GREY ZONES – EXAMINING FORECASTERS' PRACTICES AND PERSPECTIVES FOR COMMUNICATING UNCERTAINTY IN PUBLIC AVALANCHE FORECASTS

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

[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] *Colorado Avalanche Information Center, Boulder, CO, USA*

ABSTRACT: Uncertainty is inherent in avalanche forecasting, yet it is not communicated in a consistent way in public avalanche forecasts. Avalanche forecast users could benefit from clearer and more transparent communication of uncertainty. Developing a systematic approach for communicating uncertainty has potential to enhance the forecast in ways that are useful to a diverse range of forecast users with differing needs.

Complementing the results from our survey examining the perspective of forecast users (Latosuo et al., 2024), this research focuses on how avalanche forecasters conceptualize and evaluate uncertainty. An in-depth understanding of forecasters' current practices and challenges is critical for developing effective and feasible ways to communicate uncertainty when it is a consequential part of the conditions. To address this research need, we conducted qualitative semi-structured interviews with 30 North American avalanche forecasters in the spring 2025. Additionally, we observed numerous forecast team meetings to learn about the specific workflow and communication cultures of participating organizations.

Our findings highlight that forecasters carry out nuanced daily examinations of uncertainty, and this information plays a fundamental role in internal conversations of the forecasting team. Spatial and temporal scales matter; large forecast regions amplify spatial uncertainty, while publishing lead times affect forecasters' certainty about their assessment. The type of avalanche problems adds to the inherent uncertainty in the hazard condition, as do operational constraints and the influence of fatigue or stress on forecasters. Certain conditions prompt explicit uncertainty messaging in the forecasts; however, how forecasters implement the messaging varies considerably.

This research offers valuable insight into professional forecasters' perspective on uncertainty and the challenging trade-offs forecasters juggle when creating forecast products for diverse audiences. Our results inform the broader goal of designing an improved uncertainty communication framework. The lessons learned are applicable to all avalanche practitioners who communicate hazard conditions to non-expert audiences.

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

1. INTRODUCTION

> *"You have to be okay with uncertainty first off; that's a ground rule. If you're not okay guessing, it's impossible to say, is it safe or unsafe. It's a very difficult thing to find black and white in this environment. You also have to be okay with encouraging people to go. Otherwise, they're not going to buy into the avalanche forecast." (Forecaster 34)*

Uncertainty is inherent in avalanche forecasting, yet it is not communicated in a consistent way in public avalanche forecasts. In our previous survey study on avalanche forecast users' perspective on uncertainty, we learned that explicitly including uncertainty information has a significant impact on the reader's estimated amount of uncertainty in the conditions and influences their decisions to enter the backcountry (Latosuo et al., 2024). Given that explicit uncertainty communication shapes how forecast users perceive risk, could more structured guidance help forecasters communicate that uncertainty more effectively?

Forecasters play a key role in identifying the important uncertainties and pointing them out in the published forecast products. In North America, public backcountry avalanche forecasters use the Conceptual Model of Avalanche Hazard (CMAH; Statham et al., 2018) workflow to produce risk communication products for recreationists. CMAH addresses uncertainty mostly in broad terms, stating that it is "an essential element to

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

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recognize and communicate." More concretely, the CMAH anchors uncertainty in the ranges of likelihood and size assigned to each avalanche problem, visualized by the size and shape of rectangles in the avalanche hazard chart. These "bubbles" are also incorporated in the InfoEx data-sharing platform used widely in the industry (Haegeli et al., 2014).

Yet uncertainty in avalanche forecasting extends beyond these ranges of values. Additional contributing factors, such as a lack of observations or the unknown timing of peak hazard, shape forecasters' overall confidence in an assessment but are not captured by the CMAH's framework. We were interested in how avalanche forecasters map out these less formalized sources of uncertainty in their practical assessment process.

