Multidate Mapping Approach to Determine Alpine and Subalpine Vegetation Variations on Mount Jacques Cartier, Quebec, Eastern Canada (1973–2004)

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Abstract

Recent global warming trends have affected mountainous areas, especially in mid-latitude regions where the cryosphere component has shrunk rapidly over the last century. Among the potential impacts of warming, a shift from alpine to subalpine vegetation habitat has been observed by many researchers in Europe and Western Canada and the United States through changes to snow cover duration and distribution and to the timber line. The effects of global warming on the mountainous regions of Eastern Canada have been insufficiently studied. The Gaspé peninsula in Quebec has a particular climate and ecosystem that is typically found in areas further north (for example there are areas of tundra and herds of caribou).

This paper evaluates the magnitude of changes to alpine and subalpine vegetation cover over the last three decades in this region. A multidate mapping approach was used to delimitate the alpine and subalpine habitat on a local scale, through an analysis of factors such as the mosaic of land cover types. The mapping technique used for this case study is based on digitalized aerial photographs and combined with a Geographical Information System. The results show no major altitudinal shifts of the timber line toward the hilltop, in contrast to what has been reported by many other researchers for other mountainous regions. However an increase of the surface covered by vegetation patches was observed, together with a reduction in the surface area of the block field. These preliminary results are meaningful for the mountain climate and ecosystem of the region that constitutes a biogeographical island of alpine tundra at this latitude.

1. Introduction

Among the potential impacts of global climate change on the alpine and subalpine areas are an increase of the air temperature and a greater amount of snow during the autumn and winter season. The alpine vegetation is also affected and recent research already shows that the snowbeds communities species composition has changed (Björk and Molau, 2007) and that timberline have shifted many meters toward the higher mountain areas for certain regions (Beniston, 2003; Kullman, 2007). Different approaches can be used to quantify the spatial vegetation migration or landscape fragmentation for different environments including alpine and subalpine areas. A classical approach consists of making quadrats and transects, which represents an efficient way to describe the floristic composition at a local scale (Pfeffer et al., 2003). At a regional scale remote sensing images or aerial photographs can be used to extract information for mapping alpine vegetation. The image classification can be made manually by a user or automatically. The latter is less appropriate for a heterogeneous terrain where the vegetation distribution follows a patchy pattern (Lindblad et al., 2006).

Another key factor for mountain studies is the scale at which the studies are made. The spatial variability is one of the main challenge for researchers who work on heterogeneous environments such as mountains (Jones et al., 2001). As mentioned previously, the latitudinal factor is important. In the presence of a high vertical gradient, however, the spatial features can change rapidly in a short horizontal distance. The scale is then a crucial factor that must be chosen with care to ensure that the main purpose of the study will be clearly addressed. In alpine and subalpine environments the abiotic factors that influence the vegetation cover distribution vary, but the slope (angle, form and aspect), the surface roughness, the soil type and humidity and the snow conditions (snow depth, snow duration,…) are important at both mesoscale (100 m to 10 km) and microscale (1 m to 100 m).

For Eastern parts of Canada and the United States very few studies about the potential impacts of recent warming on mountain areas are available. Even fewer studies climate of the Gaspé peninsula have been conducted. The lack of knowledge about the climate can be explained partly by the lack of complete meteorological datasets in the interior of the country, as most of the meteorological stations are located along the coast where the influence of continentality and the altitudinal gradient are small or non-existed. Since the work of Gagnon (1970) no major studies about the Chic Choc climate have been published. On the other hand, the alpine and subalpine vegetation habitats of the Mount Jacques-Cartier have been studied at the end of the 1970's by Boudreau (1981). This sector is a fully preserved area that is used by the caribou (Rangifer tarandus caribou) an endangered species (Mosnier et al., 2003).

At the regional scale (southern Quebec) the mean annual temperature has slighty increased (Yagouti et al., 2006) during the 1960-2003 period. However, due to the lack of complete meteorological datasets for the inland part of the Gaspé peninsula, the magnitude of the temperature variability is still difficult to evaluate. Assuming that alpine vegetation is particularly sensitive to climate changes (Keller et al., 2005), a multidate mapping approach was then used to determine the magnitude and size of vegetation cover changes. The vegetation here is used as a potential indicator of a recent warming climate (since the early 1970's).

