DID PUBLISHING AVALANCHE DANGER SUB-LEVELS CHANGE THE BEHAVIOUR OF FORECASTERS AND FORECAST USERS?

Frank Techel[*1], Leonie Schäfer[2], Antoine Zaninetti[1], Sascha Brunner[4], Célia Lucas[1], Günter Schmudlach[3], Ross Purves[2]

[1] *WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland*
[2] *University of Zurich, Switzerland*
[3] *Skitourenguru GmbH, Zurich, Switzerland*
[4] *Independent*

ABSTRACT: Avalanche danger levels compress complex avalanche conditions into five categories, inevitably hiding variation within a level. A fundamental question in risk communication is whether communicating within-level differences explicitly changes how people make decisions. The Swiss avalanche warning service provides a rare opportunity: in winter 2022/23 it began publishing sub-level modifiers ($-$, $=$, $+$) that forecasters had already assigned internally for six winters, while leaving the forecasting methodology unchanged. We evaluated behavioural responses across the full decision chain, from tour planning, through terrain choices in the field, to outcomes, and compared forecasting practice before and after publication. Forecasting practice changed little overall. The only notable shift occurred within danger level 2, where forecasters assigned 2$+$ more frequently, likely because the published modifier communicates "close to level 3 (considerable)" without issuing level 3. In contrast, we found little evidence that publication altered recreationists' decisions at any stage of the decision chain. Instead, users already appeared to respond to within-level differences before they were made explicit, suggesting that this information was already conveyed through bulletin wording and the observed snow conditions. Publishing sub-levels thus made within-level differences in avalanche danger explicit, without evidence of the behavioural changes that some critics had feared.

KEYWORDS: avalanche forecasting, avalanche danger, risk communication

1. INTRODUCTION

Avalanche danger levels are one of the primary means by which avalanche warning services communicate regional avalanche hazard to backcountry recreationists. Danger levels generalize the severity of avalanche conditions into five discrete categories intended to support decision making and risk management. The effect of forecast information on decision making is hard to measure, but numerous studies have shown that stated or revealed choices often vary systematically with the published danger level throughout the decision process, affecting tour planning (Morgan et al. 2023; Schäfer et al. 2025), terrain choices (e.g., Winkler et al. 2021; Mannberg et al. 2026), and accident rates (e.g., Techel et al. 2022; Degraeuwe et al. 2024).

Avalanche hazard varies continuously and in a non-linear fashion, yet avalanche warning services present this continuum using five ordinal danger levels. Consequently, considerable variation exists within every danger level. Forecasters routinely distinguish these within-level differences during hazard assessment (Müller et al. 2025) and communicate them in various ways, for example through specifying slope aspect and elevation, avalanche problems, descriptions highlighting where hazardous conditions are most likely and how large avalanches may become (e.g., Hutter et al. 2021). A fundamental question, however, is whether making these within-level differences more explicit changes how people make decisions.

One approach to communicate within-level variations is the use of explicit sub-level modifiers. The Swiss avalanche warning service therefore introduced sub-level modifiers indicating where conditions lie within a danger level (Techel et al. 2020). During six forecasting seasons (since 2016/2017), forecasters *internally* assigned sub-level modifiers to danger levels (e.g., 2$-$, 2$=$, 2$+$, 3$-$, 3$=$, 3$+$; Fig. 1) depending on whether avalanche conditions are relatively high or low within a level, while leaving the underlying danger level unchanged (Techel et al. 2020; Techel et al. 2022). Previous work demonstrated that these internally assigned sub-levels capture meaningful differences in avalanche hazard. Within the same danger level, higher sub-levels are generally associated with larger avalanches and a greater likelihood of natural avalanche activity and human triggering (Techel et al. 2022). Since winter 2022/23, these sub-levels[2] have been *published* as part of the avalanche bulletin (Lucas et al. 2023).

* *Corresponding author address:*
Frank Techel, WSL Institute for Snow and Avalanche Research SLF,
Flüelastrasse 11, 7260 Davos Dorf, Switzerland;
email: techel@slf.ch

[2] In the following, we refer to sub-levels but always mean the combination of danger level and sub-level modifier.