In the absence of systematic guidelines related to uncertainty, forecasters take a variety of approaches depending on their operational scale and work procedures. This study investigates current practices among forecasters through the following research questions: 1. How do avalanche forecasters assess different sources and magnitude of uncertainty when producing forecasts? 2. What conditions and characteristics of the avalanche hazard warrant the inclusion of uncertainty information in the public forecasting products? 3. What are the current practices for sharing uncertainty information in the forecasts? 4. What are the barriers and opportunities for uncertainty information in forecasting products?

Knowing the current baseline of how avalanche forecasters evaluate uncertainty and how they disclose it to their audience can guide future solutions to this communication challenge.

2. METHODS AND MATERIALS

To examine our research question, this project used qualitative social science research methods guided by a pragmatic paradigm to learn directly from professional avalanche forecasters in their real work environment. We chose semi-structured interviews as our main data collection tool, since they have latitude to explore emerging topics of conversation, a good fit for a complex topic such as uncertainty.

2.1 Participating agencies

Our research partners were Colorado Avalanche Information Center and Avalanche Canada. These agencies share key workflows and technical features (Helgeson et al., 2023) yet vary in distinct ways giving us a broad perspective into our research question.

Colorado Avalanche Information Center (CAIC) is a state program that provides avalanche forecasts for people traveling in and through Colorado's mountains. CAIC forecasting teams work in three geographically bounded teams, and forecasters, who live in their respective zones, participate in office and field-based forecasting tasks to produce daily forecasts. CAIC operates in a continental snow climate that commonly harbors complex snowpack properties that are difficult to predict.

Avalanche Canada (AvCan) is a not-for-profit, non-government avalanche safety organization that provides avalanche forecasts across a range of regions within Canada. AvCan's forecasting area is the largest in the world, covering 300,000 km². AvCan uses an office-based forecasting strategy that allows forecasters to create products for any region across the vast operational area, spanning three different snow climates.

2.2 Data collection

Data collection had three components: interviews, meeting observations, and operational document review. Most information was gathered through semi-structured interviews following a protocol reviewed and approved by the Office for Research Ethics of Simon Fraser University. The protocol had three sections: how forecasters conceptualize and assess uncertainty; how forecasters communicate uncertainty in the forecast product; and new ideas for improving uncertainty communication. All public backcountry forecasting staff at both agencies were invited to participate; 30 CAIC and AvCan forecasters were interviewed in person or online in spring 2025, with interviews lasting 70-240 minutes each. Otter.ai generated initial transcripts, which were subsequently reviewed and corrected against audio recordings for accuracy.

We also attended forecaster team meetings regularly over a two-month period to gain a deeper understanding of work procedures and workplace culture, and examined each organization's operational documents (AvCan, 2025; CAIC, 2025; NAC, 2025) alongside daily and archived forecast products referenced in the interviews.

2.3 Analysis approach

We adopted the reflexive thematic analysis framework (Braun and Clarke, 2022) as a structured yet flexible approach for identifying and interpreting patterns of meaning in the data. During familiarization, we wrote reflexive notes for each interview while cleaning transcripts over several rounds of listening, following established practices.

