The present state of dendrochronology and tree ring calibration of the Late Glacial, and the inglorious end of the "Achterberg-wiggle"

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THE PRESENT STATE OF DENDROCHRONOLOGY AND TREE RING CALIBRATION OF THE LATE GLACIAL, AND THE INGLORIOUS END OF THE 'ACHTERBERG-WIGGLE'

J.N. Lanting & J. van der Plicht

1 Defining the problem

In our paper on Late Glacial and Late Upper Palaeolithic chronology in the Netherlands and adjacent areas we also looked for indications of the existence of wiggles in Late Glacial peat deposits with multiple radiocarbon dates (Lanting & Van der Plicht, 1995/96: 79- 83). In a 1.8 m thick peat deposit near Achterberg, studied by the *Rijks Geologische Dienst* and provided with 17 ^{14}C-dates (*ibid.*: 81, Table 2 and Fig. 7) such an indication seemed to be present. During the earlier part of the Allerød period six samples in sequence suggested a sudden change in atmospheric ^{14}C-content: first a strong increase resulting in ^{14}C-ages dropping from 12,050±90 BP (sample 12) to 11,550±80 BP (sample 11) to 10,740±60 BP (sample 10), next a decrease resulting in ^{14}C-ages of 11,070±60 BP (sample 17), 11,260±60 BP (sample 16) and 11,540±70 BP (sample 9). The Achterberg samples received thorough AAA pre-treatment. Carbon percentages and δ^{13}C values were calculated for all samples. No indications for contamination were found. Of samples 9 and 10 the alkali soluble fractions were also dated: 10,870±90, resp. 10,520±90 BP. Clearly some downward transport of younger humic substances had taken place, but that was to be expected.

Although a wiggle of c. 1000 radiocarbon years was and is highly unlikely, and no counterparts were known in the then available calibration curve (Kromer & Spark, 1998), the existence could not be fully excluded. And an 'Achterberg' wiggle seemed to explain a number of aberrant ^{14}C-age determinations of archaeological material.

That an 'Achterberg' wiggle did not exist became clear when Kromer *et al*. (2004) published a floating tree ring chronology of 1382 years in Central European pine, and the related floating calibration curve. This chronology comprised Allerød period and the beginning of the Younger Dryas period (*ibid.*: Fig. 1; this publication fig. 1). The calibration curve shows a number of small wiggles and plateaux, as could be expected, but no wiggle of 'Achterberg' size. The conclusion must be that the Achterberg peat deposit was either disturbed (cryoturbation during the Younger Dryas?) or contaminated. The aberrant ^{14}C-age determinations of archaeological material need other explanations, therefore.

But before we re-examine those dates we will have a look at the present state of dendrochronology of the Late Glacial, and at the reliability of the recently published Late Glacial part of the IntCal 13 calibration curve (Reimer *et al.*, 2013). The Greenland ice chronology GICC05 strongly suggests that absolute dendrochronology older than 10,644 BC is premature.

2 Dendrochronology of the Late Glacial in Middle Europe

In the past few decennia, there has been surprisingly fast progress on the extension of the Middle European dendrochronology, now reaching into the Late Glacial. The Middle European wood has taken a leading role in the construction of tree ring based calibration curves. Unfortunately the

