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DECADALLY RESOLVED LATEGLACIAL RADIOCARBON EVIDENCE FROM NEW ZEALAND KAURI

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ABSTRACT. The Last Glacial–Interglacial Transition (LGIT; 15,000–11,000 cal BP) was characterized by complex spatiotemporal patterns of climate change, with numerous studies requiring accurate chronological control to decipher leads from lags in global paleoclimatic, paleoenvironmental, and archaeological records. However, close scrutiny of the few available tree-ring chronologies and radiocarbon-dated sequences composing the IntCal13 ^{14}C calibration curve indicates significant weakness in ^{14}C calibration across key periods of the LGIT. Here, we present a decadally resolved atmospheric ^{14}C record derived from New Zealand kauri spanning the Lateglacial from ~13,100–11,365 cal BP. Two floating kauri ^{14}C time series, curve-matched to IntCal13, serve as a ^{14}C backbone through the Younger Dryas. The floating Northern Hemisphere (NH) ^{14}C data sets derived from the YD-B and Central European Lateglacial Master tree-ring series are matched against the new kauri data, forming a robust NH ^{14}C time series to ~14,200 cal BP. Our results show that IntCal13 is questionable from ~12,200–11,900 cal BP and the ~10,400 BP ^{14}C plateau is approximately 5 decades too short. The new kauri record and repositioned NH pine ^{14}C series offer a refinement of the international ^{14}C calibration curves IntCal13 and SHCal13, providing increased confidence in the correlation of global paleorecords.

KEYWORDS: Younger Dryas, radiocarbon calibration, IntCal13, SHCal13, ^{14}C dating.

INTRODUCTION

Importance of Accurate and Precise LGIT ^{14}C Levels

Globally, the Last Glacial–Interglacial Transition (LGIT; 15,000–11,000 cal BP) experienced highly variable climatic and environmental change accompanied by human migration and expansion. High-resolution proxy archives have been developed to investigate climate, environmental, and archaeological change through the LGIT, including interhemispheric ocean-atmosphere leads and lags using lacustrine sediments, marine sediments, and ice cores (Björck et al. 1998; Mayle et al. 1999; Turney et al. 2006; Lowe et al. 2008; Muscheler et al. 2008; McGlone et al. 2010), abrupt global sea-level rise such as Meltwater Pulse 1A

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(MWP1A; Hanebuth et al. 2000), megafaunal extinction (Cooper et al. 2015; Metcalf et al. 2016), and the expansion of modern humans into the Americas (Waters and Stafford 2007; Dillehay et al. 2008). In the Northern Hemisphere (NH), the climate during the LGIT was characterized by abrupt temperature changes that included rapid warming at 14,700 cal BP, defined by the start of the Greenland Interstadial-1 (GI-1) in the Greenland ice-core isotope stratigraphy, and sustained severe cooling during Greenland Stadial-1 (GS-1; around 12,800–11,650 cal BP) (Rasmussen et al. 2014). In marked contrast, the mid- to high latitudes of the Southern Hemisphere (SH) experienced multicentennial temperature changes that were markedly antiphase to those in the North Atlantic, including the Antarctic Cold Reversal (ACR; 14,700–13,000 cal BP), apparently asynchronous with GS-1 (WAIS Divide Project Members 2015). The precise alignment of ice sequences with radiocarbon-dated terrestrial and marine records remains uncertain (Blockley et al. 2012; Muscheler et al. 2014).

Testing hypotheses of synchronous change is heavily dependent upon ^{14}C dating, with terrestrial samples requiring accurate representation of past atmospheric ^{14}C concentration ($\Delta^{14}C$).[1] Because atmospheric $\Delta^{14}C$ varies throughout time with fluctuating ^{14}C production rates and changes in sequestration in the various global carbon reservoirs, ^{14}C ages need to be placed on a calendar timescale using independently dated ^{14}C calibration records: IntCal13 (Reimer et al. 2013) for NH and SHCal13 (Hogg et al. 2013b) for SH samples.

Atmospheric ^{14}C measurements for the past ~14,000 yr (Reimer et al. 2013), as derived from tree rings, are considered the gold standard for ^{14}C calibration due to mostly independent dendrochronological dating. The Lateglacial and early Holocene period $\Delta^{14}C$ record, as contained in IntCal13, has been compiled through largely decadally resolved ^{14}C dating of 10-yr average tree rings from the following four key tree-ring chronologies:

(a) The "absolute" tree-ring chronology: This starts[2] at 12,410 cal BP, with the oldest section represented by the Preboreal pine chronology (PPC) dendro-linked to the calendar-dated Holocene oak chronology (HOC; Friedrich et al. 2004).

(b) YD-B: A tree-ring chronology built from Swiss pines, which was dendro-matched to the earliest part of the PPC, extending the absolute tree-ring chronology by 184 yr to 12,594 cal BP (Schaub et al. 2008a; Hua et al. 2009; Kaiser et al. 2012).

(c) Tasmanian huon pine chronology: Four floating[3] Tasmanian huon pine (*Lagarostrobos franklinii*) trees combined by dendrochronology and ^{14}C curve-matching to form a 617-yr series, overlapping with YD-B in age and spanning the early Younger Dryas (YD; Hua et al. 2009).

(d) CELM: The floating 1606-yr Central European Lateglacial Master Chronology (CELM; Kaiser et al. 2012). This record overlaps in time with the huon pine series, and starts at ~14,000 cal BP (Kromer et al. 2004; Kaiser et al. 2012).

Closer scrutiny of the tree-ring chronologies and ^{14}C-dated sequences described above (a–d) has revealed some areas of concern and a general weakness in ^{14}C calibration for this time period. These are each discussed in more detail in the following sections.

[1] $\Delta^{14}C$ is the decay-corrected deviation from the standard preindustrial atmospheric ^{14}C concentration (Stuiver and Polach 1977).

[2] In this paper, we follow the convention used in Friedrich et al. (2004) in which the oldest part of a dendrochronology is referred to as the "start" and the youngest part as the "end."

[3] A "floating" tree-ring chronology is one that is not anchored by dendrochronology to a calendar year.

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(a) Absolute Tree-Ring Chronology

The continuous European oak and pine tree-ring chronology as described by Friedrich et al. (2004) started at 12,410 cal BP and is characterized as "absolute" because the tree-ring sequences were dated and linked by dendrochronology. The oldest section is represented by the Preboreal pine chronology dendro-linked to the calendar-dated Holocene oak chronology (Friedrich et al. 2004). The earliest part of the PPC (the two-tree, 215-yr "Zurich" Swiss pine chronology from Zurich-Wiedikon, connected to the younger German Cottbus chronology) has low replication, and although it utilized all available series from Switzerland and northeast and southern Germany, it could not be confirmed, with the linkage described as "tentative" in Friedrich et al. (2004). Although a ^{14}C curve-match supported this linkage (Friedrich et al. 2004), the new ^{14}C data series presented here show that decadal ^{14}C curve-matching for this time interval is unlikely to be conclusive, because all ^{14}C dates lie on the ~10,400 BP ^{14}C plateau which is ~300 yr long, spanning the interval ~12,450–12,150 cal BP. Dendrochronological reanalysis of the "Zurich" to Cottbus connection has since confirmed the unreliability of this linkage (as reported by Friedrich et al. at the 2015 Zurich IntCal-Dendro workshop).

In addition, the ^{14}C data set of the older part of the absolute tree-ring chronology has uncertainties and a gap around ~12,000 cal BP, the time interval previously occupied by the discarded larch tree-ring series from Ollon, Switzerland (Ollon(VOD)505; Hogg et al. 2013a; Reimer et al. 2013). Indeed, the 425-yr period from 12,325–11,900 cal BP in the IntCal13 database (http://intcal.qub.ac.uk/intcal13/) contains only 12 decadal ^{14}C measurements, with the low sample density significantly reducing the resolution of ^{14}C calibration for samples of this age.

(b) Extension of Absolute Tree-Ring Chronology to 12,594 cal BP Using YD-B

Hua et al. (2009) and Kaiser et al. (2012) built upon the work of Schaub et al. (2008a), and presented ^{14}C data for the Swiss pine YD-B chronology, which extended the absolute tree-ring chronology to 12,594 cal BP, with the essential link to the absolute PPC still based on the "tentative" "Zurich" pine (called KW30 in Hua et al. 2009) to German Cottbus connection (Friedrich et al. 2004).

(c) Floating Tasmanian Huon Pine Chronology

Hua et al. (2009) presented 21 ^{14}C dates from the NH YD-B chronology and a further 137 ^{14}C dates from a SH 617-yr huon pine sequence to anchor the floating 1382-yr Lateglacial pine (LGP) chronology (Kromer et al. 2004) and bridge the gap in the European tree-ring ^{14}C record during the YD. However, because of the low replication of the huon pine tree-ring chronology, which is composed of only four logs, the dendro cross-matches also relied upon ^{14}C curve-matching, introducing additional uncertainties, to identify the correct linkages. The calculated error in the older huon/LGP overlap is ±16 yr (1σ errors); no errors are stated for the younger huon/absolute tree-ring chronology overlap, although the authors do acknowledge that the agreement, although evident, is not as good for the younger time period. Although the huon sequence extended far enough towards younger ages to overlap with both KW30 ("Zurich") and Cottbus dates, it was not young enough to extend beyond the ~10,400 BP plateau and could not therefore verify the KW30/Cottbus connection.

