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Variations in the strength of the North Atlantic bottom water during Holocene

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ABSTRACT

We report here on a multi-proxy study of the changes in the dynamics and the properties of bottom water mass in the subpolar North Altantic during Holocene. Magnetic properties coupled with sortable silt and benthic carbon isotopes are investigated for Holocene marine sedimentary sequences located in the Charlie–Gibbs fracture zone (53°N) and in central (57°N) and southern Gardar drift (59°N). All the cores are located at water depths bathed by the Iceland–Scotland Overflow Water (ISOW), mixed at the southernmost locality with southern sourced water masses. The long-term variations in measured proxies are fitted with similar polynomial curves. An early Holocene event characterized by a shutdown/shoaling of the bottom circulation at the deepest sites is most likely related to the main deglacial freshwater inputs. It is followed by a progressive strengthening/deepening of the overflow water which culminates around 6 kyr, in coincidence with the Holocene thermal maximum. After 6 kyr corresponding to a drastic hydrological reorganization in the North Atlantic, a general decline in the bottom flow strength is observed until about 2 kyr B.P. when it reached its present day state. After detrending, several short periods of reduced bottom flow strength and sedimentary transport from the northern detrital sources are observed, with a periodicity of around 600 yr with no clear relationship at this time scale between surface and deep ocean.

1. Introduction

The subpolar north Atlantic Ocean plays a key role in the global oceanic circulation and therefore in the Earth's global climate system. It is currently characterized by a surface and subsurface polarward flow of warm and salty waters reaching the Nordic seas where convection takes place (McCartney, 1992; Dickson and Brown, 1994). The newly formed deep-water mass returns into the North Atlantic, passing over the Greenland–Scotland ridge. The so-called Denmark Strait Overflow Water (DSOW) in the west and the Iceland–Scotland overflow water (ISOW) in the east, then merge to form the North Atlantic Deep Water (NADW). Another northern convection site, located in the Labrador Sea and active only since 7 ka (Hillaire-Marcel et al., 2001), gives rise to the Labrador Sea Water mass (LSW) which, in south Icelandic basins, overlies and exchanges with the overflow water masses (Dickson and Brown, 1994). In the northern Atlantic Meridional Overturning Circulation (AMOC), the dynamic of the surface and deep water masses are considered to be closely related (Broecker, 1991) and any change in their dynamics and pathways and in polarward heat transport by freshwater perturbation and/or by changes in solar insolation has a major impact not only on North American and European climate but more widely on global climate (Delworth et al., 2008 and references therein).

One of the main concerns in studies of the present climatic change is its possible relationship with the AMOC. To address this question, understanding of the natural variability of the North Atlantic circulation and of its sensitivity to external perturbations is needed. This circulation has long been described as relatively stable during the Holocene, based on the absence of instabilities of large ice sheets as opposed to the last glacial period. The very significant change observed in the deep component of the AMOC during early Holocene (around 8.4–8.2 kyr) (Ellison et al., 2006; Kleiven et al., 2008; Thornalley et al., 2010) is in fact the reminiscence of the glacial period expressed as the outburst of the proglacial Agassiz lake (Barber et al., 1999). Due to the increasing number of studies of high-deposition rate Holocene sequences, evidence of millennial to centennial scale variations superimposed on longer-term trends in the North Atlantic oceanic circulation during Holocene have accumulated over the past few years. This evidence is based on studies of surface ocean proxies for sea surface tem-peratures (SST) and/or salinities (SSS) such as coccoliths, diatoms or foraminifera concentrations and assemblages (Giraudeau et al., 2000; Andersen et al., 2004a, 2004b; Ellison et al., 2006; Balestra et al., 2010), hematite-stained grains content and ice rafting detritus (Bond et al., 2001; Moros et al., 2004), alkenones (Kim et al., 2004; Moros et al., 2004; Keigwin et al., 2005; Sicre et al., 2008), dinoflagellates (Eynaud et al., 2004), oxygen isotopes in planktic foraminifera and/or Mg/Ca ratio (Hall et al., 2004; Keigwin et al., 2005; Ellison et al., 2006; Came et al., 2007; Thornalley et al., 2009; Kleiven et al., 2008; Farmer et al., 2011).

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They show regional differences probably related to changes with time of the position of the polar front, of the dynamics of the subpolar gyre and of the activity of the Norwegian and the Irmi-nger currents. The mechanisms generating them are not yet fully understood.

By contrast, only a few studies have addressed the evolution of deep ocean in the subpolar North Atlantic during the Holocene. They are based on carbon and/or oxygen isotopic composition of benthic foraminifera (Oppo et al., 2003; Hall et al., 2004; Keigwin et al., 2005; Kleiven et al., 2008; Thornalley et al., 2010; Hoogakker et al., 2011), on sortable silt (Bianchi and McCave, 1999; Hall et al., 2004; Ellison et al., 2006; Thornalley et al., 2010; Hoogakker et al., 2011), on magnetic properties (Rousse et al., 2006; Kleiven et al., 2008), on Pa/Th ratio (McManus et al., 2004; Gherardi et al., 2009), on sediment lightness (Chapman and Shackleton, 2000) and geochemical data (Fagel et al., 1997, 2004; Fagel and Mattielli, 2011). These records, identify long and/or short-term variations of the North Atlantic circulation, the amplitude and/or timing of which varies depending on the region, water-depth and proxies.

