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Interannual to multidecadal modes of Labrador climate variability inferred from tree rings

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Abstract The climate of Labrador is uniquely influenced by Labrador Sea atmosphere–ocean dynamics and related sea surface temperature, sea ice and atmospheric fluctuations in the northwest Atlantic. Here we describe composite ring width and maximum latewood density white spruce records averaged over five (four for density) treeline sites in northern Labrador, spanning the past four centuries. These records correlate significantly with surface air and sea surface temperature records for the northwest Atlantic as well as with the North Atlantic Oscillation (NAO). Temperatures over Labrador appear to have been influenced by climate processes operating on interannual to multidecadal time scales over the length of the tree-ring record. The ring width composite reveals a significant ($>99\%$ level) mode of variation centered at around 40–60 years which appears to be robust over the full length of record and may correspond to multidecadal modes identified in model and instrumental studies of North Atlantic climate. The density composite indicates significant peaks at about 21–24, 9 and 2–3 years, which generally correspond to spectral modes identified for the NAO. This density series also shows a significant ($>99\%$ level) mode of variation at 3.6 years, which is statistically coherent with the winter (DJF) Southern Oscillation Index. This mode decreases in amplitude in the 1800s period of the Little Ice Age, one of the lowest growth periods in the Labrador tree-ring series as well as other northern temperature proxies. This period was also a time of diminished solar activity and several major volcanic events, including the eruption of Tambora in 1815. The ensuing summer of 1816 was the coldest over the past four centuries as inferred from the Labrador density composite. Hardships suffered by Labrador Inuit resulting from the extreme cold period of 1816–17 are mentioned in Moravian mission records. Archaeological and ethnohistorical data also document shifts in the subsistence practices and settlement patterns of Labrador Inuit throughout the 1800s. Many of the cultural changes have been attributed to the effects of European settlement of the region, but may also be a response to the severe climatic conditions during this time.

1 Introduction

Labrador's climate is closely linked to the atmosphere–ocean-ice dynamics of the Labrador Sea and Labrador Current, and its proximity to the confluence of the subpolar and subtropical gyres (e.g. Dickson et al. 1988, 1996). The path and intensity of westerly winds or storm tracks across the Labrador Sea influence deep water formation and the transport of Gulf Stream waters northward. These features are in turn believed to be intimately related to the North Atlantic Oscillation (NAO) and its variability on interannual to multidecadal time scales (Marshall and Kushnir 1997), or alternatively to the newly proposed Arctic Oscillation or AO (Thompson and Wallace 1998). It has been suggested that the unusual positive trends in the NAO and AO in recent decades may correspond to large-scale warming and anthropogenic forcing (e.g., Thompson and Wallace 1998; Kerr 1999). These findings have stimulated interest in proxy records from the North Atlantic and Arctic regions, and their ability to yield a longer term perspective on natural and anthropogenically forced climatic change.

Recently, a suite of reconstructions and extended time series of the North Atlantic Oscillation (NAO) based on various combinations of proxy, historical and long instrumental records has been produced. These

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include reconstructions based on tree rings, mainly from Western Europe, the northeastern USA and southern Canada (Cook et al. 1998; Cook 2002), ice cores from Greenland (Appenzeller et al. 1998), long instrumental records (Luterbacher et al. 1999, 2002), and multiproxy data sources (Cullen et al. 2001). Reconstructions of Arctic and Northern Hemisphere temperatures based on circumpolar tree-ring data networks have also been developed (Jacoby and D'Arrigo 1989; D'Arrigo and Jacoby 1993; D'Arrigo et al. 1999; Overpeck et al. 1997; Mann et al. 1998, 1999). However Labrador is one key area still not very well studied or represented in these NAO and circum-Arctic paleotemperature reconstructions.

We describe composite ring width and maximum latewood density tree ring series for northern Labrador produced from ancient living and relict white spruce (*Picea glauca* [Moench] Voss) trees at five (four for density) temperature-sensitive latitudinal treeline sites (Table 1, Fig. 1). Earlier versions of chronologies from two of these locations (Salt Water Pond and Okak) were utilized in prior temperature-related studies for northern latitudes (Jacoby and D'Arrigo 1989; D'Arrigo and Jacoby 1993; D'Arrigo et al. 1996; Overpeck et al. 1997). Tree-ring width and density records have also been generated for three sites in southern Labrador (Schweingruber et al. 1993, used in D'Arrigo et al. 1996). The chronologies from Labrador are well situated to provide useful information on climate variability in this understudied but important region.

2 Methodology

We employed standard dendrochronological methods (Stokes and Smiley 1968; Fritts 1976; Holmes 1983; Cook and Kairiukstis 1990) to generate raw ring width and maximum latewood density measurements from samples collected from the locations in Table 1. Significant intercorrelations, as well as common loadings in principal components analysis, were found among the raw tree-ring measurements from these sites. These findings justified merging the data in order to generate better-replicated regional composite ring width and density chronologies for northern Labrador. Standardization of the raw measurements was performed using only conservative curve fits (i.e., negative exponential, or lines of straight or negative slope) to preserve low-frequency variations (Fritts 1976; Cook 1985; Cook and Kairiukstis 1990). We applied a two-step procedure to reduce the potential biasing effects of traditional standardization methods while preserving low-frequency variation due to climate. First, the variance of each series was stabilized prior to standardization using a data-adaptive power transformation based on the local mean and standard deviation. Second, residuals, rather than ratios, were used in curve-fitting during the standardization process (Cook and Peters 1997; E. Cook personal communication).

