Tour-Check 3.0

An Avalanche Screening Tool for Winter Backcountry Tours

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Abstract

Tour-Check is the route-screening component of topo^alpin for ski and snowshoe tour planning in the Alps. At route points sampled every 10 m, it computes a dimensionless screening value from published SLABS risk-ratio relationships and terrain predictors extracted from an independently implemented approximation of the SLABS Relevant Slope Area. The colour of the route is a SLABS-derived classification using the published predictors, including its terms for elevation and aspect, and the thresholds of its Figure 3. Tour-Check 3.0 uses no avalanche terrain classification (ATES). Each point is evaluated under the bulletin of its own warning region, combined with the bulletins of neighbouring regions near a region boundary. For the route screening index, one danger level less is assumed outside the critical aspects and elevations of the bulletin, following the rule of thumb of the Swiss bulletin interpretation guide, the elevation enters as an absolute term, and the point values are aggregated over 100 m sections and two passes. This paper documents the data, the computation, the parameters that rest on published sources or measurements, and the retrospective checks of Tour-Check 3.0 against the published version 2.0. Under reconstructed core-zone bulletins, at least one of seven points is shown orange or red at 90.9 % of 1,239 precisely located Swiss accident sites (version 2.0: 91.0 %) and at 85.0 % of 906 Austrian accident sites (85.5 %). Of the colour, only the shape of the Relevant Slope Area and a slope offset of 1.3° were set partly on the Swiss accident data; other constants were aligned with published terrain data and SLABS Figure 3. Outside the core zone the share is 79.1 % and 83.3 % under the two reconstructions, against 85.5 % and 86.8 % with the ATES floor of version 2.0. Tour-Check outputs are screening classifications, not probabilities of avalanche release, accident or fatality on an individual tour.

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1 Introduction

Route planning in winter mountain terrain requires avalanche danger to be weighed against terrain exposure. Experienced backcountry skiers combine the avalanche bulletin with their own assessment of the terrain — a process that requires specialist knowledge and experience.

Tour-Check is a feature of topo^alpin, an application for tour planning, navigation and mountain weather in the Alps (web and iOS). This document describes the methodology of the automated route assessment in Tour-Check version 3.0, the published models on which it is based, the implementation choices, and how the implementation was checked, including a retrospective evaluation at accident sites. It is a technical methodology paper, not a peer-reviewed article.

1.1 Existing approaches

Skitourenguru is a web platform for route-based avalanche risk assessment in the Alps; it rates predefined and user-defined routes. The terrain around each route point is described on a Relevant Slope Area (RSA) delineated from the elevation model[1]. In its first published form, the route rating averaged the risk indicators of the riskiest segments of the route[2]. The current version is based on a variant of the SLABS method described below[3] that assumes one danger level less outside the critical aspects and elevations and adds the absolute elevation; along a route it takes the maximum of each 100 m section, combines the sections through their complementary probabilities and counts ascent and descent as two independent passes[4].

White Risk, developed by the WSL Institute for Snow and Avalanche Research SLF, is an avalanche application (iOS and Android) with integrated tour planning for Switzerland. Users draw routes along mapped trails or freely across the terrain; the application detects crux points automatically and assesses them using avalanche terrain maps together with the current avalanche bulletin. The underlying RiskCheck framework[5] separates the probability of avalanche release from the potential consequences and combines them in a risk-based approach (probability × consequences); it also allows the assessment to be refined manually with field observations. Its automated route assessment covers Switzerland.

1.2 Our approach

Tour-Check approximates the published response relationships of the SLABS generalised additive model (GAM)[3], which screens the likelihood of an avalanche accident under the current bulletin conditions; its authors compare the model with existing probabilistic methods[6]. The colour of the route is a SLABS-derived classification using the published predictors, including its terms for elevation and aspect, and the thresholds of its Figure 3. For the route index, Tour-Check applies two published rules on top of SLABS — one danger level less outside the core zone[7], with transitions after the Quantitative Reduction Method[8] — and an absolute elevation term, as the SLABS variant of Skitourenguru does[4] (Section 5.5).

SLABS takes its terrain predictors from the Relevant Slope Area. Tour-Check computes this area itself from the elevation model, following the published description, and checks the result against the published values of the SLABS study and against the published route point data set[9] (Section 8).

All parameters of the computation are given with their values (Section 7). Where a parameter rests on a published source or on a measurement reported here, that basis is named; the remaining ones are product settings, given with their value but without the way they were chosen.

Intended use. Tour-Check is a screening aid for planning a tour, for users who can read an avalanche bulletin and the terrain themselves. It makes potentially critical sections of a route visible under the published bulletin. It is no substitute for an independent avalanche assessment, at home or in the field, and it does not use local observations. Green indicates a lower screening classification under the available inputs; it does not establish that a route or slope is safe, and it does not exclude hazardous local conditions or exposure to avalanches originating outside the modelled neighbourhood. The assessment reflects the bulletin currently selected by the application and may not correspond to the planned time of travel; users must verify the validity period and the current official bulletin. The model was developed and evaluated for ski touring; its application to snowshoe routes is exploratory and has not been separately evaluated.

2 Changes from version 2.0

Version 2.0 of Tour-Check coloured each point with the SLABS-derived screening value and the thresholds of SLABS Figure 3, and raised the colour with an ATES floor: complex and extreme terrain at least orange from danger level 3 and red from level 4, challenging terrain with steep surroundings at least orange from level 3. Version 3.0 changes the colour in one way, the route index in two, and the bulletin under which both are evaluated.

No ATES floor. The colour no longer uses an avalanche terrain classification; it is the SLABS colour of version 2.0 without the floor. The floor was a coupling rule between two models of different kind, and its specific form had little evidence behind it. Its removal lowers both the share of ordinary touring terrain shown orange and the share of accident sites flagged: by 0.1 percentage points inside the core zone and by 3.5 to 6.4 points outside (Section 8.7, Section 8.8). Whether the floor helped against runout and overhead exposure, which these checks do not sample, has not been assessed. No avalanche terrain classification enters Tour-Check 3.0; the terrain still enters through the RSA, MSA40, forest and terrain folds.

Absolute elevation in the route index. The point model of the route index takes the elevation as a factor of its own, rising with the absolute elevation up to 2,250 m and constant above (Section 5.5), instead of the SLABS term for the distance to the critical elevation, which the one-level reduction already carries.

Scaling of the route index. The scaling constant of the route index was set anew for the changed point model; it is no longer derived from a fatality rate (Section 6.3).

Bulletin per point. Version 2.0 evaluated the whole route under the most severe bulletin of all regions it touched. Version 3.0 evaluates each point under the bulletin of its own region and, near a region boundary, combines it with the bulletins of the neighbouring regions (Section 5.2). A section deep inside a region with a milder bulletin is therefore assessed more mildly than in version 2.0. Near a region boundary, the value of a point may rise or fall relative to its own bulletin alone, depending on the point values the neighbouring bulletins give. The checks of Section 8 evaluate each site under a single bulletin and do not cover this change.

The terrain data, the bulletin shown with a route and the road, tunnel and dam rules are those of version 2.0.

3 Underlying Models

SLABS (Screening the Likelihood of Avalanches on Backcountry Ski tours; Degraeuwe et al.[3]) is a binomial GAM with a logit link, fitted to discriminate between accident points and travel points.

It was fitted to 57,800 km of GPS tracks of backcountry ski tours and 1,250 avalanche accidents recorded in Switzerland over 20 winter seasons. The final model uses four predictors:

- **MSA** (Maximum Slope Angle): the 85th percentile of the local slope angles on the Relevant Slope Area of a point;
- **DL** (Danger Level): the danger level of the avalanche bulletin;
- **DCE** (Delta Critical Elevation): the elevation difference between the point and the critical elevation of the bulletin, positive inside the critical elevations;
- **AOF** (Aspect Overlapping Fraction): the fraction of the range of aspects in the Relevant Slope Area that overlaps with the critical aspects; only aspects of slopes steeper than 25° are taken into account.

SLABS evaluated RSA sizes of 40, 70, 100 and 150 m, as well as combinations that widen the area with the danger level, and found MSA40 the best predictor; the final model uses MSA40 only [3]. Tour-Check therefore uses MSA40 as well.

3.1 Published risk ratios

Factor	Class	Step RR	Chained multiplier
MSA40	20°	—	1.0
	25°	2.9	2.9
	30°	3.3	9.6
	35°	4.9	47.0
	40°	3.2	150.4
	45°	1.4	210.6
DL	per level	4.3	$\beta_1 = \ln 4.3$
AOF	1 vs. 0	3.4	$\beta_2 = \ln 3.4$
DCE	0 m vs. −500 m	5.3	
	+500 m vs. 0 m	2.7	
	+1000 m vs. +500 m	1.1	

Table 1: Pairwise risk ratios reported by Degraeuwe et al.[3, Table 1]. The step RR compares each MSA40 value with the value 5° lower. The chained multiplier is the product of the steps from MSA40 = 20°; it is used by Tour-Check and is not a value reported in the SLABS study.

The steepest increase lies between 30° and 35° (step RR 4.9); above 45°, the published curve flattens (RR 1.0 between 45° and 50°).

SLABS models MSA40 and DCE as smooth functions. The SLABS article provides an R script as supplementary material that reproduces its Figure 3 from the fitted model [3]. Tour-Check does not evaluate that script: the assessment runs in the application, and this version approximates the published response relationships from the risk ratios of Table 1. Below 20° the MSA40 factor is 1; at 20°, 25° … 45° it takes the chained multipliers and is interpolated log-linearly between them. Since the step from 45° to 50° is 1.0, the curve is flat from 45°; values above 46° are clamped, as the authors do (their Section 4.2). Along a single predictor, the chained multipliers telescope to the ratio between the endpoint model predictions when all other predictors are held fixed: $p_{25}/p_{20} \times p_{30}/p_{25} = p_{30}/p_{20}$. The combination of multipliers across predictors is a product-specific approximation. It follows the additive structure of the GAM on the logit scale, $\mathrm{logit}(p) = \beta_0 + s_1(\mathrm{MSA40}) + \beta_1\ \mathrm{DL} + s_2(\mathrm{DCE}) + \beta_2\ \mathrm{AOF}$, and is expected to be close to a probability-ratio formulation when the modelled probabilities are small. Whether this holds for the SLABS model, fitted to a data set enriched

in accidents, has not been checked; the result is a SLABS-derived screening model, not a direct reproduction of the fitted SLABS probability model.

