Snowpack stability variation at a given avalanche danger level

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Abstract: To get a more detailed picture of regional snowpack stability patterns at different danger levels a large scale field study has been performed. At four occasions during the winter 2002 stability data were collected in the region of Davos. During each 1 to 3-day sampling period between 50 and 70 full snow profiles with rutschblock tests were recorded, primarily on shady slopes. At the same time the avalanche danger was estimated based on observations in the field. For analysis the profiles were assigned to one of five stability classes: Very Poor, Poor, Fair, Good, Very Good. Relating the stability to the prevailing (verified) danger level showed distinct patterns of stability. At the danger level Low, 90% of the profiles were rated as Good, or Very Good, whereas at the danger level Considerable, more than 50% showed Poor or Very Poor stability. The coefficient of variation was about 20% independent of the danger level. Significant differences in aspect and elevation existed. Some of the variation could be explained by differences in snow depth and snowpack consolidation (ram resistance). Due to the stability variation found verification of avalanche forecasts based on single stability tests is hardly feasible.

Keywords: avalanche forecasting, snow stability, stability test, snow stability evaluation

1. Introduction

Verification of snowpack stability and avalanche danger is a prerequisite for both the development and operational application of models as well as for the improvement of conventional and computer-based avalanche forecasting. Avalanche observation is the best indicator of snowpack stability but not applicable at all levels and scales of stability. At intermediate and good stability, or alternatively at the danger levels 1: Low, 2: Moderate and partly at 3: Considerable (as described in the European avalanche danger scale), other methods than avalanche observations must be applied to verify snowpack stability. Snowpack stability tests are best suited, combined with other observations, to verify the avalanche danger at the lower levels (Föhn and Schweizer, 1995).

Soratori (1996) and Cagnati et al. (1998) proposed a first scheme to operationally verify avalanche danger. The rutschblock score is directly related to a certain level of avalanche danger. Due to the limited reliability of single rutschblock test results, mainly as a consequence of the variable nature of the mountain snowpack, this direct link of rutschblock score to avalanche danger is likely inappropriate.

To our knowledge the only study on the stability distribution at a given danger level was done by Munter (1997). During numerous avalanche courses he collected stability data based on about 12 rutschkeil (a wedge shaped variation of the rutschblock) tests evenly distributed in the four principal aspects, and related the mean and standard deviation of the rutschkeil scores to the verfied avalanche danger. As one of the results of the study Munter (1997) suggested that the number of weak spots should increase exponentially with increasing avalanche danger. Birkeland (2001) investigated snow stability (as measured by stability tests) over a mountain range on two given days in order to better understand its spatial distribution and the implications for predicting dry snow slab avalanches. Spatial stability patterns could only partly be explained by variation of terrain, snowpack and snow strength properties. Wind effects in general and small-scale variability in the snowpack in particular were likely the cause for the partial lack of correlation.

The aim of the present study is to quantitatively describe snow stability patterns at the regional scale. This will provide a basis for a more detailed description of snow stability at a given danger level which is a prerequisite for operational verification in view of quality control for avalanche forecasting.

2. Methods

At four occasions during January to March 2002 the snowpack stability was assessed at the regional scale by 50-70 full snow profiles each supplemented with a rutschblock test. The area tested (about 400 km^2) was the region surrounding Davos. However, only in four

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sub-regions of about 30 km^2 in area, stability tests were actually performed. The main part of the remaining terrain is not suited for field studies, since it is either not steep enough, part of a ski area or otherwise disturbed by skiing activity. In addition, the sub-regions were chosen such that an automatic weather station was centrally located within each sub-region. Two sub-regions (Hanengretji and Parsenn) were located north-west of the main valley that runs south-west to north-east, two were south-east of it (Bärentälli and Gatschiefer). The study areas are above tree-line (which is about at an elevation of 2000 m) and with peaks up to 3000 m. Most data were collected between 2200 m and 2700 m.

Between 8 and 12 two-person sampling teams per day collected the snowpack and stability data. Access to the study areas was usually by helicopter or by lifts in a nearby ski area. Occasionally, at bad weather and/or critical avalanche conditions all teams climbed on skins to the study areas or approached from a nearby ski area. Based on the prevailing avalanche conditions each sampling day, the teams were assigned an area with an aspect and elevation range that should be covered. Otherwise, the teams were free to decide where to sample, based first on safety considerations, and second on the requirements for a representative site. A good test location should among other things be steep enough (about 35°), not too close to a crest or cornice, and with a uniform, below average snow depth.

Sampling usually took two days to reach a sufficient number of profiles and stability tests per sub-region and aspect or elevation. Typically, on Day 1 of a sampling period, the northerly aspects were tested. On Day 2 the westerly and easterly slopes, and on Day 3 the southerly slopes were included. Temporal evolution was expected not to affect the results in January and February on the mainly shaded slopes. In addition to the profiles and stability tests on slopes during each period a full profile was taken near each of the automatic weather stations.

