Winter Climate along the St. Lawrence Valley

JERRY TOUPIN[1]

ABSTRACT

Located in Eastern Canada, the St. Lawrence Valley (between Montreal and Quebec City; ±350km) is known as one of the snowiest populated valleys in the world. Usually more than 250cm of snow falls every winter. Snowstorms are frequent, as more than 10 major snowstorms are registered every year (Plamondon, 1979) interfering greatly with human activities.

Numerical analyses (univariate analysis, discriminant analysis and stepwise multiple regression) for the 1971-1980 decade on total snow depth for the month of January reveals three winter-regional climates along this valley: A-) the southern part of Montreal; slightly warmer with less snow and less rainfall, B-) the area around Quebec City; colder with more snow and C-) an intermediate corridor in-between those two cities.

Two major variables were identified as responsible for explaining these three winter regional climates: maximum temperature and rainfall.

Keywords: Winter climate, numerical analyses, snow, St. Lawrence Valley.

INTRODUCTION

Canada remains a cold and snowy country. From coast-to-coast winter may last over five (5) months with sub-zero temperatures and snowfall well over 200cm. Part of the Canadian Rockies and eastern Canada remain some of the snowiest areas in the world. Although many studies have been conducted on physical aspect of winter in Canada and in the USA (Julander and Bricco, 2006, Kunkel *et al.*, 2006, Farnes, 2005, Brown *et al.*, 2001, Gray and Male, 1982) much remains to be done to understand what controls snow depth on the ground as it interferes greatly with human activities.

Far from being an extensive research on that topic, nevertheless conclusive at this stage the basic questions asked in this paper are the following: from numerical analyses what meteorological variables are best related to snow depth along the St. Lawrence Valley? Based on those results can we detect local winter climates along this valley? Answers can be found to a satisfying degree.

METHODOLOGY

Selections of stations, period and variables were challenging. Weather stations in Montreal and Quebec City were excluded to minimize urban effect on snow depth. Hence, the St. Lawrence Valley (homogenous topography) regroups about 30 stations providing snow depth on the ground at the end of every winter month. The 1971-80 decade was selected as well as total accumulated snow on the ground for January (snow on the ground on the last day (cm), difference between

[1] University of Alberta, Campus St. Jean, Earth and Atmospheric Sciences, 8406-91st street, Edmonton, Alberta, Canada. T6C 4G9. jtoupin@ualberta.ca

January 31st and December 31st, Table 1, these two months represent about half of the total annual snowfall) as it represents a mid-winter situation. This allowed us to select a maximum of 36 meteorological stations spread out rather evenly along the Valley. The 1971-80 decade was selected as it offers a variety of different winters (early 70's shows lots of snow (record-breaking level) as it declines toward the late 70's).

Table 1. Total accumulated snow on the ground for the month of January (1971-1980).

Station (N=36)	Snow on the ground (cm) on January 31st	Snow on the ground (cm) on December 31st	Total accumulated snow on the ground (cm) for January
Assomption-CDA	40.1	31.4	8.7
Bécancour	64.1	45.7	18.4
Berthieville	46.4	31.5	14.9
Chute Panet	75.9	53.9	22.0
Donnocona	50.9	39.7	11.2
Drummondville	38.9	30.3	8.6
Farnham	29.3	23.8	5.5
Fleury	46.1	35.1	11.0
Granby	36.2	31.6	4.6
Iberville	28.8	28.8	0.0
Laurierville	37.8	28.3	9.5
Lavaltrie-CDA	69.1	49.5	19.6
Nicolet	40.1	27.8	12.3
Québec-A	82.3	57.1	25.2
Rigaud	38.8	36.0	2.8
Rougemont	31.6	23.4	8.2
Saint-Alban	63.1	37.6	25.5
Saint-Anicet	38.6	34.7	3.9
Sainte-Anne-de-la-Pérade	41.2	36.1	5.1
Saint-Augustin	76.6	46.6	30.0
Sainte-Catherine	79.4	55.4	24.0
Saint-Cled-Nord	32.0	16.4	15.6
Sainte-Clothide-CDA	20.9	20.8	0.1
Saint-Guillaume	29.8	20.4	9.4
Saint-Hubert-A	28.5	25.9	2.6
Saint-Hyacinthe-2	37.4	32.1	5.3
Saint-Jean-Chrysostome	52.0	47.6	4.4
Sainte-Martine	38.2	28.9	9.3
Saint-Mathieu-Laprairie	38.4	35.7	2.7
Sainte-Thérèse-Ouest	53.5	42.9	10.9
Saint-Raphaël	76.2	63.2	13.0
Scott	39.0	30.3	8.7
Shawinigan	47.6	42.3	5.3
Sorel	50.8	36.1	14.7
Trois-Rivières	55.8	41.1	14.7
Verchères	56.0	39.2	16.8
Mean= 11.2cm; Standard deviation = 7.6cm			

