BRINGING THE EUROPEAN AVALANCHE DANGER SCALE TO THE 21ST CENTURY

Karsten Müller[1,*], Frank Techel[2], Christoph Mitterer[3], Stefano Sofia[4], Petter Palmgren[5], Nicolas Roux[6], Guillem M. Bellido[7], Lorenzo Bertranda[8], Giacomo Villa[9]

[1] *Norwegian Water Resources and Energy Directorate, Oslo, Norway*
[2] *WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland*
[3] *Avalanche Warning Service Tyrol, Innsbruck, Austria*
[4] *AINEVA*
[5] *The Avalanche Forecast Service at Swedish EPA*
[6] *Météo France*
[7] *Andorran Weather and Avalanche Service*
[8] *Meteomont Carabinieri*
[9] *Alpsolut, Livigno, Italy*

ABSTRACT: The European Avalanche Danger Scale (EADS) is the governing document for public avalanche warning services in Europe. It has been the common ground to assess and communicate avalanche danger, with literally no changes since its introduction in 1993. However, since then, more concepts and tools have been added to standardize the production and communication of public avalanche warnings. The most prominent are the introduction of *typical avalanche problems* and the *European Avalanche Warning Service (EAWS) Matrix*, revised definitions of key terms used during the forecasting process, and a workflow tying all these elements together. However, these developments have led to differences between the terminology used in the EADS and these newer concepts. Therefore, an updated danger scale is needed, which integrates these developments, and which focuses on communicating avalanche danger to the public. Thus, language should be simple and clear while unambiguously connected to the technical definitions. Moreover, as the danger scale is the standard used by all avalanche warning services in Europe, it needs to work well in many languages. As a first step working towards a new danger scale, we analyzed data on how the governing factors of frequency of snowpack stability and avalanche size are used in connection to the avalanche danger levels in an operational forecasting context. From these data, obtained from 15 warning services during the forecasting season 2022/2023, we extracted typical descriptions for the danger levels. It showed that these align well with the EADS at the higher danger levels. However, it also indicates that forecaster tend to emphasize instability over stability at lower danger levels. We present a brief danger scale based on usage data and discuss choices and challenges that must be tackled to bring the EADS up to date.

Keywords: avalanche danger scale, public avalanche forecasting

1. INTRODUCTION

Avalanche danger levels (*D*) are used in public avalanche forecasts to summarize the probability of avalanche occurrence and size of avalanches within a given region and period (EAWS, 2022). The European Avalanche Danger Scale (EADS) contains the definitions of the danger levels used by European avalanche warning services to communicate regional avalanche danger to the public. It is 5-level scale ranging from *1 - low* to *5 - very high* (Table 1). Avalanche danger increases exponentially from one level to the next, with a simultaneous increase in the likelihood of avalanches and avalanche size (Table 1; e.g., Schweizer et al., 2020a; Morgan et al., 2023).

*Corresponding author address:
Karsten Müller
Norwegian Water Resources and Energy Directorate
0301 Oslo, Norway;
tel: ++47 22 95 95 95;
email: kmu@nve.no

Mitterer and Mitterer (2018) have reconstructed and reported on the history behind the EADS, while there is otherwise little documentation on the process leading to a common European danger scale. Its definition is based on expert opinion by avalanche forecasters from the central Alps in 1993 who agreed on a common 5-level danger scale. Due to the lack of common guidelines, many forecasting services have established and published their own guidelines on how to apply the EADS or added additional columns on for example travel advice or typical danger signs at a given danger level (e.g., SLF, 2023). In addition, common situations that are not well described in the EADS have received their own jargon e.g., “skier's high” to express a low $D = 4$ or “low probability - high consequence” scenario often describing a high $D = 2$ or low $D = 3$.

The EADS was initially also applied in North America, however slightly different interpretation guidelines evolved also between Canada and the USA. In 2005, North American avalanche forecasters started a revision of the danger scale (Statham et al., 2010) that also lead to the development of

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

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); snow-machine; explosives. natural: without human influence.

a broader framework called the Conceptual Model of Avalanche Hazard (CMAH, Statham et al., 2018). Today, the NADS serves as a communication tool while the CMAH provides the technical definitions. Though, a direct link between the CMAH, designed as a general purpose framework, and the danger levels of the NADS has not been established.

