UNDERSTANDING THE ACTIONABILITY OF FUTURE SNOW AVALANCHE HAZARD MAPS IN ALASKA

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ABSTRACT: Climate change is altering snow and weather conditions in Alaska, creating new challenges for avalanche risk management. Researchers are developing future snow avalanche hazard maps to support planning under these changing conditions. This study examined how Alaska avalanche decision-makers use avalanche information and what makes future hazard maps actionable. We first conducted 18 semi-structured interviews with decision-makers working across avalanche forecasting, recreation, transportation, emergency management, utilities, municipalities, industry, homeowners, and other settings. Interview participants described using multiple information sources to understand avalanche conditions and make decisions. Future hazard maps were generally viewed as more useful for long-term planning than for day-to-day operations. The interview findings also informed a statewide survey completed by 198 avalanche decision-makers. In the survey, we examined actionability in terms of salience, credibility, and legitimacy and used latent profile analysis to identify segments of decision makers with unique perceptions of the anticipated actionability of hazard maps. The survey identified four actionability profiles among 188 respondents with complete data: Resistant (4.8%), Skeptical (16.0%), Receptive (66.5%), and Committed (12.8%). Respondents who perceived the maps as more salient, credible, and legitimate were generally more willing to use them. Profiles differed in how they viewed uncertainty. Respondents in the Committed profile, for example, were especially likely to view uncertainty as a normal part of avalanche science and to recognize multiple sources of uncertainty. Together, the findings show that future avalanche information must fit the decision context, connect with existing information practices, communicate uncertainty clearly, and address unique user needs to be more likely to be actionable.

KEYWORDS: Snow avalanches; actionable science; hazard maps; decision-making; uncertainty; risk communication

1. INTRODUCTION

Avalanche decisions are made in complex and uncertain environments. Practitioners and other decision-makers combine weather information, snowpack observations, avalanche forecasts, historical records, professional judgment, and local experience and observations to understand changing conditions and decide when and how to act (Johannessen and Haavik, 2024). Scientific information is therefore one part of a larger decision environment rather than a single source that determines action (Quigley et al., 2019).

Climate change adds another challenge. Changes in temperature, precipitation, and rain-on-snow events may alter the nature of avalanche hazards. In Alaska, researchers are developing future avalanche hazard maps by combining models or avalanche dynamics with downscaled climate projections (Wolken et al., 2022). Future avalanche model outputs are expected to be communicated primarily through large-scale hazard indication maps showing potential future avalanche extent (the geographic area affected by avalanches), frequency (the likelihood or return period of avalanche occurrence), and intensity (the magnitude of avalanche impacts, such as speed, depth, or impact pressure) under different climate scenarios. These products are intended to support infrastructure, land-use, preparedness, and risk-management decisions.

However, to be useful, these model outputs must be communicated effectively. Past research on the communication of avalanche hazards has tended to focus on short-term avalanche forecasts and decisions by recreators and other daily users. In this study, we turn our attention to the practitioners, decision-makers, and other professionals that make public safety, infrastructure, land use, and operations decisions that can affect the broader population. Rather than focus on short term decision making, we're interested in how future hazard maps might address decision-making on longer time horizons.

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Scientific information is unlikely to be useful simply because it is available; its value depends on whether it fits the decision being made and the needs of intended users. We use the concept of actionability to examine this fit. Actionable science refers to knowledge that guides decisions, planning, and problem-solving under uncertainty (Arnott et al., 2020; Mach et al., 2020). It is usually developed through collaboration, where scientists and decision-makers work together over time, exchange information, and learn from one another (Mach et al., 2020; Meadow et al., 2015).

Three characteristics of the information and the process of generating it are particularly important: salience, or whether information is relevant to the decision; credibility, or whether it is viewed as technically sound and trustworthy; and legitimacy, or whether the process used to produce and communicate the information is viewed as fair and appropriate (Cash et al., 2003). We use this as a theoretical lens to better understand the potential users of future hazard maps and how we can effectively structure processes of engagement and communication with them, to make this information more likely to be useful.

2. METHODS

This study used two phases. First, we interviewed Alaska avalanche decision-makers to understand how they currently use avalanche information and how they perceive future avalanche hazard maps. Second, the interviews informed a statewide survey examining how a larger group of decision-makers viewed the actionability and uncertainty of future avalanche hazard maps.

2.1 Interviews

We conducted 18 semi-structured interviews with avalanche decision-makers in Alaska. Participants worked in recreation, emergency management, transportation, utilities, municipal planning, avalanche forecasting, avalanche consulting, avalanche mitigation, industry, and residential settings. Participants were purposively recruited to represent varied decision contexts rather than proportional representation by sector.

Interviews were conducted by Zoom from January 5 to February 24, 2026, and lasted approximately 17–55 minutes. Questions focused on current avalanche information use, anticipated use of future avalanche hazard maps, salience, credibility, legitimacy, and uncertainty. Interviews were recorded with consent, transcribed, and manually checked for accuracy.

