RECENT INCREASES IN TASMANIAN HUON PINE RING WIDTHS FROM A SUBALPINE STAND: NATURAL CLIMATE VARIABILITY, CO_2 FERTILISATION, OR GREENHOUSE WARMING?

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(with four text-figures)

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Tasmanian subalpine Huon pines from the extreme high-altitude limit of the species distribution provide a summer temperature reconstruction extending back beyond 800 BC. Compared to low elevation Huon pine sites, the subalpine ring-widths exhibit a straightforward direct response to current growth-season temperatures and indicate anomalous warming of 0.33 ± 0.06°C from 1967–91. This warming is consistent with Tasmanian instrumental records and with hemispheric and global records.

The possibility that the trees are responding directly to CO_2 fertilisation is explored, using a high-precision record of CO_2, obtained from air in Antarctic ice and firn, plus direct measurements of air from Cape Grim. The temperature forcing appears capable of explaining the ring-width variations in the alpine trees over the full range of observed periods, whereas CO_2 fertilisation would require a more complex interaction and is not supported by other arguments.

Two millennia-long tree-ring reconstructions of summer temperatures from South America do not exhibit the recent warming, nor other features found in the Tasmanian record on decadal to century time-scales. In fact, the South American chronologies bear little resemblance to each other, but do, however, reflect their own regional instrumental records. The Mt Read ring-width chronology, and the instrumental temperature series used for its calibration, also co-vary with climate influences of a distinctly regional character, yet still replicate many of the features reported as hemispheric and global temperatures over the last century.

Spectral analysis of the Mt Read tree-ring data over the full 2792 years suggests that at least part of the recent warming in the instrumental records could be a consequence of "natural forcing" of the record, complicating an interpretation in terms of a greenhouse-forced warming.

Key Words: temperature reconstruction, tree rings, CO_2 fertilisation, spatial variability, Tasmania.

INTRODUCTION

Three millennia-long Southern Hemisphere (SH) summer temperature records based on tree-ring widths are represented in figure 1. Two are derived from the ring-widths of South American Alerce trees (*Fitzroya cupressoides*), one a 1114-year reconstruction from northern Patagonia (Villalba 1990), and the second a 3622-year record from Lenca, southern Chile (Lara & Villalba 1993; shown in figure 1C only back to 800 BC). The third is based on ring-widths from a stand of subalpine Huon pine (*Lagarostobos franklinii*, C.J. Quinn) trees growing at 950 m altitude on Mt Read in Tasmania, previously reported over 1089 years by Cook *et al.* (1991, 1992). The Tasmanian temperature reconstruction in figure 1A now extends to 1260 BC and is reported here over the time period 800 BC–AD 1991, where sample depth is greater than 15 independent ring-width sequences or "series". Note that sample depth increases to around 45 series or more from AD 1300. The extension prior to AD 900 (cf. Cook *et al.* 1992) was made possible by a recent collection of wood from exposed stumps and buried stem remnants at the Mt Read site and has been reported separately by Cook *et al.* (1996). The methods used for processing and calibrating the pre-AD 900 tree-ring data were identical to those used earlier (Cook *et al.* 1992), resulting in a homogeneous extension.

The recent ring-width anomaly, noted by Cook *et al.* (1991, 1992) and beginning around 1960, remains highly unusual, even as far back as 800 BC. A critical consideration has been whether the tree-ring-derived temperature anomaly represents the recent temperature change or is the result of increasing greenhouse gas concentrations in the atmosphere. The latter possibility requires that increasing CO_2 (the principal greenhouse gas emitted by human activity) exerts a direct physiological influence on tree growth, resulting in gradually increasing ring widths via an hypothesised "fertilisation effect" (as suggested by LaMarche *et al.* 1984). In this case, we would expect a calibration of ring widths against temperature records to result in an increasing over-prediction of the actual warming.

The SH mid-latitudes offer other advantages in exploring direct CO_2 influences, as a result of the simplified CO_2 climatology compared to more northern locations. The availability of more than 20 years of continuous monitoring of CO_2 from Tasmania assists in this assessment (Beardsmore *et al.* 1984). Over longer time-scales, a new, high-precision and high time-resolution Antarctic ice-core record of CO_2 over the last 1000 years is available (Etheridge *et al.* 1996).

