CONSIDERATIONS FOR EFFECTIVE UNCERTAINTY COMMUNICATION IN PUBLIC AVALANCHE FORECASTS

Eeva Latosuo[1]*, Pascal Haegeli[1,2], Julie Demuth[3], Stan Nowak[1,4], Ethan Greene[5]

[1] *Simon Fraser University, Burnaby, BC, Canada*
[2] *WSL Institute for Snow and Avalanche Research, Davos, Switzerland*
[3] *National Science Foundation, National Center for Atmospheric Research, Boulder CO, USA*
[4] *Avalanche Canada, Revelstoke, BC, Canada*
[5] *Colorado Avalanche Information Center, Boulder, CO, USA*

ABSTRACT: Uncertainty is fundamental to avalanche risk management, yet public avalanche forecasts have not communicated it as consistently as other hazard characteristics. The Conceptual Model of Avalanche Hazard addresses what type of avalanche problem exists, where it is found, how likely it is, and how large it may be, but not "How sure are you?" . Our prior research found that although forecasters routinely assess uncertainty, many struggle with when and how to communicate it within existing tiered structures. This paper develops considerations for communicating forecast uncertainty more effectively across user levels.

Using a systems-thinking approach, we examine three components of the forecast system - hazard, users, and products - and distill our understanding into four questions: Is the uncertainty decision-relevant, and to whom? What can users reasonably understand and act on? Where in the tiered structure should it appear, and how should it be communicated? We apply these questions to three high-uncertainty situations and to an existing operational element, the confidence statement, to illustrate how communication needs shift with the nature of the uncertainty.

Across these situations, decision relevance, reducibility, and user capacity varied independently, so no single approach applied across uncertainty types. Broadly relevant or irreducible uncertainty warranted direct messaging placed prominently in the forecast, while uncertainty relevant to narrower audiences suited deeper tiers with plain-language support. From these patterns, we offer five recommendations for avalanche warning services. Uncertainty communication should not be a fixed forecast component, but adapted in placement, content, and format to its nature and to users' capacity to respond - above all, relevant, actionable, and appropriate to user's decision-making contexts.

KEYWORDS: Avalanche risk communication, Uncertainty, Public avalanche forecasting, User research

1. INTRODUCTION

Uncertainty is a fundamental component in all avalanche risk management, because we make decisions with incomplete information in a dynamic hazard environment. While the Conceptual Model of Avalanche Hazard (CMAH, Statham et al., 2018) provides a standardized workflow for avalanche hazard assessment in North America that distills the assessment process into four key questions (what type, where, how likely, and how big), the overarching question of “How sure are you?” is not addressed explicitly. Uncertainty is covered in CMAH mostly in broad terms, yet Sykes and Atkins (2023) argue that it could be considered the fifth key question in avalanche hazard assessments as the fifth key question (Sykes and Atkins,2023): how certain are we about our risk assessment?

* Corresponding author address:
Eeva Latosuo, Simon Fraser University,
Burnaby, BC Canada
email: eeva_latosuo@sfu.ca

Uncertainty is equally prominent in public avalanche forecasts. In addition to the inherent uncertainty of the avalanche system itself, the forecast production process introduces additional sources of uncertainty in all of its stages (Latosuo et al., 2026). Uncertainties that originate throughout the process collectively determine the overall uncertainty of the forecast.

However, public avalanche forecasts have so far not communicated uncertainty with the same consistency as other hazard characteristics even though clearly communicating the limitations of the available information can improve users’ decision making (Doyle et al., 2019; Padilla et al., 2021). Our research on users of public avalanche forecasts suggests that communicating uncertainty more openly has the potential to benefit users' decisions and to increase their trust in the forecast as a reliable information source (Latosuo et al., 2024). In interviews with 30 public backcountry forecasters, we found that they assess uncertainty routinely in their work, but many

https://doi.org/10.15788/1790098572

struggle to determine when and how to communicate it systematically within the existing forecast structure (Latosuo et al., 2026). Hence, while there is considerable evidence highlighting the advantages of more openly communicating uncertainty, we do not know how to do it effectively.

To address this communication challenge, the objective of this paper is to share key considerations for examining how information about uncertainty could be communicated more effectively. We weigh the nature of the uncertainty, to whom it matters, and how forecast users can use this information in their decisions. The foundation of our research is the existing risk communication literature and our understanding of the nature of avalanche hazard and backcountry users.

