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IMPROVING AVALANCHE RISK ASSESSMENT FOR BACKCOUNTRY SKI TOURS: A COMPARATIVE STUDY OF THE NOVEL SLABS METHOD WITH EXISTING METHODS.

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ABSTRACT: The main danger to which backcountry skiers are exposed are dry slab avalanches triggered by skiers themselves. This study introduces SLABS (**S**creening the **L**ikelihood of **A**valanches on **B**ackcountry **S**ki tours), a novel, statistically derived probabilistic method that strikes a better balance between accident prevention and freedom of movement than traditional approaches. We fitted a Generalised Additive Model (GAM) with a binomial link to over 57.8 thousand km of GPS-tracked ski tours and 1,250 accidents recorded in Switzerland across two decades. SLABS combines the maximum slope angle, elevation, danger level, and aspect into a risk assessment. A comparison of the SLABS method with other methods (Graphical, Professional, and Quantitative Reduction Method) shows that it offers more freedom of movement for a given accident prevention rate. It is the first time that probabilistic methods are compared in terms of their trade-off between accident prevention and freedom of movement. Because the SLABS method is not suited for mental arithmetic, it is meant to be implemented on the website `www.skitourenguru.ch`. Every day, this website evaluates the avalanche risk on thousands of backcountry tours throughout the Alps to help skiers plan their next tour. For a single slope the risk assessment of SLABS provides a starting point that should be supplemented with local observations.

Keywords: backcountry skiing, avalanche, probabilistic methods, generalised additive model

1. INTRODUCTION

When travelling in the backcountry in winter the main danger for skiers are dry slab avalanches triggered by the skiers themselves. To assess the risk many decision-making frameworks (DMFs) are available. Landrø et al. (2020b) give an overview of the most commonly used DMFs and distinguish two main categories: probabilistic and analytic methods. Probabilistic methods combine information about the current conditions and the terrain into a risk score. The main inputs are the avalanche forecast (e.g. danger level) and terrain properties (e.g. slope angle, aspect, elevation). When the risk score exceeds a predetermined threshold, extra caution or return is recommended. Probabilistic methods are easy to use but give a rather general assessment that might not always be valid for a specific slope. On the other hand, analytical methods assess the avalanche risk mainly with local observations of danger signs (e.g. recent avalanches, shooting cracks or whumpf sounds), snow profiles and stability tests. Analytical methods give potentially a more locally valid assessment but danger signs are not always present or noticed and stability tests are time consuming. In practice a mix of probabilistic and analytic methods is recommended, even if some people tend to rely more on the probabilistic methods while others rely more on the analytical methods. Landrø et al. (2020a) did a survey among mountain professionals and concluded that they rely more on analytical methods. Often it is recommended that beginners stick to the recommendations of probabilistic methods supplemented as far as possible with local observations.

Up to now, probabilistic methods were mainly based on accident analysis, avalanche knowledge and experience. They are not or only partially underpinned by a statistical data analysis. Schmudlach et al. (2018b) introduced the Quantitative Reduction Method (QRM), the first probabilistic method that calculates a risk score based on both accident an travel data (non-accidents). Terrain properties are combined in a terrain indicator (TI) and actual conditions in a danger indicator (DI). A risk score is derived for combinations of TI and DI. The QRM is used by the website `www.skitourenguru.ch` since winter season 2018-2019 to provide a daily risk assessment for backcountry ski tours based on the most recent avalanche forecast. The QRM was derived from a large set of backcountry travel data and accident data; the Avalanche Risk Property Data set or ARPD (Schmudlach, 2021; Winkler et al., 2021). Degraeuwe et al. (2024) used the same dataset to derive the SLABS method (**S**creening the **L**ikelihood

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of **A**valanches on **B**ackcountry **S**ki tours). The difference with the QRM is that SLABS uses the raw input from the avalanche forecast and terrain properties instead of two indicators (TI and DI) that combine several raw inputs. SLABS combines all relevant covariates in one statistical model. It is the data that determine the coefficients, and thus the relative importance, of the covariates. The ARPD dataset almost exclusively contains dry avalanche accidents. Hence, methods derived from it assess the risk on dry slab avalanches. For the purposes of this paper, a dry slab avalanches will be referred to simply as ’avalanche’.

