#### MAPPING AND CLASSIFICATION OF POTENTIAL AVALANCHE SITES IN THE CHIC-CHOCS MOUNTAINS, QUÉBEC, CANADA, USING GEOGRAPHIC INFORMATION SYSTEMS

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ABSTRACT: Avalanche sites mapping and classification are tools that have been frequently used for managing avalanche risks. The use of geographic information systems (GIS) for such applications has great potential although it is still in development. The potential avalanche sites of the Chic-Chocs Mountains, Québec, Canada, was mapped with GIS technology, satellite images, aerial photos and 1:20 000 topographic maps. A forest map, including three different levels of forest density, was generated from the satellite image. A total of 59 potential avalanche zones were characterized in this area, including 249 avalanches paths, Moreover, in order to build an institutional memory bank of one of the most frequented area by winter sports adepts in Québec, a system was created to allow future cataloguing of avalanche occurrences inside the potential avalanche location map. Another terrain analysis was also performed to address the challenge of the access restrictions of Mount-Albert in Gaspésie National Park. A terrain classification by exposure to avalanches based on Parks Canada's technical model was performed in order to help safer management of the park's winter activities. The database linked to a GIS is the basis for the study of potential correlation between topographic parameters and weather patterns.

KEYWORDS: Avalanche; avalanche mapping; terrain classification; visualisation; geographic information systems

#### 1.INTRODUCTION

Most accidents caused by avalanches in Canada happen in the western provinces of British Columbia and Alberta. However, there are also risks associated to avalanches in the eastern provinces of Québec and Newfoundland (Stethem *et al.*, 2003). The specific problematic in the province of Quebec is that there is a general misconception of avalanche risks and little or no historical avalanche data (Hétu and Bergeron, 2004; Jones, 2002).

Since the 1900, 60 deadly avalanches were reported in many different regions of Québec (Hétu, 2006). As of the beginning of this century more extensive research has been undertaken and mitigating measures put into place to help prevent accidents like the Kangiksualudguak tragedy where a short slope avalanche struck a school killing 9 people and injuring 25 others (Hétu et Bergeron, 2004; Lied and Domass, 2000). To lead this prevention effort, the Avalanche Center of the Haute-Gaspésie (ACHG) was created in 1999. This center oversees avalanche awareness and education in the province. Moreover it provides an

\**Corresponding author's address:* Stephanie Lemieux, Centre d'Applications et de Recherches en Télédétection, Université de Sherbrooke, 2500 Bd. Université, Sherbrooke, Qc Canada J1K 2R1; e-mail: Stephanie.lemieux@gmail.com avalanche hazard forecast in a region that is increasingly exposed to avalanche risk, located within the the Gaspesie Provincial Park and the neighbouring Fauna Reserve of the Chic-Choc mountains. (SEPAQ, 2006; Boucher and Gagnon, 2002). However, no extensive avalanche mapping has yet been done. The purpose of this study is to address this need in the avalanche risk management process of this area.

The first specific objective is to build a digital avalanche atlas to localise, name and characterize the potential avalanche paths of the most frequented area of the Chic-Chocs mountains by the recreationist and to provide a platform in which the past and future avalanches events will be collected. The second objective is to classify the terrain of Mount Albert using the Avalanche Terrain Exposition Scale (ATES) proposed by Parks Canada. The results of this work could help the avalanche risk managers of the Parc de la Gaspesie to better manage the terrain restriction of Mount Albert.

The developed method uses multisource data at different scales. The analysis includes extensive terrain exploration, classification of forest areas with high resolution satellite images, investigations and a digital terrain model (elevation, slope, curvature, etc.) with the help of a geographic information system (GIS).

## 2. STUDY SITE

The Chic-Chocs mountains are situated in the north east of the Appalachian Mountains and north of the Gaspésie region. Within these mountains one will find the Québec National Parc de la Gaspésie and other Québec fauna reserves. The topography is characterised by approximately 1000 meters high alpine plateaus with steep slopes leading down the valleys. The large amount of snow precipitation in the winter and the strong and frequent winds makes that region subject to avalanches (Hétu et Bergeron, 2004; Boucher and Gagnon, 2002; Girard et Hétu, 1989).

