HUMAN-AFFECTED SNOWPACK: DISTURBANCE, COMPACTION, AND SNOWPACK DEVELOPMENT IN MOTORIZED TERRAIN

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ABSTRACT: Human activity is routinely visible in avalanche terrain, yet its role in snowpack development is often summarized with broad terms such as “tracked,” “packed,” or “compacted.” Those descriptions rarely identify how deeply snow was affected, how much terrain was altered, when the interaction occurred relative to layer formation and burial, or whether it reached a layer of concern. Previous controlled studies show that systematic boot packing and ski compaction can alter snowpack properties and stability-test responses when disturbance reaches relevant layers, while snowmobile research shows that repeated use can change physical and mechanical snow properties and that trigger penetration influences stress transmission. We present a practitioner-led case observation from Joss Mountain near Revelstoke, British Columbia: a repeated-use motorized corridor beside lower-use snow, with paired Snow Pilot profiles recorded on the same day. The lower-use profile recorded ECTP25 and CT 15 SP near 75 cm; the repeated-use corridor profile recorded ECTX and shallower compression-test breaks, together with distinctly different recorded layering. The sites were paired with contextual observations rather than experimental controls, and causation is not established. Instead, the case exposes an observational gap and motivates future work using concise human-interaction descriptors - penetration, extent, pattern, use history, and layer relation - to structure future observations of human-use history alongside snowpack development and potential fracture behavior. The resulting observation concept has implications for research comparability, professional observation, forecast interpretation, avalanche education, and communication with recreational users.

KEYWORDS: Human-Affected snowpack, observing and recording, disturbance, compaction, motorized terrain, snowpack development

1. BACKGROUND

1.1 A field question at Joss Mountain

The questions in this paper began with field observation rather than a controlled experiment. On 16 February 2026, lead author Shena Thomas approached Joss Mountain outside Revelstoke, British Columbia. Field notes recorded a regional Avalanche Canada danger rating of Considerable at all elevations, with storm-slab and persistent weak-layer concerns in the upper meter.

The access route passes through terrain with both northerly and southerly avalanche exposures, but the primary operational concern on the ascent was the north-facing terrain. From the repeated-use travel corridor, riders had greater potential human-trigger connectivity to adjacent and connected northerly start zones, while the southerly terrain visible in the broader setting had less direct human connectivity from the corridor. What stood out that day was not simply whether the snow was tracked or untracked, but how differently adjacent portions of the terrain had been used: a few isolated tracks in some places, broadly distributed use in others, and a concentrated travel corridor receiving repeated machine traffic through approximately the same terrain over time.

Tracks can become an informal cue. Previous traffic without an avalanche can be misread as evidence of stability. At the same time, repeated human use may disturb or compact snow differently depending on penetration, timing, recurrence, and relationship to buried layers. That tension - between misleading surface evidence and a potentially meaningful but poorly documented snowpack effect - was the starting point for the field question.

Field question: What physical effect, if any, had repeated motorized use produced in the main travel corridor compared with adjacent north-facing avalanche terrain, and had that interaction penetrated deeply enough - when layers were exposed or shallowly buried - to reach layers of concern?

The difficulty was not simply answering this question but documenting the observation. Existing shorthand could describe the corridor as tracked, packed, or compacted, but could not show how deeply the interaction entered the snow, how much terrain was affected, how use was arranged, when it occurred relative to layer formation and burial, or whether it reached the layers of concern. That observational gap became the starting point for this paper.

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Figure 1: Joss Mountain, British Columbia. A: broader access and valley context, including northerly and southerly avalanche terrain. B: repeated-use motorized route and adjacent avalanche terrain. C: relative locations of the lower-use and repeated-use profile sites. Google Earth imagery; annotations by the authors.

1.2 Commonly observed human-use patterns

The original field concept separated four visually distinct situations: an isolated track, multiple distributed tracks, an extensively used surface, and a repeated-use corridor surrounded by lower-use snow. These photographs are illustrative field examples rather than formal Pattern categories. Their value is that they show why “tracked” alone is an inadequate description: all four contain human use, but the depth of interaction, amount and arrangement of use, timing and recurrence, and relationship to buried layers may differ substantially. Section 2 introduces the working observation language used throughout the paper.

