Quaternary Research

doi:10.1017/qua.2020.103

Historical Perspectives on Exceptional Climatic Years at the Labrador/Nunatsiavut Coast 1780 to 1950

Marie-Michèle Ouellet-Bernier[1,2,6]*, Anne de Vernal[1,2,3], Daniel Chartier[4,6], Étienne Boucher[1,2,5,7]

[1]Institut des sciences de l'environnement, Université du Québec à Montréal, Montréal, Québec H3C 3P8 Canada
[2]Geotop Research center on the Dynamics of the Earth System, Université du Québec à Montréal, Montréal, Québec H3C 3P8 Canada
[3]Département des sciences de la Terre et de l'atmosphère, Université du Québec à Montréal, Montréal, Québec H3C 3P8 Canada
[4]Département d'études littéraires, Université du Québec à Montréal, Montréal, Québec H3C 3P8 Canada
[5]Département de géographie, Université du Québec à Montréal, Montréal, Québec H3C 3P8 Canada
[6]International Laboratory for Research on Images of the North, Winter and the Arctic, Université du Québec à Montréal, Montréal, Québec H3C 3P8 Canada
[7]Centre d'Études Nordiques, Université Laval, Québec, Québec G1V 0A6 Canada
*Corresponding author email address: ouellet.bernier.mm@gmail.com

(Received May 4, 2020; Accepted October 3, 2020)

Abstract

This interdisciplinary study presents a human perspective on climatic variations by combining documentary, discursive, instrumental, and proxy data. Historical sources were used to characterize climate variations along the coast of Labrador/Nunatsiavut during the 19th century and the first half of the 20th century. Written and early instrumental archives provided original information on the state and perception of climate before the establishment of meteorological stations, which permitted an intra-annual perspective on climatic variations. Written sources depicted the sensitivity of humans to climatic variations. Exceptional seasonal climatic events were extracted from documentary and discursive sources, which were complemented by tree-ring and early instrumental data. From 1780 to 1900, data indicated a succession of relatively warm and cold episodes. Most warm periods were described as stormy and variable. The final part of the studied records showed cold conditions from 1900 to 1925 and warm conditions from 1925 to 1950. Historical sources helped to discriminate a seasonal signal. Mild autumn-winter conditions were recorded since 1910 in relation with positive anomalies of the North Atlantic Oscillation in winter. Relatively warm spring-summer conditions were recorded after 1920, which corresponds to a phase of positive anomaly of the Atlantic Multidecadal Oscillation.

Keywords: 19th century; Recent past; Paleoclimatology; Historical climatology; Exceptional events; Coast of Labrador; Nunatsiavut; North Atlantic; Historical data; Archives of societies; Tree-ring

INTRODUCTION

Like many subarctic and arctic regions, the coast of Labrador/Nunatsiavut in eastern Canada is experiencing large climatic changes that affect the livelihood of coastal communities (e.g., Marko et al., 1994; Deser, et al., 2002; Brown et al., 2012; IPCC, 2018). Since 2000, a rapid warming has been observed in Labrador (Way and Viau, 2015), with direct consequences on mobility, hunting and fishing activities, health, and well-being (e.g., Johannessen et al., 2004; Cunsolo Willox et al., 2012, 2013; Wolf et al., 2013). Over the period spanning from 1881 to 2011, instrumental data and model simulations were used by Way and Viau (2015) to calculate a mean annual warming of ∼1.5°C (1.13 ± 0.86°C/century), which was more pronounced in winter (∼2.03°C) than summer.

Instrumental observations of climate on the Labrador/Nunatsiavut coast began at the end of the 19th century. Earlier information on meteorological and climatic conditions mostly comes from proxy data sources, such as tree-rings, varved sediments, pollen, microfossils, and biomarkers (e.g., D'Arrigo et al., 1996, 2003; Levac and de Vernal, 1997; Sicre et al., 2011, 2014; Nicault et al., 2014; Richerol et al., 2016; Roy et al., 2017). Proxy data provide information on past climate, but they are generally limited to multi-year temporal resolution, annual in the best cases. With the use of historical sources, this study aims to provide an intra-annual perspective on climate variability and to document how it has affected human activities in Labrador/Nunatsiavut.

Cite this article: Ouellet-Bernier, M.-M., de Vernal, A., Chartier, D., Boucher, É. 2021. Historical Perspectives on Exceptional Climatic Years at the Labrador/Nunatsiavut Coast 1780 to 1950. *Quaternary Research* 101, 114–128. https://doi.org/10.1017/qua.2020.103

Other studies have combined historical and proxy sources together to document past environmental conditions (e.g., D'Arrigo et al., 2003; Woollett, 2007; Lemus-Lauzon et al., 2018), but none has focused on exceptional climatic events. From a combination of meteorological reports, ship logbooks, and missionary journals (Periodical accounts, hereafter PA), Newell (1992) proposed a compilation of severe and extreme spring sea-ice events on the coast of Labrador/Nunatsiavut during the 19th century. Historical data may thus provide insight on exceptional events and seasonal climatic variations.

The sources of information used in this study were provided by journals and reports of missionaries and explorers. In addition, perceptions of climate were extracted from literary sources such as life stories, fiction, and encyclopedic novels. The overview includes the perceptions of temperature, observations of sea-ice, and seasonal records of exceptional climatic events. Instrumental and tree-ring data are also used to complete the regional picture of climatic variations along the coast of Labrador/Nunatsiavut from 1780 to 1950. Finally, paleoclimatic reconstructions from historical and tree-ring data are discussed in a northern North Atlantic context, with special attention paid to atmospheric and oceanic variability patterns, including the winter North Atlantic Oscillation (NAO; Hurrell, 1995) and the Atlantic Multidecadal Oscillation (AMO; Kerr, 2000).

BACKGROUND OF THE STUDY AREA

Regional context

The coast of Labrador/Nunatsiavut is located between the Strait of Belle Isle (~52°N) and Cape Chidley (~60°N). The Nunatsiavut Territory spans from Melville Lake to the northern extremity of the Labrador coast (Fig. 1). Since 2005, Nunatsiavut is recognized as the Labrador Inuit autonomous territory. The regional climate is directly influenced by the cold nutrient-rich Labrador Current that flows southward from Baffin Bay and Davis Strait (Fig. 1). The Labrador Current carries large quantities of icebergs from Greenland and drift ice from Baffin Bay (Banfield, 1981; Marko et al., 1994).

Meteorological data in Labrador/Nunatsiavut

The first Canadian meteorological stations in Labrador were established at the beginning of the twentieth century and their data records are discontinuous in time (Environment Canada, 2017; Fig. 2). Instrumental temperature data are available from North West River (central Labrador) and Nain (Nunatsiavut) since 1906 and 1927, respectively. The instrumental reference period used in several reconstructions is a temperature record from Happy Valley-Goose Bay that spans from 1943 to 1991 (e.g., D'Arrigo et al., 2003). The

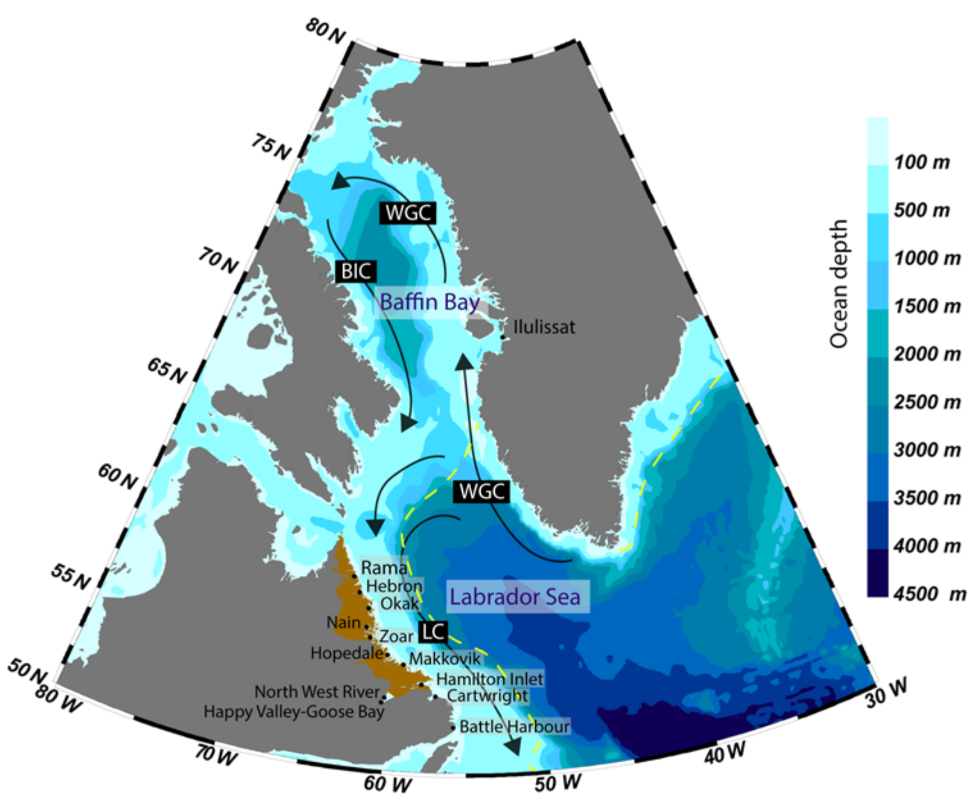

Figure 1. Locations of the main villages on the coast of Labrador/Nunatsiavut. The Nunatsiavut autonomous territory is shown in brown. Median sea-ice extent (1981–2010) is represented by the yellow dashed line (NSIDC). Major oceanic currents of the Baffin Bay/Labrador Sea area are shown by black arrows; West Greenland Current (WGC), Baffin Island Current (BIC), and Labrador Current (LC). (For interpretation of the references to color in this figure legend, the reader is referred tothe web version of this article.)

