The Holocene 8200 BP event: its origin, character and significance

Colin A. Baker

Abstract: A considerable volume of palaeoclimatic research has emerged in the last 20 years since the initial publication of the Greenland ice core records. This review focuses on the pattern of Holocene climate change that includes a remarkable oscillation in the so-called 8.2 ka BP event. The footprint of this is tracked across the North Atlantic, from its spectacular origins in the Hudson Bay megaflood, to the Greenland ice sheet, and on into Western Europe and beyond. Researchers are unanimous in recognising a sharp temperature downturn in this anomaly, but differ in their understanding of its impact on precipitation. A hypothesis of cold aridity is proposed, and the paper concludes with a speculative look into the future.

It is almost 20 years since the first publication of the Greenland GRIP ice core records by the Danish palaeoclimatologist, Willi Dansgaard. At the same time, Wally Broecker at Columbia's Lamont-Doherty Earth Observatory was developing the concept of the global ocean conveyor and proposed ice-rafted debris horizons in Atlantic seabed sediments. Rapid climatic change became an important focus, with as many as 25 Dansgaard-Oeschger cycles in the ice core oxygen isotope records corresponding to Heinrich iceberg events in the oceanic records throughout the Late Pleistocene (Fig. 1).

Our current interglacial period (Holocene) displays little variability in these palaeoclimatic records, whereas the preceding glacial period (Devensian) is noted for frequent and abrupt spikes with $\delta^{18}O$ amplitudes of 3-5‰ implying temperature swings of 8°C or more (Fig. 1) sometimes within only a few decades. Decadal oscillations like these were clearly not the expression of the Milankovitch pace-maker (Lee, 2011), and the search was on for what alternative mechanism might have been responsible. One possible hint came from the rock debris recovered from the Heinrich layers, whose primary source appeared to be Hudson Bay. Could there be a causal link between glacial meltwater released from the waning Laurentian Ice Sheet and the Atlantic Ocean conveyor circulation? And how did ocean-atmosphere coupling operate to transfer these perturbations to the atmosphere above the Greenland ice sheet?

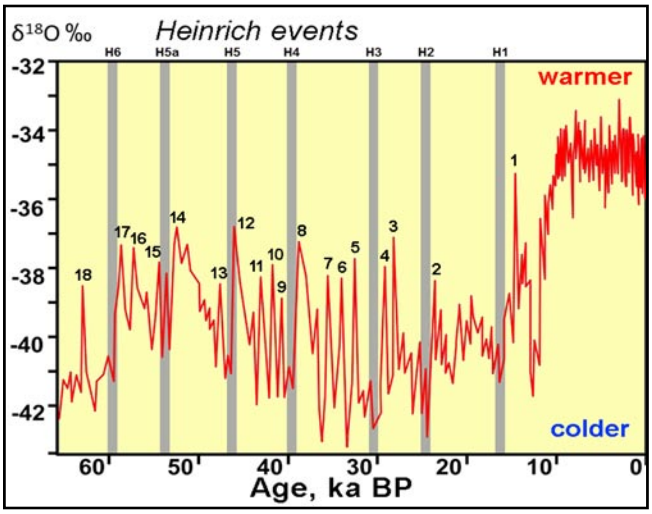

Figure 1. Climate changes for the interval from 65 ka to the present, from the Greenland Ice Sheet Project (GISP2) $\delta^{18}O$ record (after Stuiver and Grootes, 2000); the more positive values correspond to warmer conditions. Numbers 1-18 identify the warm peaks of the Dansgaard-Oeschger oscillations; grey bars are the Heinrich events, H1-H6 (after Delworth et al., 2008).

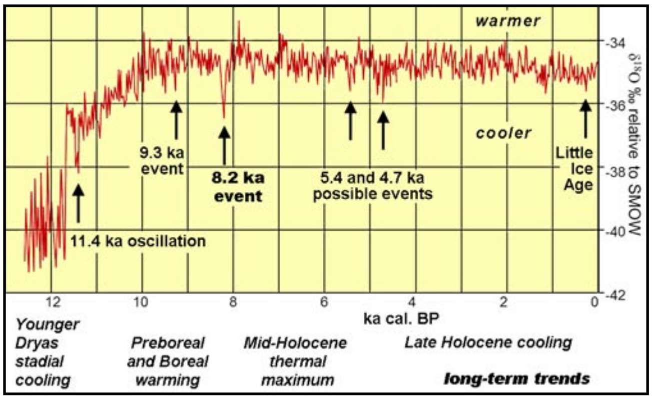

Figure 2. Holocene palaeotemperature reconstruction for Greenland, from GISP2 (after Stuiver and Grootes, 2000).

Examination of the Holocene record in three Greenland ice cores (GRIP, NGRIP and GISP2) was undertaken by Richard Alley and colleagues in 1997, whose explanatory hypothesis has proved particularly fruitful in stimulating a new wave of palaeoclimatic research. Investigating this concept of rapid climate change was driven in part by an IPCC agenda, and sparked immense media interest; the scenario of Atlantic conveyor shutdown was, and remains, a "hot" topic. Alley *et al.* (1997) were the first to identify the so-called 8.2 ka event, a striking climatic anomaly in the otherwise stable profile of the Holocene ice oxygen isotope record (Fig. 2). Numerous studies confirm this to be the most extreme and best defined signal in the whole Holocene. A chain of 8.2 ka BP events is traceable across the North Atlantic, from the Hudson Bay to Greenland to Western Europe, the Mediterranean and beyond (Fig. 3).

