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The role of the northward-directed (sub)surface limb of the Atlantic Meridional Overturning Circulation during the 8.2 ka Event

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Abstract

The so-called "8.2 ka Event" has been widely regarded as a major climate perturbation over the Holocene. It is most readily identifiable in the oxygen-isotope records from Greenland ice cores as an approximately 160 yr-long cold interval between 8250–8090 yr BP. The prevailing view has been that the cooling over Greenland, and potentially over the northern North Atlantic at least, was triggered by the catastrophic final drainage of the Agassiz-Ojibway proglacial lake as part of the remnant Laurentide Ice Sheet collapsed over Hudson Bay at around 8420 ± 80 yr BP. The consequent freshening of surface waters in the northern North Atlantic Ocean and the Nordic Seas resulted in weaker overturning, hence reduced northward heat transport. Here we present proxy records from site JM97-MD95-2011 on the mid-Norwegian Margin indicating a (sharp) decline in the strength of the eastern branch of the Atlantic Inflow into the Nordic Seas immediately *following* a uniquely large drop in (sub)surface ocean temperatures coeval with the lake outbursts. We propose that the final drainage of Lake Agassiz-Ojibway was accompanied by a major iceberg discharge from Hudson Bay, which resulted in the cooling of the northward-directed northern Gulf Stream-North Atlantic Drift-Norwegian Atlantic Current system. Since our current-strength proxy records from the mid-Norwegian Margin do *not* evidence an exceptionally strong reduction in the main branch of the Atlantic Inflow into the Nordic Seas at the time, we argue that a chilled northward-directed (sub)surface-current system and an already colder background climate state could be the main factors responsible for the 8.2 ka climate perturbation.

1 Introduction

The so-called "8.2 ka Event" has been widely regarded as a major climate perturbation over the Holocene. It is most readily identifiable in the oxygen-isotope records ($\delta^{18}O_{ICE}$) from Greenland ice cores (Fig. 1a and b) as an approximately 160 yr-long cold interval, which started abruptly at approximately 8250 ± 49 yr BP and ended similarly abruptly (NGRIP1, DYE-3) or somewhat more gradually (GRIP) at around 8090 ± 45 yr BP (Rasmussen et al., 2006, 2007). The corresponding dates in the GISP2 ice core are 8296 ± 166 yr BP and 8136 ± 163 yr BP, respectively (Grootes and Stuiver, 1997; Grootes et al., 1993; Meese et al., 1994; Steig et al., 1994; Stuiver et al., 1995).

The prevailing view has been that the cooling over Greenland, and potentially over the northern North Atlantic at least (Fig. 1a), was triggered by the catastrophic final drainage of the Agassiz-Ojibway meltwater lake as part of the remnant Laurentide Ice Sheet (LIS) collapsed over Hudson Bay (8470 yr BP, $\pm 1\sigma$ error range: 8740–8160 yr BP, Barber et al., 1999; 8420 yr BP, $\pm 1\sigma$ error range: 8500–8340 yr BP, Hillaire-Marcel et al., 2007; Fig. 1a and b). This unleashed approximately 163 000–200 000 km^3 of freshwater in probably two phases (Barber et al., 1999; Teller et al., 2002) into the Labrador Sea and the northern North Atlantic Ocean (Fig. 1a and b) bringing about an abrupt slowing down of the Atlantic Meridional Overturning Circulation (AMOC), which had been dominating heat advection to high northern latitudes since the beginning of the Holocene (Risebrobakken et al., 2003c; Thomsen and Vorren, 1986).

Here we present new palaeoceanographic data, which show that while the eastern branch of the Atlantic Inflow into the Nordic Seas did weaken at the time, the advection of chilled waters towards high northern latitudes, due to a possible iceberg discharge from Hudson Bay (Fig. 1a and b), and an already colder background climate state (Rohling and Pälike, 2005) could be the main factors responsible for the 8.2 ka climate perturbation.

2 Methods

Our interest in the strength of the eastern branch of the Atlantic Inflow (Fig. 1a) stems from the fact that at least in modern times it seems to be the main conduit for advected heat towards the Arctic (Orvik and Skagseth, 2003) and there is evidence for its existence from the beginning of the Holocene (Holtedahl, 1981; Risebrobakken et al.,

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2003c; Thomsen and Vorren, 1986; Vorren et al., 1984). Therefore, it must have played a key role in any AMOC-induced climate change.

Our choice of proxy is sortable silt, for the mean grain size of the 10–63 µm terrigenous silt fraction (i.e. sortable silt) is thought to vary independently of sediment supply in current-sorted and deposited muds, with larger values representing relatively greater near-bottom flow speeds (McCave and Hall, 2006; McCave et al., 1995). At present sortable silt offers only a qualitative record of the depositing current. It indicates when the flow might have been stronger or weaker, but it does not tell us anything about the magnitude of the changes in absolute terms. Yet, it can still provide invaluable insights into the behaviour of the eastern branch of the Norwegian Atlantic Current (NwAC, Fig. 1a) preceding the "8.2 ka Event."

