NXD2000: AN IMPROVED AVALANCHE FORECASTING PROGRAM BASED ON THE NEAREST NEIGHBOR METHOD

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ABSTRACT: To assist local avalanche forecasters, Buser (1983) developed an avalanche prediction system based on the nearest neighbor method. NXD2000 is an improved and further developed version of the program, and has been installed at several places in Switzerland, Austria, Kazakhstan, and the USA. Improvements include the introduction of explanatory variables such as settlement and a mass of wind-transported snow and functions giving certain values of a variable more load, e.g. snow surface temperature which is important in the range right below 0°C, but not far below at -20°C. We explored the influence of the functions and attempted to optimize the variable loadings at Parsenn Ski Area in Davos, Switzerland and Snowbasin Ski Area in Utah, USA.

KEYWORDS: avalanches, avalanche forecasting, avalanche forecasting models, nearest neighbors.

1 INTRODUCTION

In the early 1980s Buser (1983) developed NXD, an avalanche forecasting program based on the nearest neighbor method. Using NXD, avalanche forecasters see what happened on similar days. The detailed information available about what happened on similar days helps for planning avalanche reduction work. Further, the program helps to transfer the historical knowledge of an avalanche forecaster to his successor.

Because of its success (Buser, 1989) NXD was used and further developed at other places (Kristensen, 1994; Bolognesi, Buser 1995). However, only the use of the first version of NXD was widespread. With the increased power of personal computers, we needed a new version based on Windows95. While the method did not change, the new technology allowed increased flexibility and statistical analyses. The new version, called NXD2000, is already used at several placed all over the world.

In the first part of this paper the structure of the new program, the methods behind it and the rules to properly configure it are presented. The second part of the paper focuses on our experiences with the program at Parsenn, Davos, Switzerland and at Snowbasin, Utah, USA.

2 THE NEW PROGRAM

NXD2000 has essentially the same functionality as NXD. It searches a database for the nearest neighbors and provides the user with comprehensive information about those neighbors. It does not evaluate a warning level.

Flexibility is the main maxim of the new program. It is adaptable to any region and to different uses, such as in a ski area, for road safety, or village protection. It even can be applied to different subjects besides avalanches, such as forest fires, debris flow or ski gliding research. NXD2000 is a database program and features queries. For example, the user can query the database for any kind of information about explosives use, avalanches types, or avalanche characteristics. Results are easily copied into other programs like Word or Excel.

Persons familiar with Windows95 can easily use the program because it has a similar interface.

3 METHODS

3.1 _Variables_

The set of variables used is primarily the one Obled and Good (1980) selected for their test at the ski area Parsenn, Davos, Switzerland, because they are crucially connected with avalanche occurrence. However, not all of these variables are measured at every site. From the available variables we primarily chose those taken which describe or influence the snow pack. McClung and Tweedy (1993) correlated individual variables with an avalanche-occur-

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rence index, and Boyne and Williams (1992) analyzed the influence of meteorological variables on avalanche formation, and their work forms a basis for the selection of the variables.

3.2 Elaborate Variables

The concept of elaborate or explanatory variables was first described by Obled and Good (1980) and has been expanded since more functionality is currently available. Variables from previous days (so-called "predays") are used to calculate elaborate variables. They constitute an attempt to introduce physical knowledge about the assumed underlying phenomena. Changing from raw data to evaluated variables should involve a substantial increase of information. For instance, a day is characterized by its daily amount of precipitation. However, the quantity of fresh snow accumulated during a storm sequence is not redundant information as is, for example, the duration of the current dry period (i.e. since the last storm period). As another example, Settlement (*St*), an important factor to snow stability, is hard to measure but easy to calculate using snow height (HS_0 for the actual day, HS_{-1} for the first preday) and fresh snow (NS_0):

$$St_0 = HS_0 - HS_{-1} + NS_0 \qquad (1)$$

It is clear that derived or threshold variables may also represent non-linear effects rather than linear phenomena. Kristensen (1994) noted that some variables have critical transitions, such as temperature, wind speed and snow height. Due to the increased functionality of the new program, variables can be transformed such that small differences of values in critical transitions lead to large distances, whereas large differences of values outside lead to small distances. For example, snow temperature (*TS*) is important in the range right below freezing point but not at very low temperatures. The desired transformation can be done using a hyperbolic tangent function (see Fig. 1):

