



Solar modulation of North Atlantic central Water formation at multidecadal timescales during the late Holocene

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ABSTRACT

Understanding natural climate variability in the North Atlantic region is essential not only to assess the sensitivity of atmosphere–ocean climate signal exchange and propagation, but also to help distinguish between natural and anthropogenic climate change. The North Atlantic Oscillation is one of the controlling modes in recent variability of atmosphere–ocean linkages and ice/freshwater fluxes between the Polar and North Atlantic Ocean. Through these processes the NAO influences water mass formation and the strength of the Atlantic Meridional Overturning circulation and thereby variability in ocean heat transport. However, the impact of the NAO as well as other forcing mechanisms on multidecadal timescales such as total solar irradiance on Eastern North Atlantic Central Water production, central water circulation, and climate signal propagation from high to low latitudes in the eastern subpolar and subtropical basins remains uncertain. Here we use a 1200 yr long benthic foraminiferal Mg/Ca based temperature and oxygen isotope record from a ~900 m deep sediment core off northwest Africa to show that atmosphere–ocean interactions in the eastern subpolar gyre are transferred at central water depth into the eastern boundary of the subtropical gyre. Further we link the variability of the NAO (over the past 165 yrs) and solar irradiance (Late Holocene) and their control on subpolar mode water formation to the multidecadal variability observed at mid-depth in the eastern subtropical gyre. Our results show that eastern North Atlantic central waters cooled by up to -0.8 ± 0.7 °C and densities decreased by $\sigma_\theta = 0.3 \pm 0.2$ during positive NAO years and during minima in solar irradiance during the Late Holocene. The presented records demonstrate the sensitivity of central water formation to enhanced atmospheric forcing and ice/freshwater fluxes into the eastern subpolar gyre and the importance of central water circulation for cross-gyre climate signal propagation during the Late Holocene.

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1. Introduction

The state of the North Atlantic Oscillation (NAO) in combination with subpolar gyre dynamics (Hatun et al., 2005) determines regional sea surface heat loss and winter convection by modulating both the variability in the westerly wind stress and fresh water budgets in the North Atlantic (Curry and Mauritzen, 2005; Furevik and Nilsen, 2005; Johnson and Gruber, 2007; Marshall et al., 2001a; Marshall et al., 2001b), and thereby, influencing the intensity of the deep overturning branch of the Atlantic Meridional Overturning Circulation (AMOC) in the Nordic and Labrador Seas (Boessenkool et al., 2007; Dickson et al., 2002; Dickson et al., 2000; Eden and Jung, 2001; Hatun et al., 2005; Shindell et al., 2001b). However, the region with the strongest response

to NAO-modulated wind-stress is in the subpolar basin south of Iceland, where westerlies are up to 8 m s^{-1} stronger during extremely positive NAO (+) years (Hurrell, 1995) due to the enhanced pressure gradient between the Icelandic Low and Azores High and result, via sea surface heat loss, in sea surface temperatures (SST) several tenths of degrees (-0.7 °C) colder than on average (Furevik and Nilsen, 2005; Johnson and Gruber, 2007). Subpolar Mode Water (SPMW) forms in this region (Fig. 1) via subduction (Tomczak and Godfrey, 1994) and after formation comprise a large fraction of Eastern North Atlantic Central Water (ENACW) (Iselin, 1936; Poole and Tomczak, 1999). A positive NAO phase shift is thus associated with cooler and fresher ENACW (Johnson and Gruber, 2007; Pérez et al., 2000).

The formation, subduction and subsequent southward flow of ENACW at densities between $\sigma_\theta = 27.3$ and 27.6 kg/m^3 (Levitus, 1989; McCartney and Talley, 1982), into the STG is well established (Keffer, 1985; Levitus, 1989; McCartney and Talley, 1982; McDowell et al., 1982). ENACW formation and circulation provide therefore a direct link between both gyres and offer the opportunity to investigate the influence of atmosphere–ocean linkages in the

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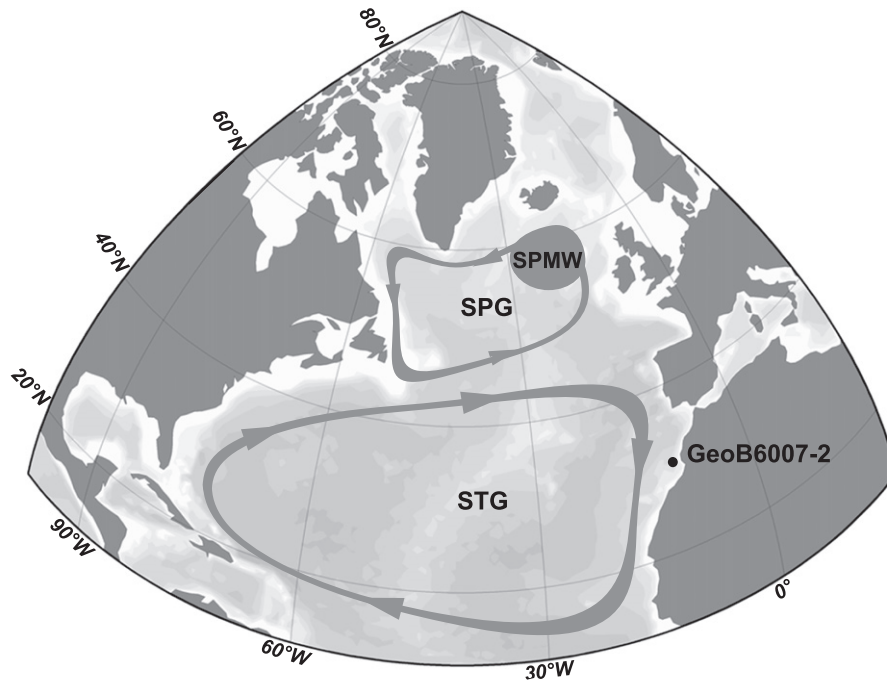


