The EAWS matrix, a look-up table to determine the regional avalanche danger level (Part A): Conceptual development

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Abstract. Avalanche forecasting plays a crucial role in mitigating risks associated with snow avalanches in mountainous regions. Standards for regional avalanche forecasting were initially developed at national levels. Therefore, the introduction of the European Avalanche Danger Scale (EADS) in 1993, still in use today, represented a milestone in harmonizing the assessment and communication of avalanche danger. Since then, standards, concepts and definitions have evolved. In this study, we present the updated European Avalanche Warning Services (EAWS) Matrix – a consensus-based look-up table designed to support consistent and transparent danger level assessments by linking snowpack stability, the frequency of snowpack stability, and avalanche size to the five danger levels. We describe the collaborative revision process involving avalanche forecasters from across Europe, including expert surveys and integrating the findings following the operational test phase spanning three winters. The updated Matrix reflects current best practices in regional avalanche forecasting. Its design aligns with the operational forecasting workflow and explicitly addresses inherent uncertainties. We highlight key findings, such as persistent ambiguities, challenges in defining frequency classes, and strategies to improve the reliability of input factors. Finally, we position the Matrix within the broader framework of the Conceptual Model of Avalanche Hazard (CMAH) and argue that the EADS should be updated accordingly.

1 Introduction

Snow avalanches represent a natural hazard in snow-covered, mountainous regions. Avalanches may lead to injury or loss of life, and can cause damage or destroy property and infrastructure. For instance, in Europe in the 50 years between 1974 and 2023, more than 5900 (annual mean: 118) people have died in avalanches (EAWS, 2023a). To reduce adverse effects resulting from avalanches, avalanche warning services disseminate regional avalanche forecasts to inform and warn the general public as well as responsible decision-makers .e.g., in local authorities, on current and expected avalanche conditions.

The assessment of current and future avalanche conditions involves the analysis of a wide variety of heterogeneous data, including field observations, measurements, models, and weather forecasts. Although the interpretation of snow and weather parameters follows a deterministic cause-and-effect approach, actual forecasting decisions are reached using inductive logic (LaChapelle, 1980). Thus, the quality of avalanche forecasts is influenced by a combination of factors, including the forecaster's experience and reliability (Stewart and Lusk, 1994; McClung, 2002), as well as the dynamic nature of the snowpack, which varies spatially and temporally (Schweizer et al., 2008). Due to the inherent uncertainty in predicting the exact timing and location of avalanche events and due to a lack of relevant data, the assessment of avalanche danger maintains a qualitative character. Unlike weather forecasting, which often involves precise numerical predictions for variables like air temperature or precipitation, in avalanche forecasts the complex and multifaceted nature of avalanche conditions is assessed and communicated using symbolic representations, encompassing danger levels, classes, terms, and text (Hutter et al., 2021). In regional avalanche forecasting, the focus of this study, the severity of expected avalanche conditions is summarized using the concept of danger levels. Despite advances in model-driven predictions of avalanche danger levels (e.g., Giraud, 1992; Pérez-Guillén et al., 2022), assessing avalanche danger levels has so far remained primarily a subjective decision-making process. While complete consensus between individual forecasters is unattainable, random variations inherent to human judgment should be minimized. Consistency between a forecaster's best judgment and the forecasts they produce is as important as consistency between forecasters, as both directly impact the quality of avalanche forecasts (Murphy, 1993; Stewart, 2001). High values for consistency lead to high-quality forecasts, which in turn, enhance the potential value of the forecast to decision-makers using them (Murphy, 1993). Consequently, high-quality forecasts can therefore increase safety when recreating in terrain exposed to avalanche hazard and contribute to reducing avalanche-related damage and loss.

The information provided in avalanche forecasts is structured following an information pyramid, with the most relevant information, a danger level (D), at the top (EAWS, 2023c). The importance of D for decision-making in avalanche terrain has been shown in numerous studies, including, for instance, during the trip planning stage (e.g., Morgan et al., 2023), impacting the decision whether to ski a slope or not (e.g., Furman et al., 2010), or the correlation between the forecast danger level and avalanche risk during back-country skiing (e.g., Techel et al., 2015; Winkler et al., 2021). Given the importance of avalanche danger levels to support decision-making for avalanche forecast users, ensuring consistent assignment of these levels is paramount. However, several studies have shown considerable variation in the use of danger levels. These variations are greater between forecasters from different or neighboring warning services (Lazar et al., 2016; Techel et al., 2018) than within a single warning service (Techel et al., 2018). Additionally, inconsistencies persist when describing dry- and wet-snow avalanche conditions in terms of the likelihood and size of natural avalanches (Clark, 2019; Hutter et al., 2021).

Several standards and tools have been developed within EAWS and related organizations to structure the process of public regional avalanche forecasting. However, some of these frameworks date back more than 30 years, during which both knowledge and terminology have significantly evolved. To enhance consistency in the assessment of regional avalanche danger levels across forecasters and warning services, the European Avalanche Warning Services (EAWS) launched a coordinated initiative to revise the core components guiding such assessments. As part of this effort, a dedicated EAWS working group redefined the factors determining the avalanche danger level (D) and established a shared operational workflow to support its assessment (EAWS, 2022c; Müller et al., 2023). In parallel, the EAWS Matrix – a central decision aid for assigning danger levels in many European warning services for many years – was revised to align with the updated definitions and terminology. This process unfolded in three main steps:

1. **Conceptual and methodological development:** Definition of key assessment factors and initial revision of the Matrix and workflow. This package of definitions, workflow, and Matrix was formally adopted by the EAWS General Assembly in 2022 (EAWS, 2022c).

2. **Operational testing:** Evaluation of the revised Matrix, workflow, and assessment factors under real operational forecasting conditions, presented in two separate analyses (Techel et al., 2024a, 2025).

3. **Refinement and integration:** Targeted adjustments based on findings from the operational testing phase, resulting in a consolidated Matrix. The proposed changes were formally adopted by the EAWS General Assembly in 2025.

This iterative exchange between methodological development and practical implementation was instrumental in enhancing the clarity, usability, and consistency of the Matrix across forecasters and warning services. It also emphasizes the importance of structured evaluation in the development of operational tools.

The aim of this contribution is to document the iterative revision of the EAWS Matrix and its accompanying workflow, to present the final revised Matrix, and to provide a critical reflection that paves the way for further refinements and contributes to the broader discussion on the future evolution of the European avalanche danger scale. The revision process has the following components outlined in two papers, this one and Techel et al. (2025):

– **Background (Sec. 2):** We provide a structured overview of existing standards for assessing regional avalanche danger in Europe and North America, with particular focus on the avalanche danger scale and the evolution of various look-up tables supporting danger level assignment. This section outlines the rationale for revising the Matrix.

– **Revision process – Step 1: Definitions and forecaster survey (Sec. 3):** We describe how the EAWS Matrix was revised, including the methodology and key outcomes, and highlight areas of uncertainty and open questions.

– **Matrix and recommended workflow (Sec. 4):** We present the revised Matrix and the accompanying workflow, as adopted by EAWS, and explain how it was intended to be tested by forecasters.

– **Companion analyses (external):** To support potential refinements to the Matrix and workflow, their operational use was evaluated in two parallel studies: one examined the reliability of estimating the input factors to the Matrix (Techel et al., 2024a), and the other focused on how the Matrix was used in day-to-day forecasting operations (Techel et al., 2025). Together, these studies provided empirical feedback based on real-world application of the Matrix.

– **Revision process – Step 2: Operational testing (Sec. 5):** We summarize the key lessons learned from the two companion analyses and describe how they informed further refinements to the Matrix.

– **Discussion (6):** We critically reflect on the consolidated Matrix, discuss known limitations, and explore how the Matrix could be integrated into the existing conceptual framework for regional avalanche forecasting in North America.

2 Background

2.1 The European Avalanche Danger Scale

Avalanche bulletins have been published since the winter 1945/1946 in Switzerland. Although neither standardized nor defined nor used in a consistent manner, avalanche danger was already described in winter 1951/1952 in Switzerland as being *low*, *moderate*, *considerable*, *high* and *very high*, sometimes in connection with modifiers like *general* and *local* (e.g., SLF, 1953, p.68 ff). A first description of the danger levels used in Switzerland was published in 1985 (Föhn, 1985), allowing consistent use by forecasters and transparent communication to users. Similarly, in France, eight «typical» avalanche situations were used to assess and communicate avalanche conditions (Giraud et al., 1987). These were later on also used in Italy. Despite the formation of a European Avalanche Warning Services (EAWS) working group in 1983, which aimed to promote cooperation across national borders, the Alpine countries France, Italy, Switzerland, Germany and Austria continued to use their own danger scales with a varying number of six to eight danger levels (Mitterer and Mitterer, 2018). In 1993, the EAWS introduced the five-level European Avalanche Danger Scale (EADS, SLF, 1993; Meister, 1995), which was largely based on the wording and definitions used in Switzerland (Föhn, 1985). This adoption of a standardized danger scale marked a pivotal moment for international avalanche warning services, simplifying procedures for all parties involved, and facilitating communication of avalanche danger particularly for forecast users when traveling to different countries (Meister, 1995). Except for minor changes in 1994, the EADS has been unchanged as of today, not only providing a common way of expressing the avalanche danger level across institutions and borders, but impacting «the forecasting process itself, as all forecasters are working to an agreed, common, and at least nominally binding definition of avalanche danger.» (Techel et al., 2018, p. 2698).

The EADS uses two columns to describe each danger level (Table 1). The first column describes snowpack stability and includes a qualitative indication of the frequency of the respective locations. The second column describes the likelihood of triggering an avalanche by indicating the typical avalanche size and their distributions, the likelihood of natural avalanches occurring or the typical load required to trigger an avalanche. Frequency of avalanches and potential triggering locations or the likelihood of avalanche release are again described qualitatively.

The EADS has several shortcomings as a tool to summarize avalanche conditions in a region:

- The terminology in the EADS is vague, leaving ample room for interpretation. For instance, clear definitions for classes describing snowpack stability and the frequency of triggering locations are lacking.

- Qualitative terms expressing probability or uncertainty are not defined, which according to Morgan (2017) is inadequate as the same term can have different meaning to different people, but also to the same person in a different context. Not surprisingly, even among avalanche professionals large differences in numeric estimates of probability were observed (Thumlert et al., 2020).

- The load necessary to trigger an avalanche is correlated to snowpack stability (Schweizer and Camponovo, 2001). Thus, both columns in the EADS contain similar and redundant information on *snowpack stability* and triggering.

