AN EXPERIENCE OF AVALANCHE DIAGNOSTIC AND FORECAST MODELS VERIFICATION

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ABSTRACT. Verification of several types of avalanche occurrence diagnostic and forecast models used by the Centre of Avalanche Safety in the Khibiny Mountains are described. Validity of one and two-dimensional empirical models, multi-dimensional statistical and stochastic models applied to separate avalanche sites and the whole area is considered. Wind speed and direction and precipitation or snowdrift intensity were used for the simple empirical models as predictors. Some more standard meteorological and snowdrift parameters were used in different schemas of discriminant analysis and by the method based on Bayes' formula. The data for last 10 – 20 years were treated. Categorically and probabilistically formulated forecasts were analysed. A correlation coefficient between forecasted and observed situations – Obukhov's criterion is calculated for categorical forecasts and Brayer's criterion for stochastic ones. Comparison of the different models quality was carried out. Warnings made by avalanche forecasters with the models and their subjective experience are evaluated too. Quality of the slushflow diagnostics is considered separately.

1. INTRODUCTION

As far as ideal avalanche forecast models are absent, there are some reasons to verify existing models, for example, to choose the best one or to evaluate possible losses due to forecast errors. Verification also can be useful for an analysis of errors and improving of the forecast models. So forecast makers and users both are interested to know the results of the verification. Of course the forecast castomers most of all want to know spatial and temporal evaluations of an avalanche risk - characteristic which takes into account the avalanche occurrence possibility, its dynamics and interaction with an object, vulnerability of the object. Unfortunately there are no such integrated models and in practice the risk evaluations are making subjectively. The models for avalanche occurrence diagnostic and forecast are discussed here. The models used at the Center of Avalanche Safety of "Apatit" JSC (CAS) from late thirties till now where selected for verification. So called, "scientific verification" was made, when forecasted avalanche occurrence was compared with reality on a base of special criteria.

2. DIAGNOSTIC AND FORECAST MODELS

Diagnostic and forecast models are considered as a set of formal rules for interpretation of input data and getting quantitative or qualitative conclusion on its base about avalanche occurrence possibility. Really the models which forecast an exact time and exact place of avalanche occurrence have not been used in CAS. Usually they just give an opportunity to say whether a period with a definite avalanche occurrence probability have begun or not. Thus it is rather a real-time avalanche diagnostics than a forecast and some models are just rules for classification of the situations which say nothing when avalanche can occurred before an a moment of diagnostics or after. When the categorical conclusions such as "avalanche situation" and "non-avalanche situation" are used the calculated and threshold probabilities are a base for them. Some of the models are applied to all genetic types of avalanches, but some of them to certain ones only. Brief description of the models is given below.

Zelenoy's (1937) method – an empirical rule worked out for a small area 5×3 km^2 with about 50 avalanche sites. It was considered that at least one avalanche release could occur in days when the wind speed at the valley weather station was more than 10 m s^{-1}. The wind speed 10 m s^{-1} is very close to the threshold wind when snowdrift starts.

Akkuratov's (1956) model – an empirical rule, which instead of indirect snowdrift characteristics uses snowdrift intensity measurements at the top of the

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mountain. The model was used for so called snowstorm avalanches, which are formed of fresh snowstorm snow and release in time of the snowstorm. Avalanche period starts when total amount of snowdrift with intensity 0.25 kg m^{-2} s^{-1} in 2 cm near surface layer is overcoming 1000 kg/m. This rule is applied to the same area as Zelenoy's model.

Linear discriminant analysis – discriminate situations with a linear function in multivariate space of diagnostic parameters. There have been used two types of a linear discriminant analysis. First one (Chernouss, 1975) was worked out for avalanche situations recognition in a grope of four avalanche sites located very close one to another and having almost the same starting zone inclination and aspect. The model was applied for snowstorm avalanches. Nine weather and snowdrift characteristics, which characterise snowfall from the beginning to the moment of diagnostics, were taken as the diagnostic parameters. In a second schema (Chernouss and others, 1998) of the analysis snowfalls were classified on avalanche and non-avalanche. A snowfall is considered as avalanche one when at least one avalanche release is observed in the area (the model is applied to the same area as Zelenoy's and Akkuratov's models. The discriminant functions where obtained for each sixth hour since snowfall beginning. An advantage of this model relatively first one is an opportunity to use different evaluations of mathematical expectations and variances of the parameters at different stages of the classification. Linear discriminant analysis was also applied for recognition of days with and without slushflows. Situations were described with daily water income (a parameter calculated on a base of standard meteorological observations) and snow height.

