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Natural Hazards and Earth System Sciences
Discussions

The Avalanche Terrain Exposure Scale (ATES) v.2

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Abstract. The Avalanche Terrain Exposure Scale (ATES) is an avalanche terrain classification system used to assess and communicate the exposure of backcountry terrain to the threat from avalanches, independent of daily hazard conditions. Commonly known as terrain ratings, these classifications are determined by an analysis of individual terrain parameters, which are then systematically combined to produce a single rating. The ATES model includes technical specifications for assessing terrain as well as corresponding communication scales for effectively sharing ratings with different kinds of backcountry users. ATES ratings are found in guidebooks and route descriptions or displayed spatially on maps. The system was originally introduced in Canada in 2004 as a risk management tool in conventional avalanche safety practices for public recreation and workplace avalanche safety. This paper introduces ATES v.2, an update to the system that expands the original scale from three levels to five by including Class 0 – Non-Avalanche Terrain, and Class 4 – Extreme Terrain. The original ATES v.1/04 and the ATES Zoning Model are merged into a single, five-level, updated version of ATES. ATES ratings can be applied as Areas, Zones, Corridors, or Routes and then communicated using models for backcountry travel and waterfall ice climbing.

1 Introduction

Exposure to avalanche hazard is a fundamental concept in avalanche risk management; when nothing is exposed, nothing is at risk. Yet most winter backcountry travel scenarios are not this simple, especially with recreational and workplace activities where the elements-at-risk such as skiers, climbers, snowmobilers, or workers are mobile and free to travel unrestricted through the landscape. In these cases, people will encounter choices with different degrees of exposure to avalanche hazard. Their risk depends upon their route selection and the degree to which they expose themselves to the avalanche hazard.

The Avalanche Terrain Exposure Scale (ATES) is an avalanche terrain rating system used to assess and communicate the degree of avalanche terrain exposure (Statham et al., 2006). Ratings are determined using both qualitative and quantitative analyses and result in a subjective measure of the degree of avalanche terrain exposure on an ordinal scale. Unlike the transient nature of avalanche hazard assessments, which rise and fall with the changing weather and snowpack conditions, ATES ratings are based upon constant parameters that do not change (e.g., slope angle, exposure) or change slowly (e.g., avalanche frequency, forest density), resulting in a static, unchanging terrain rating.

Since its introduction in Canada in 2004, ATES has been applied in many different jurisdictions and countries (e.g., Mcmanamy et al., 2008; Bogie and Davies, 2010; Gavaldà et al., 2013; Maartensson et al., 2013; Pielmeier et al., 2014; Larsen at al., 2020) and has become a widely used risk management and avalanche education tool (Haegeli et al., 2006; Floyer and Robine, 2018; Zacharias, 2020), and has been used as a research tool to measure terrain use preferences (e.g., Sykes et al., 2020; Johnson & Hendrikx, 2021; Hendrikx et al., 2022). In Canada, use of ATES has grown beyond recreational applications into legal and regulatory frameworks, and is now widely used in workplace avalanche safety plans and national parks custodial group management policies (Parks Canada, 2005b).

The objective of this paper is to present an updated version of ATES, now called ATES v.2. This new version of ATES takes into account over 20 years of practical experience with avalanche terrain ratings. During this period, advances in technology and geospatial tools have facilitated a broader application of the ATES concept, including automated ATES ratings (Larson et al., 2020), which greatly expands the potential scope of terrain classification. At the same time, continued growth of backcountry recreation has furthered the need for improved avalanche terrain tools (Klassen 2012). Terrain use patterns have changed, and ATES needs to change with them.

This paper gives an overview and background on avalanche terrain rating systems, followed by a description ATES v.2, starting with changes from previous versions before introducing three new ATES models for assessment and communication. The application of ATES is then described, including methods for assessment and presentation of terrain ratings followed by discussion on the limitations of the ATES system.

2 Background

Terrain rating systems play an essential risk management function in recreational activities such as climbing, hiking, kayaking, skiing and mountain biking. The primary objective of these systems is to simplify complex terrain attributes into easily understood categories that recreationists can use to: 1) understand the difficulty, or severity of their route beforehand and gauge this against their own skills and current conditions, 2) identify and study the crux points of their route ahead of time, and 3) recognize their position on a map in relation to the severity of the terrain around them.

In Canada, avalanche terrain classification systems are either *impact-based* or *exposure-based* (CAA 2016b). Traditional hazard mapping methods for land-use planning use impact-based hazard maps (e.g., Rudolf-Miklau et al. 2014; Jamieson and Gould, 2018; Bründl and Margreth 2021), where the frequency and magnitude of avalanches to known locations can be quantified. Hazard maps delineate zones to evaluate and manage risk to infrastructure, roads and occupied structures and can be applied to any asset with a fixed location. However, these methods become impractical when the element-at-risk is mobile with unrestricted movement in the landscape, as is the case with backcountry travel. When the element-at-risk can move anywhere, quantitative methods based on avalanche frequency and magnitude to known locations become impractical and are unrealistic for backcountry travel risk scenarios. Thus, avalanche terrain classification for backcountry recreation requires an exposure-based approach.

Canadian Mountain Holidays (1993) was the first to introduce an exposure-based terrain rating system for backcountry skiing, using three terrain categories (A, B and C) and applying these to their inventory of helicopter ski runs. Penniman and Boisselle (1996) proposed a five-level Avalanche Terrain Risk scale based upon terrain severity and modelled after river ratings. Parks Canada introduced ATES v.1/04 (Statham et al., 2006) and rated 275 backcountry ski trips (Parks Canada, 2004) and 75 waterfall ice climbs (Parks Canada, 2005a) in the national parks. Their objective was to encourage guidebook authors to adopt ATES ratings as an aid to the route descriptions in their publications. A single rating was assigned for each trail, climb or backcountry ski area, and that rating defaulted to the highest terrain class along the entire route or area (Parks Canada, 2004). This method has since been described as $\text{ATES}_{\text{linear}}$ (e.g., Thumlert and Haegeli, 2018).

While $\text{ATES}_{\text{linear}}$ was effective as a trip planning tool, its large-scale application limited its utility for field-based decision making and for activities unbounded by specific routes, such as snowmobiling. The ATES zoning model (Campbell and Gould, 2013) decoupled ATES from specific routes where the exposure is known, and encouraged a wider adoption of the ATES concept using spatial mapping. The zoning model offered an accessible methodology by using a reduced and more deterministic set of thresholds more suitable for a Geographic Information System (GIS) environment. The zoning model also introduced Class 0 (non-avalanche terrain), an essential rating level in any avalanche terrain classification system that shows where avalanches do not occur. Avalanche Canada subsequently mapped over 5000 km^2 of winter backcountry recreation areas in British Columbia using the zoning model (Avalanche Canada, 2023), which has since been described as $\text{ATES}_{\text{spatial}}$ (e.g., Thumlert and Haegeli, 2018).

3 Principal changes to the Avalanche Terrain Exposure Scale

The original ATES v.1/04 and the ATES Zoning Model have been merged and expanded from three to five levels of terrain exposure to reflect backcountry use patterns noted on both ends of the spectrum: from conservative low-risk terrain to more aggressive, high-risk terrain. These two new ATES classes are Class 0 – Non-avalanche Terrain and Class 4 - Extreme Terrain. In addition, glaciation has been removed as a distinct parameter in ATES v.2.

3.1 Class 0 – Non-Avalanche Terrain

Class 0 was first introduced by Campbell and Gould (2013) and is now being integrated into ATES v.2. Non-avalanche terrain is arguably the most important rating level due to the sheer number of people who wish to completely avoid avalanche risk. Examples such as youth groups, tourist hikers, industrial camps and workplace safety requirements often demand a complete avoidance of avalanche risk. To meet this need, managers require simple ways to direct people towards non-avalanche terrain. Figure 1 illustrates trails that are rated Class 0 in the immediate vicinity of Lake Louise, Canada, where millions of people visit annually and almost all of them want to completely avoid all avalanche risk.

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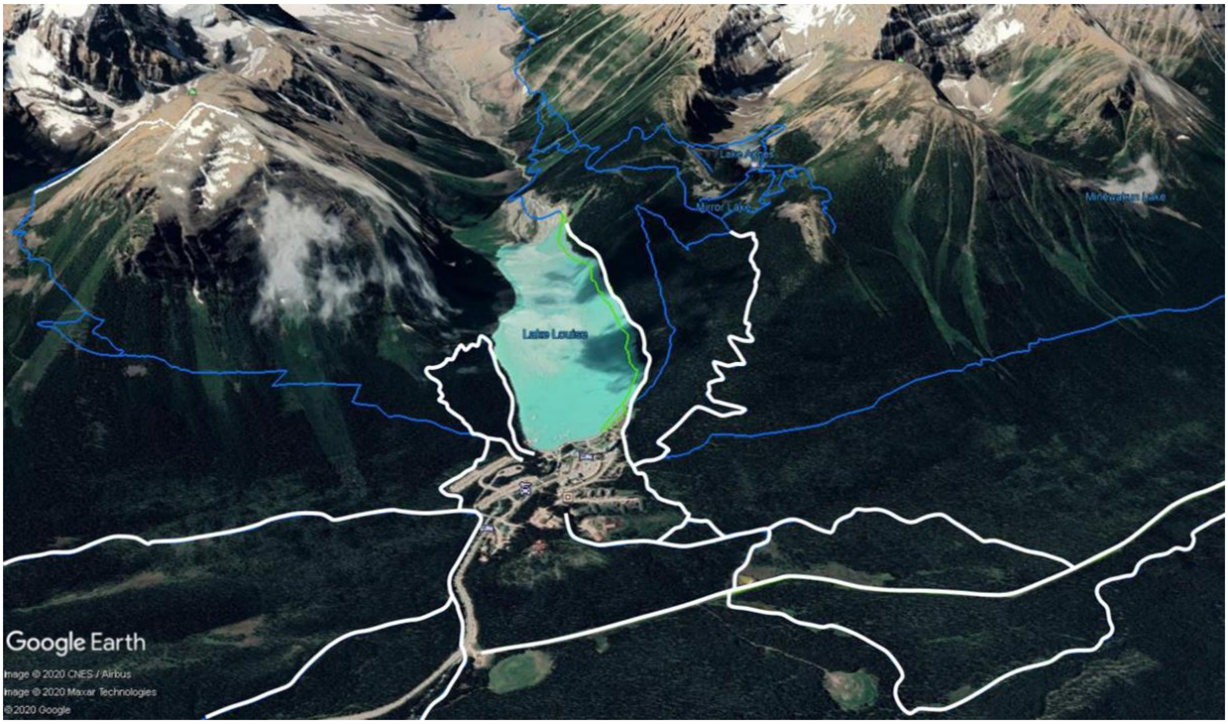

Figure 1. Designated trails in the Lake Louise area of Canada's Banff National Park, with white showing trails rated Class 0 – Non-avalanche Terrain.

