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Title:

Nordic Seas origins of a mid-Holocene global cooling event

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Abstract

Apart from long-term changes, the Earth's climate has been punctuated by numerous short-lived events that had a tremendous influence on terrestrial and marine ecosystems. The present interglacial is a relatively warm and stable period, especially compared to the preceding glacial time. However, several prominent cooling events have been identified within the Holocene, some of them of overregional importance. Based on previously published marine records from the Nordic Seas, we describe for the first time an event centered around 6.7 ka BP. Paleoceanographic proxies along the North Atlantic Drift reveal a distinct subsurface water cooling, preceded by a stepwise increase in sea-ice cover in the eastern Fram Strait. The results indicate that the onset of deep convection in the Greenland Sea and the westward shift of the main flow of Atlantic Water allowed sea-ice advection from the Barents Sea. The increased sea-ice cover weakened the Atlantic Water advection. The perturbation of the overturning circulation in the eastern Nordic Seas had far-reaching consequences, including changes in deep-water circulation in the North Atlantic, cooling over vast areas of both hemispheres, and weakening of the East Asian monsoon. The described events show that, during a relatively warm and stable interval, a fairly local cooling can occur, and the resulting sequence of environmental changes can spread globally. Understanding the mechanisms behind events that occur within generally stable intervals is invaluable for future climate predictions.

Keywords

North Atlantic, ocean circulation, planktic foraminifera, biomarkers, abrupt changes, East Asian monsoon

Introduction

The present interglacial (Walker et al., 2009) is a relatively warm and stable interval in terms of environmental conditions, especially when compared with the preceding Pleistocene epoch (e.g., Andersen et al., 2004) marked by Dansgaard-Oeschger events, or Greenland interstadials (Dansgaard et al., 1993; Johnsen et al., 1992), and Greenland stadials bundled into Bond cycles (Bond et al., 1993) recorded both in marine and terrestrial archives. However, several prominent cooling events have been identified within the Holocene (e.g., Wanner et al., 2011; Werner et al., 2013 and references therein). Some of them were proven to be of regional or overregional importance (e.g., Bond et al., 2001; Wanner et al., 2011). Bond et al. (1997) suggested a millennial-scale cyclicity of North Atlantic cooling episodes, expressed mainly as phases of increased ice rafting in the region. However, cyclicity has later been questioned (Obrochta et al., 2012) as different dynamical processes seem to have played a major role in the particular events (Wanner et al., 2011).

Three climate oscillations were recorded in the early Holocene section of Greenland ice cores (Rasmussen et al., 2007). These include the well-known 8.2 ka event (e.g., Alley and Ágústsdóttir, 2005; Rohling and Pälike, 2005; Wiersma and Renssen, 2006), the 9.3 ka event of shorter duration but almost similar amplitude (e.g., Bond et al., 1997; McDermott et al., 2001; Von Grafenstein et al., 1999), and the Preboreal Oscillation during the Holocene's first centuries (e.g., Björck et al., 1997; van der Plicht et al., 2004). The expression of these cold relapses can also be found in marine sediment records (e.g., Bond et al., 2001; Hald et al., 2007; Sternal et al., 2014; Telesiński et al., 2018; Werner et al., 2013). Another widespread climate deterioration occurred at 2.7 ka (e.g., van Geel et al., 2000) and was most probably caused by a perturbation of the Atlantic Meridional Overturning Circulation (Hall et al., 2004; Thornalley et al., 2009), initiated by a solar irradiance anomaly (Renssen et al., 2006) and a subsequent disruption of deep convection in the Nordic Seas (Telesiński et al., 2015).

Wanner et al. (2011) identified six cold relapses that interrupted periods of more stable and warmer climate over the last 10,000 years. These events, recorded in time series of temperature and humidity/precipitation and identified at least in the extratropical area of the Northern Hemisphere, were centered around 8.2, 6.3, 4.7, 2.7, 1.55 and 0.55 ka BP, thus roughly correlating to Bond events 0-5.

In this paper, we focus on the interval between 7 and 6 ka BP, generally regarded as one of the warmest intervals of the Holocene in the Northern Hemisphere, during which substantial cooling of subsurface waters, expressed as an increase in the percentage of a polar planktic foraminiferal species *Neogloboquadrina pachyderma*, is observed in several marine sediment records along the North Atlantic Drift (NAD) in the Nordic Seas. This event, centered around 6.7 ka BP, correlates roughly with the onset of cooling trends observed in different parts of the world (e.g., Bond et al., 2001; Oppo et al., 2003; Wanner et al., 2011). Thus, we examine whether the subsurface cooling in the Nordic Seas might have acted as a trigger for a widespread cooling event.