Among the deep-sea proxies mentioned above, the use of the magnetic properties is probably the less common one. Recently, Kissel et al. (2009) showed that the magnetic concentration-related parameters have the ability to trace deep water masses when the source of magnetic particles is unique. In the studied area, the magnetic particles are part of the basaltic-derived sedimentary assemblage dominantly present at the Greenland–Scotland ridge. When convection is active in the Norwegian Sea, these particles are remobilized at the sill by the ISOW and transported to the open Atlantic ocean along its path. Kissel et al. (2009) showed that the magnetic particles behave as single grains during transport from a unique source upstream. The distribution of the magnetic grains, both in concentration and grain size from the northernmost site to the southernmost one, reflects transport by ISOW-related bottom currents and deposition along its flow path. Although changes in the source supply cannot be completely ruled out, depending on the time period, Kissel et al. (2009) suggested that the changes in the magnetic properties at a given site during the Holocene illustrate changes in the efficiency of the bottom current to transport magnetic grains related to the overflow water mass.

Taking advantage of new detailed age models based on numerous radiocarbon dating, we carried on our investigations, focusing on sites characterized by the highest sedimentation rates during Holocene. We present here the detailed time evolution at these sites not only of the magnetic properties for changes in the influence of ISOW (Kissel et al., 2009) but also of the sortable silt used as a tracer of bottom flow speed changes (McCave et al., 1995; McCave and Hall, 2006) and of the benthic carbon isotopes for deep water mass properties (Curry and Oppo, 2005). This allows us to describe both the long- and short-term changes in the deep subpolar northeast Atlantic circulation.

2. Oceanographic setting, core description and sampling

The location of the different cores is reported in Table 1 and shown in Fig. 1.

The first two cores at the "heart" of this work are located in the Charlie–Gibbs fracture zone (CGFZ), an ideal position to decipher past variations in deep North Atlantic circulation during the Holocene and to reconstruct past changes in the relative contribution of the main water masses bathing the sites.

The CGFZ is a major deep E–W structure at about 52°N (Fig. 1) made of two transform valleys separated by a median ridge. The northern channel is a corridor in which most of the ISOW flowing southwestward along the Gardar drift turns westward out of the Iceland Basin into the western North Atlantic basin (Worthington and Volkmann, 1965; McCartney, 1992; Smethie et al., 2007). The total flux of the CGFZ throughflow was estimated around 3.8 Sv (LeBel et al., 2008) and mainly attributed to the westward ISOW deep flow (Smethie et al., 2007; LeBel et al., 2008). Although still debated (Dickson and Brown, 1994; Saunders, 1994; LeBel et al., 2008), a contribution up to 40% at present of southern sourced silicate-rich Lower Deep Water (LDW) derived from the Antarctic Bottom Waters (AABW) is reported (McCartney, 1992).

The two cores were retrieved at the western termination of this northern corridor. The oldest core (CH77-02, 5.9 m long), was collected in 1977 during a cruise of the R.V. *Charcot* of IFREMER. Its position at 52°42′N and 36°05′W is not as precise as those we can determine nowadays because GPS positioning did not exist at that time. Taken at 3712 m water depth, it is constituted of hemipelagic silty clays except for a slightly coarser horizon between 261 and 279 cm below sea floor (b.s.f) with no disturbances below or above. During the 2008 MD168-AMOCINT/XVII IMAGES cruise of the R.V. *Marion Dufresne*, we took a new CALYPSO Square (CASQ) core nearby (MD08-3182Cq; 52°41.99′N; 035°56.14′W; 3757 m) (Kissel et al., 2008). The advantage of the CASQ corer is that it does not create significant perturbation of the sediment, including in its top part. The new core is 11.5 m long, also made of light olive-gray hemipelagic silty clays. Below 854 cm b.s.f, it contains dropstones characterizing full glacial conditions. A sandy layer with a sharp erosional contact at the base is observed around 460 cm b.s.f with a gradual transition into light-olive gray sandy clays up to about 260 cm b.s.f (Kissel et al., 2008). This 2 m thick interval corresponds to a local turbiditic event (or slope instability) and was therefore not considered in our study.

Farther north, along the Gardar Drift which is the main path for ISOW (McCartney, 1992), we collected several other CASQ cores during the P.I.C.A.S.S.O (MD132/ IMAGES XI) cruise in 2003, all covering the Holocene sequences (Laj et al., 2004). The oceanographic setting of these cores is described in Kissel et al. (2009).

In Southern Gardar, core MD03-2676Cq (57°26.86′N; 27°54.52′ W; 2607 m), 11.88 m long, is located close to core MD99-2251

Table 1
Geographic coordinates of the cores used in this study and associated references. In italic are the cores with which we compare our own data.

Core	Lat. (N)	Long. (W)	Water depth (m)	References
CH77-02	52°42′	36°05′	3712	This study; Kissel et al. (2009)
MD08-3182Cq	52°41.99′	35°56.14′	3757	This study
MD99-2251	57°26.88′	27°54.48′	2620	This study; Ellison et al. (2006); Hoogakker et al. (2011)
MD03-2676Cq	57°26.86′	27°54.52′	2607	This study; Kissel et al. (2009)
MD03-2678Cq	58°45.74′	25°57.55′	2603	This study; Kissel et al. (2009)
MD03-2665Cq	48°36.60′	57°26.56′	3440	This study; Kleiven et al. (2008)
NEAP-4K	*61°29.91′*	*24°10.33′*	*1627*	Hall et al. (2004)
NEAP-15K	*56°21.92′*	*27°48.68′*	*2848*	Bianchi and McCave (1999)
ODP 980	*55°29.10′*	*14°42.13′*	*2180*	Oppo et al. (2003)
MD95-2015	*58°46′*	*25°57′*	*2630*	Giraudeau et al. (2000); Eynaud et al. (2004)