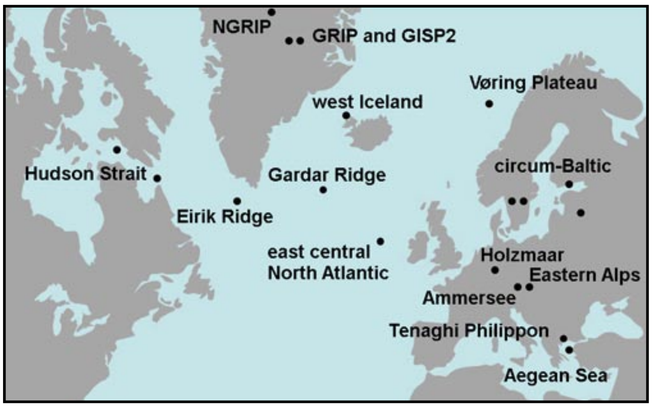

Figure 3. *Locations in the North Atlantic and Europe.*

Glacial Lake Agassiz's megaflood

During the Late Pleistocene and Early Holocene the last remaining North American ice sheet impounded its largest-ever glacial lake, the combined Lake Agassiz-Lake Ojibway, covering an area of about 1.5M km² (Fig. 4). It produced intermittent outbursts through the Mississippi, McKenzie, St Lawrence and Hudson spillways. Partial collapse of ice and meltwater discharge is believed to have generated the Younger Dryas relapse (Lee, 2011). Inevitably, the failure of the last vestige of Laurentian ice released a huge surge into the Labrador Sea and North Atlantic via the Hudson Strait. Dyke (2004) describes this final drainage as a surge of "catastrophic" proportions – a megaflood. A date of 8470±300 cal years BP is widely quoted for this spectacular event. With a rather large error margin, this figure is in fact a compound date based on ten separate radiocarbon measurements. Barber *et al*. (1999) clarify how these were obtained from marine carbonate, collected below and above a red bed marker horizon, within the Hudson Strait channel. Final flood escape is thus constrained between 8580 BP (below) and 8400 BP (above); with 95% probability error margins, a range of dates between 8740 and 8320 is possible, and a further dating in James Bay extends this to 8160 BP.

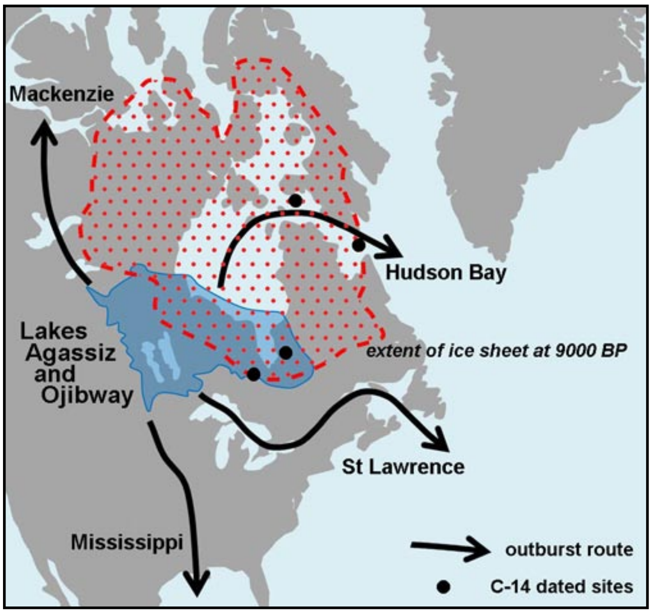

Figure 4. *Lake Agassiz and the routes of its overflow and outbursts (after Barber et al., 1999; Teller et al., 2002).*

All dates given in this paper are in calibrated years BP; they quote relevant authors' figures only where thus calibrated; otherwise, dates have been adjusted using IntCal09 (OxCal version 4.1).

The estimated volume of meltwater released from Lake Agassiz is the subject of some conjecture; figures vary from 50,000 to 500,000 km³, though Teller and Leverington's (2003) estimate of 160,000 km³ is often used. Clarke *et al*. (2004) estimate peak discharges from the Hudson Strait of between 5 and 10 M m³/sec lasting for up to a year. Put in perspective, the entire global input of freshwater from all present-day rivers into the world's oceans is equal to about 1 M m³/sec, so the term "megaflood" is no exaggeration.

These figures have been used to simulate the likely impact that an outburst would have had on oceanic and atmospheric behaviour (Gregoire *et al*., 2012). A rise in global sea level is calculated at 1.2 m for a volume of 430,000 km³ by Tornqvist *et al.* (2004); Bauer *et al*. (2004) assumed 160,000 km³ over a two-year period, corresponding to a mean sea level rise of 0.5 m, probably accompanied by large gravity waves and increased coastal flooding all around the North Atlantic. While the actual volume remains uncertain, the suggestion of near-instantaneous coastal inundation over a wide area seems entirely credible. There is no evidence for any further massive freshwater release into the North Atlantic after 8000 BP.

North Atlantic freshwater forcing

At about 8.47 ka BP the Lake Agassiz surge coincided with the start of the most pronounced Holocene cold period recorded in the North Atlantic area, the 8.2 ka BP event. Several authors explain this in terms of freshwater forcing, suppressing the normal thermohaline circulation, or, more strictly, the meridional overturning circulation (MOC), which drives the sinking of dense saline surface water, and maintains northward heat transport in the North Atlantic Ocean. Figure 5 illustrates the principal present day overturning, with North Atlantic, Irminger and Norwegian currents conveying warm water northwards, and five inter-connected, deep-water, cold currents carrying dense water southwards; descending convection (or deep water formation) is indicated at three locations. Evidence for slowing of the MOC engine is well documented in the earlier Younger Dryas and Heinrich events, but the Holocene deceleration has only been confirmed more recently.

Several research groups have performed computer simulations to test the MOC engine hypothesis, concluding that a megaflood of Lake Agassiz proportions would indeed have been capable of lowering the surface water density needed to maintain salinity-driven deep water circulation. Freshening and cooling of the North Atlantic would also have greatly increased the extent and thickness of sea ice, contributing further to overall

