EXTENSION OF THE SOUTHERN HEMISPHERE ATMOSPHERIC RADIOCARBON CURVE, 2120–850 YEARS BP: RESULTS FROM TASMANIAN HUON PINE

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ABSTRACT. Decadal samples of dendrochronologically dated pine (*Lagorostrobos franklinii*) from the Stanley River basin, Tasmania, have been radiocarbon dated between 2120–850 yr BP. This data set overlaps and extends the current Southern Hemisphere record, which covers the period 110–995 yr BP. There is good agreement between the 2 records between 995–850 yr BP, between sample replicates and with consensus values for standards. As in the younger data set, we find evidence for a distinct but variable offset between the Southern Hemisphere data and IntCal04; although this is likely due to real temporal variability in the interhemispheric offset, further work is planned to rule out possible laboratory or sample preparation differences.

INTRODUCTION

Radiocarbon dating is the most widespread method of dating geological and archaeological materials from the late Quaternary period (last ~50 ka) but has inherent difficulties. Because the $^{14}C/^{12}C$ ratio of the atmosphere has not remained constant, nullifying a fundamental tenet of radiometric dating, a ^{14}C date may not equate one-to-one with a single calendar year, and must be calibrated. Calibration has been achieved for the last 12,400 yr using a continuous series of dendrochronologically dated tree rings, all from the Northern Hemisphere. Fluctuations in atmospheric ^{14}C are primarily caused by changes in production rate due to solar and geomagnetic variability, but may also result from changes in storage and release of carbon from various reservoirs, including circulation changes in the ocean.

Ocean circulation in combination with the net air-sea exchange of carbon dioxide in the 2 hemispheres has been reasonably hypothesized to influence the ^{14}C content of the respective hemispheres. Excess efflux of subatmospheric $^{14}CO_2$ from the ocean should increase the ^{14}C age of the Southern Hemisphere relative to that of the Northern. For example, Vogel et al. (1993) found an average Southern Hemisphere offset of 41 ± 5 yr over the 19th century in South Africa, while Stuiver and Braziunas (1998) reported an offset of 23 ± 9 yr in Chilean wood over the 19th century and 38 ± 5 yr between AD 1670–1722, demonstrating apparent variability in the offset. The results of McCormac et al. (1998) also emphasized the variability of the offset in New Zealand and Irish wood between AD 1725–1895, with the Southern Hemisphere wood 27 ± 5 yr older on average.

Recently, results of an impressive cross-laboratory, interhemispheric comparison by the Waikato and Belfast laboratories (Hogg et al. 2002; McCormac et al. 2002) showed with very high precision that the atmosphere in the Southern Hemisphere was on average 41 ± 14 yr older than in the Northern Hemisphere over the period AD 955–1840. However, the offset varied from 8 to 80 yr, and showed an apparent periodicity of ~120 yr. Because there is no reason to assume that the carbon cycle or oceanographic changes that apparently drive the interhemispheric offset remain stable or can be predicted *a priori*, calibration with a local dendrochronologically dated ^{14}C curve is the most robust method of calibrating Southern Hemisphere ^{14}C dates. Here, we present preliminary results of decadal samples from Huon pine collected from the Stanley River basin, Tasmania, covering the period 2120–850 cal yr BP (170 BC–AD 1100).

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METHODS

Two specimens of subfossil Huon pine (*Lagorostrobos franklinii*) were recovered from the Stanley River in the northwest highlands of Tasmania. Specimen SRT 440A contains ~1100 rings, spanning the period 2130–1030 cal yr BP (180 BC to AD 920), and specimen SRT 44a contains ~724 rings, spanning 1550 to 826 cal yr BP (AD 400 to 1124). Both specimens are well preserved and consistently banded, and dendrochronologically dated within a well-established master framework (Buckley et al. 1997).