2. BACKGROUND

To comprehensively characterize avalanche safety systems, St. Clair and Haegeli (2023) proposed a systems thinking approach that consists of three principal components: avalanche hazard, people/communities, and services. Here, we apply this perspective to the public avalanche forecast system, whose corresponding components are avalanche hazard, forecast users, and forecast products. This background section first reviews our understanding of each of these components and then develops a set of four critical questions for reflecting on how avalanche forecasts communicate uncertainty to different users.

2.1 *Hazard: Sources and nature of uncertainty in public avalanche forecasts*

There are four major sources of uncertainty in the public avalanche forecasts (Latosuo et al., 2026). The inherent randomness and complexity of the avalanche system results in spatial and temporal variability that makes predicting individual avalanches with certainty almost impossible. We use observations and model outputs to capture what is going on, but they provide incomplete evidence and can introduce additional uncertainties. The interpretation of these data by forecasters are expert judgments that are affected by their knowledge, experience, and biases, and forecast procedures. Finally, the structure and limitations of the forecast products introduce additional uncertainty into the forecast, including ambiguous or complex language.

Uncertainty can be reducible or irreducible. Reducible uncertainty arises from limitations in knowledge and can be narrowed through additional observation, information, or improved understanding. Irreducible uncertainty, by contrast, stems from inherent variability or randomness in the system and cannot be fully eliminated. In the scientific literature, this distinction is often termed epistemic versus aleatoric uncertainty. Distinguishing between the two is fundamental to deciding what uncertainty information should be communicated to the public (Beven et al., 2018), since it determines the extent to which users can reduce, manage, or adapt to that uncertainty in their trip planning (Campbell et al., 2016). In complex avalanche hazard conditions, some uncertainty remains irreducible. The strategy is not to resolve the uncertainty but to recognize its presence, acknowledge it explicitly, and remain alert to its implications (Campbell et al., 2016).

2.2 *People: Avalanche forecast users*

The safety value of avalanche forecasts depends not only on providing hazard information, but on users' ability to understand the message and translate it into appropriate risk-reduction behavior (Engeset et al., 2018). Forecast users' level of avalanche training and experience shapes how they interpret forecast information, which information they rely on, and how they apply that information in avalanche risk-management decisions (e.g. Fisher et al., 2022a; Mannberg et al., 2026). Travelling mode preferences impact how the users interact with the terrain making it a factor in people's pre-trip planning and in-the-field behaviors (e.g. Mannberg et al. 2018; Slimkovich and Haegeli, 2025). Backcountry motivations provide another important context for understanding avalanche information needs beyond users' activity type and avalanche training level (Neweduk and Haegeli, 2025). Knowing why people recreate is critical for designing avalanche information that better resonates with their goals, needs, and capabilities.

St. Clair et al. (2021) describe avalanche bulletin users as a hierarchy of information-use patterns that increase in complexity and decision-making sophistication. At the simpler end, users rely mainly on high-level information such as the danger rating to make broad go/no-go decisions

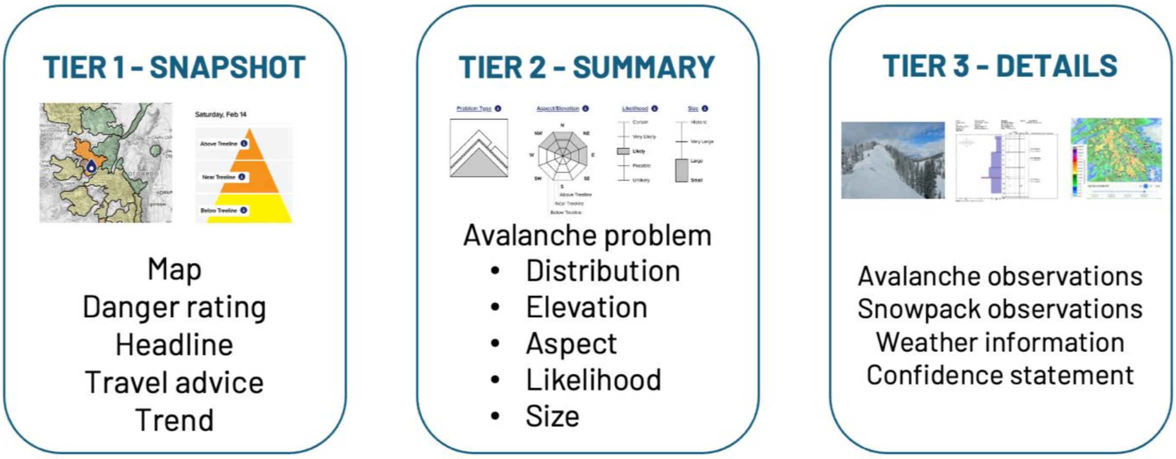

Figure 2. Schematic structure of an avalanche forecast. Its content is structured in tiers from most synthesized information (Tier1) to processed data feed and detailed evidence in advanced content (Tier3).

