RADIOCARBON VARIATIONS FROM TASMANIAN CONIFERS: RESULTS FROM THREE EARLY HOLOCENE LOGS

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ABSTRACT. Dendrochronological studies are being carried out on two conifer species in the Stanley River area of western Tasmania. The chronology for Huon pine (*Lagarostrobos franklinii*), with living trees up to 1400 yr old, extends back to 571 BC. Living celery-top pine (*Phyllocladus aspleniifolius*) trees are up to 500 yr old. Apart from living or recently felled trees, sections have been taken from 350 subfossil logs preserved in floodplain sediments. They range in age from >38 ka to modern, with good coverage for the periods 9–3.5 ka and from 2.5 ka to the present. We report here on ^{14}C measurements of decadal samples from three early Holocene logs, between 10 and 9 ka BP, providing short (*ca.* 300-yr) records of atmospheric ^{14}C variations when plotted against ring numbers. The southern hemisphere data from Tasmania can be compared and wiggle-matched with published ^{14}C calibration curves from German oak and pine. One set of measurements covers the period, *ca.* 9280–8990 cal BP, overlapping the link between the Hohenheim "Main 9" and middle Holocene master oak chronologies. The other sets of measurements from Tasmania coincide; they span the period, *ca.* 9840–9480 cal BP, overlapping the end of the German Preboreal pine and the beginning of the oak chronologies. Our measurements confirm that this part of the calibration curve is a gently sloping ^{14}C-age plateau (*ca.* 8900–8700 BP, between 10,000 and 9500 cal BP), and suggest interhemispheric ^{14}C differences close to zero.

INTRODUCTION

Radiocarbon calibration is well established for the Holocene. The differences between tree-ring ages and ^{14}C ages have been determined for the last 11,400 calendar years by high-precision ^{14}C measurements on 10- or 20-ring samples, independently dated by dendrochronology (summarized in Stuiver, Long and Kra 1993). A small part of the age difference occurs because ^{14}C ages are, by international agreement, calculated using a half-life of 5568 yr, which is known to be *ca.* 3% too short. Differences apart from this 3% reflect variations in the production rate and in the exchange of ^{14}C between oceans, atmosphere and biosphere. Most of the Holocene variation is thought to be due to changes in the ^{14}C production rate; the long-term peak-to-trough change is attributed to changes in the Earth's magnetic field strength that affect the cosmic-ray flux. Shorter-term wiggles (with amplitudes of 100 or 200 yr) are attributed to solar modulation of the cosmic-ray flux.

Late Pleistocene and early Holocene ^{14}C data from southern Germany (Becker and Kromer 1993) are from a 1768-yr-long Preboreal pine chronology. They show short-term wiggles, like those seen in recent millennia, and two plateaus (at *ca.* 10,100 and 9600 BP) with nearly constant ^{14}C ages over several hundred tree rings. The pine chronology overlaps with, and is tentatively matched by dendrochronology to, the German oak master (Becker 1993). Verification of this link by ^{14}C measurements, however, is made difficult by the existence of an additional plateau at *ca.* 8800 BP, where the link occurs.

^{14}C data for times younger than 9150 cal BP (7200 BC) are on wood from a variety of dendrochronologically dated series (Stuiver, Long and Kra 1993), including the German oak master (Becker 1993). However, many of those data were obtained before the final linkage of the German oak sequence, on series then forming the middle Holocene floating master, which was wiggle-matched to ^{14}C data from bristlecone pine. Two sets of ^{14}C data cover the period around 9000 cal BP; those

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of Kromer *et al.* (1986) and Stuiver *et al.* (1986); they are used in this paper even though they are subject to small revisions (Kromer, personal communication; Stuiver, Long and Kra 1993).

Measurements from the southern hemisphere are essential as an independent verification of the calibration curve, especially in those time windows where different data sets from the northern hemisphere are joined. Our main focus here is to compare the Tasmanian data with the early Holocene records from the northern hemisphere.

