Natural Resources Canada | Ressources naturelles Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8190

Inferred spring discharge characteristics of the Saguenay River, Quebec between ca. 1850 and ca. 1900 based on sediment texture proxy data

C.T. Schafer

2017

Celebrating 175 yrs

Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8190

Inferred spring discharge characteristics of the Saguenay River, Quebec between ca. 1850 and ca. 1900 based on sediment texture proxy data

C.T. Schafer

2017

Permanent link: https://doi.org/10.4095/306170

Recommended citation
Schafer, C.T., 2017. Inferred spring discharge characteristics of the Saguenay River, Quebec between ca. 1850 and ca. 1900 based on sediment texture proxy data; Geological Survey of Canada, Open File 8190, 52 p. https://doi.org/10.4095/306170

Abstract

This study explores the potential of sediment textural variation as a proxy for spring freshet magnitude variation of the Saguenay River using fine sand to fine silt fractions that have been preserved in Saguenay River prodelta sediments deposited in the northwestern sector of the Saguenay Fiord's North Arm. High sedimentation rates and particulate organic matter fluxes have created a poorly oxygenated seafloor environment in parts of the North Arm that is virtually free of bioturbating organisms thereby facilitating the preservation of identifiable yearly increments of sediment that accumulate mostly during the River's annual spring freshet. A particle size (2.3 to 6.3 phi i.e., 0.220 mm to 0.013 mm) median diameter (MD) proxy of spring freshet magnitude determined at one cm intervals in a piston core collected in 1982 reflects year-to-year variability of the River's spring freshet magnitude during the 19th and most of the 20th century. This study focuses on the second half of the 19th century during which MD data records an estimated 19 year long interval of relatively small MD's (LMDI) that is estimated to have occurred between ~1871 and ~1888. Compared to the later decades of the 20th century MD record, the second half of the 19th century and the early part of the 20th century to about 1912 shows a relatively higher frequency of larger average MD that appears to imply a more frequent occurrence of stronger spring freshet intervals of comparatively lower temporal variability. Within the 1850 - 1912 interval, the MD proxy suggests a generally decreasing freshet magnitude trend from ~1865 to ~1871 that is followed by the LMDI period of reduced freshet magnitudes featuring MDs that are typically less than 55 um. The LMDI is succeeded by a generally increasing MD sequence suggestive of stronger freshets that persists until about 1912. An explanation for the apparent relatively low freshet magnitudes and low year-to-year variability of spring freshets during the LMDI in relation to previous and following decades is tentatively assigned to lesser amounts of snowfall during January and April and to relatively warmer January and February temperatures acting in concert with relatively lower March and April temperatures. These seasonal conditions show a general correspondence to warm (positive) Atlantic Multi-decadal Oscillation (AMO) phases that occurred between 1860 and 1891. In contrast, during the 20th century, cool (negative) AMO phases seem to be linked to intervals that include some of the highest recorded 20th century Saguenay River freshets witnessed in the 1970's. An analysis of the North Atlantic Oscillation (NAO)/MD relationship yielded mixed results. Not surprisingly, contradicting results also emerged in a comparison of AMO and NAO phases with respect to late 19th century local newspaper weather reports. In general, cooler spring and fall weather and stormy conditions were often associated with negative AMO conditions and with both positive and negative NAO's.

Table of Contents

List of Tables

Table 9. Comparison of annual maximum mean monthly discharge (AMMMD) averages versus annual mean monthly discharge (AMMD) averages for several AMO conditions.

Table 10. Relationships between NAO and AMO conditions and newspaper-reported weather events in the Saguenay Region during the latter half of the 19th century.

List of Figures

Figure 1. Location of piston core 82008-72 in relation to dams and cities situated along the channel of the Saguenay River. Lehigh gravity core (D-1) was collected in 1979 during an earlier investigation (Smith and Schafer, 1987). Bathymetry (fathoms) in the vicinity of the two coring sites is shown in the inset located in the lower left-hand corner of the figure. The 40 fathom contour line equates to a water depth of approximately 73 m.

Figure 2. Photographs of X-radiographs from unbioturbated (upper X-radiograph, right side), partially bioturbated (lower X-radiograph) and somewhat more intensely bioturbated sections (upper X-radiograph, left side) of core 72. Relatively thin dark layers reflect OM-enriched deposits that apparently accumulate preferentially during the relatively low MMD seasons. The upper X-radiograph shows the 1912 transition at 231 cm to distinctly unbioturbated sediments that marks the beginning of increased OM discharges from the pulp mill at Kenogami.

Figure 3. Bar graph of core 72 individual one cm thick subsample MD's in microns versus core depth. The estimated ages and core depths of various dated core horizons are shown along the right side of the figure. The plot itself depicts pattern of an increasing MD trend in the decades prior to 1850, a decreasing MD trend after ~1850 and again after 1912. These trends are also reflected in averaged values for sand, the T Ratio and MD averages noted in Table 3. The post-1912 interval features relatively lower and more variable MDs that are superseded by a rising MD trend that starts just before 1971. The ~1853-~1915 interval outlines an apparent 62 year cycle of falling and rising spring freshets.

1.0 Introduction

The prodelta seafloor environment of the upper reaches of the Saguenay Fiord's North Arm features relatively high sediment organic matter concentrations, high sedimentation rates and hypoxic to anoxic bottom water conditions that are associated with seasonally-modulated organic particle transport features of the Saguenay River (Smith and Ellis, 1982; Schafer *et al.,* 1980; 1983; Smith and Schafer, 1987; Schafer *et al.,* 1990). Under these conditions, life has been difficult to impossible for local bioturbating species. The upper part of a 5.6 m long piston core collected in the study area in April of 1982 contains completely unbioturbated sediments between the 231 cm horizon and the upper part of the core where increased fluxes of local industry sources of organic matter have impacted this part of the prodelta's sediment surface since about 1912 (Pocklington, 1976; Pocklington and Leonard, 1979). Prior to 1912, there is evidence of slight mixing at annual layer boundaries, but the layers themselves are still easily recognized in X-radiographs due to prevailing high sediment rates and to fluxes of mixed industrial and naturally - derived organic matter (OM). Jones and Mann (2004) note that in rare cases, annually-layered sediments can occur in coastal or estuarine environments where deposition rates are unusually high (e.g., James Bay, D'Anglejan, 1982). This paper describes the results of grain size and OM determinations that were performed on each centimeter of a piston core and discusses what can be inferred from these data about the Saguenay River's spring freshet characteristics, especially during the 19th century period of transition from cooler Little Ice Age (LIA) to warmer early 20th century climate conditions. The 1850-1900 time span forms the latter part of an 1830s to 1890s period that is sometimes referred to as the "changeover period" (e.g., Baron and Borns, 1993). The 1850 to 1890 part of the changeover period is of particular interest because several recent studies of the De Vries/Suess solar cycle have suggested that, during the next 50 years, the cycle might be steering the Earth's climate conditions toward those that were witnessed during the last decades of the 19th century (e.g., Ludecke *et al.,* 2015; Casey, 2011; Osterberg *et al.,* 2014).

2.0 Depositional setting

The Saguenay River valley incises crystalline rocks of the Canadian Shield that are overlain by deposits of raised marine clays and littoral quartz sands. The marine clays (Leda clays) were deposited in an arm of the late glacial Champlain Sea called the *Mer de Laflamme* during a high relative sea level stand about 8000 - 11000 years before present (BP) at the time of the melting and retreat of the Late Wisconsinan ice sheet (Bouchard *et al.,* 1983). Littoral sands prograded over the clays as relative sea level fell during the subsequent interval of postglacial crustal rebound.

During the Saguenay River's annual spring freshet (April-June), meltwater from snow and frozen rain collected within its ~78000 km^2 drainage basin transports relatively easily eroded unconsolidated sediment (sands and coarse silts) along with finer grains and particulate OM from the watershed's tributaries to the main Saguenay River channel. These eroded and transported particles are likely often stored temporarily in the main river channel but are subsequently washed out into the North Arm basin during the annual freshet as both suspended load and bedload (e.g., Kesel *et al.,* 1992). Upon reaching the North Arm, the River's flow undergoes a pronounced decrease in speed as the channel widens and water depth increases from about 5 m to more than 200 m thereby promoting rapid particle deposition (see Figure 1).

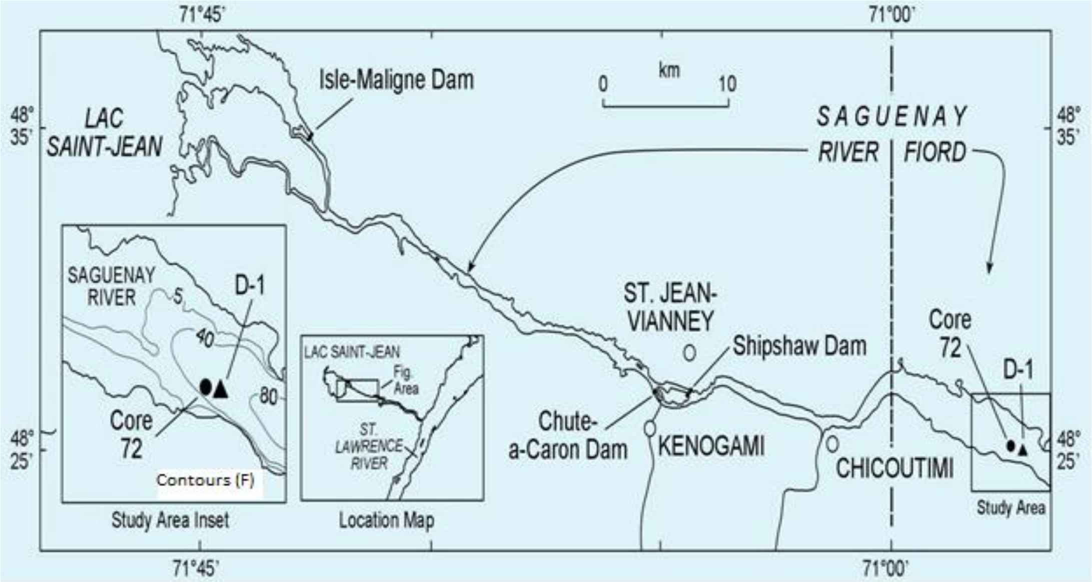


Figure 1. Location of piston core 82008-72 in relation to dams and cities situated along the channel of the Saguenay River. Lehigh gravity core (D-1) was collected in 1979 during an earlier investigation (Smith and Schafer, 1987). Bathymetry (fathoms) in the vicinity of the two coring sites is shown in the inset located in the lower left-hand corner of the figure. The 40 fathom contour line equates to a water depth of approximately 73 m.

3.0 Methods

Core 82008-72 was collected in April 1982 from a water depth of approximately 88 m (~48 fathoms) near the southern shore of the Saguenay Fiord's North Arm (Lat. 48˚25'00"; Long. 70˚51'30") using a Benthos piston corer (Figure 1; *Dawson*, 1982). In the laboratory, the core was split, described and X-rayed with a Phillips 150 KV water-cooled industrial unit. The working half of the core was cut into one cm thick slices (about 50 cm^3 wet volume per slice) and freeze dried. Dried samples were subsampled for Pb^{210} analysis and the remaining sample was weighed and then heated for eight hours at $550^{o}C$ to remove the organic matter (OM) component. After the samples cooled, they were re-weighed to estimate the OM percentage and then were soaked in a 5% solution of sodium hexametaphosphate for five hours to aid in their disaggregation after which they were sonified for 20 minutes to insure complete desegregation. Next, the samples were washed through a 420μm sieve to remove very coarse particles. The <420μm fraction was analyzed to determine its grain size distribution using a Coulter Counter Model TA II fitted with a 560μm aperture. The core's Pb^{-210} chronology was determined according to the methods given in Smith and Walton (1980) and in Smith and Schafer (1987). It was used to estimate both the variability and the long-term average annual sedimentation rate in this part of the North Arm basin. An independent measure of average annual sedimentation rate was obtained by measuring annual layer thicknesses on core X-radiographs. This study used the average of the two independent determinations that is referred to here as the composite sedimentation rate.

