# HOW AND WHY ARE SNOWPACK MODELS USED OPERATIONALLY?

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ABSTRACT: Public avalanche forecasters in North America rely on sparse weather station and field observation networks, coupled with numerical weather models, to predict avalanche danger—a challenge complicated by the large size of forecast regions (often exceeding 2500 km²). SNOWPACK models offer a more spatially comprehensive view of avalanche hazards than the sparse traditional data sources afford, yet remain underutilized operationally. This study examines how and why forecasters use SNOWPACK, focusing on two factors driving adoption: organizational familiarity/training and trust in model outputs.

We surveyed public avalanche forecasters in Canada and the United States (U.S.) during the 2025–2026 winter (n = 80, 6 forecast centers) to identify how SNOWPACK was integrated into their workflows. Results suggest that SNOWPACK frequently has an indirect influence on forecaster assessments of danger. Forecasters with longer-term exposure and more structured training reported more frequent integration, while those with more recent or limited exposure described more exploratory use. Specifically, Canadian forecasters, who have more experience and training with SNOWPACK, reported that it influenced their decisions 77% of the time compared to only 57% for U.S. forecasters.

The survey also characterized forecaster trust in SNOWPACK outputs. Lower trust was reported following atmospheric rivers, during persistent weak layer formation, and wetting front evolution. To contextualize this self-reported trust, we compared SNOWPACK-derived hazard outputs with forecasted avalanche danger and problems. General regional and seasonal trends aligned well, but problem-specific agreement varied, contributing to periods of lower perceived accuracy.

SNOWPACK model outputs and interactive dashboards are an ever-improving toolset for avalanche forecasters. The results of the survey and contextual support of the hazard analysis indicate that SNOWPACK model utility for public avalanche forecasting depends on a combination of familiarity and training as well as trust developed from applied use. This research supports more widespread operational adoption of models in two ways; first, by informing developments that would make SNOWPACK tools more accurate and useful, and second, by suggesting operational training and practice strategies for working with these tools.

KEYWORDS: avalanche forecasting, snowpack modeling, large-scale operational model chain, spatial variability, avalanche problems

## 1. INTRODUCTION

Public avalanche forecasting is fundamentally a human judgment process in which forecasters synthesize heterogeneous weather, snowpack, and observational data into a structured hazard assessment using the Conceptual Model of Avalanche Hazard and its avalanche problems (LaChapelle, 1980; Statham et al., 2018). This process is complicated by the scale mismatch between forecast regions and the sparse networks of weather stations and field observations available to characterize them (Hägeli and McClung, 2000; Techel et al., 2018). Physically based snow cover models, such as SNOWPACK, were developed in part to close this data gap, offering spatially continuous estimates of snowpack structure and stability that can complement sparse point observations (Horton et al., 2018; Lehning et al., 1999; Morin et al., 2020).

The applied use of SNOWPACK model chains has expanded considerably, with gridded regional simulations enabling large-scale visualizations (Horton et al., 2018, 2025), validation studies linking simulated stratigraphy to forecaster-assessed critical layers and avalanche problems (Herla et al., 2024, 2025), and machine-learning post-processing converting raw output into instability and danger-level products (Reuter et al., 2022; Mayer et al., 2022, 2023; Pérez-Guillén et

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al., 2022; Techel et al., 2025). These model-driven predictions discriminate stable from unstable conditions nearly as well as human forecasters (Techel et al., 2024, 2025), and parallel work on collaborative dashboards, shift-handoff tools, and visual analytics has focused on making this output usable in daily forecasting practice (Horton et al., 2020; Helgeson et al., 2023; Müller et al., 2025; Techel et al., 2025). Yet issues can arise anywhere along the model chain, from upstream weather forcings and SNOWPACK's stratigraphy predictions to downstream hazard post-processing and dashboard design. Despite this sophistication and cross-agency infrastructure investment, such as AvID and AWSOME (Helgeson et al., 2023; Herla et al., 2024), SNOWPACK-based tools remain underutilized in North America relative to their technical maturity, suggesting adoption barriers lie more in workflow integration than model performance (Horton et al., 2023).

