Surface and subsurface Labrador Shelf water mass conditions during the last 6,000 years

Annalena A. Lochte[1,2*], Ralph Schneider[1], Markus Kienast[3], Janne Repschläger[4], Thomas Blanz[1], Dieter Garbe-Schönberg[1], Nils Andersen[5]

1 Institute of Geoscience, University of Kiel, Ludewig-Meyn Str. 10, 24118 Kiel, Germany
2 HOSST Graduate School, GEOMAR Helmholtz-Centre for Ocean Research Kiel, Wischofstraße 1–3, 24148 Kiel, Germany
3 Department of Oceanography, Dalhousie University, 1355 Oxford Street, Halifax, Canada
4 Max-Planck Institute for Chemistry, Hahn Meitner Weg 1, 55128 Mainz, Germany
5 Leibniz Laboratory for Radiometric Dating and Stable Isotope Research, University of Kiel, Max-Eyth-Str. 11–13, 24118 Kiel, Germany

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Motivation

The Labrador Sea is an important region for the modern global thermohaline circulation system through the formation of intermediate Labrador Sea Water (LSW), that has been hypothesized to stabilize the modern mode of North Atlantic deep-water circulation. The rate of LSW formation is controlled by the amount of winter heat loss to the atmosphere, the expanse of freshwater in the convection region and the inflow of saline waters from the Atlantic. The Labrador Sea, today, receives freshwater through the East and West Greenland Currents (EGC, WGC) and the Labrador Current (LC; Fig.1a). While several studies suggest the WGC to be the main supplier of freshwater to the region, the role of the southward flowing LC in Labrador Sea convection is still debated. At the same time, many paleoceanographic reconstructions from the Labrador Shelf focussed on late Deglacial to early Holocene meltwater run-off from the Laurentide Ice Sheet (LIS), whereas little information exists about LC variability since the final melting of the LIS about 7,000 years ago. In order to enable better assessment of the role of the LC in deep-water formation and its importance for Holocene climate variability in Atlantic Canada, this study presents high-resolution middle to late Holocene records of sea surface and bottom water temperatures, freshening and sea ice cover on the Labrador Shelf during the last 6,000 years.

Material & Methods

Gravity core MSM45-31-1 (1150 cm core length) was recovered from the Labrador Shelf at 54°24.74 N, 56°00.53 W, at 566 m water depth (Fig. 1a) during the R/V Maria S. Merian cruise MSM45 in August 2015. The stratigraphy of the is based on 12 Accelerator Mass Spectrometry (AMS) ^{14}C measurements on mixed calcareous benthic foraminifera. Long-chained alkenones (C_{37}) were extracted from 2–3g homogenized bulk sediment in 5-cm intervals. The proportion of $C_{37:4}$ relative to the sum of alkenones [$\%C_{37:4} = C_{37:4} / (C_{37:2} + C_{37:3} + C_{37:4})$] was interpreted as an indicator for sea ice margin conditions. The U^K_{37} index (Brassell et al., 1986) was applied to estimate sea surface temperatures (SST). Bottom water temperature (BWT) estimates are based on Mg/Ca ratios in benthic foraminifera species *Nonionellina labradorica* using the calibration of Skirbekk et al. (2016). Per sample, 20 - 70 specimens of *N. labradorica* were handpicked from the >315µm size fraction, weighed, crushed between two glass plates, and finally cleaned following the full protocol of Martin and Lea (2002). Mg/Ca ratios were measured with an ICP-OES instrument. Part of the crushed samples were cleaned with ethanol absolute, decanted and dried at 40°C for stable isotope analyses, which were carried out at the Leibniz Laboratory for Radiometric Dating and Stable Isotope Research in Kiel.