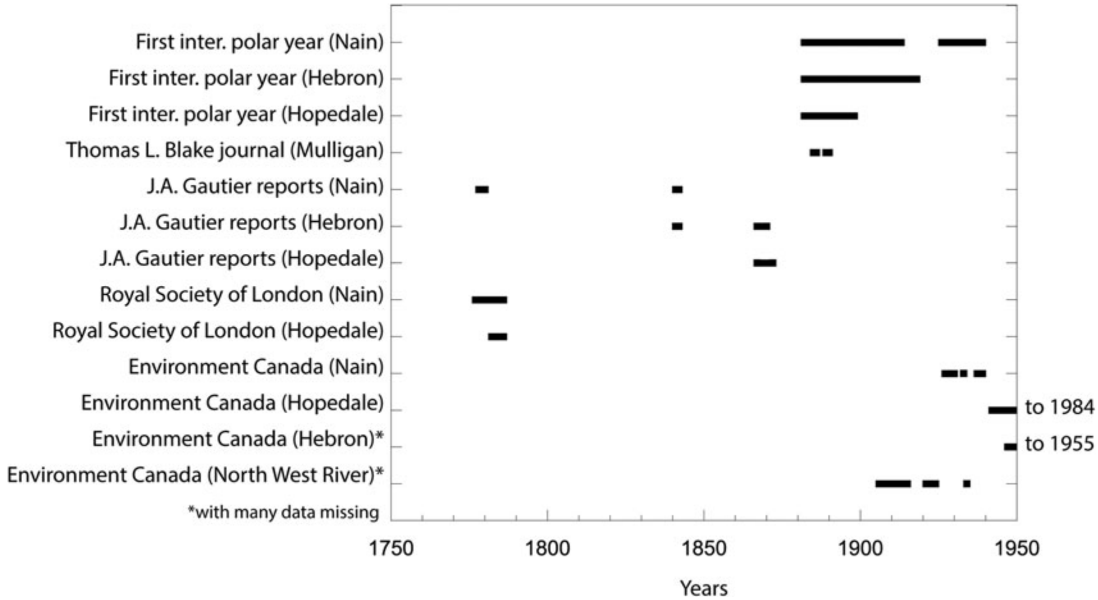

Figure 2. Instrumental meteorological data inventory of the Labrador/Nunatsiavut coast from 1750 to 1950.

investigation of historical archives has shown rare and discontinuous instrumental records prior to the 20th century (Fig. 2). Temperature observations by first settlers were usually taken during winter with thermometers fixed to the cabins (Cartwright, 1792; Blake, 1977). Therefore, instrumental data might also be biased because of exposure and accuracy of the readings, or by the instruments themselves because of mercury freezing or delayed response to sudden changes, for example.

Moravian missionaries, the *Unitas Fratrum*, also known as the Moravian Brethren, had a keen interest in natural history that complemented their religious activities. From 1771 to 1939, they made daily meteorological observations. Demarée and Ogilvie (2008) inventoried these records, but no systematic meteorological observations are available. Fragments were published in newspapers and sent to European scientists. Lüdecke (2005) extracted some of the data published in German newspapers. In addition to existing instrumental records, written comments on climatic conditions were compiled in Moravian journals. It is important to note that missionaries were originally from Europe (mainly England and Germany). Only a few of them had journeyed in Greenland previously and experienced subarctic climatic conditions (Demarée and Ogilvie, 2008).

MATERIALS AND METHODS

Historical climatology

This study employs methods related to the field of historical climatology and paleoclimatology (cf., Catchpole and Moodie, 1978; Brázdil et al., 2005). Original data presented in this study are referred to as "archives of societies." These data are interpreted together with "archives of nature" (White et al., 2018), published previously by Schweingruber (2002). Written sources, including documentary and discursive, and early instrumental sources were used together with tree-ring data. Documentary and discursive sources can be described as behavioral or communicational evidence. Behavioral evidence is observations based on the climatic vulnerability of human systems, such as transportation, settlements, or agriculture (Catchpole and Moodie, 1978). Communicational evidence refers to the capacity of humans to communicate changes in their environment, which is conveyed through artistic and pictorial artworks and written documents. For example, relationships between climate and artistic productions were demonstrated by Robinson (2005), Behringer (2010), and Metzger (2013); and Haldon et al. (2014) described the capacity of written archives to provide information on specific events, phenomena, and processes that can be discontinuous and of short duration. Therefore, subjectivity of human observation is unavoidable and can be influenced by cultural, social, and professional position.

Sources of data in Labrador/Nunatsiavut

Historical data analyzed in this study come from three source types: (1) the Moravian mission ship arrival dates on the coast of Nunatsiavut, which are a record of semi-quantitative documentary data extracted from Moravian Periodical accounts (Fig. 3); (2) the discursive qualitative data that were obtained from a variety of literary sources (life story, novel, journal) that contain observations of weather and climatic impact on the population (Fig. 4); and (3) the early quantitative instrumental data that were collected with the initiative of the First International Polar Year and part of the German Naval Observatory network. This source documents surface air temperature on the Nunatsiavut coast from 1882 to 1939 (Fig. 5). Mean, maximum, and minimum temperatures from the Nunatsiavut coast were compiled and standardized by the

https://doi.org/10.1017/qua.2020.103 Published online by Cambridge University Press

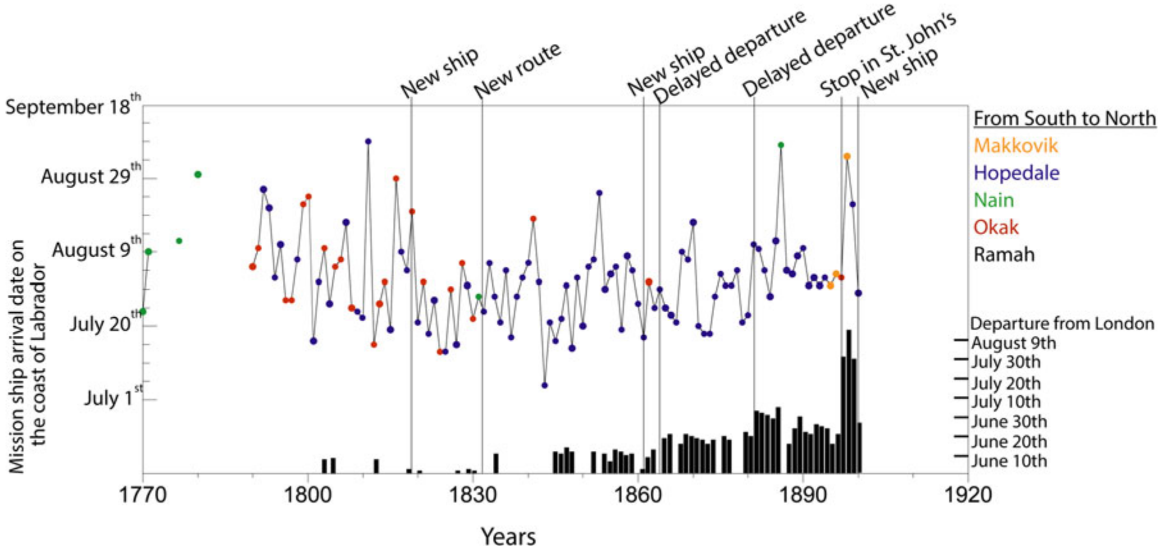

Figure 3. (color online) Mission ship arrival dates on the coast of Nunatsiavut. Color of the dots represents the first village where the ship arrived. Histogram bars show departure date from London, if mentioned in Periodical Accounts. Major transitions in ship, route or departure date are marked by vertical lines.

German Weather Service (Kaspar et al., 2015; Tinz et al., 2015).

The longest historical records, which include mostly Periodical accounts, were obtained from Moravian sources (Fig. 2). These accounts usually served as a summary of missionary life, relating religious affairs, interactions with people, food state, and some climatic conditions. In the Moravian accounts, the Inuit presence is described indirectly. The Periodical accounts are a series of 169 volumes published from 1790 to 1961, sent every year to London and shared with other missions.

Documentary data: mission ship arrival dates

Moravian missions on the coast of Nunatsiavut were visited each year from 1770 to 1926 by the mission ship, usually named "Harmony." The ship brought food, material, mail, news, and people. Its arrival was always a great event, but it was often delayed by local meteorological conditions, such as localized areas of pack ice and drift ice remaining along the coast. In 156 years of travel, the mission ship successfully reached the Nunatsiavut every summer. Mission ship arrival dates provide indirect climate-related information, but they have the advantage of being institutional and covering more than a hundred years. The mission ship successively visited all the Moravian villages on the coast of Nunatsiavut. From 1771 to 1832, the mission ship alternated its first annual visit between Okak and Hopedale. Afterwards and until 1896, it was decided to stop first in Hopedale. From 1896, the journeys on the coast started with the southernmost station, Makkovik. Due to climatic conditions or for logistic reasons, the ship might have needed to stop at other stations first. Other major changes concern the routes chosen and the week of departure. In times of war or conflict, the ship traveled to the Orkney Islands (Scotland) to avoid the English Channel. The departure date was moved one week later after 1864 in order to avoid traveling close to the sea-ice front. A further week's delay was decided after 1881. It is important to note that there are no major differences in arrival dates related to these changes because the ships did not have to wait for the sea-ice front to retreat. From 1897, the mission ship first sailed to St. John's (Newfoundland). In 1901, a

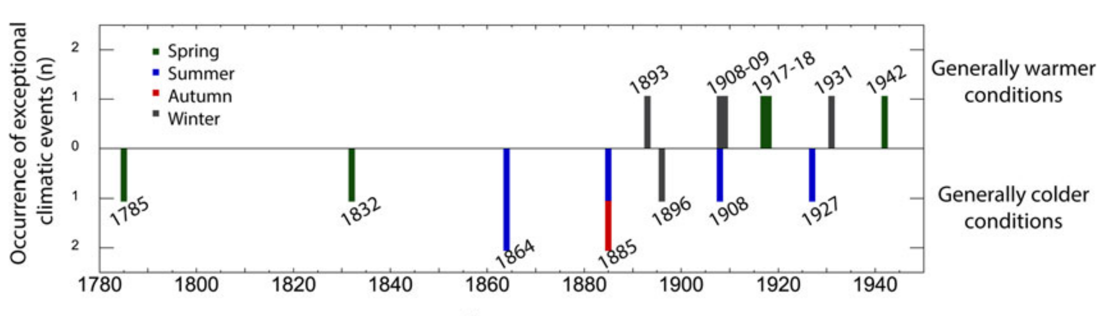

Figure 4. (color online) Seasonal mentions of exceptional weather/climate events from discursive sources, relating generally warmer or colder climatic conditions.

https://doi.org/10.1017/qua.2020.103 Published online by Cambridge University Press