(Morgan et al., 2023). More experienced users incorporate increasingly detailed information deeper in the forecast to distinguish between suitable and not suitable terrain (Fisher et al., 2021). This highlights that forecast users' have different capabilities and sophistication to process its information (St.Clair et al., 2021).

We draw on three different forecast engagement levels from St. Clair et al.(2021) typology to help evaluate how well uncertainty information in forecasts fits the needs and abilities for these forecast user types. Basic users can digest and rely on the most synthesized hazard information; danger rating, short plain language summary of hazard conditions, and terrain and travel advice. Intermediate users understand the middle tier information that describes avalanche problems with essential details on distribution, sensitivity, and consequences, and they apply it with their basic terrain skills. Advanced users can access all the tiers of the forecast information and apply it fluidly in their risk management. For some Advanced users, the forecast serves as a starting point for their own hazard assessment.

2.3 *Product: Existing structure of public avalanche forecast*

An avalanche forecast provides both knowledge and action-oriented guidance that people can use to manage risk within their own decision-making context. Knowledge-based content, such as avalanche problem types, provides users with a framework for understanding the hazard present in specific terrain (Skille et al., 2026), In addition, many avalanche warning services include explicit guidance, Terrain and Travel Advice, about what terrain to avoid and what to favour under existing conditions (Fisher et al., 2022b).

Avalanche forecasts follow an information pyramid (EAWS, n.d.) where the content is structured in tiers (Fig. 2) with increasing detail. The most important hazard assessment message is at the top of the product, Tier 1, in simple and accessible text and graphics. The focus is on the danger rating. The middle tier, Tier 2, introduces avalanche problems that explain basic hazard characteristics and connect it with terrain. Tier 2 includes many graphics that assume a level of graphic literacy to interpret them correctly (Matzen et al.2025). Deeper in the forecast, Tier 3 has detailed facts used for making the assessment.

Information seeking is one stage within the Protective Action Decision-Making Model (PADM), a broad theory describing how individuals perceive risk, evaluate protective actions, and decide how to respond (Lindell and Perry, 2012). This stage itself follows a progression from awareness to comprehension, and ultimately to application in decision-making. The tiered structure of the avalanche forecast supports the staged information-seeking process of PADM. Each tier presents information at an increasing level of detail and complexity (Fisher et al., 2022a).

The tiered design allows users to engage with the forecast at the level that matches their information needs. The tiers set a template for our explorations of where and how uncertainty can be addressed through targeted strategies.

3. KEY CONSIDERATIONS

To evaluate the effectiveness of the uncertainty communication in forecasts, there are two critical questions about the interaction between forecast users and the forecast product when the avalanche hazard situation has elevated uncertainty:

- Does the forecast product clearly communicate the uncertainty around the hazard conditions?

- Does this forecast product enable users' information-seeking and decision-making regarding the uncertain hazard?

In short, we ask if the forecast is both clear and usable with respect to uncertainty. While these questions are broad and help organize our understanding, they are not specific enough to provide tangible guidance for daily operations. Hence, we translate them into four critical questions.

1. **Is the particular uncertainty decision-relevant, and if so, for whom?** Communicating irrelevant uncertainty risks unnecessarily complicating the core hazard message.
2. **What can we reasonably expect users to understand, recognize in the field, and apply, given their level of knowledge and skill?** We need to decide how much background information or tangible guidance users need for a well-informed behavioral response.
3. **Where in the forecast structure is the uncertainty communicated?** Each tier serves a different information function and user group. We need to identify where the forecast is serving different users well and locate gaps where decision-relevant uncertainty is missing or is not accessible to the intended users.
4. **How should this type of uncertainty be communicated?** We can determine communication content and format that align best with the intended impact in the public avalanche forecasts.

We apply these four questions to four situations in public avalanche forecasting to show how the answers shift depending on the nature of the uncertainty involved. The first three examples explore typical uncertainty situations whereas the last one examines an existing operational uncertainty communication approach.

