AN AVALANCHE FORECASTING PROGRAM BASED ON A MODIFIED NEAREST NEIGHBOUR METHOD

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ABSTRACT

As a part of an avalanche forecasting system, a modified nearest neighbour program is described. The system is intended to be used with forecast values for most of the parameters. The modifications consist of 1) the use of a parameter set that better reflects the course of the weather situation, 2) the setting of initial selection criteria for certain parameters 3) a method for normalizing the distances and 4) a weighting of the avalanche probability based on the avalanche activity and the similarity of the weather situations.

INTRODUCTION

The present paper describes a computer program intended for use in connection with an avalanche forecasting operation for the highway 15 in Stryn, Western Norway. The basis of the program is the well known nearest neighbour method for recognition of periods with similar conditions, described by Buser and others (1987). The method is used to find out if and when similar conditions have been recorded earlier and to study the avalanche record for these periods. The presumption is that similar conditions with regards to the used parameters will result in similar conditions regarding the avalanche activity. A system of this kind requires a data base of observation data of relevant parameters and an avalanche data base.

To find the most similar cases (the nearest neighbours) with regards to the parameters used, each period characterized by n parameters is made a point in a n-dimensional vector space. The distance d between them is then determined by:

$$d = \sqrt{\sum_{i=1}^{n} \Delta x_i^2}$$

where Δx_i is the distance between two points with n coordinates. In standard nearest-neighbour programs, parameters considered more important with regards to avalanche release, are usually weighted, i. e. the parameter value is multiplied with a suitable weighting constant, before the calculation is performed.

PROBLEMS WITH THE NEAREST NEIGHBOUR PROCEDURE

To be able to use older data bases in previous versions of nearest neighbour programs, it was often necessary to let single parameter values characterize periods of 24 hours. These do usually not reflect the course of the weather during such a period very well. Since the conditions connected with snow stability can change dramatically within a few hours, a false impression of the avalanche probability can be the result. This seems to be the case especially in maritime areas, where there is empirical evidence for a correlation between periodic high precipitation rates and avalanche activity (Bakkehøi, 1987).

This problem is easy to solve in theory by using shorter periods. However, the length of the periods will be determined by practical considerations like the frequency of snow and weather observations, and in particular, to what degree it is possible to monitor avalanche occurrences continuously.

Another important problem is that some parameters may have critical transitions, such as temperature, wind speed and snow height. These are often unsuitable for distance calculations because they can have a very different importance, depending on their absolute values. The nearest neighbour procedure does not, for example, take into account whether temperatures are above or below freezing, but it only measures the Euclidian distance in the vector space. Even by using heavy weighting, the result may be that the obtained closest weather situations cannot be considered similar with regards to the conditions most important for avalanche release.

It is a common procedure to emphasize parameters that are considered more important with regards to avalanche activity by weighting. The effect of weighting, however, is difficult to interpret by the user. For practical use, a special set of weighting factors that have been empirically found to be appropriate, is therefore usually prepared for the end user. Arbitrary changes of the weighting factors by the user often give unexpected results.

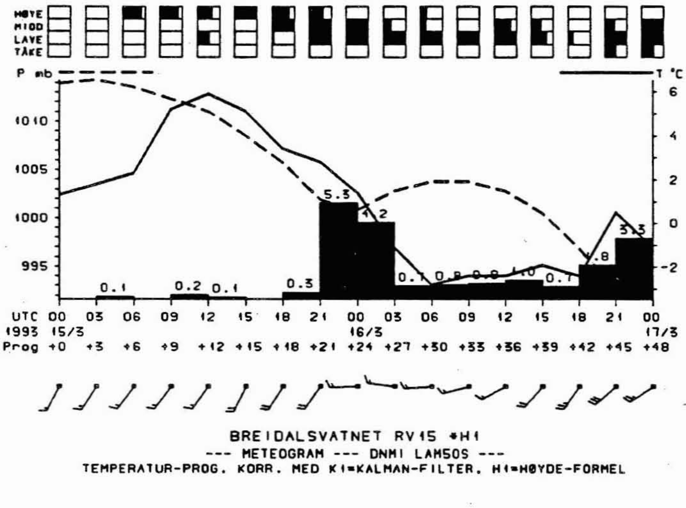
Finally, the same number of nearest neighbours found in the data base will be more similar if they are found in a densely populated region of the vector space than in a sparsely populated region. However, this fact is not evident from the measure of the distance between the nearest neighbours as long as it is not related to anything.

THE NN3-PROGRAM

Weather forecasts

The NN3 program is intended to be used to forecast avalanche hazard for up to 24 hours. This means that for most parameters, forecast values are used in the program. This procedure requires a detailed and reliable weather forecast that has the required time resolution.