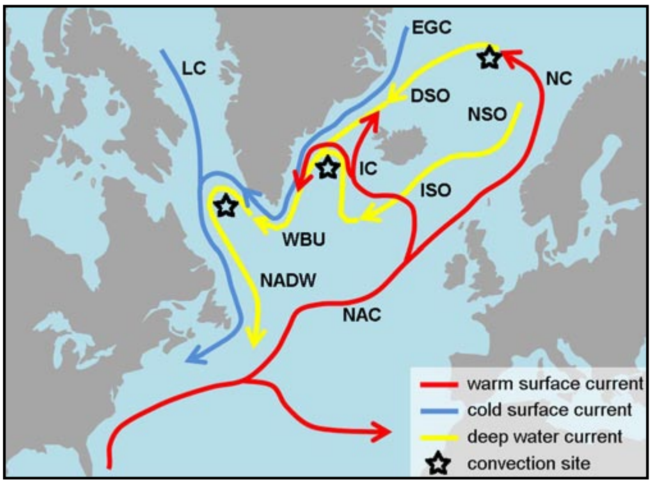

***Figure 5**. North Atlantic meridional overturning circulation (after Kleiven et al., 2008; Delworth et al., 2008; Quillmann et al., 2012). Warm surface currents: NAC = North Atlantic; NC = Norwegian; IC = Irminger. Cold surface currents: LC = Labrador; EGC = East Greenland. Deep water currents: NSO = Nordic Sea Overflow; ISO = Iceland-Scotland Overflow; DSO = Denmark Strait Overflow; WBU = Western Boundary Undercurrent; NADW = North Atlantic Deep Water.*

cooling through positive feedback. Bauer *et al*. (2004) calculate a 40% reduction in MOC, LeGrande *et al*. (2006) reach a similar figure (30-60%), capable of reducing sea surface temperatures by 2-3°C; Wiersma and Renssen (2006) estimate a drop of 5°C in sea surface temperature. Such a scenario could have persisted for many decades.

The palaeo-oceanographic record

Until ten years ago, there was little palaeoceanographic evidence to confirm these theoretical models, certainly none to match the well-documented Younger Dryas and Dansgaard-Oeschger/Heinrich events which had already shown decreases in ocean ventilation and MOC reduction as theory predicted. For the Holocene itself, Bond *et al*. (1999) had already identified cycles of ice-rafted debris (IRD) in the abyssal plain of central east North Atlantic (Fig. 3); Bond event 5 is synchronous with the 8.2 ka BP event, and petrologic tracers pointed mainly to an iceberg source in Greenland and Iceland, with ice-bearing meltwater pushing south well into the path of the warm North Atlantic Current. The authors suggested that the IRD cycles should be regarded as "mini Dansgaard-Oeschger events". In the last ten years at least four research teams (Risebrobakken *et al*. 2003; Ellison *et al*. 2006; Kleiven *et al*. 2008; Quillmann *et al*. 2008) have conducted well-dated high-resolution analyses on deep sea marine cores, using temperature-sensitive foraminifera (Fig. 6). Foram frequency, stable isotope analysis ($\delta^{18}O$ and $\delta^{13}C$), chemical ratios and sortable silt fractions have all been employed to reconstruct sea surface temperature, salinity, productivity and bottom water flow speeds.

Both the Eirik and Gardar Ridges (Fig. 3) are sites of contourite sediments, fine-grained seabed sediments deposited and streamlined along ridge contours by bottom-moving currents. Eirik Ridge is followed by the Western Boundary Undercurrent close to the Labrador Sea where the impact of the freshwater pulse must have been initially felt. It was here that Kleiven *et al*. (2006) found a sharp increase of $\delta^{18}O$ in *N. pachyderma (s)*, a polar planktonic pelagic foram, confirming the sea surface cooling by ~1.5°C, together with an abrupt decrease in $\delta^{13}C$ in the benthic foram *C. wuellerstorfi*, confirming a change in productivity related to decreased ventilation. These abrupt changes, followed by rapid recovery, are dated to a 100-year period between 8380 and 8270 BP. Ellison *et al*. (2006) examined the sortable silt fraction (a proxy for deep current flow speed) in contourite on Gardar Ridge (Iceland-Scotland Overflow), finding a significant decrease between 8450 and 8040 BP, co-registered with an increase of *N. pachyderma (s)* centred on 8290 BP. The influence of the Denmark Strait Overflow has been investigated in West Iceland (Quillmann *et al*. 2008), where Mg/Ca ratios of calcite in the benthic species *C. lobatulus* confirm cooling at around 8200 BP. Today, the Irminger Current carries relatively warm (4-7°C) and saline (35‰) water to Iceland; this was cooled by ~3°C and freshened by ~1‰ for a period lasting 100 years. Further east still, the Risebrobakken team (2003) detected a sharp increase in *N. pachyderma (s)* on the Vøring Plateau west of Norway, suggesting a similar SST decrease of 3°C for a 70-year period. Figure 7 plots these time spans, showing that the cold freshwater pulse from the Hudson Strait must have diffused across the North Atlantic within a 300 year period. This provides strong confirmation of MOC reduction, freshening and cooling as predicted by the simulation models.

The total length of Atlantic cooling (in excess of 300 years) has prompted some observers (e.g. Rohling and Pälike, 2005) to suggest that there may in fact be two forcing mechanisms at work simultaneously – MOC reduction related to the Hudson Bay meltwater discharge, and also background changes in solar radiation. Modelling studies show that changes in insolation alone were not large enough to induce the observed temperature drop over the North Atlantic, therefore meltwater release must have been involved.

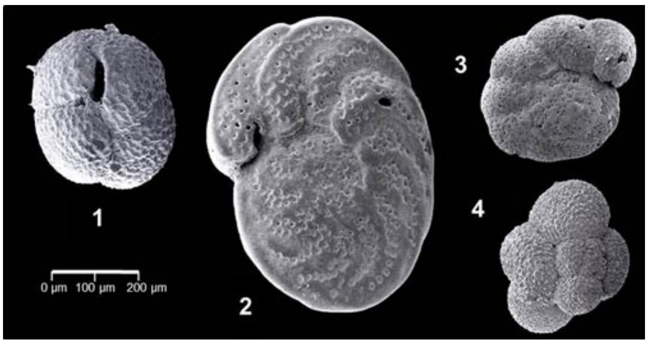

***Figure 6**. SEM images of diagnostic marine foraminifera: 1, Neogloboquadrina pachyderma (s); 2, Cibicidoides wuellerstorfi; 3, Cibicides lobatulus; 4, Globigerina bulloides (from Image Database of Foraminifera.eu-Project).*

The 8.2 ka event in the ice core record

In Greenland, six major deep-drilling projects have been undertaken over the last 40 years (Camp Century, DYE3, Renland, GRIP, GISP2 and NGRIP), the more recent of which provide a remarkably consistent pattern of Holocene temperature fluctuation (Figs. 1 and 2). Periodic cooling events are identified at 11.4 ka, 9.3 ka, 8.2 ka and 0.5 ka BP. Dating of ice cores is achieved principally by layer counting (Fig. 8), but this becomes less reliable with depth as annual layering deteriorates. Greater precision and cross-correlation are achieved by tephrochronology on known volcanic horizons.