Material and Methods

For the study, we have selected seven previously published marine sedimentary records from the eastern and northern Nordic Seas of at least multicentennial resolution. These include (Fig. 1) cores MD95-2011 (Risebrobakken et al., 2003), M17730 (Telesiński et al., 2015), M23258 (Sarnthein et al., 2003), MSM5/5-712 (Werner et al., 2013), JM10-330 (Consolaro et al., 2015), MSM5/5-723 (Müller et al., 2012) and OCE2017-GR02 (Telesiński et al., 2022). Details of the cores are given in Table 1.

As the age models of all the cores are radiocarbon-based, we recalibrated them using the Marine20 calibration curve (Heaton et al., 2020). All radiocarbon ages were calibrated using the CALIB ^{14}C age calibration software (rev. 8.1.0; Stuiver and Reimer, 1993). A regional correction of $\Delta R = -149 \pm 31$ ^{14}C years was applied for all cores except GR02. This value was calculated with the Marine Reservoir Correction database (Reimer and Reimer, 2001) and the Marine20 curve (Heaton et al., 2022, 2020) using the same whale bones samples as those used by Mangerud et al. (2006). For core GR02 no regional correction was used (Devendra et al., 2022; Telesiński et al., 2022).

It should be noted that while the four planktic foraminiferal records from the Fram Strait (GR02, MSM5/5-723, JM10-330 and MSM5/5-712) are based on the >100 µm fraction, the records from further south (M23258, M17730 and MD95-2011) are based on the >150 µm fraction, which could somewhat bias the comparison. This fact has been taken into account in the discussion. To facilitate the comparison of the records, they were smoothed using moving means of different numbers of data points, depending on their average Holocene temporal resolution (i.e., higher resolution records were averaged over a larger number of data points than the lower resolution records), to obtain an average resolution of approximately 500 years. Both raw and smoothed data are presented.

Subsurface cooling along the NAD

An increase in the relative abundance of *N. pachyderma* can be observed between ~8.5 and 8 ka BP in most of the presented records (Fig. 2). The increase in the abundance of this polar species indicates a widespread cooling of the subsurface water associated with the 8.2 ka BP event (e.g., Hald et al., 2007; Risebrobakken et al., 2003). The signal was particularly strong in the two southernmost located cores (MD95-2011 and M17730), and the subsequent return to warmer conditions lasted longer (until c. 7.6 ka BP) at these sites. In the Fram Strait, the 8.2 ka BP event was less pronounced, and already around 8 ka BP rapid warming occurred, peaking around 7.8-7.9 ka BP. This is in agreement with recent studies on the origin of the 8.2 ka BP event, indicating an increase in freshwater input into the Labrador Sea and a decrease in Atlantic Water (AW) export from the subpolar gyre into the Nordic Seas (e.g., Born and Levermann, 2010; Matero et al., 2017). As the cause of the event was located southwest of the Nordic Seas, it seems obvious that the southern part of the region was affected more than its northern part.

Shortly after the warm rebound, the relative abundance of *N. pachyderma* in the Nordic Seas started to increase again (Fig. 2) and after ~7 ka BP, a further steep increase occurred. It culminated around 6.7 ka BP, slightly earlier in the Fram Strait records than farther south. Only ~6 ka BP the *N. pachyderma* abundances decreased to levels comparable to those before 7 ka BP. In core MSM5/5-712 from the eastern Fram Strait, the cooling was twofold, with peaks centered around 6.8 and 6.2 ka BP. Originally, these were treated as two separate events (Werner et al., 2013). However, it should be noted that between the two peaks, the abundance of *N. pachyderma* remained higher than before and after them and thus the two peaks can be regarded as two phases of the same event.

Although in the southern records (MD95-2011 and M17730) the increase in *N. pachyderma abundance* was of lower amplitude than that around 8.2 ka BP, in the Fram Strait records the amplitude was greater and the event was even recorded in core GR02 from the continental slope of NE Greenland, in which the 8.2 ka BP event was absent. It should be kept in mind that the Fram Strait records are based on the >100µm fraction (Consolaro et al., 2018; Telesiński et al., 2022; Werner et al., 2015, 2013), in contrast to the >150µm fraction used in the southern cores (Risebrobakken et al., 2003; Sarnthein et al., 2003; Telesiński et al., 2015). The different size fractions might at least partly explain the difference in the amplitude of the faunal changes between the records. Subpolar species, e.g., *Turborotalita quinqueloba*, tend to reach smaller test sizes in the polar North Atlantic, so the records based on smaller fractions are more sensitive to changes in AW inflow (e.g., Kandiano and Bauch, 2002). However, this did not influence the relative differences in the amplitudes of the 6.7 ka BP event compared to the 8.2 ka BP event in individual records.