Table 1. European avalanche danger scale (EAWS, 2023b).

Danger level	Snowpack stability	Likelihood of triggering
1 (low)	The snowpack is well bonded and stable in general.	Triggering is generally possible only from high additional loads[**] in isolated areas of very steep, extreme terrain[**]. Only small and medium-sized natural avalanches are possible.
2 (moderate)	The snowpack is only moderately well bonded on some steep slopes[*]; otherwise well bonded in general.	Triggering is possible primarily from high additional loads[**], particularly on the indicated steep slopes[*]. Very large natural avalanches are unlikely.
3 (considerable)	The snowpack is moderately to poorly bonded on many steep slopes[*].	Triggering is possible even from low additional loads[**] particularly on the indicated steep slopes[*]. In certain situations some large, in isolated cases very large natural avalanches are possible.
4 (high)	The snowpack is poorly bonded on most steep slopes[*].	Triggering is likely even by low additional loads[**] on many steep slopes[*]. In some cases, numerous large and often very large natural avalanches can be expected.
5 (very high)	The snowpack is poorly bonded and largely unstable in general.	Numerous very large and often extremely large natural avalanches can be expected, even in moderately steep terrain[*].

[*] The avalanche-prone locations are described in greater detail in the avalanche forecast (elevation, slope aspect, type of terrain): moderately steep terrain: slopes shallower than about 30 degrees; steep slopes: slopes steeper than about 30 degrees; very steep, extreme terrain: particularly adverse terrain related to slope angle (more than about 40 degrees), terrain profile, proximity to ridge, smoothness of underlying ground surface.

[**] Additional loads: low: individual skier / snowboarder, riding softly, not falling; snowshoer; group with good spacing (minimum 10 m) keeping distances. high: two or more skiers / snowboarders etc. without good spacing (or without intervals); snowmachine; explosives. natural: without human influence.

– The short descriptions of each danger level do not cover the range of all possible combinations. For instance, snowpack stability decreases from *moderately well bonded* to *moderately to poorly bonded* from 2 (moderate) to 3 (considerable) while its frequency increases from *some* to *many* steep slopes. But the EADS does not provide guidance when the situation is best described by a snowpack that is *moderately to poorly bonded* on *some* steep slopes.

– When the EADS was translated into other languages, sometimes deviations from the original (German) text were introduced. Moreover, it is possible that individual warning services have developed their own guidelines on how to interpret the danger levels over the years, which may be one source for the observed differences in the use of the danger levels in the European Alps (Techel et al., 2018).

Due to these shortcomings, the European Avalanche Danger Scale (EADS) is currently undergoing revision. The updated version will address the identified issues and align the scale with the terminology and definitions currently adopted by EAWS for describing avalanche danger. Moreover, the revised EADS will need to be integrated with the operational forecasting workflow and the EAWS Matrix presented in this paper.

2.2 North American Public Avalanche Danger Scale and the Conceptual model of avalanche hazard

The EADS was, with minor adjustments, adopted in North America in 1994 (Dennis and Moore, 1996). It was used until 2007, when a revised danger scale, the *North American Public Avalanche Danger Scale* (NAPADS), was introduced (Statham et al., 2010). In contrast to the EADS, the NAPADS, was intended and designed for public communication only. This revision also triggered work on a general concept for avalanche hazard assessment resulting in the *Conceptual Model of Avalanche Hazard* (CMAH, Statham et al., 2018). The CMAH identifies the key components of avalanche hazard and structures them into a systematic, consistent workflow for hazard assessments. The method is applicable to all types of avalanche forecasting operations, and the underlying principles can be applied at any scale in space or time (Statham et al., 2018). The workflow sequentially addresses the four questions: «What type of avalanche problem(s) exists? Where are these problems located in the terrain? How likely is it that an avalanche will occur? and How big will the avalanche be?» (Statham et al., 2018, p. 671). While the CMAH has become the standard workflow for avalanche forecasting in North America, it was comparably slowly adopted in regional avalanche forecasting in Europe despite there being a general agreement with the concept. Potential reasons for this slow uptake likely include: (i) The CMAH does (deliberately) not conclude with a danger level (Statham et al., 2018). (ii) The CMAH described the locations and spatial distribution of the avalanche problem rather than solely assessing snowpack stability. Analyses in Europe clearly distinguished between the frequency of points with a certain snowpack stability (potential triggering spots) and their actual location (e.g., close to ridge lines, in bowls, ...) (Schweizer et al., 2020; Techel et al., 2020; Hutter et al., 2021) stating that only the frequency component is relevant for determining the danger level. And lastly, (iii) while the terminology used in the CMAH worked well in the English language, it worked poorly in many European languages (Müller et al., 2016).

Avalanche problems, such as persistent weak layers or wind slabs, describe typical avalanche scenarios and are integral to the CMAH and the avalanche danger assessment (EAWS, 2022a). They are defined as a ‘set of factors that describe the avalanche hazard’ (Statham et al., 2018). These factors include the sensitivity to triggers, spatial distribution and avalanche size in the terminology of the CMAH. The naming convention for avalanche problems differs slightly between North America and Europe, but are generally congruent in operational applications.

2.3 Historic development of the EAWS Matrix

The avalanche danger scales offer brief descriptions of the five danger levels, including typical values for the key factors that define each level. However, they lack clarity on the subtleties and do not specify exactly when a transition from one danger level to the next should occur. To address this limitation, look-up tables were introduced with the goal of explicitly linking danger levels to all possible combinations of the determining factors. Compared to the scale alone, these tables provide clearer and more comprehensive guidance for assigning danger levels. The intention is to achieve more consistent application of the scale and aims to harmonize danger level assessments among European avalanche forecasters.

The first look-up table formally adopted by the EAWS was the so-called *Bavarian Matrix* (BM), developed by Bavarian forecasters in 2003 (see Appendix, Figure A1). The BM was split into two sub-matrices: one relating to the potential for human-triggered avalanches and the other to natural avalanche occurrence. Relying on the terminology of the EADS, a danger level was indicated for each possible combination describing the *probability of avalanche release* and the *distribution of hazardous sites* within the two sub-matrices. The main benefit of the BM was that it provided a suggestion for scenarios for which the EADS provided no guidance. However, the BM inherited the short-comings noted for the EADS as the factors determining avalanche danger, like spatial distribution, avalanche size and probability, were still not clearly separated nor defined.

In 2016, Müller et al. (2016) attempted to bridge the gap between the concepts introduced in the CMAH and the structure of the Bavarian Matrix leading to the proposition of the *Avalanche Danger Assessment Matrix* (ADAM; see also Figure A2 in Appendix). This was the first attempt to tailor the CMAH to the specific needs of regional avalanche forecasters - an approach that laid the foundation for subsequent iterations of the EAWS Matrix. ADAM provided a workflow similar to the one suggested by the CMAH and integrated the concept of the spatial distribution in the assessment process. ADAM avoided the issue of the poorly defined probability terms used in the EADS by first evaluating snowpack stability against its spatial distribution separately, resulting in a likelihood-score ranging from *unlikely* to *very likely* when merging them. In a further step, likelihood is combined with avalanche size resulting in a danger level. ADAM was presented in two versions, one using the terminology in line with EADS and another one using the terminology from the CMAH. Thus, ADAM also provided a first translation between the terminologies of EADS and CMAH.

At about the time when Müller et al. (2016) developed ADAM, a working group of EAWS presented an updated version of the BM in 2017, which we refer to as *EAWS-Matrix-v2017*. This matrix introduced *avalanche size* as a separate dimension, and, thus, allowed forecasters to adjust the danger level described by the *distribution of hazardous sites* and the *probability of avalanche release*. However, most identified shortcoming of the EADS and BM were still present in the EAWS Matrix.

Covering the dimensions of snowpack stability (sensitivity to triggers), frequency (spatial distribution), and avalanche size, ADAM, the EAWS Matrix, and their later iterations can be seen as a specialized adaptation of the CMAH hazard chart (Fig. B1), tailored specifically to the needs of regional avalanche forecasters.

In North America, Thumlert et al. (2020) proposed numerical values to five likelihood terms, which were related to the frequency of natural avalanches releasing in 100 avalanche paths. The five likelihood terms differed compared to any of the other scales in use. Based on the concept presented in ADAM, Thumlert et al. combined these likelihood terms with avalanche size, introducing a first North American version of an avalanche danger assessment matrix (see also Figure A3 in Appendix).

Common to all the above mentioned matrices was that they were exclusively based on expert judgments and had been designed by small groups of forecasters (sometimes from only one or two warning services). As a result, avalanche forecasters in Europe did not use a common matrix when assigning a danger level; instead each warning service had a preference for one of the three matrices (BM, EAWS-Matrix-v2017, ADAM) or none. What was lacking was either data or a consensus within the European avalanche forecaster community on how to resolve the current issues. Consequently, Techel et al. (2020) tackled this issue and derived a first data-based characterization of the factors determining avalanche danger, which they termed *snowpack stability*, the *frequency distribution of snowpack stability*, and *avalanche size*. Analyzing a large data set of stability tests and avalanche observations from Switzerland and Norway, Techel et al. showed that the frequency of the locations with the lowest snowpack stability increased with increasing danger level. However, a similarly clear correlation between avalanche size and danger level was not evident. It was observed that the size of the largest avalanche per day and warning region increased only for the higher danger levels. Building upon these insights and drawing inspiration from the matrix layout employed in ADAM, Techel et al. introduced a data-driven matrix. This new matrix utilized simulated stability distributions along with information on the largest avalanche size (refer to Figure A4 in the Appendix).

3 Revision process (step 1): Definitions and forecaster survey

The terminology used in the European Avalanche Danger Scale (EADS) and the EAWS Matrix lacked clear and consistent definitions. As a first step in the revision process, we clarified these terms and established common definitions to ensure a shared understanding among avalanche forecasters. With these definitions in place, forecasters from across Europe were asked to assign a danger level to all possible combinations of the defined factors and their respective classes.