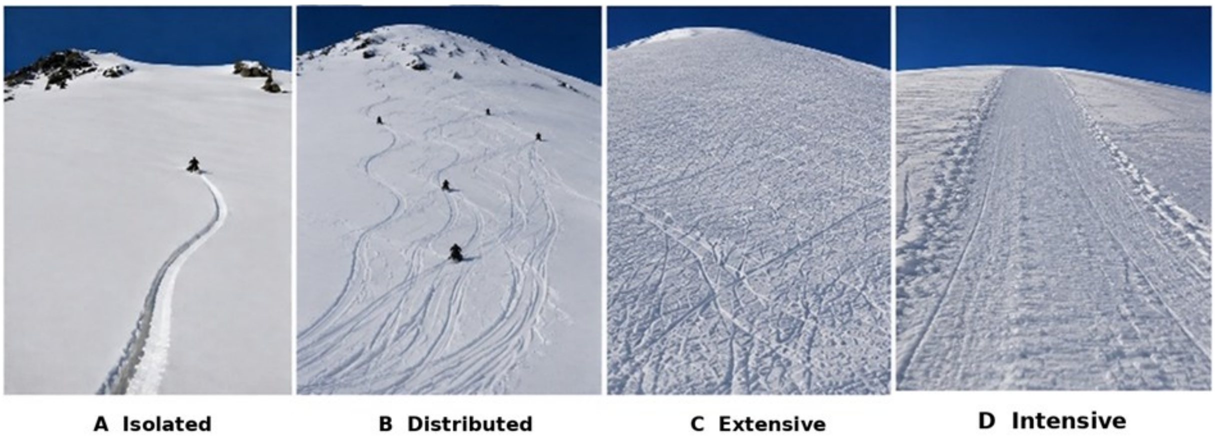

Figure 2: Four human-use situations from the original field concept. A: Isolated. B: Distributed. C: Extensive. D: Intensive. These illustrated use patterns, not stability or compaction classes.

2. WORKING OBSERVATION LANGUAGE

The vocabulary proposed and utilized is deliberately layered. Snowpack state, human-interaction description, and human-caused process answer different questions. Operationally, the interaction is described before disturbance or compaction is recorded. These are working terms, not a stability classification or finished industry standard.

2.1 Snowpack state

Table 1: Working snowpack-state terms. Human-Affected Snowpack is a condition descriptor, not a stability classification.

SNOWPACK STATE	WORKING USE IN THIS PAPER
Natural Snowpack	Snowpack with no known human-caused alteration relevant to the defined area, time period, and layer or interface being considered.
Human-Affected Snowpack	Snowpack in which relevant human activity has altered the surface, structure, layering, properties, or subsequent development of the snow. This is a snowpack condition, not a stability classification.

2.2 Observation basis and human-interaction descriptors

Relevant human interaction is first recorded as Yes / No / Unknown. Observation Basis records how it is known: Created, Witnessed, Evident, Recorded, or Unknown; more than one may apply. The interaction is then described by penetration, extent, pattern, use history, and layer relation (Table 2). Exact measurements and known history take priority over shorthand; Unknown is preferable to inference.

Table 2: Working human-interaction descriptors and shorthand. Exact observations take priority; categories are provisional and do not assign stability.

