IMPROVING STATISTICAL MODELS BY MODIFYING THE AVALANCHE VARIABLE

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Introduction

Statistical models which attempt to minimize the statistical noise caused by errors in the observational data and by the use of independent variables which cannot completely describe the variance of the dependent variable are being developed at the Northwest Avalanche Forecast Office in Seattle. This has involved both the modification of the input data used in the model development and rethinking of the forecast variable.

The quality of the models being produced must be gauged by the assistance they provide to a forecaster in a central office. The philosophy is that models provide information which can act as a parallel, redundant system to the human thought process. The statistical models should not be expected to replace or short-cut the judgmental decisions necessary in forecasting, but should be designed to facilitate them.

Statistical "Noise" in the Avalanche Variable

One of the limiting factors in the quality of statistical models is their dependability on the input observations. Although problems occasionally arise in the meteorological and snowpack observations, the most significant errors usually occur in the avalanche observations.

Observational inconsistencies in the avalanche data have long been recognized as a prime contributor to scatter in statistical models. The first difficulty lies in the number of different observers involved having varying degrees of training, dedication, and perception. This fact alone renders the more subjective observations such as size, moisture content, etc., almost useless for statistical analysis. Further, uncontrollable variations in visibility, access, or illness introduce additional uncertainties. The most important effect of these factors is the introduction of confounding variables into the statistical relations about which there is no associated information. For example, the data does not include any information about the visibility or the health of an observer on any given day, although these factors will affect the observations.

Hence, given the same set of weather and snow conditions twice, avalanches may be observed one time but not the next, although they may occur in both instances. This introduces unacceptable scatter into the statistical relationships and implies that the models can only forecast the probability of an avalanche being observed, not the probability of an avalanche occurring.

Additional noise may be introduced into the models by the intermingling of observations of naturally and artificially triggered avalanches. All conditions being the same, it is likely that more avalanches will be produced and recorded when avalanche control work is done than when it is not. Fortunately, this information is usually recorded and can be taken into account in the analysis.

The second major source of noise in the statistical models may lie in the basic idea of using avalanche occurrences as the forecast variable whereas the snowpack stability is the phenomenon of interest. Unfortunately, in most cases the occurrence or lack of occurrence of an avalanche is the only measure used for the stability of the snow.

LaChapelle et al. (1979) introduced an index which measures the stability of the snowpack in terms of the minimum trigger energy required to initiate a slab avalanche. The index is based on the logarithm of this energy in joules (Table 1). Thus a snowpack characterized by a stability index "n" is said to be conditionally stable as long as a trigger of size "n" or larger does not occur. Simply stated, the stability of the snowpack is the consequence of the antecedent weather and snow conditions, and the occurrence of an avalanche is a combination of this stability and the occurrence of a trigger. As the stability index decreases, the chance of a critical trigger occurring increases.

This type of stability approach is especially attractive for avalanche forecasts covering large areas, involving hundreds or even thousands of avalanche paths. When a large area is thought of as a unified system, the occurrence of an avalanche on individual paths naturally becomes probabilistic, being determined by the general stability state which characterizes the system and the occurrence of triggers. Thus, a given set of snow and weather conditions produces a system which contains avalanche paths with all levels of conditional stability; certain stabilities being more probable than others, depending on the antecedent conditions. The occurrence of an avalanche in an individual path within the system then depends on the product of the probability of the path having a certain conditional stability and the probability of the occurrence of a trigger of the appropriate size to cause failure (Figure 1).

When considered in terms of a unified system, some apparently anomalous occurrences become foreseeable. For example, the proverbial "pocket of instability", the occurrence of isolated avalanches in a generally stable snowpack, is seen to be associated with the occasional avalanche path whose stability state lies in the tail of the distribution for the whole system. Paths which are in lower conditional stability states ordinarily slide due to the high probability of a trigger occurrence. This leads to these isolated situations being "observed" more often than they actually occur in the whole population.

It can be seen that one of the advantages of using a stability index as the dependent variable in the statistical models, instead of avalanche occurrences, is the index's more direct dependence on the routinely measured independent variables. This should cause a substantial decrease in the statistical noise due to the removal of unmeasured, confounding variable dependencies. An additional benefit of using the stability state as the dependent variable is the removal of the dichotomy between naturally and artifically triggered avalanches.

Modification of the Observed Avalanche Data

The complete removal of errors, and hence statistical noise, from the avalanche data cannot practically be accomplished. However, two methods of screening the avalanche data before it is submitted to statistical analysis are being investigated. One method uses the usual concept of avalanche occurrence observations, while the second attempts a practical application of the stability state of the system. Both methods rely heavily on the subjective skills of an experienced forecaster.

The first method requires the careful scrutiny of the observed varibles by a forecaster, determining on which days the avalanche observations do not appear consistent with the weather and snow observations. These situations are excluded from the analysis, decreasing the noise introduced by inconsistent data. A somewhat similar approach is described by Obled and Good (1980), although their method consisted of giving added weight to those avalanche observations judged especially reliable. An unfortunate side effect of the deletion is the depletion of the avalanche occurrence sample.