3.1 Definition of factors determining avalanche danger (levels)

Following the developments described in Section 2.3, a working group of the EAWS adopted the concept and terminology used in Techel et al. (2020) for the factors determining avalanche danger, namely *snowpack stability*, the *frequency of snowpack stability*, and *avalanche size*, and provided definitions for these factors and their respective classes (EAWS, 2022c):

- The *avalanche danger level* is a function of snowpack stability, the frequency distribution of snowpack stability and avalanche size for a given unit (area and time). There are five avalanche danger levels: 5 (*Very high*), 4 (*High*), 3 (*Considerable*), 2 (*Moderate*), 1 (*Low*).
- *Snowpack stability* is a local property of the snowpack describing the propensity of a snow-covered slope to avalanche (Reuter and Schweizer, 2018). Snowpack stability is described using four classes (Table 2).
- The *frequency distribution of snowpack stability* describes the percentages of points for each stability class relative to all points in avalanche terrain. Thus, the frequency f for all points with stability class i (n_i) compared to all points (n) is $f(i) = n_i/n$. The frequency distribution of snowpack stability is described in four classes (Table 3).
- *Avalanche size* describes the destructive potential of avalanches (Table 4).

In theory, the EAWS workflow requires forecasters to estimate the frequency distribution of snowpack stability classes across all points in avalanche terrain within a warning region. Independent of the spatial scale of the forecasting problem, assessing snowpack stability has traditionally relied heavily on observations of avalanche activity, signs of instability, and stability test results (Reuter and Schweizer, 2018). More recently, this has been complemented by stability information extracted from one-dimensional physical snowpack models (e.g., Mayer et al., 2022; Herla et al., 2022; Binder and Mitterer, 2023). In practice, however, estimating snowpack stability at every point in a large region remains impossible. Forecasters therefore infer the

Table 2. Snowpack stability classes referring to the point scale, and the type of triggering typically associated with these classes. For the full table, including typical observations related to each class, see EAWS (2022c, Figures A1-A3).

Stability class	Description
Very poor	very easy to trigger (e.g., natural)
Poor	easy to trigger (e.g., a single skier)
Fair	difficult to trigger (e.g., explosives)
Good	stable conditions

Table 3. Frequency classes of snowpack stability, taken from EAWS (2022c, Table 2).

Frequency class	Description	Evidence (e.g., observations)
Many	Points with this stability class are abundant.	Evidence for instability is often easy to find.
Some	Points with this stability class are neither many nor a few, but these points typically exist in terrain features with common characteristics (i.e., close to ridgelines, in gullies).	
A few	Points with this stability class are rare. While rare, their number is considered relevant for stability assessment.	Evidence for instability is hard to find.
None or nearly none	Points with this stability class do not exist, or they are so rare that they are not considered relevant for stability assessment.	

Table 4. Avalanche size classes, taken from EAWS (2022c, Table 3).

Size class	Label	Destructive potential
1	Small	Unlikely to bury a person, except in run out zones with unfavorable terrain features (e.g., terrain traps).
2	Medium	May bury, injure, or kill a person.
3	Large	May bury and destroy cars, damage trucks, destroy small buildings and break a few trees.
4	Very large	May bury and destroy trucks and trains. May destroy fairly large buildings and small areas of forest.
5	Extremely large	May devastate the landscape and has catastrophic destructive potential.

distribution of stability classes across a region by combining sparse point observations and model data (when available), and their expertise and experiences. The estimated proportion of potentially unstable points, relative to a specific triggering level, reflects the average likelihood of triggering an avalanche in avalanche terrain within a region. This likelihood, combined with the potential avalanche size, determines the regional danger level. This approach aligns with the hazard chart in the CMAH, which categorizes avalanche danger based on the likelihood and size of avalanches (Statham et al., 2018).

3.2 EAWS Matrix survey

The revision of the factors determining avalanche danger by the EAWS in 2022 (Sec. 2.3, Tables 2-4) led to a mismatch compared with the terminology used in the *EAWS-Matrix-v2017* and EADS (Table 1). Therefore, as a first step, a matrix with the updated terminology was needed.

Most of the previous matrices (EAWS, 2005, 2017) were developed relying on the joint experience of a small group of forecasters consisting, for instance, for the *Bavarian Matrix* of one forecaster from Austria, Germany, France, Italy, Spain, and Switzerland. Unfortunately, the process on how the avalanche danger levels for individual cells within the matrices were assigned, was not documented. Beside the data-driven matrix developed by Techel et al. (2020), which relied on Swiss data and the Swiss perspective of interpreting danger levels, there is a general lack of data allowing a quantitative characterization of the danger levels. Moreover, even if relevant data were available in time and space, assigning a danger level to available evidence remains an expert judgment as avalanche danger cannot be measured or calculated (by algorithms) in a strict sense (e.g., Elder and Armstrong, 1987; Schweizer and Föhn, 1996).

3.2.1 Data and Methods

Given the subjective nature of avalanche danger assessments and the lack of relevant objective data for revising the Matrix, expert elicitation offers a structured and transparent method to harness expert judgment in complex, data-sparse contexts where human perception is central (Rowe and Wright, 2001). We therefore followed a similar path as for previous matrix versions by combining multiple expert opinions and drawing on the collective knowledge of avalanche forecasters and their perception of the factors and danger levels. It is well known that the meaning of terms can vary across individuals, cultures, and languages, and even within the same individual depending on the context (e.g., Ogden and Richards, 1925; Morgan, 2017). Therefore, some variability in how combinations of factors were linked to danger levels was expected. To minimize linguistic and cultural bias in the final matrix, we deliberately sought input from a broad cross-section of forecasters across EAWS.

Compared to earlier revisions, the current survey engaged a larger and more diverse group of experts. All EAWS forecasters were considered to possess the necessary expertise and were therefore regarded as equally competent to contribute to this task. This approach is grounded in the principle that the aggregated judgments of multiple independent experts tends to be more accurate than those of a single individual (e.g., Stewart, 2001). Additionally, by actively involving EAWS forecasters to contribute their interpretation of the matrix with the updated terminology and definitions, we aimed to gain broader engagement and greater acceptance of the revised version.

3.2.2 Survey

We invited avalanche forecasters to participate in a survey via the EAWS mailing list and/or the heads of warning services during the spring of 2022. We provided the following instructions:

1. Assign a danger level for each combination of classes describing snowpack stability, the frequency of snowpack stability, and largest expected avalanche size (Tables 2-4). For instance, assign a danger level to a scenario that could be described as «*Many* locations exist, where *poor* snowpack stability prevails. Avalanches can reach up to *size 3*.» , where italicized words describe the classes determining avalanche danger.
   (a) Begin with the most unfavorable stability class (*very poor*), which is typically associated with natural avalanches (Table 2), and assign a danger level to every frequency – avalanche size – combination.
   (b) Next, consider *poor* as the determining stability class. Assume that the frequency of locations with stability class *very poor* is *none or nearly none*, or at most *a few* (Table 3).
   (c) Repeat the process for *fair* stability. When *good* is assessed as the lowest stability class, avalanche danger is low.
2. Indicate a primary (more weight) and secondary danger level (less weight) if uncertain between two danger levels.
3. Leave the cell empty if a combination of factors is implausible or if unsure about the appropriate danger level.

Participants were encouraged to fill in all cells for which they felt confident assigning a danger level, leaving the stability category *fair* as optional with the aim to increase participation rates.

Following best practices for expert elicitation, we instructed forecasters to complete this task independently of other forecasters. Most importantly, the danger levels determined for specific combinations of stability, frequency, and avalanche size should not be discussed among forecasters until after they had submitted their responses.

We received 60 responses to the survey. To derive the updated matrix, we additionally considered the following sources:

- Working group members provided their version of the matrix at a meeting in 2019, and again in 2022 (N = 5 and 9, respectively). We employed the test-retest reliability methodology (Ashton, 2000) to evaluate the consistency of their responses and to obtain more reliable estimates. Additionally, the second round served as a pilot study to test the survey distributed to EAWS forecasters outside the working group.
- We incorporated two quantitative studies into our analysis (N = 2; Swiss data: Techel et al., 2020; Hutter et al., 2021).

In total, we had 76 responses from 12 different European countries (Table 5), which we consider a comprehensive pool of opinions reflecting the current state of avalanche danger assessment practices in Europe.

3.2.3 Survey analysis

In line with best-practice approaches when combining judgments from experts (e.g., Dietrich and Spiekermann, 2023), and not favoring any one opinion, we opted to calculate the median danger level for each combination of stability, frequency, and

Table 5. Distribution of the 76 matrix responses received by country. Forecasters in the Czech Republic, Finland, Iceland, Poland and Slovakia were approached, but did not respond.

Country	N
Andorra	3
Austria	4
France	7
Germany	5
Great Britain	7
Italy	18
Norway	15
Romania	1
Slovenia	1
Spain	5
Switzerland	8
Sweden	2

avalanche size. In addition, we checked whether the median danger level was also the danger level proposed by the majority of respondents. Since respondents could provide both a first and second danger level, we weighted their answers accordingly:

- If a forecaster provided a single danger level, this danger level was weighted with 100.
- If a forecaster provided two danger levels, the first danger level was weighted with 67 and the second with 33.

3.2.4 Survey results

Figure 1 shows the distribution of responses for each factor combination and danger level. As can be seen, a range of factor combinations was used for each danger level. While the survey provides insights into the most typical combinations for each danger level, there were also some combinations, which were rarely or never selected (blank cells). In line with the definition of the avalanche danger levels, Figure 1 shows that, as danger levels increase, snowpack stability decreases while frequency and avalanche size increase. Notably, the combinations with the highest response rate for each danger level often have secondary choices diagonally above or below that value. This suggests that two factors can offset each other to qualify for the same danger level. For instance, a higher probability of triggering might be balanced by lower consequences (smaller avalanches).