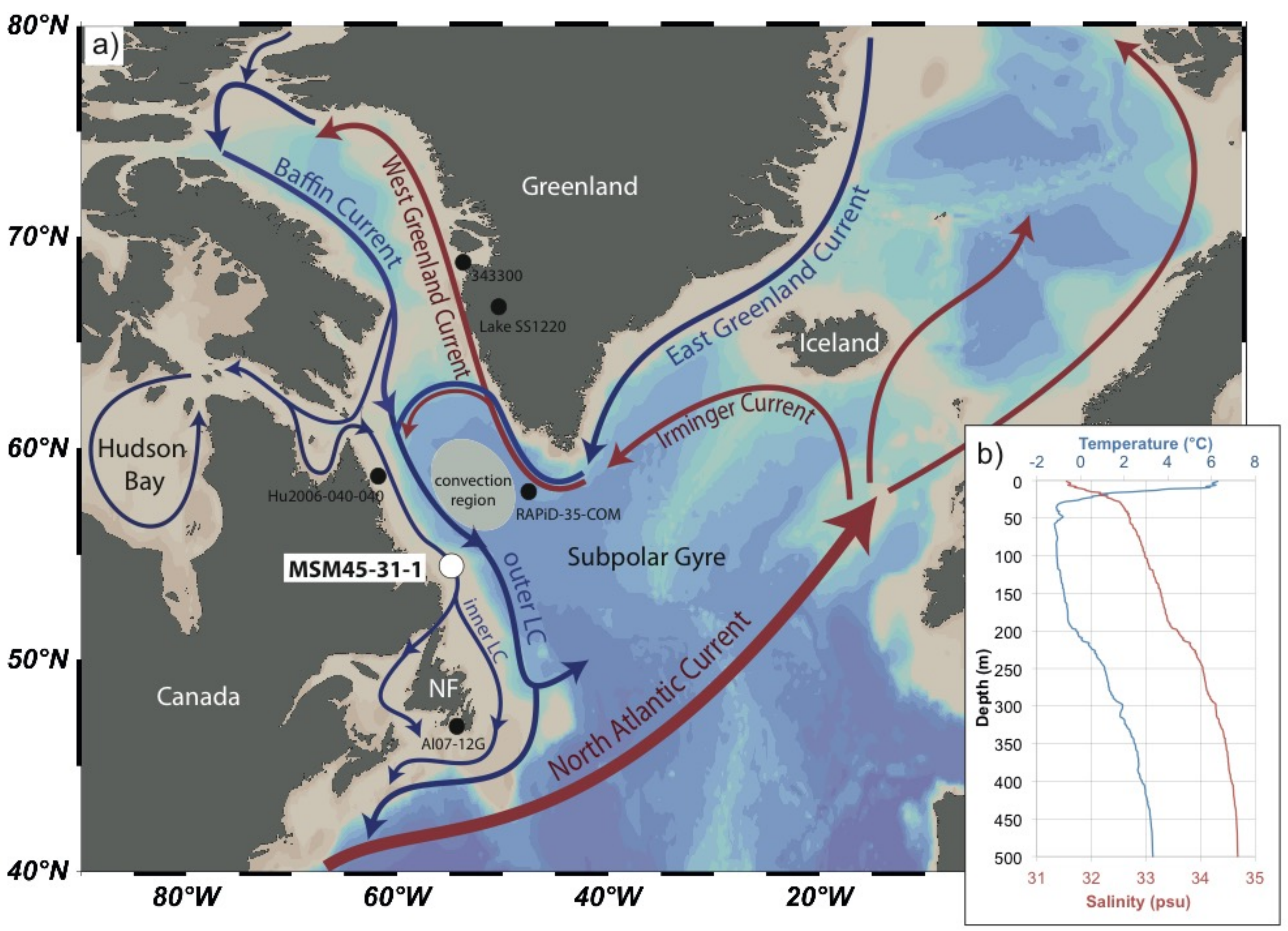

Figure 1: a) Map of the North Atlantic showing modern surface circulation with cold (blue) and warm (red) currents (adopted from Lazier and Wright, 1993; Rhein et al., 2011). A shaded area indicates the convection region of LSW. Core MSM45-31-1 is marked by a white dot, other cores referred to are marked by black dots. NF = Newfoundland. b) Depth profiles of temperature (blue) and salinity (red) of the water column near the core site at 54°28.53N, 56°04.33W obtained from CTD deployment during cruise MSM45 in August 2015.

