The Importance of the Air Temperature Variable for the Snowmelt Runoff Modelling Using the SRM Model.

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ABSTRACT

Runoff regimes in most northern basins are controlled by the melting snow cover. A common method for evaluating runoff consists in correlating ambient air temperature and recorded hydrometric gauge values. The air temperature is the principal variable to estimate the importance of the melting of the snow cover when using a global empirical model such as the snowmelt runoff model (srm). The temperature, which is often only measured at one weather station, must be extrapolated to the whole basin according to some kind of lapse rate. This extrapolation often assumes that air temperature is representative for a wide region, which is often not the case. The estimation of temperature values is critical especially for large basins where the surface processes are largely influenced by a forest cover. This project has two objectives: 1) applying a mostly high mountain snowmelt runoff model (srm) to the Batiscan river basin, in the province of Québec, which is principally forest covered and has a rolling hill topography; 2) investigate the impact of the extrapolation strategy for estimating temperature values and its importance in the runoff modelling. Our results showed that the weather station, used to perform the runoff modelling, should be located in the most representative land cover of the study area. Otherwise, the values of a synthetic regional weather station were more reliable for the modelling. Finally, before pursuing any snowmelt modelling with the srm, the temperature values must be evaluated based on the location of the weather station to see if they are representative of the total study area.

Keyword: SRM, Air Temperature, Snowmelt, Forest, Modelling.

INTRODUCTION

The fundamental purpose for any hydrological modelling in a drainage basin is linked to a better understanding of water circulation as a process and as a resource (Ferguson, 1999; Kustas *et al.*, 1994). In most northern hemisphere countries, snowmelt is the principal source of water required for the economic, social development and growth of these regions (Horne and Kavvas, 1997). In Québec, like in any northern region, hydrological modelling is employed as a predictive tool to prepare for catastrophic events, like the 1996 Saguenay floods, or to analyse recurring spring events which bear important social and economic costs (Blöschl and Kirnbauer, 1991).

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The necessary information required to run a hydrological model is often so difficult to gather that a more simple empirical approach is often preferred to the determistic schemes. One of the more popular drainage basin flow analysis model correlate ambient air temperature values with gauge station hydrometric measurements (Zuzel and Lloyd, 1975). Air temperature is presented as the principal variable to estimate snowmelt in a empirical model such as the Snowmelt Runoff Model (SRM) (Brubaker *et al.*, 1996; Blöschl, 1991). It is fundamental to obtain accurate and representative temperature values for the purpose of modelling. This is particularly important for basins covering large surface areas (Rango and Martinec, 1981). A strict and rigorous approach must be applied to determine the air temperature conditions over the total hydrological modelling area. Different studies have pointed out that accurate modelling results often come from the precise understanding of the atmospheric variables in play used in the modelling strategy (Leavesly, 1989).

More specifically, this project addressed two objectives. First, to apply the empirical high mountain Snow Runoff Model (SRM) to a mostly low relief and forested drainage basin and, secondly, to estimate the impact of the air temperature value acquisition strategy on the hydrological modelling.

STUDY AREA

The study area selected to analyse the performance of the SRM is the Batiscan River basin in the province of Québec, Canada, (47° 10' North, 72° 13' West). Draining a surface area of approximately 4325 km^2, the Batiscan River is one of many tributaries of the Saint-Lawrence River. The basin has an altitude range of approximately 756 m, from 106 m to 862 metres above sea level (Figure 1). For the purpose of modelling, the study area was not subdivided, and the SRM was applied globally over the basin.

Forest cover occupies 73% the entire basin, approximately 3151 km^2, and is almost entirely public land. The southern part of the basin is covered with the mixed forest stands of the Canadian North-East and the northern part of the basin is principally boreal. The agricultural land-use is limited to the extreme southern regions, covering 745 km^2 of the Batiscan basin. Finally, surface water, developed, and bare land cover approximately 429 km^2 of the study area.