Rank-ordering the danger level responses for each combination of stability, frequency, and avalanche size, we derived the median danger level, referred to as D^1, and any second danger level, D^2, falling within the interquartile range (Figure 2a). Analyzing the responses across the 45 cells, we find that 27 cells contain a D^2, indicating considerable variability in opinions. A clear majority vote existed for only 18 of the 45 possible factor combinations (Fig. 2b). Not surprisingly, the cells with highest agreement define the limits of the danger scale (*fair-a few-1*, $D^1 = 1$: 97%; *very poor-many-5*, $D^1 = 5$: 99%; Figure

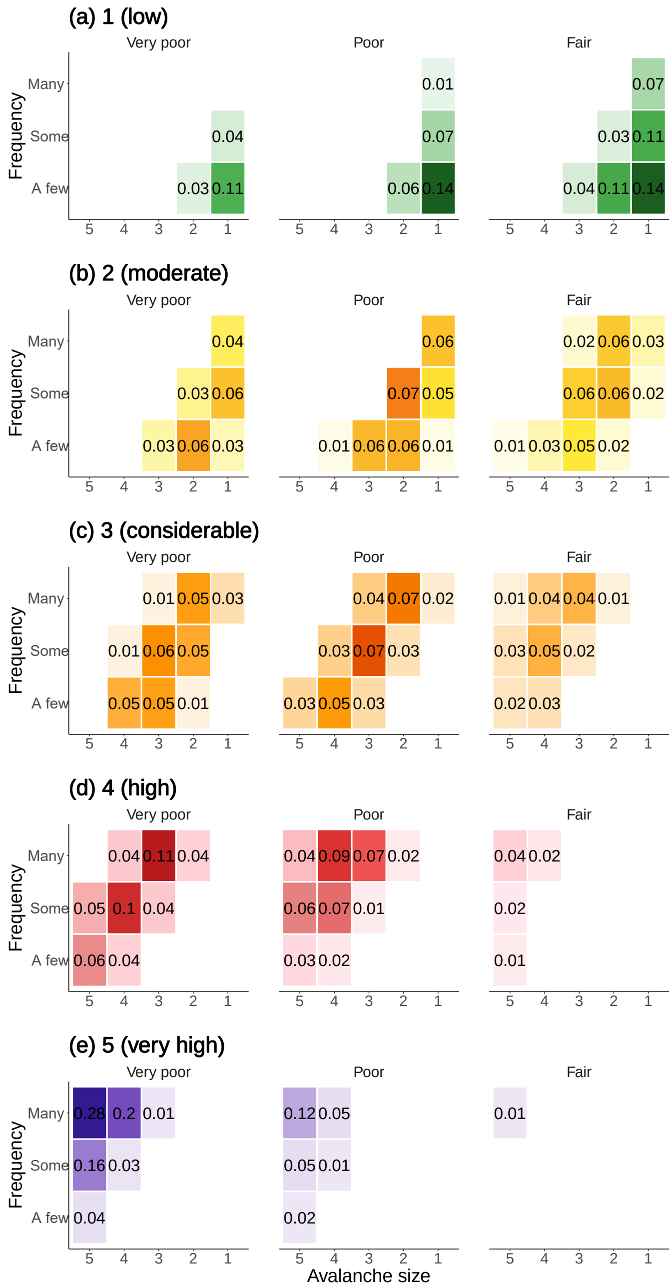


Figure 1. Distribution of survey responses for each danger level (a: $D = 1$ to e: $D = 5$). Shown are the proportions for each combination of stability, frequency, and avalanche size summing up to 1 for each D. Values are displayed if they received ≥ 0.01 of the votes. Stronger color saturation indicates a larger proportion of responses favoring a specific combination.

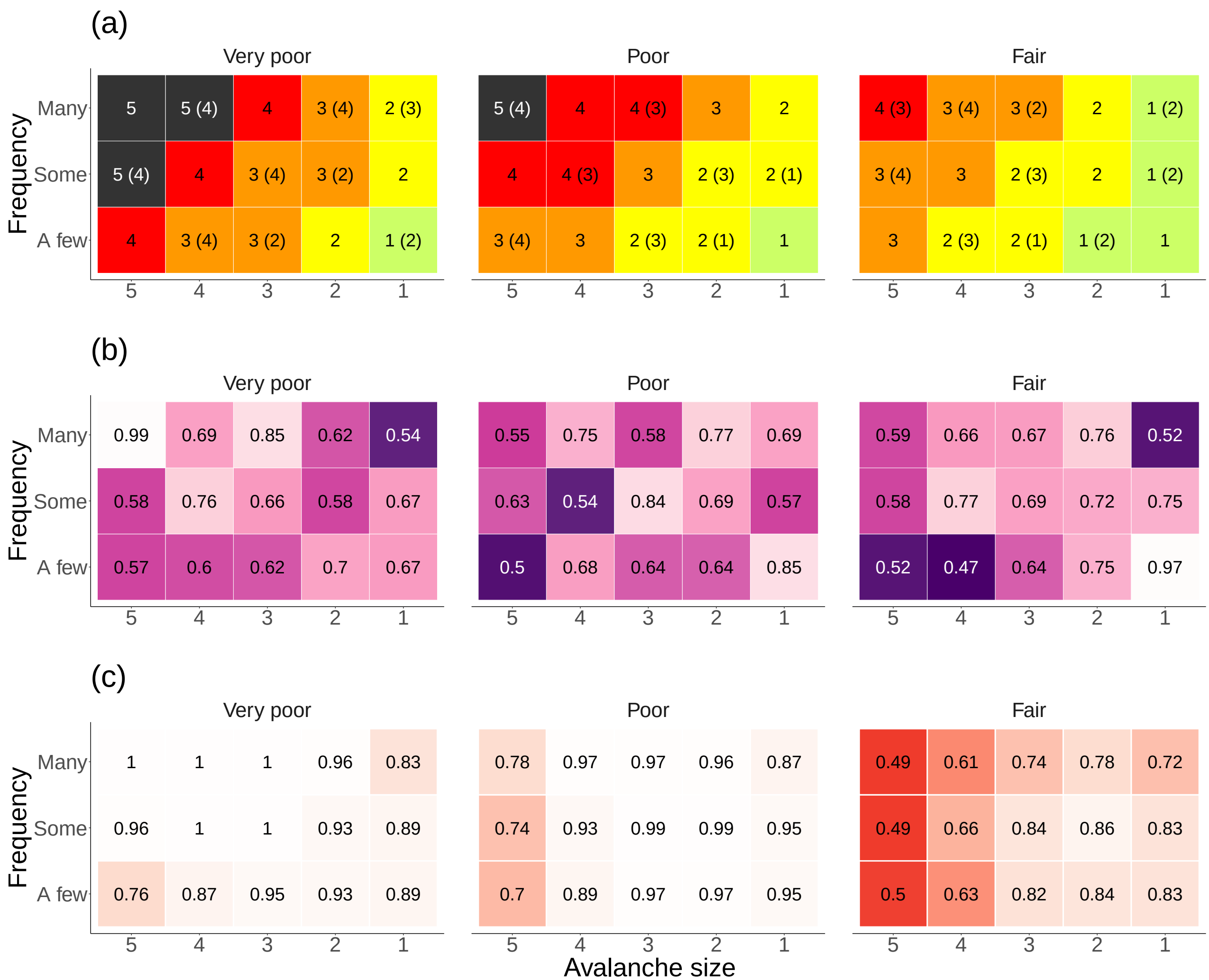


Figure 2. Survey responses for each combination of stability (panels), frequency (y-axis), and avalanche size (x-axis). (a) Median danger level (D^1), with the second most frequent level (D^2) shown in brackets if within the interquartile range (see text for details). (b) Proportion of responses that agree with D^1. (c) Proportion of responses providing a danger level estimate. Stronger color saturation indicates lower agreement (b) or fewer responses (c).

2b). The other two cells that stand out with regard to a high agreement of responses are *very poor-many-3* ($D^1 = 4$: 85%) and *poor-some-3* ($D^1 = 3$: 84%). These two combinations align well with the description of danger levels 3 (considerable) and 4 (high) in the EADS (Tab. 1), which likely explains the clear preference for one danger level in the survey. Otherwise, cells of comparably high agreement are scattered across the matrix, with no obvious pattern connected to one of the factors or to D. On average across all cells, one danger level was supported by 67% of the votes, the remaining votes generally went to a second danger level. Seven combinations showed particularly low agreement rates (proportion ≤ 0.55), indicating that the median danger level may be less representative for these cases (e.g., *fair-a few-4*).

Figure 2c illustrates the support, or the percentage of responses, for each specific combination. On average, respondents provided danger level values for 85% of the possible 45 combinations. Notably, cells with *very poor* and *poor* stability received responses from 72 of the 76 respondents ($\geq 95\%$) for 17 of the 30 combinations. Although stability *fair* was optional in our survey, it received responses in over 82% of cases when combined with frequency classes *a few* and *some* and avalanche *sizes 1, 2, and 3*. *Fair* stability had lower response rates when paired with avalanche size 4 ($\leq 66\%$) or size 5 ($\leq 50\%$). Possibly, this indicates that a considerable share of forecasters rated these combinations as less plausible.

It is not surprising that the 76 responses from various European countries and warning services revealed considerable variability in the assignment of D across most factor combinations. Moreover, as shown in EAWS (2022b), 'cultural' differences can be observed when comparing responses by country. For instance, the mean response by Scottish forecasters resulted in five matrix cells with $D^1 = 5$, whereas only two such cells were assigned $D^1 = 5$ by Norwegian or Swiss forecasters. Similar 'cultural' differences have been documented before, such as when assigning danger levels (Lazar et al., 2016; Techel et al., 2018) or estimating avalanche size (Hafner et al., 2023). Despite the EADS being in use for three decades, the absence of unambiguous, standardized guidelines – and a shared understanding of definitions – likely contributes to these variations across European Avalanche Warning Services (Techel et al., 2018).

Given these divergent perceptions of danger levels, it was all the more important to involve a large number of forecasters with varied operational backgrounds to ensure that the updated Matrix would reflect a broad and representative understanding across services.

4 EAWS matrix and associated workflow

The findings presented above led to the development of an updated matrix (Figure 3), hereafter referred to as the *EAWS Matrix* or simply the *Matrix*. The design of the Matrix builds on the recognition that the frequency of locations with the weakest snowpack stability is often the most decisive factor for determining the avalanche danger level (Techel et al., 2020). This concept is reflected by displaying three separate panels for the stability classes *very poor*, *poor*, and *fair*, which are connected by arrows from left to right (Figure 3). For each stability class, combinations of frequency (y-axis) and avalanche size (x-axis) are summarized in a separate panel. The layout supports a step-by-step assessment: the forecaster starts in the upper left corner, where the most severe conditions are represented, and works through the Matrix by sequentially ruling out less likely combinations. This progression helps ensure that more serious scenarios are considered first, before settling on the cell that best reflects the expected conditions.

