt together with their adjacent levels (2 and 8 respectively) bringing the total number to seven levels. This new scale is presented in Table 3.

The entropy of this new scale can be calculated and compared to the initial one, with expected values of the frequencies taking into account the new definition of the levels. It can be seen in Table 4 that the entropy would be higher (2.6 bit) and close to the maximum of a 7 elements code ($\mathrm{Log}_2 7 = 2.8$) . The lowest two frequencies are reached by level seven ("AVALANCHE SITUATION") and level four ("GENERAL ACCIDENTAL HAZARD") , which do not contribute much to information from a pure quantitative point of view. But although those situations do not occur frequently it appears useful to identify them by specific degrees, due to their threatening character.

1	**LOW HAZARD**	Snowpack generally stable. Natural release is unlikely. Accidental release hazard is weak
2	**LOCAL ACCIDENTAL HAZARD**	Snowpack mainly stable, with local latent instability. Natural hazard low but small avalanches may occur in steep slopes. Accidental hazard is marked, in some local places.
3	**LOCAL NATURAL HAZARD**	Snowpack mainly stable with local or temporary instability. Natural release is likely in some slopes . Accidental release hazard is marked in some local places
4	**GENERAL ACCIDENTAL HAZARD**	Latent instability of the snowpack in many slopes and orientations . Natural hazard low or local, but high accidental hazard (triggered release) widespread throughout area
5	**NATURAL HAZARD**	Surface instability is marked for many orientations. Natural release is likely in many slopes, mostly in surface layers. Accidental release hazard is marked in many places
6	**HIGH NATURAL HAZARD**	High general instability of snow-cover. Numerous natural releases are expected . Accidental release hazard also marked and widespread
7	**AVALANCHE SITUATION**	Very instable snowpack . Large snow accumulations may induce natural release of exceptional avalanches regarding size or path followed .

TABLE 3 . New avalanche hazard scale proposed .

LEVEL	1	2	3	4	5	6	7
equivalent in former scale	1+2	3	5(-)	4	5(+)	6	7+8
Expected frequency (%)	**11**	**32**	**17**	**6**	**17**	**12**	**5**
ENTROPY : 2.6 bit							

TABLE 4 . Expected frequency distribution for the new hazard scale, and corresponding entropy.

INTERPRETATION BY "USERS"

Although the avalanche hazard index is only a summarized information , and poor in comparison to a complete avalanche report, the use of such a scale appeared as a major step in avalanche prevention , and proved to be well appreciated by media and public authorities , as well as by skiers. As a complement to the classical avalanche report, it is an efficient communication tool, when sufficient explanation is delivered, in such a way that the numerical expression does not overshadow the full definition of the various levels and namely their qualitative aspect. An additional interest is that it allows objective skill evaluation of avalanche forecasts [4] , thus giving a way to assert, if needed,their credibility.

Some users find it convenient to rely directly on the hazard degree announced to decide wether they close a road or not, wether they start a ski tour or not etc. It must be pointed out that the hazard gradation is a global information which leaves aside all considerations regarding how the "user" will be exposed at risk (e.g. route , schedule ...) . Therefore one should not refer to the only hazard degree to assess liability of any part ("user" or "forecaster") in case of accident.

Owing to the multidimensional character of hazard, the index cannot be directly interpreted in terms of avalanche release probability , but a useful quantitative information is provided by the relative frequency of each degree over a long period. For instance , the concept of "AVALANCHE SITUATION" is well illustrated by the fact that this degree is only reached in 5 % of the cases, and we can point out that in 60 % of the cases hazard is only thought to be "LOW" or "LOCAL" . The relative frequencies are indeed the only well defined, easily measurable parameters and, if the forecasters keep these frequencies stable for similar winter conditions , it provides essential references for a right interpretation of the hazard scale.

Through the scale presented above that is inspired from swiss and french hazard scales , we propose an element in the way towards unified information methods among the different countries involved in avalanche prevention.

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