A nonparametric test of the statistical significance of the difference between averages of various sediment texture, OM, river discharge, snow, and total precipitation data for various time intervals represented in the core was determined using the Standard Error of the Difference (SE) statistic (Moroney, 1973). In a sample of n_1 items whose standard deviation is SD_1 and in a sample of n_2 items whose standard deviation is SD_2, the variance for the distribution of the difference between sample means $(X_1 - X_2)$ is equal to the sum of their individual squared standard deviations (SD^2) and is given by:

$$\mathrm{Var}\,(X_1 - X_2) = \frac{(SD_1)^2}{n_1} + \frac{(SD_2)^2}{n_2}$$

The SE is calculated by dividing the square root of the sum of the two squared SD values into the difference between the two mean values or:

$$SE_{X1,\,X2} = \frac{X_1 - X_2}{\sqrt{\frac{(SD_1)^2}{n_1} + \frac{(SD_2)^2}{n_2}}}$$

A difference of more than two SE's between two sample mean values is considered as *probably significant* and a difference between two means of three or more SE's is regarded as *definitely significant*. The probability of a difference between two means of three or more SE's arising by chance in random sampling is considered to be less than one half of one percent ($P = <0.005$).

Saguenay River monthly discharge data analyzed for this report was extracted from a 1914-1989 data set supplied by Environment Canada for the gauging station at Isle Maligne (# 02RH001) near the mouth of Lake Saint-Jean. Temperature and precipitation data sets for Father Point and Chicoutimi (stations 7061440 and 7061442) were also supplied by Environment Canada as per a request by the authors in 1990. A compilation of 19th century weather information reported in local Saguenay Region newspapers was obtained from history researchers at the University of Quebec at Chicoutimi under the terms of a Geological Survey of Canada contract (# 23420-1-M539/01-osc/mas). The contract produced a 5 volume set of findings based on reviews of *Le Canadien*, *Le Progress du Saguenay* and *Varia Saguenayensia* that together constituted a total of more than 1500 pages (Girard *et al.,* 1992a, b, c, d, and e). The five volumes cover the 1807 to 1898 period.

4.0 Results

4.1 Chronology

4.1.1 ^{210}Pb dating

^{210}Pb geochronology results for core 72 suggest that the sediments at the coring site accumulated at an average rate of about 2.80 cm yr^{-1}. Conversely, annual layer thickness measured in X-radiographs yielded an average sedimentation rate of 2.66 cm yr^{-1}. As such, based on a grand average composite sedimentation rate of 2.73 cm yr^{-1} derived from both methods, the 558 cm long core should cover approximately a 190-year period (i.e., 1982 - ~ 1792). The core 72 composite sedimentation rate is generally comparable to the average sedimentation rate of 2.85 cm yr^{-1} determined for nearby core D-1 that was collected in 1979 by Smith and Schafer (1987).

4.1.2 Events of known age

The 1912 (231 cm), 1924 (200 cm) and 1971 (55 cm) horizons of core 72 are readily evident from median diameter (MD) and x-radiograph data. A distinctive layer of gray-coloured postglacial Leda clay was deposited at these times throughout much of the North Arm basin as the result of a major landslide that occurred in May 1971 (Smith and Schafer, 1987; Schafer *et al.,* 1980, 1983, 1990). The bottom of the 1971 clay layer is clearly visible in the split halves of core 72 at a depth of 54 – 55 cm. The 1912 horizon is easily distinguished in X-radiographs at a core depth of 231 cm. It is marked by a change to distinctly sharp (unbioturbated) annual layer boundaries that reflect the sudden increase of industrially-produced OM concentrations to values that are often higher than 8%, and by lighter thick sand-rich spring freshet sediments with darker and thinner overlying late summer, fall and winter OM-enriched deposits (Schafer *et al.,* 1983, 1990; Smith and Schafer, 1987). The sharp 1912 OM percentage increase above 231 cm is coincident with the installation and operation of the first large pulp processing machines at the Kenogami pulp mill in 1912. The city of Kenogami is situated on the bank of the Saguenay River about 28 km upstream from the core 72 location (see Figure 1). The higher post – 1912 OM flux appears to have eliminated virtually all bioturbating species in the northwestern part of the North Arm basin from which core 72 and the older Lehigh core D-1 were retrieved. It has apparently fostered the dominance of anoxic versus hypoxic seafloor conditions in this part of the Saguenay River prodelta, an area that lies directly in the path of the River's discharge plume.

4.1.3 Other age determinants

The 1912 OM reference horizon was used in conjunction with the composite sedimentation rate described earlier to estimate the approximate core depths of two 19th and two 20th century core horizons discussed below and the potential error engendered in using the composite sedimentation rate for dating extrapolations. For example, when the composite sedimentation rate and 1912 reference horizon were used to estimate the base of the 1971 slide deposit (a 59 years difference), the method produced an age date of 1976 i.e., 5 years later than the event. A smaller slide that occurred at Kenogami in 1924 was identified by extrapolating up-core from the 1912 horizon to the 1924 horizon using the composite sedimentation rate. This technique predicted the depth of the 1924 slide at about 198 cm supported by both the 200 cm and 201 cm subsamples that contain high percentages of relatively fine particles (5.3-6.3 phi), and by comparatively low MD values of less than 35 microns.

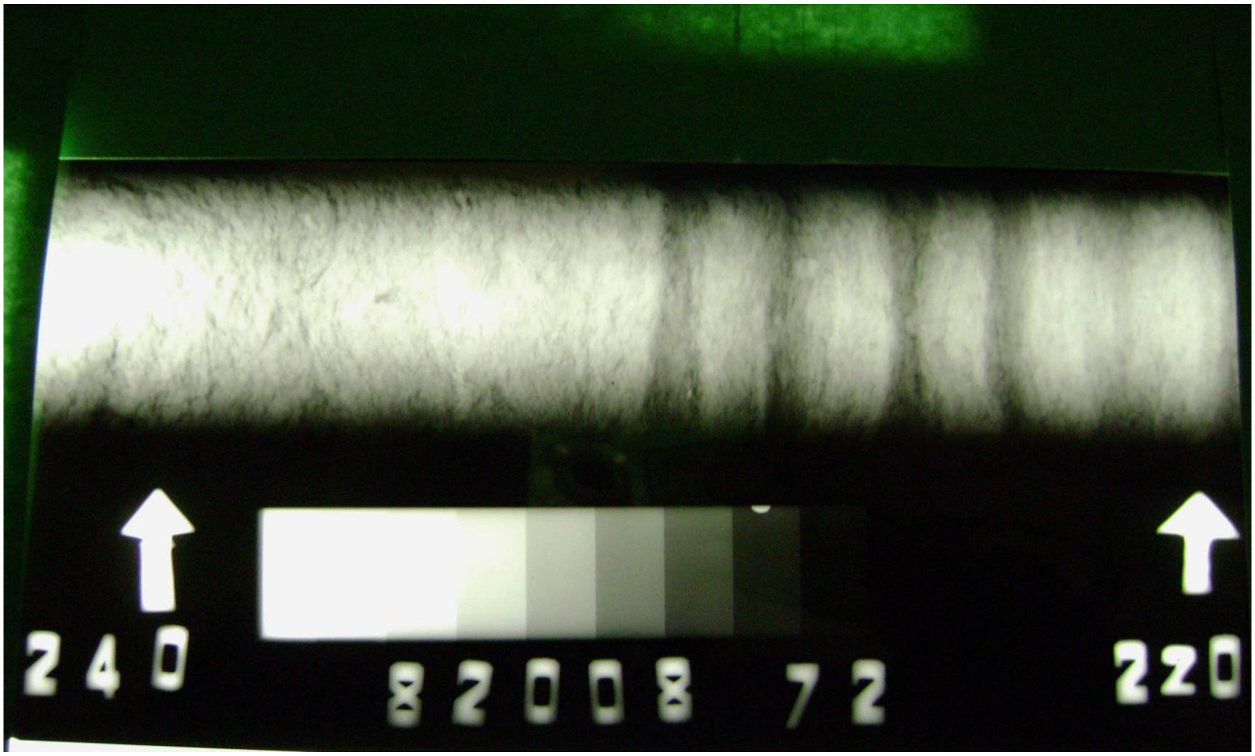
For older (pre-1912) sections of the core, age extrapolations based on the use of the composite sedimentation rate method, and with reference to the temporal variation of the sediment accumulation rate (landslide deposits omitted) given for nearby core D-1 in Schafer and Smith (1987), indicate a potential dating error of $^{+}/_{-}$ one year for the ~1900 level of core 72. Potential dating error results for the ~1850 and ~1800 horizons are respectively +/- 6 years and +/- 12 years. In light of the degree of dating uncertainty, core interval textures and OM comparisons presented in the following parts of this paper have been confined primarily to half-century averages. Consequently, the detailed discussion of the ~1850 -~1900 textural signal (below) must, therefore, be viewed in light of the potential dating error inherent in the extrapolation method.

4.2 Sedimentary structure

Observations of the split wet core surface, and of related X-radiographs, indicate three distinctive sediment structure types (Figure 2; Table 1). Annually deposited layers having very sharp (unbioturbated) boundaries throughout the 0 – 231 cm core section corresponds to the 1982 – 1912 period (e.g., Figure 2, upper image, right side). Two older intervals (231 cm [1912] – 258 cm [~1902] and 319 cm [~ 1879] – 433 cm [~ 1838]) appear to be relatively more intensely bioturbated (Figure 2, upper image, left side). Two other core sections showing faint layering (incomplete bioturbation) occur between 259 cm and 318 cm and between 434 cm and 558 cm (e.g., Figure 2, lower image). These two deeper core intervals are estimated to correspond respectively to the ~1902 – ~ 1878 and to the ~ 1837 – ~ 1792 periods.

4.3 Organic matter

Average OM percentage is highest in the 0 – 231 cm [1982 – 1912] core section and shows a regular decrease in the older and deeper core sections reaching an average value of less than 4% in the oldest section (Table 1).