Southern hemisphere data are also important because the offset from the northern hemisphere may have varied in earlier times due to changes in global carbon fluxes. The current latitudinal ^{14}C gradient in atmospheric CO_2 shows lower (older) values in the northern hemisphere due to fossil fuel releases, and at high northern and southern latitudes due to deep ocean mixing (Levin *et al.* 1992). At Tasmanian latitudes, $\Delta^{14}C$ values *ca.* 4–7‰ higher (30–60 yr younger) than mid-latitudes of the northern hemisphere are observed. Pre-industrially, the southern oceans may have been a net source of CO_2 due to the release of "old" carbon, taken up in the North Atlantic ocean and transported over many centuries to the south (Broecker and Peng 1992); thus, southern hemisphere ^{14}C ages may have been "older" than northern hemisphere values, *i.e.,* the modern interhemispheric gradient may have been reversed. Over past centuries, changes in interhemispheric ^{14}C differences might reflect changes in deep water formation, a major uncertainty in current global carbon budgeting (Enting and Mansbridge 1987). The pre-industrial southern hemisphere has been reported at 36 yr older in recent centuries (Lerman, Mook and Vogel 1970; Vogel *et al.* 1986). We did not find evidence to support such an age offset in our first sets of results from Tasmania, at *ca.* 8260–7910 cal BP and AD 1600–1800 (Barbetti *et al.* 1992).

We began dendrochronological studies 13 yr ago on two conifer species in the Stanley River area of western Tasmania (SRT; 145°E, 42°S; Francey *et al.* 1984). We sampled living trees as well as logs exposed in the river banks in 1981, and excavated in floodplain sediments between 1982 and 1994. We have now obtained sections from over 350 well-preserved subfossil logs. The chronology for Huon pine (*Lagarostrobos franklinii*) currently extends from 571 BC to the present. We are beginning to build a floating chronology from 9–3.5 ka BP (calendar years), using the numerous logs with overlapping ages in this period. This has resulted in a 2400-yr record spanning the period 6 to 3.6 ka cal BP, with several shorter floating sequences in earlier time periods. We have not yet found Huon pine logs between *ca.* 3.5 and 2.5 ka BP, but we hope to close this gap by excavating in nearby areas. One locality has yielded two logs with ages >38 ka, and their wide rings suggest a warm climate; they may be of Last Interglacial age. Living celery-top pine (*Phyllocladus aspleniifolius*) trees are up to 500 yr old, and about 20 subfossil celery-top logs have been recovered, the oldest of which are two with ages centered at 13.0 and 12.7 ka BP (SRT-462 and -157; Barbetti *et al.* 1992). Another log (SRT-444) is centered at 7.3 ka BP; the others are younger but as yet too few to construct a chronology. A single subfossil log of King William pine (*Athrotaxis selaginoides*), SRT-684, aged 14.3 ka BP, has been recovered. This species no longer grows in the Stanley River Valley.

Four Huon pine logs, SRT-416, -450a, -449 and -447 are between 8 and 9 ka BP (*ca.* 9–10 ka cal BP), and we present here the results of decadal ^{14}C measurements on three of them. (Only one ^{14}C measurement was taken on SRT-447.)

Methods

We polished cross-sections from the logs and split them into consecutive 10-ring samples, except for the innermost and outermost parts, where the rings were narrow, and we took up to 40 rings per sample. We reduced the wood samples to *ca.* 0.5 mm particle size in a cutting mill, and prepared holocellulose following the method of Head (1979). We used standard techniques (Gupta and Polach 1985) to prepare benzene samples (4 ml). Stable carbon isotope ($^{13}C/^{12}C$) measurements were made on subsamples of the combustion CO_2 at the CSIRO Division of Atmospheric Research.