The increase in *N. pachyderma* abundance between 7 and 6 ka BP was accompanied by changes in other proxies from the presented records. Most notably, a stepwise increase of the P_BIP_{25} index in core MSM5/5-723 (Werner et al., 2015) around 7 ka BP (Fig. 3B) indicates an increase in sea-ice cover (Müller et al., 2011). In the same record, the fragmentation of planktic foraminifera increased parallel to the relative abundance of *N. pachyderma* (Fig. 3C), indicating the increased impact of cold, corrosive Arctic surface waters on the study area (Werner et al., 2015). The enhanced dissolution of planktic foraminiferal tests in the Fram Strait might also partly explain the particularly high percentages of *N. pachyderma* in this area, as thin-walled tests of subpolar species (e.g., *T. quinqueloba*) can be dissolved more easily in a corrosive environment than the thick-walled specimens of *N. pachyderma* (e.g., Ofstad et al., 2021). Both in the Fram Strait (core JM10-330) and the Norwegian Sea (cores M17730 and MD95-2011), a distinct decrease in planktic foraminiferal abundance occurred between 7 and 6 ka BP (Fig. 3D), which might also be related to the increased dissolution of foraminiferal tests. An increase in ice rafting can also be observed in the Fram Strait (core MSM5/5-712) around that time (Fig. 3E). Meanwhile, the alkenone-based reconstruction from the northern Norwegian Sea (core M23258) shows that the interval during which the subsurface cooling occurred was one of the warmest within the Holocene in terms of sea surface temperatures (Fig. 3F), in line with the September insolation at 78°N (Fig. 3A).

Causes and consequences of the 6.7 ka BP event

The middle part of the Holocene is generally considered the warmest and most stable interval. It is characterized by high summer temperatures in the mid- and high-latitude areas of the Northern Hemisphere (e.g., Alverson et al., 2003; Deevey and Flint, 1957; Nesje and Kvamme, 1991; Renssen et al., 2009; Wanner et al., 2011, 2008). Although the June insolation, which is the strongest in the Northern Hemisphere, was already in decline (Laskar et al., 2004), the July and August insolation was still quite high, while the September insolation reached its maximum only around 6 ka BP (Fig. 3A). Furthermore, large ice sheets delaying ocean warming through katabatic winds and meltwater discharge were mostly gone in the middle Holocene (e.g., Hormes et al., 2013; Seidenkrantz et al., 2012). This is well reflected in sea surface temperature (Fig. 3F; Calvo et al., 2002; Łącka et al., 2019; Martrat et al., 2003) and terrestrial records (e.g., Thompson et al., 2022) covering this interval. Depending on the region and paleoenvironmental proxies used, large discrepancies exist in the boundaries of the warmest phase of the Holocene (e.g., Kaufman et al., 2004). However, regardless of the exact timing of the middle Holocene (e.g., Renssen et al., 2009; Walker et al., 2019; Wanner et al., 2011, 2008), the interval between 7 and 6 ka BP falls within most of its definitions. Thus, this time interval can be regarded as the warmest part of the present interglacial, at least in the mid- and high-latitudes of the Northern Hemisphere. Despite this, distinct subsurface water cooling is observed along the NAD, suggesting a decrease in AW advection into the Nordic Seas.

After the 8.2 ka event, the AW inflow into the eastern Nordic Seas resumed, as shown by the decrease in the percentages of *N. pachyderma* in all the discussed records (Fig. 2). The Iceland-Scotland Overflow Water flow speed also shows a distinct increase around that time (Hall et al., 2004). This indicates an intensification of the overturning circulation in the Nordic Seas probably related to the end of the widespread meltwater discharge from the Greenland Ice Sheet (GIS) (Seidenkrantz et al., 2012) and the subsequent onset of deep convection in the

Greenland Sea (Telesiński et al., 2022; Thornalley et al., 2013). This increase in overturning circulation resulted in subsurface warming observed in the southernmost cores (MD95-2011 and M17730-4) at ~7.5 ka BP. However, since the main AW flow has been shifted towards the Greenland Sea (Telesiński et al., 2022), in cores located farther north (M23258-2 and in the Fram Strait), after brief initial warming at 7.8-7.9 ka BP, cooling can be observed starting shortly thereafter. Subsurface water cooling might have triggered or at least enhanced a stepwise sea-ice expansion in the eastern Fram Strait that occurred around 7 ka BP (Fig. 3B). Increased sea-ice cover, in turn, must have influenced surface waters. Distinct surface water cooling can be observed in a record from Storfjordrenna, south of Svalbard (Fig. 3F; Łącka et al., 2019), suggesting that the sea ice was advected into the eastern Fram Strait from the western Barents Sea. Further south, however, no sign of cooling can be observed (Calvo et al., 2002; Martrat et al., 2003; Risebrobakken et al., 2010), indicating that the surface temperature decrease was limited roughly to the sea-ice-covered area.

