

SOUTHERN HEMISPHERE CLIMATE: THE MODERN RECORD

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(with seven text-figures)

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ISSN 0080-4703. National Institute of Water and Atmospheric Research (NIWA), PO Box 109 695, Newmarket, Auckland, New Zealand (MJS); and Climatic Research Unit, University of East Anglia, Norwich NR4 7TJ, United Kingdom (PDJ).

This study presents observed trends and variability in the modern climate record for the Southern Hemisphere. High-resolution records of past climate from dendroclimatic studies, which are limited to a few areas, are also presented for the last few centuries. Sufficient land and marine surface temperature observations exist to enable reconstruction of surface temperature trends since 1860. These results are derived from high-quality, long-term climate datasets. These data show that annual surface air temperatures have warmed by 0.6°C over the period 1860 to 1994. Trends are similar for all four seasons. The pattern of annual land-only surface temperature trends reflects these broad trends, but is somewhat different. Over the entire period the warming amounts to 0.4°C. Australian and Southern African trends more closely resemble the hemispheric; South American trends differ. In Antarctica, the record commenced only in 1957 and shows slight warming.

The Southern Oscillation is an important driver of interannual variability in temperature and precipitation throughout Oceania (Australia, New Zealand and the South Pacific) and southern Africa. Finally, there is a very limited number of potential terrestrial high-resolution proxy records to extend the climate record prior to the mid 19th century for the Southern Hemisphere. These show no consistent trend.

Key Words: Southern Hemisphere, climate trends, temperature, Southern Oscillation, tree-rings, Australia, southern Africa, South America.

INTRODUCTION

Global mean surface temperatures for the land and sea have increased by 0.3°–0.6°C over the last 100 years, with the four globally averaged warmest years being in the 1980s and the early 1990s. A relative global cooling at the surface and the tropospheric cooling of a few tenths of a degree occurred during 1992 and 1993; these have been attributed to the recent Mt Pinatubo volcanic eruption in June 1991 (Nicholls *et al.* 1996a), offsetting an El Niño event persisting throughout this period; normally such events cause warmer than average global temperature anomalies. For the globe, 1995 was the warmest year on record.

Data from continental areas comprising 37% of the global landmass for the period 1951–90 have shown that the observed warming over the past several decades is primarily due to an increase in the daily minimum (night-time) air temperatures, with little contribution from daily maximum (daytime) air temperatures (Karl *et al.* 1993). Minimum air temperatures increased by 0.84°C compared with only 0.28°C for maximum air temperatures, resulting in a significant decrease of the diurnal temperature range (DTR, the difference between maximum and minimum temperatures).

McGuffie & Henderson-Sellers (1994), in examining historical cloud cover observations from North America, Europe, India and Australia, note an increasing trend in cloudiness in all these regions. Modelling studies (Hansen *et al.* 1995, Taylor & Penner 1994, Jones *et al.* 1994) indicate that DTR decreases result from negative radiative forcing, located over continental areas. The models suggest that increases in continental cloud cover associated with the regional presence of anthropogenic sulphate aerosols might cause some negative radiative forcing for continental

areas. However, Jones *et al.* (1994) suggest some indirect negative forcing from this source over the Southern Oceans.

Beyond the underlying trends in climate, the El Niño–Southern Oscillation (ENSO) phenomenon (Rasmusson & Carpenter 1982, van Loon & Shea 1987, McBride & Nicholls 1983) causes significant climate variability at the interannual time-scale (Salinger *et al.* 1995) and can influence precipitation trends on the decadal time-scale (Nicholls 1992).

It is clear that the factors described above play important roles in climate trends and variability, in conjunction with variation in the main circulation features of the Southern Hemisphere. This study presents observed trends and variability in the modern climate record for the Southern Hemisphere, including high-resolution records of past climate from dendroclimatic studies.

DATA AND METHODS

Enough land and marine surface temperature observations exist to enable reconstruction of surface temperature trends since 1860. The land surface–air temperature data base developed by Jones & Briffa (1992) has been substantially reanalysed (Jones 1994). The data have been gridded as anomalies from the 1961–90 reference period on a 5° × 5° grid. The sea surface temperature (SST) data have been taken from an updated version of the Global Ocean Surface Temperature Atlas (GOSTA) marine data set (Bottomley *et al.* 1990). The corrections to SST in the GOSTA data set are more recent, being those published in Folland & Parker (1995).