Winter climate along the St. Lawrence Valley was determined from the total accumulated snow depth in January. Overall, six (6) meteorological variables were selected for the month of January based on their strong correlation with the total accumulated snow depth for each station: average maximum temperature, average minimum temperature, average snowfall, average rainfall, average number of days with temperature over 0°C and the nivometric coefficient (% of precipitation in the form of snow). From this, 3 major statistical analyses were performed: univariate analysis (BMDP2D), discriminant analysis and stepwise multiple regression (SPSS).

RESULTS AND DISCUSSION

Univariate analysis and Discriminant analysis

Table 1 shows total accumulated snow on the ground for January ranging from 0 (Iberville) to 30 cm (Saint-Augustin), with a mean of 11.2 cm and 7.6 cm as standard deviation. The univariate analysis allowed classifying 4 groups based on the mean (11.2), the minimum value (0), versus negative sigma σ^- (3.6), positive sigma σ^+ (18.8) and the maximum value (30) of total accumulated snow (cm) on the ground for January: 0-3.6 cm, 3.7-11.2 cm, 11.3-18.8 cm, and 18.9-30 cm. This result was processed through a discrimant analysis (including the 6 meteorological variables) in order to try to classify different winter climates. Table 2 and Figure 1 show the result. Overall, half of all the stations (snow depth) are related to the maximum temperature (F = 10.3, Table 3).

Table 2. Means and standard deviations from the discriminant analysis on the six selected variables.

	Means				Standard deviations			
Group	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
1	–5.48	–6.20	–6.95	–7.68	0.35	0.93	0.56	0.49
2	–14.78	–16.07	–16.56	–17.93	0.69	1.34	0.69	1.29
3	22.15	24.73	24.37	27.19	3.67	4.90	3.67	9.59
4	52.83	60.74	58.56	67.61	4.33	10.91	5.72	12.71
5	8.18	7.58	6.36	5.46	1.00	1.39	0.56	0.65
6	0.71	0.68	0.69	0.73	0.02	0.04	0.03	0.06
Number of stations N=36	5	16	9	6	5	16	9	6

1: Average maximum temperature (°C), **2**: Average minimum temperature (°C), **3**: Ave- rage minimum temperature (°C), **4**: average snowfall (cm), **5**: average rainfall (mm), **6**: nivometric coefficient.

Group A represents a milder climate with five (5) weather stations; Rigaud, Iberville, Ste-Clothide-CDA, St-Hubert-A and St-Mathieu-Laprairie, mainly south of Montreal with less precipitation (snowfall averaging 52.8 cm, less rainfall: 22.15 mm) and milder temperatures (maximum average temperature = –5.48°C). At the other end of the valley, Group D shows a colder climate with more snow, is associated with six (6) weather stations; Chute-Panet, Lavaltrie-CDA, Québec-A, St-Alban, St-Augustin and Ste-Catherine and is mainly located north and northwest of Quebec City with more precipitation; more snowfall (averaging 67.6 cm) and rainfall (27.19 mm), colder (maximum average temperature –7.68°C). Group B and C are heterogeneous and not always well classified according to the discriminant analysis. Nevertheless, it represents an intermediate winter climate between the local winter climate (maximum average temperature ranging between –6.20 and –6.95°C, average snowfall between 58.6 and 60.74 cm and average rainfall around 24.5 mm) south of Montreal and the one surrounding Quebec City. This allows us to recognize three (3) local winter climates along the St. Lawrence Valley.