DESCRIPTOR	WORKING QUESTION	WORKING SHORTHAND / MEANING
Penetration	How deep?	0-20 cm / 21-50 cm / 51-100 cm / >100 cm / Unknown. Exact measurement takes priority.
Extent	How much of the defined area?	1-25% / 26-50% / 51-75% / 76-100% / Unknown. Exact percentage or mapped area takes priority.
Pattern	How arranged?	Isolated: one/few separated features; Distributed: multiple separated features; Extensive: broad use across a large portion; Intensive: repeated/overlapping use of the same snow; Unknown.
Use History	When / across how many cycles?	Current: current observation period; Recent: after the most recent significant storm/loading event but before observation; Storm-cycle: repeated within the current storm/loading cycle; Multi-cycle: spans >1 storm/loading cycle; Unknown. Record Single/Repeated and dates/times when known.
Layer Relation	Where relative to a layer/interface?	Above: remains above; Reaches: extends to; Through: crosses into immediately underlying snow; Beyond: continues farther into the snowpack so relation to deeper layers/interfaces can be documented separately; Unknown.

2.3 Human-caused processes

Disturbance and compaction describe human-caused physical processes, not snowpack state. All compaction is disturbance; not all disturbance is compaction. Record compaction only when settlement and/or densification is observed or measured.

Table 3: Working human-caused process terms. These are recorded after the interaction is described and do not assign stability.

HUMAN-CAUSED PROCESS	WORKING USE IN THIS PAPER
Disturbance	A human-caused physical alteration of the snow surface, structure, or layering, whether or not settlement or densification occurs.
Compaction	A form of disturbance in which human loading or repeated activity causes settlement and/or densification of the affected snow.

3. RELEVANT RESEARCH

3.1 Compaction and snowmobile effects

Controlled compaction research shows that compaction is not a single treatment. Wieland et al. (2012) found that systematic early-season boot packing increased density and hardness in targeted basal layers and prolonged differences in ECT behavior relative to an adjacent untreated plot. Saly et al. (2016) compared several compaction treatments and found the clearest test differences where treatment interacted with the slab-weak-layer system. Tracks alone therefore communicate less than treatment depth, spatial extent, timing, and layer interaction.

Fassnacht et al. (2018) measured changes in density, hardness, ram resistance, and basal crystal properties under different levels of snowmobile use. Effects were more pronounced where use began in a shallower snowpack, reinforcing the importance of recording when repeated use begins relative to snow depth and layer development.

3.2 Penetration, loading, and fracture propagation

Thumlert and Jamieson (2013) analyzed 1,420 skier and snowmobile loading events, including penetration, effective depth, snow structure, and stress transmission. Softer snow allowed added stress to penetrate deeper, while more supportive structure limited penetration. Penetration therefore changes the effective distance between a surface load and buried layers, but does not describe historical compaction by itself.

Motorized pilot observations summarized by Stewart-Patterson (2019) indicate that snowmobile penetration varies with movement; uphill trenching and downhill carving produced the greatest measured penetration in that small, explicitly non-conclusive dataset. Penetration should therefore be observed rather than assigned by activity type.

Fracture mechanics also explains why spatial geometry may eventually matter. Failure initiation and crack propagation are distinct, and slab/weak-layer properties can contribute to propagation or arrest (Gauthier and Jamieson, 2006; Gaume et al., 2015). Increasing load can reduce critical cut length in PSTs (Birkeland and van Herwijnen, 2016), while natural snowpack variability can promote or inhibit avalanche formation (Schweizer et al., 2008). None of these studies establishes a disturbance percentage, track spacing, or use pattern that prevents propagation; they instead justify recording geometry for future study.

3.3 Human-use history as data

Mechanized-skiing operations show that human-use history can be reconstructed. Haegeli and Atkins (2016) combined GPS tracking with guiding records, and Sykes et al. (2023) demonstrated the scale of GPS-based operational datasets. Such records establish where and when people travelled, but not penetration, compaction, or layer disruption by themselves. Linking use history to measured snowpack effects is a separate observational problem.

4. JOSS MOUNTAIN CASE OBSERVATION

4.1 Paired profiles and limitations

Two Snow Pilot profiles were completed on 16 February 2026 in nearby north-facing terrain at Joss Mountain. One was a lower-use reference selected to represent Natural Snowpack under the working definition. The second was located within the repeated-use motorized route but approximately a few steps from the most recent visible tracks. The sites were in the same general elevation band and weather regime, but they were not identical terrain points: the profile records show elevations of 1950 m and 1920 m and slope angles of 39° and 36°, respectively.