240
82008 72
220

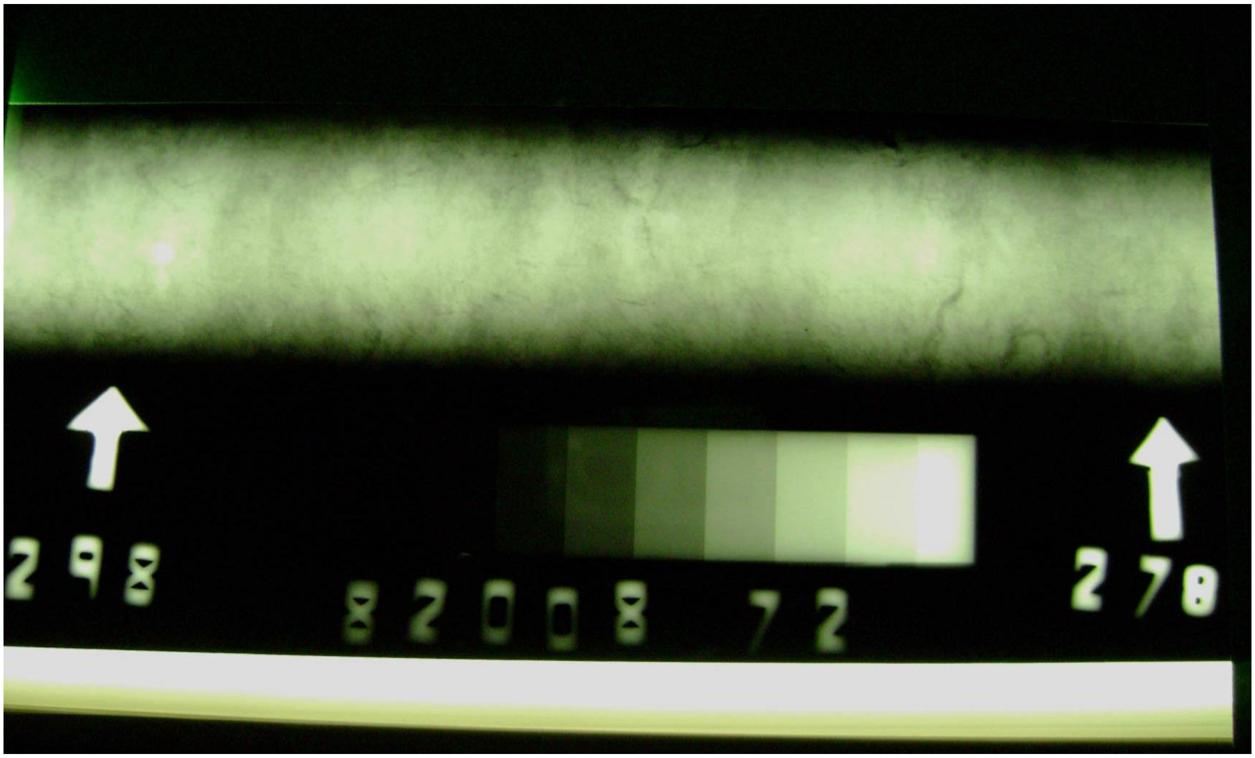


Figure 2. Photographs of X-radiographs from unbioturbated (upper X-radiograph, right side), partially bioturbated (lower X-radiograph) and somewhat more intensely bioturbated sections (upper X-radiograph, left side) of core 72. Relatively thin dark layers reflect OM-enriched deposits that apparently accumulate preferentially during the relatively low MMD seasons. The upper X-radiograph shows the 1912 transition at 231 cm to distinctly unbioturbated sediments that marks the beginning of increased OM discharges from the pulp mill at Kenogami.

Interval No.	Section/period	Structure	Average OM (%)	Int. 2	Int. 3	Int. 4	Int. 5
1	**0 - 231 cm** **1982 - 1913**	**DLM**	**9.94**	**SE = 11.7**	**SE = 21.6**	**SE = 22.6**	**SE = 23.3**
2	**231 - 258 cm** **1912 - ~1902**	**BIO**	**5.74**		**SE = 5.7**	**SE = 6.5**	**SE = 7.1**
3	**259 - 318 cm** **~1902 - ~1878**	**SLM**	**4.25**			**SE = 2.4**	**SE = 4.2**
4	**319 - 433 cm** **~1879 - ~1838**	**BIO**	**4.03**				**SE = 1.6**
5	**434 - 558 cm** **~1837 - ~1792**	**SLM**	**3.89**				

Table 1. Occurrence of distinctly laminated (DLM), slightly laminated (SLM) and more intensely bioturbated (BIO) sections of core 72 observed in X-radiographs. The table also shows the down-core decrease in average OM percentages and the SE values for the statistical difference for OM averages of the five core sections. The comparison of OM averages for intervals 4 and 5 is the only instance in which the corresponding SE is less than 2 (*not significant*).

5.0 Discussion

5.1 Varve-like deposits

Each annual layer deposited at the coring site typically consists of a comparatively thick and coarse lithic particle basal layer that accumulates during the spring freshet and an overlying relatively fine-textured and thinner OM - enriched layer that builds up during the remainder of the year. The structure, texture and composition of typical seasonally-deposited layers observed at the coring site are distinctive from those linked to major floods and especially to local sediments sourced from landslides of postglacial-age raised marine clays (e.g., Leduc *et al.,* 2002; St. Onge and Hillaire-Marcel, 2001; Schafer *et al.*,1980; 1990). During much of the 20th century, the averaged May + June mean monthly discharge (MMD) of the Saguenay River was almost three times as large as the January + February average MMD (Table 2). The low fall and winter river discharge magnitude (Table 2), in conjunction with OM-driven locally depressed bottom water oxygen concentrations, helps to explain the preserved unbioturbated varve-like deposits that occur in the northwestern area of the North Arm. Standard Deviations and Coefficients of Variation (CV) of averaged MMD data show a similar seasonal pattern with highest values during spring freshet months and lowest values during winter months.

Discharge Data/Seasonal Period	**May - June**	**Sept. - Oct.**	**Jan. - Feb.**
Seasonal Average MMD (M^3S^{-1})	**X_1 = 2652**	**X_2 = 1450**	**X_3 = 939**
Std. Dev.	**999**	**480**	**279**
Coef. Var. (%)	**37**	**33**	**30**
Std. Error Difference $X_1 – X_2$	**12.4 (P=<0.005)**		
Std. Error Difference $X_1 – X_3$	**18.7 (P=<0.005)**		

Table 2. Averaged MMD's for the Saguenay River during spring, fall and winter months for the 1914 to 1989 period measured at the Isle Maligne dam (station 062901). The large values of the Standard Error (SE) for the difference between bimonthly mean values reflects the pronounced contrast between averaged seasonal discharge magnitudes despite the construction of three dams during the first half of the 20th century. SE values greater than 4 are considered to be *very significant* (Moroney, 1973).

5.2 Why median diameter?

Previous sediment core investigations that have addressed year-to-year textural/spring freshet associations in this part of the Fiord during the 20th century have focused primarily on the total sand fraction (e.g., Smith and Schafer, 1987; Smith and Ellis, 1982). In contrast, this report relies instead on half-century averaged MD data for the following reasons. Firstly, the MD parameter is a more comprehensive measure of the particle size distribution compared to just one size fraction, and one that can be easily adapted for other similar paleohydrologic investigations. Secondly, a Factor Analysis carried out on core D-1 data (Smith and Schafer, 1987) showed that Factor 1 (74% of total variance) had high loadings on the 5-6 phi (medium and fine silt) size classes while Factor 2 (24% of total variance) was loaded on the 3-4 phi sizes (very fine sand). These results imply that, in addition to the total sand fraction, the transport of a range of silt-size particles is likely also related to seasonal river discharge variations and should therefore be considered in developing an utilitarian proxy textural indicator of river discharge. This notion is consistent with well-known and time-tested particle erosion and transport models (e.g., Hjulstrom, 1939; Sly *et al.,* 1982; 1983). Thirdly, the more easily eroded and transported fine sand (2-3 phi) + very fine sand (3-4 phi) fraction average for the ~1850-~1900 interval is more than 0.5% to 1.3% higher, and its standard deviation is lower than for the other two half century intervals (Table 3). More importantly, the between-intervals SE test of MD averages indicates a significant difference between the ~1850-~1900 interval with respect to all of the other intervals being considered (Table 4). All other sand fraction average comparisons, yielded SEs of less than 2.0 (not significant). Fourthly, SEs for T ratio values (fine sand+ very fine sand/medium silt) half century average comparisons show only two significant differences for the ~1800-~1850/~1850-~1900 and the ~1850-~1900/1950-1982 intervals. All other comparisons of T ratio averages feature SEs of less than 2.0 and are considered as being *not significant*. Lastly, it has been observed during this study that various parts of the total sand fraction of core 72 sometimes do not show the expected direct relationship to spring freshet magnitude seen in previous studies of 20th century deposits that use the entire sand population (e.g., core D-1; Smith and Schafer, 1987; Smith and Ellis, 1982; Schafer *et al.*,1983). For example, for the 3.7 phi fraction (very fine sand) of core 72, its weight percentage is greater than 20% for the June 1974 mean monthly discharge of 4230 M^3Sec^{-1} but is only about 15% for the higher May 1976 MMD of 4940 M^3Sec^{-1}. A similar inverse relationship for these two years is also evident for the 3.3 phi (very fine sand) fraction.

PARAMETER/INTERVAL	**~1800-~1850**	**~1850-~1900**	**~1900-1950**	**1950-1982**
Fine + Very Fine Sand (%)	9.54	10.51	9.19	9.99
Std. Dev. F+VF Sand	4.16	3.93	4.86	5.35
Av. Ratio T = 2.3-4.0 phi/5.0-6.0 phi	1.15	1.37	1.25	1.16
Std. Dev. Ratio T	0.68	0.64	0.79	0.66
Av. Median Diameter (microns)	49.91	53.56	50.74	49.59
Std. Dev. Median Diameter	8.79	7.98	10.72	10.03
Number of Subsamples/interval	129	137	141	101

Table 3. Core 82008-72: Interval averages of textural parameters. The ~1850-~1900 interval is marked by its higher percentage and lower standard deviation (better sorting) of fine plus very fine sand, by a higher T –ratio and by a somewhat larger average MD compared to the one older and two younger intervals.

5.3 Sediment grain size

MD determinations for core 72 range between 24.18 um to 84.14 um (Figure 3). Several adjacent relatively small MDs are prominent within an interval (~52-~54 cm) that records the flux of "Leda Clay" carried to the basin at the head of the Fiord by the Saguenay River following the 1971 Saint-Jean Vianney Landslide (Schafer *et al.,* 1980;1983). Averaged half century MD results for core 72 (along with fine+very fine sand and T-ratio 50-year averages) show their highest value for the ~1850-~1900 interval (Table 3). MD averages for that interval also feature the smallest standard deviations compared to the other two half-century intervals and the one 32 year interval (Table 3). These textural differences are also reflected by MD averaged interval statistical comparisons that show SE values of more than 2.0 (*probably significant*) for the ~1850-~1900 MD average compared to SEs for the other three intervals suggestive of something distinctive about the ~1850 - ~1900 data (Table 4). In the ~1850-~1900 section of core 72, only 4 of the 137 subsamples (~3%) have MDs of less than 40 um. In contrast, subsamples with median diameters less than 40 um are relatively frequent between ~1900 and 1950 (16%), and are often also observed as well during the first half of the 19th century (10%)

(Figure 3). The basic temporal pattern of MD variation in the ~1850 -~1900 interval is generally U-shaped with relatively more variable and rapidly declining MD's between ~1850 and ~1870. A post-LMDI trend of rising MD's occurs between ~1889 and ~1905. However, the apparent rate of MD increase for this younger interval is less than the rate of decrease observed for the older pre-LMDI interval. The span of the LMDI is estimated to have occurred from about ~1871 to ~1888. The discussion section that follows below presents information on climate conditions that may provide clues to explain some of the reasons for the spring freshet magnitude variation pattern suggested by core 72 MD proxy data.

INTERVAL	**~1800 - ~1850**	**~1850 - ~1900**	**~1900 - 1950**	**1950 - 1982**
~1800 -~1850	----	3.47	0.69	0.25
~1850 -~1900		----	2.49	3.28
~1900 - 1950			----	0.85
1950 - 1982				----

Table 4. SE values for comparisons of MD average values for the four multi-decadal intervals. They indicate that the ~1850-1900 MD average is statistically different at the *probably significant* SE level or better from the one older and the two younger core intervals.