Transcripts were analyzed in ATLAS.ti. Coding was guided by the study framework and focused on conceptual and instrumental information use, salience, credibility, legitimacy, and different types of uncertainty. One researcher conducted the initial coding, and a second researcher reviewed the coding. Differences were discussed and resolved before the final analysis.

2.2 Statewide survey

Interview findings informed an online statewide survey of people who use avalanche information in their work in Alaska. Participants included avalanche practitioners and people working in emergency management, transportation, recreation, municipal government, natural resources, utilities, industry, and residential settings. The survey was distributed through professional organizations, partner social networks, agency mailing lists, and snowball sampling. A total of 198 respondents completed the survey.

The survey measured perceived salience, credibility, and legitimacy of future avalanche hazard maps. Respondents also reported anticipated use of future maps for operational and planning decisions and their views of uncertainty, including whether uncertainty was manageable and normal in avalanche science and several possible sources of uncertainty.

2.3 Actionability profiles

Latent profile analysis was used to identify groups of respondents based on their ratings of salience, credibility, and legitimacy. Respondents with missing data on these measures were excluded, leaving 188 respondents for the profile analysis. Models with three, four, and five profiles were compared using statistical fit, profile size, and interpretability. The four-profile solution provided the strongest balance among these criteria.

3. RESULTS

3.1 Avalanche decisions draw on multiple information sources

The interviews showed that avalanche decision-makers rarely rely on a single source of information. Participants described comparing weather information, forecasts, field observations, monitoring data, historical records, maps, and professional judgment. Information served both conceptual (awareness building) and instrumental (decision making) purposes. For conceptual contexts, practitioners used information to understand conditions, recognize patterns, and update their understanding of risk. In instrumental contexts, they used information to support mitigation, access restrictions, make travel decisions, and for infrastructure planning.

This multi-source approach provides important context for future avalanche hazard maps. The

maps would not enter an empty information environment. Instead, practitioners would likely evaluate them alongside information they already know, trust, and use.

3.2 Future hazard maps are more closely aligned with planning

Interview participants made a clear distinction between short-term operational decisions and longer-term planning. Current operational decisions depended strongly on immediate weather, snowpack conditions, field observations, and forecasts. Future avalanche hazard maps were generally viewed as less relevant to day-to-day decisions and more useful for infrastructure, land-use, preparedness, and other planning decisions.

"On a day-to-day or seasonal time frame, they're not that useful."

This distinction suggests that actionability depends partly on matching the time scale of the information to the time scale of the decision.

3.3 Salience, credibility, and legitimacy shape anticipated use

Interview participants described several conditions that could make future hazard maps more actionable. Salience depended strongly on decision context: participants wanted information tied to specific locations, infrastructure, and planning needs. Credibility depended on scientific quality and transparency about data, methods, assumptions, and limitations. Legitimacy depended on how the information was developed and communicated, including opportunities for practitioners and communities to contribute knowledge and feedback.

"If they don't actually represent what we're seeing in the field, then there's a big error."

3.4 Four actionability profiles emerged

The statewide survey identified four profiles among the 188 respondents with complete responses: *Resistant* (n = 9; 4.8%), *Skeptical* (n = 30; 16.0%), *Receptive* (n = 125; 66.5%), and *Committed* (n = 24; 12.8%). The profiles showed progressively higher perceptions of actionability. Mean salience increased from 2.17 in the *Resistant* profile to 4.88 in the *Committed* profile; credibility increased from 3.33 to 4.78; and legitimacy increased from 3.24 to 4.78. All three dimensions differed significantly across profiles ($p < .001$).

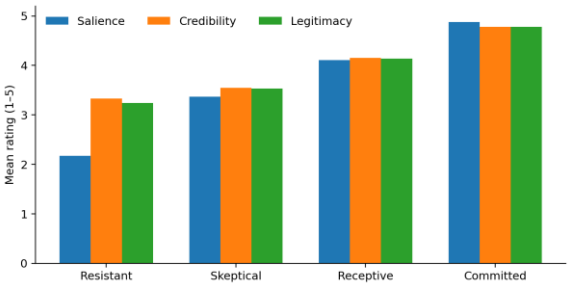


Figure 1: Mean salience, credibility, and legitimacy ratings by actionability profile.

The *Receptive* profile accounted for about two-thirds of the analytic sample. This suggests that most respondents viewed future avalanche hazard maps favorably, while smaller groups expressed either strong reservations or strong support. At the same time, if we want to reach the largest number of practitioners, we might tailor the engagement process and communication towards the salience, credibility, and legitimacy views of the *Receptive* segment.

3.5 Actionability was related to anticipated map use

The profiles also differed in anticipated use of future avalanche hazard maps. Respondents who rated the maps as more salient, credible, and legitimate were generally more willing to use them in decision-making. The survey also supported the interview finding that future maps are likely to become one additional source within an existing information system rather than replace forecasts, observations, or professional expertise.

