THE NORTHEASTERN RAINY CONTINENTAL SNOW CLIMATE: A SNOW CLIMATE CLASSIFICATION FOR THE GASPÉ PENINSULA, QUÉBEC, CANADA

*Francis Meloche[1,4], Francis Gauthier[1,4], Alexandre Langlois[2,4], Dominic Boucher[3]

[1] *Département de Biologie, Chimie et Géographie, Université du Québec à Rimouski, Rimouski, Canada*
[2] *Département de Géomatique appliquée, Université de Sherbrooke, Sherbrooke, Canada*
[3] *Avalanche Québec, Sainte-Anne-des-Monts, Canada*
[4] *Center for Nordic studies, Université Laval, Québec, Canada*

ABSTRACT: Snow climate classification has been a subject in avalanche research for the past decades. A good comprehension of the snow climate and snow avalanche regime of a specific region is the foundation of reliable avalanche forecasting. Recent studies have added snow climate classification to understand new regions that don't fit the snow climate classification in western North America. The Gaspe Peninsula, located in eastern Canada, is threatened by snow avalanches. The need to determine a snow climate classification in order to fully understand his connection to the snow avalanche regime is important to make reliable avalanche forecasting. This study focus on two study areas: the north coast of the Gaspe Peninsula and the Chic-Chocs range. The meteorological suggest a continental snow climate and maritime snow climate classification. The snowpack data reveal a cold and thin snowpack with facets and melt-freeze crusts. The presence of persistent instabilities varies between winter season. We suggest a new nomenclature for these types of snow climate as northeastern rainy continental snow climate.

KEYWORDS: Snow climate, Snowpack, avalanche hazard, Gaspé Peninsula, Avalanche Problem.

1. INTRODUCTION

Snow climate classification has been developed to characterize the climatic context of a mountain range (Armstrong & Armstrong, 1986; LaChapelle, 1966; McClung & Schaerer, 2006; Mock & Birkeland, 2000; Shandro & Haegeli, 2018). The concept of snow and avalanche climates has been used to address a specific avalanche forecasting and mitigation program (McClung & Schaerer, 2006). Three main snow climate classifications exist in the literature: continental, maritime and transition (LaChapelle, 1966). Mock & Birkeland (2000) have proposed a flow chart algorithm with weather data as input to determine the snow climate. Recently, Shandro & Haegeli (2018) propose to use avalanche problem for a better characterization of the avalanche hazard.

The Gaspé Peninsula in eastern Canada is threatened by snow avalanches in the Chic-Chocs Range and on the north shore of the peninsula (Figure 1). The climate of the regions is a cold temperate climate (Gagnon, 1970) with maritime influence (Fortin & Hétu, 2011; Gauthier et al, 2017). This contradiction in the climatic conditions makes the snow classification difficult for the peninsula. Although the winter climate of the region has been well described by many authors (Fortin & Hétu, 2013; Fortin et al., 2011; Gauthier et al., 2017). More meteorological and snowpack evidence is needed to explain the snow avalanche regime of the region. In order to fully understand the climate conditions and its relevance to snow avalanche regime and forecasting: the goal of this study is described and proposed a snow climate classification for the Gaspé Peninsula and explore is applicability to other northeastern coastal area.

* *Corresponding author address:*
Francis Meloche, UQAR, Rimouski, Canada;
tel: +1 418-723-1986
email: francis.meloche@uqar.ca

2. STUDY AREA

The two study area is located on the Gaspé Peninsula (Figure 1). Glacier has created u-shape valley into the mountainous plateau going from the north side of the Chic-Choc massif to the St-Lawrence (Figure 1). The annual precipitation ranges from 800 mm at sea level to 1 600 mm in the mountains, with 40% falling as snow (Germain et al, 2010). This topographical and geographical context affects the depressions coming on the peninsula creating local effect. These storms are commonly Alberta's clippers, Colorado's lows and Hattera's low (Nor'easter) (Fortin & Hétu, 2014). Snow avalanche cause by snow storms explains the majority of snow avalanches for the regions (Germain et al., 2009; Fortin et al., 2011). Major snow avalanches regime of both study area has been compared annually and no synchronism was found between the low-coastal scree slope and the highland of the Chic-Chocs. This result suggests the influence of local effect on the snow avalanche regime (Germain et al, 2010).

