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Globally synchronous climate change 2800 years ago: Proxy data from peat in South America

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Abstract

Initial findings from high-latitude ice-cores implied a relatively unvarying Holocene climate, in contrast to the major climate swings in the preceding late-Pleistocene. However, several climate archives from low latitudes imply a less than equable Holocene climate, as do recent studies on peat bogs in mainland north-west Europe, which indicate an abrupt climate cooling 2800 years ago, with parallels claimed in a range of climate archives elsewhere. A hypothesis that this claimed climate shift was global, and caused by reduced solar activity, has recently been disputed. Until now, no directly comparable data were available from the southern hemisphere to help resolve the dispute. Building on investigations of the vegetation history of an extensive mire in the Valle de Andorra, Tierra del Fuego, we took a further peat core from the bog to generate a high-resolution climate history through the use of determination of peat humification and quantitative leaf-count plant macrofossil analysis. Here, we present the new proxy-climate data from the bog in South America. The data are directly comparable with those in Europe, as they were produced using identical laboratory methods. They show that there was a major climate perturbation at the same time as in northwest European bogs. Its timing, nature and apparent global synchronicity lend support to the notion of solar forcing of past climate change, amplified by oceanic circulation. This finding of a similar response simultaneously in both hemispheres may help validate and improve global climate models. That *reduced* solar activity might cause a global climatic change suggests that attention be paid also to consideration of any global climate response to *increases* in solar activity. This has implications for interpreting the relative contribution of climate drivers of recent 'global warming'.

Keywords: climate change; peat stratigraphy; proxy-climate data; solar forcing; *Sphagnum*; Holocene

1. Introduction

The first post-glacial climatic schema was devised a century ago, based on studies of peat stratigraphy in Scandinavia [1,2]. It was long-held and widely applied in and beyond Europe, but its millennial-scale climatic

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periods were later recognised as too simplistic [3]. Subsequently, initial data from high-latitude ice cores held sway, creating a picture of a relatively benign and invariable Holocene (i.e., post-glacial) climate [4]. Climate variability within the Holocene is now a major research focus [5], particularly in the context of discerning from proxy-climate data archives the magnitude, frequency and rate of past climate changes, so that these may be compared with recent 'global warming' inferred from instrumental meteorological records [4].

Renewed proxy-climate studies of bogs in northwest Europe, initially based either on determination of changes in peat humification [6] or plant macrofossil assemblages [7], provide more detailed evidence for major past climatic changes during the mid-late Holocene. The use of high-precision dating [8], combined with multiproxy techniques, provided evidence for a major climate downturn in parts of northwest Europe, radiocarbon dated to *c.* 2650 BP (^{14}C age, uncalibrated) [9–11]. This climatic change was attributed to a rapid reduction in solar activity [12] that caused increased cloudiness and led to bogs in mainland northwest Europe showing evidence for sudden cooler and wetter climatic conditions. Linkages were claimed to other types of sedimentary climate archive outside Europe, which provide evidence for climate change at *approximately* the same time [9], while new climate-model simulations now suggest there could be centennial-scale amplification of solar forcing by oceanic circulation changes at that time [13]. However, the non-European proxy-climate data archives were not dated with a similar degree of dating precision or accuracy, and the hypothesis that the claimed climate shift was global, and caused by reduced solar activity, has recently been disputed, based on contrary evidence from peat bogs in Ireland [14].

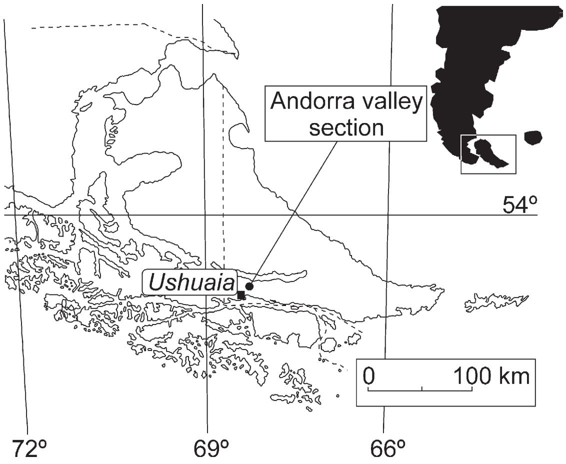

Fig. 1. Location of Valle de Andorra bog, near Ushuaia, Tierra del Fuego.

