



1 **Is there evidence for a 4.2ka B.P. event in the northern North Atlantic region?**

2 Raymond S. Bradley¹ and Jostein Bakke²

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4 ¹Department of Geosciences/Climate System Research Center, University of Massachusetts,
5 Amherst

6 ²Department of Earth Science/Bjerknes Centre for Climate Research, University of Bergen
7

8 **Abstract**

9 We review paleoceanographic and paleoclimatic records from the northern North Atlantic to assess
10 the nature of climatic conditions at 4.2ka BP, which has been identified as a time of exceptional
11 climatic anomalies in many parts of the world. The northern North Atlantic region experienced
12 relatively warm conditions in the early Holocene (6-8ka B.P.) followed by a general decline in
13 temperatures after ~5ka B.P., which led to the onset of Neoglaciation. Although a few records do
14 show a distinct anomaly around 4.2ka B.P. (associated with a glacial advance), this is not
15 widespread and we interpret it as a local manifestation of the overall climatic deterioration that
16 characterizes the late Holocene.

17

18 **1. Introduction**

19 Detailed studies of two sediment cores in the North Atlantic (at ~65° and ~54°N) by Bond et al
20 (1997) revealed quasi-periodic variations in the percentage of hematite-stained grains and
21 Icelandic glass during the Holocene, which were interpreted as evidence for pulses of ice-rafting.
22 They argued that during these episodes, “*cool, ice-bearing surface waters shifted across more than*
23 *5° of latitude, each time penetrating well into the core of the North Atlantic Current*”. One of the
24 8 Holocene episodes (later dubbed “Bond events”) occurred at ~4.2ka calendar years B.P.
25 Subsequently, Bond et al. (2001) argued that these colder episodes were driven by changes in solar
26 insolation (cf. Wanner and Bütikofer, 2008; Wanner et al., 2011), notwithstanding the fact that
27 total solar irradiance did not vary by more than ±0.15% over this period (Vieira et al., 2011; Roth
28 and Joos, 2013; Wu et al. 2018). Other paleoceanographic studies have been unable to reproduce
29 the record of ice-rafting reported in Bond et al., (1997) (e.g. Andrews et al., 2014) yet the literature
30 is replete with studies that have tried to identify a signal linked to the timing of Bond events in
31 other paleoclimatic records from around the world (e.g. Fleitmann et al., 2003; Gupta et al., 2003;



32 Wang et al., 2005; Pèlachs et al., 2011). Here we review sedimentary records from the northern
33 North Atlantic (north of 60°N) with a focus on evidence for an “event” around 4.2ka B.P. This
34 region is of significance as it is the core region for ventilation of the North Atlantic which drives
35 the Atlantic Meridional Overturning Circulation (AMOC), with global teleconnections through the
36 conveyor belt system of ocean currents. We do not focus on records from Iceland as these have
37 been reviewed separately by Geirsdóttir et al. (2018).

38 The North Atlantic has a very distinct pattern of sea surface temperatures, reflecting the ocean
39 currents that traverse the region (Figure 1). Warm sub-tropical water enters the region from the
40 southwest via the Gulf Stream (North Atlantic Current) and this transfers heat to sub-polar latitudes
41 north of Scandinavia by way of the Norwegian Atlantic and West Spitsbergen currents, as well as
42 around the western and northwestern coast of Iceland via the Irminger current. In contrast, cold
43 polar water exits the Arctic Ocean via the East Greenland current, which extends to around the
44 southern tip of Greenland. The region between these water masses is where deepwater formation
45 occurs, driving the large-scale Atlantic Meridional Overturning Circulation (AMOC). On the
46 timescale of the Holocene, there have been significant changes in the characteristics and position
47 of these major oceanographic features, as recorded by various paleoceanographic proxies.

48

49 **2. Paleoceanographic evidence**

50 First, we consider a transect of sediment cores that are aligned along the axis of the main influx of
51 Atlantic water entering the North Atlantic, from north of the UK to west of Svalbard (Figure 1)
52 Sea-surface temperatures have been tracked using alkenones and diatoms, which reflect conditions
53 in the photosynthetic mixed layer of the ocean surface, and by the relative abundance of
54 *Neogloboquadrina pachyderma* (s), which is diagnostic of cold polar water (Figure 2). All studies
55 reveal higher SSTs in the early Holocene, with the largest anomalies (relative to today) at high
56 latitudes (that is, there was strong polar amplification of the warming) (Andersson et al., 2010).
57 This early Holocene warming was a consequence of orbital forcing: June/July insolation was ~10%
58 higher than today at the start of the Holocene in the northern parts of the region, but the peak
59 warming was delayed due to the influence of the decaying Laurentide and Scandinavian Ice Sheets
60 and associated icebergs and freshwater (Renssen et al., 2009, 2012; Zhang et al., 2016).
61 Consequently, maximum temperatures were a few thousand years later than the peak insolation,
62 punctuated by a short-lived cooling event around 8.2ka B.P. associated with the final major



63 freshwater discharge event of the Laurentide Ice Sheet (Barber et al., 1999; Rohling and Pälike,
64 2005). Thereafter, as insolation declined so sea surface temperatures declined steadily, or by some
65 estimates, in a more step-like manner (e.g. Calvo et al., 2002; Risebrobakken et al., 2010). For
66 example, Birks and Koç (2002), Andersen et al. (2004) and Berner et al. (2011) all found that
67 August SSTs at 67°N (core MD95-2011) were 4-5°C warmer than today from ~9000-6500 years
68 B.P., then steadily declined. These analyses were based on diatoms, but similar results (albeit with
69 a smaller change in temperature, ~2.5°C, perhaps reflecting a different seasonal bias) were
70 obtained in a study of alkenones from the same core (Calvo et al., 2002). Studies further north,
71 paint a similar picture (Sarnthein et al., 2003; Risebrobakken et al., 2003, 2010; Werner et al.,
72 2014). This pattern of maximum SSTs in the first half of the Holocene and cooling thereafter is
73 seen throughout the eastern North Atlantic, in all proxies that are indicative of conditions in the
74 photic zone (Rimbu et al., 2003; Leduc et al., 2010; Sejrup et al., 2016). The timing of the onset
75 of cooling varies, but in all cases cooling was well underway by ~5.5ka B.P., in what some refer to
76 as a “transition period” that subsequently led to much cooler conditions in the late Holocene (after
77 3.5ka B.P.) (e.g. Aagaard-Sorensen et al., 2014; Andersen et al., 2004; Leduc et al., 2010; Sejrup
78 et al., 2016). Although there were short-lived cooling episodes superimposed on the overall first
79 order pattern of temperature change (e.g. Werner et al., 2014), there is no evidence for quasi-
80 periodic cooling episodes disrupting the northward flux of Atlantic water, as described by Bond et
81 al (1997). Proxies of sub-surface conditions (below the mixed layer) – Mg/Ca ratios and oxygen
82 isotopes in forams, as well as foram assemblage changes – generally do not show the same pattern
83 of pan-Holocene cooling as the SST proxies, often indicating slight warming through the Holocene
84 (e.g. Andersson et al., 2010; Sejrup et al., 2011). But these records also do not show a pattern of
85 quasi-periodic cooling events. Could this be because of low resolution in sampling, or poor
86 chronologies? This seems very unlikely as many of these records are from high-deposition rate
87 sites, providing high resolution records that are generally well-dated (e.g. Berner et al., 2011).
88 Indeed, one exceptionally well-dated, high resolution sediment core from the Storegga Slide region
89 (90 AMS ¹⁴C dates over 8000 calendar years) provides oxygen isotope data on planktonic forams
90 at a resolution of ±20 years within the core of the Norwegian Atlantic Current at ~64°N. This
91 clearly shows multi-decadal to century-scale variability throughout the last 8000 years, but none
92 of the cold water flux episodes that one would expect to see, based on the work of Bond et al.
93 (1997). We therefore conclude that there is no signal of a 4.2ka B.P. event in paleoceanographic



94 proxies from regions influenced by the flux of warm water from the sub-tropical Atlantic into the
95 Nordic Seas. Cooling had set in more than a millennium earlier in this region.