IMAGES piston core MD95-2011 and box core JM97-948/2A (66°58.19′ N, 07°38.36′ E, water depth: 1048 m, Fig. 1b) were extracted from a Holocene high-accumulation area (HA) along the flow path of the eastern NwAC (Fig. 1a) at the Vøring Plateau on the mid-Norwegian Margin. Although the current has most probably not been in direct contact with the HA, we think that it has indirectly influenced sedimentation there and that past changes in its strength have been preserved by these deposits (Tegzes, 2013; Tegzes et al., 2014a).

The split cores were sampled at 1 cm intervals. Bulk samples were wet-sieved to separate the fine ($d < 63$ µm) from the coarse fraction ($d > 63$ µm). The dried and disaggregated fine fractions were subsampled and, in order to remove the biogenic component (McCave and Hall, 2006), were de-carbonated and de-silicated, using 1 M acetic acid and 2 M sodium carbonate solution, respectively. The de-carbonated and de-silicated fine fractions were stored in 0.02 M sodium polyphosphate solution in a cold room until measurement. They were then disaggregated, further subsampled and run on a Beckman Coulter® Multisizer™ 3, fitted with a 140 µm aperture tube, using Beckman Coulter ISOTON® II diluent. They were measured several times, each time in a different random order, at a concentration of 5–10 % and a stirrer speed of 40. The target size range was

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set to 10–63 µm, excluding the fine-silt and clay component (McCave and Hall, 2006; McCave et al., 1995).

The age-depth model was constructed using mixed-effect regression, which relies on the mid-point estimates of the calibrated ages (Heegaard et al., 2005). The two cores were treated independently. The age control for JM97-948/2A is based on nine ^{210}Pb and two Accelerator Mass Spectrometry (AMS) ^{14}C dates (Andersson et al., 2003); and it represents the last 582 yr. The age model for MD95-2011 rests on twenty-nine AMS ^{14}C dates and the presence of the Vedde ash layer (Berner et al., 2011; Dreger, 1999; Grönvold et al., 1995; Risebrobakken et al., 2011, 2003c); and covers the rest of the Holocene.

We present two alternative time series based on exactly the same set of measurements (Fig. 2). The traditionally used sortable-silt index is an arithmetic average computed from the *differential volume* distribution of grains within a sample; while true mean grain size is the arithmetic average calculated from the *differential number* distribution of grains within a sample. We are inclined to think that true mean grain size is less prone to random effects and better reflects changes in prevailing current conditions than the sortable-silt index (Tegzes, 2013; Tegzes et al., 2014b). Although the focus of the present study is the "8.2 ka Event," considering the qualitative nature of sortable-silt records, in order to put the magnitude of current-strength changes at the time into a context we have also included the Late-Holocene sections of these time series for reference (Tegzes, 2013; Tegzes et al., 2014a).

3 The weakening of the eastern NwAC concomitant with the lake outbursts

While the sortable-silt index from JM97-MD95-2011 (Vøring Plateau, mid-Norwegian Margin, Fig. 1b) shows a remarkably clear and abrupt drop between 8481–8447 yr BP (±1σ error range: 8725–8204 yr BP, Fig. 2), true mean grain size values exhibit a more gradual decline, reaching a minimum at 8269 yr BP (±1σ error range: 8445–8093 yr BP, Fig. 2). Not only is the pattern of change different, but also its relative amplitude. It is even more curious that the Late-Holocene segments of the respective records indicate comparable (sortable-silt index) or much larger (mean grain size) fluctuations in current strength (Fig. 2). Considering the above there exists the possibility that the change in ocean circulation preceding the "8.2 ka Event" might not have been uniquely dramatic in the context of post-deglacial conditions.

Nonetheless, both time series suggest that the eastern NwAC must have been overall weaker in the Early Holocene than the Late Holocene and that it recovered much slower following the collapse of the ice dam over Hudson Bay than after much larger slowdowns over the past 4200 yr (Fig. 2). Whether this was due to the initial instability of the current in the Early Holocene or the nature of the forcing is difficult to tell.

We will first focus on the traditionally used sortable-silt-index time series and its relationship to other records from the same core.

4 The relative timing of events at the Vøring Plateau

Of the planktic foraminiferan species *Neogloboquadrina pachyderma* has been analysed for oxygen isotopes (Risebrobakken et al., 2011, 2003c), but only its sinistral (deep-dwelling) morphotype record ($\delta^{18}O_{NPS}$) shows a uniquely large abrupt positive excursion with respect to the entire Holocene within the interval of interest (Fig. 4b and c). This variant calcifies earlier in the season than its dextral morphotype and likely records winter-time or at least mean annual conditions (Andersson et al., 2010). We think that due to its depth habitat and reproductive season *N. pachyderma* sinistral is probably more sensitive to changes in the core temperatures of the eastern NwAC.

