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Archaeological and palaeoecological indications of an abrupt climate change in The Netherlands, and evidence for climatological teleconnections around 2650 BP

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ABSTRACT: A sudden and sharp rise in the ^{14}C content of the atmosphere, which occurred between ca. 850 and 760 calendar yr BC (ca. 2750–2450 BP on the radiocarbon time-scale), was contemporaneous with an abrupt climate change. In northwest Europe (as indicated by palaeoecological and geological evidence) climate changed from relatively warm and continental to oceanic. As a consequence, the ground-water table rose considerably in certain low-lying areas in The Netherlands. Archaeological and palaeoecological evidence for the abandonment of such areas in the northern Netherlands is interpreted as the effect of a rise of the water table and the extension of fens and bogs. Contraction of population and finally migration from these low-lying areas, which had become marginal for occupation, and the earliest colonisation by farming communities of the newly emerged salt marshes in the northern Netherlands around 2550 BP, is interpreted as the consequence of loss of cultivated land. Thermic contraction of ocean water and/or decreased velocity and pressure on the coast by the Gulf Stream may have caused a fall in relative sea-level rise and the emergence of these salt marshes. Evidence for a synchronous climatic change elsewhere in Europe and on other continents around 2650 BP is presented. Temporary aridity in tropical regions and a reduced transport of warmth to the temperate climate regions by atmospheric and/or oceanic circulation systems could explain the observed changes. As yet there is no clear explanation for this climate change and the contemporaneous increase of ^{14}C in the atmosphere. The strategy of ^{14}C wiggle-match dating can play an important role in the precise dating of organic deposits, and can be used to establish possible relationships between changing ^{14}C production in the atmosphere, climate change, and the impact of such changes on hydrology, vegetation, and human communities.

KEYWORDS: climate change; archaeology; palaeoecology; teleconnections; 2650 BP.

Introduction

Natural variations in atmospheric ^{14}C, which are reflected as wiggles in the radiocarbon calibration curve (Stuiver *et al.*, 1993) severely limit the possibilities for fine-resolution dating of changes in vegetation and climate recorded in lake deposits and raised bogs (e.g. van Geel, 1978; Magny 1993a; Barber *et al.*, 1994). Van Geel and Mook (1989) stressed the importance of the strategy of ^{14}C wiggle-match dating (WMD) of organic deposits, and the fact that WMD can reveal relationships between ^{14}C variations and short-term climatic fluctuations caused by solar and/or geomagnetic variations. Kilian *et al.* (1995) have shown that, by using the strategy of WMD, raised-bog deposits in particular can be dated more precisely. Hence the raised-bog archive can be compared effectively with other proxy data archives, the more so because WMD showed that an unexpected ^{14}C reservoir effect plays a role in raised-bog deposits. As a consequence, individual conventional radiocarbon dates (and calendar ages derived from these dates after calibration) from ombrotrophic mires appear to be 100 to 250 yr too old, and therefore cannot be used for a detailed comparison with other, well-dated proxy data. Wiggle-matching is an elegant way of identifying this reservoir effect, and of estimating its magnitude. Moreover, Kilian *et al.* (1995) showed that the sharp rise of $\delta^{14}C$ between 850 and 760 calendar yr BC (as it is known from the dendrochronologically dated ^{14}C calibration curve; see Fig. 1), appeared to be synchronous with the transition from the so-called 'Older *Sphagnum* Peat' (mainly *Sphagnum* sect. *Acutifolia*: *S. rubellum*), to 'Younger *Sphagnum* Peat' (dominated by *Sphagnum imbricatum* and *S. papillosum*) at the Sub-boreal/Sub-atlantic transition in northwest European raised bogs. This change represents one of the most clearly defined climate shifts during the Holocene, and was used by Blytt and Sernander in their classic division of the Holocene (Sernander, 1910). The Sub-boreal was interpreted as representing a relatively warm, dry period and the Sub-atlantic as a humid and, especially in the beginning, a cold episode.