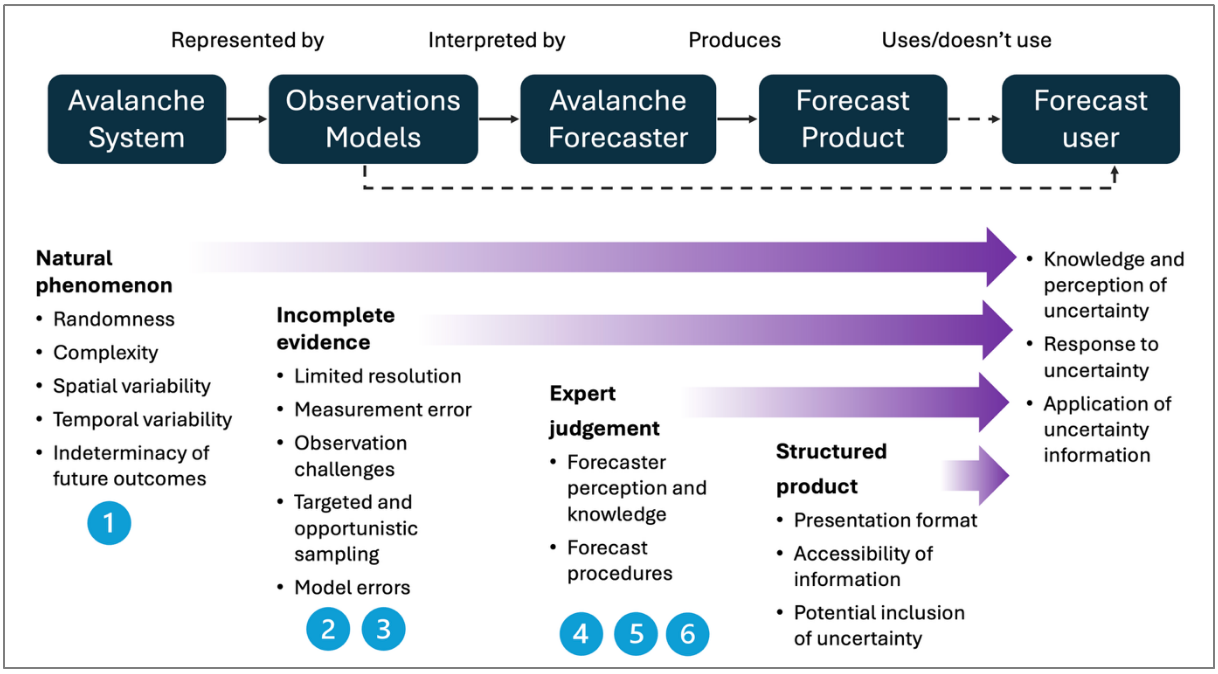

Figure 1. Sources of uncertainty in avalanche forecasting process. Purple arrows show the accumulation of uncertainty over the process. The numbered circles correlate with the bold headings in Section 3.1, for example Avalanche problem types (1) the blue circle with 1 originates in Avalanche system.

Coding began with semantic codes drawn from the interview protocol and progressed toward latent codes; recurring concepts were organized into the themes presented below (Saldaña, 2021). We triangulated interview findings against meeting observations and operational documents.

3. RESULTS

The results section follows the interview protocol. We first share insights about how forecasters assess uncertainty, followed by how they communicate it using both text-based and visual elements. Results include illustrative quotes from both Coloradan and Canadian interviewees; randomized identifying codes reference individual forecasters to protect confidentiality.

The findings also relate to the whole forecast production process (Fig. 1). The assessment section follows steps between the System and the Forecaster; the communication section focuses on the Forecast Product. Forecasters consider Forecast Users when creating the Forecast Product, an important theme throughout many conversations.

3.1 *Factors affecting uncertainty in the hazard assessment process*

Our analysis highlights that forecasters conduct nuanced daily assessments of uncertainty, considering the completeness and reliability of available data and their confidence in the spatial and temporal distribution of avalanche hazard. We also observed that forecasting teams discuss uncertainty in almost every meeting, even when it does not warrant emphasis on that day's published forecast.

Avalanche problem types (1)

Inherent uncertainty in avalanche hazard varies by snowpack characteristics categorized as avalanche problems (Statham et al., 2018). The primary source of elevated uncertainty was the persistent slab problem. As a mid-snowpack problem, the exact distribution of the problematic layer is difficult to know, and field evidence about its sensitivity can be hard to collect.

"I'm very biased, but continental snowpack persistent slab problems are tricky. It's one of the harder avalanche problems to forecast for because the timing and the behavior don't always line up. It's good to voice the uncertainty around it." (Forecaster 4)

When persistent slab develops into deep persistent slab, forecasters worry about latent hazard hiding its clues; remote triggering and delayed activity add further surprise. In guidance documents (Statham et al., 2018; CAIC, 2024; NAC, 2025), this low-likelihood, severe-consequence situation often corresponds with a moderate danger rating - a mismatch, in many forecasters' minds, with the actual hazard people must negotiate. Some forecasters lean into travel-advice descriptors and select a more conservative rating to better convey their concern.