Until relatively recently, the use of proxy-climate techniques had not been explored in bogs outside Europe. Recent research that has since taken place on bogs in Asia has not used the same macrofossil technique as applied in northwest Europe but has instead relied mainly upon bulk, stable-isotope measurements of peat cellulose [15]. However, exploratory work on peat from a South American bog in Tierra del Fuego [16] showed that Southern Hemisphere mires from cool temperate environments might be analysed using the same macrofossil technique as developed for peats in northwest Europe. Now, we can report the results of multi-proxy analyses from a Southern Hemisphere peat profile that for the first time used identical techniques to those applied in studies of European raised mires.

2. A peat climate-archive from southern South America

The study site is located in the Valle de Andorra, 10 km northeast of Ushuaia, Tierra del Fuego (Argentina) (Fig. 1). Here, an extensive mire has recently been intersected by drainage ditches, permitting easy access both for stratigraphic study and for sampling by monolith. Stratigraphic changes could be observed as clear horizontal bands, which extended for tens of metres along sections of the mire [16].

A new peat section taken from the mire was subsampled contiguously at 1 cm intervals and analysed for plant macrofossils – a method shown to give replicable results between multiple cores from the same mire [17,18] – and peat humification. This degree of high resolution in plant macrofossil analysis has the advantage of permitting precise identification of major climate shifts. The plant macrofossil data show that the peat bog was largely dominated by *Sphagnum magellanicum* for most of the record. Within the third millennium BP of the Andorra peat core, the inferred climate perturbation of highest magnitude is near the base of the sampled section. It is marked by changes in peat humification (shown in Fig. 2 by a fall and then by a rise in percentage light transmission), implying shifts in surface wetness of the mire, first to dryness and then to wetness. Simultaneously, there is a marked fluctuation in the percentage of identifiable *Sphagnum* recorded in the peat – with a fall to a low point of 30%, followed by a sharp increase to 85% – which affirms a major perturbation in surface wetness over that period, although there is undoubtedly a connection between vegetation composition of the peat and its degree of humification.

The peat of highest humification is rich in ericaceous remains, implying a relatively dry bog surface. Dating of

