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Use of Expert Knowledge in Avalanche Forecasting

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ABSTRACT

Two computerised modules for avalanche forecasting, including the results of field testing and experience with the products have been discussed. The modules refer to 'numerical prediction system' and a 'rule-based expert system'. The numerical portion of the system uses discriminant analysis (both parametric and nonparametric) and Bayesian statistics to yield estimates of the probability of avalanching based on calculations in 6-7 dimensional discriminant space. Two years of field testing (1992-94) has shown that the predictive capability of the system is very consistent, an accuracy of about 80 per cent has been achieved. Rule-based expert system interprets snowpack structure from snow pit profiles. This part of the system consists of non-numerical algorithms. The system has been field-tested in four field areas during the winter of 1993-94. This has resulted in the refinement of the rules and the product is considered to be suitable for operational use.

1. INTRODUCTION

In this paper, two computerised modules for avalanche forecasting, including field testing and experiences with them, have been discussed. The two modules are (i) AUBC: a numerical prediction system which combines a numerical estimate of the probability of avalanching and an expert's degree of belief using Bayesian statistics, and (ii) snow profile assistant: an expert system for snow profile interpretation, entirely independent of the numerical data analysed by the former module. They provide computer assistance to persons with only a basic level of experience, in forecasting avalanches with a predictability efficiency of 80 per cent.

Avalanche forecasting consists of prediction of current and future snow stability. Current research at the University of British Columbia is aimed at changing forecasting from an intuitive art to a science. The approach comprises the development of numerical and expert system modules using all the data available (numerical and non-numerical) to a forecaster. The strategy can be defined in three parts as outlined below.

Part I provides an explanation of data classes McClung and Schaerer[1] and their relation with the scale, character and formulation of the forecasting problem. Essentially, the method consists of ranking the data into three classes based upon their relevance and ease of interpretation with regard to avalanche forecasting. Here, it may be noted that some data have numerical character while some others have non-numerical character. Figure 1 gives a schematic of data classes according to the foregoing scheme. The higher the class number, the less easy it is to interpret the data with respect to avalanche potential. Class III data consist mainly of snow and weather data taken at regular intervals, e.g. data taken at snow study plots and from local mountain-top weather information. This class of data consists of observations, which are correlated and mainly of numerical type. We use these data in numerical algorithms in the numerical portion of our system. Class II data are taken to assess if the snowpack has any weakness in it and, if so, what is the avalanche potential. Typical information comes from the analysis of snowpack stratigraphy. This class of data is largely of non-numerical character. An expert system has been

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developed to interpret snow profiles. The expert system is described in subsequent paragraphs. Class I data are those which have direct bearing on stability prediction of a snowpack. These data are largely non-numerical but the evidence is usually so direct that no computer analysis is needed to assist the forecaster in prediction. Examples include: avalanche occurrences, crack propagation and results of stability tests.

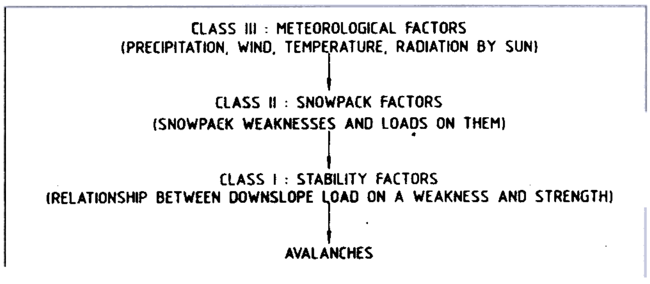

Figure 1 Simple causal chain showing data classes used in forecasting avalanches. The higher the class number, the less direct is the interpretation with respect to snow stability.

Part II describes the numerical portion of the system. This part uses discriminant analysis (both parametric and non-parametric) and Bayesian statistics to give estimates of the probability of avalanching based on calculations in 6- or 7-dimensional (depending on whether dry or wet avalanches are expected) discriminant space.