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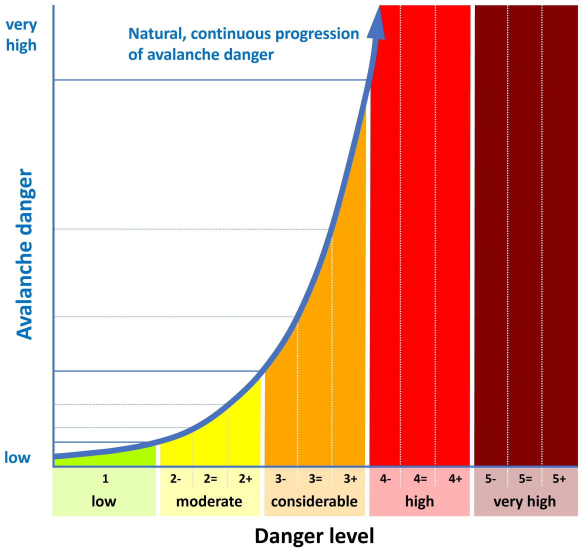

Figure 1: Avalanche danger sub-levels used in the Swiss avalanche bulletin. Because avalanche danger changes continuously and increases disproportionately across the five danger levels, the sub-level modifiers ($-$, $=$, $+$) indicate whether conditions are at the lower, middle, or upper end of a danger level (SLF 2026).

While surveys conducted shortly after the introduction showed that most users correctly understood the concept of sub-levels (Lucas et al. 2023), an important practical question remained unanswered: does publishing this additional information change how people behave? A lower sub-level (e.g., $3-$) might be interpreted as "almost level 2", encouraging users to accept greater exposure. Conversely, an upper sub-level (e.g., $3+$) could be perceived as "almost level 4", leading to more conservative decisions. Whether making within-level information explicit measurably influences recreationists' decisions has not yet been empirically evaluated. Switzerland provides a rare opportunity to address this question. Avalanche forecasters have assigned sub-levels operationally since winter 2016/17, but they were not published until winter 2022/23. The underlying forecasting methodology remained unchanged. This makes it possible to isolate the effect of making within-level information explicit from changes in the forecast itself.

In this study, we estimate behavioural responses across the full decision chain – from tour planning, through terrain choices in the field, to eventual outcomes – using route clicks on a tour-planning platform, condition reports, model-predicted touring activity, GPS tracks, and avalanche accident records, comparing four winters after publication with the six preceding winters. We thereby test whether publishing sub-levels leads to systematic changes in recreationists' choices within a given danger level.

2. DATA

To evaluate responses across the full decision chain, we combined operational avalanche forecasts with several datasets representing forecasting practice, tour planning, touring activity, terrain exposure, on-tour decisions, and avalanche accidents (Tab. 1). All analyses were restricted to backcountry ski touring in the Swiss Alps and to forecasts containing a dry-snow danger rating. Off-piste skiing (lift-accessed terrain outside marked runs) was excluded because decisions in lift-accessed terrain may differ systematically from those made during backcountry tours (e.g., Zweifel and Wäger 2008; Sykes et al. 2020; Yoshizawa et al. 2025).

Operational avalanche forecasts, published daily by WSL Institute for Snow and Avalanche Research SLF, provided the assigned danger level and sub-level for each Swiss forecast micro-region and day.

Tour-planning behaviour was represented by route clicks on the Skitourenguru planning platform. Each record contains the selected route and the time of the click. The platform rates routes using a green–orange–red risk indicator that incorporates avalanche danger sub-levels. These were supplied to *Skitourenguru* before their public release in the avalanche bulletin. Users were therefore indirectly exposed to sub-level-informed route recommendations throughout the study period. Previous work has shown that route clicks are related to observed backcountry touring activity, with observed activity typically peaking one day after peaks in route clicks (Schäfer et al. 2025).