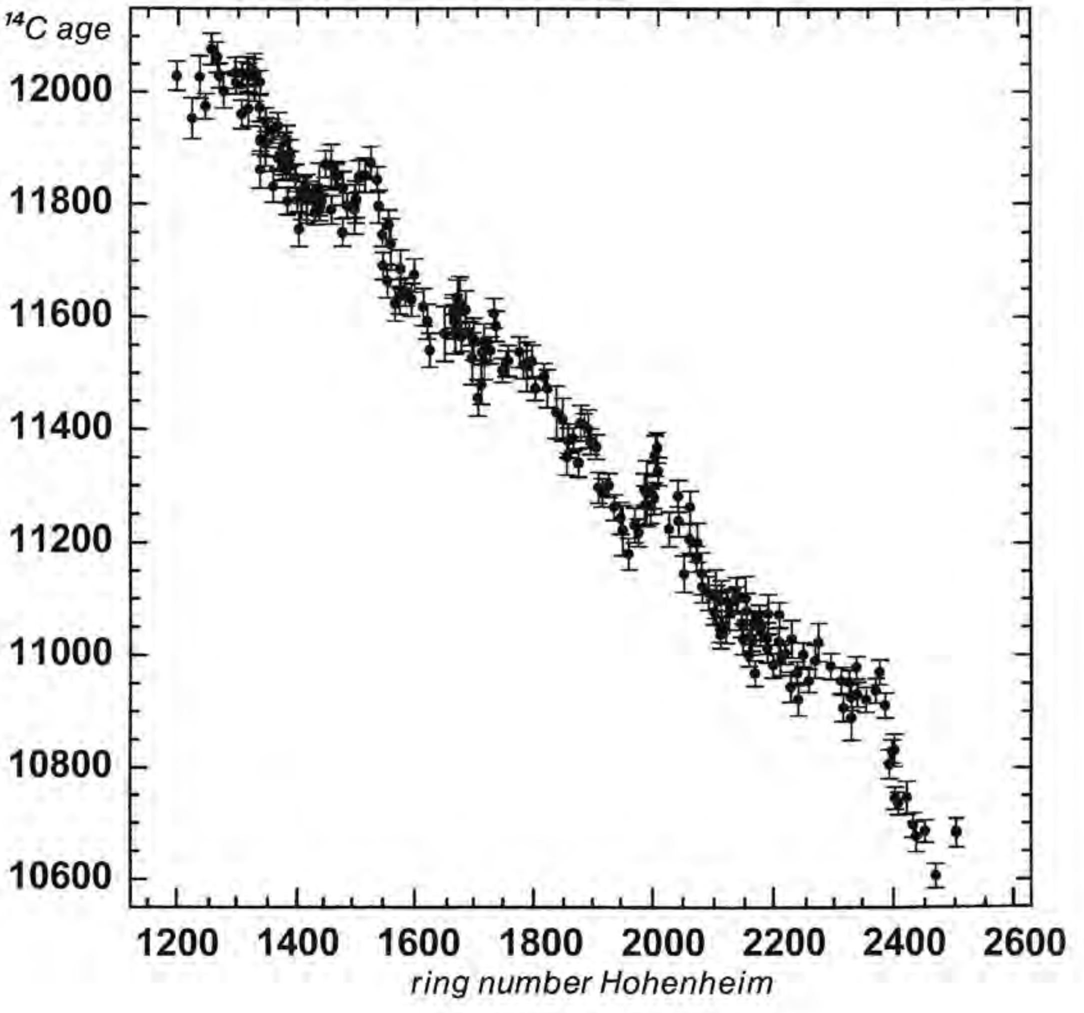


Fig. 1 Edited version of the floating 1382 rings of the Late Glacial including calibration curve of Kromer *et al.* (2004: Fig.1). Only the vertical axis with ^{14}C ages in BP, and the horizontal axis with Hohenheim tree-ring numbers are plotted. On the right, the strong decrease of the curve after ring ca. 2390 which is related to the Younger Dryas is visible.

extension of the dendrochronology turned out to be not a straightforward process. On several occasions corrections had to be made in already published chronologies. These were due to simple mistakes and to statistically unsound correlations. Many absolute dates obtained via tree ring calibration, and published by archaeologists, turned out to be erroneous only a few years after publication, because of these new developments. Even now the reader still has to check when exactly a sample was dated, and which calibration curve was used. It is obviously of crucial importance that the published calibration curves be correct.

Until recently Middle European dendrochronology was mainly the research field of the Institute of Botany of the University Stuttgart-Hohenheim. On several occasions this laboratory has had to apply changes. For this we refer to the publications of Spurk et al. (1998), Kromer et al. (1998) and Friedrich et al. (2004). This last article still shows the current state of knowledge of Hohenheim. Hardly any work has been done on the late glacial dendrochronology in the past ten years (M. Friedrich, pers.comm.). Therefore the following statements still stand:

- The Hohenheim oak chronology starts at 8480 BC
- The Hohenheim pine chronology ends at 7942 BC
- The linking of pine chronology to oak chronology is certain
- The pine chronology could be extended to 10,461 BC, using data from several laboratories. A larix tree from Ollon (Switzerland) with 363 tree rings played an important role. This role was not

so much the building of the tree ring chronology, but the dating of wood samples for the purpose of tree ring calibration curve IntCal04 (Reimer et al., 2004)

- The Younger Dryas-Preboreal transition is located at 9641 BC.

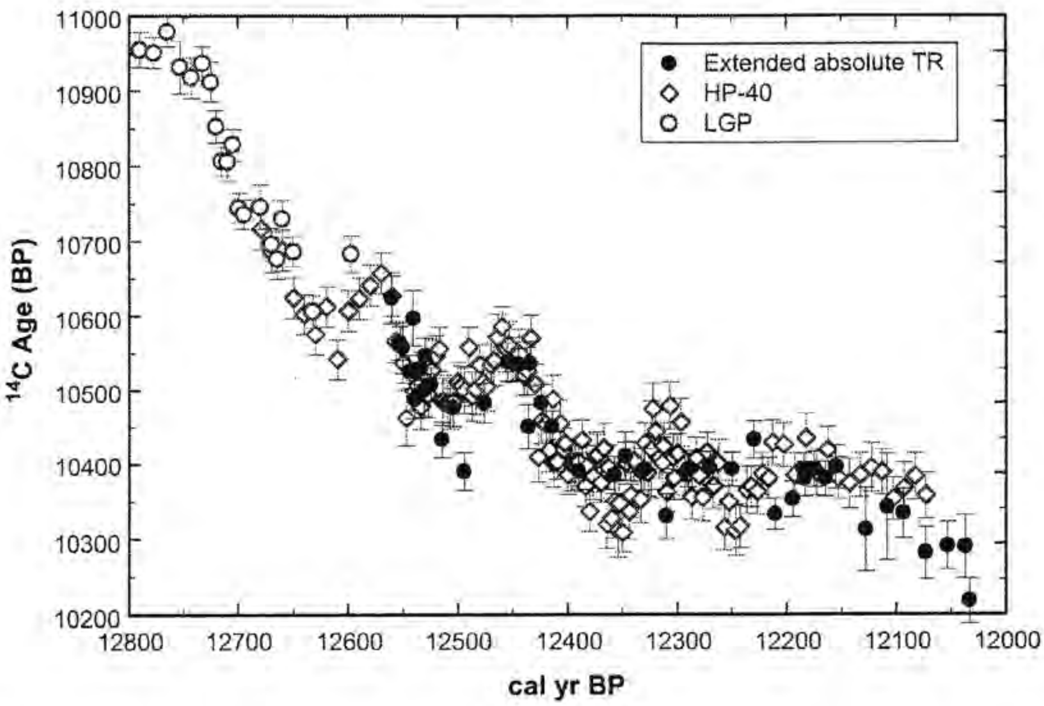
In the past decade, major contributions to Late Glacial dendrochronology have been obtained from Zürich. Schaub et al. (2008) have published an extension of the dendrochronology to 10,644 BC. This extension concerned a series of 412 rings, which were indicated as 'Younger Dryas B' by the investigators. This extension was mentioned in the explanation of the IntCal09 curve (Reimer et al., 2009: 1117), with the addition that ^{14}C dates of this new wood had been processed in the curve up to 10,607 BC. The ^{14}C dates of tree ring series YD-B were published by Hua et al. (2009). Reimer et al. (2013) mention that ^{14}C dates of wood of the Ollon-larch needed to be deleted from the file, because this tree was fitted incorrectly to the pine curve (see also Hogg *et al*, 2013). This concerns measurements in the IntCal09 curve between 9844 and 10,178 BC. This does not mean that the absolute dates of rings older than 10,178 BC are being questioned. Even without Ollon there is an overlap of almost 130 years between the series of 415 rings from 20 pines from Avenches (Switzerland), the oldest ring dating to 10,108 BC (Friedrich et al., 2004; 1117) and a series of 483 rings from 28 pines from Cottbus (Germany) and two pines from Zürich, the youngest ring dating to 9979 BC (ibid.). The problem is that the Ollon-larch delivered the main part of the ^{14}C dates in the trajectory mentioned above (Kromer & Spurk, 1998:1120-1121). Only a minor part of dates were obtained from wood of other trees. The final form of the IntCal curve can therefore only be calculated when substitute ^{14}C dates become available.