Differences in the relative vertical behaviour of temperature and CO_2, and/or in the tree responses to each with altitude, suggest useful comparisons between low and high altitude Huon pine chronologies. A network of seven Huon pine chronologies ranging in elevation from 200–

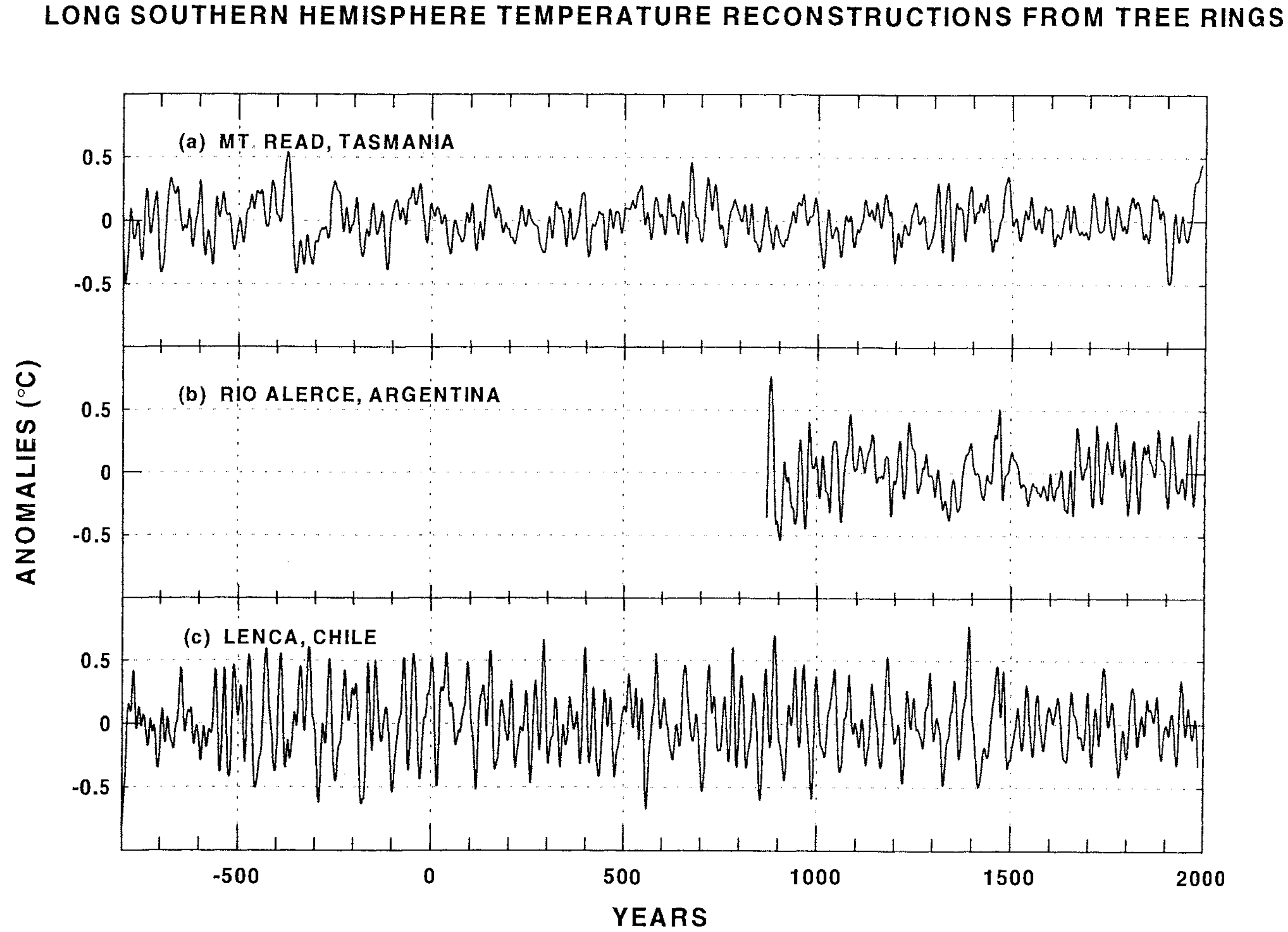

FIG. 1 — Warm-season (November–April) temperatures for Tasmania reconstructed from Huon pine tree rings at Mt Read (A). The reconstruction over the period 800 BC–AD 1991 has been smoothed with a 20-year low-pass filter to highlight multidecadal fluctuations. For comparison, two millennia-long tree-ring reconstructions of summer temperatures for parts of Argentina (B) and Chile (C) are shown.