The DCE curve runs through $\mathrm{RR}(-500) = 1/5.3$, $\mathrm{RR}(0) = 1$ and $\mathrm{RR}(+500) = 2.7$. Between these points the risk ratio itself (not its logarithm) is interpolated piecewise with the cubic $3t^2 - 2t^3$, with t normalised separately on each of the two intervals (-500 to 0 m and 0 to $+500$ m), so that the curve has zero slope at -500, 0 and $+500$ m. Below -500 m it falls on geometrically by the same factor of 5.3 per 500 m, to $1/5.3^2$ at $-1{,}000$ m, and is held constant below; SLABS reports no ratio there, so this continuation is a choice of Tour-Check. Above $+500$ m it rises by a factor of 1.1 per 500 m, geometrically, and is held constant from 960 m (their Section 4.2). The colour uses this curve; the route index uses the elevation term of Section 5.5 instead.

SLABS yields risk ratios between conditions, not an absolute accident probability. In the words of the authors, the absolute value of the modelled probability "is not meaningful because of under-reporting: we have a high percentage of accidents and only a small fraction of the travel data"[3].

4 Terrain Inputs

SLABS was fitted to terrain values computed by Skitourenguru on the Relevant Slope Area. Tour-Check reproduces this area from its published description and precomputes, for every 10 m cell of the covered region, the three values the model needs at a point: MSA40, the aspect interval of the RSA and whether the point lies in closed forest.

4.1 Elevation model and forest cover

Elevation. The elevation model is the 5 m Alpine mosaic assembled from the national airborne-LiDAR terrain models, documented in the ATES methodology report[10]. SLABS computes on a 10 m grid (swissALTI3D); the 5 m model is therefore averaged over blocks of 2×2 cells. Slope, aspect, plan curvature and terrain folds are derived on this 10 m grid. Aspects are referred to geographic north, corrected for the convergence of the projected grid at each cell.

Forest cover. Closed forest ends the RSA (Section 4.2). It is taken from the Alpine forest mosaic of 19 October 2026, on the grid of the elevation model, documented in the same report[10]. Each region has exactly one source. Where airborne height data are freely available, the canopy cover is the fraction of 1 m cells whose vegetation height is at least 5 m, limited to an official forest mask — in Switzerland from the vegetation height model of the National Forest Inventory[11], in Austria from the difference of the national surface and terrain models[12]. In Lombardy, Piedmont, Veneto, Friuli Venezia Giulia and Liguria no such data are freely available; there the Copernicus Tree Cover Density 2024[13] stands in. A cell counts as closed forest from a cover of 30 %. This threshold was set against the forest field of the published route point data set, which is derived from the Swiss topographic landscape model (Section 8.4).

Region	Source	Date of the forest data
Switzerland, Liechtenstein	WSL vegetation height model of the NFI (stereo aerial imagery), resource "2018–2025"	edition 2025
Austria	BEV airborne laser scanning, surface − terrain model 1 m; BFW forest map	edition 15 Sep 2022
Bavaria	LDBV DOM20 (image-based) − DGM1; ATKIS forest and woodland	continuously updated aerial survey
Slovenia	nDMP of the national laser scan; RABA land use	2023–2025; 2026
Aosta Valley	DSM − DTM 2 m; Art. 33 forest map	2005/2008
South Tyrol	DSM − DTM 2.5 m; forest type map	2004–2006; 2001–2008
Trentino	canopy height model 1 m; land use "Bosco"	2006–2007; 31 Dec 2017
France (04, 05, 06, 26, 38, 73, 74)	IGN LiDAR HD canopy height; OCS GE	2021–2023
Lombardy, Piedmont, Veneto, Friuli VG, Liguria	Copernicus Tree Cover Density, 10 m	2024

Table 2: Sources of the forest cover in the forest mosaic of 19 October 2026. Where two dates are given, the first is the height data, the second the forest mask.

Age of the forest data. The forest data show the forest at the date in Table 2, not today. In South Tyrol, the Aosta Valley and Trentino they predate the windthrow of storm Vaia (October 2018) and the bark-beetle damage that followed; where that forest is gone, Tour-Check still sees it and ends the RSA at its edge — the colours there are milder than the terrain is. Tour-Check keeps these data until newer ones are available. In these regions, forest-related colour reductions may underestimate exposure, and the colours should not be read as reflecting current forest protection.

Copernicus regions. Tree Cover Density measures the tree cover seen by Sentinel-2, not vegetation height. It does not separate dwarf pine from forest, counts orchards and vineyards as tree cover, and blurs forest edges and gaps at 10 m. In South Tyrol, where both are available, it shows a mean cover of 38.5 % against 29.1 % from the height data (correlation 0.80) and about 450 km² more forest, concentrated in the Überetsch, the Vinschgau and around Merano, where orchards and vineyards are a likely cause; this has not been checked against land-use data. Conversely, the older height data show 84 km² of dense forest where Copernicus sees open terrain, in the Vaia area — a difference that may include real forest loss since the height data were recorded. Too much forest ends the RSA too early and lowers MSA40, which may produce non-conservative classifications. The 30 % threshold has not been checked against Tree Cover Density.

4.2 Relevant Slope Area

The RSA is the area around a point that is relevant for avalanche release when a skier stands on it [13]. It is delineated in two stages: a base form oriented to the fall line, then cropped at terrain edges and forest.

Stage 1: base form. On slopes of 5° and more the base form is a D-shape: a large circular sector upslope (radius r_1, opening angle α), a small one downslope ($r_2 = kr_1$, same angle) and the two straight sides joining them. Between 5° and 45° the shape narrows linearly from $\alpha = 120°$, $k = 0.3$ to $\alpha = 30°$, $k = 0.1$: on steep slopes the relevant terrain lies above and below, on gentle slopes to the sides. On slopes under 5° the base form is a circle. Both forms have the area of a circle of 40 m

radius before scaling, so that MSA40 means the same amount of terrain on every slope. They are then scaled:

- with inclination, the D-shape grows linearly from a factor 1 at 25° to 2.5 at 55°;
- towards ridges (negative plan curvature) both forms shrink from a plan curvature of −4, to a factor 0.25 at −20 and to nothing at −35; a form whose radius would fall below 10 m is dropped, and the point keeps only its own cell;
- in gullies (positive plan curvature) the circle grows from a factor 1 at +20 to 1.5 at +50.

SLABS describes the base form in principle and refers to a reference implementation for the details[3, 14]. The constants above and the equal-area sizing of the two forms are those of that implementation; Tour-Check implements the geometry independently and contains none of its code. Plan curvature is computed after Wood[15] on the 10 m grid with a window of 7 cells, as in the Skitourenguru data, and converted to their scale with a factor of 980, measured point by point against their values (Section 8.4).

Stage 2: cropping. SLABS describes the second stage in one sentence: the base form is cropped where terrain edges or forest separate terrain from the point. SLABS describes how folds are measured, but not how they are accumulated along a path, how their sign is treated, nor the threshold. Tour-Check follows each straight path from the point to every cell of the base form. Along the path it sums the angle of the terrain folds it crosses, measured as in SLABS: the largest angle between five pairs of surface normals on a circle of 10 m radius, positive at convex edges (ridges, slope breaks) and negative at concave ones (gullies, the foot of a slope). Only convex folds count. A cell is cut off once the sum reaches 45°, and every cell behind a cell of closed forest is cut off as well. The point's own cell never blocks: a point in forest keeps its own slope and the terrain around it up to the first forest cell.

The threshold of 45° and the exclusion of concave folds were calibrated against two complementary references — the growth of the MSA values with the radius at accidents in the SLABS data and the terrain indicator of the published route point data set — which both point to this value (Section 8.5).

4.3 Values at a point

On the cropped RSA, Tour-Check computes:

- **MSA40:** the 85th percentile of the local slope angles of all cells of the RSA;
- **aspect interval:** the shortest arc of aspects that contains the aspects of all cells of the RSA steeper than 25°, as start and width in degrees from geographic north. If no cell is steeper than 25°, the RSA has no interval;
- **closed forest:** whether the point's own cell is closed forest.

A zero-width interval represents a single aspect value, contributed by one or more cells steeper than 25° in the RSA; AOF is then 0 or 1, by that aspect, as the definition of SLABS gives it. This is the rule in closed forest: the forest ends the RSA, the point's own cell never blocks, and little more than this cell remains. Of 4,000 points on 40 straight 1 km lines placed at random across the Alps, 34 % of those with MSA40 ≥ 30° had width 0 — 79 % of the points in closed forest, 8 % in open terrain, where ridges and convex edges crop the RSA. In forest, AOF can therefore change from one point to the next with the aspect of a single cell.

The values are precomputed at a resolution of 10 m and 0.1°. Each region is computed from the same elevation model with a 1 km margin around its border, so that neighbouring regions agree where they overlap.

5 Model Architecture

5.1 Avalanche bulletin

The EAWS-compatible avalanche bulletin (CAAML v6) of the warning region supplies:

- the **danger level** (1–5), differentiated by elevation band where applicable;
- the **critical elevation** of each avalanche problem — usually the lower bound of the elevations it applies to, for some problems (e.g. wet snow) an upper bound;
- the **critical aspects** of each avalanche problem.

CAAML gives elevation bounds in metres or as `treeline`. Tour-Check reads `treeline` as a fixed elevation in all regions and for lower and upper bounds alike; the tree line varies across the Alps (Degraeuwe et al. place it at about 2200 m in their data [3]); Tour-Check uses 1,800 m, a product setting. A bound that is neither metres nor `treeline` is ignored. Where a band has both a lower and an upper bound, the lower bound is used.

European warning services determine the danger level with the EAWS Matrix, adopted in its revised form by the EAWS General Assembly in 2022 [16]; its operational use is analysed in [17]. The matrix combines snowpack stability, its frequency distribution and avalanche size. Because Tour-Check takes the published danger level as input, changes in how warning services apply the matrix carry over directly into the assessment.