Oxygen-isotope ($\delta^{18}O$) variations are a function of air temperature at the time of snowfall, colder episodes being marked by more negative values, since cold snow is depleted in heavier oxygen-18. The degree of cooling is calculated with reference to standard pure water (SMOW). Thus the Younger Dryas stadial (Fig. 2, ~12 ka BP) has a value at or below -40‰, and Holocene values rise to about -35‰ (Fig. 2, ~10 ka BP). Time resolution in the GRIP curve is 50 years, but a finer 20-year resolution is achieved in GISP2. Chronologies of three ice cores (DYE3, GRIP and NGRIP) have been synthesised in a revised timescale (GICC05, Greenland Ice Core Chronology 2005) by employing an improved 5-year resolution (Vinther *et al.*, 2006). Such time resolution varies with ice core depth, chosen proxy, and the researchers' choice of running averages to create meaningful trends. Hence a 5-year floating average (using the GICC05 data) was employed successfully by both Thomas *et al*. (2007) and Rasmussen *et al*. (2007) to reproduce the detailed shape of the 8.2 ka BP anomaly.

This most pronounced of all Holocene cold episodes has a $\delta^{18}O$ differential amounting to about half that of the Younger Dryas stadial, but over twice that of the Little Ice Age, prompting Seppa *et al*. (2007) to comment that this was "a unique feature within the last 10,000 years in terms of magnitude and abruptness". Decline in oxygen isotope values is matched by equally dramatic changes in other proxy indicators: a decrease in methane (showing a decline in biogenic sources), an increase in chlorides (showing uptake of sea-salt in a strengthened circulation), an increase in calcium (from continental dust) and an increase in ammonium (signalling greater forest-fire frequency). Thomas *et al*. (2007) also describe low snow accumulation rates in the 8.2 ka BP ice layers (31% lower than the Holocene average). This figure together with continental dust and increased fire frequency points to greater dryness. The 8.2 ka BP downturn was thus both cold and dry. It is this co-registration of six proxies that confirms the profound significance of the climatic reversal (Alley *et al*. 1997; Alley and Agustsdottir, 2005).

At least three studies have succeeded in accurately establishing the timing of the event (Fig. 7). Thomas *et al*. (2007) see the full event lasting 160±5 years, starting in 8247 BP, with an extreme central event of 69±2 years beginning 8212 BP. Slightly earlier figures are reported by Rasmussen *et al*. (2007) with the full event starting 8300 BP, lasting 160 years, and with a shorter 5-year central event. Using methane and $\delta^{15}N$ from trapped air bubbles, Kobashi *et al*. (2007) arrive at slightly later dates, suggesting a rapid cooling and drying at 8175±30 BP that established in less than 20 years, with an extreme cold spell lasting 60 years and a recovery period of 70 years, giving a total duration of 150 years. The combined evidence from these three sources places the climatic anomaly confidently within the period 8300 BP to 8000 BP. Further work on ECM (Electrical Conductivity Measurement) in three ice cores (Vinther *et al*., 2006) has identified fall-out from an Icelandic volcanic eruption located inside the $\delta^{18}O$ minimum, dated at 8236±47 BP, part of an Early Holocene interval characterised by significant increases in volcanic aerosol production (Zielinski *et al*., 1994). This is an important point in the light of suggestions that the 8200 BP event might be thought of as a reliable analogue for future climate change; on the contrary, it may have involved a fortuitous combination of forcing factors (solar reduction, freshwater release and volcanic emissions acting together), and is therefore unlikely to be repeated in the same way in the future.

		Dating (years BP)
Lake Agassiz flood (Hudson Strait)	below red bed (east) below red bed (west) above red bed (west) above red bed (east)	*Barber et al, 1999*
Eirik Ridge (Western Undercurrent)		*Kleiven et al, 2008*
Gardar Ridge (Iceland-Scotland Overflow)		*Ellison et al, 2006*
West Iceland (Denmark Strait Overflow)		*Quillmann et al, 2008*
East central North Atlantic (abyssal plain)		*Bond et al, 1997*
Norwegian Current (Nordic Sea Overflow)		*Risebrobakken et al, 2003*
Greenland ice cores GRIP/GISP2		*Thomas et al, 2006*
Greenland ice cores GRIP/NGRIP		*Rasmussen et al, 2006*
Greenland ice core GISP2		*Kobashi et al, 2007*
Southern Baltic Sea area		*Seppa et al, 2005, 2007*
North Germany (Holzmaar)		*Prasad et al, 2009*
South Germany (Ammersee)		*von Grafenstein et al, 1999*
Eastern Alps (EACC)		*Nicolussi et al, 2009*
Tenaghi Philippon (Greece)		*Pross et al, 2009*
Aegean Sea		*Katsouras et al, 2008;* *Marino et al, 2009*

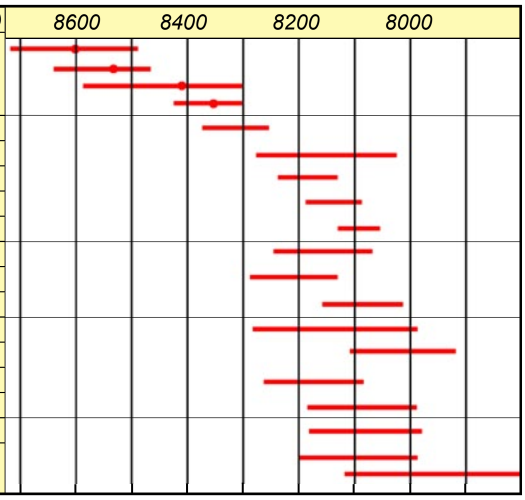

***Figure** 7. Co-ordinated time spans of North Atlantic and European 8.2 ka BP events, as described in the text.*

Cooling in Europe in the 8.2 ka event

Throughout Europe, there is now an improved network of Holocene palaeorecords benefiting from high time-resolution and firm, calibrated, radiocarbon control. Figure 3 displays a selection of such sites from which it has been possible to gauge the likely impact that the North Atlantic anomaly had at 8.2 ka BP.