The ring-width composite series extends from AD 1459–1998 and consists of 146 individual samples from 100 trees (Fig. 2A). The density composite covers the period AD 1605–1998, and is based on 76 samples from 54 trees (Fig. 2B). Typically there is greater attrition of samples for densitometry, hence the reduced sample size for the density composite. Series intercorrelation was $r = 0.576$ among all ring width series and 0.540 among all density series. For both ring width and density the sample size declines in the earlier and later parts of the series. The mean segment length is 215 years for ring width and 256 years for density, indicating that the maximum usable low-frequency variance retained in these series is about 145 and 170 years, respectively, or 2/3 the series length (Cook et al. 1995).

Two criteria often employed to evaluate the reliability of tree-ring chronologies are the RBAR (average correlation between series) and expressed population signal (EPS) statistics (Wigley et al. 1984; Cook and Kairiukstis 1990). The values for these two statistics, based on 50-year moving windows with 25-year overlaps, are presented in the lower plots in Fig. 2A, B. The RBAR is an indication of common variance among the tree-ring samples comprising the chronology. The EPS statistic measures the degree to which the finite-sample chronology compares with a theoretical chronology based on an infinite number of trees. It has no measure of significance per se, however a value exceeding 0.85 is considered acceptable by some researchers (Wigley et al. 1984). Both RBAR and EPS range from 0 to 1 (Wigley et al. 1984). The mean RBAR is 0.22 between all ring width series, and 0.28 between all density series; the mean EPS is 0.82 for ring width and 0.92 for density. The RBAR and EPS values are most stable after about 1580 for ring width and the middle 1600s for density. We therefore limit our analyses to the periods from AD 1580–1998 and 1660–1998, respectively.

3 Results

Based on our previous observations of temperature-sensitive white spruce near treeline in Labrador (D'Arrigo et al. 1996) as well as other northern locations (e.g., Jacoby and D'Arrigo 1989), we interpret the composite ring width chronology to be an indicator of summer temperature conditions as well as an integrator of annual, low-frequency temperature trends. As is typical of such series, the density composite is considered to reflect extended warm season temperatures, primarily on interannual to interdecadal scales (Schweingruber 1988; D'Arrigo et al. 1992). The density parameter can also be particularly sensitive to the aftermath of volcanic eruptions (Jones et al. 1995; D'Arrigo and Jacoby 1999; Jacoby et al. 1999; see later).

Table 1 Labrador tree-ring sites used in this study. All are of the species white spruce (*Picea glauca*). RW is ring width, DEN is maximum latewood density. Also see Fig. 1

Site	Years	Latitude (N)	Longitude (W)	Elevation (M)
Okak	1655–1992 RW 1655–1992 DEN	57 30	62 26	0–150
Medusa Bay	1690–1996 RW 1690–1996 DEN	56 55	61 30	0–50
Nutak	1700–1996 RW 1700–1996 DEN	57 30	61 45	0–50
Salt Water Pond	1526–1998 RW 1605–1998 DEN	56 31	61 55	10–150
Eyeglass Lake	1459–1960 RW	57 55	61 36	0–200

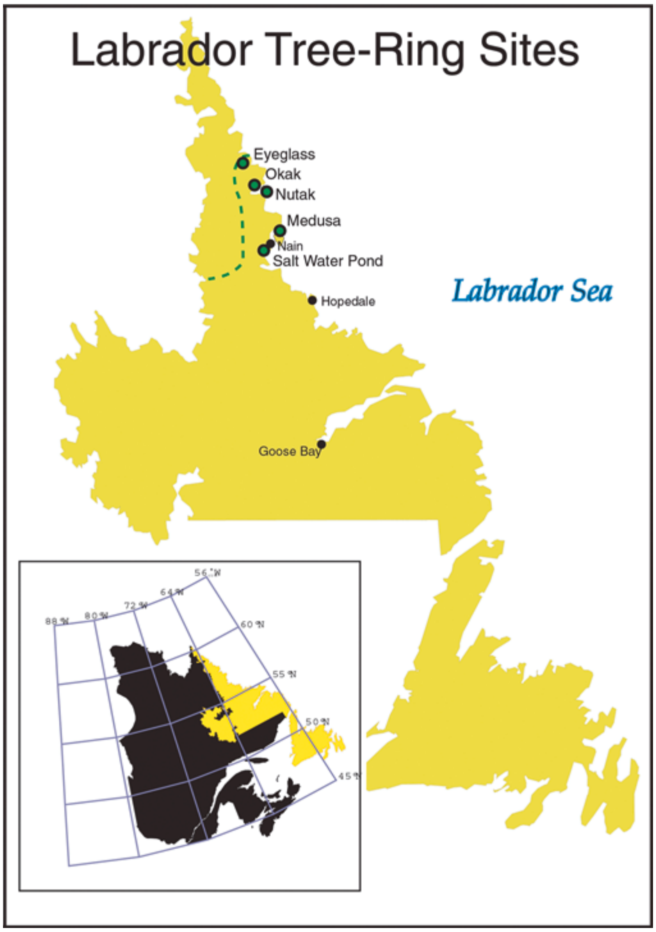


Fig. 1 Map of Labrador showing tree-ring sites (*circles*) for which ring width and density data have been merged into composite series (see also Table 1). *Dotted line* indicates approximate position of northern treeline. *Goose Bay*, *Hopedale* and *Nain* meteorological stations also shown (see text)