(d) Floating CELM Chronology

Kaiser et al. (2012) compiled an inventory of Lateglacial tree-ring chronologies from Switzerland, Germany, and France. Building upon the work of Schaub (2007) and Schaub et al. (2008a,b),

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Kaiser et al. (2012) initially constructed the Swiss Lateglacial Master Chronology (SWILM). Comparisons of the independently established tree-ring chronologies from Germany (Friedrich et al. 1999, 2001a,b, 2004) and Switzerland provided a cross-check and permitted formation of the Central European Lateglacial Master Chronology (Kaiser et al. 2012).

Based on initial European floating Lateglacial tree-ring chronologies (Friedrich et al. 1999, 2001a,b), Kromer et al. (2004) constructed a 1382-yr Lateglacial pine ^{14}C series with 106 ^{14}C dates from German and Swiss tree-ring series covering the ^{14}C age interval of ~12,300–10,600 BP. Additional Lateglacial pine ^{14}C dates from Swiss sites were obtained by Schaub et al. (2005, 2008a). A revised ^{14}C data set (which includes the LGP series of Kromer et al. 2004) comprising 232 dates from the CELM and covering the ^{14}C age interval of 12,357 to 10,612 BP, was included in IntCal13 (Reimer et al. 2013).[4] Various studies place the LGP end date between ~12,500 and 12,850 cal BP (see details below). It is clear that these floating records need to be more tightly constrained, to reduce calibration errors across the LGIT.

Importance of New Zealand Subfossil Kauri

Subfossil kauri (*Agathis australis*) logs ranging in age from late Holocene to at least Oxygen Isotope Stage (OIS) 7 (243,000–191,000 cal BP; Marra et al. 2006) are preserved in remarkable condition in anaerobic bogs scattered from Waikato to Northland in the upper North Island of New Zealand (Ogden et al. 1992; Palmer et al. 2006, 2015); see Figure 1. Some of the buried trees have more than 2000 rings and diameters greater than 4 m. Living trees have recently been linked to late-Holocene subfossil logs (Boswijk et al. 2006, 2014) and numerous floating chronologies mainly from OIS 3 (60,000–25,000 cal BP) have also been constructed (Palmer et al. 2015; Turney et al. 2016). This wood contains high-resolution information about past environments, including climate and landforms, and is therefore a scientific resource of international significance (Turney et al. 2007).

Kauri logs were extracted from two geographic locations for this study. The first location was a farm site near Towai (35°30.393′S, 174°10.376′E; Figure 1) in Northland where a cohort of 37 subfossil kauri logs of YD age has recently been discovered (Hogg et al. 2013a, 2016). The second site (Finlayson Farm, tree FIN11) near Kai Iwi Lakes in Northland (35°50′S, 173°39′E; Figure 1) contains a single YD/early Holocene-aged log, which overlaps in age with the Towai series.

The development of a robust 1451-yr kauri tree ring chronology from Towai and highly replicated decadal ^{14}C analysis of the Towai wood by multiple laboratories enables us to address the YD calibration issues outlined above. Decadal ^{14}C measurements were published by Hogg et al. (2016). Here, we present individual kauri measurements from ~13,130–11,370 cal BP, with additional details relating to the reconstruction of the LGIT/early Holocene NH ^{14}C record. In combination with the key NH data sets, we report improved SH and NH atmospheric tree-ring-based ^{14}C data comparison curves, spanning the interval ~14,200 to the present. The new tree-ring-based ^{14}C data sets, which can be accessed using OxCal (Bronk Ramsey 2009), are not an official replacement for IntCal13 or SHCal13, but we propose they should be used in the interim as a tool for assessing possible LGIT/early

[4]It should be noted that the youngest sample from the CELM chronology, as given in the IntCal13 data set, is from tree Gänziloh 3 (G3: HD-22487), part of the YD-A chronology, which is not discussed in this paper. This sample has a calendar age 11.5 yr younger than the youngest sample from the LGP ^{14}C series, which comes from tree Gänziloh 5 (G5: HD-22482). This distinction is important when discussing the end dates of the CELM and LGP ^{14}C series.

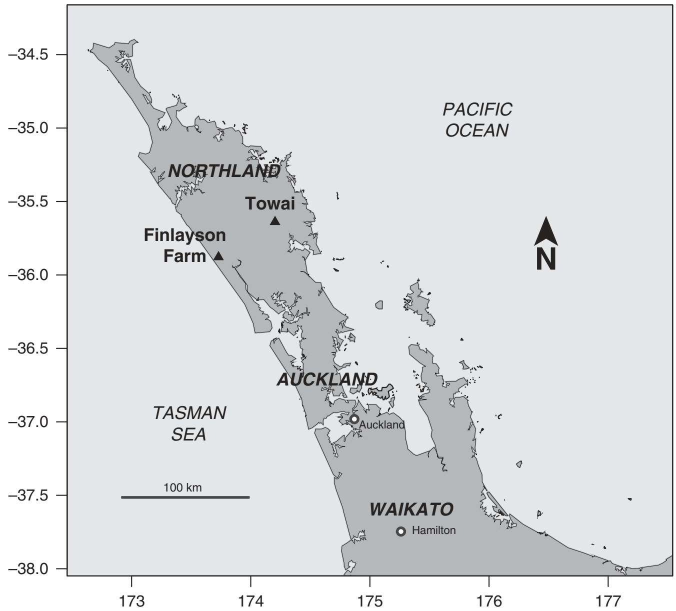

Figure 1 Location of Younger Dryas/early Holocene subfossil kauri sites Towai and Finlayson Farm (FIN11), Northland, New Zealand.

Holocene calibration errors in the official calibration curves and testing hypotheses of regional and global synchroneity.

METHODS

Dendrochronology

The 1451-yr Towai floating subfossil kauri chronology compiled from 91 radial strips derived from 37 trees is well replicated and securely cross-dated with an average cross-correlation coefficient between all series of 0.71 (Hogg et al. 2013a, 2016). The chronology has only 0.63% missing rings, with a mean ring width of 1.13 mm and average series length of 551 yr. Utilizing the expressed population signal (EPS; Wigley et al. 1984) threshold of >0.85 as a measure of satisfactory replication to avoid dendrochronological dating errors, the Towai chronology has inadequate sample depth for the first (oldest) 115 rings and the last (youngest) 164 rings. The kauri tree FIN11 has two measured radii and 533 rings. Through comparison of the two radii, we estimate that the log contains a maximum of 10 missing rings. No crossmatch has been identified between the FIN11 tree-ring sequence to the Towai tree-ring chronology. However, comparison of the ^{14}C series indicates there is a ~185-yr overlap between the ^{14}C chronologies, with FIN11 extending a further ~290 yr into the early Holocene. The FIN11 measurements provide additional confidence in the lock of the Towai kauri series with the secure Lateglacial/early Holocene dendro-dated NH wood series forming IntCal13.

Wood Treatment and Δ^{14}C Measurement

High-precision (HP) liquid scintillation (LS) spectrometry and accelerator mass spectrometry (AMS) ^{14}C dating have been undertaken on cellulose extracted from decadal kauri samples covering the entire Younger Dryas Stadial and the beginning of the Holocene. Six ^{14}C dating

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Table 1 Individual laboratory contributions to the Towai and FIN11 ^{14}C data sets.

Chronology	University of California at Irvine AMS	University of Waikato high-precision LSC	University of Waikato AMS	University of Oxford AMS	ETH Zurich AMS	University of Heidelberg GPC
TOWAI 145 decades 778 analyses	144 decades holocellulose rings: 865–2205 & 2225–2305	117 decades α-cellulose rings: 1135–1935 & 2015–2305	4 decades α-cellulose rings: 1205, 1235, 1285, 1315	117 decades α-cellulose rings: 955–2115	12 decades α-cellulose rings: 1205–1315	10 decades holocellulose rings: 1215–1265 & 1285–1315
FIN11 48 decades 244 analyses	48 decades holocellulose rings: 25–342 & 375–528	—	45 decades α-cellulose rings: 55–342 & 375–528	—	—	—

laboratories made contributions in compiling the ^{14}C data sets (Table 1). Detailed wood pretreatment procedures and ^{14}C analytic methods for the principal participating laboratories (University of California at Irvine, UCI; University of Waikato, Wk; University of Oxford, OxA) are given by Hogg et al. (2013a).

RESULTS

We present here the results of 789 ^{14}C measurements for the Towai chronology and a further 246 measurements from FIN11. ^{14}C decadal means, rejection criteria, and statistical analysis methods for both data sets are given in Hogg et al. (2016). From a total of 1035 results, 11 were rejected from the Towai chronology and 2 from the tree FIN11. Individual analyses are given as an XLS file (Radiocarbondating results.xls) in the online Supplementary Material (sheets named "Towai accepted," "FIN11 accepted," and "TOWAI_FIN11 rejected"). The χ^2 agreement indices indicate a high level of reproducibility within each decade for both data sets—see Hogg et al. (2016) for details. We also present the NH data with reassigned calendar ages (Radiocarbondating results.xls/NH).