3.1 <u>Example 1: Unknown amount of new storm snow</u>

The incoming storm is forecast to bring a large amount of new snow but the range of accumulation teeters between Moderate and Considerable danger levels.

In this situation, uncertainty primarily originates in weather model output and is reducible through field observation. Because the link between new-snow amount and elevated hazard is taught in introductory avalanche courses, and many users can estimate snow depth in the field, this uncertainty is easy to comprehend at the knowledge level and can likely be handled by many users. It also translates cleanly into action-oriented guidance via measurable thresholds: "If you see more than 30 cm of new snow, treat the danger as Considerable", paired with direct guidance: "Stay off terrain steeper than 30 degrees."

Capacity to respond varies by experience. Basic users mainly need to know when to turn around, Intermediate users whether to travel in lower-angle terrain. Advanced users benefit from understanding the full range of possible conditions.

This uncertainty suits **Tier 1** content of clear conditional (if-then) statements in the headline that link a recognizable field cue to a predefined response (Gollwitzer and Sheeran, 2006), reinforced by impact-based visuals showing the upper end of the snow range (Siegel and Kulp, 2021). In **Tier 2**, the storm-slab size graphic could highlight this range with an additional salient uncertainty cue (Waugh et al., 2025); in **Tier 3**, Advanced users can use detail on specific sources of uncertainty, such as storm track or timing.

Takeaway: This uncertainty is reducible, relevant to all users, and readily converted into a clear conditional threshold, well suited to simple if-then guidance in Tier 1, with additional supporting detail layered into Tiers 2 and 3.

3.2 <u>Example 2: Deep persistent slab</u>

The incoming storm is forecast to add snow on a deep persistent layer that has recently reactivated causing large avalanches and displayed surprising characteristics of concern (human triggering, remote triggering, wide propagation).

This is among the most difficult uncertainty situations to assess and manage in avalanche risk management. Its source lies in complex and often unexpected snowpack properties with limited reliable evidence on distribution or sensitivity, making it largely irreducible through further field observations. In addition, potential for very severe consequences weighs in the decisions heavily.

Because of its irreducibility and severe consequences, being aware of this type of uncertainty is critical for *all* forecast users. **Tier 1** should make its serious, persistent nature clear, e.g., a headline "Stay vigilant about deadly and unpredictable snowpack". Unusual conditions call for more than routine hazard presentation, and visual cues enhance attention and response (Dallo et al., 2022). Ideas for transient visual cues include temporary banner, or warning icon that pulses in opacity or size.

Given the severity of consequences, guidance should be direct rather than nuanced since the knowledge available does not resolve into any action beyond avoidance. When consequences are severe and uncertainty is irreducible, a precautionary approach favoring large safety margins is warranted (Kriebel et al., 2001). It is difficult to find trustworthy evidence in the field to reliably rule out the hazard, which makes it challenging for even Advanced users to dynamically manage the hazard in the field. Detailed local terrain and avalanche hazard information is necessary to make more advanced terrain choices. Guidance should reflect this; Advanced users benefit from explicit wide-margin guidance, while Basic and Intermediate users are better served by a recommendation of complete avoidance.

Because this uncertainty is relevant to everyone, salient information should appear across **all three tiers**: **Tier 1** with simple avoidance guidance, **Tier 2** with likelihood/size ranges and tangible imagery to highlight severe consequences, and **Tier 3** with the nuanced snowpack detail most accessible to Advanced users. When risk is too complex for standard forecast elements, longer-form narrative, such as a blog post or video about the forecaster's cautious mindset, can supply users with additional context (Sillman et al., 2021). Social media posts could help get the message across to the lower tier users.

Takeaway: This uncertainty is irreducible and consequential enough to be relevant to every user, including experts warranting salient, direct, avoidance-oriented messaging across all three tiers, supplemented by narrative formats or educational media when standard elements cannot capture the whole complexity.

3.3 Example 3: Spatial uncertainty of weak layer distribution

The layer of concern is buried surface hoar, which above treeline elevations is confined primarily to aspects that remained sheltered from wind. Some locations don't have many snowpack observations to help dial down the distribution.

Unlike the previous two situations, while uncertainty is relevant for all users, the accompanying guidance is not equally actionable for everyone. The recommendation to avoid affected aspects and elevations and to verify the weak layer status in the field presumes terrain and snowpack identification knowledge Basic users may not have. For these users, the forecast needs to communicate the uncertainty as awareness information rather than expect them to act on it.