Given the wide variability in avalanche conditions, compressed into a mere five potential categories, it is evident that each danger level encompasses a multitude of scenarios, of which few are explicitly described by the EADS, while many fall in between. Look-up tables – the Bavarian Matrix (e.g., Valt and Berbenni, 2013) and later the EAWS Matrix (Müller et al., 2023) – were introduced to resolve finer details and provide guidance for situations that are not explicitly described in the EADS. These look-up tables have undergone continuous development over the past two decades (Müller et al., 2016; Techel et al., 2020a; Müller et al., 2023). The European avalanche danger scale, in contrast, has remained unchanged since 1993. As a result, EADS and EAWS Matrix, initially closely linked, have gradually diverged. To ensure a unified and coherent framework for avalanche danger assessment and communication, it is essential to reestablish a robust connection between them.

As part of an EAWS work-group, the authors have worked on developing a workflow and revising the Matrix over the last 7 years. Many of our discussions have included the European Avalanche Danger Scale and its wording. We presented an updated matrix at the general assembly of the EAWS in June 2022 (Müller et al., 2023). After its inauguration, European avalanche service were encouraged to track their choices of the three factors in the EAWS Matrix along with the issued danger level over the coming forecasting season. We received data from 15 services that tracked their choices over longer periods during the 2022/22023 season (Müller et al., 2024). Müller et al. (2024) investigated how forecasters applied the EAWS Matrix and how each relevant factor (snowpack stability, its frequency, and avalanche size) was used at each danger level. In addition, the survey on the EAWS Matrix and data on its operational usage provide valuable insights on how avalanche danger levels are typically described in forecast products. In this paper, we use the same data to derive typical descriptors for each danger level and compare them to the existing European Avalanche Danger Scale.

The objective of this paper is to lay out potential ways forward to update and align the EADS with concepts and terminology that have evolved over the recent decades. It is intended to nourish discussion and will to a large extend contain experiences and opinions by the authors. We list points, that we think need to be considered and are open for discussions improving the EADS and related concepts.

2. METHODS & RESULTS

We continue on the analysis presented in Müller et al. (2024) focusing on their Table 8 which compares the most common terms chosen for the respective danger levels with the terms used in the EADS. We reproduced it here for readability (Table 2).
The *combined* column in Table 2 shows the class for the specific factor that was part of the most commonly used combination of factors e.g., the most common combination at D=2 was *poor - some - size-2*, closely followed by *poor - few - size-2*. The *individual* column shows the class that was commonly used at the given danger level independently of the combination with other factors. Using D=2 as an example again, we see that frequency *few* was chosen most often by forecasters. In all three columns, stability, frequency and avalanche size increase gradually with increasing danger level. Looking at each danger level, however, we can see that the usage data sometimes deviates from the standard in the EADS. At D=1 frequency is *few* in all three cases. While the EADS opens up for size-2 avalanches, the usage data favors *size-1* avalanches but rather sees an increased use of *poor* stability. The trend is even more pronounced at D=2 where *poor* stability is commonly used despite the EADS suggesting *fair* stability. This trend is slightly compensated by combining *poor* stability with the frequency *few* instead of *some* as suggested by the EADS. Avalanche size at D=2 is not well defined in the EADS - just stating “very large (size-4) avalanches are unlikely” - making a direct comparison to the most frequently used size (*size-2*) ambiguous. All three columns for 3-considerable resolve around *poor* stability, a frequency of *some* and an avalanche size of 3. However, for the individual factors stability shows a slight tendency to *very poor* and avalanche size to *size-2*. The EADS is more open with a frequency of either *some* or *many* and avalanche sizes of 3 or 4. At 4-high, we can see the best agreement between the usage of factors and the EADS. D=4 is generally described by *very poor* snowpack stability in *many* locations and avalanches of *size-3*. The EADS including also *size-4* avalanches, is the only difference.