DISCUSSION

Calendar Placement of Towai and FIN11 Data Sets

The floating Towai and FIN11 ^{14}C time series were curve-matched against IntCal13 (Reimer et al. 2013) with the match restricted to the time interval unaffected by the removal of the Ollon505 data set (Hogg et al. 2013a; Reimer et al. 2013), i.e. IntCal13 ^{14}C data points younger than ~10,260 BP. The Towai ^{14}C data set includes 18 such measurements younger than 10,260 BP. The curve-match utilized the OxCal Reservoir Offset ("Delta_R") function (Bronk Ramsey 2009) with a wide uniform prior of –120 to +120 yr to account for the interhemispheric (IH[5]) offset. It also employed outlier analysis (Bronk Ramsey 2009) using Outlier_Model ("SSimple",N(0,2),0,"s") with {Outlier, 0.05} (which allows individual samples—roughly 1 in 20—to be outliers) to down-weight outliers. A curve-match between the

[5]The ^{14}C interhemispheric offset (also known as the N/S ^{14}C offset or the interhemispheric gradient) is the difference in atmospheric ^{14}C concentration between the two hemispheres. It results from enhanced outgassing of ^{14}C-depleted CO_2 from the proportionally larger SH oceans and causes SH atmospheric samples to be ~40 yr older during the Holocene.

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Table 2 Agreement data for comparison of floating Lateglacial kauri data to various calibration data sets.

Run nr	**Floating data set** (decades used) [Calibration data set]	Agreement (OxCal) (%)	Agreement (χ^2§)	IH offset# (Modeled Delta_R, yr)	Calibrated mean age (cal BP)	Calibrated range (cal BP)
2-1	**TOWAI** (Youngest 18) [IntCal13*]	A_c = 262.3 A_n = 16.7	df = 17 T = 3.4 (5% 27.6)	38.5 ± 7.8	11,694 ± 7	13,134–11,694 ± 7
2-2	**FIN11** (All 48) [IntCal13*]	A_c = 298.7 A_n = 10.2	df = 47 T = 14.5 (5% 63.0)	36.9 ± 3.5	11,366 ± 3	11,869–11,366
2-3	**TOWAI** (Youngest 18) [FIN11]	A_c = 91.9 A_n = 16.7	df = 17 T = 16.3 (5% 27.6)	—	11,690 ± 3	13,130–11,690

*Offset function = ((U(-120,120))).
§χ^2 agreement test: df = degrees of freedom; T = chi-square test statistic; 5% = comparison T-test value with a <5% probability of arising due to chance alone.
#If Holocene SH ^{14}C data sets are curve-matched against a NH calibration curve, the IH offset has a positive sign, as in column 5 above. This becomes negative when Holocene NH data sets are matched against SH curves. To avoid confusion, all curve-matches in this paper are assumed to be SH ^{14}C data matched against NH curves, irrespective of the origin of the ^{14}C data.

same, youngest, 18 Towai data points and FIN11 provided a check on the consistency of the Towai and FIN11 data sets. Results for the three curve-matches are summarized in Table 2.

The Towai chronology curve-match to IntCal13 (Table 2, run 2-1; Figure 2A) has high agreement for both individual analyses and the model as a whole (model agreement index A_c = 262.3%) with the youngest decade having a mean calendar age of 11,694 ± 7 cal BP and the decadal midpoints lying between 13,134 and 11,694 ± 7 cal BP.

All 48 FIN11 decades were curve-matched to IntCal13 using the same Delta_R uniform offset prior of –120 to 120 yr (Table 2, run 2-2; Figure 2A). The model as a whole shows very good agreement (A_c = 298.7%), with the youngest FIN11 decade having a mean calendar age of 11,366 ± 3 cal BP. The FIN11 decadal midpoints therefore range from 11,869 to 11,366 cal BP (Figure 2A). As the curve-matches are based upon decadal data only, we consider the very low errors given here and elsewhere in this paper may be overly precise.

To test the calendar placement of the Towai chronology, we constructed a calibration data set from the FIN11 results and compared the Towai ^{14}C time series with FIN11 (Table 2, run 2-3). Although the agreement indices are lower (A_c = 91.9%), the agreement is still acceptable. Using the FIN11 data, the Towai chronology youngest decade midpoint has a mean calendar age of 11,690 ± 3 cal BP. The two Towai chronology runs have produced statistically identical results (Table 2, runs 2-1 and 2-3).

For final placement of the Towai chronology, we have chosen the comparison with IntCal13 rather than FIN11. Although the FIN11 comparison produced a more precise result, the FIN11 tree is not dendrochronologically secure and may have up to 10 missing rings. On the basis of the three curve-matches as outlined above, we have assigned a calendar age range for the Towai ^{14}C time series of 13,134–11,694 cal BP with a 1σ error of ±7 yr.

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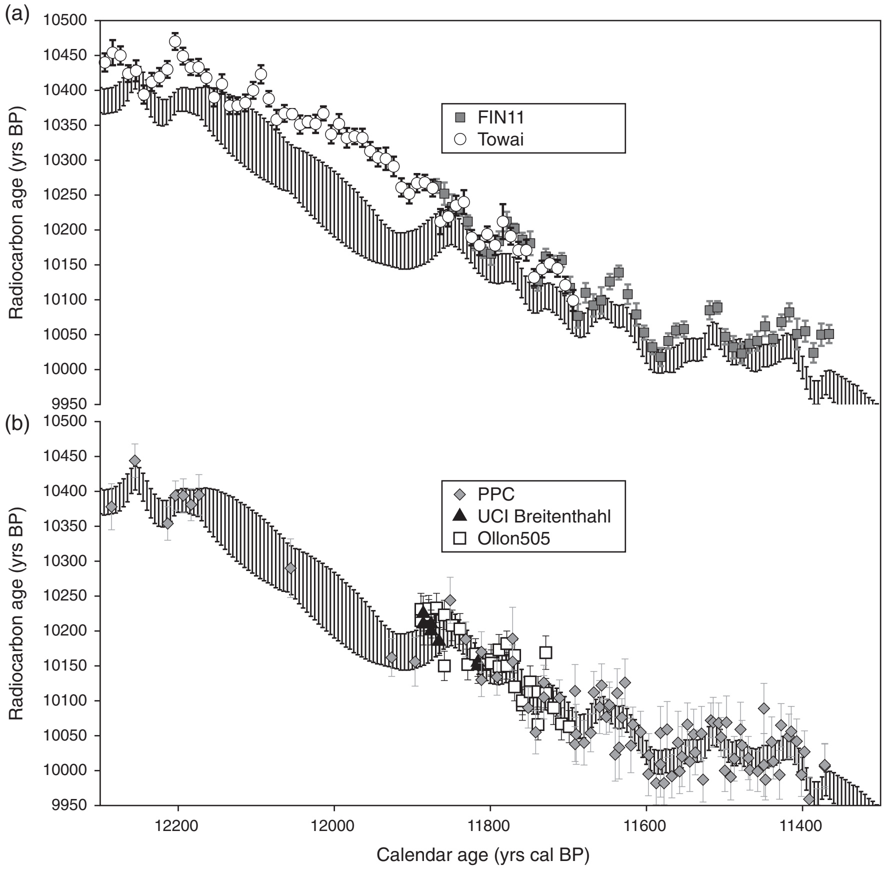

Figure 2 (A) Floating SH Towai and FIN11 data sets. (B) NH data sets: (i) Known calendar-age: Preboreal pine chronology (PPC) and Breitenthal (UCI); (ii) Floating: Ollon505 (new Wk and HD data; Hogg et al. 2013a). IntCal13 curve (black 1σ error bars) given in both plots.

Despite the possibility of up to 10 missing rings in the tree FIN11, the majority of the FIN11 measurements match the IntCal13 data points and curve closely (Figure 2A). The FIN11 ^{14}C time series confirms there is no measurable change at decadal timescales in the IH offset at the beginning of the Holocene. The youngest 18 measurements from the Towai chronology also lock securely with both FIN11 and IntCal13 data points.

The comparison of YD/early Holocene SH data points and the IntCal13 curve in Figure 2A shows the SH data points deviate from the shape of IntCal13 from ~12,200 to 11,900 cal BP, the time interval previously occupied by the original Ollon505 measurements and for which no replacement NH data are yet available. Figure 2B shows the equivalent NH data: the absolute Preboreal pine chronology measurements (Friedrich et al. 2004), supplemented by a few new UCI AMS results from the known-age Breitenthal tree-ring series (Table 3). Two PPC dates from Tapfheim17 (11,926.5 cal BP, HD-16342 and 11,896.5 cal BP, HD-16427) may be a little young. We have also included measurements from the floating Ollon505 tree-ring series, as positioned in Hogg et al. (2013a). Although it is not conclusive, the NH data points for samples older than ~11,900 cal BP also tend to depart from IntCal13 and support the view that IntCal13 is too young between ~12,200 and 11,900 cal BP.

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Table 3 New UCI ^{14}C determinations from the PPC Breitenthal tree-ring chronology (tree 198).

UCI lab number	Ring numbers (range)	Midring number	cal age (midring)	^{14}C age (yr BP)	1σ error
117837	123–132	127.5	11,085	10,115	20
117838	123–132	127.5	11,085	10,110	20
117839	113–122	117.5	11,816	10,155	20
117840	113–122	117.5	11,816	10,150	25
117841	63–72	67.5	11,866	10,185	20
117842	63–72	67.5	11,866	10,185	20
117845	53–62	57.5	11,876	10,210	20
117846	53–62	57.5	11,876	10,200	20
117843	43–52	47.5	11,886	10,225	25
117844	43–52	47.5	11,886	10,210	30

Refinement of the Lateglacial Atmospheric $\Delta^{14}C$ Record

(a) Extension of Absolute Tree-Ring Chronology Using the YD-B Measurements

The youngest of the YD-B ^{14}C dates from the KW30 series (the "Zurich" trees originally included in the PPC absolute tree-ring chronology by Friedrich et al. 2004 and Schaub et al. 2008a) as positioned in IntCal13 are plotted with contemporaneous PPC and Towai data points in Figure 3.