This paper focuses on the comparison between the new SLABS method and the most common probabilistic methods used in Switzerland: the Graphical Reduction Method (GRM), the Professional Reduction Method (PRM) (Munter, 2017) and the Quantitative Reduction Method (QRM). All methods are applied to the ARPD. We assess their performance in terms of the trade-off they offer between accident prevention and freedom of movement. This is only possible because the ARPD contains accidents and travel data (i.e. non-accidents). To our knowledge it is the first time that such a comparison is performed. Probabilistic methods have been compared by other authors (McCammon and Haegeli, 2007) but only in terms of prevention rates. Such an analysis ignores the fact that probabilistic methods are not perfect, they often advice against a route even when no avalanche would be triggered. Imagine a probabilistic method that recommends to go on a ski tour only when the danger level is 1-Low. This method would have an accident prevention rate of about 95 %. But with the knowledge that only about 25 % of ski tours occurs at danger level 1-Low this method drastically restricts the freedom of movement.

2. DESCRIPTION OF THE DATASET

The model proposed in this paper is based on the Avalanche Risk Property Data set (ARPD). The ARPD consists of a set of covariates attached to travel points and accident points. The accident points serve as event-points, the travel points as non-event-points. A technical description of the ARPD is provided in Schmudlach (2021). A summary of the the ARPD can be found in Winkler et al. (2021). This section describes the most important variables of the ARPD to understand the statistical model behind SLABS, the SLABS method and the comparison with other probabilistic methods.

2.1 The travel data

Travel data about backcountry skiing was provided by the online platforms `www.gipfelbuch.ch`, `www.camptocamp.org` and `www.skitourenguru.ch`. The original GPS data were carefully cleaned: points on roads were removed, points close to ski slopes (freeriding) were excluded, points outside Switzerland were discarded, and spikes and artefacts were removed. Travel data are available for the winter seasons from 2005-2006 to 2020-2021. The total data set contains 5.78 million travel points, 57.8 thousand kilometres and 8558 tours. We estimate that this represents about 0.5 per thousand of the backcountry travel in the period from season 2001-2002 to season 2020-2021 (the period for which also accidents are available).

2.2 The accident data

In Switzerland, the WSL Institute for Snow and Avalanche Research (SLF) maintains a database including all reported avalanche accidents. This data has been used in numerous studies to explore accident patterns. We considered only accidents that comply with the following criteria: 1) Winter seasons from 2001-2002 to 2020-2021 2) At least one person was caught 3) The accident record is marked in the database as reliable and accurate 4) An avalanche forecast from the previous evening is available 5) The reported activity is backcountry skiing or snowboard touring (in contrast to off-piste skiing with mechanical ascending devices).

2.3 The covariates

For each point in the ARPD a set of covariates was collected. This section describes the covariates that are eligible for the model and some others that are used for model validation. The covariates refer either to the terrain, to the avalanche forecast or to both. All terrain related covariates were calculated from the Digital Elevation Model *swissALTI3D* (Swisstopo, 2018) with a resolution of 10 m and approximate accuracy of 1 m.

- **Slope Angle (*SA*)**: The local slope angle is calculated with the GDAL tool *gdaldem* (GDAL/OGR contributors, 2021).
- **Maximum Slope Angle (*MSAx*) with** $x \in [40, 70, 100, 150]$: *MSAx* is the 85th percentile of the local slope angles on the Relevant Slope Area (RSA) of a specific location. The parameter x is a measure for the size of the RSA. The aim is to consider the slope properties in a wider environment around the skier’s position. For an explanation how the RSA is determined see Schmudlach and Köhler (2016).
- **Aspect (*ASPECT*)**: Slope aspect calculated with the GDAL tool *gdaldem* (GDAL/OGR contributors, 2021). Slopes with aspect 0° and 90° face North and East, respectively.
- **Elevation (*ELE*)**: The elevation above sea level of the point in meters.