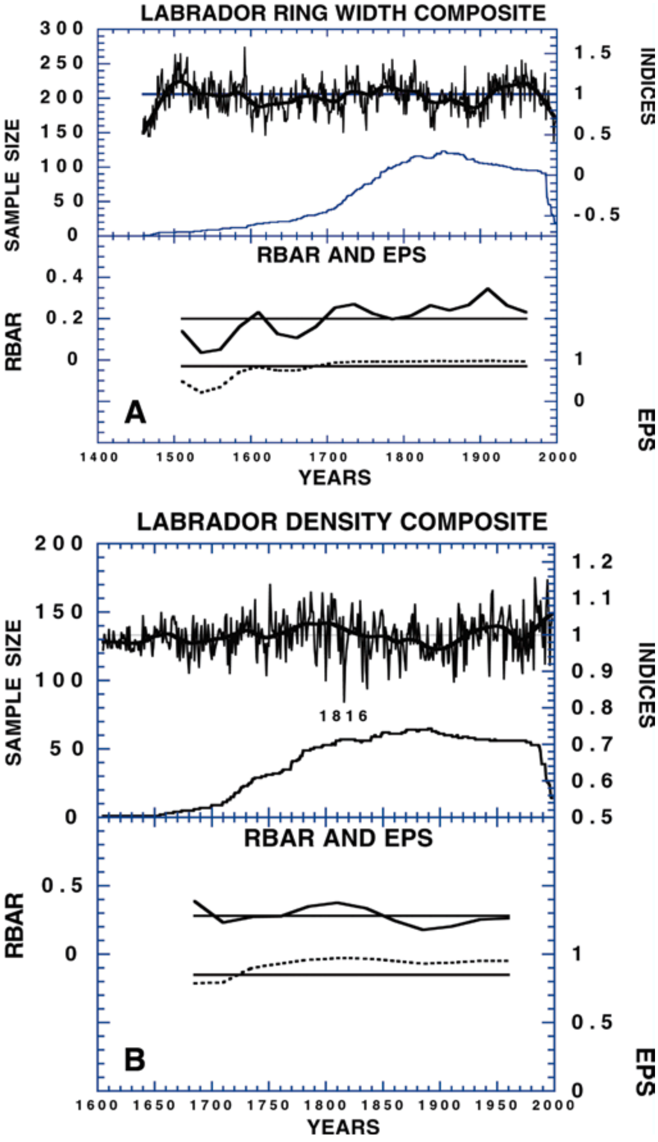


Fig. 2 **A** *Upper plot*: ring width composite chronology from 1459–1998 and (*lower line*) changing sample size over time. *Filtered curve* emphasizes interdecadal variations. *Lower plot*: RBAR and eps (relative to mean and 0.85 level cutoff, respectively) statistics. RBAR (average correlation between series) is *solid line*, eps (expressed population signal) is *dotted line*. **B** As in **A** for density composite series from 1605–1998. Indices are the dimensionless indices created in the ARSTAN standardization process (Cook 1985)

These ring width and density records provide complementary information with which to assess climate variations in northern Labrador and vicinity over the past four centuries.

As one means of evaluating the temperature signal in the ring width and density composites, these series were compared to monthly temperatures from the closest meteorological station with a continuous record, for Goose Bay, Labrador, extending from 1942–91 (Fig. 1). Instrumental records nearer the tree-ring sites, in Nain and Hopedale, are not continuous. Correlations between Nain and Goose Bay temperatures are statistically significant for most months for the few years of overlapping data, thereby justifying the use of the Goose Bay record. Significant, positive correlations were found for both ring width and density parameters with temperature in the warm season months (Fig. 3). The negative correlation between spring temperature and ring width observed in Fig. 3 has been noted in other northern tree-ring studies (Jacoby and Cook 1981). Warmer Aprils can allow transpiration to occur while the ground is still frozen, resulting in desiccation injury. This is thought to be due to early springs resulting in photosynthesis while the ground is still frozen and ensuing desiccation. The highest correlations (Fig. 4) were identified between ring width and averaged June–September temperatures (r = 0.51, 0.001 level), and between density and May–September temperatures (r = 0.56, 0.001 level). Indication of the larger scale signal in the Labrador ring width composite is shown by a correlation of r = 0.39 with a revised version of the annual Arctic temperature reconstruction of D'Arrigo and Jacoby (1993) over the common period from 1655–1970.

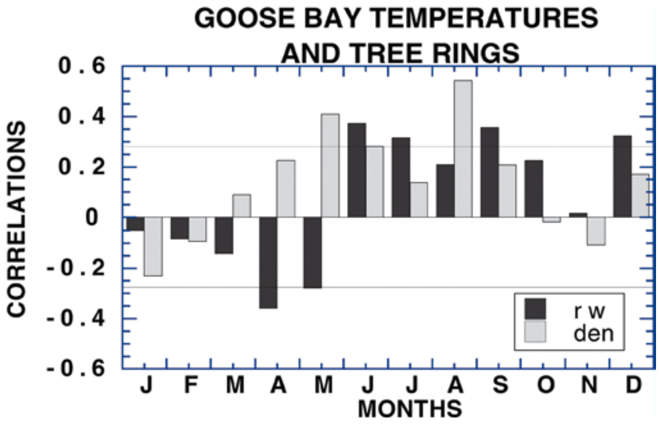


Fig. 3 Correlation plot comparing the ring width and density composite series with Goose Bay, Labrador temperatures for 1943–1991 for January to December of current growth year. *Horizontal lines* indicate two-tailed 95% confidence limits. Station data obtained from Historical Climate Network, which performs various types of quality control for outliers, homogeneity, etc. (GHCN, http://www.ncdc.noaa.gov/ol/climate/research/ghcn/ghcnqc.html). Positive correlations are identified for both parameters in the warmer months