Decadal samples were manually milled using a Dremel® drill at slow speed with a carbide burr, yielding ~10 mg of raw material. The raw material was chemically pretreated with a modified deVries treatment (1N HCl, 1N NaOH [until clear, at least 2×], 1N HCl, all at 90 °C), rinsed copiously with Milli-Q™ water, and dried overnight on a heating block. Aliquots (~1.5–2 mg) of the pretreated material were sealed in evacuated quartz tubes containing copper oxide and silver and combusted at 900 °C. The resulting CO_2 was cryogenically purified, transferred to individual graphitization reactors, and reduced to elemental carbon in the presence of iron catalyst and a stoichiometric excess of hydrogen (Vogel et al. 1984). The graphite-iron mixture was then pressed into individual aluminum target holders and measured via accelerator mass spectrometry (AMS) at CAMS.

Individual targets were cycled in a prescribed sequence to attain ~300–500k ^{14}C counts in 50,000 counts per acquisition cycle. Data are normalized to the OXI oxalic acid standard (J Southon, unpublished data) and reported as conventional ^{14}C age according to Stuiver and Polach (1977). Background correction is facilitated by the analysis of similarly pretreated and prehandled ^{14}C-free wood, QL-4766, a wood sample shown to be of infinite age at the University of Washington laboratory. Sample-specific $\delta^{13}C$ values (relative to V-PDB) were measured via continuous-flow isotope ratio mass spectrometry at the Stanford Isotope Laboratory, on ~0.8-mg splits of the pretreated wood.

The accuracy of our results was monitored using a sample of alpha-cellulose provided by the Belfast laboratory, which was pretreated with 1N HCl and rinsed with Milli-Q water prior to conversion to graphite. We assessed the precision of our data with measurement of replicate unknowns and repeated measurement of an Irish oak sample, Q1323, previously measured at Belfast. Three years of the oak sample were milled and pretreated exactly the same as the Huon pine samples, and measured repeatedly with each batch of unknowns.

RESULTS

Figure 1 shows the result of 99 replicate analyses, of which 63% overlap the 1-σ analytical uncertainties. For samples with 2 or more measurements, the reported value is a weighted mean. The means of measurements on the Belfast cellulose, Q1323, and QL-4766 are given in Table 1. The alpha-cellulose, dendrochronologically dated at 1510 BC, has a ^{14}C age of 3247 ± 22 (G McCormac, personal communication), which corresponds well with our ^{14}C age of 3243 ± 34 (Table 1). The Irish oak, Q1323, was used to monitor the entire sample preparation procedure, and yields a standard deviation of 26 yr ($n = 18$). Note that our measured age is on 3 yr of a bidecadal sample and thus is not comparable to the age published by Pearson et al. (1986). The Huon data overlap the published Wk-Qub data for the period 995–855 BP, a total of 15 decadal samples. The 3 data sets show reasonable agreement (Figure 2), overlapping at 1 σ.

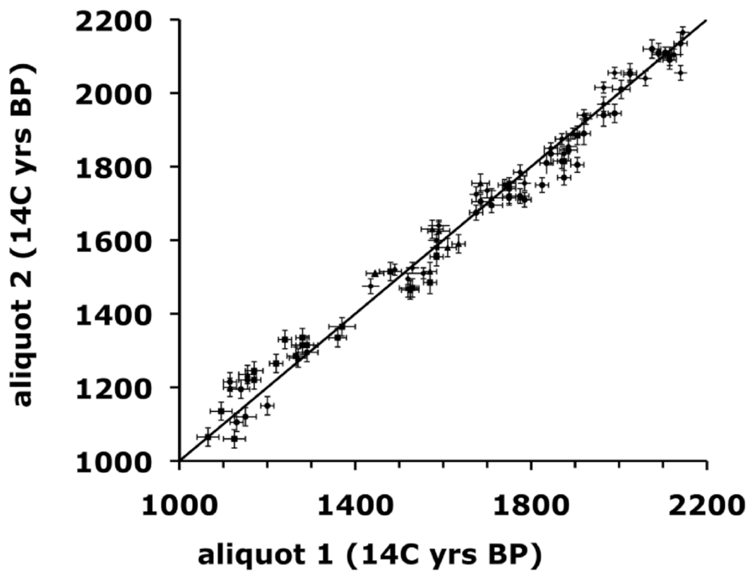

Figure 1 Comparison of results for complete- process replicates made on selected samples ($n = 99$) included in this study. Error bars on data points represent 1-σ analytical error.