The seven specific study areas, presented in figure 1, were chosen in relation to the park's winter recreational activities, like backcountry skiing and snowboarding, and to their relative proximity. The total area covered by the sectors is approximately 20 km<sup>2</sup>. The seven sectors are defined in this study as being the most frequented areas by the recreationists, therefore the more exposed to avalanche risk.



Figure 1. Study sites. Background: high resolution SPOT satellite image acquired in October 2005. *A*) Monts Vallières-de-Saint-Réal B) Blanche-Lamontagne C) Hog's Back D) Champs de Mars E) Mont Albert F) Lac aux Américains G) Mines Madeleine.

#### 3. METHODOLOGY

#### 3.1 Data description

The data acquired to meet the two main objectives of the project include: Aerial photos of 1:15 000 dating from 1963, 1972, 1986 and 1992, digital topographic data 1:20 000, SPOT multispectral satellite images (10 m. resolution), SPOT panchromatic satellite image (5 m. resolution), avalanche reports recorded or from local memories, and photos from field campaigns.

The data was used to perform spatial and terrain analysis, to classify forest densities, to create the maps and to build the database that is linked to the digital atlas with the help of a GIS. The results were validated with terrain recognisance and by comparing them with the terrain characteristics data of a recent study that covered some of the same avalanche paths (Germain, 2005).

#### 3.2 Digital avalanche atlas

Figure 2 represents the general steps that were followed to create the digital avalanche atlas. The photo-interpretation of the region reaching as far back as 1963 allowed us to localise areas that had avalanche characteristics and clues of past avalanches like openings in the forest. The aerial photos were also georeferenced to create polygons or lines representing potential avalanche paths in the software ArcGIS.



Figure 2. Steps to create digital avalanche atlas

The topographic analysis with a GIS included the creation of slope classes usually associated to the different parts of an avalanche path using a digital elevation model with a 10 meter resolution. For example, these classes represented the area where the slope reached reference angles (10, 15, 20, 24, 30, 35, 40° and above), 10° being the reference point for the runout zone of high magnitude avalanches (Stethem et al., 2003). The slope classes are illustrated figure 3. representing in the topographical analysis executed in ArcGIS. Figure 3 also shows georeferenced polygons and lines of potential avalanche paths on an aerial photo background. This figure also shows the vegetation type and density classes derived from the segmentation and classification of the SPOT multispectral image using the software eCognition.





As for the investigation, many key local people were questioned about any information they would have about past avalanche events. Only the events having enough details about avalanches were added in the database. All the avalanche bulletins created by the ACHG were also screened in order to get information about avalanches that were noted, as well as data from the Parc de la Gaspésie about past avalanche accidents and avalanche localisation maps (archive over the 1987-1998 period). Each avalanche reported is associated to a number that serves as the common field between the polygons and the avalanche data to allow the software to link the information to the avalanche areas.

## <u>3.3 Classification of the terrain by exposition to avalanches</u>

Figure 4 represents the steps followed to accomplish the second objective.



Figure 4. Steps to perform the classification of Mount Albert by exposition to avalanche terrain.

The first step, the delimitation of the zones, is crucial because the terrain analysis was done by zones instead of routes or trips as for the parks in western Canada. This is due to the fact that only 2 areas are accessible in the Mount Albert sector because of the access restrictions in place to protect the woodland caribous. Once the zones were delimited, they were analysed and associated to a final class level taking into consideration every parameter of the technical model. Here are the parameters that carry more weight thus default priorities: slope angle, terrain traps, avalanche frequency, interaction with avalanche paths, route options, and exposure time. The glacier parameter was not taken into consideration because no glaciers are present in the sector studied. The other parameters with less weight, slope shape, forest density, start zone density and runout zone characteristics, were also taken into account in order to attribute to the delimitated zones the final class level of exposition to avalanches.