Each point is evaluated under the bulletin of the warning region it lies in and, near a region boundary, under the bulletins of the neighbouring regions as well (Section 5.2). Of the bulletins published for a region, Tour-Check uses the one the map shows, and only while it is valid: once its validity has ended, it counts as missing. A region without a valid bulletin does not enter; if none of the regions the route touches has one, or the route lies outside every warning region, Tour-Check gives no assessment (Section 11). Points of a route with no valid local or neighbouring bulletin are evaluated under the bulletin shown with the route (Section 5.2). Tour-Check does not select a bulletin by the planned date of the tour. Morning and afternoon are not distinguished; the highest rating and all avalanche problems of the day apply throughout.

Météo-France publishes its bulletins (BRA) per massif in its own format; they are converted to CAAML v6 with up to two elevation bands and, where the BRA forecasts a change during the day, an earlier and a later rating. The converted bulletins carry no avalanche problems, so in the French Alps all aspects count as critical and the critical elevation comes from the elevation band of the highest danger rating.

For Swiss bulletins, the published sub-level is evaluated where available. The SLF publishes sub-levels for dry-snow avalanche danger from danger level 2 onward. The sub-levels reflect the expected increase in locations with poor stability and in the number and size of avalanches [18]; Tour-Check moves the continuous danger level of the model by 0.25 down for $n-$ and up for $n+$, within the range 1–5. The continuous value is an internal model argument for the log-linear danger-level factor $\exp(\beta_1 \cdot (\mathrm{DL} - 1))$; it does not change the communicated danger level — 3− remains level 3. SLABS was presented for danger levels 1–4; Tour-Check continues the factor of 4.3 per level to level 5, an extrapolation beyond the published model.

SLABS covariates at a point. The bulletin enters the model through three values, as in SLABS:

- **DL:** the danger level of the bulletin; where it gives several ratings (elevation bands or times of day), the highest. The elevation of the point enters through DCE, and in the route index through the elevation term (Section 5.4, Section 5.5).

- **DCE:** the depth of the point inside the critical elevations, in metres, positive inside. It is measured against the avalanche problem that covers aspects of the point's RSA and in which the point lies deepest; above a lower bound it counts upwards, below an upper bound downwards. Where no problem covers them, or the RSA has no aspect interval, all problems are used, then the elevation band of the highest danger rating, and finally a fallback critical elevation of 1,400 m. A band with a lower rating marks no core zone: with low below 2,800 m and moderate above, the core zone begins at 2,800 m and a point at 1,500 m lies 1,300 m below it.
- **AOF:** the fraction of the aspect interval of the RSA that lies inside the critical aspects of the avalanche problems. Each of the eight EAWS aspects covers a sector of 45°; the overlap of the interval with the union of the critical sectors, divided by the width of the interval, gives a value between 0 and 1, as in SLABS (their Appendix A.3). An RSA without a cell steeper than 25° has no interval and AOF = 0, because SLABS counts only these aspects. Without avalanche problems all aspects count as critical. An interval of width 0 counts as the sector that contains its aspect; an aspect on the boundary of two sectors belongs to the clockwise one.

With several avalanche problems, AOF uses the union of their critical aspects, while DCE is taken from the single problem in which the point lies deepest. The two values can therefore come from different problems; SLABS, fitted to one core zone per bulletin, does not say how to combine them. The result is a synthetic combination of inputs that need not describe any single published avalanche problem, and it is not assumed to be conservative relative to a problem-wise assessment.

At danger level 1 without avalanche problems, Tour-Check uses the core zone SLABS assumes for this level: aspects from west via north to south-east above 2000 m[3].

5.2 Warning regions and bulletin selection along a route

Which bulletin applies to a route depends on two things: which warning region contains each point of it, and which of several regions counts when the route crosses more than one.

Gap-free warning regions. The warning regions are the EAWS micro-regions[19] at a fixed version (CC0 1.0). Before use they are cut to the territory of their warning service and to the Alpine perimeter of the application. A territory is a country or, in Italy, a region or autonomous province with its own service; Switzerland and Liechtenstein form one territory, and so does Austria with its six services. The services do not draw their regions to coincide at their borders, so that gaps remain between them; in the region geometries of 25 October 2026 there were 5,908 gaps enclosed on all sides and at most 1,000 m wide, together 207 km². The territories themselves are first made into a set without gaps or overlaps by the coverage cleaning of GEOS and PostGIS[20]. A gap between regions is then closed if it is enclosed on all sides by regions and at most 1,000 m wide (the diameter of its largest inscribed circle), with two departures from that cleaning: the border of a territory is a barrier, so that each piece of a gap goes only to regions of the territory it lies in; and each place goes to the nearest region of its territory, not to the neighbour with the longest shared boundary. Bays at the outer edge of the regions are not enclosed and stay open: beyond the edge no service is responsible.

Closing a gap does not make a service responsible for it: no service drew it. Where a closed piece touches more than one region of its territory, all of them are **candidates** for it, and a place near a region boundary may lie in more than one region. For the bulletin, a place therefore has every region that may apply; for the map, it has one.

Transition at region boundaries. A route can cross several warning regions: at a national border, at the boundary between two regions of one service, or by ascending through one region to a summit in another. To smooth the transition near region boundaries, Tour-Check combines the

point values computed under neighbouring bulletins in a distance-weighted geometric mean. The approach follows the procedure Skitourenguru describes[4], which combines regions within $0.8r$ of a boundary, r being the radius of the largest circle inside the region; Skitourenguru does not publish its weights, and Tour-Check defines its own from each region's signed distance and radius. Each region j near the point receives a weight from its own signed distance s_j to the point (positive inside the region, negative outside) and its own radius r_j,

$$u_j = \min\left(1, \max\left(0, \frac{1}{2} + \frac{s_j}{1.6 r_j}\right)\right),$$

one half on its boundary, rising linearly to 1 at $0.8r_j$ inside and falling to 0 at $0.8r_j$ outside; the weights u_j are then normalised to sum to 1. A point belongs to its region alone when it lies at least $0.8r$ from the region's boundary and outside the reach of every neighbour; a large region therefore reaches further into a small neighbour than the other way round. Because every weight depends only on the position of the point and not on which region contains it, the weights change continuously across every boundary — between two regions, where a third region lies within reach, at points where three regions meet, and where a place lies in two candidate regions; there both count by their depth. On the boundary between two regions alone, both count one half. A region without a valid bulletin drops out and the others share its weight; regions across a national border take part like any other. Continuity refers to these weights: it does not remove discontinuities caused by the terrain inputs, other model rules, bulletin updates or the colour thresholds.

At each point, the colour value and the route-index value are computed separately under each contributing bulletin, the colour value including the road divisor of Section 6.2, and combined as weighted geometric means (Section 5.4). The colour thresholds of Section 6.1 apply to the combined colour value; the tunnel and dam rule is applied last and sets the colour to green without entering the mean. The danger level shown for the point is that of the bulletin with the largest weight. The radius r_j is computed on the region geometries with the polylabel method, to 25 m.

Points without a bulletin of their own. If no valid bulletin is available for any region the route touches, Tour-Check gives no assessment. If one is available for part of the route only, a point at which no surrounding region has a valid bulletin, or that lies outside every warning region, is evaluated under the bulletin shown with the route (below). Such points have no locally issued forecast as input. Weights remain continuous only where the regions around a point have bulletins; where the last of them drops out, the point changes to this fallback.

The bulletin shown with a route. The application shows one bulletin with a route: of all regions the route touches, the most severe valid one,

1. the higher danger level within the elevation range of the route, from its lowest to its highest point, as the continuous value of Section 5.1 including the Swiss sub-level (3+ before 3=) — a rating of 3 above 2,400 m does not count as 3 for a route that stays below 2,000 m; if the route carries no elevations, or no rating of a bulletin touches its range, the highest rating of that bulletin counts;
2. at equal level, the larger core zone;
3. at equal core zone, the region the route enters first.

This is the rule Skitourenguru uses for the bulletin it shows with a route[21]. The **size of the core zone** is our own operationalisation, as the source does not define it: for each of the eight aspects, the share of the elevation range 1,000–4,800 m covered by an avalanche problem that names this aspect, averaged over the aspects. The same holds for a single place, such as the bulletin shown for

a location: if more than one region may apply, the most severe bulletin is shown and the regions are named. It is also the fallback for points without a bulletin of their own.

Near a boundary, the evaluation of a point therefore combines the core zones of several bulletins, while SLABS was fitted to one core zone per evaluation. The geometric mean lies between the values under the individual bulletins: lower than the highest of these point values and higher than the lowest. The bulletin with the higher danger level need not give the higher value at every point, since the core zones of the bulletins differ.

5.3 MSA40 harmonisation offset

SLABS was fitted to MSA40 from swissALTI3D and the RSA of Skitourenguru. At precisely located Swiss accidents selected as in the SLABS study, the mean MSA40 of Tour-Check lies 1.3° below the mean SLABS reports, with a similar spread (Section 8.5.1). This compares published summary statistics, not paired values at identical accident locations. Tour-Check adds 1.3° to MSA40 before the SLABS risk ratios evaluate it, as a harmonisation parameter; its transferability across terrain types and regions has not been established. Near the steepest part of the curve (step RR 4.9 per 5°), 1.3° corresponds to a factor of about 1.5 in the slope term. The precomputed terrain values keep MSA40 as defined; the compensation is applied where the SLABS risk ratios receive their input.

5.4 Point values

Tour-Check 3.0 evaluates every route point twice: for the colour with the SLABS-derived model, using the published predictors and thresholds, for the route index with the one-level reduction of the bulletin interpretation guide.

Colour. The colour value is the SLABS-derived product of the risk ratios,

$$c_i = \mathrm{RR}_{\mathrm{MSA40}}(\mathrm{MSA40} + 1.3° - \delta_i) \times e^{\beta_1 (\mathrm{DL}\ -1)} \times \mathrm{RR}_{\mathrm{DCE}}(\mathrm{DCE}) \times e^{\beta_2\ \mathrm{AOF}} / A$$

with the risk ratios, coefficients and DCE curve of Table 1, the reduction δ_i of the slope for display (Section 6.2) and the reference constant A of Section 6.1. This is the base colour value of version 2.0, before its ATES floor.

