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► **To cite this version:**

Marie-Alexandrine Sicre, Kaarina Weckström, Marit-Solveig A. Seidenkrantz, Antoon Kuijpers, Marion Benetti, et al.. Labrador current variability over the last 2000 years. *Earth and Planetary Science Letters*, 2014, 400, pp.26-32. 10.1016/J.EPSL.2014.05.016 . hal-01060154

**HAL Id: hal-01060154**

**<https://hal.science/hal-01060154>**

Submitted on 15 Jan 2022

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# 1 Labrador Current variability over the last 2000 years

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## 21 **Abstract**

22 The ice-loaded Labrador Current (LC) is an important component of the western North Atlantic  
23 circulation that influences the position and strength of the northern limb of the North Atlantic  
24 Current (NAC). This flow of cold and fresh Polar Waters originating from the Arctic has a marked  
25 impact on the North Atlantic climate, yet little is known about its variability beyond the  
26 instrumental period. In this study, we present the first sub-decadal alkenone-based 2000-year long  
27 sea-surface temperature (SST) records from the western Labrador Sea, a climatically crucial region  
28 at the boundary between the LC and the NAC. Our results show a clear link between the LC  
29 strength and the Northern Annular Mode (NAM), with a stronger NAM and a more vigorous LC  
30 during the Medieval Climate Anomaly (MCA). This suggests enhanced LC activity upon future global  
31 warming with implications for the Atlantic meridional overturning circulation (AMOC).

32 **Keywords:** ocean variability, temperature proxy, last millennia, Labrador Sea, Newfoundland,  
33 Northern Annular Mode

34

## 35 **1. Introduction**

36 Climate in the North Atlantic region is strongly influenced by Arctic Ocean waters exported to the  
37 mid-latitudes of the North Atlantic Ocean through Fram Strait (Eastern Route) and the Canadian  
38 Archipelago/western Labrador Sea (Western Route) (Fig. 1). These low-density waters affect deep  
39 convection in the Labrador and Greenland Seas and, subsequently, the strength of the global  
40 thermohaline circulation and climate (*Jones and Anderson, 2008*). The LC accounts for about two  
41 thirds of the freshwater outflow from the Arctic Ocean (*Aksenov et al., 2010*). A sharp front  
42 separates the fresh and cold shelf waters of this boundary current from the warmer and saltier  
43 open-ocean waters of the Labrador Sea. Before reaching Hamilton Bank (ca. 54° N) offshore  
44 Labrador, the LC splits into a major outer branch trapped at the edge of the continental slope, and  
45 a minor inner branch (~15% of the total transport) flowing over the Newfoundland shelf (*Lazier  
46 and Wright, 1993*). Along its path, the LC has little exchange with the central Labrador Sea. In the  
47 region of Flemish Cape and the Grand Banks east of Newfoundland, the LC retroreflects northwards  
48 when encountering the NAC (*Fratantoni and McCartney, 2010*). The resulting freshening and  
49 cooling of the NAC on its way to the Nordic Seas are crucial processes controlling the rate and  
50 intensity of the AMOC, thus impacting European climate (*Czaja and Frankignoul, 2002*).

51 Today, the LC variability and the position of the northern edge of the NAC are strongly influenced  
52 by the Northern Annular mode (NAM) (*Dickson et al., 1996*), which is defined from sea level  
53 atmospheric pressure between 20 and 90°N and reflects the degree of penetration of Arctic air into  
54 mid-latitudes. Deep Icelandic lows during +NAM years favour NW winds bringing cold air from the  
55 Arctic over the Labrador Sea, which results in colder-than-normal winter SSTs, sea-ice formation  
56 and enhanced transport of ice-loaded LC waters (*Drinkwater, 1996*). In contrast, weaker Westerlies  
57 and more frequent southerly winds during -NAM years reduce winter ocean heat loss and promote  
58 warmer SSTs. NAM also induces changes in the Arctic Water gateways with implications for the  
59 deep convection. Under -NAM conditions, the Transpolar Drift of Polar Waters shifts eastwards  
60 towards Fram Strait (*Morison et al., 2012*). The East Greenland Current (EGC)/ West Greenland  
61 Current (WGC) system is subsequently enhanced, which intensifies buoyancy-driven transport  
62 (*Dickson et al., 1996*) and leads to a more southerly NAC, as seen during the persistent and