The publication of Hua et al. (2009) seemed to be a break-through. Based on wiggle-matching a floating tree ring curve of 617 tree rings of Huon pine from Tasmania, the floating curve of 1382 rings of Kromer et al. (2004; figure 1) is connected to the absolute dated part of the calibration curve. Hua et al. (2009:2985) state that their curve HP-40 has an overlap of 88±11 years with the curve of Kromer et al., and more than 500 years with the absolute dated Middle European tree ring curve. The uncertainty of this wiggle-matching is estimated as not larger than 20 years (fig. 2a). In the following, we will discuss other possibilities for linking these tree ring series. We argue that the solution obtained by Hua et al. (2009) is probably not the most logical one. The latter was used for the construction of the presently recommended calibration curve IntCal13 (Reimer et al., 2013). In hindsight, this now seems premature. Our arguments are based on both additional dendrochronological records and from the Greenland ice core chronology.

3 Chronology YD-A of the dendrolab in Zürich

The dendrochronological argument comes from Switzerland. Recently, a further extension of the floating late glacial chronology was published by Kaiser et al. (2012). This concerns an extension to the older part of the ZHLG-chronology that Schaub et al. (2008) published previously. As the title of Kaiser's paper says, a challenging process indeed, as it appears. The tree ring series SWILM (Swiss Late Glacial Master chronology) which includes 1606 rings was constructed in Zürich. This series could be supported and reinforced with wood from Germany to the tree ring series CELM (Central European Late Glacial Master chronology) with the same length. Part of CELM is the floating sequence of 1382 rings, which was published by Kromer et al. (2004). Note that the ring numbers of Kromer et al. (2004) do not correspond with the ones of Schaub et al. (2008) and Kaiser et al. (2012). Hohenheim and Zürich use their own numbering system. Not enough wood samples of the older part of SWILM/CELM have been ^{14}C dated. Kaiser et al. (2012:Fig. 6) published a graphical overview of the then available datings of SWILM wood, reaching to ca. 12,350 BP. The oldest dates of the floating tree ring calibration curve of Kromer et al. (2004:Fig. 1) are ca. 12,050 BP.

Schaub et al. (2008:84) assumed a gap of ca. 150 years between the youngest ring of the floating Late Glacial chronology ZHLG-1 and the beginning of the absolutely dated Middle European



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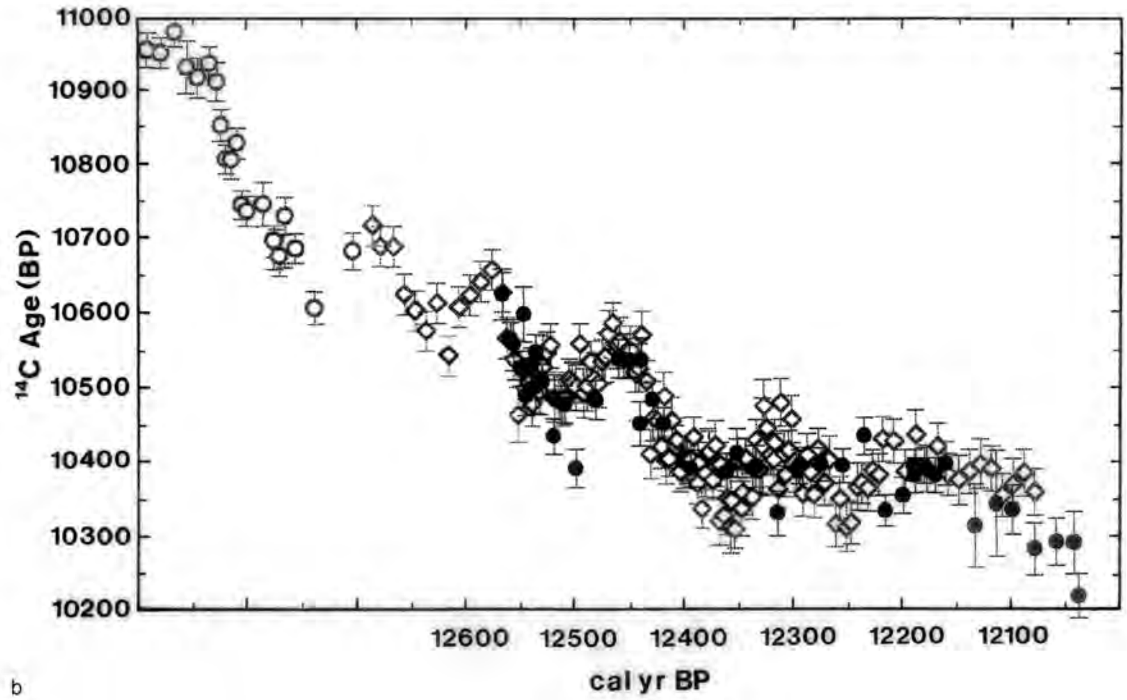