Part III lays down the method of using the non-numerical data in the system. This portion consists of an expert system to analyse snow profiles. The input information consists of data taken from a standard snowpack profile or test profile[1]. These data are then analysed by the use of a series of rules extracted from the interviews of avalanche forecasters to produce an analysis of snow stability. The snowpack profile data used in this portion of the system are almost completely independent of snow, avalanche and weather data analysed by the numerical portion of the system (Part II above).

2. NUMERICAL PORTION OF THE SYSTEM

The data used in the analysis are numerical in character, e.g. snow, weather and avalanche occurrence information collected at regular intervals. A historical database (about 10 years of records) is analysed and compared numerically with the parameters measured at the time the forecast is sought. In addition, the forecaster's degree of belief about the probability of avalanching is converted into a probability to be combined in a dynamic (real-time) sense to yield a 'posterior' probability which is used to issue warnings. Two years (1992-94) of rigorous, operational field testing with the system shows that the predictive capability of the system is very consistent; accuracy is about 80 per cent : 1992-93 and 78 per cent : 1993-94 during both avalanche and non-avalanche periods. We believe that this accuracy gives an uncertainty which approaches the residual uncertainty in the avalanche forecasting problem.

The non-parametric discriminant analysis (nearest neighbours calculations) gives the forecaster highly relevant information about snow, weather and avalanche activity for similar situations in the past. The system produces calculations of the 30 closest points (nearest neighbours) in discriminant space (6- or 7-dimensional for Kootenay Pass, B.C.). These are compared with the present situation defined by the input data vector. The calculations are made with the Mahalanobis distance metrics so that the correlations among the variables are retained. McClung and Tweedy[2] have provided a mathematical framework for the system. The analysis includes graphical display of the avalanche activity for the 30 nearest neighbours. This comprises information about the avalanches in the past including: avalanche activity[1] (sum of the sizes on the Canadian size scale), a moisture index (average moisture content of observed avalanches : dry, moist or wet) and information about the trigger, e.g. natural or artificial. Table 1 gives an example of the numerical output of the system. Figure 2 presents graphically the summary of avalanche occurrences for 10 of 30 nearest neighbours. Graphical display were used to compare the predictor variables for the present situation with any one of the nearest neighbours. For the latter graph, standardised variables were used so that all variables range over the same scale. Figure 3 gives an example of comparing predictor variables with a past nearest neighbour. Our experience shows that the text output of nearest neighbours, the probability calculations and the graphical output are all very useful to the operational forecaster.

3. RULE-BASED PORTION OF THE SYSTEM

Avalanche forecasters also use non-numerical information to forecast avalanches. To approach the

Prediction Summary

Prediction for: 9 December 1993, 08:20

Bayesian Statistics

A priori probability of a dry avalanche day: 0.50 (forecaster's estimate)
Probability of a dry avalanche day: 0.94
Type of avalanche day predicted: Dry
A Priori probability of avalanching: 0.50 (forecaster's estimate)
Probability of avalanching: 0.89

Cluster Analysis

Ten closest points: 60 per cent avalanches
Thirty closest points: 50 per cent avalanches