Knowledge of the hazard alone does not translate into the field skill to act on it, and capacity tracks with training and experience. Basic users are less likely to have this skill. Intermediate and Advanced users have typically been introduced to aspect/elevation interpretation, though fluency varies: Advanced users apply it readily on the go, while Intermediate users may still be developing the skill. Verifying the layer's presence in the field requires an added skill limited to Advanced users.

Given its spatial nature, this uncertainty likely benefits from graphical rather than purely textual formats. In **Tier 2**, an aspect/elevation diagram could visually distinguish suspected but unconfirmed zones using texture or reduced opacity, a technique shown to shift users toward more cautious decision strategies under map-based uncertainty (Korporaal et al., 2020) with an accompanying caption noting limited field data. However, effectiveness depends on interpretability: text-based risk descriptions have, in some contexts, prompted stronger protective responses than visualizations, particularly among viewers with lower graph literacy (Matzen et al., 2024). Visualizations may need pairing with plain language guidance for Basic users, while Intermediate and Advanced users may benefit more directly from the spatial visualization itself. In **Tier 3**, Advanced users could access underlying observation data (e.g., a map of snowpack observations) to judge uncertainty themselves, with brief notes on why some zones remain low on data.

Takeaway: This uncertainty is relevant to all users, but actionable only by users with sufficient terrain-reading and field observation skills. The forecast must communicate the same uncertainty differently depending on whether the user can act on it or simply needs to be aware of it. Spatial/graphical encoding in Tier 2 could be paired with plain language guidance for users who may not be able to interpret the visualization alone.

3.4 Example 4: Existing uncertainty communication product

Avalanche Canada (2023) and the New Zealand Avalanche Advisory (NZAA, 2026) both publish forecaster confidence statements, which can shape how users interpret accompanying information by signaling how much weight to place on the expected outcome (Padilla et al., 2021). Each statement indicates a confidence level (low, moderate, or high) reflecting the strength of available evidence, with bullets describing that evidence (NZAA, 2026). Though not labeled as "uncertainty" statements, low/moderate confidence speaks directly to condition uncertainty, and the bullets describe its sources.

The confidence statements have different placements in the forecasts of the two warning services. Avalanche Canada positions its confidence statement in **Tier 3**, but for example during deep slab conditions, supplements it with **Tier 1** messaging. For example, a headline reading "There is a lot of uncertainty with the reactivity of deeply buried weak layers" is paired with the Tier 3 statement: "Moderate confidence. Uncertainty is due to the complexity of the snowpack's structure" (Avalanche Canada, 2023). This also reflects format choices: plain language framing at the headline level is paired with structured detail for users who seek it out. Having a consistent uncertainty messaging across the tiers can increase the effectiveness if it is designed to fit at the specific location.

NZAA places its confidence statement in **Tier 1** by default, reaching all users and framing the rest of the forecast as warranting a more cautious interpretation (Padilla et al., 2021). This matches more directly with the goal of raising broad awareness rather than reserving it for users who read as far as Tier 3.

Takeaway: Two operational products already explicitly communicate uncertainty through confidence statements but differ in tier placement. This is an established illustration of Question 3, where Tier 1 placement more directly serves broad-awareness intent than a Tier 3-only default. Avalanche Canada's layered pairing of headline and structured detail illustrates Question 4, showing that format can vary by tier within a single product.

4. MAIN INSIGHTS

Together, these four situations show that no single answer to the four critical questions applies uniformly across uncertainty types.

Relevance was consistent across all three hypothetical situations: storm-snow, deep-slab, and spatial weak-layer uncertainty were each decision-relevant to every user, regardless of experience. What varied was actionability. Storm snow guidance could be applied by any user through a simple threshold. Deep slab guidance narrowed to avoidance for most users, since reliable field evidence to rule out the hazard is difficult to obtain. Spatial weak layer guidance scaled with training, from awareness-level messaging for Basic users to direct verification for Advanced users alone.

Reducibility shapes tone and directness. Storm-snow uncertainty can be resolved through field observation and translated into a measurable conditional threshold, while deep-slab uncertainty is largely irreducible, warranting direct, precautionary guidance rather than detailed explanation.