96 Next, we consider studies in the western part of the North Atlantic, north of Iceland on the
97 Icelandic Shelf, and further to the east, near Denmark Strait. Here, many studies have examined,
98 *inter alia*, foraminiferal assemblages, coccoliths, dinoflagellate cysts and sea-ice biomarkers and
99 ice-rafted debris (IRD) reflecting transport of material in the cold East Greenland Current (e.g.
100 Andrews et al., 1997; Jennings et al., 2002; Giraudeau et al., 2004; Solignac et al., 2006; Sicre et
101 al., 2008; Justwan et al., 2008; Perner et al., 2015; Moossen et al., 2015; Cabedo-Sanz et al., 2016;
102 Kolling et al., 2017). In this region, warmest conditions occurred around 6.0 ± 1.5 ka B.P. (the
103 timing depending on location); these conditions were associated with minimal input of IRD,
104 reflecting the recession of tidewater glaciers onto land along the eastern coast of Greenland, and a
105 weak East Greenland Current, with minimal stratification of the water column at that time as the
106 flux of warmer, more saline Irminger Current water increased (Justwan et al., 2008; Jennings et
107 al., 2011; Werner et al., 2014; Telesinski et al., 2014; Perner et al., 2016). Conditions began to
108 change by $\sim 5.0\pm 0.5$ ka B.P. (the timing varying geographically) when cold water diatoms and
109 forams, sea-ice (as tracked by the biomarker index, IP_{25}) and IRD started to increase, and the water
110 column became more stratified as the East Greenland Current strengthened (Moros et al., 2006;
111 Telesinski et al., 2014; Perner et al., 2016; Kristiansdottir et al., 2017). These changes correspond
112 to the re-advance of glaciers in East Greenland, part of the much more widespread onset of
113 neoglaciation that is well-documented in many regions around the North Atlantic (Solomina et al.,
114 2015). Warmer conditions (strengthened Irminger Current) developed over the past 2000 years, but
115 this period is also characterized by a series of minor fluctuations in the extent of ice in the region,
116 with much colder conditions after ~ 1.0 ka B.P. when the coldest conditions of the last 8000 years
117 occurred, with abundant IRD and sea-ice in Denmark Strait and off the north coast of Iceland
118 (Bendle and Rosell-Mele, 2007; Andresen et al., 2013; Cabedo-Sanz et al., 2016; Kolling et al.,
119 2017). None of these records show evidence of an unusual anomaly at 4.2ka B.P.; rather, the
120 overall cooling of the late Holocene began 500-1000 years earlier (cf. Orme et al., 2018). Similar
121 variability is also seen further south and southwest of Iceland, at $\sim 59^\circ$ N (Farmer et al., 2008; Moros
122 et al., 2012; Orme et al., 2018) though there is evidence from dinocysts for an anomaly in the
123 seasonality of SSTs at ~ 4.5 ka B.P., perhaps related to a westward shift in the Sub-Polar Gyre,
124 allowing warmer Atlantic water to influence the site (van Nieuwenhove et al., 2018).



125 This review of paleoceanographic studies extending from southern Greenland to Fram
126 Strait, and from western Svalbard and the southern Barents Sea southward to 60°N, provides no
127 evidence for a significant change in major oceanographic conditions that could be linked to the
128 4.2ka B.P. climate anomaly seen elsewhere. Rather, the evidence points to a more gradual change
129 that was well under way by ~5ka B.P., from the relatively warm conditions of the early Holocene
130 (driven by precessional forcing) to much colder conditions that have characterized the last 3
131 millennia.

132

133 **3. Terrestrial records from around the North Atlantic**

134 **3.1 Eastern Greenland and the Greenland Ice sheet**

135 Lake sediment records from sites along the coast of eastern Greenland provide a record of
136 Holocene environmental conditions that generally reinforce the paleoceanographic evidence
137 discussed earlier. A “Holocene Thermal Maximum” (characterized *inter alia* by longer ice-free
138 conditions, higher levels of lacustrine productivity, increased evaporation, more tundra vegetation
139 and higher levels of terrestrial plant material transferred to lakes) is clearly seen from ~8ka B.P.
140 (or earlier) to ~5.0±0.5ka B.P. (e.g. Kaplan et al., 2002; Andresen et al., 2004; Schmidt et al., 2011;
141 Balascio et al., 2013; Wagner and Bennike, 2015; Axford et al., 2017; van der Bilt et al., 2018a).
142 Thereafter, conditions became colder, often with a decline in vegetation cover, an increase in the
143 flux of coarse-grained sediments, and a shift in the types of chironomids and diatoms present,
144 towards species that thrive in cooler conditions. At the same time, in glacierized watersheds, the
145 growth of glaciers led to an increase in the flux of minerogenic material which is a diagnostic
146 signal of the onset of late Holocene neoglaciation across the region. In Kulusuk Lake (65°N) this
147 change occurred at ~4.2ka B.P., when there was an abrupt increase in clastic sediments from
148 glaciers that had probably disappeared during the mid-Holocene warm period (Balascio et al.,
149 2015). A similar transition is seen in sediments from nearby Ymer Lake, where a higher frequency
150 of avalanches and a longer season with ice-cover is thought to have favored the transfer of coarser
151 material into the lake after ~4ka B.P. At another site in the same region, the Holocene thermal
152 maximum was identified (via the evaporative enrichment of δD in leaf wax n-alkanes) from 8.4 to
153 4.1ka B.P, followed by a decrease in evaporation as the open water season became shorter. At the
154 same time, there was an increase in the flux of clastic sediments and terrestrial organic material
155 into the lake as river runoff increased (Balascio et al., 2013). In all of these studies, it is clear that



156 there was a fairly rapid transition from warm mid-Holocene conditions to the colder, wetter late
157 Holocene that encompassed the 4.2ka B.P. interval of interest. In some cases, there is evidence
158 for a short-lived “event” at around that time (e.g., at Kulusuk Lake; Balascio et al., 2015) but this
159 appears to be simply part of the overall deterioration in climate that led to ice growth across the
160 region. There is currently no evidence for a more widespread glacial advance at 4.2ka B.P. Given
161 that cooling was persistent over the last 5000 years, and the elevational threshold for glacierization
162 is close to mountain tops across the region (declining in elevation poleward), it is understandable
163 that different locations would have experienced the onset of neoglaciation at, different times.
164 However, as the ELA continued to lower over the last 3-4 millennia, glaciers that had greatly
165 diminished in size, or disappeared entirely, during the Holocene Thermal Maximum were
166 eventually regenerated, with the exact timing varying across the region. In the case of Kulusuk
167 Lake, it seems reasonable to conclude that the steady decline in temperatures and the specific
168 hypsography of that basin led to a positive mass balance, with early ice growth and associated
169 sediment input to the lake around 4.2ka B.P.