63 extreme  $\bar{N}$ AM phase in the late 1960s (the 'Great Salinity Anomaly' (GSA)) (*Dickson et al., 1988*).  
64 Buoyancy gain combined with diminished ocean heat loss reduces deep convection in the central  
65 Labrador Sea and thus weakens the subpolar gyre (SPG) circulation (*Dickson et al., 1996*). In  
66 contrast, under  $^+N$ AM conditions, Arctic Waters are routed through the Canadian Archipelago and  
67 the LC transport increases under the influence of stronger NW winds (*Fratantoni and McCartney,*  
68 *2010*). Concurrently, increased ocean heat loss favors enhanced convection in the central Labrador  
69 Sea, thus reinforcing SPG circulation and mixing with subtropical waters through the intergyre  
70 circulation (*Marshall et al., 2001*).

71 In recent years, efforts have been made to produce high-resolution SST reconstructions of the last  
72 millennia (*PAGES 2k Consortium, 2013; Cunningham et al., 2013*). However, despite its  
73 significance for the AMOC, the Labrador Sea region has hitherto remained poorly documented at  
74 decadal time scales over the past thousand years. Here, we present two sub-decadal alkenone-  
75 derived SST records from northeastern and southeastern Newfoundland coastal waters covering  
76 the last 2000 years. The NE site was selected to be representative of LC waters, while the SE site is  
77 located in the boundary zone between the LC and the Gulf Stream. The alkenone records thus  
78 allow us not only to track changes in SSTs but also to evaluate variations of the LC/Gulf Stream  
79 boundary.

80

## 81 **2. Material and Methods**

### 82 **2.1. Sediment sampling.**

83 A set of one box-core and one gravity core were collected at each study site during the research  
84 cruise on the Russian RV *Akademik Ioffe*, September 23-28, 2007. Box-core AI07-04BC (39.5 cm)  
85 and gravity core AI07-03G (460 cm) were retrieved from Bonavista Bay (48°44N, 53°29W; 329 m  
86 depth), offshore northeastern Newfoundland (Fig. 1). Box-core AI07-11BC (47°14N; 54°36W, 233  
87 m water depth, (41 cm) and gravity core AI07-12G (47°08N; 54°33W; 230 water depth, 459 cm)  
88 were collected in Placentia Bay, off southeastern Newfoundland. The cores were taken from small  
89 sedimentary basins identified by a Parasound sub-bottom profiler and show no evidence of  
90 sediment re-working. Strong currents prevail over the shelf, but local sedimentary basins in fjords  
91 and open bays in direct connection to the open ocean offer suitable sedimentary conditions. The  
92 box-cores were analyzed every 0.5 cm over the first 2 cm, and then every 1 cm. The gravity cores  
93 were analyzed every 0.5 cm.

94

## 95 **2.2. Sediment dating.**

96 Dating of the box-cores (AI07-04BC and AI07-11BC) was performed from excess activity of  $^{210}\text{Pb}$   
97 ( $^{210}\text{Pb}_{\text{xs}}$ ) (Fig. 2) (Weckström et al., 2013).  $^{210}\text{Pb}$ ,  $^{226}\text{Ra}$  and  $^{137}\text{Cs}$  activities were analysed using a  
98 low background, high efficiency, well-shaped  $\gamma$  detector (Schmidt et al., 2009), calibrated with  
99 certified reference material (IAEA-RGU-1). Activities are expressed in  $\text{mBq g}^{-1}$  and errors are based  
100 on 1 SD counting statistics. Excess  $^{210}\text{Pb}$  was calculated by subtracting the activity supported by its  
101 parent isotope,  $^{226}\text{Ra}$ , from the total  $^{210}\text{Pb}$  activity in the sediment. Errors in  $^{210}\text{Pb}_{\text{xs}}$  were calculated  
102 by propagation of errors in the corresponding pair ( $^{210}\text{Pb}$  and  $^{226}\text{Ra}$ ). The sedimentation rate was  
103 calculated from  $^{210}\text{Pb}_{\text{xs}}$  profiles using a constant flux-constant sedimentation (CF:CS) model. The  
104 SE Newfoundland core displays a two-layer  $^{210}\text{Pb}_{\text{xs}}$  profile, which was taken into account when  
105 calculating the sedimentation rate. Age models were calculated assuming an age of 2007 at the  
106 core-tops. No clear signs of disturbance caused by bioturbation are observed in the surface  
107 sediments. Furthermore, the lithology of the gravity cores indicates fine laminations throughout the  
108 sediment sequence, which provides evidence for the sedimentary record being undisturbed by  
109 biological reworking.