The land and marine surface temperature series have been combined to produce hemispheric average surface tem-

peratures. Surface temperature series have been prepared for the land masses of Australia, southern Africa, South America and Antarctica by selecting the appropriate grid box for each area and combining the anomaly series.

Climate trends in Oceania (Australia, New Zealand and the South Pacific) have been examined in more detail. For Australia, an exhaustive search of documentation regarding observational practices, instrumentation, site relocation and exposure of instruments has been conducted for temperature stations (Torok & Nicholls 1993, Nicholls *et al.*, in press). A set of 149 stations in small towns or rural locations opened by 1910, with high-quality temperature records which have been used to calculate spatial average temperatures (Salinger *et al.*, in press). Thiessen polygons were used to calculate spatial averages of temperatures across the country (Sumner 1988).

Lavery *et al.* (1992) described the selection of 191 high-quality, long-term rainfall stations of sufficient quality for monitoring changes in rainfall through the 20th century. This data set has now been supplemented with additional stations, most of which are composites of two or more neighbouring stations of high quality. A total of 341 high-quality records, starting before 1910, were used to prepare All-Australia averages of annual rainfall (Salinger *et al.* 1996).

Trends in mean, maximum and minimum air temperatures, sunshine and cloud amount in the South Pacific from 1951 to 1991 and before have been examined, using stations from the South Pacific Historical Climate Data Network (Collen 1992, Fouhy *et al.* 1992, Salinger *et al.* 1992). The data were homogenised, using the procedures of Rhoades & Salinger (1993) for 37 South Pacific sites. From the newly homogenised historical monthly climate data sets for the South Pacific, 41 stations were analysed for precipitation trends.

Finally, climate trends back to AD 1400 are derived from high-resolution palaeoclimatic records from tree-rings. Methods involved in reconstructing climate series from these sources are discussed in Salinger *et al.* 1994. Although such records have their own limitations, they can be precisely dated. However, dendroclimatic studies in the Southern Hemisphere have been limited to a few areas. The vast areas of ocean limit the number of potential high-resolution proxy records.

RESULTS

Trends in the Southern Hemisphere and Four Land Masses

The combined land and marine series (fig. 1) show that annual surface air temperatures have warmed by 0.6°C over the period 1860 to 1994. Trends are similar for all four seasons. The coolest periods occur in the early 1860s and during the 1870s, when temperature departures are 0.4°C below the 1961–90 normal. The first decade of the 1900s was particularly cool. A period of warming occurred in the 1930s, then Southern Hemisphere temperatures fluctuated. A period of strong warming occurred after 1975, and the last decade up to 1991 was the warmest in the entire record. Temperature departures of 0.3°C above the 1961–90 normal occurred in the late 1980s. The impact of volcanic aerosols from the winter 1991 eruptions is seen in the record for 1992 and 1993.

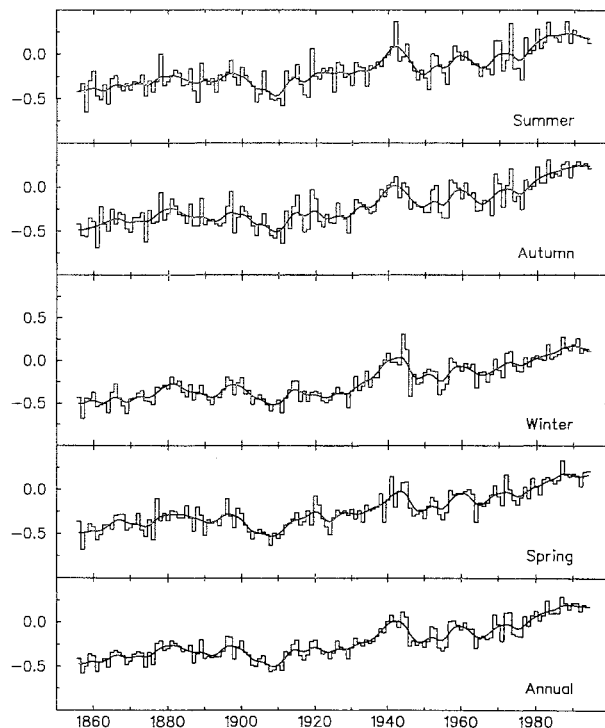


FIG. 1 — Southern Hemisphere combined land and marine surface air temperatures by season, 1856–1994. Standard Austral seasons are used. Data are expressed as anomalies from the period 1961–90. The time series have been smoothed with a ten-year Gaussian filter.