2.1 Usage-driven danger level descriptions

Based on common classes at each *D* presented in Table 2, we have created a short description for each danger level in Table 3. In the upper table we have based the description on the most frequently used combinations, while the lower table shows an example when regarding the most frequent class used individually at each *D*.

The descriptions in Table 3 *a* and *b* are the same for D=1 and D=4, and vary only slightly for D=2 and D=3. When using the combined data D=2 and D=3 differ only by one avalanche size class. Looking at the classes individually, a larger gap opens with snowpack stability tending towards the next higher class at D=3 and frequency tending towards the next lower class at D=2. At D=2, both the *combined* and *individual* based description deviate clearly by one class in snowpack stability. We had no usage data for D=5.

3. DISCUSSION

The EADS has been in use since 1993. The Bavarian Matrix in 2005, and later the EAWS Matrix, have been developed in Europe as a refinement and additional tool to the danger scale (Müller et al., 2016, 2023). In North America, the CMAH and the NADS have been introduced as an extension and enhancement of the European danger scale in 2010 (Statham et al., 2010, 2018). Terminology in between Europe and North America have diverged, as has the terminology between the EADS and the EAWS Matrix and related concepts. It is imperative to establish a close link between the danger scale as it is central for regional avalanche forecasting and especially public communication of avalanche danger.

3.1 Objective of the danger scale

The first step towards an updated EADS is to define a clear objective on where and how it should fit into the newer concepts. Statham et al. (2010) stated “revisions to the danger scale as a public communication tool” to be one of their objectives when introducing the NADS. We suggest a similar objective when revising the EADS and relieving it of its double purpose of being both a public communication tool and of it being *the* technical description of avalanche danger.
When introducing the EADS in North America, the North American community saw several issues with the EADS (Statham et al., 2010). One issue was that the danger scale was used to communicate avalanche danger to the public, while it also served as the definition of the danger levels for the professional forecaster. These two purposes were often at odds as public communication requires simple language and classification, while the definition required clarity and detail on a technical level. Another major drawback was a lack of clarity in low probability - high consequence situations (Statham et al., 2010), which were not clearly defined in the scale. The dedicated goal of the danger scale was declared to be that of public risk communication (Statham et al., 2010). With this in mind a third column containing a travel advice, explaining in simple

Table 2: Characterization of danger levels as described in the EADS and the most frequent combinations used during the season 2022/2023 at the respective *D*. The latter summarizes the results shown in Figure 8 in Müller et al. (2024) for the seven groups of warning services, with the most frequent factor shown in the column *individual* and the most frequent combination of factors in the column *combined*. The first value indicates the most frequently used class or combination, values in brackets indicate if a second class or combination was associated with a danger level more than 30% of the time.

	Matrix use - combined			Matrix use - individual			EADS		
D	stab	freq	size	stab	freq	size	stab	freq	size
1 - low	F (or P)	Fe	1	F (or P)	Fe	1	F	Fe	1 or 2
2 - moderate	P	So (or Fe)	2	P	Fe (or So)	2	F	So	n.d., ¡4
3 - considerable	P	So	3	P (or VP)	So	2 (or 3)	P	So or Ma	$\leq$ 3 or 4
4 - high	VP	Ma	3	VP	Ma	3	VP (or P)	Ma	3 or 4
5 - very high	–	–	-	–	–	-	VP	Ma	4 or 5

Stability (stab): fair (F), poor (P), very poor (VP); frequency (freq): a few (Fe), some (So), many (Ma); avalanche size (size): 1 - 5.

Table 3: Table presenting concise descriptions of danger levels, highlighting the classes most frequently utilized. The upper table (a) showcases the predominant classes from the most frequently observed combination of classes. Conversely, the lower table (b) illustrates the single class most commonly associated with each danger level across all combinations.

a) Description based on single-most frequent combination of classes.

Danger level	Description
1 - low	Fair or occasionally poor stability exists in a few locations. Avalanches are generally small.
2 - moderate	Poor stability exists in some locations. Avalanches can reach medium size.
3 - considerable	Poor stability exists in some locations. Avalanches can be large.
4 - high	Very poor stability exists in many locations. Avalanches can be large.
5 - very high	— No data available —

b) Description based on highest individual frequency for each class.