Much of the existing literature, however, evaluates these model chains retrospectively—quantifying agreement or skill against forecaster assessments after the fact (Herla et al., 2024, 2025; Pérez-Guillén et al., 2022; Techel et al., 2024). Less is known about how forecasters use these tools in real time, what drives their trust in specific outputs, and how training and experience shape adoption. This study addresses that gap through a survey of public avalanche forecasters in Canada and the United States (US) across the 2025–2026 winter, characterizing how, why, and under what conditions SNOWPACK is integrated into operational forecasting. The results are intended to guide a dual strategy for wider operational adoption: (1) software design and interface refinements to eliminate product failure points, and (2) targeted training and operational practices to navigate known model limitations.

## 2. METHODS

We performed a user survey and coinciding quantitative analysis leveraging the expanding SNOWPACK simulation toolsets available to avalanche professionals. The questions and analysis follow a conceptualized SNOWPACK operational pipeline: 1. weather inputs, 2. physics modeling of stratigraphy, 3. stability post-processing, and 4. dashboard hazard indices. Respondents were primarily using the Avalanche Canada model dashboard, and a few were using locally run SNOWPACK simulations. Within the dashboard, individual toolsets are available for visually interpreting new snow, wind slab, persistent weak layers, and wet snow-focused avalanche problems, their relative hazard, and their contribution to the overall hazard severity, all expressed in unitless indexes from 0 to 100.

### 2.1 Weekly Forecaster Survey

We conducted a survey to qualitatively understand the ways in which public avalanche forecasters apply SNOWPACK dashboards and toolsets into their operational workflows in near-real time during the 2025-2026 winter concurrently in Canada and the US. Participants answered questions characterizing primary avalanche problems being forecasted and identifying what tools they utilized. Additionally, respondents assessed the usefulness of, their trust in, and the influence of the SNOWPACK-generated outputs and characterized the relative alignment or disagreements of these outputs against their mental models of current conditions in a combination of multiple-choice and free-text answer formats. We classify misses as upstream stages (Stage 1 weather inputs and Stage 2 physical stratigraphy) and downstream stages (Stage 3 stability post-processing and Stage 4 dashboard hazard indices).

The weekly forecaster survey received 78 unique responses (Canada = 36, US = 42) from 28 different avalanche forecasters (Canada = 20, US = 8) spanning 5 months of the season (December–April). It is worth noting that 14% (n = 5) of the Canadian responses were incomplete enough to limit their use, and 42% (n = 18) of the US responses came from one individual forecaster.

### 2.2 InfoEx Professional Survey

We also evaluated the results of a parallel, shorter survey of avalanche professionals utilizing SNOWPACK dashboards through InfoEx in Canada. This three-question survey focused on what the professionals used the toolsets for and how much it aligned with their understanding of current conditions. The survey did not include specific questions of trust, influence, utility, or avalanche problems.

The InfoEx professional survey received 139 unique responses from 7 different operations. 30% (n = 43) of the responses were from a single ski patrol, 39% (n = 55) of the responses were from a single Avalanche Canada professional field team, and the remaining 31% of responses were primarily from other Avalanche Canada professional field teams (27%, n = 38), a guiding operation, private operational forecasters, and highway forecasters (2%, n = 3). Despite the relatively high count of responses, one question or more was skipped 68% (n = 94) of the time.

### 2.3 Comparative Quantitative Analysis

To ground our qualitative survey findings, we analyzed the AvID platform's outputs against the regional forecasted danger and avalanche problems in both Canada and the United States through the entirety of the 2025-2026 winter. We extracted the hazard (overall hazard, new snow, wind slab, persistent slab, and wet snow individually) output values from the Avalanche Canada model dashboard and all danger level and avalanche problems from overlapping public avalanche centers. Comparisons of these two datasets focused on identifying spatial and temporal trends and patterns in agreement (or disagreement) of avalanche problem type, snow climate, or danger by using both ordinal and logistical regression to determine the relative fit of avalanche danger and problems between the two. We also explored mixed effects modeling of climatic (regional temperature and precipitation data from PRISM) and avalanche problem-specific base rates to understand spatial patterns of variance observed in our initial analysis. The findings of this comprehensive analysis far exceed the scope of this paper and are available as a supplement on the AvaCollabra website (https://avacollabra.net/).