In contrast, for subsurface waters, the expansion of the sea-ice cover had much more far-reaching implications. Increased sea-ice cover enhanced further stepwise subsurface cooling (Fig. 2) by acting as a positive feedback mechanism (e.g., Gildor et al., 2003), i.e., by strengthening the halocline and causing the AW to sink deeper below it. The subsurface water cooling culminated around 6.7 ka BP. It was the most pronounced in the Fram Strait, but it was marked in all records along the NAD from the central Norwegian Sea to the NW Greenland Sea. Such a strong subsurface water cooling associated with a disruption of AW advection in a region as important for ocean circulation as the Nordic Seas could have had far-reaching consequences. Indeed, several studies, which we discuss below, report environmental perturbations that occurred after ~6.5 ka BP and could have a causal link with the described cooling event.

A trend of decreasing contribution of high-$\delta^{13}C$ North Atlantic Deep Water (NADW) relative to low-$\delta^{13}C$ Southern Ocean Water (SOW) that began at about 6.5 ka BP and culminated around 5 ka BP was recorded in the subpolar NE North Atlantic (Oppo et al., 2003). A decrease in NADW contribution in the NE North Atlantic suggests that, despite active deep convection in the Greenland Sea (e.g., Telesiński et al., 2022), the overturning circulation in the eastern Nordic Seas was weakened, most probably by the described decrease in AW advection into this area. Further consequences that are being linked with the decreasing contribution of NADW in the NE North Atlantic (Oppo et al., 2003) include meteorological conditions at high latitudes which were especially winter-like (i.e., more similar to those during the YD and the glacial) from 6.1 to 5.0 ka BP. This is indicated by high sea-salt sodium flux in Greenland ice-core data, suggesting enhanced storminess (O'Brien et al., 1995; Rhodes et al., 2018). Finally, a large proportion of cold, relatively fresh, ice-bearing surface water entering the NE North Atlantic from north of Iceland is indicated by a high relative abundance of hematite-stained grains (indicating that they originated from sedimentary deposits in Svalbard and eastern Greenland containing red beds) in sedimentary records from this area (Bond event 4; Bond et al., 2001). This is also in agreement with a decrease in AW advection from the North Atlantic into the Nordic Seas. All three indications (Bond et al., 2001; O'Brien et al., 1995; Oppo et al., 2003) suggest that the interval between ~6.5 and 5 ka BP was one of the most severe climate events of the Holocene. This interval can be directly linked to the 6.7 ka BP event in the Nordic Seas not only because of the temporal convergence but also because the Nordic Seas are a key area for the Atlantic Meridional Overturning Circulation, one of the most important mechanisms regulating both oceanic and climatic environmental changes in the North Atlantic region (e.g., Johns et al., 2011). Modelling studies confirm that any perturbation in overturning circulation might bring large-scale climate responses: prominent cooling over the northern North Atlantic and neighbouring areas, sea-ice increases over the Nordic Seas and to the south of Greenland, and a significant southward rain-belt migration over the tropical Atlantic (Liu et al., 2020, 2017).

Based on the carefully selected Holocene time series of temperature and humidity/precipitation, as well as reconstructions of glacier advances, Wanner et al. (2011) analysed the spatiotemporal pattern of six cold relapses of widespread reach during the last 10,000 years. One of the identified events occurred within the Holocene Thermal Maximum, between 6.5 and 5.9 ka BP. It was characterised by a predominance of negative temperature anomalies in the Southern Hemisphere. Similarly, the inner area of North America was cool, in contrast to the area around Scandinavia where a majority of positive temperature anomalies occurred during this time. Especially the latter might seem surprising in the face of the cooling described here. However, first of all, the widespread event peaked at around 6.3 ka BP (Wanner et al., 2011), i.e., ~400 years after the peak of cooling in the Nordic Seas. The cooling and its consequences propagated time-transgressively away from its source, and by the time the widespread event reached its maximum, in the Nordic Seas the temperatures were already rising (Fig. 2). Second, cooling at 6.7 ka BP affected the subsurface water masses, while the surface waters were affected only locally, close to Svalbard (Fig. 3F). For this reason, the air temperatures around the Nordic Seas were not directly affected by the event. Finally, subsurface cooling had the largest amplitude in the Fram Strait, while off Scandinavia (e.g., site MD95-2011) it was rather mild (Fig. 2).