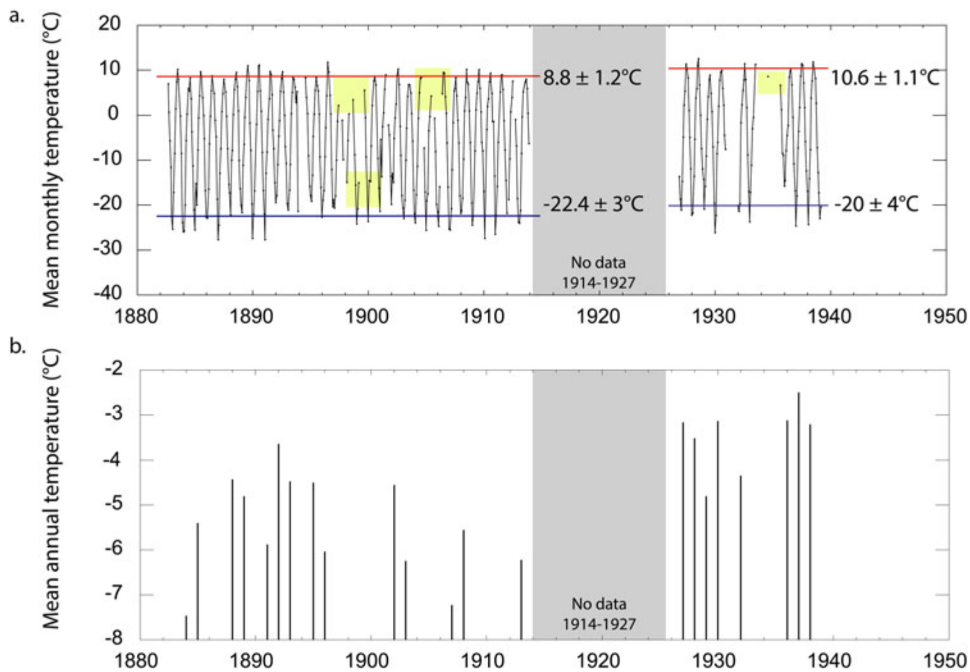

Figure 5. (color online) Mean monthly and annual temperature in Nain from 1882 to 1939. (a.) Mean monthly temperature (°C) in Nain. Red lines show mean August temperature (warmest month), blue lines show mean January temperature (coldest month). Areas in yellow highlight missing values in the record. (b.) Mean annual temperature (°C) in Nain. All data are from the First International Polar Year extracted by the German Weather Service.

new vessel was bought, and two trips were carried out each summer. The stronger construction of the new ship and the absence of passengers during the first passage allowed slightly earlier arrivals on the coast of Nunatsiavut (PA, vol.5, no. 50). For this reason, the mission ship arrival dates record ends in 1897. Therefore, with the aim to produce a continuous record, we chose to present the first arrival date on the coast of Nunatsiavut.

Mission ship arrival dates are a result of logistic choices, sailing, and climatic conditions. Among climate parameters, early sea-ice retreat is associated with a rapid ablation due to warm air and rapid removal of ice by southerly winds. In contrast, late sea-ice retreat is related to weaker pressure gradients and reduced southerly winds (Crane, 1978). Presence of drift ice and icebergs along the coast of Labrador/Nunatsiavut results from both local and regional conditions (Marko et al., 1994).

Discursive data

Discursive data refer to a category of documentary sources: the personal sources created by individuals. These sources are generally short and discontinuous. Furthermore, they are sensitive to the author's mobility and own perception of the place. Nevertheless, they can still address the relationship between natural phenomena and human experience (White et al., 2018). This relationship involves the human capacity to communicate information (Catchpole and Moodie, 1978) and how this information is selected. Climate parameters are often presented indirectly in discursive sources because these personal accounts emphasize extreme weather events that directly affect the human population. These events are unpredictable and variable in strength, time, and place (Ouellet-Bernier and de Vernal, 2018). In addition, discursive sources include works of fiction, and this cultural discourse permits a connection between climate and the represented territory (Chartier, 2007). Fictional accounts are usually set in the real world: "In short, works of fiction are not wholly imaginative, and factual accounts are not purely objective descriptions of the world" (Catchpole and Moodie, 1978, p. 118–119). Individual perception and the selection of events confer subjectivity to discursive sources, but this shortcoming can be overcome by integrating additional sources (White et al., 2018).

Here, we make use of a corpus of works that represents 12 discursive sources. The sources were dated, located, and referred to a specific climatic parameter, such as sea-ice cover, presence of drift ice, temperature, and storm occurrence. One autobiography written by Thomas L. Blake was used: *The Diary of Thomas L. Blake, 1883–1890*, which presents a few thermometer measurements and observations of exceptional climatic events. It is dated daily, and it provides information on weather and its influence on people. Two novels based on true stories written by Elliott Merrick (1992, 1998) were chosen: *The Northern Nurse* is the story of Kate Austen who worked as a nurse in Labrador from 1927 to 1930; the second novel tells Merrick's own experience of the area through life and fictional stories. Another novel written by Sir Wilfred T. Grenfell (1911) presents the author's experience of adventures and life along the Labrador coast. The journals of the explorers Captain George Cartwright

https://doi.org/10.1017/qua.2020.103 Published online by Cambridge University Press

Table 1. Mean monthly temperatures (°C) in Nain and standard deviations calculated from the mean daily temperature at 7 or 8 a.m. from First International Polar Year (data from the German Weather Service; Kaspar et al., 2015; Tinz et al., 2015).

Nain	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1882–1913	−22.4 ± 3	−21.2 ± 4.7	−16.1 ± 3	−7.4 ± 2.5	−0.2 ± 1.3	4.7 ± 1.1	8.5 ± 1.4	8.8 ± 1.2	5.4 ± 1.2	−0.5 ± 1.4	−7.1 ± 3.1	−16.7 ± 3.3
1927–1939	−20 ± 4.0	−20.4 ± 3	−13.3 ± 4.6	−5.1 ± 2.3	1.4 ± 2.1	6.7 ± 1.7	10.2 ± 1.5	10.6 ± 1.1	7.1 ± 1.2	1.2 ± 1	−7.2 ± 2	−13.3 ± 3.7
Total	−21.8 ± 3.3	−21 ± 4.3	−15.4 ± 3.6	6.8 ± 2.7	0.2 ± 1.7	5.2 ± 1.5	8.9 ± 1.6	9.3 ± 1.4	5.8 ± 1.4	−0.1 ± 1.5	−7.1 ± 2.9	−15.9 ± 3.7

(1792) and Hesketh Prichard (1911), and of the missionaries Alpheus Spring Packard (1891), Henry Gordon (1972), and Frederick William Peacock (1986) were selected because they provide rich descriptions of climate, environment, and interactions with people. An encyclopedic journal written by Patrick William Browne (1909) was used because he referred to some tragic weather events. Two scientific reports complete the corpus: the reports by Jean-Alfred Gautier (1879) summarize parts of Moravian missionary instrumental data based on a compilation of monthly and annual mean temperatures; the last report found in Battle Harbour from an unknown author (1832) presents a day-to-day record of ice break-up in the bay during the spring of 1832, with mentions of temperature and wind direction. An author's experience of the land is a prerequisite for use in the climate discussion. It allows for the comparison of climatic conditions of one year to previous years. However, all documents were written by authors of European and American origins, with exception of Thomas L. Blake who was born in Hamilton Inlet and was of English and Inuit descent. Depending on cultural, social, or economic factors, authors highlight climatic parameters that have a direct impact on their life. Impacts on resources, infrastructure, and livelihood (particularly mobility) are highlighted. Authors focus mostly on economic vulnerabilities, such as delayed fishing and sailing seasons, difficulty of mobility on ice, and material damages. The missionary Frederick Peacock presented an example of social vulnerability when he mentioned the early pack ice break-up after the disastrous epidemic of 1918 (Peacock, 1986). Sea-ice cover, floating ice in spring, and delayed/early freeze-up/break-up are the main climatic parameters depicted in discursive sources. Figure 4 shows seasonal mentions of generally warmer or colder climatic conditions. We noted the dominance of spring and summer mentions of exceptional climatic conditions.

Early instrumental data

Data collected for the First International Polar Year provide the longest temperature record from the coast of Labrador/Nunatsiavut for the period prior to 1950. After the First International Polar Year in 1882, the German Polar Commission established six meteorological stations in Nunatsiavut (Taylor, 1981; Demarée and Ogilvie, 2008). The physicist Karl Richard Koch (1852–1924) traveled to the mission stations during summer 1882 to train missionaries to make meteorological observations (Demarée and Ogilvie, 2008). Every day, three to five measurements were taken to record the daily mean, minimum, and maximum temperatures. In addition, missionaries noted atmospheric pressure, wind strength and direction, clouds, and sky conditions. The stations were established in Nain, Okak, Hopedale, Zoar, Hebron, and Rama. Instruments were provided by the German Naval Observatory (Lüdecke, 2005). There is no evidence that the location of the six meteorological stations has changed during the period of measurement. Döll (1937) published a synthesis of these data.

We present a time series of mean monthly and annual temperature at Nain from 1882 to 1913 and from 1927 to 1939 (Table 1; Fig. 5). Mean monthly temperature was calculated from daily temperature at 7 or 8 a.m. Months with more than five missing values were excluded. Mean annual temperatures were calculated when the 12-months mean temperature was available, which led to a discontinuous record. The months of November, December, and January record the largest inter-annual variability likely because of sea-ice and snow (Table 1; Curry et al., 1995).

Tree-ring data

Tree-ring records are presented to compare historical data with an independent and annually resolved proxy record. A series of the mean maximum ring density (MXD) of white spruce (*Picea glauca* [Moench] Voss) was used because it generally responds to late summer temperature and records a strong climatic signal (Jacoby and D'Arrigo, 1995; D'Arrigo et al., 1996; McCarroll et al., 2003). Standardized density data expressed in terms of gram per cubic decimeter were extracted from the National Climatic Data Center (NOAA) paleoclimate database. The MXD of 115 individual samples from three sites of the Labrador coast (Schweingruber, 2002) were averaged. The coefficient of correlation of the series from the three sites is $r = 0.693$. The overall record covers 1709–1988 with a mean segment length of 223 years. We limited our analysis to the period spanning from 1780–1950 in order to make comparison with historical data. D'Arrigo et al. (2003) underlined the regional teleconnection existing between white spruce MXD and sea surface temperature of Labrador Sea from May to September.