170 Ice cores from Greenland provide records of past climate variations from oxygen isotopes,
171 glaciochemistry and physical characteristics, which are broadly consistent with those from coastal
172 lake sediments. Alley and Anandakrishnan (1995) examined evidence for summer melting in the
173 GISP2 ice core, as recorded by changes in the physical properties of the ice. Their analysis was at
174 a relatively low resolution, but they showed maximum Holocene summer temperatures from
175 ~7.5ka B.P., followed by a two-step transition to colder conditions, from ~6.5 to 5.5ka B.P., and
176 ~4.5 to 4ka B.P., with persistently low summer temperatures (minimal melting) thereafter. After
177 adjusting for ice thickness changes, Vinther et al. (2009) also showed that there was an overall
178 decline in temperature at the Summit of the Greenland Ice Sheet (73°N, 3210 masl) over the last
179 ~9,000 years (interpreted from changes in $\delta^{18}\text{O}$ in the GISP2 ice core) with the warmest 20 year
180 period ~7970 years b2k, and the coldest ~300 years b2k. These two periods differed in mean
181 temperature by ~4.9°C (though it is unclear if this was mean annual temperature as small changes
182 in the seasonality of snowfall on the ice sheet could have drastically changed the apparent
183 temperature over time). Superimposed on the long-term temperature decline there were
184 multidecadal anomalies on the order of $\pm 1^\circ\text{C}$. One of the largest of the negative anomalies after
185 the well-known 8.2ka B.P. event began ~4400 b2k and reached a minimum at 4340 b2k, but by
186 4200 b2k, temperatures had sharply increased (Figure 3). The 8.2ka B.P. cooling episode was the



187 result of freshwater flooding of the North Atlantic as the Laurentide Ice Sheet collapsed, so a
188 different explanation is required to explain the later anomaly, and it seems plausible that this short-
189 lived cooling event was a consequence of the massive eruption of Hekla (in Iceland) at ~4.2ka B.P.
190 (recognizing that there are dating uncertainties in both the ice core and tephrochronological
191 databases). Kobashi et al. (2017) also reconstructed mean annual temperature, derived from the
192 differential diffusion of argon and nitrogen isotopes in firn prior to its densification into ice. This
193 provided a temperature record which is similar to that of Vinther et al (2009) but with more multi-
194 decadal to century-scale variability. Although it also shows a negative temperature anomaly
195 around 4.5ka B.P., this is well within the normal variability of the record; a more significant
196 temperature decline is seen somewhat later, centered on ~3.5ka B.P. In summary, there is no
197 compelling evidence for a distinct climatic anomaly at 4.2ka B.P. in ice cores from Greenland.

198

199 **3.2 Svalbard**

200 Lake sediment records from Svalbard record changes in climate at the northernmost limit of North
201 Atlantic water (the West Spitsbergen Current). All studies describe a warm early Holocene phase
202 when many of the glaciers seen today were small or absent. On Amsterdamoya, at the northwestern
203 edge of Svalbard, warm and dry conditions spanned the interval from 7.7 to 5ka B.P., and nearby
204 glaciers were small or absent by 8.4ka B.P., only re-forming in the late Holocene (Gjerde et al.,
205 2018; de Wet et al., 2018). To the southwest, on the Mitrahavoya Peninsula, there is also evidence
206 that glaciers reached their minimum size by the mid-Holocene, but subsequently re-formed or re-
207 advanced. Karlbreen began to grow around 3.5ka B.P. (Røthe et al., 2015) but in the neighboring
208 watershed of Hajeren an abrupt increase in minerogenic sediments at 4.25 ka B.P. registered the
209 onset of neoglaciation in the basin (van der Bilt et al., 2015). Paleotemperature estimates (from
210 alkenones) in the same record indicate this advance was triggered by an abrupt drop in temperature
211 at that time; thereafter, temperatures remained low (van der Bilt et al., 2018b). Other records from
212 the region indicate that the first neoglacial advances of glaciers occurred around 4.6ka B.P. (e.g.
213 Svendsen and Mangerud, 1997; Reusche et al., 2014).

214

215 **3.3 Scandinavia**

216 As most glaciers in Scandinavia had their largest areal extent during the “Little Ice Age” (~A.D.
217 1400-1850), information about past glaciers in Norway during the late Holocene is based on



218 reconstructions from indirect evidence, mainly sediments deposited in distal glacier-fed lakes (e.g.
219 Nesje 2009, Bakke et al., 2010; 2013). After several large glacier advances in the earliest Holocene,
220 the climate was in general warm during the early Holocene (8.5-6.5ka B.P.) and most glaciers
221 melted away (Nesje 2009) (Figure 4). Around 6 ka B.P. glaciers start to re-grow mainly as a
222 function of decreasing summer insolation over the Northern Hemisphere (Wanner et al. 2008). The
223 regrowth of glaciers shows a gradual increase in glacier size interrupted by smaller glacier
224 advances (Bakke et al, 2010, 2013; Vasskog et al., 2012). Along a coastal south-north transect in
225 Scandinavia different locations have experienced the onset of neoglaciation at different times,
226 mainly as a function of altitude (cf. Geirsdóttir et al., 2018). Around 2ka B.P. many glaciers
227 reached present day size with a maximum glacier extent during the Little Ice Age (Nesje 2009). A
228 review of more than 20 papers shows that none of them indicate any abrupt anomalous change in
229 glacier extent connected to a perturbation of climate around 4.2 ka. (Bakke et al., 2005a; 2005b;
230 2008; 2010; 2013; Dahl and Nesje; 1992; 1994; 1996; Lauritzen 1996; Snowball and Sandgren,
231 1996; Seierstad et al., 2002; Lie et al., 2004; Nesje et al. 2009; Vasskog et al., 2011; 2012 Støren
232 et al., 2008; Wittmeier et al., 2015; Shakesby et al., 2007; Kvisvik et al., 2015, Gjerde et al., 2016).
233 Investigating this further, we examined other terrestrial evidence mainly pollen, macrofossil and
234 diatom records derived from lake sediments (e.g. Bjune et al., 2005; Velle et al., 2005). They have
235 a time resolution somewhat lower than the glacier reconstructions (typical 500 yr spacing) but they
236 all reflect the general decrease in summer insolation over the northern hemisphere and no abrupt
237 transition close to 4.2ka B.P. (Bjune, 2005; Bjune et al., 2004, 2006; Velle et al., 2005). The only
238 terrestrial evidence from Scandinavia that shows a clear anomaly at 4.2ka B.P. is a speleothem
239 record of $\delta^{18}\text{O}$ from Northern Norway (Lauritzen and Lundberg 1999) where higher temperatures
240 are recorded, peaking at 4.2ka, before a rapid decrease to much colder temperatures at ~ 3.7 ka B.P.

241

242 4. Conclusions

243 A review of paleoceanographic and terrestrial paleoclimatic data from around the northern North
244 Atlantic reveals no compelling evidence for a significant climatic anomaly at ~ 4.2 ka B.P. In
245 particular, there is no supporting evidence for “*cool, ice-bearing surface waters...penetrating well*
246 *into the core of the North Atlantic Current*” at that time, as described by Bond et al., (2001). The
247 region experienced relatively warm conditions in the early Holocene (6-8ka B.P.) followed by a
248 general decline in temperatures after ~ 5 ka B.P., signaling the onset of Neoglaciation. Although a



249 few records do show a distinct anomaly around 4.2ka B.P. (associated with a glacial advance), this
250 is not widespread and we interpret it as a local signal of the overall climatic deterioration that
251 characterized the late Holocene.