In the summer of 2007, different temporal series of air photos were acquired for the area, specifically the summit plateau, and a short field work campaign was done at the end of the summer. In this study monochrome air photos were digitized and integrated into a GIS, and manual classification was carried out. The main goal of this study is to evaluate whether habitat changes happens, and if so what is the amplitude of such change, for the highest summit of the region (Mount Jacques Cartier) between 1973 and 2004. We discuss the limitation of the using this method and propose some processes that can explain why changes happened.

2. Study area

The Gaspé peninsula is located on the eastern part of southern Quebec in Canada between New Brunswick in the south, on the other side of the Baie des Chaleurs and the Côte Nord region on the other side of the Saint Lawrence river in the north (Fig. 1). The mountains of the Gaspé peninsula are a part of the Appalachian Chains that is subdivided in the Chic Choc mountains in the west and McGerrigles mountains in the east separated by the Sainte Anne river. Mount Jacques Cartier is the higher peak in the Gaspé peninsula (1268 m) and the second highest peak in Quebec province. The mid-latitude climate characterizing the region is a humid continental climate with no dry season following the Köppen climate classification. The mean annual precipitation is above 1600 mm (± 60% fall as snow) and the mean annual air temperature is 2.1°C.

The influence of air masses is greatly changes greatly with season cycle in the region a fact which explains and it can explain the precipitation and temperature of the region. Hufty (2001) shows that the main air masses affecting the region are from Continental Polar and Polar Pacific Modified (W), Polar Return (SW) and Arctic Modified (NW, W) the latter being usually associated with strong winds during the winter period. Secondary air masses are the Maritime Tropical (SW), Arctic (NW) and the Atlantic Maritime Polar (E,NE), the latter often the source of snowstorms and heavy snowfall during the winter season. The influence of the air masses are important in order to understand the climate and the ecoregion of the area because synoptic climatology is directly coupled with surface conditions. Following

