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Snow avalanche prediction using a probabilistic method

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ABSTRACT Observations of avalanches and weather conditions at the avalanche research station at Strynefjell, Western Norway, are statistically analyzed. Data from five different avalanche paths in the vicinity of the avalanche station are correlated with wind, temperature and precipitation measurements. Only direct action avalanches are analyzed, that means those released when it is snowing and blowing. The analysis gives as a result that the three-day sum of precipi-tation in advance of a released avalanche can be fit to a Gaussian normal distribution for the probability on each single path. The curves vary, but paths with the same characteristics in the starting zone seem to fit very well.

Prévision d'avalanches par méthode probabiliste

RESUME Des observations d'avalanches et de conditions atmospériques à la station de recherche en avalanches à Strynefjell, à l'ouest de la Norvège, sont analysées statistiquement. Les données obtenues pour cinq couloirs d'avalanche différents dans les environs de la station sont correlées avec les mesures de vent, température et précipitation. Seules les avalanches d'action directe sont analysées, i.e. les avalanches déclenchées durant une tombée de neige par grand vent. Le résultat de l'analyse révèle que la cumulation de la précipitation pendant les trois jours qui précèdent le déclenchement d'une avalanche peut être modelée par une distribution Gaussienne normale de la probabilité dans chaque couloir d'avalanche. Les courbes de distribution varient, mais les couloirs avec caractéristiques semblables dans la zone de déclenchement ont apparamment des courbes semblables.

INTRODUCTION

Different methods for avalanche forecasting have been developed taking into account a lot of snow and weather parameters which will influence the release of an avalanche. This is summarized in papers by LaChapelle et al. 1978 and Buser et al., 1985. But altogether, the methods used give only an indication of when avalanches will occur. The most important parameters seems to be precipitation, wind and temperature in addition to good knowledge of the snow stratigraphy at the present time. Even though the precipitation and wind condition are the best parameters to predict the avalanche hazards, all records indicate that avalanches may occur within wide limits. For example, a factor of five between lowest and highest measured amount of precipitation during a storm period before a release of the avalanche is frequently observed. Sometimes a situation seems more or less equal to an earlier situation with high avalanche activity without any avalanches released and vice versa.

Avalanche hazard forecasts are mostly needed by the road authorities, at ski fields, and at construction sites placed in avalanche terrain. For permanent buildings and houses it is not accepted to live with a high avalanche risk. The avalanche risk is a product of the probability for an avalanche to occur, the size of the avalanche and the consequences. For a road with a specific amount of traffic it might, for instance, be acceptable to have a probability of 20% for an avalanche passing the road under the present situation. If the risk level is higher, the road might be closed or the avalanche can be artificially released. A simple method to forecast the avalanche probability is therefore of great advantage. Forecasters have, to some degree, used information from avalanche paths nearby, but as Judson (1983) has poin-ted out, a good index path one winter can fail completely the next.

OBSERVATIONS

The Norwegian geotechnical Institute (NGI) established in 1973 an avalanche research station at Strynefjell in Western Norway in the valley Grasdalen 930 m a.s.l. well above the tree line. The climate is maritime and strongly influenced by the cyclonic activity in the Atlantic ocean. The precipitation during the winter (November - April) has a mean value of 855 mm, and the maximum winter snow heights have varied between 1.3 m and 4.7 m. The number of periods which can give direct action avalanches are five as a mean, but up to nine situations are recorded during one winter. Some of these situations are accompanied by mild air from the sea which brings the temperature above the freezing level at the research station. But in most cases the temperature in the starting zones are below $0^{o}C$.

The valley Grasdalen is approximately 7 km long, U-shaped and surrounded by mountains reaching well above 1600 m a.s.l. The main road No. 15 follows the valley for 1.5 km, and it is exposed to avalanches on the whole length. A gallery of 100 m length has been built to protect against the most frequent avalanche, but still the road is blocked by avalanches two to three times each winter. In most cases the road has been closed due to avalanche forecasts prior to its being blocked.