Each team visited 2-5 sites per day. At each site, each team, observed a full snow profile, including ram hardness and a rutschblock test. In addition, they recorded observations on avalanche activity, snow surface properties, occurrence of whumpf-sounds or any other relevant stability information. Finally, they estimated the prevailing avalanche danger level for that day and the sub-region they sampled. This is comparable of estimating the class of snowpack stability. In contrast to North America, observers in Switzerland are much more used to assign a given avalanche situation to a level of avalanche danger than to a stability class.

The profiles with corresponding rutschblock test result (RB score, release type and fracture type) (Schweizer, 2002) were assigned to a certain stability class (1: Very Poor, 2: Poor, 3: Fair, 4: Good, 5: Very Good) according to the scheme proposed by Schweizer and Wiesinger (2001). This stability rating system is based on snowpack properties (as measured by profiles supplemented with stability tests).

These stability data were then analyzed per period with emphasis on stability patterns between sub-regions, aspects or elevations (mainly by trial and error). Data were also compared to verified and predicted avalanche danger levels. Nonparametric statistics were used, primarily the Mann-Whitney *U*-test to decide whether two stability distributions were different based on a level of significance of $p=0.05$. The Kruskal-Wallis *H*-test was applied to compare more than two independent samples.

3. Results

As envisaged data were collected during four sampling periods. During the last period there was a

Table 1: Summary of field campaigns with corresponding avalanche danger. The avalanche danger, predicted verified, and analyzed, is given as danger level (1 to 5, Low to Very High), elevation above which the level prevails, and sector of aspects (clockwise): part of the compass with the highest danger. The predicted danger is the one as given in the avalanche forecast of the morning of the first sampling day. The verified level is the danger as observed and reported by the sampling teams. The analyzed danger level is derived from the stability distribution based on the profiles and stability tests collected by the sampling teams. If, for the sector of aspects, "extreme" is given, this means that the danger only prevails on a few extremely steep, shady and rocky slopes independent of elevation; whereas "all" means in all aspects.

Period	Date	Days	Profiles	Avalanche danger		
				predicted	verified	analyzed
1	21-23 Jan 2002	2½	62	1, extreme	2, >2300, W-N-E	2, >2300, W-N-E
2	12-13 Feb 2002	2	73	3, >2400, W-N-E	3, >2300, NW-N-NE	3, >2300, NW-N-NE
3	26-27 Feb 2002	1½	50	3, >1800, all	3, >2300, W-N-SE	3, >2300, W-N-NE
4	18-19 Mar 2002	1½	62	2, >2500, NW-N-NE	2, >2600, NW-N-NE	1-2, >2500, W-N-E
5	20 Mar 2002	½	8	3, >2200, W-N-S	3, >2300, W-N-E	3, >2300, W-N-E

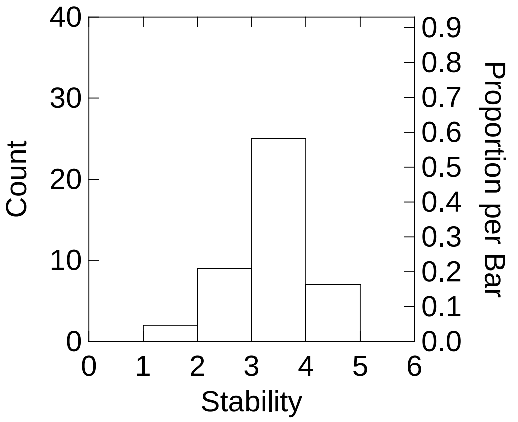

Figure 1: Stability distribution during the first period (21-23 January 2002) for the sub-regions BRT-HGR-PAR (N=43, median: 3, mean: 2.86±0.74). The distribution is typical for Moderate avalanche danger.

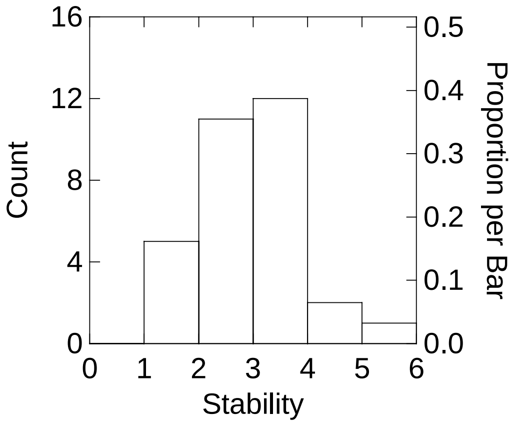

Figure 2: Stability distribution during the second period (12-13 February 2002) for the sub-regions BRT-HGR-PAR (N=31, median: 2, mean: 2.45±0.96). The distribution is typical for Considerable avalanche danger.

snowfall event, so that the third day during the last period was analyzed separately and called Period 5 (Table 1).