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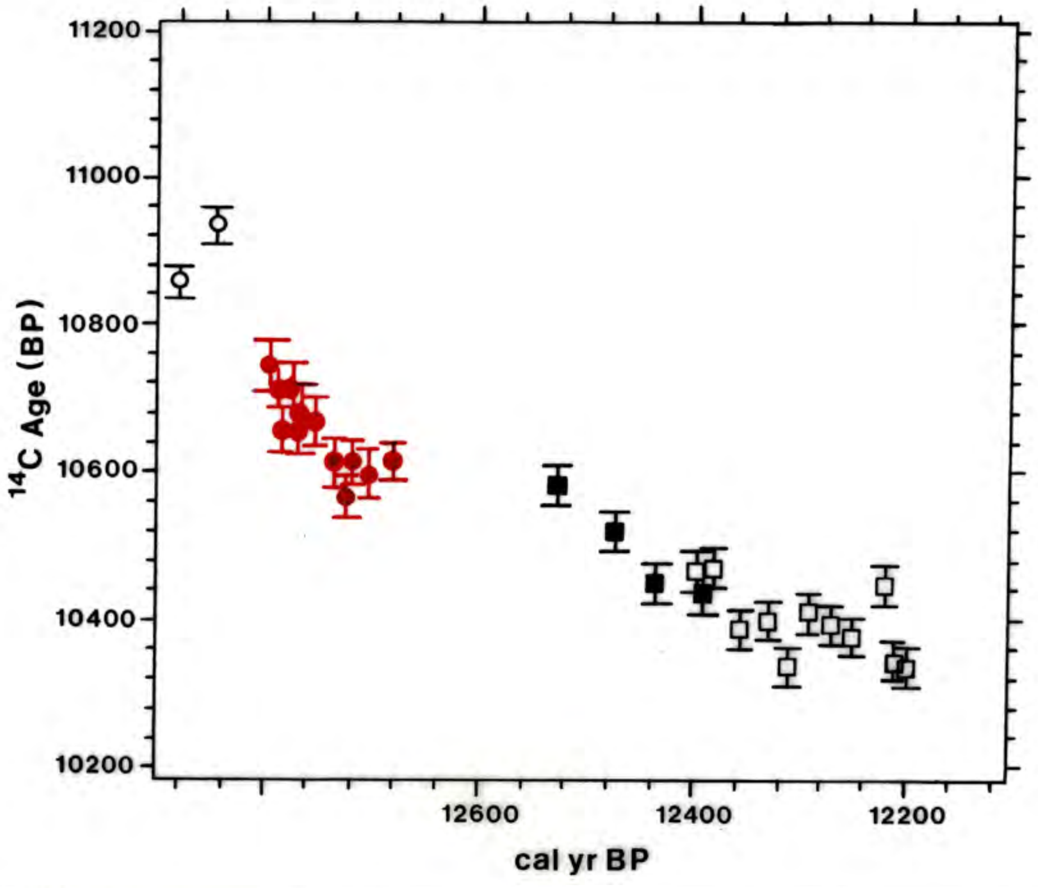
Fig. 2a Graphical presentation of the linking of the absolutely dated part of the Middle European tree-ring curve (TR) to the floating curve (LGP) of Kromer et al. (2004) by Hua *et al.* (2009:Fig.3). This is based on using a floating curve of 617 rings of *Huon pine* from Tasmania (with a correction of 40 years for the differences between both hemispheres: HP-40). Curve HP-40 is tied to TR and LGP by wiggle matching.

Fig. 2b Modified version of Fig. 2a, where the floating curve LGP is moved 100 years in the older direction.



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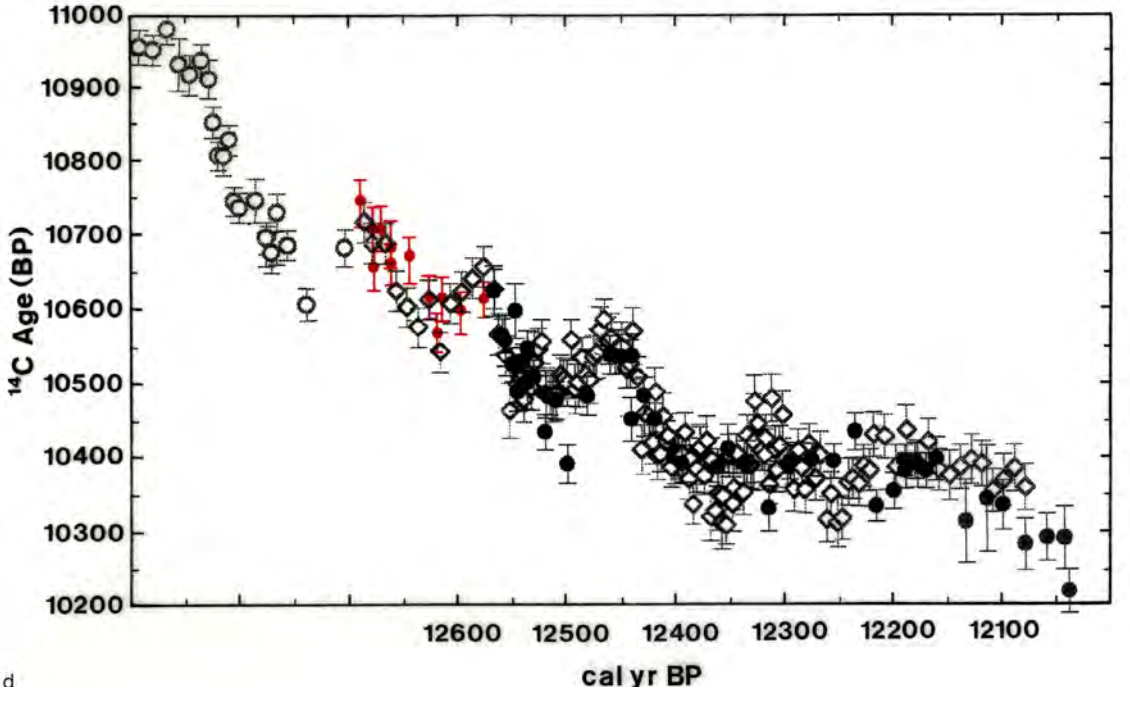

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Fig. 2c Edited version of Fig.3b from Schaub *et al* (2008). The Cariaco dates have been left out. Left are the two youngest ^{14}C dates of the floating chronology ZHLG-1 (open circles), the ^{14}C dates of the floating chronology YD-A (red symbols) and the oldest ^{14}C dates of the absolutely dated Middle European tree-ring chronology (squares: the black symbols represent chronology YD-B).The distances of ZHLG-1 and YD-A relative to each other and to the absolutely dated chronology are arbitrary.