JM97-MD95-2011 (Vøring Plateau, mid-Norwegian Margin, Fig. 1b) has been referenced in several papers (e.g. LeGrande and Schmidt, 2008; LeGrande et al., 2006; Rohling and Pälike, 2005) as one of the few "North-Atlantic" *marine* cores that actually recorded the "8.2 ka Event." However, it is important to note the timing of this sharp and short-lived positive excursion in $\delta^{18}O_{NPS}$ (between 8516 and 8412 yr BP, $\pm 1\sigma$ error range: 8760–8182 yr BP, Fig. 3e). Firstly, it better corresponds with the best estimates for the timing of the final drainage of Lake Agassiz-Ojibway [8470 yr BP, $\pm 1\sigma$ error range: 8740–8160 yr BP (Barber et al., 1999); and 8420 yr BP, $\pm 1\sigma$ error range: 8500–8340 yr BP (Hillaire-Marcel et al., 2007); Fig. 3a] than the cooling as recorded in Greenland ice (between 8250 ± 49 and 8090 ± 45 yr BP, Rasmussen et al., 2006, 2007, Fig. 3i).

More importantly, the sortable-silt index from the same core (i.e. we cannot invoke age-model uncertainties) shows an abrupt drop *succeeding* the sharp increase in $\delta^{18}O_{NPS}$ (Fig. 3e). Therefore, at least initially, the latter cannot indicate surface cooling triggered by the slowing down of the current. Moreover, while it takes about a millennium for the current-strength proxy to recover, oxygen-isotope values need less than a century.

The record of the relative abundance of *N. pachyderma* sinistral in the core has lower resolution over the interval of interest, thus we do not know whether it would show a short-lived anomaly around 8200 yr BP (Fig. 3d). Nonetheless, it seems that the $\delta^{18}O_{NPS}$ spike coincides with a somewhat broader maximum in the relative abundance of *N. pachyderma* sinistral (Fig. 3d and e). However, this is not unique with respect to the Holocene (Fig. 4a). Hence, the question remains what the sharp but transient increase in $\delta^{18}O_{NPS}$ values could represent.

5 The possibility of re-sedimentation

Rumohr et al. (2001) found evidence for older allochthonous specimens of *N. pachyderma* sinistral in *deglacial* deposits at the peripheral parts of the HA. They were not able to correlate short-term oxygen-isotope signatures in adjacent cores tens of kilometres apart and what they considered anomalous values closely related to increased sand content.

The $\delta^{18}O_{NPS}$ spike in MD95-2011 (Fig. 4b) (Risebrobakken et al., 2011, 2003c) does coincide with a uniquely large positive excursion in the weight percent of the coarse fraction ($d > 63$ µm; Fig. 4e and f) (Moros et al., 2004). The maximum in the

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weight percent of grains larger than 150 µm (Fig. 4f) is due to an abrupt increase in both the ice-rafted debris (IRD, Fig. 4g) and *N. pachyderma* sinistral (Fig. 4h) *and* dextral (Fig. 4i) content of the sediment (B. Risebrobakken, personal communication, 2012; Risebrobakken et al., 2003c). Peak values in IRD count (B. Risebrobakken, personal communication, 2012) are comparable to those in deposits of Last Glacial Maximum (LGM) age at a nearby site (MD95-2010, Vøring Plateau, mid-Norwegian Margin) (Dokken and Jansen, 1999). This could all be indicative of re-working at the HA.

Nevertheless, the sortable-silt index, which is the volume-percent-weighted arithmetic average of the 10–63 µm terrigenous silt fraction, does not show a significant increase coincident with the coarse fraction, only a marked drop 1 cm up in the core (Fig. 4k). We would assume that if some process had transported allochthonous foraminiferans and coarser grains to our site, it would also have rendered the sortable-silt fraction much coarser. Since the two grain-size categories do not exhibit the same trend they must have been influenced by independent processes such as changes in the strength of the eastern NwAC (Fig. 1a) and ice rafting, as originally proposed by Moros et al. (2004), and the $\delta^{18}O_{NPS}$ spike (Fig. 4b) should therefore represent a climate signal.

6 The lake-outburst theory

Model simulations can systematically reproduce a major reduction in the AMOC by injecting freshwater either into Hudson Bay or the Labrador Sea (Fig. 1a) (e.g. LeGrande et al., 2006; Renssen et al., 2001). However, most experiments are initialised from a state where similarly to the present there is intermediate water formation in the Labrador Sea (for an exception see LeGrande and Schmidt, 2008). Yet, winter convection was unlikely to have occurred there before 7000 yr BP (Hillaire-Marcel et al., 2007). This means that if the final drainage of the proglacial lake did cause the AMOC to slow down the floodwater pool had to survive the journey in the northern Gulf Stream-North Atlantic Drift-Norwegian Atlantic Current system (Fig. 1a) to the high-latitude

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deep-convection sites in the Nordic Seas (Fig. 1a) without being diluted, by mixing with ambient waters, to the extent that it could no longer affect the overturning circulation.