We made ^{14}C measurements using 7-ml Teflon® vials in a low-level Wallac Quantulus 1220™ liquid scintillation counter. We calculated conventional ^{14}C ages using modern standard values derived from measurements of ANU sucrose and NBS oxalic acid, but we assumed an uncertainty of ± 0.1 or ± 0.2 counts min^{-1} for the standard, considerably larger than the typical Poisson deviation of ± 0.07 counts min^{-1} associated with an individual standard measurement. Measurement uncertainties associated with these samples range from *ca.* ± 55 to ± 65 yr, depending on the counting time (5000 or 2500 min). The measurements reported here were made between June 1990 and May 1992 (except for the earlier pilot results).

RESULTS

^{14}C results (Table 1) from two logs, SRT-416 and -450a, provide short records of atmospheric ^{14}C variations, 340 and 240 yr long, respectively. Many of the results, especially those from the inner rings, are *ca.* 8800 BP, and thus the two logs appear to overlap in time. Unfortunately, SRT-450a is particularly influenced by lobate growth and wedging, prejudicing convincing tree-ring cross-dating among the ring-width patterns. Thus, we have tried to match them using only the ^{14}C data.

We used a smoothing spline with 50% attenuation at 30 yr (typically 3 samples) to interpolate the ^{14}C measurements and provide equally spaced data at one ring-number (=1 yr) intervals for each log. The interpolated SRT-450a ring numbers were then stepped relative to SRT-416 ring numbers to obtain the root-mean-square (rms) differences in ^{14}C between the two sets of samples for each step. We obtained a minimum rms difference of 51 yr with SRT-450a ring 0 equivalent to SRT-416 ring 114. Figure 1 shows the results of this normalization with the SRT-416 data and smoothing spline plotted against mid-sample ring number, and the fitted SRT-450a data and smoothing spline superposed. The coincidence of several features in the records, the most marked being the ^{14}C age decline in the outer rings, gives confidence in the matching process. The heavy dark curve, the average of these two smoothing splines, is used for comparison with the northern hemisphere data.

Figure 2 shows the results of a comparison of the SRT-416 and -450a data with the data from Kromer and Becker (1993). We used a similar approach of minimizing ^{14}C differences. The Preboreal pine and the Hohenheim "Main 9" oak chronologies were merged and fitted with a 30-yr smoothing spline to provide interpolated annual values—Figure 2A shows this spline plotted against the Kromer and Becker (1993) age (expressed in calendar years before AD 1950). Also shown in Figure 2A is the average SRT-416, -450a curve of Figure 1, which has been stepped along the German oak curve (taking 1 ring number = 1 yr) seeking a minimum rms difference in ^{14}C. Figure 2B illustrates the sequence of rms differences obtained by this procedure. The time axis corresponds to the mean age over the ring segments being compared. Two minima are defined by this process, with rms differences ≈69 yr at −9697 and −9652 yr. To choose between these two minima, we also plotted the mean difference between the ^{14}C values in Figure 2B. The −9652 yr rms minimum also corresponds to a mean (German-Tasmanian) difference of −1.5 yr, compared to +28 yr at the −9697-yr minimum. For this reason, as well as the correspondence in the marked drop in ^{14}C at −9500 yr, we prefer the −9652 yr rms minimum (^{14}C = 8721 BP on the spline fit to the German data), which is the case shown in Figure 2. Here, the SRT-416 ring zero corresponds to −9838 yr before AD 1950, and SRT-450a ring zero to −9724 yr. Thus, SRT-416 appears to span, and SRT-450a to border, the proposed overlap between the "floating" Preboreal pine, and the anchored M9 oak chronologies of

TABLE 1. Radiocarbon Dates from Stanley River Huon Pine Logs, SRT-416, -447 and -450a*