Touring activity was represented in two complementary ways. First, we used user-generated condition reports documenting completed ski tours from Gipfelbuch, Camptocamp and Hikr. Second, we used cross-validated predictions from an activity model trained on user-generated tour reports to estimate backcountry touring activity for each forecast micro-region and day (Schäfer et al. 2025). The model used the avalanche information available to users as a predictor: the danger level before publication and the danger level including its sub-level after publication.

Terrain exposure was represented by two datasets. Ski difficulty ratings were obtained from *Campto-*

Table 1: Datasets and behavioural proxies used in this study. Data availability differs between datasets.

Decision stage	Dataset	Behavioural proxy or response	Before publication	After publication
Forecasting practice	Avalanche forecasts	Distribution of avalanche danger sub-levels	116'444[a]	88'773
Tour planning	Route clicks	Proportion of clicks on demanding routes	1.6 million[b,c]	3.5 million
Touring activity	Condition reports	Relative number of reported tours	21'730[b]	12'788
	Activity model predictions	Relative model-predicted touring activity	99'178[a]	79'480
Terrain exposure	Condition reports (ski rating)	Proportion of tours with ski difficulty rating ≥ 3	5'923[b]	3'788
	GPS tracks	Proportion of track points in typical avalanche terrain	1'626[b]	1'366
On-tour decision	Condition reports (turning around)	Proportion of tours terminated before reaching the summit	12'883[b]	3'631[d]
Behavioural outcome	Avalanche accidents	Accident occurrence normalized by model-predicted touring activity	389[b]	440

[a] micro-regions $\times$ days; [b] number of route clicks, condition reports, GPS tracks, or avalanche accidents
[c] since Nov 2020; [d] only two of four winters

camp condition reports. In addition, GPS tracks provided the routes travelled by backcountry recreationists (collected from the platforms *Camptocamp*, *Gipfelbuch*, *Hikr*, *Skitourenguru*). The first reflects the steepness of the chosen route, whereas the second captures where people actually travelled.

On-tour decisions were represented by *Gipfelbuch* condition reports indicating whether a tour had been terminated before reaching the summit.

Finally, avalanche accidents involving backcountry ski tourers were obtained from the Swiss avalanche accident database. The dataset was restricted to backcountry touring and excluded accidents in off-piste terrain.

3. METHODS

Although the datasets represent different stages of the decision process (Tab. 1), all analyses followed the same logic: we compared the relationship between the assigned sub-level and the respective behavioural response before and after publication.

3.1. Study design

The publication of sub-levels in winter 2022/23 created a natural before–after setting. Because publication affected all users simultaneously, a control group is not available. Consequently, any temporal change coinciding with winter 2022/23 could potentially be attributed either to publication or to unrelated developments. The analyses therefore assess changes in the relationship between sub-levels and behavioural responses rather than providing a controlled estimate of the causal effect of publication.

3.2. Data preparation

Each observation was linked to the valid avalanche bulletin for its location and day. The assigned danger level, including its sub-level modifier, served as the explanatory variable. For each response, we compared the sub-level relationship before and after publication. Danger level 1 has no sub-levels (Fig. 1), while 4$-$, 4$=$, and 4$+$ were combined because of sparse observations.

Routes were classified as demanding at SAC ski touring grade ZS or higher (Schweizer Alpen-Club (SAC) 2025, approx. equivalent to French AD), GPS track points in typical avalanche terrain (terrain indicator TI ≥ 0.5; Schmudlach et al. 2018), and reported tours with ski difficulty rating ≥ 3, corresponding to sustained slopes of about $35°$ with short sections up to 40–$45°$ (Camptocamp n.d.). Touring activity was normalized within each winter so that the winter mean equalled one. Turning back was treated as a binary response, and accident occurrence was normalized by model-predicted touring activity.

3.3. Statistical analysis

For visualization, response estimates were calculated for each winter and subsequently averaged within each period; t-based 95% confidence intervals (CIs) quantify variation among winter-specific estimates. In behavioural figures, CIs were displayed only where estimates from at least three qualifying winters were available (cell minima: 200 clicks, 20 GPS tracks or *Camptocamp* tours, and 30 turn-back reports). Danger level 4 was treated as descriptive and shown without CIs. Individual winters are displayed in all figures.