## 4. RESULTS

#### 4.1 Potential avalanche areas

In the seven sectors of the study site, 59 potential avalanche areas were localised comprising 2 to 12 paths. A total of 249 avalanches paths were localised, given an identification number and characterized in a digital database. Approximately a hundred of the avalanche paths were validated visually on the terrain. The potential avalanches areas represent 5,8% of the total study site, this being approximately 31km<sup>2</sup> on a total of 532 km<sup>2</sup>. The database and maps localising every avalanche path are available upon request from the authors.

The avalanche areas and paths for the Mount Albert sector are presented in figure 5. The areas are labelled with a number, and the paths inside the areas have the same number followed by a specific decimal number.



Figure 5. Digital atlas for the Mount Albert sector.

The runout zone limits of the avalanche areas or paths were delimited based on vegetation disturbance clues that were visible on the aerial photos or by the slope angle class of 10° on the digital elevation model for the alpine areas. Because the photointerpretation was done over a time scale of 40 years, pictures dating from 1963 to 1992 and with recent satellite image dating from 2004-2005, we noted the sudden creation or the gradual disappearance of vegetation clues in some avalanche areas created by high magnitude avalanches destroying mature timber. Consequently, we delimited the boundaries of these areas based on the farthest reach of the runout zones, in other words, the longest return period known and took note of it in the database.

Figure 6 shows the avalanche area number 19, represented in the avalanche atlas of Mount Albert sector in figure 5. The figure 6 demonstrates an example of a chronologic sequence in which we can notice the vegetation clues (at the bottom center of each picture) left by an avalanche of a magnitude that has not occurred since at least 1963.



Figure 6. Chronologic sequence of an avalanche area in a particular Mount Albert sector: sector 19.

To validate the method used in this study to localise and characterise the potential avalanche zones, we compared our data with the terrain data from the study recently done by Daniel Germain (Germain, 2005). 34 of the 36 avalanche paths falling into the study site of the present study were located. The 2 paths missing are relatively short, of the order of 60 to 80 meters long. This could explain the reason they were not seen on the satellite image or on the aerial photos.

Several characteristics measured by Germain's sampling were also compared to our data found with the help of the GIS, such as starting zone slope angle, starting zone altitude, end zone slope angle, end zone altitude, vertical drop and aspect, the beta angle and horizontal reach to the beta point. These topographical characteristics appear with good agreement, showing the great potential of our approach.

## 4,2 Forest cover analysis

The vegetation cover was also analysed with the SPOT multispectral satellite image. The image was classified into 12 classes of vegetation and density. The vegetation map classified into 4 classes (deciduous, mixed forest; coniferous and recent clear cuts) and 2 types of vegetation (high vegetation and low vegetation) is presented in figure 7. Each class is divided into 3 levels of forest density based on the percentage of tree crown coverage relative to ground coverage (OIFQ, 1997). The forest classification with the satellite image resulted in 11,4% deciduous, 16,7% mixed and 34,2% coniferous forest of the total study site. The recent clear cuts represent 8,5 km<sup>2</sup>, this being 1.6% of the total area. The forest classification map shows that approximately 62% of the study site in covered in forest.



Figure 7. Forest classification of the study site based on the SPOT multispectral image acquired in October 2005. (*Legend shown in figure 3*).

For validation purposes, the density classes derived from the satellite image were compared to the ecoforest map of the region (Ministère des ressources naturelles, 2000) even though some of the classes were not exactly the same. This comparison between the 2 forest classifications is shown in table 1, where the NA category corresponds to different forest density classes.