Route index. The point model of the route index uses the same slope response and danger-level coefficient, without display adjustments, but replaces the DCE response with an absolute-elevation term and holds the AOF term at its core-zone value; outside the core zone, one danger level less is assumed. Inside the core zone the two point values therefore need not agree either. With the effective danger level

$$\mathrm{DL}_{\mathrm{eff}} = \mathrm{DL} - (1 - \mathrm{AOF} \cdot h), \quad h = \min\left(1, \max\left(0, \frac{\mathrm{DCE} + 100\mathrm{m}}{200\mathrm{m}}\right)\right)$$

the point value is

$$q_i = \mathrm{RR}_{\mathrm{MSA40}}(\mathrm{MSA40} + 1.3°) \times e^{\beta_1 (\mathrm{DL}_{\mathrm{eff}} - 1)} \times \mathrm{RR}_{\mathrm{ele}} \times e^{\beta_2} / A$$

with the risk ratios and coefficients of Table 1, the elevation term $\mathrm{RR}_{\mathrm{ele}}$ of Section 5.5 and the reference constant A of Section 6.1. The full reduction of one level applies where AOF or the elevation weight h is zero — entirely outside the critical aspects, or more than 100 m below the critical elevation — and lowers the value by a factor of 4.3 from β_1. In the transitions it is smaller: at the

critical elevation with all aspects critical, half a level. More than 100 m above the critical elevation and with all aspects critical, the full danger level applies. The AOF term is held at its core-zone value. At danger level 1 the effective level can fall below 1; the exponential form of Table 1 is then continued.

The rule follows the rule of thumb of the Swiss bulletin interpretation guide: for slopes that do not meet both the aspect and the elevation criteria of the bulletin, it has become customary in ski touring to assume a danger level one lower; the guide calls the rule proven, with exceptions, and suitable for planning a tour but not for the assessment in the field[7] (p. 32). The guide also describes the edges of the critical aspects as transition zones of about an eighth of a circle and gives elevations in steps of 200 m (p. 33). The transitions are linear over ±100 m at the critical elevation and proportional to the share of critical aspects, as in the transition functions of the Quantitative Reduction Method [8]; that the two shares are multiplied is a choice of this implementation. Skitourenguru uses the same rule in its SLABS variant[4].

Winkler et al. measured the risk of backcountry skiers within the core zone at 7.3 times that outside at danger level 2, 5.4 times at level 3 and 5.8 times over all levels[22] (Section 4.3.5). The one-level reduction (factor 4.3) is smaller than these aggregate core-zone contrasts, and in that sense on the cautious side; this motivates the rule but does not establish conservative values for individual points.

5.5 Elevation term

SLABS describes the elevation through its distance to the critical elevation (DCE). In the point model of the route index, the position relative to the critical elevation is already carried by h; the SLABS variant of Skitourenguru adds the absolute elevation as a term of its own[4]. That variant uses MSA70; Tour-Check keeps MSA40 and takes over only the form of the term. Tour-Check uses it in the route index; the colour keeps the DCE term of SLABS:

$$\mathrm{RR}_{\mathrm{ele}} = 4.91^{\frac{\min(\mathrm{ele},\,2250\mathrm{m})-2000\mathrm{m}}{1000\mathrm{m}}}$$

The term rises by a factor of 4.91 per 1,000 m up to 2,250 m and is constant above; it is 1 at 2,000 m. Factor and limit are a product calibration. The term is not a causal effect of elevation: part of it may reflect where bulletins place the core zone.

5.6 Computational procedure

Where several bulletins contribute to a point, steps 2, 3 and 5 are performed separately for each bulletin and combined as described in Section 5.2 before the colour classification and the route aggregation. For each point along the route, sampled at 10 m intervals:

1. Retrieve terrain data: elevation, MSA40, aspect interval, closed forest.
2. Evaluate the bulletin: DL, DCE and AOF of the point (Section 5.1).
3. Colour value c_i of Section 5.4, with the harmonisation offset of 1.3° (Section 5.3); in closed forest and below 1,500 m the slope used for display is reduced (Section 6.2).
4. Colour: from c_i with the thresholds of Section 6.1; on roads c_i is divided by an elevation-dependent factor first, and in a tunnel and near a dam the point is green.
5. Route-index value q_i of Section 5.4, with the same offset and the elevation term (Section 5.5), without display adjustments.
6. Route indicator: the highest q_i of each 100 m section, repeated sections removed, two counted passes, scaled and mapped to 0–3 (Section 6.3).

6 Risk Representation

6.1 Three-colour scheme

Each route point is assigned a colour from its colour value:

Colour	Label	Meaning
Green	No flag	Lower screening classification under the available inputs
Orange	Caution	Elevated screening classification; increased attention required
Red	Critical	High screening classification; reconsider the choice of route

Table 3: Three-colour scheme for the route display, with the labels shown in the application.

These labels are Tour-Check screening classifications. They are not names of, or substitutes for, the five levels of the European Avalanche Danger Scale, and a section without a flag is not established to be safe.

$$\text{colour} = \begin{cases} \text{red} & \text{if } c \geq 6.73 \\ \text{orange} & \text{if } c \geq 2.52 \\ \text{green} & \text{otherwise} \end{cases}$$

Reference constant. $A = 580$ scales the product of the risk ratios to the scale on which SLABS Figure 3 draws its colour boundaries. It is fitted to that figure and is not an empirically estimated average risk of Tour-Check. SLABS states no such constant; with this value the SLABS-derived classifier with the thresholds of the figure agrees with 98.4 % of its digitised cells, and the same value results whether it is fitted to danger levels 1–2 or 3–4 (Section 8.3).

Thresholds. The thresholds are those of SLABS Figure 3, 2.52 for orange and 6.73 for red. SLABS selected them so that approximately 80 % of the accident observations of its study data fall at least into the elevated class and 60 % into the high class [3]. Tour-Check takes them over without a calibration of its own, so that the accidents of Section 8.7 check the thresholds without having set them.

6.2 Terrain adjustments

The terrain adjustments act only on the colour. The route indicator is always calculated from the unadjusted (calibrated) MSA40.

Roads: Tour-Check follows the road rule that Skitourenguru publishes for its segment risk [4]. Points within 20 m of an OpenStreetMap road — the OpenMapTiles classes `track`, `service`, `minor` (unclassified and residential roads), `tertiary`, `secondary`, `primary` and `trunk` — have their colour value divided before the colour thresholds: by 4 below 400 m, by a factor that falls linearly from 4 to 1 between 400 and 1,600 m, and not at all above. The rationale given there: lower down, there is usually no continuous snow cover between a road and the slope above it; high up and outside the forest, a road offers no protection and is often buried. Footpaths, steps and mountain paths (`path`, including `footway` and `steps`) are not roads in this sense, because they run on the slope itself. As in Skitourenguru, points in a tunnel and within 20 m of a dam are shown green: in a tunnel there is no avalanche risk, and the steep face of a dam is not avalanche terrain [4]. Tour-Check counts a point as in a tunnel when it lies within 20 m of an OpenStreetMap way marked as a tunnel; a route that passes over a tunnel within 20 m is therefore shown green there as well, a known simplification.

SLABS discarded GPS tracks that followed a road or driveable track for more than 70 % of their length[3]; that selection of training data does not validate the rule.

Forest and low elevations: the slope used for the colour is reduced by 3° where the point lies in closed forest, and below 1,500 m by an amount that grows linearly to 10° at 1,000 m and stays at 10° below; both reductions add up. They are product settings. Near the steepest part of the slope curve, 10° lowers the colour value by a factor of about
16. The RSA

already ends at the forest edge, and SLABS itself sees forest only in this way, through MSA40[3]. The starting zones of fatal backcountry-touring avalanches in Switzerland lay at 2,497 m on average, 95 % of them between 1,495 and 3,502 m (winters 1994/95 to 2013/14)[23]. Both adjustments enter the accident-site check of Section 8.7, which is computed with all display rules.

6.3 Route indicator

The colours identify the route sections assigned higher screening classifications; the route indicator aggregates over the **whole** tour. It is a dimensionless route screening index and gives the value and colour of the tour-check mark. It uses the point values q_i of Section 5.4 without the display adjustments of Section 6.2, so a route whose mark is green can contain orange or red sections; the coloured track shows them.

From point to route. SLABS gives no rule for routes. Tour-Check divides the counted route into sections of 100 m along the track and lets the highest point value of each section count for its whole length:

$$S = \sum_k \ell_k \cdot \max_{i \in I_k} q_i$$

with I_k the points of section k that count after deduplication (below) and ℓ_k the counted length of the section, at most 100 m; the last section of a route is usually shorter. Each counted point stands for half the distance to each neighbour, at most 100 m each, so that thinned long tracks keep their length and gaps in the terrain data do not. Deduplication comes first: the sections are laid on the counted length only, and a point whose length extends across a section boundary counts in both sections. The risk of a tour is decided at its cruxes[5]. Skitourenguru also takes the maximum of each 100 m section and counts two passes[4]; Tour-Check takes both steps over and adds the sections instead of combining their probabilities. The summed values are relative model values weighted with distance, not accident probabilities of independent exposures.

Repeated route sections. A point within 40 m — the radius of MSA40 — of a point already counted that lies more than 40 m back along the route does not count. A track that returns on its ascent line therefore carries the terrain of the ascent once, and the legs of a kick turn closer than 40 m count once; a descent over other terrain counts in full. The rule is a geometric heuristic: it does not identify slopes. The result depends on the direction of the track, because the sections start at its beginning and because deduplication counts the first of two passes. Near-parallel tracks more than 40 m apart are counted twice.

Two counted passes. Ascent and descent are counted as two passes. This is a deliberately precautionary assumption intended to represent repeated exposure on a typical out-and-back ski tour; it does not estimate the direction-specific probability of an avalanche accident. It may overstate exposure on traverses, one-way descents and hut approaches.

Scaling. SLABS gives relative risks only; absolute probabilities are biased by under-reporting[3]. The index is

$$z = 2 \cdot c \cdot S$$

with the scaling constant $c = 2.0 \times 10^{-9}$ per metre, a product calibration. Unlike in version 2.0, it is not derived from an accident or fatality rate. z is a route screening index with deliberately precautionary aggregation assumptions, not a validated probability of an accident or a fatality on an individual tour.

