ZONING WITH THE AVALANCHE TERRAIN EXPOSURE SCALE

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ABSTRACT: During the past three winters over 4000 km^2 of avalanche terrain in five mountain ranges in western Canada was zoned with the Avalanche Terrain Exposure Scale (Statham et al., 2006) at the basin-scale (100 m to 1 km). Because the current ATES system isn't intended for this more deterministic application there are shortfalls with respect to subjectivity of terrain parameters and the lack of a non-avalanche terrain class. Although some digital terrain analysis was used to draw the initial ATES polygons, the methods relied primarily on the judgment of qualified field workers. This paper describes an approach and methodology for ATES zoning, and explores ideas for a more deterministic model including classification for non-avalanche terrain.

1. INTRODUCTION

The Avalanche Terrain Exposure Scale (ATES) was developed by Parks Canada in 2004 (Statham et al., 2006) to classify the overall seriousness of a specific route with respect to exposure to avalanche terrain. A technical model (Table 1) was developed to guide expert assessors by using eleven avalanche terrain parameters to categorize a route into three classes of avalanche terrain exposure: Class 1 "Simple", Class 2 "Challenging", or Class 3 "Complex".

With frequent use of terms like *mostly*, *generally*, *large percentage*, *primarily*, *minimal*, and *limited*, this model has a high degree of subjectivity. There is also a certain amount of redundancy within and between the eleven parameters (e.g. forest density, start zone density, interaction with avalanche paths, and exposure time). For its purpose of guiding expert judgment in classifying a pre-determined route into three different exposure categories, this subjectivity and redundancy works well. However, it poses challenges for the purpose of Geographical Information System (GIS) assisted ATES zoning.

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2. BACKGROUND

2.1 GIS and ATES

Delparte (2008) developed a GIS algorithm that used a reduced set of ATES parameters to zone the Asulkan Valley in Glacier National Park, Canada. Forest density, slope angle, slope shape, and start zone density parameters were determined with 5 m Digital Elevation Models (DEM) and manually digitized forest cover data, while avalanche frequency and interaction with avalanche path parameters were determined with statistical runout modeling. A decision tree algorithm was developed based on thresholds obtained through a series of interviews with the original authors of ATES. An interesting result of the decision tree development was that slope angle and forest density emerged as the most important of the parameters used.

For primarily treed terrain, a slope angle threshold of < 30˚ was used for Class 1, > 45˚ for Class 3, while anything in between defaulted into Class 2. For open terrain the threshold for Class 1 was reduced to < 25˚, assuming no exposure to avalanche paths, and Class 3 remained at > 45˚. The ATES classification for intermediate slope angles in open terrain, < 25˚ with exposure to avalanche paths in open terrain, and for all terrain with mixed trees, depended on the total of weighted scores assigned to parameters such as avalanche frequency, slope shape, start zone density, and interaction with avalanche paths. Although promising, the results were only considered useful for supplementing traditional field based methods of avalanche hazard zoning, so a certain amount of manual adjustment was needed to produce accurate ATES zones.

The Norwegian Water Resources and Energy Directorate use a similar GIS algorithm to generate draft maps of ATES zones, which are then refined with field surveys (Lytskjold, 2012, pers. comm.). The input data are all raster layers including 25 m DEMs, forest cover, as well as start zones and run out zones delineated as part of a previous project.

Table 1: The Avalanche Terrain Exposure Scale technical model v1.04 (Statham et al., 2006). Parameters listed in **bold-type** default the assessed route into that class.

	Class 1 “Simple”	Class 2 “Challenging”	Class 3 “Complex”
Slope angle	Angles generally < 30º	**Mostly low angle, isolated slopes > 35º**	**Variable with large % > 35º**
Slope shape	Uniform	Some convexities	Convoluted
Forest density	Primarily treed with some forest openings	Mixed trees and open terrain	Large expanses of open terrain. Isolated tree bands
Terrain traps	Minimal, some creek slopes or cutbanks	Some depressions, gullies and/or overhead avalanche terrain	**Many depressions, gullies, cliffs, hidden slopes above gullies, cornices**
Avalanche frequency (events:years)	1:30 ≥ size 2	1:1 for < size 2 **1:3 for ≥ size 2**	1:1 < size 3 **1:1 ≥ size 3**
Start zone density	Limited open terrain	Some open terrain. Isolated avalanche paths leading to valley bottom	Large expanses of open terrain. Multiple avalanche paths leading to valley bottom
Runout zone characteristics	Solitary, well defined areas, smooth transitions, spread deposits	Abrupt transitions or depressions with deep deposits	Multiple converging runout zones, confined deposition area, steep tracks overhead
Interaction with avalanche paths	Runout zones only	Single path or paths with separation	**Numerous and overlapping paths**
Route options	Numerous, terrain allows multiple choices	A selection of choices of varying exposure, options to avoid avalanche paths	**Limited chances to reduce exposure, avoidance not possible**
Exposure time	None, or limited exposure crossing runouts only	**Isolated exposure to start zones and tracks**	**Frequent exposure to start zones and tracks**
Glaciation	None	**Generally smooth with isolated bands of crevasses**	**Broken or steep sections of crevasses, icefalls or serac exposure**