This is a paired contextual field observation, not an experimental treatment/control design. Historic pass counts, penetration depths, exact disturbance extent at buried layers, and the timing of every relevant interaction were not measured. Natural spatial variability, micro terrain, wind effects, and other snowpack processes remain competing explanations for any differences between the profiles (Schweizer et al., 2008). The data are presented to motivate research questions, not as evidence that traffic caused the differences.

Table 4: Recorded comparison data from the two Snow Pilot profiles. These nearby, non-identical sites are contextual observations, not an experimental control pair.

RECORDED FIELD	LOWER-USE PROFILE	REPEATED-USE CORRIDOR PROFILE
Date / time	16 Feb 2026, 11:00	16 Feb 2026, 15:30
Elevation / aspect / slope	1950 m / N / 39°	1920 m / N / 36°
HS / PF	255 cm / 60 cm	270 cm / 30 cm
Stability tests	ECTP25 @ 75 cm; CT 15 SP @ 75 cm	ECTX; CT 29 BRK @ 43 cm; CT 29 BRK @ 47 cm
Use context	Lower-use reference selected to represent Natural Snowpack under the working definition	Within repeated-use motorized route; ~1 m from most recent visible track

The lower-use profile identified a problematic layer at approximately 75-76 cm. The repeated-use profile recorded fresh snow over tracks from 0-20 cm and deeper intervals noted as histories of tracks and rain (20-47, 47-75, and 75-95 cm). These are profile observations and do not establish the cause of the differences.

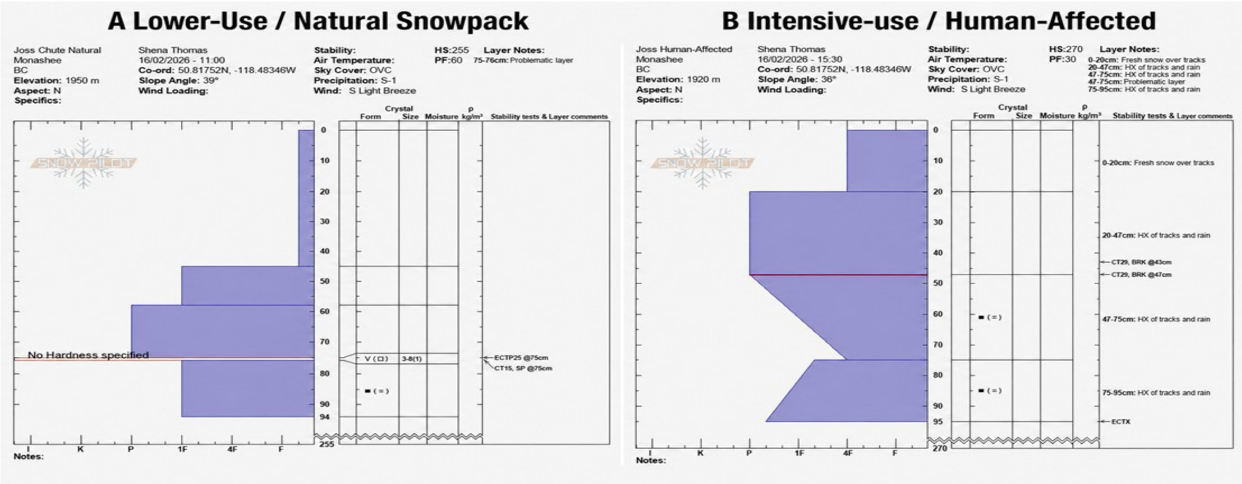

Figure 3: SnowPilot profiles from the Joss Mountain case. A: lower-use reference selected to represent Natural Snowpack under the working definition. B: Human-Affected Snowpack within the repeated-use route. Recorded differences do not establish causation.