- **Plan Curvature (*PLANC*)**: The plan curvature, calculated with the GRASS tool *r.param.scale* (GRASS Development Team, 2021).
- **Terrain Fold (*FOLD*)**: *FOLD* visualises ridges, valley bottom lines, hillside toes or slope edges. *FOLD* is defined by the maximum angle between 5 pairs of normal vectors placed oppositely on a circle with radius 10 m around the point. More details you find in Schmudlach et al. (2018b).
- **Distance to Ridge (*DIST_RIDGE*)**: The distance in meters to the nearest ridge.
- **Forest Density (*FD*)**: Tree cover density according to Corine Land Cover data (ESA, 2017). FD is expressed in percent.

A second set of covariates is derived from the avalanche forecast issued by the Swiss avalanche warning service (SLF) at 17:00h the day before:

- **Danger Level (*DL*)**: The danger level provided by the avalanche forecast: 1-Low, 2-Moderate, 3-Considerable, 4-High. Level 5-Very High is too rare and thus not considered.
- **Critical Aspects (*CA*)**: Critical aspects as indicated in the avalanche forecast, 8 sectors of 45°.
- **Critical Elevation (*CE*)**: Critical elevations as indicated in the avalanche forecast.
- **Avalanche Problems (*AP*)**: Avalanche problems like fresh snow, wind-drifted snow, old snow, glide snow or wet snow. This information is only available from winter season 2012-2013 onwards.

The danger level is valid for locations inside the critical elevations and aspects. These locations are also called the core zone. For *DL* 1-Low, no core zone is specified in the Swiss avalanche forecast, which according to the interpretation aid (WSL Institute for Snow and Avalanche Research SLF, 2021) means that all aspects and elevations are equally affected. Winkler et al. (2021) have shown that this is not the case and have determined the following risk-based values for critical elevation and critical aspects for *DL* 1-Low: critical aspects from West over North to South-East and critical elevations above 2000 m. In this paper we use the same definition at level 1-Low.

A third and last set of covariates is derived from combining the avalanche forecast with terrain features:

- **Delta Critical Elevation (*DCE*)**: The elevation difference between *ELE* and *CE*. *DCE* tells how deep the point is inside the core zone in terms of elevation. *DCE* is positive inside the critical elevations and negative outside.
- **Aspect Overlapping Fraction (*AOF*)**: The fraction of the range of aspects in the relevant slope area (RSA) that overlaps with the critical aspects as indicated by the avalanche forecast. Only aspects with slope angles $> 25°$ are taken into account. 0 means that all aspects in the RSA are outside the critical aspects, 1 means the all aspects in the RSA are inside.

This is a selection of the most important covariates, a complete list is available in Degraeuwe et al. (2024).

3. THE STATISTICAL MODEL UNDERPINNING THE SLABS METHOD

This section summarises the extensive description (Degraeuwe et al., 2024) of the statistical model that was fitted to the accident and travel data. A Generalized Additive Model (GAM) was used to express the logit of the probability that a data point is an accident as a function of a set of significant covariates. The logit of a probability p is defined as: $\text{logit}(p) = \ln(\frac{p}{1-p})$. The values of $\text{logit}(p)$ lie between $-\infty$ and ∞. To fit the GAM the *mgcv* package available in R (R Core Team, 2021; Wood, 2017) was used. The covariates were selected with a step-wise 5-fold cross validation: the dataset was split up in five independent datasets of which four were used for training and the fifth for validation. Starting from a zero-covariate model, covariates were added one by one and the new covariate resulting in the model with the best (lowest) Bayesian Information Criterium (BIC) was retained. This step-wise selection resulted in the following model for the logit of the probability on an accident (p):

$$\text{logit}(p) = \beta_0 + s_1(MSA40) + \beta_1 DL + s_2(DCE) + \beta_2 AOF \quad (1)$$