Seppa *et al.* (2005, 2007) synthesise well-dated pollen records in Scandinavia and the southern Baltic rim, in which hazel, elm and alder decline simultaneously and abruptly between 8300 and 8000 BP south of 61°N. Nicolussi *et al.* (2009) identify a 200-year period of very poor tree growth from 8200-8000 BP in the detailed Eastern Alps Conifer Chronology. Further Alpine evidence is given by Tinner and Lotter (2001) from varved sediments that register a sudden collapse of hazel woodland at around 8.2 ka BP: hazel, normally well-adapted to continental conditions and seasonal drought, appears to have succumbed in less than twenty years. At Ammersee (southern Germany) a long $\delta^{18}O$ profile from benthic ostracods (von Grafenstein *et al.* 1999) provides isotopic evidence of a strong downturn over 200 years, and another high-resolution analysis from Holzmaar, North Germany (Prasad *et al.* 2009), detects a 180-year anomaly with remarkable precision, seasonally resolved into summer cooling (from 8117 to 7929 BP) and cold dry winters (8089-8006 BP). Time spans for these studies show that climatic deterioration across Western Europe struck within the interval 8300 BP to 7950 BP (Fig. 7).

A comprehensive pollen approach to temperature reconstruction in Europe, undertaken by Davis *et al.* (2003) places these findings in broader context (Fig. 9). In this vegetational study, surface air temperatures were assigned to 93 tree, shrub and herb taxa using Plant Functional Type analysis. Using over 2000 radiocarbon-dated pollen sequences, the mean annual, mean coldest and mean warmest monthly temperatures were then calculated for the complete Holocene, with a time resolution of 100 years. Postglacial recovery finds

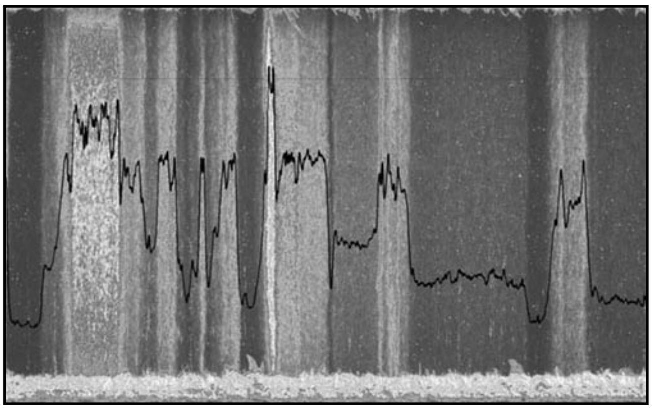

Figure 8*. Ice layering in core from the North Greenland Ice Core Project (NGRIP) showing annual banding from about 1800 m depth (about 20,000 years old). The black trace shows variations in light intensity measured by a line scanner (courtesy of Søren Wedel Nielsen, Texas A & M University).*

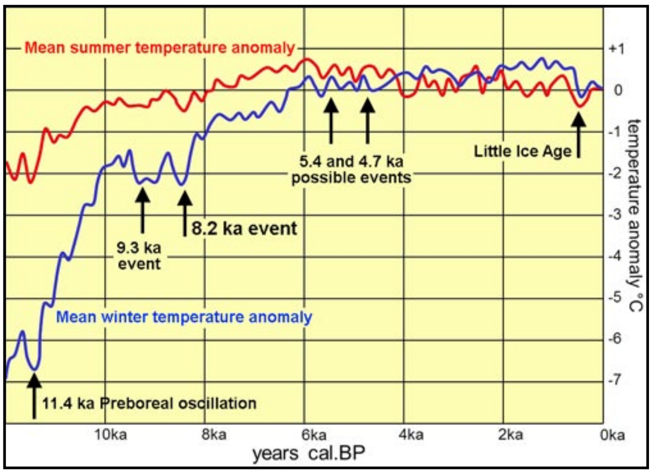

Figure 9*. Holocene temperature reconstruction for central western Europe (after Davis et al., 2003).*

clear expression in both winter and summer curves, with the latter rising to an attenuated peak at 6000 BP (the thermal maximum). The gap between summer and winter curves closes gradually, showing a narrowing of seasonal temperature range, and thus a move from the more extreme continental conditions of the Early Holocene towards more oceanic moderation in the Middle Holocene. Cooling periods are recognised at several points: 11.5 ka, 9.4-9.0 ka, 8.5 ka, 5.7 ka and 0.5 ka BP. Three of these events match those already identified within the GISP2 record (Fig. 2), but the 8.2 ka BP event makes a slightly early appearance. An apparent mismatch like this might correspond to the earlier Rasmussen chronology rather than the Thomas equivalent (Fig. 7).

Northern hemisphere reach

In the Mediterranean region the Early Holocene warm humid optimum is widely recognised in Sapropel S1 in numerous marine cores. Climatic deterioration at around 8.2 ka BP is observed in a marker horizon within S1 and is particularly well-preserved in the Aegean and Adriatic Seas (Rohling *et al.* 1997; Marino *et al.* 2009). Another key location is Tenaghi Philippon (Fig. 3), where a well-documented pollen sequence confirms cold dry conditions coincident with the mid-S1 interval (Pross *et al.* 2009; Peyron *et al.* 2011). Evidence within the wider Mediterranean basin is reviewed by Jalut *et al.* (2009), and links to the Middle East are discussed by Rohling and Palikë (2005). Farther afield, Jin *et al.* (2007) critically examine the 8.2 ka BP record in the Far East.

Aridity or humidity?

What was the hydrological response to the 8.2 ka BP anomaly? Clear expression of drought is undeniable in the Greenland ice cores (Alley *et al*., 1997; Thomas *et al*., 2007), and model simulations (Wiersma and Renssen, 2006; LeGrande *et al*., 2008) point to general drying across the whole of the North Atlantic region and into the Mediterranean. In western Europe, the

Figure 10. The frozen River Thames in 1677 during the Little Ice Age; a painting by artist unknown, now in the Museum of London. These conditions give some hint as to the severity of cold aridity and the inevitable environmental crisis that struck Britain as the 8.2 ka event during the Later Mesolithic.

impressive Holzmaar record clearly registers drier conditions in both summer and winter. Cold aridity in the broader region around the North Atlantic is inferred from reactivated aeolian sediments (sand dunes, cover sands and loess), identified and luminescence-dated to around 8200 BP at several locations: Michigan and Ohio (USA), Britain, Finland, Denmark, Netherlands, Germany, Spain, Portugal and the Canary Islands.