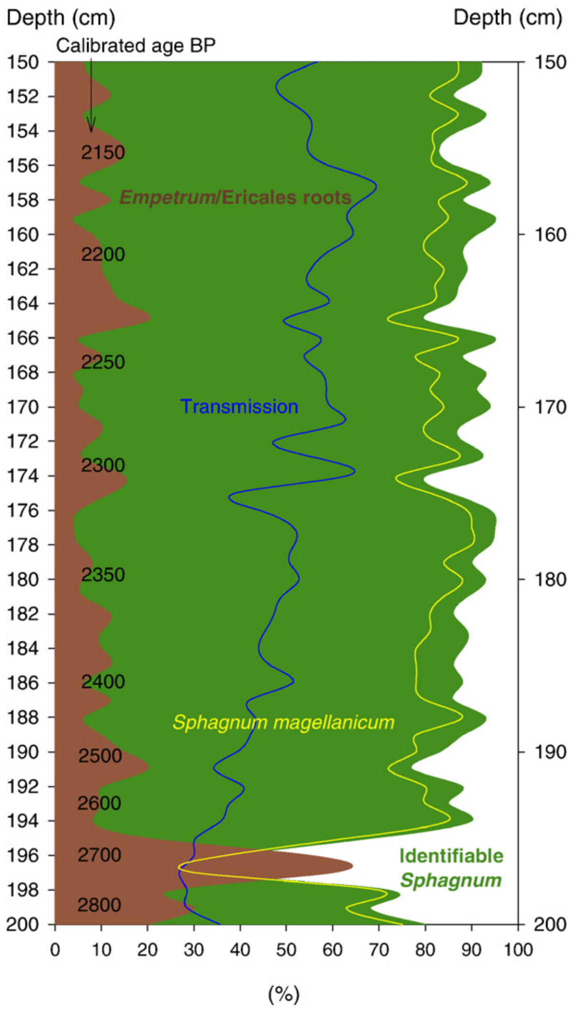

Fig. 2. Percentages of identifiable *Sphagnum* [that is: *S. magellanicum* leaves and *Sphagnum* stems] and percentage light transmission through alkali extract of peat [low values indicate dryness; high values indicate wetness] in contiguous 1 cm samples of the third millennium cal. BP, plotted against *Empetrum*/Ericaceae roots [note pronounced rise and fall from peak value, indicating dryness, at 197 cm]. Calibrated radiocarbon ages are derived by linear interpolation between the wiggle-matched mid-point estimates produced by the program Bpeat, performed using dated *Sphagnum* samples only, in a 2-section model (see Table 1 for uncalibrated ages of dated samples).

a piece of ericaceous wood from a depth of 199 cm yielded a radiocarbon age of 2704±22 BP (*c*. 2755 cal. BP or *c*. 805 cal. BC using the Southern Hemisphere calibration curve [19]). This is consistent with the dating results (see Table 1) from a closely spaced series of samples of mono-specific *Sphagnum* leaves in horizons just below and above the peak in dryness, which has been wiggle-matched successfully (Fig. 3) using the program Bpeat [20]. This procedure shows that the peat bog surface became relatively dry at just younger than *c*. 2820 cal. BP; the 'best' age estimated by Bpeat for the dry peak at 197 cm is *c*. 2733 cal. BP, and increased mire surface wetness is estimated by Bpeat as being underway by *c*. 2706 cal. BP (although a precision to the nearest 10 years is in these instances more realistic; the wood date was excluded from the mono-specific, *Sphagnum*-based wiggle-match, because it was on different material).

The calibrated age of *c*. 2820–2744 cal. BP (199–197 cm in Figs. 2 and 3 and Table 1) that encompasses the start of this climatic perturbation matches the reported age of an abrupt climate shift recorded from mires in the northern hemisphere in the Netherlands [9,10,12] and elsewhere [11], from which a marked increase in oceanicity of European climate was inferred for *c*. 850 cal BC (*c*. 2800 cal. BP) [21]. The data from both the European and South American mire sites therefore suggest a globally synchronous climate shift. This is likely to be equivalent to the SubBoreal–SubAtlantic transition of the original Blytt–Sernander climatic schema [1,2], which in the earlier studies on bogs in Europe was estimated either imprecisely, at *c*. 800–500 BC [7], or inaccurately, *c*. 2800 BP (uncalibrated) [22], for reasons explored more fully below.

3. Precise dating of the so-called 'SubBoreal–SubAtlantic' climate deterioration

Studies on bogs in Europe conducted in the mid-latter part of the 20th century had led to the concept of a major climatic deterioration sometime in the third millennium BP. Its radiometric dating had proved problematic for three reasons: first, because of ignorance about a variable offset between radiocarbon and

Table 1
High-precision dated samples from Valle de Andorra, from the third millennium BP

Sample name	Material	Depth (cm)	Date (^{14}C BP)
SUERC-3877	*Sphagnum*	153	2196±25
SUERC-3878	*Sphagnum*	157	2236±25
SUERC-3881	*Sphagnum*	161	2256±19
SUERC-3882	*Sphagnum*	165	2255±25
SUERC-3883	*Sphagnum*	169	2238±25
SUERC-3884	*Sphagnum*	173	2241±21
SUERC-3886	*Sphagnum*	180	2398±23
SUERC-3887	*Sphagnum*	184	2418±25
SUERC-3888	*Sphagnum*	188	2465±21
SUERC-3891	*Sphagnum*	192	2508±26
SUERC-3892	*Sphagnum*	196	2577±23
SUERC-5570	*Sphagnum*	198	2717±30
SUERC-6312	Ericales wood	199	2704±22
SUERC-5573	*Sphagnum*	199	2805±30
AA-54895	*Sphagnum*	200	2866±41

