A MULTI-SOURCE, INTERNATIONAL ANALYSIS OF AVALANCHE PROBLEM TYPES IN FATAL INCIDENTS (2017–2026)

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ABSTRACT: Avalanche danger ratings have appropriately received substantial research attention because they provide the primary regional summary of avalanche hazard. In contrast, avalanche problem types—now a central component of operational forecasting under the Conceptual Model of Avalanche Hazard—have received comparatively little quantitative evaluation despite conveying complementary information about the nature, location, and expected behavior of avalanche hazards. This study addresses that gap. It analyzes 883 fatal avalanche incidents (1,239 fatalities) from the 2017–18 through 2025–26 seasons using the International Fatal Avalanche Database (IFAD), a multi-source international fatal avalanche database drawing records from the United States, Avalanche Canada, seventeen EAWS member nations, Japan, and South America. To the authors' knowledge, this constitutes the most comprehensive multi-national problem-type fatality analysis yet published. Of 675 classified incidents (877 classified fatalities), the most operationally significant finding is that Persistent Slab (262 deaths; 29.9% of classified fatalities) generates its highest fatality counts at Danger Level 1–Low (38 deaths)—the highest count of any problem type at that level—and 47 at Level 2–Moderate, showing that low-to-moderate ratings do not necessarily mean persistent weak-layer hazard has resolved. Wind Slab accounts for the largest overall share (338 deaths; 38.5%), including 102 deaths at Danger Level 2–Moderate, confirming that regional danger ratings understate problem-specific risk at lower levels. Backcountry skiing and snowboarding accounts for the majority of activity-classified fatalities. Cross-agency classification differences at the Wind Slab/Storm Slab boundary are documented and addressed in the analysis. These findings suggest that Persistent Slab bulletin entries warrant explicit prominence at Low and Moderate danger levels independent of the overall rating, and that cross-agency problem-type harmonization is a prerequisite for further international safety analysis.

KEYWORDS: avalanche problem types, danger scale, persistent slab, fatality analysis, international harmonization

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1. INTRODUCTION

No prior study has combined CAIC, Sierra Avalanche Center, Utah Avalanche Center, Avalanche Canada, EAWS, and Japan records into a unified problem-centered fatality analysis at this scale, nor linked those records to the documented inconsistency in Wind Slab/Storm Slab classification (de Leeuw and Birkeland, 2023). To the authors' knowledge, no previously published international fatal avalanche database harmonizes avalanche problem classifications, danger ratings, and activity categories across five national and regional reporting systems within a single schema. Systematic global analyses of problem-specific fatality patterns remain limited: Greene et al. (2006) established foundational relationships between danger levels and fatalities, predating widespread formal problem classification, and Techel et al. (2016) examined European trends without problem-type disaggregation.

Avalanche problem types are the operational framework through which forecasters communicate the character of prevailing snowpack instabilities in public bulletins. Building on the Conceptual Model of Avalanche Hazard (CMAH) by Statham et al. (2018), forecasting agencies across North America, Europe, Japan, and South America specify primary problem types alongside the five-level danger rating, enabling terrain-specific decision-making beyond what the rating alone conveys (Haegeli and Atkins, 2012; Fisher et al., 2022). Each problem type carries distinct physical mechanisms, spatial distribution patterns, triggering characteristics, and consequence profiles.

The International Fatal Avalanche Database (IFAD) was developed to address this gap by integrating these disparate reporting systems into

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a common analytical framework. Although the underlying source databases span more than two centuries, this study focuses on the eight harmonized seasons from 2017–18 through 2025–26, the first period in which all source streams apply broadly consistent CMAH problem-type vocabulary. Four research questions guide the analysis:

(1) What is the fatality burden by problem type globally and by source?

(2) How do problem types differ in lethality and danger-level distribution?

(3) What does documented Wind Slab/Storm Slab classification inconsistency imply for multi-source comparisons?

(4) What are the operational implications?