RESULTS

Mean monthly and annual temperatures in Nain from early instrumental measurements

Early instrumental data show large amplitude variations of winter temperatures, with January temperatures 5°C lower

https://doi.org/10.1017/qua.2020.103 Published online by Cambridge University Press

than average in 1890 and 1911 in Nain (Fig. 5). The amplitude of variations in the series appears more pronounced in winter than in summer. Mean annual temperature was more than 1°C below average in 1884–1885, 1891, 1896, 1907–1908, and 1913, and more than 1°C above average in 1892, 1927–1928, 1930, and 1936–1938. From 1884 to 1938, the mean annual temperature was −4.82°C, which is 3°C lower than modern values (−1.82°C in 2005–2010). The coldest and warmest years were recorded in 1884 and in 1937, respectively. On average, the early instrumental time series at Nain is characterized by much lower mean January temperatures (−22.4 ± 3°C from 1882 to 1913; −20 ± 4°C from 1928 to 1939) than the modern series (−16.74 ± 8°C in 2005–2010 at 7 a.m.; cf., Environment Canada, 2017). The mean August temperature was relatively close (8.8 ± 1°C from 1882 to 1913; 10.6 ± 1°C from 1928 to 1939) to the modern one (9.89 ± 3°C in 2005–2010 at 7 a.m.; cf., Environment Canada, 2017).

Exceptional climatic years on the coast of Labrador/Nunatsiavut

Exceptional years were determined by signs of climate that were found in documentary and discursive sources (Chartier, 2007, 2019; Walter, 2014). They were presented together with standardized seasonal temperature anomalies calculated from early instrumental data (Fig. 6). Standardized anomalies helped to identify exceptional values. Positive anomalies referred to warmer climatic events and negative anomalies to colder climatic events. Exceptional climatic years interpreted from the mission ship arrival dates were extracted by isolating values below the 10th and above the 90th percentiles. Our analysis indicates 13 extreme warm and 12 extreme cold years over a total of 109 years. Exceptional mission ship arrival dates were added to the summer series in Figure 4, based on discursive comments about climate that were assumed to represent an expression of exceptional conditions. A positive value (+1) corresponds to a comment referring to warmer climatic conditions and a negative value (-1) to a comment referring to colder climatic conditions. The number of discursive data available increases at the end of the 19th century and beginning of the 20th century. Cold spring and summer conditions were reported from ∼1895 to 1915, while winter conditions appeared to be particularly cold only from ∼1900 to 1910. After 1925, relatively warm spring and summer instrumental temperatures were recorded, and favorable conditions were mentioned in discursive sources. The warming trend of the last century appeared weaker in autumn and winter than spring and summer.

The tree-ring record (MXD) is presented with summer temperature anomalies identified from instrumental data and exceptional climatic events mentioned in documentary and discursive sources (Fig. 7). A regime analysis performed on MXD data with a R package (Gaussian HMM1d; Nasri et al., 2020) shows alternations of favorable and unfavorable growing conditions during the 19th century. The optimal number of regimes was defined based on the goodness of fit test (p-value) proposed by Rémillard (2013). We calculated the p-value for one (p-value = 0.6), two (p-value = 0.52), and three (p-value = 0.74) regimes. We chose the number of regimes that had the lowest p-values (i.e., two regimes). Below average MXD are recorded during the 1790s, 1810s, 1830s, 1860s, and 1910s. A period of moderate MXD value is also identified from ∼1875 to 1895. The 20th century began with a period of low MXD values from 1900 to 1925 (average ∼980 g/dm^3). The last sequence, ranging from ∼1925 to 1950, shows the longest continuous record of high MXD (average MXD ∼1014 g/dm^3) (Fig. 7). Tree-ring maximum density and exceptional climate events from discursive sources corroborate one another with 69% consistency. The consistency between these sources rises to 80% when looking exclusively at spring and summer mentions, and slightly decrease to 60% when using only winter mentions. The greater consistency between tree-rings and historical data in spring and summer can be explained by the fact that MXD mostly depends upon growing season temperatures. Tree-ring density and mission ship arrival dates have 64% consistency. The mission ship arrival dates depend more on local drift ice and record different climatic parameters than the tree-ring density.

DISCUSSION

The climatic variations of the Labrador/Nunatsiavut coast as inferred from historical sources and tree-ring data can be compared with instrumental temperature values of West Greenland to better understand the regional context. The temperature records made at Ilulissat from 1808 to 2013 provide a suitable basis for comparison (Climate Research Unit, University of East Anglia; Vinther et al., 2006; Cappelen and Vinther, 2014; Fig. 6). At Ilulissat, the recent (1961–1990) mean annual air temperature is −4.9 ± 3.3°C (Box, 2002) and sea-ice cover extends from mid-December to mid-May. Similar to Labrador/Nunatsiavut, the warmest decades in the Ilulissat time series occurred in the 1930s and 1940s, while the coldest was recorded in the 1810s (Vinther et al., 2006). Pearson correlation coefficients (p) between the temperature records of Nain and Ilulissat are ∼0.5 for autumn and spring, and ∼0.2 for winter. No significant correlation exists between their respective summer data. Hence, the correlation analyses suggest some common mechanisms influencing the local climate at Nain and Ilulissat, at least in autumn and spring. In the Labrador/Nunatsiavut region, the climate variability has been associated with the North Atlantic Oscillation (NAO) in winter (December–March) and the Atlantic Multidecadal Oscillation (AMO) (e.g., Finnis and Bell, 2015; Boucher et al., 2017; Fig. 7). A positive winter NAO index corresponds to low atmospheric and oceanic temperature over eastern Canada and extensive sea-ice cover in the Labrador Sea (Drinkwater, 1996; Banfield and Jacobs, 1998; Kvamstø et al., 2004; Hurrell and Deser, 2010). Such conditions are characterized by a strong influence of westerly winds that have a cooling effect on Labrador Sea surface waters (Kieke and Yashayaev, 2015). Boucher et al. (2017)

https://doi.org/10.1017/qua.2020.103 Published online by Cambridge University Press

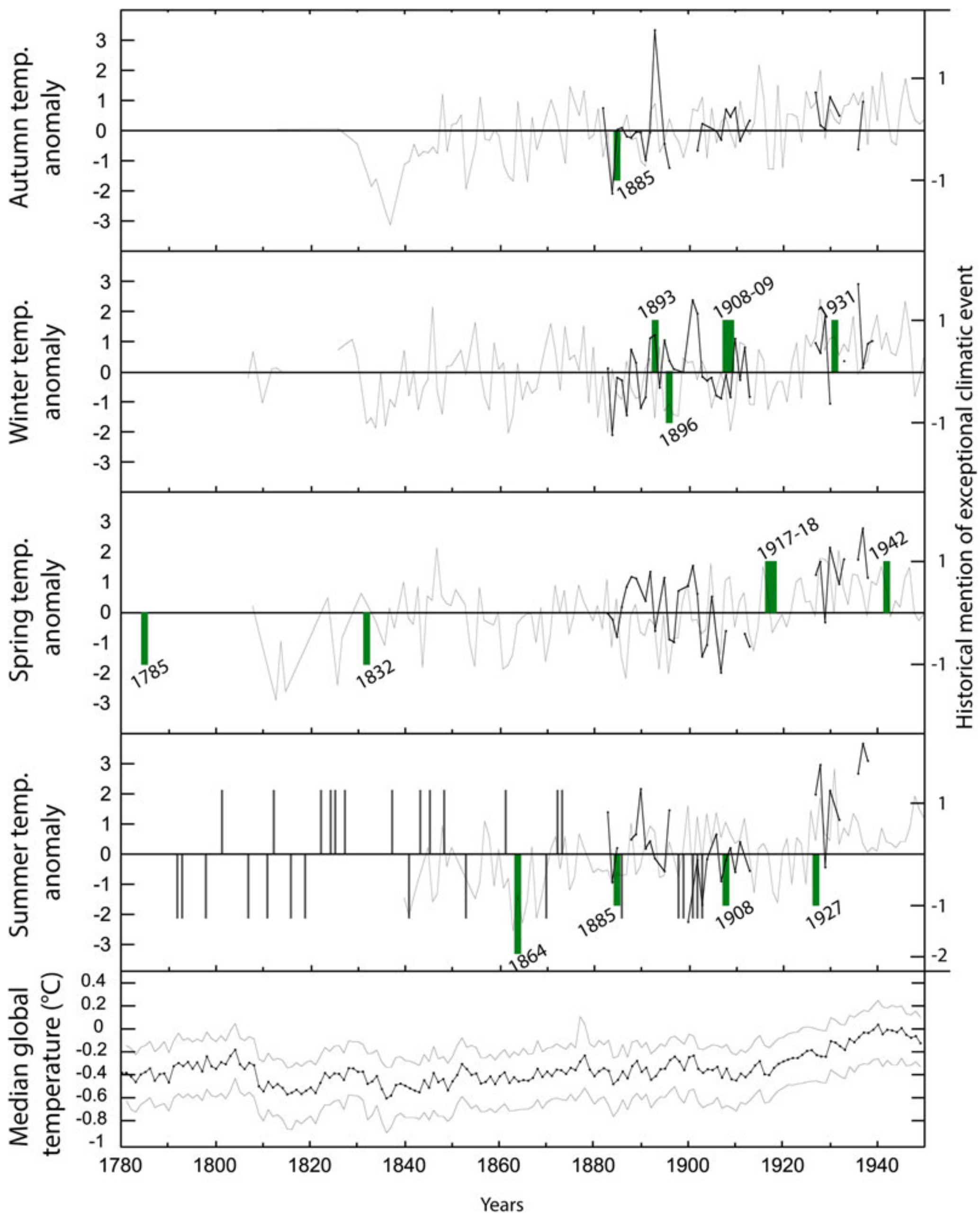

Figure 6. (color online) Seasonal climatic anomaly extracted from historical data. Mean seasonal temperature (temp.) standardized anomalies from early instrumental data; data from Nain, Nunatsiavut in black (this study); data from Ilulissat, Greenland in light gray (Vinther et al., 2006). The Ilulissat monthly temperatures are infilled with regressed values based on observation from 4 sites (Aasiaat, Qeqertarsueaq, Upernavik, and Uummannaq) located along the west coast of Greenland (Vinther et al., 2006). Historical mentions of positive or negative exceptional climatic events from discursive sources (one or two occurrences) are shown by green bars. Mission ship arrival date exceptional years are shown by black bars in the summer graph. Median global temperature anomalies (°C) extracted from PAGES 2k Consortium (2019) are shown in black, and the 2.5th and 97.5th percentiles in gray.

demonstrated a correlation between Labrador black spruce growing season and sea surface temperature, which suggests an indirect relationship between MXD and winter NAO. The AMO, which is the variability of sea surface temperature in the North Atlantic, recorded positive (warmer) values in 1860–1880 and 1940–1960 (Enfield et al., 2001). Negative AMO values were recorded from the late 1700s to the early 1800s, and during the late 1800s to 1920, during intervals characterized by extensive Arctic sea-ice cover (Miles et al., 2014).