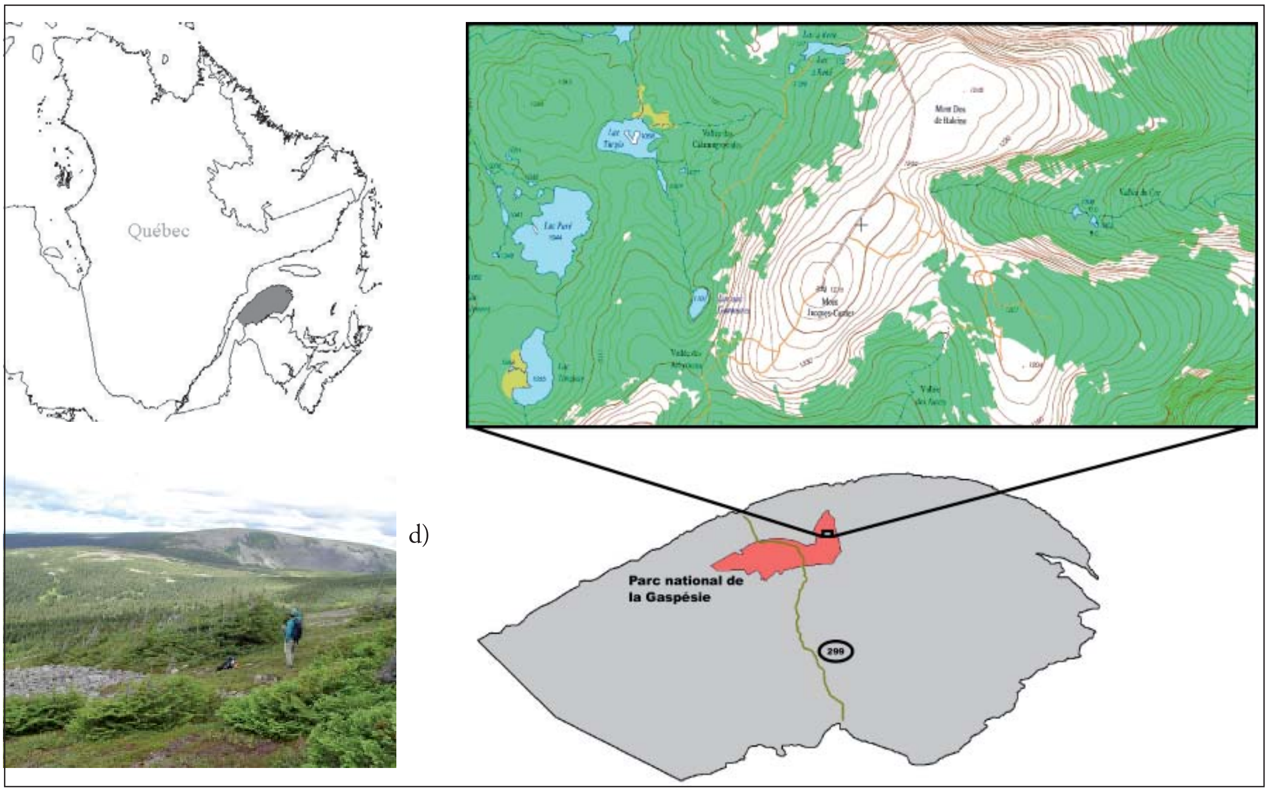

Fig. 1: The Gaspé peninsula is located in the southern Québec (a); Mount Jacques Cartier summit (1268 m) is located at 48°56,26'' N; 65°56,33'' W (b) the Gaspé provincial Park is located in the peninsula, less than 30 km from the northern coast (c); a view of the Mount de la Passe from the N-E slope near the Mount Jacques-Cartier summit (d).

Boudreau (1981) three altitudinal zone can be defined for Mount Jacques Cartier : the alpine zone (above the timberline, 975-1268m), the subalpine zone (900-975 m) and the montane forest (250-900 m). The subalpine zone is a transitional zone between the two others that is mainly covered by krummholz.

3. Methods

This work is part of a larger project consisting of evaluating the potential impacts of a warming temperature in the study area. We did not have a long-term data on either vegetation description or meteorology directly at the study site. The available data are sparse in time and space. Hence our work utilizes two series of aerial photos to explore the potential effects of warming climate on vegetation cover response.

3.1. Photo interpretation and vegetation mapping

The plateau of Mount Jacques Cartier is relatively flat and covers almost 80 km^2. Initially seven time-series (1948; 1970; 1973, 1975; 1986; 1992; 1994; 2004) have been investigated to evaluate the vegetation cover distribution through the time period from the 1970's to the beginning of the 21st century. The 1986 and 1992 series are infrared images but all the others are black and white photos. The scale is 1:15,000 for all images except that for 1994, which is 1:50,000. After a first overview of the changes that can be seen by standard photo interpretation methods several were discarded mainly because of poor images quality due for example to the presence of clouds or the presence of snow on the ground, despite the fact that the images were taken during the summer. Finally two time series, 1973 and 2004, were used to evaluate the vegetation cover changes for four predetermined zones that are all located on the plateau of Mount Jacques Cartier (Fig. 2). Having finalized our choice of images, the second step was to digitized them. MapInfo™ (version 9.2), a geographic information system software, was then used to create a map for each dataset.

Provencher and Dubois (2007) suggest that it is preferable to use colour and high resolution images (e.g. 1:15,000) when a vegetation inventory is made by photo interpretation. In the case of the present study monochrome contact prints were enough detailed enough to establish the vegetation limits. Colour prints can be useful for vegetation identification but this is not essential to get the edge and limits of vegetation patches.

Moreover if an attempt at vegetation identification is made it requires detailed field work that is usually obtained by traditional vegetation sampling such as transect and quadrat as has already been done by Boudreau (1981) for the study area. At the scale used in our study the species identification for each zone it is not relevant because we want to evaluate the spatial variation of the alpine vegetation area cover rather than the community's species composition.

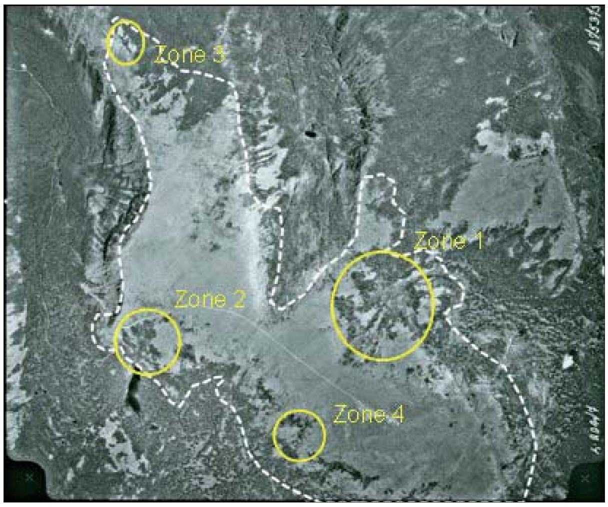

Fig. 2: Four zones location on the plateau of Mount Jacques Cartier.

