A probabilistic model to evaluate optimal density of snow stations

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Abstract: Daily new snow measurements are important for avalanche forecasting and tourism. In Switzerland new snow is measured at many stations, which belong to different networks and are only partially coordinated. We developed a probabilistic model to evaluate the efficiency of different station layouts. The model takes into account the spatial structure of heavy snowfall events and the location of the stations together with their autocorrelation. In order to capture at least 80% of the snowfalls, an ideal network requires a spacing of about 15 km. Spacings of 20 km result in only 50% capture probability, which means that at least half of all local snowfall peaks in these areas will be missed. The Swiss operational snow station network widely fulfills the optimal requirements, actually is in some places too dense while in other too sparse. The model was used to develop a new optimized station network.

Keywords: snow station, snow climatology, optimal selection, snowfall intensity, spatial variability

1. Introduction

One of the most important parameters for the evaluation of the avalanche hazard is daily new snow (McClung and Schaerer, 1993). The quality of the hazard estimation largely depends on accurate new snow forecasts and measurements. However, new snow forecasts do not have a very high spatial resolution contributing to major uncertainties for avalanche forecasting on a regional and local scale. A sufficiently dense network of stations measuring new snow is indispensable for a high resolution real-time avalanche hazard estimation. On a complex mountain topography such as the Swiss Alps an adequate distribution of snow stations is necessary also for many other applications relying on highly resolved snow data. Examples are: snow climatological mapping and trend analyses, determination of snow loads for engineering purposes, knowledge of snow distribution for resort management and touristic information and calculation of snow reserves for hydro-electric power production. Thus, the determination of an ideal network density for snow stations reaches far beyond avalanche warning purposes.

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Bastin et al. (1984) developed a method for the optimal selection of rain gauge locations. The major restriction of their model is that they assume spatial isotropy and stationarity of the random field of rainfall – an assumption which is not realistic in mountain areas with strong orographic gradients. Our method is free of these assumptions, but requires a computer-intensive calculation scheme based directly on the observed probability. Previous studies highlighting the spatial extent of precipitation areas are rare and mainly concern rain (Germann and Joss, 2001; Asquith and Famiglietti, 2000; Krzysztofowicz, 1999). However, Spreitzhofer (1999) discusses spatial characteristics of heavy snowfall events in Austria. In any case the spatial variability of precipitation is generally recognized as being large and the rainfall rate at the ground is known to easily vary by a factor 10 within 2 km distance (Gabella et al., 2000).

2. Methods

To calculate the capture probabilities data from 107 manually recording snow and weather stations between 1150 and 1850 m a.s.l. were used (Fig. 1). The elevation zone was limited to the mid altitudes in order to reduce altitude effects on the snowfall distribution. The period evaluated was from 1970 to 1999. For every event with daily snowfall exceeding 20, 30 and 50 cm (HN20, HN30, and HN50) and with the cumulative three day sum exceeding 75 cm (HN3/75) the area was calculated. The resulting histogram was then converted to an area-probability relationship (Fig. 2).

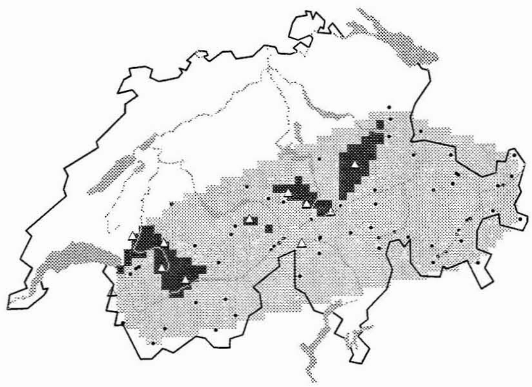

Figure 1: Stations (black dots and triangles) and interpolated HN30-area (black areas) of an exemplary day. White triangles show stations with HN > 30 cm, black dots are stations with HN ≤ 30 cm and the grey area encompasses the entire interpolation area.

This relationship is the basis for calculating the capture probability, CP. The total capture probability for an isolated station where the radius of influence is exceeded is given by the function in Figure 2.

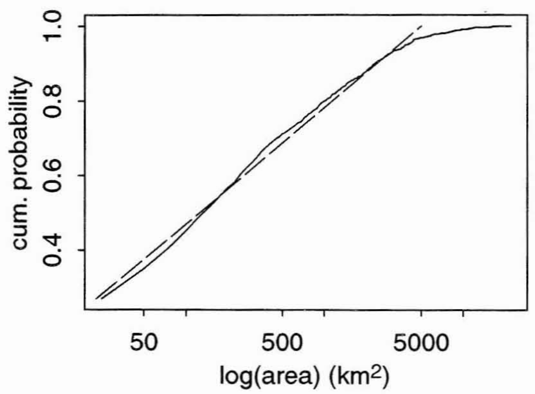

Figure 2: Probability and area for HN30 in 25 km² resolution in logarithmic scale. The dashed line is a linear approximation for areas smaller than 5000 km².