Placement follows relevance and severity, not a fixed rule. Uncertainty that is broadly relevant and highly consequential is pushed into Tier 1 regardless of its usual depth in the forecast structure, as seen in the deep-slab example and in NZAA's default placement of its confidence statement. Uncertainty that is more selectively actionable, such as spatial distribution, is better suited to deeper tiers paired with plain-language support for users who cannot fully interpret or apply it.

Format follows the nature of the uncertainty, not convention. Conditional if–then statements suit measurable thresholds; narrative formats suit complex or irreducible situations that exceed the explanatory capacity of standard forecast elements; spatial-graphical formats suit uncertainty with a geographic dimension, though their effectiveness depends on the user's ability to read them.

Finally, **knowledge** does not always resolve into **action**. In the deep-slab and confidence statement examples, forecasters could communicate what they know without offering differentiated action beyond broad avoidance or awareness, perhaps sharing "forecaster mindset". This suggests that some uncertainty is best communicated as input to users' judgment rather than as a specific instruction.

5. RECOMMENDATIONS

Our explorations point to five concrete recommendations for how avalanche warning services can adapt uncertainty communication to the situation at hand.

1. Match tactics to reducibility. Reducible uncertainty, such as storm-snow accumulation, is already well served: forecasters use low-friction, accessible strategies, such as conditional thresholds and familiar icons, across tiers. Irreducible, high-consequence uncertainty, such as deep slab instability, is not. These events are rare and hard to comprehend, and the gap is a lack of standard front-loaded messaging for this case. We recommend that forecasters treat irreducibility itself as a trigger for pushing awareness, precaution, and avoidance guidance into Tier 1, so the uncertainty frames the rest of the forecast rather than waiting to be discovered in deeper tiers.

2. Place high-impact uncertainty where users will see it. Confidence statements show both the promise and the risk of placement choices. Avalanche Canada has used them consistently since 2008, but positions them at the end of the forecast, where only about a third of users scroll (Nowak et al., 2026). New Zealand's newly adopted statement sits at the front, reaching all user types by default. We recommend that decision-relevant confidence or uncertainty statements default to early placement, reserving deeper-tier placement for uncertainty that is genuinely lower-stakes or user-specific.

3. Tailor depth to user capacity, not just topic. Not all uncertainty needs to reach every user at the same depth. The spatial weak layer example showed that placing detailed information in deeper tiers keeps the core hazard message uncluttered for less experienced users, without withholding it from those who can act on it. The gap is that this kind of placement decision is currently made ad hoc. We recommend that the avalanche warning service decide on operational criteria on when, how, and to whom particular uncertainty content should be published. That would ensure that choices are consistent across forecasters and forecast days.

4. Build in flexibility for day-to-day variability. Uncertainty's importance shifts daily, from negligible to requiring focused caution, but a static forecast format struggles to reflect that shift. We recommend intermittent or transient visual elements, cues that appear only when uncertainty is elevated, to raise salience without permanently adding content to the product on routine days.

5. Use complementary channels for complex context. Users respond well to the overall forecast signal (Mannberg et al., 2026), but the concise, technical daily format has limited room for complex or contextual explanation. We recommend forecasters use longer-form or mixed-media channels (e.g. blog posts and videos) deliberately and specifically for elevated-uncertainty situations, rather than as an ad hoc addition. These channels can also distill the situation into a direct, simple message for Basic or infrequent users; social media offers a way to reach people who may not visit the forecast website at all.

Together, these recommendations embody the principles established in the synthesis. Uncertainty communication should be adapted, in content, placement, depth, salience, and channel, to the nature of the uncertainty and the user's capacity to act on it, rather than treated as a fixed forecast element.

These recommendations are offered with few scoping considerations. Our explorations rely on deliberately coarse categories, such as user types and communication needs, to make a high level of abstraction around uncertainty practically workable, even though these concepts exist on a continuum. Grounded primarily in North American public avalanche forecasting, the approach is intended as a tool for reflection and evaluation rather than a validated set of interventions, and its conclusions may not transfer directly to other regions without further empirical testing.

6. CONCLUSION

Uncertainty is a fundamental component in all avalanche risk management yet avalanche warning services currently do not communicate it to their forecast users consistently. To address the communication challenge, we examined the nature of uncertainty, who it matters to, and how the forecast can support users' information seeking and decision-making under conditions of elevated uncertainty using four common public forecasting examples.