Publication effects were tested by adding a sub-level $\times$ period interaction. Proportions, including turn-back rates, were analysed using quasi-binomial generalized linear models, and accident counts using quasi-Poisson models with log model-predicted activity as an offset; interactions were evaluated using F-tests. Relative activity was analysed using linear mixed-effects models with a random intercept for winter to account for repeated sub-level estimates within winters, and interactions were evaluated using likelihood-ratio tests. Changes in sub-level assignment were assessed using winter-level comparisons and permutation tests.

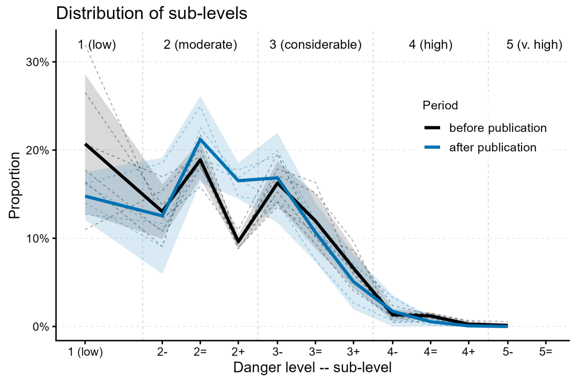

Figure 2: Distribution of forecasted avalanche danger sub-levels before (black) and after (blue) publication. Thick solid lines show the unweighted mean of the winter-specific proportions within each period, thin dashed lines show individual winters, and shaded areas show the corresponding 95% confidence intervals of the period means across winters.

4. RESULTS

4.1. Sub-level assignment by forecasters

Publication was not accompanied by a systematic shift towards generally higher or lower assignments: the weighted mean sub-level was 2.15 before and 2.19 after publication (permutation test, $p = 0.66$), and the distributions were similar from 3$-$ upwards (Fig. 2). Within danger level 2, however, assignments shifted upwards after publication. Conditional on danger level 2 being issued, the share of 2$+$ rose from 23.3% to 33.3% and that of 2$-$ fell from 31.2% to 24.6% ($p = 0.014$), while 2$=$ was largely unchanged (45.5% vs. 42.1%). Overall, 2$+$ accounted for 9.6% of all forecasts before and 16.5% after publication of sub-levels ($p = 0.005$); each of the four winters after publication exceeded all winters before publication, and the six winters before publication showed no trend (8.8–10.9%), indicating a step change rather than a gradual drift. The proportion of level 1 was lower after publication (14.8% vs. 20.7%) but varied strongly between winters and plausibly reflects snow conditions.

4.2. Backcountry tour planning

As contextual evidence on tour planning, we analysed clicks on ski touring routes on the *Skitourenguru* planning platform (Fig. 3a). Because its risk indicator incorporated sub-levels throughout the study period, including before their public release, this analysis does not directly test the effect of publication. In both periods, clicks on demanding routes peaked at danger level 2$-$ and subsequently declined with increasing sub-level. The relationship did not differ between periods (interaction: $p = 0.28$). Descriptively, click proportions were lower after publication at danger level 1 and 2$-$ but converged or reversed at higher sub-levels, providing no consistent temporal pattern.

4.3. Backcountry touring activity

To investigate whether publication of sub-levels affected the decision to undertake a backcountry tour, irrespective of the chosen route, we analysed model-predicted backcountry touring activity (Fig. 3b), normalized within each winter to account for differences in overall activity between winters. Model predictions provide estimates for all forecast-region days, including those without user-generated reports, reducing sensitivity to uneven spatial and temporal reporting coverage. Because the predictions are derived from observed reports and are not an independent activity proxy, we additionally analysed the reports directly as a sensitivity analysis (not shown).

Both model-predicted and observed activity were highest at danger level 2$-$ and subsequently declined with increasing sub-level. For model-predicted activity, differences between the periods were largest within danger level 2, whereas differences within danger level 3 were generally small. There was no evidence that the relationship between sub-level and model-predicted activity differed between periods (interaction: $p = 0.10$).

