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Northern source for Deglacial and Holocene deepwater composition changes in the Eastern North Atlantic Basin

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ABSTRACT

Over the last decades extensive research has been carried out on changes in the Atlantic Meridional Overturning Circulation and its role during the last deglacial period. At present, only a few high-resolution data sets from the deep eastern North Atlantic exist for this period. It therefore remains uncertain whether deepwater changes in the Eastern North Atlantic Basin were governed by alternating contributions of northern and southern deepwater or whether the Eastern North Atlantic Basin reflects changes in the initial composition and source of North Atlantic deepwater. Furthermore, it is still debated whether such changes are triggered by Northern or Southern Hemisphere climatic changes.

In this centennial to decadal scale resolution study we investigate deepwater composition changes in the Eastern North Atlantic Basin over the last 15 ka BP. We used sediment cores GEOFAR KF16 and MD08-3180 (37.984° N; 31.118° W, wd 3050 m/37.999° N; 31.134° W, wd 3064 m), obtained from a small basin at the eastern flank of the Mid Atlantic Ridge south of the Azores Islands. Under modern conditions the coring site is situated at the boundary between southern Lower Deep Water and northern Eastern North Atlantic Deep Water consisting of Iceland Scotland Overflow Water and Labrador Sea Water. Distinct differences between the three water masses in terms of ventilation state, temperature and salinity signatures are ideal for tracking changes in the deglacial North Atlantic deepwater distribution using paired benthic foraminiferal stable isotopes ($\delta^{13}C$, $\delta^{18}O$) and Mg/Ca bottom water temperature reconstructions.

The results show a close coupling of low bottom water temperature (1.5 °C) and $\delta^{13}C$ (0–0.5‰) values during cold Heinrich event 1, the Younger Dryas and the Preboreal, that were coeval with a major $\delta^{18}O$ depletion of deepwater. The strong similarities between subtropical Eastern North Atlantic Deep Water and subpolar North Atlantic surface and deepwater changes indicate that deglacial changes in Eastern North Atlantic Deep Water distribution were triggered in the North Atlantic. Consequently, this would imply that changes in the North Atlantic also contributed to deglacial changes in Antarctic bottom water composition. During the early Holocene stepwise increasing $\delta^{13}C$ values suggest increasing Eastern North Atlantic Deep Water production and/or increasing Eastern North Atlantic Deep Water ventilation with minor but distinct interruptions (at 10.8, 10.6, 9.1, 8.4, 8.1 and 7.2 ka BP), which were most probably also triggered in the subpolar North Atlantic.

1. Introduction

The Atlantic Meridional Overturning Circulation (AMOC[1]) governs the North Atlantic climate system by transporting warm and saline surface water toward North Atlantic deepwater convection sites, where it cools, descends, and returns as deepwater flow. Changes in the AMOC strength are not only related to changes in northward heat transport but also with severe changes in the Atlantic deepwater distribution (e.g. Gherardi et al., 2009; Labeyrie et al., 2005; Michel et al., 1995; Oppo et al., 2003; Sarnthein et al., 1994; Thornalley et al., 2010; Waelbroeck et al., 2011). As the deep ocean may act as a trap for carbon during glacial periods, the reconstruction of deglacial changes in this system are of major interest in order to understand feedback mech-

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Abbreviations

AMOC	Atlantic Meridional Overturning Circulation
LGM	Last Glacial Maximum
H1	Heinrich Event 1
BA	Bølling–Allerød
YD	Younger Dryas
DSOW	Denmark Strait Overflow Water
ISOW	Iceland–Scotland Overflow Water
NADW	North Atlantic Deep Water
LSW	Labrador Sea Water
LDW	Lower Deep Water, a derivate of AABW
AABW	Antarctic Bottom Water
ENADW	Eastern North Atlantic Deep Water
GNADW	Glacial North Atlantic Deep Water
lGNADW	lower Glacial North Atlantic Deep Water
uGNADW	upper Glacial North Atlantic Deep Water
$\delta^{18}O_w$	temperature corrected $\delta^{18}O$ values
$\delta^{18}O_{ivc}$	ice volume corrected $\delta^{18}O$ values
$\delta^{18}O_{w\text{-}ivc}$	temperature and ice volume corrected $\delta^{18}O$ values

anisms of our climate system during glacial terminations (Adkins, 2013; and citations therein).

The evolution of the AMOC and the Atlantic deepwater distribution has been extensively investigated during the last decades using different approaches. In the classical approach, stable oxygen and carbon isotope data from benthic foraminifera are used to reconstruct water mass salinities and deepwater ventilation (e.g. Michel et al., 1995; Oppo et al., 2003; Sarnthein et al., 1994). This approach is controversially discussed due to the non-conservative behavior of $\delta^{13}C$, that might be overprinted by the remineralization of organic matter originating from local productivity changes, or from accumulated material (Mackensen et al., 1993). More recently, transects of combined $\delta^{13}C$ and $\delta^{18}O$ were used to reconstruct deepwater sources and geometry in the Atlantic basin, including the influence of Northern Hemisphere brine water (Labeyrie et al., 2005; Oppo et al., 2003; Sarnthein et al., 1994; Thornalley et al., 2010; Waelbroeck et al., 2011). Combined benthic foraminifera Mg/Ca and stable isotope analyses were used to reconstruct bottom water temperature changes (e.g. Marcott et al., 2011; Skinner et al., 2003) and to identify changes in the distribution of deepwater masses. Piotrowski et al. (2008, 2012) and Roberts et al. (2010) used the $^{143}Nd/^{144}Nd$ ratio (εNd) as a tracer for water mass sources, whilst overturning rates were reconstructed by the $^{231}Pa/^{230}Th$ ratios (Gherardi et al., 2005, 2009; Lippold et al., 2012; McManus et al., 2004; Roberts et al., 2010). These reconstructions suggest a dramatic reorganization of the AMOC system over the last Deglacial (19–10.5 ka BP).