SUA-no.	Tree-ring span (yr)	$\delta^{13}C_{PDB}$ (‰)	^{14}C (yr BP)	St. dev.	Center ring	Tree ring (yr BP)
SRT-416					*Ring 0 at 9838*	
5257	331–340	−23.6	8554	56	336	−9503
5161†	316–340	−24.6	8646	41	328	−9510
5256	321–330	−23.7	8605	56	326	−9513
5255	311–320	−24.1	8745	56	316	−9523
5254	301–310	−23.8	8625	56	306	−9533
5253	291–300	−24.1	8644	56	296	−9543
5252	281–290	−23.8	8845	56	286	−9553
5251	271–280	−23.6	8633	55	276	−9563
5250	261–270	−24.6	8635	55	266	−9573
5249	251–260	−24.6	8667	55	256	−9583
5248	241–250	−23.8	8724	55	246	−9593
5247	231–240	−24.2	8799	55	236	−9603
5246	221–230	−24.4	8817	55	226	−9613
5245	211–220	−24.5	8758	55	216	−9623
5244	201–210	−24.1	8982	56	206	−9633
5243	191–200	−23.4	8836	55	196	−9643
5242	181–190	−23.9	8932	56	186	−9653
5241	171–180	−23.9	8682	64	176	−9663
5240	161–170	−24.4	8769	64	166	−9673
5239	151–160	−24.8	8767	64	156	−9683
5238	141–150	−24.9	8736	65	146	−9693
5237	131–140	−24.9	8841	65	136	−9703
5236	121–130	−25.1	8793	65	126	−9713
5235	111–120	−25.2	8929	65	116	−9723
5234	101–110	−25.6	8814	65	106	−9733
5233	91–100	−25.5	8677	65	96	−9743
5232	81–90	−25.9	8735	64	86	−9753
5231	71–80	−25.9	8760	64	76	−9763
5230	61–70	−26.5	8800	65	66	−9773
5229	51–60	−26.0	8797	65	56	−9783
5228‡	31–50	−25.7	8820	65	41	−9798
5227‡	1–30	−25.7	8895	65	16	−9823
		Averages	8758		189	
SRT-447					*Ring 0 at 10,064*	
5094†	114–152	−24.0	8933	53	133	−9931
SRT-450a					*Ring 0 at 9724*	
5209	231–242	−23.8	8538	55	237	−9488
5210	221–230	−23.6	8553	55	226	−9499
5092†	19–239	−24.1	8549	52	219	−9505
5211	211–220	−24.6	8795	64	216	−9509
5212	201–210	−24.6	8717	64	206	−9519
5213	191–200	−24.8	8655	64	196	−9529
5214	181–190	−24.6	8697	64	186	−9539
5215	171–180	−24.6	8704	64	176	−9549
5216	161–170	−24.7	8705	64	166	−9559
5217	151–160	−25.5	8687	64	156	−9569
5218	141–150	−26.0	8590	64	146	−9579
5219	131–140	−25.3	8666	61	136	−9589
5220	121–130	−25.0	8688	64	126	−9599
5223‡	101–120	−26.2	8814	65	111	−9614
5224‡	81–100	−25.9	8823	65	91	−9634
5225§	41–80	−26.9	8784	65	61	−9664
5226§	1–40	−26.9	8769	65	21	−9704
		Averages	8690		157	

*10-ring samples unless otherwise noted; † Pilot sample; ‡20- or 30-ring sample; §40-ring sample