β_0, β_1 and β_2 are the intercept, the coefficient of *DL* and the coefficient of *AOF*, respectively. $s_1()$ and $s_2()$ are the smoothers of *MSA40* and *DCE*, respectively. The relation between the $\text{logit}(p)$ and each covariate is shown in Fig. 1. The distance between the horizontal dashed lines corresponds to the logit of the risk ratio between two consecutive danger levels. Table 1 lists some selected risk ratios. The covariates are now discussed in the order they were selected:

1. **A smoother $s_1()$ for *MSA40*.** The other maximum slope angles (*MSAx* with $x \in [70, 100, 150]$) scored worse. Figure 1a shows the smoother of *MSA40*. The logit of the accident probability, $\text{logit}(p)$, increases strongly with slope angle, especially between 30° and 40°. The risk ratios between 35° and 30° and between 40° and 35° are 4.9 [4.1, 5.8] and 3.2 [2.8, 3.6], respectively (Table 1). Above 40° the increase of $\text{logit}(p)$ flattens off.

2. **The Danger Level, *DL*.** Although *DL* is a categorical covariate, it was also included as continuous covariate in the model selection. The continuous covariate resulted in a better model with a slightly lower *BIC*. *DL* as continuous covariate makes it easy to implement the intermediate danger levels (Techel et al., 2022) that are published by the Swiss avalanche warning service from winter 2022-2023. The risk ratio between two consecutive danger levels is 4.3 [3.9, 4.7] (Table 1).
3. **A smoother $s_2()$ for *DCE*.** This smoother rises almost linearly up to 500 m above the critical elevation, then it flattens as shown in Fig. 1c. Table 1 shows that at the CE the risk is 5.3 [3.9, 7] times higher than 500 m below the CE. This increase continues above the CE; 500 m above the CE the risk is 2.7 [2.3, 3.1] times higher than at the CE. Then the rise flattens off.
4. **Aspect Overlapping Fraction, *AOF*.** Compared to the risk ratio between danger levels, its effect is smaller (Fig. 1d). Inside critical aspect the risk is 3.4 [2.7, 4.2] times higher than outside (Table 1).

The following covariates were tested but did not result in a model with lower *BIC*: *FOLD*, *PLANC*, and *FD*. The avalanche problems were not significant, indicating that it is the stability that matters (*DL*), not the underlying cause. *DIST_RIDGE* was tested but discarded because of its high correlation with *DCE*. Also interactions were tested. The interaction between the smoother for *MSA40* and *DL* was not significant, meaning that the smoother, s_1, is valid for all danger levels. Also the interaction between *AOF* and *DCE* is not significant.

label	value	ref.value	RR	CI
MSA40	25	20	2.9	[1.9, 4.4]
MSA40	30	25	3.3	[2.5, 4.3]
MSA40	35	30	4.9	[4.1, 5.8]
MSA40	40	35	3.2	[2.8, 3.6]
MSA40	45	40	1.4	[1.3, 1.6]
MSA40	50	45	1.0	[0.9, 1.1]
DL cont.	2	1	4.3	[3.9, 4.7]
DL cont.	3	2	4.3	[3.9, 4.7]
DL cont.	4	3	4.3	[3.9, 4.7]
DL cat.	2	1	5.7	[4.3, 7.3]
DL cat.	3	2	3.9	[3.4, 4.4]
DL cat.	4	3	10.1	[4.3, 20.2]
DCE	0	-500	5.3	[3.9, 7]
DCE	500	0	2.7	[2.3, 3.1]
DCE	1000	500	1.1	[0.9, 1.4]
AOF	1	0	3.4	[2.7, 4.2]

Table 1: Selected Risk Ratios and their 95 % confidence interval calculated with model of eq. 1, only the risk ratios for *DL* cat. were calculated with a model with DL as a categorical covariate.