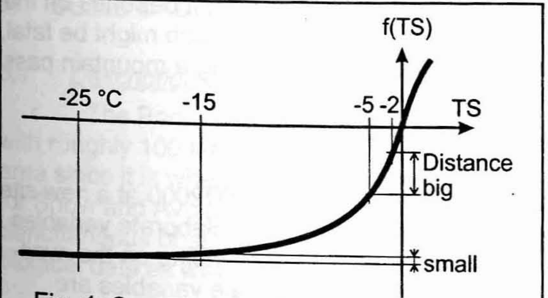

Fig. 1: Snow temperature is more heavily weighted right below freezing point than at very low temperatures.

$$TS' = 20 * \tanh(0.2 * TS) \qquad (2)$$

A similar function applies to air temperature and snow height. If snow height (*SH*) is low, no avalanches will occur even during large snowfalls because terrain roughness anchors the snow. Therefore a function is used to separate days with snow height below surface roughness (*Sr*):

$$SH' = \tanh((SH - Sr) * sp) + 1 \qquad (3)$$

The constant *sp* defines the sharpness of the separation, and is arbitrarily chosen to be 0.03.

Snow drift is key factor in avalanche formation. Lacking a simple equation for a snow drift index, we used the following formula:

$$Sd_0 = V_0^{\,2} * (1 + NS_0) \qquad (4)$$

The equation is based on our knowledge that the force of the wind increases by the square of the speed, and the more it snows the bigger is the snow drift. If it does not snow, at high wind speeds still there will still be snow drift. The total snow drift index is the sum of the indexes of the current day and the two predays weighted by 0.1 and 0.01. Some observers have found a dependency of the snow drift to the 3rd power of wind speed, with a threshold wind speed of 5 m/s (Dyunin and Kotlyakov, 1980). However, changing the relation to the 3rd power of wind speed did not improve the quality of the nearest neighbors, so we used the original equation. Still, there is a need for a more physically based formula.

All elaborate variables are multiplied by constants so their standard deviations are similar. This ensured that elaborate variables with small variations have the same effect on the results as those with large variations when the variable weights are changes.

3.3 Nearest Neighbors

The elaborate variables span a n-dimensional space, in which each day is represented by a point. To find the neighbors we have to define a measure, that the distance between two points (days) can be calculated. We use the weighted measure:

$$d = \sqrt{\Sigma_i p_i \Delta x_i^{\,2}} \qquad (5)$$

where p_i is the weight of the elaborate variable i. Usually Δ means the difference, except when the elaborate variable represents a direction. In this case the difference between day *l* and day *m* is calculated as follows:

$$\Delta = \min(|x_{il} - x_{im}|, 360 - |x_{il} - x_{im}|) \qquad (6)$$

The elaborate variables are not orthogonal. If two elaborate variables are correlated, we can take care of this by the weighting vector.

Like Buser (1983), we chose the model to select ten nearest neighbors. The theoretical optimal number of neighbors ranges from 8 to 30, depending on the number of days in the data file and the number of elaborate variables.

3.4 Observations

Avalanche forecasters want to know whether avalanches are likely on a certain slopes, and, the size and type of the slides. Therefore, avalanche observations should contain information on size, location, type and damage, as well as actions of avalanche control. Such classifications are important since they allow the forecaster to get comprehensive information about the nearest neighbors. Besides the detailed information about what happened on a certain day, such information facilitates statistical analyses of the avalanche activity and explosive control work in the area over several seasons. In Switzerland the avalanche information recorded in NXD2000 is follows the standard reporting form used by the SLF. The avalanche occurrence list found in McClung and Schaerer (1993) can also be applied to NXD2000.