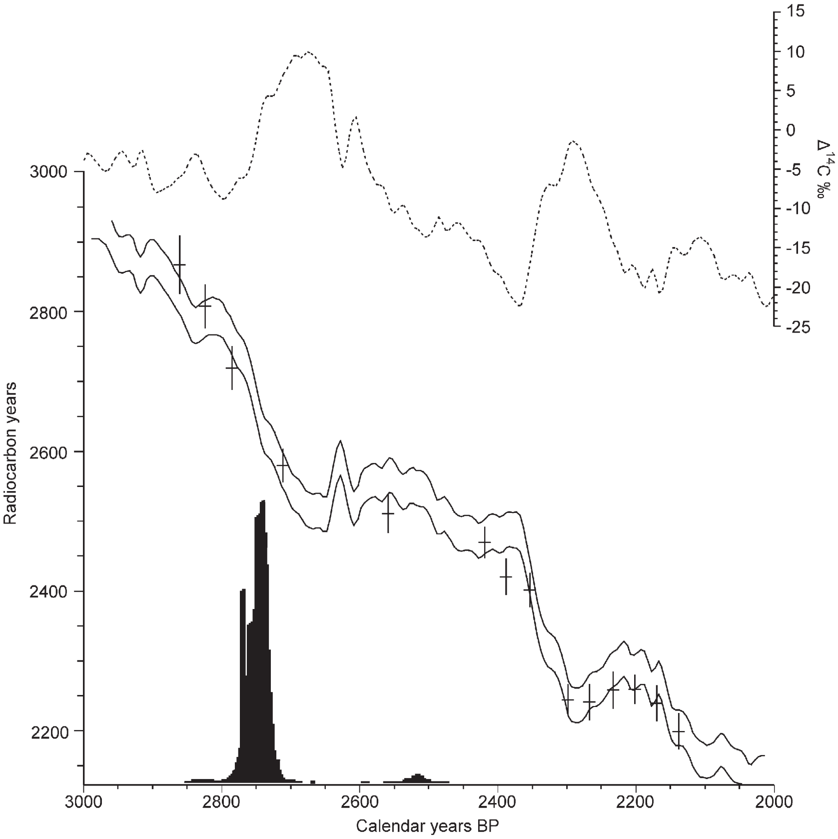

Fig. 3. Wiggle-match dating by the program Bpeat [20] of *Sphagnum* leaf samples, dated by AMS ^{14}C, on the steep fall that precedes the dating 'plateau' in the Southern Hemisphere calibration [19] curve SHCal04. The estimated 'best' fit for the age of the dry peak at 197 cm depth is also shown. Δ^{14}C curve (units on right-hand axis) for the period is shown for comparison.

calendar years; second, because of the requirement for bulk samples for conventional radiocarbon dating; and third, owing to the discovery of a pronounced radiocarbon 'plateau' in the calibration curve, *c*. 2450 BP. It was therefore not clear whether the mires provided evidence for one major synchronous climatic shift just before this plateau, or that each mire crossed a threshold at differing times during the *c*. 340 cal. yr [23] of the dating 'plateau' (Fig. 3).

New methods of dating peat, using AMS ^{14}C dating of small samples of above-ground plant remains (principally *Sphagnum*) [8], has led to markedly improved precision and accuracy, and several sites in Europe now suggest that the so-called SubBoreal–SubAtlantic climate deterioration can be placed at *c*. 2800 cal. BP [11]. However, these improvements have not been matched in other sedimentary archives reliant on radiocarbon dating. For example, the European mire data were correlated with a range of archives elsewhere [9], including vegetation changes recorded from pollen analyses of lake sediments in Cameroun, Africa [10], and later with palaeoecological and geological data from Chile, which suggested a climate shift roughly 2700 BP, and this led to a suggestion that there was a global climate change at around this time [24]. Our data from the South American mire now provide evidence for a climate perturbation at the same time in bogs in both the northern and southern hemispheres — albeit from the sole analysed South American site that has been analysed using identical techniques as in Europe. It is now confirmed as not just a climate change recorded in bogs in Europe, tenuously teleconnected to other climate archives elsewhere, but the implication of the present study is that it might be found globally and synchronously in climate archives from sites and sediment types that are sensitive to changes in climate oceanicity.