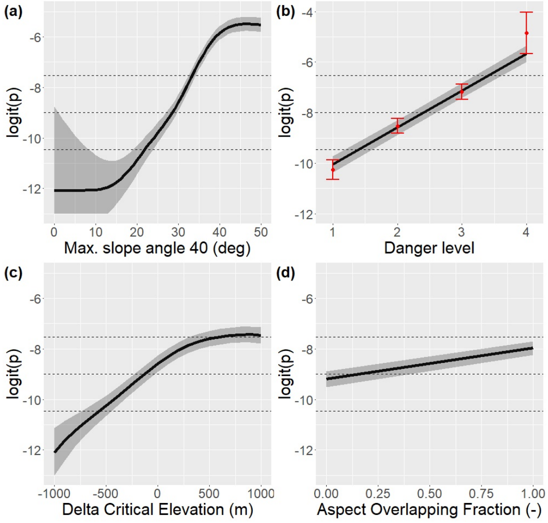

Figure 1: $\mathrm{logit}(p)$ as a function of single covariates with 95 % prediction confidence intervals. All plots have the same Y-axis range. The horizontal dashed lines correspond to the difference between two consecutive danger levels. a) Smoother of *MSA40*. b) Continuous and categorical (red) danger level *DL*. c) Delta Critical Elevation, *DCE*. d) Aspect Overlapping Fraction (*AOF*)

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4. A NEW PROBABILISTIC METHOD: SLABS

The final model presented in the previous section is combined with accident prevention rates of 60 % and 80 % for *high* and *elevated* risk, respectively. This provides the basis for the new probabilistic method: SLABS (**S**creening the **L**ikelihood of **A**valanches on **B**ackcountry **S**ki tours). In the SLABS method two small modifications are applied to the statistical model presented in the section above. The smoothers for *MSA40* and *DCE* decline slightly after 46° and 960 m, respectively. These declines were ignored, the (relative) risk was kept at the maximum value for *MSA40* and *DCE* values above 46° and 960 m, respectively. These declines are not significant and are due to lack of data. We do not see physical reasons for these small declines. Figure 2 shows the risk assessment by the SLABS method as a function of *DCE* and *MSA40*: red stands for *high*, orange for *elevated* and green for *slight* risk. There is a sub-plot for danger levels 1-Low to 4-High. All sub-plots apply to locations completely inside the critical aspects. The plots for points outside the critical aspects are similar but the zones are shifted slightly to higher values of *MSA40* and *DCE*. These plots are available in Degraeuwe et al. (2024). The black lines show the risk ratio with respect to the average risk. Note the large range in relative risks. With a combination of four covariates it is possible to distinguish between risks that are between 1000 times lower and almost 100 times higher than the average risk. The black dots are the accident points. It is clear from the plots that choosing less steep slopes and staying at lower altitudes decreases the risk ratio. The risk ratio increases strongly at higher danger levels and to lesser extent inside the critical aspects. It is also important to note that there are accident points in the green areas. No method can guarantee absolute safety.