The pattern of annual land-only surface temperature trends reflects these broad trends, but is somewhat different. Over the entire period, the warming amounts to 0.4°C . However, the coolest period in the land-only record occurs in the 1890s, with temperatures 0.5°C below the 1961–90 normal. This period was one of particularly cool autumns and winters. The warming since 1975 has also been less marked over land areas. The trends are different in each of the four continents.

Australian trends show that the period 1860 to the mid 1880s was relatively warm, with temperature anomalies of 0.4°C above the 1951–80 normal (fig. 2). A smaller number of stations exist from before 1910. Preliminary tests, however, indicated that a reliable country-wide average cannot be calculated for the period before this date, because of the poor spatial coverage. In addition, changes in the exposure of thermometers prior to 1910 (Nicholls *et al.* 1996) cast doubts on the use of the temperature data prior to this date, even though attempts have been made to correct for changes in exposure. So only the record since 1910 should be considered reliable. Temperatures in Australia were about 0.2°C less than the 1961–90 normal from the 1920s until the 1950s but warmed to 0.3°C above these by 1990.

Trends in southern Africa (fig. 2) more closely resemble the hemispheric trends. The coolest periods occurred around 1860 and 1880, with temperatures 0.7 and 1.0°C below those for the reference period. Temperatures warmed in the 1910s and fluctuated close to normal from 1920 to 1975. Subsequently, they have warmed to 0.5°C above normal. South American trends show cool conditions throughout the 1860s and around 1890, when temperatures

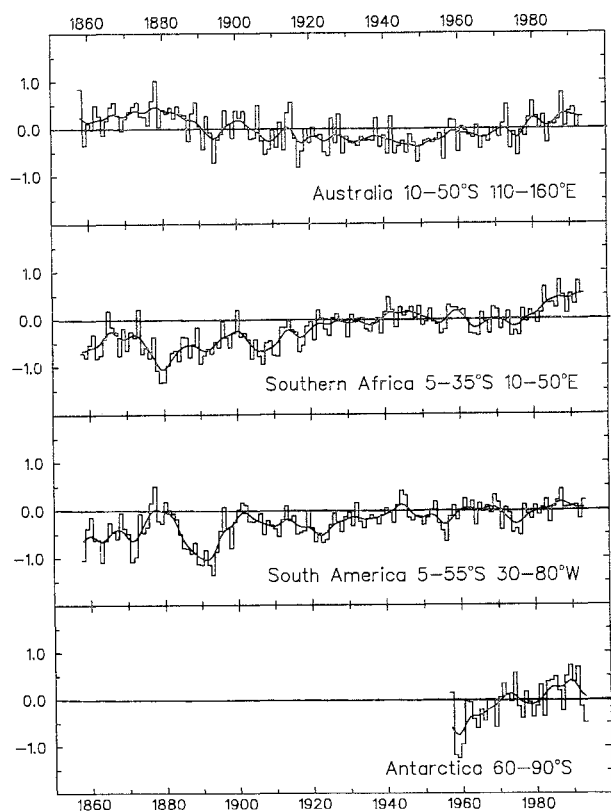


FIG. 2 — Surface land air temperature series estimated for Australia (10° – 50° S, 110° – 160° E), southern Africa (5° – 35° S, 10° – 50° E), South America (5° – 55° S, 30° – 80° W) and Antarctica (60° – 90° S). Data expressed as in figure 1.

were 0.5° and 1.0° C less than normal. Subsequently, temperatures warmed to slightly below the reference period from 1900 to 1940 and have fluctuated close to normal since. In Antarctica, the record commenced in 1957. Land surface air temperatures warmed by 1.1° C by 1991. They cooled in 1993 and 1994.

Trends in Australia

Time series of the All-Australia areal averages of mean minimum and maximum temperatures are shown in figure 3. Average Australian maximum and minimum temperatures have increased substantially since 1910, with most of the change occurring since about 1950. The increase has been larger in the minimum temperatures. A positive trend of typically 1° C has occurred in minimum temperature at nearly all stations since 1910. The trends in maximum temperature have been more spatially variable, with negative trends through eastern New South Wales. The diurnal temperature range has decreased over much of the country, especially in the east.