3.5 Problems

There are several problems that restrict the use of the nearest neighbor method:

- Continuity of Data:
  Calculations of elaborate variables require several predays, so missing measurements lead to gaps. For example, if there are no measurements on Sunday, no nearest neighbor search is possible until Wednesday, when fresh snow accumulated during the three predays is used as an elaborate variable.
- Sharp changes of variables time period:
  Often variables characterizing periods of 24 hours are used. However, conditions connected with snow stability can change dramatically within a few hours. This may result in a false impression of the avalanche probability (Kristensen, 1994). Shorter periods cannot be used, because the length of the period is determined by practical considerations like to what degree it is possible to monitor avalanche occurrences continuously. With automatic observation stations snow and weather data are available more frequently, which may in the future allow us to extract trends from these time series.
- Missing or imprecise avalanche observations:
  To ensure the quality of nearest neighbor search, avalanche observations must be reliable and complete. Days without observation should be marked, so neighbors are not misinterpreted as good days. This also should be kept in mind when interpreting the neighbors. There may be days without avalanches simply because nobody recorded them, such as New Years Eve or foggy and stormy days. Other problems are days at the beginning of the ski season when no avalanche control was performed. Finally, any wrong or imprecise inputs may lead to misinterpretation of the neighbor day found.
- Homogeneity of data and observations:
  Changes in the location or the method of weather and snow measurements might interrupt the time series or lead to data inconsistencies to which the model is sensitive. If the changes are too large, the older data cannot be used. In the best case the old and the new series overlap, and multiple regression analyses can be used to derive correction function.

  Over the years there are changes in the avalanche control. This changes the time and quantity of the avalanche activity, which has to be considered when analyzing the neighbors.
- Definition of an avalanche day:
  One of the main questions is, what makes an avalanche day. It is not clear whether an avalanche 400 m long is twice as dangerous as one 200 m long or if a day with ten observed avalanches is twice as dangerous as one with only five. It could also be argued that, in a tourist area, one avalanche on a clear day is potentially more dangerous than several during stormy weather.

  Usually it is defined as at least one avalanche per day. No distinction is made between catastrophic avalanches and harmless small snow glides. However, it depends on the site, in a ski area one small slab might be fatal, whereas the same slab along a mountain pass road would not be noticed.

4 OPTIMIZATION

When installing NXD2000 at a new site, it is important to select the elaborate variables and set their weights. Depending on the available variables, the elaborate variables are chosen as described above. The formulas have to be adjusted because the location of the measuring station relative to the starting zones i different at each site. Initially, weights have to be set according to the experience of the local avalanche expert, i.e. if wind is the dominant cause for avalanches, then wind variables should be weighted more. Currently, there is no method to optimize the weights other than trial and error, where the local avalanche expert suggests which weight to increase or decrease when looking at days with a bad number of avalanche neighbors. Occasionally there might be the need to add a new elaborate variable, when some bad neighbors have similar characteristics.

NXD2000 can search the neighbors for all days in the database at once. This enables a calculation of overall model performance by determining the following values:

1. For all the days in the database that have avalanches, the average number of neighbors that have avalanches, the range (maximum and minimum number of neighbors with avalanches), and the standard deviation.
2. For all days in the database without avalanches, the average number of neighbors with avalanches, the range, and the standard deviation.

With this analysis there are two primary goals. First, for days with avalanches we want to maximize the number of neighbor days that also have avalanches. Likewise, for days without avalanches, we want to minimize the number of neighbors with avalanches. After trying new weights the user can quickly evaluate if model performance has increased. Second, we want to give the avalanche worker an idea of how many neighbors would tend to indicate that a particular day would have avalanches. For example, we can tell the model user that, on average, a day with avalanches usually has four or more neighbors with avalanches. However, the user still must be aware of that some days with avalanches have no neighbors with avalanches.