Indicator and colour. z is mapped to an indicator 0–3 by linear interpolation in $\log_{10}(1/z)$ between the points of the curve published by Skitourenguru [24] (Table 4); below 0.5 the curve is extended linearly to 0, and values beyond 3 are held at 3. Green is below 1, orange below 2, red from 2. Skitourenguru fitted the curve to two surveys in which backcountry skiers rated tours under given bulletins[24]. The curve and its thresholds are Skitourenguru's own definition, not derived from a peer-reviewed source; adopting them is a product decision of Tour-Check.

Indicator	0	0.5	1.0	1.5	2.0	2.5 / 3.0
$\log_{10}(1/z)$	6.59[a]	5.88	5.17	4.71	4.31	3.92 / 3.53

Table 4: Indicator curve after Skitourenguru[24]. [a] Linear extension of the published curve, which starts at 0.5.

Without a bulletin there is no assessment: the track and the profile stay uncoloured, and the mark shows a grey shield without a number.

7 Parameter register

All parameters of Tour-Check 3.0, with the published source or the measurement in this paper they rest on; product settings are given with their value only:

Parameter	**Value**	**Basis**
Risk ratios MSA40, DL, AOF, DCE	Table 1	SLABS[3]
RSA base form	D-shape, constants of the reference implementation	[1][14]
RSA fold threshold	45°, convex	SLABS Table A.3, route point data set (Section 8.5)
Plan-curvature scale	980	route point data set (Section 8.4)
Closed forest	30 %	route point data set (Section 8.4)
MSA40 offset	+1.3°	SLABS Table A.3 (Section 8.5.1)
Reference constant A	580	SLABS Figure 3 (Section 8.3)
Colour thresholds	2.52 / 6.73	SLABS Figure 3[3] (Section 6.1)
Route index: one level outside the core zone	factor 4.3	SLF interpretation guide[7]
Route index: transition	±100 m, share of critical aspects	QRM[8]
Road divisor	4 → 1, 400–1,600 m	Skitourenguru[4]
Tunnels and dams	green within 20 m	Skitourenguru[4]

Parameter	Value	Basis
Section length, passes	100 m, 2	Skitourenguru[4]
Indicator curve	Table 4	Skitourenguru[24]
Danger level 1 without problems	W–N–SE above 2,000 m	SLABS[3]
Region transition: reach	$0.8r$, r the largest inscribed circle	Skitourenguru[4]
Repeated sections	within 40 m	radius of MSA40 (Section 6.3)
Route index: elevation term	$\times 4.91$ per 1,000 m above 2,000 m, constant from 2,250 m	product calibration; form after Skitourenguru[4] (Section 5.5)
Route index: scaling c	2.0×10^{-9} per metre	product calibration
`treeline`	1,800 m	product setting
Fallback critical elevation	1,400 m	product setting
Swiss sub-level	± 0.25 levels	product setting
Slope reduction in closed forest	3°	product setting
Slope reduction at low elevations	0° at 1,500 m → 10° at 1,000 m and below	product setting
DCE below −500 m	$\div 5.3$ per 500 m, constant below −1,000 m	product setting (Table 1)
Region transition: weights	each region ½ on its boundary → 1 at $0.8r_j$ inside, 0 at $0.8r_j$ outside; normalised	product setting (Section 5.2)
Region transition: inscribed circle	polylabel, to 25 m	product setting (Section 5.2)
Gaps between warning regions	closed up to 1,000 m wide	product setting (Section 5.2)

Table 5: Parameters of Tour-Check 3.0 with their basis. Above the line: parameters resting on a published source or a measurement reported here; below: product settings.

8 Verification and Retrospective Evaluation

8.1 Approach

The evaluation comprises implementation checks, agreement analyses against published reference outputs, and retrospective accident-screening analyses in Switzerland and Austria. These analyses are not independent external validation: the Swiss accident and route-point data sets overlap with the data used during method development. They answer five questions in turn, from the inputs to the product:

1. **Terrain values** (Section 8.4): are slope, aspect, plan curvature, folds and forest computed as in the data SLABS was fitted to?
2. **Relevant Slope Area** (Section 8.5): does the RSA reproduce the MSA values the SLABS study reports at accidents, and the terrain indicator of the published route point data set?

3. **Route points** (Section 8.6): how close is the result on all route points of Switzerland, and where does it differ?
4. **Accident sites** (Section 8.7): how many Swiss and Austrian accident sites does Tour-Check 3.0 flag, compared with version 2.0, and how much ordinary route does it colour?
5. **Accidents against touring terrain** (Section 8.8): how well does the colour separate accident sites from ordinary touring terrain under the same bulletins?

The shape of the RSA and the harmonisation offset of 1.3° were set on the accident sample of the SLABS study and on a sample of route points. The colour has no other parameter set on these accidents: its thresholds are those of SLABS Figure 3. Of the 1,473 accidents located to 100 m or better, 1,239 lie inside and 234 outside the core zone; the 376 of the winters from 2021/22 on do not belong to the SLABS sample and were used to set no parameter of the colour. The Austrian accidents were not used to set any parameter. All accident results, including the later winters and Austria, were however available when version 3.0 was chosen over the alternatives; they are not independent of that choice.

8.2 Data

Data set	Content	Used for
SLF accidents[25]	Swiss avalanche accidents with danger level, coordinate accuracy and whether the release lay in the critical aspects and elevations	RSA, calibration, accident-site check
LAWIS[26]	Austrian avalanche incidents with danger level	accident-site check
Route points[9]	1.96 million points on Swiss ski-touring routes, every 10 m, with the terrain values of Skitourenguru	terrain, RSA, routes
SLABS Table A.3 and Figure 3[3]	MSA40–MSA150 and local slope at the accidents of the study; colours by danger level	RSA, reference constant

Table 6: Data sets used in the evaluation.

Accident sample. The SLABS study used Swiss ski-touring accidents from the winters 2001/02 to 2020/21 with at least one person caught, a bulletin of the previous evening, an exact date and coordinates accurate to at least 500 m; for each accident it took seven points along 60 m of the fall line below the release point, 10 m apart[3]. The same selection from the SLF data yields 1,263 accidents (SLABS: about 1,250). Their local slope angle on the 10 m grid has a mean of 34.3° (median 34.9°, SD 8.5°) against 34.7° (35.1°, 7.7°) in Table A.3: the summary statistics of sample and elevation model are broadly consistent with the study before any RSA is involved.

Route points. The route point data set of Skitourenguru, published with the thesis of Furrer[9], samples the Swiss ski-touring routes every 10 m and gives, for each point, the values Skitourenguru computes from swissALTI3D at 10 m: slope, aspect, fold, plan curvature, forest, roads and paths, elevation, and the **terrain indicator** (TI). TI is a value between 0 and 1 that describes how suitable the terrain around a point is for triggering an avalanche, computed on an RSA with a radius of 100 m [19]. It is the continuous form of the terrain classification of Schmudlach and Köhler[1]. Furrer treats

caution sections with TI < 0.25 as doubtful[9]; this value is used below as the boundary of avalanche terrain. The data set also marks the sections that Skitourenguru flags as **caution** sections. The RSA of Tour-Check covers the Swiss route-point data set except at the margin of the elevation model, so only 163 points are excluded and 1.95 million points remain.

8.3 Colours against SLABS Figure 3

Figure 3 of the SLABS study shows the colour of the model for every combination of MSA40 and DCE, for each danger level inside and outside the critical aspects. Its colours were read once into a reference table: in each of the eight panels (danger levels 1–4, inside and outside the critical aspects), 30 values of MSA40 (20.5–49.5°) by 100 values of DCE (−987.5 to +1487.5 m), each cell taking the majority colour around its centre; 23,723 cells are readable. The SLABS-derived classifier — the risk ratios of Table 1 with the DCE term, the thresholds of the figure and $A = 580$, without the rules of Tour-Check — agrees with 98.4 % of the cells; 0.15 % (36 cells) differ by two levels, all in one narrow band at DCE +840 to +940 m next to a colour boundary. This checks the implementation of the published risk ratios and fixes A; it is not an estimate of predictive accuracy. The colour of Tour-Check 3.0 adds the slope offset and the display rules (Section 6.1). The check uses MSA40 without the offset of Section 5.3, because the figure is already on the scale of SLABS.

8.4 Terrain values

Tour-Check derives slope, aspect, plan curvature and folds from the 5 m Alpine mosaic averaged to 10 m; the route point data set from swissALTI3D at 10 m. At 20,000 random route points the values agree closely:

Value	Agreement with the route point data set
Slope	mean difference +0.11°, correlation 0.95
Aspect	median difference −0.03° after referring both to the same grid north
Fold	correlation 0.90
Plan curvature	rank correlation 0.94; ratio of quantiles ≈ 980
Closed forest	canopy cover ≥ 30 % at 10 m: Cohen's $\varkappa = 0.65$ (50,000 points)

Table 7: Terrain values of Tour-Check against the published route point data set[9].

The scale of the plan curvature is not given in the documentation of the data set; it was measured here as the ratio of the quantiles of both values on slopes of 10° and more. Fitting the mean and spread of plan curvature in Table A.3 instead gives 886; the direct point-by-point comparison is preferred. Of the canopy-cover thresholds tested against the forest field of the route data (derived from the Swiss topographic landscape model), 20 % and 30 % separate equally well ($\varkappa = 0.65$).

8.5 Relevant Slope Area

Against SLABS Table A.3. Table A.3 of SLABS lists, for its accidents, the mean, median and standard deviation of MSA40, MSA70, MSA100 and MSA150. How these values grow with the radius depends on the shape of the RSA, and they were used to choose between readings of the description:

- **Base form.** In Table A.3, the mean grows by 1.1° from MSA40 to MSA150. With a circle of the same area it grows by 2.1°; with the D-shape, which reaches further up- and downslope than to the sides, by 1.2°.