2. DATA AND METHODS

2.1. Source Streams and Harmonization

Data were acquired through source-specific extraction workflows, prioritizing direct access to structured records where available and spreadsheet conversion where necessary. Downstream harmonization involved four steps. First, duplicate incidents appearing in multiple source streams were identified using date, location, and fatality-count matching. Second, source-specific problem-type vocabularies were mapped to the nine-problem CMAH schema, including folding Japan Avalanche Network records originally held in source-specific text fields into the standard schema. Third, the five-level danger scale was harmonized, with Japan Avalanche Network (JAN) ratings mapped directly. Fourth, field-completeness indicators were generated to flag records missing problem type, danger rating, or activity. A data-integrity audit identified six United States and Canadian records that had been correctly captured but left without a source-dataset tag; these were retagged to their originating agency rather than treated as new records, correcting a prior double-count of five 2026 Avalanche Canada incidents.

Where the same incident appeared in multiple source streams, the originating agency's record was given priority over aggregate or secondary sources. New Snow (EAWS) and Storm Slab (North America, Japan) were retained as distinct categories throughout; no harmonization was applied across this boundary because prior work indicates that these labels are not used equivalently across agencies (de Leeuw and Birkeland, 2023).

The South American record from Cerro López, Bariloche, in September 2024 was sourced from CIAv Bariloche / AAGM and classified as Wind Slab on the basis of the forecasted "Placas de Viento" bulletin problem and a post-incident snowpack profile confirming a wind-deposited slab over a faceted weak layer.

2.2. Database and Temporal Scope

The full IFAD database contains 2,285 fatal avalanche incident records: 1,051 from the United States, 578 from Avalanche Canada, 611 from EAWS, 44 from Japan, and one from South America. The 2017–18 season was selected as the first season in which all source streams applied broadly consistent CMAH problem-type vocabulary, yielding a harmonized analytical window of 883 incidents and 1,239 fatalities. All statistical analyses in this paper use the 2017–18 through 2025–26 window; the longer historical record is retained in IFAD for context but is not included in the inferential analysis.

For the United States, California records were drawn from the Sierra Avalanche Center, Utah records from the Utah Avalanche Center, and all other state records from CAIC. Japan data span 2013–26, with 18 of 44 incidents falling within the analytical window. Avalanche Canada's public database extends to 1782 and provides the longest continuous national fatal avalanche record used here (578 incidents; 1,077 fatalities), while EAWS agencies contribute only to the harmonized analytical window because standardized problem-type records are not available before 2017–18.

2.3. Denominator Structure

The analysis uses several nested and non-nested subsets, each defined by a specific field-level filter (Table 1b). The total analytical window includes all 883 incidents and 1,239 fatalities. The problem-type-classified subset includes 675 incidents and 877 fatalities. The danger-rated subset includes 591 incidents drawn from the problem-type-classified records. The region-by-problem tests are restricted to EAWS and North America, where 658 problem-classified incidents support the comparison. The Wind Slab versus Persistent Slab test is further restricted to the two problem types of interest, yielding 458 incidents. The activity-classified subset is independent of problem-type classification and includes 1,100 fatalities with usable activity fields.

2.4. Statistical Analysis

Descriptive statistics summarize incidents, fatalities, and mean fatalities per incident by source and problem type. Cross-tabulations compare problem types by source and by danger

level. Chi-square tests assess whether observed distributions differ from expected distributions under independence, and Cramér's V is reported as a measure of effect size (Cohen, 1988). Where sparse cells required collapsing categories to meet the 20% rule for chi-square validity (Cochran, 1954), this is noted alongside the results.

3. RESULTS

3.1. Dataset Overview

The harmonized analytical window captures 883 incidents and 1,239 fatalities. Of 675 incidents with a classified primary problem type, EAWS contributes 475 (70.4%), North America 183 (27.1%), Japan 16 (2.4%), and South America 1 (0.1%). The reduction from 883 total incidents to 675 classified represents 208 records (23.6%) where problem type could not be determined from available source data.

Table 1: Fatal incidents and fatalities by source, 2017–18 to 2025–26.