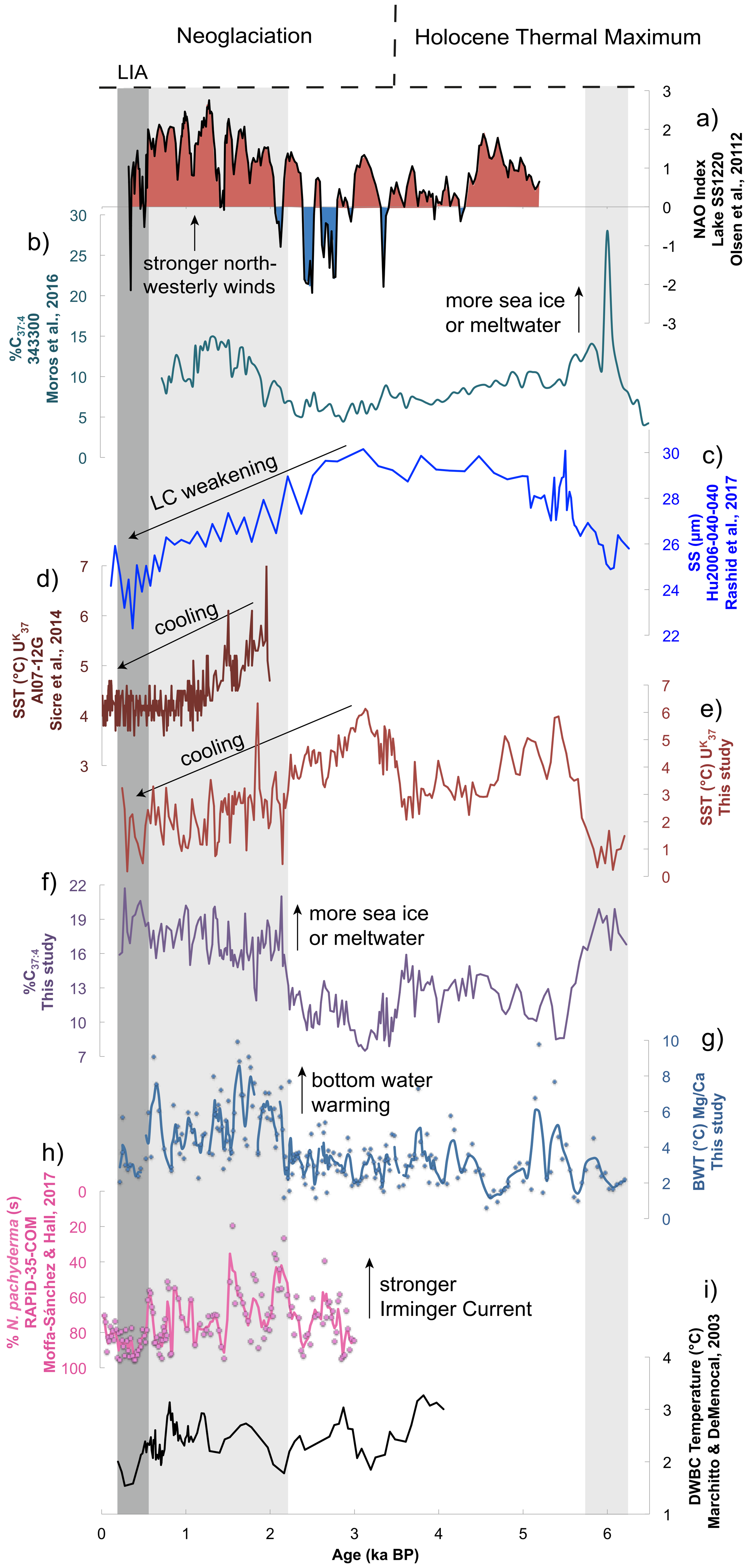

Figure 2: a) The NAO index (Olsen et al., 2012) with positive (red) and negative (blue) phases. b) $\%C_{37:4}$ in core 343300 (Moros et al., 2016). c) SS mean (µm) in core Hu2006-040-040 (Rashid et al., 2017). d) SST record in Newfoundland core AI07-12G (Sicre et al., 2014). e) SST record based on the U^K_{37} index (this study). f) Higher proportions of $\%C_{37:4}$ are interpreted to reflect a longer sea ice season or meltwater. g) BWT estimates are based on Mg/Ca ratios in benthic foraminifera *N. labradorica* and reflect subsurface conditions. h) Lower abundances of polar water planktic foraminifera species *N. pachyderma* in central Labrador Sea core RAPiD-35-COM indicate warming due to stronger IC inflow (Moffa-Sánchez and Hall, 2017). i) Mg/Ca temperature estimates representing Deep Western Boundary Current (Marchitto and deMenocal, 2003). Grey vertical bars highlight periods of pronounced oceanographic change.

Results & Discussion

According to major changes in surface and bottom water conditions, the record has been divided into three main environmental intervals:

From 6.2 to 5.6 ka BP: SST estimates show the lowest values of the record (Fig. 2e), while $\%C_{37:4}$ is high at about 18% (Fig. 2f), suggesting a cool period that is also evident in a core from the western Greenland coast (Moros et al., 2016; Fig. 2b). BWT estimates are also relatively low at about 3°C (Fig. 2g).

From 5.6 to 2.1 ka BP: SST estimates are in maximum range of 2 - 6°C (Fig. 2e) and $\%C_{37:4}$ shows the lowest values in this interval (Fig. 2f) in correspondence to a late Holocene Thermal Maximum. BWT reconstructions remain at average values of 3.1°C (Fig. 2g), which corresponds to modern conditions at the core site (Fig. 1b).