DATA AND METHODOLOGY

The SRM used in this study, utilised ambient air temperature values combined to a degree-day coefficient in order to estimate the ablation factor of the snow cover (Martinec *et al.*, 1998). The SRM is a semi-distributed hydrological model which as been applied principally in high mountain environments where it obtains excellent results (Ferguson, 1999). It as never been applied to a drainage basin in the Province of Québec.
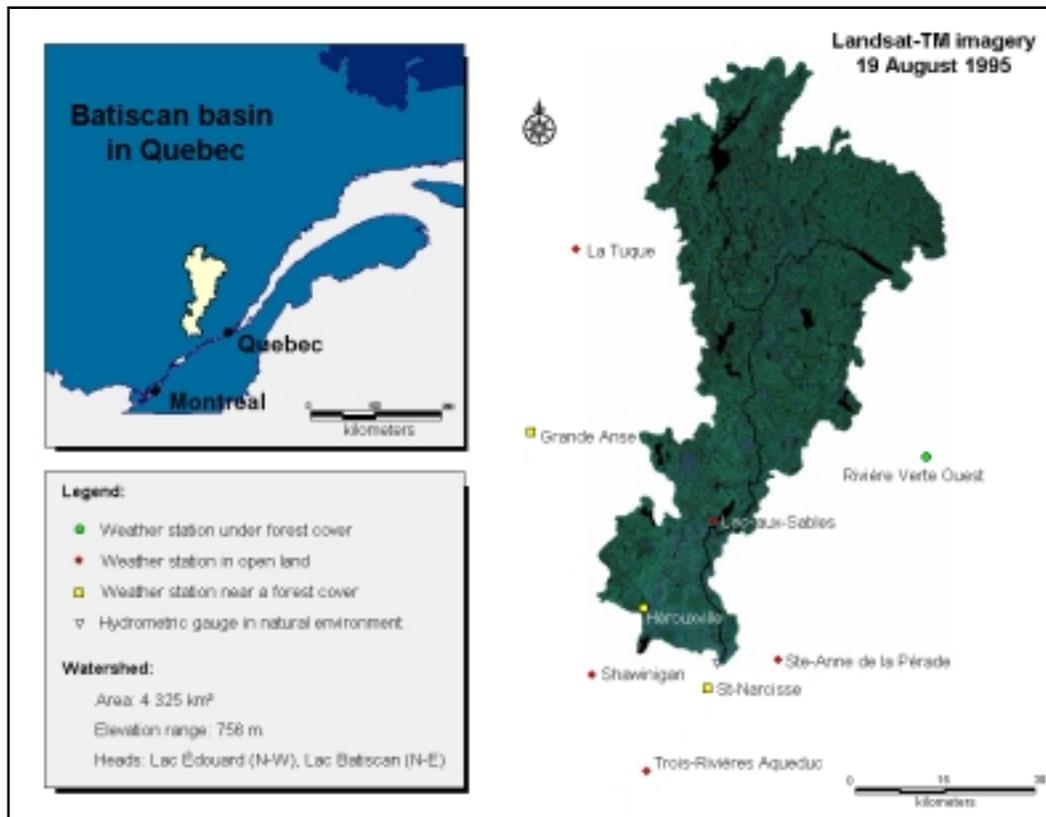
Figure 1 The Batiscan River basin.

For this project, 14 different modelling attempts were performed over the Batiscan River basin for the 1996 snowmelt season (March, April, and May). Each modelling run was done using the same set of parameter values, which were previously calibrated and adjusted to the basin. Only the temperature and precipitation values were changed between each run. For this analysis, the precipitation values were estimated using the same method as employed to acquire the temperature values.

Firstly, the parameters were determined in regards to the climatic and hydrological conditions of the study basin. These values are listed below (Table 1).

Table 1. The parameter values given in the modelling of the Batiscan River basin.

	T_{crit}	L	γ	a	C_S	C_R	k
March	2,54	17,8	0,78	0,088	0,90	0,90	$x = 1,0213$
April	2,54	17,8	0,87	0,564	0,85	0,85	$y = 0,0388$
May	2,54	17,8	0,84	0,924	0,80	0,80	

T_{crit} corresponds to the critical temperature (°C), L time lag (hrs), γ the temperature lapse rate in (°C/100 m), a the degree-day factor (cm/°C/jour), C_S and C_R are runoff coefficients expressing the losses as a ratio of runoff; precipitation (snow or rain) and k recession coefficient.