Rainfall has generally been greater since about 1950 (fig. 4), relative to earlier in the century. This is due mainly to increased summer rainfall in northeastern Australia (Nicholls & Lavery 1992), which, in turn, reflects an increase in the frequency of precipitation events rather than in their intensity (Nicholls & Kariko 1993). Suppiah & Hennessey (1996) reported an increase in the frequency

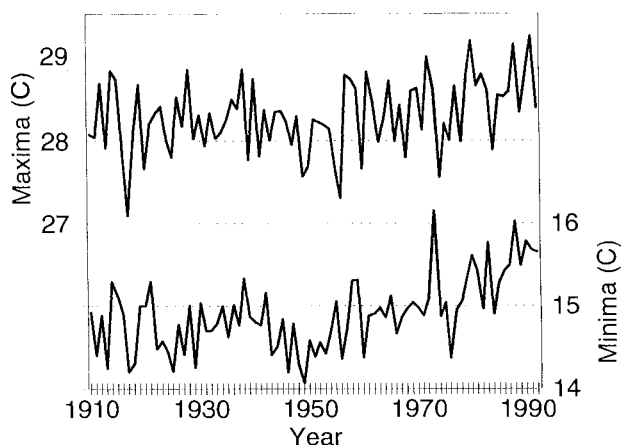


FIG. 3 — Time series of All-Australia areal averages of annual mean minimum and maximum temperatures. (Prepared by S. Torok and N. Nicholls, after Salinger et al., in press.)

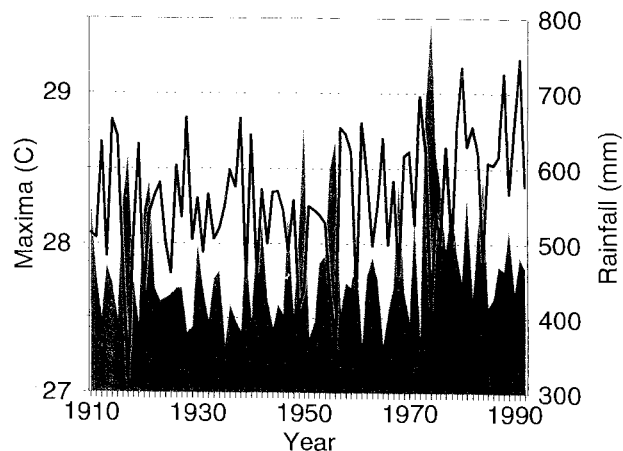


FIG. 4 — Time-series of All-Australia areal averages of annual rainfall (stipple), and annual mean maximum temperatures (line). (Prepared by B. Lavery and N. Nicholls, after Salinger et al., in press.)

of extreme rainfall events at a majority of stations during northern Australian summers since 1910. Few of the increases are statistically significant (Karl *et al.* 1993).

Interannual variations in annual mean maximum temperature and rainfall are strongly (negatively) correlated (fig. 4). However, the recent increase in maximum temperatures has not been accompanied by a decrease in rainfall, as would be expected from this relationship. This suggests that the recent decadal-scale increases in temperature represent a climate process separate from that controlling the interannual variations.

Trends in the South Pacific

The South Pacific divides into two coherent regions that share similar trends and variations (fig. 5). The first lies to the northeast of the South Pacific Convergence Zone (SPCZ).

This region is an area dominated by easterly trade winds and includes Kiribati, the Tokelaus, the Northern Cook Islands and the Marquesas and northern Tuamotu Islands of French Polynesia. In this region, mean annual island surface air temperatures show a decrease from the 1940s to 1970 by 0.2°C , followed by a rapid increase of 0.7°C by 1990 (fig. 6). The decade 1981–90 is the warmest of the entire record, and is 0.5°C warmer than the 1951–80 reference period. Despite climate warming here, minimum temperatures have increased almost twice as much as maximum air temperatures over the period 1951–90. At the same time there has been a 7% decrease in sunshine, and cloud cover has increased (Salinger 1995).

Rainfall trends are largely consistent, although there are no records prior to 1920. Many areas in this region became slightly drier after 1950, with annual amounts decreasing by about 5%. However, in the 1980s significant increases occurred, with rainfall being 30% above the 1951–80 period. In this region of the South Pacific, El Niño years are warmer and wetter and anti-El Niño years cooler and drier than the average.

The second climate region in the South Pacific is the large area that lies to the southwest of the SPCZ (Salinger *et al.* 1995). It comprises New Zealand, New Caledonia, Vanuatu, Fiji, Tonga, Niue, the Southern Cook Islands and the Austral Islands of French Polynesia. Temperatures in this region trend upwards throughout this century, the

increase amounting to 0.9°C (fig. 6). Temperatures increased rapidly between 1920 and 1930, and again after 1980.