Further indications suggest that a cold North Atlantic area and a southward shift of the Intertropical Convergence Zone during the 6.5-5.9 ka BP cold relapse could have weakened the East Asian monsoon (Liu et al., 2017; Wanner et al., 2011; Xiao et al., 2009). It is also suggested that reduced solar activity was at the origin of the 6.5-5.9 ka BP cold relapse (Wanner et al., 2011). However, the solar irradiance minimum occurred at only ~6.3 ka BP (Vonmoos et al., 2006). While we find it plausible that changes in solar activity could have amplified the cooling and enhanced its spreading across both hemispheres (see, e.g., the discussion on the influence of solar activity on the 2.7 ka BP event in Telesiński et al., 2022, 2015; van Geel et al., 2000), it seems unrealistic to be a root cause as it occurred already within the cooling.

The described environmental changes that occurred during the 6.5-5 ka BP interval show how the consequences of a fairly local event such as the one at 6.7 ka BP in the Nordic Seas can spread across the entire globe. Although a direct causal relationship between the 6.7 ka BP event and its widespread implications might be difficult to prove and requires further studies, it certainly is possible, and the temporal convergence is very compelling. Therefore, we assume that the 6.7-ka BP event could have acted as a trigger for the widespread cooling event.

The discussed sequence of events has important implications for the present-day environmental conditions and future predictions. It shows that even during a relatively warm and stable interval, a fairly local cold spell can occur, and its consequences can spread across both hemispheres. The ongoing warming of the Arctic (e.g., McKay and Kaufman, 2014; Schiermeier, 2007; Spielhagen et al., 2011; Walczowski and Piechura, 2007) is a harbinger of changes that will affect the entire planet (e.g., Boulton et al., 2014). However, these changes do not necessarily have to be straightforward or uniform (e.g., Cohen et al., 2020). Based on the paleoenvironmental proxy records presented here, we suggest that, for example, increased meltwater input from Svalbard glaciers and the GIS caused by increasing air temperatures (e.g., Hetzinger et al., 2021; van den Broeke et al., 2016) could lead to a similar cooling as the one that occurred 6.7 ka BP with comparable consequences reaching far beyond the Nordic Seas (e.g., Rahmstorf et al., 2015; Yang et al., 2016). For this reason, paleoreconstructions of such events should be taken into account in future climate predictions.

Summary and conclusions

The analysis of published marine sedimentary records retrieved along the NAD in the Nordic Seas allowed us to identify a subsurface water cooling event centered around 6.7 ka BP. After the 8.2 ka BP event, the overturning circulation in the Nordic Seas resumed. However, due to the onset of deep convection in the Greenland Sea, the main AW flow was shifted westward. This allowed sea-ice advection from the Barents Sea into the eastern Fram Strait. The increased sea-ice cover strengthened the halocline, the NAD was subducted below the fresher surface water, and its flow was weakened. Consequently, AW advection into the eastern Nordic Seas was reduced, resulting in subsurface water cooling.

The disruption of AW advection in a region as important for ocean circulation as the Nordic Seas must have had far-reaching consequences. Indeed, several environmental changes subsequent to the 6.7 ka BP event exhibit not only temporal convergence, but also probable causal relationships proved by both proxy-based and modelling studies. These include: (a) a trend of decreasing contribution of NADW relative to SOW in the NE North Atlantic starting at 6.5 ka BP and culminating at 5 ka BP (Oppo et al., 2003), (b) especially winter-like meteorological conditions at high northern latitudes from 6.1 to 5.0 ka BP (O'Brien et al., 1995), (c) a large proportion of cold, fresh, ice-bearing surface water entering the NE Atlantic from north of Iceland (Bond event 4; Bond et al., 2001), (d) negative temperature anomalies in the North Atlantic area, inner North America and the Southern Hemisphere between 6.5 and 5.9 ka BP (Wanner et al., 2011), and (e) weakened East Asian monsoon between 6.4 and 6.05 ka BP (Xiao et al., 2009). Therefore, we assume that the 6.7 ka BP event was a trigger for the widespread cooling event.

The 6.7 ka BP event in the Nordic Seas and its consequences show that even during a relatively warm and stable interval, a fairly local cold spell can occur, and the resulting sequence of environmental changes can spread even globally. Understanding the mechanisms behind events that occur within a generally warm interval is invaluable for future climate predictions.

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Figure captions

Fig. 1. Location of cores used in the study (dots) as well as present-day surface (red and blue arrows) and deep water circulation are shown. AF – Arctic Front, EGC – East Greenland Current, JMC – Jan Mayen Current, NAC – North Atlantic Current, PF – Polar Front, RAC – Return Atlantic Current, WSC – West Spitsbergen Current.

Fig. 2. Relative abundance of polar planktic foraminiferal species *N. pachyderma* in records from the eastern and northern Nordic Seas. Increases in the abundance of *N. pachyderma* associated with the 8.2 ka BP and 6.7 ka BP events are marked with the blue shading.

