Cent. Eur. J. Geosci. • 1(3) • 2009 • 312-317
DOI: 10.2478/v10085-009-0027-2

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Central European Journal of **Geosciences**

January snow accumulation in the St. Lawrence Valley (1961-1990)

Research Article

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Received 25 May 2009; accepted 5 July 2009

Abstract: Located in Eastern Canada, the St. Lawrence Valley (between Montreal and Quebec City; ±350 km) is known as one of the snowiest populated valleys in the world. Usually more than 250 cm of snow falls every winter. Snowstorms are frequent, as more than 10 major snowstorms are registered every year [1] interfering greatly with human activities. Numerical analyses (univariate analysis, discriminant analysis and stepwise multiple regression) for the 1961-1990 period 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

1. Introduction

Canada is a cold and snowy country. From coast-to-coast winter may last over five (5) months with sub-zero temperatures and snowfall well over 200 cm. 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 [2–6] 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.

2. 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 1961-90 period was selected as well as total accumulated snow on the ground for January (snow on the ground on the last

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day (cm), difference between 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 30 meteorological stations spread out rather evenly along the Valley.

Table 1. Total accumulated snow on the ground for the month of January (1961-1990).

Station (N=30)	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	33.0	23.0	10.0
Bécancour	56.0	35.0	21.0
Berthieville	48.0	32.0	16.0
Donnacona	51.0	35.0	16.0
Drummondville	36.0	27.0	9.0
Farnham	21.0	18.0	3.0
Fleury	33.0	25.0	8.0
Granby	32.0	26.0	6.0
Iberville	26.0	18.0	8.0
Laurierville	48.0	31.0	17.0
Nicolet	32.0	23.0	9.0
Québec-A	70.0	48.0	22.0
Rigaud	31.0	24.0	7.0
Rougemont	35.0	26.0	9.0
Saint-Alban	60.0	34.0	26.0
Saint-Anicet	35.0	31.0	4.0
Sainte-Anne-de-la-Pérade	43.0	30.0	13.0
Saint-Augustin	60.0	34.0	26.0
Sainte-Catherine	71.0	46.0	25.0
Sainte-Clothide-CDA	18.0	16.0	2.0
Saint-Guillaume	28.0	19.0	9.0
Saint-Hubert-A	27.0	23.0	4.0
Saint-Hyacinthe-2	36.0	26.0	10.0
Sainte-Martine	27.0	20.0	7.0
Sainte-Thérèse-Ouest	46.0	33.0	13.0
Scott	35.0	25.0	10.0
Shawinigan	49.0	36.0	13.0
Sorel	48.0	32.0	16.0
Trois-Rivières	54.0	38.0	16.0
Verchères	47.0	28.0	19.0
			Mean= 12.5 cm Standard deviation = 6.8 cm

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 [7, 8]: univariate analysis (BMDP2D), discriminant analysis and stepwise multiple regression (SPSS).

3. Results and discussion

3.1. Univariate analysis and discriminant analysis

Table 1 shows total accumulated snow on the ground for January ranging from 2 (Ste-Clothide-CDA) to 26 cm (Saint-Alban and Saint-Augustin), with a mean of 12.5 cm and 6.8 cm as standard deviation. The univariate analysis allowed classifying 4 groups based on the mean (12.5), the minimum value (0), versus negative sigma σ^- (3.6), positive sigma σ^+ (18.8) and the maximum value (26) 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 18.9-26 cm. This result was processed through a discriminant 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). The squared Mahalanobis distance (discriminant analysis, Table 3) is based on correlations between our 6 meteorological variables and the pattern from the accumulated snow depth for January. Every time a station doesn't fit the model, the program labels it as an incorrect classification and suggests a different group (A, B, C, D). As we can see from Table 3, stations from group A, C and D are almost perfectly classified while many stations in group B (an intermediate zone) would be better classified in group A.

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=30	5	16	9	6	5	16	9	6

1: Average maximum temperature (°C), **2:** Average minimum temperature (°C), **3:** Average rainfall (mm), **4:** average snowfall (cm),
5: average number of days with temperature above 0° C (mm),
6: nivometric coefficient.

Group A represents a milder climate with four (4) weather stations; Rigaud, Iberville, Ste-Clothide-CDA, and St-Hubert-A, 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 also four (4) weather stations; 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.