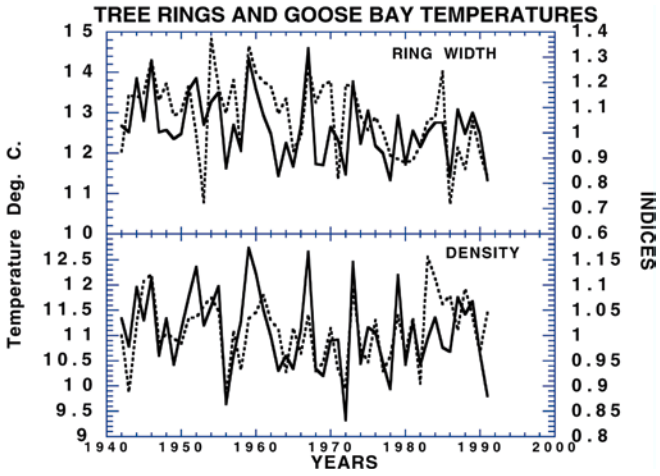


Fig. 4 Time series plots comparing Goose Bay temperatures with ring width and density composite chronologies for 1942–1991 common period. For ring width, the comparison is made with June–September temperatures ($r = 0.51$), and for density the comparison is with May–September temperatures ($r = 0.56$)

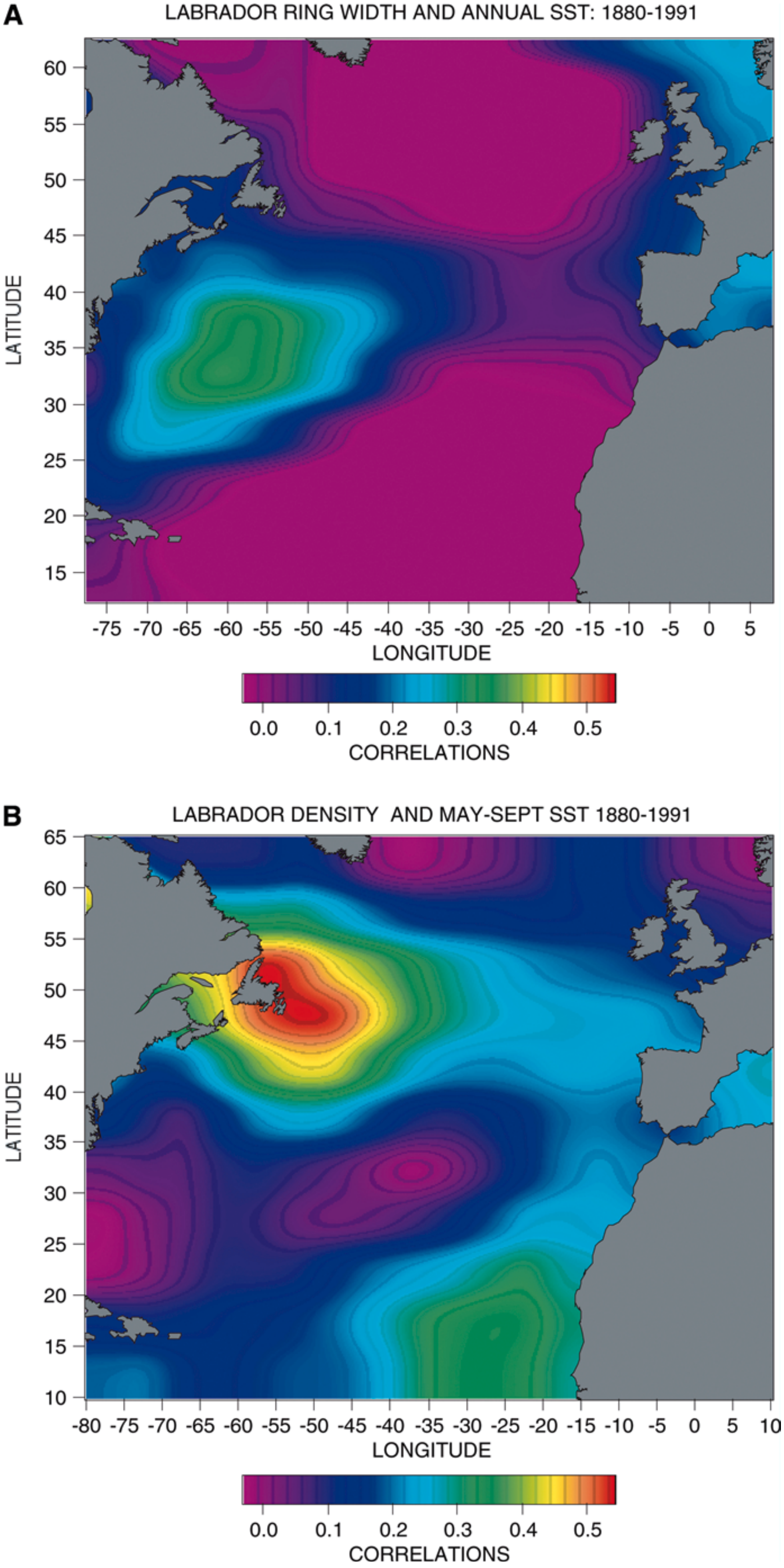
To further investigate the temperature signal in the Labrador data, spatial correlation maps were used to relate the tree-ring series to North Atlantic sea surface temperatures (SSTs) from 1880–1991 (Kaplan et al. 1998) (Fig. 5). The ring width series shows an area of strongest positive correlation with annual SST in the vicinity of the Gulf Stream. The density series shows the strongest positive correlation with warm season SST, particularly in the area near Newfoundland and vicinity (see D'Arrigo et al. 1996). The density relationship is of particular interest because this region, being at the junction of the subtropical and subpolar gyres, is characterized by very high SST variability (Deser 1996). Statistical and instrumental analyses indicate that the SST variability in this region is tied to the NAO, and is linked to sea ice in the Labrador Sea, although this mechanism is not well understood (Deser 1996). Both tree-ring series are significantly and positively correlated (albeit weakly) with the monthly NAO index in the warmer months (Fig. 6). Temperature at Goose Bay also correlates positively with the NAO in summer.