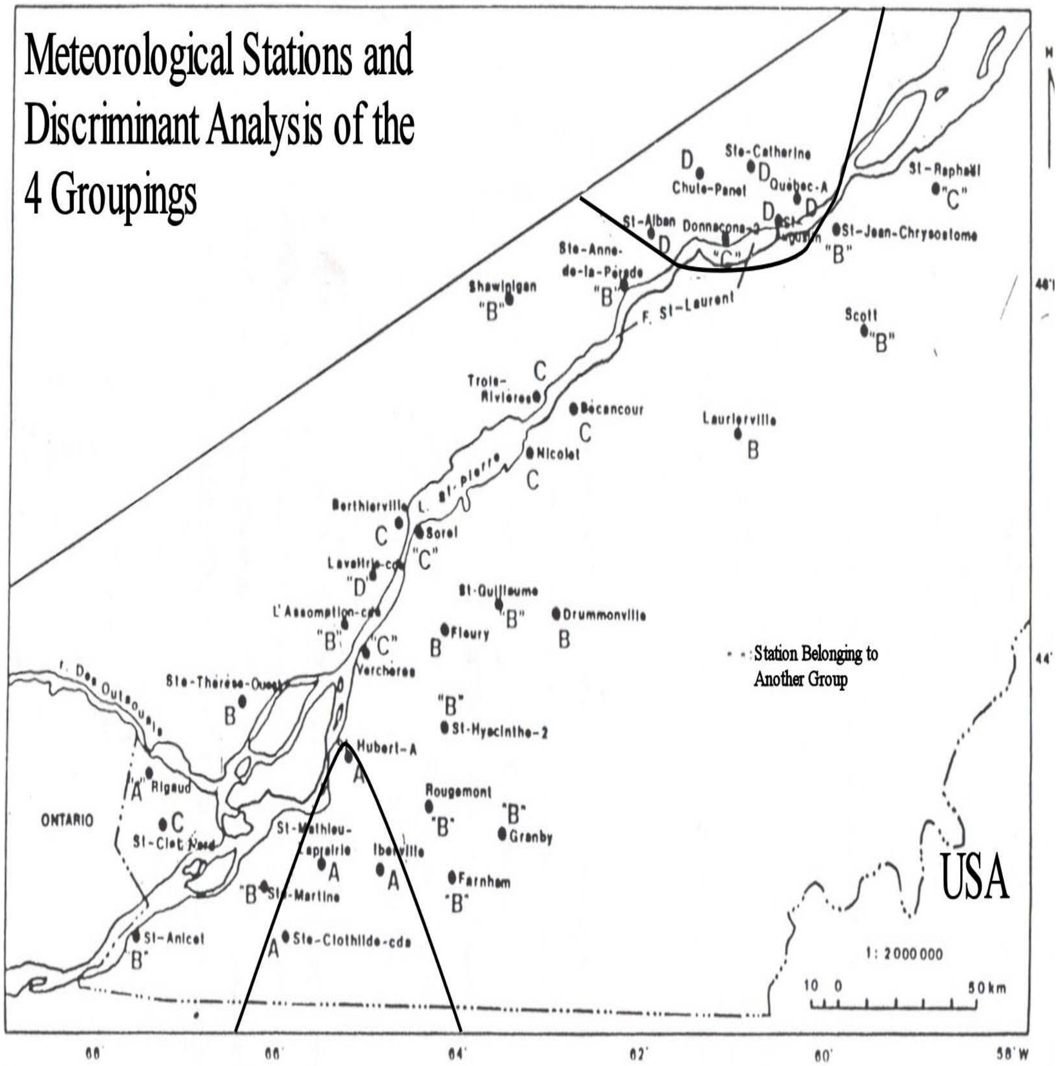

Figure 1. Meteorological stations and discriminant analysis of the four groupings.