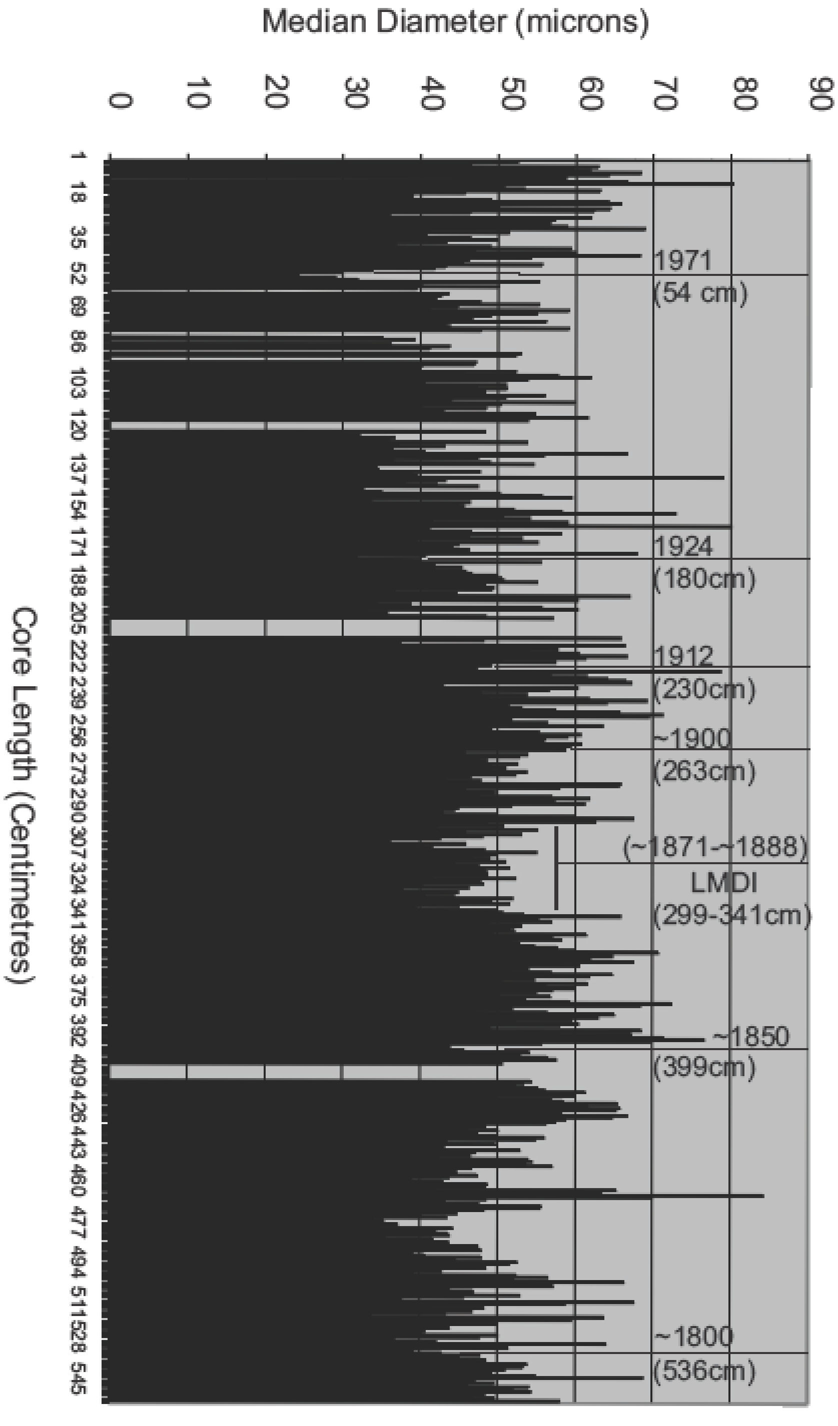

Median Diameter (microns)
0
10
20
30
40
50
60
70
80
90
1971
(54 cm)
1924
(180cm)
1912
(230cm)
~1900
(263cm)
(~1871-~1888)
LMDI
(299-341cm)
~1850
(399cm)
~1800
(536cm)
1
18
35
52
69
86
103
120
137
154
171
188
205
222
239
256
273
290
307
324
341
358
375
392
409
426
443
460
477
494
511
528
545
Core Length (Centimetres)

FIGURE 3

Figure 3. Bar graph of core 72 individual one cm thick subsample MD's in microns versus core depth. The estimated ages and core depths of various dated core horizons are shown along the right side of the figure. The plot itself depicts pattern of an increasing MD trend in the decades prior to 1850, a decreasing MD trend after ~1850 and again after 1912. These trends are also reflected in averaged values for sand, the T Ratio and MD averages noted in Table 3. The post-1912 interval features relatively lower and more variable MDs that are superseded by a rising MD trend that starts just before 1971. The ~1853-~1915 interval outlines an apparent 62 year cycle of falling and rising spring freshets.

5.4 Spring freshet variations and teleconnections

The following discussion of spring freshet modulators and "teleconnections" should be viewed in light of the numerous precautions regarding the interpretation of factors that control hydrologic responses to climate variability. For example, Fleming and Moore (2007) have stated categorically (and rightly so) that "even regionally coherent anomalies in meteorological forcing associated with a given climate mode can elicit different magnitudes, directions, and/or timing of hydrologic response within a region and even between adjacent watersheds…" As such, it would not be surprising if future research adds to, or contradicts, some of the interpretations offered below.

5.4.1 Precipitation and temperature effects

In certain areas, and over longer time scales, the scientific literature points to an inverse relationship of temperature with respect to floods and to peaks in seasonal discharge (e.g., Knox, 1993; DePutter *et al.,* 1998) although this relationship would be expected to vary from one region to another (e.g., Baker, 1987; Fleming and Moore, 2007). Other studies (e.g., Hartley and Keables, 1998; Rajagopalan *et al.,*1998) point to the importance of changing atmospheric circulation regimes in relation to annual snowfall that could modulate the influence of temperature, precipitation and snow storage and, in turn, spring freshet magnitude. To the degree that they are temperature-driven, it seems possible that such circulation regimes might develop in some regions as a consequence of changes in both extra-terrestrial and terrestrial forcing (e.g., Nigam and DeWeaver, 1998; Morgan, 1992; Enfield *et al.,* 2001; Landscheidt, 2001). An indication of the interplay between temperature and precipitation was revealed in a comparison of Saguenay River discharge magnitude and precipitation stored as snow (Smith and Schafer, 1987). They determined a correlation of $r = 0.62$ ($p = 0.001$) between precipitation stored as snow and freshet magnitude and noted that a 20th century decrease in both river freshet magnitude and the amount of precipitation stored as snow occurred abruptly in this part of Quebec during the latter part of the 1940's.

The ~1871 -~1888 LMDI interval of apparently reduced freshet magnitudes, was reported as generally one of relatively "cool" to "somewhat cool" average annual temperatures, "dry" to "somewhat dry" average annual conditions, and one of relatively cool fall seasons in southern New England (Baron *et al.*, 1993). Also, in their study of Maine agriculture between the years 1785 and 1885, Smith *et al*. (1981) noted that "The climate throughout the period was cool with short intervals of warm weather…. No major climate shift was at issue." Slonosky (2001), commenting on temperatures in Quebec during the 1740's part of the Little Ice Age, remarked that "instrumental data indicate that the climate, even during these short periods was variable, with mild winters alternating with severe ones." Chicoutimi temperature data for the late 19th century could not be found for this discussion. However, a complete record for the 1877 – 1925 interval was obtained for Father Point near the city of Rimouski which lies about 100 km downstream from the mouth of the Saguenay Fiord and about 200 km northeast of Chicoutimi. Averaged January and February temperatures for the 1877 -1882 period indicate relatively warmer winter weather at that time and location compared to both early and late 20th century intervals observed at Father Point, Rimouski and Chicoutimi i.e., in general agreement with the findings of Smith *et al.* (1981) for the Maine area (Table 5). Warmer winter months and colder spring temperatures might act sequentially by initially causing lesser amounts of precipitation stored as snow, while cooler spring temperatures could reduce the rate of melting of precipitation stored as snow and thus the magnitude of the spring freshet. These conditions offer another possible explanation for the years of relatively lower LMDI freshet magnitudes suggested by the MD proxy record. Central Europe spring temperature reaches its nadir around

1885 and is in general agreement with the eastern Quebec trend for March and April (e.g., Ludecke *et al*., 2015).

LOCATION	INTERVAL	January	February	March	April	# of years
Father Point	1877 – 1882	-12.49	-9.65	-6.27	0.21	6
Father Point	1921 – 1925	-14.51	-12.63	-5.48	0.40	5
Chicoutimi	1977 – 1979	-14.83	-13.86	-4.80	2.86	3

Table 5. Averages of mean monthly temperatures (winter and spring) at Father Point, Rimouski and Chicoutimi in degrees C for several 19th and 20th century intervals.

Total snowfall versus the Saguenay River's average may/June mean monthly discharge (MMD) points to the temperature/snow storage interaction. For example, 1977 was a particularly high total snowfall year as recorded at Chicoutimi (+ 400 cm) i.e., the highest total snowfall between 1960 and 1979. However, the River's average May/June MMD was only 2610 M^3/sec. In contrast, 1974 and 1976 May/June average MMD's were respectively 3880 M^3/sec and 3750 M^3/sec while the total snowfall in those two years was respectively about 390 cm (1974) and just under 350 cm (1976). Given the relatively higher 1977 total snowfall, the smaller magnitude of the 1977 freshet likely reflects a number of factors including temperature, total precipitation (TP), water vapour content of the atmosphere that controls the evaporation of snow, and possible river flow management policy for that year. Other possible explanations for the relatively low 1977 May/June average MMD include the fact that December 1976 and January to March average 1977 TP for Chicoutimi was respectively 14% and 19% lower in those months compared to 1974 and 1976. Two of the lowest TP months during 1977 occurred in March and May and they registered about half of the TP for those two months witnessed in 1974. In addition, March 1977 mean monthly temperature (MMT) at Chicoutimi was almost 6 degrees warmer than noted for that month in 1974 and 1976. It may have contributed to the exceptionally high April 1977 MMD for that year which was 22% higher than in April 1974 and 13% higher than in April 1976. May 1977 MMT at Chicoutimi ranged from about 1 to 5 degrees C warmer for that month compared to the May 1974 and May 1976 MMT's. The nine-month pre-freshet interval for those three years shows that October, November, December and June temperatures were respectively 2.0, 0.5-3.0, 1.0-6.0, and 2.5 to 3.5 degrees cooler in 1977 compared to those months in 1974 and 1976. TP and MMT differences appear to account for at least some of the reduced magnitude of the 1977 spring freshet and possibly for the shift in the discharge peak from June in 1974 and 1976 to May in 1977.