Based on the composite ring width chronology (Fig. 2A), we infer that there were both colder and warmer episodes during the period of overlap with the Little Ice Age, which are in broad agreement with larger scale trends for the Arctic over the past several hundred years (D'Arrigo and Jacoby 1993; Overpeck et al. 1997; Crowley 2000). From this Labrador ring width record we infer that there was cooling in the early to middle 1600s, cooling during the late 1600s-early 1700s (the Maunder Minimum period, Eddy 1976), warming in the middle to late 1700s, and cooling in the 1800s. There is increasing warmth from the late 1800s through the mid twentieth century, followed by decreased ring width values over the past several decades (Fig. 2A). This recent decline may partly relate to the cooler temperatures recorded for Goose Bay around this time. However, the decreased ring widths may also corroborate other observations of decreased temperature sensitivity, or response, in some treeline sites due to drought stress and other factors (e.g., Jacoby and D'Arrigo 1995; Barber et al. 2000). The composite density chronology shows similar patterns of change to those seen in the ring width series. However unlike the ring width composite there is an increase in density values in recent decades to some of the highest levels on record.

We analyzed the spectral properties of the Labrador ring width and density composite data using multi-taper-method (MTM, Mann and Lees 1996) spectral analysis for the periods from 1580–1998 and 1660–1998, respectively. To further characterize the behavior of these modes of variation and their amplitude and frequency modulation over time, we performed singular spectrum analysis or SSA, a data-adaptive technique for extracting weak signals embedded in red noise based on the application of principal components analysis to the autocorrelation function (Vautard and Ghil 1989; Vautard et al. 1992).

For the ring width composite, the MTM analysis reveals significant (99% level) variability at >85, 40–60 and 2–3 years (Fig. 7A). There is also a peak at around 21 years, significant at the 90% level. The SSA technique identified important oscillatory modes or waveforms that display varying degrees of amplitude modulation over time. In SSA, the eigenvector pairs accounting for the most variance in the ring width composite were found at 20.41 and 47.62 years, similar to those seen in the MTM analysis (Fig. 8). The 20.41-year waveform may be associated (but is not coherent) with the NAO or possibly with the Hale solar magnetic cycle (Rogers 1984; Schneider and Schonwiese 1989; Plaut et al. 1995; Cook et al. 1998). This waveform demonstrates

Fig. 5 Spatial correlation maps comparing Labrador ring width and density composites with, respectively, annual (a) and May–September (b) North Atlantic SSTs based on Kaplan et al. (1998) data set. These seasons show the strongest relationships with the ring width and density data



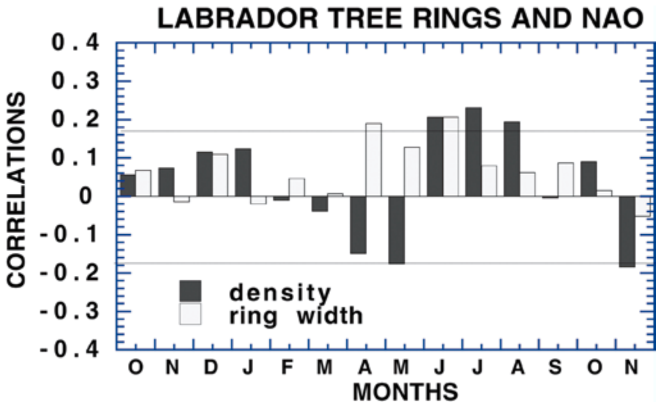


Fig. 6 Correlations between Labrador ring width and density composites with the monthly NAO index of Hurrell (1995) for 1866–1998 for October of previous year to November of current growth year. *Horizontal lines* indicate two-tailed 95% confidence limits