Fig. 1. Study area: the location of core GeoB6007-2 (30.85°N, 10.27°W at 899 m depth) marked by a black circle. Simplified SPG and STG positions and circulation patterns are indicated by gray loops modified after Bamberg et al. (2010). The formation region of SPMW is marked by a circle between ~50–63°N east of 25°W (Levitus, 1989; McCartney and Talley, 1982).

subpolar North Atlantic on central water formation and cross gyre climate signal propagation.

In addition to the NAO, recent numerical model simulations (Ammann et al., 2007; Swingedouw et al., 2010) and paleoproxy reconstructions (Knudsen et al., 2009) as well as the re-analysis of published proxy data (Lockwood et al., 2010; Lohmann et al., 2004) provide support for the existence of ocean–atmosphere linkages over the subpolar basin that communicate and amplify relatively small radiative changes in total solar irradiance (Δ TSI) (Lean, 2010; Shindell et al., 2001b) into a climate signal extending beyond the northeastern Atlantic region at multidecadal timescales. The NAO and possibly Δ TSI are thus two important factors controlling recent and long-term variability in atmosphere–ocean linkages over the north Atlantic at multidecadal timescales.

However, the impact of multidecadal variations in NAO mode and Δ TSI on meridional climate signal transfer in the North Atlantic remains uncertain for the Late Holocene. The lack of evidence for past and present records assessing atmospheric and mid-depth ocean linkages is due to the scarcity of high resolution, undisturbed, and well-dated marine records (Sicre et al., 2008), and a focus on SST proxies in the recent literature, rather than proxies for bottom water temperatures (Katz et al., 2010) needed to reconstruct central water properties.

In the present study we investigate oceanic central water connections between mid-depth subpolar and subtropical latitudes. We present a high resolution 1200-yr long paleotemperature and stable isotopic record based on benthic foraminifera collected at 900 m depth from the northwest African continental shelf in the eastern boundary of the STG thus providing new insights into natural mid-depth climate signal propagation. In particular, we discuss two hypotheses on atmospheric mid-depth oceanic linkages and their relationship to NAO and Δ TSI variability at multidecadal timescales. The first hypothesis is that mid-depth cooling in the eastern boundary of the STG is caused by enhanced Ekman pumping resulting in a shoaling of the local thermocline in conjunction with positive NAO years (Curry and McCartney, 2001). A shoaling at 900 m depth may

then allow the incursion of relatively cooler and fresher Antarctic intermediate water (AAIW) to result in colder and fresher mid-depth temperatures in the eastern STG. The second hypothesis proposes that colder mid-depth temperatures in the eastern STG originate from the subpolar gyre and represent the formation of colder SPMW and ENACW during positive NAO years that are subducted and transported underneath the North Atlantic Current into the STG (Keffer, 1985; Levitus, 1989; McCartney and Talley, 1982; McDowell et al., 1982); (Fig. 2).

2. Materials and methods

2.1. Core location

During METEOR Leg M45 in 1999, gravity core GeoB6007-2 and multicore GeoB6007-1 were collected from the eastern boundary of

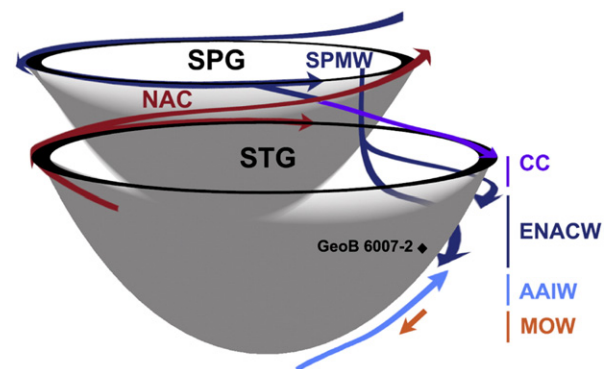


Fig. 2. Schematic representation of the formation and cross-gyre transfer of Eastern North Atlantic Central Waters (ENACW) via Subpolar Mode Water (SPMW) formation in the eastern Subpolar gyre (SPG). Also shown are the North Atlantic Current (NAC) and Canary Current as well as Antarctic Intermediate Water (AAIW) and Mediterranean Outflow Water (MOW) present below the core site underneath ENACW.

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