Secondly, in order to run the SRM, we obtained information about the snow cover. To estimate the change in snow cover over the Batiscan basin we relied on NOAA AVHRR imagery. These images are particularly efficient for the estimation of the snow cover over areas larger than 500 km^2 because of the 1.1 km^2 spatial resolution and the large 2400 km scanning width (Siedel *et al.*,

1989). Furthermore, the acquisition of AVHRR satellite imagery offers the possibility of at least one image per day at regular time periods because of the sun synchronous orbit.

Finally, the use of "synthetic" and individual weather stations is necessary to estimate the impact of changing temperature values in the hydrological modelling. Synthetic stations are defined as a series of temperature values calculated from two individual stations or more. Obviously, individual stations use temperature values provided from one station inside or in proximity to the drainage basin. Overall, five synthetic stations and nine individual stations are used for different runs of the SRM. These temperature stations are listed in table 2.

Table 2. The synthetic and individual weather used for the modelling of the Batiscan River basin.

#	Synthetic weather stations	#	Individual weather stations
1	Weighted station from SLURPAZ	6	La Tuque Station
2	Equal-weighted station from SLURPAZ	7	Lac-aux-Sables Station
3	Weighted station from Thiessen	8	Ste-Anne-de-la-Pérade Station
4	Equal-weighted station from Thiessen	9	Rivière-verte-Ouest Station
5	Average value station	10	Trois-Rivières-aqueduc Station
		11	Shawinigan Station
		12	St-Narcisse Station
		13	Grande-Anse Station
		14	Hérouxville Station

Synthetic stations

The SRM applied over a basin permits the use of only one series of meteorological variables. When more than one meteorological station were available, we created a synthetic station which used all values from available stations. Synthetic station data were estimated based on factors such as: topography, the vegetation cover of the station site, weighting each stations according to a ratio of the area of influence over the total area of the drainage basin or a simple average temperature value taken from part or all of the individual stations. The synthetic station data should represent the general climate condition of the basin while reducing the potential local effect on the registered values. For our study we tested three types of synthetic stations.
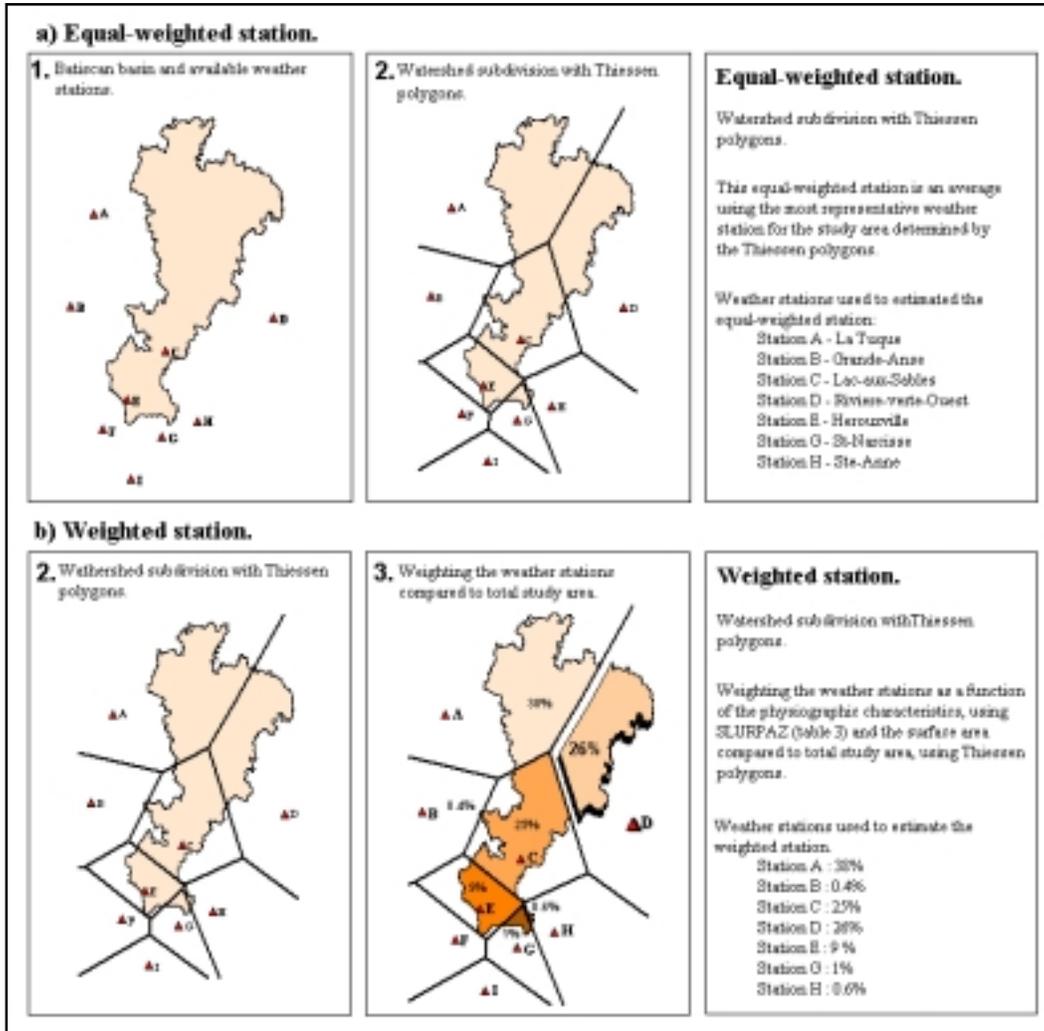
Equal-weighted stations:

The equal-weighted stations were first established by determining the most appropriate individual station that registered regional climatic condition prevailing over the drainage basin. The method used to identify the most representative stations follows a strategy of subdividing the total basin area along the lines of topographic and land-use characteristics or simply based on the linear distance between the individual stations and the border of the drainage basin. The chosen stations were not assigned any weights. The synthetic station was made up of the average temperature values of the chosen individual stations that contribute more significantly to the estimation of the weather conditions of the drainage basin (Figure 2-a).

For this analysis, two equal-weighted stations were developed to test the SRM. Firstly, (Table 2, #2) a synthetic station was determined using the individual weather stations identified by SLURPAZ (Lacroix and Martz, 1998). This algorithm calculates the area of influence of each stations based on the topographic analysis using a digital elevation model (DEM), the land-uses classification of the area (forest cover, agricultural and bare land) and the distances between the individual stations and the drainage basin (Table 3). Overall, four individual stations identified by SLURPAZ were used to calculate this equal-weighted station. Secondly, the other synthetic station (Table 2, #4) was obtained based on a Theissen polygon delineation of the drainage basin using the individual stations as the centroïds. The shape of the polygons was not influenced by any physical characteristics such as topography and forest covers. However, only seven stations out of nine for which the individual area of influence overlaps the drainage basin were retained in the

calculation of the synthetic station. This method allowed every station which touched the drainage basin to participate equally (Table 3).

Figure 2. Method to define synthetic weather station.

The weighted stations:

These stations account for the importance (weights) of the individual stations over the total study area (Figure 2-b). The weights are given to the selected stations identified previously for the estimation of the equal-weighted stations (Table 3). The first of these synthetic weighted stations, were obtained using SLURPAZ (Table 2, #1). Using this software, the weights assigned to the individual stations were based on surface area overlapping the drainage basin and distance that separated the station with the study area. The second synthetic weighted station was determined based on the Thiessen polygons. The weights for the seven individual stations selected were established using the proportion of the total drainage basin for which each individual stations overlap (Table 3).

The regional station:

The third and last synthetic station (Table 2, #5) was created using the average temperature values from all nine individual weather stations present in the vicinity of the drainage basin. This

last synthetic station did not account for topography, surface cover or any particular area of influence.

The individual stations

Modelling runs were performed separately using each of the nine individual weather stations (Table 2, #6 to #14) in or in proximity of the drainage basin.