Initially eight different classes of vegetation were chosen, but there classes were not all present in the study area. Although vegetation description is not detailed here, a simplified classification containing only three classes was finally kept for the vegetation mapping. Vegetation classes are all located in the alpine tundra and the most common plant communities are summarized in Fig. 4 (in accordance with Boudreau, 1981).

The merging of different classes is mainly explained by the difficulty of clearly distinguishing the limits between some vegetation classes (gradual transition without evident edge or cut) and the small size of the study area where many of the previous classes are simply absent. Another interesting approach, described by Keller et al. (2005), consists in using the habitat zones rather than alpine plant species. This second approach used five classes for the habitat zones for alpine plant species : 1- snowbeds; 2- ridges; 3- swards (relatively flat areas); 4- scree; 5- rocks. Nevertheless, because the study area contained only classes 3 and 5, this approach was not used. Two snowbeds (class 2) were observed during the field work (see field data collection section) but they are out of the study area on the SW slope. The fact that the plateau is relatively flat means that classes 2 and 4 are absent.

3.2. Field data collection

The field data was conducted in mid-August 2007, a period similar to the acquisition period of the two air photos datasets (meaning a similar phenological stage for the vegetation can be assumed). About 40 points were reached in the field using a GPS (Garmin Explorer) with a vertical precision of ± 4-7 meters. Air photos were brought in field for validation

Classes	Plant communities
Meadows / Alpine / Grassland	Carex bigelowii, Polytrichium juniperinum, Vaccinium uliginosum
Shrubs	Diapensia lapponica, Ledum groenlandicum, Empetrum nigrum, Phyllodoce caerulea
Rocks	Mainly recovered by different lichens and moss species

Fig. 3: Vegetation class description.

purposes, and the surface area of approximatively ten different patches have been measured in detail using a metric tape. No detailed vegetation inventory had been done.

4. Results and discussion

Different kinds of vegetation changes, whether expansion or contraction, can occur in alpine areas. A shift of the timber line was first considered but no evidence of such a shift was observed. Nevertheless other behaviour can occur for example Tape et al. (2006) observed three types of shrub expansion in an arctic environment: new colonization, patch in-filling and individuals getting larger. Our results clearly show new colonization and patch in-filling for all the study area (Fig. 4).

The results derived from the four zones in the study area are summarized in Figure 5. The results indicate a decrease of meadows (-0.11% per year) and rocks (-0.27% per year) classes for the four zones from 1973 to 2004. By contrast the shrub's expansion proceed at +0.28% per year during the same period. The changes for the meadows areas are almost all negative except for zone 2 where a positive growth was observed. The rocks areas indicate a decline of the area in three zones and no changes for one zone. The shrubs area show a clear expansion for all zones with a large growth rate for zones 1 and 3 and subtle changes for zones 2 and 4.

In the arctic environment an increase of both the mean winter air temperature and the snowpack depth increases the nutrients available and thus soil conditions are more favourable to vegetation colonization or expansion (Tape et al., 2006). This situation seems also plausible for temperate cold environments even if some differences need to be taken into account such as an increase of the occurrence of rain-on-snow events, thaw-refreeze cycles, etc.

4.1. Restricting factors

For the Gaspé peninsula the threat of plant migration and even extinctions could be serious in regard to the very small altitudinal gradient (a few hundreds meters only). The predominance of rocky surfaces means that soil is either absent or poorly drained, except for a few depressions. These factors are negative for plants propagation at least for short and mid-term periods. Another restricting factor for vegetation expansion is the presence of permafrost at the top area on the Mount Jacques Cartier. In the early 1970's Gray and Brown (1979) showed that a relic permafrost is present at the top of the Mount Jacques Cartier. The current situation is unknown, but if the permafrost is still in place, as is probably the case, this is another obstacle for the vegetation expansion toward higher elevations.