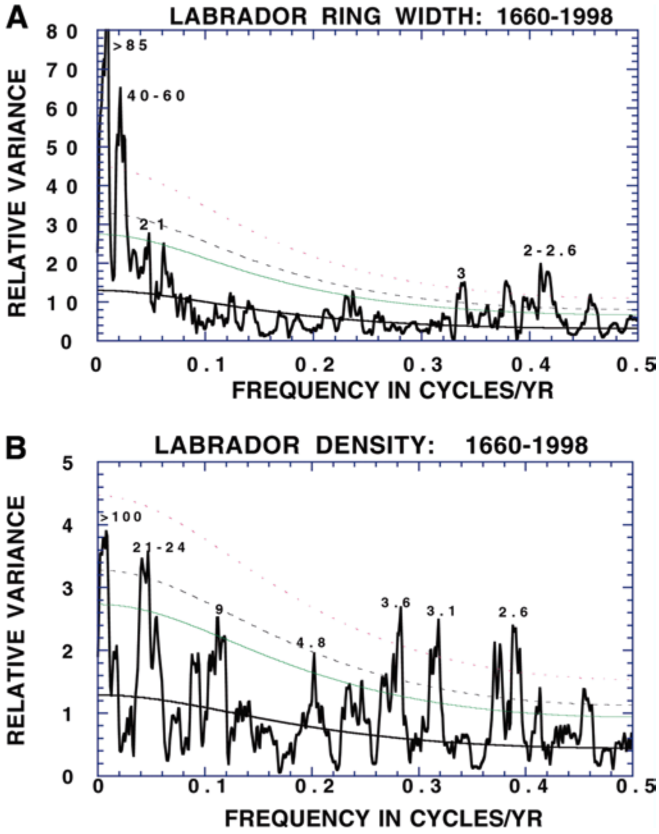


Fig. 7 **A** MTM spectral analysis of Labrador ring width composite over the period 1660–1998. **B** MTM analysis of density series for 1660–1998. *Thick curve* is level of red noise representing null hypothesis. *Thin lines* indicate 90, 95 and 99% confidence levels. *Significant peaks* are labeled

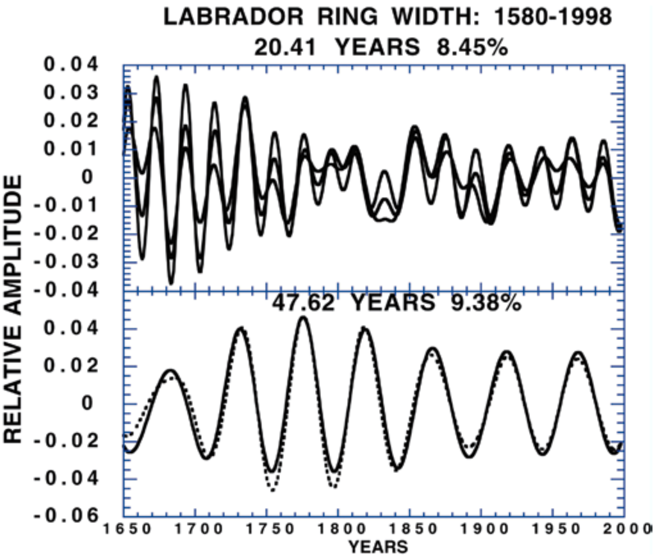


Fig. 8 Dominant oscillatory modes of variation identified using singular spectrum analysis (SSA) for Labrador ring width composite over the period 1580–1998. Fraction of variance accounted for by each waveform also indicated. M, the order of the autocovariance matrix, is 110 (Vautard and Ghil 1989; Vautard et al. 1992)

somewhat decreased amplitude around the early to middle 1800s (Fig. 8).

The 48 year mode of variation indicates robust behavior over its length. This peak is roughly comparable to other modes of multidecadal climate variability (including a proposed Atlantic Multidecadal Oscillation, AMO) identified in recent model and proxy data analyses of Northern Hemisphere climate (e.g. Black et al. 1999; Delworth and Mann 2000; Kerr 2000; Rittenour et al. 2000). The AMO is thought to be driven by the atmosphere's NAO and is related to the strength of the westerlies across the Labrador Sea (Delworth and Mann 2000). The nature of North Atlantic multidecadal variability is not well understood. In their analyses, Delworth and Mann (2000) identified multidecadal modes at 52–56 years in model integrations and 70 years in multiproxy analyses of Atlantic climate, and presented evidence for their existence over the past several centuries. Given the model approximations, the difference in timing between the model and proxy modes was considered negligible (Kerr 2000). Other model studies described in Stocker (1994) indicate modes of variation in the Atlantic of 30–70 years, with possible centers of action in the Labrador Sea. Many more instrumental, proxy and modeling studies are needed to confirm the existence of this variation and its mechanisms.

The density results indicate statistically significant (95% level or higher) band-limited power at >100, 21–24, 3.1–3.6 and 2–3 years (Fig. 7B). Peaks at 9 and 4.8 years are not significant at this level. Overall, these features are quite similar to those seen in a 4000-year New England varve record for the late Pleistocene (17,500–13,500 calendar years before present; Rittenour et al. 2000). In that study, a 3.5 years mode was attributed to the El Niño-Southern Oscilation (ENSO), being within the conventional ENSO bandwidth of 3–7 years. The Labrador density record is coherent with the winter (DJF) Southern Oscillation Index (SOI, 1877–1995,

R. Allan, Hadley Centre, UK) at 3.7 years, above the 95% level of significance. Consistent with this observation, instrumental studies indicate significant teleconnections between ENSO and the climate of northeastern Canada (e.g. Halpert and Ropelewski 1992). As found in the ring width and density composites, there is a 22-year peak in the varve series which may relate to the NAO or to solar effects, as well as a >40 year (multidecadal) mode (Rittenour et al. 2000; Kerr 2000). Peaks at around 8–9 and 2–3 years, as seen in the density and varve records, have also been associated with the NAO (Rogers 1984; Schneider and Schonwiese 1989; Plaut et al. 1995).

In SSA (Fig. 9), dominant modes of density variation were extracted at 200, 25, 8.6, 3.6 and 2.6 years, closely similar to those identified in the MTM density spectrum. The 200 year peak exceeds the resolvable level of low-frequency variance due to segment length (Cook et al. 1995). The 3.6 years peak shows a pronounced decrease in amplitude in the 1800s. Diminished amplitude of a similar mode of variation around this time period was also noted in a reconstruction of the winter SOI based on proxies from ENSO-sensitive regions (Stahle et al. 1998). Thus there may have been decreased importance of this mode and its related (rather weak) teleconnection to ENSO in northeastern North America around this time, although much more data is needed to confirm this possibility. The 8.6 year mode shows fairly stable behavior over its length, while the 25 year waveform has its greatest amplitude in the early to middle 1800s.