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253 **References**

254 Aagaard-Sørensen, S., Husum, K., Hald, M., Marchitto, T., and Godtlielsen, F.: Sub-sea surface
255 temperatures in the Polar North Atlantic during the Holocene: Planktic foraminiferal Mg/Ca
256 temperature reconstructions, *The Holocene*, 24 (1), 93-103, **2014**.

257 Alley, R.B. and Anandkrishnan, S.: Variations in melt-layer frequency in the GISP2 ice core:
258 implications for Holocene summer temperatures in central Greenland, *Annals of Glaciology*,
259 21, 64–70, **1995**.

260 Andersen, C., Koc, N., Jennings, A., and Andrews, J.T.: Nonuniform response of the major surface
261 currents in the Nordic Seas to insolation forcing: implications for the Holocene climate
262 variability, *Paleoceanography and Paleoclimatology*, 19 (2), **2004**.

263 Andersson, C., Pausata, F.S.R., Jansen, E., Risebrobakken, B., and Telford, R. J.: Holocene trends
264 in the foraminifer record from the Norwegian Sea and the North Atlantic Ocean, *Climate of the
265 Past*, 6, 179–193, **2010**.

266 Andresen, C.S., Björck, S., Bennike, O. and Bond, G.: Holocene climate changes in southern
267 Greenland: evidence from lake sediments, *J. Quaternary Science*, 19 (8), 783-795, **2004**.

268 Andresen, C.S., Hansen, M.J., Seidenkrantz, M.S., Jennings, A.E., Knudsen, M.F., Nørgaard-
269 Pedersen, N., Larsen, N.K., Kuijpers, A. and Pearce, C.: Mid-to late-Holocene oceanographic
270 variability on the Southeast Greenland shelf, *The Holocene*, 23 (2), 167-178, **2013**.

271 Andrews, J.T., Smith, L.M., Preston, R., Cooper, T. and Jennings, A.E.: Spatial and temporal
272 patterns of iceberg rafting (IRD) along the East Greenland margin, ca. 68°N, over the last 14
273 cal. Ka, *J. Quaternary Science* 12, 1–13, **1997**.

274 Andrews, J.T., Bigg, G.R. and Wilton, D.J.: Holocene ice-rafting and sediment transport from the
275 glaciated margin of East Greenland (67-70°N) to the N. Iceland shelves: detecting and modeling
276 changing sediment sources, *Quaternary Science Reviews*, 91, 204-217, **2014**.

277 Axford, Y., Levy, L.B., Kelly, M.A., Francis, D.R., Hall, B.L., Langdon, P.G. and Lowell, T.V.:
278 Timing and magnitude of early to middle Holocene warming in East Greenland inferred from
279 chironomids, *Boreas* 46 (4), 678–687, **2017**.



- 280 Bakke, J., Nesje, A., Dahl, S.O.: Utilizing physical sediment variability in glacier-fed lakes for
281 continuous glacier reconstructions during the Holocene, northern Folgefonna, western Norway,
282 *The Holocene* 15 (2), 161–176, **2005a**.
- 283 Bakke, J., Dahl, S. O., Paasche, Ø., Løvlie, R. and Nesje, A.: Glacier fluctuations, equilibrium-
284 line altitudes and palaeoclimate in Lyngen, northern Norway, during the Lateglacial and
285 Holocene, *The Holocene*, 15 (4), 518-540, **2005b**.
- 286 Bakke, J., Lie, Ø., Dahl, S.O., Nesje, A. and Bjune, A.E.: Strength and spatial patterns of the
287 Holocene wintertime westerlies in the NE Atlantic region, *Global and Planetary Change*, 60,
288 (1-2), 28-41, **2008**.
- 289 Bakke, J., Dahl, S.O., Paasche, Ø., Simonsen, J.R., Kvisvik, B., Bakke, K. and Nesje, A.: A
290 complete record of Holocene glacier variability at Austre Okstindbreen, northern Norway: an
291 integrated approach, *Quaternary Science Reviews*, 29 (9), 1246–1262, **2010**.
- 292 Bakke, J., Trachsel, M., Kvisvik, B.C., Nesje, A. and Lyså, A.: Numerical analyses of a multi-
293 proxy data set from a distal glacier-fed lake, Sørsendalensvatn, western Norway, *Quaternary*
294 *Science Reviews*, 73, 182-195, **2013**.
- 295 Balascio, N.L., D'Andrea, W.J., Bradley, R.S., Perren, B.B.: Biogeochemical evidence for
296 hydrologic changes during the Holocene in a lake sediment record from Southeast Greenland,
297 *The Holocene* 23 (10), 1428–1439, **2013**.
- 298 Balascio, N.J., D'Andrea, W.J. and Bradley, R.S.: Glacier response to North Atlantic climate
299 variability during the Holocene, *Climate of the Past*, 11, 1587-1598, **2015**.
- 300 Barber, D.C., Dyke, A., Hillaire-Marcel, C., Jennings, A.E., Andrews, J.T., Kerwin, M.W.,
301 Bilodeau, G., McNeely, R., Southon, J., Morehead, M.D. and Gagnon, J.M: Forcing of the cold
302 event of 8,200 years ago by catastrophic drainage of Laurentide lakes, *Nature*, 400, (6742),
303 344-348, **1999**.
- 304 Bendle, J.A., and Rosell-Melé, A.: High-resolution alkenone sea surface temperature variability
305 on the North Icelandic Shelf: implications for Nordic Seas palaeoclimatic development during
306 the Holocene, *The Holocene*, 17 (1), 9-24, **2007**.
- 307 Berner, K.S., Koç, N., Godtliebsen, F., and Divine, D.: Holocene climate variability of the
308 Norwegian Atlantic Current during high and low solar insolation forcing, *Paleoceanography*
309 *and Paleoclimatology*, 26 (2), PA2220, **2011**.



- 310 Bond, G., Showers, W., Cheseby, M., Lotti, R., Almasi, P., Priore, P., Cullen, H. and Bonani, G.:
311 A pervasive millennial-scale cycle in North Atlantic Holocene and glacial
312 climates, *Science*, 278 (5341), 1257-1266, **1997**.
- 313 Bond, G., Kromer, B., Beer, J., Muscheler, R., Evans, M.N., Showers, W., Hoffmann, S., Lotti-
314 Bond, R., Hajdas, I. and Bonani, G.: Persistent solar influence on North Atlantic climate during
315 the Holocene, *Science*, 294 (5549), 2130-2136, **2001**.
- 316 Bjune, A.E.: Holocene vegetation history and tree-line changes on a north–south transect crossing
317 major climate gradients in southern Norway – evidence from pollen and plant macrofossils in
318 lake sediments, *Review of Palaeobotany and Palynology*, 133, 249–275, **2005**.
- 319 Bjune, A.E., Bakke, J., Nesje, A., Birks, H.J.B.: Holocene mean July temperature and winter
320 precipitation in western Norway inferred from palynological and glaciological lake-sediment
321 proxies, *The Holocene*, 15, 177–189, **2005**.
- 322 Bjune, A.E., Birks, H.J.B., Seppä, H.: Holocene vegetation and climate history on a continental –
323 oceanic transect in northern Fennoscandia based on pollen and plant macrofossils, *Boreas*, 33,
324 211–223, **2004**.
- 325 Cabedo-Sanz, P., Belt, S. T., Jennings, A. E., Andrews, J. T., and Geirsdóttir, Á.: Variability in
326 drift ice export from the Arctic Ocean to the North Icelandic Shelf over the last 8000 years: a
327 multi-proxy evaluation, *Quaternary Science Reviews*, 146, 99-115, **2016**.
- 328 Calvo, E., Grimalt, J., and Jansen, E.: High resolution U37K sea surface temperature
329 reconstruction in the Norwegian Sea during the Holocene, *Quaternary Science Reviews*, 21
330 (12-13), 1385-1394, **2002**.
- 331 Dahl, S.O. and Nesje, A.: Paleoclimatic implications based on equilibrium line altitude depressions
332 of reconstructed Younger Dryas and Holocene cirque glaciers in inner Nordfjord, western
333 Norway, *Palaeogeography, Palaeoclimatology, Palaeoecology*, 94, 87-97, **1992**.
- 334 Dahl, S.O. and Nesje, A.: Holocene glacier fluctuations at Hardangerjøkulen, central-southern
335 Norway: a high-resolution composite chronology from lacustrine and terrestrial deposits, *The
336 Holocene*, 4, 269–277, **1994**.
- 337 Dahl, S.O. and Nesje, A.: A new approach to calculating Holocene winter precipitation by
338 combining glacier equilibrium-line altitudes and pine-tree limits: a case study from
339 Hardangerjøkulen, central southern Norway, *The Holocene*, 6, 381–398, **1996**.
- 340 de Wet, G., Bakke, J., D’Andrea, W.J., Balascio, N.L., Bradley, R.S. and Perren, B.B.: Holocene