4. Cause of the climatic event

The apparently globally synchronous nature of this climate perturbation implies a universal driver. A hypothesis had been proposed for northwest Europe that reduced solar activity led to increased surface wetness in

European mires [12]: fluctuations in the concentrations of cosmogenic isotopes ^{14}C and ^{10}Be, in tree rings and ice cores respectively, were considered to reflect changes in solar activity, and those fluctuations were compared with proxy-climate data from mires. The possibly contemporaneous data from Chile, and also pollen data from sub-arctic Argentina [25], prompted the hypothesis that there was *global* evidence for solar forcing [10,24] at approximately the same time, but this remained to be confirmed. Recently, the direction of the climate shift was shown to be different in Ireland from that in mainland Europe, because during the 850–760 cal. BC (2800–2710 cal. BP) solar minimum, Irish bogs apparently were dry, but synchronously became wet *c*. 740 cal. BC (*c*. 2690 cal. BP) [14]. This finding appeared to challenge the nature of solar forcing claimed earlier for a climate shift in mainland European mires at *c*. 850 cal. BC, although it is based only on peat humification records and not on analysis also of plant macrofossils.

By using AMS ^{14}C dating of small samples of identified above-ground plant remains, the steep fall in the radiocarbon calibration curve (which precedes the dating 'plateau') is now a positive assistance to pinpointing the onset of the climatic deterioration. The direction of change from our Andorra bog in Tierra del Fuego is the same as those apparently recorded in the Irish bogs, and the timing is almost identical (within the limits of the calibration). So, a similar response might now be interpreted for the same time for bogs on the Atlantic margin of Europe and southern South America. However, any postulated mechanism has to account for why bogs on the Atlantic margin were apparently affected differently from bogs in The Netherlands and maritime parts of Germany. An explanation may lie in the observed greater spatial variability in changes in precipitation as compared with regional temperature, which may be expected to display greater spatial coherence [26].

These new data from Tierra del Fuego imply that the early–mid third millennium BP witnessed a climatic perturbation that was of fast rate (within 120 yr) and of high magnitude. Contrary to doubts recently expressed [14], they reinforce the interpretation of a solar-driven climate change between 2800 and 2710 cal. BP [11,24]. Furthermore, they suggest that it was global in extent and that it might therefore be recorded as a high-magnitude event in areas that are sensitive to changes in oceanicity. There is evidence that in several regions some human populations were adversely affected [10,20], although elsewhere others benefited [27]. Moreover, the climate shift to dryness that we have recorded in the South American mire was followed by an increase in mire surface wetness, which is synchronous with a similar change recorded in Irish mires [14]. These results may be contrasted with earlier climate-simulations, some of which have assumed a lag between past climate changes in the northern and southern hemispheres [28]. The proxy-climate data therefore provide background variability to validate existing climate models, and so ultimately may improve climate-model scenarios of future climate.

5. Implications for recent climate change

That rapid, high-magnitude climate changes might be produced within the Holocene by an inferred *decline* in solar activity [12,13,24,29–31] has implications for rapid, high-magnitude climate changes of the opposite direction — climatic warmings, possibly related to *increases* in solar activity. For the past 100 yr any solar influence would for the most part (with the notable exception of the mid-20th century) have been in the opposite direction (i.e. to help generate a global climate warming) to that inferred for *c*. 2800–2710 cal. BP. In a recent review, Bard and Frank [32] allow that solar variability might have contributed to the Medieval Warm Period, but are cautious in appraising the contribution of solar variability to 20th century warming. Current views suggest that the recent rate and magnitude of 20th century AD climate change is unparalleled in the last 1200 yr [33] and largely reflects an imprint of increased atmospheric gas concentrations, although at the same time, solar activity has risen to high levels [34,35]. However, whilst new climate-model simulations now show the amplifying effect of oceanic circulation for solar-induced global *cooling* events [13], and our new proxy-climate data suggest that the major event of the third millennium BP was globally synchronous, further research is required to establish to what extent oceanic circulation might amplify globally the climate effect of an *increase* in solar activity. This is important for calculating the relative contribution of forcing factors behind the rate and magnitude of recent warming of global climate, recorded instrumentally since the late 19th century.