1000 m above sea level, has been recently developed (Buckley *et al.*, pers. obs.). This study reinforces and quantifies systematic behaviour previously recognised between the Mt Read subalpine stand (one of the rare occurrences of the species above 500 m; Peterson 1990) and low elevation trees. Buckley *et al.* demonstrate a clear elevational dependence for the temperature response of Huon pine in western Tasmania, with temperature-sensitivity increasing with elevation. A rotated Principal Component Analysis reveals a distinct clustering of the chronologies into two groups divided by elevation, centred around the 700 m contour. There is an increase in the quality of cross-dating in the chronologies with an increase in elevation, combined with a general strengthening of the temperature response in the growing season. The lower-elevation chronologies are of generally poorer quality and show signs of physiological "pre-conditioning", suggesting that non-climatic factors such as competition and stand dynamics are having an effect along with climate. These results are consistent with the expected physiological response regimes based on two ecological principles; the principles of Limiting Factors and Ecological Amplitude, respectively, as outlined by Fritts (1976). The lowest of the Huon pine chronologies is the multimillennial Stanley River series, which has the potential to span much of the last 10 000 years and beyond, and has an independent use in the calibration of the radio-carbon calendar (Barbetti *et al.* 1992; Francey *et al.* 1984).

If we accept that the Tasmanian tree-ring reconstruction of temperature is valid, the question remains — over what temporal and spatial scales can the reconstruction be considered representative? For example, not only is the Tasmanian record in figure 1 the only one exhibiting pronounced warming over recent decades, but there is little agreement with the South American chronologies over the past millennium. Even the Chilean and Argentinian records appear to differ from each other. The fact that neither South American record indicates any recent anomalous warming is fully consistent with the local instrumental temperature records used to calibrate the temperature signals in those tree-ring series (fig. 6 in Villalba 1990, fig. 2 in Lara & Villalba 1993). It appears that summer temperatures in the Argentinian–Chilean sector of South America have not warmed in accordance with larger scale temperature increases seen in the SH by Jones & Briffa (1992), and that the proxy temperature records being compared here have distinct regional signals, which should not be considered representative of hemispheric or global climate changes. The degree to which the Tasmanian reconstruction represents a defined, regional climate variability must be considered before any inferences about warming beyond the appropriate region can be made.

The particular strength of a high time-resolution millennia-long reconstruction is the ability to address the question of historical precedents for certain features, especially periodically recurring features. This is particularly true for the Huon pine reconstructions because of the unusual depth and segment length of samples, with many ring series well in excess of 1000 years and with a mean segment length of 613 years in this study. By comparison, the South American chronologies have comparable segment lengths but far inferior sample depths, particularly in the earliest portion. In this context, we review a detailed spectral scrutiny of the 2792 year Huon pine temperature reconstruction by Cook *et al.* (1996), who postulated the degree to which observed persistent "natural" periodic variations can account for the recent anomalous warming in both tree-ring reconstruction and instrumental record.

THE TEMPERATURE RECONSTRUCTIONS

The temperature reconstruction derived from the subalpine Mt Read tree rings is based on two independently developed instrumental temperature records for Tasmania (fig. 2). The "Cook" temperature series is an average, based on the Hobart, Launceston and Low Head land-based station records. This regional average is the same one used to calibrate and verify the temperature reconstruction model (Cook *et al.* 1991, 1992). The "Jones" temperature series is based on data supplied by Dr P.D. Jones of the Climatic Research Unit, University of East Anglia. It is an average record based on Hobart, plus sea surface temperature (SST) measurements from within a 5° × 5° grid square that completely encompassed the island state of Tasmania. The Jones data were originally in anomaly units. They have been transformed to absolute temperatures by regressing them on the Cook temperature series. Although the two data sets are not completely independent (each is based partly on the same Hobart record), the methods used to regionalise the data were different, and the Jones data were also adjusted to correct for inhomogeneity problems in the SSTs. Over the last century, the temperature records exhibit considerable variance on decadal and higher frequencies. Similar variation is also exhibited in the tree ring reconstruction (fig. 2C). Note that, although the tree ring data are expressed in units of °C, the relative variation from ring to ring is completely determined by the measured ring widths and, in this sense, can be treated as a statistically independent variable.

The two warmest 25-year periods, estimated from the unsmoothed tree-ring record (fig. 2C), are 387–363 BC (0.35 ± 0.05°C) and 1967–91 (0.33 ± 0.06°C). Varying the period between 20 and 30 years did not change the ranking or essential timing of the current warm event. For example, redoing this analysis for 20-year periods resulted in the two warmest periods being AD 716–735 (0.42 ± 0.14°C) and 1970–89 (0.39 ± 0.07°C), while a 30-year period selected AD 713–742 (0.33 ± 0.10°C) and 1960–89 (0.28 ± 0.06°C). While not unique, the most recent warming is a rare event that exceeds the long-term mean by at least 4.5 standard errors and has probably not been exceeded for at least the past 1200 years, and perhaps longer, depending on the time window being evaluated.