To assign a danger level using the Matrix, forecasters begin by evaluating the frequency of locations with *very poor* stability. If such locations are absent or deemed irrelevant for danger assessment (i.e., *none or nearly none*, see Table 3), the assessment proceeds to the next stability class, following the directional flow of the Matrix. This stepwise evaluation may continue through the *poor* and, if necessary, *fair* classes. If stability is assessed as *good*, the danger level is set to *1 (low)* by default. In situations

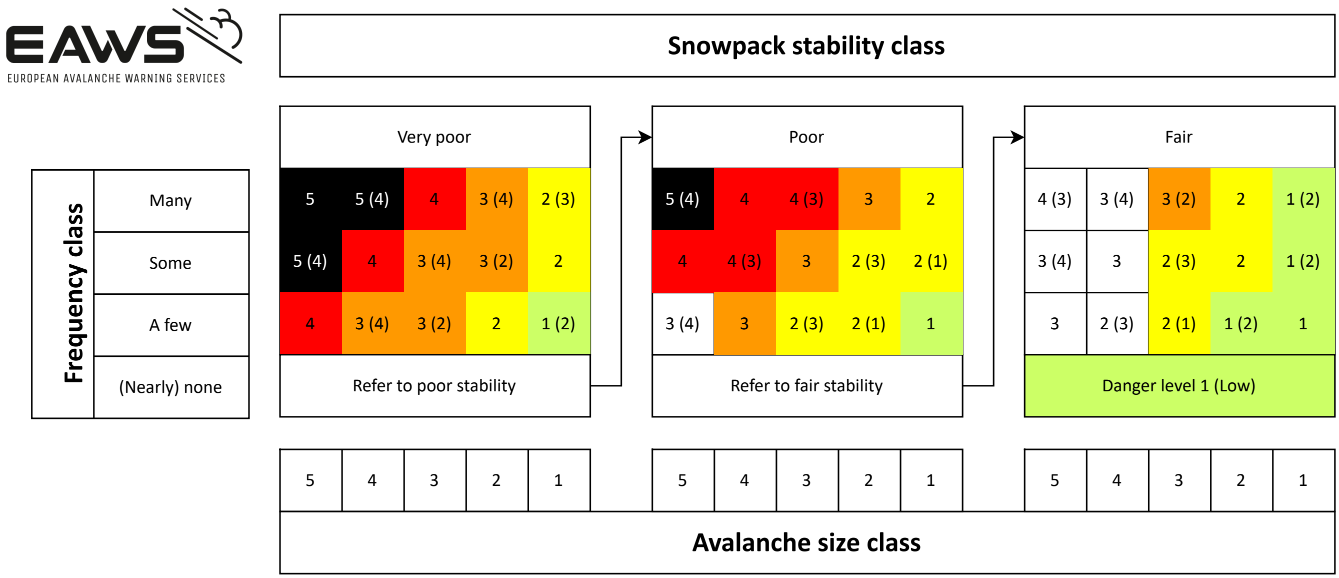


Figure 3. EAWS Matrix, as accepted by the EAWS General Assembly in 2022 (taken from EAWS, 2022c). For a detailed explanation refer to the text.

where both the lowest and next-lowest stability classes are relevant – e.g., when the latter is significantly more frequent – forecasters may consider more than one panel. The final step involves estimating the largest avalanche size that can be reckoned with under the observed or anticipated conditions.

The combination of selected stability, frequency, and avalanche size classes results in one matrix cell indicating the danger level that best represents the situation within a region. However, as the survey results did not always yield a clear danger level consensus for a given factor combination (Figure 2b), the matrix displays either one or two danger levels per cell. Displayed are the respective integer values of the danger levels (e.g., 1 for *1 (low)*). The median danger level, D^1, reflects the most common and average response among forecasters and determines the cell's color. If the interquartile range of responses includes a second, distinct danger level, this level is displayed in brackets as D^2. By including a second danger level, the matrix intentionally retains the variation in expert opinion. For example, for the combination *very poor – some – size 3* (Figure 3), the matrix shows $D^1 = 3$ and $D^2 = 4$. As illustrated in Figure 2b, 34% of forecasters favored a danger level other than *3 (considerable)* for this combination. Matrix cells are left uncolored if fewer than 70% of respondents provided a danger level estimate (Figure 2c).

To support the operational application of the EAWS Matrix, the EAWS working group developed a workflow outlining the necessary steps for determining the avalanche danger level within a warning region (Müller et al., 2023). This workflow, like the Matrix itself, is largely aligned with the CMAH, but is explicitly tailored to the context of public regional avalanche forecasting. It assumes that the forecast area is large enough to include multiple mountains, elevation bands, aspects, and varied terrain features such as ridges, gullies, and open slopes. As a result, terrain is not treated as an independent factor influencing

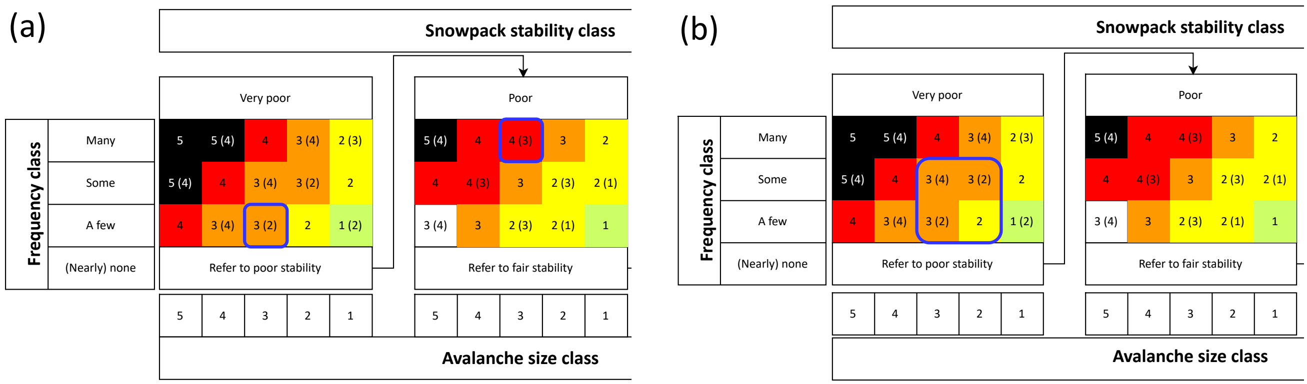


Figure 4. EAWS Matrix (extract) with several cells marked as relevant (blue border) to accommodate (a) a range of possible combinations or (b) uncertainty. In (a), two combinations of stability and frequency are considered (*very poor - a few*, *poor - some*), in (b) uncertainty relates to frequency (*a few* or *some*) and avalanche size (*size 2 or 3*). For explanations refer to text.

the danger level. However, specific terrain features might be mentioned in the corresponding avalanche forecast (e.g., Hutter et al., 2021).

The workflow entails assessing all relevant avalanche problems within a region, evaluating snowpack stability, frequency, and avalanche size for each of them, and then using the EAWS Matrix to assign a danger level. Each avalanche problem is assessed separately. If two Matrix cells are considered relevant for a single problem, the one resulting in the higher danger level is chosen (Figure 4a). The highest danger level across all considered avalanche problems is then communicated for the warning region. In situations with overlapping avalanche problems, the issued danger level may exceed that of the individual problems. This structured approach ensures that all relevant factors are systematically evaluated, promoting consistency in the assessment of avalanche danger levels.

5 Revision process – Step 2: Operational testing

The EAWS Matrix reflects the collective judgment of many European avalanche forecasters, but was initially developed as a desktop exercise—a so-called *cold-state* assessment (Roiser and Sahakian, 2013), as the experts answered the survey outside an operational context and without the emotional or situational pressures of a real forecast setting. In psychology, this distinction refers to cold cognition – reasoning in a calm setting without emotionally charged consequences – versus hot cognition, which involves decision-making under time pressure or stress (e.g., Roiser and Sahakian, 2013; Loewenstein, 2005). To transition from the conceptual foundation to a reliable tool for operational danger level assessment, we evaluated how the Matrix performed in day-to-day forecasting practice.

We focused on two critical aspects of working with the Matrix, presented in two separate studies: one assessed the reliability with which forecasters could estimate the Matrix input factors (Techel et al., 2024a), as reliable input estimation is a prerequisite for meaningful use of the Matrix; the other examined how the Matrix was applied during real-time operational forecasting

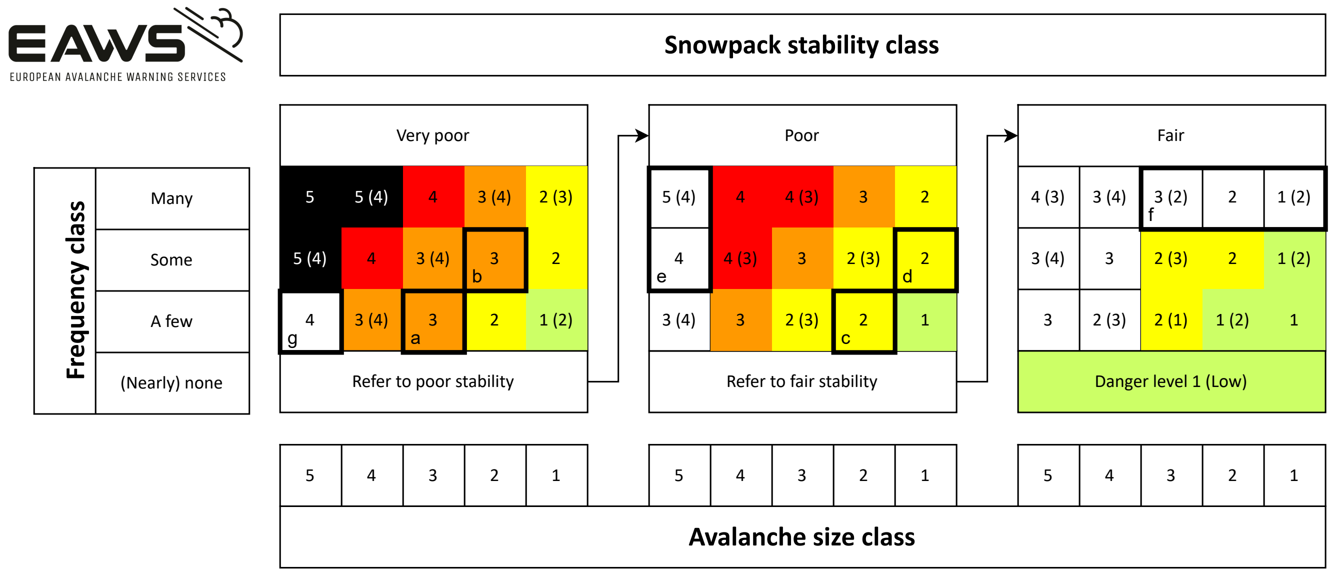


Figure 5. Revised EAWS Matrix integrating insights from Techel et al. (2025). Cells *a–d* consistently associated with a single danger level (D) during operational use and therefore no longer display an alternative level (D^2). Cells *e–g*, which received limited support in the expert survey and were not or rarely selected during operational forecasting, are shaded white to highlight elevated uncertainty and the lack of consensus among European avalanche forecasters.

across Europe (Techel et al., 2025). Below, we summarize the key findings most relevant for improving the Matrix and its associated workflow, based primarily on data collected from 26 European warning services over one to three forecasting seasons, following the Matrix's initial release in 2022 (EAWS, 2022c).

