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IS THERE ANY EVIDENCE FOR REGIONAL ATMOSPHERIC ^{14}C OFFSETS IN THE SOUTHERN HEMISPHERE?

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ABSTRACT. Center for Accelerator Mass Spectrometry (CAMS) Tasmanian Huon pine (*Lagarostrobos franklinii*) decadal measurements for the interval AD 745–855 suggest a mean interhemispheric radiocarbon offset (20 ± 5 yr), which is considerably lower than the previously reported mean interhemispheric offset for the last 2 millennia (44 ± 17 yr). However, comparable University of Waikato (Wk) New Zealand kauri (*Agathis australis*) measurements show significantly higher values (56 ± 6 yr), suggesting the possibility of a temporary geographic (intrahemispheric) offset between Tasmania, Australia, and Northland, New Zealand, during at least 1 common time interval. Here, we report 9 new Wk Tasmanian Huon pine measurements from the decades showing the largest Huon/kauri difference. We show statistically indistinguishable Wk Huon and Wk kauri ^{14}C ages, thus dispelling the suggestion of a ^{14}C geographic offset between Tasmania and Northland.

INTRODUCTION

While it is well established that atmospheric radiocarbon concentrations ($\Delta^{14}C$) vary between the hemispheres (the interhemispheric or North/South offset), there is little definitive data on ^{14}C variation within the hemispheres (intrahemispheric offsets). McCormac et al. (1995) investigated location-dependent differences in atmospheric $\Delta^{14}C$ in tree rings by quasi-simultaneous analysis of 9 contemporaneous sample pairs (500–320 BC) of dendrochronologically dated bristlecone pine from the western United States and Irish oak and found a mean offset of –41 ± 9.2 yr, with the American wood older. They also analyzed the IntCal86 (Pearson and Stuiver 1986; Stuiver and Becker 1986; Stuiver and Pearson 1986) and IntCal93 (Pearson and Stuiver 1993; Stuiver and Becker 1993; Stuiver and Pearson 1993) calibration data sets and concluded that these too showed intrahemispheric offsets between America, Ireland, and Germany, with the offsets probably related to either the influence of the oceans or dominating local effects, such as bog oaks differing in ^{14}C from oaks growing in large river systems. McCormac et al. (1995) concluded that the small magnitude of the offsets would have little impact upon individually calibrated dates but warned that location-dependent calibration curves may be necessary for high-precision ^{14}C wiggle-matching. Their call for future calibration efforts to include quasi-simultaneous measurements of tree rings from different regions has gone largely unheeded, with most subsequent studies (e.g. Damon et al. 1999; Sakamoto et al. 2003; Imamura et al. 2007; Ozaki et al. 2007) producing local data sets only, with the potential for laboratory bias to mask any real location-dependent differences.

Manning et al. (2010) and earlier publications (see Manning et al. 2010 for details) dated 23 contemporaneous decadal sample pairs for the interval AD 1420–1649 from 2 absolutely dated tree-ring chronologies, Turkish pine (*Pinus nigra*) from western Anatolia and German oak (*Quercus robur*) from southern Germany. Although the mean difference between the 23 sample pairs suggested no offset between Anatolia and southern Germany, a closer analysis of the data showed clear trends, with Turkish pine systematically older for some intervals, but younger for others. The authors concluded that the local offsets were of short duration only and restricted to times of solar minima, characterized by strongly rising atmospheric ^{14}C levels (rapidly decreasing ^{14}C ages compared to calendar ages). They postulated the offset was the result of a seasonal ^{14}C signal amplified by climate change.

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Zimmerman et al. (2010) measured decadal, dendrochronologically secure Tasmanian Stanley River Huon pine (*Lagarostrobos franklinii*) samples, pretreated by a modified de Vries acid-base-acid method, for the interval 165 BC to AD 1095 (2115–855 cal BP). They found an average offset to IntCal04 (Reimer et al. 2004) of 42 ± 26 yr but also note a 90-yr interval, AD 775–855 (1175–1095 cal BP), where there was zero interhemispheric offset. The data are plotted in Figure 1 (CAMS Huon).