Although it is a basic competency of an avalanche professional to identify where avalanches can occur and where they cannot, this task is not trivial. For land-use planning applications, determining an avalanche free perimeter is a complex process involving vegetation analysis, mapping of historic events, climate analysis and runout modelling (Jamieson and Gould, 2018). This level-of-effort is usually impractical for mapping backcountry avalanche hazard. Determining a Class 0 – Non-avalanche Terrain rating requires high confidence in the assessment and can have little to no uncertainty. For this reason, the use of ATES Class 0 is optional, and Class 1 can include Class 0 terrain.

3.2 Class 4 – Extreme Terrain

In ATES v.1/04, Complex terrain has broad criteria that encompasses much of the popular terrain used for alpine recreation, specifically alpine ski touring, snowmobiling and ice climbing. According to backcountry skiing guidebooks for western Canada, 71% of ski tours in the Coast Range (Baldwin, 2009) and 76% in the Canadian Rocky Mountains (Scott and Klassen, 2011) are rated Class 3 – Complex terrain. Harvey et al. (2018) considered ATES to have limited practical value in the Swiss Alps because too many tours would inherently be classified as Complex. This lack of a finer resolution within Complex terrain has limited the value of an ATES rating for experienced recreationists who spend much of their time in steep mountain terrain.

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As backcountry recreation continues to grow, this style of terrain is becoming ever more popular. Freeriding and ice climbing routinely travel through or below high consequence avalanche terrain that presents as its own distinct class of terrain, now known as Class 4 – Extreme Terrain (Figure 2).

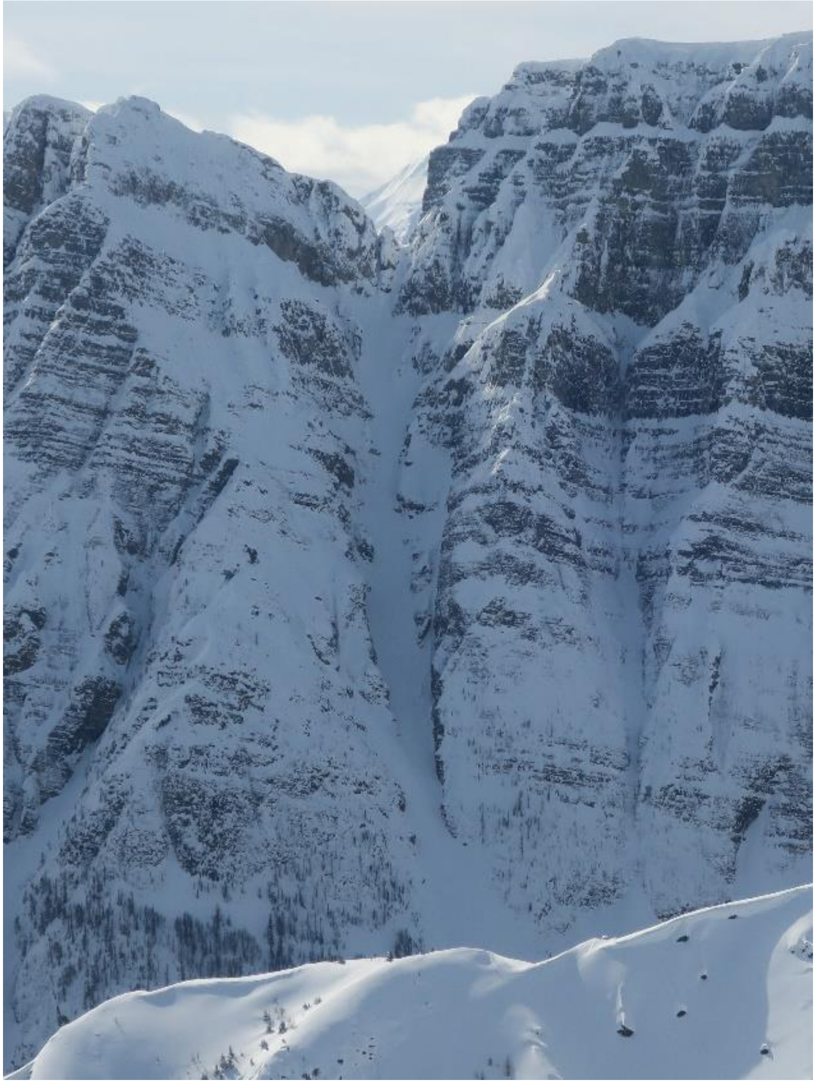

Figure 2. The Kindergarten Couloir, a popular freeriding route in Canada's Kootenay National Park, is an example of Class 4 – Extreme Terrain.

3.3 Removal of glaciation

Glaciation was an important parameter in the original ATES v.1/04 (Statham et al., 2006), and all glaciated terrain automatically defaulted into at least Class 2 – Challenging Terrain, irrespective of any other ATES parameters. If a glacier presented with "broken or steep sections of crevasses, icefalls or serac exposure", then the rating defaulted to Class 3 – Complex terrain. There was no Class 1 – Simple Terrain on a glacier. This was intended to capture the complexity of glacier travel but had the effect of defaulting flat or low angled glaciers into an ATES Class 2 rating, even when there was little or no avalanche terrain. Notably, the ATES Zoning Model (Campbell and Gould, 2013) did not consider glaciation, creating a conflict between these two models.

ATES is primarily concerned with terrain exposed to snow avalanche hazard. Ice avalanches are distinct from snow avalanches in that their failure mechanism follows a different process (Pralong et al., 2005), leading to their inherent unpredictability by field practitioners. For these reasons, glaciation as an independent parameter has been removed from ATES v.2, but crevasses remain as an important terrain trap consideration. This will have the effect of down classifying low-angled glaciated terrain that was previously Class 2 – Challenging Terrain, into Class 1 or Class 0 terrain.

4 Avalanche Terrain Exposure Scale v.2

ATES is an ordinal, five-level terrain rating system that helps people gauge their exposure to avalanche-prone terrain, and it follows the communication theory of *source-channel-receiver* (Wogalter et al., 1999). The source is the person, or group doing the assessment and determining the rating, the channel is the method of communication (e.g., website, app, guidebook, etc.), and the receiver is the end user of the information.

ATES is a terrain model that uses two types of definitions to meet its dual objectives of assessment and communication. The Communication Models (Tables 1 and 2) are simple by design, and achieve the primary objective of ATES by relating terrain ratings to different receiver groups. The Technical Model (Table 3) is designed for the source (i.e., the terrain assessor) as a specialized reference for identifying, analysing, and classifying avalanche terrain exposure. Although these two types of ATES definitions use different language to achieve different objectives, their thresholds correspond: ATES says the same thing in two different languages, one technical and one non-technical. The system uses numbers, signal words and colours as options to communicate the rating level.

4.1 ATES Communication Models

First and foremost, the purpose of ATES is avalanche risk communication. Regardless of the techniques used to assess the terrain exposure, ATES ratings are ultimately defined by and must meet the criteria specified in the Communication Models, as these are what is published to the receiver groups. The Communication Models describe terrain ratings in the language of the receiver group and are light on technical detail with a priority on comprehension. Tables 1 and 2 describe and rank avalanche terrain in a simple way, similar to how the Avalanche Danger Scale (Statham et al., 2010; EAWS, 2024) describes and ranks avalanche danger; they are both the summary output of a technical assessment, intended for public avalanche risk communication. When used in combination, these models of avalanche danger and terrain offer a simplistic, but powerful way to illustrate good risk management through the interaction of snow, terrain and people (Haegeli et al., 2006).

Table 1. ATES for backcountry travel.

Terrain rating	Class	Description for backcountry travel
Non-Avalanche	**0**	No known exposure to avalanches. Very low-angle or densely forested slopes located well away from avalanche paths, or designated trails/routes with no exposure to avalanches.
Simple	**1**	Exposure to low-angle or primarily forested terrain. Some forest openings may involve the runout zones of infrequent avalanches and terrain traps may exist. Many options to reduce or eliminate exposure.
Challenging	**2**	Exposure to well-defined avalanche paths, starting zones, terrain traps or overhead hazard. With careful route finding, options exist to reduce or eliminate exposure.
Complex	**3**	Exposure to multiple overlapping avalanche paths or large expanses of steep, open terrain. Frequent exposure to overhead hazard. Many avalanche starting zones and terrain traps with minimal options to reduce exposure.
Extreme	**4**	Exposure to very steep faces with cliffs, spines, couloirs, crevasses or sustained overhead hazard. No options to reduce exposure; even small avalanches can be fatal.

Waterfall ice climbing is a specialized activity, often very exposed to avalanche hazard and high risk (Statham and Hueniken, 2023). Ice climbers are a unique audience in that their routes are often inside avalanche paths, meaning that climbers can be exposed for long periods of time to slopes overhead that cannot be assessed in conventional ways. The primary emphasis of ATES for waterfall ice climbers is exposure time and avalanche frequency. How frequently does the route avalanche, and how long will climbers be exposed to it?