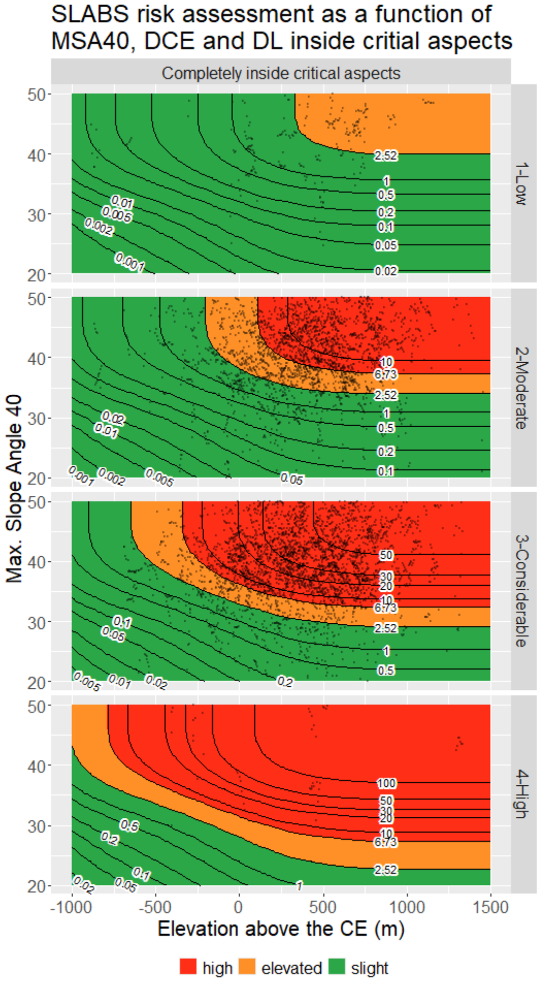

Figure 2: Risk assessment of the SLABS method as a function of *MSA40*, *DCE*, and *DL* inside the critical aspects ($AOF = 1$). The black lines represent the risk ratio with respect to the average risk. The black dots are the accident points.

5. RESULTS: COMPARISON OF PROBABILISTIC METHODS

In this section we compare the GRM, PRM, QRM and SLABS method. Each method is applied to all travel and accident points of the data set to give an indication of the risk. (e.g. the categories slight, elevated or high for the GRM, the residual risk value of the PRM, or the $logit(p)$ value of SLABS). Then we check for each category or value how many accidents are correctly detected and how many travel points are by mistake labelled as an accident. The corresponding fractions of accidents and travel points are calculated by dividing them by the total number of accidents and travel points, respectively. These two fractions are called True Positive Rate (TPR) and False Positive Rate (FPR). Where a *positive* result means an accident. The TPR is the accident prevention rate. The FPR is the share of the terrain that has to be avoided to achieve a desired prevention rate. It is a measure for the restriction of the freedom of movement. A plot of the TPR against the FPR is called the *Receiver Operating Characteristic* (ROC) (Fawcett, 2006). We would like to have a ROC that has a high TPR for small FPR, or high prevention rates for few restrictions of movement. This means that the area under the ROC should be big. The *Area Under Curve* (AUC) is a commonly used quality indicator of binary classification models. A model with an AUC of 1 distinguishes perfectly between accidents and non-accidents while a model with an AUC of 0.5 is no better than random. This will be the criterion to compare the methods.

To calculate the risk scores for the GRM and PRM a choice about the slope angle had to be made. To approximate their use in practice the local slope angle (*SA*), *MSA40*, *MSA70* and *MSA100* were used at danger levels 1-Low, 2-Moderate, 3-Considerable and 4-High, respectively. Schmudlach et al. (2018a) found that *MSA70* corresponds best to what experts consider the relevant slope at level 3-Considerable. In this way the slope angle in a wider area is considered at higher danger levels. In case of the PRM the residual risk for a small group with safety distances ($RF_3 = 3$) was calculated. Figure 3a shows the ROC for the GRM, the PRM, the QRM and the SLABS method for all points, and Fig. 3b shows the ROC for points in avalanche terrain (i.e. $TI > 0.25$). Table 2 gives the AUC for all points and the ones in avalanche terrain. The former AUCs are higher because non-avalanche terrain contains many additional travel points, but practically no additional avalanche accidents. Travel points are located predominantly at the top right of the ROC. Removing them flattens the ROC and shifts the lower left branch the right. The GRM and PRM have the lowest AUC, the QRM scores much better and the SLABS method has the highest AUC. This means that for a given TPR or accident prevention rate the SLABS method restricts the freedom of movement less than the QRM, and much less than the PRM or the GRM.

AUC	GRM	PRM	QRM	SLABS
Everywhere	0.873	0.858	0.926	0.943
Avalanche terrain	0.834	0.812	0.87	0.895

Table 2: Area Under Curve (AUC) of the Reciever Operation Characteristics (ROC) in Figure 3 of each probabilistic method in all terrain (everywhere) and in avalanche terrain only. The Area Under Curve (AUC) should be as big as possible.

