BACKCOUNTRY TERRAIN USE PATTERNS UNDER VARYING AVALANCHE FORECAST CONDITIONS IN THE CANADIAN ROCKIES: INSIGHTS FROM STRAVA ACTIVITY DATA

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ABSTRACT: Understanding how backcountry recreationists adjust their terrain choices in response to avalanche hazard remains a key gap in avalanche risk research. Although prior studies have inferred skier behaviour from GPS tracks, online engagement, or mobile phone records, few combine spatially explicit recreation data with avalanche terrain classification and detailed forecast information, including both danger ratings and avalanche problem types. We examine backcountry activity across two case study areas in the Canadian Rockies using an integrated methodology combining Strava activity data, Avalanche Canada forecasts (danger rating and problem type), and Avalanche Terrain Exposure Scale (ATES) maps to quantify how use is distributed across terrain classes under varying hazard conditions.

Results show that temporal factors—especially weekends and seasonal progression—are the primary drivers of overall activity, consistent with findings from the Swiss Alps. However, a critical discrepancy emerged between Strava heatmap data, which captures broader user bases across all terrain types and Strava Metro data. While Mount Revelstoke (predominantly road-accessible terrain) shows reliable terrain-danger relationships with ~174,000 recorded trips, Rogers Pass and Glacier National Park (high-exposure backcountry terrain) yielded sparse Metro activity despite heatmap evidence of substantial recreational use. This indicates that terrain selection patterns can be reliably assessed for road-accessible recreation but not for avalanche-exposed backcountry populations using Metro filtering alone.

We assess both the potential and critical limitations of Strava as a scalable, privacy-respecting proxy for backcountry use in mountain areas. Despite systematic biases toward accessible terrain and younger, technology-adopting user populations, our analysis demonstrates that evaluation of user behavior relative to temporal avalanche conditions is achievable using crowdsourced activity data. Strava heatmap analysis confirmed that activity is distributed across terrain classes at landscape scales; however, standard Metro data downloads do not provide the temporal granularity required for daily hazard-behavior analysis, particularly in remote backcountry terrain. To overcome this critical limitation, we recommend an API-based workflow for acquiring segment-level activity counts at daily and monthly resolution, combined with heatmap validation and local expert consultation. This integrated approach enables characterization of how diverse user populations respond to avalanche conditions in both road-accessible and high-exposure terrain, supporting robust, scalable monitoring of recreation-hazard dynamics when data limitations are properly acknowledged and addressed. We propose an integrated API-based methodology combining daily/monthly Strava segment data, heatmap validation, and terrain analysis for future studies of backcountry user response to avalanche conditions. Such frameworks can support efforts to incorporate spatially explicit recreation dynamics into avalanche communication frameworks and wildlife–recreation interaction models while maintaining awareness of population-specific data biases.

KEYWORDS: avalanche terrain, terrain selection, backcountry users, avalanche problems, mountain parks, crowdsourced recreation data, user-generated content

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1. INTRODUCTION

Avalanche hazard information is intended to support decision-making in avalanche terrain by describing the likelihood and potential size of avalanches and identifying the conditions and terrain in which avalanche problems are expected. However, communication of avalanche hazard does not directly determine user behaviour. Backcountry users must interpret available information, combine it with their own experience and perception of snow and terrain, and translate it into decisions about where, when, and how to travel, with increasing acknowledgment that heuristic-based decision-making is a key driver of behaviour in the backcountry (Schäfer et al., 2026).

This process may generate gaps between communicated hazard, perceived hazard, planned behaviour, and observed behaviour (Toft et al., 2025). While terrain selection can be an important risk mitigation strategy when users adapt their routes towards less exposed terrain under elevated avalanche danger, users may report that they consider avalanche hazard information when planning an activity, while their actual terrain choices may not necessarily reflect the spatial distribution of the hazard described in the Avalanche Bulletin. Understanding whether and how often this adaptive behavior occurs remains a key gap in avalanche risk research.