Table 1. Example of numerical output from the numerical system, AUBC

Date	Time	Avalanches	Magnitude	Moisture	Distance
14 February 1984	06:00	Y	17.0	1.00	0.30
30 December 1986	06.00	Y	13.0	1.00	0.35
1 January 1986	18:00	Y	4.5	1.00	0.47
30 March 1985	18:00	N			0.71
23 November 1987	06:00	N			1.03
19 March 1987	06:00	N			1.18
14 March 1988	06:00	N	–	–	1.29
6 March 1988	06:00	Y	14.0	1.00	1.49
18 January 1991	18:00	Y	21.0	1.00	1.50
23 February 1986	18:00	Y	18.0	1.22	1.64
13 January 1987	18:00	Y	15.5	1.00	1.66
6 January 1986	06:00	Y	6.0	1.00	1.68
4 February 1990	06:00	Y	37.0	1.05	1.85
17 November 1986	06:00	N	–	–	1.93
23 December 1986	06:00	Y	15.5	.00	1.13
30 December 1983	06:00	N		–	2.14
25 November 1983	06:00	Y	8.0	1.00	2.32
14 December 1986	06:00	N			2.33
22 November 1990	06:00	N			2.44
1 December 1986	06:00	N			2.46
7 February 1983	06:00	N			2.49
5 March 1988	06:00	N			2.49
24March 1985	06:00	N	–	–	2.54
8 December 1983	06:00	Y	4.0	1.00	2.56
18 November 1986	18:00	N			2.59
19 November 1984	06:00	N		–	2.70
2 March 1987	18:00	Y	2.5	1.00	2.71
18 December 1990	06:00	Y	27.0	1.00	2.74
15 March 1986	06:00	N	–	–	2.80
24 January 1984	18:00	Y	8.0	1.00	2.81