Mean air temperature averaged over New Zealand has been compared rigorously with quality-controlled sea surface temperature over the surrounding ocean surface. There is very good agreement that the New Zealand annual air temperature and that of the surrounding ocean surface have warmed by 0.7°C since the beginning of this century.

Although lower temperatures occur during El Niño events and higher temperatures during anti-El Niño events, the effects of the strong El Niños of the 1980s were swamped by climate warming from other causes. The climate warming in this zone is expressed by similar increases in both maximum and minimum air temperature, with little trend in sunshine, cloud cover or temperature range.

Climate Trends over the Last 500 Years

There is a very limited number of potential high-resolution proxy records to extend the climate record prior to the mid 19th century. To date, only four high-resolution dendroclimatic reconstructions span this time period (fig. 7). All these series are summer temperature reconstructions. The tree-ring studies from similar regions in temperate South America (Argentina) show few similarities. Tree-ring series

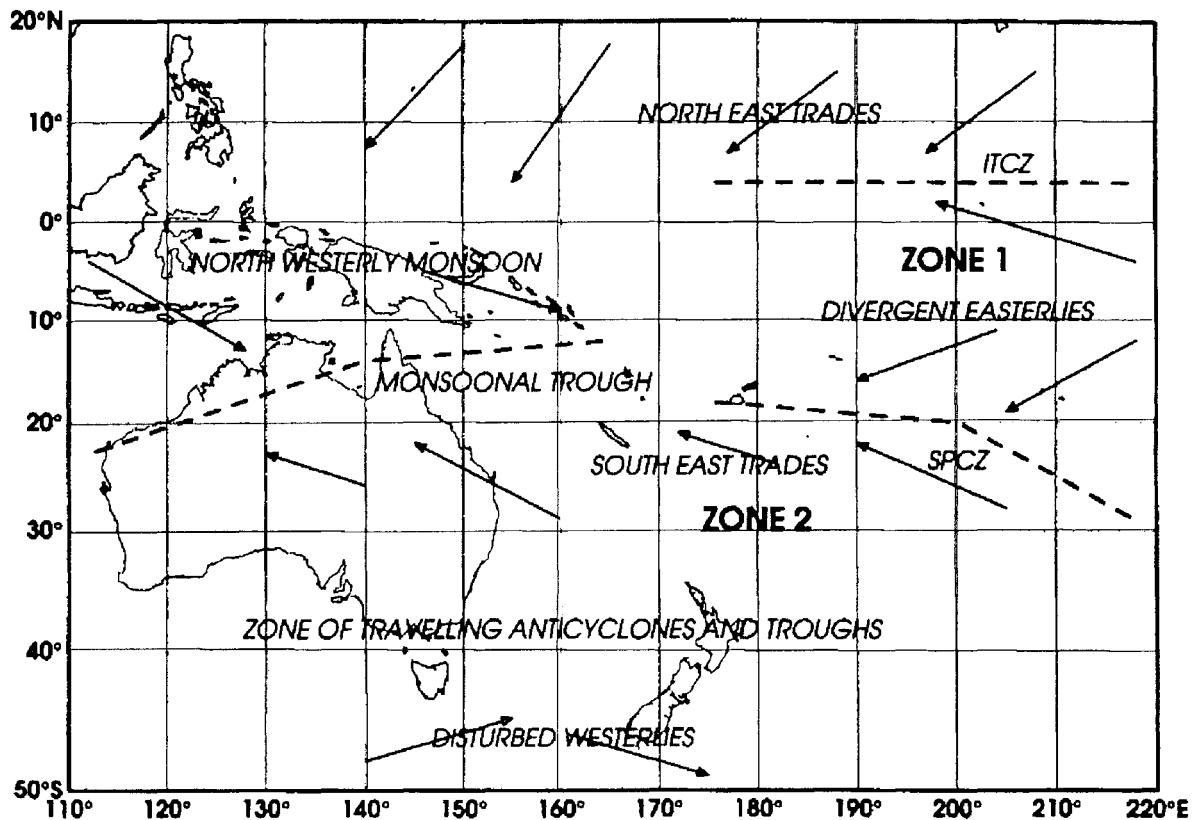


FIG. 5 — Typical summer circulation in the South Pacific, and the two climate zones. Zone 1 includes all the area northeast of the South Pacific Convergence Zone (SPCZ), as far north as the Intertropical Convergence Zone (ITCZ). Zone 2 includes all the area to the southwest of the SPCZ.