The oldest of the Zurich pine KW30 measurements, HD-20109, in its IntCal13 position (12,401 cal BP), is >100 ^{14}C yr older than the equivalent Towai decadal value and causes the shape of the IntCal13 curve to deviate towards older ^{14}C ages at this point. Because of the caveat by Friedrich et al. (2004) that the link to the PPC is tentative, we compared the KW30 data points with the Towai kauri data set, to see if an alternative time range was possible for this series. We used OxCal with a uniform prior of (U(–120,120)) to account for the IH offset. The curve-match of KW30 with Towai resulted in six possible solutions (Table 4) of which only the younger two can be ignored with their large negative Delta_R values discordant with the expected IH offset values of ~40 yr, as indicated by the younger Towai/FIN11 data sets. This still leaves four possible positions, however, none of which can be entirely discounted.

As we were unable to assess the reliability of the Zurich pine KW30/German Cottbus linkage using only KW30 ^{14}C data, we matched the entire YD-B ^{14}C chronology (including KW30) as a group to Towai to see if the larger ^{14}C data series could provide a finite solution. Agreement data are given in Table 5. The YD-B tree-ring ^{14}C data set, as it is positioned in IntCal13, is shown in Figure 4A.

Solution 3 can be ignored as the model fails for this position. Solution 2 (Figure 4C) can also be discounted, as the agreement index is low (63.4%), the YD-B data points at ~12,280 cal BP in this location are misaligned with the oldest PPC measurements, and the IH offset is –54 yr, compared with Holocene values averaging ~40 yr. Apart from the considerations discussed above, solution 1 is considered the most likely position, as it has the highest agreement index (202.6%) and closely follows the shape of the Towai data, with IH offset values (48 ± 10 yr) statistically indistinguishable from the Holocene average of ~40 yr.

The accepted solution 1 calibrated age range for the YD-B series indicates that the ~10,400 ^{14}C BP plateau, as reported in IntCal13, is ~5 decades too short (Figure 4B). While ^{14}C data sets

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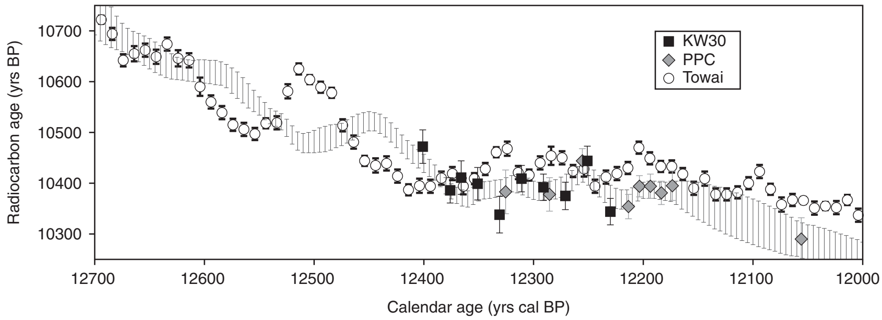

Figure 3 Positioning of YD-B KW30 measurements as included in IntCal13 (data as tabulated in the IntCal13 database–HD atmospheric, Set 5 Division 2). IntCal13 curve (black 1σ error bars) is also given.

Table 4 Possible fits for ^{14}C dates from tree KW30 compared with the Towai data set using a uniform reservoir function of Delta_R = (U(–120,120)).

Curve-matched solution	Range (cal BP)	Mean age (youngest sample) (cal BP)	IH* offset (yr)	Agreement (OxCal) (%)^	Agreement (χ^2)†
1	12,316–12,293	12,305 ± 4	36 ± 11	A_c = 133.3	T = 2.0
2	12,267–12,252	12,260 ± 4	28 ± 11	A_c = 133.1	T = 2.2
3	12,172–12,144	12,154 ± 5	35 ± 10	A_c = 111.5	T = 3.4
4	12,129–12,077	12,120 ± 4	27 ± 11	A_c = 117.2	T = 2.9
5	12,041–11,964	12,001 ± 22	–15 ± 15	A_c = 123.6	T = 2.1
6	11,944–11,904	11,929 ± 7	–48 ± 12	A_c = 74.9	T = 5.6

^*n* = 10 , An = 22.4%.
†df = 9 (5% 16.9).
*IH = as derived from modeled Delta_R. See comments about the sign of the IH offset in the caption of Table 2.

Table 5 Possible solutions for chronology YD-B compared with Towai using a uniform reservoir function of Delta_R = (U(–120,120)).

Curve-matched solution	Calibrated mean age (youngest sample) (cal BP)	Calibrated range (cal BP)	IH* offset (modeled Delta_R, yr)	Agreement (OxCal) (%)^	Agreement (χ^2)†
1	12,292 ± 5	12,301–12,279	48 ± 10	A_c = 202.6	T = 9.5
2	11,973 ± 4	11,980–11,965	–54 ± 7	A_c = 63.4	T = 21.4
3	11,879 ± 4	11,888–11,866	–87 ± 8	Not calculating range	Not calculating range

^*n* = 26, An = 13.9%.
†df = 25 (5% 37.6).
*IH = as derived from modeled Delta_R. See comments about the sign of the IH offset in the caption of Table 2.

from individual trees within YD-B cannot be satisfactorily curve-matched because of the ~10,400 ^{14}C BP plateau, the high YD-B chronology agreement values resulting from a match against Towai, provide confirmation in the integrity of this ^{14}C chronology and maintenance of Holocene-like IH offset values for this time interval.

IntCal13 contains another series of Swiss pine ^{14}C measurements for this period from a tree called Landikon F4 lying between 12,407.5 and 12,297.5 cal BP. Although it is not identified as such in

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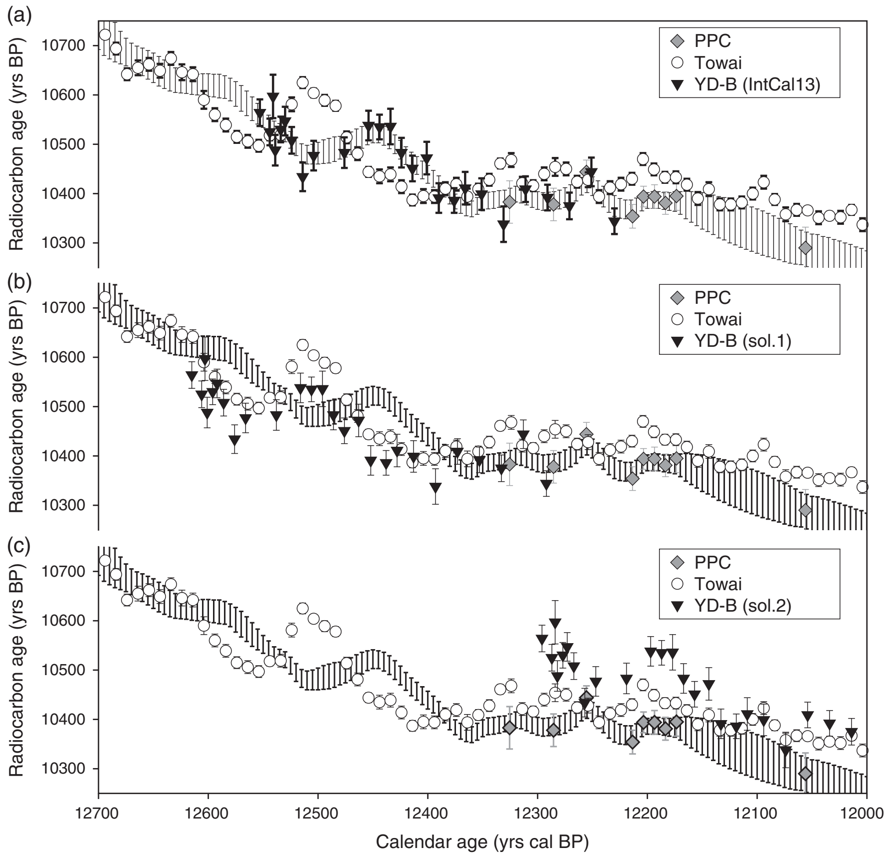

Figure 4 Positioning of ^{14}C dates from the YD-B tree-ring series: (A) as given in IntCal13; (B) curved-matched solution 1; (C) curve-matched solution 2. IntCal13 curve (black 1σ error bars) given in all plots.

IntCal13, this tree is floating (F Kaiser 2012, personal communication). We compared the Landikon F4 data points with the Towai kauri data set using a Delta_R uniform prior of U(–120,120) to see if the Landikon F4 data could help identify the correct shape for the NH curve. Landikon F4 locks onto Towai in six possible places, and as there is no single obvious solution, this data set cannot be used to identify the correct shape of the NH curve. Unless this sequence can be dendro-linked to other NH chronologies, it should be removed from future IntCal iterations.

(b) Connection of YD-B Tree-Ring Chronology to Floating Central European Lateglacial Pine Records (CELM)

Various methods have been used to obtain estimated calendar ages of the floating NH Lateglacial tree-ring ^{14}C series. Kromer et al. (2004) curve-matched the LGP dates against the marine Cariaco reference data set of Hughen et al. (2000) and found the sequence terminated at 12,844 ± 32 cal BP. Muscheler et al. (2008, 2014) correlated the Lateglacial ^{14}C tree-ring records to ice-core timescales using the common cosmic production signal in the tree-ring ^{14}C and ice-core ^{10}Be concentrations. They determined the youngest part of the LGP record of Kromer et al. (2004) at ~12,500 cal BP (Muscheler et al. 2008) and considered the IntCal13 placement (IntCal13, data set 5 division 9–http://intcal.qub.ac.uk/intcal13/) of 12,597 cal BP too old (Muscheler et al. 2014).