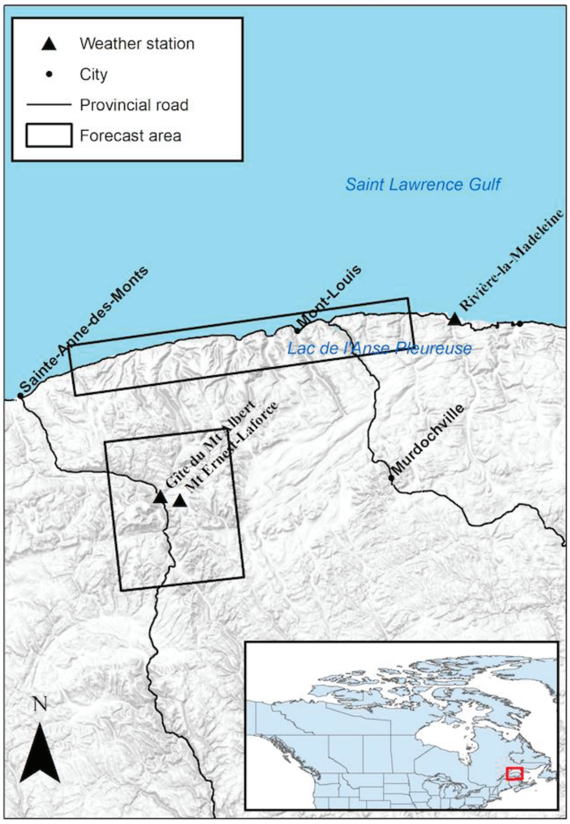

Fig. 1. Study area with the two forecast areas of Avalanche Québec and the weather stations: Cap-Madeleine (29m), Gîte du Mt Albert (253m) and Mt Ernest-Laforce (630m).

3. METHODOLOGY

Multiple methodologies from different studies focusing on snow and avalanche climatology of the past decades were used to describe the snow avalanche climate of the Gaspe Peninsula (Mock and Birkeland, 2000; Sturm et al, 1995; Shandro and Haegeli, 2018). We first used the Mock and Birkeland (2000) flow chart to classify the snow climate of both study area. Then we used snowpack data (Sturm et al, 1995) and forecasted avalanche problem data (Shandro and Haegeli, 2018) to better described snow avalanche hazard in the study area. The database represents winter snow and avalanche regime for every winter season from December first to March 31st.

3.1 Meteorological database

The meteorological data is provided from various organizations (Avalanche Québec, MDDELCC and Environment Canada). Data for the Chic-Chocs Range is collected at the station Gîte du Mt Albert (253m) and Mont Ernest-Laforce (630m) (Figure 1). Along the coast, the data from Cap-Madeleine's weather station is used (29m) (Figure 1). The dataset cover the winter season 2012-2013 to 2017-2018 from December to March, according to the methodology proposed by Mock and Birkeland (2000). Meteorological variables were derived using the Mock and Birkeland (2000) methodology.

3.2 Snowpack database

Snow profiles were made by Avalanche Québec technicians. Snow pit is dug each two days in the winter season at different aspects and altitude. Snow grain type classification was made for every layer according to the *Observational guidelines and recording standards for weather, snowpack and avalanche* from the Canadian Avalanche Association (CAA, 2014).

3.3 Forecasting database

Avalanche problems are issued every day from avalanche technicians and forecaster according to Avalanche Canada terminology (CAA, 2014). The avalanche problems provide information on the type of snow instability present during the period cover by the bulletin. The avalanche problem is thus a reliable proxy to analyze the spatio-temporality of avalanche hazard (Shandro and Haegeli, 2018). The data covers 6 seasons from 2012-2013 to 2017-2018 for the Chic-Chocs range. The data for the Chic-Chocs was analyzed for the past six winter seasons.