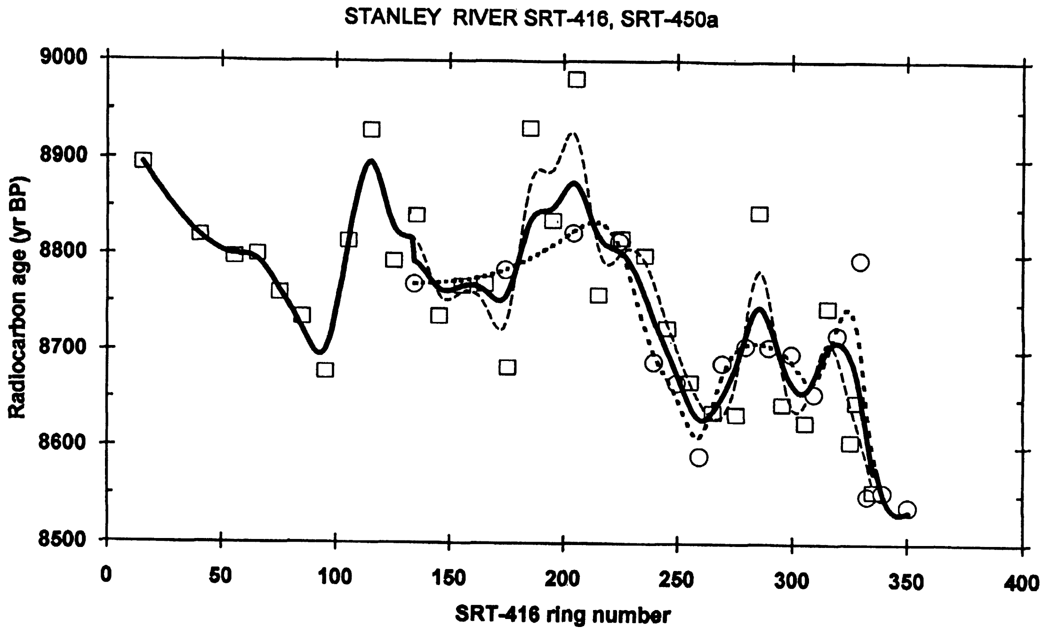

Fig. 1. Merging of the ^{14}C records from two Huon pine logs (^{14}C ages ~8800 BP). □ = ^{14}C ages from Stanley River Huon pine log SRT-416 plotted *vs.* SRT-416 ring number; ––– = an interpolating spline with 30-yr smoothing. ○ and • • • • = similar "time" series from SRT-450a. The SRT-450a data are plotted *vs.* SRT-416 ring number, after fitting by minimization of the rms ^{14}C differences between the logs. ▬ = average of the individual ^{14}C spline series.

Kromer and Becker (1993). Given the importance of confirming this link, plans to re-analyze the SRT logs with high precision at the Heidelberg laboratory are now being implemented. The single determination of a ^{14}C age of 8933 BP for a 39-yr sample around ring number 133 in SRT-447, which corresponds to –9931 yr before AD 1950 on the spline fit to the Kromer and Becker (1993) data, suggests that this log will substantially contribute to this task.

With the preferred matching represented in Figure 2A, there is clearly no significant latitudinal difference in ^{14}C, although Figure 2B favors a northern hemisphere ^{14}C greater than or equal to that of the southern hemisphere; however, the uncertainties are large (*ca.* 70 yr).

Table 2 lists ^{14}C data for the fourth Huon pine log, SRT-449, and Figure 3 shows the results of applying a similar matching procedure. In this case, a reference spline was constructed by fitting the merged oak chronologies of Kromer *et al.* (1986), Kromer and Becker (1993) and Stuiver *et al.* 1986. The measured ^{14}C values for SRT-449, on a time scale corresponding to the rms "best fit", are also superposed. We also obtained dual minima for SRT-449, as in Figure 2B. We preferred a minimum rms difference of 64.5 yr with a mean difference of –3 yr (oak-Huon) over an rms difference of 65.6 yr with a mean difference 48 yr. SRT-449 ring zero corresponds to –9281 yr before AD 1950 for the preferred solution (and to –9331 yr for the 48-yr oak excess case).