During the first period (21-23 January 2002) there was a significant difference in stability between the sub-regions Bärentälli (BRT) and Gatschiefer (GAT). Bärentälli was the most unstable, Gatschiefer the most stable sub-region. As the stability in the other two sub-regions Hanengretji (HGR) and Parsenn (PAR) were closer to the stability in Bärentälli, these three sub-regions were analyzed together. The difference in stability between BRT-HGR-PAR and GAT was significant (p=0.009). Whether all cases, or grouped in BRT-HGR-PAR and GAT, stability on westerly and easterly slopes was not significantly different from stability on northerly slopes. Accordingly, the stability distribution found for the group BRT-HGR-PAR (Fig. 1) should be representative for Moderate avalanche danger, since this danger level had been verified (Table 1). The relatively large number of profiles rated as Very Poor and Poor confirms the verification of danger as Moderate.

During the second period (12-13 February 2002) there were many clear signs of instability as e.g. numerous “whumpf”-sounds. Two teams even triggered a slab avalanche, one remotely, the other at the top near the crest, so nobody got caught. Accordingly, all teams consistently rated the danger during the second period as Considerable, maybe even some higher. Again the sub-region BRT proved to be the most unstable, and GAT as the most stable of the four sub-regions. Elevation was not considered as only five profiles were taken below 2300 m a.s.l. The northerly aspects had a weaker snowpack than the westerly and easterly aspects. However, analyzing all four sub-regions jointly, did not show a significant difference (p=0.21). Nevertheless, the stability distributions were quite different. About 50% Poor or Very Poor profiles from slopes of northerly aspect, and only about 30% from slopes of westerly/easterly aspects. The stability distribution from the slopes of westerly/easterly aspect were quite similar to the stability distribution found in the first period (p=0.27) which was definitely assigned to Moderate danger. Similar results emerge if aspect is analyzed for the regions grouping BRT-HGR-PAR vs. GAT. Finally, the stability distribution found in the northerly aspects of the sub-regions BRT-HGR-PAR is definitely assigned to Considerable danger (Fig. 2).

During the third period (26-27 February 2002) the teams again rated the avalanche danger as Considerable, but slightly less critical than the period before. Again the sub-region BRT was the most unstable of the four sub-regions, suggesting a grouping of BRT vs. GAT-HGR-PAR which revealed a significant difference (p=0.024). During this period profiles with stability tests were taken on avalanche slopes of all four aspects. The grouping of aspects was not straightforward (Fig. 3). The westerly slopes were the most unstable. South and flat slopes were more stable than the rest. Analyzing the westerly and northerly slopes jointly vs. the rest revealed a statistically significant difference (p=0.045). If the sub-regions were analyzed separately to find differences in aspect, it showed that for the sub-region BRT profiles from different aspects were not different. For the grouping GAT-HGR-PAR the profiles from the slopes in the sector of aspects W-N-SE were more unstable than from slopes in the remaining sector (SW-S) (p=0.048). Finally, the stability distribution from the sub-region BRT (N=16, median: 2-3, mean: 2.38±0.89) should be typical for Considerable avalanche danger, whereas the stability distribution for the slopes of aspect W-N-SE from the sub-regions

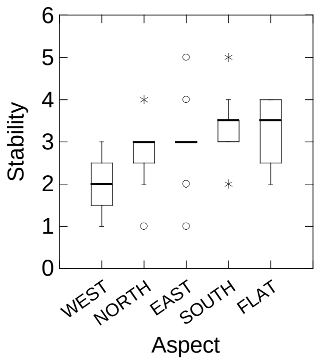

Figure 3: Stability for different aspects as found during the third period (26-27 February 2002), all sub-regions considered jointly (N=50).

(GAT-BRT-PAR) indicates a somewhat lower degree of avalanche danger (N=25, median: 3, mean: 2.84±0.75).

During the fourth period (18-19 March 2002) the avalanche danger was significantly lower. All teams rated the danger as Moderate or lower, but only in the northerly slopes and at higher elevation. There were no significant difference between the four sub-regions. For all regions the median stability was 4: Good. Profiles were taken at elevations between 2100 m and 2900 m. Observers suggested that stability should be better below 2600 m, and accordingly poorer above 2600 m. In fact, Figure 4 suggests a dependence of stability on elevation, and in particular to differentiate at 2500 m. The linear regression was significant (*p*=0.002) if the profiles taken on glaciers at about 2900 m that were much more stable, were not considered. Comparing snowpack stability above and below 2500 m shows a significant difference, even if the profiles on glaciers at about 2900 m are included (*p*=0.011). Above 2500 m, the westerly and easterly slopes were not significantly different from the northerly slopes. Comparing the slopes from the sector W-N-E above 2500 m with the rest of the profiles showed a significant difference (*p*=0.032). So the rest, i.e. all the profiles below 2500 m, and all the profiles above 2500 m, but not from aspects in the sector W-N-E, should correspond to Low avalanche danger (Fig. 5).