Table 3. Individual stations used to calculate the synthetic stations and their respective weights.

Stations indentified by SLURPAZ	Weights (%)	Stations identified by the Theissen polygons	Weights (%)
Lac-aux-Sables	39	La Tuque	28
Hérouxville	9	Grande-Anse	0.4
St-Narcisse	1	Lac-aux-Sables	25
La Tuque	51	Rivières-verte-Ouest	26
		Hérouxville	9
		St-Narcisse	1
		Ste-Anne	0.6

RESULTS

Modelling snowmelt in a forested environment using the SRM.

The modelling results were evaluated using a determination coefficient (R^2), also known as the Nash-Sutcliffe coefficient (equation 1). In this study the results varied between –0.07 and 0.73, five modelling attempts showed a R^2 above 0.60 (figure 3).

(1)
$$R^2 = 1 - \frac{\sum_{i-1}^{n} (Q_i - Q'_i)^2}{\sum_{i=1}^{n} (Q_i - \overline{Q})^2}$$

Where, R^2 represents a measure of the precision of the SRM results, Q_i ; measured daily runoff, Q'_i ; the modelled daily runoff and $\overline{Q}$; the average daily runoff which corresponds to a long time average of the measured daily runoff.

Modelling attempts over the full temporal period using each of the five synthetic stations generally show modelled runoff values which were less then the measured values (Figure 4). On the other hand, the modelling runs using each of the individual weather stations gave, in most cases, output runoff values higher than the measure values. This overestimation existed for a short period between the middle of April to the beginning of May, the peak snowmelt season. Only two of the nine individual stations did not overestimate the runoff values for this time period: the modelling run using the La Tuque and Lac-aux-Sables stations.

Modelling snowmelt based on different series of temperature values

The variations in R^2 were directly attributed to changes in the series of temperature values inserted in the 14 modelling runs.

The synthetic weather stations

Firstly, the two modelling attempts using the equal-weighted synthetic stations showed R^2 above 0.60. The modelling run using the stations selected by SLURPAZ give a R^2 just slightly above

0.60 while the run using the Theissen polygon station selection showed a R^2 of 0.66. Secondly, the two modelling efforts using weighted stations showed R^2 results which were inferior to 0.60. The R^2 results for SLURPAZ and the Theissen approach were 0.34 and 0.54 respectively. Finally, the R^2 result obtained from the average regional station was 0.62.
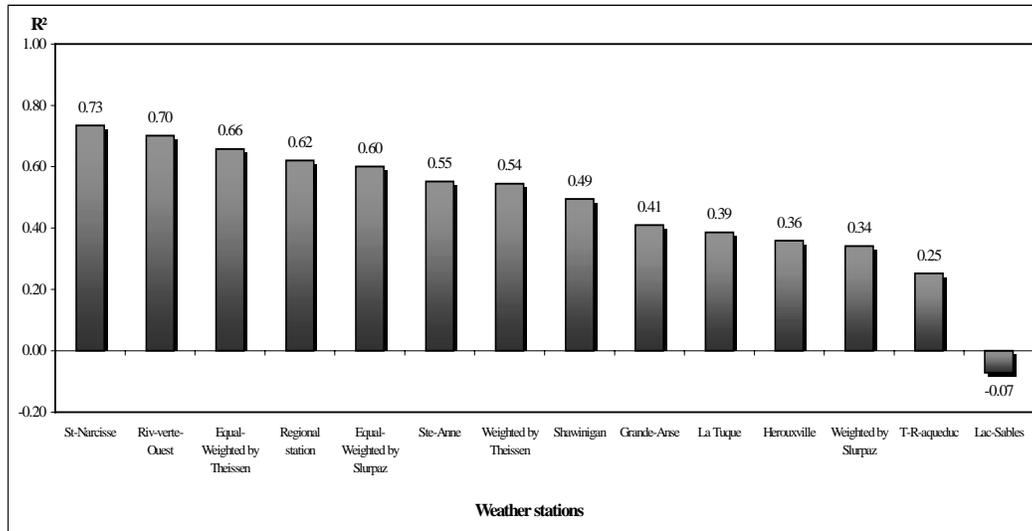