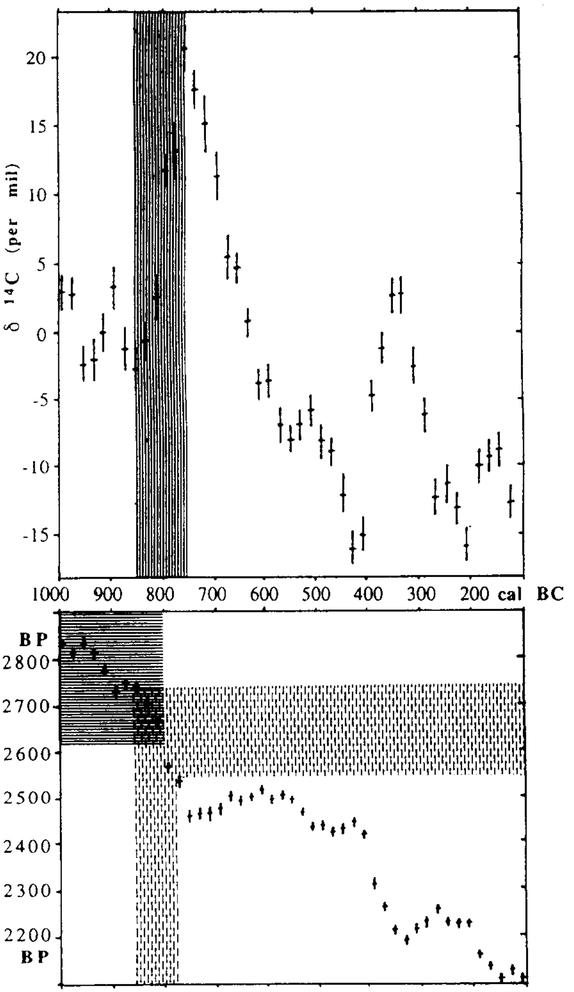

Figure 1 Relevant part of the ^{14}C calibration curve (below) with corresponding fluctuations in $\delta^{14}C$ (above). Based on Stuiver *et al.* (1993). The period of considerable rise in the ^{14}C content of the atmosphere between ca. 850 and 760 calendar yr BC is indicated by vertical hatching in the upper part. Horizontal hatching shows the later part of the settlement phase in West Friesland. The dashed vertical hatching indicates the period during which the shift from 'Older' to 'Younger' *Sphagnum* Peat in raised bogs took place (see also Fig. 3). Note the synchroneity between the end of the settlement phase in West Friesland and the shift in peat types. Both were caused by an abrupt climatic deterioration. The colonisation of the newly emerged salt marsh area in the northern Netherlands occurred in the same period.

In this paper we describe the closely dated, detailed evidence for climate change at the Sub-boreal/Sub-atlantic transition as reflected in the raised bog core Engbertsdijksveen-I (Fig. 2), and combine this evidence with archaeological information for the impact of that change on human populations in The Netherlands. We discuss the climate change around 2650 BP as the most plausible reason for: (i) the abandonment of Late Bronze Age settlements in marginal areas in the northern Netherlands, and (ii) colonisation of coastal salt marsh areas of the provinces of Friesland and Groningen by the displaced populations. Finally, we consider the evidence for a synchronous climate change from elsewhere in Europe and from other areas in the world.

Detailed evidence for climate change as reflected in the raised-bog deposit Engbertsdijksveen-I

The complete set of palaeoecological data from Engbertsdijksveen-I, eastern Netherlands (Fig. 2) was presented by van Geel (1978). Selected data from this site, namely peat-forming mosses (*Sphagnum* species) and the pollen curve of *Corylus avellana* (hazel) are presented in Fig. 3. During the period from ca. 3350 to 2550 BP, *Corylus* (growing outside the areas covered with raised bogs) often showed relatively low pollen percentages when 'wet' peat (*Sphagnum cuspidatum*) was formed in the raised bog. Relatively high percentages of *Corylus* pollen, alternating with these minima, were observed in peat layers that had been formed in relatively dry conditions. Van Geel (1978) interpreted these data as indicating climatic control over the bog hydrology and bog vegetation and also over the pollen production of

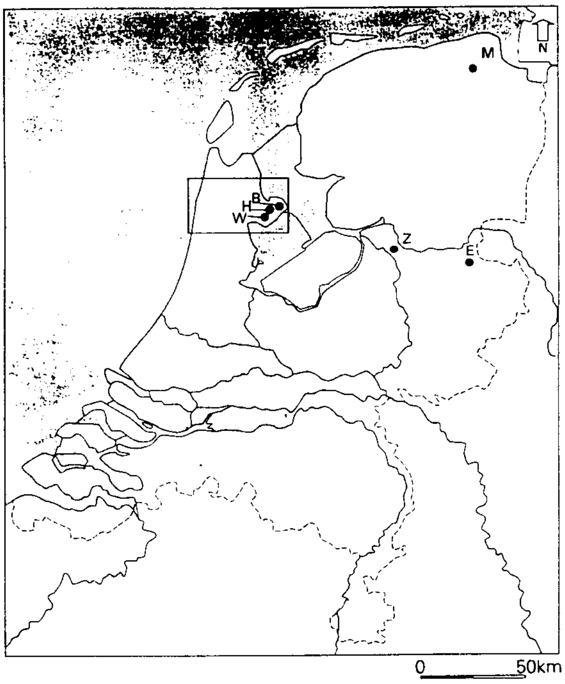

Figure 2 Map of The Netherlands showing the area of West Friesland and the sites mentioned in the text. E, Engbertsdijksveen; M, Middelstum; Z, Zwolle; B, Bovenkarspel; H, Hoogkarspel; W, Westwoud.