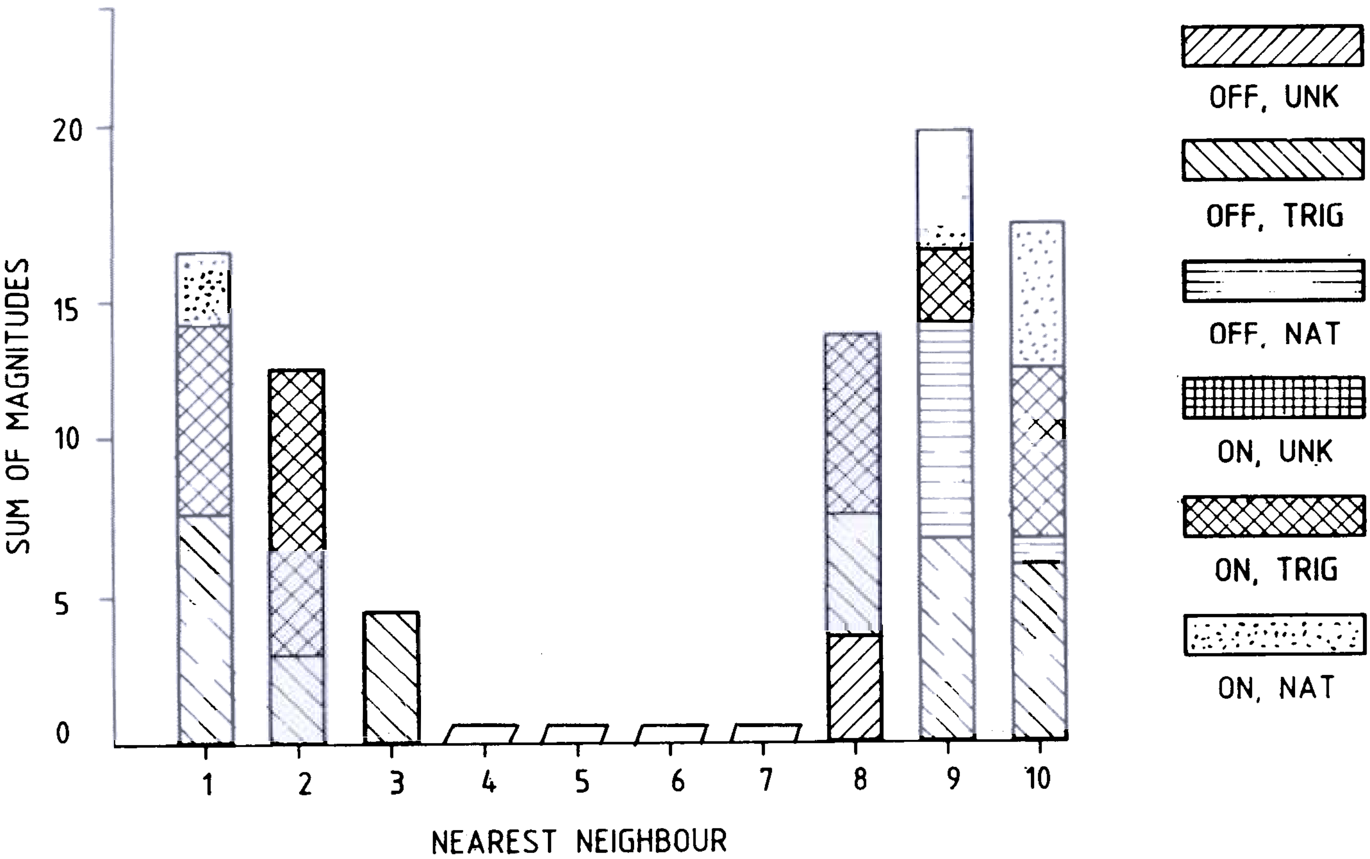

Figure 2. **Graphical presentation of avalanche activity for the first 10 neighbours for the predictor day in Table 1**

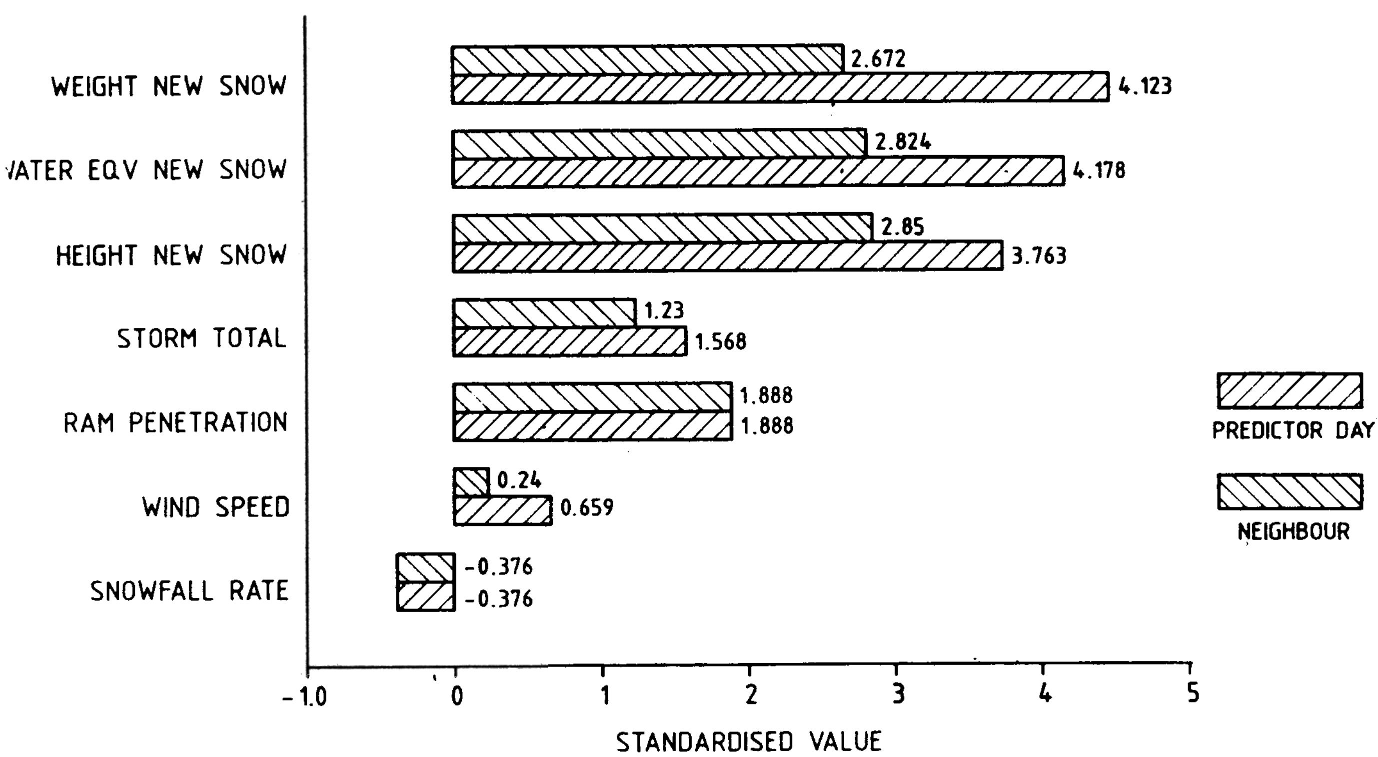

Figure 3. **Graphical presentation of predictor variables for the predictor day against the last nearest neighbour.**