Source	*Inc.*	*Deaths*	*Mean*
United States[2]	180	218	1.21
Avalanche Canada	73	93	1.27
EAWS (17 nations)[1]	611	907	1.49
Japan	18	20	1.11
South America[3]	1	1	1.00
TOTAL	883	1,239	1.40

[1] EAWS country breakdown: France 115/205, Italy 147/195, Switzerland 112/182, Austria 113/151, Norway 40/56, Slovakia 16/30, Spain 18/24, Other (Romania, Germany, Poland, Slovenia, Andorra, Czechia, Iceland, Finland, Sweden, UK) 50/64. Format: incidents/deaths.

[2] Combines CAIC, Sierra Avalanche Center (CA), and Utah Avalanche Center (UT).

[3] Cerro López, Bariloche, Argentina, Sep 2024. Wind Slab; Danger Level 3–Considerable; backcountry ski mountaineering. Source: CIAv Bariloche / AAGM.

Table 1b maps every denominator used in this paper to a single reference point. The activity-classified total is an independent field and is not a subset of the problem-classified total.

Table 1b: Denominator map: sample sizes used throughout this paper.

Quantity	*N*	*Basis*
Total analytical window	883 inc. / 1,239 deaths	All records, 2017–18 to 2025–26 (Table 1)
Problem-type classified	675 inc. / 877 deaths	Known primary problem type (Tables 2, 3)
+ also danger-rated	591 inc.	Subset also carrying a danger rating (Figure 2, §3.6)
Region × Problem test	N = 658	EAWS + North America, problem-classified (§3.4)
WS vs. PS test	N = 458	Subset above, two problem types only (§3.4)
Activity classified	1,100 deaths	Independent field; not a subset of the 877 (Figure 3, §3.7)

Inc. = incidents. WS = Wind Slab; PS = Persistent Slab.

3.2. Fatalities by Season and Source

Figure 1 disaggregates the 1,239 fatalities by winter season and contributing source. EAWS contributes the majority of fatalities in every season, with the largest single-season total in 2025–26 (149 deaths) and the smallest in 2019–20 (54 deaths). United States totals peak in 2020–21 (38 deaths). The single South America record falls within the 2023–24 season bucket by calendar mechanics, though the event occurred during the Southern Hemisphere winter of September 2024; this is noted for transparency and does not affect any other analysis.

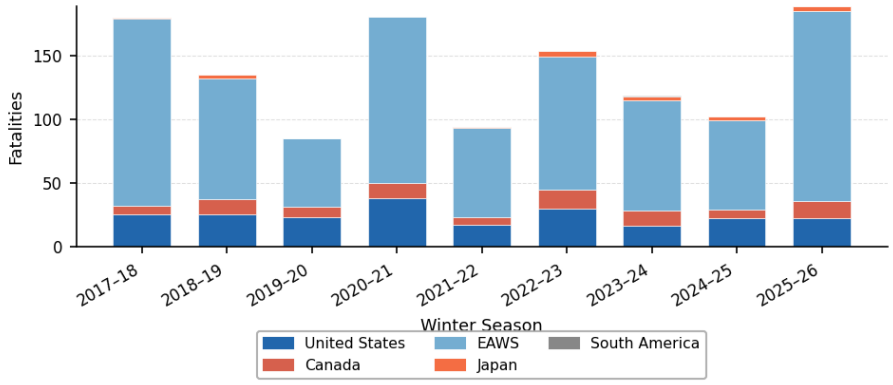


Figure 1: Fatalities by winter season and contributing source, IFAD, 2017–18 to 2025–26. All values fully reconciled from the corrected IFAD merged database (see Section 2.1).

3.3. Fatalities by Problem Type

Among 675 classified incidents, Wind Slab accounts for 338 deaths (38.5%) of the 877 classified fatalities, Persistent Slab 262 (29.9%), New Snow 116 (13.2%), Wet Snow 60 (6.8%), Storm Slab 51 (5.8%), Cornice 23 (2.6%), Deep Persistent Slab 18 (2.1%), Glide Avalanche 7 (0.8%), and Loose Snow 2 (0.2%) (Table 2). Per-incident fatality rates are highest for Wet Snow (1.46), Storm Slab (1.42), and Deep Persistent Slab (1.38). A chi-square test confirmed the EAWS/North America Wind Slab vs. Persistent Slab divergence is not attributable to sampling variation (chi-sq = 61.6, df = 1, N = 458, $p < 0.001$, Cramér's V = 0.367, a moderate effect by Cohen's (1988) thresholds).