In the second method, an experienced forecaster evaluates the data available for each day and assigns a representative value of the stability index to the area in question. On days when avalanches and their associated triggers are observed, these observations are used to define the stability index. On days when no avalanches are observed, either due to observational difficulties or to their true non-occurrence, the forecaster makes a subjective decision as to the appropriate stability index. The merit of this approach is that no data are excluded from the analysis, except in those instances where the independent variables are missing or inconsistent.

These two methods of screening the data have the important asset of introducing the knowledge of experienced individuals into the guidance products. The additional subjectivity which is introduced into the final models may be more than compensated for by the increased homogeneity imposed on the data sets by the use of a single person's judgment rather than the differing judgments of many persons.

Conclusion

Statistical models developed to aid operational forecasters are most needed to give reliable guidance in borderline avalanche situations. This reliability probably cannot be realized unless statistical noise can be minimized in the input data. The most obvious way of improving the avalanche observation data base is to eliminate those instances where the avalanche observations appear inconsistent with the weather and snow conditions. However, even if the avalanche occurrence data were error free, an inherent problem exists in using avalanche occurrence as the forecasted variable.

The problem is created by a non-unique relationship between avalanche occurrence and the independent variables, especially when a large area is being considered. In this context, avalanche occurrences must be thought of as a combination of conditional stabilities existing in the snowpack, which are uniquely determined by the snow and weather conditions, and the occurrence of triggers of sufficient magnitude to cause failure, which is probably not uniquely determined by these conditions. As no information on the occurrence of various magnitude triggers is included in the independent variables, only limited skill can be expected from models forecasting avalanche occurrence.

The use of a stability related parameter, such as the stability index, seems to be a necessary requirement to improve the reliability of statistical models in the important borderline situations. Moreover, viewing a large area of avalanche paths as a unified system, which may be characterized by a certain stability state, may make the resulting statistical guidance extremely useful to the regional avalanche forecast.

Acknowledgements

Special thanks to E.R. LaChapelle whose original thoughts and discussions formed the basis for this paper. Additional thanks to W. Good and M. Moore for their helpful discussions.

References

LaChapelle, E.R., Ferguson, S.A., Marriott, R.T., Moore, M.B., Reanier, F.W., Sackett, E.M., and Taylor, P.L. 1979. Central Avalanche Hazard Forecasting, Summary of Scientific Investigations. Report 23.4 Washington State Highway Commission, Olympia, Washington.

Obled, C. and Good, W. 1980. Recent Developments in Avalanche Forecasting by Discriminant Analysis Techniques: A Methodological Review and Some Application to the Parsenn Area. J. Glaciology, 25, No. 92, pp. 315-346.

Table 1 Stability Indices (after LaChapelle et al. 1979)

STABILTIY INDEX	ENERGY REQUIRED TO TRIGGER SLAB RELEASE, JOULES	EXAMPLES	
0	Under 10^1 J	Random natural perturbations	(Absolute instability)
1	10^1 J	Falling snow clod	(Conditional instability)
2	10^2 J	Man walking in snow	
3	10^3 J	Small cornice fall; fall of standing skier	
4	10^4 J	Medium cornice, fall of skier moving 5 m/s	
5	10^5 J	Large cornice fall	
6	10^6 J	1 kg TNT, dynamic loading by small avalanche	
7	10^7 J	10 kg TNT, major cornice collapse	
8 or more	10^8 J	Earthquake, dynamic loading by a major avalanche	