Evaluation of the incomplete snowfall record for Chicoutimi allows only a tentative comparison between average January through April snowfall for the 1877 – 1882 period in relation to the 1923 – 1930 and the 1971 – 1979 intervals (Table 6). Monthly averages show that there was more snowfall in January through March during the 1970's compared to the 1877-1882 period. This pattern is distinct from the snowfall record for Quebec City that is marked by virtually continuous annual snowfalls in excess of 400 cm yr^{-1} between 1873 and 1888 that do not recur again until 1908. This difference offers a good example of the spatial variation of precipitation over small distances (e.g., Bradley *et al*., 1987: Wigley *et al*., 1981). Based on the meager amount of temperature and snowfall data presented here, the tentative explanation for the LMDI interval seems to be linked generally to comparatively lower January through April snowfall and to relatively warm January and February temperatures. In contrast to the comparatively small MDs of the LMDI interval, the first two and last two decades of the ~1850-~1900 period show, respectively, a gradual decrease and a post-LMDI gradual rise of MDs that are both associated with more variable and higher MD values than noted for the LMDI, and which are suggestive of changes in the intensity and variability of the climate conditions that modulated the spring freshet during those decades. According to Karl *et al.* (1993), 78% of the variance in regional snow cover in North America can be explained by the anomalies of monthly mean maximum temperature that can vary regionally. An example of this phenomenon might be the flows of the Mississippi River that appear to have been relatively higher between 1873 and 1885 (Perry, 2001) i.e., opposite to what appears to have occurred in the Saguenay watershed during the LDMI.

INTERVAL	January	February	March	April	# of years
1877-1882	51.5	42.6	30.2	14.4	6
1923-1930	57.3	35.0	36.8	18.1	8
1971-1979	62.0	60.0	47.2	18.3	9

Table 6. Averages of mean monthly snowfall amounts at Chicoutimi in centimetres for several 19th and 20th century intervals (Station 7061440).

Overall, the entire ~1850-~1900 interval in the Saguenay Region appears to be contemporaneous with a gradual change beginning about ~1865 from wetter/snowy to less wet and back to wetter/snowy conditions by the mid ~1870's. The apparently less wet conditions of the 1877-1882 part of the LMDI are coeval generally with relatively higher January/February winter temperatures, lower March/April spring temperatures and by relatively lower amounts of snow during those months. A re-emergence of more frequent less wet/snowy years, and of greater year-to-year spring freshet variability, through the early and middle 20th century is also suggested in a comparison of 1913-1971 versus ~1912-~1850 averaged MDs (Table 7).

CORE 72	**1971-1913 INTERVAL 54-230 cm (X_1)**	**1912-~1850 INTERVAL 231-408 cm (X_2)**	**STANDARD ERROR (SE)**
No. of subsamples	159	175	
Average Median Diameter (um)	47.7	54.3	6.8 (P=<0.005)
Std. Dev. of A.M. Diameter (um)	9.7	8.1	
Coef. Var. of A.M. Diameter (%)	20	15	

Table 7. Comparison of average MD, standard deviation and coefficient of variation of the average 1971-1913 and the 1912-~1850 MDs of core 72. The SE value of 6.8 for the difference between the two MD averages is considered to be *definitely significant*.

5.4.2 Teleconnections

Climate researchers often note that the modulators of annual to decadal-length climate states (and therefore of variations in temperature and precipitation) are multifold and often include a *teleconnection* aspect (e.g., Landscheidt, 2001; Slonosky, 2001; Rind, 2001; Kniveton and Todd, 2001; Perry, 2001). For example, a cursory examination of the location of the Icelandic Low (IL), as defined by maps of 50 KPA heights supplied by P. Louie (Environment Canada, Atmospheric Environment Service), indicate that during some of the 20th century Saguenay river high discharge years, the IL tends to lie along a band between northern Hudson Bay and NW Greenland during the month of April. Conversely, for low discharge spring freshet years, April IL's are often (but not always) found in a band that lies between northern Europe and Siberia. Consequently, a comprehensive consideration of climate versus spring freshet magnitudes must include, in addition to local temperature and precipitation data, an analysis of the influence of variations in atmospheric circulation, temporal changes of sea surface temperatures and solar-related forcing as well (e.g., Morgan, 1992; Slonosky, 2001; Landscheidt, 2001; Perry, 2001). There is some evidence that river discharges in eastern Quebec appear to be controlled to a significant degree by regional atmospheric circulation patterns. For example, Rousseau and Slivitzky and (2003) describe a northeasterly trend in Quebec regarding differences in mean annual river runoff between composite years of extreme negative and positive values of the Arctic Oscillation (AO). Their results describe a northeasterly trend of correlation coefficients ranging from 0.13 in the Saguenay River watershed to 0.52 for the Natashquan River drainage basin in southeastern Quebec. A high (positive) AO index is the result of below normal Arctic sea-level atmospheric pressure that stimulates enhanced surface westerly winds in the North Atlantic region. Its negative phase is coeval with weaker zonal winds, and the injection of very cold air into the middle latitudes. The AO's larger counterpart, the North Atlantic Oscillation (NAO), controls the strength and direction of westerly winds and storm tracks across North America (e.g., Gray *et al*., 2004). In its negative phase, the NAO features relatively high atmospheric pressure over Iceland compared to the Azores and during these times the U.S. east coast experiences more cold air outbreaks and more snowy weather conditions. The Icelandic Low (IL) and the Arctic High (AH) tend to be located farther south during negative NAO conditions and are simultaneously weak. This pattern weakens westerly winds and provokes colder winters in North America. Ranking the 15 highest and 15 lowest Saguenay River annual maximum mean monthly discharges (AMMMD) between 1914 and 1989 shows a poor correspondence between relatively high AMMMDs and NAOs with NAOs of either sign occurring in almost equal amounts for both high and low AMMMD conditions (Table 8). Hurrell (1996) finds that the NAO can only account for about 31% of winter surface temperature changes north of about 20 degrees N so that the aforementioned results are probably not that unusual. Jones and Mann (2004) note that the proxy record of past regional [climate] variations only rarely agrees with the pattern of hemispheric or global mean variations and that the NAO may have exhibited late 20th century behavior that is anomalous in a longer-term context. On the other hand, Slonosky (2001) mentions a higher frequency of negative NAOs in Western Europe during the Little Ice Age.

North Atlantic sea surface temperatures (SST) for the 1856-1999 period contain a 60-80 years cycle that has an 0.4^{o} C range that is referred to as the Atlantic Multi-decadal Oscillation (AMO). Warm (positive) AMO phases occurred generally from about 1860 to 1891 and from 1926 to about 1964. Cool (negative) phases occurred from about 1905 to 1925 and between 1970 and 1990 (Enfield *et al*., 2001). Negative AMO's show a slightly higher association with high AMMMDs compared to low AMMMDs (Table 8). In general, high AMMMD years show a slight bias toward negative NAO and AMO conditions while low AMMMD years show a very slight bias to positive NAO and AMO conditions. In contrast, the slightly greater occurrence of positive AMO conditions during the 15 lowest AMMMD years is consistent generally with relatively warmer Northern Hemisphere conditions. It is interesting to note that there seems to be a general inverse relationship between the Saguenay River MD proxy spring freshet record for the ~1850 - ~ 1900 interval with respect to the 1856-1900 instrumental Northern Hemisphere temperature record given in Jones and Mann (2004). A comparison of specific AMO conditions with respect to annual mean monthly discharge (AMMD) averages does not show any significant relationships (Table 9). Jones and Mann (2004) cite work by Seager *et al.* (2002) that points to modelling evidence suggesting that atmospheric influences, as opposed to ocean circulation influences, are likely to dominate climate variability in the extratropical Northern

Hemisphere but note also that the proxy record of past regional variations rarely follows the pattern of hemispheric or global mean variations.

El Nino and La Nina data for the 1950 – 1989 period (www.ggweather.com/enso/ONI.htm) suggest that both conditions have had no consistent impact on Saguenay River freshet magnitudes. There are only two years (1974 and 1976) in which a relatively high AMMMD occurs during a relatively strong La Nina and only one high AMMMD occurrence during a relatively strong El Nino (1983). La Nina conditions are coeval with New England fall season conditions that are relatively "wet" and "somewhat warm" while those for the 1983 El Nino are recorded as "normal" and "warm" (e.g., Baron *et al*., 1993). In contrast, the LMDI period climate in New England is described mostly as "cool" to "somewhat cool" and "dry" to "somewhat dry". An attempt to briefly examine this issue from a wider perspective prompted a comparison of teleconnections between ENSO events and Saguenay River average annual mean monthly discharge data (AMMD's) for the 1950 – 1989 interval. The comparison yields a pattern similar to what was observed for the AMMMD/ENSO relationship. Among the 15 highest AMMD's, there is only one year (1958) during which a strong El Nino was developed and only one year (1974) when a strong La Nina was present. Among the 15 lowest AMMD years, there is only one year (1987) during which a moderate El Nino condition occurred.

RANK OF AMMMD Highest to Lowest (H>L)	YEAR	NAO SIGN	AMO SIGN	RANK L>H	YEAR	NAO SIGN	AMO SIGN
1	1976	+	-	1	1944	+	+
2	1929	-	-	2	1941	-	+
3	1917	-	-	3	1963	-	+
4	1928	+	+	4	1961	+	+
5	1937	+	+	5	1988	+	-
6	1947	-	+	6	1987	-	-
7	1919	-	-	7	1962	-	+
8	1924	-	-	8	1980	+	-
9	1942	-	+	9	1956	-	+
10	1921	+	-	10	1968	-	-
11	1936	-	+	11	1975	+	-
12	1974	+	-	12	1972	+	-
13	1920	+	-	13	1957	+	+
14	1983	+	-	14	1952	+	+
15	1916	-	+	15	1985	-	-
NUMBER OF POST-1945 YEARS	4				13		
RANGE OF AMMMD(M^3/sec)	4940-4040				1310-2080		
% NEGATIVE NAO		53				47	
%NEGATIVE AMO			60				47

Table 8. 15 Highest versus 15 lowest annual maximum mean monthly discharges (AMMMD) based on data extracted from the 1914-1989 Saguenay River discharge record measured at the Isle Maligne gauging station (# 02RH001). Post-1945 years represent the number of AMMMD years following the post-dam building era along the Saguenay River (Isle Maligne, 1926: Chute-a-Caron, 1931: Shipshaw, 1943).

Average AMMMD's for specific AMO year intervals suggest that relatively high discharge rate spring freshets were more prevalent during "Mostly negative" and "Negative" (cooler) AMO intervals (Table 9). In contrast, multi-year averages of AMMD's during "Typically positive" versus "Mostly negative" and "Negative" AMO conditions were not statistically different. Ineson *et al.* (2011) argue that negative AMO intervals are often linked to solar minimums that are manifested by weaker westerly winds and milder climates in southern parts of Canada.

Time Interval	**A**	**B**	**C**
Year Range	1973-1979	1970-1925	1924-1916
AMO Condition	Mostly negative	Typically positive	Negative
Interval average of AMMMD	3393 $M^3S^{-!}$	2845 $M^3S^{-!}$	4236 $M^3S^{-!}$
Standard Dev.	1007	933	528
Coef. Variation	30%	33%	12%
Standard Error	A versus B = 1.1 Not significant	B versus C = 4.4 Def. significant	A versus C = 2.7 Prob. significant
Interval average of AMMD	1565 $M^3S^{-!}$	1468 $M^3S^{-!}$	1476 $M^3S^{-!}$
Standard Dev.	165	173	237
Coef. Variation	11%	12%	16%
Standard Error (SE)	A versus B = 1.1 Not significant	B versus C = 0.9 Not significant	A versus C = 1.6 Not significant

Table 9. Comparison of annual maximum mean monthly discharge (AMMMD) averages versus annual mean monthly discharge (AMMD) averages for several AMO conditions.