From 2.1 ka BP to present: SST estimates reveal a general cooling trend starting at about 3 ka BP (Fig. 2e), corresponding to the Neoglaciation. A similar cooling trend was also observed around Newfoundland (Sicre et al., 2014; Fig. 2d). At 2.1 ka BP, $\%C_{37:4}$ levels shift to higher values of 17% on average (Fig. 2f), suggesting a sudden increase in sea ice. At the same time, BWTs shift to higher values (Fig. 2g), suggesting an abrupt warming in Labrador Shelf bottom waters. The sudden shift in both records correspond to the start of a period characterised by predominantly positive NAO conditions (Olsen er al., 2012; Fig. 2a), which would have promoted stronger north westerly winds and enhanced the transport of sea ice from the Arctic. At the same time, an increased inflow of Atlantic waters was reconstructed in the central Labrador Sea (Moffa-Sanchez & Hall, 2017; Fig. 2h), which may have caused the warming in Labrador shelf bottom waters.

Conclusions

Overall, middle to late Holocene conditions in Labrador Shelf waters display variability that can partly be related to atmospheric forcing, such as NAO-like conditions. Between 6.2 and 5.6 ka BP, our records imply a cold episode with strong sea ice cover on the Labrador Shelf that has also been evident in other cores from the North Atlantic region. This cold episode was followed by a generally warmer interval from about 5.6 to 2.1 ka BP corresponding to a late Holocene Thermal Maximum. After about 3 ka BP, our SST record shows a gradual cooling trend in association with the Neoglaciation, which has also been observed in other surface records from the Labrador Sea region. However, at 2.1 ka BP our record shows an abrupt shift to enhanced sea ice cover and warmer bottom waters on the Labrador Shelf that corresponds to a shift from predominantly negative to predominantly positive NAO-like conditions. We associate the cooling seen in surface waters with stronger north-westerly winds and harsher winters in the region during positive NAO, while the warming in bottom waters was possibly related to a stronger inflow of the westward retroflection of the WGC in response to a stronger supply of the IC that was seen in the central Labrador Sea.

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