End of the 18th century and the 19th century

During the 19th century, historical records emphasize cold periods. Limited references to warm conditions can be explained by two reasons other than climate. First, missionaries focused

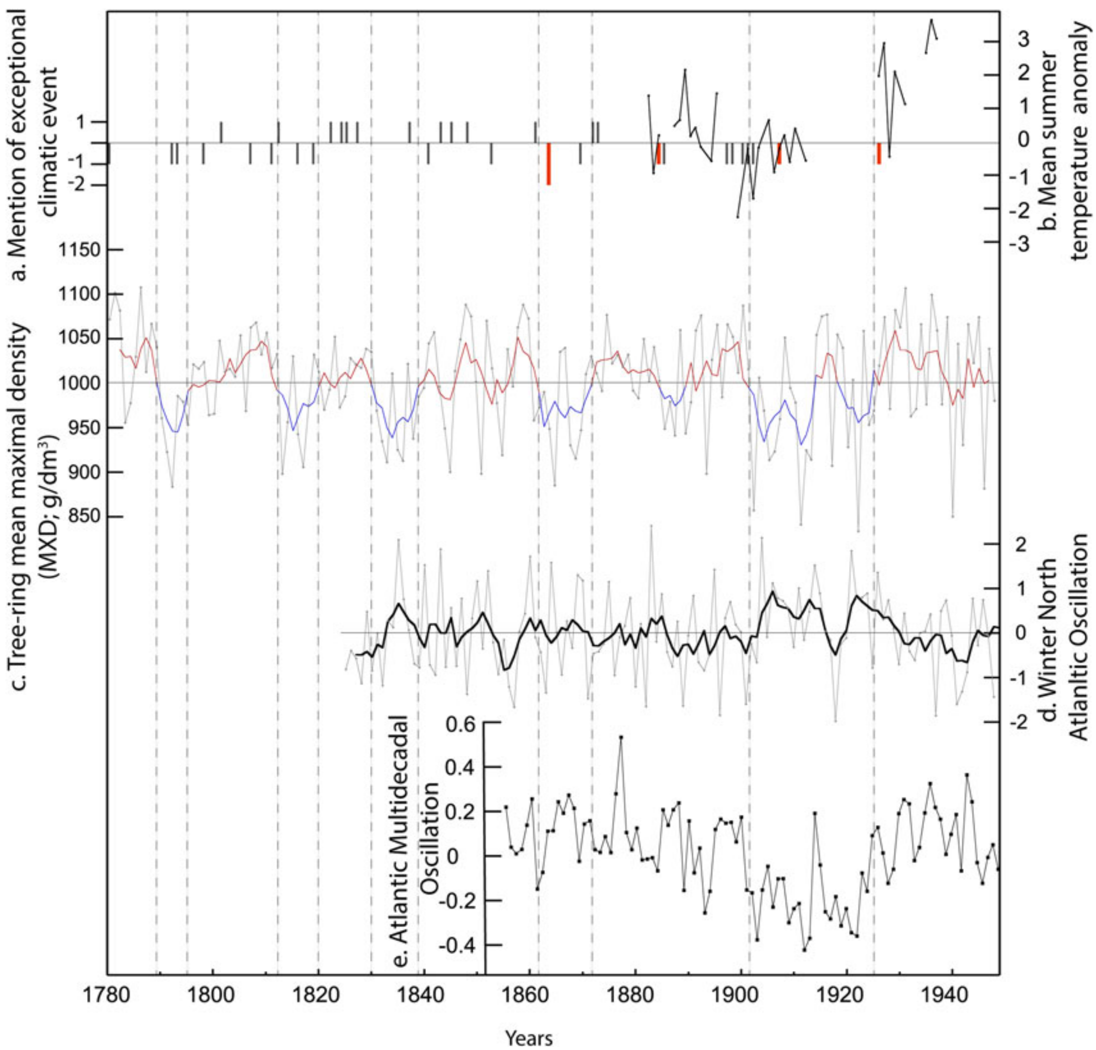

Figure 7. Summer climate variations as recorded in historical and dendrochronological sources from the coast of Labrador/Nunatsiavut, 1780 to 1950. (a.) Mention of positive and negative exceptional climatic events. Gray bars show documentary data, red bars show discursive data. Each bar corresponds to an individual occurrence. (b.) Mean summer temperature anomalies recorded from Nunatsiavut. (c.) Tree-ring mean maximum density in gray. Red and blue curves show a five-years running mean, colors represent the regime changes (positive and negative). Dashed vertical bars delimited the main regime changes (obtained from Gaussian HMM1d package). (d.) Winter North Atlantic Oscillation normalized index (Jones et al., 1997) in gray. Black curve shows a five-years running mean. (e.) Atlantic Multidecadal Oscillation (smoothed curve of Kaplan SST dataset; Enfield et al., 2001).

on cold climatic events because they correspond to unfavorable and difficult living experiences. Second, during most of the 19th century, food scarcity and epidemics were experienced periodically. These events, rather than climatic observations, attracted attention in the mission records.

During the end of the 18th century, solar activity was lower, and volcanism was more active than at present (Crowley, 2000). In western Europe, this period corresponded to cold climatic conditions and is referred to as part of the so-called "Little Ice Age." Although there were certainly many cold years around this time, the term should be treated with caution because there is considerable spatial and temporal variation (Ogilvie and Jónsson, 2001). In Moravian Periodical accounts, cold conditions and large quantities of snow were reported during the early winters of 1791, 1793, 1802, 1808, 1810–1812, and 1815–1817. Abundant sea-ice was often mentioned in springtime (Fig. 6). Frequently delayed arrival dates of the mission ship suggest particularly severe ice conditions in summer. From 1790 to 1820, seven exceptional arrival dates were recorded. Prior to 1790, only three mission ship arrival dates were available, and among them the arrival date in 1780 was exceptionally late. From 1809 to 1817, severe climatic conditions prevailed year-round. A winter famine among the Inuit population was reported during winter 1809–1810. The Periodical account of 1817 mentioned: "The Captain and mate report, that though for these three years past they have met with an unusual quantity of ice on the coast of Labrador, yet, in no year, since the beginning of the Mission, in 1769, has it appeared so dreadfully on the increase" (PA, vol. 6, p. 405). Tree-ring data also show low MXD from ~1810 to 1820, which indicates cold summer conditions (Fig. 7).

https://doi.org/10.1017/qua.2020.103 Published online by Cambridge University Press

The year 1816, known as the "Year without a summer," was described as being characterized by a large quantity of drift ice and cold climatic conditions (cf., Harrington, 1992; Demarée and Ogilvie, 2011; Brönnimann et al., 2018). It is the only year the mission ship could not reach Hopedale. After the volcanic eruption of the Tambora in April 1815, a general cooling of the Northern Hemisphere was recorded (cf., Stoffel et al., 2015). Moreover, the global temperature reconstruction suggests colder temperature in the 1810s (PAGES 2k Consortium, 2019; Fig. 6). Missionaries reported (October 28, 1816): "As in almost every part of Europe, so in Labrador, the elements seem to have undergone some revolution during the course of last summer" (PA, vol. 6, p. 270). The ice remained along the Labrador/Nunatsiavut coast all summer and probably until the winter freeze-up (Newell, 1983). Parfitt et al. (2020) showed that tree-rings from Labrador recorded extremely low tree-ring width and late wood density in 1816, 1836, and 1865, which corresponded to years marked by major volcanic eruptions and unfavorable climatic conditions indicated by historical records presented in this study. Instrumental records from Greenland show large negative anomalies during the 1810 decade (data only available for springtime).

D'Arrigo et al. (2003) and Brice-Bennett (1981) underlined the unpredictable and colder climatic conditions that affected whale and seal migrations at the beginning of the 19th century. Until 1900, the tree-ring MXD record showed a succession of relatively warm and cold periods, each spanning ~10 to 20 years (Fig. 7). During the 1830s, low tree-ring MXD indicated the occurrence of unfavorable summer conditions, and the Periodical accounts described violent storms and tempestuous and harsh climatic conditions during summers and winters. In 1832, the Mission Captain experienced a succession of storms and sailed in large quantities of drift ice on his way to the Labrador/Nunatsiavut coast, which is consistent with the testimony of abundant spring ice in Battle Harbour (Unknown Author, 1832). Ice conditions became slightly more severe from 1833 to 1836 (Newell, 1983). From 1831 to 1833 and from 1835 to 1837, abundant summer drift ice was reported by Brice-Bennett (1996). Greenland autumn and winter temperature series showed negative temperature anomalies from 1830 to 1840. Such anomalies can be associated with a positive phase of the NAO (Fig. 6).

Instability persisted in weather conditions during the 1840s (PA, vol. 13, 16, 20). Serious storms at sea in 1834, 1841, 1851, and 1852 are described in Missionaries archives (Moravian Brethren, 1877). The tree-ring data from 1850 to 1860 show formation of high-density wood formed in a late-growing season. In general, warmer conditions are associated with variable and stormy weather, which could be related to the negative phase of NAO that is characterized by high cyclonic activity in the Labrador Sea area (Hurrell and Deser, 2010). Such conditions carry drift ice away and delay the formation of land fast ice to late fall. Relatively warm conditions also resulted in a later freezing of the bays, which delayed the beginning of winter seal hunting on ice.

From about 1860 to 1870, a lower tree-ring MXD regime is observed (Fig. 7). Newell (1983) noticed a return to more severe than normal conditions from 1860 to 1880 (1964–1979 reference period). In 1864, the missionary Alpheus Spring Packard (1891) mentioned in his journal that people complained about the lateness of the warm season. In July, immense and unusual quantities of ice were found in the bay of Hamilton Inlet. The mission ship also encountered an unusual amount of drift ice (Packard, 1891). Three successive years of epidemic were recorded in 1863–1865 (PA, vol. 25). From early instrumental data, Jean-Alfred Gautier (1879) suggested that the winters of 1867–1868 and 1868–1869 were exceptionally cold in Hopedale. Winter 1868–1869 was ~3–4°C colder than the 1868–1874 average (Gautier, 1879). Negative summer temperature anomalies from 1860 to 1880 and negative winter and autumn temperature anomalies from 1880 to 1890 are also outlined in the Ilulissat record. Consistent climate oscillations thus characterize the Nunatsiavut and West Greenland temperature during these periods.