Danger level	Description
1 - low	Fair or occasionally poor stability exists in a few locations. Avalanches are generally small.
2 - moderate	Poor stability exists in a few or even some locations. Avalanches can reach medium size.
3 - considerable	Poor or even very poor stability exists in some locations. Avalanches can occasionally be large.
4 - high	Very poor stability exists in many locations. Avalanches can be large.
5 - very high	— No data available —

words on how to act in or close to avalanche terrain, was added to the danger scale.

In Europe, we are moving in the same direction. With the EAWS Matrix and its definitions providing the technical framework, the EADS could be restructured to serve as a pure communication tool. However, we believe that a direct link between Matrix and Scale is needed since both serve public regional avalanche forecasting.

3.2 Quantitative and data-driven support

Today, we can analyse how forecasters chose danger levels and apply the danger scale in connection to related concepts (CMAH, EAWS Matrix) or observations (e.g., avalanche activity Schweizer et al. (2020b) or stability test scores Techel et al. (2020b); Schweizer et al. (2020a)).

Table 3, which is based on the hundreds of judgments forecasters made about the factors determining avalanche danger and the corresponding danger level during the forecasting season 2022/2023, provides a starting point for a brief version of the EADS based on usage data and the terminology used in the EAWS Matrix. We created a short description for each danger level based on the factors most commonly applied to it according to the EAWS Matrix. However, it is imperative to validate and refine this approach with data from multiple forecasting seasons. The proposal and examples presented here serve as a starting point, awaiting confirmation and refinement through future data collection and analysis. In addition, the final wording needs to be critically revised with public communication as the main focus. The wording should be non-technical, but key terms should be either integrated into both the Scale and Matrix or standard look-up tables linking the two need to be established.

Danger levels are qualitative terms that are not measurable and thereby hard to validate (Schweizer et al., 2020a; Techel and Schweizer, 2017). The description for some danger levels contains a vague quantification e.g. "numerous large avalanches". Ideally, an updated definition could contain quantitative parameters connected to each danger level. Several studies have analyzed the relation between quantities of typical observations and the issued danger level (e.g., Techel et al., 2020a; Schweizer et al., 2020a; Techel et al., 2022). Models to predict *D* based on certain observations or combinations of observations have been established and already put to use (e.g., Mayer et al., 2023). This knowledge should be used to introduce some level of quantification into the definition of the avalanche danger levels. Remote sensing of avalanche activity (Eckerstorfer et al., 2017) or spatially distributed snowpack modelling (Herla et al., 2022) might diminish the current lack of spatial information on key parameters that forecasters today often face. Thus, allowing for a better quantitative assessment of avalanche danger in the future and thereby the possibility for more objective judgement and validation.

3.3 Level of detail

Discussions on the reduction or increase on the number of danger levels have been going on since the introduction of the EADS (Mitterer and Mitterer, 2018; Valt and Berbenni, 2013). Today, it is a well known scale. Arguments to reduce or add levels therefore need to be very strong to justify such a drastic change. When revising the danger scale, we should strive for a clear separation of the danger levels. Danger level 2 and 3 are the two most commonly applied and often constituting around 80% of the winter days (Techel and Schweizer, 2017; Techel et al., 2020a; Müller et al., 2024). According to the usage data in Müller et al. (2024), factors describing D=2 and D=3 seem to intertwine. The discussion on the introduction of sub-levels indicates the demand for a more detailed scale at least on the professional level (Valt and Berbenni, 2013; Techel et al., 2022; Lucas et al., 2023).