Finally, we leveraged both qualitative and quantitative datasets to investigate the weeks when forecasters identified "mismatches" between the modeled outputs and their own mental model with the corresponding issued avalanche forecasts and SNOWPACK outputs from that week and specific forecast zone. We express each response week's disagreement relative to a typical week in the same regions with values ranging from 0 (unusual agreement for that region) to 1 (normal disagreement) to 2 (twice the disagreement).

## 3. RESULTS

### *3.1 <u>Weekly forecaster survey results</u>*

The survey answers illustrate SNOWPACK interpretation differences between Canadian and US forecasters and varying self-identified levels of utility, trust, and influence. Canadian forecasters responded with generally higher overall and problem-specific utility scores as well as reporting higher forecast influence than the US forecasters (Table 1). On the other hand, US forecasters reported higher model trust and more frequent alignment with expectations than their Canadian counterparts.

Table 1: Country-specific survey results.

| ***Metric*** | ***Canada (n = 31)*** | ***US (n = 42)*** |
|---|---|---|
| Mean overall utility | 5.54/10 | 4.7/10 |
| Mean problem-specific utility | 5.34/10 | 4.25/10 |
| Direct forecast influence | 26% | 17% |
| Output trust ("Yes" answer) | 65% | 79% |
| Aligned with expectations | 32% | 51% |
| Overestimated hazard/problem | 23% | 9% |
| Missed something important | 12% | 5% |
| Hard to interpret | 11% | 1% |

The general themes of "misses" were downstream for Canadian respondents and upstream for US respondents. Hazard calibration was the most frequent simulation "miss" identified by forecasters responding to the survey, with Canadians reporting the model overestimated the hazard or problem and US forecasters reporting the simulation underestimated the hazard or problem. Additional trends in misses identified in a multiple-choice format question focused on persistent weak layer identification, overcomplicated stratigraphy, overestimated snow depths, and wetting front progression. Additional coding of free-text miss descriptions highlighted "misses" with crust formation, total snow depth, and weather inputs.

Considering problem-specific findings, persistent slab problems dominated responses (n = 37) due to a continent-wide midwinter drought. Across persistent slab, storm slab (n = 11), and wind slab (n = 10) problems, forecasters reported direct model influence ~20% of the time, indirect influence ~50%, and no influence ~30% (Figure 1a). Modeled outputs "aligned with expectations" ~40% of the time across these primary problems, while "surfacing something new" in persistent and storm slab scenarios (Figure 1b). These three primary problems also shared higher trust and utility ratings as compared to wet snow avalanche problems (Table 2).

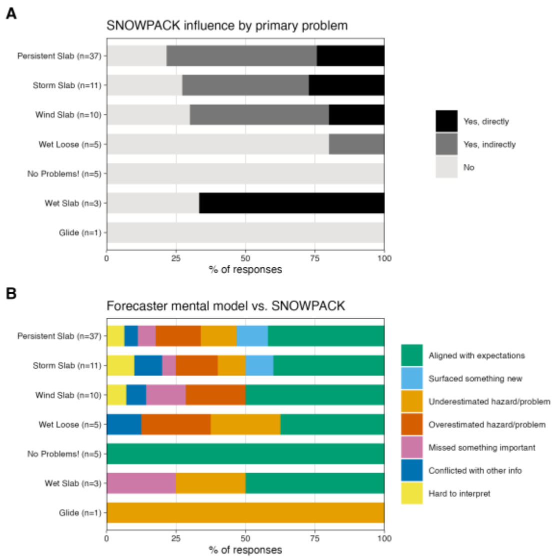


Figure 1: Primary avalanche problem-specific SNOWPACK influence (A) and forecaster interpretations of SNOWPACK outputs compared to their mental models (B).