Table 3 gives an overview of the TPR and FPR at the thresholds used by the different models. The GRM assigns a *slight* risk to combinations of slope angle and danger level in such a way that an accident pre-

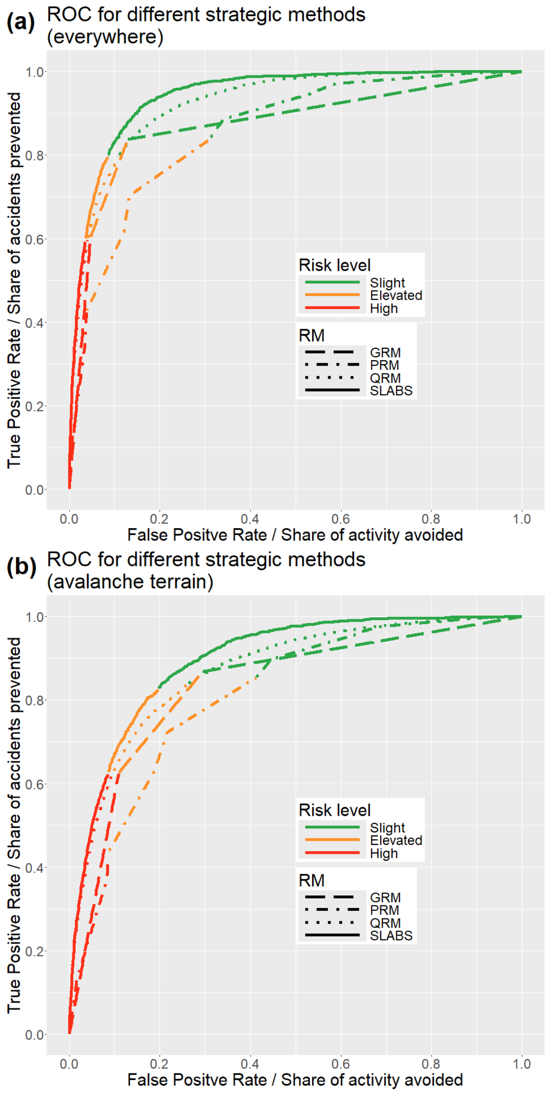

Figure 3: ROC for the GRM, PRM, QRM and SLABS. The blue numbers on the left are the average slopes of the ROC of the SLABS method over 0.1 TPR intervals. They represent the relative risk between points in the interval and the average risk over all data (left) or in avalanche terrain (right).

Everywhere

(FPR, TPR)	GRM	PRM	QRM	SLABS
Slight-Elevated	(0.13, 0.84)	(0.31, 0.84)	(0.11, 0.8)	(0.09, 0.8)
Elevated-High	(0.05, 0.6)	(0.04, 0.42)	(0.04, 0.6)	(0.04, 0.6)
Avalanche terrain				
Slight-Elevated	(0.29, 0.87)	(0.41, 0.85)	(0.26, 0.84)	(0.2, 0.83)
Elevated-High	(0.11, 0.63)	(0.09, 0.44)	(0.1, 0.63)	(0.09, 0.62)

Table 3: FPR-TPR pairs at borders between risk levels for each probabilistic method in Figure 3. The False Positive Rate (FPR) corresponds to the **share of activity avoided** and should be as small as possible. The True Positive Rate (TPR) corresponds to the **share of accidents avoided** and should be as big as possible.

vention rate or TPR of 84 % is reached but 13 % of the travel points have to be avoided. In avalanche terrain the prevention rate is 87 % but 29 % of the terrain has to be avoided. If only points with *high* risk are avoided the prevention rate in avalanche terrain sinks to 63 % but only 11 % of the avalanche terrain has to be avoided. The PRM does not make a difference between *slight* and *elevated* risk. We introduced an additional threshold at a residual risk of $1/3$. This corresponds to the reduction factor a small group has to reduce the risk by using safety distances. The prevention rate for points with a *slight* risk are similar to the GRM but the FPRs are bigger, so the PRM is more restrictive than the GRM. When only the points with *high* risk are avoided the PRM becomes less restrictive (lower FPR) than the GRM but the prevention rate decreases about 20 % points compared to the GRM. This more aggressive strategy is due to the $RF_3 = 3$ for small groups keeping safety distances. The thresholds of the QRM were set such that 60 % and 80 % of accidents are prevented when points with *high* respectively *elevated* risk are avoided. For similar prevention rates as the GRM, the QRM offers more freedom. For the SLABS method the same thresholds were adopted. It offers more freedom of movement than the other methods at every prevention rate.