Bayes' formula – the model was worked out by Zuzin (1989) and has been used in CAS since 1978. The model is applicable for all genetic types of avalanches without any differentiation. A situation is considered as avalanche one when at least one avalanche release is observed in the area for which all above-mentioned models have been used. On a basis of meteorological measurements and avalanche release records two groups of the empirical probability densities of such parameters as: snow height, daily precipitation, mean daily wind speed, mean daily temperature – were obtained for days with and without avalanches. Bayes' formula is using these distributions to recalculate apriori probability of avalanche situation taking into account the data on current situation, described with the same parameters. In practice 24 h gliding averages are used as input parameters for classification of gliding one day periods on avalanche and non-avalanche. Bayes' formula was also applied for recognition of days with and without slushflows. Situations were described same way as for discriminant analysis.

Statistical simulation – the main idea of the method to generate input data for deterministic models of snow cover mechanical stability on mountain slopes (Chernouss, 1994). The data are generated in accordance with statistical lows of the snow cover parameters spatial distributions. The simulation was used for two dimensional slope of arbitrary configuration. Parameters of the snow cover were represented by stochastic functions and snow stability for real slopes was calculated for separate profiles. Evaluations of snow height, density and shear strength mathematical expectations, their variances and autocorrelation functions were used as input parameters for the model. The results of the classification were the probabilities of snow release for different segments of the profile and probability of avalanche release.

Synoptic model – It is for snowstorm avalanches forecasting. The model (Izhboldina, 1975) binds avalanche releases with previous synoptic situations (24 hours before). Each situation was described with a set of parameters to evaluate avalanche releases probability. Later (Polkhov and Izhboldina, 1977) the method was formalised by discriminant analysis using.

3. CRITERIA FOR THE MODELS VERIFICATION

The categorical and probabilistic forecasts were verified with different characteristics and criteria using: 1) $P \times 100\%$ – percentage of correct forecasts, when forecasts coincide with observations, 2) "post agreement" - $P_a \times 100\%$ – percentage of correct forecasted avalanche situations, $P_n \times 100\%$ – percentage of correct forecasted non-avalanche situations, 3) "prefigurance" - $P^a \times 100\%$ – percentage of correct "avalanche" forecasts, $P^n \times 100\%$ – percentage of correct "non-avalanche" forecasts, 4) Q – Obukhov's criterion (1955) for alternative forecasts, 5) χ^2 criterion, 6) Brier's criterion (1958) for probabilistic forecasts. Contingency tables were a base for calculations of all criteria for categorical forecast verification. Obukhovs' criterion:

$$Q = 1 - \alpha - \beta$$

where $\alpha = 1 - P_a$ and $\beta = 1 - P_n$, changing from 0 for random, climatological, inertial or other "blind" forecast models to 1 for an ideal model, make a sense of correlation coefficient between forecasts and observations. The higher Q the better the model. To evaluate a significance of the differences between the results obtained with tested forecast model and some "blind" model χ^2 criterion is applied. Briers' criterion expression for probabilistic forecasts is:

$$E = 1 - \frac{1}{2N}\sum_{j=1}^{2}\sum_{i=1}^{N}(P_{ij} - E_{ij})^2$$

where: j – 1,2 – numbers of classes, j = 1 – avalanche situations, j = 2 – non-avalanche situations, i - number of situation, P_{ij} – calculated probability that i – situation belongs to j – class, E_{ij} are 1 or 0 depending on whether i – situation belongs to j – class or not. As for Obukhov's criterion, it is equal 1 for ideal forecasts when all situations have been forecasted with probability equal 1.

4. RESULTS AND DISCUSSION

As it was said already, all models except synoptic one can be considered as only diagnostic ones if real time input data are used for them. All of them can be used as forecast ones if to use forecasted input parameters or extrapolate the output data in time. Here mainly the results of verification for diagnostic models are presented, special reservations are making for forecast models.

Zelenoy's model worked well for avalanche situations (P_a = 0.85), but it gave too many errors in recognising of non-avalanche situations (P_n = 0.25). Q criterion was equal 0.20 only. If to modify the model by adding two necessary conditions for avalanche occurrence – fresh snow presence and thaw absence - P_n grows to 0.50 and Q to 0.30, P_a decrease very slightly to 0.80.

Akkuratov's model . It was difficult to verify this model for whole area which it was worked out, because very frequently a genetic type of released avalanches was unrecognised. When the model was applied for classification of situations for the group of four avalanche sites (as in the first type of discriminant analysis) obtained Q – value was 0.43. Of course for whole area Q will be higher.

Linear discriminant analysis. For the first type of discriminant analysis the next results were obtained: P = 0.85; P_a = 0.60; P_n = 0.97; P^a = 0.91; P^n = 0.83; α = 0.40; β = 0.03; Q = 0,57. Correlation between forecasts and observations essentially higher than for Zelenoy's and Akkuratov's methods. That could be achieved due to using of additional parameters for describing of the situations. The characteristics of the verification of second type of discriminant analysis presented in Table 1.