The research station operates as a standard climatic station with three manually taken observations per day. In addition, snow measurements for snow and avalanche research works are taken. Registration of the avalanches is performed during the storm period or just after, and time for the avalanche occurence is justified by checking the new snow height on the avalanche debris if possible.

The entire valley is exposed to avalanche activity, but some distinct paths slide more frequently than others, and have their own names like Ryggfonn, Storfonn etc. (fonn means avalanche). Five of the most distinct and frequent avalanche paths in the valley have therefore been treated in this analysis. The number of avalanches in each of those paths varied from 23 to 37 observations during the period 1974 to 1984. Many of these avalanche situations are caused by thawing weather with rain or sunshine, and they are excluded from the sample of this study.

The release of a direct action avalanche is a function of the current weather situation and the snow stratigraphy in the starting zone. Snow stratigraphy will to a great extent determine when the avalanche is triggered. As an example, weather data from different situations with direct action avalanches at Raffelsteinfonn is presented in Table 1 below. Both loose and slab avalanches are included, but as a consequence of the accompanying wind most of the avalanches are slabs.

TABLE 1 Meteorological Observations at 930 m combined with Avalanches at Raffelsteinfonn

Date	Precip.last 3 days (mm)	Precip.last 5 days (mm)	Temperature development	Wind direction	Max. speed m/s
75.01.01	59.0	59.0	-8.3 - -1.2	N-S-SW	12
75.12.01	6.5	15.1	-9.0 - -0.7	E-S	11
75.12.10	77.4	121.0	-7.0 - -0.3 -6.8		
76.03.01	35.8	35.8	-6.0 - 0.0	SE-S-W	12
76.03.28	66.6	67.8	-8.1 - 0.3	NE-S-SW	10
78.01.02	54.9	68.5	-14.0- -1.5	N-SW	12
78.02.22	23.8	42.2	-12.9- -13.3	SW-NW-E	11
79.02.06	16.1	21.0	-13.0- -5.0	E-S-SW	10
79.03.06	75.8	94.2	-1.1 - -0.3	S-SW	10
80.01.15	35.3	35.3	-7.0 - -4.0	S-SW-N	10
80.04.11	25.5	32.5	-7.8 - 0.0	S-N-S	10
80.12.03	44.0	44.0	-10.0- -8.7	SW-N	14
80.12.09	45.8	45.8	-10.0 - 0.0	S-SW-N	10
81.12.04	47.4	47.4	0.0 - -0.6	NW-N	12
83.01.11	57.4	108.3	-5.0 - 4.0	S-SW-SE	12
83.01.21	91.4	114.7	-13.0- 0.7	N-NW-SW-W	12
83.03.09	59.6	68.3	$^{+}$ 0.0	W-S-W-S	12

The accumulated new snow depth in each situation has been measured too, but with high wind speed the snow will drift and the measurements will be inaccurate. The precipitation gauge is a standard Norwegian type with wind screen, and the opening is a square with area 225 cm^2. The wind will influence the catchment of the gauge, especially when the precipitation is snow.

ANALYSIS AND RESULTS

The figures in Table 1 do not give any exact information on when the avalanche is triggered, and they illustrate the difficulties of avalanche forecasts. The other four avalanche paths analyzed demonstrate the same casualty with no specific trend. In all the situations the wind speed has been high enough for heavy snow drift, and the temperature has been below the melting point in the starting zone, each without significant variation. Only precipitation showed enough variance to suggest a measure of probability. As a consequence of these random precipitation values, they were plotted on normal distribution paper.

The 3-day sum of precipitation for Raffelsteinfonn is presented and in addition the curve for Gaussian normal cumulative distribution based on the same data is shown on Fig. 3. Data from the four other avalanche paths are also plotted on normal distribution paper, and they coincide in the same way as for the Raffelsteinfonn data with the theoretical normal distribution.