The operational analysis presented in Techel et al. (2025) revealed two main insights, both of which contributed directly to the revised Matrix presented in Figure 5. First, several Matrix cells were rarely or never used in operational practice ($< 1\%$ of cases), meaning the danger levels assigned to these cells could not be empirically validated. Notably, these same cells corresponded to cells with low support ($\leq 80\%$) in the expert survey (Figure 2b). To reflect the resulting uncertainty, these six cells (labeled *e–g* in Figure 5) are now white in the revised Matrix. Second, the analysis showed that some Matrix cells were used almost exclusively for a single danger level, even though the Matrix had displayed two levels (with one in brackets). To reflect this stronger operational consensus, we removed the bracketed danger level from the four affected cells (marked *a–d* in Figure 5).

6 Discussion

The main purpose of the EAWS Matrix is to enhance consistency between individual forecasters and warning services. To ensure a consistent and practical application of the EAWS Matrix, it is crucial that the definitions for the factors are clear and easily applicable in an operational setting. For instance, avalanche size is defined based on physical measurements, such as volume or mass, or by the destructive potential of the avalanche. Similarly, the definition of snowpack stability is closely linked to observable triggering mechanisms (e.g., explosives or a skier). Thus, both avalanche size and snowpack stability can be assessed using observational data. These definitions, grounded in physical evidence, also support clearer mental imagery – that is, forecasters can more readily form vivid internal representations of what a size 3 avalanche or *very poor* stability might look like, even in the absence of direct observation. In contrast, it is difficult to unambiguously define frequency classes, particularly when considering that the frequency of locations with *very poor* or *poor* stability is generally low. Moreover, the number of potentially unstable locations must often be inferred from sparse observations, though, models may increasingly provide this information (Herla et al., 2024; Techel et al., 2024b). When relevant data is limited or unevenly distributed within a region, the uncertainty of the assessment increases. Given clear definitions, it would be crucial that all forecasters possess a sound understanding of and consistently adhere to these. However, even if definitions for all factors and their classes were clear, inconsistencies cannot be completely eliminated. The interpretation of current conditions, often based on limited observations, combined with the inherent uncertainties in numerical weather prediction models, will inevitably lead to variations in interpretation among forecasters. Thus, inconsistency also becomes a function of data availability and reliability.

Improving the reliability of factor assessments is essential for consistent and accurate use of the EAWS Matrix (Techel et al., 2024a). This can be supported by: (1) increasing the availability of relevant data, such as short-term snowpack simulations to reduce uncertainty; (2) strengthening forecasters' skills in information retrieval and interpretation through targeted training and regular operational exchange; and (3) aligning forecast resolution – spatially, temporally, and categorically – with the resolution of forecasters' assessments given the available data. It is also important to regularly compare how different forecasters assess the factors for the same conditions. If their assessments vary widely, consistency can be improved through focused training and by combining input from several forecasters, making use of the "wisdom of crowds" to increase overall accuracy (Techel et al., 2024a).

Currently, about half of the Matrix cells do not show full consensus and still include a secondary danger level in brackets (D^2). While many of these cells are rarely used, two stand out as being frequently selected for two adjacent danger levels—both in the survey and in operational practice: *poor–some–size 2* and *very poor–some–size 3* (Techel et al., 2025). Showing two danger levels thus reflects a persistent ambiguity. Operational testing, however, did not clarify the reasons behind this ambiguity or offer clear strategies for resolving it. Particularly in warning services where forecasters more frequently chose D^2 over D^1, *poor–some–size 2* was often also linked to 3 (considerable). In contrast, other services assigned this danger level primarily when conditions were assessed as having either lower stability (*very poor*), higher frequency (*many*), or larger avalanche size (*size 3*) (Techel et al., 2025). This highlights a core challenge: the Matrix's structure itself influences how it is applied – particularly among forecasters who tend to stick with the primary danger level. As such, further targeted discussion and investigation of these transition zones is critical to refine guidance and reduce interpretive variability in Matrix use.

It is essential that forecasters can express uncertainty inherent in the forecasting task when working with the Matrix. As suggested in Sec. 4, this may include the option to select multiple cells. To facilitate discussion in case of variations, forecasters could indicate where within a class their assessment lies – toward the lower or higher end, or near the center (e.g., as in Switzerland Lucas et al., 2023). Indicating the relative trends within a factor class could help identify patterns, inform consensus-building, and ultimately highlight whether further subdivision of broad classes like *some* is warranted.

6.1 Relation to Conceptual Model of Avalanche Hazard (CMAH)

The CMAH provides a systematic framework for avalanche hazard assessment by addressing avalanche problems, their location, the associated likelihood of avalanches, and their size. It has a broad scope and was designed to serve various avalanche operations from back-country guiding to road safety to regional public forecasting. In contrast, the EAWS Matrix was developed specifically to standardize regional public avalanche forecasts across Europe.

While both the CMAH and the EAWS Matrix aim to support consistent and reliable hazard assessments, they handle the spatial component differently. The CMAH focuses on the spatial distribution of the avalanche problem. The EAWS Matrix, however, centers on the frequency of locations with the weakest snowpack stability – an approach that reflects empirical findings that the frequency of the lowest stability class is often the most decisive factor when determining the danger level (Techel et al., 2020). Importantly, these two concepts – spatial distribution of avalanche problem and frequency of snowpack stability – do not always align. Presumably, it is generally easier to assess where the avalanche problem exists in the terrain than it is to assess the frequency of the different classes of snowpack stability. Thus, simply translating the spatial distribution of an avalanche problem to the frequency of potential triggering locations given a specific trigger, can lead to a mismatch likely overestimating the frequency term and, consequently, leading towards higher danger ratings. Whether the reliability of assessing the spatial distribution or the frequency class is higher has not yet been investigated. However, in forecasts, often a combination is used (Hutter et al., 2021): frequency descriptors are often used to describe the number of triggering locations in a region and can be linked to specific danger levels. However, they are commonly paired with location-specific narrative, helping forecasters convey both *how often* avalanches may occur and *where* within the terrain they are most likely.

Despite these differences, the Matrix and CMAH are complementary. Several European services where forecasters are trained primarily using the CMAH – such as in Sweden and Scotland – have successfully integrated the Matrix into their operations. However, it is important to emphasize that neither CMAH nor the Matrix in its current state with a D^2 should be applied rigidly. Avalanche forecasting is an iterative process carried out under significant uncertainty, often with sparse or ambiguous data. The Matrix is intended to support structured thinking and reduce inconsistency in similar conditions. Its design has been shaped by the CMAH's structured approach, adapted to the operational needs of regional forecasting in Europe.

As discussed in Section 4, the Matrix guides forecasters from left (very poor stability) to right (fair stability), reflecting the central role of the weakest stability class in determining D (Techel et al., 2020). Conceptually, the Matrix can be seen as a variant of the CMAH hazard chart. In this interpretation, snowpack stability and its frequency jointly represent the CMAH dimension of the *likelihood of avalanches*, which is then combined with *avalanche size*. This approach follows the alternative layout proposed as ADAM (avalanche danger assessment matrix) by Müller et al. (2016, , see also FigureA2) and further developed in the data-driven Matrix by Techel et al. (2020, , see also Figure A4).

(a) Frequency of snowpack stability

Stability Matrix		Frequency class		
		Few	Some	Many
Snowpack stability class	Very poor	VpFe	VpSo	VpMa
	Poor	PFe	PSo	PMa
	Fair	FFe	PSo	FMa

(b) Sorted by lowest stability class

Danger Matrix		Avalanche size class				
		1	2	3	4	5
From stability matrix	VpMa	2 (3)	3 (4)	4	5 (4)	5
	VpSo	2	3	3 (4)	4	5 (4)
	VpFe	1 (2)	2	3	3 (4)	4
	PMa	2	3	4 (3)	4	5 (4)
	PSo	2	2 (3)	3	4 (3)	4
	PFe	1	2	2 (3)	3	3 (4)
	FMa	1 (2)	2	3 (2)	3 (4)	4 (3)
	FSo	1 (2)	2	2 (3)	3	3 (4)
	FFe	1	1 (2)	2 (1)	2 (3)	3

(c) Sorted by resulting danger level

Danger Matrix		Avalanche size class					
		1	2	3	4	5	
From stability martix	VpMa	2 (3)	3 (4)	4	5 (4)	5	
	PMa	2	3	4 (3)	4	5 (4)	Very similar
	VpSo	2	3	3 (4)	4	5 (4)	
	PSo	2	2 (3)	3	4 (3)	4	
	VpFe	1 (2)	2	3	3 (4)	4	Very similar
	FMa	1 (2)	2	3 (2)	3 (4)	4 (3)	
	FSo	1 (2)	2	2 (3)	3	3 (4)	Very similar
	PFe	1	2	2 (3)	3	3 (4)	
	FFe	1	1 (2)	2 (1)	2 (3)	3	

Figure 6. EAWS Matrix (Fig. 5) rearranged to follow the CMAH workflow. Panel (a) shows a matrix of snowpack stability and frequency combinations, representing the *likelihood of avalanches* as defined in the CMAH. In panel (b), these combinations are paired with avalanche size and reordered by increasing snowpack stability. Panel (c) then sorts the same rows by decreasing resulting danger level (D), allowing visual identification of rows that produce very similar danger ratings. Rows where the maximum difference across all avalanche sizes is less than one danger level are marked with grey triangles and labeled "very similar." These rows can be considered for merging without significant loss of information, as demonstrated in the compact Matrix shown in Figure 7.

Figure 6 shows the EAWS Matrix rearranged according to the CMAH workflow. This layout facilitates comparisons across stability–frequency combinations and highlights opportunities for simplification, such as merging rows with near-identical danger ratings. A compacted version is presented in Figure 7.