Table 1 Process standard and blank (^{14}C-free wood) prepared and analyzed simultaneously with the SRT sample sequence. Dates are given in yr BP.

Sample	*n*	Mean (yr BP)	Standard dev	Reported value (yr BP)
BelCell	11	3243	34	3247 ± 22
Q1323[a]	18	4132	26	4199 ± 12
QL-4766	14	50,894	1760	—

[a]Q1323 is a bidecadal sample that was kindly provided by the Qub lab. Because only 3 yr of the Q1323 sample were milled, processed, and analyzed, our analyses of the Q1323 wood are not comparable to the result given by Pearson et al. (1986).

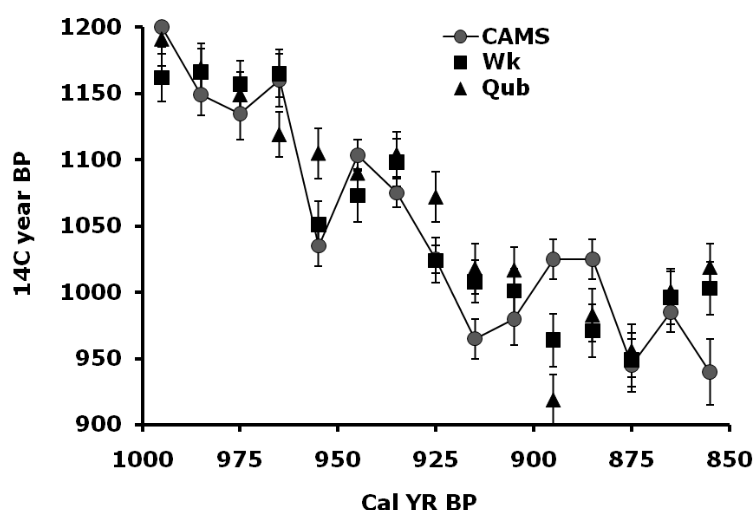

Figure 2 Overlap interval between this study and data of Hogg et al. (2002). With few exceptions, the Huon pine between 995–955 yr BP reported here agrees within 1-σ error with measurements made at the Waikato (Wk) and Belfast (Qub) laboratories.

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DISCUSSION

The Huon pine data (Table 2) show a similar structure to the IntCal04 curve (Reimer et al. 2004), but are generally older (Figure 3), almost certainly because the latter is composed of Northern Hemisphere data. Two brief periods show no offset, in particular from 1095–1175 BP, and bear further examination to reproduce this result. The average offset between the new data and IntCal04 is 42 ± 26 yr, indicating relatively large variability (Table 3).

Table 2 Measurements on decadal samples of Huon pine (*Lagorostrobos franklinii*) collected in the Stanley River basin, Tasmania. Left-hand column (*n*) gives the number of replicates measured for each decade; for $n > 1$, ^{14}C age reported is a weighted mean. Dendro age is according to master chronology developed by Buckley et al. (1997); analytical precision on $\delta^{13}C$ is 0.1‰.