- 341 climate change reconstructed from proglacial lake Gjoavatnet on Amsterdamoya, N.W.
342 Svalbard, *Quaternary Science Reviews*, 183, 188-203, **2018**.
- 343 Farmer, E.J., Chapman, M.R. and Andrews, J.E.: Centennial-scale Holocene North Atlantic
344 surface temperatures from Mg/Ca ratios in *Globigerina bulloides*, *Geochemistry, Geophysics,*
345 *Geosystems*, 9 (12), **2008**.
- 346 Fleitmann, D., Burns, S.J., Mudelsee, M., Neff, U., Kramers, J., Mangini, A. and Matter, A.:
347 Holocene forcing of the Indian monsoon recorded in a stalagmite from southern Oman,
348 *Science*, 300, (5626), 1737-1739, **2003**.
- 349 Geirsdóttir, Á., Miller, G.H., Andrews, J.T., Harning, D.J. and Anderson, L.S.: The onset of
350 Neoglaciation in Iceland and the 4.2ka event, *Climate of the Past Discussion* (in review), **2018**.
- 351 Giraudeau, J., Jennings, A.E. and Andrews, J.T.: Timing and mechanisms of surface and
352 intermediate water circulation changes in the Nordic Seas over the last 10,000 cal years: a view
353 from the North Iceland shelf, *Quaternary Science Reviews*, 23 (20-22), 2127-2139, **2004**.
- 354 Gjerde, M., Bakke, J., Vasskog, K., Nesje, A. and Hormes, A.: Holocene glacier variability and
355 Neoglacial hydroclimate at Ålfotbreen, western Norway, *Quaternary Science Reviews*, 133, 28-
356 47, **2016**.
- 357 Gjerde, M., Bakke, J., D'Andrea, W.J., Balascio, N.L., Bradley, R.S., Vasskog, K., Ólafsdóttir, S.,
358 Røthe, T.O., Perren, B.B. and Hormes, A.: Holocene multi-proxy environmental reconstruction
359 from Lake Hakluyvatnet, Amsterdamøya Island, Svalbard (79.5°N), *Quaternary Science*
360 *Reviews*, 183, 164-176, **2018**.
- 361 Gupta, A.K., Anderson, D.M. and Overpeck, J.T.: Abrupt changes in the Asian southwest monsoon
362 during the Holocene and their links to the North Atlantic Ocean, *Nature*, 421 (6921), 354, **2003**.
- 363 Jennings, A.E., Knudsen, K.L., Hald, M., Hansen, C.V. and Andrews, J.T.: A mid-Holocene shift
364 in Arctic sea-ice variability on the East Greenland Shelf, *The Holocene*, 12 (1), 49-58, **2002**.
- 365 Jennings, A., Andrews, J. and Wilson, L.: Holocene environmental evolution of the SE Greenland
366 Shelf North and South of the Denmark Strait: Irminger and East Greenland current
367 interactions, *Quaternary Science Reviews*, 30, 980-998, **2011**.
- 368 Justwan, A., Koç, N. and Jennings, A.E.: Evolution of the Irminger and East Icelandic Current
369 systems through the Holocene, revealed by diatom-based sea surface temperature
370 reconstructions, *Quaternary Science Reviews*, 27, 1571-1582, **2008**.



- 371 Kaplan, M.R., Wolfe, A.P. and Miller, G.H.: Holocene environmental variability in southern
372 Greenland inferred from lake sediments, *Quaternary Research*, 58, 149-159, **2002**.
- 373 Kobashi, T., Menviel, L., Jeltsch-Thömmes, A., Vinther, B.M., Box, J.E., Muscheler, R.,
374 Nakaegawa, T., Pfister, P.L., Döring, M., Leuenberger, M. and Wanner, H: Volcanic influence
375 on centennial to millennial Holocene Greenland temperature change, *Scientific Reports*, 7,
376 1441-1451, **2017**.
- 377 Kolling, H.M., Stein, R., Fahl, K., Perner, K. and Moros, M.: Short-term variability in late
378 Holocene sea ice cover on the East Greenland Shelf and its driving
379 mechanisms, *Palaeogeography, Palaeoclimatology, Palaeoecology*, 485, 336-350, **2017**.
- 380 Kristjánsdóttir, G.B., Moros, M., Andrews, J.T. and Jennings, A.E.: Holocene Mg/Ca, alkenones,
381 and light stable isotope measurements on the outer North Iceland shelf (MD99-2269): A
382 comparison with other multi-proxy data and sub-division of the Holocene, *The Holocene*, 27,
383 52-62, **2017**.
- 384 Kvisvik, B., Paasche, Ø. and Dahl, S.O.: Holocene cirque glacier activity in Rondane, southern
385 Norway, *Geomorphology*, 246, 433–444, **2015**.
- 386 Lauritzen, S.E: Calibration of speleothem stable isotopes against historical records: a Holocene
387 temperature curve for North Norway?, *Karst Waters Institute Special Publication*, 2, 78-80,
388 **1996**.
- 389 Lauritzen, S.E. and Lundberg, J.: Calibration of the speleothem delta function: an absolute
390 temperature record for the Holocene in northern Norway, *The Holocene*, 9, 659–669, **1999**.
- 391 Leduc, G., Schneider, R., Kim, J.H. and Lohmann, G.: Holocene and Eemian sea surface
392 temperature trends as revealed by alkenone and Mg/Ca paleothermometry, *Quaternary Science
393 Reviews*, 29 (7), 989-1004, **2010**.
- 394 Lie, Ø., Dahl, S.O., Nesje, A., Matthews, J.A., Sandvold, S.: Holocene fluctuations of a
395 polythermal glacier in high-alpine eastern Jotunheimen, central southern Norway, *Quaternary
396 Science Reviews*, 23, 1925–1945, **2004**.
- 397 Moossen, H., Bendle, J., Seki, O., Quillmann, U. and Kawamura, K.: North Atlantic Holocene
398 climate evolution recorded by high-resolution terrestrial and marine biomarker
399 records, *Quaternary Science Reviews*, 129, 111-127, **2015**.