As input values for the parameters we use data from the Norwegian limited area atmospheric model LAM50 (Fjukstad and others 1990). This model is based on a horizontal grid of 50x50 kilometres and 31 vertical layers. This comparatively dense grid takes into account the main features of the Norwegian mountain ranges and the temperatures are corrected for elevation. The model is run four times daily and the weather forecasts are distributed through a bulletin board system run by the Norwegian Meteorological Institute.



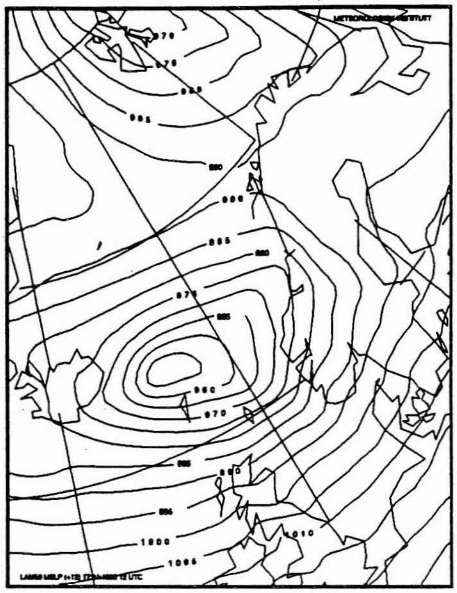


Figure 1. Weather graph, or meteogram, (above) based on the LAM50 (right).

Output from the model gives a 48-hour forecast with a three-hour resolution for sites that can be chosen anywhere in the grid. The data is presented either as a graph ('meteogram') or as characters.

These weather forecasts have been used in conventional avalanche warning operations for about five years in western Norway and there seems to be a good correlation with the measured parameters on the sites. However, some caution is necessary when using forecasts of this kind, since they are pure computer products based on mathematical-/physical models.

Parameter set

The use of a parameter set that better reflects the development of the weather situation, requires several daily observations. This is most often only practicable by using automatic observations. The measurable parameters are limited by costs and technical limitations, but many parameters that are connected to avalanche occurrences, especially in a maritime climate, are fairly easily measured.

Today, automatic weather stations with high data sampling rates have been in use for some time. The data base used in the NN3 program represent 3-hour periods, corresponding to the interval between data points in the available weather forecast. The data is acquired by an automatic weather station that uses a sampling rate of one hour. The weather data base used for the program is updated automatically with the observed data from the automatic weather station.

The parameter set chosen for NN3 is adapted to the maritime climatic conditions of western Norway, at about 62 degrees north. For these conditions, the parameters seem to have a good correlation with avalanche release. Often, precipitation during a five day period seems to be the single most important parameter (Bakkehøi, 1985). The parameters used here reflect the development of the wind velocity, wind direction and temperature through 24 hours. The accumulated precipitation is represented by six parameters reflecting the development during the last five days. In all, the parameter set consists of 22 parameters.

Scaling of parameters

In NN3 the parameters, except the wind directions, are normalized according to their bandwidth, i.e., their maximum and minimum values observed. In case new values outside previous limits are observed, the new normalizing constants are used automatically.

The distances between the wind directions are calculated by determining the vectorial differences between them.

Weighting

Each individual parameter can be weighted with a weighting factor if required.

Selection criteria

In NN3, absolute values for the intervals of certain parameters can be set. Only situations in the data base that fulfil these selection criteria are then selected for distance calculation. For those parameters where no criteria are to be used the MAX and MIN values can be entered in the criteria column.

Normalized distance

The main purpose of the distance value is to sort the nearest neighbours. The value of the distance will vary depending on the weighting of the different parameters and the distances obtained from two different calculations may not be comparable. The distance can be expressed as

$$d=\sqrt{\sum_{i=1}^{n}\left(w_i\frac{vf_i-vo_i}{max_i-min_i}\right)^2}$$

where

n is the number of parameters
w_i is the weighting factor for parameter i
vf_i is the forecast value of parameter i
vo_i is the observed value of parameter i in the data base
max_i and min_i are the maximum and minimum values of parameter i

The values given by the expression above will depend on the weighting factors used. To make it easier to compare distances from different calculations, the distance can be normalized:

$$dn=\frac{100}{\sqrt{\sum_{i=1}^{n}\left(w_i\right)^2}}d$$

Now the theoretical maximum distance, regardless of weighting, will always be 100.

As reference the distance between vf and the furthest possible point in the vector space can be used. Another useful reference is the distance to the 'furthest neighbour' in the used data base.

This also makes it possible to set a distance criterion and to restrict the selection of situations that do not meet this criterion.