Richardson (2010, pers. comm.) developed a GIS-based ATES rating algorithm that classifies 500 m grid cells using DEM data. Parameters include slope angle, elevation (for forest density), and cumulative slope angle (for slope shape). This approach uses proportion thresholds of parameter values rather than parameter thresholds to determine the class. For instance, if <10% of the grid cell is ≥30˚ then it is Class 1, or if > 50% of the grid cell is ≥ 30˚ and > 20% is above treeline then it is Class 3. The thresholds for these proportions were based on expert opinion and are an attempt at quantifying some of the subjective terms used in the ATES technical model (Table 1).

2.2 Scale

Since avalanches can occur at a variety of spatial scales and terrain exists at a variety of spatial scales, terrain-based models of avalanche exposure must either be scale-dependant or account for a variety of spatial scales. With a general scale-independent set of parameters, the ATES technical model v.1.04 (Table 1) can be applied at a variety of spatial scales. Because of this it is important to be clear about the scale at which the model is being applied, regardless of whether the purpose is for classifying a specific route or zoning an area of terrain.

For example, when classifying a specific route, the route and therefore the scale are always defined. However, along that route there will likely be variations in the avalanche exposure, and more so with longer routes. Similarly, for the purpose of zoning, at the basin-scale (100 m to 1 km) an overall rating of Class 3 can be assigned to a basin, but there will likely be several Class 2 or even Class 1 areas within that zone at the slope- or feature-scale.

Furthermore, the smaller the scale used, the more definite the classifications will be, and in order to be accurate enough for route finding, Schweizer et al. (2003) suggest a spatial scale of at least 20-30 m is required.

3. METHODOLOGY

The following methods were developed for Canadian Avalanche Centre projects with Recreation Sites and Trails BC and BC Parks, and first reported in Campbell and Marshall (2010). Since then through these projects, as well as through Alpine Solutions Avalanche Services projects with the Yukon Avalanche Association and Yukon Government, over 4000 km^2 of terrain has been zoned with these methods. The Avalanche Forecast Center of the Val d'Aran in Spain has also adopted this methodology for zoning in the Pyrenees.

Contrary to the raster-based approach used in the projects outlined in Section 2, this methodology uses a vector-based approach where polygons are extended outwards based on expert judgement for thresholds of all the ATES parameters. Similar to the raster-approach, this method is subject to its own scale issues. Take, for example, a classic avalanche path. Within the trim lines there are no options to reduce exposure, so the polygon would default to Class 3 “Complex”. However, extending the polygon boundaries outside the trim lines, would inevitably introduce options to reduce exposure.

To date, zones produced with this methodology are drawn at the basin-scale (100 m to 1 km) and are therefore not appropriate for route finding. Precision is often high (~30 m) during the preliminary zoning phase, with the intention of reducing precision in order to increase accuracy during the field surveys and final zoning. Common routes and high-use areas are often given special attention for accuracy and precision; however, the ATES polygons are entirely terrain-based and completely independent of trips or routes.

3.1 Preliminary zoning

Accessibility as well as limited resources were important considerations when developing these methods. They were the primary motivation for choosing freely available Google Earth and MicroDEM software over expensive full-featured GIS platforms, and sacrificing the ability to automatically generate preliminary zones with computer algorithms. However, one of the main advantages of computer models over manual digitization is the avoidance of bias (McClung and Schaerer, 2006) due to human factors. Nonetheless, we find that with practice and frequent calibration through field-surveying one's own preliminary zones, manually digitized ATES zones using these methods often require little adjustment after field verification. It is also reasonably efficient; often taking less than day to zone a typical backcountry recreational area.