6. CONCLUSIONS

In this paper we presented a new probabilistic method to assess avalanche risk ratios on backcountry ski tours: SLABS (**S**creening the **L**ikelihood of **A**valanche risk for **B**ackcountry **S**kiing). A Generalised Additive Model (GAM) was fitted on a unique data set of both backcountry travel data and accidents. The model considers slope angle, danger level, elevation and aspect. Limits for *high* and *elevated* risk are set in such a way that accident prevention rates of respectively 60 % and 80 % are achieved when *high* or *elevated* risk terrain is avoided. These limits correspond to typical prevention rates of probabilistic methods, measured in McCammon and Haegeli (2007).

We were able to quantify the effect of four covariates on avalanche risk ratios: the non-linear relation with the slope angle, the risk ratios between danger levels, and the effect of elevation and aspect with respect to the core zone. We demonstrated that the risk varies about 5 orders of magnitude between the safest and most riskiest conditions. Hitherto the importance of individual risk factors had never been quantified.

These factors were already used by the GRM and PRM but not combined in the most optimal way. Especially the effect of aspect is overrated by the PRM while the effect of elevation with respect to the critical elevation is underrated. The size of *relevant slope* in which the maximum slope angle has to be considered could be quantified too. A control radius of about 40 m resulted to be most appropriate.

This paper presents the first complete analysis of the performance of existing reduction methods. In McCammon and Haegeli (2007) prevention rates for several methods were calculated but the False Positive Rate was ignored because travel data were not available. Because this study combines travel and accident data, for each probabilistic method the share of terrain that has to be avoided (False Positive Rate) to guarantee a desired accident prevention rate could be determined. The more freedom a method gives for a given prevention rate the better it is. The GRM is simpler and offers more freedom of movement for similar prevention rates than the PRM. Though the limit between *elevated* and *high* risk used by the PRM allows more freedom of movement at a lower risk prevention rate than the GRM. The QRM scores better than the GRM and the PRM. The SLABS method based on a GAM gives the most freedom of movement for any given accident prevention rate.

SLABS is not only the most accurate probabilistic method, but also the one with the best scientific basis. In order to make SLABS applicable in practice, a front-end is needed, such as already exists with `www.skitourenguru.ch`. As probabilistic method, SLABS remains an initial estimate for a single slope. During a ski tour, it should be supplemented with an independent assessment of the avalanche danger on site. Observations in the terrain can tip the decision in either direction: continue or return. These local observation should be important factors that are not included in the model, such as:

- Recent skiing activity on the slope. Since we had no information about the presence of tracks, our method gives risk ratios for an average travel activity. If many tracks are present on a slope it is probably safer than the model indicates. If no tracks are present the slope is probably less safe than the model indicates.

- Danger signs that do not match with the current danger level. E.g. recent spontaneous avalanches, whumpf sounds and cracks at danger level 1-Low or 2-Moderate where these are unusual.

- Local variation of the snow cover. The avalanche forecast is not able to predict local variations in the snow cover and stability. E.g. local accumulations of wind-drifted snow increase the risk while on a blown-off slope the risk is lower.

- Safe terrain features like ridges, dense forests, human made artefacts or, the other way round, terrain traps.

Unfortunately we cannot quantify these effects. Only a qualitative assessment can be made about the avalanche risk from such local observations. Some observations might indicate an increase and others a decrease in risk. Combining the risk assessment of SLABS with local observations is still a big challenge. Assessing the avalanche risk is still associated with big uncertainties. However, with this study we believe to have quantified better some of the most important factors. By implementing the SLABS method in the website `www.skitourenguru.ch` this knowledge will be made available to the public which hopefully contributes to everyone's safety.

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