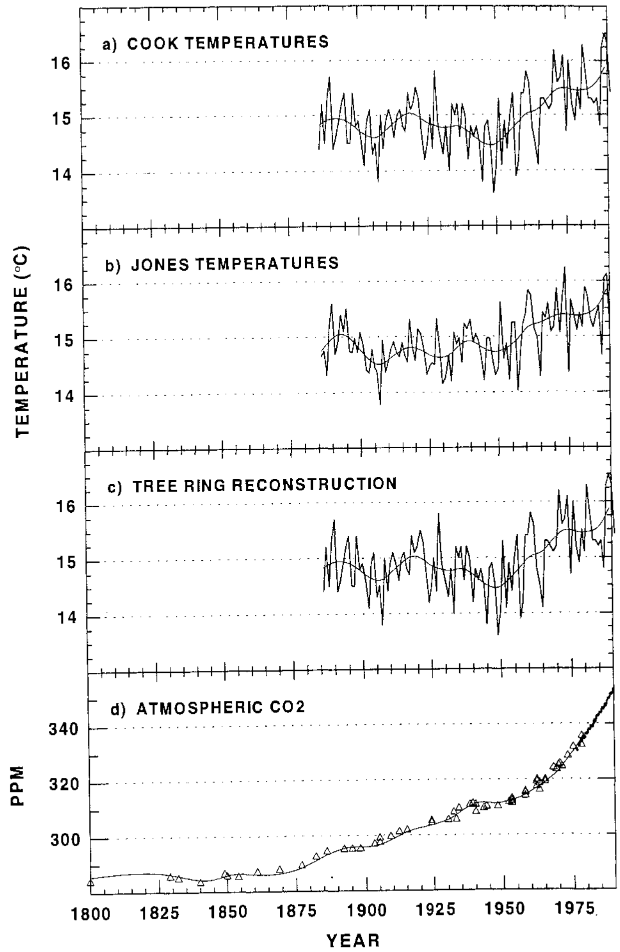

FIG. 2 — A comparison of the reconstructed temperatures (C) with two independently derived warm-season instrumental temperature records (A, B) for Tasmania. The common period is 1886–1989. The yearly values have superimposed upon them smoothed curves that highlight longer-term trends in the records. Also shown are atmospheric CO_2 trends derived from Law Dome ice cores (Δ), Cape Grim monthly averages (•) and a smoothing spline with 50% attenuation at 50 years (line). Note – the Cape Grim data are normalised to the 1957–90 South Pole data of Keeling et al. *(1989) which, on this scale, are indistinguishable from the spline fit.*

CO_2 FERTILISATION OR CLIMATE?

A common question asked about the recent Huon pine radial growth increase is whether it is a direct response to CO_2 fertilisation or, perhaps, a composite effect of both climatic warming and increasing CO_2 (i.e. requiring that the trees are a more effective palaeo-thermometer only when CO_2 is elevated), as both atmospheric CO_2 and temperature have generally increased over recent decades. A direct fertilisation effect is expected to influence tree metabolism, by supplying more raw material for photosynthesis of carbohydrates and through the regulation of stomatal closure by the internal leaf CO_2 concentration (Telewski & Strain 1994). Increased CO_2 levels may directly inhibit whole-plant respiration and, as stomata close in response to high internal CO_2 concentration in the leaves, less water is lost due to transpiration. The net effect of this reduction in transpiration, coupled with an enhancement in photosynthetic productivity, is an increase in Water Use efficiency (WUE) and, presumably, in growth rates. It should be noted, however, that growth enhancement in the form of increased annual radial growth due to direct fertilisation by increased CO_2 is contentious, and the evidence equivocal at best. It is possible that some other aspect of growth is being enhanced by increased CO_2, but this is not reflected in the width of annual rings.

An historical record of CO_2 in the atmosphere is shown in figure 2D. The bulk of the record (to AD 1978) is derived from measurements in air trapped in bubbles in an Antarctic ice core from Law Dome, 67°S, 113°E (Etheridge *et al.* 1996). The ice core record has higher precision and time resolution than previous records. Also, for the first time, the ice-core measurements overlap direct measurements at the South Pole from 1957 (Keeling *et al.* 1989) and at Cape Grim from 1976 (Beardsmore *et al.* 1984 and pers. obs.), so that possible modification and smoothing of the trace gas concentrations by the trapping processes is elucidated.