Table 2: Avalanche problem-specific survey results and common misses.

| ***Avalanche Problem (dashboard metric)*** | ***Relevant Results*** | ***Common Misses*** |
|---|---|---|
| Persistent slab (persistent weak layers) | 77% of responses trust output | Presence/absence of specific weak layers, weak layer depth and distribution, overcomplicated stratigraphy and crusts, underestimated new snow depth, and total snow depth |
| Storm slab (new snow) | Highest utility reported among respondents (mean rating: 5.5/10) | Overestimated new snow depth, underestimated new snow depth, overcomplicated stratigraphy, and persistent weak layer identification |
| Wind slab (wind slab) | Highest trust reported among respondents (80% of responses) | Wind slab development, overestimated new snow depth, spatial resolution, and overcomplicated stratigraphy |
| Wet loose and wet slab (wet snow) | Lower trust (<70%) and lower utility ratings (3.7/10) | Wetting front progression, freezing levels, overcomplicated stratigraphy, and underestimation of the wet snow hazard |

## 3.2 InfoEx professional survey results

The spatial scale of operations responding in the InfoEx survey was generally smaller, and the needs of these users appeared different from those of the forecasting operations discussed above. Between user groups, the professional field teams reported lower frequencies of "aligned with expectations" than the ski patrol (45-55% and 65%, respectively). The InfoEx responses highlighted SNOWPACK conflict themes focused on upstream outputs: crusts, wet snow, new snow hardness, and weak-layer depths.

## 3.3 Quantitative Comparison results

Our comparative analysis of avalanche forecasts and AvCan SNOWPACK dashboard relevant metrics resulted in general seasonal alignment, with specific regional, avalanche problem, and timing mismatches that add context to the survey responses. The overall danger was forecasted higher than the modeled hazard in transitional climates and lower than the modeled hazard in maritime and continental climates. Further analysis indicated a distinct spatial structure inherent in the dataset that informs the regional variance seen in our outputs. This variance in mismatched forecasts and SNOWPACK outputs is partially explained by climatic temperature and precipitation patterns while being sensitive to base rates for local avalanche problem character and frequencies. The regional character of natural snowpacks and climatic conditions (maritime, intercontinental, and continental) also aligned with these avalanche problem-specific biases.

Looking more closely at individual avalanche problems, maritime regions struggled most frequently with accurate alignment between the persistent and wind slab avalanche problems and modeled outputs (Table 3). The modeled outputs generally aligned best in transitional regions, while continental regions also showed generally good alignment but with more extreme deviations when misaligned.

Table 3: Avalanche climate-generalized problem-specific SNOWPACK hazard output compared to the issued avalanche forecast.

| ***Avalanche Problem (dashboard metric)*** | ***Maritime*** | ***Transitional*** | ***Continental*** |
|---|---|---|---|
| Danger (hazard) | Model hazard higher | Neutral | Model hazard higher |
| Persistent slab (persistent weak layer) | Model hazard higher | Neutral | Neutral |
| Storm slab (new snow) | Model hazard higher | Model hazard lower | Neutral |
| Wind slab (wind slab) | Model hazard higher | Neutral | Model hazard lower |
| Wet loose and wet slab (wet snow) | Neutral | Neutral | Model hazard lower |

Temporal comparisons between issued forecasts and the SNOWPACK simulated outputs revealed additional problem-specific timing differences at problem onset. SNOWPACK simulations typically lead the forecast issuance of persistent slab problems by 3 days (in 60% of matched onsets). Storm slab problems occur nearly simultaneously, as would be expected. Wind slab problems were marginally simulation lead but suffered from frequent model-only or forecast-only onsets. The simulated wet-instability signal is weak and poorly timed. Its onsets matched the issued forecast least well of any problem, and where they did match, lagged the forecast by about a day.

The quantitative mismatch between forecasts and SNOWPACK outputs were generally aligned to survey responses. In the weeks forecasters reported a mismatch, the forecast and SNOWPACK disagreement averaged 1.4 times the regional norm, against 1.1 in the weeks they reported the model aligned with their expectations (medians ratios relative to the regional norm 1.2 and 0.9, respectively; Mann-Whitney $p = 0.049$). The weeks forecasters flagged also were, for those regions, the weeks of greatest model-forecast disagreement.