Nevertheless, those mild climate locations may lie outside the climate regime that governs conditions for the Saguenay Region. For example, according to Wagner (1977), the two most severe winters of the 20th century (until 1977) were 1976/77 (May Saguenay R. AMMMD= 4940 M^3S^{-1}) and 1916/17 (June Saguenay R. AMMMD= 4900 M^3S^{-1}). These two winters correspond to the first and third ranked discharges of the 15 highest AMMMD's of the 1914-1989 Saguenay River discharge record. The 1976/77 freshet occurred during a positive NAO and a negative AMO but they were of opposite sign for the 1916/17 freshet. As such, the relatively low freshet discharges indicated for the LMDI could be provisionally interpreted to be mostly a function of positive AMO conditions while the higher discharges of the pre and post LMDI periods are likely more closely linked to negative [cooler] AMO conditions. The AMO, in itself, is not likely the singular predictor of Saguenay River freshet magnitudes. For example, during the LMDI, the AMO was in a positive mode from 1873 to 1880 (47% of the time) and in a negative mode between 1882 and 1885 (23% of the time), although MD proxy data imply relatively smaller freshet magnitudes throughout the entire LMDI.

From another perspective, the timing of relatively intense spring freshet events in this region of Quebec may be a function of at least two climatic conditions involving either (i) transitions from longer intervals of cooling temperatures to ones of warming temperatures and (ii) persistent cool and wet autumn conditions. For example, and being mindful of cautions regarding the spatial variation of precipitation over small distances, it is interesting to note that one of the larger 20th century Saguenay River spring freshets (1928; May AMMMD=4870 M^3S^{-1}) occurred during a trend of rapidly rising Montreal mean annual temperature that followed a previous three year period (1923-1926) of decreasing mean annual temperatures in that part of Quebec. By comparison, at Chicoutimi, the annual snowfall average for years 1923, 1924 and 1926 was only 172 cm compared to 301 cm for the 1927-1929 period. The average AMMD for those two intervals was respectively 1386 M^3S^{-1} and 1763M^3S^{-1}. In the Montreal area, exceptionally high lake levels witnessed in the early 1860's follow a decade of decreasing mean annual temperatures (Hillaire-Marcel *et al.,* 1981). The highest recorded lake levels of the 19th century in the Montreal area (1886-1887) correspond closely to the reversal of that cooling trend in 1886 and, coincidentally, to near the end of the LMDI in core 72 (~1871 - ~1888). Lake Erie water levels were consistently relatively high between 1845 and 1885 and again between about 1965 and 2000 (Wiles *et al*., 2009; www.great-lakes.net/teach/envt/levels/lev_3.html.). The earlier 19th century high lake level interval corresponds to a period of mostly positive AMO's while the more recent one shows both negative and positive trending AMO's. A relatively strong negative AMO within the 1965-2000 period occurred between 1971 and 1977 and had its nadir in about 1975 i.e., between two high Saguenay River AMMMD years (1974 and 1976). In contrast to the variability of recorded Saguenay River spring freshets, AMMD's, and of MD proxy values, an investigation of Rhine River flow between 1808 and 2006 indicated that winter and spring runoff had increased considerably but that mean annual runoff for summer and fall seasons, and for whole years, has not varied "considerably" during the past 200 years (Hanggi and Weingartner, 2011). They concluded that the amount of precipitation, and especially air temperatures associated with that watershed, were not able to significantly alter the River's annual discharge characteristics.

5.4.3 Dam construction versus river discharge

In retrospect, the larger number of post dam construction years found among the 15 lowest AMMMD years could perhaps be construed as being, in part, related to Saguenay watershed water management policies. However, the wide temporal distribution of the 4 post dam construction years included in the 15 highest AMMMD group (Table 8) suggests that management of the River's spring freshet has been minimal, except for possible instances to avoid flooding of the coastal areas of Lac St. Jean (see Figure 1)? Nevertheless, the higher frequency of Saguenay River "back-to-back" bimonthly spring freshet discharges noted between 1930 and 1914 before completion of the first large dam in 1929 (9 of 16 years) might be indicative of the influence of spring freshet management resulting from Ilse Maligne dam operation policies after that year, and of the subsequent added influence of the Shipshaw and Chute-a-Caron dams near Kenogami that were completed in 1943 (Schafer *et al.,* 1990)? In contrast, Guillen and Palanquez (1992) found that before the construction of large reservoirs in the lower Ebro River basin (Spain) at the end of the 1960's, the sediment transport was estimated to be about 1.0×10^{7} metric tons yr^{-1}. This amount was reduced to around 0.3×10^{6} metric tons yr^{-1} after dam construction i.e., a reduction of more than 99%. On a seasonal scale, the effects Ebro River of dams have engendered a reduction in the River's annual discharge variation and the virtual suppression of peaks in sediment transport. Textural, sedimentation rate and river discharge data results for the 20th century section of core 72 indicate that this has not been the case for the Saguenay River (e.g., Smith and Schafer, 1987).

5.5 Newspaper stories

19th century newspaper reports for the Saguenay Region were compiled by Girard *et al.*(1992a,b,c,d,e) and were translated and summarized by N. Barette during the summer of 1993 (N. Barette, University of Quebec at Chicoutimi, pers. com). They offer information on the occurrence of atypical weather events worthy of publication at the time i.e., between 1807 and 1898.

5.5.1 Spring freshet flooding and forest fires

Significant spring Freshet flooding occurred in 1871, 1876, 1890, and 1896 i.e., during and after the LMDI (~1871-~1888). Negative AMO's are recorded for all four years and positive NAO's for the last three. Forest fires of note were reported in June of 1870 and 1881 and in August of 1891 (before, during and following the LMDI).

5.5.2 Winter weather

Warm winters were prevalent between 1838 and 1859, a core 72 interval characterized by relatively high MDs, but there were no unusually warm winters reported between 1860 and 1877 during a period of predominantly positive AMO's. They are mentioned once again for years 1878 and 1884 i.e., during the latter part of the LMDI interval and during intervals of rising positive and rising negative AMO's. The winter of 1878 was coeval with an exceptionally positive (+2.0) AMO and was described as "warm everywhere in Canada" while the early part of the winter of 1884 was noted as being warm enough to allow plowing until December 1st, after which it transformed into a very snowy winter (AMO= -0.4). Exceptionally snowy years were reported for 1854, 1861, 1868, 1869, 1886, and 1887 i.e., before and near the end of the LMDI. The last five years are associated with positive AMO's. The snowstorm of March 12, 1869 occurred during a positive AMO interval and a positive NAO year. It was described as "the most important snowstorm of history" and one that deposited between 213 cm and 301 cm of snow.

An 1886 winter storm (negative NAO and positive AMO) deposited up to 550 cm of snow in some places. For the Saguenay Region, the winter of 1892 (slightly positive AMO and negative NAO) featured "two more months of nice season compared to Quebec City." Cold and snowy winters had returned by 1894 (NAO > +2.0, AMO > -1.0). Newspapers noted that, in that year, several families reported having used up their winter supply of firewood by the end of December. The snow accumulation by the end of December 1894 was described as being more than the total 1893 accumulation that was deposited under negative AMO and NAO conditions.

5.5.3 Spring and Fall weather

Spring weather of note was reported in the newspapers for the years, 1862, 1873, 1874, 1876, 1882, 1883, 1891, and 1893. Heavy frost was mentioned in the Saguenay Region in 1862 (negative AMO) from May 23 through May 26. The spring of 1874 (positive NAO, negative AMO) was described as very cold and rainy. Very slow snow melting was noted for 1876 (positive NAO, negative AMO) that "delayed the seed." A similar delay in planting was reported for the spring of 1882 (positive NAO, negative AMO). By 1883 (negative NAO and AMO), spring conditions had warmed and, "contrary to the rest of the province, in the Lake Saint-Jean [area] we sowed corn very early." "Vegetation was reported as being one month early" at Chicoutimi in the spring of 1891 (negative NAO and AMO) but a province-wide cold spring returned in 1893 (negative NAO and AMO). Cold and rainy fall weather was reported for 1864, 1871 and 1873. At St. Prime and St. Felicien, an autumn of 1873 frost "destroyed some part of the crop." Cold and dry falls were reported for 1880 (positive NAO and AMO) and 1885 (negative NAO and AMO). In 1885, a "heavy autumn frost destroyed all crop in the Saguenay Region." A return to warmer spring weather in 1891 (negative NAO and AMO) was heralded by the "appearance of a summer carriage" on the streets of Chicoutimi before the first day of April, an event that was reported as not having occurred in the previous 22 years i.e., 5 years before the estimated start of the LMDI.

5.5.4 Stormy conditions

All seasons for the years 1850, 1851 and 1852 were exceptionally stormy. In 1857 (negative AMO), the spring and summer seasons featured “an abundance of storm.” A violent storm at Chicoutimi in July 1880 (positive NAO and AMO) resulted in a partial loss of crops. Fall season storms were mentioned in 1859 (positive AMO) for the area along the coasts of the Lawrence River. The autumn of 1881 (negative NAO and negative AMO) was reported as being very stormy and 1884 (positive NAO, negative AMO) was described by the newspapers as one of abundant storms (rain, hail and snow) that also featured a hurricane in October that precipitated both snow and rain along the St. Lawrence River. It was reported as “the most important storm for the last 40 years” (implying that similar storms of the previous 4 decades were of a lower intensity). During that same year (1884), the Gulf of St. Lawrence between “Pointe Esquimaux” and “Pointe des Monts” [i.e., about a 200 km length of the Gulf’s north shore between Baie Trinite and Havre Saint-Pierre] was entirely frozen such that “for the first time the mailman can use that [as an] ice bridge.” In September of 1885 (negative NAO and AMO), The Lake Saint-Jean area experienced an unusual hailstorm featuring hailstones “as big as hazel nuts” with accumulations of up to 30 cm at some locations. A July, 1887 (positive NAO and AMO) article described a wind storm at Bagotville as “the most important gust [of wind] for the last 18 years” suggesting that wind storms of similar intensity were relatively rare or absent during most LMDI summers. In June of 1892 (negative NAO and positive AMO), a hailstorm in the lake Saint-Jean area was said to have produced hailstones of about 2.5 cm in diameter. As the climate shifted toward warmer conditions near the start of the 20th century, hurricanes appear to have become more intense. For example, on May 28, 1914 (positive NAO, negative AMO) a storm described as a hurricane reached the Saguenay Region. Newspaper reports noted that buildings were raised, trees uprooted and wind speeds reached 95 km hr^{-1}.

Weather conditions in relation to AMO and NAO conditions are summarized in Table 10. Not surprisingly, late 19th century seasonal weather conditions do not show strong correspondences to AMO and NAO conditions. In general terms, positive AMO’s were often associated with warm snowy winters while some cold snowy winters featured both negative and positive NAO's. Warm and cold spring weather was often linked to negative AMO's and to both negative and positive NAO's. Cold and dry falls featured instances of positive and negative AMO's and NAO's but showed a tendency to occur when NAO's and AMO's were of the same sign. Summer storms in the Saguenay region tended to occur often during negative AMO and positive NAO conditions while autumn storms tended to be coeval with various AMO and NAO conditions having the same sign.

SEASON	INTERVAL/ YEAR	NAO/AMO CONDITION	NEWSPAPER WEATHER REPORTS
WINTER	1838 -1859	-AMO until 1850	Generally warm winters.
	1860 - 1877	Typically -AMO,+NAO	Generally cold winters.
	1868-69	+AMO,-NAO	Very snowy years.
	1869	+AMO,+NAO	“most important snowstorm” [March].
	1878	+AMO,+NAO	“warm everywhere”
	1884	-AMO,+NAO	Warm until December, then very snowy. Gulf of St. Lawrence frozen over from Pt. Esquimaux to Pt. Des Monts.
	1886	+AMO,+NAO	550 cm snow in some places.
	1886-87	+AMO,-NAO	“very snowy years”
	1892	+AMO,-NAO	“two more months of nice season”
	1893	-AMO,+NAO	“total snowfall less than that observed by December 1894”
	1894	-AMO,+NAO	“cold snowy winters return”
SPRING	1862	-AMO	Heavy frost, May 23-26.
	1874	+AMO,-NAO	Very cold and rainy.
	1876	-AMO,+NAO	Slow spring snowmelt.
	1882	-AMO,+NAO	Delayed seed planting.
	1883	-AMO,-NAO	Warmer spring conditions.
	1891	-AMO,-NAO	Spring started one month early.