Once the area of interest is defined (Figure 1), ATES zones are based on expert judgment informed by prior knowledge of the terrain, Google Earth imagery and terrain modeling, publically-uploaded Panoramio embedded photos, as well as slope angle and forest cover overlays.

Figure 1: The Tutshi Chutes area in the Yukon (outlined in white) shown in Google Earth. High resolution imagery is available for the east end of the area, making forest cover and terrain features easy to visualize. However, most of the area of interest has lower resolution imagery, which isn't particularly useful except for determining general vegetation patterns and major terrain features.

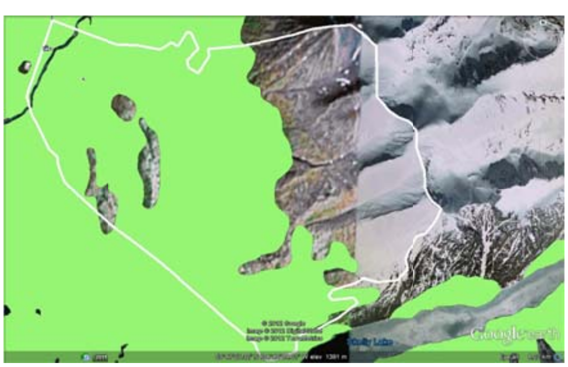

Figure 2: In the absence of high resolution imagery, vegetation overlays can be used to supplement the low resolution imagery to give a better indication of forest cover. This particular example shows forested areas in green. Note that there are only two classes of vegetation in this example; forested and non-forested. But the vegetation overlays used for the analysis in the next section have three classes; primarily treed, mixed, and open.

3.1.1 Slope angle overlays

Slope angle overlays are generated with MicroDEM software using 20 m DEMs and an eight-neighbours calculation. With these overlays it's possible to visualise key default ATES parameters (i.e. slope angle and terrain traps) as well as other important parameters (i.e. slope shape), making them one of the more relied upon tools. It is important to remember that elevation errors inherent to DEMs and image overlay scaling issues can lead to slope angle inaccuracies at very small scales. However, the accuracy is considered adequate for the scale at which the ATES zones are delineated.

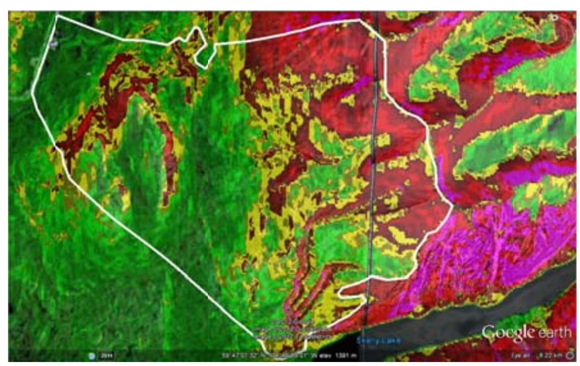

Figure 3: Slope angle overlays viewed in Google Earth with the Tutshi Chutes area outlined. Slopes less than 20 degrees are shaded in green, 20-30 degrees in yellow, and over 30 degrees shaded in red and purple.

3.2 Field surveys

Due to the inaccuracy of digital terrain modelling and the inability to digitally visualize important ATES parameters, field surveys are a necessary part of the process if high accuracy is required. Parameters such as avalanche frequency, interaction with avalanche paths, exposure time, and route options are often only possible to assess in the field.

Helicopter assisted field work is often most efficient and effective for large complex areas, especially if ground-based travel is hazardous or difficult. Ground travel is still an essential component for more complex areas, and to enable 'placing oneself in the terrain'. Field trips usually take place in winter, when the terrain can be assessed with snow cover, but summer surveys can also work, and are especially useful for glacier assessment. Cameras, inclinometers, GPS receivers, altimeters, as well as copies of the ATES technical model, are all invaluable tools to have in the field.

Field maps (Figure 4) of the preliminary zoning are printed on waterproof paper and taken into the field where they are annotated with adjusted polygon boundaries, major avalanche paths, decision points, and any other avalanche terrain or area information.