Table 2: Fatalities by primary avalanche problem type, 2017–18 to 2025–26.

Problem Type	*Inc.*	*Deaths*	*Mean*	*% Class.*[1]
Wind Slab	262	338	1.29	38.5%
Persistent Slab	205	262	1.28	29.9%
New Snow	90	116	1.29	13.2%
Wet Snow	41	60	1.46	6.8%
Storm Slab	36	51	1.42	5.8%
Cornice	20	23	1.15	2.6%
Deep Persistent Slab	13	18	1.38	2.1%
Glide Avalanche	6	7	1.17	0.8%
Loose Snow	2	2	1.00	0.2%

[1] % of 877 classified fatalities. New Snow and Storm Slab retained as distinct categories (see Section 3.5). Inc = incidents.

3.4. Problem Distributions by Regional Source

Table 3 presents the full problem-by-source breakdown, fully reconciled with Japan's complete classified record. EAWS dominates Wind Slab (229 incidents, 301 deaths) and New Snow (89 incidents, 115 deaths). UAC contributes the majority of United States Persistent Slab incidents, reflecting the Wasatch Range's transitional-continental snowpack. Avalanche Canada provides resolved sub-problem classification including 11 Deep Persistent Slab incidents absent from all other sources. Japan's 16 classified incidents span five problem types, with Wind Slab and Storm Slab tied as the most frequent (6 incidents each). A chi-square test across the full 2×8 problem-type distribution confirmed this regional divergence is highly significant (chi-sq = 263.9, df = 8, N = 658, $p < 0.001$, Cramér's V = 0.63, a large effect): EAWS and North American programs classify fundamentally different problem-type profiles. This test is restricted to EAWS and North America; Japan (16 classified incidents) and South America (1 incident) are excluded because their small samples would produce expected cell counts too sparse to support valid chi-square inference across eight categories.

Table 3: Source × problem breakdown (incidents/deaths), 2017–18 to 2025–26.

Source	*Wind Slab*	*Persistent Slab*	*Deep Pers. Slab*	*New Snow*	*Storm Slab*	*Wet Snow*	*Cornice*	*Glide Aval.*	*Loose Snow*	*Total*
United States	11/13	59/69	2/2	1/1	24/39	4/4	17/20	1/1	—	119/149
Aval. Canada	15/17	27/33	11/16	—	6/6	1/3	3/3	—	1/1	64/79
EAWS	229/301	117/157	—	89/115	—	35/51	—	5/6	—	475/630
Japan	6/6	2/3	—	—	6/6	1/2	—	—	1/1	16/18
South America	1/1	—	—	—	—	—	—	—	—	1/1

Source	Wind Slab	Persistent Slab	Deep Pers. Slab	New Snow	Storm Slab	Wet Snow	Cornice	Glide Aval.	Loose Snow	Total
TOTAL	262/338	205/262	13/18	90/116	36/51	41/60	20/23	6/7	2/2	675/877

Format: incidents/deaths. US = CAIC + SAC (CA) + UAC (UT). EAWS uses "New Snow"; North America and Japan use "Storm Slab". Deep Persistent Slab absent from EAWS and Japan. SA: Wind Slab, Cerro López, Sep 2024.

