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Suborbital-scale surface and deep water records in the subtropical North Atlantic: implications on thermohaline overturn

Katharina Billups [a,*], Nathan Rabideaux [b], Jared Stoffel [c]

[a] University of Delaware, 700 Pilottown Road, Lewes, DE 19958, USA
[b] Rensselaer Polytechnic Institute, 110 8th St. Troy, NY 12180, USA
[c] University of Dayton, 300 College Park, Dayton, OH 45409, USA

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ABSTRACT

We reconstruct millennial-scale variations in sea surface hydrography and deep water flow in the northwestern subtropical Atlantic (Ocean Drilling Program Leg 172 Sites 1056 and 1063) with a focus on Marine Isotope Stage (MIS) 9. Together with published records from this region, the new data also afford a longer-term perspective on millennial-scale changes in meridional overturning circulation spanning two full interglacial intervals (MIS 9 and 11) as well as two full glacial intervals (MIS 10 and 12). Planktic foraminiferal $\delta^{18}O$ values indicate relatively stable conditions during the peak warmth of MIS 9, but three large cold excursions disrupt the otherwise smooth transition toward glacial MIS 8. There is no unique response in the Site 1063 benthic foraminiferal $\delta^{13}C$ values that would suggest a concomitant decrease in the relative flux of NADW during these events. Similarly, there is no persistent correlation between millennial-scale variations in surface and deep water hydrography over the entire MIS 8–13 interval. While millennial-scale variations at the sea surface are most pronounced during glacial intervals (and the transitions toward glacial intervals), millennial-scale variations in the deep water hydrography tend to be largest during the warm periods. This observation supports that rapid changes in thermohaline circulation are sensitive to driving forces other than those directly related to ice sheet size. Time series analysis shows that spectral power in the benthic foraminiferal $\delta^{13}C$ record contains periodicities related to the second (~10 kyr) and fourth harmonics (~5 kyr) of precession in this record (~20 kyr) pointing to the importance of tropical processes.

1. Introduction

Two main mechanisms have been proposed to explain millennial-scale changes in thermohaline overturn. During intervals of glaciations high latitude ice sheets, and in particular their meltwater, affect millennial-scale fluctuations in deep water circulation (e.g., MacAyeal, 1993; Oppo and Lehman, 1995; Mayewski et al., 1997; Schulz et al., 1999; Benway et al., 2010). Broecker et al. (1990) were the first to propose a model relating millennial-scale climate fluctuations observed in Greenland ice core records to thermohaline circulation. McManus et al. (1999), however, observe that in the subpolar North Atlantic, millennial-scale deep water proxy variations persist through interglacial intervals suggesting that other processes are important controls on deep water formation on this scale. Low latitude surface water hydrographic variations may be important controls on meridional overturning via poleward heat transport in surface current and subsequent deep water formation (Boyle and Keigwin, 1987; Vidal et al., 1997; Chapman and Shackleton, 1998; Rühlemann et al., 1999; Hagen and Keigwin, 2002; Healey and Thunell, 2004; Schmidt et al., 2006; Benway et al., 2010). A recent study finds correlation between high frequency surface and deep water variations in the North Atlantic and tropical insolation forcing illustrating the importance of tropical forcing on meridional overturning circulation during mid Pleistocene glacial and interglacial stages (Ferretti et al., 2010).

Millennial-scale climate variability during Pleistocene interglacial intervals has been studied extensively because of the potential to provide analogs for Holocene climate stability. Among these, Marine Isotope Stage (MIS) 11 has received much attention because insolation forcing, in particular low eccentricity values, is similar to insolation forcing of the Holocene (Bauch et al., 2000; Hodell et al., 2000; Droxler et al., 2003; Dickson et al., 2009). Numerous studies have illustrated that MIS 11 climate was relatively stable at high latitudes (Oppo et al., 1998; McManus et al., 1999, 2004). However, relatively large instabilities, or cold events, characterize this

* Corresponding author. Tel.: +1 302 645 4249.
E-mail address: kbillups@udel.edu (K. Billups).

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interval of warmth in the subtropical Atlantic where these events can be related to changes in deep water circulation (Billups et al., 2004).

MIS 9 has received far less targeted attention from the paleoceanographic community although some argue that it is a better analog for Holocene insolation forcing than MIS 11 (Ruddiman, 2007). The analogy arises because the amplitude of the insolation minimum is similar between these two interglacial periods due to the relative phasing of obliquity and precession (Ruddiman, 2007). There are millennial-scale records that span MIS 9 in the Atlantic Ocean (e.g., McManus et al., 1999; Helmke and Bauch, 2003; Voelker et al., 2010; in press), but few studies have concentrated on MIS 9 climate *per se*. High resolution studies of MIS 9 have focused on depositional changes in the subtropical Atlantic (Franz and Tiedemann, 2002) and vegetation changes in southwestern Europe (Desprat et al., 2008). Thus far, no studies have addressed millennial-scale changes in subtropical Atlantic surface water hydrography or deep water circulation during MIS 9.