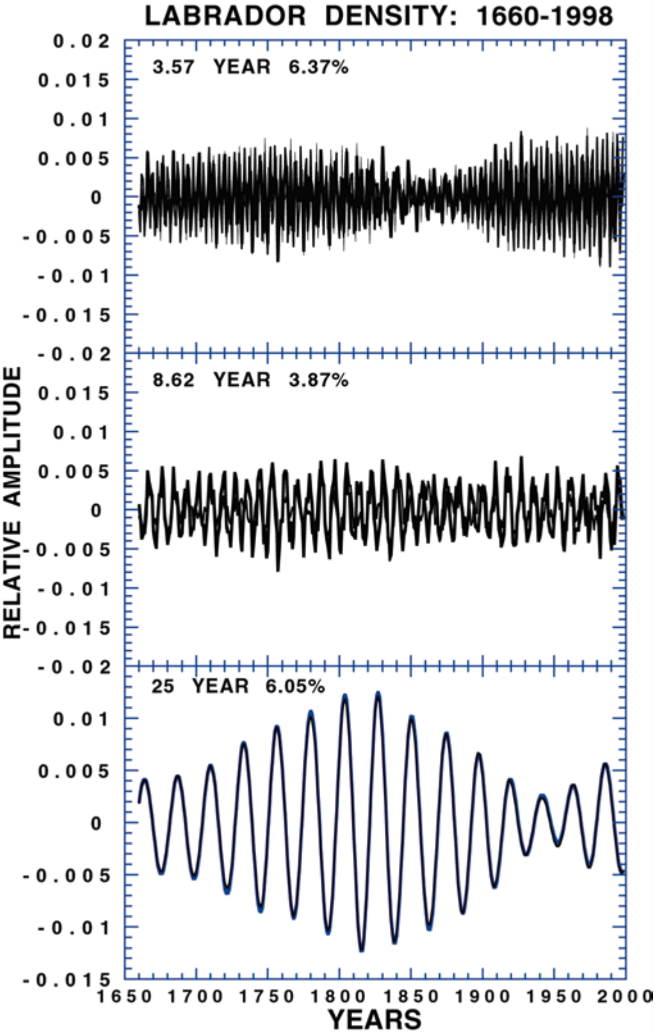


Fig. 9 As in Fig. 8, for SSA of Labrador density composite over 1660–1998. M, the order of the autocovariance matrix, is 100

4 Climatic, forest and cultural shifts in the 1800s

Cooling in the 1800s and subsequent warming are considered to be the most notable features of circum-Arctic climate over the past four centuries (e.g., Grove 1988; Overpeck et al. 1997). These trends are apparent in the Labrador composites although, as noted, the ring width series shows decreased growth in recent decades (Fig. 2).

One of the few nearby proxy records available for comparison with the Labrador series is a 600-year tree-ring width chronology from treeline Quebec, based on living and dead black spruce trees (Payette et al. 1985). In that study, a shift in growth habit from stunted krummholz to erect trees was observed around the time that warming took place around the late 1800s, at the end of the Little Ice Age. It was postulated that this shift was a large-scale phenomenon throughout northern Quebec. The transition was also marked by mass mortality of old-aged spruce in the region (Payette et al. 1985). There are some similar features between this chronology and our Labrador white spruce ring width series, which also indicates milder conditions beginning in the late 1800s. Both records show peak warmth in the mid twentieth century and subsequent decline in ring widths. Treeline sites along the northern Labrador coast near Okak and northward (Fig. 1) exhibit similar ecological and morphological characteristics to those described by Payette et al. (1985). For example, a morphological shift from a forest dominated by krummholz to one of large erect stems can be seen. Near Eyeglass Lake (Fig. 1), we have observed a mix of old, mostly deceased stems with krummholz form, mixed with straight-bole trees that were established in the past 100 years. A total of 25 dead standing and downed krummholz stems were sampled, of which 14 died between 1870 and 1904. Thus, this feature appears to be part of the landscape in northern Labrador as well.

Another nearby proxy record is a 500-year time series of June temperature derived from varve sediment laminae at Soper Lake, Baffin Island. This record indicates cold conditions in the eighteenth century and nineteenth century, followed by significant warming (Hughen et al. 2000). The 1800s, as mentioned, represent a low amplitude period in the 3.6 year waveform in the density composite (Fig. 9). This time period was also one of decreased solar activity and coincides with several major volcanic events (Grove 1988), as well as ENSO events (Ortlieb 2000). Thus, there appear to have been a number of significant factors modifying the climate during this time.

The year 1816 is the lowest value in the Labrador density series over the past four centuries, 3.4 standard deviations below the long-term mean (Fig. 2B). It coincides with the "year without a summer" in eastern North America following the 1815 eruption of Tambora, which has been hypothesized to have had profound climatic and demographic impacts in many areas of the globe (e.g., Harington 1992). Similarly, some of the most severe conditions ever recorded for northern Labrador took place in the spring and summer of 1816, based on Moravian missionary reports (Brice-Bennett 1981) and sea-ice data for the Labrador Sea (Newell 1992). In northern and central Labrador the early formation of fast ice, starting in November 1816, was followed by a cold, stormy winter with an extraordinarily heavy snowfall. The summer of 1817 was no better, as landfast ice remained in bays until early July in the Hopedale area and until the end of July in the Okak region. An enormous drift-ice expanse remained off the coast until August (Brice-Bennett 1981). Most marine mammals stayed far offshore, and those that were in the vicinity of Inuit and Moravian settlements were inaccessible due to the stormy weather and ice-choked waters. Moravian reports describe Inuit as suffering from hunger as a result of these conditions. Severe famine has also been reported for other areas of eastern Canada during the years around 1816 (e.g., Suffling and Fritz 1982). Although dry fog was reported in eastern Labrador by the Moravians following the 1783 Laki, Iceland eruption (Demaree et al. 1998), the density composite indicates near-normal conditions in this year (index value is 0.986 versus mean of 1.0).