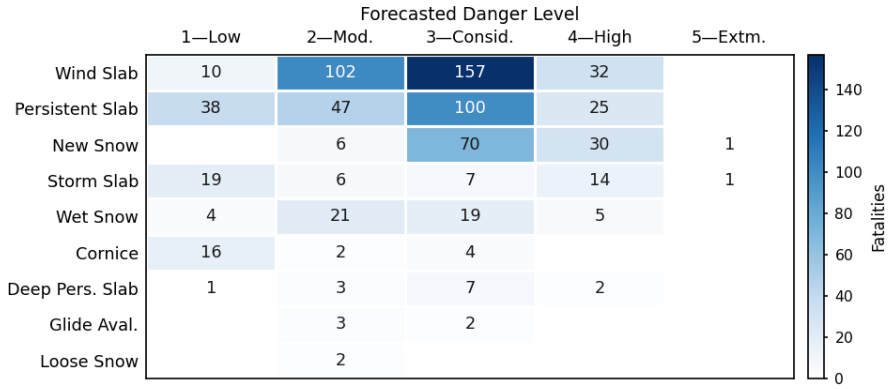


Figure 2: Recorded fatalities by forecasted danger level × primary problem type, IFAD, 2017–18 to 2025–26 (n = 591 incidents with both variables classified). All cells fully verified from the corrected IFAD merged database.

3.5. New Snow and Storm Slab: Schema Divergence and Professional Inconsistency

Table 3 reveals a fundamental cross-agency divergence: EAWS records 89 New Snow incidents (115 deaths) with zero Storm Slab events; North American and Japanese agencies record 30 Storm Slab incidents (45 deaths combined) and minimal New Snow, reflecting genuinely different frameworks for fresh-snow instability. Merging these categories would misattribute 115 EAWS fatalities to a label not used in those bulletins. Beyond this schema divergence, de Leeuw and Birkeland (2023) document intra-professional inconsistency within North America: nearly 20% of operations submitted storm slab reports for aspect-dependent, lee-aspect problems meeting wind slab criteria. This misclassification likely inflates North American Storm Slab counts and deflates Wind Slab by an unknown amount, qualifying the distributions in Table 3.

3.6. Interaction with Danger Scale

Of 675 classified incidents, 591 (87.6%) also carry a classified danger rating and appear in Figure 2 (Table 1b). The 84 records missing a danger rating are distributed across sources, with pre-2020 CAIC and Avalanche Canada records accounting for the majority; they do not concentrate in any particular problem type. A chi-square test on this 591-incident cross-tabulation, with problem type collapsed to five named categories plus an "Other" group for cell-count adequacy, confirmed a significant but moderate association (chi-sq = 137.2, df = 15, $p < 0.001$, Cramér's V = 0.28), indicating that danger ratings and avalanche problem types describe complementary dimensions of avalanche hazard. This result should be read with some caution: 6 of 24 cells (25%) had an expected count below 5; the large sample size and strong significance make a spurious result unlikely, and the effect size should be treated as approximate.

Among the 591 cross-classified records, three patterns are operationally significant. Persistent Slab generates 38 deaths at Danger Level 1–Low, the highest count of any problem at that level, and 47 at Level 2–Moderate, showing that a Low or Moderate rating does not necessarily mean persistent weak-layer hazard has resolved. Wind Slab contributes 102 deaths at Level 2–Moderate, its second-highest cell after Level 3–Considerable (157 deaths), showing that terrain-specific Wind Slab hazard can remain important at moderate regional danger. New Snow and Storm Slab concentrate at Levels 3 and 4, consistent with their dependence on active storm cycles.

3.7. Activity Group Analysis

Activity classification is a separate field from problem-type classification and is not a subset of the 877 problem-classified fatalities (Table 1b); of the full 1,239 fatalities, 1,100 (88.8%) carry a usable activity code, with the remaining 139 (11.2%) excluded from Figure 3. Figure 3 disaggregates these 1,100 fatalities into seven categories. Backcountry skiing and snowboarding dominates (654 deaths; 59.5%),

followed by snowmobiling/snowbiking (110; 10.0%), mountaineering/climbing (102; 9.3%), and occupational/other categories (186 combined; 16.9%). This concentration in an informed, equipped recreational user group points to problem-specific communication gaps—not information unavailability—as the primary safety challenge.