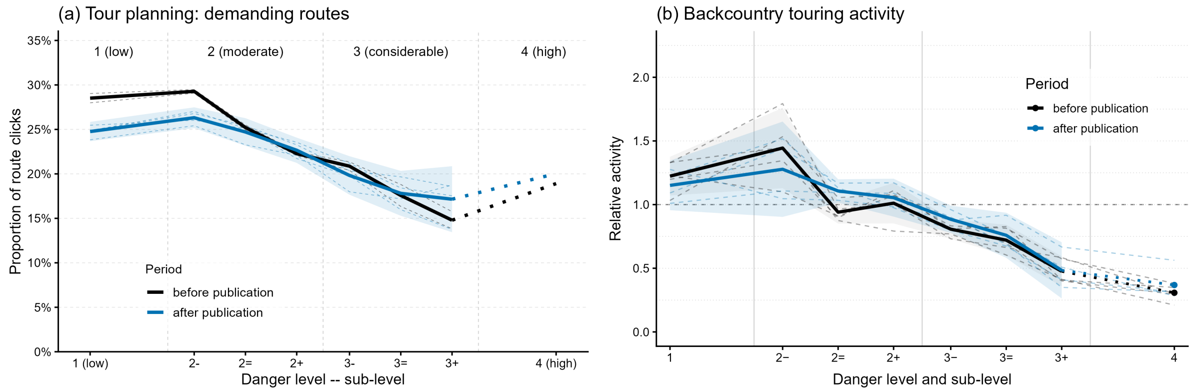

Figure 3: (a) Proportion of clicks on demanding ski touring routes on *Skitourenguru* and (b) model-predicted backcountry touring activity normalized within each winter so that the winter mean equals one. Thick solid lines show period means, thin dashed lines individual winters, and shaded areas 95% confidence intervals across winters. Confidence intervals are shown only where qualifying estimates are available for at least three winters. Estimates for 4 (high) are shown descriptively using dotted lines and without confidence intervals because observations were sparse. In (a), there was insufficient data for the before period to calculate CI.

The directly observed tour reports showed a similar overall relationship with avalanche danger and likewise provided no evidence that the activity–sub-level relationship changed after publication (interaction: $p = 0.71$). Descriptively, observed activity at 3$+$ was lower after publication, whereas this difference was small in the model predictions; uncertainty in the observed estimates was substantial. Overall, neither analysis provided evidence that publication of sub-levels altered the relationship between avalanche danger and the decision to undertake a backcountry tour.

4.4. Terrain exposure

To investigate whether publication was associated with changes in terrain selection, we compared two terrain proxies before and after publication. For GPS tracks (Fig. 4a), we analysed the proportion of track points located in typical avalanche terrain within the forecast core zone, that is in the aspects and elevations where the forecast danger level applies. For *Camptocamp* reports (Fig. 4b), we analysed the proportion of tours with a ski rating ≥ 3.

Across both terrain proxies, terrain exposure was generally higher after publication. For GPS tracks, the proportion of track points located in typical avalanche terrain increased by 1–7 percentage points across most sub-levels. For *Camptocamp* reports, the proportion of tours in steeper terrain increased by up to 11 percentage points. Overall, both proxies showed similar relationships between terrain exposure and avalanche danger before and after publication, with no evidence that these relationships differed between periods (interaction: GPS $p = 0.58$, *Camptocamp* $p = 0.28$). Descriptively, however, the decline from 2$+$ to 3$-$ was less pronounced after publication in the GPS data but somewhat more pronounced in the *Camptocamp* ski ratings. These opposing patterns provide no consistent indication of a change in terrain selection at the boundary between danger levels 2 and 3. Higher terrain exposure was also observed at danger level 1, where no sub-level exists, indicating that the overall increase cannot be attributed to the publication of sub-levels. Instead, it may reflect broader differences between the two periods, such as changes in the reporting population or a general shift towards the use of steeper and more exposed terrain, independent of the publication of sub-levels. Overall, we found no evidence that publication of sub-levels altered the relationship between terrain choice and avalanche danger.