## 4. DISCUSSION

### *4.1 Synthesis by avalanche problem*

Our findings generally point to well-aligned outputs that follow the seasonal cycles of avalanche problems. The survey and quantitative analysis offer deeper insight into avalanche problem-specific outcomes, and we summarize those specificities in Table 4.

Table 4: Avalanche problem-specific summaries of model skill, forecaster insight, and proposed improvements.

| ***Avalanche Problem (dashboard metric)*** | ***Model Skill*** | ***Forecaster Insight*** | ***Proposed Improvements*** |
|---|---|---|---|
| Persistent slab (persistent weak layers) | Better in transitional and continental climates and less reliable in maritime; confusion around persistent weak layer index during initial storm cycles | Surfaces something new for many forecasters; predicts the onset of a persistent weak layer problem earlier than forecast by ~3 days | Metrics should work equally well for all climates; further training on interpreting the numeric persistent weak layer index means |
| Storm slab (new snow) | Directly aligns with NWP snowfall forecasts; generally accurate | Easy to use and interpret; improves awareness of spatial distribution of snowfall | Subtle slab properties such as hardness would add value to purely new snow-based metrics (especially for smaller spatial scale operations) |
| Wind slab (wind slab) | Documented limitation; model not configured to handle many core processes and uses a rudimentary drift index | Relatively high trust; potential misunderstanding of model limitations or critical use of additional tools | Develop more snow processes (in progress); train forecasters to be critical of model accuracy and limitations |
| Wet loose and wet slab (wet snow) | Rudimentary index; stratigraphy has interpretable information about the wetting front | Many reported issues and mismatches; anecdotal evidence that visualizing the wetting front is useful | Develop metrics and tools that better identify key wet snow processes |

### 4.2 *Improving operational forecast use*

Survey responses of operational use of SNOWPACK provided valuable feedback to drive future development of the model and dashboards, as well as guidance for additional training. Our research suggests upstream-focused work should continue to improve snow processes representation for wind-driven effects, wet snow transitions, and hardness profiling. Additionally, downstream-focused development should prioritize improved post-processing of outputs and dashboard refinement, especially for identifying and indexing persistent weak layers, creating a wind slab index, and building wetting front tools.

There are inherent disconnects between the naturally mental-model-driven process of avalanche forecasting, communicating danger, and SNOWPACK simulations. Our study suggests that increasing use of these relatively new toolsets is the primary way to resolve these obvious gaps. Repetition accompanied with critical thought allows practitioners to understand the strengths, weaknesses, and limitations of the simulations rather than taking all outputs as equal. Our survey demonstrated that forecasters with more familiarity with the model and dashboard focused their attention on the more potentially valuable downstream outputs, and those tools had greater influence on their final forecast. In contrast, forecasters with less familiarity tended to focus on the upstream, harder-to-digest-at-scale, individual profiles, with higher trust in the assumed physical realism but less influence on their final forecast. Therefore, our research suggests that targeted standardized training emphasizing the core differences between simulated representations of snow and hazard to forecasters field observations and mental models will resolve common misconceptions and shift users from basic profile critics to leveraging integrated downstream toolsets.

Additional considerations for future training should include discussions of semantic terminology differences, spatial scale, and temporal mismatches. SNOWPACK output naming and definitions do not explicitly mirror the Conceptual Model of Avalanche Hazard, European Avalanche Warning Services, or other similar avalanche problem and danger frameworks that avalanche forecasters are most familiar with, resulting in misunderstanding or misuse of the dashboards. Informing forecasters of these semantic mismatches ensures that their interpretations and application of outputs are accurate. Spatial scale differences between operations represented in the survey highlighted the differences in interpretation of SNOWPACK simulations, with larger operational areas focusing on downstream tools and smaller operational areas favoring upstream specificity such as point stratigraphy. The timing differences found in the comparative analysis often reflected the gap between when a possible avalanche problem was identified (by forecaster or simulation) and when it was communicated in the public forecast. Including these subtle but necessary components in SNOWPACK simulation training prevents forecasters from dismissing output as inaccurate, inapplicable, and untrustworthy.