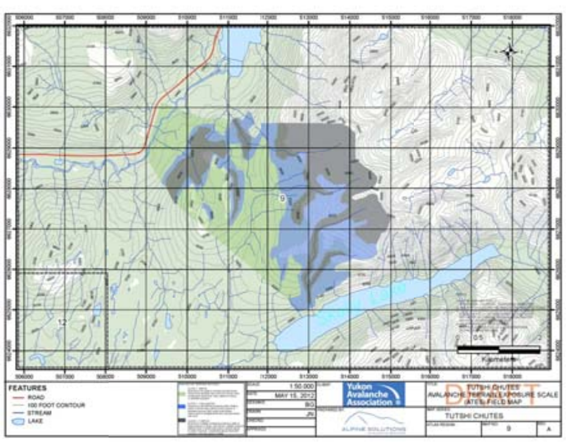

Figure 4: Field map for the Tutshi Slopes area in the Yukon showing preliminary zones of Class 1 "Simple" terrain in light green, Class 2 "Challenging" terrain in blue, and Class 3 "Complex" terrain in dark grey.

3.3 *Final zoning*

The final zones (Figure 5) incorporate all the adjustments made during the field survey. They are usually in the form of printable maps and digital overlays. Although no formal error analysis was performed, a 10 to 20 m polygon overlap is used to express the uncertainty associated with the ATES zones. The maps are usually not drawn at a sufficiently small scale to see this overlap; however it becomes important in a digital viewer, such as Google Maps, with uncontrollable and limitless zoom.

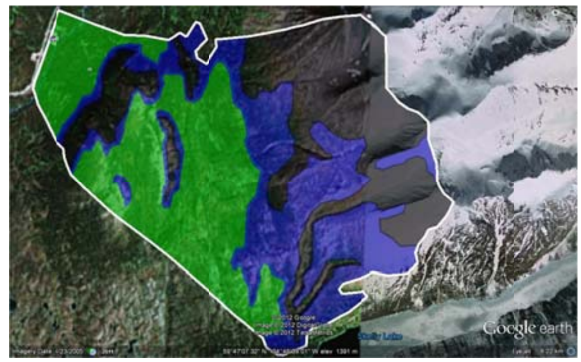

Figure 5: Final ATES overlay for the Tutshi Chutes area in the Yukon showing Class 1 "Simple" terrain shaded in green, Class 2 "Challenging" terrain in blue, and Class 3 "Complex" terrain shaded in dark grey. When compared to (and using grid references from) the field map shown in Figure 5, there is an obvious corridor of Class 1 terrain added at UTM 511000 6628700 after the field survey. A 10-20 m polygon overlap, intended to express uncertainty, can also be seen in this example.

4. NON-AVALANCHE TERRAIN

By definition Class 1 terrain must have some areas that are affected by avalanche hazard. We feel a fourth class that specifies non-avalanche terrain may be appropriate for some areas depending on the resolution, as well as the intended use of the ATES zoning. The development of 'Class 0' category is not a new idea, and has been considered by Statham (2012, pers. comm.) as well as others. As an example, it would be beneficial for parties to be aware of locations that would be acceptable in all avalanche conditions to establish a camp, turn off transceivers, and freely roam within a designated area. If Class 0 terrain is to be formally considered an established zone that could be incorporated into a GIS (or more objective) based methodology, there would need to be specific parameters that indicate that it is virtually impossible for an avalanche to occur in, or reach the Class 0 location..

The development of specific thresholds that define the existence of avalanche terrain is a relatively straightforward task – most basic level avalanche texts clearly specify the primary parameters (e.g. slope incline greater than 25°, open terrain, etc.), But almost all indicate rare events do occur outside of these thresholds, which implies that the determination of non-avalanche terrain is a more complex process. This is apparent if wet snow avalanches or very low frequency avalanche events (which initiate, or run into mature forested terrain) are considered. Although most would agree that there is extensive terrain in the mountains that is non-avalanche terrain, it is clearly not a simple task to define the parameters that completely rule out the possibility of avalanches ever reaching a given location in the mountains, unless the point is a prominent high point (e.g. high ridge or summit).

In her analysis, Delparte (2006) determined that slope angle and forest density are the two most important parameters (of those considered in her analysis) for ATES classification. We feel this is generally correct even when considering all ATES parameters. Although the slope angle threshold can be considered robust (universally accepted) for avalanche initiation, avalanche runout is clearly not confined to this threshold slope angle. Runout extent can be objectively defined somewhat by the use of numerical modelling, which Delparte (2006) also incorporated in her analysis. However, runout models do not generally take into account wet snow avalanches which (on rare occasion) have been observed to run great distances on extremely low angle terrain - 8° to 12° or less (Mears, 1992). This variation in runout extent can present a high level of uncertainty in regards to developing Class 0 parameters.

