KEEPING PEOPLE SAFE IN OUR MOUNTAINS – TOWARD AN AUTOATES-BASED AVALANCHE MODELING SYSTEM FOR THE SOUTHERN ALPS, AOTEA-ROA NEW ZEALAND

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ABSTRACT: Snow avalanches present risks to people and infrastructure in mountain environments worldwide. In Aotearoa New Zealand, growing participation in alpine recreation and tourism, together with changing snow and weather conditions, is increasing the need for accessible and reliable tools that support avalanche risk management. The New Zealand Avalanche Advisory provides regional forecasts of current avalanche conditions, but there is currently no nationally implemented system for systematically classifying exposure to avalanche terrain. Such terrain information could complement existing avalanche forecasts and support more informed route selection and backcountry travel decisions. The Avalanche Terrain Exposure Scale (ATES) provides an established framework for classifying and communicating exposure to avalanche terrain, while the recent development of AutoATES has enabled terrain classification to be automated over large areas. This study evaluates and adapts the AutoATES framework for application in Aotearoa New Zealand through the development of New Zealand mountain ATES (NZmATES). The modeling framework integrates terrain characteristics, potential avalanche release areas, simulated avalanche runout and vegetation effects to automatically classify terrain according to avalanche exposure. The approach is initially applied to the Craigieburn Range in the Southern Alps, where model outputs are being evaluated and refined using historical avalanche information and local alpine expertise. A graphical user interface has also been developed to facilitate parameter adjustment, model calibration and application across different mountain environments. This pilot study demonstrates the feasibility of applying AutoATES in New Zealand and establishes a framework for systematic validation and expansion of NZmATES across the Southern Alps. Ultimately, NZmATES is intended to complement existing avalanche forecasting by providing detailed, terrain-based information that can be combined with current snowpack and weather conditions to support safer decision making in New Zealand's mountains.

KEYWORDS: Avalanche Terrain Exposure Scale (ATES), Terrain, Avalanche Hazard, New Zealand

1. INTRODUCTION

Aotearoa New Zealand's Southern Alps are strongly influenced by their maritime setting, producing a relatively warm, high-precipitation alpine environment in which seasonal snow conditions can respond rapidly to changes in temperature, precipitation and weather systems (Cullen et al., 2019; Little et al., 2019). This snow environment is changing as the regional climate warms, with observations showing rising snowlines across the Southern Alps (Salinger et al., 2021; Lorrey et al., 2022). These changes are likely to alter not only the extent and persistence of seasonal snow, but also the types and timing of avalanche activity. In particular, warming is expected to reduce dry-snow avalanche activity in some REGIONS while increasing the relative importance of wet-snow avalanche processes, including wet-slab release at higher elevations (Eckert et al., 2024). These changes have important implications for avalanche risk and the ways in which people use New Zealand's mountain environments.

Snow avalanches already present a significant hazard to people traveling and recreating in the Southern Alps. Slab avalanches are particularly dangerous and account for the majority of avalanche fatalities internationally (Thakur et al., 2025). Recreation is central to this risk: more than 90% of fatal avalanche accidents are associated with recreational activity and are human triggered (Toft et al., 2024; Markov et al., 2025). In New Zealand, this exposure is particularly relevant given the importance of skiing, climbing, tramping and other forms of alpine recreation, and the growing number of people accessing backcountry terrain.

New Zealand is already a popular destination for mountain recreation and is targeting almost five million international visitors annually by 2034 (Tourism Growth Roadmap, 2025). Increasing recreational use, combined with changes in the seasonal snow environment, reinforces the need for effective avalanche risk assessment and com-

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munication. The New Zealand Avalanche Advisory (NZAA) provides regional forecasts of current avalanche conditions, while terrain represents the relatively persistent component of avalanche risk and can be characterised independently of day-to-day snow and weather conditions. A nationally consistent, detailed terrain classification system would therefore complement existing avalanche forecasting by helping users understand their exposure to avalanche terrain and make more informed route-selection and risk-management decisions.

2. BACKGROUND

The three most important factors to consider when modeling avalanche hazard are terrain, weather, and snowpack characteristics, with terrain being the greatest indicator of avalanche release (Thakur et al., 2025; Buhler et al., 2013). As such, a complete, detailed terrain model designed to help assess and communicate avalanche hazard should be the foundation of any avalanche modeling initiative.