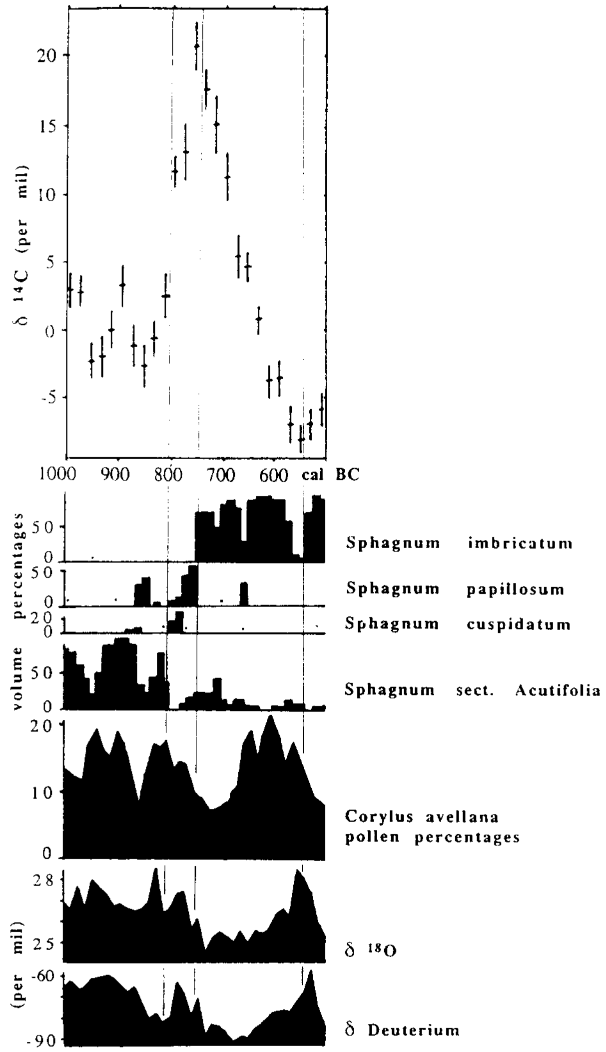

Figure 3 $\delta^{14}C$ for the period 1000 to 500 cal BC (after Stuiver *et al.*, 1993), combined with a selection of data from samples 118 to 155 of the raised bog core Engbertsdijksveen-I (van Geel, 1978; Brenninkmeijer *et al.*, 1982). For the lower part, the time-scale in calendar years is based on ^{14}C wiggle matching (Kilian *et al.*, 1995). The abrupt rise of $\delta^{14}C$ around 800 calendar yr BC coincides with the shift from 'Older' to 'Younger *Sphagnum* Peat': after a start of the very hygrophilous *Sphagnum cuspidatum* and *S. papillosum*, the peat is formed mainly by *Sphagnum imbricatum*.

Corylus. During periods of rainy late winters and spring frosts, the pollen production and dispersal of hazel will have been hampered, because a shrub flowering as early as *Corylus* does is sensitive to conditions characteristic of Sub-atlantic climates (Godwin, 1975, p. 272). During such periods, relatively wet local conditions occurred in raised bogs (as indicated by a temporary increase of the very wet-growing *S. cuspidatum*). The climatic deterioration during the later part of the Sub-boreal and the transition to the Sub-atlantic progressed by alternations of two steps forward and one step backward. Figure 3 shows fluctuations during the second half of this period of stepwise climatic deterioration. Fine-resolution dating of the sample series was possible by using ^{14}C wiggle matching (Kilian *et al.*, 1995). The most important shift took place around 800 calendar yr BC: *Sphagnum* sect. *Acutifolia* shows a decline and *S. papillosum* and subsequently *S. imbricatum* become important peat formers. *Sphagnum imbricatum* has a preference for oceanic conditions with a high air humidity. According to Dickson (1973) it has a sub-oceanic range in Europe at present, but it is now virtually extinct over a large part of its former range. In Europe two subspecies are found and, according to Stoneman *et al.* (1993), any *Sphagnum imbricatum* found on ombrotrophic mires is likely to be the subspecies *austinii*. Although its present-day niche has narrowed to hummock-top situations, in the past it occupied a wider range with respect to the water table (often 'fresh', unhumidified peat formed in relatively wet conditions of lawns and low-hummocks).

The *Corylus* pollen curve shows a pronounced decline when *S. papillosum* and *S. imbricatum* take over the succession in the raised bog Engbertsdijksveen (Fig. 3). ^{14}C wiggle matching enables high-resolution comparisons to be made between (i) these reactions of *Corylus* and the local bog vegetation and (ii) the contemporaneous former changes in ^{14}C content of the atmosphere (see the corresponding values of $\delta^{14}C$ in the upper part of Fig. 3).