Table 2. ATES for waterfall ice climbing.

Terrain rating	Class	Description for waterfall ice climbing
Non-Avalanche	**0**	Routes with no exposure to avalanches except small sluffs and spindrift.
Simple	**1**	Routes with brief exposure to very low frequency avalanches starting from above or crossing occasional short slopes.
Challenging	**2**	Routes with long exposure to low frequency avalanches or brief exposure to high frequency avalanches starting from above or crossing a few short slopes. Options exist to reduce exposure.
Complex	**3**	Routes with long exposure to high frequency avalanches starting from above or crossing steep slopes with terrain traps below. Minimal options to reduce exposure.
Extreme	**4**	Routes with long and sustained exposure to very high frequency avalanches starting from above and crossing multiple steep slopes with terrain traps below. No options to reduce exposure.

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4.2 ATES Technical Model

The ATES Technical Model (Table 3) is designed for avalanche terrain identification, analysis and evaluation to determine an ATES rating. The model describes avalanche terrain exposure using eight distinct parameters, each with thresholds for the five ordinal ATES classes. Any given area, zone, corridor or route can include terrain that meets different classes of ATES criteria, and combining different criteria into a single rating is a subjective exercise with some guidance. Within the total of 40 criteria, there are six bold defaults that when met, automatically place the ATES rating into that category or higher. Otherwise, the overall rating is an evaluation based predominantly on expert judgement, analysing the terrain against each ATES parameter for best fit, comparing this to levels above and below, and then deciding what the best overall ATES rating is. Peer review of ATES ratings from other qualified individuals is important for error correction and improving confidence in the assessment.

The following sections describe each of the eight parameters (Table 3) that define the ATES Technical Model by describing their influence on terrain severity and the range of thresholds from Class 0 to Class 4.

4.2.1 Exposure

Exposure is the situation of people, infrastructure, housing and other tangible assets located in hazard-prone areas (United Nations, 2016). For avalanche risk, exposure is the position of the element-at-risk in relation to a specific avalanche hazard measured in both space and time. In other words: specifically, *where* and *for how long* something is exposed to an avalanche hazard.

When ATES ratings are being applied to specific routes, the locations are pre-defined by the route and the exposure is known. This contrasts with ATES ratings for areas or zones, where there is no predetermined route. In this case the assessment must consider “potential exposure” within a spatially mapped area. When the end-user plans a specific route on the map, then their exposure becomes known and can be applied to the ATES ratings.

ATES uses a range of descriptive terminology to characterize the spatial and temporal exposure. The spatial exposure range is *none - runouts only - single paths - multiple paths - inside/under starting zones*. The temporal exposure range is *none - minimal – intermittent - frequent – sustained* and assumes the typical time it takes to cross an area.

4.2.2 Slope angle and forest density

Slope angle is the primary terrain factor in avalanche release. Slab avalanches typically initiate within the range of 25-55° (McClung and Schaerer, 2023), with most initiating on slopes that have an incline of 30-45°. Within any single slope, it is the steepest part of the slope that matters most. This is known as the “critical slope”, which is the steepest angle from the horizontal averaged over 10-20 m in the starting zone. (Schweizer et al., 2003; McClung and Schaerer, 2023).

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Table 3. ATES Technical Model. Bold text indicates default values that automatically place the ATES rating into that category or higher.

	Class 0 Non-Avalanche Terrain*	**Class 1 Simple Terrain**	**Class 2 Challenging Terrain**	**Class 3 Complex Terrain**	**Class 4 Extreme Terrain**
Exposure	No known exposure to avalanche paths	Minimal exposure crossing low-frequency runout zones or short slopes only	Intermittent exposure managing a single path or paths with separation	***Frequent exposure to starting zones, tracks or multiple overlapping paths***	Sustained exposure within or immediately below starting zones
Slope angle *and* **Forest density**	Very low-angle (<10°) open terrain or steeper areas of dense forest	Low-angle (< 20°) terrain or steeper slopes in dense forest with openings for runout zones or short slopes	Moderate-angle (< 30°) open or gladed terrain with some open slopes or glades > 35°	Moderate to high-angle (< 35°) terrain with a large proportion of open slopes > 35° and some isolated glades or tree bands	High-angle, open terrain averaging > 35° with a large proportion of slopes > 45° and few or no trees
Slope shape	Straightforward, flat or undulating terrain	Straightforward undulating terrain	Mostly planar with isolated convex or unsupported slopes	Convoluted open slopes with intricate and varied terrain shapes	Intricate, often cliffy terrain with couloirs, spines and/or overhung by cornices
Terrain traps	No avalanche-related terrain traps	Occasional creek beds, tree wells or drop-offs	Single slopes above gullies or risk of impact into trees or rocks	Multiple slopes above gullies and/or risk of impact into trees, rocks or crevasses	Steep faces with cliffs, cornices, crevasses and/or risk of impact into trees or rocks
Frequency-magnitude	***Never***	***< 1:100 - 1:30 for ≥ Size 2***	1:1 for < Size 2 ***1:30 - 1:3 for ≥ Size 2***	1:1 for < Size 3 ***1:1 for ≥ Size 3***	10:1 for ≤ Size 2 > 1:1 for > Size 2
Starting zone size and density	No known starting zones	Runout zones only except for isolated, small starting zones with < Size 2 potential	Isolated starting zones with ≤ Size 3 potential or several start zones with ≤ Size 2 potential	Multiple starting zones capable of producing avalanches of all sizes	Many very large starting zones capable of producing avalanches of all sizes
Runout zone characteristics	No known runout zones	Clear boundaries, gentle transitions, smooth runouts, no connection to starting zones above	Abrupt transitions, confined runouts, long connection to starting zones above	Multiple converging paths, confined runouts, connected to starting zones above	Steep fans, confined gullies, cliffs, crevasses, starting zones directly overhead
Route options	Designated trails or low-angle areas with many options	Numerous, terrain allows multiple choices; route often obvious	***A selection of choices of varying exposure; options exist to avoid avalanche paths***	Limited options to reduce exposure; avoidance not possible	No options to reduce exposure

* *The use of Class 0 is optional due to the reliability needed to make this assessment; otherwise, Class 1 includes Class 0 terrain.*

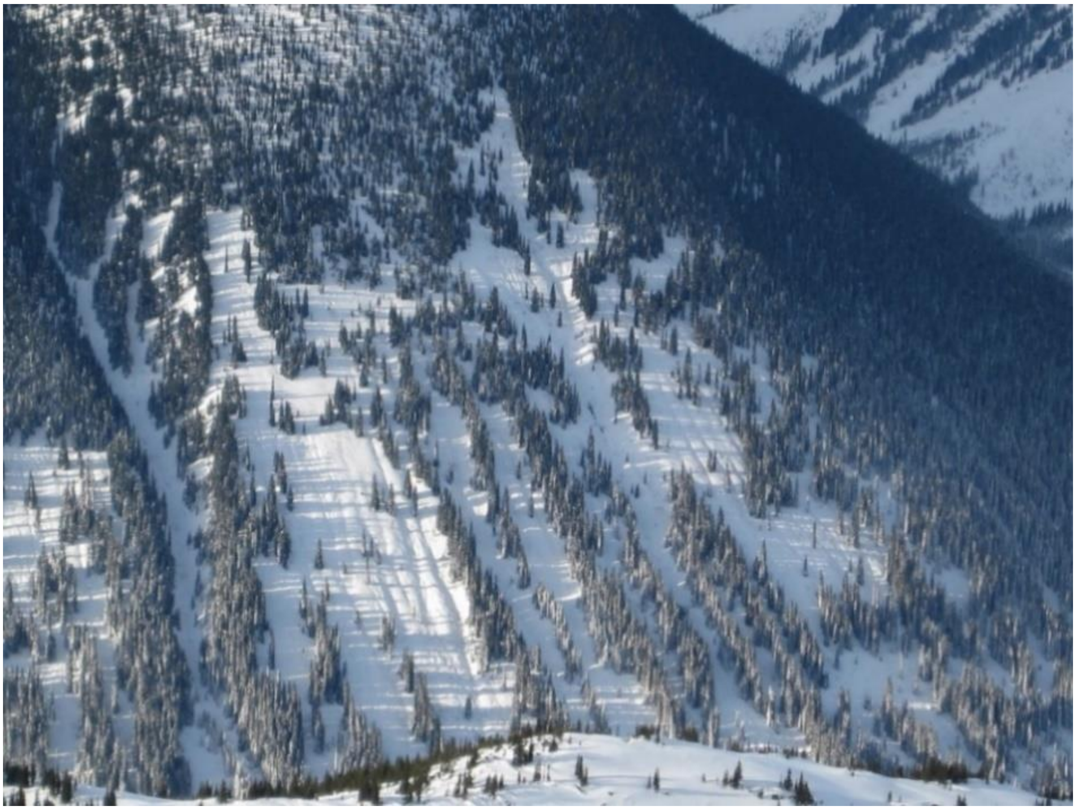

Figure 3. The interaction between slope angle and forest density is illustrated here where dense forest anchors the snowpack while the steep, open glades are avalanche paths.

The relationship between slope angle and avalanche release is modified by forest cover (Figure 3) since dense trees can anchor the snowpack and reduce or eliminate the avalanche hazard. The degree of anchoring effect depends on tree spacing and stem diameter (Weir, 2002; Rudolf-Miklau et al., 2014) as well as crown coverage and ground roughness from lying or standing trees that exceed snow-depth (Bebi et al., 2009). Forest cover also modifies the snowpack structure by sheltering the snowpack from wind effects and by blocking incoming and outgoing solar radiation.

Table 4. ATES slope angle terminology and associated values.