110 The age models for the gravity cores (AI07-03G and AI07-12G) were established using the  
111 depositional model option in the OxCal 4.1 software using marine  $^{14}\text{C}$  calibration curve Marine09  
112 with an average  $\Delta R$  of  $139 \pm 61$  years (Solignac et al., 2011; Jessen et al., 2011; Reimer et al.,  
113 2009)(Table 1). Core AI07-03G spans the last 5740 years (age of core-top  $170 \pm 90$  cal yr BP  
114 according to the age model), with sedimentation rates ranging from 36 to 143 cm/kyr. Only the  
115 age model for the last 2000 years is shown here (Fig. 3). The age model is based on 7 AMS  $^{14}\text{C}$   
116 dated samples of mixed benthic foraminifera or shell fragments (1 outlier) and was constructed  
117 with a k-value of 150 yielding an agreement index of  $A_{\text{model}}$  of 110%. AI07-12G covers the last  
118 6000 years, with the core-top at  $176 \pm 102$  cal. yr BP, and sedimentation rates ranging from 69 and  
119 98 cm/kyr. The age model of the last 2000 years (Fig. 3) is based on 6 AMS  $^{14}\text{C}$  dated mixed  
120 benthic foraminifera and shell fragments (2 outliers) and was constructed with a k-value of 50  
121 yielding an agreement index of  $A_{\text{model}}$  of 84%. Age model uncertainties range from  $\sim 70$ -110 years  
122 (core AI07-03G) and  $\sim 70$ -115 years (core AI07-12G).

123

## 124 **2.3. Alkenone analyses**

125 Alkenones were extracted from freeze-dried sediments (methanol/methylene chloride; 1:2 v/v),  
126 purified by open column silica gel chromatography and then analyzed by gas chromatography on a  
127 Varian CX3400 equipped with a CP-Sil-5 capillary column (50 m x 0.32 mm i.d.) and a flame  
128 ionization detector (*Ternois et al., 1996*). SSTs were calculated from the  $U^{K^1,37}$  index  $C_{37:2}/(C_{37:2} +$   
129  $C_{37:3})$  using the calibration of *Prahl et al. (1988)* ( $SST = (U^{K^1,37} - 0.039)/0.034$ ). Internal precision  
130 for SST estimates is less than 0.5°C (*Ternois et al., 1996*).

131

### 132 **3. Results and discussion**

#### 133 **3.1 Alkenone-SST signal over the recent decades**

134 SSTs for the recent decades were obtained from the two box-cores (AI07-04BC; AI07-11BC)  
135 (locations shown in Fig. 1) and compared to the NAM index (Fig. 4a). The NE Newfoundland record  
136 covers 80 yrs (AI07-04BC; 1925-2007 AD) while the SE Newfoundland one spans 125 yrs (AI07-  
137 11BC; 1880-2007 AD), the former allowing a higher temporal resolution (2.5 yrs) than the latter  
138 (4.1 yrs) (Fig. 4b,c). SSTs vary between 4.5 and 5.5°C off NE Newfoundland, and between 3.5 and  
139 4.5°C, off SE Newfoundland. This is at odds with the generally warmer instrumental SSTs in SE  
140 Newfoundland (Fig. 5), suggesting differences in the alkenone production patterns between the two  
141 sites.