4.5. Turning back

To investigate on-tour decision making, we analysed *Gipfelbuch* condition reports indicating whether recreationists turned back before reaching the summit (Fig. 5a). The proportion of tours where participants turned back generally increased with avalanche danger, from 4–5% at danger level 1 to about 10% at danger level 3$=$. There was no evidence that the relationship between sub-level and turning back differed between the periods before and after publication (interaction: $p = 0.60$). Although the overall turn-back rate was higher after publication (5.7% before vs. 7.3% after, $p = 0.001$),

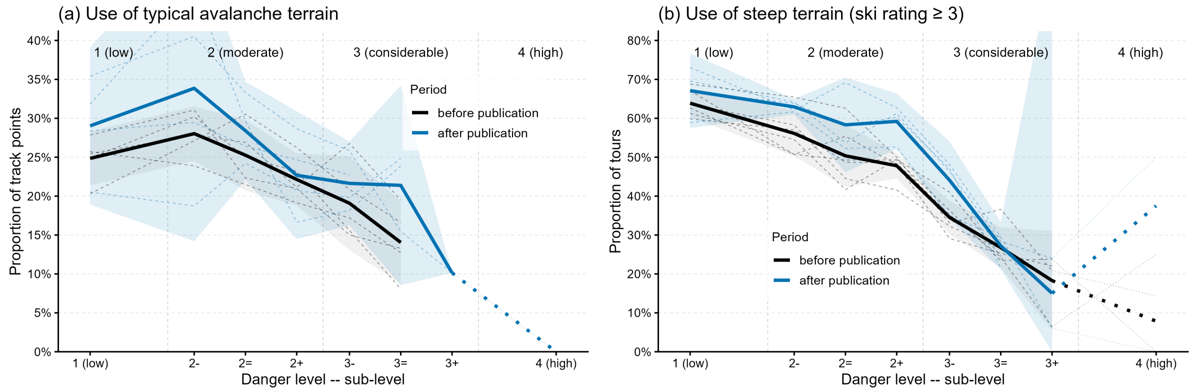

Figure 4: (a) Proportion of GPS track points located in typical avalanche terrain within the forecast core zone and (b) proportion of *Camptocamp* tours with ski rating ≥ 3. Display conventions and treatment of sparse estimates as in Fig. 3. In (a), there was insufficient data for *before* for 3$+$ and 4 (high).

this increase occurred across all danger levels, including danger level 1, where no sub-level exists. It is therefore unlikely to be attributable to the publication of sub-levels. Instead, it may reflect broader between-period differences, as discussed in Section 4.4.. The increase may also be related to the higher observed terrain exposure after publication (Fig. 4), as more demanding or exposed tours could create more situations in which parties decide to turn back. However, terrain exposure and turn-back were assessed using separate data sources and could not be linked at the level of individual tours. Overall, we found no evidence that publishing sub-levels influenced turn-back decisions during a tour.

4.6. Avalanche accidents

Finally, we investigated whether publishing sub-levels was associated with changes in avalanche accident occurrence (Fig. 5b). The annual number of recorded accidents increased overall and in an almost continuous fashion from 47 in winter 2016/17 to 117 in winter 2025/26, although it varied among winters. The steady increase likely reflects at least in part increased reporting over time. For each winter and sub-level, we divided accident counts by model-predicted touring activity and expressed the resulting rate relative to the winter-wide accident-to-activity ratio. This accounts for exposure and removes between-winter differences in the overall accident-to-activity ratio. Two alternative normalization approaches, based on the frequency with which sub-levels were issued and on observed user-generated touring activity, produced qualitatively similar results (not shown).