From our data it is evident that the palaeoecological indications of an abrupt climatic deterioration coincide with the sharp rise in $\delta^{14}C$ between ca. 850 and 760 calendar yr BC. In contrast, the decline of $\delta^{14}C$ (namely during the ^{14}C plateau period between ca. 760 and 550 calendar yr BC) was a phase of recovery of *Corylus*, at least of its pollen production and dispersal. We interpret this as a temporary, slight climatic improvement. However, the ecological threshold for a change in the local *Sphagnum* species composition was not exceeded. When $\delta^{14}C$ rose again (after 550 calendar yr BC) *Corylus* declined and pollen percentages remained low in the following part of the Sub-atlantic. Figure 3 also shows corresponding values of δdeuterium and $\delta^{16}O/^{18}O$ (after Brenninkmeijer *et al.*, 1982). Changes of the quantities of these isotopes are influenced partly by climate change and partly by the species composition of the peat samples. Specific fractionation of the isotopes by the different plant species plays a role and, at the present stage of our knowledge and with the measuring equipment available, separation of the climate signal from changes caused by the species composition of the samples is not possible (van Geel and Middeldorp, 1988). Figure 3 indicates that the isotope signals more or less parallel the botanical evidence for a climate change. The lowest values (interpreted by Brenninkmeijer *et al.* (1982) as indicative of the coldest conditions) occur when *Sphagnum imbricatum* starts to become the most important peat former.

The end of Late Bronze Age settlements in marginal areas in The Netherlands: additional evidence for climate change around 2650 BP

West Friesland

Tidal activity ceased about 3500 BP in this part of the province of Noord-Holland as a consequence of the gradual closure of a tidal inlet. When the area became dry land, differential compaction of the marine sediments caused inversion of the relief. A dendritic system of sandy and loamy ridges (deposits formed in, and along, the former main channels) in between relatively low-lying areas of clayey deposits developed. This landscape was attractive for farmers, who colonised the area around 3350 BP. The broad, sandy ridges became very densely inhabited during the

Middle and Late Bronze Age (Ijzereef and Van Regteren Altena, 1991). Extensive archaeological investigations have been undertaken on these settlement sites, and detailed archaeobotanical and archaeozoological studies have been carried out in order to gain information on husbandry and the environment. Two periods of habitation were distinguished. For the Early Period about 40 radiocarbon dates are available, ranging from 3350 to 2845 BP. Many house plans, which were situated on top or on the flanks of the sandy or loamy ridges belong to this period. In the Late Period, for which 13 radiocarbon dates are available, ranging from 2760 to 2620 BP (Table 1), people adapted to the increasing wetness of the area by building their houses on dwelling mounds (*terpen* in Dutch) and changing their economy (Ijzereef, 1981; Buurman, 1988, in press). However, the settlement areas eventually became so wet that no further adaptations were possible as the limits of technological knowledge and socio-economic organisation were reached. The area was abandoned shortly after 2620 BP and was not reoccupied until medieval times.

Inundation of the area during the Bronze Age reflects both impeded drainage and climatic deterioration. There is archaeological evidence for a rise of the water table at an average rate of about 12 cm 100 yr^{-1} in the Early Period (G. F. Ijzereef, pers. comm., 1996). This was caused mainly by impeded drainage following the closure of the tidal inlet (Zagwijn, 1986; Roep and Van Regteren Altena, 1988). During the Late Period there was a rapid rise of about 45 cm, and there were two phases of *terp* building. During the first phase of this *terp* building period small areas of ca. 15 m x 20 m were used, surrounded by rather shallow ditches. In the last phase, very wide and deep ditches were dug at a greater distance from the houses. New houses were built on higher platforms. All ^{14}C dates for the period of accelerated rise of the water table fall between 850 and 800 calendar yr BC.

Apart from the archaeological evidence there is also ample palaeoecological evidence for an accelerated water table rise in this period (Ijzereef, 1981; Pals *et al.*, 1980; Van Geel *et al.*, 1983; Buurman *et al.*, 1995). Recently we realised that the period of the terpen phase is contemporaneous with the beginning of a rapid increase in ^{14}C content of the atmosphere, and there are indications that increasing wetness and the final abandonment of the area may reflect an abrupt climatic change.

High-resolution dating of the climate-induced transition of 'Older' to 'Younger *Sphagnum* Peat' in raised bogs (see above) corresponds to the end of the Bronze Age habitation in West Friesland. In earlier papers (Pals *et al.*, 1980; Van Geel *et al.*, 1983) a climatic cause for the abandonment and inundation of West Friesland was suggested, but now, with the strategy of ^{14}C wiggle matching of raised bog deposits, we can pin-point the corresponding climate-induced changes more precisely and make a direct link with the archaeological evidence for a rising water table.

Table 1 Radiocarbon dates of the 'terpen' phase (extremely wet conditions) of the excavated settlements at Bovenkarspel-Het Valkje, Westwoud and Hoogkarspel. Most of the dates are contemporaneous with the first half of the phase of rapidly increasing values of atmospheric radiocarbon between 850 and 760 calendar yr BC (compare with Fig. 1).