Not all studies agree with this interpretation, however. A shift to *wetter* conditions, for example, has been proposed for the 8.2 ka BP event in Britain (Macklin and Lewin 2003; Vincent *et al*. 2011), in Sweden (Seppa *et al*. 2005; Snowball *et al*. 2010) and in the Alps (Spötl *et al*. 2010). How do we account for these conflicting views? Dating uncertainties may be involved, while coarse time resolution can sometimes fail to detect short-term (decadal) oscillations. Palaeoclimatic interpretation of $\delta^{18}O$ proxies (in lake carbonates and speleothems, for example) is not always straightforward (Frisia *et al*. 2006; Spötl *et al*. 2010). In Norway, a period of significant glacial advance (the Finse event) occurs at 8200 BP, but this can be interpreted in terms of either increased winter snowfall or cooler summers with reduced ablation (Nesje *et al*. 2006).

Researchers increasingly recognise that answers must be sought at the detailed seasonal level. Hammarlund *et al*. (2005), for example, envisage strong seasonality in the Scandinavian examples, with dry cold winters alternating with cool (but more humid) summers. Another approach sees the 8.2 ka BP downturn expressing itself in a variety of different regional climates; one size may not fit all. This might seem a rather fail-safe, non-falsifiable working hypothesis, and it is suggested that a concept of cold aridity would provide a more consistent and workable framework. Further well-dated high-resolution investigations are clearly needed.

Some commentators have drawn a parallel with the Little Ice Age (Fig. 10). As far as it goes, this is a helpful analogue for understanding blocking anticyclone drought, but there are important differences. The Little Ice Age in all probability was driven by reduction in solar radiation alone. In contrast, the 8.2 ka BP event was more complex; it was a unique event in the Holocene, unlikely ever to be repeated. The temperature reversal at 8.2 ka BP was far greater than the Little Ice Age downturn, suggesting that environmental conditions in Europe were considerably worse at that time (Fig. 2).

Will history repeat itself?

In a word, no. But this has not prevented some sections of the media from peddling an alarmist message. In the late 1990s, emerging data from the Greenland ice cores and Atlantic marine cores popularised the concept of rapid climate change. Freshening of North Atlantic waters by global warming of the Greenland ice sheet could, it was said, theoretically shut down the Atlantic conveyor, plunging Western Europe into a glacial freeze within a decade or two. Following an IPCC report in 2001, predicting the possibility of imminent Atlantic conveyor shutdown, the New York Times ran an editorial in 2002 entitled “The Heat Before the Cold”, and the BBC screened a Horizon documentary on “The Big Chill” in November 2003. These voices lent credibility to a provisional study (Bryden *et al*. 2005) suggesting a 30% reduction in MOC between 1957 and 2004.

Picked up by the more sensational tabloid press, the story grew, fuelled by further speculation as portrayed in the 2004 disaster movie “The Day after Tomorrow” (which The Guardian described as a great movie but lousy science), and Al Gore’s “An Inconvenient Truth” in 2006. Meanwhile, theoretical modelling had already raised doubts. In 2004, the Lamont-Doherty Earth Observatory stated that in the event of a complete shutdown of the thermohaline circulation Europe might be cooled by 2-4°C, but the Gulf Stream itself, being partially wind-driven, would continue to be propelled onwards by the prevailing westerlies; Greenland ice-melt freshening would largely be confined to the Labrador Sea region. Later, Cunningham *et al*. (2007) published new data, revising the short-term figures of Bryden *et al.* (2005), to demonstrate that they were actually part of a natural cycle of variability. NASA have since published evidence (2010) confirming no significant slowing in the North Atlantic circulation since 1995, and certainly no change in circulation strength between 2002 and 2009.

An influential congressional report (Delworth *et al*. 2008) concludes that a 30% reduction in MOC strength is very probable during the 21st century, but that circulation collapse would be highly unlikely. It is emphatically not possible, in the authors' view, for global warming to cause an ice age. The report does warn, however, that global warming *of itself* will be responsible for MOC reduction, to which will be added an *uncertain* amount of freshening as a result of Arctic and Greenland ice-melt. The possibility therefore of complete MOC collapse beyond the end of the 21st century "cannot be entirely excluded". Thus the most likely scenario for Europe in this century will be a gradual slowdown (but not shutdown) of the North Atlantic Ocean circulation, but a repetition of the dramatic climate change reconstructed for the 8.2 ka BP event will not pose a threat in our lifetimes.

Acknowledgements

The author thanks the library staff at BGS Keyworth for kind assistance in locating some of the less accessible references in this literature review. Andy Howard, David Knight, Mark Bateman and Tony Waltham offered useful advice in its compilation, and Richard Hamblin is thanked for reviewing the draft and making helpful suggestions.

References

Alley, R.B. & Agustsdottir, A.M., 2005. The 8k event: cause and consequences of a major Holocene abrupt climate change. *Quat. Sci. Rev.,* **24**, 1123-1149.

Alley, R.B., Mayewski, P.A., Sowers, T., Stuiver, M., Taylor, K.C. & Clark, P.U., 1997. Holocene climatic instability: a prominent widespread event 8200 yr ago. *Geology*, **25**, 483-486.

Barber, D.C., Dyke, A., Hillaire-Marcel, C., Jennings, A. E., Andrews, J.T., Kerwin, M.W., Bilodeau, G., McNeely, R., Southon, J., Morehead, M.D. & Gagnon, J-M., 1999. Forcing of the cold event of 8,200 years ago by catastrophic drainage of Laurentide lakes. *Nature*, **400**, 344-348.

Bauer, E., Ganopolski, A. & Montoya, M., 2004. Simulation of the cold climate event 8200 years ago by meltwater outburst from Lake Agassiz. *Palaeoceanography,* **19**, PA3014.