4.2 What the paired observations add

The paired profiles place measured snowpack information beside the visual field story. The lower-use profile recorded propagation on the layer near 75 cm (ECTP25; CT 15 sudden planar). The repeated-use corridor profile recorded ECTX and hard compression-test breaks at shallower interfaces, together with a different recorded layering sequence. These contrasts are real observations from the recorded profiles; their cause is unresolved.

A photograph establishes human presence and pattern; a profile characterizes snow at one point. Neither alone explains causation. Testing human effects requires documented use history together with repeatable snowpack measurements.

5. DISCUSSION

5.1 Penetration and layer relation (reference Table 2)

A label such as "snowmobile disturbance" is too broad. Exact penetration takes priority; working shorthand is 0-20, 21-50, 51-100, >100 cm, or Unknown. Layer Relation records Above, Reaches, Through, Beyond, or Unknown. Through crosses the interface into immediately underlying snow; Beyond continues farther into the snowpack so relation to deeper layers can be documented separately. Neither term establishes stress transmission, bridging, triggering, or deeper-layer interaction. Timing remains inseparable from depth.

5.2 Extent and pattern (reference Table 2)

Extent records show how much of a defined area shows relevant human use or observed effect; exact percentage or mapped area takes priority, with 1-25%, 26-50%, 51-75%, 76-100%, or Unknown as shorthand. Pattern records Isolated, Distributed, Extensive, Intensive, or Unknown. Extensive use is broad across the area; Intensive use repeatedly occupies or overlaps the same snow over time. Neither establishes compaction, and no threshold for altered propagation or arrest is established.

5.3 Use history and subsequent snowpack development (reference Table 2)

Human interaction with snow is not only spatial; it is stratigraphic and temporal. Use History records when interaction occurred and whether it recurred as the snowpack developed. Working shorthand is Current, Recent, Storm-cycle, Multi-cycle, or Unknown; retain actual dates/times and recurrence (Single / Repeated) when known. Current means during the observation period; Recent means since the most recent significant storm/loading event but before observation; Storm-cycle means repeated across more than one use period within the current storm/loading cycle; Multi-cycle spans more than one storm/loading cycle. Fassnacht et al. (2018) show that snow depth when snowmobile use begins changes the resulting physical snowpack effect. Later snowfall, wind loading, settlement, crust formation, metamorphism, and continued traffic can preserve, bury, erase, or further modify an earlier human effect.

5.4 Intensive use, compaction, and load transmission

Repeated motorized travel can create an Intensive use pattern along an established route and, where settlement and/or densification is observed, compaction. Practitioners may colloquially describe such routes as "bridged," but the established snow-mechanics concept of bridging concerns how supportive overlying snow redistributes a load. Intensive use or observed compaction should therefore not be assumed to provide a mechanically meaningful bridge or a safe route through otherwise hazardous terrain. Two separate research questions are more defensible: (1) did historical traffic alter the slab, weak layer, or interface while those layers were accessible, and (2) does the present-day human-affected snow transmit a new load differently from adjacent Natural Snowpack? The current case answers neither question.

5.5 Human-Affected Snowpack and forecast interpretation

Public avalanche forecasts describe expected conditions across broad regions and elevation bands (Avalanche Canada, 2026). Human-use history may be one source of local snowpack variability within that regional picture.

This does not imply that a regional forecast is inaccurate or that heavily used terrain has lower hazard. The concern is transfer of experience: repeated non-events in heavily used Human-Affected Snowpack may build confidence that is then carried into nearby lower-use terrain under the same regional forecast.

Recognizing Human-Affected Snowpack may therefore help educators and practitioners separate evidence of previous use from evidence of stability and avoid transferring highly local experience to terrain with a different use history.

5.6 Implications across avalanche practice

Although motorized terrain provides this case, the observation problem also applies to boot packing, skier/snowboarder traffic, mechanized operations, ski-area mitigation, and repeated travel routes. Clearer language could improve comparison across terrain, seasons, disciplines, and studies without creating a new stability rating.

The potential value is observational: more comparable research treatments, clearer field communication, and better separation of previous use from evidence of stability. These are proposed applications, not demonstrated operational outcomes. Avalanche relevance remains a separate professional assessment.