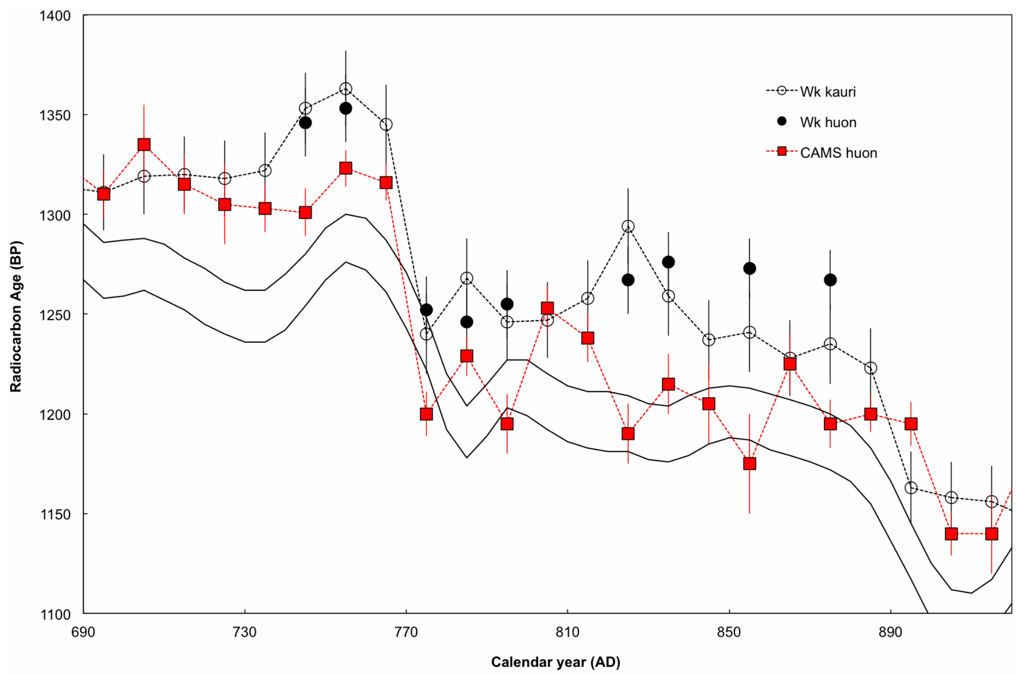

Figure 1 CAMS Huon, Wk kauri, and Wk Huon measurements from AD 690 to 950 plotted against the IntCal09 1σ envelope (solid line; Reimer et al. 2009). Note the younger CAMS measurements for the interval AD 775–855 and the agreement between the consistently older Wk kauri and Wk Huon data sets.

In contrast, Hogg et al. (2011) dated decadal samples from the New Zealand kauri (*Agathis australis*) chronology from Northland, New Zealand, for a similar time period (195 BC–AD 995; 2145–955 cal BP) and found a mean offset to IntCal09 of 49 ± 21 yr (error based upon the spread of the measurements). Although the offset showed variability (–5 to 100 yr), it was maintained over the entire data set and did not show a prolonged interval of zero offset as seen in the CAMS Huon measurements. The data for the time period AD 690–915 are also shown in Figure 1 (Wk kauri).

The CAMS Tasmanian Huon ^{14}C results could be evidence for a sustained reduction in the interhemispheric gradient during the 1st millennium AD. However, because this is not reflected in the Northland kauri data, which are on average 39.6 ± 10.4 yr older than the Huon for the interval AD 775–855 (Hogg et al. 2011), the younger Huon dates may represent a local offset. Indeed, Rodgers et al. (2011) suggest the possibility of intrahemispheric offsets within the Southern Hemisphere, which contains a significant ^{14}C gradient.

Although a ^{14}C geographic offset between Tasmania and New Zealand seems unlikely, given that both locations experience a very similar pattern of atmospheric circulation, with air movement dominated by westerly winds originating over the Southern Ocean, the possibility of a Tasmanian/New

Zealand offset is an important issue that needs investigating, as the Tasmanian Huon pine and New Zealand cedar (*Libocedrus bidwillii*), silver pine (*Lagarostrobos colensoi*), and kauri tree-ring chronologies make important contributions to Southern Hemisphere ^{14}C calibration (Hogg et al. 2002, 2011). This paper compares published Tasmania and New Zealand ^{14}C data sets that cover common time intervals to see if they suggest possible offsets. It then presents the results of 9 high-precision analyses of decadal Huon/kauri sample pairs, analyzed at the University of Waikato carbon dating facility and covering the interval AD 745–875, to determine if the CAMS data is indeed evidence for a local offset between Tasmania and New Zealand during this time period.

EVIDENCE FOR LOCAL OFFSETS DURING THE 2ND MILLENNIUM AD

Various Southern Hemisphere 2nd millennium AD data sets cover the time interval AD 1620–1780, which was characterized by extreme and rapidly changing ^{14}C levels. New Zealand measurements utilize crossdated New Zealand cedar from Takapari (40°04′S, 175°59′E) and Hihitahi (39°32′S, 175°44′E) Forest Parks. Decadal samples were pretreated to α-cellulose, with duplicate radiometric (liquid scintillation spectroscopy) measurements by University of Waikato (Wk) and Queen's University Belfast (UB) (Hogg et al. 2002). A third New Zealand data set is based upon a ring-counted sequence rather than a precise dendrochronology, utilizing a single matai (*Prumnopitys taxifolia*) tree from Peel Forest Park (43°54′S, 171°14′E), using decadal samples pretreated to cellulose, with radiometric (gas counting) measurements by the Rafter Laboratory (NZ) (Sparks et al. 1995).

