COMMUNICATING LIKELIHOOD AND PROBABILITY FOR OPERATIONAL SNOW AVALANCHE FORECASTING

*The following article by **Scott Thumlert** and his colleagues is based on a presentation he gave at the CGS GeoRisques / GeoHazards 8 workshop held in Quebec City in June 2022. The associated paper was published in the proceedings of that workshop and will be available on the CGS Geohazards Committee website (www.cgs.ca/geohazards_committee.php) shortly.*

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"Even if avalanche forecasting is probabilistic and includes uncertainty, it should be grounded in clear definitions, and uncertainty should not stem from nebulous terms but the nature of the problem."

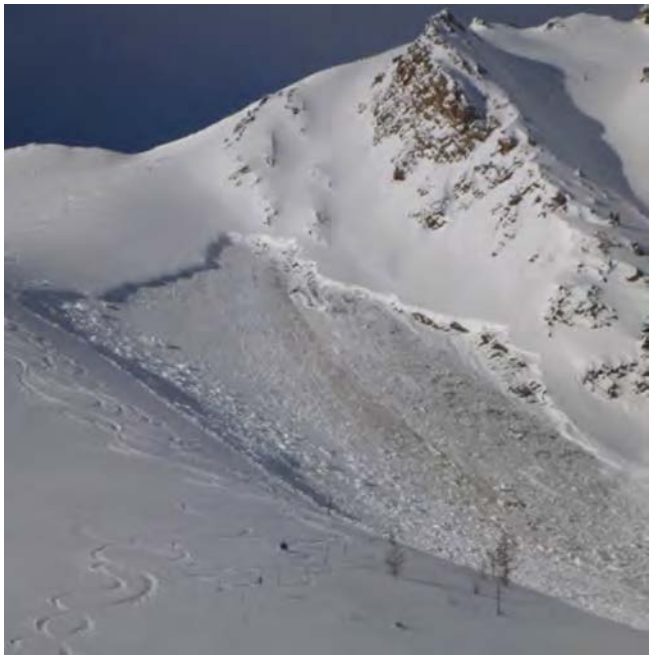

Figure 1: A deep slab avalanche release in the Canadian Rocky Mountains (photo by Applied Snow and Avalanche Research, University of Calgary).

Introduction

Operational snow avalanche forecasting refers to the short-term assessment of avalanche hazard performed by practitioners, that is, workers engaged in field operations. The following points about avalanche forecasting are important to communicate for readers that may be more familiar with other geohazards:

- Avalanche starting zones can release many times annually, therefore, return periods are often less than one year.
- Practitioners often make decisions under high levels of uncertainty, largely stemming from the lack of complete knowledge how the snowpack varies spatially across complex mountain terrain.
- Practitioners often have more experience-based backgrounds than technical backgrounds.
- Operational avalanche forecasting is utilized in diverse applications such highway and railway corridors, mining operations, guided backcountry recreational travel and ski resorts.
- Practitioners engage in a mixture of field and office decision-making.

Snow avalanche forecasters in North America have widely adopted the Conceptual Model of Avalanche Hazard (CMAH) (Statham et al. 2018) as a systematic, risk-based workflow for avalanche forecasting. The model defines the "Likelihood of Avalanche(s)" as "the chance of an avalanche releasing within a specific location and time period, regardless of avalanche size." It uses an ordinal scale with five terms: UNLIKELY, POSSIBLE, LIKELY, VERY LIKELY and ALMOST CERTAIN. These subjective probability estimates of likelihood are combined with the practitioner's estimate of "Destructive Avalanche Size" (i.e. consequence) to form

his/her assessment of avalanche hazard (Figure 2). This process is integral to daily forecasting work.

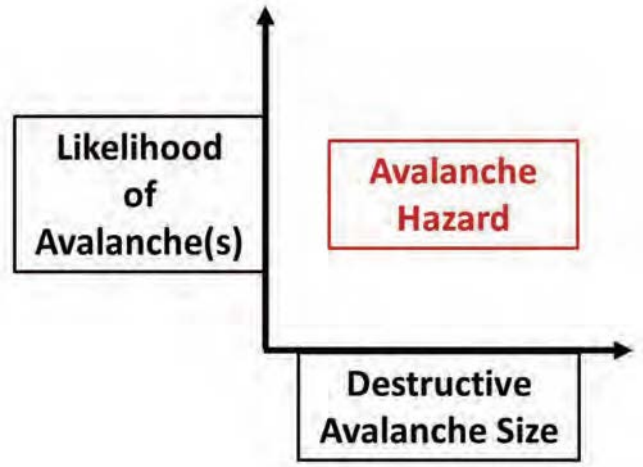

Figure 2: Conceptual model for the combination of "Likelihood of Avalanche(s)" and "Destructive Avalanche Size" as part of a snow avalanche hazard assessment.