Table 3. Classification functions from the discriminant analysis.

	Incorrect classifica-tions	Squared Mahalanobis distance							
		A		B		C		D	
GROUP A									
Rigaud	B	0.5	0.34	0.1	0.42	1.7	0.19	5.2	0.03
Iberville		0.1	0.66	1.8	0.28	5.7	0.04	11.3	0.00
Ste-Clothide-CDA		0.3	0.70	2.2	0.26	6.3	0.03	12.2	0.00
St-Hubert-A		0.0	0.55	0.9	0.35	3.9	0.08	8.7	0.00
St-Mathieu-Laprairie		0.0	0.51	0.7	0.37	3.4	0.09	8.0	0.01
GROUP B									
L'Assomption-CDA	C	2.7	0.10	0.5	0.33	0.1	0.39	1.8	0.17
Ste-Anne-de-la-Pérade	D	8.2	0.00	3.6	0.08	0.8	0.36	0.0	0.53
Ste-Thérèse-Ouest		1.2	0.22	0.0	0.41	0.8	0.28	3.5	0.07
Shawinigan	D	9.0	0.00	4.1	0.07	1.0	0.34	0.0	0.57
Drummondville		0.5	0.34	0.1	0.42	1.7	0.19	5.2	0.03

Farnham	A	0.4	0.73	2.6	0.24	7.0	0.02	13.2	0.00
Fleury		1.0	0.26	0.0	0.42	1.0	0.25	4.0	0.05
Granby	A	0.1	0.47	0.5	0.39	2.9	0.11	7.2	0.01
Laurierville		1.6	0.19	0.1	0.40	0.6	0.31	3.0	0.09
Rougemont	A	0.3	0.70	2.2	0.26	6.3	0.03	12.2	0.00
St-Anicet	A	0.8	0.78	3.6	0.19	8.5	0.01	15.3	0.00
St-Guillaume	A	0.2	0.43	0.3	0.41	2.5	0.13	8.5	0.01
St-Hyacinthe	A	0.0	0.51	0.7	0.37	3.4	0.09	8.0	0.01
St-Jean-Chrysostome	D	9.0	0.00	4.1	0.07	1.0	0.34	0.0	0.57
Ste-Martine	A	0.0	0.51	0.7	0.37	3.4	0.09	8.0	0.01
Scott	C	4.2	0.05	1.2	0.23	0.0	0.42	0.9	0.28
GROUP C									
Berthierville		2.3	0.13	0.3	0.35	0.2	0.36	2.2	0.14
Donnacona-2	D	9.0	0.00	4.1	0.07	1.0	0.34	0.0	0.57
St-Clet-Nord		4.8	0.04	1.5	0.20	0.0	0.43	0.6	0.32
Trois-Rivières		5.4	0.03	1.8	0.18	0.1	0.42	0.4	0.36
Bécancour		4.8	0.04	1.5	0.20	0.0	0.43	0.6	0.32
Nicolet		2.7	0.10	0.5	0.33	0.1	0.39	1.8	0.17
Sorel	B	0.5	0.34	0.1	0.42	1.7	0.19	5.2	0.03
St-Raphaël	D	9.0	0.00	4.1	0.07	1.0	0.34	0.0	0.57
Verchères	B	1.9	0.16	0.2	0.38	0.4	0.34	2.6	0.11
GROUP D									
Chute-Panet		9.9	0.00	4.7	0.05	1.3	0.32	0.0	0.61
Lavaltrie-CDA	C	2.7	0.10	0.5	0.33	0.1	0.39	1.8	0.17
Québec-A		9.9	0.00	4.7	0.05	1.3	0.32	0.0	0.61
St-Alban		9.9	0.00	4.7	0.05	1.3	0.32	0.0	0.61
St-Augustin		10.7	0.00	5.3	0.04	1.6	0.29	0.1	0.65
Ste-Catherine		12.6	0.00	6.6	0.03	2.4	0.25	0.3	0.70
GROUP TOTAL	Correct Percentage								
A	80.0	4		1		0		0	
B	25.0	7		4		2		3	
C	55.6	0		2		5		2	
D	83.3	0		0		1		5	
Total	50.0	11		7		8		10	