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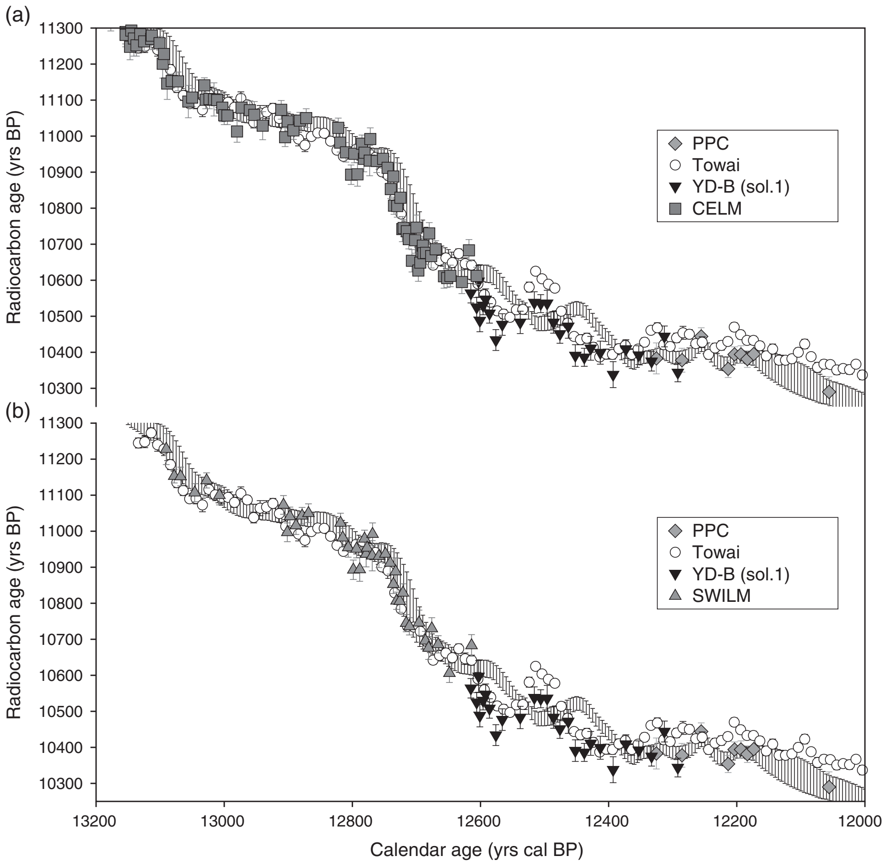

Figure 5 Positioning of ^{14}C dates from (A) the CELM ^{14}C series and (B) the SWILM series, compared with the Towai, PPC, and YD-B (solution 1) data sets. IntCal13 curve (black 1σ error bars) also given.

Hua et al. (2009) linked the LGP dates of Kromer et al. (2004) to huon pine tree rings and derived an end date of 12,597 ± 16 cal BP. Bronk Ramsey et al. (2012) obtained an LGP end date of 12,627 ± 35 cal BP based upon comparisons with the Lake Suigetsu data set.

The youngest 72 CELM ^{14}C measurements (obtained from the IntCal13 database) overlap with the Towai data set and were compared with it using a uniform Delta_R prior of –120 to 120 yr. Despite the wide uniform prior, the model produced a single solution, with the youngest CELM date (G3: HD-22487) having a mean calendar age of 12,606 ± 3 cal BP with a mean IH offset of 2.2 ± 6.5 yr. This positioning places the youngest of the LGP samples (G5; HD-22482) at 12,618 ± 3 cal BP. As the curve matches are based upon decadal data only, we consider the ±3 calendar year error overly precise. This calendar age is statistically indistinguishable from the IntCal13 placement and that determined by Hua et al. (2009) and Bronk Ramsey et al. (2012), but disagrees with the findings of Muscheler et al. (2014). The region of overlap between the CELM and Towai data sets is shown in Figure 5A.

To obtain the best possible fit between the CELM dates and Towai, we wanted to include in the match the short (~30 yr) ^{14}C plateau occurring in the Towai curve at ~11,240 BP. This necessitated inclusion of CELM ^{14}C dates older than the Towai curve (e.g. ~11,300 BP). As a result of

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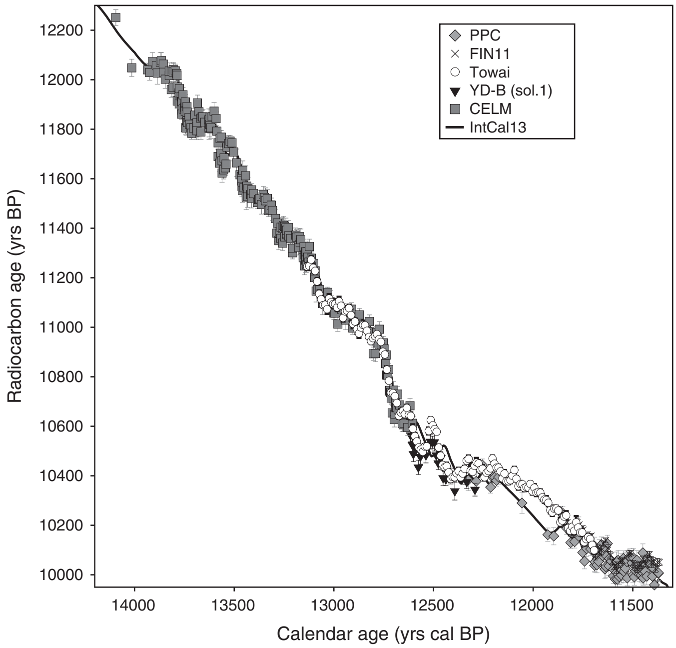

Figure 6 The complete SH Towai and FIN11 ^{14}C time series plotted with the NH CELM, YD-B, and PPC data sets. IntCal13 curve shown as a black line.

this, no agreement data are available. However, it is clear from the plot and the outlier results that the CELM data generally agree well with Towai in the region of overlap. Seven data points (~10%) have posterior outlier values >10% (with one sample with a value of 29%), however, which suggests some additional scatter.

We also separately matched the 44 ^{14}C dates from the youngest part of the SWILM GAENALCH series (Kaiser at al. 2012), the youngest date from which is G5 (HD-22482). The advantage in using this series is that it completely spans the oldest part of the Towai chronology and 38 of the ^{14}C dates (~87%) come from only two overlapping trees, G71 and G5, which together span the interval ~13,120–12,610 cal BP. The other six SWILM ^{14}C dates come from the trees G28, G63, and G101. This model shows that the youngest SWILM date from G5 has a mean calendar age of 12,615 ± 2 cal BP and a mean IH offset of –13.2 ± 6.3 yr. In the model run for the CELM dates described above, the same sample had a mean age of 12,618 ± 3, so the two runs resulted in statistically indistinguishable calendar placement. The SWILM data points are shown in Figure 5B. The complete SH Towai and FIN11^{14}C time series are plotted with the NH CELM, YD-B (solution 1), and PPC data sets in Figure 6.

A summary of the calendar positioning of the SH (Towai and FIN11) and NH (PPC, YD-B, CELM) ^{14}C time series derived from this research compared with the findings of Hua et al. (2009) is given in Figure 7.

A comparison of the CELM and SWILM data sets with Towai and the time series plot in Figure 6 appear to show a sustained reduction in the IH offset for time periods older than ~12,700 cal BP. The IH offset for this older time interval is close to 0 yr (Table 6), compared with 48 to 37 yr for the younger YD-B, Towai, and FIN11 data sets. The IH offset for the time interval ~13,100–12,600 cal BP is clearly anomalous compared with typical values for younger

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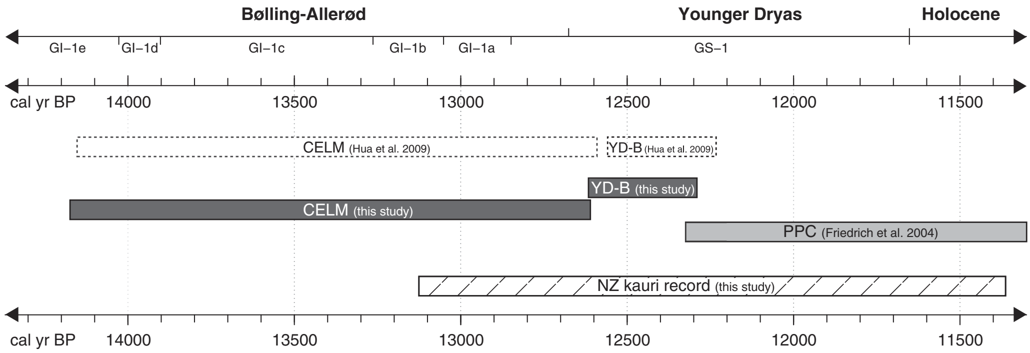

Figure 7 Temporal distribution of Northern and Southern Hemisphere Lateglacial tree-ring chronologies. The SH New Zealand kauri record (cross-hatched bar) has been locked to the absolutely dated Preboreal pine chronology (light gray; PPC; Friedrich et al. 2004) by ^{14}C and serves as a ^{14}C backbone through the Younger Dryas. The new kauri record enabled accurate curve-matching of the Northern Hemispheric floating Central European Lateglacial Master Chronology (black; CELM; Kaiser et al. 2012) and Younger Dryas B (black; YD-B; Hua et al. 2009). The former positions of the CELM and YD-B chronologies (dashed lines; Hua et al. 2009) are revised and adjusted in this work. The starting series of the PPC in this diagram is the Cottbus chronology beginning at 12,325 cal BP: the "Zurich" pine KW30 series is the end (youngest) member of the Hua et al. (2009) YD-B series. In addition to the calendar timescale (cal BP), the diagram also shows the INTIMATE Greenland Isotope event stratigraphy (on the GICC05 timescale in cal BP; Blockley et al. 2012; Rasmussen et al. 2014) and European climate stratigraphy, including the Lateglacial Interstadial (the Bølling/Allerød); the onset of the YD is as given in Rach et al. (2014).