5 USING NXD2000 AT DAVOS PARSENN

5.1 Description of the area

The Parsenn area (Davos, Switzerland) with roughly 100 km^2, was selected as a study area since it is where the Swiss Federal Institute for Snow and Avalanche Research is located. Simultaneous observations of snow and meteorological data as well as avalanche activity have been recorded there for more than 40 years. The size of the area remained unchanged over the years. The selected area contains both gullies and avalanche slopes of various sizes, aspects and slope angles, and the number of potential paths is large compared to the daily avalanche activity (up to 59 per day to 183 avalanche paths). The total number of avalanches varied from 100 to 300 per year except for the past two winters when the number was twice as high (See Fig. 2).

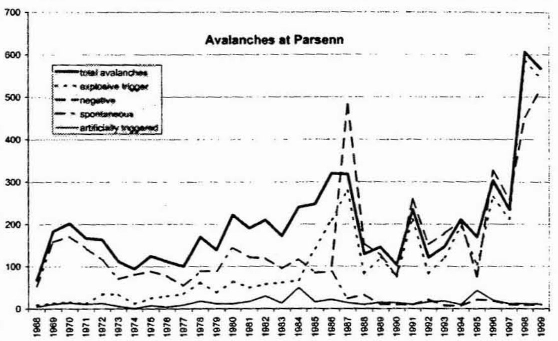

Fig 2: Policy of avalanche control in the ski area Parsenn, Davos changed after 1985.

Avalanche control has been conducted since 1968, but there have been changes in the policy. In the 1970s and early-1980s the ski runs were closed during dangerous situations, in the late-1980s and even more in the 1990s the pressure to keep all of the ski runs open increased. This resulted in an increase in the use of explosives and therefore a decrease in spontaneous avalanches after 1985 (see Fig. 2). The latter also results from the fact that spontaneous avalanches in areas that did not endanger ski runs were only occasionally reported. After 1995 the snow safety patrol began even more preventive avalanche control. Even when the danger was not high they shot avalanches, with a goal to get the snow down from the dangerous slopes. Thus, in springtime when it is not possible to trigger avalanches due to the low temperatures in the morning, there is little snow in the starting zones and fewer wet slabs can form during the intense afternoon sun.

This change in the policy of avalanche control affects the result of the nearest neighbors in the way that less dangerous days might have more avalanches, whereas on sunny spring days the number is reduced.

Variable	Unit
Snow water equivalent	g/mm^2
New snow	cm
Penetration depth	cm
Snow height	cm
Snow temperature	-°C
temperature at midday	°C/10
Snowdrift	0 or 1
Wind speed	km/h
Wind direction	DEG/10
Cloudiness	%
sunshine	Min
Solar radiation	Wh/m^2

Table 1: Snow- and weather data used at Parsenn, Davos Switzerland.

5.2 Variables

Table 1 lists the raw input data from daily measurements covering the winter periods since 1968. These data are representative of the potential starting zone of avalanches (2000 – 3000 m a.s.l.) because they were measured at an approximate altitude of 2500 m.

5.3 Experience with the elaborate variables and their weights

Since 1980 at Parsenn the NXD program has been used and improved (Buser, 1983, 1989). These settings were used in NXD2000. Clearly, improving the long-running model will be difficult. We expect that elaborate variables with small correlations to "avalanche day" or to the number of avalanches, like solar radiation, would have little effect on the result. However, setting their weight to zero decreased the model performance, so they might be important in the fine selection of the neighbors.