accuracy achieved by forecasters through experience (traditional method without the use of computer analysis), a need was felt to use the same 'data' sources which they use. To encompass this information, a rule-based expert system has been developed to interpret snowpack structure from snow profiles. In contrast to the use of expert knowledge in a dynamic, Bayesian sense (Part II), one could describe the use of expert knowledge in this portion as static : rules are essentially fixed from one forecast to another. The data in this part of the system are nearly independent of the data analysed in the numerical portion of the system (Part II). This portion of the system consists of non-numerical algorithms developed on the basis of the rules described by expert forecasters. The software was developed initially from influence diagrams constructed for slab and loose snow avalanches (both wet and dry). These diagrams define the rule structure in a casual, graphical sense. The system has been field-tested in four field areas during the winter of 1993-94. This resulted in refinement of the rules to give a product which can be used operationally for assistance to forecasters. The system was built within the expert system shell LEVEL 5 OBJECT and it runs on an IBM-compatible personal computer.

The system analyses each layer in the snowpack in combination with those that surround it. For loose snow avalanche potential, only the top layer needs to be analysed and rules have been instituted based mainly on hardness, temperature, crystal forms (state of metamorphism), crystal size and shape, densitv and water content. For slab avalanche potential, the entire snowpack is considered by first assessing whether the slab structure is present, i.e. if a relatively thin weak layer is contained between two layers with greater hardness or strength. Analysis takes into account hardness, crystal forms (state of metamorphism), crystal size, shape and state of bonding to adjacent layers, temperature, temperature gradient, layer thicknesses, water content, and information from stability tests[1].

The snow profile analysis is reported on screen by text for the three most significant layers with respect to avalanche potential. A graphical display, including the analysis (stratigraphy) of all the layers of the snowpack is also prepared (Fig. 4). For each analysis, a 'certainty factor' (Ref: 3, p. 4-5) is given for a relative ranking of layers for avalanche potential. The certainty factor is a number between 0 and 1 which increases in value cumulatively for a layer depending on the accumulated potential for the layer to play a role in future avalanching. For the graphical display, we highlight all layers for which the certainty factor exceeds a threshold that we set (for example, 0.6 at present).

4. DISCUSSION

The modules described in this paper are intended to provide computer assistance to persons wishing to forecast avalanches. They cannot and should not be used by people without field experience. The basic premise is that to forecast avalanches by computer assistance, the same data sources as used by successful forecasters based on experience shall be used. The success of the numerical module in our field testing is based upon two related features of the model. First, the snow and weather variables are correlated and we retain the correlations throughout the calculations, including the nearest neighbour analysis. The field results show that the system approaches human capability in forecasting accuracy. The second important feature of the system is the use of Bayesian statistics. Field testing shows that the most consistent forecast comes from the posterior probability which combines the (conditional) numerical forecast with the forecaster's degree of belief (roughly *a priori* probability). This feature allows information to enter the forecast from outside the numerical information included in the numerical forecast alone.

The rule-based snow profile interpretation expert system is mainly targeted for people with somewhat limited field experience. The two parts of snowpack stability evaluation from snowpack profiles comprise : (i) gathering the information, the first level of experience, and (ii) the analysis and interpretation of the stability. The expert system is designed to help this second part. Most experienced avalanche forecasters would be able to handle both parts of this process but people with only a basic level of experience will most likely find the expert system of greater significance.