Data from the First International Polar Year indicated low temperatures in 1883–1885. In Nain, negative temperature anomalies occurred in autumn and winter from 1883 to 1890 (Fig. 6). Similarly, in the Periodical accounts (vol. 33), the two successive winters of 1883–1884 and 1884–1885 were described as colder than average, and from July 1883 to July 1884, no month had passed without frost and snow. Mean annual temperature in 1884 was ~2°C lower than the 1884–1938 average (Fig. 5b). In his journal, Thomas L. Blake attested to cold and tempestuous conditions in 1885. Snow had fallen since October 10th, and a substantial amount of ice in a river close to Hamilton Inlet was present from October 28th (Blake, 1977). Demarée and Ogilvie (2011) investigated the *Journal de l'Unité des frères*, written by missionaries from Switzerland, and found mentions of cold winters in 1883–1884 and "cold fog" in summer 1884. Tree-ring MXD series show low values from about 1884 to 1890. It is possible that these conditions were the result of the Krakatau eruption in 1883. In Greenland and Labrador/Nunatsiavut, a few studies have mentioned the relationship between the 1883 cooling and the Krakatau eruption (Vinther al., 2006; Demarée and Ogilvie, 2011; Way and Viau, 2015; Birkel et al., 2018). However, the 1883 cold extreme might also be linked with a larger cooling trend observed in the previous years (e.g., Way and Viau, 2015). A switch to a positive winter NAO occurred during this period (Fig. 7).

Cold, snowy, long, and severe winters were mentioned in PA from 1888 to 1891. Blake (1977) also noted freezing of mercury in January and February 1888 and 1889. In contrast, the 1890s generally correspond to positive temperature anomalies, especially in winter (Fig. 6). After 1891, a switch to negative NAO took place and persisted until ~1900 (Fig. 7). In 1892, mean annual temperature in Nain was −3.64°C, while the mean from 1884 to 1938 was about −4.82°C (Fig. 5c). In 1893, high MXD values suggest a favorable growing season, and discursive data indicate unusually warm winter conditions. The Greenland temperature series presented variable climatic conditions that do not show systematic warm or cold climatic trends (Vinther et al., 2006; Cappelen and Vinther, 2014).

First half of the 20th century

The first half of the 20th century was characterized by a cold climate until ∼1925, which was followed by warmer conditions until the end of the record. From 1900 to 1925, a strongly positive NAO and negative AMO were recorded (Fig. 7). According to historical data, the cold period started after 1895, during which the mission ship had difficulties at sea. The winter 1896–1897 was severe in Battle Harbour: "No one here remembers such a cold winter, with continual frost and gale from the North-West" (PA, vol. 3, no. 30, p. 270). Tree-ring MXD values and instrumental temperatures decreased after ∼1900, suggesting colder conditions during late summers until 1925 (Fig. 7). From 1903 to 1908, the mean annual temperature in Nain was about 1.5°C lower than the overall mean of 1884 to 1938. The lowest temperatures were recorded in 1903, 1907, 1908, and 1913 in Nain (Fig. 5b). The autumn seal harvest was reported to be less productive because sea-ice formed early in the season (PA, vol. 5, no. 55–58, vol. 7, no. 75–79). Outbreaks of influenza, measles, and probably Poliomyelitis occurred, especially during winters of 1868–1869, 1875–1876, 1882, 1904–1905, and 1908 (cf., Demarée and Ogilvie, 2011). In addition, discursive data present a stormy winter in 1908. The writer Patrick William Browne (1909) described a storm event during which over 40 schooners were destroyed in Hamilton Inlet.

Early instrumental sources from Nunatsiavut show seasonal dissimilarity, with a warming trend beginning around 1910 in autumn and winter, and around 1920–1925 in spring and summer (Fig. 6). Warm winter conditions were noted in discursive sources and early instrumental sources from 1908 to 1910. Periodical accounts mentioned mild and stormy autumns with considerable quantities of drift ice in spring. It was observed that winter started 2–3 weeks later than usual, which had negative consequences for autumn seal hunting at sea (PA, vol. 7, no. 84–85). Newell (1990) showed marked change in spring sea-ice during the 1920s. In West Greenland, a rapid temperature increase was observed from ∼1920 in autumn and winter, and after ∼1925 in spring and summer. After 1925, high-density tree-ring and positive temperature anomalies correspond to a persistently positive AMO until the end of the record and slightly negative winter NAO after 1930.

Warm spring conditions were described in discursive sources in 1917 and 1918. These descriptions are consistent with a small increase in tree-ring MXD before a decline from 1919 to 1925 (Fig. 7). In 1917, a missionary named Henry Gordon, who was based in Muddy Bay close to Cartwright (Fig. 1), wrote in his journal that spring came early with negative consequences for hunters and trappers who struggled to cross ice-free waterbodies (Gordon, 1972). The Moravian missionary Frederick William Peacock wrote after the epidemic of 1918 in Nain that the sea-ice moved quickly from the bay (Peacock, 1986). The winter of 1918–1919 is known for a tragic outbreak of Spanish flu that decimated the Inuit population (cf., Them days, 2015; Burgel, 2018). The warmest part of the record is observed between 1925 and 1940, with six of the warmest years recorded during this interval (Fig. 5). Mean summer and spring temperatures show more positive anomalies than those of autumn and winter (Fig. 6). During the same interval, MXD recorded exceptionally high values (average of 1014.95 g/dm^3). From discursive sources, the novelist Elliott Merrick described unusually abundant drift ice in the Labrador Sea until the end of August 1927 (Merrick, 1998), which might be associated with an enhanced iceberg calving from Baffin Island and Greenland. He stated that February was milder in 1931 than during previous years (Merrick, 1992). The beginning of the 20th century was marked by socioeconomic changes. Increased contact with fishermen and explorers weakened the exclusive influence of Moravians on Inuit life. Populations of Okak and Hebron were displaced respectively in 1956 and in 1959. The forced relocation of Inuit populations was a traumatic event that left painful memories and deep cultural impacts (Brice-Bennett, 2017).

CONCLUSION

Historical data were used to characterize climatic variations during the 19th and the first half of the 20th century on the coast of Labrador/Nunatsiavut. Human-related indicators bring original information regarding the state of climate, its perception, and how it affected the local population. These sources are subjective, but together with instrumental and proxy data such as tree-ring records, they offer new perspectives on climatic variations that can complement climate reconstructions. It is difficult to assess the impact of exceptional climatic events on Inuit and Moravian life because the 19th century was marked by major cultural changes. The establishment of several mission stations along the coast of Nunatsiavut modified the traditional Inuit sociocultural and economic structures: family, hunting, traveling, and trading changes (Brice-Bennett, 1996). Moravian missionaries originated mainly from England and Germany, and only a few of them had previously experienced subarctic climate. They were probably more vulnerable to climate events, which may result in over-representation of cold climatic conditions in these sources. Their dependence on European supplies led the Mission ship to face dangerous situations and sail despite the occurrence of spring sea-ice in the Labrador Sea. Nevertheless, spring and summer mentions of exceptional climatic events are highly coherent with tree-ring maximum density values (80%).

Historical and tree-ring records from the coast of Labrador/Nunatsiavut showed a regional response to climatic variations. On a regional scale, unfavorable climatic conditions showed relationship with northern North Atlantic conditions during phases of positive winter NAO (Fig. 7), which suggested that major exceptional cold periods were associated

https://doi.org/10.1017/qua.2020.103 Published online by Cambridge University Press

with regional atmospheric conditions. From 1780 to 1810, warm global temperatures evidenced from the compilation of the PAGES 2k Consortium (2019) are consistent with the Labrador/Nunatsiavut coast tree-ring MXD record. However, documentary and discursive data showed the occurrence of cold climatic conditions. Hence, a possible bias induced by human perception of climate is possible. The Labrador/Nunatsiavut climate record of the beginning of the 20th century appeared to be strongly related to the North Atlantic climatic conditions, as expressed by the AMO index. Global air temperature began to warm ~1900–1910 (Fig. 6), but the regional warming was more sustained after 1925. From 1925 to 1950, highly positive temperature anomalies in instrumental data from the coast of Nunatsiavut and West Greenland are described by a negative NAO phase and a positive AMO index, which suggested warming on a large regional scale.

The interdisciplinary approach promoted here is innovative. Historical and proxy-related sources are used together to address scientific questions related to livelihood and past climatic conditions. This approach highlighted natural variations of climate and how people communicate it. By integrating direct testimony of climate or weather-related events, there is a focus on climatic features that played a decisive role for populations. The punctual and non-systematic character of discursive sources may bias climatic reconstructions. However, in combination with documentary sources, they represent a connection for human perspective on past climatic variations and exceptional events. These sources should be considered together with instrumental and proxy data to correctly interpret interrelationships between climate and human activities. Moreover, consistency between the independent sources of climate information helps address the issues of data reliability.

ACKNOWLEDGMENTS

This work was supported by the Social Sciences and Humanities Research Council (SSHRC) of Canada, the *Fonds de recherche du Québec - Nature et technologies* (FRQNT), and the Northern Scientific Training Program (Polar Knowledge Canada). It is a contribution to the Canada-Germany project ArcTrain, which is supported by the Natural Science and Engineering Research Council (NSERC) of Canada. We acknowledge the work of the German Weather Service (*Deutscher Wetterdienst*; DWD) who extracted, digitalized, and standardized the high-resolution temperature record of the First International Polar Year. Authors are thankful for the library and collections access provided by Them Days, the Labrador Institute (Happy Valley-Goose Bay), the Moravian Church Headquarters (London), and the International Laboratory for Research on Images of the North, Winter and the Arctic (Montreal).

REFERENCES

Banfield, C., 1981. The climatic environment of Newfoundland. In: Macpherson, A.G., Macpherson, J.B. (Eds.), *The Natural Environment of Newfoundland, Past and Present*. Department of Geography, Memorial University of Newfoundland, St. John's, pp. 83–153.

Banfield, C.E., Jacobs, J.D., 1998. Regional patterns of temperature and precipitation for Newfoundland and Labrador during the past century. *Canadian Geographer/Le Géographe canadien* 42, 354–364. https://doi.org/10.1111/j.1541-0064.1998.tb01351.x.