- 400 Moros, M., Andrews, J.T., Eberl, D.D. and Jansen, E.: Holocene history of drift ice in the northern
401 North Atlantic: Evidence for different spatial and temporal modes, *Paleoceanography*, 21 (2),
402 **2006**.
- 403 Moros, M., Jansen, E., Oppo, D.W., Giraudeau, J. and Kuijpers, A.: Reconstruction of the late-
404 Holocene changes in the Sub-Arctic Front position at the Reykjanes Ridge, north Atlantic, *The*
405 *Holocene*, 22 (8), 877-886, **2012**.
- 406 Nesje, A.: Latest Pleistocene and Holocene alpine glacier fluctuations Scandinavia, *Quaternary*
407 *Science Reviews*, 28 (21-22), 2119-2136, **2009**.
- 408 Nesje, A., Matthews, J.A., Dahl, S.O., Berrisford, M.S., Andersson, C.: Holocene glacier
409 fluctuations of Flatebreen and winter precipitation changes in the Jostedalbreen region,
410 western Norway, based on glaciolacustrine records, *The Holocene* 11, 267–280, **2001**.
- 411 Nesje, A., Jansen, E., Birks, H.J.B., Bjune, A.E., Bakke, J., Andersson, C., Dahl, S.O., Klitgaard-
412 Kristensen, D., Lauritzen, S.-E., Lie, Ø., Risebrobakken, B., Svendsen, J.-I.: Holocene climate
413 variability in the Northern North Atlantic Region: a review of terrestrial and marine evidence.
414 In: Drange, H., Dokken, T., Furevik, T., Gerdes, R. and Berger, W. (Eds.), *The Nordic Seas:*
415 *An Integrated Perspective*, Geophysical Monograph Series, vol. 158, pp. 289–322, **2005**.
- 416 Orme, L.C., Miettinen, A., Divine, D., Husum, K., Pearce, C., Van Nieuwenhove, N., Born, A.,
417 Mohan, R. and Seidenkrantz, M.S: Subpolar North Atlantic sea surface temperature since 6 ka
418 BP: Indications of anomalous ocean-atmosphere interactions at 4-2 ka BP, *Quaternary Science*
419 *Reviews*, 194, 128-142, **2018**.
- 420 Pèlachs, A., Julià, R., Pérez-Obiol, R., Soriano, J. M., Bal, M. C., Cunill, R. and Catalan, J.:
421 Potential influence of Bond events on mid-Holocene climate and vegetation in southern
422 Pyrenees as assessed from Burg lake LOI and pollen records, *The Holocene*, 21 (1), 95-104,
423 **2011**.
- 424 Perner, K., Moros, M., Lloyd, J.M., Jansen, E. and Stein, R.: Mid to late Holocene strengthening
425 of the East Greenland Current linked to warm subsurface Atlantic water, *Quaternary Science*
426 *Reviews*, 129, 296-307, **2015**.
- 427 Perner, K., Jennings, A.E., Moros, M., Andrews, J.T. and Wacker, L.: Interaction between warm
428 Atlantic-sourced waters and the East Greenland Current in northern Denmark Strait (68°N)
429 during the last 10600 cal a BP, *J. Quaternary Science*, 31, 472-483, **2016**.



- 430 Renssen, H., Seppä, H., Heiri, O., Roche, D. M., Goosse, H. and Fichefet, T.: The spatial and
431 temporal complexity of the Holocene thermal maximum, *Nature Geoscience*, 2 (6), 411, **2009**.
- 432 Renssen, H., Seppä, H., Crosta, X., Goosse, H. and Roche, D. M.: Global characterization of the
433 Holocene thermal maximum, *Quaternary Science Reviews*, 48, 7-19, **2012**.
- 434 Reusche, M., Winsor, K., Carlson, A.E., Marcott, S.A., Rood, D.H., Novak, A., Roof, S., Retelle,
435 M., Werner, A., Caffee, M. and Clark, P.U.: 10Be surface exposure ages on the late-Pleistocene
436 and Holocene history of Linnébreen on Svalbard, *Quaternary Science Reviews*, 89, 5-12, **2014**.
- 437 Rimbu, N., Lohmann, G., Kim, J.H., Arz, H.W. and Schneider, R.: Arctic/North Atlantic
438 Oscillation signature in Holocene sea surface temperature trends as obtained from alkenone
439 data, *Geophysical Research Letters*, 30 (6), **2003**.
- 440 Risebrobakken, B., Jansen, E., Andersson, C., Mjelde, E. and Hevrøy, K.: A high-resolution study
441 of Holocene paleoclimatic and paleoceanographic changes in the Nordic
442 Seas, *Paleoceanography*, 18 (1), **2003**.
- 443 Risebrobakken, B., Moros, M., Ivanova, E.V., Chistyakova, N. and Rosenberg, R.: Climate and
444 oceanographic variability in the SW Barents Sea during the Holocene, *The Holocene*, 20 (4),
445 609-621, **2010**.
- 446 Rohling, E. J. and Pälike, H.: Centennial-scale climate cooling with a sudden cold event around
447 8,200 years ago, *Nature*, 434 (7036), 975, **2005**.
- 448 Roth, R. and Joos, F.: A reconstruction of radiocarbon production and total solar irradiance from
449 the Holocene 14C and CO2 records: implications of data and model uncertainties, *Climate of*
450 *the Past*, 9, 1879-1909, **2013**.
- 451 Røthe, T., Bakke, J., Vasskog, K., Gjerde, M., D'Andrea, W.J. and Bradley, R.S.: Arctic Holocene
452 glacier fluctuations reconstructed from lake sediments at Mitrahelvøya, Spitsbergen,
453 *Quaternary Science Reviews*, 109, 111-125, **2015**.
- 454 Sarnthein, M., Van Kreveld, S., Erlenkeuser, H., Grootes, P.M., Kucera, M., Pflaumann, U. and
455 Schulz, M.: Centennial-to-millennial-scale periodicities of Holocene climate and sediment
456 injections off the western Barents shelf, 75° N, *Boreas*, 32 (3), 447-461, **2003**.
- 457 Schmidt, S., Wagner, B., Heiri, O., Klug, M., Bennike, O. and Melles, M.: Chironomids as
458 indicators of the Holocene climatic and environmental history of two lakes in Northeast
459 Greenland, *Boreas*, 40, 116–130, **2011**.