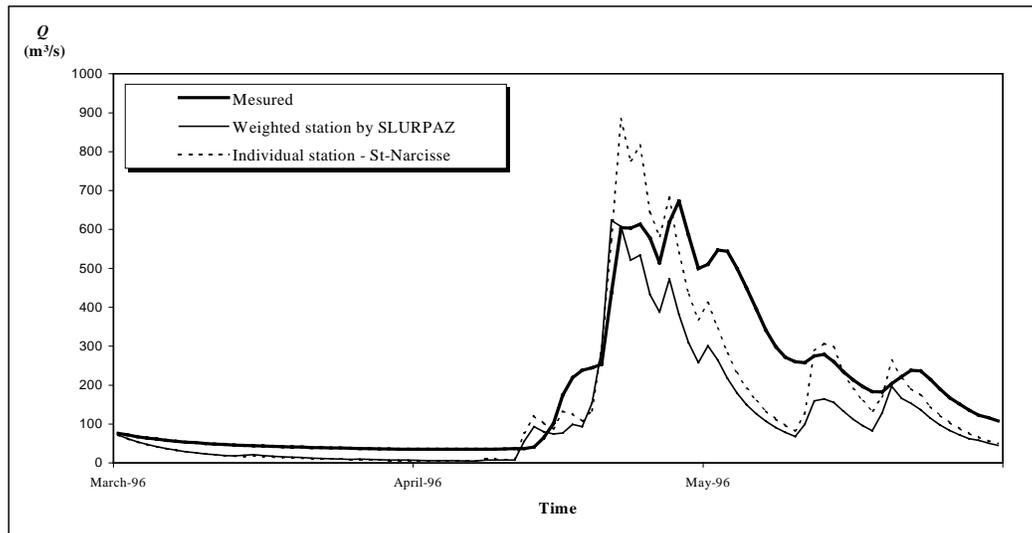Figure 3. Modelling precision (R^2) for the Batiscan River basin.

Figure 4. Modelling the runoff for the Batiscan River using a synthetic and an individual weather station.

The individual weather stations

The nine modelling attempts using the individual weather stations gave results that were very different. Only two modelling runs gave R^2 results that were above 0.60. They were the modelling results provided from the Rivière-verte-Ouest (0.70) and the Saint-Narcisse (0.73) weather stations and they were the best modelling results obtained overall.

DISCUSSION

While usually applied to high mountain environments, often in basins supporting a glacier cover, the SRM showed potential to model snowmelt from forested, low relief environments. Furthermore, examining the modelling results clearly showed how the modelled and measured runoff was directly controlled by the temperature values. In fact, temperature values that were representative of the whole drainage basin were crucial for the SRM model.

Modelling using the synthetic stations

The modelling runs performed using the equal-weighted stations showed good results. These stations dampened the local climatic effects that existed around the individual weather stations.
The temperature values registered from these synthetic stations were less "spiky" than those of the individual measurements.

The modelling run for the SLURPAZ weighted station, which accounted for topography, vegetation cover, and the area of influence of individual stations based on the distance to the drainage basin, gave poor results. Based on SLURPAZ weighting strategy, we expected the SLURPAZ weighted synthetic station would have performed better. A detailed analysis of the selected station used to produce this synthetic station showed that they were not located in or close to a forested environment, but rather in open-land areas. The SLURPAZ station registered temperature values that accounted less for forested areas than other synthetic stations. The weighting strategy used by SLURPAZ, first, followed a classification of the weather stations according to surface cover and topography and, second, determined the weights according to the distance of each station from the drainage basin. In our study, SLURPAZ selected two stations, Lac-aux-Sables and Hérouxville, which were both located inside the drainage basin but in open-land areas. This selection had an important impact on the modelling results.

For the same reason, the modelling results from the weighted station from the Thiessen polygons strategy also showed poor results. Again, dividing the area using the Thiessen polygons did not account for land cover.