After accounting for exposure, accident rates increased progressively with avalanche danger. Using model-predicted activity, relative accident rates increased approximately 35-fold from 1 (low) to 3$=$ in both study periods. The corresponding descriptive increases were smaller when rates were normalized by observed activity (19-fold before vs. 29-fold after publication) or sub-level frequency (15-fold vs. 22-fold). There was no evidence that the relationship between sub-level and accident rate differed between periods for any of the three normalization approaches (interaction tests: model-predicted activity, $p = 0.56$; observed activity, $p = 0.89$; sub-level frequency, $p = 0.76$). Likewise, there was no indication that publishing sub-levels increased accident occurrence at the lower sub-levels. Descriptively, the mean relative accident rate at 3$+$ was lower after publication, but uncertainty was substantial.

5. DISCUSSION

Overall, publishing sub-levels had little measurable effect on recreationists' behaviour, despite representing a substantial change in how forecast information was communicated.

5.1. Forecasters

The clearest change following publication occurred among forecasters rather than users. Within danger level 2, assignments shifted towards more frequent use of 2$+$ after publication, while the overall distribution of sub-levels remained largely unchanged. A plausible explanation is that publication gave the upper sub-level a communicative function it previously lacked: before publication, 2$+$ was an internal annotation that users never saw, whereas afterwards it provided a way to communicate conditions close to danger level 3. The

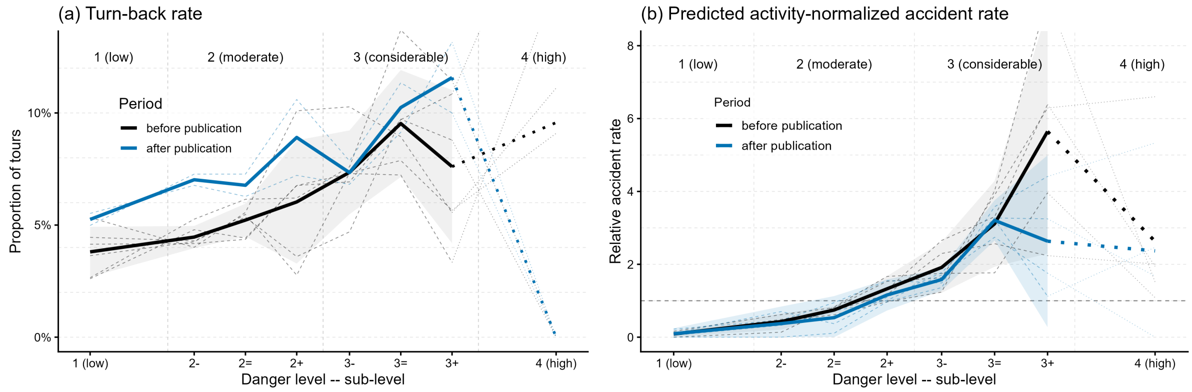

Figure 5: (a) Proportion of tours that were turned back before reaching the summit and (b) avalanche accident rates normalized by model-predicted backcountry touring activity. Display conventions and treatment of sparse estimates as in Fig. 3. In (a), there was insufficient data for the *after* period to calculate CI.

alternative explanation, that winters after publication simply contained more situations warranting 2+, cannot, however, be ruled out, though this explanation seems unlikely. The six winters before publication show no temporal trend, whereas all four winters afterwards consistently exhibit higher frequencies of 2+. Whether this shift represents a desirable improvement in forecast communication or an unintended tendency to avoid issuing danger level 3 remains an operational question for discussion within the warning service.

5.2. Interpreting the limited behavioural response

Across the behavioural proxies, we confirmed that recreationists react to environmental conditions but found remarkably little evidence that publishing sub-levels altered recreationists' behaviour. The absence of measurable behavioural changes does not imply that sub-levels are uninformative. Behaviour consistently varied with sub-level, both within and between danger levels, regardless of whether the modifiers were publicly visible.

Our findings instead suggest that much of this information already reached users before publication. Avalanche forecasters communicated these differences through the bulletin text, the spatial frequency and locations of potential avalanche trigger points, and other forecast elements (Hutter et al. 2021), while planning tools such as *Skitourenguru* already incorporated sub-levels into their risk estimates. Recreationists also updated their decisions based on the conditions encountered in the field. The value of publishing sub-levels may therefore lie less in altering decisions than in making the severity of avalanche conditions more transparent, particularly for less-experienced users. Encouragingly, this increased transparency did not lead to the feared interpretation that lower sub-levels justify more aggressive terrain choices, although continued monitoring remains warranted.