- **Cropping.** Of the readings of stage 2 that were tested — convex and concave folds, summed or single, over a range of thresholds — only cropping at summed convex folds of 30–60° raises MSA40 towards Table A.3 (mean from 40.4° to 41.1°); cropping at concave folds, at all folds or at single folds lowers it. Across MSA40–MSA150, convex thresholds of 30–45° come closest to the published means, medians and standard deviations.

Against the terrain indicator. The terrain indicator of the route point data set is computed on an RSA with the same base form and cropping. At 10,000 random route points, TI was compared with the MSA of the Tour-Check RSA at the same radius (100 m) for each convex threshold, with and without forest:

RSA (100 m)	Rank correlation	AUC (TI > 0.25)	R^2
no cropping, without forest	0.66	0.85	0.49
convex 45°, without forest	0.71	0.88	0.54
no cropping, with forest	0.74	0.89	0.65
convex 45°, with forest	0.78	0.92	0.74

Table 8: MSA100 of Tour-Check against the terrain indicator of the route point data set, 10,000 route points. R^2 is the in-sample share of the variance of TI at the individual points explained by a two-variable binned lookup: the mean TI in 200 classes, 20 quantile classes of MSA100 times 10 quantile classes of the area of the cropped RSA. The class means are not tested on separate data.

Convex thresholds from 30° to 60° rank TI equally well, 45° marginally best; together with Table A.3 (30–45°) this gives 45°. Forest is the larger effect: without it, MSA in forested valleys takes in the steep flanks the forest separates from the route, and the in-sample variance explained by the lookup drops from 74 % to 54 %.

8.5.1 The calibration gap

With these choices, MSA40 at the accident points still lies below Table A.3. The gap depends on how accurately the accident is located:

Coordinates	Accidents	Mean	Median	SD	Gap
SLABS Table A.3	≈ 1,250	42.5°	41.4°	8.7°	
exact	780	41.2°	40.1°	8.5°	−1.3°
≤ 100 m	1,097	41.2°	40.0°	8.7°	−1.3°
250 m	107	39.5°	39.4°	10.4°	−3.0°
500 m	59	35.8°	37.2°	11.9°	−6.7°
all	1,263	40.8°	39.9°	9.1°	−1.7°

Table 9: MSA40 of Tour-Check at the accident sample of SLABS, by the coordinate accuracy recorded by the SLF.

Lower MSA40 values at less accurately located accidents are consistent with location uncertainty affecting terrain extraction; the analysis does not isolate this effect from differences in accident selection or terrain. At accidents located to 100 m or better, the mean MSA40 lies 1.3° below Table A.3 at a similar spread; Tour-Check compensates this offset (Section 5.3). Part of it may come from the elevation model — a 5 m mosaic averaged to 10 m smooths edges slightly more than swissALTI3D at 10 m — and part from unpublished details of the original RSA.

8.6 Route points

On all 1.95 million route points, MSA40 of Tour-Check is compared with TI. For a comparison of judgements, MSA40 is thresholded at the value that marks the same share of points as avalanche terrain as TI > 0.25 does (35 % of the points; MSA40 > 27.8°, MSA100 > 30.7°). MSA100 is

computed on the same RSA with a radius of 100 m, the radius of TI; it is a reference for the comparison, not an input of the model.

	MSA40	MSA100	Local slope
Rank correlation with TI	0.70	0.78	0.50
AUC for TI > 0.25	0.86	0.91	0.74
Same judgement, all points	80.0 %	84.7 %	
open terrain	82.1 %	86.2 %	
forest	57.5 %	68.6 %	
AUC for caution sections	0.676	0.698	0.652

Table 10: Tour-Check against the terrain indicator of the published route point data set[9] on the 1.95 million Swiss route points. TI itself reaches an AUC of 0.711 for caution sections.

Half of the points lie within ±5.1° of the MSA40 that has the same rank as their TI, 90 % within ±14.2°. MSA100, at the radius of TI, agrees more closely than MSA40; the difference between the two is the difference in radius, not a defect of either. Both separate the caution sections of the data set almost as well as TI itself and much better than the local slope. The agreement is lowest in forest (57 %). There, TI is attenuated: 8.8 % of the forest points count as avalanche terrain by TI, 51 % for MSA40. Tour-Check keeps MSA40 in forest as SLABS defines it.

8.7 Accident sites

The accident-site check compares Tour-Check 3.0 with the published version 2.0, both computed by the route assessment of the application with all display rules and on the same terrain values, so that the comparison is paired and the difference comes from the rules alone.

Accidents. A Swiss accident site counts as flagged when at least one of its seven fall-line points is shown orange or red under the danger level of the accident day. The SLF records whether the release lay in the critical aspects and elevations, not the aspects and elevations themselves; three bulletins are reconstructed: inside the core zone (all aspects critical, critical elevation 200 m below the release), outside because of the aspect (all aspects except that of the release) and outside because of the elevation (critical elevation 200 m above the release). Only accidents located to 100 m or better are used. LAWIS records neither the core zone nor the coordinate accuracy; for Austria, all ski-touring incidents with a slab or unknown avalanche type and a danger level are evaluated with the core-zone bulletin. The results are any-of-seven flagged shares of accident sites under scenario bulletins, not detection rates of real accident tours.

Bulletin	n	Version 2.0		Version 3.0		Discordant, p
		≥ orange	red	≥ orange	red	
inside core zone	1,239	91.0 %	77.7 %	90.9 %	77.7 %	1 / 0, 1.000
outside: aspect	234	85.5 %	44.9 %	79.1 %	44.9 %	15 / 0, < 0.001
outside: elevation	234	86.8 %	41.0 %	83.3 %	41.0 %	8 / 0, 0.008

Table 11: Swiss accidents located to 100 m or better, winters 2001/02 to 2024/25: share shown at least orange and red. The accidents outside the core zone are evaluated under both reconstructed bulletins. Discordant pairs for at least orange (only version 2.0 / only version 3.0) with exact McNemar p. 95 % Wilson intervals inside the core zone: 89.2–92.4 % (2.0) and 89.1–92.4 % (3.0).

DL	n	Version 2.0		Version 3.0	
		≥ orange	red	≥ orange	red
1 — low	60	0.0 %	0.0 %	0.0 %	0.0 %
2 — moderate	325	87.1 %	61.5 %	87.1 %	61.5 %
3 — considerable	430	94.0 %	87.0 %	92.8 %	87.0 %
4 — high	90	96.7 %	91.1 %	96.7 %	91.1 %
all	906	85.5 %	72.5 %	85.0 %	72.5 %

Table 12: Austrian ski-touring accidents (LAWIS), core-zone bulletin: share shown at least orange and red. One level 5 accident is included in the total. At least orange: 95 % Wilson intervals 83.1–87.7 % (2.0) and 82.5–87.2 % (3.0); discordant pairs 5 / 0, exact McNemar p = 0.062.

Under a single bulletin, the colour of version 3.0 is that of version 2.0 without the ATES floor, so it can only flag fewer sites, never more. Inside the core zone the floor made almost no difference: one Swiss site of 1,239 and five Austrian sites of 906 lose their orange, and no site its red. Outside the core zone, where the floor reached accidents below a release zone, version 3.0 flags 79.1 % instead of 85.5 % where the release lay outside the critical aspects, and 83.3 % instead of 86.8 % where it lay below the critical elevation; the red share is unchanged. The reconstruction through the elevation places the release 200 m below the critical elevation of a bulletin that names all aspects.

Winters after the SLABS data. SLABS was estimated, and the RSA and the MSA40 offset of Tour-Check were set, on accidents up to the winter 2020/21; no parameter of the colour was set on the later winters, but their results were available when the versions were compared. Of the 305 accidents of the winters 2021/22 to 2024/25 inside the core zone, Tour-Check 3.0 flags 91.8 % at least orange (95 % interval 88.2–94.4 %) and 79.0 % red, as version 2.0 does; outside the core zone, 84.5 % of 71 under both reconstructions, against 90.1 % (aspect) and 87.3 % (elevation).

Point rule. Counting a site as flagged when any of its seven points is orange or red raises the share against a single point. For version 3.0 inside the Swiss core zone, 90.9 % of the sites are flagged by any of seven points, 87.2 % at the central point, 86.9 % by the majority (at least four) and 78.9 % at the point of the recorded coordinate; in Austria 85.0 %, 79.9 %, 79.8 % and 75.1 %.

Flagged share on ordinary route points. Stricter colours flag a larger share of accident sites, but also of ordinary route. At 20,000 random Swiss route points under five typical bulletins, the share of route shown orange or red is:

Bulletin	Version 2.0		Version 3.0	
	≥ orange	red	≥ orange	red
low	2.4 %	0.0 %	2.4 %	0.0 %
moderate, NW–NE above 2000 m	7.2 %	2.1 %	7.2 %	2.1 %
considerable, W–E above 2200 m	22.7 %	9.3 %	15.4 %	9.3 %
considerable, all aspects above 1800 m	29.8 %	16.4 %	24.6 %	16.4 %
high, all aspects above 1800 m	44.1 %	32.9 %	40.4 %	29.5 %

Table 13: Share of 20,000 random Swiss route points shown at least orange and red, under five typical bulletins.

At low and moderate danger both versions colour the same route; the floor acted only from considerable danger on. There version 3.0 shows 3.7 to 7.3 percentage points less of the route at least orange, at high danger also 3.4 points less red.

8.8 Accidents against touring terrain

How many accident sites a colour flags says little without how much ordinary terrain it colours. This exploratory comparison therefore sets accident points against touring terrain under the same scenario bulletins. Both are evaluated under the bulletins reconstructed for the accidents (Section 8.7), not under the complete historical bulletins:

- **Accidents:** the 1,473 Swiss accidents, inside the core zone with the core-zone bulletin, outside with the reconstruction through the elevation. For each accident, the share of its seven fall-line points in a colour; these shares are averaged over the accidents with equal weight.
- **Touring terrain:** the same 6,000 random points of the published Swiss route points[9], drawn from the whole of Switzerland, each evaluated under the reconstructed bulletins of 150 accidents drawn at random with equal weight; the share is taken over all 900,000 evaluations.

The **lift** is the accident share in a colour divided by the terrain share. The scenario bulletins are derived from the accident locations themselves — inside the core zone the critical elevation lies 200 m below the release — so part of the separation comes from the design. The lift is conditional on these bulletins; it compares the two versions and is not a measure of discrimination under independently issued forecasts.