Bond, G.B., Showers, W., Cheseby, M., Lotti, R., Almasi, P., deMenocal, P., Priore, P., Cullen, H., Hajdas, I., Bonani, G., 1997. A pervasive millennial-scale cycle in North Atlantic Holocene and glacial climates*. Science,* **278**, 1257-1266.

Bryden, H.L., Longworth, H.R. & Cunningham, S.A.., 2005. Slowing of the Atlantic meridional overturning circulation at 25°N. *Nature*, **438**, 655-657.

Clarke, G.K.C., Leverington, D.W., Teller, J.T. & Dyke, A.S., 2004. Paleohydraulics of the last outburst flood from glacial Lake Agassiz and the 8200BP cold event. *Quat. Sci. Rev.,* **23**, 389-407.

Clarke, G.K.C., Bush, A.B.G. & Bush, J.W.M., 2009. Freshwater discharge, sediment transport, and modeled climate impacts of the final drainage of Glacial Lake Agassiz. *J. Climate*, **22**, 2161-2180.

Cunningham, S.A., Kanzow,T., Rayner, D., Baringer, M.O., Johns, W.E., Marotzke, J., Longworth, H., Grant, E., Hirschi, J., Beal, L., Meinen, C.S. and Bryden, H., 2007. Temporal variability of the Atlantic meridional overturning circulation at 26.5°N. *Science,* **317**, 935-938.

Davis, B.A.S., Brewer, S., Stevenson, A.C., Guiot, J. and 141 data contributors, 2003. The temperature of Europe during the Holocene reconstructed from pollen data. *Quat. Sci. Rev*, **22**, 1701-1716.

Delworth, T.L., Clark, P.U., Holland, M., Johns, W.E., Kuhlbrodt, T., Lynch-Stieglitz, J., Morrill, C., Seager, R. & Weaver, A.J., 2008. The potential for abrupt change in the Atlantic meridional overturning circulation. Chapter 4 in *Abrupt Climate Change*, Final SAP Report presented to the U.S. Congress by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research.

Dyke, A.S., 2004. An outline of North American deglaciation with emphasis on central and northern Canada. *Developments in Quaternary Sciences*, 2B.

Ellison, C.R.W., Chapman, M.R., & Hall, I.R., 2006. Surface and deep ocean interactions during the cold climate event 8200 years ago. *Science,* **312**, 1929-1932.

Frisia, S., Borsato, A., Mangini, A., Spötl, C., Madonia, G. & Sauro, U., 2006. Holocene climate variability in Sicily from a discontinuous stalagmite record and the Mesolithic to Neolithic transition. *Quat. Res.,* **66**, 388-400.

Gregoire L.J., Payne, A.J. and Valdes, P.J., 2012. Deglacial rapid sea level rises caused by ice-sheet saddle collapses. Nature, **487**, 219-222.

Hammarlund, D., Björck, S., Buchardt, B., and Thomsen, C.T., 2005. Limnic responses to increased effective humidity during the 8200 cal. yr BP cooling event in southern Sweden. *J. Palaeolimnology*, **3**, 471-480.

Jalut, G., Dedoubat, J.J., Fontugne, M. & Otto, T., 2009. Holocene circum-Mediterranean vegetation changes: climate forcing and human impact. *Quaternary International,* **200**, 4-18.

Jin Z., Yu J., Chen H., Wu Y., Wang S., & Chen S., 2007. The influence and chronological uncertainties of the 8.2 ka cooling event on continental climate records in China. *The Holocene*, **17**, 1041-1050.

Katsouras, G., Gogou, A., Emeis, K-C., Bouloubassi, I, Triantaphyllou, M. V. & Lykousis, V., 2008. Biogeochemical evidence for late climatic variability in the Aegean Sea during the formation of Holocene sapropel S1. *1st MedCLIVAR-ESF Summer School*, Rhodos, Greece.

Kleiven, H.F., Kissel, C., Laj, C., Ninnemann, U.S., Richter, T.O. & Cortijo, E., 2008. Reduced North Atlantic deep water coeval with the glacial Lake Agassiz freshwater outburst. *Science,* **319**, 60-64.

Kobashi, T., Severinghaus, J.P., Brook, E.J., Barnola, J.-M., & Grachev, A.M., 2007. Precise timing and characterization of abrupt climate change 8200 years ago from air trapped in polar ice. *Quat. Sci. Rev*, **26**, 1212-1222.

Lee, J., 2011. Cool Britannia: from Milankovitch wobbles to Ice Ages. *Mercian Geologist*, **17**, 274-279.

LeGrande, A.N., Schmidt, G.A., Shindell, D.T., Field, C.V., Miller, R.L., Koch, D.M., Faluvegi, G. & Hoffmann, G., 2006. Consistent simulations of multiple proxy responses to an abrupt climate change event. *Proc. Nat. Acad. Sci.,* **103**, 837-842.

Macklin, M.G. & Lewin, J., 2003. River sediments, great floods and centennial-scale Holocene climate change. *J. Quat. Sci.*, **18**, 101-105.

Marino, G., Rohling, E.J., Sangiorgi, F., Hayes, A., Casford, J.L., Lotter, A.F., Kucera, M., & Brinkhuis, H., 2009. Early and middle Holocene in the Aegean Sea: interplay between high and low latitude climate variability. *Quat. Sci. Rev,* **28**, 3246-3262.

Nesje, A., Bjune, A.E., Bakke, J., Dahl, S.O., Lie, Ø. & Birks, H.J.B., 2006. Holocene palaeoclimate reconstructions at Vanndalsvatnet, western Norway, with particular reference to the 8200 cal. yr BP event. *The Holocene*, **16**, 717-729.

Nicolussi, K., Kaufmann, M., Melvin, T.M., van der Plicht, J., Schiessling, P. & Thurner, A., 2009. A 9111 year long conifer tree-ring chronology for the European Alps: a base for environmental and climatic investigations. *The Holocene*, **19**, 909-920.