Step 1: F-Test	**Variables**	**Value of F**
	Average maximum temperature	10.3
	Average minimum temperature	7.5
	Average rainfall	0.8
	Average snowfall	2.3
	Average number of days with temperature over 0°C	8.5
	Nivometric coefficient	1.9

Hence at this step, the univariate and the discriminant analyses allowed us, with respect to this methodology, to identity three (3) local winter climates along the St. Lawrence Valley (Figure 1). The immediate southern part of Montreal (as illustrated by the solid line, including St-Hubert-A, St-Mathieu-Laprairie, Iberville and Ste-Clothide-CDA) represents a milder winter climate with less precipitation (snow: ±53 cm and rain: ±22 mm), while the immediate area, north and northwest of Quebec City (about 350km from Montreal) is colder and snowier (±68 cm) with slightly more rain (±27 mm) includes: Chute-Panet, Québec-A, St-Alban, St-Augustin and Ste-

Catherine. The corridor divides the two sectors between stations which are mainly represented by letters B and C translates into an intermediate winter climate along the St. Lawrence Valley.

Stepwise multiple regression

This step allowed us to confirm what was found with the discriminant analysis; that the average maximum temperature is mainly related (about 45%) to the total accumulated snow on the ground for January. Furthermore, the average amount of rainfall was also partially responsible (6%) to explain such a distribution (Table 4). These two variables combined explain over 51% (R^2) of this snow pattern.

Table 4. Results from the stepwise multiple regression.

Variable	Value of F	R	R^2	Increase in R^2 (%)	Beta
Average maximum temperature	26.56	0.669	44.77	44.77	–0.67
Average rainfall	17.3	0.716	51.24	6.47	0.25

The stepwise multiple regression also calculates residues (Figure 2) from its equation. At this level, the average maximum temperature and the average amount of rainfall for each weather station are tested with the predicted total accumulated snow on the ground for January 1971-80. Figure 2 shows this result. Overall, this model less explains only 5 stations out of 36.