Fig. 2d Graphical presentation of our proposal to insert the dating of the floating chronology YD-A of Schaub *et al*. (2008:Fig. 3b) into the edited version of Hua *et al*. (2009: Fig. 3) shown in fig. 2b. Floating chronology ZHLG-1 is part of floating curve LGP of Kromer *et a*l (2004); chronology YD-B is part of the absolutely dated Middle European tree-ring chronology. The floating chronology YD-A, marked in red, can only coincide with the oldest part of curve HP-40.

chronology. In that gap the floating tree ring chronology YD-A would fit, but with statistically too short an overlap with both mentioned chronologies. Comparison with Kromer et al, (2004:Fig 1) shows that ZHLG-1 ends about 80 years before Kromer's curve. In comparison with that curve the gap should be ca. 70 years.

Kaiser et al. (2012) did not refer to the claim by Hua et al. (2009) that the floating curve of Kromer et al. (2004) connects directly to the absolutely dated part of the tree ring calibration curve, although they did cite Hua et al. for other reasons. Instead, the authors claim that there is a gap between SWILM/CELM and the beginning of the absolutely dated Middle European tree ring chronology, whose length they estimate to be 100-110 years (Kaiser et al., 2012:83, sub 2.1.2.3). They mainly follow Schaub et al. (2008) in thinking that a part of the Swiss Younger Dryas A (YD-A) of 212 rings should fit in this gap. The ^{14}C dates of YD-A wood are shown in a graph by Schaub et al. (2008: Fig. 3B). A simplified version of this graph is shown here (fig. 2c). Kaiser et al. will undoubtedly have seen that these ^{14}C dates fit without any difficulty into the older part of the floating tree ring chronology of 617 rings Huon pine of Hua et al. (2009). As it is also known that chronology YD-A cannot be convincingly tied to either the absolutely dated part of the tree ring calibration curve or the SWILM/CELM (Kaiser et al., 2012: 83), it seems most logical to place the trees in the gap between both parts, with statistically too short overlaps to both sides.

4 The Greenland ice chronology and the length of the Younger Dryas

It is also possible to investigate the analysis of Hua et al. (2009) and Kaiser et al. (2012) using the Greenland ice core chronology. Thus far this has not played a role in the published literature. Recently thorough analysis of data from the GISP2, GRIP and NGRIP ice cores produced the Greenland Ice Core Chronology 2005, abbreviated GICC05 (Rasmussen et al., 2006). GICC05 provides (amongst other things) dates with a maximum counting error (MCE) for the beginning and ending of the climatic periods during the Late Glacial (Rasmussen et al., 2006: Table 3). The MCE represents 2-sigma uncertainties (Andersen et al., 2006:3253). The following dates are relevant here:

- Transition Younger Dryas – Preboreal	9704±99 BC
- Transition Allerød – Younger Dryas	10,897±138 BC
- Transition Bølling – Allerød	12,076±169 BC

In the ice chronology, the Older Dryas is considered as belonging to the Allerød period (Rasmussen et al., 2006: Fig. 1). The length of the Older Dryas is a few decades at most. The uncertainties are relatively large, which makes a useful comparison of tree ring- and ice chronologies impossible. However, the Greenland ice records provide estimates of the lengths of the Late Glacial climate periods (ibid.: Table 3). These lengths and their MCEs are:

- Younger Dryas	1193±39 years
- Allerød, including Older Dryas	1178±31 years
- Bølling	618±17 years

5 Combining dendrochronology and ice chronology shows IntCal13 to be premature

Friedrich et al. (2004: 1120) recognized the transition Younger Dryas – Preboreal in their pines at 9641 BC, based on an abrupt increase in ring thickness. The beginning of the Younger Dryas has not yet been reached in the absolutely dated part of the tree ring calibration curve. This part stretches until 10,644 BC, and therefore includes 1004 rings which were formed during the Younger Dryas. The beginning of the Younger Dryas has been recognized in the floating part of the calibration curve by Kromer et al. (2004: Fig. 1 and 2), at Hohenheim ring c. 2390, about 110 rings before their latest dating in the series of 1382 rings (fig. 1). In total, this provides about 1114 rings for the Younger Dryas. As the Younger Dryas lasted for 1193±39 years (95% confidence interval) according to GICC05, about 80±39 years are missing. Direct adjustment of the floating curve of Kromer et al. to the absolutely dated part of the tree ring calibration curve, as Hua et al. (2009) proposed based on their wiggle match, is therefore very unlikely. The proposal of Kaiser et al. makes more sense, although the length of the gap is still open to debate: between 40 and 120 years.

What happens when the floating part of 1382 years is moved 100 years in the older direction, according to the proposal of Kaiser et al., can easily be demonstrated using the curve published by Hua et al. (2009: Fig.3)(fig. 2a). In fact, a curve arises where the youngest date of the floating curve becomes ca. 15 years older than the oldest date of the ^{14}C dated part of the absolutely dated curve extended by Hua et al (fig. 2b). The oldest date of Hua et al. seems to be at the top of a small wiggle, whose slope on the older side is part of the floating curve, and whose slope on the younger side is the oldest part of the absolutely dated curve by Hua et al. (2009). The ^{14}C dates of chronology YD-A (Schaub et al., 2008: Fig 3B; fig. 2c) fit perfectly into the slope on the younger side and the beginning of the slope of an adjacent younger wiggle (fig. 2d). Of course this does not mean that this represents the correct adjustment. But it does show that the proposal of Hua et al. (2009) used for IntCal13 is not the only solution. In fact, the match of the oldest part of HP-40 with chronology YD-A presented here is at least as good as the one with the youngest part of the floating curve of Kromer et al.