Behringer, W., 2010. *A Cultural History of Climate*. Polity Press, Cambridge, UK, 280 pp.

Birkel, S.D., Mayewski, P.A., Maasch, K.A., Kurbatov, A.V., and Lyon, B., 2018. Evidence for a volcanic underpinning of the Atlantic multidecadal oscillation. *NPJ Climate and Atmospheric Science,* 1, 1–7. https://doi.org/10.1038/s41612-018-0036-6.

Blake, T.L., 1977. *The Diary of Thomas L. Blake, 1883–1890*. Them Days, Happy Valley-Goose Bay, NL, 80 pp.

Boucher, E., Nicault, A., Arseneault, D., Bégin, Y., Karami, M.P., 2017. Decadal variations in Eastern Canada's taiga wood biomass production forced by ocean-atmosphere interactions. *Scientific Reports* 7 (1), 1–13.

Box, J.E., 2002. Survey of Greenland instrumental temperature records: 1873–2001. *International Journal of Climatology* 22, 1829–1847. https://doi.org/10.1002/joc.852.

Brázdil, R., Pfister, C., Wanner, H., Von Storch, H., Luterbacher, J., 2005. Historical climatology in Europe—the state of the art. *Climatic change* 70, 363–430. https://doi.org/10.1007/s10584-005-5924-1.

Brice-Bennett, C., 1981. *Two opinions: Inuit and Moravian missionaries in Labrador, 1804–1860*. Master thesis, Department of Anthropology, Memorial University of Newfoundland, St. John's.

Brice-Bennett, C., 1996. *The Northlanders: A history of the population, socio-economic relations and cultural change of Inuit occupying the remote northern coast of Labrador*. Unpublished report, Labrador Inuit Association, Nain, Labrador, Canada.

Brice-Bennett, C., 2017. *Dispossessed. The Eviction of Inuit from Hebron, Labrador*. Imaginaire Nord, Montréal.

Brönnimann S., White S., Slonosky V., 2018. Climate from 1800 to 1970 in North America and Europe. In: White S., Pfister C., Mauelshagen F. (Eds.), *The Palgrave Handbook of Climate History*. Palgrave Macmillan, London. https://doi.org/10.1057/978-1-137-43020-5_25.

Browne, P.W., 1909. *Where the Fishers Go: The Story of Labrador*. Cochrane Publishing Company, New York, 406 pp.

Brown, R., Lemay, M., Allard, M., Barrand, N., Barrette, C., Bégin, Y., *et al*.., 2012. Climate variability and change in the Canadian Eastern Subarctic IRIS region (Nunavik and Nunatsiavut). In: Allard, M., Lemay, M. (Eds), *Nunavik and Nunatsiavut: From Science to Policy. An Integrated Regional Impact Study (IRIS) of Climate Change and Modernization*. ArcticNet Inc., Quebec City, pp. 57–93.

Burgel, A., 2018. *We All Expected to Die: Spanish Influenza in Labrador, 1918–1919*. ISER Books, St-John's, 392 pp.

Cappelen, J., Vinther, B.M., 2014. SW Greenland temperature data 1784–2013. *Danish Meteorological Institute, Technical Report*, 14-06, p. 1–1. http://www.dmi.dk/fileadmin/Rapporter/TR/tr14-06.pdf

Cartwright, G., 1792. *A Journal of Transactions and Events During a Residence of Nearly Sixteen Years on the Coast of Labrador*. Allin and Ridge, Newark, NJ, 239 pp.

Catchpole, A., Moodie, D., 1978. Archives and the environmental scientist. *Archivaria* 6, 113–136.

Chartier, D., 2007. Towards a Grammar of the Idea of North. Nordicity, Winterity. *Nordlit* 22, 35–47. https://doi.org/10.7557/13.1498.

Chartier, D., 2019. *What is the "Imagined North"? Ethical principles. Imaginaire Nord and Arctic Arts Summit, coll*. Montreal and Harstad, pp. 157.

Crane, R.G., 1978. Seasonal variations of sea-ice extent in the Davis Strait-Labrador Sea area and relationships with synoptic-scale atmospheric circulation. *Arctic* 31, 413–517. https://doi.org/10.14430/arctic2671.

Crowley, T.J., 2000. Causes of climate change over the past 1000 years. *Science* 289, 270–277. https://doi.org/10.1126/science.289.5477.270.

Cunsolo Willox, A., Harper, S., Edge, V., Landman, K., Houle, K., Ford, J., Government, R.I.C., 2013. 'The land enriches the soul:' on environmental change, affect, and emotional health and well-being in Nunatsiavut, Canada. *Emotion, Space and Society* 6, 14–24. https://doi.org/10.1016/j.emospa.2011.08.005.

Cunsolo Willox, A., Harper, S.L., Ford, J.D., Landman, K., Houle, K., Edge, V.L., 2012. 'From this place and of this place:' climate change, sense of place, and health in Nunatsiavut, Canada. *Social science and medicine* 75, 538–547. https://doi.org/10.1016/j.socscimed.2012.03.043.

Curry, J.A., Schramm, J.L., and Ebert, E.E., 1995. Sea-ice-albedo climate feedback mechanism. *Journal of Climate* 8, 240–247.

D'Arrigo, R.D., Buckley, B., Kaplan, S., Woollett, J., 2003. Interannual to multidecadal modes of Labrador climate variability inferred from tree rings. *Climate Dynamics* 20, 219–228. https://doi.org/10.1007/s00382-002-0275-3.

D'Arrigo, R.D., Cook, E.R., Jacoby, G.C., 1996. Annual to decadal-scale variations in northwest Atlantic sector temperatures inferred from Labrador tree rings. *Canadian Journal of Forest Research* 26, 143–148. https://doi.org/10.1139/x26-015.

Demarée, G.R., Ogilvie, A.E., 2008. The Moravian missionaries at the Labrador coast and their centuries-long contribution to instrumental meteorological observations. *Climatic change* 91, 423–450. https://doi.org/10.1007/s10584-008-9420-2.

Demarée, G.R., Ogilvie, A.E., 2011. Climate-related information in Labrador/Nunatsiavut: evidence from Moravian missionary journals. *Bulletin des Séances-Mededelingen der Zittingen, Académie Royale des Sciences d'Outre-Mer–Koninklijke Academie voor Overzeese Wetenschappen* 57, 391–408.

Deser, C., Holland, M., Reverdin, G., Timlin, M., 2002. Decadal variations in Labrador Sea-ice cover and North Atlantic sea surface temperatures. *Journal of Geophysical Research* 107, 3-1–3-12. https://doi.org/10.1029/2000JC000683.

Döll, L., 1937. Klima und wetter an der Kuste von Labrador. *Archiv der Deutschen Seewarte* 57, p. 1–21.

Drinkwater, K.F., 1996. Atmospheric and oceanic variability in the Northwest Atlantic during the 1980s and early 1990s. *Journal of Northwest Atlantic Fishery Science* 18, 77–97. https://doi.org/10.2960/J.v18.a6.

Enfield, D.B., Mestas-Nuñez, A.M., Trimble, P.J., 2001. The Atlantic multidecadal oscillation and its relation to rainfall and river flows in the continental US. *Geophysical Research Letters* 28, 2077–2080. https://doi.org/10.1029/2000GL012745.

Environment Canada, 2017. *Historical Data, Nain*. Government of Canada.

Finnis, J., Bell, T., 2015. An analysis of recent observed climate trends and variability in Labrador. *Canadian Geographer/Le Géographe canadien* 59, 151–166.

Gautier, J.A., 1879. *Commentaries on the Meteorological Observations by Moravian Missionaries on the Labrador Coast, St. John's*. Memorial University of Newfoundland, Centre for Newfoundland Studies, 30 pp.

Gordon, H., 1972. *The Labrador Parson, Journal of the Reverend Henry Gordon, 1915–1925*. Transcript by F. Burnham Gill, St. John's, 254 pp.

Grenfell, W.T., 1911. *Down North on the Labrador*. Fleming H. Revell Company, New York, Chicago, Toronto, London, Edinburgh, 229 pp.

Haldon, J., Roberts, N., Izdebski, A., Fleitmann, D., McCormick, M., *et al*., 2014. The climate and environment of Byzantine Anatolia: integrating science, history, and archaeology. *Journal of Interdisciplinary History* 45, 113–161. https://doi.org/10.1162/JINH_a_00682.

Harrington, C.R. (Ed.), 1992. *The Year Without a Summer? World Climate in 1816*. Canadian Museum of Nature, Ottawa, 576 pp.

Hurrell, J.W., 1995. Decadal trends in the North Atlantic Oscillation: regional temperatures and precipitation. *Science* 269, 676–679. https://doi.org/10.1126/science.269.5224.676.

Hurrell, J.W., Deser, C., 2010. North Atlantic climate variability: the role of the North Atlantic Oscillation. *Journal of Marine Systems* 79, 231–244. https://doi.org/10.1016/j.jmarsys.2009.11.002.

Jacoby, G.C., D'Arrigo, R.D., 1995. Tree ring width and density evidence of climatic and potential forest change in Alaska. *Global Biogeochemical Cycles* 9, 227–234. https://doi.org/10.1029/95GB00321.

Johannessen, O.M., Bengtsson, L., Miles, M.W., Kuzmina, S.I., Semenov, V.A., *et al*., 2004. Arctic climate change: observed and modeled temperature and sea-ice variability. *Tellus A: Dynamic Meteorology and Oceanography* 56, 328–341. https://doi.org/10.1111/j.1600-0870.2004.00060.x.

Jones, P.D., Jónsson, T., Wheeler, D., 1997. Extension to the North Atlantic Oscillation using early instrumental pressure observations from Gibraltar and south-west Iceland. *International Journal of Climatology* 17, 1433–1450. https://doi.org/10.1002/(SICI)1097-0088(19971115)17:13<1433::AID-JOC203>3.0.CO;2-P.

Kaspar, F., Tinz, B., Mächel, H., Gates, L., 2015. Data rescue of national and international meteorological observations at Deutscher Wetterdienst. *Advances in Science and Research* 12, 57–61. https://doi.org/10.5194/asr-12-57-2015.

Kerr, R.A., 2000. A North Atlantic climate pacemaker for the centuries. *Science* 288, 1984–1985. https://doi.org/10.1126/science.288.5473.1984.

Kieke, D., Yashayaev, I., 2015. Studies of Labrador sea water formation and variability in the subpolar North Atlantic in the light of international partnership and collaboration. *Progress in Oceanography* 132, 220–232. https://doi.org/10.1016/j.pocean.2014.12.010.