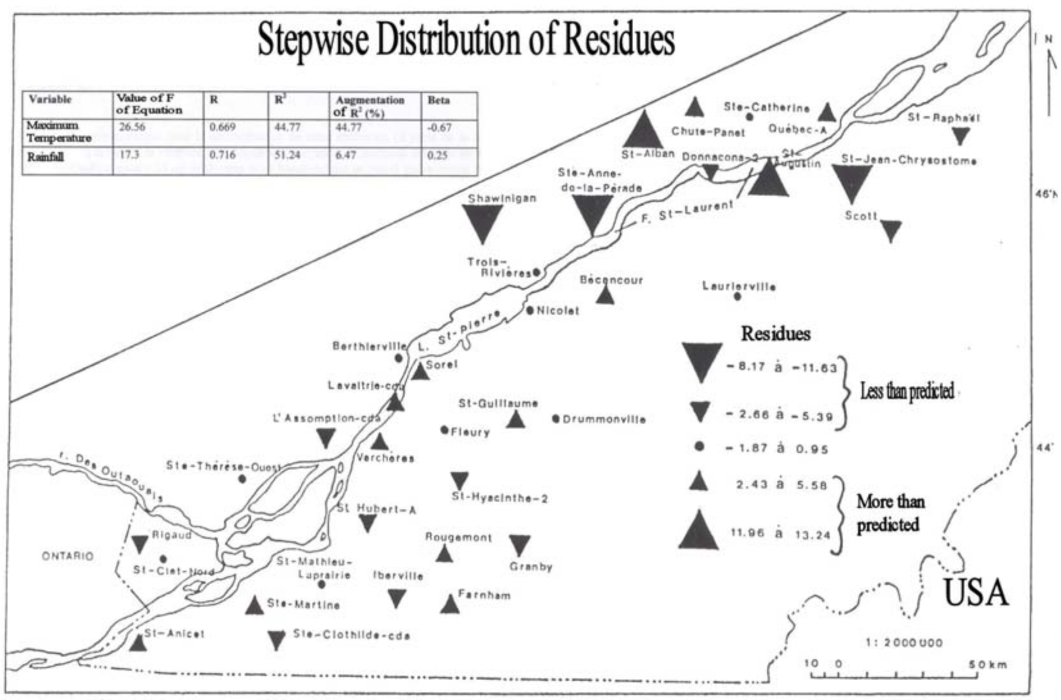

Figure 2. Stepwise distribution of residues.

Those stations are located at the fringe of grouping D and B-C (just south of Quebec City). While two (2) stations: St-Alban and St-Augustin accumulated more snow than predicted (between 11.96 and 13.24 cm), three (3) stations: Shawinigan, Ste-Anne-de-la-Perade and St-Jean-Chrysostome accumulated less snow (between –8.17 and –11.63 cm) than predicted. Hence, these weather stations are the least explained by their average maximum temperature and their average amount of rainfall in accumulating total snow on the ground for January 1970-81. In this specific case, other unknown variables could play a role in that dynamic.

Consequently, the average maximum temperature and to a lesser degree the average total rainfall dictate a great deal of the average total snow accumulated on the ground along the St. Lawrence Valley. Ferland (1968) had already noticed the difference between Montreal and Quebec City where snow tends to fall with temperature ranges between −3.9 and −1.1°C in Montreal, but between –6.7 and –3.9°C in Quebec City.

CONCLUSION

Although incomplete, the methodology developed in this paper combined with numerical analyses lead to a better understanding of the winter climate along the St. Lawrence Valley, one of the snowiest, populated valleys in the world.

Univariate and discriminant analyses applied to the total accumulated snow on the ground for January 1971-80 revealed three (3) local winter climates: (1) an area just south of Montreal; slightly warmer with less snow and rainfall, (2) an area around Quebec City, colder with more precipitation (snow and rainfall) and (3) an intermediate corridor between those two (2) areas.

The use of the discriminant analysis and the stepwise multiple regression identified the average maximum temperature and to a lesser degree the average total rainfall as the best two (2) main variables related to this snow pattern. Identical analyses were also performed for the 1981-1990 decade and the 1961-1990 period showing similar results.

Further studies including variables such as topography and the proximity of the Gulf of the St. Lawrence River (open water) could eventually contribute to an even better understanding of its winter climate.

REFERENCES

Brown R. et al. 2001. Development of a Gridded North American Monthly Snow Depth and Snow Water Equivalent Dataset for GCM Validation. *58th Eastern Snow Conference: 333-340.*

Dixon W.J. 1983. BMDP-Statistical software. University of California Press. 734p.

Farnes P.E. 2005. Climate Change in Montana. *73rd Western Snow Conference; 45-56.*

Ferland M. 1968. Les régimes de température accompagnant les chutes de neige. *Cahiers de géographie de Québec ; 25 :145-152.*

Gray D.M., Male, D.H. 1981. Handbook of Snow: Principles, Processes, Management and Uses. Willowdale Pergamon Press. 776p.

Julander, R., Bricco, M. 2006. An examination of external influences imbedded in the historical snow data of Utah. *74th Western Snow conference: 61-72.*

Kunkel, K. 2006. Issues with identification of trends in 20th century U.S. snowfall. *74th Western Snow conference: 99-107.*

Norusis, M.J. 2006. SPSS 15.0 guide to data analysis. Prentice Hall. 651p.

Plamondon, M. 1979. Études des tempêtes de neige survenues dans la ville de Québec (1965-1975) et de leur incidence sur la circulation routière. Thèse de maîtrise, Université Laval, Département de géographie. 262p.