ATES was initially developed in Canada as an avalanche hazard modeling and communication tool and has proven to be an effective solution in both its place of origin and abroad. The intent of ATES is to inform risk management decisions through the simplification of terrain analysis (Sykes et al., 2024). Since its inception in the early 2000s, ATES has been developed into a computer algorithm, written in Python, designed to automate ATES terrain classification across large and under-observed areas (AutoATES) (Sykes et al., 2024). However, while ATES has proven to be a robust model for both avalanche terrain hazard assessment and communication, further research is required with regards to variable delineation, application in untested climates, expert validation of outputs, and optimization of use as a device for hazard communication (Sykes et al., 2024).

Most avalanche susceptibility studies and hazard communication initiatives, including ATES, have been developed in Europe and North America, leaving a relative paucity of research in other regions (Thakur et al., 2025). Additionally, calibration should consider the application of an existing avalanche model to a new region, to ensure accurate hazard assessment and uncover parameter variability and interaction changes (Veitinger and Sovilla, 2016). A model calibration should involve both historical avalanche data and feedback from regional alpine experts, as it is commonly accepted that numerical avalanche models must rely on local experts with detailed knowledge of the terrain being modeled, to ensure accuracy of prediction (Gruber and Bartelt, 2007).

Vegetation - especially dense mountain forests - can stabilize the snowpack and mitigate avalanche hazards in the release areas. In locations where ATES has previously been implemented, vegetation cover has had a significant influence on model output; however, release areas in NZ are generally above treeline. As such, parameterization of AutoATES in NZ should reflect regional snow and vegetation characteristics.

The purpose of this pilot study is to assess the viability of AutoATES in Aotearoa New Zealand and establish the framework for the development of New Zealand mountain ATES (NZmATES). NZmATES is intended to provide a nationally consistent, terrain-based classification system that complements existing avalanche forecasting by providing detailed information on exposure to avalanche terrain. The Craigieburn Range was selected as the initial testing site, where the existing AutoATES framework was adapted to better represent New Zealand terrain and vegetation characteristics and be calibrated against historical records of avalanches. A graphical user interface was developed to facilitate parameter testing, model evaluation and refinement as the approach is applied across different mountain environments. This pilot study therefore provides the first step towards systematic validation and expansion of NZmATES across the Southern Alps, with the longer-term goal of providing nationwide avalanche terrain mapping to support informed route selection and avalanche risk-management.

3. SITE DESCRIPTION

The Craigieburn Range avalanche forecasting region was chosen as the initial testing site. Craigieburn Range is in the Canterbury High Country section of the Southern Alps, roughly 25 km east of the Main Divide (Figure 1). The average elevation is 1800 m, with five peaks rising above 2000 m, and it boasts valley side slope angles in the 30–40-degree range. It also serves as a popular alpine activity center, as five of the 18 ski fields in NZ are found within the region. Its terrain profile, existing ski fields, avalanche atlases and historical data, and local expertise highlighted it as an appropriate test site for the development of NZmATES.

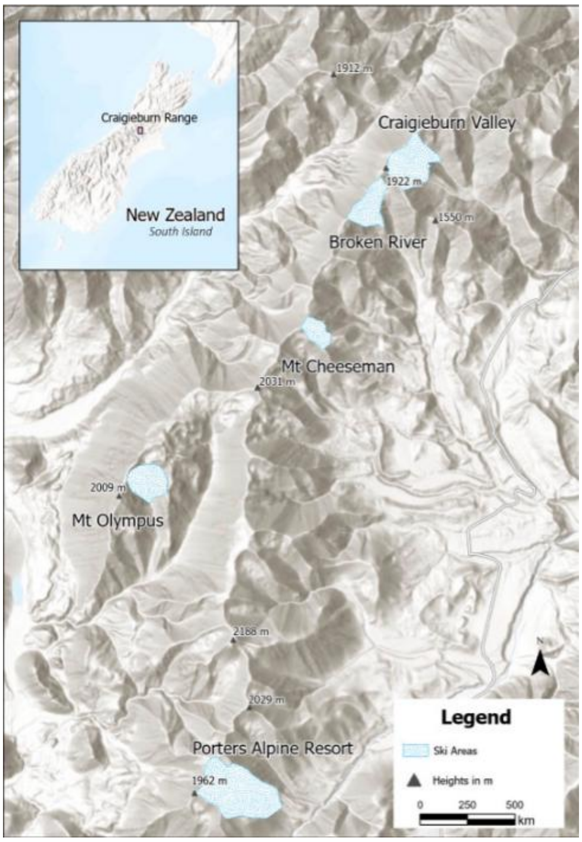

Figure 1: The Craigieburn Range, South Island, New Zealand. Adapted from Berg (2025).