Previous approaches to understanding avalanche-related decision-making have often relied on self-reported behaviour or on observations of travel behaviour in avalanche terrain. Surveys can provide information about users' knowledge, experience, perceptions, and stated decision-making processes (Hallandvik et al., 2017; Landrø et al., 2020), but are subject to the limitations inherent in self-reported data. Observational approaches, including GPS-based tracking, provide information about actual terrain use and travel behaviour, but generally provide less direct information about the factors and considerations underlying those decisions (Johnson & Hendrikx, 2021). This has driven a wave of research into behaviour, including studies on decision-making processes, risk-taking behaviour, group dynamics, demographics, used equipment, and terrain use of backcountry skiers using surveys, questionnaires, and interviews (Furman et al., 2010; Happ et al., 2023; Mannberg et al., 2018; Marengo et al., 2017; Nichols et al., 2018; Silverton et al., 2009; Valle et al., 2022; Zweifel et al., 2006), which are sometimes combined with accident statistics (Niemann et al., 2022; Pfeifer et al., 2018; Techel et al., 2015; Winkler et al., 2021, 2016). Recent innovations in crowdsourced data offer complementary approaches to understanding recreation behaviour and human-wildlife interactions. Schäfer et al. (2026) demonstrated that online engagement data can predict daily backcountry skiing activities on a regional scale. While online engagement shows good alignment with GPS activity on the next day, they found that backcountry skiers' online information seeking is driven by more extreme conditions than those reflected in actual behaviour. Nonetheless, online engagement data provide a cheap and scalable alternative source of revealed preference data, especially compared to privacy-sensitive GPS data or resource-intensive in-situ surveys.

Similarly, Strava Metro data offers an accessible, privacy-respecting proxy for understanding recreation behaviour patterns across multiple regions and seasons, enabling correlation with avalanche forecasts at unprecedented spatial-temporal resolution. Strava has increasingly been adopted as a research tool for recreation monitoring and management. Reinhardt et al. (2024) tested Strava Metro's usability for rural recreation planning by validating bike ride-counts against trail counter data in Vermont. They integrated traffic count data to determine peak times for both bikers and vehicles where safety concerns may arise, demonstrating that Strava data provides supplementary insights into trail usage patterns, intensity variations, and visitor use hotspots when combined with traditional methods of data collection. Vilalta Capdevila et al. (2024) provide a comprehensive comparison of application-based tools like Strava with traditional recreation monitoring methods, demonstrating that crowdsourced platforms capture recreation patterns at scales and temporal resolutions unattainable through conventional on-site surveys or trail counters alone. This advancement in monitoring capability has expanded the application of Strava data beyond basic recreation planning to more sophisticated hazard and conservation assessments. Beyond recreation planning, recent research has leveraged Strava to assess human-wildlife interactions. Morgan et al. (2026) combined 6 years of high-resolution GPS data from 36 free-ranging mountain lions in California's Santa Cruz Mountains with spatially and temporally explicit measures of recreational intensity derived from Strava activity data. This application demonstrates that recreation-intensity mapping using crowdsourced data can inform integrated wildlife and hazard management strategies in protected areas, making it a valuable tool for assessment of human-wildlife-hazard overlap.

This study develops an integrated field methodology combining Strava activity data, Avalanche Bulletin information, and Avalanche Terrain Exposure Scale (ATES) classification. Building on previous applications of Strava for recreation monitoring and behavioral studies, this work explores the utility of crowdsourced activity data in evaluating terrain use relative to temporally varying avalanche risk. Specifically, this study assesses the potential and limitations of Strava data as a scalable, privacy-respecting tool for understanding how backcountry recreationists use avalanche terrain and respond to varying hazard conditions in the Canadian Rockies. Specifically, we examine whether Strava activity patterns correlate with avalanche danger ratings and problem types, and whether users shift toward different terrain under based on the avalanche conditions of the day. We recognize Strava's limitations—bias toward younger, technology-adopting users; exclusion of non-smartphone participants—yet its volume and spatial-temporal resolution offer opportunities to detect recreation behaviour patterns at landscape scales.

2. METHODS

The study areas focused on Mount Revelstoke National Park and Glacier National Park in the Canadian Rockies, where popular backcountry ski areas within the Park, such as Rogers Pass are highly frequented for recreationist during winter month.

Automated ATES v2.0 methodology (Toft et al., 2024 and Sykes et al., 2024) was used to create provisional Avalanche Terrain ATES terrain layers at 25 m resolution. AutoATES integrates digital elevation models, forest mapping, and Flow-Py avalanche runout simulation to classify terrain into Simple, Challenging, Complex, and Extreme exposure classes. ATES provides the terrain exposure variable for analysis.

Daily avalanche danger ratings and primary problem types (January–April 2025) were retrieved using the validanger R script. This Daily danger levels (1–5) and primary problem types (windslab, persistent slab, storm slab, dry loose, cornice, gliding, wet loose, wet slab) where extracted for the avalanche forecasting areas of Mount Revelstoke and Glacier National parks.

Strava Heatmaps and Strava Metro activity data for January–April 2025 was obtained at segment granularity with daily trip counts for winter activities (Figure 1). Strava Metro provides privacy-aggregated activity counts from GPS traces, without individual-level information.