Increasing the weight of snow temperature 4 times and doubling the weight of the new snow variables improved the result by 2%. Adding the elaborate variable settlement and doubling the weight of snow drift brought further improvements. Looking at non-avalanche days with too many avalanche neighbors showed that days with little snow did not have avalanches even when it snowed a lot. This result clearly demonstrates that if snow height is below surface roughness, blocks or bushes prevent avalanches. Adding a new elaborate variable, such that snow heights above surface roughness lead to small distances analogous to snow temperature, and improved the model 2%. Like Boyne and Williams (1992), Temperature development on the predays has a high influence on avalanche activity. Analyzing the neighbors showed that on days when temperature at midday dropped from about -1° C to –10° C even if there was snowfall no avalanches occurred. Changing the formula of the elaborate variables temperature midday analogue to snow temperature and adding the second preday lead to further improvement.

Our overall improvement was about 6%. Table 2 shows the details. Most of the improvements are changes of one to two neighbors.

Day has avalanches	orig.	Impr.
Sum of Avalanche Neighbors	5972	6319
Number of avalanche days	1542	1542
Average number of neighbors	3.873	4.098
Standard deviation	2.681	2.734
Day has no avalanches		
Sum of Avalanche Neighbors	9260	8573
Number of non avalanche days	5248	5248
Average number of neighbors	1.764	1.634
Standard deviation	1.707	1.773

Table 2: Improvement of the weights and elaborate variables

5.4 Analysis of exceptional days

The large standard deviation (Table 2) indicates that there are avalanche days with only few avalanche day neighbors and no avalanche days with many avalanche neighbors. There are 211 days out of the 6791 days dataset, which had no avalanches but more than 5 neighbors with avalanches and 292 days with avalanches but less than two neighbors with avalanches. Some of these days are right before the season, where only the situation was checked but no avalanche control was done. Other days were at the end of a snow fall period in which the avalanche control had been performed on the days before, but not on all of the neighbor days found, which also had much snow on the predays. This might be enhanced by the increased use of explosives. This contributes also to the opposite when avalanche control work has not been done on the predays, but in the neighbors such days show up. Because the program also indicates predays with avalanches, these situations are easy to recognize for an experienced avalanche forecaster.

This does not explain all of the odd days. They need further investigation to understand the weather type of those days, which we will use as a base to further improvements. However, the result is promising since 6288 days show good results.

6 USING NXD2000 AT SNOWBASIN

6.1 *Area description, methods*

Snowbasin Ski Area was chosen as a test site for NXD2000 in North America for several reasons. First, it encompasses a variety of complex avalanche terrain. Second, it has 15 years of consistent weather and avalanche records. Finally, Snowbasin is the venue for the 2002 Olympic Downhill and Super-G Alpine races.

Snowbasin is located approximately 30 km north of Salt Lake City in Utah's Wasatch Mountains. Elevations at Snowbasin range from 1950 to 2895 m, and in 1998 the area expanded from approximately 4 to nearly 13 km² in preparation for the Olympics. The extensive avalanche terrain at the area necessitates a variety of avalanche control measures, including 25 hand charge routes, 9 avalauncher sites, 9 explosive trams, a 75mm recoilless rifle, and a Gaz-Ex exploder. In total, the area has approximately 225 avalanche paths with over 468 points where the ski patrol uses explosives for avalanche reduction work.

6.2 *Variables*

The weather data used for NXD2000 was collected at a number of sites throughout the ski area. Snowfall, snow water equivalent, snow depth, and air temperature data are from a nearly-level forest clearing at an elevation of 2300 m, while lower elevation wind data are from a prominent mid-elevation knob at 2425 m. All of these data are from the same locations and have been collected in a similar manner since the 1986/87 season. An avalanche destroyed a prior weather station in February 1986. Ridgetop wind data first became available in 1991, with the installation of an anemometer at the top of Mount Ogden (2895 m). An additional ridgetop wind sensor was installed at the top of Strawberry (2819 m) in 1998. Since this latter station will provide more consistent data into the future, we used a multiple regression analysis to derive a correction factor, which allowed us to extrapolate the wind data from Mount Ogden to the Top of Strawberry back to 1991 for use with the model. Thus, two versions of NXD have been installed at Snowbasin. The first version uses the lower elevation wind data and goes back to 1987, while the second version uses the ridgetop wind data and goes back to 1991. The weather data used are listed in Table 3.