Avalanche data

An avalanche data base with details of individual avalanches regarding time, location and characteristics is used in connection with the model. The quality of the avalanche database is critical for this kind of system. The use of short periods will restrict the use of the system to places where there is an almost continuous monitoring of avalanche activity.

It is often valuable information to know about avalanche occurrences outside the periods of the nearest neighbours. The period on both sides of the nearest neighbour period in which to include avalanches can be set, for example to 12 hours.

The probability of avalanches inferred from the listing of similar situations, is given a weighted value with regards to the similarity (i.e., distance) of the nearest neighbours and the rating of the avalanche activity according to the magnitude and the number of avalanches.

In some cases, avalanche observations can be difficult even in road maintenance operations. Sometimes avalanches stop just short of the road without being noticed. Road closures during storms can last for days, making it impossible to record the avalanches during this time. This means that, unless reliable automatic sensing equipment is used, there is no guarantee that all avalanches are recorded at the exact time of occurrence.

To remedy this problem to some extent, added to the data base of parameter values there is also an a posteriori rating of the avalanche situation in general for each period. This rating is a rather subjective description of the general conditions for avalanche release, the magnitude and the number of avalanches a.s.o., based on observations at the time. The rating corresponds to the five step European avalanche hazard code.

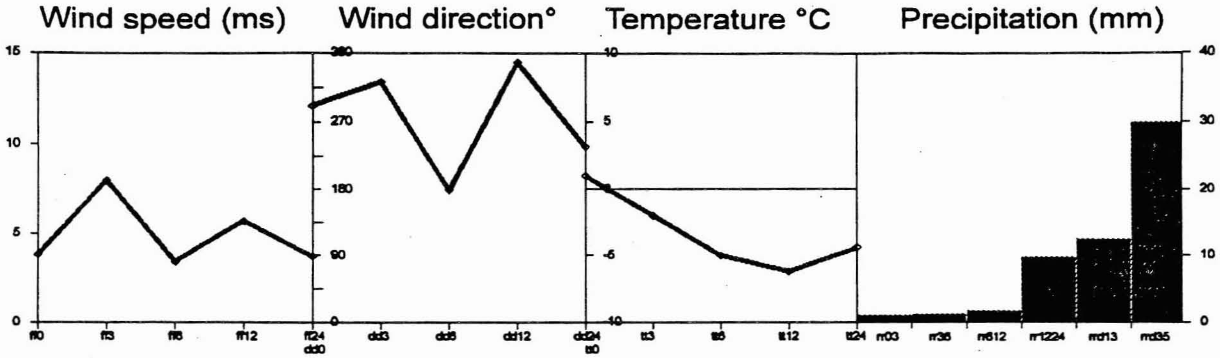
USING NN3

Forecast

The parameter set in the forecast will usually consist of a mixture of measured and forecast values. Typically, the situation 24 hours from present is to be assessed. This means that observed precipitation data from the four previous days, and data for the other parameters observed at the time, will be used. Values for the other parameters will be taken from the weather forecast.

The parameters used here reflect the development of the wind velocity, wind direction and temperature through 24 hours. As an example tt0 means temperature at the time for which the forecast should be valid. tt3, tt6, tt12 and tt24 are the temperatures at 3, 6, 12 and 24 hours before this time.

The precipitation parameters take into account the accumulated precipitation during five days. The first four intervals are the same as for the previous parameters, while rrd13 and rrd35 constitute the accumulated precipitation 1 to 3 days ago and 3 to 5 days ago respectively.



FORECAST

Forecast made: 940127 Time: 12.00

FORECAST:

		Wind Speed 24 h. m/s					Wind Direction 24 h. degrees					Temperature 24 h. °C					Precipitation 5 days mm accumulated						Snow height (cm)
Date	Time	ff0	ff3	ff6	ff12	ff24	dd0	dd3	dd6	dd12	dd24	tt0	tt3	tt6	tt12	tt24	rr03	rr36	rr612	rr1224	rrd13	rrd35	ss
940128	1200	3.8	8	3.4	5.7	3.7	291	322	179	348	237	1.0	-2.0	-5.0	-6.2	-4.4	1.1	1.3	1.8	9.9	12.5	30.1	155

Figure 2. Input menu for forecast and observed parameter values.

The forecast example in figure 2 above shows a rise of the air temperature to just above freezing (0°C) towards the end of the coming 24-hour period. The preceding 5-day period also has had new snow amounting to 43 mm of water equivalent precipitation. A situation like this is often experienced as critical with regards to avalanche activity.

Data base search

After the forecast has been imported from the weather forecast file, or it has been entered manually, a search in the data base can be performed.