142 Today, the NE Newfoundland site is mainly influenced by the LC and sea-ice covered for 2-3  
143 months per year ( $\pm 1$  month)  
144 ([http://nsidc.org/data/docs/noaa/g00799\\_arctic\\_southern\\_sea\\_ice/index.html](http://nsidc.org/data/docs/noaa/g00799_arctic_southern_sea_ice/index.html)). SSTs range from  
145 0.5°C in winter to  $\sim 11^\circ\text{C}$  in summer (annual mean 4.2°C) (Fig. 5). Off SE Newfoundland SSTs are  
146 slightly higher, spanning from 0.9°C in winter to 12.5°C in summer (annual mean 5.4°C) (Fig. 5).  
147 This site, located at the southern edge of the LC where it borders towards the NAC, is generally  
148 ice-free during winter. Owing to the pronounced hydrographical gradients in the Newfoundland  
149 region, distinct biological seasonal patterns occur over rather short distances (*Nezlin et al., 2002*).  
150 Off NE Newfoundland, where the influence of the LC is stronger, primary production follows a  
151 typical Arctic regime with a slow increase from January to June, followed by a decrease towards  
152 stable values from August to December. Off SE Newfoundland, less impacted by the LC,  
153 phytoplankton blooms in spring and fall, as generally observed at mid-latitudes. These differences  
154 are primarily ascribed to the water column structure affecting light and nutrient conditions in the  
155 upper layer (*Nezlin et al., 2002*). Under strong turbulent mixing conditions such as those in LC

156 waters (NE Newfoundland), nutrients are available, but cells tend to disperse into deeper layers  
157 where light becomes limiting for phytoplankton growth. As the water column stabilizes, primary  
158 production progressively increases and reaches its highest level relatively late (spring/summer). In  
159 contrast, generally weaker mixing in the less turbulent waters off SE Newfoundland allows for a  
160 phytoplankton bloom already in early spring, resulting in alkenone production at cooler  
161 temperatures than off NE Newfoundland. In addition, along NE Newfoundland sea ice generally  
162 persists until early May, while waters offshore SE Newfoundland are usually ice-free all year. An  
163 earlier phytoplankton blooming in ice-free waters off SE Newfoundland would result in colder  
164 alkenone (early spring) SSTs compared to NE Newfoundland where alkenone production would not  
165 take place until sea ice has melted (late spring-summer). A positive temperature offset was  
166 previously reported off North Iceland (*Sicre et al., 2011*), close to the polar front where, during  
167 heavy ice years, alkenone-SSTs appear systematically biased towards warmer months when  
168 compared to instrumental data, suggesting that sea ice retarded the spring bloom. We can thus  
169 conclude that both turbulent conditions and sea ice occurrence likely contribute to a shift towards  
170 warmer values of the alkenone-derived SSTs in NE Newfoundland. Higher values by  $\sim 1^\circ\text{C}$  off NE  
171 Newfoundland ( $4.5\text{-}5.5^\circ\text{C}$ ) as compared to SE Newfoundland ( $3.5\text{-}4.5^\circ\text{C}$ ) would thus reflect  
172 delayed blooming (*Nezlin et al., 2002*) due to the presence of sea ice (*Sicre et al., 2011*).

173 Figure 4 shows the time-series (Fig. 4b,c) at both sites and the NAM index (Fig. 4a). Proxy records  
174 NE and SE of Newfoundland exhibit decadal-scale variability superimposed on a general cooling  
175 trend and show differences over the common time window (1930-2007). Correlations were  
176 calculated between SSTs and NAM index values for the two cores (AI07-04BC and AI07-11BC). The  
177 number of degrees of freedom between the two time series was computed following *Bretherton et*  
178 *al. (1999)*, taking into account the autocorrelation of each time series. Because alkenone-derived  
179 SSTs represent an average value over the sediment sampling step (1 cm and 0.5 cm for the top  
180 two cms), correlations were calculated between SSTs and the NAM index value averaged over the  
181 time interval of each sediment layer, i.e. corresponding to 1 cm in most of the core and 0.5 cm at  
182 the top. We found that the NE Newfoundland SSTs are negatively correlated with the NAM index  
183 average over the same time interval as the SSTs ( $r=-0.63$ , with  $p < 0.05$  according to a 2-sided  
184 Student test and with 23 degrees of freedom). The statistical significance of this correlation is  
185 confirmed by a bootstrap approach with 1000 permutations. In particular, lowest SST values are  
186 reached during the late 1980s and early 1990s of high  $^+\text{NAM}$  (*Drinkwater, 1996; Morison et al.,*  
187 *2012*), as expected from strong NW winds. Increased sea ice has previously been described for the