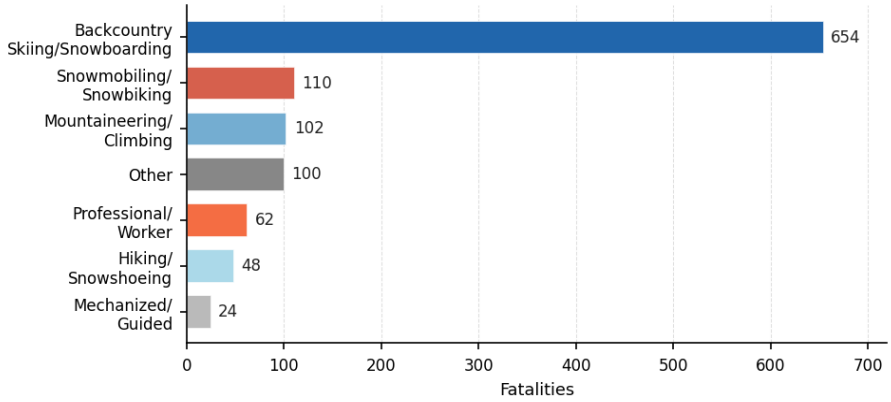


Figure 3: Recorded fatalities by recreational and occupational activity, IFAD, 2017–18 to 2025–26 (n = 1,100 classified deaths; 139 lacking activity classification excluded). Categories harmonized from source-specific vocabularies; “Other” includes resident, roadway, and inbounds incidents.

4. DISCUSSION

This dataset measures only fatal outcome probability within confirmed fatal incidents; it does not measure hazard frequency or exposure. Wind Slab accounting for the largest share of recorded fatalities (38.5%) reflects the large, systematically classified EAWS contribution—229 of 262 Wind Slab incidents originate from EAWS—combined with Wind Slab’s spatial ubiquity in European Alpine terrain. Persistent Slab’s second-place position (29.9%) reflects its extended reactive lifetime across both EAWS and North American records. These proportions should not be read as rankings of inherent danger per unit of exposure.

4.1. Wind Slab: Dominant but Spatially Elusive

The core operational challenge of Wind Slab is spatial resolution: wind slabs form on specific micro-terrain features covering only a small fraction of the regional forecast area. A Moderate or Considerable rating can describe aggregate stability while still being consistent with a locally lethal wind slab on a particular lee feature. The Moderate-danger fatality concentration noted in Section 3.6 is therefore not a forecasting failure but a structural property of how regional ratings interact with spatially discontinuous hazard. Bulletin language naming specific aspects and elevation bands, rather than the regional danger number alone, is the most actionable communication available to forecasters (Fisher et al., 2022).

4.2. Persistent Slab: Lethal at Every Danger Level

The 38 Persistent Slab deaths at Danger Level 1–Low are the highest count of any problem at that level. A Low rating does not indicate that persistent weak-layer hazard, equivalent to Persistent Weak Layer in UAC terminology, has resolved. Combined with 47 deaths at Moderate, Persistent Slab generates its largest fatality contribution at the two levels most users consider acceptable for consequential terrain. UAC records confirm this most clearly: Persistent Slab dominates the majority of UAC classified incidents in the Wasatch Range’s transitional-continental snowpack. A Persistent Slab bulletin entry at Low or Moderate danger is a safety-critical signal, not a formality.

4.3. Wind Slab and Storm Slab

The de Leeuw and Birkeland (2023) finding has two practical implications for this analysis. First, North American Wind Slab fatality counts are likely conservatively estimated: some incidents classified as Storm Slab in Canadian and US programs may have met wind slab criteria. Second, the per-incident fatality mean difference between Wind Slab (1.29) and Storm Slab (1.42) may partly reflect a classification artifact, with larger, more aspect-concentrated avalanches classified as storm slab elevating that category’s mean. The appropriate response is not to merge the categories, which would suppress the operational distinction, but to adopt standardized, field-testable boundary criteria in CAA, AAA, and EAWS training programs.