Variable	Unit
A.M. Sun	y/n
P.M. Sun	y/n
Avg. Wind 2425m	mph
Dir. Wind 2425m	°
Max Temp	°F
Min Temp	°F
New Snow	in
Rain	in
SWE	in
Snow Depth	in
Avg. Wind Topstraw	mph
Dir. Wind Topstraw	°

Table 3: Snow and weather data used at Snowbasin, Utah, USA

Snowbasin's avalanche data follow the standard U.S. avalanche classification for size, type, areal extent, and other characteristics (Perla and Martinelli, 1978; McClung and Schaerer, 1993). Avalanche control route leaders and the snow safety director logged avalanche data onto the so-called U.S. Forest Service green sheets, and loaded these data into the program. While installing NXD2000 at Snowbasin, we configured the program such that the data fields matched the U.S. avalanche data classification.

6.3 *Experience with the variable weights*

A backcountry avalanche forecaster with 10 years of experience, in addition to three years of ski patrol experience at Snowbasin, adjusted the variable weights to try to maximize the performance of NXD2000. As with the Parsenn, we attempted to maximize the number of avalanche-day neighbors for each avalanche day and minimize the number avalanche-day neighbors for each non-avalanche day. We changed weights only if the new weights made sense from the point of our experience at Snowbasin. We initially used the shorter dataset, which used ridgetop wind data, to increase the speed of our computations. Then, the results were used to fine-tune our longer dataset that did not include ridgetop winds. Finally, we looked at exceptions – non-avalanche-days with more than five avalanche-day neighbors, and avalanche-days with zero or one avalanche-day neighbors – to see how well the model performed for avalanche forecasting.

Experience with NXD2000 at the Parsenn provided the initial weights for the variables (Table 4). Our data analysis showed the two top predictors of avalanche activity at Snowbasin are new snow and snow drift; other important factors were snow water equivalent, pre-day snowfall and snow water, wind speed for the current day and the pre-day, and snow depth. As such, we over-weighted snowfall and snow drift, while under-weighting settlement and new snow settlement, thereby improving the average number of neighbors by 12%. Further refinements over several runs improved the performance to 16% better than the initial weights, to an average of almost five neighbors with avalanches for every avalanche day (Table 4) and less than 0.8 neighbors with avalanches for days without avalanches. These refinements involved under-weighting temperature data, increasing the snow depth weight, and increasing snow drift even more, while under-weighting wind speed. We took this latter approach to make sure we focused on wind events with snow available for transport, and not on windy days when there was not transportable snow. We under-weighted the temperature data because we focused on dry slab avalanches, which are the most prevalent avalanche problem at Snowbasin. To focus primarily on wet snow avalanches the forecaster might want to use an entirely different set of weights. Standard deviations for all our runs are rather large, indicating significant scatter in the data.

Elaborate Variable	**Orig.**	**Run 1**	**Run 2**
New snow	1	3	3
Pre-day new snow	1	1	1
Snow water equivalent	1	1	1.5
Snow water pre-day	0.5	0.5	0.5
Snow depth	1	1.5	2
Snow depth reduced	1	0.5	0.5
Settlement	1	0.5	1
Settlement new snow	1	0.5	0.5
Temperature jump	1	0.5	0.5
Avg wind	3	1	1
Avg wind pre-day	3	1	0.25
Wind direction	1	1	1
Wind direction pre-day	1	1	0.25
Snow drift	1	3	4
Temperature variation	1	0.5	0.5
Temp. var. pre-day	0.5	0	0
Max temperature	1	1	1
Max temp. pre-day	0.5	0.5	0.25
Morning sun	0.5	0.5	0.25
Afternoon sun	0.5	0.5	0.25
Day has avalanches			
Average number of neighbors	4.22	4.75	4.92
Standard deviation	3.12	3.26	3.25
Day has no avalanches			
Average number of neighbors	0.76	0.85	0.77
Standard deviation	1.33	1.47	1.46

Table 4: Improvement of the weights and elaborate variables at Snowbasin, Utah, USA

We then applied these trial-and-error "optimal" weights to our longer dataset, and found our results to be similar. Some small changes made minor improvements of around 1%, so we decided to simply use the optimal weights as derived from our initial dataset. The overall improvement from the initial weights for this longer dataset was an encouraging 19%, from 3.9 to 4.7 neighbors with avalanches for every avalanche day.