Excavation Bovenkarspel-Het Valkje:		
wood	GrN-7475	2760 ± 35 BP
charcoal	GrN-8561	2745 ± 30 BP
charcoal	GrN-7507	2745 ± 30 BP
charcoal	GrN-7508	2740 ± 40 BP
charcoal	GrN-7509	2710 ± 35 BP
charcoal	GrN-8563	2690 ± 25 BP
charcoal	GrN-8562	2685 ± 30 BP
wood	GrN-8334	2650 ± 30 BP
charcoal	GrN-8564	2620 ± 20 BP
Excavation Westwoud:		
charred seeds	UtC-2355	2700 ± 70 BP
charcoal	UtC-2356	2660 ± 60 BP
Excavation Hoogkarspel:		
charcoal	GrN-5051	2680 ± 50 BP
charcoal	GrN-5048	2650 ± 45 BP

Zwolle-Ittersumerbroek

At Zwolle-Ittersumerbroek near the River Ijssel a Late Neolithic–Bronze Age–Early Iron Age settlement area was excavated on a relatively low coversand plateau (Waterbolk, 1995a, b). The end of local settlements was caused by a rise of the water table and related peat growth and deposition of clays and sands by the River Ijssel. The youngest radiocarbon dates of the settlement (2670 ± 35 BP, 2600 ± 30 BP and 2540 ± 30 BP) indicate that the area became uninhabitable (apparently as a consequence of impeded drainage) during the period of sharp increase of $\delta^{14}C$ (see Fig. 1) and an abrupt climate change (see Fig. 3). However, rising water tables in the central part of The Netherlands may also have been caused by impeded drainage due to the closure of the tidal inlets, which were also coastal outlets of the rivers Vecht and Ijssel (Zagwijn, 1986, pers. comm., 1996).

There is additional archaeological evidence for inundation and abandonment of marginal areas in The Netherlands during the period of transition from Bronze Age to Iron Age (Van Geel *et al.*, in press) but in most cases radiocarbon dates are not available.

The beginning of habitation in the coastal marshes of the northern Netherlands

The loss of cultivated land in areas that were marginal from a hydrological point of view caused depopulation, and the question arises as to where the human populations of these areas migrated. A causal relationship between the developments in marginal areas of Pleistocene sandy soils and the colonisation of the salt marshes in the northern Netherlands was found by Waterbolk (1959, 1966). Arguments for migration to the salt marsh areas were based on archaeological evidence: pottery of the so-called Ruinen-Wommels type was found in both areas. Migration was explained as a consequence of environmental change (e.g. extension of raised bogs, exhausted soils) and an increased population density in the Pleistocene areas. In the context of the present paper, radiocarbon dates of the earliest settlements in the salt marsh area are particularly important. The start of the settlement at Middelstum (Boersma, 1983) is dated 2555 ± 35 BP, which indicates that the earliest colonisation occurred during the period of climate change, when $\delta^{14}C$ showed a steep rise. The colonisation of the salt marsh area was not related only to the above-mentioned environmental changes in the adjacent Pleistocene areas. Earlier migration was not possible, because salt marshes emerged for the first time during the Holland-VI regression period (its start is dated 2650 BP; Roeleveld, 1976; Griede, 1978). We postulate that a climate change and a contemporaneous slowing in sea-level rise are related to a thermic contraction of ocean water and/or of reduced velocity and pressure on the coast by the Gulf Stream. Moreover, after this climate change in the temperate zone more water accumulated in glaciers, as ground-water in soils, and in fens and bogs.

Evidence for climate change elsewhere in Europe and on other continents

A climatic change cannot have been restricted to The Netherlands and adjacent parts of Europe. Major changes in the radiocarbon content of the atmosphere occurred world-wide and the sharp rise of the ^{14}C content of the atmosphere between 850 and 760 calendar yr BC may have been synchronous with abrupt climate changes elsewhere. As a consequence, sudden and important environmental changes may have taken place, which affected plants, animals and also people. These changes may have been particularly pronounced in areas where thresholds were crossed, because those areas were already marginal from a hydrological point of view. Apart from changes in vegetation composition, the effects of climate deterioration have also been recorded in tree rings, and in a range of geomorphological activity, including glacier advances, avalanches, landslides in mountainous areas and rising lake levels. We wanted to compare our evidence for climate change from sites in The Netherlands with data from elsewhere. A literature review revealed various indications of an abrupt climate change at the Sub-boreal–Sub-atlantic transition, and we present a selection of examples below. Radiocarbon dates on these various lines of evidence seem to span several centuries, but this is probably a consequence of the rapidly increasing ^{14}C content of the atmosphere during the period concerned. On the calendar time-scale the period of radiocarbon ages between 2750 BP and 2450 BP lasted only for ca. 90 yr (namely, from ca. 850 to ca. 760 calendar yr BC).