Daily Strava segment activity counts were spatially cross-referenced with ATES terrain, assigning each segment its maximum ATES class. On each day, activity was aggregated by ATES class and compared against daily danger rating and primary avalanche problem type. This characterized how activity was distributed across terrain.

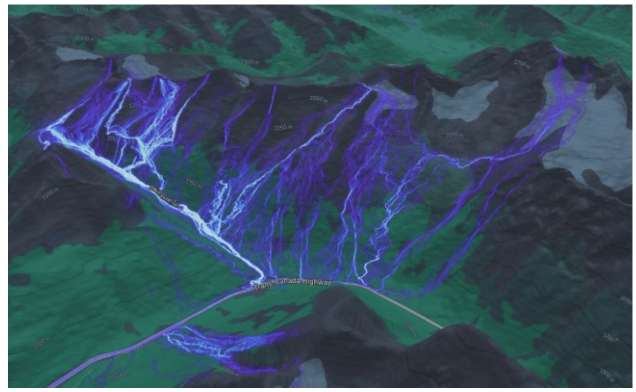

Figure 1. Strava Heatmaps of winter use in Rogers Pass

2. RESULTS

2.1 Analysis of ATES terrain use by strava tracks

Analysis of Strava Global Heatmap data from winter activities in April 2025 shows that recreational activity is distributed across terrain classes in proportions consistent with terrain availability in each study area (Figure 2). In Mount Revelstoke National Park, where Simple terrain dominates at 72.3% of available terrain, the vast majority of recorded Strava activity (99.8%, 173,855 trips) occurs on Simple terrain, with only 0.2% (395 trips) on Challenging terrain. Complex terrain (14.1% available) and Extreme terrain (2.5% available) receive minimal activity. This distribution is appropriate given the park's terrain composition and reflects the concentration of accessible trail networks in lower-elevation, simpler terrain (Figure 3).

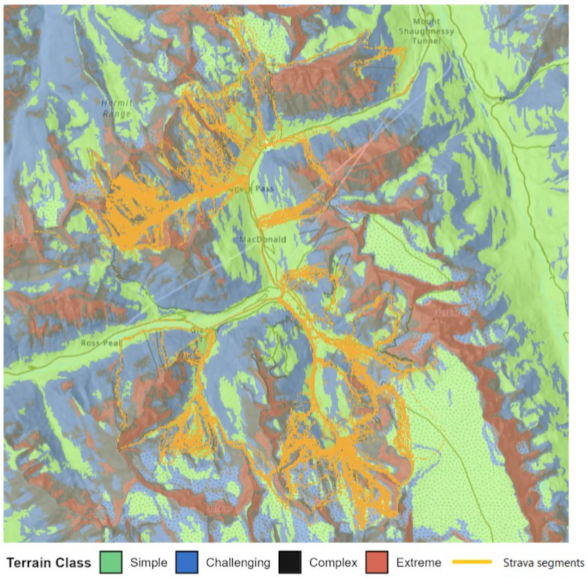

Figure 2. Strava heatmap segments with activity on top of the ATES classification in Glacier NP.

In contrast, Glacier National Park exhibits a more balanced terrain-activity relationship reflective of its diverse topography: Simple terrain (36.3% available) accounts for approximately 30% of activity, Challenging terrain (36.7% available) captures approximately 35% of activity, and Complex terrain (19.2% available) accounts for approximately 18% of activity. This proportional use suggests that users access and utilize the full range of terrain classes available within the park's trail network.

Figure 3. Distribution of available terrain per ATES class and % of use (hatched) by strava tracks in Mount Revelstoke NP, Glacier NP and only Rogers Pass.

Rogers Pass, with its terrain composition heavily weighted toward Complex terrain (60% available), shows correspondingly higher proportional use of Complex terrain (approximately 60% of recorded activity). Simple terrain (7% available) and Challenging terrain (12% available) receive lower proportional activity consistent with their limited availability. These results demonstrate that Strava heatmap data realistically captures the distribution of winter recreational activity across different terrain exposure classes, with activity patterns reflecting both terrain availability and accessibility within each park.

2.2 Analysis of strava activity based on terrain and avalanche conditions

To assess how winter backcountry recreationists adjust terrain choices in response to avalanche hazard, we crossed daily Strava Metro activity data (January–April 2025) with corresponding avalanche danger ratings and problem types retrieved from Avalanche Canada forecasts, and matched both datasets to Avalanche Terrain Exposure Scale (ATES) terrain classifications. This aimed to study whether users shifted their terrain selections across Simple, Challenging, Complex, and Extreme terrain classes under varying avalanche conditions, given the danger level and the main avalanche problem of the day.