Time since snowfall beginning (h)	Threshold probability for O_{max}	O_{max}	P_a	P_n	P
6	0.10	0.23	0.87	0.36	0.43
12	0.15	0.29	0.57	0.72	0.70
18	0.15	0.36	0.67	0.69	0.69
24	0.20	0.43	0.63	0.80	0.77
30	0.20	0.43	0.67	0.76	0.74
36	0.20	0.36	0.61	0.75	0.72
42	0.20	0.45	0.73	0.72	0.73
48	0.30	0.46	0.69	0.77	0.75
54	0.35	0.57	0.72	0.85	0.81
60	0.30	0.63	0.84	0.79	0.81
66	0.30	0.60	0.89	0.71	0.78
72	0.30	0.65	0.94	0.71	0.80
78	0.40	0.79	0.94	0.85	0.89
84	0.45	0.80	0.93	0.87	0.90
90	0.50	0.84	0.91	0.93	0.92

Table 1. The results of snowfalls categorical diagnostics on "avalanche" and "non-avalanche" for different periods since snowfall beginning. Snowfalls of 1980 – 84.

It is evident that quality of the classification increases with time since snowfall beginning, that is averaged trajectories avalanche and non-avalanche snowfalls in a space of the diagnostic parameters diverge more and more with time. Classification of the snowfalls at different stages is an advantage of this type of analysis comparatively with first one.

Bayes' formula. Verification of the model was made on data for ten winters. The result was extremely high – E = 0.85. Comparison of the calculated integral probability of avalanche situations - P with empirical one - P_e (Zuzin, 1989) is given in Table 2.

P	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80
P_e	0.11	0.22	0.34	0.46	0.60	0.74	0.87	1.00

Table 2. The results of comparison of the calculated integral probability - P with empirical one - P_e

Statistical simulation. This model is not verified enough reliable because of data absence. Twenty situations (8 avalanche and 12 non-avalanche ones) were discriminated on avalanche and non-avalanche (by highest probability) and only one error was got, non-avalanche situation was recognised as avalanche one.

Synoptic model. This models gives an opportunity to forecast avalanche releases a day before their occurrence with accuracy P_a = 0.55 – 1.0 depending on a type of the synoptic situation. Due to big indefiniteness in forecasting of places where the avalanches can occurred and absence of consumers for such forecasts in the Khibini Mountains they were stopped as a formal procedure and now synoptic information is taken into account only subjectively.

Some results of verification of subjective conclusions on avalanche danger. In practice a final categorical formulation of avalanche forecast are making subjectively on a base all available information. It is interesting to verify this forecast too. If to try to make forecast formulations more definite in time and space its validity drops sharply. The results of the forecast verification for nine winters are below.

		Observed situations: avalanche	Observed situations: non-avalanche
Forecasted situations	avalanche	41 P_a=0.263 P^a=0.011	3812 β=0.037
Forecasted situations	non-avalanche	115 α=0.737	100256 P_n=0.963 P^n=0.999

Table 3. Contingency table for subjective 3 hour avalanche occurrence forecasts for each of eight separate avalanche sites.

Quality of such forecast is very low. Only one of one hundred "avalanche" forecast is accurate. Only 26% of avalanche situations are forecasted correctly. Q = 0.23 is very low. But test with χ^2 criterion showed that with probability 0.9999 there is significant difference between these forecast and random ones. And above all such forecasts are real forecasts in time and space and are most valuable for their consumers. Only forecasts when besides avalanche occurrence its run out distance is evaluated are some more valuable for the consumers. In Table 4 the results of verification of such forecast are presented.

		Observed situations: avalanche	Observed situations: non-avalanche
Forecasted situations	avalanche	6 P_a=0.25 P^a=0.002	3491 β=0.034
Forecasted situations	non-avalanche	18 α=0.75	100709 P_n=0.966 P^n=0.9998

Table 4. Contingency table for subjective 3 hour avalanche danger forecasts for each of eight separate avalanche sites. Whether or not an avalanche reach objects in the run out zone (railroads, automobile roads, open pits).

Q - value the forecasts almost same as for only avalanche occurrence prediction, but P^a in five times more worse.

Slushflow diagnostic models. Results of the discriminant analysis model verification for the Khibini Mountains: P = 0.85; P_a = 0.79; P_n = 0.86; P_a = 0.06; P_n = 0.997; α = 0.21; β = 0.14; Q = 0,65; and for mountains of Norway: P = 0.87; P_a = 0.76; P_n = 0.84; P_a = 0.40; P_n = 0.97; α = 0.24; β = 0.16; Q = 0,60. Quality of the diagnostics enough high for first numerical models.