The most obvious difference between the CO_2 and temperature records (and tree-ring records) is that high-frequency variations are much less pronounced in the CO_2 record. However, caution is required because the air trapped in an annual layer of ice is a composite of air from many years due to diffusion in the firn (the mean time for CO_2 to mix to the bottom of the firn is 10–15 years at this site) and the rate of bubble close-off (the time for an annual firn/ice layer to pass through a density horizon of around 800 kg m^{-3}). The Law Dome cores include the highest accumulation sites ever used for CO_2 reconstructions, for which the bubble close-off contribution is minimal, and typical smoothing in the ice bubbles remains around the diffusion time of 10–15 yr.

For the present purposes, we can assess the possible high frequency variations in the Mt Read CO_2 climatology more directly, by reference to the continuous monitoring program operated at Cape Grim, less than 120 km to the northwest of Mt Read. There can be large diurnal variations in CO_2 in a boundary layer with photosynthesising and respiring plants. It is important to appreciate that the relevant comparison of CO_2 environments is constrained to the periods when photosynthetic CO_2 assimilation is occurring. These periods are heavily biased to times of high solar radiation, which also induce convective atmospheric mixing, so that generally CO_2 levels are close to latitudinal background values as measured at Cape Grim, and from aircraft above Cape Grim (Fraser *et al.* 1992). This was demonstrated in the dense temperate rainforest of the Stanley River (Francey *et al.* 1984) and will be even more applicable at the more exposed subalpine site. The Cape Grim data, in figure 2D are monthly averages measured by non-dispersive infra-red analyser during conditions of strong winds off the west to southwest (marine) sector. The amplitude in the seasonality in background air at these latitudes is quite small (around 1 ppmv in 350 ppmv). The inter-annual CO_2 variation in the relevant summer months (November to April) around the long-term trend is even smaller. Thus, despite the smoothing due to diffusion and trapping, the ice-core data appear to be a good representation, with regard to the relative amplitudes of seasonal, interannual and long-term secular behaviour, of the CO_2 environment experienced by the trees on Mt Read.

To explore the possibility that the significant long-term increase in atmospheric CO_2 contributes directly to increased ring width, we focus on the inter-relationship between ring width, temperature and CO_2 over a range of time scales. If the overall increase in tree-ring indices is suppressed (either by pre-whitening to remove autoregressive persistence or by first-differencing to strictly emphasise year-to-year variations), correlations with temperature remain high and statistically significant at the 5% level (Cook *et al.* 1991). This stable relationship would be expected if the link between climate and tree growth acted as a minimum-delay, causal input-output process. Surprisingly, over the length of the available CO_2 record, correlations with temperature and ring-width are obtained despite the apparent smoothness of the CO_2 record in figure 2D. The most likely reason is that, independent of CO_2-ring-width interactions, atmospheric CO_2 responds to temperature via vegetation and soil respiration rates (Dai & Fung 1993).

The key point is that different mechanisms (different response coefficients) are required to explain the interdependence between CO_2 and the ring-width index on both decadal and century frequencies, unlike the relationship between ring index and temperature, which is similar over annual up to century time-scales. For a CO_2 forcing, the change in ring widths (expressed in °C) since the 1960s requires a coefficient of around 100 ppm/°C. By contrast, on decadal time-scales, the relationship between 10-year smoothed residuals from a long-term trend (>50-year smoothing) results in a coefficient close to 1 ppm/°C. In the Cook & Jones temperature series (figs 2A, B), and the ring widths (fig. 2C), the ratio of decadal variation amplitudes to the long-term secular changes (maximum variation shown by the spline fits) is close to 1:1.

This argument can be taken further using the temperature data alone, as follows. Calibrating (involving all available frequencies) the tree rings against the Cook *et al.* temperature data set in figure 2, over only the 1967–91 period, gives an anomaly of 0.33 ± 0.06°C; calibrated against the Jones *et al.* temperatures (generally exhibiting larger variations), the reconstructed anomaly is 0.40 ± 0.06°C. The two instrumental temperature records show warming of 0.44 ± 0.10°C (fig. 2A) and 0.49 ± 0.11°C (fig. 2B), respectively over the period. With a low-frequency contribution from CO_2 fertilisation in the ring width record, we would expect the calibration process to result in the reconstruction overestimating the actual temperature change rather than underestimating it as occurs in both cases here.

