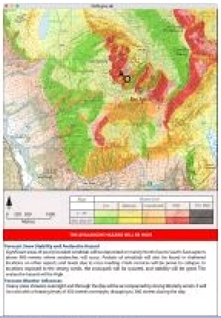
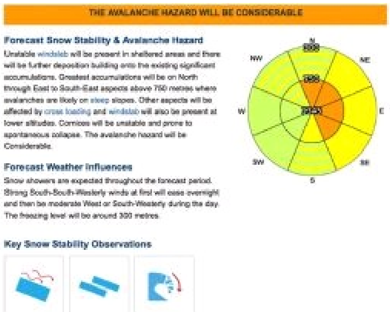
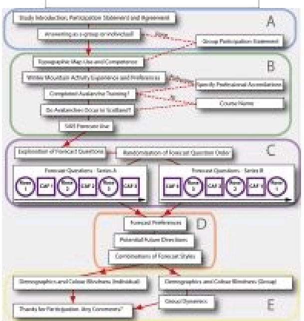
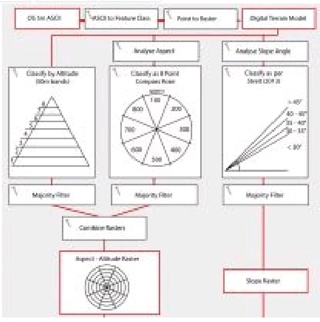
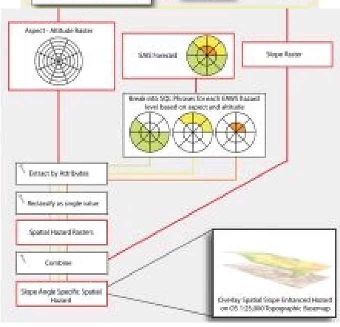
# GIS-based Cartographic Representation of Avalanche Forecasts









Annually, snow avalanches in Scotland are the cause of a significant loss of life. As a naturally occurring disaster they are unique in nature, usually being highly localised events, and often in remote areas. Their victims are often voluntarily at risk for recreation purposes and become the trigger of their own avalanche.

Typically, avalanche prone areas are often those that recreationists most desire to use. Controlling access to these areas is ethically dubious and efforts to increase the safety of recreationists must therefore focus on educating and informing risk-based decision processes.

## Avalanche Forecasting

Avalanche forecasting seeks to safeguard recreationists in winter mountain environments using risk-based decision-making. However, current methods of representing avalanche forecasts, such as Rose Diagrams, are abstract and require an ability to synthesize geospatial information based on being able to read a topographic map.

To inform recreationists, most avalanche prone countries possess an avalanche information service. Professionals routinely interpret the spatial and temporal distribution of hazards and abstractly present these in the form of a forecast. Recreationists can then inform the planning of excursions into avalanche-prone terrain, avoiding high-risk slopes that pose a hazard.

Understanding an avalanche forecast requires extraction of geospatial information from an abstract diagram and application and applying it to a topographic map – a synthesis that requires a degree of skill and is a potential source of error. Recently, geospatial technologies have been applied to the visualisation of avalanche hazards - simplifying this process for recreationists. This has brought the advent of an increasing number of avalanche hazard communication styles - including the introduction of phone apps. Whilst studies highlight significant potential for such visualisations - to improve the accuracy with which recreationists understand avalanche hazards - research in the field has so far been limited or small in scale. A significant opportunity therefore existed to assess the way recreationists interpret both traditional forecasts and visualisations of avalanche hazards.

Scotland is ideally situated for such research as it has a complex avalanche situation that poses a threat solely to recreationists. Lochnagar and Ben Nevis were chosen as the study sites because of their varied topography and ability to test different avalanche forecast styles on, and to enable the assessment of a recreationist’s interpretation of a forecast. The use of two areas is also important for the survey questionnaire, as it counters familiarity with either area. Each area covered about 20km$^2$. Critically, both areas fall within the Scottish Avalanche Information Service (SAIS) forecast regions.

The study reported in this article explores the feasibility of using Cartographic Avalanche Forecasts (CAFs) as a novel visualisation method to help improve recreationists' understanding of spatial avalanche hazards. The aim of this study is to explore whether new methods of visualization are effective in aiding the understanding of hazards.

## Making the Cartographic Visualisation

Avalanche forecast data was taken from the SAIS online archive. SAIS produces forecasts that follow the EAWS Avalanche Hazard Scale. Forecasts used in this study all had a hazard rating of Considerable or above to provide sufficient complexity for recreationists to interpret. Six sets of forecast data that met the criteria were selected randomly.