Rearranging the Matrix according to the ADAM design aligns it with the classic structure of hazard matrices, where hazard increases from the lower left to the upper right corner (Duijm, 2015). This makes the connection to CMAH more visible and intuitive. The workflow also becomes closer to CMAH logic: first determine the likelihood of avalanches (through stability and frequency), then assess consequences (avalanche size). The layout also reveals structural improvements – such as merging similar rows – and highlights clusters of rarely used or unsupported combinations. Notably, problematic combinations like *very poor–some–size 3* and *poor–some–size 2* appear adjacent in this layout and span danger levels 2, 3, and 4, highlighting the continuous nature of avalanche danger and emphasizing the need for refinement. Compared to earlier matrices, specifically the ADAM matrix (Fig.A2) and the data-driven matrix (Fig.A4), the rearranged EAWS Matrix (Fig. 7) offers greater detail and is fully compatible with current EAWS standards.

A trade-off of this compact representation is that it obscures which specific stability–frequency combination led to a given danger level on the right hand side of the chart (Fig. 7). However, this information could still be tracked or annotated during operational use.

(a)

Stability Matrix		Frequency class		
		Few	Some	Many
Snowpack stability class	Very poor	D	B	A
	Poor	E	C	B
	Fair	F	E	D

(b)

Danger Matrix		Avalanche size class				
		1	2	3	4	5
From stability matrix	A	2 (3)	3 (4)	4	5 (4)	5
	B	2	3	4 (3)	4	5 (4)
	C	2	2 (3)	3	4 (3)	4
	D	1 (2)	2	3	3 (4)	4
	E	1	2	2 (3)	3	3 (4)
	F	1	1 (2)	2 (1)	2 (3)	3

Figure 7. Compact version of the EAWS Matrix layout shown in Fig. 6 panels (a) and (c). Rows highlighted in Figure 6c as being similar have been merged and are given the same letter, which can be transferred to (b) when combining with avalanche size.

7 Conclusions

Public avalanche forecasting requires both a robust assessment of current and future conditions and effective communication of the associated hazard. Today, this process is largely categorical in nature—using defined factor classes, avalanche problems, and danger levels. The quality and consistency of these forecasts depend not only on data availability and forecaster expertise, but also on the clarity, applicability, and shared understanding of the categories themselves.

In this paper, we presented the revision process behind the updated EAWS Matrix, involving broad engagement from European avalanche warning services. The updated Matrix (Section 5) reflects the most recent consensus among forecasters across Europe. It has been well received as both an operational forecasting tool and a training aid, offering a structured framework for determining avalanche danger levels (D) based on three key factors: snowpack stability, the frequency of snowpack stability, and avalanche size.

The introduction of a secondary danger level (D^2) in selected cells recognizes that uncertainty and disagreement still persist, especially in combinations with low survey response rates, different perceptions, or inconsistent operational use. Particularly noteworthy are the cells *very poor–some–size 3* and *poor–some–size 2*, which frequently span two danger levels (i.e., 3–4 and 2–3, respectively). These cases highlight the need for better definitions – especially of the frequency class *some* – and call for closer examination of transition zones between danger levels.

Improving the consistency of factor assessments will require progress on several fronts: increasing the availability of relevant data (e.g., high-resolution snowpack simulations), enhancing forecaster training and operational exchange, and aligning forecast resolution with the granularity of expert judgment. Evaluating and improving inter-rater reliability (IRR) is critical for ensuring forecast quality. Where IRR is low, interventions such as targeted training and forecast aggregation can improve consistency.

The Matrix should not be applied rigidly. Instead, we recommend allowing forecasters to select multiple cells when appropriate to reflect complex or uncertain conditions. Additionally, enabling forecasters to indicate where within a class their assessment lies (e.g., near the lower or upper end of "some") may support more nuanced and transparent decision-making.

While originally developed as a standalone tool, the EAWS Matrix closely aligns with the Conceptual Model of Avalanche Hazard (CMAH). Its structure and logic can be visualized in an ADAM-style layout – mirroring classic risk matrices – where likelihood and potential impact are considered sequentially. Such a redesign could simplify the Matrix, clarify transition zones, and emphasize its conceptual link to the CMAH.

At present, the updated Matrix, workflow, and terminology described here—and formally documented in EAWS guidelines (EAWS, 2022c)—diverge from the current European Avalanche Danger Scale (EADS). A revision of the EADS that incorporates these updated definitions, structures, and principles is overdue. The Matrix and its accompanying tools represent a significant step forward in harmonizing hazard assessment and risk communication across Europe, and ongoing monitoring, data collection, and collaborative refinement will be key to further progress.

Appendix A: Avalanche Danger Matrices

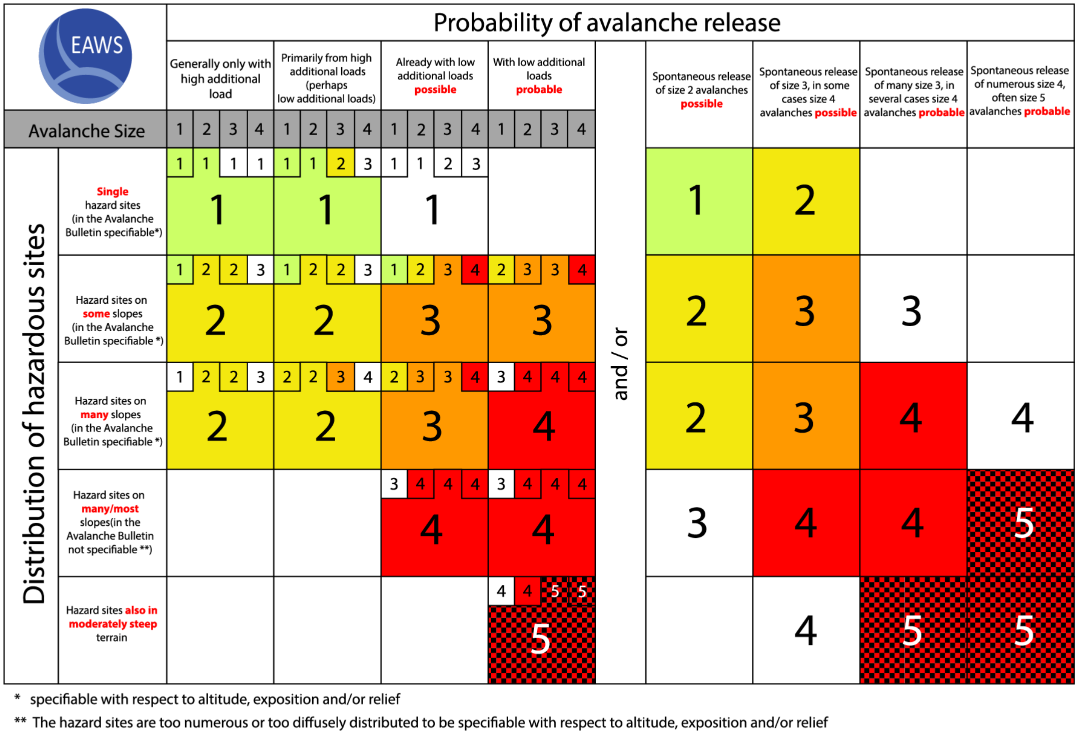


Figure A1. The figure depicts the EAWS-Matrix-v2017 (figure taken from EAWS, 2017), which is essentially identical to the Bavarian Matrix (BM EAWS, 2005) when considering the large cells only. The BM illustrates the distribution of hazardous zones against the probability of avalanche release. Initially, the left-hand side, which dealt with artificially triggered avalanches, lacked the factor of avalanche size entirely. Meanwhile, the right-hand side focused on naturally triggered avalanches, providing indications of expected sizes in the column headings. However, an update in 2017 integrated avalanche size (small cells) into the left-hand side as a third dimension, leading to its transformation into the EAWS-Matrix-v2017 (EAWS, 2017).