For the satellite image classification, we grouped every vegetation surface or the other surfaces without forest cover including the alpine areas in the no forest class. When we combined the low density class with the no forest class for both types of data classification, we find equivalent surfaces (203 km<sup>2</sup> for ecoforest map and 196 km<sup>2</sup> for the satellite image). It seems that the satellite image classification overestimate the areas of high forest density (81-100%) conversely to the ecoforest map that overestimates the intermediate density areas (41-80%). This could result from the spectral signature of the under layer vegetation disturbing the analysis of the satellite data as well as the topography modifying the reflection of the vegetation. In future studies, rectification of the

topographical effects would be necessary before the classification analysis.

Table 1. Comparison of density classes (areas in  $\rm km^2$ ) between the SPOT satellite image and ecoforest map.

	No forest	0- 40%	25- 40%	41- 80%	81- 100%	Trees 1.5 and 6 m
Eco- forest map	107	NA	86	217	76	10
Sat. Image	164	32	NA	147	153	NA

The analysis of the 10 meter resolution SPOT image shows the potential of this type of image integrated in a GIS. The fact that the analysis is based on the spectral signature of elements makes it possible to know the forest cover for every area studied automatically and systematically. Furthermore, this analysis could be done regularly over time, at every satellite overpass, thus updating the data in as close to real time as possible.

Because the analysis of the satellite imagery was done with a general optic it appears that the image resolution was not precise enough for the lower forest density areas (between 0 and 25% of forest cover). It would be probably better to work with Ikonos or QuickBird satellite images having a 1 meter resolution. Moreover, the ecoforest map derived from aerial photos does not provide enough precise forest density classes to evaluate the avalanche potential of the terrain I in relation to forest density cover.

## 4.3 Inventory of avalanche events

Forty-five avalanches were reported dating between 1986 and 2006 and were integrated in our database. These avalanche reports are situated in 19 different avalanche paths. The number of avalanches catalogued is relatively small considering that hundreds of avalanches of all sizes may run during a winter in the study area. For example, ninety avalanches were reported in a study done in the winter 1989 (Girard and Hétu, 1989). However, the avalanche events of this study were not added to our database because the information about each event was not precise enough. Thus, the lack of basic information, like the date and the specific localisation of the avalanches, explains the reason why only a few avalanche events were reported in the database. However, the avalanches catalogued in the study are exceptional either because of the size or because of the involvement of people.

Each avalanche reports contain lots of information about climatic and snow conditions that caused the avalanches. The parameters noted in the database about the avalanche events followed the Canadian Avalanche Association guide "Directives d'observation et des normes d'enregistrement des conditions météorologiques, du manteau neigeux et des avalanches (CAA, 2002). The integration of the avalanche database reports with the digital atlas makes it possible to extract every parameter of the database. In other words, the analysis of these parameters in a GIS allows a better understanding the processes involved and to compare the behaviour of each avalanche paths as well as to visualise the spatial distribution of these events. Figure 8 shows a thematic map of the number of avalanches reported per avalanche path for the Mount Albert sector.

However, a bigger sample and more detailed information about avalanche events would be necessary to make use of the full potential of the avalanche database integrated to the digital avalanche atlas in a GIS.



Figure 8. Number of avalanche reports per avalanche path for the Mount Albert sector.

# <u>4.4 Classification of Mount Albert by exposure to avalanche terrain</u>

The results of the classification of the Mount Albert areas by the ATES are shown in figure 9. The delimitation of the boundaries of the areas was done using the natural contours of the terrain like ridges, streams, cirques and or altitude. Thirty-eight areas were finally delimited. Each of them were analysed in relation to every parameter of the technical model of Parks Canada, except the glacier parameter. We found that six areas were classified as 1 (simple terrain or low avalanche potential), 12 areas were classified as 2 (challenging terrain or medium avalanche potential) and finally, 20 areas were classified as 3 (complex terrain or high avalanche potential). The number associated with each areas of figure 9 represents their identification number.



Figure 9. Classification of Mount Albert areas by exposition to avalanche terrain.

In terms of surface, 32% of the total surface of the Mount Albert sector is classified as 1, 27% of the surface is classified as 2 and 41% as 3. Note that the summit plateau, having a relatively large surface, was not included in any of the areas. Thus it was not part of the percentage calculation. If so, the surface percentage of class 1 areas would increase considerably.