While most studies focus on the meltwater contained by Lake Agassiz-Ojibway (Fig. 1b), according to Barber et al. (1999) more than 50 % of the 500 000 km^3 of freshwater displaced around the time of the lake outbursts had been locked up in the ice dam over Hudson Bay (Fig. 1a and b). According to Dyke et al. (2004) the incursion of the Tyrrell Sea into southern Hudson Bay following the second drainage event was virtually instantaneous. Therefore, there exists the possibility that the ice dam did not simply melt away, but physically disintegrated concomitant with the lake outbursts and potentially large amounts of ice were exported via Hudson Strait and transported in the Labrador Current into the northern North Atlantic Ocean (Fig. 1a and b). This could have relevance not only to the nature (icebergs vs. floodwaters) and magnitude, but also to the temporal evolution of the freshwater forcing as the ice could not have left Hudson Strait as rapidly as the meltwater from the lake (Fig. 1a and b) (Barber et al., 1999). In addition, if routed into the northern Gulf Stream-North Atlantic Drift system (Fig. 1a), icebergs could ensure that the freshwater discharge survived further north as a concentrated pool, making it more likely that it could affect the high-latitude deep-convection sites.

7 Evidence for increased ice rafting off Newfoundland around 8500 yr BP

According to Bond et al. (2001) the percentages of certain lithic grain species, namely of hematite-stained grains (HGS), fresh Icelandic volcanic glass (IG), and detrital carbonate (DC), in the 63–150 µm size fraction of marine sediments in the northern North Atlantic are particularly sensitive indicators of the amounts and trajectories of glacial ice and/or sea ice circulating in surface waters. Such records from sediment cores VM28-14 (Denmark Strait, Fig. 1b), MC52-VM29-191 (Rockall Trough, off Ireland, Figs. 1b and 5) and MC21-GGC22 (off Newfoundland, Figs. 1b and 5) evidence

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quasi-synchronous multi-centennial fluctuations in drift ice across the region (Bond et al., 2001).

The large detrital-carbonate peak in MC21-GGC22 (44°18′ N, 46°16′ W, water depth: 3958 m, Fig. 1b, Fig. 5) at around 8500 ± 105 (±1σ) yr BP (the closest dated horizon in the core), however, breaks this pattern. We propose that this represents an interval of increased ice rafting from Hudson Bay (Fig. 1a and b). The question is: could these icebergs drift towards the Nordic Seas (Fig. 1a) and affect the deep-convection sites there?

In a modern-day context site MC21-GGC22 is located east of the Newfoundland Shelf in the deep ocean right below the flow path of the northern Gulf Stream (Fig. 1a and b). In addition, the prominent peak in the detrital-carbonate record from this location falls within dating uncertainties of the $\delta^{18}O_{NPS}$ spike in JM97-MD95-2011 (Vøring Plateau, mid-Norwegian Margin, Figs. 1b, 3b and e). This could be indicative that as the ice dam over Hudson Bay was disintegrating the icebergs discharged were at least partly routed into the northern Gulf Stream-North Atlantic Current-Norwegian Atlantic Current system (Fig. 1a and b). As they drifted north they not only freshened but also significantly cooled (sub)surface waters (Wiersma and Jongma, 2010).

As we have noted already in a different context the dry-weight percent of the coarse fraction in JM97-MD95-2011 (Fig. 1b) (Moros et al., 2004; M. Moros, personal communication, 2012) shows a unique, strikingly large maximum in perfect synchroneity with $\delta^{18}O_{NPS}$, meaning that it also increases sharply *preceding* the abrupt drop in the sortable-silt index (Fig. 3c and e). X-ray diffractometry-based estimates of the quartz/plagioclase ratio (Moros et al., 2004) and IRD counts in the > 150 µm size fraction (B. Risebrobakken, personal communication, 2012) confirm that the abrupt coarsening of the sediment reflects an interval of increased ice rafting around 8481 yr BP (±1σ error range: 8725–8238 yr BP). As yet no provenance studies are available for JM97-MD95-2011, thus we cannot establish the possible source of this event. However, it is unlikely that the icebergs originating from Hudson Bay (Fig. 1a and b) could survive that far north. Therefore, the ice-rafting event that did leave a trace in sediments

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on the mid-Norwegian Margin (Fig. 3c) must have had a more local source. Nevertheless, it could still be a consequence of the advection of colder waters to high northern latitudes.