Discussion and Conclusion

^{14}C data from the Stanley River and from German Preboreal pine and oak show trend changes on a time scale of a century or two, such as those seen throughout the Holocene. Both data sets show a plateau in the calibration curve, with nearly constant ^{14}C ages (*ca.* 8900–8700 BP) over five centu-

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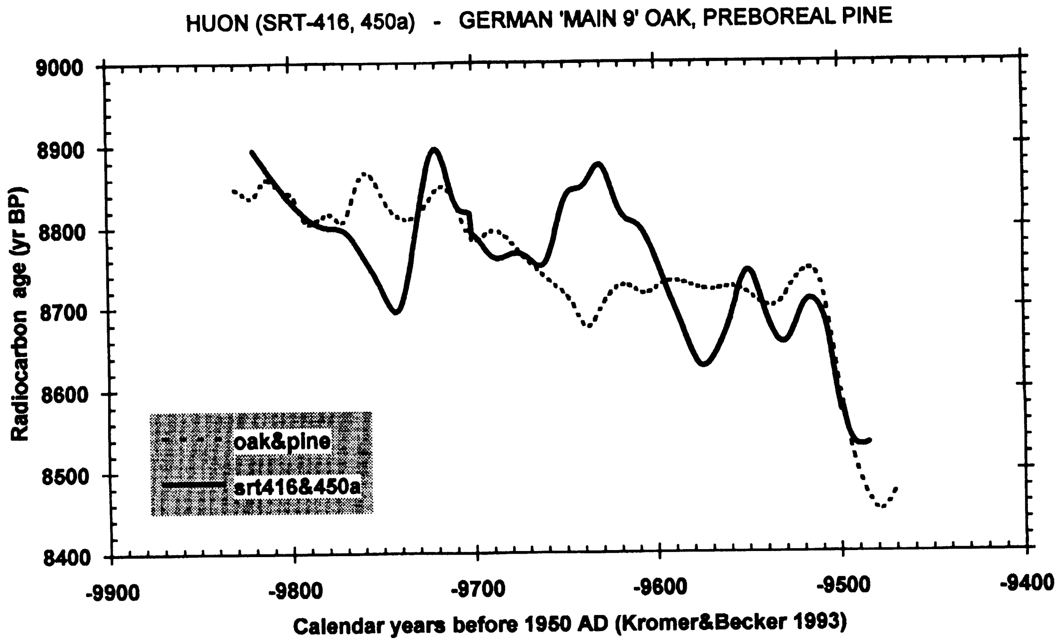

Fig. 2A. Comparison of the ~8800 BP Huon pine with merged and interpolated data from German Preboreal pine and oak (Kromer and Becker 1993). ▬ = merged SRT-416 and -450a ^{14}C data from Figure 1, expressed *vs.* calendar years before AD 1950.