Over the last ten winters of forecasting in a variety of situations, we have directly observed discrepancies in how avalanche practitioners were using the likelihood scale. Further, we became aware of the depth of research showing large differences in the ways people understand, communicate and use these types of qualitative expressions of probability. Discrepancy between interpretations of likelihood expressions has been shown to create communication problems, reduce forecasting accuracy and ultimately compromise decision making. In a classic example, in 1961 during the cold war, US President John F. Kennedy asked his Joint Chiefs of Staff to evaluate the planned Bay of Pigs invasion. They assessed the probability of success to be about 30% and communicated that as "The plan has a FAIR CHANCE of success." Kennedy interpreted FAIR CHANCE as favourable odds and approved the operation that ended in a stunning defeat for the US. The Joint Chiefs later reported, "we thought that other people would think FAIR CHANCE would mean 'not too good'". The varying interpretations of FAIR CHANCE were identified as the key misunderstanding of the entire project (Wyden 1979).

We decided to dig into how snow avalanche practitioners think about the likelihood terms in terms of percentage probabilities.

Practitioner Survey

We asked avalanche practitioners from avalanche operations around the world (75 responses) to put a percentage number beside each of the likelihood words - UNLIKELY, POSSIBLE, LIKELY, VERY LIKELY, and ALMOST CERTAIN- for what they interpreted the words to mean about the probability of avalanches. That is, what percentage probability comes to mind when you say LIKELY? Figure 3 shows the results.

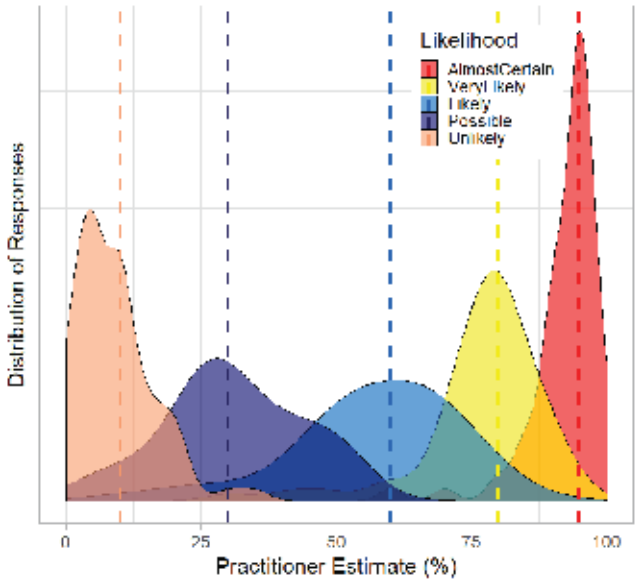

Figure 3: Probability interpretations from avalanche practitioners associated with words used to forecast the "Likelihood of Avalanche(s)" (CMAH). Median values shown as dashed lines.

We observed distinct median values that are similar to forecasting experts in other industries. We also observed a very large range in probabilities associated with the likelihood terms, and perhaps most importantly, we observed large overlap between categories with average practitioner estimates for POSSIBLE, ranging from 0-66%, and UNLIKELY, ranging from 0-55%. This result is alarming and it's not hard to imagine a communication problem developing if one practitioner thinks 5% for POSSIBLE and another uses 35% for UNLIKELY!

While this large range and overlap is startling and potentially challenging to work with, it is not altogether surprising given the extensive research on this topic. Are there specific reasons for the large range and overlap from snow avalanche practitioners? We hypothesize the following reasons:

1. Likelihood of Avalanche(s), as defined in the CMAH, results from a combination of sensitivity to triggers and spatial distribution and has not yet been explicitly defined in terms of numerical probability ranges. That is, avalanche practitioners do not yet have training or guidance on what probabilities should be used for forecasting avalanches.

2. Natural and human-triggered avalanches are relatively rare, so the experienced-based probabilities from practitioners are likely lower than what many people commonly associate with the likelihood words. That is, some practitioners provided probabilities for actual human-triggered and natural releases (lower values), whereas some provided the more common numbers associated with likelihood words (higher values).

3. The reference definition for Likelihood of Avalanche(s) in the CMAH is highly dependent on the forecast's spatial scale.

Strategies

Researchers in other industries (e.g. climate science, intelligence agencies and medicine) discovered similar wide ranges and overlap of probability interpretations for likelihood words, and subsequently developed strategies to improve communication in their respective communities. Can these strategies be adopted by the avalanche industry specifically to help with risk communication? Here are a few relevant concepts, well-established in the literature, for communicating probability:

1. Explicitly combining numerical probabilities with verbal likelihood terms improves risk communication. For example, combining the FAIR CHANCE term with the numerical probability range 10-30% to write "FAIR CHANCE (10–30%) of avalanche release."