A colder Atlantic Inflow (Fig. 1a) could *initially* significantly reduce the temperature gradient across the Nordic Seas (Fig. 1a) thus weakening the local anticyclonic atmospheric circulation pattern centred on Greenland. This could result in a less directional southward transport of icebergs from the Arctic through the Fram Strait in the East Greenland Current (EGC, Fig. 1a), which could thus more easily drift into the eastern Nordic Seas (Fig. 1a). A colder NwAC (Fig. 1a) could ensure a greater survival rate of icebergs further south. However, as explained below, as the permanent ice cover started extending southeastwards in the western Nordic Seas and as the iceberg discharge from Hudson Bay ceased the trend in atmospheric circulation around Greenland was reversed and the icebergs originating from the Arctic and the western Nordic Seas no longer affected the mid-Norwegian Margin. This could also explain the coincidence of the $\delta^{18}O_{NPS}$ spike with the maximum in the coarse fraction of the sediment in JM97-MD95-2011 (Fig. 3c and e).

8 The double-pulse nature of (sub)surface-ocean cooling

We have argued, based on existing chronology, that the prominent spike in the foraminiferan oxygen-isotope time series from our site is likely not the cold event recorded in Greenland ice. $\delta^{18}O_{NPS}$ values from JM97-MD95-2011 do show a second positive excursion (8269–8198 yr BP, $\pm 1\sigma$ error range: 8445–8029 yr BP) immediately following the minimum in mean grain size (Fig. 3f). However, since this second spike does not exceed noise level in the oxygen-isotope record, it is defined by only a single data point and we cannot back it up with a synchronous increase in the relative abundance of *N. pachyderma* sinistral because of an unfortunate gap in that time series (Fig. 3d), we cannot attribute any significance to this second positive excursion in $\delta^{18}O_{NPS}$.

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Nevertheless, Ellison et al. (2006b) identified two uniquely large, closely-paced (sub)surface ocean cooling events in the Early-Holocene part of their foraminiferan abundance record (Fig. 3h) from site MD99-2251 (Gardar Drift, Fig. 1b) in the subpolar North Atlantic. The first of these coincides within dating uncertainties with the lake outbursts (Fig. 3a) and peak iceberg discharge (Fig. 3b) accompanying the collapse of the ice dam over Hudson Bay, similarly to the cooling recorded in the oxygen-isotope composition of *N. pachyderma* sinistral in JM97-MD95-2011 (Vøring Plateau, mid-Norwegian Margin, Fig. 3f). The second (sub)surface ocean cooling event at site MD99-2251 (Gardar Drift, Fig. 3h) appears to be significantly younger (Hillaire-Marcel et al., 2007), and better corresponds with the cooling over Greenland (Fig. 3i). Therefore, we propose that the first positive excursion in the relative abundance of *N. pachyderma* (sinistral) in MD99-2251 reflects only the initial change in upper-ocean conditions, which led to or at least played a role in the subsequent climate perturbation, while the second maximum reflects the climate perturbation itself.

Estimates of coeval seawater oxygen-isotope compositions ($\delta^{18}O_{SEAWATER}$, Fig. 3g) (Ellison et al., 2006b) suggest that in both cases upper-ocean cooling was accompanied by surface-water freshening at site MD99-2251 (Fig. 1b). The combined impact of floodwaters and melting icebergs originating from Hudson Bay (Fig. 1a and b) could easily explain the first minimum in $\delta^{18}O_{SEAWATER}$. Although it is highly speculative, concomitant with colder climate conditions, a potentially more southerly permanent sea-ice extent and changed atmospheric circulation patterns, increased Arctic drift-ice export into the subpolar North Atlantic (Bond et al., 2001) could account for the second surface-water freshening event.

Kleiven et al. (2008) found that applying a marine reservoir age correction of zero ($\Delta R = 0$) throughout the interval of interest when calibrating radiocarbon dates from sediment core MD03-2665 (Eirik Drift, Fig. 1b) from the Labrador Sea south of the tip of Greenland led to reversals in their age model coincident with pronounced maxima in planktonic $\delta^{18}O_{NPS}$ values (not shown). They attributed this to an increased influence of the East Greenland Current (EGC, Fig. 1a and b) at their site coeval with the second surface-water freshening event at site MD99-2251 (Gardar Drift, Fig. 1b). Stronger northerly winds could spread drift ice into the subpolar North Atlantic, which could both further cool (in addition to a general decrease in surface temperatures) and freshen the Subpolar Gyre (SPG). However, there exist no palaeo-salinity time series from MD03-2665 to confirm this.

Contrary to the unequivocal uniqueness of the twin-maxima in the relative abundance of *N. pachyderma* sinistral in MD99-2251 (Fig. 3h) the significance of the second $\delta^{18}O_{SEAWATER}$ minimum in particular is more difficult to judge due to the limited length of the published record (Fig. 3g) (Ellison et al., 2006b). While the decrease in $\delta^{18}O_{SEAWATER}$ values coincident with the first abrupt increase in the relative abundance of *N. pachyderma* sinistral is 0.75 ‰, it is "only" 0.41 ‰ concomitant with the second sharp positive excursion in the temperature proxy. It is also more difficult to pinpoint the start of the second event in the oxygen-isotope record (Fig. 3g). Hence, it could be less significant.

