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Labrador current variability over the last 2000 years

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ABSTRACT

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

1. Introduction

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

Today, the LC variability and the position of the northern edge of the NAC are strongly influenced by the Northern Annular Mode (NAM) (Dickson et al., 1996), which is defined from sea level atmospheric pressure between 20° and 90° N and reflects the degree of penetration of Arctic air into mid-latitudes. Deep Icelandic lows during $^{+}$NAM years favor NW winds bringing cold air from the Arctic over the Labrador Sea, which results in colder-than-normal winter SSTs, sea–ice formation and enhanced transport of ice-loaded LC waters (Drinkwater, 1996). In contrast, weaker Westerlies and more frequent southerly winds during $^{-}$NAM years reduce winter ocean heat loss and promote warmer SSTs. NAM also induces changes in the Arctic Water gateways with implications for the deep convection. Under $^{-}$NAM conditions, the Transpolar Drift of Polar Waters shifts eastwards towards Fram

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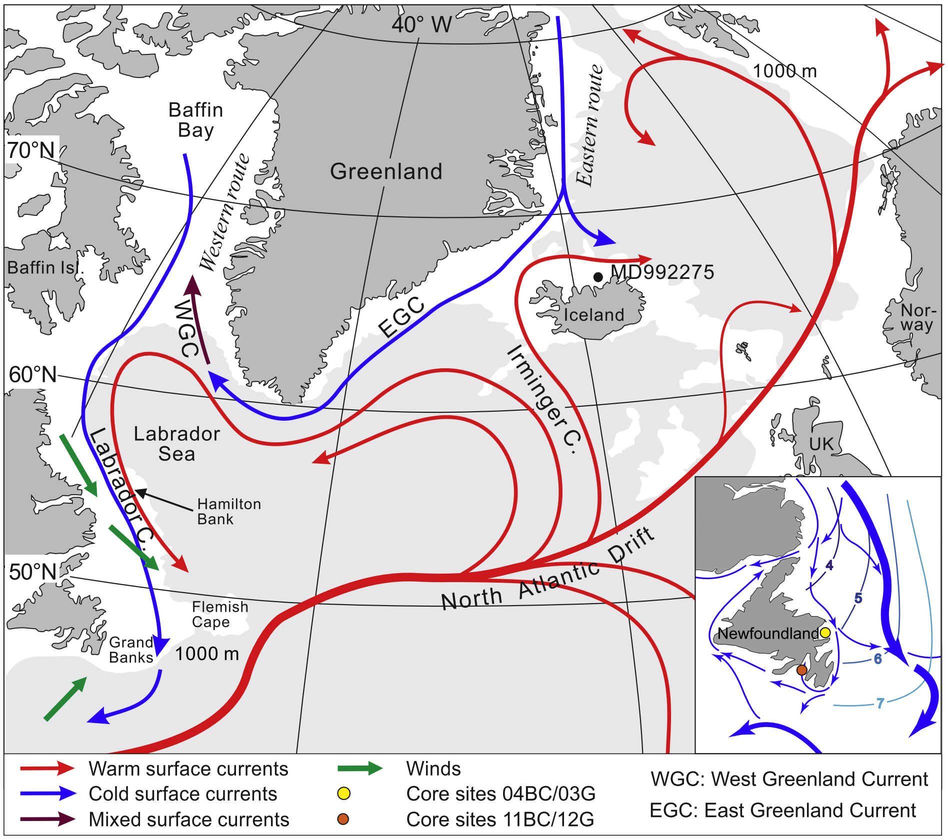

Fig. 1. Map showing North Atlantic surface currents, the study area, regional wind directions and the coring sites. Red/blue arrows indicate warm/cold surface currents, respectively; the prevailing wind directions are marked with light blue arrows. Core sites are shown on the insert map with the detailed surface hydrology of the Newfoundland area (thick blue arrows = Outer Labrador Current, thin blue arrows = Inner Labrador Current). Also shown in the insert are SST isolines (in °C) based on the NODC (Levitus) World Ocean Atlas 1998 (1.0 degree latitude × 1.0 degree longitude global grid; 10 meter depth; data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/). The isolines represent April–June means for the years 1900–1997, thus largely overlapping with the time period covered by our two box cores. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Strait (Morison et al., 2012). The East Greenland Current (EGC)/West Greenland Current (WGC) system is subsequently enhanced, which intensifies buoyancy-driven transport (Dickson et al., 1996) and leads to a more southerly NAC, as seen during the persistent and extreme $^{-}$NAM phase in the late 1960s (the 'Great Salinity Anomaly' (GSA)) (Dickson et al., 1988). Buoyancy gain combined with diminished ocean heat loss reduces deep convection in the central Labrador Sea and thus weakens the subpolar gyre (SPG) circulation (Dickson et al., 1996). In contrast, under $^{+}$NAM conditions, Arctic Waters are routed through the Canadian Archipelago and the LC transport increases under the influence of stronger NW winds (Fratantoni and McCartney, 2010). Concurrently, increased ocean heat loss favors enhanced convection in the central Labrador Sea, thus reinforcing SPG circulation and mixing with subtropical waters through the intergyre circulation (Marshall et al., 2001).

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

2. Material and methods

2.1. Sediment sampling

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

2.2. Sediment dating

Dating of the box-cores (AI07-04BC and AI07-11BC) was performed from excess activity of ^{210}Pb (^{210}Pb$_{xs}$) (Fig. 2) (Weckström et al., 2013). ^{210}Pb, ^{226}Ra and ^{137}Cs activities were analyzed using a low background, high efficiency, well-shaped γ detector (Schmidt et al., 2009), calibrated with certified reference material (IAEA-RGU-1). Activities are expressed in mBq g^{-1} and errors