Across the analyzed situations, relevance, reducibility, and user capacity varied independently of one another, meaning no single uncertainty type followed the same communication path. Broadly relevant, highly consequential, or irreducible uncertainty, such as deep-slab instability, warranted direct messaging pushed into Tier 1, while narrowly relevant uncertainty, such as spatial weak-layer distribution, was better suited to deeper tiers paired with plain-language support. Existing operational products already reflect this variability in practice, as seen in the differing tier placement of confidence statements between Avalanche Canada and the New Zealand Avalanche Advisory.

Our reflections highlight that uncertainty communication should not be treated as a fixed component of the forecast. Its salience, placement, content, and format should be considered according to the type of uncertainty, its consequences, its relevance to decisions, and users' capacity to respond. This argues for operational guidance that helps forecasters determine when uncertainty should remain in deeper forecast tiers; when it should be brought forward as a cautionary frame; and when complementary communication channels are needed.

As a final step in our research project, we are using think-aloud sessions to examine how backcountry users interpret, navigate, and apply revised forecast products grounded in these considerations. This phase focuses on validating use processes and communication effects, particularly users' awareness, comprehension, and application of uncertainty information as they read the forecast for their typical risk-management needs.

ACKNOWLEDGEMENTS

We are grateful to the Coast Salish peoples on whose traditional and unceded territories Simon Fraser University and our research program reside. We thank the members of the SFU Avalanche Research Program who contributed to our thinking. We used ChatGPT 5.6 for copy-editing and grammar suggestions during the final drafting phase. The authors conducted all substantive analysis and editorial decisions exclusively. We are grateful to the Colorado Avalanche Information Center for funding this research.

REFERENCES

Avalanche Canada: Archived avalanche forecast for 27 January 2023, https://avalanche.ca/forecasts/archive/2023-01-27?lat=50.727313&lng=-117.527502, last access: 25 August 2026.

Beven, K. J., et al..: Epistemic uncertainties and natural hazard risk assessment – Part 2: What should constitute good practice?, Nat. Hazards Earth Syst. Sci., 18, 2769–2783, https://doi.org/10.5194/nhess-18-2769-2018, 2018.

Campbell, C., et al..: Technical Aspects of Snow and Avalanche Risk Management, Canadian Avalanche Association, Revelstoke, B.C., Canada, 2016.

Dallo, I., Stauffacher, M., and Marti, M.: Actionable and understandable? Evidence-based recommendations for the design of (multi-)hazard warning messages, International Journal of Disaster Risk Reduction, 74, 102917, https://doi.org/10.1016/j.ijdrr.2022.102917, 2022.

Doyle, E. E. H., Johnston, D. M., Smith, R., and Paton, D.: Communicating model uncertainty for natural hazards: A qualitative systematic thematic review, International Journal of Disaster Risk Reduction, 33, 449–476, https://doi.org/10.1016/j.ijdrr.2018.10.023, 2019.

EAWS: Information pyramid, European Avalanche Warning Services, https://www.avalanches.org/standards/information-pyramid/, last access: 19 August 2026.

Engeset, R. V., Pfuhl, G., Landrø, M., Mannberg, A., and Hetland, A.: Communicating public avalanche warnings – what works?, Nat. Hazards Earth Syst. Sci., 18, 2537–2559, https://doi.org/10.5194/nhess-18-2537-2018, 2018.

Fisher, K. C., Haegeli, P., and Mair, P.: Impact of information presentation on interpretability of spatial hazard information: lessons from a study in avalanche safety, Nat. Hazards Earth Syst. Sci., 21, 3219–3242, https://doi.org/10.5194/nhess-21-3219-2021, 2021.

Fisher, K. C., Haegeli, P., and Mair, P.: Exploring the avalanche bulletin as an avenue for continuing education by including learning interventions, Journal of Outdoor Recreation and Tourism 37, 100472, https://doi.org/10.1016/j.jort.2021.100472, 2022a.

Fisher, K. C., Haegeli, P., and Mair, P.: Travel and terrain advice statements in public avalanche bulletins: a quantitative analysis of who uses this information, what makes it useful, and how it can be improved for users, Nat. Hazards Earth Syst. Sci., 22, 1973–2000, https://doi.org/10.5194/nhess-22-1973-2022, 2022b.

Gollwitzer, P. M. and Sheeran, P.: Implementation Intentions and Goal Achievement: A Meta-analysis of Effects and Processes, in: Advances in Experimental Social Psychology, vol. 38, Elsevier, 69–119, https://doi.org/10.1016/S0065-2601(06)38002-1, 2006.