DATA BASE SEARCH

DATABASE: FONNBU — Grasdalen, Stryn 930 m WINTERS: 1989-1993 NUMBER OF OBSERVATIONS: 6257

DATABASE SELECTION CRITERIA:

	ff0	ff3	ff6	ff12	ff24	dd0	dd3	dd6	dd12	dd24	tt0	tt3	tt6	tt12	tt24	rr03	rr36	rr612	rr1224	rrd13	rrd35	ss
MIN	0.0	0.0	0.0	0.0	0.0	250	180	135	135	MIN	-0.5	-20.0	-20.0	-20.0	-20.0	0.0	0.0	0.0	0.0	10.0	15.0	80
MAX	10.0	10.0	10.0	10.0	10.0	300	MAX	MAX	MAX	MAX	2.0	-0.5	-1.0	-1.0	-1.0	5.0	5.0	10.0	15.0	25.0	40.0	MAX

WEIGHTING FACTORS:

ff0	ff3	ff6	ff12	ff24	dd0	dd3	dd6	dd12	dd24	tt0	tt3	tt6	tt12	tt24	rr03	rr36	rr612	rr1224	rrd13	rrd35	ss
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0

DISTANCE CRITERION (% of maximum): 50

AVALANCHES INCLUDED (+/-h): 12

Figure 3. Input menu for selection criteria and weighting factors.

In the example above, selection criteria are set for periods with temperatures below freezing, but increasing to above -0.5 °C at the end of the period. We are also looking for periods where the height of snow on the ground is at least 80 cm, the precipitation has been between 35 and 100 mm the last five days, a.s.o.

Note that in this case all the weighting factors are set equal to one, except for the snow height parameter (ss), which has no weight at all. That means that snow height will not be considered when we are looking for the nearest neighbours. The only requirement of this parameter is that it must have a value of 80 cm or more, since in this particular case, we consider it unimportant after the ground surface roughness is smoothed out.

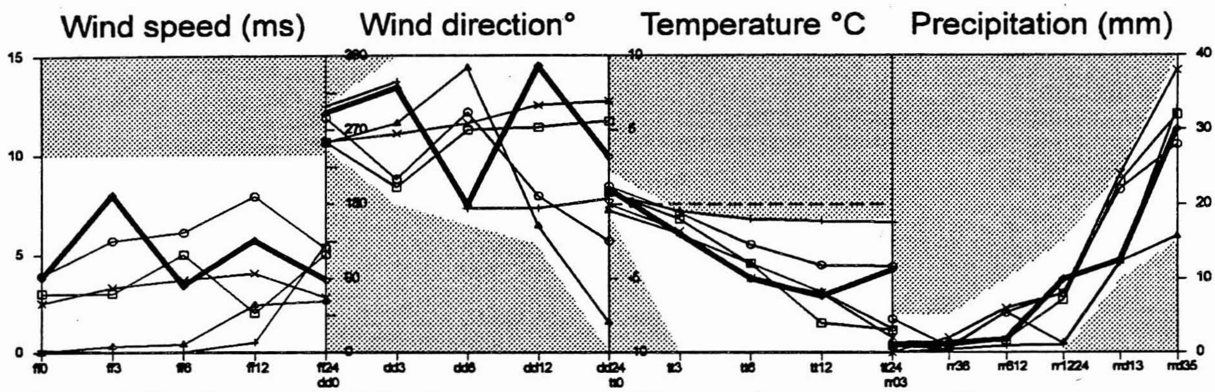


Figure 4. The forecast and the five nearest neighbours after using the selection criteria above (represented by the shaded areas).

Output from the calculation can be controlled by both the distance criterion option and the setting of maximum number of neighbours to be included. Using selection criteria will also limit the number depending on their strictness and the size of the data base.

Test runs with the same forecast and same data base, but without the selection criteria, show that none of the neighbours obtained in the first test were included among the five nearest neighbour. Neither did any of these have a temperature development during the 24 hours that was comparable with the forecast.

Weighting of the temperature parameters to take this into account did also not yield nearest neighbours that were comparable with regards to temperature development. The reason for this is that weighting does not give any control over the absolute values of the parameters. Heavy weighting of one or a few parameters also effects the comparison of the other parameters.

CONCLUDING REMARKS

The program is interactive and it is depending on a knowledgeable user who sees what is important in the current situation and with the current snow conditions. Although the option exists, weighting is seldom necessary or recommended. In most cases, the use of selection criteria that discards the neighbours that are dissimilar with regards to the parameters considered most important, should make weighting obsolete. Admittedly, this procedure demands more of the user, since weighting factors usually are prepared by experts. However, it is much easier for the user to interpret the effect of selection criteria, and changing them does not affect the nearest neighbour comparison.

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