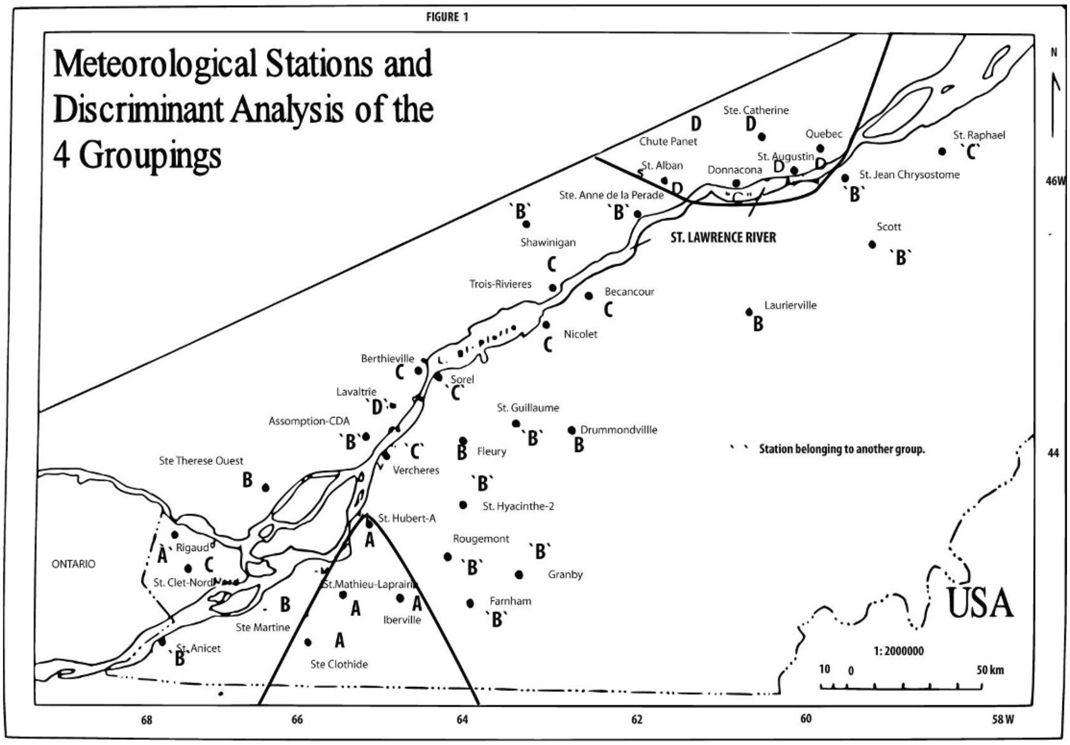

Figure 1. Meteorological stations and discriminant analysis of the 4 groupings.

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, 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 350 km from Montreal) is colder and snowier (± 68 cm) with slightly more rain (± 27 mm) includes: 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.

3.2. 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 3. Classification functions from the discriminant analysis.

	Incorrect classifications	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
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
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
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
Verchères	B	1.9	0.16	0.2	0.38	0.4	0.34	2.6	0.11
GROUP D									
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	B	C	D
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 0^0 C	8.5
		Nivometric coefficient	1.9

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 1961-90. Figure 2 shows this result.

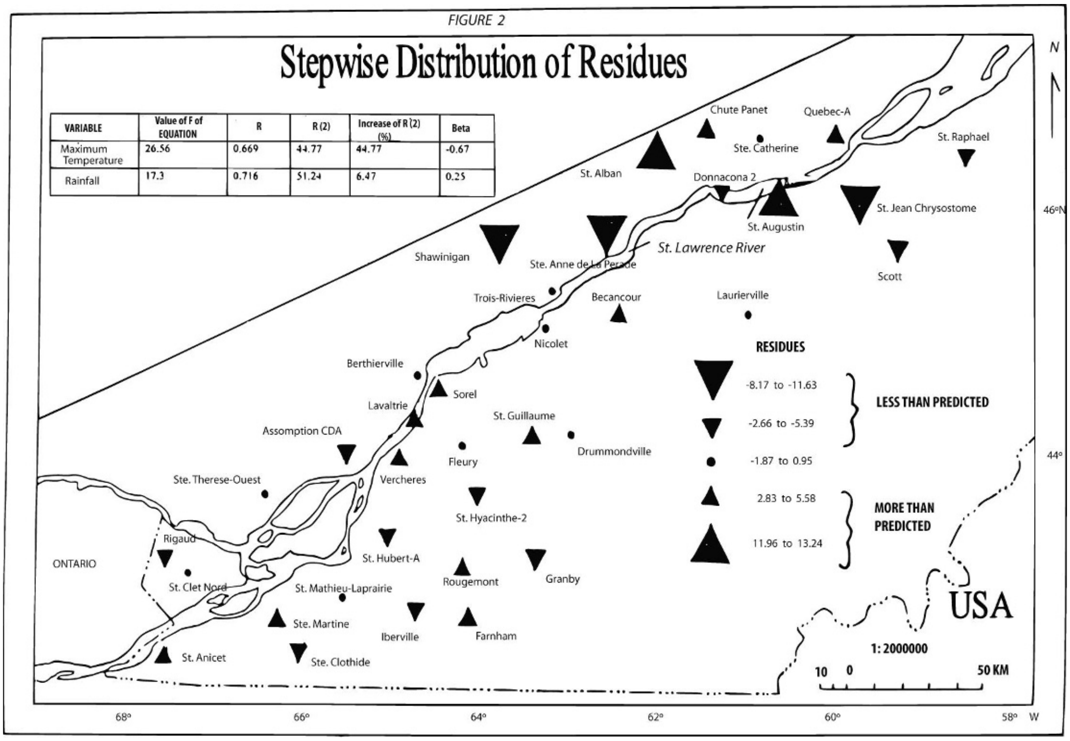

Figure 2. Stepwise distribution of residues.

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), two (2) stations: Shawinigan, Ste-Anne-de-la-Perade and 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 1961-90. 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 [9] 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.

4. 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 1961-90 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 1971-1980 decade and the 1981-1990 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.

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