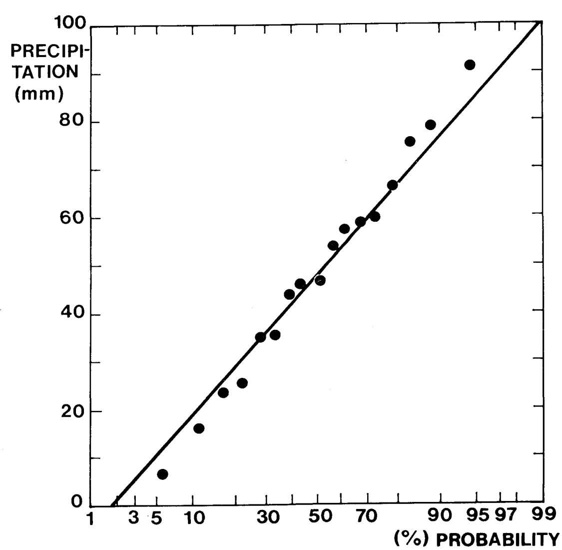

FIG.1 Cumulative probability distribution of three-day precipitation at Raffelsteinfonn causing avalanche occurence.

The normal distribution curves for the five different avalanche paths are presented in Fig. 2. The precipitation for 50% probability varies for the paths between 45 to 60 mm as a 3-day sum. With 90 mm of precipitation, the probability for an avalanche to occur, varies between 95 to 98 per cent, while the probability varies between 2 and 25 per cent with 30 mm of precipitation in these five different paths.

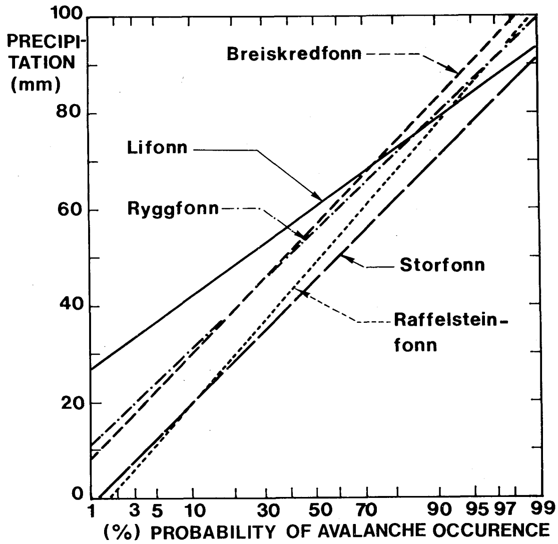

FIG.2 Distribution curves for five avalanche paths presented on normal distribution paper.

The 5-day sum of precipitation has been investigated too, but the plots have a far wider scatter than for the 3-day sum, see Fig. 3 from the Ryggfonn avalanche. A direct-action avalanche situation usually builds up for a shorter period than five days, and the snow pack is also stabilizing during the snowfall period. Of course, the stabilizing of the snowpack goes slower with low temperature, and therefor such situations will last longer.

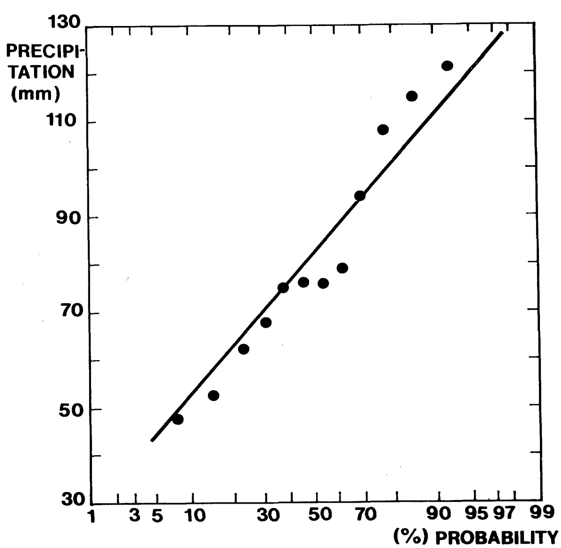

FIG.3 Cumulative probability distribution on five-day precipitation at Ryggfonn causing avalanche occurence.