Colour	**At least orange**			**Red**		
	accidents	**terrain**	**lift**	**accidents**	**terrain**	**lift**
Version 3.0	82.7 %	12.3 %	6.7	63.4 %	7.3 %	8.7
Version 2.0	83.8 %	14.4 %	5.8	63.4 %	7.3 %	8.7

Table 14: Accident points against touring terrain under reconstructed scenario bulletins: 1,473 Swiss accidents (mean share of their seven fall-line points) against 6,000 random Swiss route points under the bulletins of 150 random accidents (74 at considerable, 67 at moderate, 8 at low and 1 at high danger). The lift is conditional on accident-derived scenario bulletins.

The ATES floor of version 2.0 coloured 2.1 percentage points more of the touring terrain (14.4 % against 12.3 %) and 1.1 points more of the accident points. In this scenario comparison, the additional points flagged by the floor were less enriched in accident points than the route-point sample as a whole. This does not establish that the additional warnings were unnecessary, in particular for runout and overhead exposure, which the fall-line points below the release do not sample. Counted per accident site rather than per point, any of seven points, the floor raised the flagged share from 89.7 % to 90.3 %.

8.9 Limitations of the evaluation

- **Sensitivity, not specificity:** the accident analyses measure how many accident sites are flagged. The route-point analyses give the share of ordinary route shown orange or red, but not whether these points were dangerous on a given day. Completed tours provide exposure observations, not ground-truth labels of safe terrain.
- **Reconstructed bulletins:** the accident data give the danger level and, in Switzerland, whether the release lay in the core zone, but not the critical aspects and elevations. The analyses are scenario analyses at historical accident sites, not a historical evaluation against the bulletins of the day. The core-zone bulletin is favourable to the model; outside the core zone, which of the two reconstructions is the typical case is not known.
- **Calibration and evaluation on Swiss data:** the RSA and the slope offset were set on Swiss data; Austria enters only the accident-site check.
- **Terrain indicator as reference:** TI is computed on a 100 m RSA and attenuated by roads, elevation and forest; it is a reference for the shape of the RSA, not the truth about MSA40.

- **No independent validation:** the RSA, the slope offset and the display rules were developed within the implementation assessed here, partly on the same Swiss data. The analyses are internal checks against published values and data, not an external validation.
- **Any-of-seven metric:** an accident site counts as flagged if one of seven points is orange or red; at the point of the recorded coordinate alone the shares are lower.
- **Route index:** the accident-site checks concern the colours; they do not test the route indicator.
- **Danger level 1:** none of the 60 Austrian accidents at danger level 1 is flagged, in either version.
- **Release sites, not runout:** the seven points lie within 60 m below the release. They do not sample runout zones, overhead exposure or the routes actually travelled.
- **Region boundaries:** every accident site and route point is evaluated under one bulletin. The transition between the bulletins of neighbouring regions (Section 5.2) is not covered by these checks.

9 Discussion

9.1 Strengths

- **RSA after SLABS:** MSA40 and AOF are computed on a Relevant Slope Area delineated from the terrain, with continuous AOF, and checked against the published values of the SLABS study and the published route point data set.
- **The colour of a published model:** the colour is SLABS-derived, with the published predictors and thresholds; set partly on the Swiss accident data were only the shape of the RSA and the slope offset.
- **Checked against the published figure:** after fitting one reference constant, the SLABS-derived classifier agrees with 98.4 % of the readable cells digitised from SLABS Figure 3.
- **Without a terrain classification:** without the ATES floor of version 2.0, the flagged shares inside the reconstructed core-zone scenarios differ only slightly, and less ordinary touring terrain is coloured at considerable and high danger (Section 8.7, Section 8.8).

9.2 Limitations

- **Outside the core zone:** without the ATES floor, version 3.0 flags 3.5 to 6.4 percentage points fewer Swiss accident sites outside the core zone than version 2.0 (Section 8.7).
- **Bulletin per point:** away from region boundaries, a point is evaluated under the bulletin of its own region, not the most severe bulletin of the route as in version 2.0; the weights of the transition are a product setting, and neither has been evaluated (Section 5.2, Section 8.9).
- **Two point models:** the colour and the route index evaluate a point differently (Section 5.4); a section can count fully in the index where the colour is green, and the other way round.
- **Unpublished details of the RSA:** details of fold accumulation, sign handling and the cropping threshold are not fully specified in the published description. Tour-Check selected these implementation choices against two references (Section 8.5); an offset of 1.3° remains and is compensated (Section 5.3).
- **Approximated smoothers:** the SLABS smoothers are approximated from the risk ratios of Table 1 and combined multiplicatively across predictors (Table 1), not evaluated from the supplementary R script.
- **Elevation term of the route index:** a product calibration, not a causal effect of elevation; part of it may reflect where bulletins place the core zone (Section 5.5).

- **Avalanche-problem domain:** SLABS rests mainly on accidents under new-snow, wind-drifted-snow and old-snow problems. Few accidents in its data involved wet avalanches, and glide-snow avalanches are almost never skier-triggered; the model is less well established for these problems[3].
- **No terrain exposure from above:** Tour-Check assesses the release potential around a point; exposure to avalanches released far above it, in runout zones and below gullies, is not represented. Version 2.0 covered part of it with the ATES floor; version 3.0 does not.
- **Forest data:** the forest is shown at the date of its source (Table 2), in parts of Italy before storm Vaia, and in five Italian regions from satellite tree cover instead of vegetation height.
- **No local observations:** the assessment uses the regional bulletin, not local observations such as wind loading, recent avalanches, shooting cracks, whumpfing or solar radiation.
- **Ski touring data:** SLABS was fitted to GPS tracks and accidents of backcountry skiers, and the evaluation counts ski-touring accidents. Tour-Check also assesses snowshoe routes; whether the colours and the indicator carry over to snowshoe hikers, who use terrain differently and had a lower avalanche fatality rate per day[27], has not been evaluated.
- **Two passes for every route:** the route indicator counts ascent and descent as two equal passes. For traverses, one-way descents and hut approaches this overstates exposure.
- **Tunnels:** points within 20 m of a tunnel are shown green, following the tunnel rule of Skitourenguru with a distance set by Tour-Check. The basemap does not say how deep the tunnel lies, so a route passing over a tunnel is shown green there as well, even where the slope above it is steep.
- **Static terrain:** temporary hazards such as cornice fall and wet-snow release are not represented.
- **No absolute probability:** the route indicator rests on relative risk ratios and a product calibration. It has not been validated as a probability of release, burial or death on an individual tour.

10 Known Shortcomings and Planned Work

- **Forest data predating Vaia and the bark beetle.** In South Tyrol (2004–2006), the Aosta Valley (2005/2008) and Trentino (2006–2007) the forest data predate the windthrow of storm Vaia and the bark-beetle damage that followed. Newer canopy height data are needed.
- **No forest height data in five Italian regions.** Lombardy, Piedmont, Veneto, Friuli Venezia Giulia and Liguria publish no freely available vegetation height data; Copernicus Tree Cover Density stands in, with the limitations of Section 4.
- **Outer margin.** The Ligurian Alps and other outer parts of the Alpine arc lie outside the elevation model; Tour-Check has no terrain values there.
- **Bulletin.** Tour-Check does not select by the planned date of the tour and does not distinguish morning and afternoon (Section 5.1). Planned: assess a tour against the bulletin valid for its planned date.
- **Outside the core zone.** Which reconstruction of an accident outside the core zone is typical, and with it how many of these accident sites the colour flags (Section 8.7), is to be examined against bulletins of accident days that name the critical aspects and elevations.
- **Route direction:** assess ascent and descent separately instead of counting two equal passes.
- **Smoothers:** evaluate the fitted SLABS smoothers, which the R script in the supplementary material of[3] reproduces, instead of interpolating between the risk ratios of Table 1.
- **Independent evaluation:** a temporally or spatially separate test sample with bulletins of the accident days.

11 Coverage

Tour-Check 3.0 requires two data sources per region: the precomputed RSA values (Section 4) and an EAWS-compatible avalanche bulletin (daily). The RSA values are computed for the Alpine region covered by the elevation model, on the elevation model and forest mosaic documented in the ATES methodology report[10].

Region	Bulletin source
Switzerland, Liechtenstein	SLF (CAAML v6, incl. sub-levels)
Austria	Euregio, Carinthia, lawinen-warnung.eu (CAAML v6)
Bavaria	lawinen-warnung.eu (CAAML v6)
South Tyrol, Trentino	Euregio (CAAML v6)
Slovenia (Alpine arc)	ARSO via lawinen-warnung.eu (CAAML v6)
Aosta Valley, Piedmont, Lombardy, Veneto, Friuli VG	AINEVA (CAAML v6)
French Alps	Météo-France (BRA, converted to CAAML v6)

Table 15: Regional coverage of Tour-Check 3.0.

Without a bulletin, or where the RSA values are missing, there is no Tour-Check. Points of a route with no valid local or neighbouring bulletin take the bulletin shown with the route (Section 5.2).

12 Availability, Versions and Author

Data. The published inputs and their terms of use are listed in Section 13. This paper publishes aggregate results only, none of these data sets. Citing a source does not by itself settle its terms of use.

Code. The implementation is the provider's own and is not published (Section 13).

Versions. This paper describes Tour-Check 3.0 with the Alpine elevation model of 14 October 2026, the forest mosaic of 19 October 2026 and the RSA of 19 October 2026. All figures in Section 8 were computed from these data with the rules of this paper, each under a single bulletin (Section 8.9).

Author. Timo Braun develops and operates topo^alpin, the application that contains Tour-Check, and is responsible for this paper (contact: info@topoalpin.app).

13 Licences

Software and data licences are separate questions and are listed separately. Most data licences below require the attribution of the source and of the licence on every use. The terrain data and the roads rest in part on sources under the Open Database Licence (ODbL): the vegetation height model of WSL and OpenStreetMap. The ODbL distinguishes between a database, a derivative database and a produced work, and a publicly used derivative database can carry share-alike and access obligations (ODbL §§ 4.3–4.6) that go beyond attribution. How the derived terrain data are to be classified under the ODbL is a legal question that this paper does not assess.