Evidence from Europe

1. Leuschner (1992) has interpreted accumulated germination, respectively dying off and growth-reduction phases of bog oaks from Ostfriesland (NW Germany) as the effect of changes to wetter and cooler conditions. From 855 to 835 calendar yr BC a clear reduction in growth is apparent.
2. According to Godwin (1975), more-or-less desiccated surfaces of raised bogs and blanket bogs became rapidly waterlogged at the Sub-boreal–Sub-atlantic transition as a consequence of climatic deterioration. A characteristic layer of aquatic *Sphagnum* species was deposited in pools on the mire surfaces or, in places where calcareous water could overflow them, a layer of *Cladium–Hypnum* peat developed. The change to wetter conditions favoured the extension of *Sphagnum imbricatum*, a strongly Atlantic moss, which played a significant role in building the raised bogs not only of England, Wales and Ireland, but also northern Germany and The Netherlands (Godwin, 1975). From peat-stratigraphical data in raised bogs, Barber (1982) concluded that a catastrophic decline to a cooler and/or wetter climate occurred around 2850–2550 BP. Charman (1990, 1995) interpreted the stratigraphic change of blanket mires at ca. 2700 BP in northern Scotland as reflecting increased surface wetness in response to climate change.
3. A Bronze Age settlement phase on Stannon Down, Cornwall, England (Mercer, 1970) was succeeded immediately by the formation of peat on hut floors and field surfaces. Although radiocarbon dates were not available, the author interpreted the abandonment of the settlement as the result of peat growth related to the changing climate at the Sub-boreal–Sub-atlantic transition.
4. In Carbury Bog, Ireland, a sharp transition from 'dry' peat, rich in Ericaceae, to *S. imbricatum* peat was dated by wiggle matching to around 800 calendar yr BC (unpublished).
5. According to Ballantyne (1993) radiocarbon dating of organic matter buried by solifluction lobes in the Scottish mountains indicate an accelerated downslope movement around 2500 BP. Similar evidence is given by Matthews *et al.* (1993).
6. In Bridge *et al.*'s (1990) records of fossil *Pinus* from Scottish blanket bogs, there are no data for the period between 2670 and ca. 1800 BP. Apparently the tree line was considerably lower during that period.
7. Similar results were obtained by Eronen and Huttunen (1993) in Fennoscandia, where there are few dates on subfossil *Pinus* between 2600 and 2000 BP. Records of glacier activity also point to a climate deterioration after 3000 BP (Karlén, 1993).
8. Blikra and Nemec (1993) recorded a period of snow avalanching in western Norway around 2600 BP, and Nesje (1993) found evidence for an expansion of glaciers.
9. There is archaeological and palynological evidence that the Halne area (Hardangervidda Plateau, southern Norway) was used for grazing by domesticated animals between 4900 and 2800 BP (Moe *et al.*, 1988). For the period from 2800 to 2200 BP there are no indications of grazing of domesticated animals, in our opinion most probably as a consequence of a change of climate.
10. According to Berglund (1991) groundwater levels in southern Sweden rose around 2750 BP, which caused an extension of fenlands. At Lake Bjäresjö, where a peat deposit began to form in the early Holocene an abrupt rise in the water table during the Late Holocene is reflected in a transition from peat to limnic deposits (Gaillard and Berglund, 1988). The top of the peat was dated 2680 ± 50 BP and 2690 ± 60 BP (evidently contemporaneous with the sharp rise in $\delta^{14}C$, see Fig. 1).
11. In the Alps there is evidence for a lowering of the upper forest limit around 2800 BP (Burga, 1993). Indications of an increase of solifluction in the Alps are described by Gamper (1993) and Veit (1993). The largest glacier in the Italian Alps is Chiacciaio dei Forni. Orombelli and Pelfini (1985) dated its maximal Holocene extension as 2750 ± 130 BP.
12. Magny (1993a, b) presented records of Holocene lake-level fluctuations and glacier movements from the Jura and French Subalpine regions. He found chronological correlations between these fluctuations and the atmospheric ^{14}C record (lake transgressions and glacier advances were in phase with ^{14}C maxima) and he suggested that the short-term ^{14}C variations are an empirical indicator of Holocene palaeoclimates. At 800 calendar

yr BC a major climatic deterioration was recorded in the lakes. Dendrochronological dates from lake-shore settlement sites in the area north of the Alps indicate that no sites were in use and no new sites were occupied during a period of several centuries after 850 calendar yr BC (Becker *et al.*, 1985).