Peyron, O., Goring, S., Dormoy, I., Kotthoff, U., Pross, J., de Beaulieu, J-L., Drescher-Schneider, R., Vannière, B. & Magny, M., 2011. Holocene seasonality changes in the central Mediterranean region reconstructed from the pollen sequences of Lake Accesa (Italy) and Tenaghi Philippon (Greece). *The Holocene*, **21**, 131-146.

Prasad, S., Witt, A., Kienel, U., Dulski, P., Bauer, E. & Yancheva, G., 2009. The 8.2 ka event: evidence for seasonal differences and the rate of climate change in western Europe. *Global and Planetary Change,* **67**, 218-226.

Pross, J., Kotthoff, U., Müller, U.C., Peyron, O., Dormoy, I., Schmiedl, G., Kalaitzidis, S. & Smith, A.M., 2009. Massive perturbation in terrestrial ecosystems of the Eastern Mediterranean region associated with the 8.2 kyr climatic event. *Geology,* **37**, 887-890.

Quillmann, U., Marchitto, T.M., Andrews, J.T., Jennings, A.E., & Dean, W.E., 2008. North Atlantic cooling and freshening at 8.2 ka detected in foraminiferal Mg/Ca and d180 ratios. *Proc 38th International Arctic Workshop.*

Rasmussen, S.O., Vinther, B.M., Clausen, H.B. & Andersen, K.K., 2007. Early Holocene climate oscillations recorded in three Greenland ice cores. *Quat. Sci. Rev,* **26**, 1907-1914.

Risebrobakken, B., Jansen, E., Andersson, C., Mjelde, E. & Hevrøy, K., 2003. A high-resolution study of Holocene palaeoclimatic and palaeoceanographic changes in the Nordic Seas. *Palaeoceanography*, **18**, 1017.

Rohling, E.J., Jorissen, F.J. & de Stigter, H.C., 1997. 200-year interruption of Holocene sapropel formation in the Adriatic Sea. *J. Micropalaeo.*, **16**, 97-108.

Rohling, E.J. & Pälike, H., 2005. Centennial-scale climate cooling with a sudden cold event around 8,200 years ago. *Nature*, **434**, 975-979.

Seppa, H., Hammarlund, D. & Antonsson, K. 2005. Low- and high-frequency changes of temperature and effective humidity during the Holocene in south central Sweden: implications for atmospheric and oceanic forcings of climate. *Climate Dynamics*, **25**, 285-297.

Seppa, H., Birks, H.J.B., Glesecke, T., Hammarlund, D., Alenius, T., Antonsson, K., Bjune, A.E., Heikkilä, M., MacDonald, G.M., Ojala, A.E.K., Telford, R.J. & Veski, S., 2007. Spatial structure of the 8200 cal yr BP event in Northern Europe. *Climate of the Past,* **3**, 225-236.

Snowball, I., Muscheler, R., Zillen, L.,Sandgren, P, Stanton, T. & Ljung, K., 2010. Radiocarbon wiggle matching of Swedish lake varves reveals asynchronous climate changes around the 8.2 kyr cold event. *Boreas*, **39**, 720-733.

Spötl, C., Nicolussi, K., Patzelt, G., Boch, R. & "Daphne" team (Heidelberg speleothem group), 2010. Humid climate during deposition of sapropel 1 in the Mediterranean Sea: assessing the influence on the Alps. *Global Planetary Change,* **71**, 242-248.

Stuiver, M. & Grootes, P.M., 2000. GISP2 oxygen isotope ratios. *Quat. Res.*, **53**, 277-284.

Teller, J.T., Leverington, D.W. & Mann, J.D., 2002. Freshwater outbursts to the oceans from glacial Lake Agassiz and their role in climate change during the last deglaciation. *Quat. Sci. Rev*, **21**, 879–887.

Teller, J.T. & Leverington, D.W., 2003. Glacial Lake Agassiz: a 5000 year history of change and its relationship to the $\delta^{18}O$ record of Greenland. *Bull. Geol. Soc. Amer.,* **116**, 729-742.

Thomas, E.R., Wolff, E.W., Mulvaney, R., Steffensen, J.P., Johnsen, S.J., Arrowsmith, C., White, J.W.C., Vaughn, B. & Popp, T., 2007. The 8.2 ka event from Greenland ice cores. *Quat. Sci. Rev*, **26**, 70-81.

Tinner, W. & Lotter, A.F., 2001. Central European vegetation response to abrupt climate change at 8.2 ka. *Geology*, **29**, 551-554.

Törnqvist, T.E., Bick, S.J., González, J.L., van der Borg, K. & de Jong, A.F.M., 2004. Tracking the sea-level signature of the 8.2 ka cooling event: new constraints from the Mississippi Delta. *Geophysical Research Letters*, **31**, L23309.

Vincent, P.J., Lord, T.C., Telfer, M.W. & Wilson, P., 2011. Early Holocene loessic colluviation in northwest England: new evidence for the 8.2 ka event in the terrestrial record? *Boreas*, **40**, 105-115.

Vinther, B.M., Clausen, H.B., Johnsen, S.J., Rasmussen, S.O., Andersen, K.K., Buchardt, S.L., Dahl-Jensen, D., Seierstad, I.K., Siggaard-Andersen, M.-L., Steffensen, J.P., Svensson, A.M., Olsen, J. & Heinemeier, J., 2006. A synchronized dating of three Greenland ice cores throughout the Holocene. *J. Geophys. Res.*, **111**, D13102.

von Grafenstein, U., Erlenkeuser, H., Brauer, A., Jouzel, J. & Johnsen, S.J., 1999. A mid-European decadal isotope-climate record from 15,500 to 5,000 years BP. *Science,* **284**, 1654-1657.

Wiersma A.P. and Renssen, H., 2006. Model-data comparison for the 8.2 ka BP event: confirmation of a forcing mechanism by catastrophic drainage of Laurentide lakes. *Quat. Sci. Rev*, **25**, 63-88.

Zielinski, G.A., Mayewski, P. A., Meeker. L. D., Whitlow, S., Twickler, M. S., Morrison, M., Meese, D. A., Gow, A. J. & Alley R. B., 1994. Record of volcanism since 7000 B.C. from the GISP2 Greenland ice core and implications for the volcano-climate system. *Science,* **264**, 948-952.

Colin A. Baker
Ruddington NG11 6DB
cabaker135@aol.com