		$\delta^{13}C$		Mid-point		^{14}C age	
n	Sample ID	(‰)	Dendro age	BC/AD	cal yr BP	(yr BP)	±
1	Z9	–24.97	161–170 BC	–165	2115	2170	15
1	Z8	–24.56	151–160 BC	–155	2105	2160	15
2	G8	–25.82	140–150 BC	–145	2095	2130	11
1	Z7	–23.81	131–140 BC	–135	2085	2150	15
2	G7	–24.07	120–130 BC	–125	2075	2123	11
2	Z6	–23.97	111–120 BC	–115	2065	2165	11
3	G6	–23.72	100–110 BC	–105	2055	2115	9
1	Z5	–23.49	91–100 BC	–95	2045	2135	15
3	G5	–24.56	80–90 BC	–85	2035	2105	9
3	Z4	–24.21	71–80 BC	–75	2025	2122	11
2	G4	–23.78	60–70 BC	–65	2015	2114	12
2	Z3	–24.07	51–60 BC	–55	2005	2113	11
3	G3	–23.82	40–50 BC	–45	1995	2052	9
2	Z2	–24.40	31–40 BC	–35	1985	2013	12
3	G2	–24.33	20–30 BC	–25	1975	2002	9
1	Z1	–23.51	11–20 BC	–15	1965	2040	15
1	G1	–23.64	10 BC–AD 0	–5	1955	2040	15
2	Z10	–23.37	AD 1–10	5	1945	2068	12
1	G9	–24.04	AD 10–20	15	1935	2055	15
1	Z11	–23.81	AD 21–30	25	1925	2025	15
1	G10	–22.78	AD 30–40	35	1915	1995	15
1	Z12	–22.80	AD 41–50	45	1905	2015	15
2	G11	–23.11	AD 50–60	55	1895	2012	12
1	Z13	–22.99	AD 61–70	65	1885	1975	20
1	G12	–23.73	AD 70–80	75	1875	1950	20
2	Z14	–23.45	AD 81–90	85	1865	1940	11
2	G13	–23.58	AD 90–100	95	1855	1940	11
3	Z15	–23.72	AD 101–110	105	1845	1973	11
1	G14	–23.85	AD 110–120	115	1835	1945	15
1	Z16	–22.37	AD 121–130	125	1825	1890	15
2	G15	–22.32	AD 130–140	135	1815	1895	11
1	Z17	–22.49	AD 141–150	145	1805	1875	15
1	G16	–22.73	AD 150–160	155	1795	1865	20
3	Z18	–22.81	AD 161–170	165	1785	1883	9
1	G17	–22.87	AD 170–180	175	1775	1850	15
2	Z19	–22.86	AD 181–190	185	1765	1929	13
2	G18	–23.63	AD 190–200	195	1755	1905	11

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n	Sample ID	$\delta^{13}C$ (‰)	Dendro age	Mid-point BC/AD	Mid-point cal yr BP	^{14}C age (yr BP)	±
3	Z20	–23.54	AD 201–210	205	1745	1880	9
3	G19	–23.18	AD 210–220	215	1735	1861	10
2	Z21	–22.98	AD 221–230	225	1725	1852	12
2	G20	–23.02	AD 230–240	235	1715	1846	13
4	Z22	–23.01	AD 241–250	245	1705	1848	8
3	G21	–23.46	AD 250–260	255	1695	1750	9
2	Z23	–21.96	AD 261–270	265	1685	1765	12
3	G22	–22.13	AD 270–280	275	1675	1760	9
3	Z24	–21.51	AD 281–290	285	1665	1779	9
2	G23	–21.94	AD 290–300	295	1655	1773	11
2	Z25	–21.82	AD 301–310	305	1645	1825	12
2	G24	–21.71	AD 310–320	315	1635	1804	12
1	Z26	–22.13	AD 321–330	325	1625	1805	15
1	G25	–21.61	AD 330–340	335	1615	1805	15
3	Z27	–23.06	AD 341–350	345	1605	1738	10
2	G26	–23.24	AD 350–360	355	1595	1760	11
3	Z28	–22.11	AD 361–370	365	1585	1709	9
1	G27	–22.08	AD 370–380	375	1575	1715	15
2	Z29	–23.61	AD 380–390	385	1565	1715	11
1	G28	–23.97	AD 390–400	395	1555	1680	15
2	Z30	–22.56	AD 401–410	405	1545	1738	14
1	Z31	–22.25	AD 411–420	415	1535	1695	20
1	Z32	–22.42	AD 421–430	425	1525	1675	20
3	Z33	–21.79	AD 431–440	435	1515	1651	10
1	Z34	–21.81	AD 441–450	445	1505	1625	20
1	Z35	–22.17	AD 451–460	455	1495	1635	20
2	Z36	–22.03	AD 461–470	465	1485	1638	11
2	Z37	–22.65	AD 471–480	475	1475	1623	11
1	Z38	–22.31	AD 481–490	485	1465	1645	20
2	Z39	–22.50	AD 491–500	495	1455	1615	12
2	Z40	–22.54	AD 501–510	505	1445	1611	12
1	Z41	–22.45	AD 511–520	515	1435	1665	15
2	Z42	–22.58	AD 521–530	525	1425	1603	11
1	Z43	–22.57	AD 531–540	535	1415	1605	15
2	Z44	–21.94	AD 541–550	545	1405	1568	11
2	Z45	–22.16	AD 551–560	555	1395	1549	12
1	Z46	–22.25	AD 561–570	565	1385	1560	20
2	Z47	–21.79	AD 571–580	575	1375	1564	12
3	Z48	–22.54	AD 581–590	585	1365	1535	9
1	Z49	–22.03	AD 591–600	595	1355	1495	15
1	Z50	–22.10	AD 601–610	605	1345	1480	20
2	Z51	–21.89	AD 611–620	615	1335	1480	14
4	Z57	–23.45	AD 621–630	625	1325	1508	8
1	Z58	–21.63	AD 631–640	635	1315	1500	20
1	Z59	–22.33	AD 641–650	645	1305	1440	15