4. METHODS

This study implements an automated avalanche terrain classification workflow that links (i) potential release area (PRA) delineation, (ii) avalanche runout simulation, and (iii) ATES class generation from combined terrain and exposure indicators. The workflow is implemented in Python and consists of three computational stages executed in sequence: PRA extraction from terrain derivatives, runout simulation from PRA release cells, and a rule-based ATES classifier that integrates slope, runout, overhead exposure, and forest effects (Figure 2).

This process is based on the tools developed by Toft et al. (2024), the code for which is available via Github repository at https://github.com/AutoATES/AutoATES-v2.0.git (accessed January 2026). However, it was determined that the approach used for PRA calculation in AutoATES v2.0 needed to be adjusted to better represent terrain and vegetation characteristics in NZ. Thus, after a review of several existing approaches for release area calculation, the object-based image analysis approach presented by Buhler et al. (2018) was determined to be the best fit for this use case.

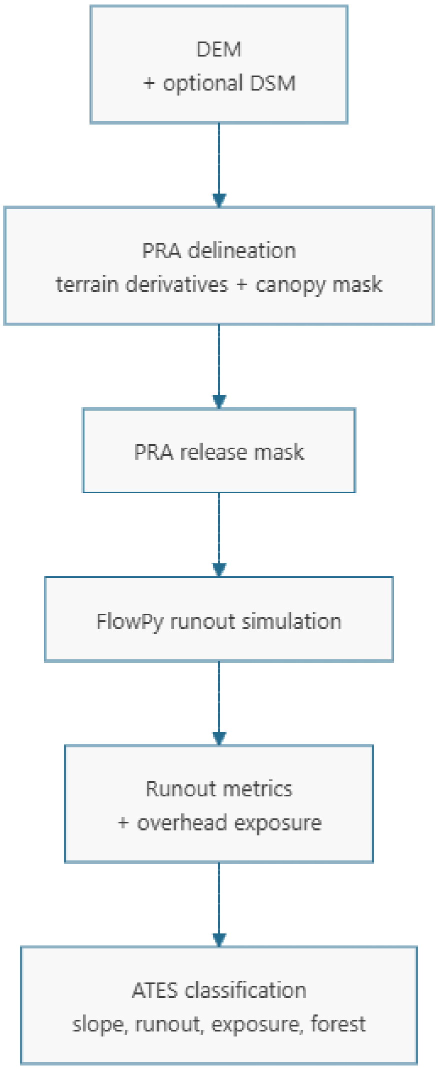

Figure 2: The full processing chain, simplified.

This approach calculates characteristics for use in PRA delineation and allows for the consideration of canopy cover as a Boolean value. These calculations were developed into Python functions using open-source libraries, and the resulting code was used in the final NZmATES implementation.

4.1 Input data and preprocessing

Core raster inputs are a Digital Terrain Model (DTM) and a Digital Surface Model (DSM), the difference of which allows for the estimate of canopy cover. All computations assume co-registered rasters with identical array shapes for any jointly used layers. Where DSM geometry differs from DTM geometry, DSM is reprojected and resampled to the DTM grid using bilinear interpolation.

The DTM and DSM used were provided at 1 meter resolution by Toitu te Whenua (Land Information New Zealand) and resampled to 10 meter resolution for the pilot study.

4.2 Potential release area delineation

The potential release area delineation (PRA) is accomplished through the translation of the object-based approach outlined by Buhler et al. (2018) into the Python programming language. It first calculates the characteristics of the terrain using a sliding window algorithm across the input DTM, then applies filters to these characteristic rasters using user-defined thresholds, derives the canopy mask, and removes small, disconnected results from final consideration.