4. RESULTS

4.1 Snow climate classification

The results of the snow climate classification using Mock and Birkeland (2000) flow chart shows a continental climate classification with maritime exception (table 1). Both study area is characterized by cold temperature and small amount of precipitation. The average temperature for the highest weather station of the Chic-Choc is below the threshold for continental classification (-7°C) for every winter (table 1). The station for the coast area is near this threshold from -5 to -7 °C, showing warmer conditions along the coast. The cold air temperature and the shallow snowpack of December are key driver to facet metamorphism (e.g. McClung and Shaerer, 2006). 2012-2013 and 2015-2016 were both warmer at every weather station, resulting in more rain events during the winter season (table 1).The decisive criterion that classifies the majority of the winter season is the mean December temperature gradient above 10°C/m and the rainfall above 8 cm. The region is characterized by mean cold air temperature and thaw events.

	Air temp (°C)	SWE (mm)	Rainfall (mm)	Dec_TG (°C/m)	Snowclimate
Cap-Madeleine (29m)					
2012-2013	-5.5	234.6	146.9	62.4	Maritime
2013-2014	-9.3	194.8	0.4	N/A	Continental
2014-2015	-8.9	185.4	33.9	55.4	Continental
2015-2016	-5.2	126.5	81.0	60.0	Maritime
2016-2017	-6.6	226.0	20.7	103.1	continental
2017-2018	-6.7	243.3	13.8	72.9	continental
Gite du Mt Albert (230m)					
2012-2013	-8.2	316.3	135.1	20.6	Maritime
2013-2014	-12.7	296.3	37.5	40.1	Continental
2014-2015	-13.5	304.3	70.1	45.7	Continental
2015-2016	-9.3	341.2	85.3	50.3	Maritime
2016-2017	-10.8	380.7	39.0	76.2	Continental
2017-2018	-8.3	307.4	51.1	29.0	Continental
Mt Ernet-Laforce (630m)					
2012-2013	-9.7	466.2	91.0	15.4	Maritime
2013-2014	-13.9	457.1	23.3	23.2	Continental
2014-2015	-13.7	401.6	72.8	13.3	Continental
2015-2016	-9.5	358.1	103.5	N/A	Maritime
2016-2017	-11.7	454.0	37.6	23.5	Continental
2017-2018	-10.4	405.6	50.7	17.8	Continental

Table 1: Snow Climate Classification results for the winter 2012-2013 to 2017-2018. SWE: Snow water equivalent. Dec_TG: mean December temperature gradient.

Climatic conditions of the region suggest cold event for facet metamorphism and thaw events. The thawing events increase the ice layering in the snowpack, as experience in other northeast mountain such as Mt Washington (Joosen, 2008).

4.2 *Snowpack characteristics*

Analysis of snow grain types is a good proxy to characterize the dominant metamorphism process such as rounding or faceting (e.g. Madore et al., 2018). The results suggest three main snow grain types for both study areas: Faceted crystals (23%) and melt-freeze crusts (22.5%) and fragmented precipitation particles (21.5%)(Figure 2). The Chic-Chocs range is mainly dominant by facets layer (30 %). Along the coast, the facet is less present (16%)(Figure 2). The dominance of facets is in accordance with the dominance of strong metamorphism and continental classification for both study area (Table 1). The melt-freeze crust is present in both study area in a different but significant proportion: 28% coast and 16% Chic-Chocs (Figure 2). The melt-freeze crust explains the maritime influence with thawing/rain-on-snow event. The absence of surface hoar is a characteristic of the region.