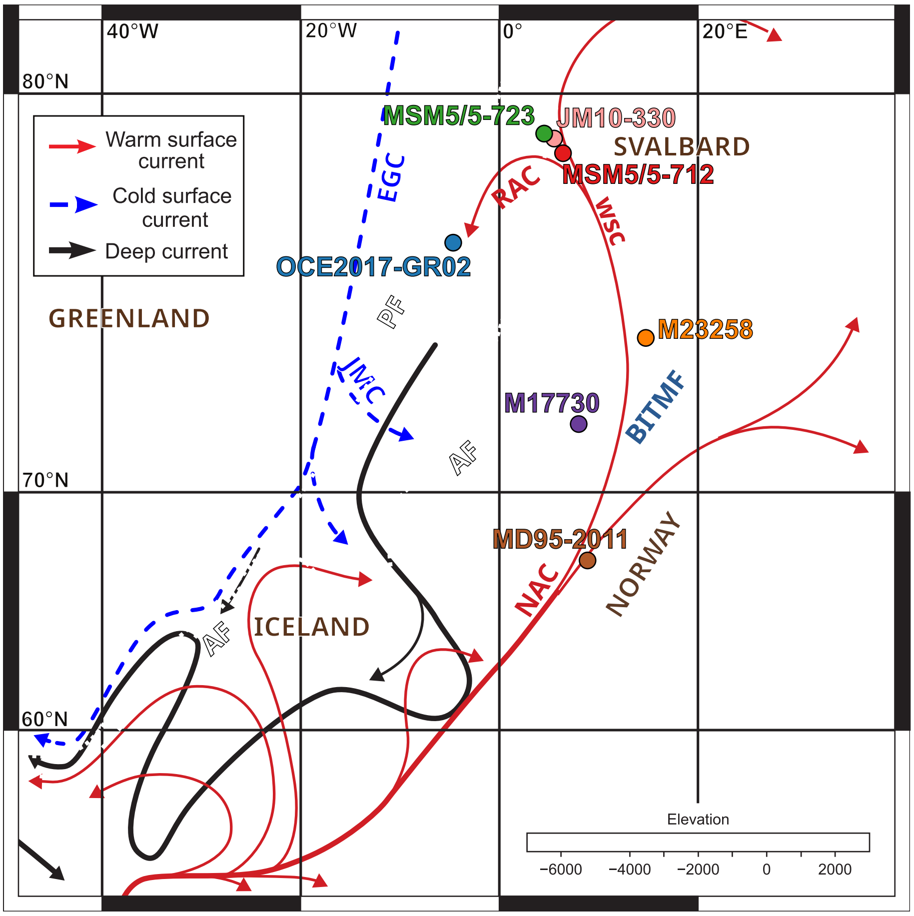
Fig. 3. Paleoenvironmental proxies indicating changes associated with the 6.7 ka BP event. A) Insolation at 78°N for June, July, August, and September (Laskar et al., 2004). B) P_BIP_{25} index derived from biomarker data from core MSM5/5-723 (Werner et al., 2015). C) Fragmentation of planktic foraminifera tests in core MSM5/5-723 (Werner et al., 2015). D) Planktic foraminiferal abundance in cores JM10-330 (Consolaro et al., 2018), M17730 (Telesiński et al., 2015) and MD95-2011 (Risebrobakken et al., 2003). E) Ice-rafted debris flux in core MSM5/5-712 (Werner et al., 2013), F) Alkenone-based sea-surface temperature reconstructions from cores JM09-020 (Łącka et al., 2019) and M23258 (Martrat et al., 2003). The 6.7 ka BP event is marked with blue shading.