Korporaal, M., Ruginski, I. T., and Fabrikant, S. I.: Effects of Uncertainty Visualization on Map-Based Decision Making Under Time Pressure, Front. Comput. Sci., 2, 32, https://doi.org/10.3389/fcomp.2020.00032, 2020.

Kriebel, D., et al..: The precautionary principle in environmental science., Environmental Health Perspectives, 109, 871–876, https://doi.org/10.1289/ehp.01109871, 2001.

Latosuo, E., Haegeli, P., Demuth, J., Greene, E.: User's awareness and response to uncertainty information in public avalanche forecasts, in: Proceedings International Snow Science Workshop, International Snow Science Workshop, 2024.

Latosuo, E., et al.: Grey Zones – Examining Forecasters' Practices and Perspective for Communicating Uncertainty in Public Avalanche Forecasts, in: Proceedings International Snow Science Workshop, International Snow Science Workshop, 2026.

Lindell, M. K. and Perry, R. W.: The Protective Action Decision Model: Theoretical Modifications and Additional Evidence:Risk Analysis, 32, 616–632, https://doi.org/10.1111/j.1539-6924.2011.01647.x, 2012.

Mannberg, A., Toft, H. B., Stefan, M. A., Aase, M. J., and Hetland, A.: Do backcountry skiers react to the avalanche forecast? Measuring avalanche terrain exposure using a continuous score, Cold Reg. Sci. Technol. , 251, 105039, https://doi.org/10.1016/j.coldregions.2026.105039, 2026.

Matzen, L. E., Howell, B. C., Tuft, M., and Divis, K. M.: Transparent Risks: The Impact of the Specificity and Visual Encoding of Uncertainty on Decision Making, Computer Graphics Forum, 43, e15094, https://doi.org/10.1111/cgf.15094, 2024.

New Zealand Avalanche Advisory: Avalanche forecasts, https://www.avalanche.net.nz/, last access: 25Aug 2026.

Nowak, S., Rigby, N., Latosuo, E., Haegeli, P.: How do people read the forecast? Two seasons of section-level digital analytics in Canada, in: Proceedings International Snow Science Workshop, International Snow Science Workshop, 2026.

Padilla, L. M. K., Powell, M., Kay, M., and Hullman, J.: Uncertain About Uncertainty: How Qualitative Expressions of Forecaster Confidence Impact Decision-Making With Uncertainty Visualizations, Front. Psychol., 11, 579267, https://doi.org/10.3389/fpsyg.2020.579267, 2021.

Siegel, Z. S. and Kulp, S. A.: Superimposing height-controllable and animated flood surfaces into street-level photographs for risk communication, Weather Clim. Extrem., 32, 100311, https://doi.org/10.1016/j.wace.2021.100311

Sillmann, J., et al..: Event-Based Storylines to Address Climate Risk, Earth's Future, 9, e2020EF001783, https://doi.org/10.1029/2020EF001783, 2021.

Skille, T. T., Dassler, T., and Boilen, S.: Building a shared vocabulary: toward a typology for the human factor in avalanche terrain, J. Outdoor Recreat. Tour., 53, 100997, https://doi.org/10.1016/j.jort.2025.100997, 2026.

Statham, G., et al..: A conceptual model of avalanche hazard, Nat Hazards, 90, 663–691, https://doi.org/10.1007/s11069-017-3070-5, 2018.

St. Clair, A., Finn, H., and Haegeli, P.: Where the rubber of the RISP model meets the road: Contextualizing risk information seeking and processing with an avalanche bulletin user typology, Int. J. Disaster Risk Reduct. , 66, 102626, https://doi.org/10.1016/j.ijdrr.2021.102626,2021.

St. Clair, A. and Haegeli, P.: Toward improved effectiveness of public avalanche safety services: A framework for asking constructive questions, in: Proceedings of International Snow Science Workshop, International Snow Science Workshop, 2023.

Sykes, J. and Atkins, R.: Characterising the 2023 season, Canadian Avalanche Association Spring Conference, Penticton, BC, Canada, May 2, 2023.

Waugh, N., Sutton, J., Fischer, L., and Orton, G.: What does it mean to stand out? How visual design and presentation affect attention and memory in a warning message, Weather, Climate, and Society, 17, 79–99, https://doi.org/10.1175/WCAS-D-23-0140.1