Table 6 Interhemispheric (IH) offset values for different tree-ring series or time intervals. See comments about the sign of the IH offset in the caption of Table 2.

^{14}C data set (decades used)	Calibration data set	IH offset (yr)* (modeled Delta_R)	Time interval (cal BP)	Time span (yr)
CELM (Youngest 72)	Towai	2 ± 7	13,125–12,606	519
SWILM (Youngest 44)	Towai	–13 ± 6	13,121–12,614	507
YD-B	Towai	48 ± 10	12,615–12,292	323
Towai (Youngest 18)	IntCal13	38 ± 8	11,864–11,694	170
FIN11	IntCal13	37 ± 4	11,869–11,366	503
2nd millennium AD	Measured^	40 ± 13	995–105	900

^Hogg et al. (2002).
*IH = as derived from modeled Delta_R.

time periods including the Holocene. If the reduction in offset noted in this research is confirmed by analysis of contemporaneous SH/NH sample pairs, it could be associated with increased ventilation of the Southern Ocean following the termination of the Antarctic Cold Reversal. This possibility is discussed fully in Hogg et al. (2016).

Comparisons with Other ^{14}C Time Series

In the following section, we compare the Towai ^{14}C data set with other ^{14}C records:

i. Huon pine (Hua et al. 2009);

ii. Speleothems (Bahamas: Beck et al. 2001; Hoffmann et al. 2010; HuluH82: Southon et al. 2012);

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Table 7 Calendar placement of huon pine ^{14}C tree-ring series compared with Towai.

Data set (curve)	Mean age (youngest sample) 2σ cal BP ranges	Mean age (youngest sample) (cal BP)	*n*	Outliers >10%	Difference in age from Hua et al. (2009) (cal yr)
SRT779 (Towai)	12,363 (95.4%) 12,351	12,357 ± 3	24	0	53 ± 11
SRT781 (Towai)	12,271 (95.4%) 12,247	12,260 ± 11	34	6	43 ± 16
SRT782 (Towai)	12,137 (22.1%) 12,126	12,132 ± 6	35	2	59 ± 13
	12,091 (73.3%) 12,073	12,082 ± 9			9 ± 14
SRT783 (Towai)	12,330 (95.4%) 12,318	12,322 ± 15	41	7	42 ± 19

iii. Lake Suigetsu terrestrial plant macrofossils (Bronk Ramsey et al. 2012);

iv. Marine archives including Cariaco (Hughen et al. 2004, 2006) and corals (Edwards et al. 1993; Bard et al. 1998; Burr et al. 1998, 2004; Cutler et al. 2004; Fairbanks et al. 2005; Durand et al. 2013).

i. Huon Pine

The Tasmanian huon pine ^{14}C chronology spans 617 yr during the early Younger Dryas (Hua et al. 2009). We compared the huon pine ^{14}C data with the Towai series using an outlier model ((“SSimple”,N(0,2),0,“s”) with {Outlier, 0.05}) to improve the agreement. A comparison of all four huon trees as linked by Hua et al. (2009) resulted in poor agreement with low convergence. Agreement was significantly better comparing the trees individually with Towai (Table 7), which also shows the differences between this comparison and the solution given by Hua et al. (2009). Three of the four trees show a solution with a single range, with a mean difference of 42–53 yr older. The solution for SRT782 has a bimodal distribution and, using the three other results, we are able to identify the first (older) solution (22.1%) as the most likely one for this tree. Hua et al. (2009) were unaware of the possibility of two positions for tree SRT782, which resulted in a more random spread of ^{14}C ages on the 10,400 BP plateau. The four huon ^{14}C series are plotted against Towai data in Figure 8.

Although the huon data show more variability, the structure visible in the ^{14}C distributions is clearly displayed by both huon and Towai data sets.

ii. Speleothems

Bahamas speleothems (GB89-24, Beck et al. 2001 and GB89-25, Hoffmann et al. 2010)

The two Bahamas speleothem records show relatively high levels of detrital thorium and large dead carbon fraction (DCF) values: 1512 ± 244 yr for GB89-24 and 2139 ± 313 yr (revised to 2500 ± 90 yr in IntCal13 based on modeling against the Lake Suigetsu data set) for GB89-25-3. In addition, both records deviate significantly from the tree-ring data, particularly for samples younger than ~13,000 cal BP, and large errors have therefore been assigned to the DCF-corrected values in IntCal13. The growth of the Bahamas speleothems was slowing down in the YD, before finally ceasing in the early Holocene when they became submerged. During the interval ~12,600–12,100 cal BP, the GB89-24 data are clearly too young, while the GB89-25 data set is close to ~500 yr too old. The two speleothem data sets are compared with the NH and SH data sets in Figure 9A.

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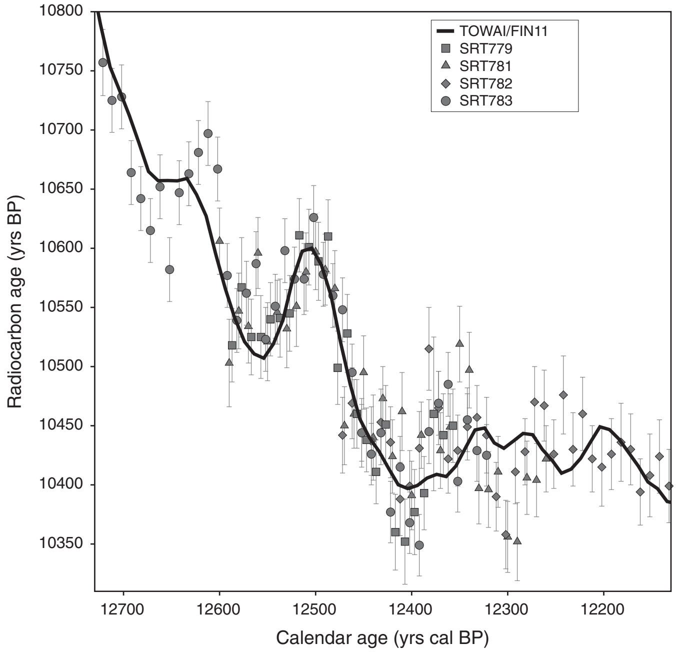

Figure 8 Tasmanian huon data sets (Hua et al. 2009) plotted with Towai/FIN11 5-point moving average.

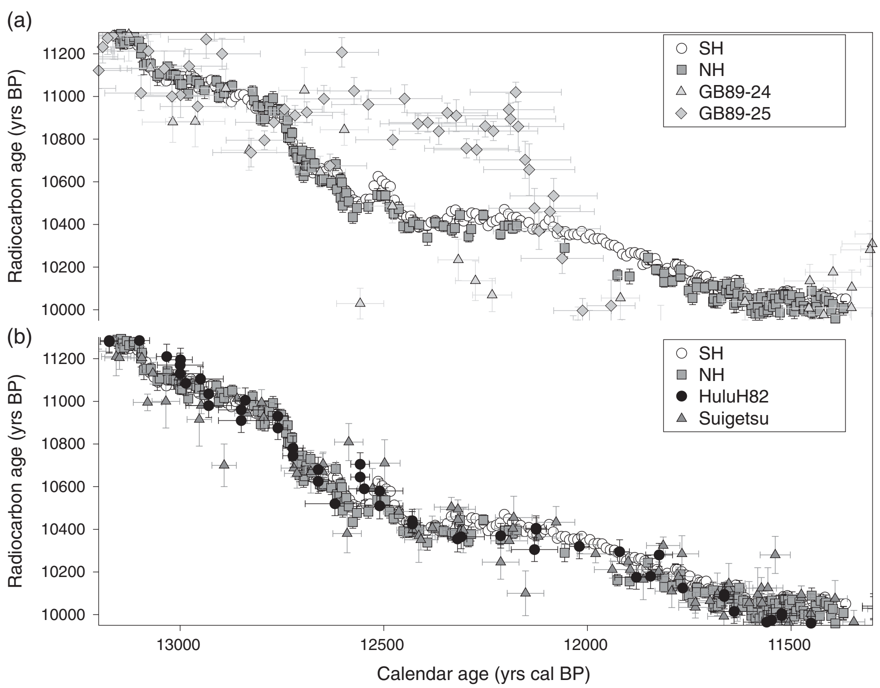

Figure 9 Comparison of YD terrestrial records with tree-ring ^{14}C data sets: (A) GB89-24 (Beck et al. 2001) and GB89-25 (Hoffmann et al. 2010) speleothems and (B) HuluH82 speleothem (Southon et al. 2012) and Lake Suigetsu macrofossils (Bronk Ramsey et al. 2012).

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Table 8 Calendar placement of HuluH82 speleothem and Lake Suigetsu macrofossil ^{14}C values compared with Towai/FIN11, using Outlier_Model("RScaledN",N(0,1),U(0,4),"r") with {Outlier, 0.05} and Delta_R(U(-120,120));.