"Basically, we're saying, in not so many words, we don't know if it's gonna avalanche, but the consequences are high if it does, so you should watch out. The message is to use that uncertainty to make firm decisions of avoiding those slopes." (Forecaster 7)

These conditions can go dormant for a lengthy period, so forecasters feel their assessment repeats day after day even while concerned that the next active cycle could start and surprise them. Wet slab hazard poses a related but compressed-timeline challenge: there is rarely enough field data on free water content, the main driver of wet slab problems (Mitterer & Schweizer, 2013), and timing is highly aspect-, elevation-, and microclimate-specific. All the details make it difficult to describe concisely in a regional forecast.

"The uncertainty around wet slabs is that it takes a unique set of factors. It's not as straightforward as there's a slab over a weak layer. Midwinter wet slab is not as simple or cut and dry." (Forecaster 16)

Weather forecast related uncertainty (2)

All forecasters mentioned weather-related uncertainty as a routine challenge. Weather models can disagree on the location, timing, and amount of precipitation and wind, and the longer a storm lasts, the more uncertainty accumulates as observational data lags behind.

"It is challenging because you're forecasting 24-48 hours out. Any uncertainty in the weather is then amplified in the uncertainty in the outlined forecast and how things may change as we're laying out our products." (Forecaster 1)

Forecasters use weather thresholds (precipitation amounts, temperature changes) to move between danger ratings. This practice requires local knowledge that takes newer forecasters time to develop.

"An inch of water in Summit County is a lot no matter what the snowpack is, but at Wolf Creek Pass, an inch of water could be nothing… It's such a stab in the dark." (Forecaster 7)

Uncertainty due to limited observations (3)

Forecasters feel more certain when they have robust amount of higher-quality avalanche, weather, and snowpack observations as their evidence; remote automated weather station density also affects available evidence. Missing observations were most common in remote regions, long storm cycles, and early-season conditions that restrict travel. AvCan's office-based assessment of large regions involves different observational uncertainty than Colorado's smaller, field-based zones; AvCan forecasters rely heavily on field team technicians and the InfoEx platform.

"The first few bulletins you're putting out for a data sparse area with no field team, it could be anything, I just don't know." (Forecaster 24)

Intermediate danger levels (4)

Uncertainty is most prominent during intermediate hazard conditions, since low and high danger ratings have clearer boundary conditions (Statham et al., 2010); there is simply more variation within moderate or considerable danger. Forecasters use informal subclasses internally (e.g., "spicy moderate," level 2.8) that do not transfer into public ratings in North America, unlike European services that use sublevel qualifiers (Techel et al., 2022).

"That spooky moderate stuff is so difficult for us… People see yellow, and they think that's one step up from green, and it's fine. Yellow, moderate includes deadly avalanches that are unlikely. It's just such a hard place to be." (Forecaster 6)

Several interviewees also noted that one of the most difficult forecasting decisions is to drop the danger rating. Forecasters have observed that backcountry users behave very differently once the danger drops, so they want to be very certain before moving to low danger.

"I'm more comfortable making a step from considerable to moderate and having some uncertainty about whether it's likely or possible, but moving from possible to unlikely is a different threshold. For us to go green, we should be confident." (Forecaster 11)

Work system constraints (5)

Daily work procedures and environment also shape uncertainty assessment. Publishing time plays a role. CAIC and AvCan publish each afternoon for the following day, creating a 12-hour lag during which conditions can change, and more field observations often arrive after posting. Agencies have systems to revise the forecast when needed, for example, the morning forecaster reviews the previous day's threshold notes and regional observations to determine if the danger rating should be elevated. Uncertainty also increases when a forecaster returns from a break, since the return to shift often means sticking with the previous forecaster's interpretation until their own mental model updates, which often takes a day. Limited resources and time pressure add further strain; the number of forecast products one person can complete per shift is capped, and this has become more relevant as the number of forecast zones fluctuates daily with flexible forecasting polygons.