Löffler (2007) has shown that the high variability of the local temperature in high mountain environments, mainly associated with the local topography, altered the functionality of the ecosystem. The work of Keller et al. (2005) demonstrates the same thing and they posit that the precipitation, temperature, wind and radiation are not sufficient to explain a change of the vegetation pattern in mountain areas. The snow cover and relief are also crucial factors for plant phenology and distribution. Other factors such as nutrients, soil characteristics (organic content, pH, moisture, etc.) also play an important role in vegetation growth and spatial distribution (Jones et al, 2001).

4.2. Expanding factors

The presence of heavy snowfalls for this region (Gagnon, 1970) could represent an insulation factor that might be favourable for the survival rate of the plants in the harshest areas. The plateau is a significant fetch for wind that removes the snow from the top area and deposits the redistributed snow on the lee side creating large snowbeds on the south-eastern side because most of the snowstorm and bliz-

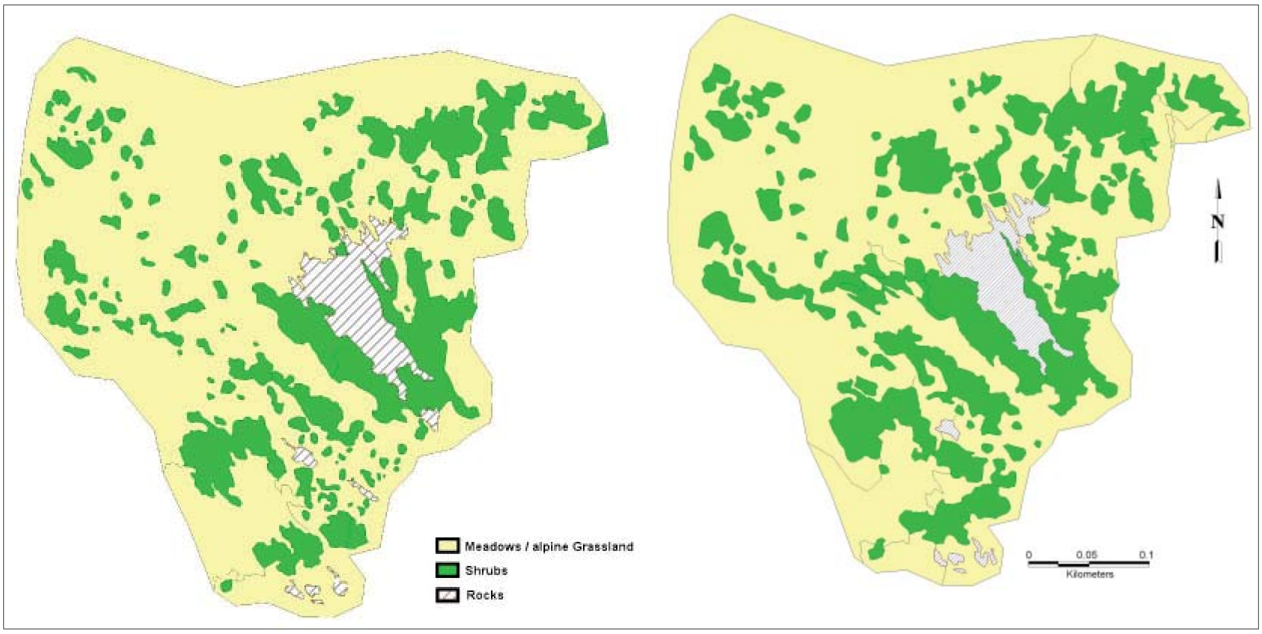

Fig. 4: Example of vegetation modification for zone 1.

1973 / Classes	**Area (m^2)**			
	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**
Meadows	97 476	17 150	2 702	28 486
Shrubs	31 830	37 130	8 463	7 494
Rocks	6 794	21 950	3 965	0
Total	136 100	76 230	15 130	35 980

2004 / Classes	**Area (m^2)**			
	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**
Meadows	91 520	18 903	2 242	28 387
Shrubs	38 210	38 150	9 517	7 593
Rocks	6 370	19 177	3 371	0
Total	136 100	76 230	15 130	35 980

Classes	**Area changes (m^2) / %***			
	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**
Meadows	/ -6.11	/ 10.22	/ -17.02	/-0.35
Shrubs	/ 20.04	/ 2.75	/12.45	/1.32
Rocks	/ -6.24	/ -12.63	/-14.98	/0

* + : area increase or – : area decrease.