Avalanche Danger and Activity Levels

Across the three study areas, avalanche danger showed minimal correlation with total activity volume, particularly at Mount Revelstoke where road-accessible trails dominate. These findings reflect the behavior of road-accessible trail users captured by Strava Metro and do not necessarily represent backcountry skiers or users in high-exposure avalanche terrain, as discussed in Section 3. This pattern reflects a fundamental constraint: Strava Metro data, in standard download formats, captures primarily lower-angle, road-accessible terrain where avalanche danger ratings have limited behavioral influence. The absence of temporal variation in terrain choice across danger levels is less a behavioral finding than a methodological artifact—high-exposure avalanche terrain, where users might demonstrate meaningful hazard-adaptive behavior, remains largely invisible in the accessible data stream.

However, this constraint reveals an opportunity. By integrating Strava activity (now with higher temporal resolution via Metro API) with avalanche danger ratings and problem types, we demonstrate a proof of concept for automated, scalable monitoring of recreation-hazard relationships. While current data captures only road-accessible populations, the framework—linking crowdsourced activity, terrain classification, and forecast information at daily granularity—provides a replicable template for future studies. Overcoming the backcountry data gap requires methodological innovation (multi-source data fusion, specialized winter sports platforms, local expert validation) discussed in detail in Section 3, but the foundation for automated hazard-behavior monitoring is now established.

Problem Types and Seasonal Patterns

Avalanche problem type distributions showed clear seasonal trends. Persistent slab dominated January–February (29.2% of days), windslab peaked in March–April (32.5%), and storm slab occurred throughout the season (22.5%). Despite these shifts in avalanche problem classification, terrain selection remained remarkably insensitive to problem type. Mount Revelstoke users selected Simple terrain on more than 90% of days regardless of problem type, with Challenging terrain accounting for less than 1% of activity. This stability suggests the road-accessible user population captured by Strava Metro either lacked awareness of problem-specific hazard advice or consisted predominantly of pedestrian/leisure-class activity on low-angle terrain. Terrain choice did not shift in response to communicated problem classifications (Figure 4).

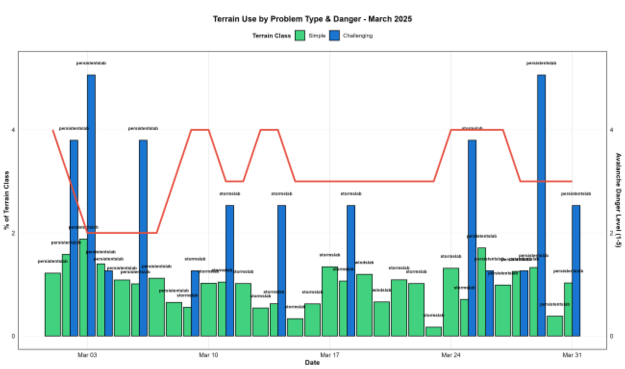

Figure 4. Daily use of ATES class in Glacier NP compared to the avalanche danger level and main problem of the day during March 2025.

April 2025 recorded the highest concentration of High and Considerable danger days (11 of 30). Despite these warnings, Simple terrain accounted for >99% of Mount Revelstoke activity. Temporal factors—weekends, seasonal progression, and late-April snow stability—showed stronger associations with recreation intensity than formal danger ratings. Activity peaked during the final two weeks of the season when visible field conditions indicated stable snowpack and spring skiing conditions were most appealing.

Critical Data Limitation: Strava Metro vs. Heatmap Discrepancy

A fundamental mismatch between available terrain distribution and recorded Strava Metro activity revealed a critical limitation for hazard-behavior analysis. Mount Revelstoke has 72.3% Simple terrain, yet 99.8% of recorded activity occurred there. More problematically, Glacier National Park (36.3% Simple, 36.7% Challenging, 19.2% Complex, 7.8% Extreme) recorded only 235 trips across 7 active days, and Rogers Pass (13.6% Simple, 13.5% Challenging, 59.7% Complex, 13.2% Extreme) yielded negligible Metro activity in Challenging and Complex terrain despite these classes representing 73% of available terrain.

This discrepancy became apparent when comparing Metro data to Strava heatmap-derived terrain presence. The heatmap analysis revealed substantially higher activity in Challenging and Complex terrain across Glacier and Rogers Pass than Metro data indicated. This suggests that winter backcountry activities—particularly ski touring and snow sports—were not fully present in Strava Metro. Metro activity filtering is optimized for pedestrian and cycling activity on road-accessible corridors; it systematically underrepresents backcountry ski touring and snow-specific activities that dominate high-altitude, high-exposure terrain in winter.