Another classification was performed for the Mount Albert sector taking into consideration the parameter *exposition to dominant winds* that is not present in the technical model the ATES. As opposed to the other terrain parameter of the ATES, this parameter evaluates the avalanche potential according to the snow component. Figure 10 shows the results of this classification for the same thirty-eight areas. Since the dominant winds of the region are from the north and north-west, we attributed a class of exposition to avalanche terrain in relation to that direction. The numbers inside the areas represent their classification number according to the ATES parameter (class number from figure 9).

The areas situated under the dominant winds are more favourable to snow accumulation. However, this parameter cannot be considered like the other ATES parameters that are more "stable" in time. Snow storms can sometime come from the south or east. The study site is particularly affected by the north and north-west dominant wind because of its high frequency and its strength. As a result, they redistribute the snow and ablate the hillsides exposed to the dominant winds.



Figure 10. Classification of Mount Albert areas in relation to their exposition to dominant winds. (see the pie chart under the legend for the orientation associated to the 3 classes)

## 5. DISCUSSION

The method used to locate and to analyse topographical characteristics of the certain potential avalanche zones and to integrate the avalanche events database showed its efficiency. Using GIS capabilities, we are also able to isolate terrain parameters or some avalanche events to create thematic maps that would tell us more about the specific signature of the avalanche paths. One of the main advantages of the digital atlas is that it can be easily updated. Future topographical avalanche events or new

characteristics collected in the field and the discovery of new avalanche paths will be easily added to the database and drawn into the GIS. This version of the digital atlas is a tool or platform on which the future information and knowledge about the avalanche problematic of the Chic-Chocs can be grouped, shared and studied.

However, this study also showed that the potential of the tool to visualise and synthesise the information of the database will only be fully exploitable when there will be more details associated with the avalanche events reported.

From the classification of the Mount Albert areas based on the ATES, we notice that most of the terrain of this sector is highly exposed to avalanches but that there also exist many areas of less or no exposition to avalanches. This tool permitted a general localisation of the areas more or less exposed. The classification map could become another tool for managing avalanche risk in the sector. From a managers' point of view, the classification map give another vision of the territory showing its potential for winter activities. As mentioned before, the major problematic of the Mount Albert sector is the terrain access restriction to most areas. In the sector, only 2 areas are open to practice winter activities, like backcountry skiing or snowboarding, making it impossible for the recreationists to select terrain according to their capacities or on the snow stability conditions. Moreover, the 2 open areas are classified as being class 2 and 3, medium avalanche potential or challenging terrain and high avalanche potential or complex terrain.

From a recreationists point of view and putting forward the possibility of the Mount Albert sector being entirely open, the classification map could be a complementary tool to the avalanche bulletin issued by the ACHG for the park. The park's visitors could use the map to better plan their trips and make more advised terrain choices according to the snow stability.

The relatively small and confined avalanche terrain found in the region, compared to other mountainous regions of Canada, could be seen as less problematic to create a safe environment for the people by informing them about the risk in time and space.

#### 6. CONCLUSION

The avalanche problematic of the Chic-Chocs has been growing since the past decades because of the increasing number of visitors coming to practice winter activities in the avalanche terrain of the Parc de la Gaspésie, the Chic-Chocs reserve and other neighbouring reserves. Actions were taken to face the problem, like the creation of "avalanche danger" signs in the most frequented areas and the effort of the ACHG to educate and inform the visitors and recreationists staying in the Chic-Chocs about the presence of avalanche danger.

This research project put a new tool forward to integrate and analyse spatial data about avalanches. This type of system should improve management and prevention of avalanche risks. The mapping done within this study is considered as a minimum standard in risk management but is also innovative because of the use of GIS as a platform to do spatial analysis and because of inclusion of the use of the new avalanche terrain exposition scale.

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