Initially, a series of CAFs were created. The process for creating CAFs was based on some work on intrinsic risk visualisation and involved two main stages; (a) creating a GIS framework; (b) inputting SAIS forecasts. The framework for creating CAFs consisted of elevation and aspect – the key spatial components of the avalanche forecast. Additionally, the slope angle should be included; although it is a component of an avalanche hazard external to the forecast, it is critical to risk comprehension.

In order to derive slope, elevation and aspect, Digital Terrain Models (DTMs) were obtained for both study areas. These were downloaded from Edina Digimap (http://digimap.edina.ac.uk/). The GIS used was ESRI's ArcMap 10.5. Slope and aspect were then derived from the DTMs for each area using 3D Analyst tools in ArcMap. Altitude, slope and aspect were reclassified into categories that complement the SAIS forecast using 50m elevation bands and an eight point compass rose. Slope angles were reclassified following an existing schema and lie within with the brackets of approximate avalanche risk based upon slope angle. Once reclassified, rasters for slope, elevation and aspect were cleaned using the Majority Filter tool - reducing noise within the rasters - in a similar style to others.

To facilitate the input of the SAIS avalanche forecast, the ArcGIS Combine tool was used to join the elevation and aspect rasters to produce a single Aspect-Altitude raster. This also created a separate Slope Raster, divided into bands of the probability of inducing an avalanche.

The current SAIS graphic presentation of the avalanche forecast is in the form of a Rose Diagram; converting this information into a CAF requires breakdown of the Rose information by EAWS' hazard rating. The spatial distribution of individual hazard levels was specified using SQL queries and extraction from the Altitude-Aspect raster. Viewing these hazard rasters together, when overlaid on a topographic basemap, provides a spatial visualisation of the entire forecast.

Initially, slope was symbolised as a gradient of increasing red saturation with the greatest saturation representing the most dangerous slope angles. However, this confused the EAWS symbology as it was not clear whether red indicated steep slopes or a high-risk avalanche hazard. Such visual confusion when specifying slope angle on busy topographic maps is an issue also highlighted by others. An alternative solution was therefore adopted whereby saturation of the EAWS hazard level colours was varied dependent upon slope angle. As topographic maps are visually busy and colour perception can be an issue, slope symbology was simplified at this point to represent the critical division in avalanche risk assessment - more than 30 degrees or less than 30 degrees.

A further issue is posed by the SAIS symbology for localised hazards. To show these hazards, slope angles below 35 degrees were symbolised as the general hazard level, whilst slopes over 35 degrees were symbolised as the localised hazard level. The change in saturation between slopes less than 30 degrees and more than 30 degrees was maintained.

## Additional Refinements to the Map

To aid in the production of the final maps used for testing the CAF, the following steps were undertaken:

***Graphic Design and Post Processing*** - Whilst some researchers have used Adobe Photoshop to blur the boundaries between zones of hazard to communicate uncertainty, this was not appropriate in this case because avalanche hazards in Scotland have high spatial variability and, as such, all spatial detail should be retained. To improve small area interpretation, the OS map symbology beneath the CAF forecast layers was redefined. The legend used for CAFs shows hazards symbolised with hues from the EAWS hazard rating scale, and slopes symbolised by saturation, and colours are shown 50% transparent on a 1:25,000 OS topographic map background.

The Unsharp Mask in Adobe Photoshop was applied to each CAF (A = 300 / R = 1 / T = 30). The sharpening carried out on PsCS6 was harsher than would be desirable for printed maps to optimise the forecast for display on digital interfaces. Additionally, a selective colour filter was applied to redefine black text and symbology from the OS map.

***Colour Assessment of CAFs*** - The colours used to symbolise CAFs have a potentially significant impact upon their interpretation and accessibility, especially for the colour vision impaired. Colour Contrast Analyser v2.4 was used to analyse the contrast ratios of colours and saturations used in the symbology of CAFs. Additionally, Adobe Illustrator CS6 was used to produce colour vision impaired "soft proofings" of the legend for CAFs.

***Contact with Professionals*** - Contact with avalanche professionals is recommended by some researchers to subjectively verify the results of DTM analysis and forecasting. Examples of CAFs were therefore shown to experts qualified in avalanche assessment for comment; experts were considered to be individuals who work in the field of avalanche forecasting, or who hold qualifications enabling them to deliver avalanche education.