Two data sets from Tasmania, Australia, utilize crossdated Huon pine—Sydney University (SUA) radiometric measurements from tree SRT-31B (Barbetti et al. 1992) and Australian Nuclear Science and Technology Organisation, ANSTO (OZ) AMS measurements from tree SRT-225 (Hua et al. 2004). Both Huon trees were obtained from the Stanley River (42°S, 145°E) with holocellulose extracted from the SUA samples, and α-cellulose from the ANSTO samples. We have also included measurements on southern Chilean wood samples (coihue, *Nothofagus dombeyi*, 54°S; Stuiver and Braziunas 1998) made at the University of Washington (QL; McCormac et al. 2002) for comparison.

None of the laboratories producing these data sets have measured both Tasmanian and New Zealand wood as decadal sample pairs, however, making it difficult to assess if laboratory bias is contributing to the offsets. The 6 data sets from AD 1620–1780 are shown in Figure 2 with offsets given in Table 1. The average difference between the Wk and UB duplicate New Zealand cedar data sets of 14.2 ± 6.4 yr provides a benchmark for potential offsets resulting solely from laboratory bias.

Table 1 Laboratory offsets for New Zealand, Tasmanian, and Chilean measurements from AD 1620–1780. σ1 is the average standard deviation based on quoted laboratory errors and σ2 is the observed standard deviation in the age difference. The error multiplier $k = \sigma2/\sigma1$.

Laboratories	Offset (^{14}C yr)	σ1	σ2	*k*
New Zealand cedar duplicate analyses				
Wk cedar – UB cedar	14.2 ± 6.4	25.9	23.6	0.9
Offsets with other New Zealand data sets				
Wk/UB cedar – NZ matai	2.8 ± 6.5	23.5	30.6	1.3
Offsets with international data sets				
Tasmania				
Wk/UB cedar – OZ Huon	–10.1 ± 6.5	26.1	24.2	0.9
Wk/UB cedar – SUA Huon	57.5 ± 6.3	30.7	28.5	0.9
S. Chile				
Wk/UB cedar – UW coihue	–2.1 ± 4.4	15.6	14.0	0.9

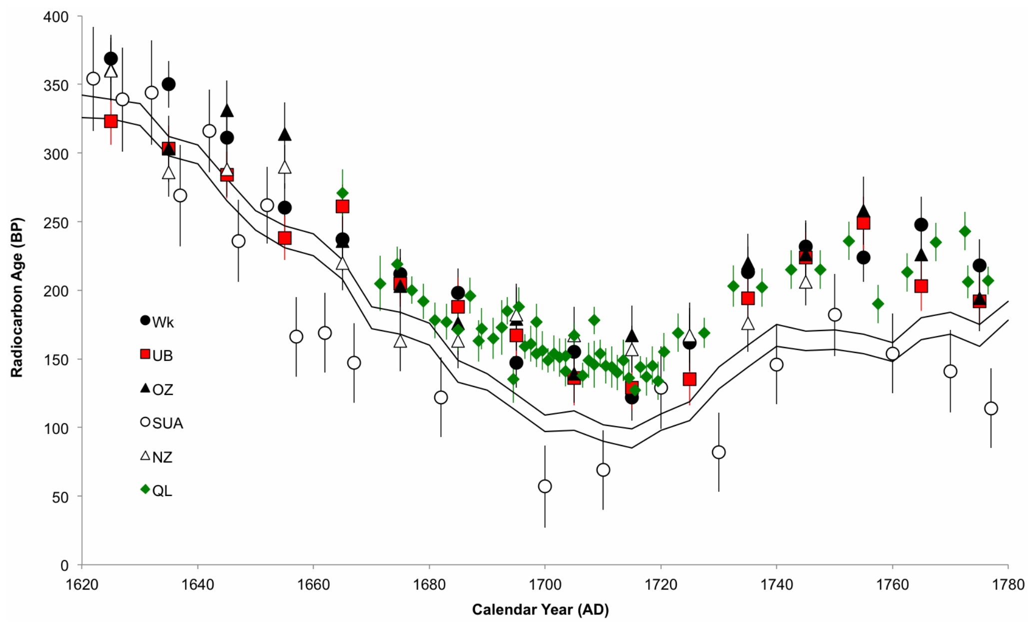

Figure 2 Southern Hemisphere 2nd millennium AD (AD 1620–1780) ^{14}C data sets. The 1σ envelope of the IntCal09 curve is shown as a solid line for comparison.

There is a high level of agreement between the Wk/UB cedar data set and the NZ matai, OZ Huon, and QL coihue measurements both in terms of mean offsets and the spread of the measurements. The SUA data set, however, is clearly offset from the remaining Southern Hemisphere measurements, with many data points even younger than IntCal09. It will therefore be excluded from any further discussion.