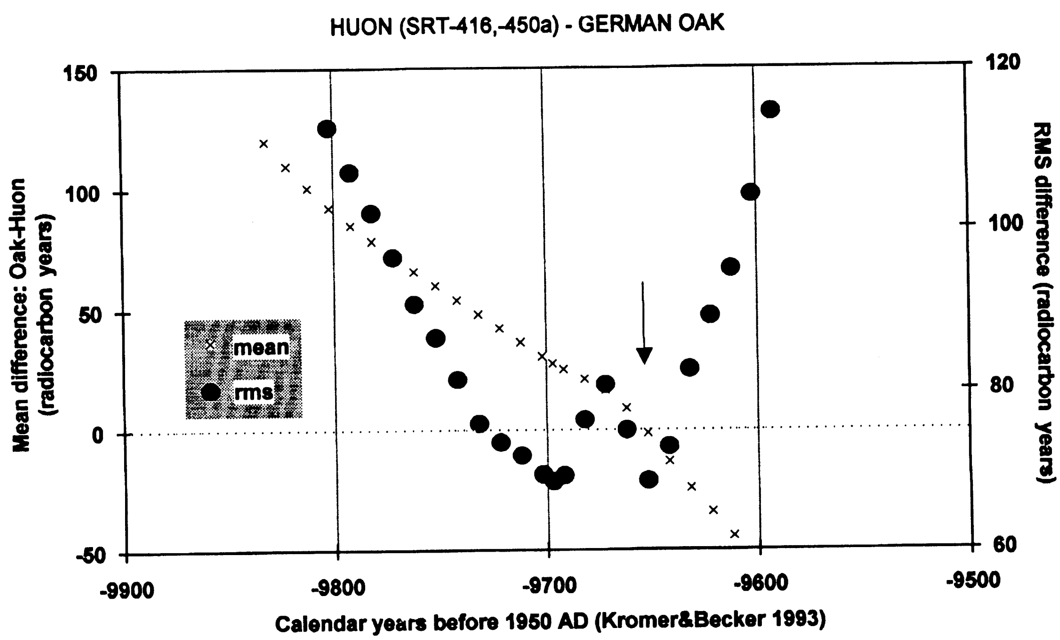

Fig. 2B. The procedure to establish the minimum rms difference between the SRT and German ^{14}C ages; also the mean difference in ^{14}C ages (German-Tasmanian) as the SRT series is moved in time along the German time axis. The arrow indicates the "preferred" solution.

TABLE 2. Radiocarbon Dates From Stanley River Huon Pine Log SRT-449*

SUA-no.	Tree-ring span (yr)	$\delta^{13}C_{PDB}$ (‰)	^{14}C (yr BP)	St. dev.	Center ring	Tree ring (yr BP)
SRT-449					*Ring 0 at 9281*	
5091†	185–235	–23.2	8073	50	210	–9071
5181	281–294	–22.1	8086	54	288	–8994
5182	271–280	–22.0	8221	54	276	–9006
5183	261–270	–22.3	8136	54	266	–9016
5184	251–260	–22.4	8146	54	256	–9026
5185	241–250	–22.3	8136	54	246	–9036
5186	231–240	–22.7	8229	54	236	–9046
5187	221–230	–22.4	8224	54	226	–9056
5188	211–220	–22.6	8226	54	216	–9066
5189	201–210	–23.2	8216	54	206	–9076
5190	191–200	–23.2	8156	55	196	–9086
5191	181–190	–22.6	8079	54	186	–9096
5192	171–180	–23.0	8249	55	176	–9106
5193	161–170	–22.8	8206	54	166	–9116
5194	151–160	–22.4	8275	55	156	–9126
5195	141–150	–22.4	8259	55	146	–9136
5196‡	131–140	–22.5	7967	54	136	–9146
5197	121–130	–22.4	8282	55	126	–9156
5198‡	111–120	–22.6	8026	54	116	–9166
5199	101–110	–22.7	8184	55	106	–9176
5200	91–100	–22.4	8295	55	96	–9186
5201‡	81–90	–22.3	8058	55	86	–9196
5202	71–80	–22.4	8300	55	76	–9206
5203	61–70	–22.0	8348	55	66	–9216
5204	51–60	–22.2	8307	55	56	–9226
5205	41–50	–22.4	8336	55	46	–9236
5206	31–40	–22.5	8216	55	36	–9246
5207	21–30	–22.2	8320	55	26	–9256
5208§	1–20	–22.2	8326	55	11	–9271
		Averages	8224		152	

*10-ring samples unless otherwise noted
†Pilot sample
‡Rejected ^{14}C datum
§20-ring sample

ries in early Holocene time (*ca.* 10 to 9.5 ka calendar yr BP). This "plateau" region actually has a gentle slope, of *ca.* 0.5 ^{14}C yr for every year.

Tasmanian ^{14}C data from SRT-449 have been matched with ^{14}C data from German oak. When compared with the "Main 9" data (Kromer and Becker 1993), and the unified German oak data (Kromer *et al.* (1986), with ring 0 at 7230 BC; Stuiver *et al.* (1986), with ring 1 at 7215 BC), our match places ring 0 of SRT-449 at –9281 yr cal BP. Our data then appear, on average, to be slightly but not significantly younger than the data from the northern hemisphere.