4.2.1 Terrain derivatives

PRA delineation begins with first- and second-order terrain derivatives from the DTM. Slope angle (*S*) is computed from DTM gradients and converted to degrees:

$$S = \arctan\left(\frac{\sqrt{(\partial_x Z)^2 + (\partial_y Z)^2}}{\Delta}\right) \cdot \frac{180}{\pi}$$

where value *Z* is the DTM elevation raster (meters), *∂* is the elevation change along the *x* and *y* axes, and Δ is grid spacing (5 m in the current PRA implementation). A distance-weighted smoothing filter is applied to suppress local noise. Aspect (*A*) is computed as:

$$A = \text{atan2}(-\partial_x Z, -\partial_y Z) \cdot \frac{180}{\pi}$$

Plan (*Kplan*) and profile (*Kprof*) curvature are computed from second derivatives:

$$\kappa_{plan} = \frac{Z_{xx}(\partial_y Z)^2 - 2Z_{xy}(\partial_x Z)(\partial_y Z) + Z_{yy}(\partial_x Z)^2}{(\partial_x Z)^2 + (\partial_y Z)^2}$$

$$\kappa_{prof} = \frac{Z_{xx}(\partial_x Z)^2 + 2Z_{xy}(\partial_x Z)(\partial_y Z) + Z_{yy}(\partial_y Z)^2}{(\partial_x Z)^2 + (\partial_y Z)^2}$$

Ruggedness (*Ru*) is estimated from local angular dispersion of unit normal vectors within a moving window:

$$R_u(p) = \frac{1}{|W|}\sum_{q \in W} \arccos\left(\mathbf{n}(q) \cdot \bar{\mathbf{n}}\right)$$

within a window *W* around cell *p* and ruggedness is the mean angular deviation from the mean normal (*n*).

Fold (*Fd*) is approximated as absolute divergence of horizontal normal components, and is used to assign weights to slope values for final PRA calculations:

$$F_d = \left| \frac{\partial n_x}{\partial x} + \frac{\partial n_y}{\partial y} \right|$$

Canopy height is defined as $H_c = Z_{DSM} - Z$. A canopy mask is generated by thresholding canopy height at a user-selected minimum canopy height, and canopy cells are excluded from candidate PRA masks.

4.2.2 PRA decision rules

PRA candidate cells are identified by conjunction of threshold masks:

$$M_{pra} = \mathbb{1}[s_{min} \le S \le s_{max}] \cdot \mathbb{1}[R_u^{norm} \le r_{max}] \cdot \mathbb{1}[\,|\kappa_{plan}| \le c_{max}]$$

Where *S* is the derived slope, *R* is the derived ruggedness, *K* is the derived curvature, and *C* is the canopy mask.

4.2.3 Object filtering and final products

Connected components below a minimum area threshold (default 500 m^2) are removed. If canopy masking is active, object filtering is repeated after canopy exclusion. The resulting PRA raster is polygonized, smoothed using positive/negative metric buffering, and rasterized back to a final binary PRA map, to remove minor gaps and inconsistencies in the calculated raster.

4.3 Runout Simulation

Runout simulation is conducted using FlowPy, a Python library that uses PRA-positive cells as release starts and propagates flow-like mass over a neighborhood graph using local topographic gradients, friction control, persistence, and forest effects (Damboise et al., 2022). Computation is parallelized by splitting release cells into column-bounded subsets with approximately balanced release counts.

Release cells are sorted by descending elevation so that release areas at higher elevations are processed first. For each start cell, the algorithm expands a dynamic frontier of downstream cells. Duplicate child targets are merged by summing incoming flux and retaining maximum energy-line height.

4.4 ATES classification

The ATES classifier consumes:

1. DEM (for slope and domain metrics)
2. canopy raster (boolean or percent mode)
3. runout travel-angle raster
4. overhead raster (cell count final, z-delta final, or combined overhead exposure)

5. PRA mask

It then classifies pixels using user-defined thresholds for slope, travel-angle, and overhead exposure, using the methods outlined by Toft et al. (2024).

4.4.1 Forest adjustment and PRA context

While the current AutoATES v2.0 algorithm allows for canopy to be interpreted as percent canopy density, for NZmATES, canopy cover is treated as a Boolean value. Preliminary ATES classes are remapped using lookup tables conditioned by forest presence/absence and whether pixels lie within PRA or runout terrain.

4.4.2 Island filtering and final map

Small, isolated “class islands” of classified terrain are removed using a minimum area threshold. Removed cells are backfilled using neighborhood interpolation, rounded to valid class integers, and clipped to class range. The resulting raster is the final ATES output and is symbolized by value using established ATES colors for classes 0-4 (Statham and Campbell, 2024) (Figure 3).