188 same period (*Weckström et al., 2013*). Conversely, correlation between NAM and SSTs off SE  
189 Newfoundland is not significantly different from 0 at the 95% confidence level ( $r=0.07$ ). Local  
190 atmospheric and hydrographical conditions most likely explain the different SSTs/NAM relationship.  
191 While the NE Newfoundland site is located in the subpolar zone which strongly responds to NAM  
192 today (*Thompson and Wallace, 1998*), the SE Newfoundland site is transitional in-between subpolar  
193 and subtropical climate influences and also reflects the (sub)tropical ocean signal propagated by  
194 the NAC. Correlations between proxy SSTs and the NAM index at both sites are fully consistent  
195 with the modern SST/NAO correlation map for in the North Atlantic region (*Marshall et al., 2001*)  
196 and subsequently reinforce our interpretation of the two proxy records. Even more importantly, the  
197 remarkable agreement with *Marshall et al. (2001)* emphasizes that our SST records are of large-  
198 scale significance.

199

### 200 **3.2 SST variability over the last two millennia**

201 SSTs of the last ~2000-yr from NE and SE Newfoundland were reconstructed from two gravity  
202 cores (AI07-03G; AI07-12G) and compared with SSTs from N. Iceland (Figs. 1 and 6). Due to  
203 minor losses of surficial sediments during the coring operation, the core-top ages are estimated to  
204 be 1775 AD for AI07-03G and 1770 AD for AI07-12G. Off NE Newfoundland, SSTs range between  
205 4.5 and 6°C and show decadal-scale variability with a colder interval at 1000-1350 AD,  
206 approximately concurrent with the Medieval Climate Anomaly (MCA) (Fig. 6b). Both the well-  
207 defined onset and termination of this interval occurred within only a few decades. During the Little  
208 Ice Age (LIA), SSTs are generally warmer than during the MCA, showing marked warm spells at  
209 ~1470-1480 AD and cold ones at ~1440-1460 AD and ~1710-1750 AD. In contrast, SSTs off SE  
210 Newfoundland rapidly decrease until ~1000 AD and thereafter fluctuate around ~4°C (Fig. 6c). The  
211 absence of contrasting MCA/LIA conditions here is notable and consistent with dinocyst data from  
212 the same core (*Solignac et al., 2011*) as well as with alkenone data off Nova Scotia (*Keigwin et al.,*  
213 *2003*). At the NE site, dinocyst variability was even smaller, being primarily affected by freshwater  
214 supply and productivity during this time interval (*Solignac et al., 2011*).

215 The two sites thus clearly show different oceanographic patterns during the last 2000 years. The  
216 SE site mainly illustrates the general late Holocene cooling trend of the North Atlantic region with  
217 little or no clear difference between the MCA and LIA. In contrast, the NE Newfoundland site shows  
218 strong multi-centennial SST variability and colder SSTs during the MCA. This surface-water cooling



219 can be compared to the present-day ocean response to strong NW winds during <sup>+</sup>NAM years  
220 (*Drinkwater, 1996; Morison et al., 2012*) (Fig. 4). Likewise, warmer SSTs before 1000 AD and after  
221 1350 AD (LIA) can be linked to LC weakening as a result of reduced NW winds combined with more  
222 frequent southerly winds during <sup>-</sup>NAM years (*Morison et al., 2012*). Note that the MCA cooling in NE  
223 Newfoundland corresponds to a warming of a similar magnitude ( $\sim 1^{\circ}\text{C}$ ) observed in North Iceland  
224 shelf waters (Figs. 1,6a; MD99-2275), which has been attributed to <sup>+</sup>NAM-type atmospheric  
225 circulation and an enhanced AMOC (*Sicre et al., 2011; Trouet et al., 2009*). Previous low-resolution  
226 SST reports from the NW Atlantic also hypothesized <sup>+</sup>NAO-like conditions during the MCA (*Keigwin,*  
227 *1996; Seidenkrantz et al., 2007; Seidenkrantz et al., 2008*). Furthermore, higher proportions of  
228 subpolar waters at intermediate depths evidenced at the Rockall Trough (*Copard et al., 2012*) are  
229 in agreement with stronger Westerlies and intensified SPG circulation in a <sup>+</sup>NAM scenario. This  
230 coherent regional pattern of proxy records is overall consistent with the *Trouet et al. (2009)* and  
231 *Olsen et al. (2012)* long-term reconstructions of the NAO index and the suggestion of a persistent  
232 positive phase during the MCA (*Seidenkrantz et al., 2007; Seidenkrantz et al., 2008; Trouet et al.,*  
233 *2009, 2012; Ribeiro et al., 2012; Andresen et al., 2013*). Although this mode of variability operates  
234 mainly at interannual time scales, the SST/NAO correlation tripole shows a pronounced signature at  
235 decadal time scales as well (*Marshall et al., 2001*) suggesting the role of NAM on climate at lower  
236 frequency (*Boessenkool et al. 2007*).