Data set (curve)	Mean age (youngest sample) (cal BP)	Mean age (youngest sample) 2σ cal BP ranges	*n*	Outliers >10%	Published calendar age (cal BP)	Error in curve match age (yr)
HuluH82* (Towai/FIN11)	11,627 ± 14	11,647 (77.7%) 11,622 11,612 (17.7%) 11,592	38	1	11,664 ± 24	37 ± 28
Suigetsu# (Towai/FIN11)	11,683 ± 5	11,688 (95.4%) 11,679	50	0	11,681 ± 40	2 ± 40

*Speleothem measurements corrected for DCF.
#Four outliers with posterior outlier values >30% removed.

HuluH82 (Southon et al. 2012)

The Hulu Cave H82 speleothem (HuluH82), from a site in eastern China, provided an atmospheric ^{14}C record with calendar ages established by U-Th series dating and spanning 26,800–10,600 cal BP. The atmospheric data set was determined by subtracting the DCF from the measured ^{14}C ages. The DCF, determined by comparison of contemporaneous speleothem and IntCal09 tree-ring measurements, was found to be remarkably constant with a value of 450 ± 50 yr.

The HuluH82 data agree very closely with the Towai/FIN11 data sets (Figure 9B) except for two data points at 12,558 cal BP, which appear to be ~170 ^{14}C yr too old. We compared HuluH82 with Towai/FIN11, using a uniform Delta_R of –120 to +120 yr and Outlier_Model ("RScaledN",N(0,1),U(0,4),"r"); with {Outlier, 0.05} to test the accuracy and precision of both data sets for the common time interval (Figure 9B and Table 8).

The HuluH82 measurements matched against Towai/FIN11 have a high agreement index (Acomb = 192.9, n = 38, An = 11.5), with only one outlier >10%. Although the modeled age is close to the measured calendar ages within errors, the curve-match has effectively shifted the HuluH82 series ~37 yr towards younger ages. We are unsure why the HuluH82 12,558 cal BP values are older, but they may reflect a discrepancy in the U-Th ages or an error in the match of the ^{14}C curves (and hence on the shape of these curves).

iii. Lake Suigetsu

Floating terrestrial ^{14}C data were obtained from measurements on terrestrial plant macrofossils extracted from varved sediments in Lake Suigetsu ($SG06_{2012}$), Japan (Bronk Ramsey et al. 2012). We compared $SG06_{2012}$ data with Towai, using a uniform Delta_R of –120 to 120 yr and Outlier_Model("RScaledN",N(0,1),U(0,4),"r") with {Outlier, 0.05} to test the accuracy and precision of both data sets for the common time interval (Table 8 and Figure 9B). The Suigetsu data set also matches Towai closely (Acomb = 146.3, n = 50, An = 10.0) when the four most prominent outliers are removed (Table 8). Despite the larger scatter and higher uncertainties, the Suigetsu data, within its stated uncertainties, conforms to Towai data and reinforces the view that the Towai kauri data set is correctly linked to IntCal13.

The Suigetsu and HuluH82 data for the interval ~12,200–11,900 cal BP seem to follow the Towai curve and not the younger IntCal13 envelope, although there are too few data points for this to be definitive.

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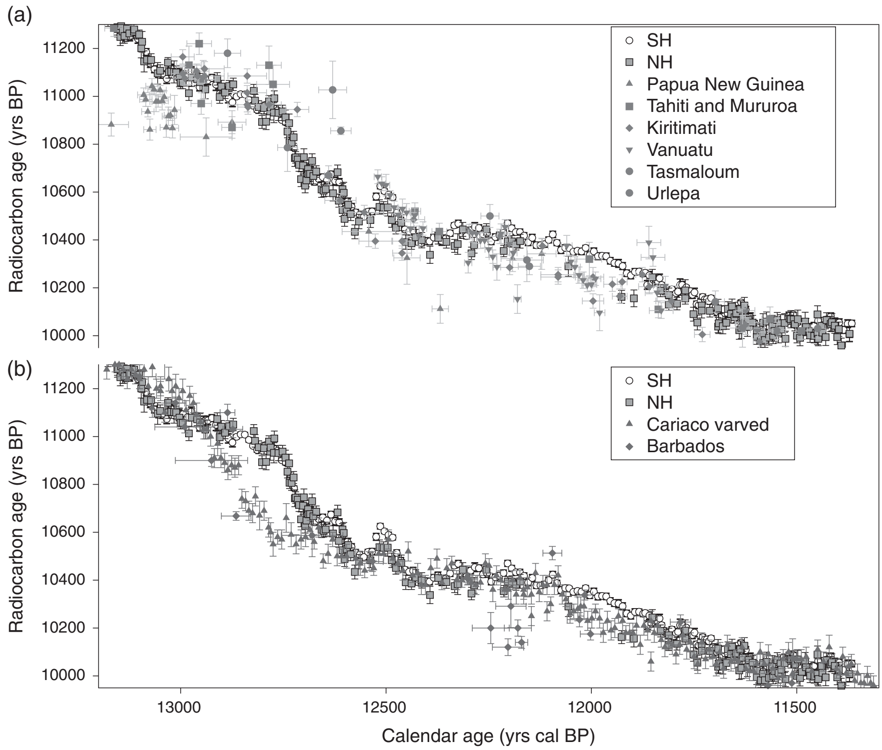

Figure 10 Comparison of marine records with tree-ring ^{14}C data sets: (A) Pacific marine corals (Papua New Guinea: Cutler et al. 2004; Edwards et al. 1993; Burr et al. 2004. Tahiti and Mururoa: Bard et al. 1998; Durand et al. 2013. Kiritimatai: Fairbanks et al. 2005. Vanuatu: Burr et al. 1998. Tasmaloum: Cutler et al. 2004. Urlepa: Cutler et al. 2004); (B) North Atlantic marine (Cariaco varved sediments: Hughen et al. 2004, 2006. Barbados corals: Bard et al. 1998; Fairbanks et al. 2005).

iv. Marine ^{14}C Archives

A comparison of marine and tree-ring ^{14}C data is important because it provides a means of calculating the local marine reservoir correction (R value, the difference in ^{14}C yr between the marine and atmospheric ^{14}C ages) for each marine archive. In using marine data to provide an atmospheric ^{14}C record, an assumption is made that the R value is constant and it is already known that this is not always the case. The R value in Cariaco Basin varved records, for example, deviates significantly during distinct intervals in both the YD (Kromer et al. 2004; Muscheler et al. 2008; Hua et al. 2009; Hogg et al. 2016) and Heinrich Stadial 1 (Southon et al. 2012; Reimer et al. 2013) and for this reason, the derived atmospheric ^{14}C values for these time intervals were omitted from IntCal13. Comparison of marine data with the more accurate SH and NH records presented here could provide more robust R values and hence more reliable atmospheric data derived from the marine archives.

The reservoir-corrected Pacific coral records are compared with the tree-ring records in Figure 10A. The Kiritimatai (Fairbanks et al. 2005), Tahiti and Mururoa (Bard et al. 1998), Vanuatu (Burr et al. 1998), Tasmaloum (Cutler et al. 2004), and Tahiti (Durand et al. 2013) records (Figure 10A) are in general agreement with the tree-ring data sets, suggesting that the R values for these sites are accurate, at least for this time period. This contrasts with Papua New Guinea (PNG) data (Figure 10A; Edwards et al. 1993; Burr et al. 2004; Cutler et al. 2004),

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which are 150–320 ^{14}C yr too young for the interval 14,180–10,670 cal BP. Reservoir age discrepancies in the PNG records are likely caused by the complex interplay of ocean currents encircling PNG, as indicated by marine shell/identified charcoal paired dates and pre-1950 shell dates derived from archaeological sites, with R values for the Huon Peninsula ranging from 71 ± 51 yr to 611 ± 16 yr (Petchey and Ulm 2012). The large range of R values for PNG have resulted in a large error term for ages used in IntCal13 (R = 495 ± 155), with the R errors propagated with the ^{14}C date measurement errors.

The reservoir-corrected Atlantic marine records are compared with tree-ring data in Figure 10B. As noted by earlier studies (e.g. Kromer et al. 2004; Hua et al. 2009; Hogg et al. 2016), the Cariaco Basin varved foraminifera sediment record shows very good agreement before ~12,920 cal BP and after ~12,640 cal BP. The interval ~12,920 to 12,640 cal BP shows systematic differences, however, due to reduced R value, possibly as a result of freshwater hosing reducing Atlantic Meridional Overturning Circulation (AMOC), discussed more fully by Hogg et al. (2016). The Barbados coral records (Bard et al. 1998; Fairbanks et al. 2005) are in reasonable agreement with the tree-ring data sets except for some data points around 12,100–12,250 cal BP, but follow Cariaco in deviating towards younger ages in the ~12,920–12,640 cal BP interval.

Revised Southern Hemisphere and Northern Hemisphere Tree-Ring-Based Comparison Curves for the LGIT

We have improved the calendar-age positioning of LGIT/early Holocene NH tree-ring ^{14}C records, as a result of anchored Towai and FIN11 kauri data sets and repositioned NH floating YD-B and CELM ^{14}C series, allowing us to develop comparison curves that span almost all of the LGIT. As a consequence, we can now present tree-ring-based SH (SHkauri16) and NH (NHpine16) comparison curves, which can be accessed from the OxCal web site (https://c14.arch.ox.ac.uk/oxcal) and are not subject to the errors occurring in SHCal13 and IntCal13. These errors include ages that are too young between ~12,200–11,900 cal BP (the time interval previously occupied by the Swiss larch Ollon505 data set; Hogg et al. 2013a), and the time interval ~12,450–12,150 cal BP, where the ~10,400 ^{14}C BP plateau is ~5 decades too short, resulting in a better placement of the YD-B and CELM pine series.