Consequently, Strava Metro data biases inferences toward road-accessible, lower-angle terrain, particularly at Rogers Pass. Mount Revelstoke, which contains substantial Simple terrain and accessible areas, showed more representative activity capture and thus more reliable terrain-danger associations. Conversely, sparse Metro activity at Rogers Pass and Glacier reflects a recording artifact rather than actual winter backcountry use patterns in avalanche-exposed terrain.

2 DISCUSSION AND CONCLUSIONS

3.1 Strava Heatmap Terrain Analysis: Strengths and Spatial Patterns

Integration of Strava heatmap data with ATES terrain classification successfully revealed the spatial distribution of winter recreation activity across avalanche-exposed terrain. Segment-level data demonstrated that users accessed terrain spanning Simple (36–72% by park) to Extreme classes (2–13%), with Rogers Pass showing balanced use of Challenging and Complex terrain. This spatial granularity, difficult to achieve through traditional surveys, show the potential of this methodological approach. However, heatmaps lack temporal resolution necessary to link terrain choices to daily avalanche conditions.

Strava Metro data offers promising potential for daily-resolution analysis of recreation-hazard relationships. Unlike heatmaps, Metro provides daily activity counts per segment, enabling direct comparison between recreation intensity and avalanche danger level on identical calendar days. The absence of activity data at Rogers Pass and Glacier may reflect either (1) limited backcountry user adoption of Strava recording, or (2) Strava's privacy policies that exclude low-activity segments from public datasets. Metro minimum user thresholds (if applied) would filter backcountry-specific, low-traffic segments while retaining heavily-used road-accessible segments, biasing the dataset toward accessible terrain regardless of actual backcountry use. This granularity opened the possibility of examining whether users shift terrain choices in response to communicated hazards in real time.

Yet our analysis revealed a fundamental caveat: high-alpine winter activities, particularly ski touring and backcountry snow sports in avalanche terrain, are not effectively recorded or categorized and provided by Strava Metro. Metro activity filtering is optimized for pedestrian and cycling activity on road-accessible corridors.

This limitation is starkly evident: Rogers Pass, comprising 60% Challenging and Complex terrain and representing one of North America's premier backcountry ski touring destinations, yielded only ~25 total Metro activity records over four months. Glacier National Park's high-alpine terrain similarly showed disproportionately low Metro activity. The discrepancy between Strava heatmap (which captures broader user bases) and Metro data (road-accessible pedestrians) confirms that winter backcountry activities remain largely invisible to Metro filtering. Consequently, Metro data provides a reliable window into road-accessible, lower-angle terrain (Mount Revelstoke: ~174,000 trips), but can misrepresents avalanche-exposed backcountry behavior.

Beyond the Metro caveat, Strava exhibits well-documented broader limitations. Demographic bias toward younger, wealthier users skews activity toward day-hikers. Underrepresentation of true backcountry specialists is substantial: dedicated backcountry users may not record every tour, may use GPX devices or alternative platforms, or may be reluctant to share location data. Winter coverage gaps further bias seasonal patterns, particularly for activities like ski touring that depend on specialized equipment and niche user bases.

Strava Strengths for Studying Behavioral and Decision-making Dynamics on Avalanche Terrain

Despite limitations, Strava demonstrates three key strengths for regional recreation analysis: (1) Unprecedented spatial-temporal resolution at segment granularity across entire regions, enabling forecast correlation at scales impossible with surveys; (2) Privacy maintenance—no individual-level data, only aggregates, protecting user confidentiality; (3) Volume—174,250 observations over 120 days at Mount Revelstoke alone provides statistical power. Methodological verification through ride-data cross-checking strengthens confidence in crowdsourced platforms.

3.2 Concluding Remarks

Strava heatmaps effectively characterize regional terrain use patterns but lack temporal resolution for avalanche-behavior analysis. Metro provides temporal granularity but can exclude some winter backcountry patterns and users. Neither source alone is sufficient for comprehensive winter recreation-hazard analysis. API-based data extraction of temporal user data, combined with heatmap validation and local expert consultation, may represent a future workflow for accessing additional data and understanding how diverse user backcountry users respond to avalanche conditions in mountain ecosystems. Such integrated frameworks are essential for understanding the spatial and temporal patterns of backcountry winter recreation, enabling land managers and avalanche safety professionals to improve hazard assessment, communication, and mitigation.

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