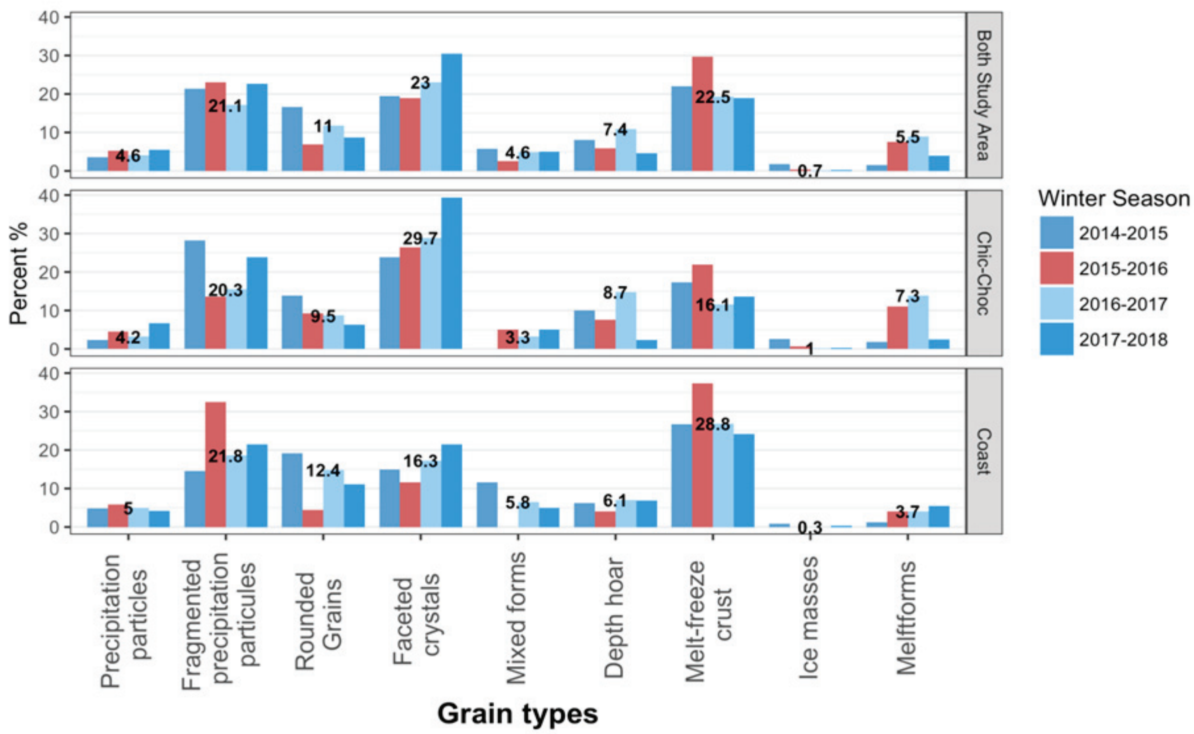

Fig.2 : Representation of the presence of snow grains type for the winter seasons 2014-2015 to 2017-2018. The season 2015-2016 for the coast area have only 3 snow profile. Approximately 10-20 snow profile was dug every winter season for both study site. The number represents the average for all the season. The color of each year is the result of the snow climate classification (Table 1): blue years represented continental classification and red years are maritime classification.

Difference in the prevalence of facets (more in the Chic-Chocs) and the melt-freeze crusts (more on the Coast) show the maritime influence more present along the coast. Fragmented precipitation particles represent the second most prevalent snow grains type for both study area with presence around 15 to 20%.

4.3 Avalanche Problems

The analysis of the past forecasting data reveal dominant snow avalanche hazard (Shandro and Haegeli, 2018). The region is characterized by the dominance of wind slab avalanche problem for every winter season (58.5%).