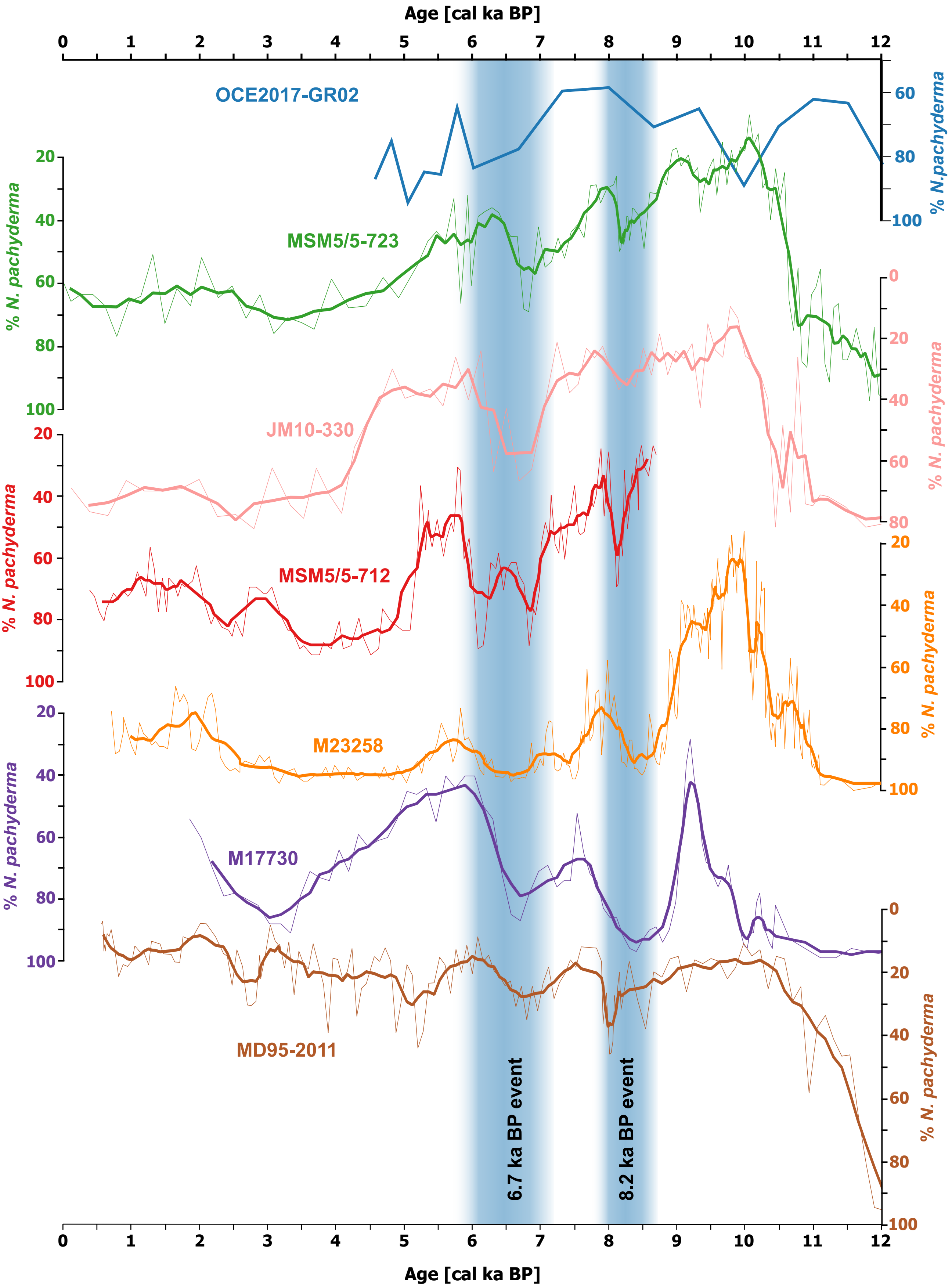
Tables

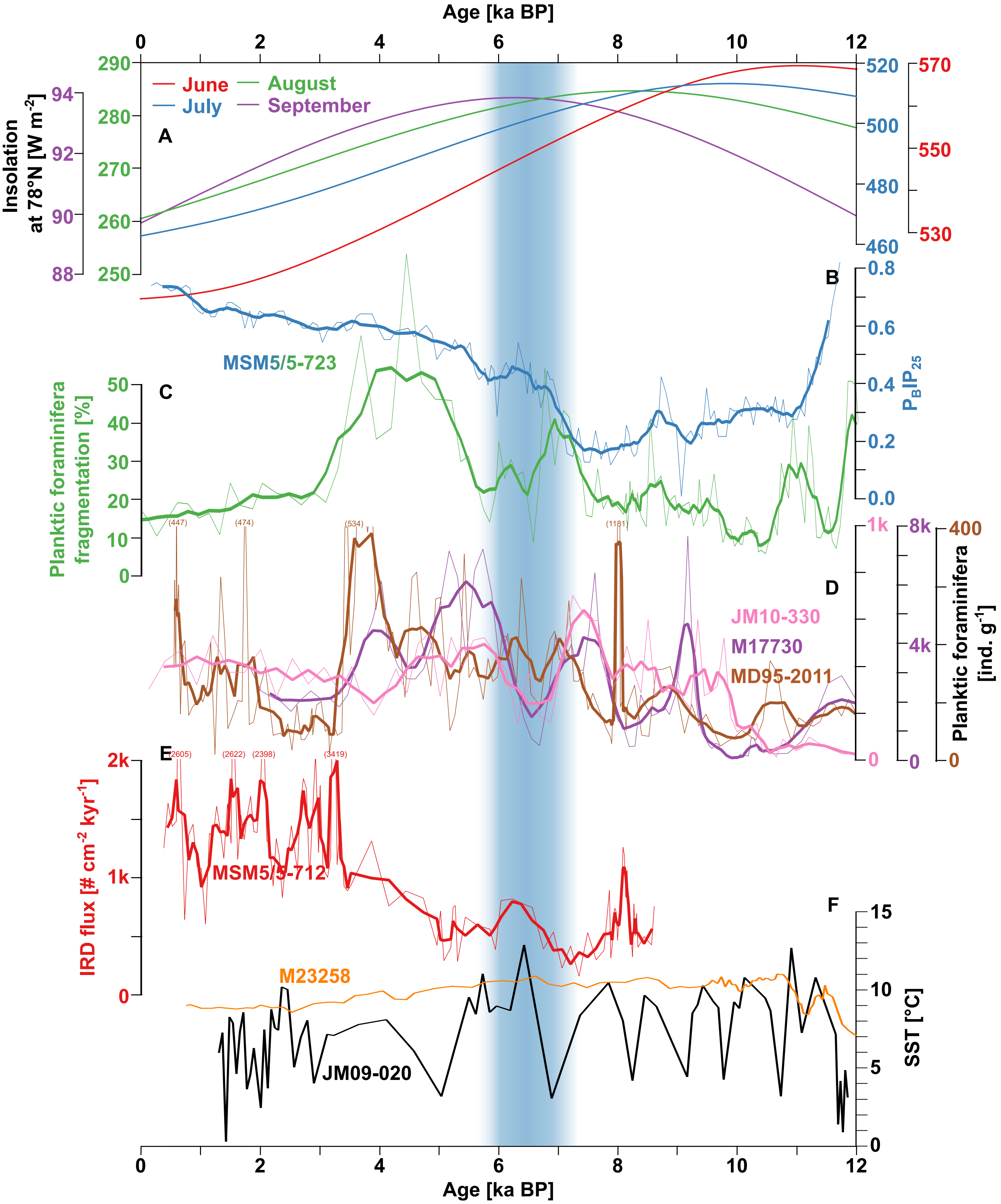
Table 1. Details on cores used in the study. KAL – Kastenlot core, PC – piston core, GC – gravity core.