The consistency of the New Zealand, Tasmanian, and Chilean data, with offset levels similar to or less than those resulting from laboratory bias alone, provides evidence that there was no measurable geographic ^{14}C offset between these regions during this time period.

ANALYSIS OF 1ST MILLENNIUM AD SAMPLE PAIRS

To identify any potential regional differences between Tasmania and New Zealand in the 1st millennium AD, we analyzed 9 decadal Huon/kauri sample pairs from the interval AD 745–875. Decadal Huon samples were extracted from the same individual used in the Zimmerman et al. (2010) study, tree SRT-440 from the Stanley River in the NW Highlands of Tasmania (42°S, 145°E). Equivalent kauri samples were derived from the Harding tree-ring chronology (36.0°S, 173.8°E; tree Har010, Hogg et al. 2011).

All samples were pretreated to α-cellulose, comprising a 4-step process including solvent extraction, bleaching with acidified $NaClO_2$, NaOH extraction, and acidification with HCl (Hogg et al. 2011) at the University of Waikato. $\Delta^{14}C$ analyses were made by liquid scintillation spectrometry using LKB Wallac Quantulus™ 1220 spectrometers with laboratory protocols and counting parameters optimized for high-precision measurement. Results for all 3 data sets are given in Table 2. The data are shown in Figure 1 (Wk Huon) along with the CAMS Huon and Wk kauri data sets, given for comparison.

Table 2 University of Waikato measurements on selected decades of Tasmanian Huon pine – SRT440: AD 745–875 (1205–1075 cal BP). CAMS Huon (Zimmerman et al. 2010) and Northland kauri (Hogg et al. 2011) data given for comparison.

Year AD	Wk Huon lab nr	Wk Huon ^{14}C BP	$\delta^{13}C$ (‰)	CAMS Huon ^{14}C BP	Wk kauri ^{14}C BP	Offset Wk Huon – CAMS Huon	Offset Wk Huon – Wk kauri
745	29100	1346 ± 17	–19.9	1301 ± 12	1353 ± 18	45 ± 21	–7 ± 25
755	29101	1353 ± 17	–19.6	1323 ± 9	1363 ± 19	30 ± 19	–10 ± 25
775	29103	1252 ± 17	–20.0	1200 ± 11	1240 ± 20	52 ± 20	12 ± 26
785	29104	1246 ± 17	–19.9	1229 ± 10	1268 ± 20	17 ± 20	–22 ± 26
795	29105	1255 ± 17	–20.0	1195 ± 15	1246 ± 19	60 ± 23	9 ± 25
825	29108	1267 ± 17	–19.5	1190 ± 15	1294 ± 19	77 ± 23	–27 ± 25
835	29109	1276 ± 15	–20.0	1215 ± 15	1259 ± 20	61 ± 21	17 ± 25
855	29111	1273 ± 15	–19.9	1175 ± 25	1241 ± 20	98 ± 29	32 ± 25
875	29113	1267 ± 15	–20.0	1195 ± 12	1235 ± 20	72 ± 19	32 ± 25
					Offset	53.3 ± 7.1	–4.3 ± 8.5
					$\sigma 1$	21.7	25.4
					$\sigma 2$	24.6	21.7
					k ($\sigma 2/\sigma 1$)	1.1	0.9

Although the 9 Waikato Huon measurements are significantly different (Wk Huon 53.3 ± 7.1 yr older) from the equivalent CAMS Huon data, they are statistically indistinguishable from the equivalent Waikato kauri data (Wk Huon 4.3 ± 8.5 yr younger). The high levels of agreement between the Waikato Huon/kauri sample pairs show unequivocally that laboratory bias and not a regional ^{14}C offset between Tasmania and New Zealand was responsible for the younger CAMS ages for the interval AD 745–855.

CONCLUSIONS

Rodgers et al. (2011) highlight the possibility of a significant ^{14}C gradient within the Southern Hemisphere. Although parts of the 2nd millennium AD were characterized by extreme and rapidly changing ^{14}C levels, measurements from Chile, Tasmania, and New Zealand all show comparable values, with no evidence of geographic (intrahemispheric) offsets at these times. During an earlier period, CAMS Tasmanian Huon pine decadal measurements for the interval AD 745–855 show a statistically significant ^{14}C offset with comparable University of Waikato New Zealand kauri measurements, suggesting the possibility of a temporary, geographic offset between Tasmania, Australia, and Northland, New Zealand, for this time interval. However, from the decades showing the largest Huon/kauri differences, 9 new Waikato Tasmanian Huon samples extracted from the same individual as that utilized for the CAMS measurements show statistically indistinguishable Huon and kauri ^{14}C ages, thus dispelling the suggestion of a geographic offset between these adjacent regions.

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