If two or more stations are within the diameter of influence (in the example 80 km), the cumulative probability is given by

$$CP_{ind} = 1 - ((1 - CP_A) \cdot (1 - CP_B) \cdot (...)) \quad (1)$$

where CP_A is the independent CP of station A and CP_B the independent CP of station B. However, in reality the stations are autocorrelated. The closer they are, the higher is the autocorrelation γ, which depends on the distance between the two stations. γ ranges from 0 (low) to 1 (high autocorrelation). Figure 3 illustrates the calculation of γ:

$$\gamma = \frac{\int CP_{ind,AB}}{\int CP_A} \quad (2)$$

$\int CP_{ind,\,AB}$ is the integrated probability of the intersection of the two influence areas of A and B after Equation 1 and $\int CP_A$ is the integrated probability of the entire influence area of A. In order to get values from 0 to 1, γ has to be standardized with the situation when both stations fall together (distance = 0).

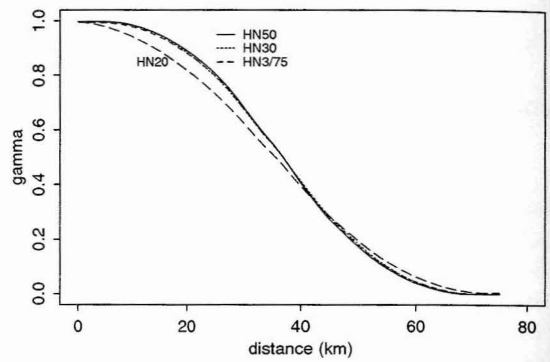

Figure 3: Autocorrelation for the different variables. Only HN20 shows a different function, the other variables are all very similar.

The assembling of the total probability was done step by step, taking into account cumulative probability and autocorrelation.

3. Results and Discussion

The resulting map for the operation network und a new snowfall of 20 cm is shown in Figure 4 a), for a snowfall of 50 cm in Figure 4 b). Figure 4 a) shows a very high probability except along the national border and in the lowlands. In fact, many stations have a very high redundancy, which gives little or no additional information about areas lying further away. Somewhat surprising was the low probability along the borders. Because the information exchange is not yet trans-national, these ridges often have probabilities below 0.8. Because the same situation is also valid for the neighboring countries (France, Italy, Austria), avalanche forecasts in these zones are based on sparse information. Figure 4 b) shows the same network but for the snowfall of 50 cm. Because the area of such snowfalls is smaller and more localized, more areas with lower capture probability show up. Especially the southern part of Switzerland has in this case a very low capture probability, which means that the peak of snowfall events and therefore the level of avalanche hazard will be systematically underestimated.

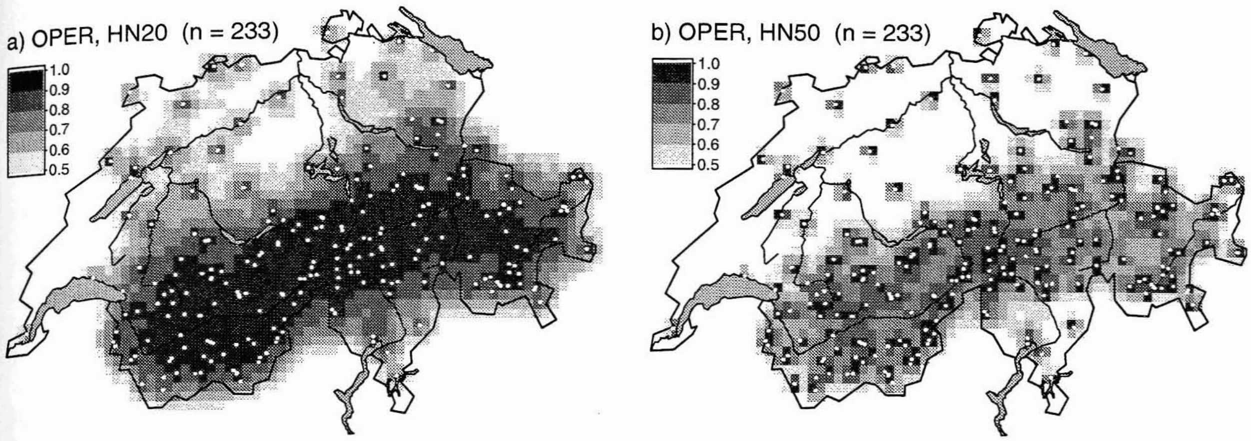

Figure 4: Capture probability for the operational snow network in Switzerland for daily events of 20 cm new snow (HN20) and of 50 cm new snow (HN50).

Based on this method, different scenarios for station network can be simulated and the consequences assessed (Laternser, 2002).

4. Conclusions

The direct calculation of capture probability for a new snow fall event of a certain intensity circumvents the difficult to validate assumptions which must be made with classical methods. The method can be applied to other regions and helps to evaluate and visualize areas where the information is insufficient. In this context national borders require special attention, because there the probability to capture a snow fall event is very low.

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