- 460 Sejrup, H.P., Hafliðason, H. and Andrews, J.T.: A Holocene North Atlantic SST record and
461 regional climate variability, *Quaternary Science Reviews*, 30 (21-22), 3181-3195, **2011**.
- 462 Sejrup, H.P., Seppä, H., McKay, N.P., Kaufman, D.S., Geirsdóttir, Á., de Vernal, A., Renssen,
463 H., Husum, K., Jennings, A. and Andrews, J.T.: North Atlantic-Fennoscandian Holocene
464 climate trends and mechanisms, *Quaternary Science Reviews*, 147, 365-378, **2016**.
- 465 Shakesby, R.A., Smith, J.G., Matthews, J.A., Winkler, S., Quentin Dresser, P., Bakke, J., Dahl,
466 S.O., Lie, Ø., Nesje, A.: Reconstruction of Holocene glacier history from distal sources:
467 glaciofluvial stream-bank mires and a glaciolacustrine sediment core near Sota Sæter,
468 Breheimen, southern Norway, *The Holocene*, 17, 729–745, **2007**.
- 469 Sicre, M.A., Jacob, J., Ezat, U., Rouse, S., Kissel, C., Yiou, P., Eiríksson, J., Knudsen, K.L.,
470 Jansen, E. and Turon, J.L.: Decadal variability of sea surface temperatures off North Iceland
471 over the last 2000 years, *Earth and Planetary Science Letters*, 268 (1-2), 137-142, **2008**.
- 472 Seierstad, J., Nesje, A., Dahl, S.O. and Simonsen, J.R.: Holocene glacier fluctuations of
473 Grovabreen and Holocene snow-avalanche activity reconstructed from lake sediments in
474 Grningstlsvatnet, western Norway, *The Holocene*, 12 (2), 211-222, **2002**.
- 475 Snowball, I. and Sandgren, P.: Lake sediment studies of Holocene glacial activity in the Kårsa
476 valley, northern Sweden: contrast in interpretation, *The Holocene*, 6, 367–372, **1996**.
- 477 Solignac, S., Giraudeau, J. and de Vernal, A.: Holocene sea surface conditions in the western North
478 Atlantic: spatial and temporal heterogeneities, *Paleoceanography*, 21 (2), **2006**.
- 479 Solomina, O.N., Bradley, R.S., Hodgson, D.A., Ivy-Ochs, S., Jomelli, V., Mackintosh, A.N.,
480 Nesje, A., Owen, L.A., Wanner, H., Wiles, G.C. and Young, N.E.: Holocene glacier
481 fluctuations, *Quaternary Science Reviews*, 111, 9-34, **2015**.
- 482 Støren, E.N., Dahl, S.O. and Lie, Ø.: Separation of late-Holocene episodic paraglacial events and
483 glacier fluctuations in eastern Jotunheimen, central southern Norway, *The Holocene* 18, 1179–
484 1191, **2008**.
- 485 Svendsen, J. I., and Mangerud, J.: Holocene glacial and climatic variations on Spitsbergen,
486 Svalbard, *The Holocene*, 7 (1), 45-57, **1997**.
- 487 Telesiński, M.M., Spielhagen, R.F. and Lind, E.M.: A high-resolution Late glacial and Holocene
488 palaeoceanographic record from the Greenland Sea, *Boreas*, 43 (2), 273-285, **2014**.



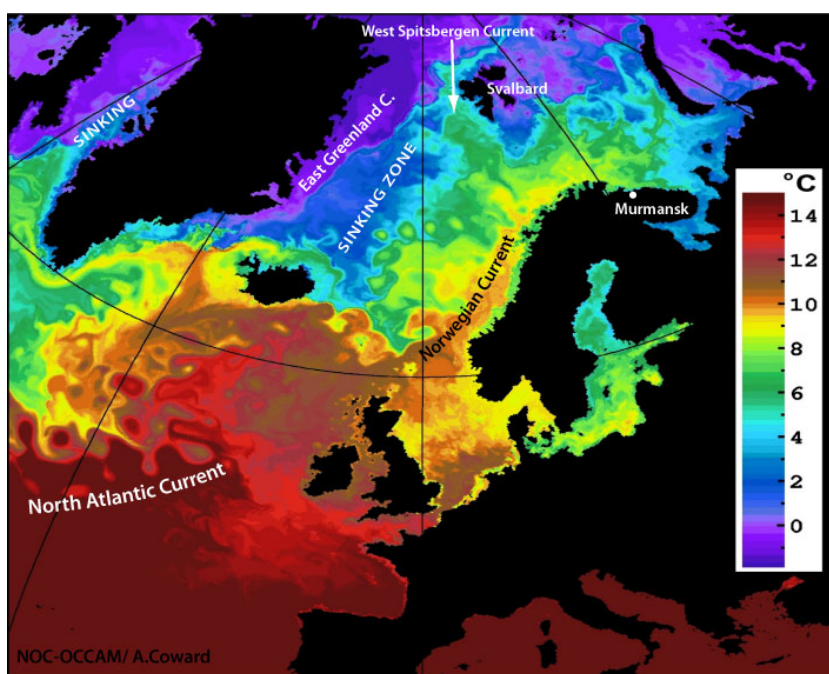
- 489 Van der Bilt, W.G.M, Bakke, J., Vasskog, K., D’Andrea, W.J., Bradley, R.S. and Ólafsdóttir, S.:
490 Reconstruction of glacier variability from lake sediments reveals dynamic Holocene climate in
491 Svalbard, *Quaternary Science Reviews*, 126, 201-218, **2015**.
- 492 Van der Bilt, W.G.M., Rea, B., Spagnolo, M., Roerdink, D.I., Jorgensen, S.I. and Bakke, J.: Novel
493 sedimentological fingerprints link shifting depositional processes to Holocene climate
494 transitions in East Greenland, *Global and Planetary Change*, 164, 52-64, **2018a**.
- 495 Van der Bilt, W.G.M., D’Andrea, W.J., Bakke, J., Balascio, N.L., Werner, J.P., Gjerde M. and
496 Bradley, R.S.: Alkenone-based reconstructions reveal four-phase Holocene temperature
497 evolution for High Arctic Svalbard, *Quaternary Science Reviews*, 183, 204-213, **2018b**.
- 498 Van Nieuwenhove, N., Knudsen, M.F., Pearce, C., Røy, H. and Seidenkrantz, M.-S.: Meltwater
499 and seasonality influence on subpolar Gyre circulation during the Holocene, *Palaeogeography,*
500 *Palaeoclimatology, Palaeoecology*, 502, 104-118, **2018**.
- 501 Vasskog, K., Nesje, A., Støren, E.N., Waldmann, N., Chapron, E., Ariztegui, D.: A Holocene
502 record of snow-avalanche and flood activity reconstructed from a lacustrine sedimentary
503 sequence in Oldevatnet, western Norway, *The Holocene*, 21, 597-614, **2011**.
- 504 Vasskog, K., Paasche, Ø., Nesje, A., Boyle, J.F., Birks, H.J.B.: A new approach for reconstructing
505 glacier variability based on lake sediments recording input from more than one glacier,
506 *Quaternary Research*, 77, 192-204, **2012**.
- 507 Velle, G., Larsen, J., Eide, W., Peglar, S.M., Birks, H.J.B.: Holocene environmental history and
508 climate of Råtåsjøen, a low alpine lake in south-central Norway, *J. Paleolimnology*, 33, 129–
509 153, **2005**.
- 510 Vieira, L.E.A., Solanki, S.K., Krivova, N.A. and Usoskin, I.: Evolution of the solar irradiance
511 during the Holocene, *Astronomy and Astrophysics*, 531, A6, **2011**.
- 512 Vinther, B., Buchardt, S.L., Clausen, H.B., Dahl-Jensen, D., Johnsen, S.J., Fisher, D.A., Koerner,
513 R.M., Raynaud, D., Lipenkov, V., Andersen, K.K., Blunier, T., Rasmussen, S.O., Steffensen,
514 J.P. and Svensson, A.M.: Significant Holocene thinning of the Greenland ice sheet, *Nature*,
515 461, 385-388, **2009**.
- 516 Wagner, B., and Bennike, O.: Holocene environmental change in the Skallingen area, eastern
517 North Greenland, based on a lacustrine record, *Boreas*, 44 (1), 45-59, **2015**.