“There’s a clear human bias around how many zones I am able and willing to take on a day. Around five is kind of max, there’s been days when I’ve done seven or eight and it’s so hard to get done.” (Forecaster 11)

Fatigue, stress, and cognitive workload (6)

Exhaustion and pressure affect both decision quality and forecasters’ capacity to cope with uncertainty. The season is long and includes intense periods causing cumulative fatigue. Several forecasters described difficulty disconnecting even off duty, and fatigue builds further during long, dynamic storm cycles.

“As the storm continues, you have a few things that go against you, and your data is not as good anymore. Your decision making is not as good anymore. You are tired.” (Forecaster 25)

Weariness can also follow a significant avalanche event, as accident investigations add workload and, at times, real emotional toll, especially when forecasters are part of the impacted community. Cognitive workload is a related factor, particularly for newer forecasters and less familiar zones. New forecasters work harder to be certain, experienced forecasters can draw more confidence from recognizing patterns across past seasons.

3.2 Current approaches to uncertainty communication

“We have pressure to serve the user and to not be wrong, because the consequences of being wrong are pretty high, which is why we are conservative [in the forecast]. That’s our only time to influence someone […] one chance to influence people’s behavior.” (Forecaster 22)

While uncertainty assessment is integral to forecast teams’ daily conversations, this internal evaluation does not necessarily result in explicit communication to users. Our interviews revealed that forecasters struggle to determine when communicating uncertainty benefits users, and judgments about its relevance vary considerably across agencies and individuals.

Text-based elements

The Headline (or forecast summary, in Colorado) is considered the most critical message in the product, so forecasters use it sparingly for uncertainty, worried about diluting the main hazard message. Uncertainty here is often tied to weather. Terrain and Travel Advice is used more directly to translate uncertainty into a terrain decision, e.g., “These are tricky conditions, stick to simple terrain.”

If-then statements are a routine tool for explaining conditional risk, giving readers tangible thresholds to track and doubling as internal guidance for morning updates.

“The if-then statements are always a go-to tool. If you see this, then do this. That provides actionable advice about the uncertainty we’re talking about.” (Forecaster 9)

Narrative-based, longer-format writing can also make uncertain conditions more relatable than technical language allows.

“I sometimes rely on stories from my past. There was an example this year, where I wrote in the forecast discussion how I haven’t seen spooky conditions like this since 2021…” (Forecaster 9)

CAIC forecasters have fewer character restrictions but follow strong stylistic guidance. Some mentioned using field reports and photo captions creatively to add content that doesn’t fit elsewhere. AvCan maintains a concise, standardized style with limited character counts. This increases consistency but leaves little room to explain complex or long-lasting conditions.

“We’re in this period with Avalanche Canada, where we’re trying to condense our forecast product and make it quite short and succinct… but we’re losing the ability to give context and background to our forecast.” (Forecaster 2)

AvCan also publishes longer-format blog posts with additional context and case studies, though forecasters wonder how widely they are read.

AvCan was the first avalanche warning service globally to include confidence statements in public forecasts, in 2008; the practice is also integrated into InfoEx (Haegeli et al., 2014), AvCan’s main data source. Forecasters rate overall confidence (low, moderate, high) and select bulleted sources of uncertainty from 42 predetermined statements. They value this feature but admit they most often choose the middle rating, a less distinct signal than low or high.

“There’s a direct correlation between the confidence statement and the extent to which the public needs to verify conditions. The vast majority of days, somewhere between 80 and 90%, are moderate. […] I’m hoping the public reads that and they know that there is an onus on them to verify conditions.” (Forecaster 23)

Canadian forecasters value the rationale bullets even more than the overall rating, but the primary drawback identified was placement. The confidence statement sits at the end of the forecast, where users may miss it, and several forecasters suggested moving it directly below the headline or danger rating so it can prime cautious reading of everything that follows.

Visual elements

Danger-rating maps are the entry point to every product but carry no indication of uncertainty. Both AvCan and CAIC use dynamic forecast regions, where polygon size shifts with the distribution of the danger rating (Buhler et al., 2023); CAIC forecasters use smaller polygons to signal better-understood, more certain conditions, and larger polygons to signal the opposite.