There are physiological arguments that support a direct effect of temperature on photosynthesis. Read & Busby (1990) demonstrated that the optimum temperature for photosynthesis in Huon pine is around 20°C, with a drop-off in net photosynthesis below 10°C. Growth-season maximum temperatures at the Mt Read site are expected to be in the range of 5–9°C (on the basis of dry and saturated air lapse rate calculations), so that photosynthesis in these high-altitude trees is operating in a regime of strong temperature sensitivity. While two nearby Huon pine chronologies developed from lower elevation (<600 m), warmer sites at the Stanley and Harman Rivers do not show a systematic growth increase in recent decades; on the other hand, the increase is evident in different tree species at other subalpine locations in Tasmania (LaMarche & Pittock 1982) and New Zealand (D'Arrigo *et al.* 1995).

LaMarche *et al.* (1984) argued for an enhanced growth-rate sensitivity to CO_2 at high altitudes; however, the evidence for this effect is inconclusive (LaMarche *et al.* 1986 and accompanying correspondence). They seek a CO_2-moderated effect at altitudes between 4 and 6 km. This is very much higher than the 1 km altitude involved here, and physical differences due to CO_2 or O_2 partial pressure are very much smaller at this lower altitude. The relatively small partial pressure differences between the 1 km altitude and lower-elevation Huon pine tree-ring chronologies (<about 600m), and the lack of sustained growth increase in the lower altitudes trees also argues further against any obvious large-scale CO_2 fertilisation effect on Tasmanian Huon pines. The lack of evidence for a fertilisation influence on Huon pine ring widths is in accord with the review of Cook (1995), who concluded that previous evidence for hypothesised CO_2 fertilisation is largely negative or equivocal, with the exception of some pines, which have developed a strip-bark cambial growth morphology (Graybill & Idso 1993). We note that the Huon pine trees used in this study do not exhibit strip bark cambial growth.

To examine the other possibility, that the high correlation requires the coincidence of both high temperatures and high CO_2, a dynamic regression method based on the Kalman filter (Van Deusen 1990) was used to test for a time-dependent relationship in the high-frequency correlation between tree rings and temperature over the 1886–1989 period. This encompasses an increase in CO_2 concentration of about 65 ppmv or 23% above a pre-anthropogenic background of ~280 ppmv. No statistically significant trend towards increasing correlation between tree rings and temperature was found, even though some correlation might have been anticipated from the obvious improvement in temperature data quality over the period. Thus, there is no clear evidence for a link between temperature sensitivity and high CO_2 in our data. In support of this result, Gifford (1992) argued on physiological grounds, that the influence of enhanced CO_2 on temperature sensitivity will be smaller at lower rather than higher temperatures, in the opposite sense to that required to explain the high altitude anomalous response.

Thus, while a CO_2 fertilisation cannot be totally excluded, non-linear or multiple forcing of unspecified physiological origin(s) is required. In contrast, a direct temperature influence on photosynthesis, approximately uniform on all observed time-scales of ring width variation, is compatible with the subalpine Huon pine observations.

SPECTRAL ANALYSIS OF THE MOUNT READ RECONSTRUCTION

One of the more significant opportunities provided by a 2800-year record with single-year time resolution is that of searching for periodic natural forcing functions on time-scales up to centuries. There are familiar signals associated with solar forcing on decadal and longer time-scales, though a mechanistic link with detectable climate influences is unproven. There are also characteristic planetary frequencies associated with atmospheric and oceanic circulation, which might be anticipated on these time-scales. Cook *et al.* (1996) explored the interdecadal climate variability in the Tasmanian record over the three millennia and found that 41% of the variance for periods longer than a decade is confined to four frequency bands, with mean periods at 31, 57, 77 and 200 years. These frequencies were indicated in the initial 1000 year record (Cook *et al.* 1991) and reinforced in the extended record. Using autoregressive techniques, it was found that 51% of the mean anomalous warming since around 1965 can be accounted for by the oscillatory modes. To the extent that the reconstruction represents a global phenomena, this would suggest that enhanced greenhouse warming is required to explain only about half of the warming since 1965. However, caution is required. While the spectral analysis identifies periodic forcing, it does not provide information on the "stationarity" of the forcing functions. These might vary substantially in amplitude and phase and still produce statistically significant spectral peaks. Without independent mechanistic information about the forcing, the utility of spectral analyses in a predictive capacity is limited.