Core ID	Latitude	Longitude	Water depth [m]	Core type	Location	References
GR02	77°05' N	5°20' W	1200	GC	NW Greenland Sea	Telesiński et al. 2022, Devendra et al. 2022
MSM5/5-723	79°09' N	5°20' E	1350	KAL	E Fram Strait	Müller et al. 2012, Werner et al. 2015

JM10-330	79°08' N	5°36' E	1297	GC	E Fram Strait	Consolaro et al. 2015, 2018
MSM5/5-712	78°55′ N	6°46′ E	1491	KAL	E Fram Strait	Müller et al. 2012, Werner et al. 2013
M23258	75°00' N	13°58' E	1768	KAL	N Norwegian Sea	Sarnthein et al. 2003, Martrat et al. 2003
M17730	72°07' N	07°23' E	2749	KAL	N Norwegian Sea	Telesiński et al. 2015
MD95-2011	66°58' N	07°38' E	1048	PC	central Norwegian Sea	Risebrobakken et al. 2003


40°W
20°W
0°
20°E
80°N
70°N
60°N
Warm surface current
Cold surface current
Deep current
MSM5/5-723
JM10-330
SVALBARD
MSM5/5-712
EGC
RAC
WSC
OCE2017-GR02
GREENLAND
PF
M23258
JMC
M17730
BITMF
AF
MD95-2011
NAC
NORWAY
AF
ICELAND
Elevation
−6000
−4000
−2000
0
2000


Age [cal ka BP]
0
1
2
3
4
5
6
7
8
9
10
11
12
OCE2017-GR02
% N.pachyderma
60
80
100
MSM5/5-723
% N. pachyderma
20
40
60
80
100
JM10-330
% N. pachyderma
0
20
40
60
80
MSM5/5-712
% N. pachyderma
20
40
60
80
100
M23258
% N. pachyderma
20
40
60
80
100
M17730
% N. pachyderma
20
40
60
80
100
MD95-2011
% N. pachyderma
0
20
40
60
80
100
6.7 ka BP event
8.2 ka BP event
Age [cal ka BP]


Age [ka BP]
0
2
4
6
8
10
12
A
June
July
August
September
Insolation
at 78°N [W m-2]
94
92
90
88
290
280
270
260
250
520
500
480
460
570
550
530
B
MSM5/5-723
PBIP25
0.8
0.6
0.4
0.2
0.0
C
Planktic foraminifera
fragmentation [%]
50
40
30
20
10
0
D
(447)
(474)
(534)
(1181)
JM10-330
M17730
MD95-2011
1k
8k
400
4k
0
0
0
Planktic foraminifera
[ind. g-1]
E
(2605)
(2622)
(2398)
(3419)
IRD flux [# cm-2 kyr-1]
2k
1k
0
MSM5/5-712
F
M23258
JM09-020
SST [°C]
15
10
5
0
0
2
4
6
8
10
12
Age [ka BP]