237 Enhanced AMOC and northward heat transport during the MCA could also have triggered coastal  
238 glacier melting, subsequently increasing the discharge of cold/melt waters into Greenland coastal  
239 waters, while further offshore, the warm Irminger Sea Water signal was still present. This pattern  
240 has been documented in several studies showing surface-water cooling and/or increased sea-ice  
241 during the MCA in coastal W/SW-Greenland sites (*Jensen et al., 2004; Seidenkrantz et al., 2007;*  
242 *Seidenkrantz et al., 2008; Andresen et al., 2011*), while elevated SSTs were observed further  
243 offshore between  $\sim 1000$ -1350 AD (*Ribeiro et al., 2012*) and 800-1330 AD (*Sha et al., 2012*).  
244 Therefore, apart from the SST response to direct wind forcing, colder LC waters during the MCA  
245 may also in part reflect advection of freshwater and ice by the WGC (*Morison et al., 2012*), since  
246 south of David Strait the majority of this flow turns westwards and reaches the continental slope of  
247 W-Labrador (Fig. 1) (*Schmidt et al., 2007*). Moreover, as outlined before (see Fratantoni and  
248 McCartney, 2010), a re-routing of Arctic waters through the Canadian Archipelago may be another  
249 important factor explaining negative SST anomalies of the LC during Medieval times.

250 During the LIA, warmer SSTs found along NE Newfoundland coincide with colder and heavy ice  
251 years off North Iceland (*Massé et al., 2008*). This pattern compares well with surface ocean  
252 conditions during  $\bar{\text{NAM}}$  years, the GSA being an extreme example. Large quantities of freshwater  
253 and ice exported through Fram Strait (*Dickson et al., 1996*) contribute to the reduction of Labrador  
254 Sea convection. Thus, NAM not only affects local climate through wind forcing but also exerts  
255 control on the convective activity of the Labrador region by activating either the *Fram Strait Route*  
256 ( $\bar{\text{NAM}}$ ) or the *Canadian Archipelago Route* ( $+\text{NAM}$ ), with different consequences for the AMOC.

257

#### 258 **4. Conclusions**

259 Our two distinct SST records, one within the LC (NE Newfoundland) and the other at the northern  
260 edge of the NAC (SE Newfoundland), provide new insight into the overall interaction between the  
261 LC and the NAC. The SE Newfoundland SST record reveals an overall weaker influence of the NAC  
262 through the last 2000 years with only little variability at (multi)centennial scale. In contrast, the NE  
263 Newfoundland record shows that LC circulation is tightly linked to Arctic atmospheric conditions  
264 (NAM), which in turn modulate the advection pathway of cold, ice-loaded Polar Waters from the  
265 Arctic. This is illustrated by virtue of a generally enhanced LC during the MCA, and an overall  
266 weaker LC and likely decreased AMOC during the LIA (*Lund et al., 2006*). If this MCA/LIA pattern is  
267 to be considered analogous to generally warmer/colder climates in the subpolar North Atlantic, it  
268 would suggest the possibility of increasing LC strength in a future warmer climate. This would not  
269 only imply a colder future climate off eastern Canada, but would also affect regional ocean-  
270 atmosphere interaction off Newfoundland, deep convection in the Labrador Sea, NAC heat  
271 transport, and thus, climate in the larger North Atlantic realm.

272

273 **Acknowledgements.** The research presented here was supported by the French LEFE/INSU NAIW  
274 project (CNRS/INSU) and the ERC 203441 starting grant ICEPROXY project. K.W. was funded via a  
275 Marie Curie IEF grant (agreement no. 236678). MSS and AK received funding via the TROPOLINK  
276 and OCEANHEAT projects supported by the Danish Council for Independent Research Natural  
277 Science (FNU Grants 09-069833 and 12-126709). The cruise was funded by the Danish Council for  
278 Independent Research, Natural Science (project no. 272-06-0604/FNU) and carried out within the  
279 Danish–Russian collaboration project ‘Joint paleoceanographic investigations in the Labrador Sea  
280 region’. This work is a contribution to the EU FP7 project ‘Past4Future’ (project no. 243908).