Throughout the early 1800s severe weather conditions prevented people from gaining access to their prey. Particularly bad years were reported in 1801–02, 1806 (when there was widespread famine and people resorted to eating their dogs), 1809, 1810 (when harp seals arrived before ice had cleared out of bays), 1811, and 1815. Throughout the 1820s Inuit continued to experience a great deal of variability in the sea-ice conditions and this was reflected in their uneven hunting success (Brice-Bennett 1981). During this period some Inuit living in coastal Labrador changed their subsistence practices and settlement patterns. They abandoned their practice of inhabiting large communal houses in favor of small, single family dwellings built near the mission stations at Okak, Nain, and Hopedale.

The year 1821 marked the last time a large whale was reported captured along the Labrador coast, though Inuit harvested whales found stranded in 1823 and 1825 (Brice-Bennett 1981; Taylor and Taylor 1977). Whether cessation of whaling was the result of the absence of whales due to heavy ice conditions that kept the sea mammals away or a severely depleted population due to years of over-hunting on the part of European and American whalers, or whether Inuit stopped pursuing the animals due to the collapse of a baleen market is unclear. Regardless of the cause, the cessation of whaling had profound ramifications on Inuit society, for whaling and the distribution of whale products bound families and communities together in networks of interdependence and mutual support (Kaplan and Woollett 2000).

Throughout the early 1800s the Inuit economy relied heavily on ringed and harbor seals, and caribou. They spent more time exploiting resources of inner island regions as well as the interior, as opposed to the ice edge. After 1810, the summer caribou hunt became rare, and Inuit tended to remain in inner island and inner bay regions (Taylor and Taylor 1977; Brice-Bennett 1981). These shifts resulted from Moravian influences as well as the highly variable and extreme climate conditions. The mission introduced the sealing net (Inuit traditionally hunted seals using harpoons), and encouraged converted hunters to exploit waters close to the stations so as to avoid falling under the influence of heathen relatives. They also encouraged the development of a cod and char fishery, in order to ensure that the Moravian communities would have enough resources to support the converts through the winter (Brice-Bennett 1981). Through this period Inuit along the coast experienced food shortages on a regular basis, and it was widely known that the mission stations had surplus foods available to Inuit who were converts. In a very real sense, the foods stockpiled by the mission stations came to serve as the safety nets once provided by whaling.

In the 1820s the Moravian Mission stations stores began to encourage Inuit to trap fur-bearing animals, as trade in skins was particularly profitable. In the early 1800s the Hudson's Bay Company (HBC) limited its operations to southern Labrador. However, in the 1860s the Company expanded its operations throughout northern Labrador in direct competition with Moravians who expanded into this area as well (Kaplan 1983). Their establishments were set up in a leaf-frog fashion, the Moravians remained in Hebron, the HBC established a post in Saglek, the Moravians moved into Ramah Bay, and the HBC built a post in Nachvak. Both European groups demanded loyalty from Inuit with whom they dealt, and both encouraged fishing and fur trapping. Inuit, once linked together by broad regional trade networks now focused their attention on the particular European establishments from which they could gain economic advantage and derive security (Kaplan (1983, 1985). By the late 1800s Inuit ceased living in large fall and winter settlements in inner island regions. Instead, they dispersed along the length of the coast, establishing small communities in inner island and inner bay locations. While they continued to rely on various types of seals, they intensified their pursuit of fish and fur-bearing animals.

The cooling that characterized the early 1800s and the climatic instability documented in various climatic records for the nineteenth century prompted some of the cultural changes evident along the coast. However, to understand fully the economic and social changes of the period requires understanding that they were triggered by a confluence of climatic and historical factors.

The causes of the nineteenth century subsistence and settlement pattern changes need further investigation. However, the unpredictable and extreme environmental conditions of the first half of the 1800s in all likelihood affected the maritime-adapted Labrador Inuit, forcing them to change their seasonal rounds. The environmental stresses the Inuit experienced made the adoption of a mixed economy involving traditional subsistence practices as well as a new reliance on European technologies and establishments an attractive adaptation strategy.

5 Summary

We have shown that the Labrador tree-ring data reflect interannual and multidecadal temperature variations in the northwest Atlantic sector. We have also presented evidence for their modulation over time. These variations include a significant, multidecadal waveform at about 40–60 years in ring width that exhibits regular oscillations over its length and may relate to a proposed mode of variability in North Atlantic climate. Significant modes of variation, possibly corresponding to those of the NAO or solar effects are also observed. There are significant, albeit weak, correlations with the NAO in the warmer months. A significant 3.6 year mode of variation in the density series is coherent with the winter SOI and displays diminished amplitude in the 1800s. It coincides with a widespread cold period seen in many Arctic and North Atlantic proxies and may be linked to solar and/or volcanic forcing, and possibly ENSO. The coldest summer in the past 400 years occurred in 1816 according to the density composite, following the eruption of Tambora in the previous year. Severe cold conditions, combined with opportunities presented by resident European establishments, influenced the subsistence practices and settlement patterns of coastal Labrador Inuit around during this period of time.

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