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		$\delta^{13}C$		Mid-point		^{14}C age	
n	Sample ID	(‰)	Dendro age	BC/AD	cal yr BP	(yr BP)	±
2	Z60	–21.91	AD 651–660	655	1295	1391	13
1	Z61	–22.42	AD 661–670	665	1285	1405	15
2	Z62	–21.68	AD 671 680	675	1275	1378	14
2	Z63	–22.30	AD 681–690	685	1265	1326	13
2	Z64	–21.31	AD 691–700	695	1255	1310	12
1	Z65	–22.21	AD 701–710	705	1245	1335	20
1	Z66	–22.04	AD 711–720	715	1235	1315	15
1	Z67	–21.60	AD 721–730	725	1225	1305	20
2	Z68	–21.73	AD 731–740	735	1215	1303	12
2	Z69	–21.73	AD 741–750	745	1205	1301	12
3	Z70	–23.57	AD 751–760	755	1195	1323	9
4	Z71	–23.66	AD 761–770	765	1185	1316	9
2	Z72	–24.41	AD 771–780	775	1175	1200	11
3	Z73	–22.97	AD 781–790	785	1165	1229	10
1	Z74	–23.63	AD 791–800	795	1155	1195	15
2	Z75	–23.70	AD 801–810	805	1145	1253	11
2	Z76	–22.49	AD 811–820	815	1135	1238	12
1	Z77	–22.85	AD 821–830	825	1125	1190	15
1	Z78	–22.57	AD 831–840	835	1115	1215	15
1	Z79	–22.05	AD 841–850	845	1105	1205	20
1	Z80	–22.43	AD 851–860	855	1095	1175	25
1	Z81	–22.42	AD 861–870	865	1085	1225	15
2	Z82	–22.77	AD 871–880	875	1075	1195	12
3	Z83	–22.20	AD 881–890	885	1065	1200	9
2	Z84	–22.72	AD 891–900	895	1055	1195	11
2	Z85	–22.39	AD 901–910	905	1045	1140	11
1	Z86	–21.92	AD 911–920	915	1035	1140	20
1	Z87	–21.67	AD 921–930	925	1025	1185	20
2	Z88	–21.69	AD 931–940	935	1015	1163	11
1	Z89	–21.89	AD 941–950	945	1005	1180	15
1	Z90	–21.72	AD 951–960	955	995	1200	15
2	Z91	–21.50	AD 961–970	965	985	1149	16
1	Z92	–22.05	AD 971–980	975	975	1135	20
1	Z93	–21.40	AD 981–990	985	965	1160	20
1	Z94	–23.34	AD 991–1000	995	955	1035	15
2	Z95	–22.85	AD 1001–1010	1005	945	1103	12
2	Z96	–23.81	AD 1011–1020	1015	935	1075	11
2	Z97	–23.13	AD 1021–1030	1025	925	1025	11
1	Z98	–22.54	AD 1031–1040	1035	915	965	15
1	Z99	–20.96	AD 1041–1050	1045	905	980	20
1	Z100	–21.07	AD 1051–1060	1055	895	1025	15
1	Z101	–21.32	AD 1061–1070	1065	885	1025	15
1	Z102	–21.73	AD 1071–1080	1075	875	945	20
1	Z103	–23.25	AD 1081–1090	1085	865	985	15
1	Z104	–22.79	AD 1091–1100	1095	855	940	25