4.4.3 Variables for initial ATES calculation

The default parameters for PRA delineation (Buhler et al., 2018), FlowPy detrainment (Damboise et al., 2022), and AutoATES classification (Toft et al., 2024) were used for the initial ATES calculation, and are listed in Table 1.

Table 1: PRA, FlowPy, and ATES default values used for initial ATES calculation.

PRA default values

Parameter	***Value***
Slope Minimum	> 30
Slope Maximum	< 60
Ruggedness	<= 0.06
Curvature	<= 6
Object area	> 500 m^2
Cluster tolerance	1
Canopy height	> 2m

FlowPy default values

Parameter	***Value***
Alpha angle	25
Exponent	8
Flux threshold	0.0003
Max z	270

ATES default values

Parameter	***Value***
Slope Angle Thresholds	15/18/28/39
Alpha Angle Thresholds	24/33
Overhead Exposure Thresholds	5/40
Island Size	30000 m^2
Window Size	3

5. RESULTS

The ATES algorithm was first tested in a subregion of the Craigieburn Range, the Craigieburn Valley Ski Area (Figure 3). This subregion was chosen for three reasons. Its relatively steep slopes and rocky terrain allow for full tests to be conducted of the automation of terrain characteristic calculation. Additionally, the canopy cover found in several of its valleys at lower elevations allowed for testing of the vegetation component of the ATES calculation sequence. Finally, availability of local expert guidance enabled early-stage model validation and recalibration.

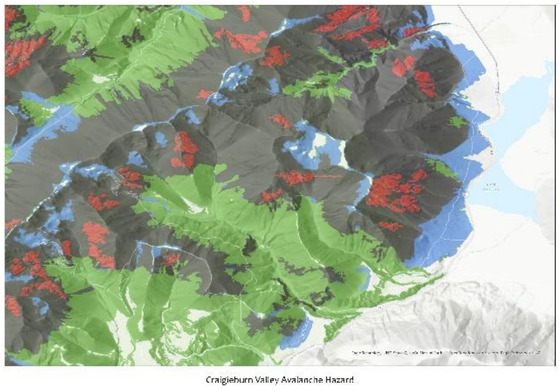

Figure 3: Example NZmATES map of Craigieburn Valley, New Zealand, indicating simple terrain (green), moderate terrain (blue), complex terrain (black), and extreme terrain (red).

5.1 Test results

The output ATES raster generated over the study site showed uniform distribution across the five exposure categories, with a mean value of 2.01. Low hazard scores (0-1) were observed on flat peaks and inside heavily forested areas, while high scores (3-4) were primarily found along steep slopes with high levels of exposure (Figure 4).

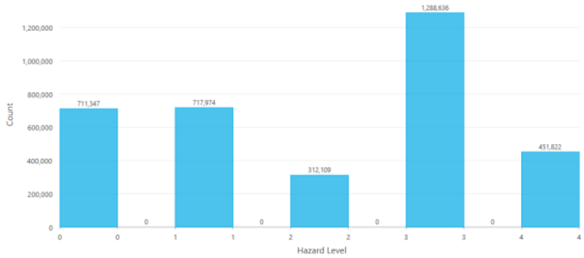

Figure 4: Distribution of ATES hazard values across the Craigieburn Valley, New Zealand

Each step in the NZmATES workflow was assessed for time and space complexity, as well as computing power and efficiency, to assess hardware requirements for its extension from local to national scale.

5.2 <u>ATES calculator interface</u>

Though satisfactory for initial testing of the NZmATES workflow, as testing and refinement continues, the set of parameters in Table 1 is likely to require adjustment to accurately represent terrain hazard characteristics in NZ. To account for this, a graphical user interface (GUI) was created using the Streamlit library, a Python-native web browser framework designed for data processing workflows (Khorasani et al. 2025) (Figure 5). This GUI allows the researcher to define an area of interest (AOI), set calculation parameters, and view processing logs, without altering the underlying Python scripts.