13 According to Piotrowski (1995) the fortified lake-margin settlement Biskupin (central Poland) was abandoned due to an abrupt climate change (a progressive cooling and a significant increase in humidity), which resulted in a rapidly rising lake level and subsequent social and economic collapse. Niewiarowski *et al.* (1992) dated the base of lake sediment on top of the old soil surface in the settlement as 2540 ± 100 BP. This date fits with the period of sharply rising $\delta^{14}C$ values between ca. 850 and 760 calendar yr BC, but the age of the sediment may also fall within the ^{14}C plateau (ca. 760 to 420 calendar year BC). According to dendrochronological data (Wazny, 1994), Biskupin was in use between 747 and 722 calendar yr BC, and growth of tree rings was markedly reduced between 750 and 722 calendar yr BC. The abandonment of Biskupin appears to have occurred at about the same time as the end of settlement sites in marginal areas in The Netherlands and in the Alpine region.

Evidence from North America

1 Bhiry and Filion (1996) studied a Holocene peat succession in a dune-swale environment of southern Québec. Macrofossil data indicated that: (i) xerophilous and mesophilous trees (*Tsuga canadensis, Pinus strobus, Betula alleghaniensis*) declined on the dune ridges after ca. 3000 BP, (ii) *Larix laricina* dominated the site after ca. 3000 BP until 1900 BP and reached old ages only until ca. 2600 BP, (iii) *Sphagnum recurvum* increased abruptly soon after 3000 BP and has remained abundant until the present. The *Larix* maximum in old trees (ca. 2600 BP) and the following sharp decline corresponds with the period of sharply rising $\delta^{14}C$ (Fig. 1) and hence in Québec also marked changes of vegetation and climate appear to have been synchronous with that rise. Moreover, in northern Québec, Payette and Gagnon (1985) showed that the deforestation in the forest tundra became increasingly marked after 3000 BP. This was also confirmed by Gajewski *et al.* (1993) from pollen data. Fire-mediated aeolian activity also declined between 2800 and 2500 BP as a result of cooler and wetter conditions (Filion *et al.*, 1991), and gelifluction increased world-wide at the same time (Morin and Payette, 1988; Filion *et al.*, 1991).

2 Smith (1993) described an increase in solifluction activity associated with excessive waterlogging (cold and humid 'Neoglacial' after 2800 BP) in North America. Jirikowic *et al.* (1993) and Davis *et al.* (1992) also found evidence for a rapid climate change (the start of a cold and wet period in Nevada and California) coinciding with the maximum in $\delta^{14}C$ around 750 calendar yr BC and they suggested a link between both phenomena.

3 Meyer *et al.* (1992) interpreted a minimum in fire-related debris flows and concurrent stream-terrace formation in Yellowstone Park as the effect of relatively cool and wet conditions at ca. 2700 BP.

Evidence from South America

1 Melief (1985) and Salomons (1986) recorded a downward shift of the upper forest limit in the Colombian Andes as a consequence of a change to cool and wet conditions at ca. 2700 BP. Also Kuhry (1988) found evidence for a shift to colder climate at about that time in Colombia.

2 From palynological evidence, Heusser (1990) concluded that the climate became cooler and more humid in subtropical Chile. Lumley (1993; see also Ritchie, 1995) recorded a catastrophic decline of the tree *Pilgerodendron uviferum* at ca. 2600 BP on the Taitao Peninsula in southern Chile. She interpreted this as resulting from an attack of a plant pathogen just after volcanic ash deposition. However, we prefer to consider an abrupt climate change as a possible cause for the decline. In southernmost subarctic Argentina, an increase of *Astelia pumila* in a cushion bog, dated 2630 ± 90 BP, is indicative of a sudden decline of temperature and a wetter climate (Heusser, 1995).

Evidence from New Zealand

McGlone and Moar (1977) report a decline of the frost- and drought-sensitive small tree *Ascarina lucida* around 2600 BP on southern North Island and on South Island.

Evidence from Japan

Tsukada (1967) dated 'recurrence surfaces' (transitions from strongly decomposed peat, formed in relatively dry local conditions, to less decomposed peat formed in wet conditions) in Japanese raised bogs at around 2650 BP.

Evidence from the Caribbean

Curtis and Hodell (1993) studied isotopes and trace elements in sediments of a freshwater lake in Haiti. They concluded that the climate was very dry during the interval between ca. 2500 and 1500 BP.

Evidence from tropical Africa

From palynological evidence in Cameroun, Reynaud-Farrera *et al.* (1996) recorded a drastic change of the vegetation cover as a consequence of dryness after ca. 2730 BP. This change to relatively dry conditions was also observed elsewhere in the central African rainforest belt (Elenga *et al.*, 1994; Giresse *et al.*, 1994). Shortly after that climate change Neolithic populations migrated into the area.