"Our original idea of showing the outline of the polygons was really to communicate uncertainty to people. The bigger the area that they see, the more they're going to realize that our uncertainty is at high level." (Forecaster 32)

However, it is unclear whether users notice this implication, since polygons change daily with no easy way to track the shift.

The main visual uncertainty elements are the likelihood and size graphics for each avalanche problem, which can show a range instead of a point value. Forecasters noted that the size scale reads as roughly linear even though the underlying steps are exponential, a misinterpretation problem consistent with prior risk-communication research (Morgan et al., 2023). They also note that these graphics do not fully capture potential consequences. Forecasters increasingly pair text and graphics with photos and video of representative avalanches to ground the scale in the real world.

> *"If I write three paragraphs, people aren't going to chew through the three paragraphs, but if I put an image and I put a sentence or two sentences, then it's going to convey that uncertainty in that message." (Forecaster 30)*

4. UNCERTAINTY COMMUNICATION CHALLENGES AND OPPORTUNITIES

Our findings point to a forecaster who is never simply assessing a hazard or issuing a product in isolation, but who is embedded in a web of relationships, with the hazard, the forecast product, and the people who rely on it (St.Clair and Haegeli, 2023). These relationships shape how uncertainty is understood and expressed. Viewed this way, the tensions identified across these relationships emerge as different expressions of a single underlying trade-off: standardized clarity versus contextual richness. The sections below trace that trade-off from its origin in how forecasters assess the hazard, through its translation into a published product, to its reception by a diverse audience.

Forecaster ↔ Hazard

Uncertainty in an avalanche forecast does not originate at a single point. It accumulates and transforms as it moves through the system, from physical process to published product (Fig. 1), and this pipeline is central to answering RQ1: forecasters manage several distinct sources that compound as they pass from the hazard itself, through observations and models, to the forecaster's own judgment.

The first source is the natural phenomenon: avalanche hazard is inherently random and variable in space and time, and future outcomes are indeterminate regardless of evidence. The irreducible uncertainty is most visible in persistent and deep persistent slab problems, whose randomness resists direct observation regardless of forecaster skill.

The second source is incomplete evidence, the gap between the hazard and what forecasters can actually observe. Limited observation density, measurement error, and necessarily opportunistic field sampling leave gaps that must be filled with judgment. This is where weather-related uncertainty and limited-observation findings belong: both describe forecasters reasoning from partial evidence toward a full regional picture.

The third source is expert judgment itself. Even with identical evidence, forecaster perception and experience introduce variance, a bias rooted in professional identity as much as in the conditions themselves. Forecasting is inherently collaborative, and colleagues routinely challenge one another's interpretations, but that collaborative check bounds individual variance rather than eliminates it. This variance shows up in how intermediate danger levels get negotiated internally ("spicy moderate") and in how work system constraints - publishing lag, shift transitions, workload, fatigue - shape the conditions under which judgment is exercised. Notably, this is the one source of uncertainty that is not a property of the hazard at all, but of the human system built around interpreting it.

These three sources do not stay separate; each is filtered through the forecaster's judgment and carried forward into the structured product, where uncertainty either survives translation into something the user can act on, or is lost to format constraints.

Forecaster ↔ Product

Translating hazard understanding into a publishable product is where uncertainty runs up against format. Production follows shared organizational procedures (Statham et al., 2018; CAIC, 2024; NAC, 2025; AvCan, 2025) but the final product is still shaped by the individual forecaster. Most barriers (RQ4) identified in our interviews arose during the translation step rather than the assessment step.

The core tension is between standardized clarity and contextual richness. Character limits, fixed templates, and predetermined statement menus support consistency, but constrain where and how nuance can be expressed. Notably, AvCan forecasters expressed how well the predetermined confidence statement bullets worked to explain their rationale most of the time. Many forecasters shared about times when they knew what they wanted to say about uncertainty without having a clear place to put it. This is a structural barrier, not a stylistic inconvenience (RQ3, RQ4).