## Assessing the Maps

To assess the potential of the CAFs, an online questionnaire was devised; this approach specifically sought to reach a wider audience than the controlled experiment carried out by Streit (2013). This approach also allowed access to large active groups of recreationists using social media such as the British Backcountry Facebook group. Google Forms was used as the online platform for the questionnaire survey as it allows for the inclusion of high-resolution maps and diagrams. The CAF survey was conducted in five sections. For the most part Likert-type scales were used. Dashed red lines indicate skip logic questions, with criterion for skip logic given alongside.

The survey included a brief introduction to the study; consent was sought from respondents for their involvement; participants were also asked whether they were answering the survey as an individual or a group, in an effort to control the effect of group dynamics on hazard assessments. Respondents were informed that the survey would take up to 20 minutes, and were reminded throughout not to treat the survey as any kind of avalanche education. Respondents were also asked to self-assess their competence and frequency of topographic map use. A secondary set of questions was used to determine respondents' experience across a range of the most common Scottish winter mountain activities. To provide comparison with the work of others, respondents were also asked to detail their preferences for slope angle and fresh snow. Finally, respondents were asked about their experience in avalanche hazard assessment, including how often they use the SAIS avalanche forecast, and whether they have received any formal avalanche training.

Six forecasts were presented to survey respondents. A standardised template - in the style of an online forecast - was created for each forecast using Adobe Illustrator CS6. This ensured the layout of each question was the same, regardless of whether it related to a CAF or an abstract Rose Diagram forecast. 164 recreationists were assessed for their preference and interpretation of both CAFs and Rose Diagrams. Statistical analysis of the data collected was used to draw links between recreationists' backgrounds, preferences, and their interpretation of forecast styles.

## The Outcome

This study set out to explore the feasibility of a cartographic avalanche forecast in a Scottish context, and to assess the way recreationists interpret such a forecast compared with the current abstract Rose Diagram method. The creation of Cartographic Avalanche Forecasts (CAFs) was successful using a DTM framework. The resulting CAFs are highly specific in appearance, showing the distribution of avalanche hazards at a $5m^2$ resolution. Whilst this specificity initially appears as an indicator of success, experts in avalanche hazard assessment have been critical of this method, arguing that the resolution of DTM data is not high enough to realistically portray the complex Scottish avalanche situation that varies over a very small spatial scale. The experts believe the specificity of CAFs will give false confidence to recreationists, resulting in the acceptance of forecasted hazards as reality, and overlooking the need for small-scale interpretation. Alternatively, they believe the cognitive challenge of reading a Rose Diagram to be positive, as it forces recreationists to interpret and accept small scale spatial hazards and inaccuracies forecasting them.

Additionally, using standard “traffic light” symbology of the European Avalanche Warning Service in CAFs is deemed problematic. Contrasts between forecast colours are often poor, creating visual confusion when overlain on a topographic basemap. Furthermore, the use of a Red-Green hazard symbology in CAFs is found to be ineffective for colour vision deficient recreationists.

Recreationists were found to be more accurate deriving hazards and slopes using the CAF method compared with using the Rose Diagram method, concurring with the results of previous studies.

Additionally, for both forecast types a cumulation of recreationists' skill in topographic map reading, experience in uncontrolled environment mountain activities, and familiarity with the avalanche forecast is found to significantly positively correlate with both accuracy and confidence. On-piste and off-piste skiing were found to be the activities most predisposed to using avalanche prone slopes. However, skiing-skill did not significantly correlate with the correct interpretation of a hazard in avalanche forecasting.

Critically, the CAF method is found to differentially alter recreationists' confidence. Less-skilled recreationists gain confidence when using CAFs; whereas a handful of highly-skilled recreationists lose confidence. Explanations for this change become clear in respondents' forecast preferences. Typically, less-skilled respondents prefer the CAF method because it is easier to use but also because it is more accurate or increases certainty in their choices. Alternately, highly-skilled respondents tend to prefer the Rose Diagram method or are indifferent, several citing issues surrounding the over specificity of CAFs and relating this to false confidence. This change in confidence is exactly the concern raised by experts. Although CAFs are no more accurate than Rose Diagrams, they give the impression of being so. Whilst some highly-skilled recreationists are able to realise this effect, the majority are not, and hence prefer the CAF.

In conclusion, there is not currently data of a high enough resolution to create an accurate CAF. However, there is potential for CAFs to increase the accuracy with which recreationists can interpret the avalanche forecast. Critically, this potential should be treated with care, as an increase in the confidence of low-skilled recreationists is an undesired and potentially dangerous effect of using CAFs. Nonetheless, recreationists prefer the CAF method and any provision of such a service is therefore likely to see a large uptake.