We reconstruct millennial-scale changes in meridional overturning circulation in the northwestern subtropical Atlantic with a specific focus on interglacial/glacial events of MIS 9 and 8 (334–260 Ka) and then take a broader view on late Pleistocene glacial and interglacial stages (MIS 13–8; 500–260 Ka). A depth transect of sites was drilled during Ocean Drilling Program (ODP) Leg 172 in the sediment drift along the Blake Bahama Outer Ridge (BBOR) and the Bahama Bank (Fig. 1) designed to reconstruct suborbital climate variability in the northwestern subtropical Atlantic (Keigwin et al., 1998). We generate new planktic and benthic stable isotope data for two of these sites, Site 1056 and 1063, in order to reconstruct variations in surface and deep water hydrography, respectively. We hypothesize that a correlation between surface and deep water records in the subtropical Atlantic on the millennial-scale supports a link between poleward heat transport in the surface ocean and high latitude deep water formation (e.g., Oppo et al., 2001; Keigwin and Jones, 1994). Planktic and benthic foraminiferal stable isotope records at these sites have been published for MIS 10–13, and we put together a composite that encompasses two full interglacial (MIS 11 and MIS 9) and two full glacial intervals (MIS 12 and 10). The length of this record (250 kyr) allows statistical tests for the presence or absence of significant concentration of power at millennial-scale periodicities through time.

Table 1
Summary of site locations and references for data sources.

Site	Long/Lat (°)	Water Depth	MIS[a]	Type[b]	Reference
1056	76W/32N	2167 m	8–10.2	PF	This study
			10–12	PF	Billups et al. (2004)
			8–10.2	BF	Franz and Tiedemann (2002)
			10–13	BF	Chaisson et al. (2002)
1063	58W/34N	4583 m	8–10.2	BF	This study
			10–13	BF	Poli et al. (2000)
1058	75W/32N	2984 m	12–13	PF	Billups et al. (2006)
980	15W/55N	2179 m	8–13	BF	McManus et al. (1999)
U1308	24W/50N	3872 n	8–13	BF	Hodell et al. (2008)

[a] MIS stands for Marine Isotope Stage.
[b] Type refers to benthic foraminifera (BF) or planktic foraminifera (PF).

2. Approach

2.1. Hydrographic setting

The northwestern subtropical Atlantic is an ideal region to study the relative stability of surface and deep ocean hydrography because its role in meridional overturning circulation. ODP Site 1056, the focus of our surface hydrographic reconstructions, was drilled on BBOR at about 32°N, 76°W (~2200 m water depth, Table 1), underlying the warm waters of the northwestern limb of the subtropical gyre, close to the northern boundary of the Gulf Stream (e.g., Fig. 1). The Gulf Stream is a major component of the North Atlantic climate system and thermohaline overturn (Schmitz and McCartney, 1993). It transports warm surface water to high northern latitudes and contributes to North Atlantic warm anomalies of up to ~10 °C (Rahmstorf, 2002). Winter time cooling of the relatively warm surface, as well as seasonal sea ice and associated brine formation, contribute to deep convection and deep water mass formation in the subpolar gyres of the North Atlantic (North Atlantic Deep water, NADW e.g., Pickard and Emery, 1990). The deep water masses then flow southward. In the deep equatorial Atlantic, NADW and Antarctic Bottom Waters (AABW) meet and mix in proportions relative to the strength of their formation at the source areas. Site 1063 (34°N, 58°W, ~4600 m water depth, Table 1), the focus of the deep water mass reconstructions, lies close to the modern day mixing zone of NADW with AABW

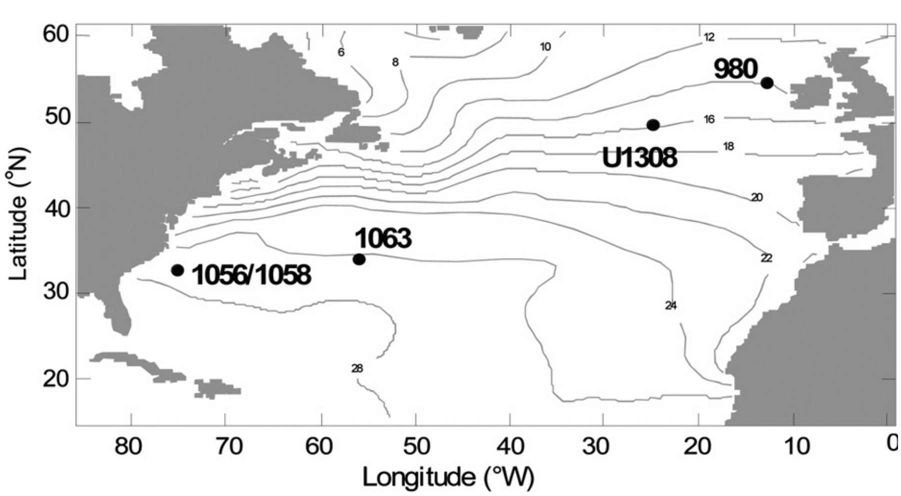

Fig. 1. Location of Sites 1056 (32°N, 76°W, 2167 m) and 1063 (34°N, 58°W, 4583 m) with respect to average late summer sea surface temperatures (Levitus and Boyer, 1994). Also shown are the location of Sites 980 (55°N, 14°W, 2179 m) and U1308 (50°N, 24°W, 3872 m), which are important monitors of the $\delta^{13}C$ of dissolved inorganic carbon in deep water. The figure was generated using the interactive web site of the Lamont Doherty Geological Observatory.