Fig. 5: Analyses results of land surface cover for each class from aerial photographs of 1973, 2004 and the changes (%) between the two periods.

zard come from the northeast. Germain et al. (2005) have studied the region and they hypothesize that vegetation is trapping the blowing snow. The snowpack has a feedback effect because snow trapped by vegetation protects it from desiccation and low temperatures. The structural character of the snowpack is another important factor that controls plant survival rates because ice features, such as ice layers through the snowpack, might affect the gaseous exchanges between the plant and the atmosphere (Jones et al, 2001). Moreover alpine plant species and communities are highly sensitive to an increase of temperature.

In regards to predicted local or regional warming, even a small increase for the study area can mean a modification of the snowpack which will thus modify climatic variables to a critical level. Groisman et al. (1994) target sensitive regions, calling them snow transient regions, that might be particularly sensitive to climatic change. Gaspé peninsula can be consider a sensitive region where the interannnual standard deviation of the presence of snow cover for each season varies from 0.20 to 0.25 (calculated for a 20 year period) during the spring period (April-May). Yagouti et al. (2006) analysed climatic trends for southern Québec between 1960 and 2003 period, and argued that the warming trend for Gaspé peninsula is not clear. This situation is partly explained by the large size of the peninsula and the small number of meteorological stations over the region. Most of the stations are located along the coast at a low altitude, which obscures the altitudinal gradient and continentality effect of the mountainous areas in the middle of the peninsula. Nevertheless the Saint-Jean-de-Cherbourg meteorological station (44.84°N, -66,47°W; 358 m), which seems to be the more representative of the central area, showed a slight increase of the maxima and minima air temperatures during both winter (max.: +1.5°C; min: +1°C) and spring (max.: +0.5°C; min.: +1°C) for the 1960–2003 period. This situation could be favourable to a vegetation expansion assuming a statu quo of the edaphic conditions.

Conducting intensive research in the early 1990's, Grabherr (1994) observed an altitudinal increase of high alpine species toward the summit of different mountains in the Alps. He concluded that for his study area (western Austria and eastern Switzerland) a shift of the altitudinal vegetation belts happened at a rate of 8–10 per decade, assuming a mean air temperature increase of 0.7°C for a period of 7–9 decades. Yagouti et al. (2006) estimated a similar trend for the mean annual air temperature increase of about 0.5°C from 1960 to 2003 (Saint-Jean-de-Cherbourg station). However, as mentioned previously, no evidence of an altitudinal shift has been observed at our study site.

5. Conclusion and future works

The results presented here must be interpreted with care and more in-depth analysis of both the vegetation classification method and the climatic trends is necessary. An increasing trend of the vegetation cover area for the four zones is still insufficient to get a complete picture of the situation because species changes are more relevant than community changes in order to the impacts of climate change (Becker et al., 2007). However this study represents a first attempt to estimate the vegetation modification for the higher summit of the region. As already mentioned, little information is available about the climate of the Eastern Canada mountainous areas. The main conclusion of this study is that new colonization and in-filling of the vegetation patches happened during the study period in the Mount Jacques Cartier plateau. The climate conditions are more susceptible to explain the vegetation expansion than edaphic conditions which are less prompt to occur, i.e. about 30 years.

This study is a part of a more comprehensive project that consists to evaluate the climate changes in the Chic Choc Mountains since the end of the 1940's. A particular effort is made to understand the main consequences of a warming climate of the region in regards to the altitude and the continentality. Future research is still needed in many areas. Our future efforts will be on:

1. establishing more monitoring datasets of the geographical and meteorological processes along an altitudinal gradient to reconstruct all the alpine vegetation habitats instead of being limited to the plateau;

2. creating a detailed DEM in which existing information could be integrated to facilitate data management and spatial surfaces changes through time;

3. updating plant species diversity monitoring at Mount Jacques-Cartier and expanding the observations to other summits in the region (e.g. Petit Mont Saint-Anne where a meteorological station is present);

4. applying a simple logistic growth model (as suggest by Tape et al., 2006) to quantify more exactly the rate of increase of shrub patch through time;

5. proceeding to homogenization of temperatures and precipitations over the region (Fortin et al., 2007).

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