Kvamstø, N.G., Skeie, P., Stephenson, D.B., 2004. Impact of Labrador sea-ice extent on the North Atlantic Oscillation. *International Journal of Climatology* 24, 603–612. https://doi.org/10.1002/joc.1015.

Lemus-Lauzon, I., Bhiry, N., Arseneault, D., Woollett, J., Delwaide, A., 2018. Tree-ring evidence of changes in the subarctic forest cover linked to human disturbance in northern Labrador (Canada). *Ecoscience* 25, 135–151. https://doi.org/10.1080/11956860.2018.1436244.

Levac, E., de Vernal, A., 1997. Postglacial changes of terrestrial and marine environments along the Labrador coast: palynological evidence from cores 91-045-005 and 91-045-006, Cartwright Saddle. *Canadian Journal of Earth Sciences* 34, 1358–1365. https://doi.org/10.1139/e17-108.

Lüdecke, C., 2005. East meets west: meteorological observations in Greenland and Labrador since the 18th century. *History of Meteorology* 2, 123–132.

Marko, S., Fissel, D., Wadhams, P., Kelly, P., Brown, R., 1994. Iceberg severity of eastern North America: its relationship to sea-ice variability and climate change. *Journal of Climate* 7, 1335–1351.

IPCC, 2018. Masson-Delmotte, V., Zhai, P., Pörtner, H.O., Roberts, D., Skea, J., *et al.* (Eds.), Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. https://www.ipcc.ch/sr15/.

McCarroll, D., Jalkanen, R., Hicks, S., Tuovinen, M., Gagen, M., Pawellek, F., Eckstein, D., Schmitt, U., Autio, J., Heikkinen, O., 2003. Multiproxy dendroclimatology: a pilot study in northern Finland. *The Holocene* 13, 829–838. https://doi.org/10.1191/0959683603hl668rp.

Merrick, E., 1992. *The Long Crossing and Other Labrador Stories*. University of Maine Press, Orono, ME, 136 pp.

Merrick, E., 1998. *The Northern Nurse*. Countryman Press, Woodstock, VT, 314 pp. [original work published 1942]

Metzger, A., 2013. Art et science des nuages au Siècle d'or hollandais. *Géographie et cultures* 85, 87–109.

Miles, M.W., Divine, D.V., Furevik, T., Jansen, E., Moros, M., Ogilvie, A.E., 2014. A signal of persistent Atlantic multidecadal variability in Arctic sea-ice. *Geophysical Research Letters* 41, 463–469. https://doi.org/10.1002/2013GL058084.

Moravian Brethren, 1877. Brief Account of the Missionary Ships Employed in the Service of the Mission on the Coast of Labrador, from the Year 1770 to 1877. London, Printed by Norman and Son, for the Brethren's Society for the Furtherance of the Gospel, 26 pp.

Nasri, B.R., Boucher, É., Perreault, L., Rémillard, B.N., Huard, D., Nicault, A., Members of ARCHIVES-PERSISTENCE projects, 2020. Modeling hydrological inflow persistence using paleoclimate reconstructions on the Québec-Labrador (Canada) Peninsula. *Water Resources Research* 56, e2019WR025122. https://doi.org/10.1029/2019WR025122.

PAGES 2k Consortium (Neukom, R., Barboza, L.A., Erb, M.P., Shi, F., Emile-Geay, J., *et al.*), 2019. Consistent multidecadal variability in global temperature reconstructions and simulations over the Common Era. *Nature Geoscience* 12, 643–649. https://doi.org/10.1038/s41561-019-0400-0.

Newell, J.P., 1983. Preliminary analysis of sea-ice conditions in the Labrador Sea during the nineteenth century. In: Harington, C.R. (Ed.), Climatic Change in Canada 3. *Syllogeus* 49, 108–129.

Newell, J.P., 1990. *Spring and Summer Sea-ice and Climate Conditions in the Labrador Sea, 1800–Present*. Ph.D., Dissertation. University of Colorado, Boulder, CO.

Newell, J.P., 1992. The climate of the Labrador Sea in the spring and summer of 1816, and comparisons with modern analogues. In: Harington, C.R. (Ed.), *The Year Without a Summer? World Climate in 1816*. Canadian Museum of Nature, Ottawa, pp. 245–254.

Nicault, A., Boucher, E., Tapsoba, D., Arseneault, D., Berninger, F., *et al.*, 2014. Spatial analysis of black spruce (*Picea mariana* (Mill.) BSP) radial growth response to climate in northern Québec—Labrador Peninsula, Canada. *Canadian Journal of Forest Research* 45, 343–352. https://doi.org/10.1139/cjfr-2014-0080.

Ogilvie, A.E.J., Jónsson, T., 2001. "Little Ice Age" research: a perspective from Iceland. *Climatic Change* 48, 9–52. https://doi.org/10.1023/A:1005625729889.

Ouellet-Bernier, M.-M., de Vernal, A., 2018. Proxy Indicators of Climate in the Past. In: Chiotis, E. (Ed.), *Climate Changes in the Holocene: Impacts and Human Adaptation*. CRC Press, Boca Raton, FL, pp. 41–76. https://doi.org/10.1201/9781351260244.

Packard, A.S., 1891. *The Labrador Coast: A Journal of Two Summer Cruises to that Region*. N.D.C. Hodges, New York, 558 pp.

Parfitt, R., Ummenhofer, C.C., Buckley, B.M., Hansen, K.G., D'Arrigo, R.D., 2020. Distinct seasonal climate drivers revealed in a network of tree-ring records from Labrador, Canada. *Climate Dynamics* 54, 1897–1911. https://doi.org/10.1007/s00382-019-05092-6.

Peacock, F.W., 1986. *Reflections from a Snowhouse*. Jesperson Press, St.John's, 163 pp.

Periodical Accounts [PA], 1790–1961. *Periodical accounts relating to the missions of the Church of the United Brethren established among the heathen*. Brethren's Society for the Furtherance of the Gospel, London, 169 volumes.

Prichard, H.H., 1911. *Through Trackless Labrador*. William Heinemann, London, 254 pp.

Rémillard, B., 2013. Chapter 10.2 of *Statistical Methods for Financial Engineering* Chapman and Hall/CRC Financial Mathematics Series, Taylor and Francis Inc., Washington.

Richerol, T., Fréchette, B., Rochon, A., Pienitz, R., 2016. Holocene climate history of the Nunatsiavut (northern Labrador, Canada) established from pollen and dinoflagellate cyst assemblages covering the past 7000 years. *The Holocene* 26, 44–60. https://doi.org/10.1177/0959683615596823.

Robinson, P.J., 2005. Ice and snow in paintings of Little Ice Age winters. *Weather* 60, 37–41. https://doi.org/10.1256/wea.164.03.

Roy, N., Bhiry, N., Woollett, J., Delwaide, A., 2017. A 550-year record of the disturbance history of white spruce forests near two Inuit settlements in Labrador, Canada. *Journal of the North Atlantic* 31, 1–14. https://doi.org/10.3721/037.006.3101.

Schweingruber, F.H., 2002. NOAA/WDS Paleoclimatology - Schweingruber - Dorothea Lake - PCGL - ITRDB CANA049, Mountain Lake Newfoundland - PCGL - ITRDB CANA050, Mountain Lake Newfoundland Ufe - PCGL - ITRDB CANA051. NOAA National Centers for Environmental Information. https://doi.org/10.25921/xzmh-bx98. Accessed [October 22, 2019]

Sicre, M.A., Hall, I.R., Mignot, J., Khodri, M., Ezat, U., Truong, M.X., Eiriksson, J, Knudsen, K.L., 2011. Sea surface temperature variability in the subpolar Atlantic over the last two millennia. *Paleoceanography* 26, PA4218. https://doi.org/10.1029/2011PA002169.

Sicre, M.A., Weckström, K., Seidenkrantz, M.S., Kuijpers, A., Benetti, M., *et al.*, 2014. Labrador current variability over the last 2000 years. *Earth and Planetary Science Letters* 400, 26–32. https://doi.org/10.1016/j.epsl.2014.05.016.

Stoffel, M., Khodri, M., Corona, C., Guillet, S., Poulain, V., *et al.*, 2015. Estimates of volcanic-induced cooling in the Northern Hemisphere over the past 1,500 years. *Nature Geoscience* 8, 784–788. https://doi.org/10.1038/NGEO2526.

Taylor, C., 1981. First International Polar Year, 1882–83. *Arctic* 34, 370–376. https://www.jstor.org/stable/40509211.

Them Days (Ed.), 2015. *Nunatsiavut*. Them Days, Happy Valley-Goose Bay, 196 pp.

Tinz, B., Leiding, T., Sedlatschek, R., Otten-Balaccanu, H., Gates, L., Gloeden, W., Rosenhagen, G., Röhrbein, D., 2015. Quality control of marine meteorological data with validat. *Internal Deutscher Wetterdienst document*, 28 pp.

Unknown Author, 1832. Battle Harbour – 1832. *Them Days* 6, 34–42 and 34–46.

Vinther, B.M., Andersen, K.K., Jones, P.D., Briffa, K.R., Cappelen, J., 2006. Extending Greenland temperature records into the late eighteenth century. *Journal of Geophysical Research* 111, D11105. doi:10.1029/2005JD006810.

Walter, F., 2014. *Hiver. Histoire d'une saison. Éditions Payot & Rivages, coll. "Histoire Payot",* Paris, pp. 464.

Way, R.G., Viau, A.E., 2015. Natural and forced air temperature variability in the Labrador region of Canada during the past century. *Theoretical and Applied Climatology* 121, 413–424. https://doi.org/10.1007/s00704-014-1248-2.

White, S., Pfister, C., Mauelshagen, F. (Eds.), 2018. *The Palgrave Handbook of Climate History*. Palgrave Macmillan, London, 651 pp. https://doi.org/10.1057/978-1-137-43020-5_1.

Wolf, J., Allice, I., Bell, T., 2013. Values, climate change, and implications for adaptation: evidence from two communities in Labrador, Canada. *Global Environmental Change* 23, 548–562. https://doi.org/10.1016/j.gloenvcha.2012.11.007.

Woollett, J., 2007. Labrador Inuit subsistence in the context of environmental change: an initial landscape history perspective. *American Anthropologist* 109, 69–84. https://doi.org/10.1525/aa.2007.109.1.69.