The Swiss forecasting service assigns sub-levels to each danger level. Their usage of sub-levels shows that sub-levels D=2+ and D=3- are more common than a straight 2-moderate or 3-considerable, indicating that this bias might be inherent in other forecasting service too (Techel et al., 2024)[in this proceeding]. As a consequence, the factor combinations for D=2 and D=3 seem closer together when only looking at operational data without information on sub-divisions of levels or factors. For example, Techel et al. (2024) show distinctly different factor combinations when just comparing danger levels 1, 2=, 3=, and 4=, which correspond to about the middle of each level. Sub-levels (danger rating and factors) allow for a more detailed analysis of the chosen danger levels. Techel et al. (2024) show that the magnitude of disagreements between forecasters when disagreeing on a danger level or a factor is generally small (one sub-level rather than one full level) when they are allowed to use a finer scale. Thus, while keeping the EADS simple, supporting concepts such as the EAWS Matrix should opt for a more detailed division of the classes and levels allowing forecasters to convey their judgement at the highest level of detail.

On the larger scale and when seen in connection with other geohazards and extreme weather events, coarser scales are common. It seems also that less experienced users would struggle to recall a more detailed scale (Morgan et al., 2023). MeteoAlarm, for example, is an Early Warning Dissemination System that provides awareness information from European meteorological and hydrological services. It uses a 4-level color scale of transparent/no concern, yellow/moderate, orange/severe and red/extreme to ensure coherent interpretation throughout Europe (EUMETNET, 2024). Although, several European warning services use MeteoAlarm, there is no European standard yet on how to translate the 5-level avalanche danger scale to MeteoAlarm's 4-levels. MeteoAlarm does not use numbers to indicate its levels, but uses signal words only. Statham et al. (2010) also stated that using numbers 1-5 in the danger scale might indicate a false linear increase (see also Morgan et al., 2023)) and emphasizes that numbers (e.g., danger level 4) are meaningless for an audience unfamiliar with the scale, while signal words (e.g., high) convey meaning even without knowing the scale. Despite their concerns, numbers are part of the NADS today. We propose to consider the removal of numbers when updating the EADS.

3.4 Language & design

The language used in the EADS should match its objectives. If public communication will be at its core, then language should be simple and unambiguous. The number and content of its columns should be revised. Currently, there is an overlap between the columns since snowpack stability described in the left column and triggering described in the right column of the EADS are reciprocal to each other (Table 1). We suggest a column containing simple descriptions as presented in Table 3 and columns on how to act according to the danger for the most prominent users groups: public safety and recreational users. The terminology currently used in the EADS, but related concepts such as the Matrix and CMAH, are still vague and contain terms that have a varied and broad meaning, not only to people in general, but also avalanche professionals specifically (e.g., Morgan, 2017; Thumlert et al., 2020; Hutter et al., 2021). Multiple languages in Europe make it of course more challenging to ensure common meaning across countries. However, here too, simple language and a clear purpose will be an advantage. Ideally, the NADS and EADS should be merged in the long run when it is apparent that both grow closer in purpose, terminology and design.

Avalanche warnings are today disseminated mainly via the internet and consumed on digital devices. Universal design is nowadays a legal requirement in many countries. An updated danger scale should therefore incorporate universal design e.g., by using a colorblind-safe color palette.

4. CONCLUSION

Bringing the European Avalanche Danger Scale to the 21st century is a logical next step in the development and standardization of regional avalanche forecasting in Europe, and potentially also worldwide. The EADS and its terminology need to be aligned with state-of-the art concepts such as the CMAH or the EAWS Matrix as soon as possible given the current discrepancy. An updated definition needs to have a clear objective and be in line with the concepts it is embedded in. Usage data and quantitative analysis are useful to identify typical avalanche conditions and how they are described using the available terminology at each danger level. Such data also provide insight on how forecasters apply existing standards and – equally important – where they deviate from them. The danger levels are a definition serving public avalanche warning services to convey information on avalanche danger to its users. Thus, we should strive for a non-technical but unambiguous wording. Danger levels described in the scale should handle common situations and be clearly separable from each other. The need for a more detailed classification requested by avalanche professionals should be handled by tools like the EAWS Matrix or CMAH (which both might require even finer classifications than in their current versions). Digital dissemination of forecast products and thereby danger levels is standard practice today and should therefore be part of the design process of an updated EADS. We have not been able to suggest a new or fully updated European Avalanche Danger Scale here due to too many open questions. Therefore, we tried to collect important points that should be considered when tackling this task, hoping to stimulate discussions and additional points within the avalanche community.

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