3.6 High actionability did not mean ignoring uncertainty

Uncertainty was a central theme in the interviews. Participants repeatedly described uncertainty as unavoidable in avalanche work. One mountain guide stated, "*Uncertainty is always present, it's never not. There's no such thing as 100% certainty."* Rather than waiting for uncertainty to disappear, practitioners described using experience, multiple sources, and professional judgment to make decisions.

The four actionability profiles did not differ significantly in their perceived ability to manage uncertainty, $F(3, 183) = 1.64$, $p = .181$. They did differ in the extent to which they viewed uncertainty as a normal part of avalanche science, $F(3, 184) = 12.18$, $p < .001$. Mean ratings increased from 3.00 among *Resistant* respondents to 4.54 among *Committed* respondents.

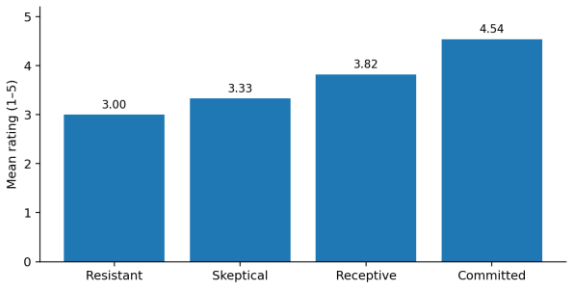


Figure 2: Mean rating that uncertainty is a normal part of avalanche science by actionability profile.

The *Committed* profile also rated all four measured sources of uncertainty more highly than the other profiles: limitations in modeling and forecasting, limited local data, differences among experts, and changing climate conditions. Strong support for future hazard maps therefore did not depend on believing that the maps were certain.

4. DISCUSSION

The interview and survey findings point to a common conclusion: the value of future avalanche hazard maps depends on how well they fit the decisions and information practices of intended users. The interview and survey findings also help us think about what is most important to each segment of decision makers, to help us better tailor our communication of the future hazard maps.

First, future maps should be treated as complements to existing information, not replacements for it. Avalanche practitioners already work within a multi-source information environment. They combine observations, forecasts, weather information, historical records, maps, and professional judgment. Future hazard maps will need to fit within this information ecosystem. What remains unclear is how practitioners and decision makers might use or ignore specific sources of information when they conflict with each other. For example, given the importance of historical and observational information, it is uncertain how future avalanche hazard maps might be interpreted if their results are contrary to past observations.

Second, time horizon matters. The interviews showed greater perceived value for long-term planning than for daily operations. Survey respondents rated the maps most highly for understanding changes in avalanche risk over the next 10 years and 11–30 years from now. This information might shape the default views of the hazard maps. Further, a map designed to support infrastructure or land-use decisions may need different information, scale, and communication than a product intended to support immediate safety decisions.

Third, users are not a single audience. The survey identified four groups with different perceptions of salience, credibility, and legitimacy. Most respondents were *Receptive*, but about one-fifth were *Resistant* or *Skeptical*. Users with lower perceptions of credibility or legitimacy may need closer engagement and clearer explanations of methods, assumptions, and limitations. The profiles should not be treated as fixed types of people because they represent response patterns to these future hazard products but rather are a tool for designing more intentional communication.

Finally, uncertainty does not need to disappear before information becomes useful. Both phases suggest that avalanche decision-makers are accustomed to working under uncertainty. The *Committed* profile is especially interesting; although they rated future maps most favorably, they also recognized uncertainty most strongly. Transparent uncertainty communication and high perceived actionability can therefore coexist.

5. PRACTICAL IMPLICATIONS

- Connect maps to decision contexts. Products should clearly identify the decisions they are designed to support, particularly infrastructure, land-use, preparedness, and other long-term planning decisions.
- Fit new information within existing information practices. Future maps should complement current forecasts, field observations, monitoring data, historical records, and professional judgment.
- Show how the information was produced. Clear descriptions of data sources, model assumptions, validation, and limitations can help users assess credibility.
- Include practitioners and communities. Engagement during product development can help identify local information needs, improve relevance, and strengthen legitimacy. These results should provide a valuable jumping off point for conversations and help identify audiences who would benefit the most from deeper engagement, such as the *Resistant* or *Skeptical* profiles.
- Communicate uncertainty directly. Hazard maps should explain important sources of uncertainty and what those uncertainties mean for use.
- Allow for different users. Communication should address different starting points rather than assuming that all users evaluate future hazard maps in the same way.

6. CONCLUSION

Future snow avalanche hazard maps have the potential to help Alaska decision-makers prepare

for changing avalanche conditions, particularly for long-term planning. Their usefulness, however, will depend on more than the quality of the underlying models and science. How they are communicated is also important.

The interviews showed that practitioners already work within a complex information environment and routinely make decisions under uncertainty. The statewide survey showed substantial differences in how users perceive the salience, credibility, and legitimacy of future maps. Most respondents were receptive to the information.

Future avalanche hazard information will therefore be most useful when it is designed around the decisions people need to make, fits alongside the information they already use, clearly communicates its strengths and limits, and involves intended users in its development.

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