During the Last Glacial Maximum (LGM[2]) (23–17.9 ka BP), deepwater circulation was characterized by a vigorous overturning at intermediate depths (1000 to 2000 m water depth (wd)), whereas deepwater renewal rates were more sluggish below 2000 m wd (Adkins, 2013; Boyle and Keigwin, 1987; Duplessy et al., 1988; Gherardi et al., 2009; Lippold et al., 2012; Oppo and Fairbanks, 1987; Sarnthein et al., 1994). However, not all proxies agree with this simplified concept of deepwater circulation. During the Deglacial, the most drastic reduction in deepwater overturning occurred during Heinrich event 1 (H1[3]) (17.9–14.9 ka BP), with a general decrease in overturning affecting all depth levels as inferred from $^{231}Pa/^{230}Th$ ratios (e.g. Gherardi et al., 2005; Gherardi et al., 2009; McManus et al., 2004). A first strengthening of the AMOC after this breakdown occurred during the Bølling–Allerød (BA[4]) (14.9–12.9 ka BP), associated with a moderate southward water transport at all levels below 1000 m (Gherardi et al., 2009). The circulation mode during the BA was therefore intermediate between a more active LGM circulation and a nearly collapsed H1 overturning (Gherardi et al., 2009). During the Younger Dryas (YD[5]) the deepwater circulation decreased again, including a decrease in deepwater renewal rate below 3000 m wd compared to the BA, whereas the intermediate circulation at ~2000 m wd was maintained (Gherardi et al., 2009). At the onset of the Holocene, a strengthening of the AMOC was probably related to increasing deepwater formation in the Nordic Seas (Colin et al., 2010) and its southward propagation as Denmark Strait Overflow Water (DSOW[6]) and Iceland–Scotland Overflow Water (ISOW[7]) that formed the major component of North Atlantic Deep Water (NADW[8]). This strengthening of AMOC was interrupted by several decadal to centennial scale events (Hoogakker et al., 2011a; Oppo et al., 2003) of which the 8.2 event with a meltwater induced AMOC reduction of about 50% was the most prominent (Kleiven et al., 2008). The modern North Atlantic circulation started between 8 and 6 ka BP with the onset of modern Labrador Sea Water (LSW[9]) production (Colin et al., 2010; Hoogakker et al., 2011a; Kissel et al., 2013; Solignac et al., 2004; Thornalley et al., 2013) and was associated with decreases in the ISOW and NADW strength and an increase in southern Lower Deep Water (LDW[10]) (Fig. 1) (Hoogakker et al., 2011a).

Previously it was proposed that deglacial cold periods H1 and YD, considered as shallow overturning phases, were coupled with an increasing influence of southern sourced deepwater that flushed the North Atlantic basin (e.g. Gherardi et al., 2005; McManus et al., 2004; Meckler et al., 2013; Oppo et al., 2003; Sarnthein et al., 1994). In this way, a simple, two end member see–saw like pattern between the southern and northern deepwater sources was proposed (e.g. Skinner et al., 2003). However, more recent studies indicate a more complex deepwater distribution pattern. During the H1 and the YD, the north–south seesaw pattern might be partially overprinted by brine waters of North Atlantic origin (Labeyrie et al., 2005; Meland et al., 2008; Thornalley et al., 2010; Waelbroeck et al., 2011). The latter, traced by its depleted $\delta^{13}C$ and $\delta^{18}O$ signatures within the subpolar North Atlantic, were identified in a North Atlantic N–S transect between 900 m and 2200 m wd (Waelbroeck et al., 2011).

Additionally, the comparison of εNd data from the eastern and western North Atlantic basins (Piotrowski et al., 2012) indicates that during the YD, the deepwater composition changed in the Eastern North Atlantic Basin to a lesser extent than in the western basin. This pattern might be explained by a restricted southern deepwater intrusion into the Eastern North Atlantic Basin. This untested hypothesis would imply that the deepwater composition in the Eastern North Atlantic Basin is governed by long-term changes in North Atlantic deepwater source composition rather than by changes between the volume of northern and southern deepwater.

Changes in the deepwater source composition could be tested using bottom water temperature and salinity reconstructions derived from combined Mg/Ca and $\delta^{18}O$ measurements from benthic foraminifera, but data coverage for the deep North Atlantic is sparse. This deficiency is due to a possible bias in the Mg/Ca-derived temperature signal by carbonate ion saturation changes (e.g. Yu and Elderfield, 2008). Existing reconstructions from the Iberian Margin (Skinner et al., 2003) indicate bottom water temperature of about −1.5 °C during the LGM and −1 °C during the H1 in the deep North Atlantic and deepwater warming of 3–4 °C into the Holocene with a cold reversal to about 0 °C during the YD that