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392

393 **Figure Captions**

394

395 **Figure 1.** Map showing North Atlantic surface currents, the study area, regional wind directions  
396 and the coring sites. Red/blue arrows indicate warm/cold surface currents, respectively; the  
397 prevailing wind directions are marked with light blue arrows. Core sites are shown on the insert  
398 map with the detailed surface hydrology of the Newfoundland area (thick blue arrows = Outer  
399 Labrador Current, thin blue arrows = Inner Labrador Current). Also shown in the insert are SST  
400 isolines (in °C) based on the NODC (Levitus) World Ocean Atlas 1998 (1.0 degree latitude x 1.0  
401 degree longitude global grid; 10 meter depth; data provided by the NOAA/OAR/ESRL PSD, Boulder,  
402 Colorado, USA, from their Web site at <http://www.esrl.noaa.gov/psd/>). The isolines represent  
403 April-June means for the years 1900-1997, thus largely overlapping with the time period covered  
404 by our two box cores.

405

406 **Figure 2.**  $^{210}\text{Pb}$  profiles of box-cores AI07-04BC and AI07-11BC and age models established from  
407 the  $^{210}\text{Pb}$  data.

408 **Figure 3.** Age model of gravity cores AI07-03G and AI07-12G based on calibrated  $^{14}\text{C}$  dates. The  
409 age models were established with the depositional model option in the OxCal 4.1 software using  
410 marine  $^{14}\text{C}$  calibration curve Marine09 with an average  $\Delta R$  of  $139\pm 61$  years (*Solignac et al.,*  
411 *2011; Reimer et al., 2009*).

412 **Figure 4.** Comparison of alkenone-derived SST reconstructions from recent sediments and NAM  
413 index values. **(a)** the NAM index was obtained from  
414 [http://climatedataguide.ucar.edu/guidance/hurrell-wintertime-slp-based-northern-annular-mode-](http://climatedataguide.ucar.edu/guidance/hurrell-wintertime-slp-based-northern-annular-mode-nam-index)  
415 [nam-index](http://climatedataguide.ucar.edu/guidance/hurrell-wintertime-slp-based-northern-annular-mode-nam-index). The thick black line is the running 3-year mean, i.e. the temporal resolution of our  
416 proxy record **(b)** alkenone-derived SSTs off NE Newfoundland (Bonavista Bay; box-core AI07-  
417 04BC) in light blue, and **(c)** off SE Newfoundland (Placentia Bay; box-core AI07-11BC) in dark  
418 blue.

419 **Figure 5.** Monthly mean temperature at the NE Newfoundland site (Bonavista Bay) in light blue,  
420 and at SE Newfoundland (Placentia Bay) in dark blue. Data have been obtained from the OES  
421 database ([http://www2.mar.dfo-](http://www2.mar.dfo-mpo.gc.ca/science/ocean/coastal_temperature/coastal_temperature.html)  
422 [mpo.gc.ca/science/ocean/coastal\\_temperature/coastal\\_temperature.html](http://www2.mar.dfo-mpo.gc.ca/science/ocean/coastal_temperature/coastal_temperature.html)) in area 3Lb for the NE

423 Newfoundland site and 3Ps for SE Newfoundland. Dotted lines represent annual means at both  
424 sites.

425 **Figure 6.** SST proxy reconstructions for the last 2000 years from off Newfoundland and North  
426 Iceland. Alkenone-derived SST reconstruction from **(a)** Off North Iceland obtained from the  
427 Calypso core MD99-2275 (*Sicre et al., 2011*) **(b)** NE Newfoundland obtained from the gravity  
428 core AI07-03G and box-core AI07-04BC for the upper part, and **(c)** SE Newfoundland obtained  
429 from the gravity core AI07-12G and box-core AI07-11BC 04BC for the upper part. The grey  
430 shading broadly indicates the Medieval Climate Anomaly (MCA). Black diamonds indicate AMS <sup>14</sup>C  
431 - dated sediment layers used to build the age model.

432