## 5. CONCLUSION

This study set out to understand how and why public avalanche forecasters integrate SNOWPACK models in their workflows, given that these tools remain underutilized in operational forecasting in North America. Combining a season-long survey with a parallel quantitative comparison, we found that SNOWPACK's operational value depends on more than model accuracy alone. While seasonal-scale hazard trends were generally well captured, problem-specific mismatches continued to limit forecaster trust and forecast influence, particularly for less experienced users. The study's findings point toward two complementary paths forward: (1) targeted upstream and downstream model development focused on the most-utilized toolsets (persistent weak layers and new snow) and known limitations (wind and wet snow), and (2) prioritizing structured, ongoing training that clarifies SNOWPACK's semantic, spatial, and temporal differences from operational conceptual models. Future research should widen this survey across multiple seasons and additional forecast centers to capture a larger range of conditions and use cases.

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## REFERENCES

Hägeli, P., & McClung, D. M. (2000). New perspective on computer-aided avalanche forecasting: Scale and scale issues. Proceedings of the 2000 International Snow Science Workshop, October 1-6, Big Sky, Montana, 66–73. https://arc.lib.montana.edu/snow-science/item.php?id=708

Helgeson, G., Nowak, S., Cooperstein, M., Horton, S., Barney, J., Lazar, B., Greene, E., & Klassen, K. (2023). The Avld project: Collaborative solutions to avalanche forecasting challenges. International Snow Science Workshop Proceedings 2023, Bend, Oregon, 9–17. https://arc.lib.montana.edu/snow-science/item.php?id=2847

Herla, F., Haegeli, P., Horton, S., & Mair, P. (2024). A large-scale validation of snowpack simulations in support of avalanche forecasting focusing on critical layers. Natural Hazards and Earth System Sciences, 24(8), 2727–2756. https://doi.org/10.5194/nhess-24-2727-2024

Herla, F., Haegeli, P., Horton, S., & Mair, P. (2025). A quantitative module of avalanche hazard – comparing forecaster assessments of storm and persistent slab avalanche problems with information derived from distributed snowpack simulations. Natural Hazards and Earth System Sciences, 25(2), 625–646. https://doi.org/10.5194/nhess-25-625-2025

Herla, F., Widforss, A., Binder, M., Müller, K., Horton, S., Reisecker, M., & Mitterer, C. (2024). Establishing an operational weather & snowpack model chain in norway to support avalanche forecasting. International Snow Science Workshop 2024, Tromsø, Norway, 168–175. https://arc.lib.montana.edu/snow-science/item.php?id=3129

Horton, S., Haegeli, P., Klassen, K., Floyer, J., & Helgeson, G. (2023). Adopting snowpack models into an operational forecasting program: Successes, challenges, and future outlook. International Snow Science Workshop Proceedings 2023, Bend, Oregon, 1544–1549. https://arc.lib.montana.edu/snow-science/item.php?id=3095

Horton, S., Herla, F., & Haegeli, P. (2025). Clustering simulated snow profiles to form avalanche forecast regions. Geoscientific Model Development, 18(1), 193–209. https://doi.org/10.5194/gmd-18-193-2025

Horton, S., Nowak, S., & Haegeli, P. (2018). Exploring regional snowpack patterns with gridded models. International Snow Science Workshop Proceedings 2018, Innsbruck, Austria, 1136–1140. https://arc.lib.montana.edu/snow-science/item/2722

Horton, S., Nowak, S., & Haegeli, P. (2020). Enhancing the operational value of snowpack models with visualization design principles. Natural Hazards and Earth System Sciences, 20(6), 1557–1572. https://doi.org/10.5194/nhess-20-1557-2020

LaChapelle, E. R. (1980). The fundamental processes in conventional avalanche forecasting. Journal of Glaciology, 26(94), 75–84. https://doi.org/10.3189/S0022143000010601