9 Concluding remarks

We propose that the final drainage of Lake Agassiz-Ojibway was accompanied by a major iceberg discharge from Hudson Bay (Bond et al., 2001), which resulted in the cooling of the northward-directed northern Gulf Stream-North Atlantic Drift-Norwegian Atlantic Current system. Since our current-strength proxy records from the mid-Norwegian Margin do *not* evidence an exceptionally strong reduction in the main branch of the Atlantic Inflow into the Nordic Seas at the time, we argue that a chilled northward-directed (sub)surface-current system could ultimately be responsible for the 8.2 ka climate perturbation. It could contribute to the thickening and expansion of Arctic sea ice, leading to a faster increase in surface albedo and a more effective insulation of the ocean from the atmosphere. Furthermore, the colder initial background climate state (Rohling and Pälike, 2005) could have primed the high-latitude ocean prior to the

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event. With surface waters already closer to their freezing point a colder Atlantic Inflow could more easily trigger widespread sea-ice growth.

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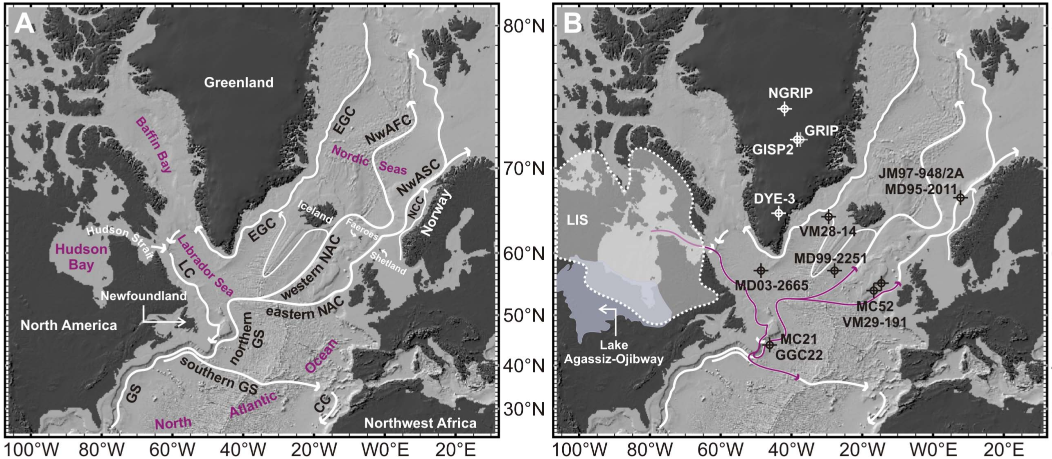

Fig. 1. (A) The modern (sub)surface-current system in the northern North Atlantic Ocean and the Nordic Seas (Orvik and Niiler, 2002). CC = Canary Current; GS = Gulf Stream; NAC = North Atlantic Current (or North Atlantic Drift); the two main branches of the Atlantic Inflow into the Nordic Seas (or the Norwegian Atlantic Current): the NwASC = Norwegian Atlantic Slope Current (i.e. the eastern NwAC) and the NwAFC = Norwegian Atlantic Frontal Current (i.e. the western NwAC); NCC = Norwegian Coastal Current; ECG = East Greenland Current; LC = Labrador Current. The basemap (identical in Fig. 1a and b) was generated by GeoMapApp© 3.3.0 (Ryan et al., 2009). **(B)** Core sites mentioned in the text in relation to the modern (sub)surface-current system in the northern North Atlantic Ocean and the Nordic Seas (same as in Fig. 1a to the left) (Orvik and Niiler, 2002). The purple arrows indicate the possible trajectories of floodwaters and icebergs from Hudson Bay. LIS = Laurentide Ice Sheet (marked by the dashed white line). Lake Agassiz-Ojibway is also shown (Teller et al., 2002).