A major fluctuation of $\delta^{14}C$ and evidence for a world-wide climate change: discussion and conclusions

From radiocarbon measurements of wood dated dendrochronologically, changes in atmospheric ^{14}C content during the Holocene have been calculated and published as $\delta^{14}C$ data. There were numerous minor fluctuations and several major changes of $\delta^{14}C$. One of the most pronounced short-lived increases in the ^{14}C content of the atmosphere occurred between 850 and 760 calendar yr BC, as a consequence of which about 300 '^{14}C years' passed in a period of less than 100 calendar years. During that period (ca. 2750 BP to ca. 2450 BP) 'radiocarbon years' were of a very short duration, whereas (as a consequence of a declining ^{14}C content of the atmosphere), during the following 300 calendar years the '^{14}C age' remained at the level of about 2450 BP (namely, from ca. 760 to ca. 450 calendar yr BC). This is the so-called 'Hallstatt plateau' in the calibration curve. Wiggle-matching of series of ^{14}C measurements in northwest European raised-bog deposits (Kilian *et al.*, 1995) has shown that the sharp rise of the ^{14}C content of the atmosphere at the Sub-boreal–Sub-atlantic transition corresponds with the contact between the 'Older' and the 'Younger *Sphagnum* Peat'. This contact (originally named 'Grenzhorizont', and later 'Schwarztorf-Weisstorf-Kontakt') is often clearly recognizable in peat profiles in northwest Europe, and it is accepted generally that it reflects climate change (Godwin, 1975; Overbeck, 1975). The decrease in decomposition and especially the change in the spectrum of peat-forming species indicates a transition from a relatively continental (warm, dry) to a more oceanic climate regime (cooler and wetter).

From archaeological and palaeoecological studies in The Netherlands it is now evident that a sudden rise in ground-water tables made marginal areas unsuitable for Late Bronze Age farming communities. The youngest radiocarbon dates from drowned settlement sites in West Friesland and from a site near the River Ijssel are contemporaneous with the contact between Older and Younger *Sphagnum* Peat in raised bogs and thus with the sharp change in the ^{14}C calibration curve between ca. 850 and 760 calendar yr BC. By using the strategy of wiggle match dating we have been able to date climate change as reflected in raised bog stratigraphy, and link that phenomenon chronologically with the end of the habitation phase in areas under marginal conditions in The Netherlands. While in West Friesland and other marginal areas depopulation took place around 2650 BP, new settlements were established in newly exposed salt marsh areas along the northern coast. Environmental stress (lack of arable and pasture land, harvest problems, inundations, extension of fenland) was probably an important factor in the movement of groups of people to the new coastal sites. According to Griede (1978) the earliest colonisation of the Frisian coastal marshes started around 2650 BP. Again, this event coincides with the marked increase in atmospheric ^{14}C content (Fig. 1).

We suspect that, apart from the above-mentioned examples (The Netherlands, British Isles, Hardangervidda in Norway, Cameroun), climate change around 800 calendar yr BC might have had considerable effects on prehistoric people. In marginal areas in particular (e.g. regions with a relatively high ground-water table; mountainous areas near the climatic limits for cultivation of crops), climate change might have had important negative effects on prehistoric populations. However, other regions became more suitable for habitation as a consequence of the same climate change (e.g. new savanna areas in Cameroun, and newly exposed salt marshes in the northern Netherlands).

In view of the circumstantial evidence for interhemispheric coupling (climatic teleconnections), climate change at around 2650 BP may have been caused by a temporary weakening of the monsoon circulation (resulting in dryness in tropical areas) and an associated reduced southward and northward heat transportation by ocean currents and atmospheric circulation patterns, and by the related redistribution of atmospheric water vapour. Our data closely match those of the PANASH project (Paleoclimates of the Northern and Southern Hemispheres) of IGBP-PAGES (1995), the goal of which is to arrive at an understanding of world-wide climate dynamics and teleconnections in the past. Analysis of existing published data from different sources (archaeology, geomorphology, palaeoecology, dendroclimatology, isotope studies, astronomy) and palaeostudies of new sites should yield further details and a more coherent picture of climatic changes and their causes. According to De Vries (1958), Denton and Karlén (1973), Landscheidt (1987), Schmidt and Gruhle (1988), Davis (1992), Davis *et al.* (1992), Jirikowic *et al.* (1993) and Magny (1993a, b), major increases in $\delta^{14}C$ during the Holocene can be correlated with climate deteriorations and may be related to variations in solar activity. Changes in $\delta^{14}C$ are of a multicausal nature (Wigley and Kelly, 1990; Stuiver *et al.*, 1991; Stuiver, 1995). Cosmic ray flux, influenced by changes in the geomagnetic field and variations in solar output, and exchange between carbon reservoirs all play a role. It is now necessary to establish whether minor changes in $\delta^{14}C$ in the past were also related to climatic oscillations and, if so, to explain precisely why such correlations between climate change and production of ^{14}C in the atmosphere exist (Magny, 1993a, 1995). In these investigations wiggle-matched raised-bog deposits with their multivariable proxy records are potentially among the best archives. Cooperation between palaeoecologists, archaeologists, palaeoclimatologists and isotope physicists is essential if further progress is to be made in this field.

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