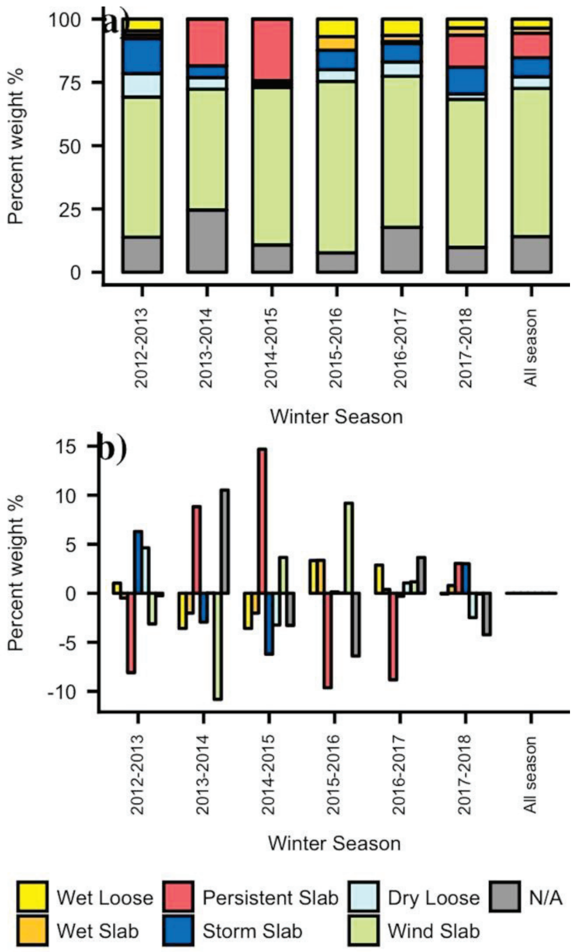

Fig.3: Representation of avalanche problems from Avalanche Québec forecasting data for the winter season 2012-2013 to 2017-2018, Chic-Chocs range data only. (a) Avalanche problem for each winter season and the mean avalanche problem percent for all winter season. (b) Anomalies for each winter season are represented by the difference from the mean of all winter season.

Wet slabs and loose wet avalanches have anomalies with none of these types of instabilities for the season 2013-2014 and 2014-2015 (-2.0% and -3.5%). These seasons also have the most persistent slab instabilities with +8.8% and +14.6% (Figure 3-b). Both of these seasons are continental with the coldest mean air temperature and the absence of significant thaw events (table 1).The persistent slab problem is the most variable instabilities throughout every winter season, with an average of 9.6% (Figure 3). The season 2012-2013, 2015-2016 and 2016-2017 has no persistent instabilities. The winters 2012-2013 and 2015-2016 were classified as maritime with warmer mean air temperature and rain-on-snow events (table1). The case where no avalanche problem was issued represent 14% for all winter season (Figure 3-a).

5. DISCUSSION

5.1 Data quality and reliability

Meteorological data used for the snow climate classification contain bias. The representability of the weather station to the study area is an issue. The Cap Madeleine weather station is nearly 20 km from the study area. However, consistency between climatic conditions, snowpack data and avalanche problem show quality in the meteorological data. The forecast data present also a certain amount of bias. Variability between winter seasons can be attributed to a change in staff and forecasting guideline toward each winter season. However, each year has anomalies that can be attributed to climatic conditions and ultimately to snow climate classification result (table 1). The combination of multiple types of data shows the robustness of the methodology develops in this study.

5.2 Difference between the coast and the inland massif

Difference in altitude, the distance from St-Lawrence Gulf and the trajectory of low-pressure cell can explain major difference in climatic conditions and snowpack structure. Some depression can affect the peninsula in different ways as the freezing level is in between both study area and cause different types of instabilities. These differences in meteorological events can create different snow layer (wind slab or melt-freeze crust) in the snowpack.

5.3 Snow climatology

The use of multiple methodologies in this snow climate research shows the specificity of north-east snow avalanche climatology and the need to use different data to fully understand the avalanche regime of a mountainous region. The result of the climate classification proposes a continental snow climate with some maritime exception. If we compare these results with data from western Canada (Shandro and Haegeli, 2018). The result shows mostly continental classification with some transition exception. The snow climate classification results of the study area don't fit into the three classic snow climate develop in western America. The snow climatology of the Japanese Alps has been described by Ikeda et al (2009) with two study areas: the Japanese sea side mountain (northern Japanese Alps) and the central Japanese Alps. Similarities were found with the central Japanese Alps and the Gaspé Peninsula. Both of these regions have the same snow climate classification results with the Mock and Birkeland (2000) methodology. Their results show continental classification results with maritime exception (Ikeda et al, 2009). The snowpack structure is similar with dominance of faceted crystals and melts forms (Ikeda et al, 2009). They propose a new nomenclature for the central Japanese Alps as rainy continental snow climate for specific characteristics (Ikeda et al, 2009). We thus propose to adopt the rainy continental for the snow climate of the Gaspé Peninsula. The term rainy continental express the major continental component and the maritime influence. The rainy continental might be a better fit for peninsular or insular continental snow climate.