Slope angle	**Slope angle values**
Very low angle	< 10°
Low angle	< 20°
Moderate angle	< 30° with some > 35°
Moderate – High angle	< 35° with large proportions > 35°
High angle	Average > 35° with large proportions > 45°

The interaction between forests and avalanches is a complex phenomenon and these processes have been simplified for their application to ATES. It is essential to know where forests have an effect on avalanches and which criteria the forests have to meet to avoid avalanche releases and reduce avalanche runout distances (Bebi et al., 2021).

Table 5. ATES forest density terminology and associated values (Campbell and Gould, 2013).

Forest density	Tree spacing[1]
Open	> 10 m average tree spacing
Gladed	3.2 – 10.0 m average tree spacing
Dense	< 3.2 m average tree spacing

[1] Based on a minimum stem diameter of 16 cm.

ATES associates common slope angle terminology with slope angle values (Table 4), common forest density terminology with tree spacing values (Table 5) and combined thresholds of both for use with GIS applications (Table 6). The interaction between slope angle and forest density is then described in the Technical Model (Table 3) across the spectrum from Class 0-4.

Table 6. Slope angle and forest density combined thresholds for GIS applications (Campbell and Gould, 2013).

Forest Density	0 - Non-Avalanche	1 - Simple	2 - Challenging	3 - Complex	4 – Extreme
Open	99% ≤ 20°	90% ≤ 20° 99% ≤ 25°	90% ≤ 30° 99% ≤ 40°	< 20% ≤ 25° 45% > 35°	< 20% ≤ 35° 45% > 45°
Gladed	99% ≤ 25°	90% ≤ 25° 99% ≤ 35°	90% ≤ 35° 99% ≤ 45°		
Dense	99% ≤ 30°	99% ≤ 35°	99% ≤ 45°		

[*] Slope angles are averaged over a fall-line distance of 20-30 m.

4.2.3 Slope shape

The shape of snow-covered terrain plays an essential role in route-finding through avalanche prone terrain. During backcountry travel, risk is routinely reduced by carefully weaving through terrain features and utilizing their shape to manage exposure. Stopping on high spots, using the terrain's shape to set a track, minimizing exposure where possible and avoiding steep, unsupported slopes are all best practices of professional mountain guides (ACMG, 2023). The more convoluted the terrain shape is, the more complicated it is to travel through it.

Although slope curvature is a possible source of tensile stress (McClung and Schaerer, 2023), the effects of microtopography and slope curvature on avalanche release are not well understood. Convex terrain is said to be unsupported because it rolls over at the top and becomes steepest near the bottom of the slope (i.e.: the toe of the slope). Yet even when an avalanche is triggered from low on the slope at its steepest part, the crack radiates outward from the trigger point, propagating upslope, downslope, and across the slope. The upslope portion of the crack frequently arrests on convexities, where a tensile fracture forms the crown face (Trottet et al., 2022).

Convoluted terrain (Figure 4) also promotes greater spatial variability of the snowpack due to an uneven distribution of snowpack depth and layering across the terrain. This is primarily due to redeposition from wind effects across the terrain, both scouring and loading snow around micro terrain features. Increasing spatial variability is directly related to more trigger points and greater uncertainty in snow slope stability evaluation (Schweizer et al., 2008). As the variance increases, it creates more propagation spots on the slope because it creates more areas where the slab is thinner so the skier can trigger the weak layer (Meloche et al., 2024). This contrasts with smooth, planar shaped terrain where a more uniform snowpack depth, and thus less spatial variability can be expected.

Figure 4. An area of Complex terrain with its slope shape defined by convoluted open slopes with intricate and varied terrain shapes. These shapes include gullies, convex (unsupported) slopes, concave (supported) slopes and many rocky areas which can act as trigger points.

Conventional avalanche safety has traditionally taught avoidance of convex terrain in favour of planar or concave slopes (Tremper, 2018) when routefinding, as concave slopes were thought to have better toe-support. However, research into avalanche accidents and the terrain-use patterns of professional guides shows more accidents on planar and concave terrain (Vontobel et al., 2013; Harvey et al., 2018), and that professional guides tend to choose planar terrain in their route selection (Thumlert and Haegeli 2018).

ATES v.2 uses the following terms to describe progressively increasing severity in slope shape: *flat – undulating – planar – convex – convoluted – intricate – cliffy*.

4.2.4 Terrain traps

Terrain traps are topographic features in avalanche paths that increase the consequences of being caught in an avalanche, including serious injury or death from an otherwise harmless avalanche.

Campbell and Gould (2013) categorized terrain traps into those that increase the likelihood and depth of burial, and those that can cause trauma to someone caught in a flowing avalanche. For example, gullies, depressions, and abrupt transitions concentrate avalanche flow, resulting in an increased depth of accumulated debris (Figure 5), while being carried over cliffs or impacting trees, rocks and other downslope obstacles can result in trauma. Trauma has been shown to be the primary cause of death in 20%-30% of avalanche fatalities (Boyd et al., 2008, Sheets et al., 2018, McIntosh et al., 2019). Campbell and Gould (2013) then ranked the severity of terrain traps in terms of increasing consequences from an otherwise harmless avalanche to one that can cause partial burial, minor injury, complete burial, or serious/fatal trauma.

ATES v.2 describes terrain traps physically, with an increasing exposure to the number and severity of specific terrain features that can result locally deep burial or traumatic injury.

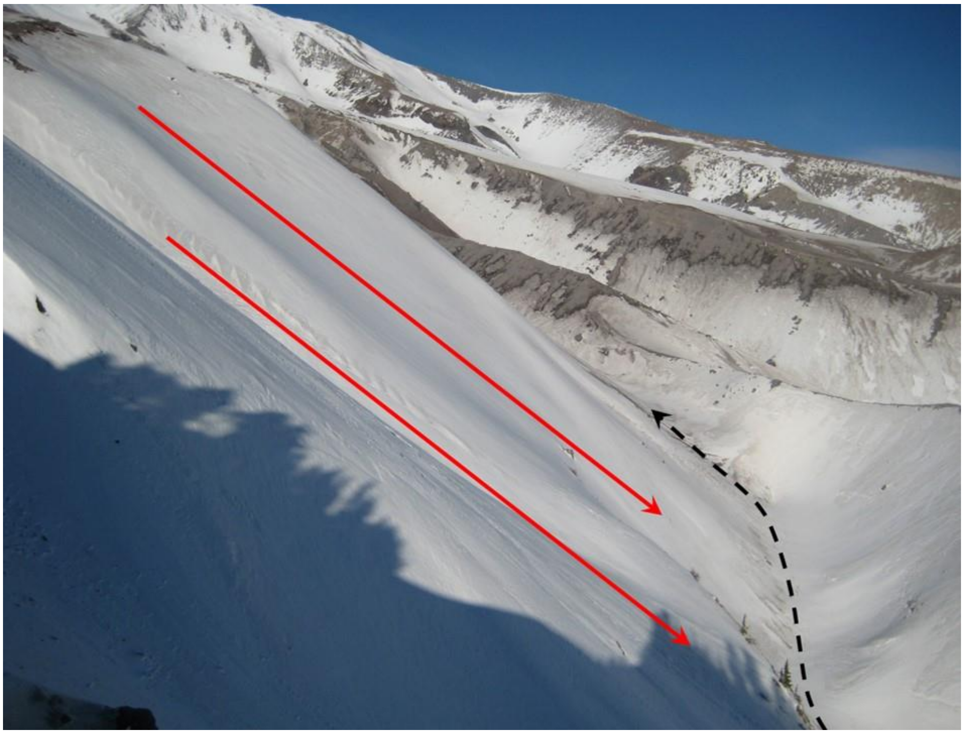

Figure 5. A dangerous terrain trap where avalanches run down the red flow lines and accumulate locally deep avalanche debris in the gully below where the route is marked in black.

4.2.5 Frequency and magnitude

The *frequency* of a natural hazard is the number of times it occurs within a specified time interval (Jackson, 2013). Avalanche frequency within a specific avalanche path is the expected (average) number of avalanches per unit time reaching or exceeding a location (CAA, 2016b). This is typically expressed in units of avalanches per year as a ratio that ranges from 1:1 (i.e., one avalanche per year) up to 1:300 (i.e., one avalanche in 300 years). Avalanche paths producing multiple avalanches per year can also be described in the same way (e.g., 3:1 is three avalanches per year).

In practice, formal assessments of avalanche frequency are commonly done during the avalanche planning process for infrastructure developments such as roads or buildings, but this practice is less common for recreation. Frequency is assessed using a combination of avalanche records, indirect observations (e.g., dendrochronology) and modelling, but in the absence of these records can often be a rough estimate based on field observations and local knowledge. Avalanche frequency is commonly expressed using terminology such as *low* and *high* which corresponds to a set of frequency ranges (Table 7).

For recreational applications, avalanche frequency is a critical measure of terrain severity; terrain that is known to produce avalanches more frequently is comparatively more dangerous to people than terrain that produces avalanches less frequently. Established commercial backcountry operations with detailed avalanche mapping are well aware of their high-frequency locations and treat them with much respect. Accordingly, avalanche frequency is a critical ATES parameter, both in the assessment (i.e., default values; Table 3) and communication of the avalanche terrain ratings (Tables 1 and 2).

Table 7. Avalanche frequency terminology and associated frequency values and ranges used in ATES.