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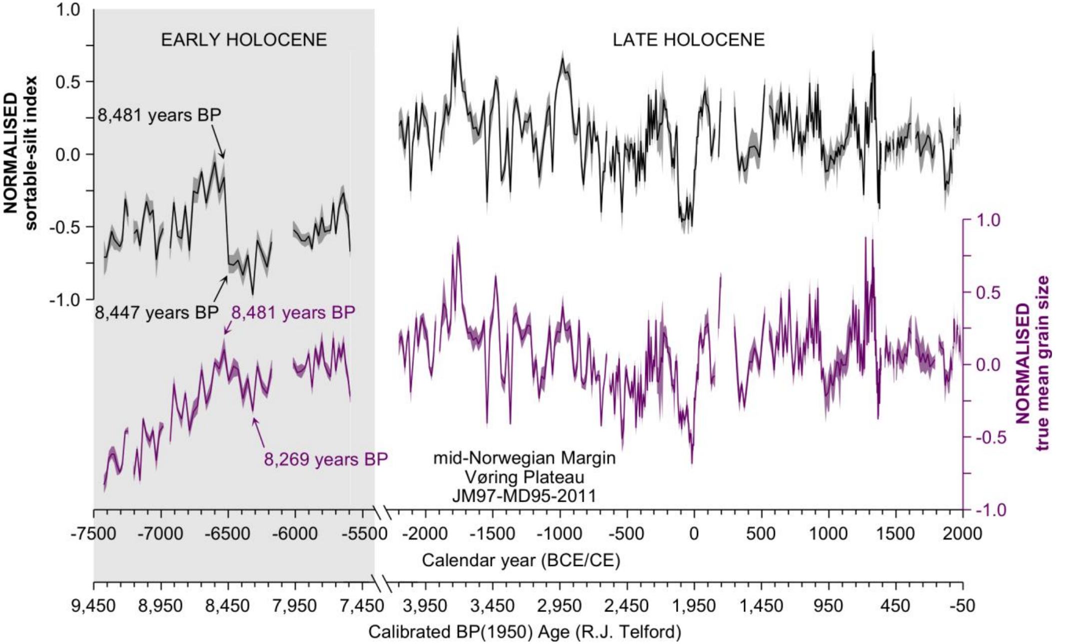

Fig. 2. The two alternative sortable-silt time series from JM97-MD95-2011 (Vøring Plateau, mid-Norwegian Margin). They have been normalised for easier comparison. The shaded envelopes indicate the spread of values resulting from repeated measurements. The mean $\pm 1\sigma$ error in the age model is ±128 yr over the Late Holocene and ±201 yr over the Early Holocene.

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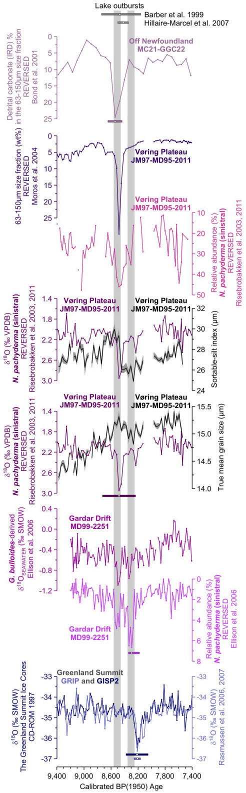

Fig. 3. The possible sequence of events following the collapse of the ice dam over Hudson Bay. **(A)** Lake outbursts (Barber et al., 1999; Hillaire-Marcel et al., 2007); **(B)** ice rafting off Newfoundland (Bond et al., 2008); **(C)** ice rafting at the mid-Norwegian Margin (unknown source) (M. Moros, personal communication, 2012); **(D)** the broader (climate) anomaly with maximum (sub)surface ocean cooling at 8481 ± 201 yr BP at the mid-Norwegian Margin (Risebrobakken et al., 2003a, b); **(E)** the unique, abrupt (sub)surface-ocean cooling event at 8481 ± 201 yr BP at the mid-Norwegian Margin (Risebrobakken et al., 2003e) and the slowing down of the eastern NwAC as suggested by changes in the *sortable-silt index*; **(F)** the unique, abrupt (sub)surface-ocean cooling event at 8481 ± 201 yr BP at the mid-Norwegian Margin (Risebrobakken et al., 2003e) and the slowing down of the eastern NwAC as suggested by variations in *true mean grain size*; **(G)** the twin surface-ocean freshening events at Gardar Drift in the subpolar North Atlantic (Ellison et al., 2006a); **(H)** the unique twin (sub)surface-ocean cooling events at Gardar Drift in the subpolar North Atlantic (Ellison et al., 2006a); **(I)** cooling over Greenland (Rasmussen et al., 2006; The Greenland Summit Ice Cores CD-ROM, 1997, Data provided by the National Snow and Ice Data Centre, University of Colorado at Boulder, and the WDC-A for Paleoclimatology, National Geophysical Data Centre, Boulder, Colorado).The horizontal bars below the records denote the ±1σ error in the respective age models. The vertical grey bars highlight the unique twin (sub)surface-ocean cooling events at Gardar Drift in the subpolar North Atlantic.