	1893	-AMO,-NAO	Province-wide cold spring.
FALL	1864,71,73	+AMO,-NAO	Cold and rainy.
	1873	+AMO,-NAO	Frost destroys part of crop.
	1880	+AMO,+NAO	Cold and dry fall.
	1885	-AMO,-NAO	Cold and dry fall and “heavy autumn frost”
STORMY	1850,51,52	NO DATA	All seasons exceptionally stormy.
	1857	-AMO	Abundance of storms in spring and summer.
	1859	+AMO,+NAO	Fall season storms and hail storms in July.
	1881	-AMO,-NAO	Very stormy weather.
	1884	-AMO,+NAO	Abundant storms (rain, hail snow) and a hurricane in October.
	1885	-AMO,-NAO	September hail storm, Lake St. Jean.
	1887	+AMO,+NAO	Strong wind storm, Bagotville.
	1891	-AMO,-NAO	Return to warm spring weather
	1892	+AMO,-NAO	Hail storm in June.
	1914	-AMO,+NAO	Hurricane, Saguenay Region.

Table 10. Relationships between NAO and AMO conditions and newspaper-reported weather events in the Saguenay Region during the latter half of the 19th century.

6.0 Summary and conclusions

6.1 Local temperature/precipitation and inferred freshet variation

Freshet proxy MD data for Saguenay River spring discharges provides an indication of the variation of freshet magnitudes that appears to extend back at least to the beginning of the 19th century. The proxy record for the ~1850 - ~1900 period reveals a short interval of relatively low and stable median diameters (LMDI) that may reflect a time of relatively reduced freshet magnitudes and lower year-to-year spring freshet variability (~1871 to ~1888) compared to earlier and later decades. Temperature records from Father Point (near Rimouski) suggest that the 1877 – 1882 portion of the LDMI, in relation to 20th century temperatures, possibly featured frequent occurrences of relatively warm January and February average temperatures and comparatively colder temperatures in March and April that bring to mind less snowy early winters and a reduction in the rate of the spring snow melt. Collectively, that interseasonal temperature pattern might have promoted a flattening of the spring freshet hydrograph? A comparison of mean monthly snowfall records for the Chicoutimi area indicate that there was, on average, about 26% less snowfall during the winter months (J,F,M,A) of 1877-1882 compared to the 1971-1979 record suggesting relatively drier winter conditions during that part of the LDMI. In contrast, snowfall during several early 20th century years was higher in January, March and April but about 18% lower in February compared to what is recorded for the 1877-1882 interval i.e., during the middle part of the LDMI thereby adding to annual snow storage just prior to the typical spring freshet months of May and June.   A pattern similar to that for snowfall is evident in the Chicoutimi total precipitation (TP) record for the relatively warmer climate of the late 20th century (1971-1979) versus the 1877-1882 interval i.e., consistently higher average monthly TP for January, February and March (~28% higher) during the 1970's. The inter-regional pattern of TP during the 1970's shows a distinctive westward increase. For example, TP at Quebec City versus Chicoutimi for the months of October through March for the 1971-1979 interval averaged about 32% higher at Quebec City but showed a strong temporal relationship (correlation coefficient = 0.9482) with the Chicoutimi record suggesting the possibility of using the longer Quebec City record for a future attempt at interpreting the pre-~1850 part of the core 72 textural proxy freshet record.

6.2 Teleconnection effects

Year-to-year variability of the NAO appears to have been relatively greater during the last decades of the 19th century interval compared to the 1970 to 1995 period. The latter 25-year interval featured five consecutive years (1972-1976) of positive NAO conditions and two more intervals consisting respectively of five consecutive positive years (1980-1984) and of eight consecutive positive years (1980 to 1995) that likely explains the observation of Jones and Mann (2004) regarding the anomalous late 20th century behavior of this atmospheric circulation index. The 1877-1882 part of the LMDI was coincident with a major positive excursion of the AMO that persisted for about four of the six years while the 1856 – 1906 period was, in general, one of relatively high year-to-year AMO variability with frequent multi-year positive AMO conditions that stand in contrast to the persistent negative AMO conditions that mark the exceptionally large Saguenay River freshets that were witnessed during the mid- 1970's.

6.3 Newspaper weather reports and Saguenay River freshets

Local 19th century newspaper reports indicate that spring freshet-related flooding, forest fires and warm winters occurred both before, during and after the LMDI. Unusually cool spring weather appears to have been frequent throughout the LMDI until about 1883, a year when newspapers reported the early sowing of corn and warmer spring conditions that may have increased the rate of early snow melting for that year. Relatively cold fall weather (both rainy and dry) occurred to a noticeable degree at the beginning and end of the LMDI. Stormy weather was prominent for the first three years of the 1850's and occasionally after 1856. A particularly violent storm that impacted Chicoutimi in July 1880 caused a partial loss of crops. The report of a hurricane in October 1884 described it as the "most important storm for the last 40 years." Both storms occurred during non-freshet months (normal 20th century freshet months include April, May and June) but their increased frequency may reflect the gradual Northern Hemisphere warming witnessed during the latter decades of the 1850-1900 portion of the “transitional period” following the end of the Little Ice Age (LIA)? An 1891 report about the occurrence of warm spring-like temperatures at Chicoutimi was said not to have occurred at that city in the previous 22 years i.e., during the entire LMDI period. Wind and hail storms were being reported relatively more often during the 1880’s than before. For example, the July 1887 Bagotville wind storm was noted in the newspapers as being the “the most important for the last 18 years.”

As the climate continued to warm through the end of the 19th and the first decades of the 20th century, there is an indication in newspaper articles that hurricanes that reached the Saguenay Region were becoming more intense. Some, such as the one that arrived on May 28, 1914 is said to have raised buildings and had winds reaching 90 km hr^{-1}. It arrived during a freshet month and might have contributed to that year’s relatively low May freshet magnitude in relation to freshet magnitudes recorded for that month witnessed over the following 10 years. Early 20th century decades of MD proxy data are comparable to the post-LMDI interval of increasing MD variability of sediments being transported to the North Arm basin of the Saguenay Fiord. A mirror image of that MD temporal pattern, although perhaps due to other forms of weather and atmospheric circulation manifestations, is also evident for the decades preceding the LMDI. The big picture of the five decade long “transitional” interval described in this report is a reminder of something mentioned by V. Slonosky (2001) to the effect that even in the 1740’s, during a time that was approaching the final phase of the LIA, there are instrumental records demonstrating that the climate during short periods was variable “with mild winters alternating with severe ones”. In the Saguenay River watershed that weather pattern appears to have persisted to the present day despite the shift to generally warmer conditions compared to those of the middle to late 19th century. The essence of both the features of the Saguenay River MD proxy record and the allied newspaper weather reports are generally consistent with the precautionary conclusions of Jones and Mann (2004) to the effect that inferences about the Earth's climate based only on regional data will likely provide a biased view of "larger-scale changes" that modulate atmospheric and ocean circulation patterns and, in turn, local climate conditions.

6.4 Significance

The continued accumulation of regional climate and paleoclimate data by the earth science community from many locations will likely provide an important source of information needed by modelers to improve the accuracy and details of their long-term climate impact predictions.

7.0 Acknowledgements

I would like to offer my (our?) appreciation to Professor C. Gerard (University of Quebec at Chicoutimi) and his associates for extracting weather information from various late 19th century Saguenay Region newspapers and to Ms. N. Barrett (University of Quebec at Chicoutimi) for translating the newspaper stories from French to English, and for organizing them in seasonal categories during her employment as a summer graduate student at the Bedford Institute of Oceanography. Special thanks are also due to Mrs. F. Cole, Geological Survey of Canada-Atlantic, for textural data extraction and processing, to Mr. D. Clattenburg, Geological Survey of Canada-Atlantic, for his meticulous laboratory analysis of core 72 subsample textures, and to Mrs. C. Currie, Geological Survey of Canada-Atlantic for graphics support. Dr. J.N Smith, Department of Fisheries and Oceans, Bedford Institute of Oceanography, generously provided sediment subsample PB^{-210} analysis and dating results that were used for calculating the composite sedimentation rate required for estimating the pre-1912 age horizons of core 72. My special thanks to Drs. J. Shaw and C.F.M. Lewis, Geological Survey of Canada-Atlantic, Bedford Institute of Oceanography for their reviews of the manuscript and for their ideas on improving the clarity and organization of the topics addressed in the paper.

8.0 References

Baker, V., 1987. Paleo flood hydrology and hydroclimatic change. *In:* The Influence of Climate Change and Climate variability on the Hydrologic Regime and Water Resources. Proceedings of the Vancouver IAHS Symposium, Pub. No. 168, p. 123-131.

Baron, W., Borns, H. and Smith, D.C., 1993. Climate Change and Northern New England Agriculture: A Case Study. *In:* Proceedings of a U.S./Canada Symposium on A Regional Response to Global Climate Change: New England and Eastern Canada, University of Maine, Water Resources Program, Portland Maine, p.174-177.

Bouchard, R., Dion, D.J. and Tavenas, F., 1983. Origine de la Preconsolidation des Argiles du Saguenay, Québec. Canadian Geotechnical Journal, v. 20, p. 315-328.

Bradley, R., Diaz, H., Eischeid, J., Jones, P., Kelly, P., and Goodess, C., 1987. Precipitation fluctuations over Northern Hemisphere land areas since the mid-19th century. Science, v. 237, p. 171-175.

Casey, J., 2011. Cold Sun. Trafford Publishing Limited, United Kingdom, 184 p.

Dawson, 1982. Cruise Report: *CSS Dawson* Cruise No. 82008, April 16-20, 1982, Bedford Institute of Oceanography, 27 p.

D' Anglejan, B., 1982. Patterns of sedimentation in the Eastmain Estuary prior to river cutoff. Naturaliste Canadian, v. 109, p. 363-374.

DePutter,T., Loutre, M-F. and Wansard, G., 1998. Decadal periodicities of the Nile river historical discharge (A.D. 622-1470) and climate implications. Geophysical Research Letters, v. 25, p. 3193-3196.

Enfield, D.B., Mestas-Nunez, A.M. and Trimble, P.J., 2001. The Atlantic Multidecadal Oscillation and its relation to rainfall and river flows in the continental U.S. Geophysical Research Letters v. 28, N. 10, p.2077-2080.

Flemming, S.W. and Moore, R.D., 2007. Local-scale controls on hydrologic responses to climate variability. Canadian Meteorological and Oceanographic Society Bulletin, v. 36, N. 1, p. 15-19.

Girard, C., Tremblay, G. And Tremblay, R., 1992a. Donnees sur le climat du nord-est Québéccois, “Le Canadien”, 1807-1847. Researche Document #1, Chicoutimi, Group de researche sur l’histoire collection, University of Québec at Chicoutimi, 354 p. (Unpublished Manuscript).

________, 1992b. Donnees sur le climat du Noord-est quebeccois, “Le Canadian”, 1850-1865. Research Document #2, Chicoutimi, Group de researche sur l’histoire collection, University of Québec at Chicoutimi, 423 p. (Unpublished Manuscript).