6 Further implications of using ice chronology

6.1 *The Greenland ice chronology and the beginning of the Older Dryas*

According to GICC05, the Older Dryas and Allerød together lasted 1178±31 years (95% confidence interval). In the floating part of the tree ring calibration curve of Kromer et al. (2004: Fig. 1 and 2), the Allerød ends at Hohenheimring ca 2390 and ca 110 years before the end of the series of 1382 rings. The beginning of the Older Dryas + Allerød should therefore be at ring ca 1212±31. The floating tree ring calibration curve shows a small dip here, at the beginning of the curve. The ^{14}C dates of this oldest part are around 12,000 BP. Therefore there seems to be no reason to doubt the assignment of this dip to the Older Dryas. But according to Kaiser et al. (2012: 81, sub 2.1.2.1.), the Older Dryas would correspond to a very pronounced dip in the tree ring thicknesses between the rings 930 and 952 of the Zürich tree ring numbers. This dip is visible in the DAEBOECH chronology (Kaiser et al., 2012: Fig.3, detail a), and possibly at the beginning of the LANBOEAL chronology (*ibid*.: detail k).

In the SWILM chronology the difference between the assumed beginning of the Older Dryas at ring 930 and the beginning of the Younger Dryas at ring 2260 is actually 1330 years, instead of 1178±31 years, as can be expected on the basis of GICC05. In this case it is clear that Kaiser et al. are mistaken. We enlarged their figures 3k (SWILM chronology) and 6 (^{14}C dates of wood of the SWILM chronology) so that they show identical absolute time scales, and did the same with figure 1 of Kromer et al. (2004). This clarifies the situation (see fig. 3). The wood immediately before the dip in the SWILM chronology between 930 and 952 shows ^{14}C ages of ca 12,450 BP. Such numbers belong to the Bølling, not to the Older Dryas. So far, there are no indications for a short cold period during the Bølling. The dip between the rings 930 and 952 is possibly a local phenomenon, not necessarily caused by a climate fluctuation.

In the DAEBOEAL chronology (Kaiser et al., 2012: Fig. 3c) a pronounced dip is visible between rings 1100 and 1130, the lowest value at ca. 1120 (fig. 4). In the SWILM chronology this dip is hidden in the broad, V-shaped depression between rings ca 960 and ca 1260. The lowest value, at ring ca. 1125, apparently corresponds with the dip in the DAEBOEAL chronology. We think that this dip is the result of the short climate deterioration during the Older Dryas. An Older Dryas between ca 1100 and ca 1130 corresponds reasonably well with the small dip at the beginning of the floating tree ring calibration curve of Kromer et al. (2004).