Two findings illustrate the mismatch between current tools and forecaster intent. Avalanche size graphics are read as roughly linear when the underlying scale is exponential (Morgan et al., 2023), understating the range of potential consequences forecasters are trying to convey. In Canada, the confidence statement, the one product element built explicitly for uncertainty, is placed at the end of the forecast rather than where it could prime how the rest is read. Forecasters repeatedly suggested moving it beneath the headline instead. Both point to the same opportunity (RQ4): existing tools could be re-evaluated with uncertainty in mind, so that uncertainty-relevant information would end up where it would have the most impact.

Forecaster ↔ People

If the product relationship is about what the format allows, the people relationship is about what the message is for. Forecasters do not treat uncertainty communication as an end in itself; rather, uncertainty is communicated in service of a strategic mindset, an operational stance combining hazard assessment with attitude (Atkins, 2014). The goal is not for users to know the forecast is uncertain, but for that uncertainty to change how they behave. Several forecasters described this as cultivating a “cautious mindset” in the reader. This reframes RQ2 and RQ3 together: uncertainty is judged relevant to include not when it is technically there, but when it requires specific attention or action from the user.

That framing runs directly into an experience/accessibility tension. Acting on a strategic mindset requires the reader to actively verify and reassess conditions, assuming a skill level many users lack. Experienced users absorb uncertainty into their own judgment, as one forecaster described: *“I need to have conservative route and decision-making points and good partners and use that uncertainty during the day… I assess carefully on a slope scale” (Forecaster 26)*. Novice users, by contrast, need direct, sometimes blunt guidance (“avoid avalanche terrain altogether”) even when the danger rating itself would not obviously call for it, but uncertainty does.

This split is the practical core of the barriers and opportunities: a single product is asked to cultivate a mindset in experienced users while issuing directives to novices, using the same words, in the same space. The current tiered forecast structure has no explicit channel for matching uncertainty communication to what a given user can actually do with it.

5. LIMITATIONS

Our research included interviews of 30 public backcountry avalanche forecasters from two avalanche warning services in North America. While we examined in depth how these forecasters approach uncertainty in their work, our sample was limited and may not capture the full range of practices across forecasting organizations. For example, European forecasters could have a very different perspective on the challenges of uncertainty due to smaller forecasting regions, robust remote telemetry networks, and available output from snowpack modeling.

As with all interview-based research, participant recall, social desirability, interviewer effects, and researcher interpretation could influence our findings. Forecasters’ accounts represent their perceptions and reported practices rather than direct forecasting behavior. However, observations of forecast meetings provided additional information about how forecasters discuss and manage uncertainty in operational settings, allowing interviews to be considered alongside observed forecasting practice.

Although the findings are not intended to be generalizable, they provide an empirical baseline for understanding how forecasters approach uncertainty in their work. By documenting current practices and identifying recurring challenges, the study can inform and support the development of operational approaches to uncertainty assessment and communication.

6. CONCLUSION

This research offers insight into professional forecasters' perspectives on uncertainty and the challenges they navigate when creating forecast products for diverse audiences. Forecasters identified common hazard conditions with elevated uncertainty that prompt them to include uncertainty information in the published product and explained how they currently communicate it within the constraints of existing formats. Because detailed, complex, and contextual uncertainty information is difficult to fit within the structure of the forecast product, forecasters end up spreading it across multiple forecast elements rather than presenting it in one consistent place.

We also learned that forecasters are challenged by an internal tension between providing accurate technical information about conditions and giving clear, actionable recommendations for the backcountry, a tension that plays out differently depending on the forecast user's experience and the nature of the uncertainty involved.

Building on this baseline of current forecaster practices and our companion user study (Latosuo et al., 2024), the next phase will test structured guidance for communicating uncertainty (Latosuo et al., 2026), including confidence statements, visual cues, and tiered messaging. Think-aloud sessions will be used to examine how backcountry users interpret and apply revised forecast products for their risk-management decisions.

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