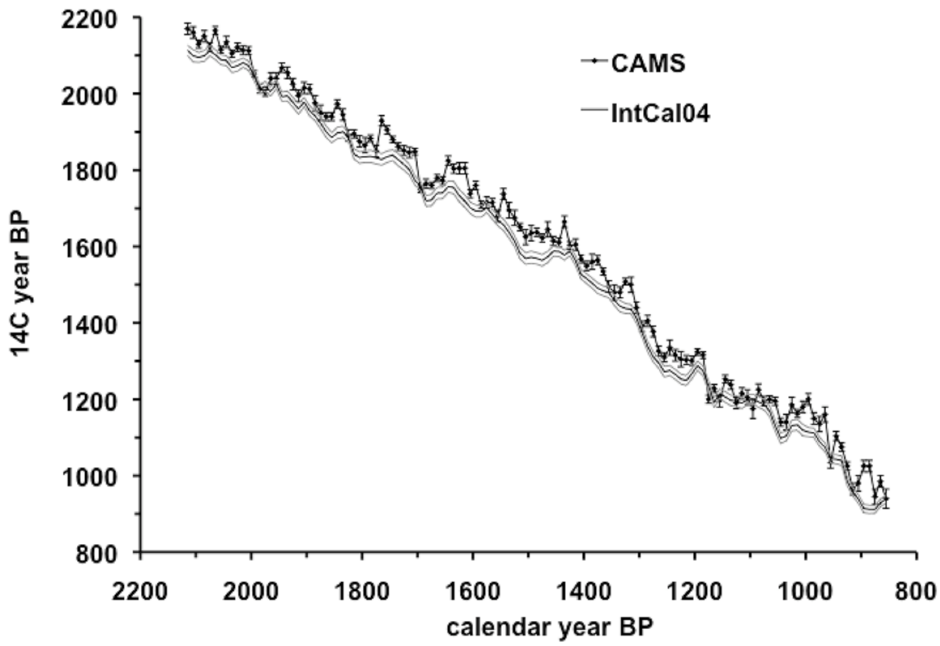

Figure 3 Stanley River Huon pine results plotted with IntCal04 (Reimer et al. 2004)

Table 3 Comparison of average offset for Southern Hemisphere data sets measured at Queen's University Belfast (Qub), Waikato (Wk) (both Hogg et al. 2002), and CAMS (this study) with IntCal04 (Reimer et al. 2004). Despite covering different time intervals, the Southern Hemisphere data sets show consistent magnitude and variability of offset. All units are years.

	CAMS	Wk	Qub
max	113	91	98
min	–35	–7	–9
avg	42	47	44
std dev	26	17	25

Our observation of a distinct but variable offset between Tasmania and IntCal04 is coherent with a comparison of the published New Zealand data and IntCal04; indeed, the offsets are nearly identical (Table 3), both in magnitude and variability. These results support the previous conclusion that there is an approximate 40-yr difference between Southern Hemisphere (SH) data and the standard calibration, with significant real variability. The consistency of our results relative to IntCal04 and the work of Hogg and McCormac supports the suggested 40-yr offset for general SH calibration. Higher-precision calibrations that take advantage of curve-matching will also require a hemisphere-specific calibration curve.

CONCLUSIONS AND FURTHER WORK

Temporal variability in the offset between the Northern and Southern hemispheres appears to be a real feature of the history of the atmospheric ^{14}C system, as evidenced by previous studies, and suggested by the variability of the Tasmanian pine data reported here compared with IntCal04. In order to examine the variability in our record for possible periodicity, several periods need to be replicated, in particular between 1095 and 1175 yr BP, where the apparent offset of the Tasmanian data appears to reduce to zero. The similarities and differences in detail between these Huon data and other Southern Hemisphere data sets will establish an extended calibration curve for Southern Hemisphere dates, and may further illuminate the question of the size and periodicity of the interhemispheric offset found previously by Hogg and McCormac (Hogg et al. 2002; McCormac et al. 2002).

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