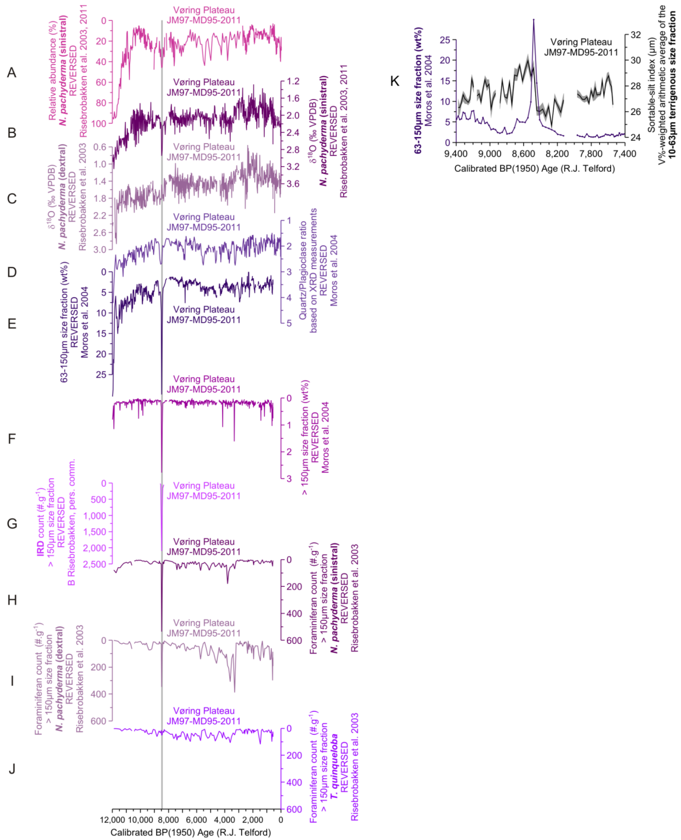

Fig. 4. The possibility of re-sedimentation at the high-accumulation area on the mid-Norwegian Margin. A comparison of various records from JM97-MD95-2011. **(A)** Relative abundance of *N. pachyderma* sinistral (Risebrobakken et al., 2003a, b). Oxygen-isotope ratios: **(B)** *N. pachyderma* sinistral (Risebrobakken et al., 2003d, e) and **(C)** *N. pachyderma* dextral (Risebrobakken et al., 2003d, e). **(D)** XRD-based quartz/plagioclase ratios (M. Moros, personal communication, 2012). Dry-weight percent of the coarse fraction (M. Moros, personal communication, 2012): **(E)** 63–150 µm size fraction and **(F)** > 150 µm size fraction. **(G)** IRD counts in samples bracketing the spike in the > 150 µm size fraction (B. Risebrobakken, personal communication, 2012). Foraminiferan counts in the > 150 µm size fraction (Risebrobakken et al., 2003b): **(H)** *N. pachyderma* sinistral, **(I)** *N. pachyderma* dextral and **(J)** *T. quinqueloba*. **(K)** A comparison of changes in the sortable-silt index (representing the coarseness of the fine fraction, 10–63 µm) and the dry-weight percent of the 63–150 µm size fraction.

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The role of the NwASC during the 8.2 ka Event

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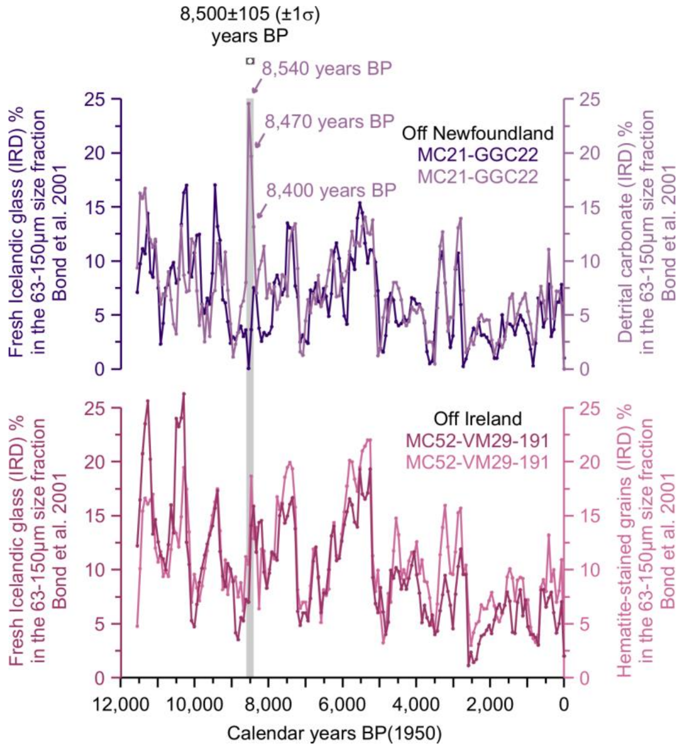

Fig. 5. The unique maximum in drift ice off Newfoundland around 8500±105 yr BP. Bottom: percentages of hematite-stained grains and fresh Icelandic volcanic glass in the 63–150 µm size fraction of sediment cores MC52-VM29–191 (Rockall Trough, off Ireland). Top: percentages of detrital carbonate and fresh Icelandic volcanic glass in the 63–150 µm size fraction of sediment cores MC21-GGC22 (off Newfoundland). Note the prominent maximum in the detrital carbonate record, while the percentages of fresh Icelandic volcanic glass drop to zero around 8500 ± 105 yr BP.

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