A forest density threshold has been suggested in a few texts. In Canada, Wier (2002) indicates avalanches 'may be suppressed' when 1000 stems per hectare is exceeded. A government avalanche safety plan in Canada has gone one step further and defined 1000 stems per hectare as the threshold for non-avalanche terrain (BC NRS, 2011). This translates to an average tree spacing of approximately 3.3 m. The implication is that this is the tree spacing required for the effects of mechanical anchoring and forest cover are sufficient to inhibit avalanche formation Depending on the tree species, and scale and variation of tree spacing, this may not deterministically rule out the existence of avalanche terrain. Especially considering statements from experts that suggest "if you can ski through the trees, avalanches can start in the trees" (Jamieson, 2002). Considering the above, we feel that forest density may not be a robust parameter for classifying an area as Class 0, unless the forest density analysis occurs at an extremely small scale (perhaps 10 m resolution).

In consideration of the above, due to the level of certainty and high degree of resolution required for mapping all non-avalanche terrain within a defined area of interest, perhaps it should be considered an optional classification for ATES zoning. Its application would be appropriate to consider for indicating established camp areas, or potentially for low risk tolerance environments (e.g. worker or custodial groups) that may benefit from not having to consider avalanche safety measures while in a specific location or area. The Class 0/1 polygon boundary would not necessary be based entirely on specific ATES parameters, but instead the determination of the boundary would be guided by a balance between the requirements for the ATES zoning, and the associated level of analysis required. As an example, at one end of the spectrum, a rough Class 0 polygon may be conservatively drawn with little analysis for a popular backcountry camp destination (Figure 6) and at the other end, a full scale hazard mapping exercise may be required to locate the boundaries of Class 0 for an established camping area in tight mountain valley (Figure 7).

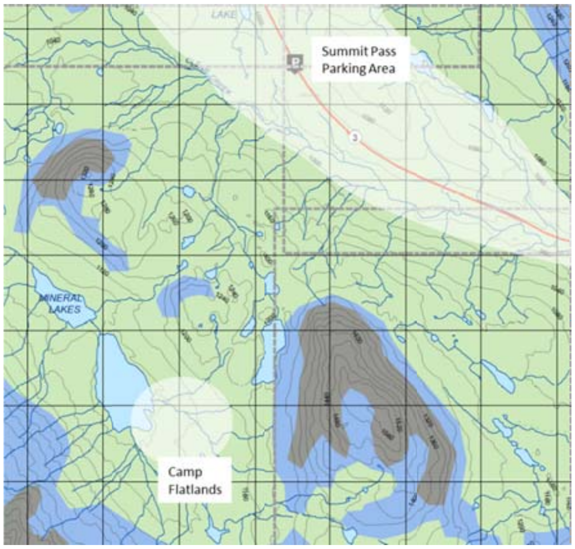

Figure 6: Example of potential Class 0 delineation based on popular backcountry camp location.

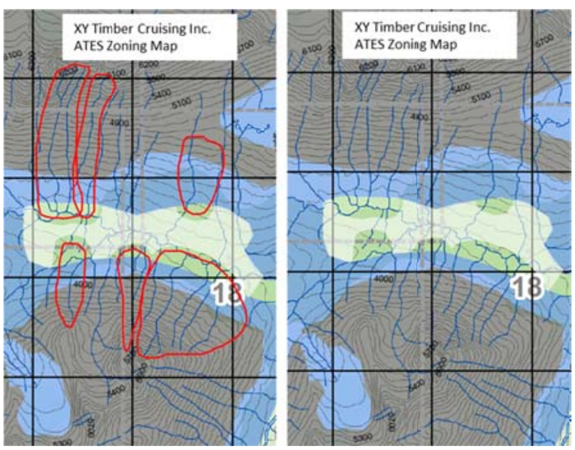

Figure 7: Example potential Class 0 delineation based on detailed Avalanche Path Mapping. Left image includes avalanche hazard mapping with maximum boundaries, and right image illustrates final ATES map with Class 0 terrain careful determined.