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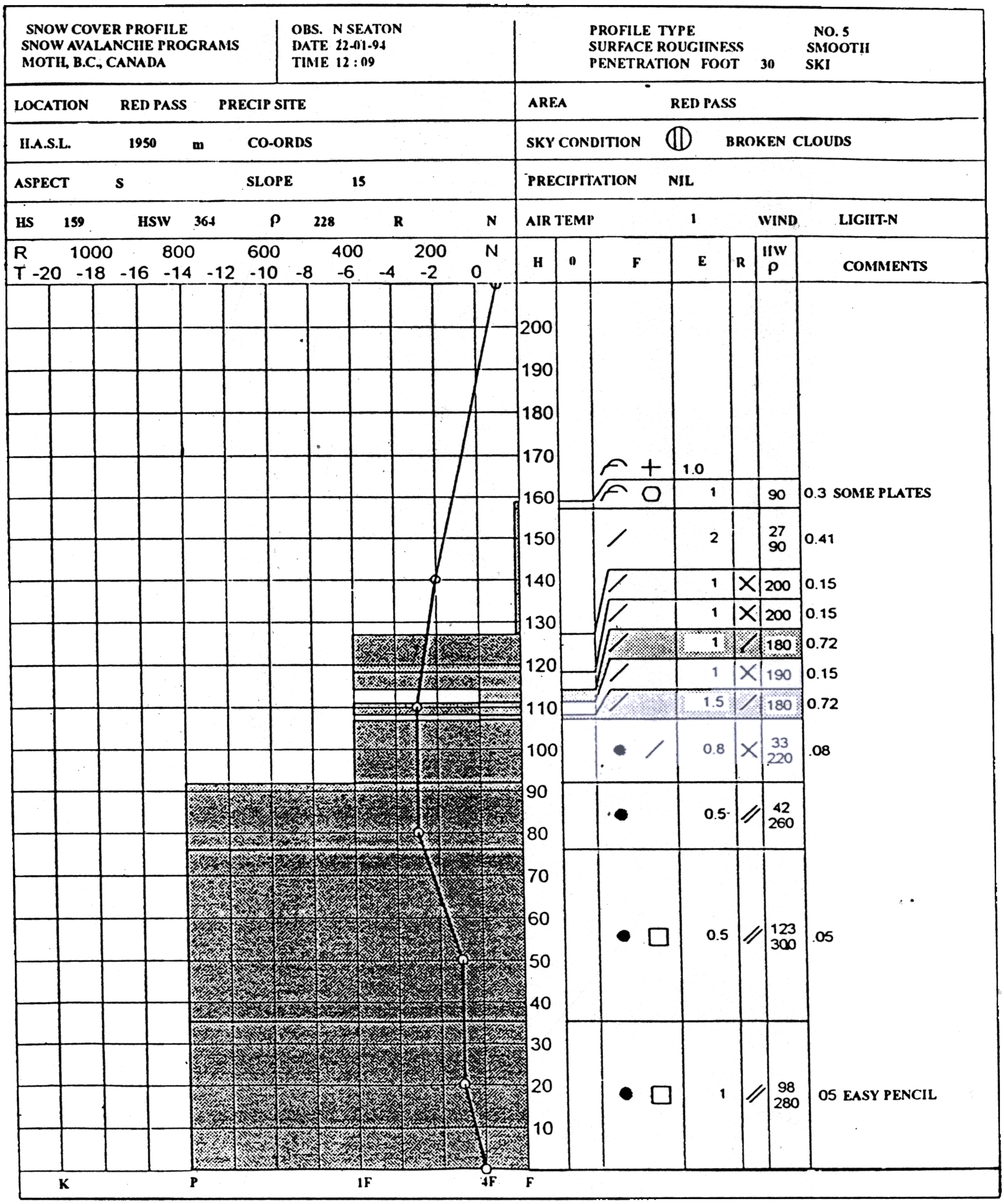

Figure 4. Graphical presentation for the module: snow profile assistant.

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