- 518 Wang, Y., Cheng, H., Edwards, R.L., He, Y., Kong, X., An, Z., Wu, J., Kelly, M.J., Dykoski, C.A.
519 and Li, X.: The Holocene Asian monsoon: links to solar changes and North Atlantic
520 climate, *Science*, 308 (5723), 854-857, **2005**.
- 521 Wanner, H. and Bütikofer, J.: Holocene Bond Cycles: real or imaginary?, *Geografie*, 113 (4), 338-
522 349, **2008**.
- 523 Wanner, H., Beer, J., Buetikofer, J., Crowley, T.J., Cubasch, U., Flueckiger, J., Goosse, H.,
524 Grosjean, M., Joos, F., Kaplan, J.O.: Mid-to late Holocene climate change: an overview,
525 *Quaternary Science Reviews*, 27, 1791-1828, **2008**.
- 526 Wanner, H., Solomina, O., Grosjean, M., Ritz, S.P. and Jetel, M.: Structure and origin of Holocene
527 cold events, *Quaternary Science Reviews*, 30, 3109-3123, **2011**.
- 528 Werner, K., Frank, M., Teschner, C., Müller, J. and Spielhagen, R.F.: Neoglacial change in deep
529 water exchange and increase of sea-ice transport through eastern Fram Strait: evidence from
530 radiogenic isotopes, *Quaternary Science Reviews*, 92, 190-207, **2014**.
- 531 Wittmeier, H.E., Bakke, J., Vasskog, K., Trachsel, M.: Reconstructing Holocene glacier activity
532 at Langfjordjøkelen, Arctic Norway, using multi-proxy fingerprinting of distal glacier-fed lake
533 sediments, *Quaternary Science Reviews*, 114, 78-99, **2015**.
- 534 Wu, C.J., Usoskin, I.G., Krivova, N., Kovaltsov, G.A., Baroni, M., Bard, E. and Solanki, S.K.:
535 Solar activity over nine millennia: A consistent multi-proxy reconstruction, *Astronomy and*
536 *Astrophysics*, 615, A93, **2018**.
- 537 Zhang, Y., Renssen, H. and Seppä, H.: Effects of melting ice sheets and orbital forcing on the early
538 Holocene warming in the extratropical Northern Hemisphere, *Climate of the Past*, 12, 1119-
539 1135, **2016**.
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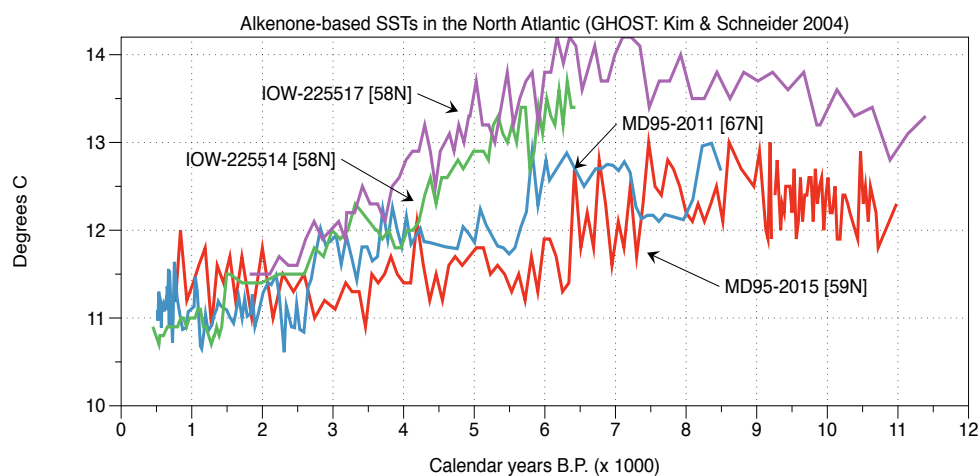


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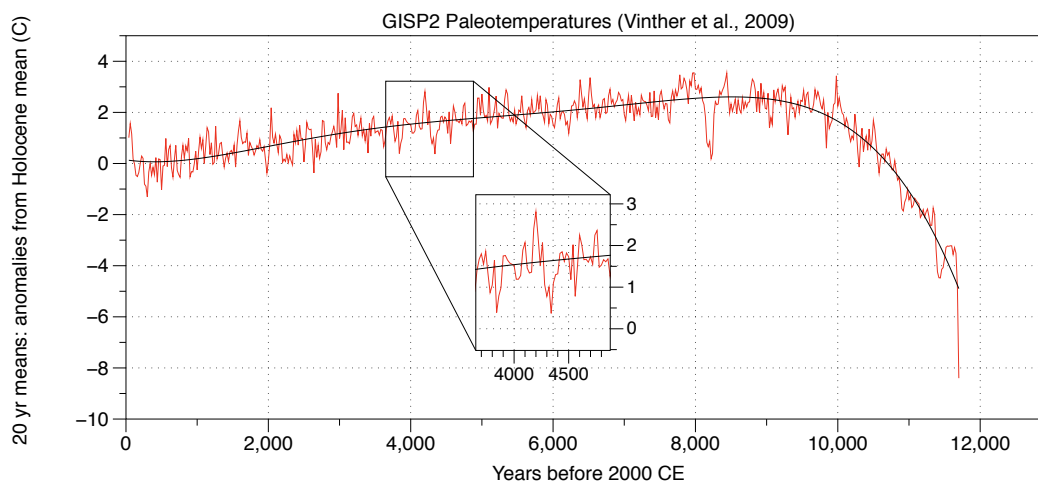
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Figure 1. Major ocean currents in the North Atlantic and associated sea surface temperatures.
(Source: NOC/UK Met-Office OSTIA data; map from <http://www.seos-project.eu>)



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Figure 2. Holocene August SSTs at various locations in the northern North Atlantic (Anderson et al., 2004) and alkenone-based SSTs from sediment cores along a N-S transect in the North Atlantic Current-Norwegian Current system (cf. Figure 1).



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581 **Figure 3.** Oxygen isotope anomalies ($\delta^{18}\text{O}$) relative to the Holocene average. Timescale is in years
582 b2k (before A.D. 2000). The interval around 4.2ka BP is enlarged in the box (Data source:
583 Vinther et al., 2009).

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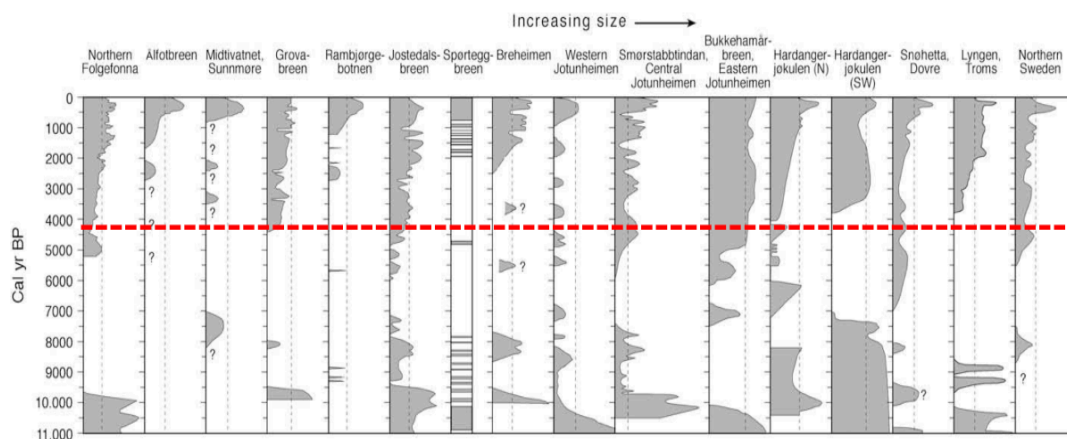
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Figure 4. Summary of glacier extent in various regions of Scandinavia during the Holocene. 4.2ka B.P. is highlighted by the red dashed line (after Nesje, 2009).