Avalanche frequency	**Average return period** (years)	**Average frequency** (avalanches: years)	**Annual probability of occurrence**	**Frequency range**	**Frequency descriptors**
Very high	0.3	3:1	1.0	>10:1 to 1:1	An avalanche occurs multiple times per year
High	1	1:1	1.0	1:3 to 3:1	An avalanche typically occurs once per year
Medium	3	1:3	0.33	1:10 to 1:1	An avalanche occurs every few years
Low	10	1:10	0.10	1:30 to 1:3	An avalanche occurs every 3 to 30 years
Very low	30	1:30	0.03	1:100 to 1:10	An avalanche occurs every 10 to 100 years
Rare	100	1:100	0.01	1:300 to 1:30	An avalanche rarely occurs

Avalanche frequency is the only ATES parameter that considers the influence of the snowpack. This is possible because frequency is a long-term measurement that depends on snow climate (Haegeli and McClung, 2007) rather than short-term

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weather fluctuations. Thus, avalanche frequency is a constant parameter for a specific location because each winter, the probability of an avalanche with a certain frequency at that location is the same.

The *magnitude* of a natural hazard is related to the energy released by the event. It is distinguished from *intensity*, which is related to the effects at a specific location or area (Jackson, 2013). Avalanche magnitude considers the destructive potential of the avalanche and is defined according to the Canadian avalanche size classification system (Table 8).

Table 8. The destructive avalanche size classification system (CAA 2016a).

Destructive Size	Avalanche Destructive Potential	Typical Mass	Typical Impact Pressure	Typical Path Length
1	Relatively harmless to people	<10 t	1 kPa	10 m
2	Could bury, injure or kill a person	10^2 t	10 kPa	100 m
3	Could bury and destroy a car, damage a truck, destroy a wood frame house, or break a few trees	10^3 t	100 kPa	1000 m
4	Could destroy a railway car, large truck, several buildings, or a forest area of approximately 4 hectares	10^4 t	500 kPa	2000 m
5	Largest snow avalanche known. Could destroy a village or a forest area of approximately 40 hectares	10^5 t	1000 kPa	3000 m

Magnitude is inversely related to frequency because large destructive avalanches occur less frequently, while smaller ones occur on a more regular basis. Magnitude and frequency are also co-related to a specific location in an avalanche path. For example, a location near the toe of an avalanche path will be affected by larger avalanches less frequently, relative to a location higher in the same path.

4.2.6 Starting zone size and density

Increasing exposure to avalanche starting zones increases the severity of the terrain rating due to a higher likelihood of triggering or getting caught in an avalanche. In the ATES Technical Model, starting zone size is described in terms of the potential size of avalanche release, whereas starting zone density refers to the number of starting zones within the area or along the route being assessed.

The number of starting zones, their size and proximity to the route all influence the terrain rating. Exposure to an isolated, single starting zone is usually less severe than exposure to multiple starting zones, but this would depend on their size and frequency. Overhead hazard (Figure 6) presents an additional challenge, particularly as the exposure becomes higher in the avalanche path and closer to the starting zone. Remote or toe triggering of slopes is an important consideration when the exposure occurs below or to the side of the starting zone.

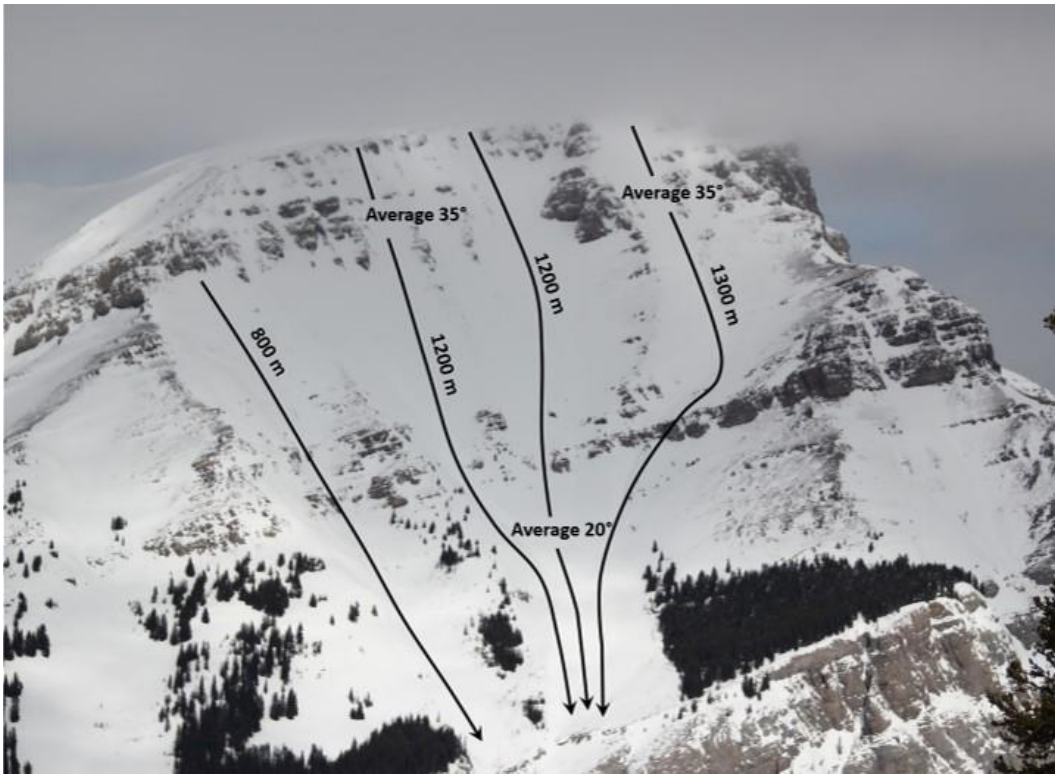

Figure 6. Multiple large avalanche starting zones and tracks converge to present significant overhead hazard above the ice climb Bourgeau Left-Hand in Canada's Banff National Park.

4.2.7 Runout zone characteristics

Runout zones are the lowest portion of an avalanche path, where avalanches begin to decelerate and continue downslope until the flow terminates. Certain terrain attributes have significant effects on the severity of avalanche exposure within runout zones. Characteristics such as runout zone shape (e.g., abrupt transitions and confinement), terrain obstacles, and ground roughness influence avalanche runout behaviour, while proximity to starting zones, interconnectedness, and surface features influence the potential for remotely triggered avalanches.

The ATES Technical Model considers two avalanche risk scenarios in runout zones: 1) being struck by a natural avalanche starting overhead, and 2) remote triggering an avalanche by propagating a crack upslope into the starting zone where an avalanche releases. Every runout zone exposure scenario is unique, from simply crossing through the runout zone to travelling up the middle of it, directly under the avalanche track.

The ATES Technical Model describes exposure to runout zones on a continuum starting with Class 1 Terrain having smooth, well-defined runouts with no connection to starting zones above (Figure 7), ranging to Class 3 and 4 Terrain where runout zones are overlapping and steep, confined, or contain terrain traps such as cliffs or crevasses. Class 3 and 4 runout zones may also have the potential for propagating remote avalanches into adjacent or overhead starting zones.

Figure 7. An avalanche runout zone with a smooth surface, well-defined boundaries and no potential to propagate into a nearby starting zones.

4.2.8 Route options

Route options are different ways to travel through the terrain and typically, every option presents a different level of exposure to avalanches, thus a different level of risk. Terrain with route options allows for different route-finding choices (Figure 8a), facilitating good risk management under various conditions. This contrasts with terrain that has limited or no route options, where people can be forced into terrain that will increase their risk (Figure 8b).

Understanding and assessing route options is a crucial backcountry travel skill that occurs continuously from the planning stage right through to execution. Route options provide an important input into ATES ratings: Class 0 Terrain may have many options and avoids all avalanche terrain, Class 1 also can have many route options, Class 2 Terrain may be exposed to significant avalanche terrain, but options usually exist to avoid it, Class 3 has limited options with avoidance not possible, and Class 4 Terrain forces mandatory, often extended exposure.

Basic risk management principles illustrate that when the avalanche hazard is high, choose routes with low avalanche terrain exposure to reduce risk; conversely, when the avalanche hazard is low, choosing routes with a higher avalanche terrain exposure may be an acceptable risk (Haegeli and McCammon, 2006). For some people though, higher levels of avalanche terrain exposure (or any avalanche terrain exposure) is never an acceptable risk, and in this case the presence or absence of route options is crucial information, especially the option to avoid avalanche terrain completely (i.e., Class 0).

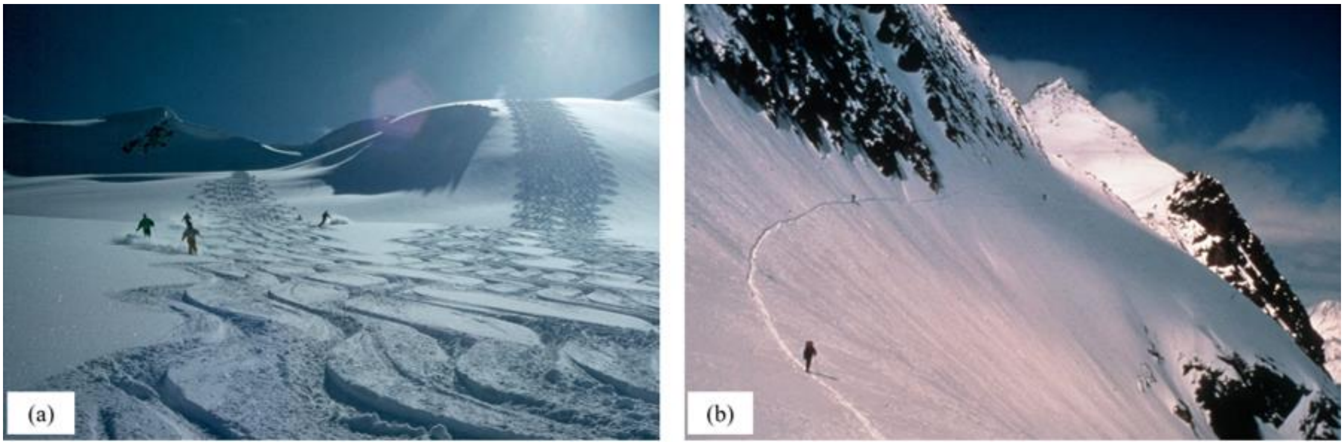

Figure 8. Terrain with options (a) is less committing and allows for more choices during times of unstable conditions. Terrain with no options (b), requires total commitment, making the route much more serious.