Appendix B: CMAH hazard chart

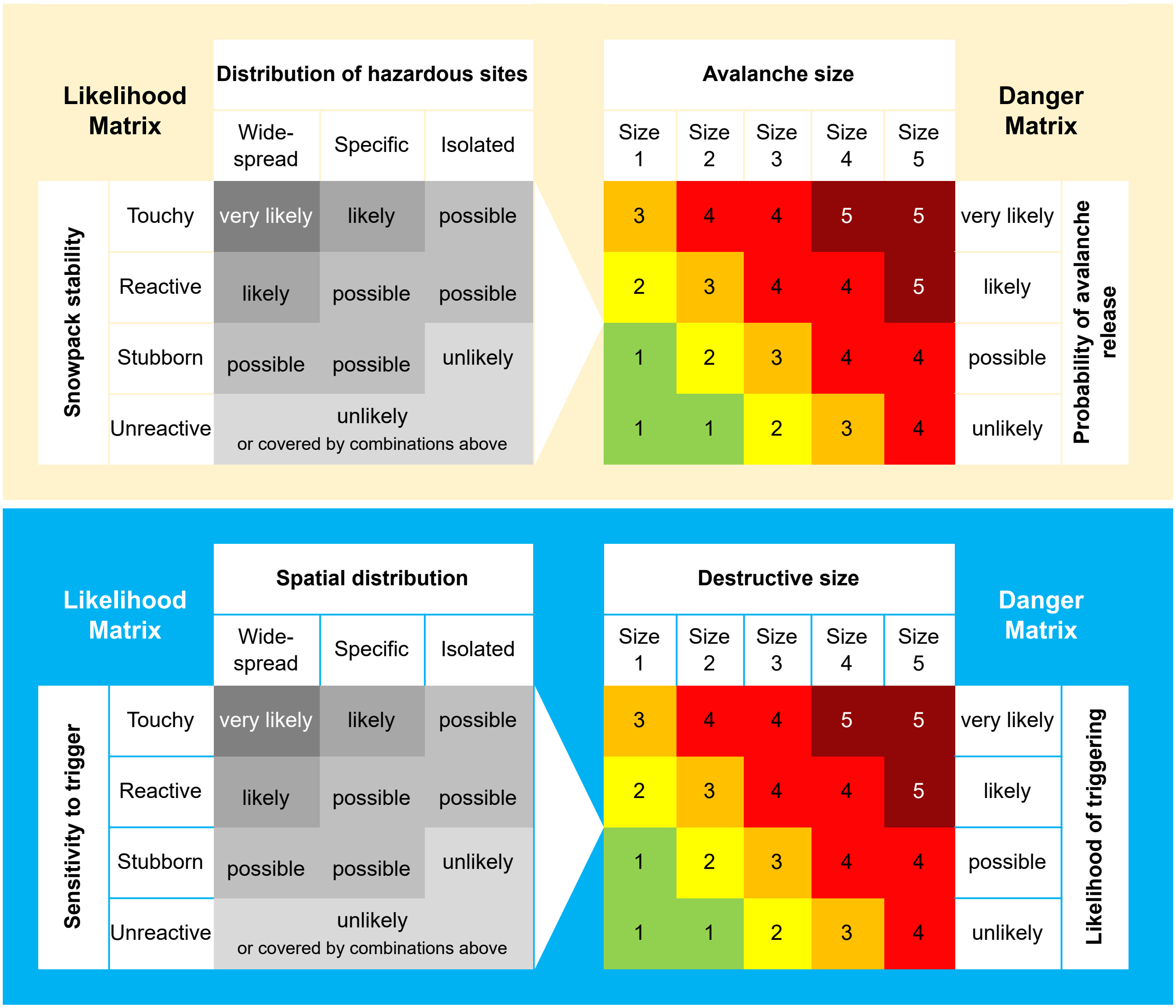
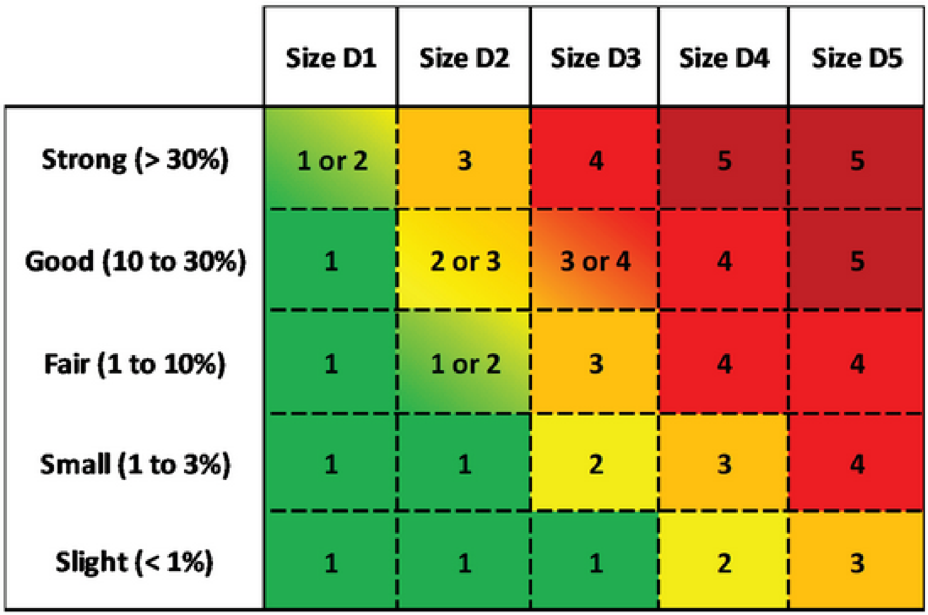


Figure A2. The Avalanche Danger Assessment Matrix (ADAM), as published by Müller et al. (2016), presents two versions: one aligning with the terminology of the European Avalanche Danger Scale (EADS, Table 1) at the top and another adhering to the Conceptual Model of Avalanche Hazard (CMAH) at the bottom. ADAM consists of a likelihood matrix (left-hand side), which defines likelihood terms based on the spatial distribution and snowpack stability (sensitivity to trigger), and the Danger Matrix (right-hand side), which provides guidelines for determining the appropriate danger level by combining the likelihood of triggering with avalanche size.



	Size D1	Size D2	Size D3	Size D4	Size D5
Strong (> 30%)	1 or 2	3	4	5	5
Good (10 to 30%)	1	2 or 3	3 or 4	4	5
Fair (1 to 10%)	1	1 or 2	3	4	4
Small (1 to 3%)	1	1	2	3	4
Slight (< 1%)	1	1	1	2	3

FIG. 2: GUIDANCE FOR COMBINING LIKELIHOOD OF AVALANCHES WITH AVALANCHE SIZE TO ASSIGN AVALANCHE HAZARD RATINGS (AFTER MULLER ET AL., 2016A; CLARK AND HAEGELI, 2018).

Figure A3. The likelihood matrix proposed by Thumlert et al. (2020) addresses concerns highlighted in their survey, revealing a broad spectrum of interpretations of likelihood terms outlined in the Conceptual Model of Avalanche Hazard (CMAH, Statham et al. (2018)) among avalanche professionals. The aim was to move away from likelihood terms commonly linked with higher probabilities and instead introduce levels of chance paired with a percentage range. The resulting likelihood matrix shown here bears resemblance to the danger matrix on the right-hand side of ADAM Müller et al. (2016). Intermediate levels are recommended for situations with higher chances and smaller avalanches.

a) stability matrix

snowpack stability	frequency: none*	few	several	many
very poor	**	D	B	A
poor	**	E	D	C
fair	-	-	E	E
good	-	-	-	-

** none or nearly none*

*** if none, refer to next higher stability class*

- no data

C cell contains less than 1% of the data

b) danger matrix

stability matrix	largest avalanche size: 1	2	3	4
A	**3** -4	**4** (-3)	**4**	**4**
B	**3** (-2/-1)	**3** (-2)	**3** (-2)	**4** -3
C	**2** (-3)	**2** -3	**3** -2	-
D	**1** -2	**2** -1	**2** -1	**3** (-2)
E	**1**	**1** (-2)	**1** (-2)	-

-3: >30%

(-3): 15-30%

Figure A4. Data-driven look-up table for avalanche danger assessment (figure and caption taken from Techel et al., 2020). The (a) *stability matrix* combines the frequency class of the most unfavorable snowpack stability class (columns) and the snowpack stability class (rows) to obtain a letter describing specific stability situations, the (b) *danger matrix* combines the largest avalanche size (columns) and the specific stability situations (letter) obtained in the stability matrix (rows) to assess the danger level. In (b): The most frequent danger level is shown in bold. If the second most frequent danger level was present more than 30% of the cases, the value is shown with no brackets, if present between 15 and 30% it is placed in brackets. In (a) and (b): Cells containing less than 1% of the data are marked.

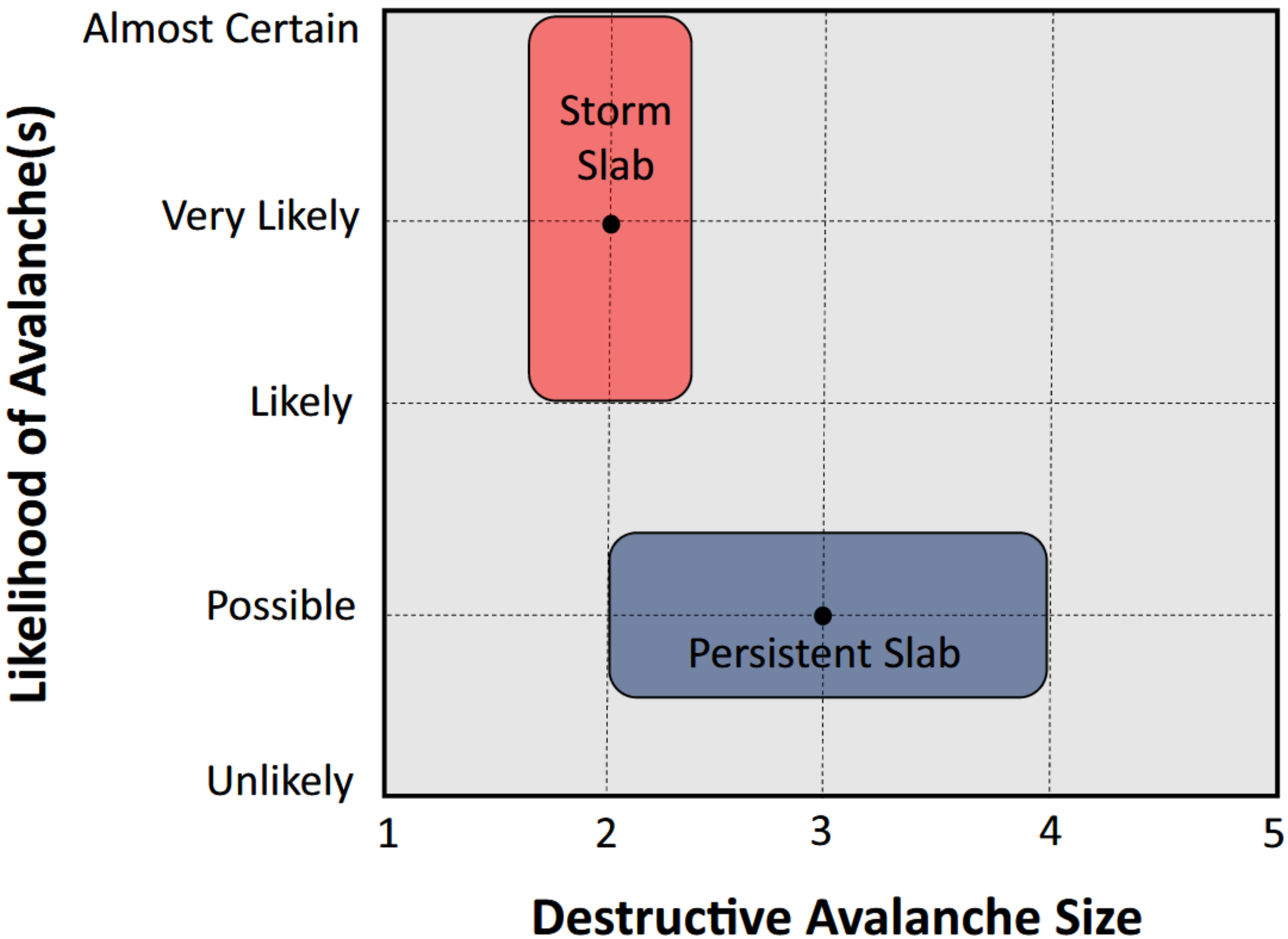


Figure B1. Avalanche hazard chart illustrating two avalanche problems, adapted from Statham et al. (2018, Fig. 3). The y-axis represents increasing *likelihood of avalanches*, while the x-axis indicates increasing *avalanche size*. In this example, persistent slab avalanches are considered *possible* with sizes ranging from 2 to 4, whereas storm slab avalanches are assessed as *likely to almost certain*, predominantly around size 2.

Code and data availability. Data and code will be published at the repository envidat.org, and will also be indexed at https://opendata.swiss/en/.

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