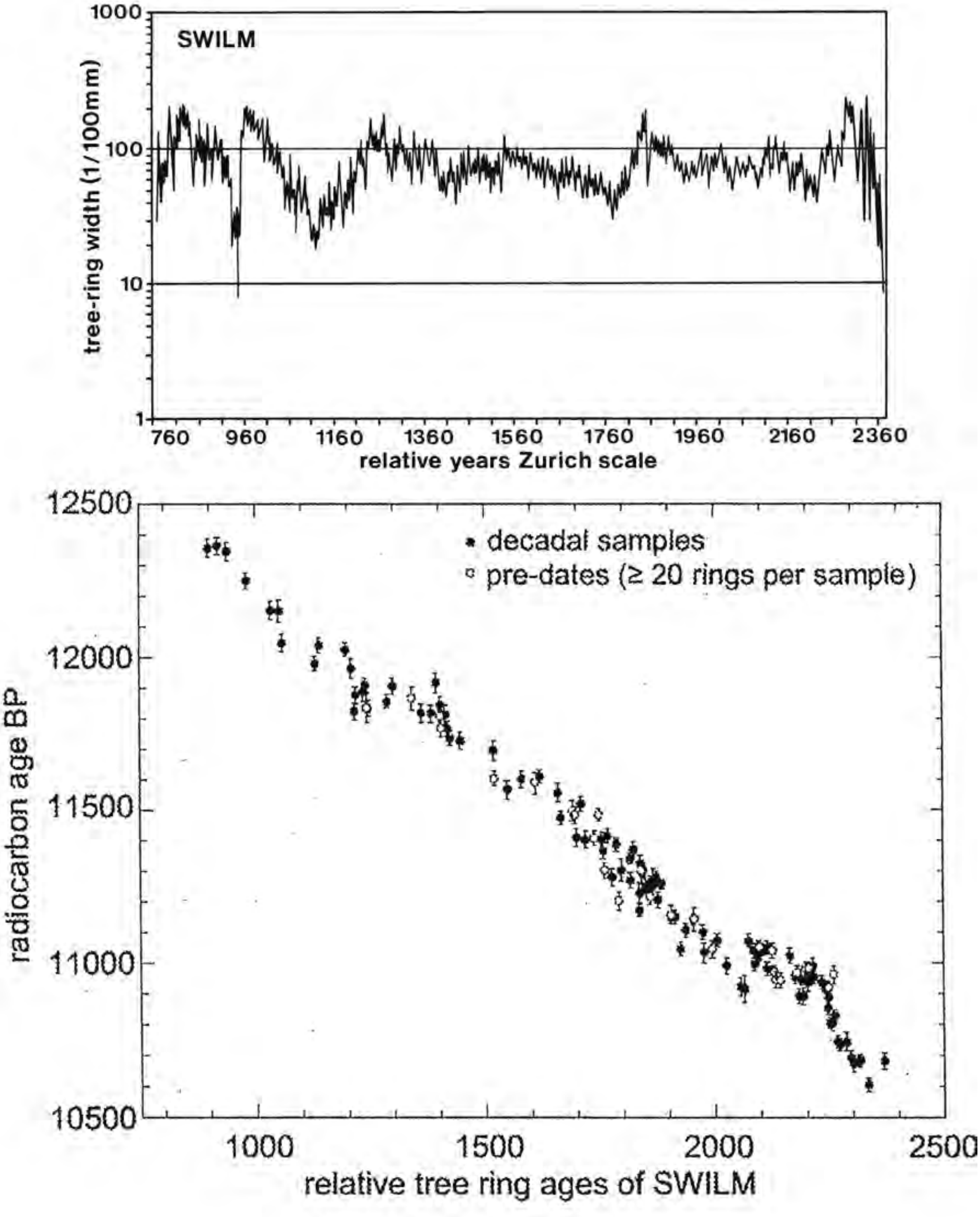

Fig. 3 Ring thicknesses of the SWILM chronology (Kaiser *et al.*, 2012: Fig. 3k) compared to that of the tree ring calibration curve of SWILM wood (ibid.: Fig. 6). The right bottom part in the lowest panel shows the striking end of the ca 110 rings including the steep decrease at the beginning of the Younger Dryas which is also visible in fig. 1. The striking dip in the upper panel at ring 960 cannot correspond to the Older Dryas, because the associated ^{14}C dates in the lower panel are too old for that.

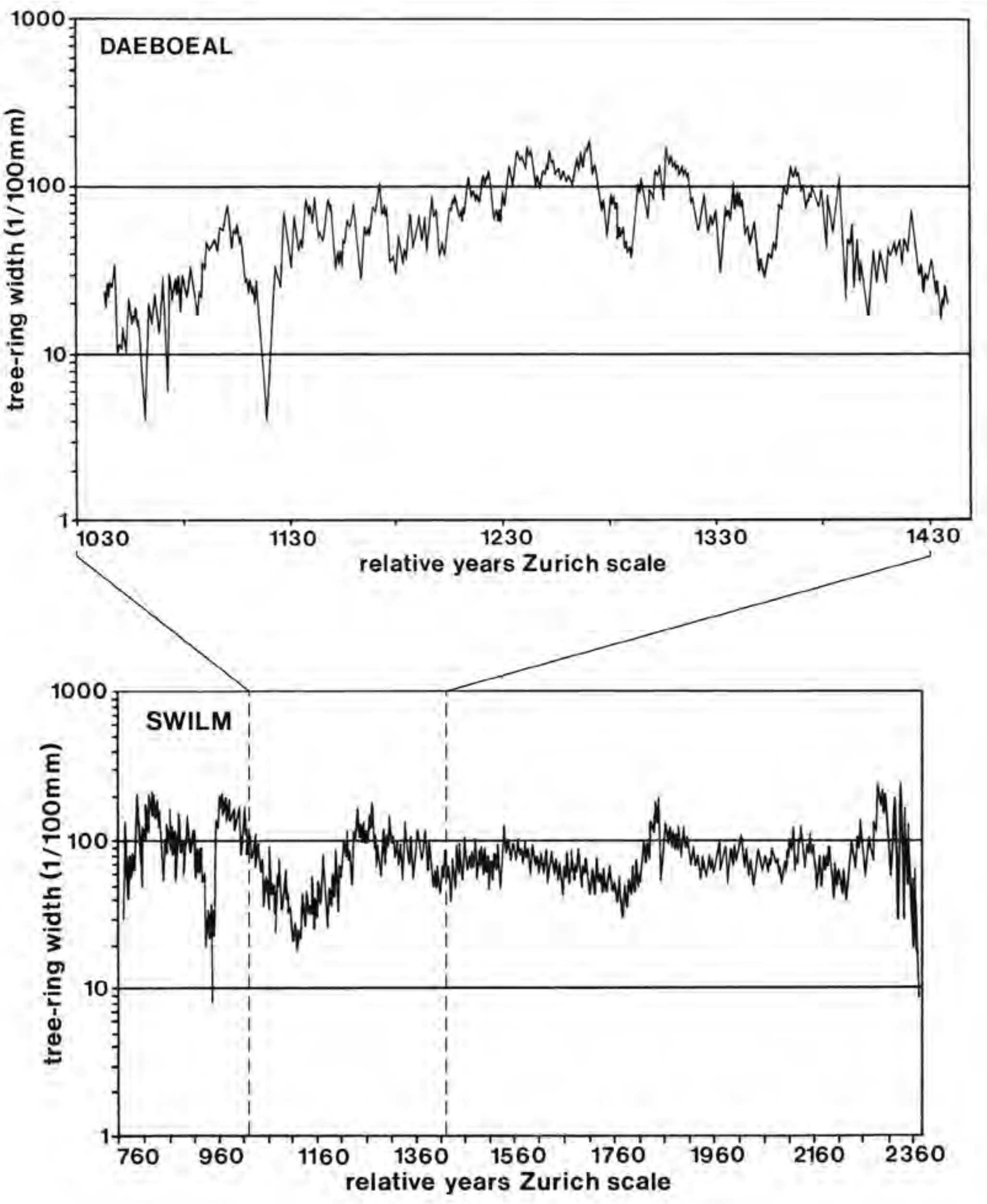

Fig. 4 Plot of the SWILM ring thicknesses (Kaiser et al., 2012: Fig. 3k), compared with the ring thicknesses in the partial chronology DAEBOEAL (ibid.: Fig. 3c). The striking dip in the ring thicknesses in the DAEBOEAL curve between rings 1100 and 1130 corresponds with the Older Dryas. In the SWILM curve, this dip is hidden in a much broader, V-shaped depression.