REGIONAL CLIMATE INFLUENCES

The recent warm-season temperature increase over Tasmania coincides with broader-scale climatic warming in the SH (Jones & Briffa 1992). However, the regional nature of the reconstruction is revealed in figure 3, which shows the spatial correlations of the temperature reconstruction with joint land/marine temperature data in 5° x 5° boxes surrounding Tasmania (data kindly provided by Dr P.D. Jones). This has been done for two 40-year time spans representing contrasting "cold" and "warm" periods (Cook *et al.* 1992). Despite inferior quality of the data in the early "cold" period, some clear spatial patterns emerge. First, the regional signal extends well to the west, north and east of the island during both periods. Figure 3 also suggests an intriguing seesaw relationship between the source regions for cold and warm temperatures over Tasmania. In the early cold period, the strongest correlations lie off the west coast. In contrast, the later warm period is more strongly influenced by temperatures east of Tasmania over the Tasman Sea. These periods of anomalously cold and warm SSTs in the two source regions have been described independently (Bottomley *et al.* 1990). In addition, since the 1940s, there has been a progressive poleward migration in the mean summer position of the subtropical high-pressure belt off the east coast of Australia (Lough 1991), a change that has been correlated with rising mean maximum temperatures over Tasmania (Coughlan 1979). The record of the mean latitude of the subtropical high is described in terms of an "L-index", due to Pittock (1973), and has been extended back to 1870 using long sea-level pressure records from Darwin, Sydney, and Hobart. Together, the pressure records explain 57% of the L-index variance over the 1942–81 period in common for the relevant warm-season months of November–April. The extended L-index is shown in figure 4B. The effect of this poleward migration is clearly evident in warm-season sea-level pressure for Hobart, Tasmania (fig. 4A), which has been anomalously high since 1960, in accord with the recent warming (cf. fig. 2A–C). Over New Zealand, a similar poleward shift of the subtropical high occurred during the 1950-80 period that was related to a major retreat of mountain glaciers on the south island (Fitzharris *et al.* 1992).

The effect of atmospheric circulation changes on Tasmanian temperatures can also be seen in a series of warm-season zonal circulation indices, calculated as the pressure differences between Hobart and Brisbane, Sydney,

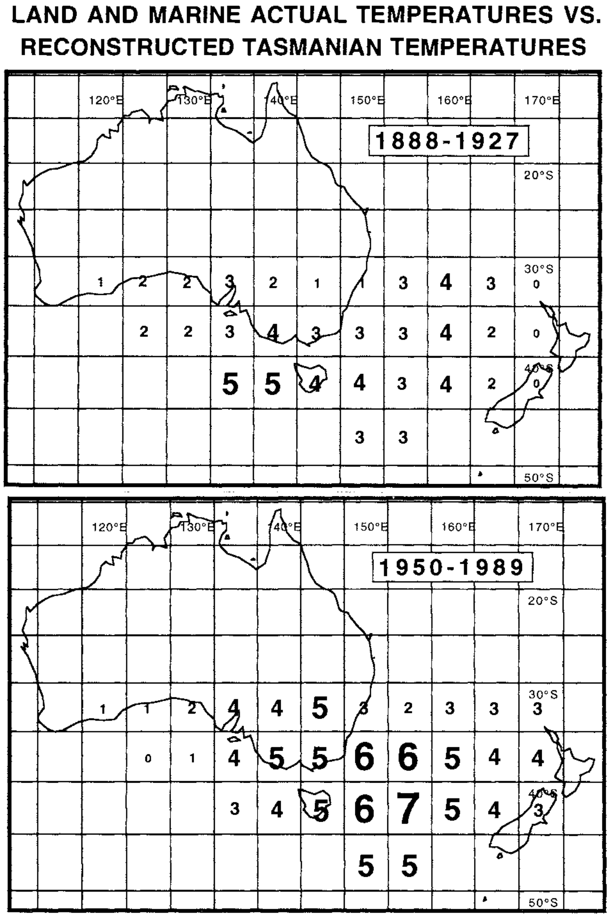

*FIG. 3 — The spatial correlations between reconstructed warm-season Tasmanian temperatures and 5° x 5° gridded land/marine temperatures around Tasmania. The numbers in the grid boxes are correlations rounded up or down to the nearest tenth and multiplied by 10. Thus, if r = 0.44, the grid box value would be 4, while r = 0.46 would yield a grid box value of 5. The correlations were computed on pre-whitened temperatures to remove the effects of autocorrelation and trend on the estimation of r. For 38 degrees of freedom, grid box values of 4 or greater (and most values of 3) are statistically significant (p<.05) assuming a 1-tailed hypothesis test (*i.e. H_o: r = 0; H_a: r > 0).*