_________, 1992c. Donnees sur le climat du nord-est Québécois, “Le Canadian”, 1866-1887. Research Document #3, Chicoutimi, Group de researche sur l’histoire collection, University of Québec at Chicoutimi, 509 p. (Unpublished Manuscript).

________, 1992d. Donnees sur le climat: Saguenay-Lac-Saint-Jean, “Le Progres du Saguenay”, 1877-1914. Research Document #4, Chicoutimi, Group de researche sur l’histoire collection, University of Québec at Chicoutimi, , Chicoutimi, Group de researche sur l’histoire collection, University of Québec at Chicoutimi, 258 p. (Unpublished Manuscript).

_________, 1992e. Donnees sur le climat: Saguenay-Lac-Saint-Jean, “Varia Saguenayensia”, 1871-1898. Research Document #5, Chicoutimi, Group de researche sur l’histoire collection, University of Quebec at Chicoutimi, 92 p. (Unpublished Manuscript).

Gray, S.T., Graumlich, L.J., Betancourt, J.L., and Pederson, G.T., 2004. A tree-ring based reconstruction of the Atlantic Multidecadal Oscillation since 1567 A.D. Geophysical Research letters, v.31, L12205, doi: 10.1029/2004GL019932.

Guillen, J. and Palanques, A., 1992. Sediment dynamics and hydrodynamics in the lower course of a river highly regulated by dams: the Ebro river. Sedimentology, v. 39, p. 567-579.

Hanggi, P. and Weingartner, R., 2011. Inter-annual variability of runoff and climate within the upper Rhine River basin, 1808-2007. Hydrological Sciences Journal, v.56, p. 34-50.

Hillaire-Marcel, C., Occheitti, S., Marchand, L., and Rajewicz, R., 1981. Analysis of Recent Climatic Changes in Quebec: Some Preliminary Data. National Museums of Canada, Syllogeous No. 33, p. 28-47.

Hurrell, J., 1996. Influence of variations in extratropical wintertime teleconnections on Northern Hemisphere temperature. Geophysical Research Letters, v. 23, p.665-668.

Hartley, S. and Keables, M., 1998. Synoptic associations of winter climate and snowfall variability in New England. Intl. Jour. Of Climatology, v. 18, p. 281-298.

Hjulstrom, F., 1939. Transportation of detritus by moving water. *In:* Recent Marine Sediments, P.D. Trask (editor), American Association of petroleum Geologists, Tulsa, Oklahoma, p. 5-31.

Ineson, S., Scaife, A., Knight, J., Manners, J., and Dunstone, N., 2011. Solar forcing of winter climate variability in the Northern Hemisphere. Nature Geoscience, v.4. p.753-757.

Jones, P.D. and Mann, M., 2004. Climate over past millennia. Rev. Geophysics, v.42, RG2002,doi:10.1029/2003RG000143.

Jones, P.D., Raper, S., Bradley, R., Diaz, H., Kelly, P., and Wigley, T., 1986. Northern Hemisphere surface air temperature variations: 1851-1984. Journal of Climate and Applied Meteorology, v. 25, p. 161-179.

Karl, T., Groisman, P., Knight, R., and Heim, R., 1993. Recent variations of snow cover and snowfall in North America and their relation to precipitation and temperature variations. Journal of Climate, v. 6, N. 7, p. 1327-1344.

Kesel, R.H., Yodis, E.G. and McCraw, D.J., 1992. An approximation of the sediment budget of the lower Mississippi river prior to major human modification. Earth Surface processes and Landforms, v. 17, p. 711-722.

Kniveton, D. and Todd, M., 2001. On the relationship between cosmic ray flux and precipitation. Ist International Conference on Global Warming and the Next Ice Age, August 19th to 24th, 2001, Dalhousie University, Halifax, Nova Scotia, Canada, p. 201.

Knox, J.C., 1993. Large increases in flood magnitude in response to modest changes in climate. Nature, v. 361, p.430-431.

Landscheidt, T., 2001. Solar forcing of ENSO, NAO and PDO. Ist International Conference on Global Warming and the Next Ice Age, August 19th to 24th, 2001, Dalhousie University, Halifax, Nova Scotia, Canada, p.62-65.

Leduc, J., Bilodeau, G., deVernal, A., and Mucci, A., 2002. Distribution of benthic foraminiferal populations in surface sediments of the Saguenay Fjord before and after the 1996 flood. Palaeogeography, Palaeoclimatology, Palaeoecology v.180, p. 207-223.

Ludecke, H., Weiss, C. and Hempelmann, A., 2015. Peleoclimate Forcing by the Solar De Vries/Suess Cycle. Journal of Climate of the Past Discussions 11, p. 279.

Mann, M., 2002. Little Ice Age – transitioning to warmer climates in North America. *In:* The Little Ice Age in the Earth System: Physical and Chemical Dimensions of Global Environmental Change. Encyclopedia of Global Environmental Change, M MacCracken and J. Perry (editors), John Wiley and Sons, Chichester, United Kingdom, p. 504-509.

Moroney, M.J., 1973. *Facts From Figures.* Penguin Books Limited, London, 472 p.

Morgan, R., 1992. Mean annual temperature distributions in eastern Canada during the past 100 years with particular reference to the cooling trend since the early 1950's. *In: The Climate of Nova Scotia* symposium, Atmospheric Environment Service, Environment Canada (June, 1992), p. 62-77.

New York Times, 1870. The Great Saguenay Fire. New York Times, July 18, 1870, p. 2.

Nigam, S. and DeWeaver, E., 1998. Influence of orography on the extratropical response to El Nino events. Jour. of Climate, v.11, Issue 4, p.716-733.

Osterberg, E., Mayewski, P., Fisher, D.,Kreutz, K., Maasch, K., Sneed, S.,and Kelsey, E., 2014. Mount Logan ice core record of tropical and solar influences on Aleutian Low variability. Journal of geophysical Research Atmospheres, v.119, Issue 19, p. 11189-11204.

Perry, C.A., 2001. A solar kick for climate: The short and the long of it. Ist International Conference on Global Warming and the Next Ice Age, August 19th to 24th, 2001, Dalhousie University, Halifax, Nova Scotia, Canada, p. 249.

Pocklington, R., 1976. Terrigenous Organic Matter in Surface Sediments from the Gulf of St. Lawrence. Journal of the Fisheries Research Board of Canada, v. 33, p. 93-97.

__________ and Leonard, J., 1979. Terrigenous organic matter in sediments of the St. Lawrence Estuary and the Saguenay Fiord. Journal of the Fisheries Research Board of Canada, v. 33, p.1250-1255.

Rajagopalan, B., Kushnir, Y. and Tourre, Y., 1998. Observed decadal mid-latitude and tropical Atlantic climate variability. Geophysical Research Letters v. 25, No. 21, p. 3967-3970.

Rind, D., 2001. Reviewing various proposed mechanisms connecting solar variability and climate, from the millennial to the seasonal scale. Ist International Conference on Global Warming and the Next Ice Age, August 19th to 24th, 2001, Dalhousie University, Halifax, Nova Scotia, Canada, p. 186.

Rousseau, A. and Slivitzky, M., 2003. Relationship Between Annual Runoff Variability and the Arctic Oscillation Index in the Northern Quebec/Labrador peninsula. *In:* Proceedings of the 18th Stanstead Seminar: Climate Variability and Predictability From Seasons to Decades, J. Derome *et al.*(editors), Canadian CLIVAR Research Network, Montreal, Quebec, Canada, p. 118-121.

Schafer, C.T., Smith, J.N. and Cote′, R., 1990. The Saguenay fiord: A major tributary to the St. Lawrence Estuary. *In*: M. El-Sabh and N. Silverberg [eds.], *Oceanography of a Large Scale Estuarine System, the St. Lawrence,* Springer-Verlag, New York. Coastal and Estuarine Studies v. 39, p. 378-420.

Schafer, C., Smith, J.N. and Seibert, G., 1983. Significance of Natural and Anthropogenic Sediment Inputs to the Saguenay Fiord, Quebec. Sedimentology, v. 36, p. 177-194.

Schafer, C., Smith, J.N. and Loring, D., 1980. Recent Sedimentation events at the head of the Saguenay fiord, Canada. Environmental Geology, v. 3, p. 139-150.

Seager, R., Battisti, D., Yin, J., Gordon, N., Naik, N., Clement, A., and Cane, M., 2002. Is the Gulf Stream responsible for Europe's mild winters? Quart. Jour. Royal Meterol. Soc., v.127, p. 2563 – 2586.

Shabbar, A., Bonsal, B. and Khandekar, M., 1997. Canadian precipitation patterns associated with the southern oscillation. Jour. Climate, v. 10, p. 3016-3027.

Slonosky, V.C., 2001. Climate and the NAO during the Little Ice Age: Instrumental records from Europe and North America. Ist International Conference on Global Warming and the Next Ice Age, August 19th to 24th, 2001, Dalhousie University, Halifax, Nova Scotia, Canada, p. 173-176.

Sly, P., Thomas, R. and Pelletier, B., 1983. Interpretation of moment measures derived from water-lain sediments. Sedimentology, v. 30, p. 219-233.

__________, 1982. Comparison of sediment energy-texture relationships in marine and lacustrine environments. Hydrobiologia, v.91, p. 71-84.

Smith, D. C., Borns, H., Barron, W., and Bridges, A., 1981. Climatic stress in Maine agriculture, 1785-1885. *In:* Climate and History (T. Wigley, M. Ingram and G. Farmer editors), Cambridge University Press, Cambridge, UK., p. 450-465.

Smith, J.N. and Schafer, C.T., 1987. Evidence of the occurrence and magnitude of terrestrial landslides in Recent Saguenay fiord sediments. *In*: Proceedings of the Conference on *Natural and Man-made Hazards,* M. El-Sabh and T.S. Muy (eds.), p. 127-135.

__________and Ellis, K., 1982. Transport mechanism for Pb^{210} , Cs^{137} and Pu fallout radio nuclides through fluvial-marine systems. Geochimica et Cosmochimica Acta, v. 46, p. 941-954.

__________and Walton, A., 1980. Sediment accumulation rates and geochronologies measured in the Saguenay Fiord using the Pb^{210} dating method. Geochimica et Cosmochimica Acta, v. 44, p. 225-240.

St. Onge, G. and Hillaire-Marcel, C., 2001. Isotopic constraints of sedimentary inputs and organic carbon burial rates in the Saguenay Fjord, Quebec. Marine Geology v. 176, P. 1-22.

Taylor, G., 1975. Saguenay river sections from fifteen cruises: 1961 – 1974. Bedford Institute of Oceanography Data Series/BI – D – 75 – 2, 37 p.

Wagner, J., 1977. The severe winter of 1976-77: Precursors and Precidents. National Weather Digest (November, 1977), p. 12-18.

Wigley, T., Ingram, M. and Farmer, G. (editors), 1981. Climate and History; Studies in Past Climates and Their Impact on Man. Cambridge University Press, London, United Kingdom, 530 p.

Wiles, G., Krawiec, A. and D’Arrigo, R., 2009. A 265-year reconstruction of Lake Erie water levels based on North pacific tree rings. Geophysical Research Letters, v.36, N.10, p. 1029.

www.ggweather.com/enso/ONI.htm. El Nino and La Nina data: 1950-1989.

www.great-lakes.net/teach/envt/levels/lev_3.html. Water levels of the Great Lakes.

www.histori.ca/minutes/minutes.do?id=10172 . Historica Minutes, The Saguenay Fire.