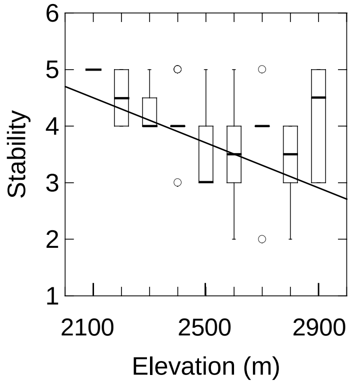

Figure 4: Dependence of stability on elevation during the fourth period (18-19 March 2002).

The fifth period (20 March 2002) followed right after the fourth period. It started snowing on 19 March 2002, and by morning of 20 March 2002 about 50 cm of new snow had fallen. Sampling possibilities were limited, but a few teams collected data nevertheless. All teams consistently rated the avalanche situation as Considerable. Due to the small number of observations (*N*=8) no grouping by elevation or aspect was possible. The stability distribution found (median: 2, mean: 2.1±0.83) confirms the assessment of Considerable avalanche danger.

4. Discussion and conclusions

The verification of avalanche danger, by observation in the field, or by analyzing the stability patterns, did not show substantial deviations from the avalanche forecast (Table 1). The main differences result from different sectors of aspect or elevations.

The stability distributions found at the different occasions cover the danger levels of Low, Moderate and Considerable. In total, not all observations are shown above, 13 different stability distributions could be analyzed. The typical distributions as given in Figures 1, 2 and 5 were confirmed. For Low danger about 90% of the profiles sampled were rated as Good or Very Good (median: 4, mean: 4.2±0.6). For Moderate danger about 20-25% of the profiles were each rated Poor or Very Poor, or Good and Very Good (median: 3, mean: 2.9±0.9). For Considerable danger about 50% of the profiles were rated Poor or Very Poor (median: 2, mean 2.4±0.9). Relative stability variation expressed as the median of the quartile coefficients of variation (Spiegel and Stephens, 1999), was 20%, in accordance with coefficients of variation found in other studies and at different scales (Kronholm et al., 2002). No relation

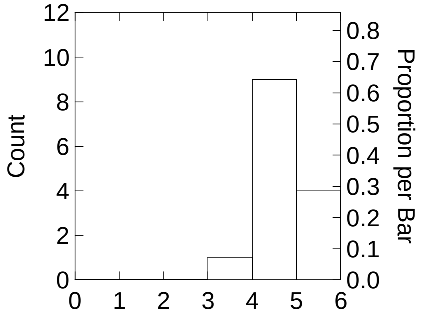

Figure 5: Stability distribution during the fourth period for all slopes below 2500 m, and all slopes above 2500 m, but not from an aspect in the sector W-N-E (N=14, median 4, mean: 4.2±0.58). The distribution is typical for Low avalanche danger.

between median stability and stability variation was found.

The field study has shown that significant variations in aspect and elevation typically exist. Aspect had clearly more influence, and level of danger, or stability, should not be averaged over aspect, unless checked for similarity. This is fully taken into account by the Swiss avalanche warning service that forecasts elevation and sector of aspects (part of the compass) for the highest prevailing danger level. However, nothing is usually said about the avalanche danger in the adjacent aspects or elevations. We have now shown that typically, the avalanche danger is one level less in the adjacent aspects and elevations, however, occasionally it is only half a danger level less.

Considering the operational verification of avalanche forecasts by snowpack stability tests, it has been shown that verification based on single stability tests is clearly not possible due to the stability variation found, even on slopes of the same aspect. However, experienced observers will likely find the appropriate spots for representative stability tests more easily, and will therefore need less tests to arrive at a reliable stability result than is suggested by the present study. Variability at the slope-scale might also increase the stability variation at the regional scale. To check this influence and the representativity of the stability test locations, during each of the periods, for a limited number of test sites, additional SnowMicroPen measurements (Schneebeli et al., 1999) in the surroundings (12 m × 12 m) of the stability test sites were performed.

In addition, preliminary analysis showed that besides terrain parameters snow depth and average ram resistance representing simple snowpack properties are well correlated with snow stability. Stability tests at sites with below than average snow depth give clearly more indicative results than from sites with a deep snow cover. Considering the rutschblock test result, besides the RB score, release type and fracture type are also highly correlated with stability, in line with the results of Johnson and Birkeland (2002).

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