6.2 *The Greenland ice chronology and the beginning of the Bølling*

According to GICC05, the Bølling lasted 618±17 years (95% confidence interval). Assuming that the Older Dryas was indeed between the rings ca 1100 and ca 1130 of the Zürich counting, the beginning of the Bølling should correspond to Zürich-ring ca. 480±17. The SWILM/CELM chronology does not start before ring 767. That means that ca 290±17 rings of the early Bølling are missing. According to Kaiser et al. (2012:80) it is unlikely that wood from that period will be found north of the Alps.

7 Prospects for extending Late Glacial dendrochronology

Kaiser *et al.* (2012: 84) indicate that the gap in the dendrochronology of the Younger Dryas could possibly be closed with pines found in the Barbiers in the southern French Alps. But more wood needs to be collected to achieve this.

Kromer *et al.* (1998) demonstrated that three short tree ring chronologies could be recognized in larches found near Revine (Treviso, Italy): Revine 1 of 219 rings, Revine 2 of 151 rings and Revine 3 of 304 rings. Radiocarbon ages are 15,150–14,750 BP for Revine 1+2, and 14,400–14,270 BP for Revine 3. Kaiser *et al.* (2012: 84–85) mention Revine, too, but also three other interesting locations: Avigliana, north of Turin, with a 253-year chronology in pine from the Bølling, Carmagnolo (Po Valley) with a 344-year chronology in pine from the Bølling, and Palughetto, north of Revine, with seven short chronologies in a.o. *Picea* and *Larix* from Bølling and Allerød. The oldest wood in Palughetto was radiocarbon dated to c. 12,500 BP.

It might well be possible to strengthen and to extend the absolute dendrochronology by means of these sites. But it will take some time before the hiatus between Revine 3 and the beginning of the Bølling, estimated to be at least 600 years wide, can be closed. The gap between Revine 3 and Revine 1+2 might be c. 400 years wide. But in the coming 10 to 20 years absolute dendrochronology might be extended to c. 16,250 BC, if money and manpower are made available.

8 Back to the aberrant ^{14}C-age determinations, previously explained by using the 'Achterberg-wiggle'

After the digression on dendro- and ice-chronology, and after having rejected the Late Glacial part of the IntCal13 calibration curve, the aberrant ^{14}C-dated in our paper on Late Upper Palaeolithic chronology (Lanting & Van der Plicht, 1995/96: 97, 98, 101, 102-3, 105, 106 and 108) need to be re-examined.

At **Oldeholtwolde**, a camp site of the younger Hamburg tradition, five samples of charred wood and charcoal from a stone-paved hearth were dated:

GrN-10724	charred wood under stones	11,540±270 BP
GrN-13083	charcoal on top of stones	11,600±250 BP
OxA-2558	charcoal on top of stones	11,810±110 BP
OxA-2559	charcoal on top of stones	11,470±110 BP
OxA-2561	charcoal on top of stones	11,680±120 BP

The wide spread of the measured ages, ignoring the standard deviations, raised concerns and was the reason for using the 'Achterberg-wiggle'. But the floating calibration curve of 1382 pine rings from the Allerød and the beginning of the Younger Dryas, published by Kromer *et al.* (2004: Fig. 1; this paper fig. 1) shows that between Hohenheim ring 1500 and 1600 ^{14}C-ages drop rapidly from c. 11,900 BP to c. 11,600 BP. The three Oxford-dates can easily be combined to a single event around ring 1550 with a radiocarbon age of 11,650 BP. The two Groningen dates have very large standard deviations and do not contradict this explanation.

It is interesting, however, that Hohenheim rings 1500–1600 undoubtedly belong to the Allerød period, and not even to the very beginning of that period: the start of Older Dryas + Allerød is situated at ring 1212±31 (see par. 6.1).

At **Duurswoude II** (Lanting & Van der Plicht, 1995/96: 98) the charcoal particles with ^{14}C-age 11,090±90 BP can no longer be considered to be contemporary with the artefacts of the Hamburg tradition. In this case transport downwards of charcoal particles from the Usselo layer by the activities of burrowing beetles is the most logical explanation.

In **Ossom's Cave** (*ibid.:* 101) the aberrant BM-dates of horse bone collagen seems to indicate a laboratory problem.

At **Marsangy** (*ibid.*: 102–3) dates OxA-178 11,600±200 BP and OxA-740 12,120±200 BP could theoretically belong to a single short-lasting settlement phase, given the large standard deviations. But more than one settlement phase seems to be more likely.

At **Andernach-Martinsberg** (*ibid.*: 105) the wide spread of ^{14}C-ages of bone collagen almost certainly indicates several periods of occupation.

At **Duurswoude-Oud Leger** (*ibid.*: 106) some artefacts of the *Federmesser* tradition, including a Tjonger point, were found c. 20 cm below a well-developed Usselo layer with a lot of charcoal. Charcoal particles found at the same level as the artefacts turned out to be of late Allerød age.

Here again, burrowing beetles may have been responsible for moving charcoal downwards. In fact Duurswoude-Oud leger might be one of the oldest *Federmesser* settlements in the northern Netherlands, not much younger than the late Hamburg site of Oldeholtwolde.

At **Een-Schipsloot** (*ibid.*: 108) the dated peat in Pit I was undoubtedly formed during the Younger Dryas. The artefacts at the bottom of the pit belong to the *Federmesser* tradition, as do the artefacts in a narrow zone at the same level at which the pit became visible. Probably wind erosion of the surface during the Younger Dryas played a role in creating this narrow zone. But as long as we do not know how this pit was made or shaped the radiocarbon date should not be used to claim a survival of the *Federmesser* tradition during at least part of the Younger Dryas. It is more likely that the pit had a natural origin during the Younger Dryas, that artefacts collected at the base and were covered by peat formed in the pit subsequently.

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