4.4. Operational Implications

Table 4 summarizes the main operational implications. Wind Slab dominates at all danger levels and therefore warrants explicit aspect- and elevation-specific bulletin language even at Level 2. Persistent Slab kills at Low and Moderate danger, so bulletin entries should remain in place for defined days after burial regardless of the overall rating. The Wind/Storm Slab boundary remains inconsistently applied, making standardized boundary criteria a priority for international training. These points support the broader argument that problem-type communication adds practical value beyond the danger scale alone.

Table 4: Operational implications by problem type.

Finding	***Key data***	***Operational implication***
Wind Slab dominates at all danger levels	338 deaths (38.5%); 102 at Danger Level 2-Moderate	Name loaded aspects and features in bulletins at Level 2; do not wait for Considerable
Persistent Slab kills at Low and Moderate danger	38 deaths at Level 1; 47 at Level 2 — highest of any problem at those levels	Maintain Persistent Slab bulletin entry for defined days post-burial regardless of rating
Wind/Storm Slab boundary inconsistently applied	~20% of Canadian storm slab submissions met wind slab criteria (de Leeuw and Birkeland, 2023)	Adopt standardized field-testable boundary criteria in CAA, AAA, and EAWS training

CMAH = Conceptual Model of Avalanche Hazard; CAA = Canadian Avalanche Association; AAA = American Avalanche Association; EAWS = European Avalanche Warning Services.

4.5. Snow Climate Limits

No globally applicable avalanche climate schema exists, and the Climatic Zone field in IFAD is entirely unpopulated. Mock and Birkeland (2000) provide a useful maritime-transitional-continental framework for western North America, and that framework has been productively applied to western Canada (Haegeli and McClung, 2003; Shandro and Haegeli, 2018). However, no equivalent exists for the European Alps or Asia, and Meloche et al. (2025) describe a rainy continental regime in the Chic-Chocs that does not fit standard classification. Future IFAD versions will need region-appropriate climate frameworks before problem-climate analysis becomes feasible.

4.6. Limitations

Three limitations shape interpretation. First, exposure denominators are unavailable, so fatality counts cannot be converted into conditional lethality rates. Second, the dataset is geographically incomplete, with Central Asia, the Andes, the Caucasus, and parts of Scandinavia absent; the single South American record is an inaugural data point, not a representative sample. Third, classification uncertainty remains, especially at the Wind Slab/Storm Slab boundary (de Leeuw and Birkeland, 2023) and in the pre-2020 North American danger-rating records that disproportionately affect Figure 2.

5. CONCLUSIONS

1. Persistent Slab (262 of 877 classified fatalities; 29.9%) generates 38 deaths at Danger Level 1–Low—the highest count of any problem type at that level—and 47 at Moderate: low-to-moderate ratings do not necessarily mean persistent weak-layer hazard has resolved.
2. Wind Slab accounts for the largest share of recorded fatalities in this dataset (338 of 877 classified fatalities; 38.5%), including 102 at Danger Level 2–Moderate, confirming that terrain-specific communication identifying loaded aspects and elevation bands is more operationally useful than the regional danger rating alone.
3. New Snow (116 of 877 classified fatalities; 13.2%) and Storm Slab (51; 5.8%) are retained as distinct categories representing genuinely different agency frameworks; together they account for 19.0% of classified fatalities.
4. Backcountry skiing and snowboarding accounts for the majority (59.5%) of activity-classified fatalities across all sources, pointing to problem-specific communication gaps as the primary safety challenge.
5. De Leeuw and Birkeland (2023) document that nearly 20% of Canadian operations used storm slab for aspect-dependent, lee-aspect problems meeting wind slab criteria. This intra-professional inconsistency qualifies Wind Slab and Storm Slab counts in Table 3

and reinforces the need for standardized boundary criteria across CAA, AAA, and EAWS.

International avalanche fatality analysis requires shared data architecture. The author calls on EAWS, the Canadian Avalanche Association, the American Avalanche Association, and the Japan Avalanche Network to adopt a common minimum data standard: a controlled problem-type vocabulary with explicit boundary criteria, a five-level danger rating linked to the forecast day, standardized activity categories, and a mandatory post-incident investigation protocol. Region-appropriate snow climate classification frameworks are a further prerequisite before problem-climate analysis becomes feasible.

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