5. DISCUSSION

Even though the methods described above are becoming established in Canadian public avalanche safety applications, there is still potential to evolve this work further. Particularly, the development of ATES zoning has highlighted the need to refine the ATES Technical Model, or develop a separate parallel model specifically for zoning. This would include developing more deterministic thresholds for parameters that can be digitally represented in GIS, in other words determine quantitative values for some of the subjective terms used in the ATES technical model (Table 1). With DEMs and forest cover data, slope angle, slope shape, and forest density can be readily quantified with GIS. With more advanced algorithms including runout models, start zone density, interaction with avalanche paths, avalanche frequency, and even route options can be quantified using certain assumptions (Delparte, 2006). An analysis of the work done to date using the methods described in Section 3 can help to determine thresholds, with respect class zone proportions, for these parameters (e.g. Richardson, 2010).

Using automated GIS algorithms could be useful for increasing consistency amongst assessors by providing another visualization tool to assist with preliminary zoning. However, due to the inability to digitally model most ATES v.1.04 parameters, it is not possible to generate ATES zones purely with GIS. For this reason, some degree of expert judgement is required. Whether this is solely in the form of manually digitized zones using terrain visualization tools or full scale field surveys depends largely on the accuracy required for the intended application and stage of mastery of the end user.

The default parameter of glaciated terrain to Class 2 “Challenging” or higher has been a point of much discussion. This is highlighted specifically in areas where there are many large flat glaciers with minimal overhead hazard. Avalanches reaching Size 2 or larger are very unlikely in this terrain and we should, therefore, have the option to zone it as Class 1 “Simple” or even non-avalanche terrain. We feel crevasses and other glacier-related mountaineering hazards are the primary concern for these large flat glaciers and using an avalanche exposure scale to describe serious glacier travel may be giving the wrong message. It's essentially recommending to be prepared and trained for avalanches when people should be prepared and trained for glacier travel. As an option, glaciers could fall under a different grading system. There are several mountaineering grading systems out there, but the International French Adjectival System is probably the most detailed when it comes to glacier travel.

Yet another discussion point is the acceptance and application of ATES zoning for workplace safety programs. Most zoning maps produced to date have been intended for self-directed backcountry recreational avalanche safety. However, there has been limited use of ATES zoning for worker safety in industries where workers may be freely roaming through avalanche terrain, as opposed to following defined routes or transportation corridors. Although the traditional use of ATES is widely accepted for workplace safety (e.g. BC NRS, 2011 and BC MOFR, 2010), the increased acceptance and standardization of ATES zoning combined with current worker safety needs may lead to more widespread use and acceptance of ATES zoning for backcountry workplace scenarios.

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7. REFERENCES

British Columbia Public Service Natural Resource Sector for General Wilderness Activities. (BC NRS). 2011. Avalanche Safety Plan.

British Columbia Ministry of Forests and Range (BC MOFR). 2010. Snow Avalanche Avoidance Policy.

Campbell, C. and Marshall, P. 2010. Mapping Exposure to Avalanche Terrain. International Snow Science Workshop (ISSW). Squaw Valley, CA.

Canadian Avalanche Association (CAA). 2002. Guidelines for Snow Avalanche Risk Determination and Mapping in Canada. McClung, D.M., Stethem, P. A. Schaerer, and J.B. Jamieson (eds.), Canadian Avalanche Association.

Delparte, D., 2008. Avalanche Terrain Modeling in Glacier National Park, Canada. Ph. D. Thesis, University of Calgary, Calgary, AB, Canada.

Jamieson, B., 2002. ENCI 753 “Avalanche Formation and Release” Lecture. University of Calgary. Sept.-Dec., 2002.

Lytskjold, B. 2012. Personal communication on 9 May 2012.

McClung, D. and Schaerer, P., 2006. The Avalanche Handbook, 3rd Edition. The Mountaineers Books, Seattle, WA.

Mears, A. 1992. Snow-avalanche hazard analysis for land-use planning and engineering. Colorado Geological Survey, Bulletin 49. Department of Natural Resources. Denver, CO.

Richardson, M. 2010. Personal communication on 19 September 2010.

Schweizer, J., Jamieson, B. and Schneebeli, M., 2003. Snow avalanche formation. Reviews of Geophyics, 41(4): 2.1 - 2.25.

Statham, G. 2012. Personal communication on 13 August 2012.

Statham, G., McMahon, B. and Tomm, I., 2006. The Avalanche Terrain Exposure Scale, International Snow Science Workshop (ISSW). Telluride, CO.