These new comparison curves, used in conjunction with the official calibration curves SHCal13 and IntCal13, will give researchers more confidence when calibrating samples within the LGIT/early Holocene. The curves contain only tree-ring-based ^{14}C data, with the SH curve spanning 13,134–0 cal BP and the NH curve 14,174–0 cal BP. Adjustments have been made to the NH comparison curve for the interval 12,164–11,874 cal BP by inserting SH kauri data, adjusted for an IH offset of 40 ± 13 yr (the measured 2nd millennium AD value derived from Hogg et al. 2002; Table 6) and adding the errors in quadrature. An approximate IH offset value of 40 yr can be justified because earlier time periods (e.g. 12,615–12,292, the YD-B interval; Table 6) as well as later time periods (e.g. 11,864–11,694, the youngest Towai dates; Table 6) have IH offset values in this range (48 ± 10 yr and 38 ± 8 yr, respectively). This approximation should be more accurate than IntCal13 for this part of the curve, but new NH data are required to confirm this. The SH and NH comparison curves for the interval 13,200–11,200 cal BP are given in Figures 11–13.

The SH curve (Figure 12) has 5-yr resolution. It uses the decadal kauri data given by Hogg et al. (2016) from 13,130–11,365 cal BP appended to SHCal13 random walk model (RWM) data from 11,360–0 cal BP. We have not averaged the decadal kauri data (Towai plus FIN11) as the 193 decadal means given by Hogg et al. (2016) are derived from 1035 measurements.

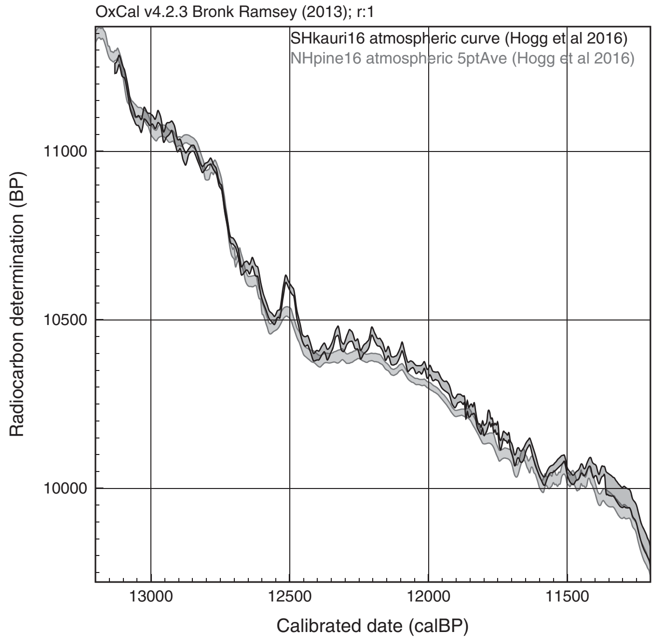

Figure 11 SH (SHkauri16, black) and NH (NHpine16, red) comparison curves for the interval 13,200–11,200 cal BP (see text for more details).

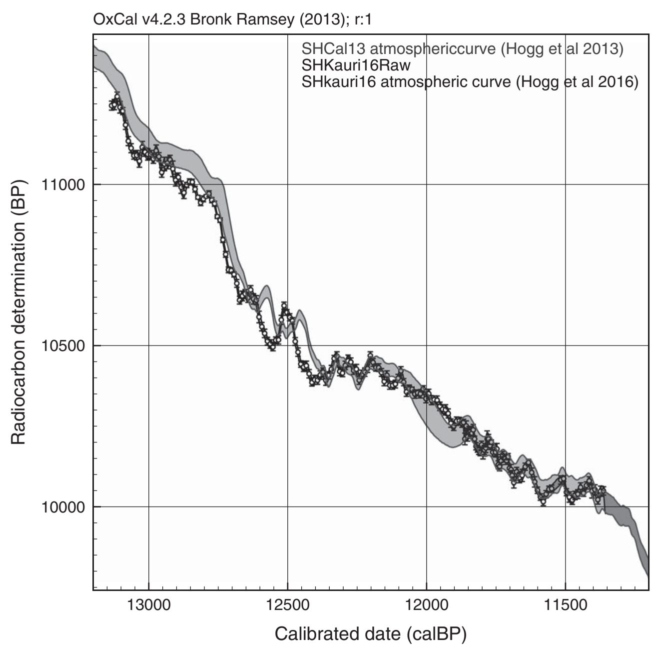

Figure 12 SH (SHkauri16) curve and data points plotted with the SHCal13 curve for the interval 13,200–11,200 cal BP. Measured Towai and FIN11 data are appended to IntCal13 RWM data at 11,365 cal BP (see text for more details).

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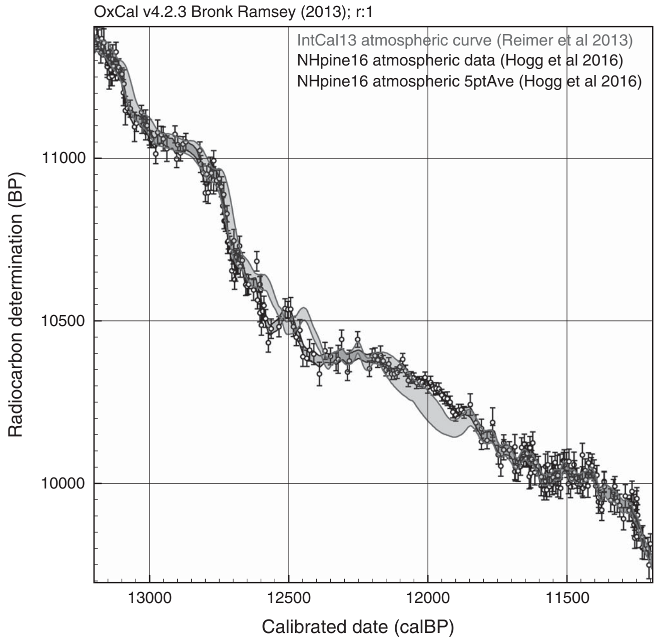

Figure 13 NH (NHpine16) curve and data points plotted with the IntCal13 curve for the interval 13,200–11,200 cal BP. A 5-point moving average has been applied to the revised decadal NH data points, from 14,120–11,420 cal BP. IntCal13 RWM data is appended at 11,415 cal BP (see text for more details).

The NH curve (Figure 13) also has 5-yr resolution. Because the NH data (online Supplementary Material, Radiocarbondating results.xls/NH) are not derived from decadal means, we have used a 5-point moving average (weighted 0.1, 0.2, 0.4, 0.2, 0.1) for the revised NH decadal measurements from 14,174–11,420 cal BP. IntCal13 RWM data is appended from 11,415–0 cal BP. Towai kauri decadal data minus an IH offset value of 40 ± 13 yr has been inserted into the interval 12,164–11,874 cal BP in the absence of other NH data as detailed above. Three NH data points (HD-16342, HD-16427, and HD-20699) in this interval may be a little too young and have been removed. It should be stressed that the comparison curves presented here are not official calibration curves and will be supplanted by SHCal and IntCal revisions that are in progress.

CONCLUSIONS

^{14}C measurements from the New Zealand 37-tree Towai kauri chronology (confirmed by additional measurements from the tree FIN11) provide a secure lock with the absolutely dated European Pre-boreal pine chronology (PPC) and define the shape of the atmospheric ^{14}C curves from ~13,100–11,700 cal BP. The ^{14}C calibration curve IntCal13 is clearly aberrant from ~12,200–11,900 cal BP, the time interval previously occupied by the discarded Ollon505 series (within the YD), with new measurements on existing calendar-dated trees from Germany in preparation. Comparisons between ^{14}C data from the YD-B chronology and Towai kauri data indicate that the YD-B chronology is incorrectly linked by dendrochronology to the PPC (Cottbus) tree-ring chronology. Because of the incorrect placement of KW30, the youngest of the YD-B series, the ~10,400 BP ^{14}C plateau in the current calibration data set IntCal13 is ~ 5 decades too short and should extend from ~12,450–12,150 cal BP. The floating Swiss pine

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^{14}C data set Landikon F4 is incorrectly located in IntCal13 and should be removed from the NH calibration data set if it cannot be dendro-linked to other NH chronologies. Furthermore, the new Towai/FIN11 kauri data sets indicate that the Central European Lateglacial Master (CELM) series begins at ~14,174 cal BP and ends at ~12,618 cal BP.

The new Towai chronology significantly improves ^{14}C calibration during the LGIT. The new SH (SHkauri16) and NH (NHpine16) comparison curves for the Lateglacial presented here are available via the OxCal calibration software, and may be used in conjunction with the official calibration curves SHCal13 and IntCal13 until revised curves are available. The ^{14}C interhemispheric offset appears to be lower during the early part of the YD, and changes at ~12,660 cal BP to Holocene-like levels, suggesting significant changes in Southern Ocean ventilation. This finding is based upon existing published data sets complied by different labs, however, and needs to be confirmed by analysis of contemporaneous SH/NH sample pairs.

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SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit http://dx.doi.org/10.1017/RDC.2016.86

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