2. The numerical probabilities used for verbal likelihood terms should fall within the published and commonly associated ranges. However, they can be further refined as the uncertainty, audience and context dictates.

3. Using frequency statements with an explicitly defined reference class greatly improves understanding of probabilities. An example frequency statement is "the expected number of times a "2" comes up when rolling a dice."

Likelihood of Avalanches

As a first attempt, we propose ideas for development of the Likelihood of Avalanche(s) scale used to forecast snow avalanches:

1. Consider this definition for Likelihood of Avalanches. Consider the avalanche paths or start zones in the forecast region where the specified avalanche problem type is expected to exist. Likelihood of Avalanches is the chance of those avalanche paths or start zones releasing within the forecast time period, regardless of avalanche size.

For example, consider this avalanche problem: Persistent Slabs – below tree line (e.g. below 1900 m, on all aspects), what is the chance of that terrain avalanching naturally or from human triggering?

This definition includes the relevant reference class - the avalanche terrain where the problem is expected to exist. This reference class merges the amount of terrain with the avalanche problem with the probability of that terrain releasing, and ultimately offers an estimation of how many avalanches are expected. (See Gigerenzer and Edwards 2003 for a good discussion of reference class and framing for decision-making.) This approach yields two main advantages: i) it automatically adjusts to the spatial scale of the forecast, and ii) it allows the translation of probability into frequency descriptions or rates of release which improves comprehension of probabilities. For example, "Persistent Slabs - LIKELY (30-100%)" can translate to "On average more than 30 out every 100 potential paths will release persistent slab avalanches."

2. Associating numerical probability ranges for each word in the scale that are more closely aligned with the underlying rates of avalanche release. This point highlights a critical question that is currently unanswered - what are the rates of avalanche release across terrain for varying hazard conditions? The probability ranges are likely lower than the results of the practitioner survey and what is presented in Table 1, and more similar to other natural hazards. As better data emerge for natural and human-triggered avalanche release rates, these probabilities are expected to evolve. It is worth noting that avalanche hazard forecasts are typically produced for a 24-hour time period, that reflects the potential for rapidly changing snow stability conditions.

3. Using terms to communicate the likelihood of avalanches that are useful in the decision-making process of avalanche practitioners. What probabilities are most useful for practitioners when expressing their likelihood judgments? This is a key question to answer. Facilitating decision-making in avalanche terrain must be the primary motivation for choosing likelihood terms. Underlying probabilities must be consistent with the intuitive and established values that are normally associated with the terms.

As evidenced in the survey results and literature, the current CMAH likelihood words are already commonly interpreted with underlying probabilities that are much higher than actual avalanche release rates. Thus, we need words that can be easily associated with these lower probabilities for use by people working in the field. That is, it is not intuitive for most people to use the word LIKELY with a probability less than 50%. Suggestions are provided in Table 1.

Chance	Probability	Frequency description (or rates of release) *
LIKELY	> 30%	On average, 30 or more out of every 100 paths or start zones in the region release the given avalanche problem type.
FAIR CHANCE	10-30%	On average, 10-30 out of every 100 paths or start zones in the region release the given avalanche problem type.
UNLIKELY	1-10%	On average, 1-10 out of every 100 paths or start zones in the region release the given avalanche problem type.
HIGHLY UNLIKELY	< 1%	On average, at most 1 out of every 100 paths or start zones in the region release the given avalanche problem type.

* Frequency description not very useful when forecasting for single path or area with few paths - use probability ranges or chance terms.

Table 1: Proposed scale describing the Likelihood of Avalanches.

Conclusions

The surveyed data from snow avalanche practitioners showed wide variation in interpretation and use of likelihood terms when forecasting avalanches. Differing interpretations of likelihood terms have been shown to reduce forecasting accuracy and compromise decision making, thus we present ideas for improving risk communication when forecasting avalanches (Table 1 and new definition for the Likelihood of Avalanches). We suggest that these and any other terms used in the future should reflect underlying data for avalanche release probabilities. As an example, the important paper by Schweizer et al. (2019) attempts to establish the relationship between reported avalanche occurrences and the avalanche danger level. We strongly encourage future studies, like the one we describe, with robust avalanche occurrence datasets to better define probabilities of avalanche release.The key take-home message from this article is that explicitly stating intended numerical probabilities with the verbal expressions can greatly improve the understanding and communication of risk. A logical development for snow avalanche forecasting will be to refine what numerical probabilities are most useful for practitioners when forecasting avalanches, match them with intuitive likelihood terms, and develop practical methods of probability assessment that facilitate coherent outcomes.

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Bruce Jamieson

Bruce Jamieson *was a Professor of Civil Engineering at the University of Calgary (1997 to 2015), specializing in snow avalanches. He supervised 24 graduate students and many research technicians. Now considerably retired, he dabbles in avalanche education videos, which are available at www.brucejamieson.ca.*