DISCUSSION

Some of the paths seem to coincide fairly well in the distribution function, but as pointed out above some of the curves differ considerably. The main reason for this can be explained by different slope inclinations in the starting zones. The path profiles are presented in Fig. 4, and as expected the path with lowest inclination like Lifonn has a probability far below the other paths for small precipitation values. Storfonn and Raffelsteinfonn slide most frequently with small precipitation values.

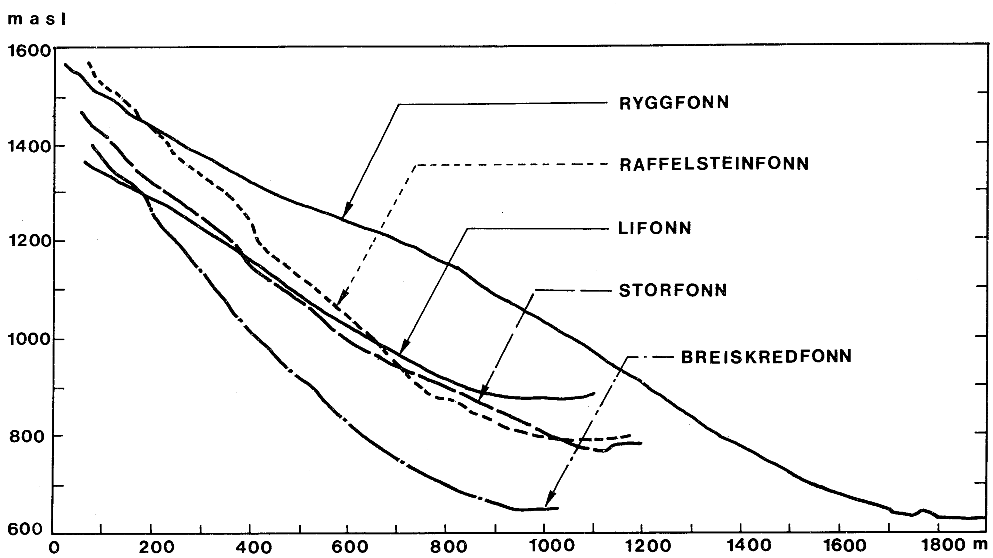

FIG.4 Terrain profiles for the five investigated avalanche paths in Grasdalen.

Other important factors are the aspect of the starting zone compared with the prevailing wind direction and the size of the erosion area. Storfonn, Breiskredfonn and Raffelsteinfonn have aspects toward SW while Lifonn is facing towards ENE and Ryggfonn has a NNE aspect. They will all be exposed to snow drift catchment when the cyclones are passing.

This analysis has been performed on avalanche paths in an area with dominating maritime climate. The snow depths are usually high in the mountains, while the temperatures vary between 0°C to -15°C. This means that the temperature gradient usually is low with very slow change of the snow stratigraphy. This is also stated by the observations at the research station. Other effects maybe more dominate in a continental climate where the snow pack changes more rapidly during the winter.

CONCLUSION

By the method described in this paper it seems possible to give avalanche hazard forecasts based on a simple analysis on the meteorological data preceding an avalanche occurrence. The 3-day sum of precipitation necessary for an avalanche occurence has a normal Gaussian distribution which implies that it is possible to give the probability for a specific avalanche to occur when the precipitation distribution during the preceding days is known. The method can only be used on direct action avalanches with temperatures low enough to give snow in the starting zone. For other types of avalanches there are effects more dominating than the precipitation, and they need to be handled separately. When the snowfall ends, the probability for an avalanche to occur decreases rapidly. With the possibility of continously recording of the snow-fall intensity and the use of geophones to record the exact release time in the avalanche paths, it might be possible to achieve better indications of the probability of avalanche release.

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