5. CONCLUDING REMARKS

Survey of the existed models applicability for verification are reduced due to short period of using. Some models exist just like conceptual ones and are formalised insufficiently. As carried verification showed it is difficult to test some models intended for specific genetic types of avalanches because of absence of reliable signs which permit indicate types by direct observations. It can be a reason of non-homogeneity of the test samples and decrease the verification results. Good classification of the situations with a model is not enough for good forecast. Besides the model should give precise forecasts in time and space. Quality of the models decrease strongly if to try forecast avalanches in a separate starting zone in a short period of time, but the models for big areas and long periods of time have a very reduced number of forecast consumers. A part of the errors in categorical forecast formulation (high misclassification of avalanche situations) can be explained by incorrect choosing of the threshold probabilities. At present there are no guidelines how to fix them and the forecasters do that subjectively. Using of the statistical simulation with a reliable deterministic model of snow cover stability are perspective. Applicable for practice stochastic forecast models should be worked out. Presented results of the verification could be used for comparison different models for a single area to choose best one or the same model in different areas to evaluate an influence of spatial and temporal variability of predictors in different geographical conditions on forecast quality.

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7.REFERENCES

Akkuratov V.N. 1956. Prognoz nastupleniya lavinnoy opasnosty po velichinam metelevogo perenosa i temperaturnogo szhatiya snega [Avalanche danger forecasting on a basis of snowdrift and temperature compression of snow] In Voprosi ispolzovaniya snega v borbe s zanosami i lavinami [Questions of snow using for a struggle with snow drifts and avalanches]. Moscow, Publishing house of Academy of Sciences of USSR, 167-183.

Akkuratov V.N. 1959. Geneticheskaya klassificaciya lavin [Genetic classification of avalanches] Trudi Elbrusscoy visokogornoy komplexnoy expedicii [Proceedings of Ebrus high mountain complex expedition]. 1(4). Nalchik, 215-232.

Bolognesi R. 1998. Inferential statistics to verify prediction models.Ann. Glaciol., 26, 367-369.

Chernouss P.A. 1975. Primenenie mnogomernogo discriminantnogo analiza dlya raspoznovaniya lavinoopasnih situacy. [An application of the multivariate discriminant analysis for avalanche danger recognition] In Issledovaniya snega i lavin v Hibinah [Snow and avalanche study in the Khibini Mountains]. Leningrad, Hydrometeoizdat, 64-70.

Chernouss P.A. Statistical modeling of snow cover stability in mountain slopes. 1994. ISSW'94. International Snow Science Workshop, 30 October-3 November 1994, Snowbird, Utah. Proceedings. Snowbird, UT, P.O. Box 49, 341-345.

Chernouss P.A., Perlikov A.M., Mokrov Ye.G. 1998. Avtomatizirovannoe rabochee mesto prognozista snezhih lavin [Automated working place of an avalanche forecaster], Data of Glaciological Studies, 84, 72-75.

Chernouss P., Tyapkina O., Hestnes E., Bakkehoi S. 1998. The differentiation of thaws in connection with slushflow occurrences. Conf. Proc. 25 Years of Snow Avalanche Research, Voss 12-16 May 1998, Publication 203, Oslo, NGI,89-93.

Izhboldina V.A. 1975. Aerosinopticheskie usloviya obrazovaniya i shoda metelevih lavin na Kolskom poluostrove [Aerosynoptical conditions of snowstorm avalanche releases in Kola Peninsula] In Issledovaniya snega i lavin v Hibinah [Snow and avalanche study in the Khibini Mountains]. Leningrad, Hydrometeoizdat, 51-63.

Obukhov A.M. 1955. K voprosu ob otcenke alternativnikh pronozov [On verification of alternative forecasts]. Izvest. Acad. Nauk SSSR. Ser. Geofiz., 4, 339-350.

Panofsky H.A., Brier G.W. 1958. Some applications of statistics to meteorology. University Park, Pensilvania, 243.

Zelenoy I.K. 1937. Snezhnie obvali v raione goroda Kirovska i svyazannie s nimy meteorologicheskie faktori [Avalanches in Kirovsk region and meteorological factors bound with them] Meteorology and Hydrology, 4-5, 147-152.

Zuzin Yu.L. 1989. Opit ispolzovaniya bayesovskogo podhoda dlya indicacii lavinnoy opasnosty v Hibinah [An experience of Baesian approach using for indication of avalanche danger in the Khibini Mountains] In Trudi tretego vsesoyuznogo soveshania po lavinam [Proceedings of third all-union workshop on avalanches]. Leningrad, Hydrometeoizdat, 185-187.