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References

[1] A. Blytt, Essay on the immigration of the Norwegian flora during alternating rainy and dry periods, Cammermeyer, Christiania, 1876.

[2] R. Sernander, On the evidence of postglacial changes of climate furnished by the peat-mosses of northern Europe, Geol. Fören. Stockh. Förh. 30 (1908) 467–478.

[3] A.G. Smith, The Neolithic, in: I.G. Simmons, M.J. Tooley (Eds.), The Environment in British Prehistory, Duckworth, London, 1981, pp. 125–209.

[4] F. Oldfield, Environmental Change: Key Issues and Alternative Approaches, Cambridge University Press, Cambridge, 2005.

[5] F. Oldfield, Introduction: the Holocene, a special time, in: A. Mackay, R. Battarbee, H.J.B. Birks, F. Oldfield (Eds.), Global Change in the Holocene, Arnold, London, 2003, pp. 1–9.

[6] B. Aaby, Cyclic climatic variations in climate over the past 5500 years reflected in raised bogs, Nature 263 (1976) 281–284.

[7] K.E. Barber, Peat Stratigraphy and Climatic Change, Balkema, Rotterdam, 1981.

[8] B. van Geel, W.G. Mook, High resolution dating of organic deposits using natural atmospheric variations, Radiocarbon 31 (1989) 151–155.

[9] B. van Geel, H. Renssen, Abrupt climate change around 2650 BP in North-West Europe: evidence for climatic teleconnections and a tentative explanation, in: A.S. Issar, N. Brown (Eds.), Water, Environment and Society in Times of Climatic Change, Kluwer, Dordrecht, 1998, pp. 21–41.

[10] B. van Geel, J. Buurman, H.T. Waterbolk, Archaeological and palaeoecological indications for an abrupt climate change in The Netherlands and evidence for climatological teleconnections around 2650 BP, J. Quat. Sci. 11 (1996) 451–460.

[11] A. Speranza, B. van Geel, J. van der Plicht, Evidence for solar forcing of climate change at ca. 850 cal. BC from a Czech peat sequence, Glob. Planet. Change 35 (2002) 51–65.

[12] B. van Geel, J. van der Plicht, M.R. Kilian, E.R. Klaver, J.H.M. Kouwenberg, H. Renssen, I. Reynaud-Farrera, H.T. Waterbolk, The sharp rise of Δ^{14}C ca. 800 cal BC: possible causes, related climatic teleconnections and the impact on human environments, Radiocarbon 40 (1998) 535–550.

[13] H. Renssen, H. Goosse, R. Muscheler, Coupled climate model simulation of Holocene cooling events: solar forcing triggers oceanic feedback, Clim. Past Discuss. 2 (2006) 209–232.

[14] G. Plunkett, Tephra-linked peat humification records from Irish ombrotrophic bogs question nature of solar forcing at 850 cal. yr BC, J. Quat. Sci. 21 (2006) 9–16.

[15] Y.T. Hong, Z.G. Wang, H.B. Jiang, Q.H. Lin, B. Hong, Y.X. Zhu, Y. Wang, L.S. Xu, X.T. Leng, H.D. Li, A 6000-year record of changes in drought and precipitation in northeastern China based on a ^{13}C time series from peat cellulose, Earth Planet. Sci. Lett. 185 (2001) 111–119.

[16] D. Mauquoy, M. Blaauw, B. van Geel, A. Borromei, M. Quattrocchio, F.M. Chambers, G. Possnert, Late Holocene climatic changes in Tierra del Fuego based on multiproxy analyses of peat deposits, Quat. Res. 61 (2004) 148–158.

[17] K.E. Barber, L. Dumayne-Peaty, P. Hughes, D. Mauquoy, R. Scaife, Replicability and variability of the recent macrofossil and proxy-climate record from raised bogs: field stratigraphy and macrofossil data from Bolton Fell Moss and Walton Moss, Cumbria, England, J. Quat. Sci. 13 (1998) 515–528.