4.3 Signal words, colours and numbers

To provide options for communicating ATES ratings to different audiences and to meet accessibility objectives, the system uses a combination of signal words, colours and numbers unique to each rating level (Table 9). Depending on the method chosen (linear or spatial) and the channels of communication (digital, map or paper), different combinations of colours, words and numbers and can be used to reach the target audience and to ensure inclusion and accessibility for all users of ATES. Signal words are single terms that are used to denote the overall level of hazard implied by a warning (Hellier and Edworthy, 2006). They draw attention to a sign or label and quickly communicate the level of hazard. For ATES, each signal word is associated with a number which serves as multilingual label. While numbers are helpful in a multilingual environment, they can be wrongly interpreted to hold some specific value or to imply linear growth between levels, which is incorrect. These numbers are simply labels.

Table 9. Signal words, numbers and colours associated with ATES.

ATES Rating	Signal word	Colour
0	Non-avalanche	White
1	Simple	Green
2	Challenging	Blue
3	Complex	Black
4	Extreme	Red

Additionally, each rating level is assigned a unique colour for labels, lines or polygons on a map. ATES v.1/04 colours were chosen to mimic the North American ski run difficulty system of green, blue, black (Statham et al., 2006) that is intuitive to North American users. European applications subsequently changed Complex terrain from black to red, to be consistent with the ski run difficulty system in Europe. As a result, European ATES maps use different colours to represent Complex and Extreme terrain.

ATES v.2 continues the original colour scheme (Table 9) with the addition of white for Class 0 and red for Class 4 Terrain. Polygon transparency settings must be chosen carefully to ensure the underlying basemap data remains visible. However, warning system colours can present difficulties for people with colour vision deficiency (CVD) and not all colours work well when overlain on maps, especially when maintaining visibility of the underlying map reference layers is important. For example, while black works well for linear ratings (lines), it is not ideal for polygons because it can obscure the basemap data.

Engeset et al. (2022) tested six different colour combinations of ATES for conflicts with the avalanche danger scale colours, and for users with CVD, recommending red for Complex, and black/red crosshatching for Extreme Terrain. Huber et al. (2023) present an ATES map for a test site in Austria using red for Complex and purple for Extreme Terrain which shows the underlying basemap data well (Figure 9). Further research is necessary to determine a colour standard that achieves the best balance of comprehension, base map visibility and CVD compliance.

No single scheme works for all target audiences, thus applying a suitable combination of colours, numbers and signal words in combination with an accessible legend is likely to achieve the best results.

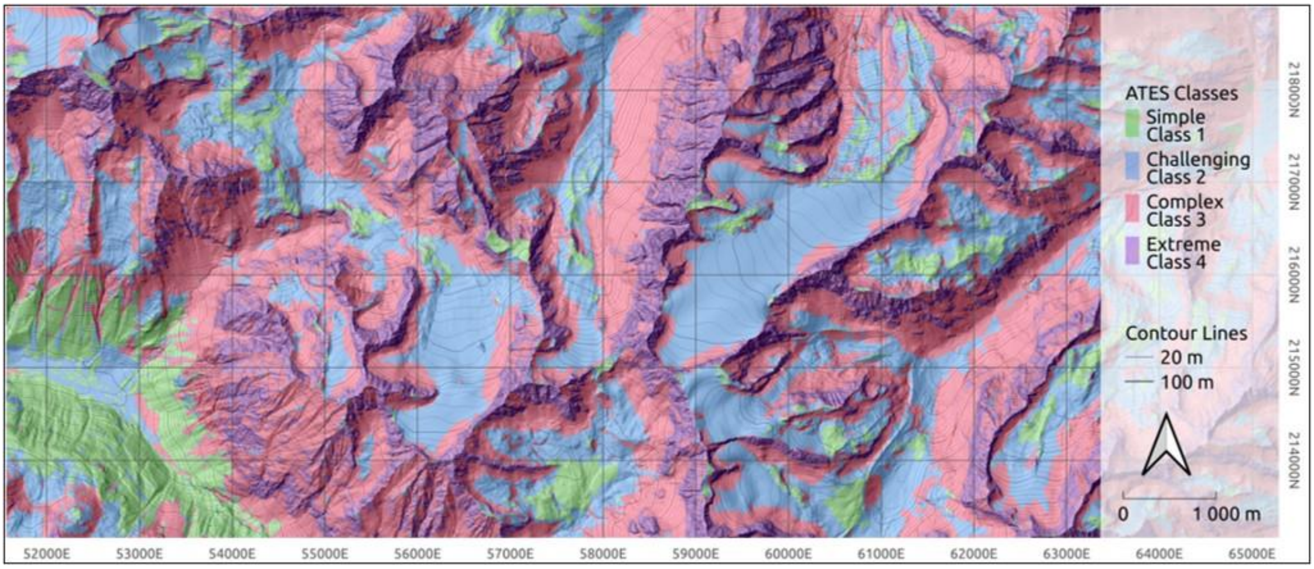

Figure 9. ATES map produced for a test site in Austria using green for Simple, blue for Challenging, red for Complex and purple for Extreme terrain (Huber et al., 2023).

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4.4 Target audience

A thorough understanding of the receiver, the target audience, is necessary for effective risk communication. Laughery and Brelsford (1991) implored warning designers to "know thy user" with regard to (1) demographics and age, (2) familiarity with the product, (3) competence (technical knowledge, language, reading ability) and (4) hazard perception.

ATES has three distinct target audiences:

1. Avalanche professionals, educators, mappers, and guidebook authors
2. Backcountry recreational travellers: skiers, snowboarders, snowmobilers, snowshoers, climbers and hikers
3. Backcountry workers: persons employed to perform work in avalanche terrain

The Technical Model (Table 3) is designed for avalanche professionals, mappers or guidebook authors to use its specifications to assess zones or routes through avalanche terrain, determine the exposure of people to that terrain, and produce a rating for each zone or route. The Technical Model also targets avalanche educators, who can use the model's specifications for teaching the specific parameters of avalanche terrain, how each is scaled, and how they interact with the exposure of people to determine the severity of avalanche terrain exposure.

The Communication Model for backcountry travel (Table 1) is targeted at all backcountry users who move through avalanche terrain, regardless of recreation type. The language gives simple advice on expectations of exposure and potential options for mitigating risk. ATES is analogous to the Avalanche Danger Scale (Statham et al., 2010, EAWS, 2024) and targets the same audience, including workers (often industrial/resource staff) who follow rules-based workplace safety practices.

The Communication Model for waterfall ice climbs (Table 2) targets winter ice climbers and focuses on the concepts of exposure time, avalanche frequency, human-triggering in terrain traps and options to reduce exposure. The system has recently been applied to Avalanche Canada's ice climbing avalanche atlas (Statham and Heuniken, 2023).

5 Application of ATES

5.1 Objectives and approach

The application of ATES starts by considering the objectives of the final product, which informs the approach to assessment and communication methods. The objective and approach depend on the target audience, their intended use of the terrain ratings and the availability of terrain data.

For example, the objective might be to facilitate recreational trip planning, in which case a single ATES rating for a specific Area or Route might be sufficient, or multiple rating segments along that route for a more precise assessment. However, a navigational aide for backcountry travellers would typically require high-resolution ATES zones or specific route segments. Over the past two decades of ATES use, four distinct approaches to ATES classification have emerged (Table 10).

Table 10. ATES feature types and their spatial representation (Sharp et al., 2023).

ATES Feature	Example Application	Spatial Representation
Areas	Rating commonly defined region with either a well-defined geographic boundary or an ambiguous one	Point (Figure 11a) or polygon (Figure 11b)
Zones	Rating a specific slope or terrain feature within a well-defined geographic boundary where ATES parameters dictate the zone boundaries	Polygon or raster (Figure 11c)
Corridors	Rating a physical or conceptual path of travel between defined starting and end points with navigational freedom within a well-defined geographic boundary or an ambiguous one	Polygon (Figure 11b) or line (Figure 11d)
Routes	Rating a physical or conceptual path of travel between a defined starting and end point with limited navigational freedom	Line (Figure 11d)