6. CONCLUSION

In this study, we present a new snow climate classification specific to the Gaspé Peninsula. This classification can be applied to a northeastern coast climate characterize by rainy continental climate. We use several methodologies to fully characterize the snow climate and avalanche regime of the study area. This methodology shows the benefit of using several methods and types of data. The combination of the flowchart of Mock and Birkeland (2000), snowpack data and avalanche problem data should be considered for snow climate studies in the future. The similarity of climatic and snowpack characteristics with the central Japanese Alps were shown (Ikeda et al, 2009). The term rainy continental shows a snow climate with a major continental component and maritime influence. We therefore propose this new nomenclature for the study area as a rainy continental snow climate.

REFERENCES

Armstrong, R. L. & Armstrong, B. R. (1987). Snow and avalanche climates of the western United States. Dans Salm, B. and Gubler, H. (eds.): Avalanche Formation, Movement, and Effects. IAHS Publication 162. Wallingford, Oxen: International Association of Hydrological Sciences, 281-294.

Canadian Avalanche Association (2014). Observation Guidelines and Recording Standards for Weather, Snowpack and Avalanches. Canadian Avalanche Association. 92 pages.

Fortin, G., Hétu, B. & Germain, D. (2011). Climat hivernal et régimes avalancheux dans les corridors routiers de la Gaspésie septentrionale (Québec, Canada), Climatologie, vol. 8, p.9-25

Fortin, G., & Hétu, B. (2013). Estimating winter trends in climatic variables in the Chic-Chocs Mountains, Canada (1970–2009). International Journal of Climatology, 34(10), 3078-3088.

Gagnon, R.-M. (1970). Le climat des Chic-Chocs. Ministère des Richesses naturelles du Québec, Service de la Météorologie, Rapport M.P.-36, 103 p.

Gauthier, F., Germain, D & Hétu, B. (2017). Logistic models as a forecasting tool for snow avalanches in a cold maritime climate: Northern Gaspésie, Québec, Canada. Natural Hazards. DOI 10.1007/s11069-017-2959-3.

Germain, D., Filion, L. & Hetu, B. (2009). Snow avalanche regime and climatic conditions in the Chic- Choc Range, eastern Canada. Climatic Change, 92(1-2): 141-167.

Germain, D., Hétu, B. & Filion, L. (2010). Tree-Ring Based Reconstruction of Past Snow Avalanche Events and Risk Assessment in Northern Gaspé Peninsula (Québec, Canada). Tree Ring and Natural Hazards : A state-of-the-art, vol.41, 51-73.

Hägeli, P. & McClung, D. (2007). Expanding the snow-climate classification with avalanche-relevant information: initial description of avalanche winter regimes for southwestern Canada. Journal of Glaciology, vol. 53: 181, p.266-276.

Ikeda, S. & Wakabayashi, R. (2009). A study of snow climates in the Japan Alps: Comparison to snowclimate in North America. Cold Regions Science and Technology, vol.59, p.119-125.

Joosen, C. (2008) The importance of micro-scale avalanche forecasting in Mount Washington's Tuckerman and Huntington ravines. Proceeding for the Internation Snow Science Workshop, Whistler 2008.

LaChapelle, E.R. (1966). Avalanche forecasting a modern synthesis, International Symposium on Scientific Aspects of Snow and Ice Avalanches. IAHS Publication 69. Gentbrugge, International Association of Hydrological Sciences, 350-356

Madore, J-B., Langlois, A. & Côté, K. (2018). Evaluation of the SNOWPACK model's metamorphism and microstructure in Canada: a case study, Physical Geography, DOI: 10.1080/02723646.2018.1472984.

McClung, D.M., & Schaerer, P. (2006). The Avalanche Handbook. 3e éd., Seattle : The Mountaineers Book, 342 p.

Mock, C.J. & Birkeland, K. (2000). Snow avalanche climatology of the Western United States. Bulletin of the American Meteorological Society, vol.81, no. 10, p. 2367-2390.

Shandro, B & Haegeli, P. (2018). Characterizing the nature and variability of avalanche hazard in western Canada. Natural hazards and Earth System Sciences, vol.18, p.1141-1158.

Sturm, M., Holmgren, J. & Liston, G.L. (1995). A Seasonal Snow Cover Classification System for Local to Global Applications, Journal of Climate, vol. 8, p. 1261-1283.