In both cases, the weighting selection strategy was based first on distance then on land cover. It was more evident that land cover played a principal role in the SRM results of low relief environments and that any weighting scheme that did not account for land cover first would fail.

The modelling results using average values from all nine individual station showed good results. In the same way as the equal-weighted synthetic stations, average temperature values reduced the local temperature effects of particular stations. Most of the nine individual weather stations used in this study were in part situated closer to the neighbouring drainage basin, the Saint-Maurice River, or if situated in the Batiscan River drainage basin they were placed in open land areas. Averaging these values tend to reduce the local affects.

Modelling using the individual weather stations.

We obtained very different results using data from each of the nine individual stations. The best results came from weather stations placed inside or close to forested environments. They were the Rivière-verte-Ouest and Saint-Narcisse weather stations. The energy exchange between the forest canopy and the melting snow cover was crucial during the melt season, especially for conifer forests. The temperature values registered in these areas tended to correspond to the temperature conditions that occurred was the overall basin which is covered mostly by conifer forest.

The worst results came from the La Tuque, Shawinigan and Grande-Anse stations. While in distance they were not far, these stations were all closer to the Saint-Maurice River than to the Batiscan River. While representing similar forested environments, the weather condition over these stations are firstly influenced by the more incised Saint-Maurice River and secondly by the

position of this stations witch was closer then urbanised area. In this case topography and general context of this stations plays a more important role than distance.

The modelling runs performed using the Lac-aux-Sables, the Sainte-Anne-de-la-Pérade, the Trois-Rivières-aqueduc and Hérouxville stations all show poor results. All of these stations are located in open-land areas. Furthermore, except for the Trois-Rivières-aqueduc station, the other three stations are all inside or less than 7 km from the Batiscan River drainage basin. Again, distance was a secondary variable in the selection of the temperature values to model snowmelt with the SRM. Land-cover was by far more important.

The impact of the temperature values in the snowmelt modelling
To reduce the effects of any one station, the use of a regional station was an ideal solution when many stations are available but none are located on the principal land-covers of the study basin. The regional station dampens the local effects. On the other hand, many extreme climatic events were attenuated, making the regional station inappropriate for modelling over short time periods (few days to a couple of weeks). To model over short time periods, an individual station ideally located under the principal land-cover was better suited. The stations showed the high-frequency changes in the weather conditions, which translated in peak flow outputs from the model (Figure 4).

As stated earlier, the precipitation values were estimated in the same way as the temperature values. While they were an important component of the modelling performance, they had a significantly smaller impact, compared to temperature, on the modelling result. In fact, in the SRM, the snow cover distribution was far more important at the beginning of the snowmelt season than the amount of snow on the ground. At this time of year, any new precipitation, if solid contributed, to the thickening of the snow cover, or if liquid, increased the water content of the snow on the ground. The importance of the precipitation variable was found in the spatial distribution of the precipitation events across the basin. However, when the snow cover becomes saturated, precipitation became more important. But again, the spatial distribution of the precipitation events was crucial. A liquid precipitation event that occurred over the whole basin, if falling on snow, will increase the melting snow cover and the runoff from this event will be added to the runoff from the melting snow, if falling on the ground, it will "simply" produce runoff. Consequently, the precipitation variable was much less important for modelling with the SRM than the temperature variable. While precipitation will increase snowmelt, it was temperature that controlled the ablation factor. A cold rain had a smaller impact than a warm rain. In the case of the Batiscan River basin, the precipitation events were, in general, uniformly distributed over the study area (Figure 5). Some stations registered an isolated precipitation event but generally followed or preceded an important event that covered the whole basin.