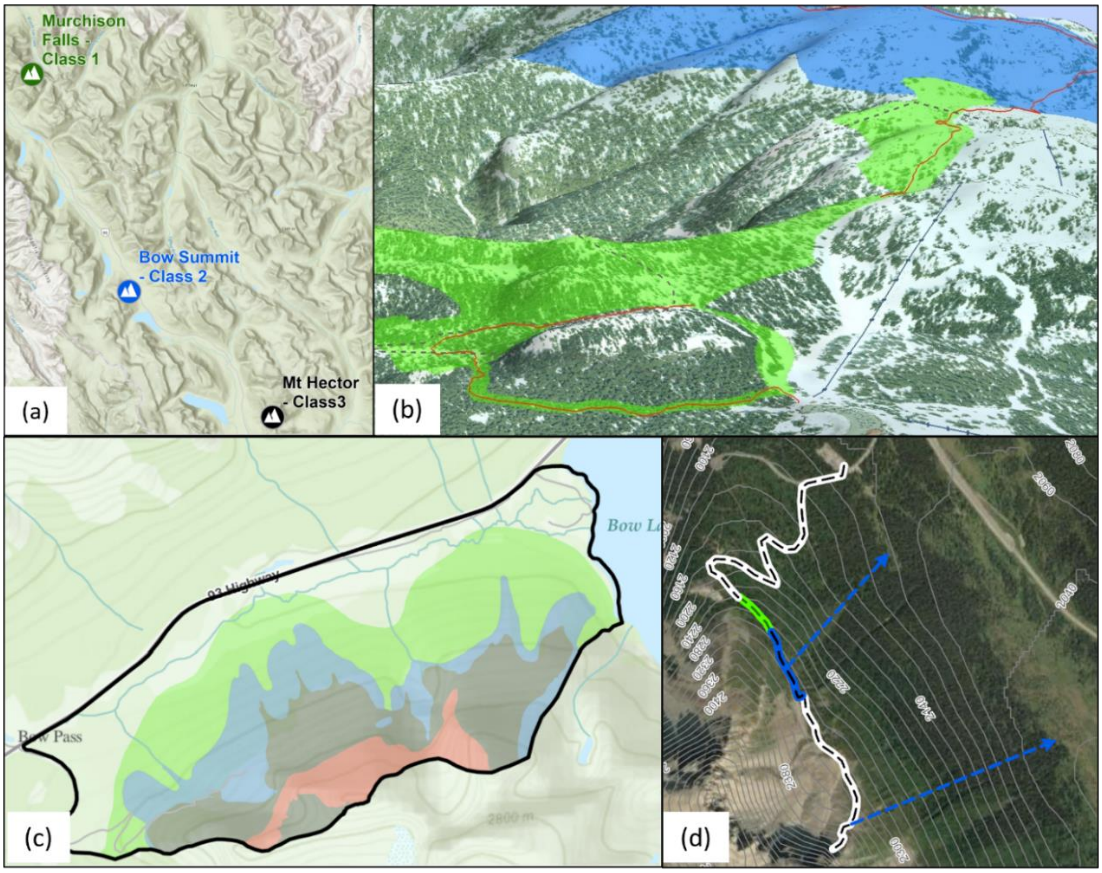

Figure 10. Spatial representations of different ATES feature types illustrating an Area represented as: (a) single-rating points, (b) single-rating polygons, (c) multi-rating zones using polygons, and (d) multi-rating corridors and routes using lines. Maps (a) and (c) Natural Resources Canada; (b) © Google Earth 2009; (d) Esri Canada.

An *Area* defines the boundaries of an overall assessment and can be given either a single rating (Figure10a, b) or broken down into smaller scale zones (Figure 10c). A *Route* defines a linear path of travel from start to finish (Figure 10d) and can be broken down into shorter route segments using lines to represent precise routes, and polygons to represent a *Corridor* of travel where navigational freedom is possible (Figure 10b). A *Zone* is a specific slope or grouping of terrain features with common ATES characteristics that uses a polygon to spatially represent the zone, typically surrounded by adjacent polygons showing their ATES zone ratings (Figure 10c).

The difference is that ATES ratings for routes rates the terrain affecting the route (i.e., actual exposure), while ATES ratings using zones rate the terrain independent of any specific route through it (i.e., potential exposure).

5.1 Spatial scale

Spatial scale refers to the size or extent of a geographic area. Table 11 describes spatial scales used in avalanche forecasting (Statham et al., 2018), and these scales also relate directly to avalanche terrain assessments.

It is crucial to understand at what scale ATES ratings are being applied at. In some scenarios, high resolution (e.g., terrain feature) zoning will not be required, in which case a larger scale (e.g., run) can be applied. To achieve this, ATES mappers must filter out terrain features or route segments that are below the target scale, and group these features together into larger scale zones or routes.

For example, when classifying a pre-determined route, the scale of the entire area is pre-defined by the route. However, along that route there will be variations in avalanche exposure. These could be represented using smaller scale ATES ratings for improved accuracy, or they could be grouped together as part of the whole route and a single rating issued for the route. Single ratings for routes should default to the highest terrain class along the route.

Similarly, for an approach using spatial mapping an overall rating of Class 3 could be assigned to an avalanche path, but there may be areas of Class 2 or even Class 1 Terrain within that path at the slope or terrain feature scale. The target scale determines how this terrain is grouped and within any single zone, the ATES rating defaults to the highest terrain class within that zone.

The smaller the scale, the higher the resolution and more precise the classifications will be, but this comes at the cost of greater effort and resources. To be accurate enough to be used as a real-time navigational aid, a spatial scale of at least 20-30 m (i.e., terrain feature) is required (Larsen et al., 2020).

5.2 Assessment methods

Evaluating avalanche terrain exposure using ATES requires qualified people skilled in avalanche terrain assessment and backcountry route-finding. Assessors with local terrain and route familiarity is a significant asset. This is necessary to analyse the interaction between people and avalanche terrain.

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Table 11. Spatial scales for ATES assessments (Statham et al., 2018).

Spatial Extent	**Description**	**Examples**	**Scale**
Terrain Feature	Individual geographic features contained within a larger slope	Convex roll, gully or terrain trap	Micro < 1 km^2
Slope	Large, open, inclined areas with homogenous characteristics bounded by natural features such as ridges, gullies or trees	Typical avalanche starting zone or wide-open area on a ski run	
Path or Run	Multiple interconnected slopes and terrain features running from near ridge crest to valley bottom	Full length avalanche paths with a start zone, track and runout zone or typical long backcountry ski run	
Mountain	An area rising considerably above the surrounding country with numerous aspects and vertical relief running from summit to valley bottom	Ski resort area or typical single operating zone in a snow cat skiing area	Meso $> 10^2$ km^2
Drainage	An area with a perimeter defined by the divide of a watershed	Typical single operating zone in a helicopter skiing area	
Region	A large area of multiple watersheds defined by mapped boundaries	Typical public forecasting area or public land jurisdiction	Synoptic $>10^4$ km^2
Range	A geographic area containing a chain of geologically related mountains	Mountain ranges or sub-ranges	

Rating avalanche terrain using ATES can be straightforward for single routes with single ratings. For uncomplicated terrain with good data, such as one well-travelled route with only a few avalanche paths or an alpine bowl with high quality mapping and imagery, sufficient accuracy can be achieved without field surveys or complex analyses. For more complicated projects such as large areas with extensive avalanche terrain, unfamiliar travel routes, significant overhead hazard or small scale/high resolution mapping, a more rigorous approach and level-of-effort is necessary. Typically, this utilizes some combination of GIS analysis, field investigations, aerial photographs, satellite image interpretation, as well as climate analysis and runout estimation.

Ratings are determined by analysing the terrain against each ATES parameter for best fit, comparing to the levels above and below, then determining what the best overall ATES rating is. Mappers ultimately develop their own techniques and work within the bounds of their organization's capacity, but the most accurate results are achieved through a collaborative approach. ATES mapping and ratings should be reviewed by peers familiar with the terrain. Sykes et al. (2024) developed the validation dataset for autoATES by having three field experts independently develop ATES maps for the same areas, then combine them into "consensus maps" which were then compared to the autoATES results.

GIS analysis provides a deterministic evaluation of some ATES parameters and helps to reduce human bias (e.g., Delparte, 2008; Campbell and Gould, 2013; Toft et al., 2024), but not all ATES parameters can be digitally modelled (i.e., exposure,

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route options) and auto-generated maps will have a degree of error. The resolution of digital elevation models (DEM) is important, because lower-resolution DEM data are especially prone to smoothing terrain features and underestimating slope angles. This error can be mitigated for smaller scale areas (e.g., single drainage) by using local expertise to verify the terrain and route-finding (Sykes et al., 2024). However, for larger scale areas such as a mountain range, local verification is impractical, thus GIS generated maps are expected to have a degree of error which should be explicitly stated.

5.2.1 AutoATES

Automated avalanche terrain classification enables large areas of mountain terrain to be analysed and coded by a computer algorithm (Figure 11). This significantly reduces the cost of producing ATES ratings, improves consistency, and makes the system more accessible. Larson et al. (2020) developed AutoATES v1.0, which was used to produce spatial ATES maps for all of Norway using only a digital elevation model (DEM) as input. AutoATES v.2.0 (Toft et al., 2024) has been updated to match the ATES v.2 model presented in this paper, and the algorithm's performance has been improved to better handle forest data, overhead exposure and flat runout zones.

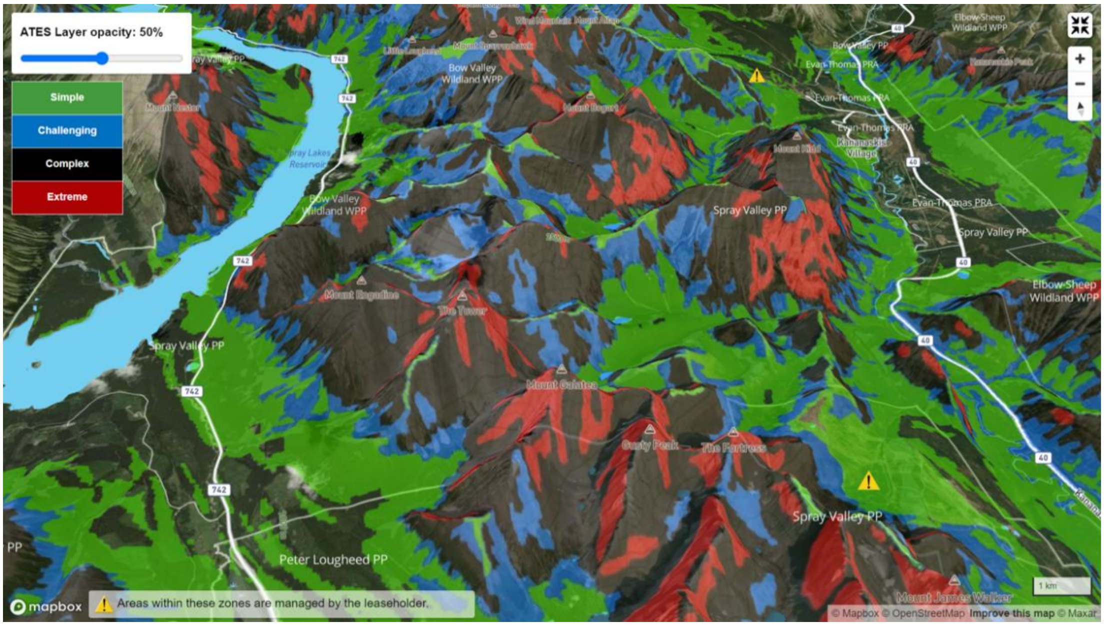

Figure 11. AutoATES mapping covering approximately 450 km^2 in Kananaskis Country, Canada (Alberta Parks, 2024). In this example, the ATES layer opacity can be adjusted to improve the visibility of the base map data and Class 1 Terrain includes Class 0 Terrain.