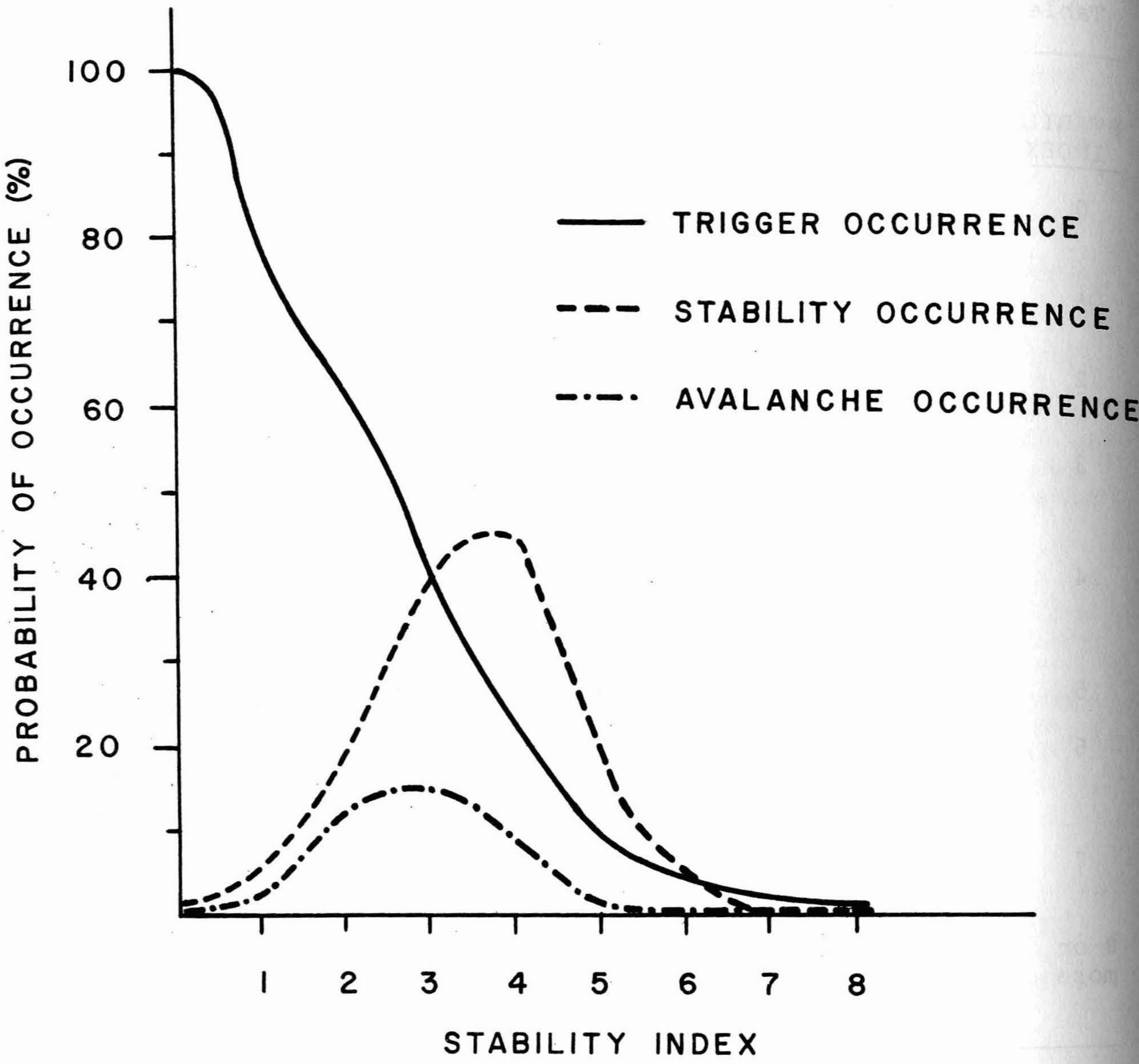

Figure 1. The graph represents a hypothetical situation, displaying the probabilities of trigger, stability and avalanche occurrence as a function of the stability index. The situation depicted is for a modetately unstable region.

Discussion

Stethem:

I will be very interested to see how those curves look and what your decision-making criteria will be in the future. There are many advanced forecasting systems that use a considerable amount of data and give far better decision-making criteria than your statistical model as it exists now.

Marriott:

There is a difference in the type of information that you need to give to a forecaster working within a small area and one working on a regional basis. I don't think we will see, in the near future, any physical model or statistical program that is going to out-forecast a good, experienced forecaster. But in a situation like this where you are getting data from a lot of different points and having to make a lot of judgmental decisions in a short period of time, you don't have time to give as much consideration as you would like to individual points.

Schleiss:

In our meeting of avalanche operations staff in Spring 1980, we agreed that an instability rating should be issued. I think the aim of a regional forecast should be only an instability rating for the area. This forecast would be improved by the local forecaster who is the only one who knows the local conditions. The information supplied by the central office, however, could be a tremendous tool for the operational forecaster.

Marriott:

I agree; we need to move toward making instability the quantity which we forecast.

Schleiss:

A problem which I find in many other areas is a change of the data base over the years as new ideas and new observers are introduced. The frequent changes make the records meaningless.

Marriott:

I think the type of data which you have from Rogers Pass is almost unique with respect to reproducibility. If all our avalanche data were like that, we would have no problems.

Schleiss:

Our basic data collection is rather simple. I can teach a person in three weeks on the job to take consistent observations as long as the person has a mountaineering background which allows him to visit the observation sites.

Boyd:

We should be consistent in terminology and Fred Schleiss is pointing out that there is an ambiguity in the use of the word hazard and therefore he is suggesting using instability or stability. If we take something that is called stability index, we should be deciding just what term means what.

Marriott:

Yes, that is true. We are introducing new tools and must be consistent, especially when we start putting the product out to the public.

Businger:

I was very interested in your curves and was wondering what the prospects are for getting some accuracy into the curve on triggers. It seems to me that this is an area where a lot of data could be collected on control routes without too much trouble.

Marriott:

As far as I know, nobody is developing that curve as yet, but I hope that we or someone else will have time to work on it.

Perla:

Why do you base your stability index on energy to the exclusion of power or stress?

<u>LaChapelle:</u>

The first try at a scale of stability was based on energy because it was the easiest to calculate and evolved out nicely for a logarithmic scale. I have also examined both power and specific power (per unit avalanche). This gets more complicated but ought to provide the basis for an improved scale and probably will in a revised stability classification. Ideally, stress would best serve for a stability scale, but in practice the calculation of the amount and especially the orientation of stress applied by trigger to the endless variations of natural snow slopes is much too complicated. I think a stability scale ought to be based on scale, not a vector quantity.