Previous research also suggests that behavioural responses to sub-levels are unlikely to be uniform across users. While users generally understand the concept, perceive it as useful, and many report that it would influence their planning decisions (Lucas et al. 2023), users differ substantially in how they seek, process, and apply bulletin information (St. Clair et al. 2021), and even users with similar experience or training may respond differently to the same forecast information (Neweduk and Haegeli 2025). Experienced recreationists integrate multiple sources of information beyond the danger rating (Morgan et al. 2023), whereas others make only limited use of avalanche forecasts (Slimkowich and Haegeli 2025). Moreover, consulting forecast information does not necessarily imply that it is retained or correctly applied in the field (Trachsel et al. submitted). Against this background, the absence of a strong average behavioural response is perhaps less surprising.

5.3. Limitations

The principal limitation of this study is that publishing sub-levels represents only one component of the information influencing recreationists' decisions (e.g., Schäfer et al. 2025). Backcountry behaviour is shaped by many additional factors, including weather, snow quality, available time, group dynamics, planning tools, and observations related to avalanche conditions such as recent avalanche activity. Consequently, even if publication had influenced decision making, its effect may have been too small to detect against these stronger determinants.

Residual confounding in the before–after design (discussed in Section 3.1.) cannot be excluded: changes coinciding with winter 2022/23 may reflect publication, broader temporal developments, or both. Moreover, exposure to sub-levels was not strictly confined to the after period: Skitourenguru users saw sub-level-informed route ratings throughout the study period, biasing our comparisons towards finding no change, and the before-period route clicks stem entirely from two pandemic winters with exceptionally high touring activity. To mitigate this, we analysed the relationship between sub-level and behaviour rather than absolute activity, normalized behavioural measures within each winter, and compared multiple independent proxies across the decision chain. Several datasets additionally cover only part of the study period (Table 1), and self-reported data are subject to reporting bias. This applies particularly for outcomes such as turning back or avalanche accidents, where the reporting decision itself may depend on the tour outcome. The proxies should therefore not be read in isolation; their consistency across the decision chain provides stronger evidence than any single dataset alone.

6. CONCLUSION AND OUTLOOK

Across seven proxies spanning the full backcountry touring decision chain, we found little indication that publishing sub-levels changed how recreationists planned tours, selected terrain, or turned back, nor did we observe behavioural patterns consistent with the misinterpretation some had feared. The most visible change occurred in forecasting practice, where the upper sub-level 2+ gained a clearer communicative role and was assigned more frequently. That behaviour varied consistently with sub-level even before publication, and that exposure-adjusted accident rates differed markedly even between sub-levels of the same danger level, both support previous studies showing that sub-levels capture meaningful differences in avalanche conditions (e.g., Techel et al. 2022). Our findings therefore shift the question from whether sub-levels carry meaningful information to how that information can best be communicated.

Several questions remain open. Our data also suggest broader changes over time that were unrelated to any detectable effect of publishing sub-levels: terrain exposure was generally higher after publication, and the number of recorded accidents increased substantially. Whether these patterns reflect growing participation, changes in the reporting populations or reporting rates, or genuine shifts towards steeper terrain and greater risk exposure remains unresolved. A survey planned for next winter will investigate users' application of sub-level information during tour planning and while on tour directly rather than through behavioural proxies. We deliberately excluded off-piste terrain, where avalanche forecasts may play a smaller role. However, with about 30% of avalanche involvements in the Swiss Alps occurring in off-piste terrain over the past two decades (Haberkorn et al. 2025), whether and how forecast information reaches these users deserves separate attention. More generally, the behavioural impact of additional forecast information remains poorly understood. For example, despite the widespread use of avalanche problems in operational bulletins, there is still little empirical evidence that this information changes decisions (Winkler et al. 2021; Mannberg et al. 2026). Future research should evaluate not only whether additional forecast elements are understood, but whether, under which circumstances, and how they reach users and influence their behaviour.

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