[18] D. Mauquoy, K.E. Barber, A replicated 3000 yr proxy-climate record from Coom Rigg Moss and Felecia Moss, the Border Mires, northern England, J. Quat. Sci. 14 (1999) 263–275.

[19] F.G. McCormac, A.G. Hogg, P.G. Blackwell, C.E. Buck, T.F.G. Higham, P.J. Reimer, SHCal04 Southern Hemisphere Calibration 0–1000 cal BP, Radiocarbon 46 (2004) 1087–1092.

[20] M. Blaauw, J.A. Christen, Radiocarbon peat chronologies and environmental change, Appl. Stat. 54 (2005) 805–816.

[21] B. van Geel, O.M. Raspopov, J. van der Plicht, H. Renssen, in: B.J. Peiser, T. Palmer, M.E. Bailey (Eds.), Natural Catastrophes During Bronze Age Civilisations, vol. 728, BAR International Series, Oxford, 1998, pp. 162–168.

[22] H. Godwin, History of the British Flora, second ed., Cambridge University Press, Cambridge, 1975.

[23] A. Speranza, J. van der Plicht, B. van Geel, Improving the time control of the Subboreal/Subatlantic transition in a Czech peat sequence by ^{14}C wiggle-matching, Quat. Sci. Rev. 19 (2000) 1589–1604.

[24] B. van Geel, C.J. Heusser, H. Renssen, C.J.E. Schuurmans, Climatic change in Chile at around 2700 BP and global evidence for solar forcing: a hypothesis, The Holocene 10 (2000) 659–664.

[25] C.J. Heusser, Palaeoecology of a Donatia–Astelia cushion bog, Magellanic Moorland–Subantarctic Evergreen Forest transition, southern Tierra del Fuego, Argentina, Rev. Palaeobot. Palynol. 89 (1995) 429–440.

[26] F. Worrall, T.P. Burt, J.K. Adamson, Trends in drought frequency: the fate of DOC export from British peatlands, Clim. Change 76 (2006) 339–359.

[27] B. van Geel, N.A. Bokovenko, N.D. Burova, K.V. Chugunov, V.A. Dergachev, V.G. Dirksen, M. Kulkova, A. Nagler, H. Parzinger, J. van der Plicht, S.S. Vasiliev, G.I. Zaitseva, Climate change and the expansion of the Scythian culture after 850 BC, a hypothesis, J. Archaeol. Sci. 31 (2004) 1735–1742.

[28] H. Renssen, H. Goosse, T. Fichefet, V. Masson-Delmotte, N. Koç, The Holocene climate evolution in the high-latitude Southern Hemisphere simulated by a coupled atmosphere–sea ice–ocean–vegetation model, The Holocene 15 (2005) 951–964.

[29] B. van Geel, J. van der Plicht, H. Renssen, Major delta-14C excursions during the Late Glacial and early Holocene: changes in ocean ventilation or solar forcing of climate change? Quat. Int. 105 (2003) 71–76.

[30] G. Bond, W. Showers, M. Cheseby, R. Lotti, P. Almasi, P. deMenocal, P. Priore, H. Cullen, I. Hajdas, G. Bonani, Persistent solar influence on North Atlantic climate during the Holocene, Science 294 (2001) 2130–2136.

[31] M. Blaauw, B. van Geel, J. van der Plicht, Solar forcing of climate change during the mid-Holocene: indications from raised bogs in The Netherlands, The Holocene 14 (2004) 35–44.

[32] A. Bard, M. Frank, Climate change and solar variability. What′s new under the sun? Earth Planet. Sci. Lett. 248 (2006) 480–493.

[33] J. Osborn, K. Briffa, The spatial extent of 20th century warmth in the context of the last 1200 years, Science 311 (2006) 841–844.

[34] R.C. Willson, Total solar irradiance trend during solar cycles 21 and 22, Science 277 (1997) 1963–1965.

[35] S.K. Solanki, I.G. Usoskin, B. Kromer, M. Schüssler, J. Beer, Unusual activity of the sun during recent decades compared to the previous 11,000 years, Nature 431 (2004) 1–12.