After adjusting the weights, we went through the dataset and ran NXD-2000 on many of the avalanche days. In general, we felt the model performed well from an operational standpoint. Days with significant avalanche activity typically had a large number of neighbors with significant avalanche activity. Further, in many cases the program did a reasonable job of differentiating between days at the beginning, middle and end of an avalanche cycle.

6.4 <u>Analysis of exceptional days</u>

Once we determined an optimal set of weights, we looked at exceptions to further analyze the model performance. First, we examined the 30 days out of our 770-day dataset that had avalanches, but only had one or zero neighbors with avalanches. We found that these days either had only minor avalanche activity (perhaps one or a couple small avalanches) or they resulted from the timing of avalanche reduction work. The latter category was more frequent. Typically, these days occurred several days after an avalanche cycle and resulted when control work was conducted to open a previously closed area. Some days were when the ski area was opening for the season, or when cornice reduction work was conducted in remote parts of the ski area. In all of these cases, the day of interest was typically a day when the weather was *not* contributing to avalanching (i.e., no new snow, light winds, etc.) but avalanche reduction work resulted in the observed avalanche activity due to the snowpack that existed prior to that day.

We also investigated days that did not have any avalanches, but had more than five neighbors with avalanches to see what sort of patterns existed. A total of only 13 of these days existed, though there were another 16 days with no avalanches that had either four or five neighbors with avalanches. An examination of these days reveals a couple patterns. First, data errors existed on three days. Checking these revealed that avalanches had actually occurred on those days. Second, on one day there had been 30 cm of new snow, but extremely low snow densities (30 kg/m³) and cold temperatures (down to -20° C) probably inhibited avalanche formation. Most of the exceptions fell into a third category. These days usually followed previous days that had avalanches and snowfall. Often the timing of the new snow was during the day when the skiing public and the ski patrol could safely ski up the snow before dangerous slabs formed. So, on these days the timing of the snowfall was critical. Had the new snow fallen at night, avalanche reduction work would have been conducted and avalanches probably would have occurred.

Our analysis of the exceptions provides encouraging information about the performance of NXD2000 at Snowbasin. For the cases when avalanches occurred, but there were no neighbors with avalanche activity, the avalanches typically resulted from aggressive avalanche control work well after the weather that created the avalanche conditions, an easily recognizable situation for a snow safety director. Cases when no avalanches occurred on a specific day, but several neighbors had avalanches, could be primarily explained by the timing of snowfall. Again, this situation is easily recognizable by an experienced snow safety person.

7 CONCLUSIONS

NXD2000 is an excellent tool for avalanche forecasters and provides them with detailed information about the neighbor days. Results at Parsenn and at Snowbasin are encouraging.

Optimizing the weights and introducing new elaborate variables brings the knowledge of the local avalanche forecaster into the program, leading to improvements at both test sites. Comparing the weights allows us to characterize the two ski areas. At Snowbasin, wind and snow drift are the dominant avalanche factors because they are weighted more than double than at Parsenn. On the other hand at Parsenn the previous days are about twice as important, perhaps because of the larger area or the longer database at that area. It would be interesting to compare several sites in more detail.

The use of explosives makes defining an avalanche day difficult, because avalanches may be triggered on days when avalanche danger is not very high. The large number of avalanches implies a high danger and may lead to misinterpretation. Letting a forecaster store their own analyses, which would be available when examining the neighbors, is a possible solution.

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