6. NEXT STEPS

Before NZmATES is expanded across the Southern Alps, the modeling framework will undergo systematic validation and optimization to establish an appropriate spatial resolution and parameter set for application in Aotearoa New Zealand. Model outputs will be evaluated against known avalanche paths digitized from existing avalanche atlases, observed avalanche locations and metadata provided by the New Zealand Mountain Safety Council, and expert assessment from mountain guides, avalanche observation teams, safety and search-and-rescue professionals, and local communities. Avalanche atlas data will be used primarily to evaluate the influence of spatial resolution by comparing NZmATES classifications generated at different resolutions against known avalanche paths. Observed avalanche records will then be grouped spatially to examine regional differences in the relationship between avalanche occurrence and terrain characteristics, allowing locally optimized ATES parameter sets to be developed. These will be compared with a national best-fit parameter set to determine whether a single parameterization can adequately represent avalanche terrain across New Zealand or whether regional calibration is required. Finally, expert assessment of the resulting terrain classifications will provide an independent evaluation of model performance. Together, these approaches will establish the spatial resolution, parameterization and validation framework required for subsequent expansion of NZmATES across the Southern Alps.

7. CONCLUSION

The ATES classification system has served as the standard for terrain-based avalanche hazard mapping for over 20 years. AutoATES has proven to be an effective tool for generating these classifications over larger swaths of terrain, and in more remote, less monitored regions. However, there remains work to be done in its validation, optimization, variable delineation, and application in untested climates.

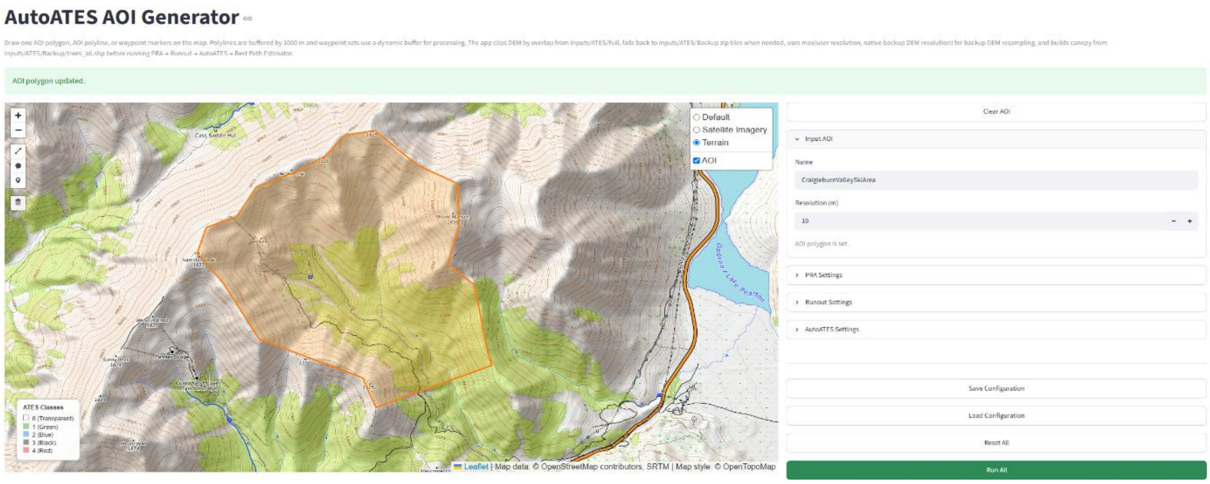

Figure 5: The NZmATES calculator web interface. Under each dropdown section to the right of the interface is a user input box for each parameter used for PRA delineation, FlowPy detrainment, and AutoATES classification.

This study presents the development of NZmATES, the first application of AutoATES in Aotearoa New Zealand, and demonstrates its initial implementation in the Craigieburn Range. The modeling framework integrates potential avalanche release areas, simulated runout, terrain characteristics and vegetation effects to automatically classify exposure to avalanche terrain, supported by a graphical user interface that facilitates parameter testing, model evaluation and refinement. The Craigieburn Range pilot provides the foundation for systematic validation against historical avalanche information and local alpine expertise, and for subsequent optimization of model parameters and spatial resolution across different mountain environments. This work represents an important first step towards a nationally consistent, high-resolution avalanche terrain classification system for Aotearoa New Zealand. Ultimately, NZmATES is intended to complement existing avalanche forecasting by providing detailed terrain-based information that can be combined with current snowpack and weather conditions to support informed route selection and avalanche risk-management decisions in New Zealand's mountains.

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