Our data from the southern hemisphere for the Holocene indicate little or no offset in ^{14}C concentration when compared with northern hemisphere data. These minimal offsets, with the southern hemi-

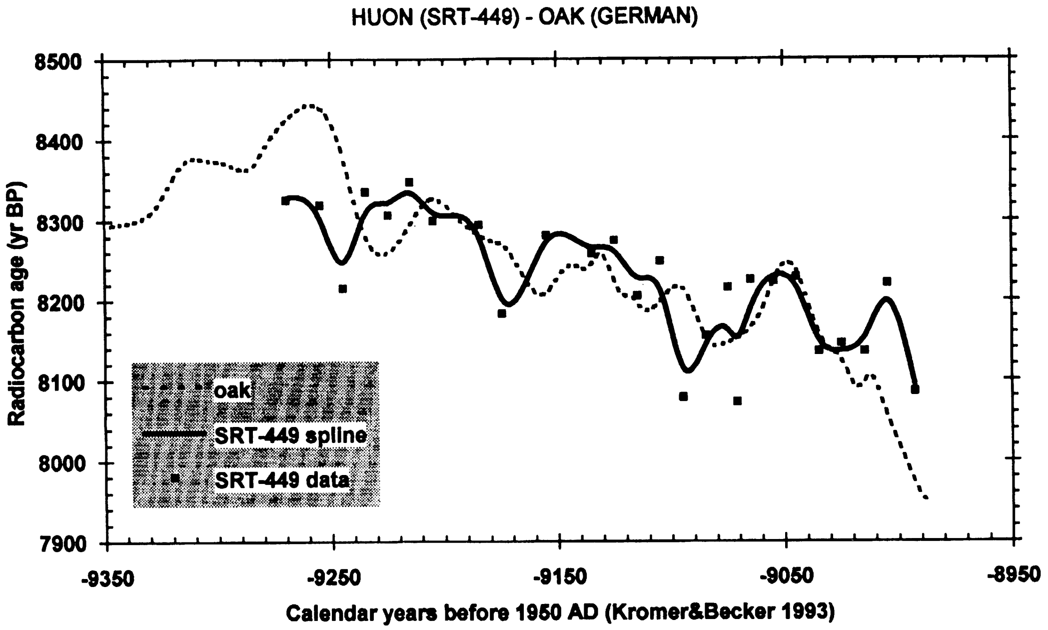

Fig. 3. Comparison of a ~8200 BP Huon pine with merged and interpolated data from German oak. ▬ = a 30-yr smoothing spline to ^{14}C ages (■) from Stanley River Huon pine log SRT-449, with ring 0 placed at 9281 cal BP, corresponding to minimum mean and rms differences. The measurements are compared with data from the Hohenheim 'Main 9' oak chronology (Kromer and Becker 1993), data from the unified German oak series with ring 0 placed at 7230 BC, *i.e.*, 9179 BP (Kromer *et al.* 1986) and data from German oak with ring 1 at 7215 BC, *i.e.*, 9165 BP (Stuiver *et al.* 1986). The oak chronologies are represented by a spline with 30-yr smoothing fitted to the merged data sets.

sphere appearing to be slightly but not significantly younger, now occur in four data sets at 9840–9480, 9280–8990 cal BP (this paper), 8260–7910 cal BP and AD 1600–1800 (Barbetti *et al.* 1992), but the uncertainties, mainly due to the precision of these preliminary determinations, but also uncertainties in interlaboratory calibration, thwart quantitative carbon budgeting constraints at this stage.

Detailed intercomparisons with other laboratories are being planned, and it should be possible eventually to estimate precisely the offset between the northern and southern hemispheres during early, mid- and late Holocene times. Extension of the Tasmanian data may eventually help refine the tentative cross-match between the German Preboreal pine and the "Main 9" oak chronologies. New sections from SRT-416, from the less eroded portion of this log submerged in the river bed, have up to 449 rings that should allow us to extend younger than the plateau and into the region of steep slope at 9500–9400 cal BP.

Acknowledgments

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