Prior to the analysis, all of the five synthetic and nine individual weather stations used could have been adequate for modelling the snowmelt. In fact, the study shows that the physical characteristics of the drainage basin, such as topography and vegetation cover and the position of the weather station had an important impact on the temperature values registered and ultimately the modelling precision. From these results, identifying the ideal position for a weather station to model snowmelt using the SRM has to be based on general topography (in higher relief environments) and on land cover (in lower relief environments). In study areas similar to the Batiscan River basin, this station should be placed on the principal land-cover type of the area at an intermediate elevation (median). This is almost the case for the Rivière-verte-Ouest station in this study area.
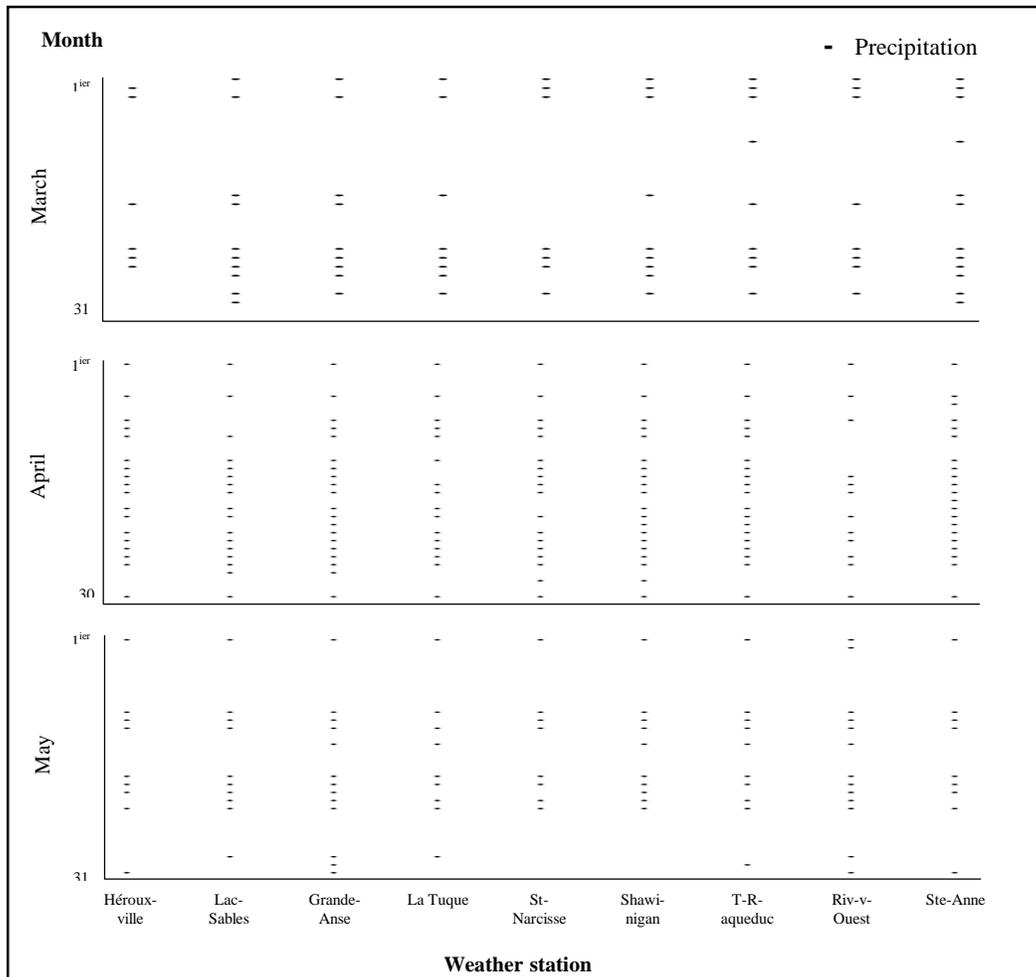
Figure 5. Precipitation events in space and time over the Batiscan River Basin.

CONCLUSION

This study focused on testing the SRM, principally developed for high-relief mountain environments, in a relatively large low-relief forested environment. The results showed that the SRM was capable of obtaining good results in this type of environment. This study also focused on the importance of the temperature variable. Again our results showed that temperature had a considerable impact on the modelling results. Identifying a representative set of temperature values was crucial for this modelling attempt.

While the SRM does account for land-cover type in its modelling strategy, the location of the weather station in relation to the principal land-cover type of the study area played an important role in obtaining good modelling results. In this study, the topography and land cover present at each weather station location had a considerable influence on the temperature values and consequently on the modelling results.

ACKNOWLEDGEMENTS

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