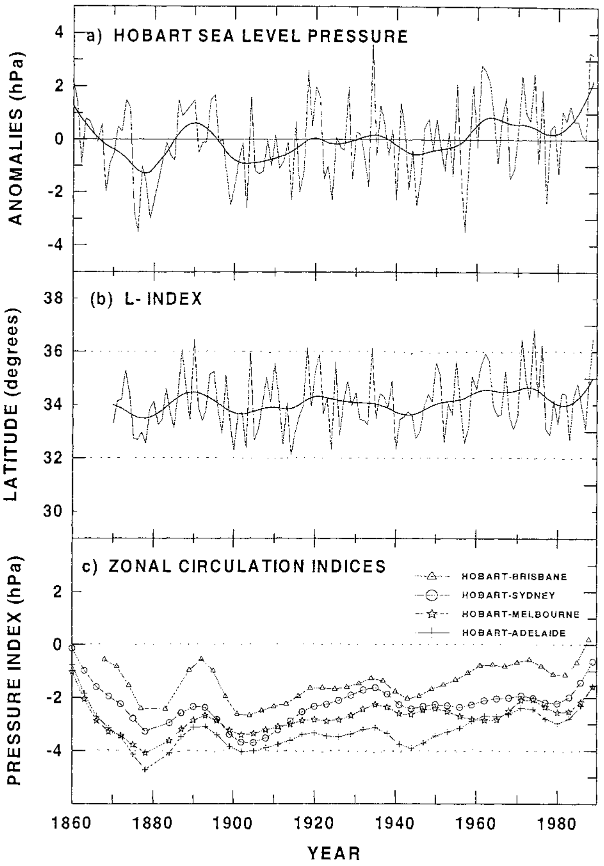

FIG. 4 — Hobart warm-season (November–April) sea-level pressure anomalies (A), the latitude of the high pressure belt off eastern Australia (B), and zonal circulation indices (C), calculated as the pressure difference between Hobart and Brisbane, Sydney, Melbourne and Adelaide. The yearly values have been smoothed to highlight fluctuations >20 years in duration. Note the anomalously high pressure over Tasmania since 1960 that is associated with the poleward migration of the subtropical high and the corresponding weakening of the zonal circulation in the recent decades. All appear to be associated with recent warming over Tasmania.

Melbourne and Adelaide (data kindly provided by Dr R.J. Allan). Since 1900 there has been a systematic decrease in this difference (fig. 4C), which would result in a weakening of the zonal westerlies over Tasmania. This weakening is also well correlated with the recent warming over Tasmania, while the more vigorous circulation indicated in the early 1900s is associated with unusually cool conditions (cf. fig. 2A–C). Similar changes in zonal circulation also occurred over New Zealand (Fitzharris *et al.* 1992), especially during 1880–1910, when the westerlies were unusually strong and temperatures over southern New Zealand unusually cold (Salinger 1979). Thus, the persistent cold and warm temperature anomalies seen in the reconstruction (fig. 1A) appear related to alternating warm-season patterns of SST around Tasmania, the mean position of the subtropical high-pressure belt, and the strength of the zonal westerlies.

These clearly regional influences on Tasmanian temperatures help explain why there is so little agreement between this warm-season reconstruction and those recently developed from tree rings from southern South America. Neither of the South American reconstructions shows evidence for recent sustained climatic warming, which is in general agreement with instrumental temperature records from that region of South America. Like the Tasmanian record, the Argentinian reconstruction is also highly regional, with little or no connection with temperatures on the Chilean side of the Andes (fig. 8 in Villalba 1990). Further back in time, the relatively well-defined "Little Ice Age" cooling during the 16th century in the Argentinian reconstruction is essentially absent in the Chilean and Tasmanian reconstructions. Likewise, there is little evidence for "Medieval Warm Period" warmth in the AD 800–1300 period in either of the Tasmanian and Chilean reconstructions. Even further back in time, as far as 800 BC, the Chilean and Tasmanian reconstructions again appear to have little in common (though we again note the small sample depth in the South American reconstructions, particularly in the early part of the records). Thus, all three millennia-long warm-season temperature reconstructions are reflecting various regional aspects of climatic variability and change. A direct comparison of these records in the time and frequency domains will be needed before any large-scale teleconnections between them can be claimed.

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