13.1 Software

The implementation is the provider's own code and is not published or licensed to third parties. SLABS is reimplemented from its publication[3], the Relevant Slope Area from its published description

[1]; the constants of the RSA base form are taken from the reference implementation that SLABS cites[14]. Tour-Check contains no code of Skitourenguru.

13.2 Data

The elevation models and the forest sources are listed with their licences in Section 14. In addition, Tour-Check and the analyses in Section 8 use:

Use	Source (holder)	Licence
Bulletins	SLF, Euregio, avalanche warning services of Carinthia, Bavaria, the Austrian states and Slovenia, AINEVA, Météo-France	terms of each service
Warning regions	EAWS micro-regions [19] (European Avalanche Warning Services)	CC0 1.0
Roads	OpenStreetMap contributors, in the OpenMapTiles schema of the base map	ODbL 1.0
Analyses	Avalanche accidents in Switzerland (SLF), version 2.0[25]	CC BY 4.0; source and DOI 10.16904/envidat.411
	LAWIS (Austrian avalanche warning services)[26]	attribution
	Route point data set BSRPD 2.1[9]	CC BY-SA 4.0
	SLABS article and its tables[3]	CC BY

Table 16: Licences of the sources Tour-Check uses in addition to the terrain data. This paper publishes aggregate results only, none of these data sets. None of this replaces a legal review.

14 Data Sources

Region	Elevation model (licence)	Forest: height data; mask (licence)
Switzerland, Liechtenstein	swisstopo swissALTI3D (swisstopo OGD)	WSL VHM NFI, resource 2018–2025, edition 2025 (ODbL with DbCL)[11]
Austria	BEV ALS-DTM (CC BY 4.0)	BEV ALS DSM − DTM, release 15 Sep 2022 (CC BY 4.0)[12]; BFW forest map (CC BY 4.0)
Bavaria	LDBV DGM1 (CC BY 4.0)	LDBV DOM20 − DGM1 (CC BY 4.0); ATKIS Basis-DLM forest and woodland (CC BY 4.0)
France	IGN LiDAR HD MNT (Licence Ouverte 2.0)	IGN LiDAR HD MNH, 2021–2023; OCS GE 2.0 (both Licence Ouverte 2.0)
South Tyrol	Province DTM 0.5 m (CC0 1.0)	Province DSM − DTM 2.5 m, 2004–2006; forest type map 2001–2008 (CC0)
Trentino	PAT LiDAR DTM 1 m (CC BY 4.0)	PAT CHM 1 m, 2006–2007 (CC BY); “Bosco” 31 Dec 2017
Aosta Valley	RAVA DTM 2 m (CC BY 4.0)	RAVA DSM − DTM 2 m, 2005/2008 (CC BY 4.0); Art. 33 forest
Slovenia	ARSO DMR1 (CC BY 4.0)	GURS CLSS nDMP, 2023–2025 (CC BY 4.0); MKGP RABA
Lombardy, Piedmont	Regional DTM 5 m (CC BY 4.0)	Copernicus Tree Cover Density 2024[13]
Veneto, Friuli VG	Regional LiDAR DTM 5 m / 1 m (IODL 2.0)	Copernicus Tree Cover Density 2024[13]

Table 17: Elevation and forest sources of the Alpine elevation model of 14 October 2026 and the forest mosaic of 19 October 2026. Licences of the elevation models as shown in the attribution of the application; forest sources as documented in the ATES methodology report[10].

References

[1] G. Schmudlach and J. Köhler, ‘Method for an automatized avalanche terrain classification’, in *Proceedings of the International Snow Science Workshop*, Breckenridge, Colorado, 2016, pp. 729–736.

[2] G. Schmudlach and J. Köhler, ‘Automated avalanche risk rating of backcountry ski routes’, in *Proceedings of the International Snow Science Workshop*, Breckenridge, Colorado, 2016, pp. 450–456.

[3] B. Degraeuwe, G. Schmudlach, K. Winkler, and J. Köhler, ‘SLABS: An improved probabilistic method to assess the avalanche risk on backcountry ski tours’, *Cold Regions Science and Technology*, vol. 221, p. 104169, 2024, doi: 10.1016/j.coldregions.2024.104169.

[4] Skitourenguru, ‘SLABS-Variante’. Accessed: Oct. 19, 2026. [Online]. Available: https://wiki.skitourenguru.com/de/articles/a0055.html

[5] S. Harvey, B. Reuter, J. Rohrer, M. Ruggli, and J. Schweizer, 'RiskCheck: a framework for avalanche risk assessment, integrating manual and semi-automated approaches', in *Proceedings of the International Snow Science Workshop*, Tromsø, Norway, 2024, pp. 1438–1445.

[6] B. Degraeuwe, G. Schmudlach, K. Winkler, and J. Köhler, 'Improving avalanche risk assessment for backcountry ski tours: a comparative study of the novel SLABS method with existing methods', in *Proceedings of the International Snow Science Workshop*, Tromsø, Norway, 2024, pp. 1645–1652.

[7] WSL Institute for Snow and Avalanche Research SLF, 'Interpretationshilfe zum Lawinenbulletin, Ausgabe November 2025'. Accessed: Oct. 24, 2026. [Online]. Available: https://www.slf.ch/fileadmin/user_upload/SLF/Lawinenbulletin_Schneesituation/Wissen_zum_Lawinenbulletin/Interpretationshilfe/Interpretationshilfe_DE.pdf

[8] G. Schmudlach, K. Winkler, and J. Köhler, 'Quantitative Risk Reduction Method (QRM), a data-driven avalanche risk estimator', in *Proceedings of the International Snow Science Workshop*, Innsbruck, Austria, 2018, pp. 1272–1278.

[9] C. Furrer, 'Artificial intelligence in ski touring: prediction of caution- and foot-sections for ski touring routes with a machine learning approach', Lucerne, Switzerland, 2024. [Online]. Available: https://github.com/skitourenguru/RoutesProperties

[10] T. Braun, 'ATES Mapping for the Alpine Region: Technical report on method and implementation', Oct. 2026.

[11] C. Ginzler, 'Vegetation Height Model NFI'. 2021. doi: 10.16904/1000001.1.

[12] Bundesamt für Eich- und Vermessungswesen, 'ALS digital surface model (DSM) and digital terrain model (DTM) of Austria, 1 m'. Accessed: Oct. 20, 2026. [Online]. Available: https://data.bev.gv.at/

[13] Copernicus Land Monitoring Service, 'High Resolution Layer Tree Cover Density, reference year 2024, 10 m resolution'. Accessed: Oct. 20, 2026. [Online]. Available: https://land.copernicus.eu/en/products/high-resolution-layer-tree-cover-density

[14] G. Schmudlach, 'Implementation details in C# code for delineation of the Relevant Slope Area (RSA)'. Accessed: Oct. 19, 2026. [Online]. Available: https://info.skitourenguru.com/download/code/RelevantSlopeArea_BaseForm.zip

[15] J. Wood, 'The geomorphological characterisation of digital elevation models', 1996.

[16] K. Müller, F. Techel, and C. Mitterer, 'The EAWS matrix, a decision support tool to determine the regional avalanche danger level (Part A): conceptual development', *Natural Hazards and Earth System Sciences*, vol. 25, pp. 4503–4525, 2025, doi: 10.5194/nhess-25-4503-2025.

[17] F. Techel, K. Müller, C. Marquardt, and C. Mitterer, 'The EAWS matrix, a decision support tool to determine the regional avalanche danger level (Part B): operational testing and use', *Natural Hazards and Earth System Sciences*, vol. 26, pp. 1161–1181, 2026, doi: 10.5194/nhess-26-1161-2026.

[18] F. Techel, S. Mayer, C. Pérez-Guillén, G. Schmudlach, and K. Winkler, 'On the correlation between a sub-level qualifier refining the danger level with observations and models relating to the contributing factors of avalanche danger', *Natural Hazards and Earth System Sciences*, vol. 22, pp. 1911–1930, 2022, doi: 10.5194/nhess-22-1911-2022.

[19] European Avalanche Warning Services, 'eaws-regions: Micro-regions of the European avalanche warning services'. Accessed: Oct. 25, 2026. [Online]. Available: https://gitlab.com/eaws/eaws-regions

[20] PostGIS Project, 'ST_CoverageClean: Computes a clean (edge matched, non-overlapping, gap-cleared) polygonal coverage'. Accessed: Oct. 25, 2026. [Online]. Available: https://postgis.net/docs/ST_CoverageClean.html

[21] Skitourenguru, 'Einführung in Skitourenguru'. Accessed: Oct. 24, 2026. [Online]. Available: https://www.skitourenguru.com/calc_data2/doc/Intro_DE.pdf

[22] K. Winkler, G. Schmudlach, B. Degraeuwe, and F. Techel, 'On the correlation between the forecast avalanche danger and avalanche risk taken by backcountry skiers in Switzerland', *Cold Regions Science and Technology*, vol. 188, p. 103299, 2021, doi: 10.1016/j.coldregions.2021.103299.

[23] F. Techel, B. Zweifel, and K. Winkler, 'Analysis of avalanche risk factors in backcountry terrain based on usage frequency and accident data in Switzerland', *Natural Hazards and Earth System Sciences*, vol. 15, pp. 1985–1997, 2015, doi: 10.5194/nhess-15-1985-2015.

[24] Skitourenguru, 'Risiko-Indikator (grün, orange und rot)'. Accessed: Oct. 19, 2026. [Online]. Available: https://wiki.skitourenguru.com/de/articles/a0021.html

[25] WSL Institute for Snow and Avalanche Research SLF, 'Avalanche accidents in Switzerland since 1970/71'. 2023. doi: 10.16904/envidat.411.

[26] Avalanche warning services of Austria, 'LAWIS avalanche incident database'. Accessed: Oct. 20, 2026. [Online]. Available: https://www.lawis.at/

[27] K. Winkler, A. Fischer, and F. Techel, 'Avalanche risk in winter backcountry touring: status and recent trends in Switzerland', in *Proceedings of the International Snow Science Workshop*, Breckenridge, Colorado, 2016, pp. 270–276.