Lehning, M., Bartelt, P., Brown, B., Russi, T., Stöckli, U., & Zimmerli, M. (1999). Snowpack model calculations for avalanche warning based upon a new network of weather and snow stations. Cold Regions Science and Technology, 30(1–3), 145–157. https://doi.org/10.1016/S0165-232X(99)00022-1

Mayer, S., van Herwijnen, A., Techel, F., & Schweizer, J. (2022). A random forest model to assess snow instability from simulated snow stratigraphy. The Cryosphere, 16(11), 4593–4615. https://doi.org/10.5194/tc-16-4593-2022

Morin, S., Horton, S., Techel, F., Bavay, M., Coléou, C., Fierz, C., Gobiet, A., Hagenmuller, P., Lafaysse, M., Ližar, M., Mitterer, C., Monti, F., Müller, K., Olefs, M., Snook, J. S., Van Herwijnen, A., & Vionnet, V. (2020). Application of physical snowpack models in support of operational avalanche hazard forecasting: A status report on current implementations and prospects for the future. Cold Regions Science and Technology, 170, 102910. https://doi.org/10.1016/j.coldregions.2019.102910

Müller, K., Techel, F., & Mitterer, C. (2025). The EAWS matrix, a decision support tool to determine the regional avalanche danger level (Part a): Conceptual development. Natural Hazards and Earth System Sciences, 25(11), 4503–4525. https://doi.org/10.5194/nhess-25-4503-2025

Pérez-Guillén, C., Techel, F., Hendrick, M., Volpi, M., van Herwijnen, A., Olevski, T., Obozinski, G., Pérez-Cruz, F., & Schweizer, J. (2022). Data-driven automated predictions of the avalanche danger level for dry-snow conditions in Switzerland. Natural Hazards and Earth System Sciences, 22(6), 2031–2056. https://doi.org/10.5194/nhess-22-2031-2022

Pérez-Guillén, C., Techel, F., Volpi, M., & van Herwijnen, A. (2025). Assessing the performance and explainability of an avalanche danger forecast model. Natural Hazards and Earth System Sciences, 25(4), 1331–1351. https://doi.org/10.5194/nhess-25-1331-2025

Reuter, B., Viallon-Galinier, L., Horton, S., Van Herwijnen, A., Mayer, S., Hagenmuller, P., & Morin, S. (2022). Characterizing snow instability with avalanche problem types derived from snow cover simulations. Cold Regions Science and Technology, 194, 103462. https://doi.org/10.1016/j.coldregions.2021.103462

Statham, G., Haegeli, P., Greene, E., Birkeland, K., Israelson, C., Tremper, B., Stethem, C., McMahon, B., White, B., & Kelly, J. (2018). A conceptual model of avalanche hazard. Natural Hazards, 90(2), 663–691. https://doi.org/10.1007/s11069-017-3070-5

Techel, F., Helfenstein, A., Mayer, S., Pérez-Guillén, C., Purves, R., Ruesch, M., Schmudlach, G., Soland, K., & Winkler, K. (2024). Human vs. Machine—Comparing model predictions and human forecasts of avalanche danger and snow instability in the Swiss Alps. International Snow Science Workshop 2024, Tromsø, Norway, 31–38. https://arc.lib.montana.edu/snow-science/item.php?id=3108

Techel, F., Mitterer, C., Ceaglio, E., Coléou, C., Morin, S., Rastelli, F., & Purves, R. S. (2018). Spatial consistency and bias in avalanche forecasts – a case study in the European Alps. Natural Hazards and Earth System Sciences, 18(10), 2697–2716. https://doi.org/10.5194/nhess-18-2697-2018

Techel, F., Müller, K., Marquardt, C., & Mitterer, C. (2026). 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, 26(3), 1161–1181. https://doi.org/10.5194/nhess-26-1161-2026

Techel, F., Purves, R. S., Mayer, S., Schmudlach, G., & Winkler, K. (2025). Can model-based avalanche forecasts match the discriminatory skill of human danger-level forecasts? A comparison from Switzerland. Natural Hazards and Earth System Sciences, 25(9), 3333–3353. https://doi.org/10.5194/nhess-25-3333-2025