AutoATES mapping can be adapted to local conditions by tuning the model parameters based on feedback from avalanche experts. Sykes et al. (2024) performed validation testing on AutoATES v.2.0 in Connaught Creek and Bow Summit areas of Canada. Manual ATES maps for each area were made independently by three field experts, then compared and consolidated by consensus into a single “benchmark map” for each area. The benchmark maps were used as a validation dataset to tune the input parameters of AutoATES to the local characteristics of each study area. AutoATES v.2.0 maps were then produced for the same areas, compared to these benchmark maps (Figure 12) and found to agree with 74.5% of Connaught Creek and 84.4% of Bow Summit ATES ratings (Sykes et al., 2024).

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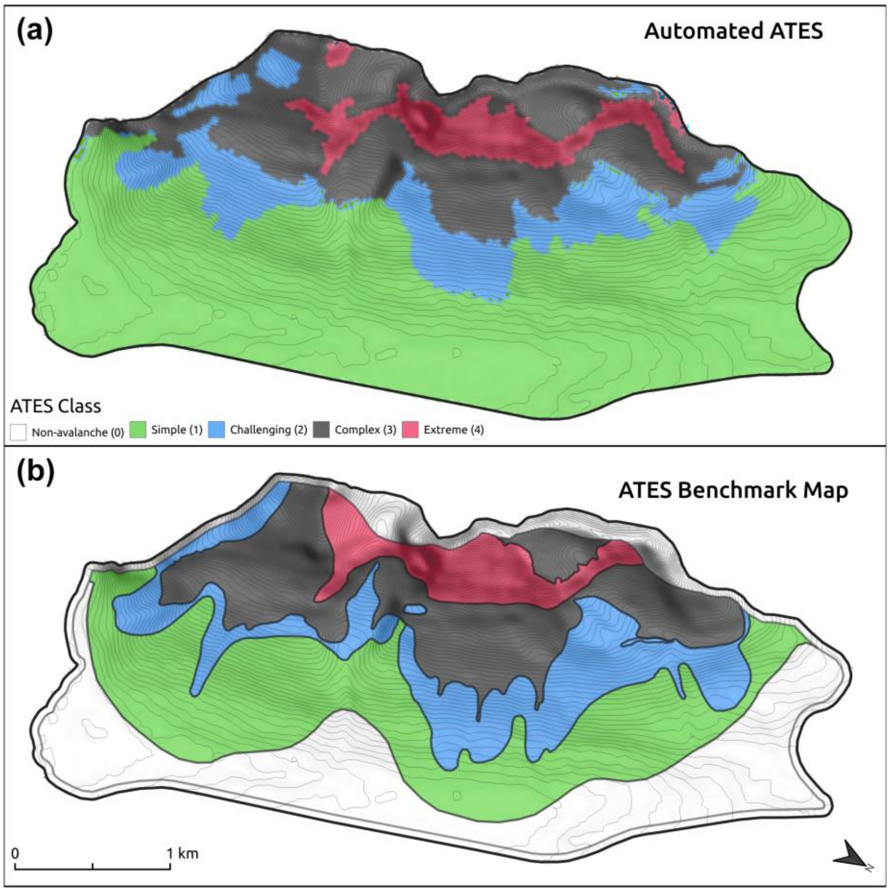

Figure 12. AutoATES for the Bow Summit study area (a) and the ATES benchmark map used for validation (b). The benchmark map results from the consensus of three manual maps made independently by three field experts (Sykes et al., 2024). The benchmark (manual) mapping includes Class 0, while the autoATES map does not use Class 0.

One of the biggest advantages of automated ATES mapping is that it can downscale zones to a much higher resolution than is practical with manual mapping. While it is possible to manually downscale to a smaller scale, this requires a level-of-effort that may not be cost effective, particularly in synoptic or meso scale areas such as a region or range (Table 11). This limits the scope of manual mapping in comparison to automated mapping, which can cover entire mountain ranges consistently, and at smaller scales.

5.3 Presentation

ATES ratings can be displayed visually on maps or marked-up photos as Areas, Zones, Corridors or Routes (Figure 10). Coloured lines and/or transparent polygons with fuzzy set boundaries can illustrate ATES ratings, ideally with the underlying ATES terrain attributes stored (Sharp et al., 2023). Fuzzy set boundaries incorporate uncertainty by overlapping and fading the boundary between adjacent ATES polygons, indicating that the boundary is not a precise line but rather an area of transition. In addition to maps, ATES ratings for specific routes can be communicated using words, numbers and colours. Backcountry recreation guidebooks, brochures and online information commonly use textual ATES ratings as an adjunct to a detailed route description, map and other important information about a specific route.

6 Limitations

ATES is an avalanche terrain assessment and communication system that relies heavily on expert knowledge and judgement (Toft et al., 2024). Despite developments to make it more deterministic and desktop-based (Campbell and Gould, 2013), applying and using ATES remains primarily an exercise in judgement that requires ground truthing and peer review. Although ATES incorporates the terrain parameters necessary for subject matter experts to capture their interpretation of the avalanche terrain, interpretations vary between individuals and can lead to inconsistency in application; two experts rating the same avalanche terrain using ATES may have different results. These differences highlight the subjectivity in manual ATES ratings and the challenge of having multiple individuals produce consistent ATES ratings and maps (Sykes et al., 2024, Schmudlach and Köhler, 2018).

Manual interpretation of geospatial data combined with observed terrain parameters is a time-consuming process which limits the scope of manual ATES mapping to high-traffic areas such as popular recreation areas and pre-defined worksites. ATES ratings for a specific route is less time consuming since the exposure is known and the assessment focusses on a linear route or corridor, rather than all the terrain in the area. In these areas, costs can be justified relative to the large number of backcountry users (Sykes et al., 2024) and terrain familiarity of local experts, but this is impractical for large swaths of mountainous terrain. Landscape scale ATES mapping is not practical using manual methods, and the development of autoATES (Toft et al., 2024) has been an important step towards enabling a broader implementation.

ATES and autoATES maps illustrate “potential exposure” across landscapes, but cannot assess true exposure or the possibility of route options because there is no route. Once a route has been planned on the map, either explicitly or conceptually, then the ATES ratings can be utilized for trip planning. Modern digital mapping applications that enable route planning are well suited to include an ATES layer, whereby the user can draw their route on the map and then turn on/off an ATES layer to see how their route intersects with the ATES ratings. Without route planning tools or routes pre-drawn on the maps, spatial ATES maps are limited in their practical application.

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7 Conclusion

Terrain rating systems play an essential risk management function in recreational outdoor activities such as climbing, hiking, kayaking, skiing, and biking. Combined, these systems have helped millions of recreational users plan and execute their activities by simplifying complex terrain attributes into easily understood categories that can be used to manage risk and improve the experience.

Recreational avalanche risk is a complex interaction between snowpack, terrain and people, where terrain is the only factor that is constant over time. It is often said that “when unstable snow is the problem, terrain is the solution” and for decades professional mountain and ski guides have considered terrain assessment and route selection to be the principal mitigating factor in backcountry avalanche risk management: when nothing is exposed, nothing is at risk.

Public avalanche bulletins warn about backcountry avalanche danger, which is constantly changing and carries uncertainty, but this is only part of the avalanche risk equation. Ultimately, people choose their own risk by making decisions about where, when and how they travel. Even during periods of high avalanche danger, a simple reduction in exposure can reduce or eliminate the risk. On small-scale terrain features, even minor adjustments in how one is exposed to the danger will change their risk – a few meters in either direction can be the difference between a low and high-risk situation. Thus, controlling terrain exposure is the most important avalanche risk management skill necessary for winter backcountry travel, and the objective of ATES is to make that more explicit and easier to understand for backcountry users.

ATES began in 2004 as a simple avalanche terrain rating system for specific backcountry ski tours, intended for trip planning and implemented in response to an avalanche disaster in Canada’s Glacier National Park. Soon after, ATES was used to rate avalanche exposure on waterfall ice climbs, and by 2010 ATES ratings were being mapped into zones using basic GIS. In 2020, the autoATES algorithm enabled landscape scale mapping of ATES ratings, enabling more accessible, widespread ATES mapping.

This paper introduces ATES v.2, which builds on 20 years of operational experience using ATES as a risk management tool in avalanche safety practices for public recreation and workplace avalanche safety. The updated five-level ATES adds Class 0 – Non-Avalanche Terrain and Class 4 – Extreme Terrain to the original three-level system. Additionally, ATES v.1/04 and the ATES Zoning model are combined into a single Technical Model for assessment, with two corresponding Communication Models for backcountry travel and waterfall ice climbing. Using ATES v.2, avalanche terrain exposure can be mapped as Areas, Zones, Corridors or Routes. Alternatively, specific routes can be given a terrain rating, or series of ratings, to accompany a route description, similar to how rating systems are used for rock climbing and whitewater.

8 Author contributions

GS was the original creator and author of ATES v.1/04 and led the implementation of Parks Canada’s initial application of ATES to backcountry tours and waterfall ice climbs in Canada’s national parks. CC developed the ATES Zoning Model and was the first to apply spatial ATES mapping through his work with Avalanche Canada. Both authors have continued to develop

and apply the ATES method to recreational and workplace applications, and both helped to develop the validation dataset for autoATES. GS led the development of this manuscript with support from CC.

9 Competing interests

Both authors declare that they have no conflicts of interest.

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