6. TOWARD A PRACTICAL OBSERVATION APPROACH

The working sequence is deliberately observational: define context and human interaction, record how it is known, describe the five descriptors, then record disturbance/compaction and snowpack state. Table 5 summarizes the sequence.

Applied to Joss Mountain, Observation Basis is Created/Evident and Recorded; Pattern is Intensive; Use History is Multi-cycle and Repeated; historical Penetration and pass count are Unknown; buried-layer Extent was not quantified; and historical Layer Relation is Unknown. The paired profiles document differences, not avalanche significance or causation.

Existing professional methods should continue to document terrain, weather, snowpack, tests, and avalanches. The proposed contribution is narrower: structure human-interaction observations so they can be compared more consistently. Avalanche relevance is evaluated separately.

6.1 Working observation flow

The field flow is ordered to reduce inference; established snowpack, weather, test, and avalanche observations continue throughout.

Table 5: Working Human-Affected Snowpack observation flow. Read top to bottom; record Unknown rather than infer.

OBSERVATION	WHAT TO RECORD
Context	Area • date/time • layer/interface
Human interaction	Yes • No • Unknown
Observation basis	Created • Witnessed • Evident • Recorded • Unknown (multiple may apply)
Describe	Penetration • Extent • Pattern • Use History • Layer Relation Record exact values or known history when available. **(Table 2)**
Observed snowpack effect	Disturbance: Observed • Not observed • Unknown Compaction: Observed/measured • Not observed • Unknown
Snowpack state	Natural • Human-Affected • Unknown

6.2 Compatibility with established observation practice

Professional systems, including the Canadian Avalanche Association Observation Guidelines and Recording Standards (OGRS), already document terrain, weather, snowpack, tests, and avalanches (CAA, 2024). Human-Affected Snowpack is presented here as an independent observation concept that may sit beside such systems; this paper does not propose implementation into or adoption by OGRS.

The framework is a small observation language, not a parallel recording system. Its shorthand categories require testing for repeatability, communication value, and duplication with established observations.

7. FUTURE WORK

The Joss Mountain observation suggests a research design rather than a conclusion. Future work should compare multiple paired sites through time and capture penetration, extent, pattern, use history, and layer relation in repeated-use motorized terrain, broadly ridden slopes, boot-packed/skier-compacted terrain, and nearby lower-use references.

The working categories require field testing for repeatability, inter-observer agreement, usefulness, and cross-discipline applicability before broader recommendation. Comparison with established systems may identify duplication or gaps; integration into any standard would require a separate collaborative process.

Snow-science questions also remain: which human effects persist, and how might disturbance or compaction relate to triggering, weak-layer continuity, crack initiation, propagation, or arrest? Repeated human alteration may also create persistent firm interfaces that later participate in weak-layer/bed-surface configurations or influence subsequent weak-layer development. These are research questions, not conclusions of the Joss case.

8. CONCLUSION

Human activity can become part of snowpack developmental history. Existing research shows that compaction can alter snowpack properties under some conditions, snowmobile use can change physical/mechanical snow properties, penetration affects the relationship between surface loading and buried layers, and fracture propagation depends on the coupled slab-weak-layer system. Their interaction in uncontrolled recreational terrain remains poorly understood.

The Joss Mountain case does not show that repeated machine traffic stabilized the route. It shows that adjacent snow with different use histories can present different field observations while words such as “tracked” or “packed” carry little detail. Human effects can be part of snowpack development; tracks document use, not stability; and observations can improve even while the mechanics remain under investigation.

Human-Affected Snowpack should therefore be treated as an observation and research problem, not a stability conclusion. The next step is repeatable observation, paired with controlled studies where feasible, that tests relationships among human-use history, snowpack development, and potential fracture behavior. The preliminary framework describes interaction before recording disturbance/compaction and leaves avalanche relevance to established professional assessment.

We have already documented how weather changes the snowpack. If human activity also changes its development, that history deserves comparable observational clarity.

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