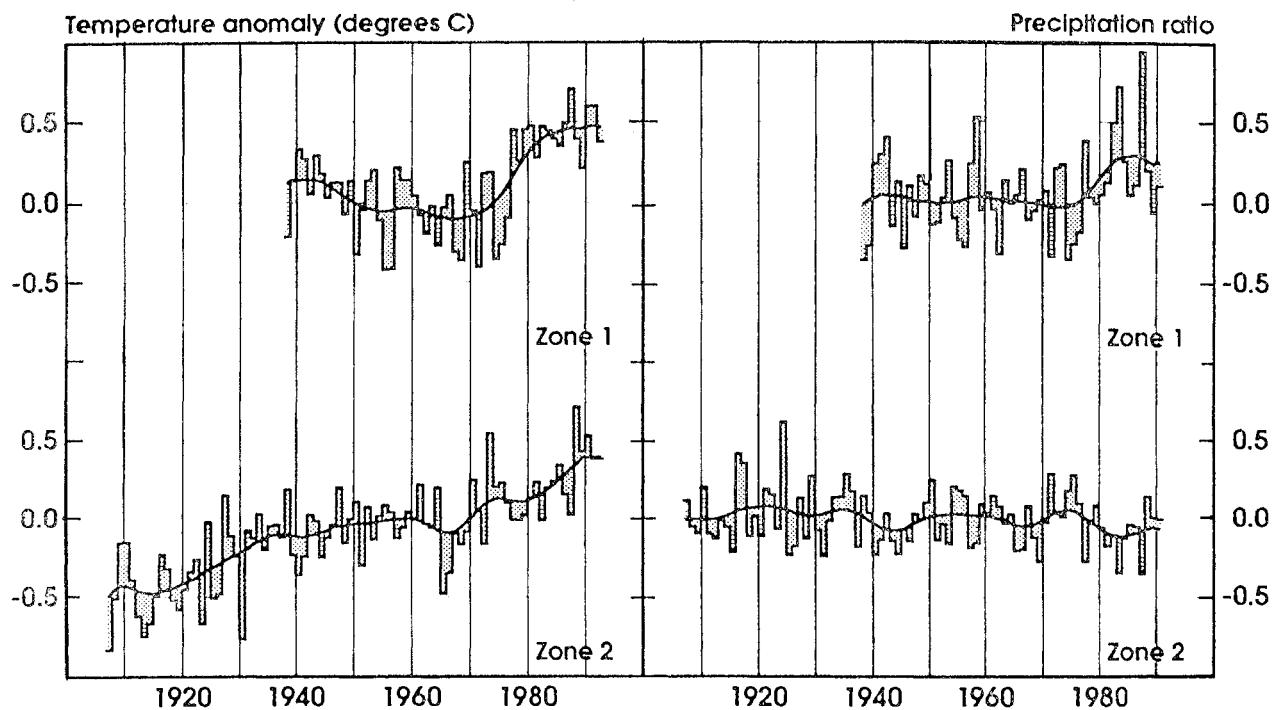


FIG. 6 — Climate trends in zones 1 and 2. Annual temperature data are expressed as departures from the 1951–80 reference period mean, and annual precipitation data are ratios based on the reference period mean.

from northern Patagonia (37° – 39° S) suggest that three cold periods occurred in the last 500 years (Boninsegna 1992): the early 1500s, the late 1600s and the late 1700s. This is based on three chronologies of *Fitzroya cupressoides* and is of December–February temperature. By contrast, tree-ring series from central Patagonia (41° S) suggest that conditions this century have been very similar to those since about 1660 (Villalba, 1990). This series is of December–May temperature, based on 20 chronologies of *Araucaria araucana*. Only the period 1530–1650 is a period of cooler summer temperature. Another South American series (Lara & Villalba 1993) does not show any strong trends.

Tree-ring width records from Tasmania (Cook *et al.* 1992) are of summer temperatures based on a chronology of *Lagarostrobos franklinii*. This shows that over the last 500 years there has been a cool period at the end of the 19th and early in the 20th century. This contrasts with the New Zealand tree-ring record, where warm-season reconstructions show cooler periods in the mid 1700s and 1800s (Salinger *et al.* 1994), at a time similar to that during which New Zealand mountain glaciers were in a more advanced state (Fitzharris *et al.* 1992). The beginning of the 20th century was cold with subsequent warming, which agrees with the instrumental record. This last reconstruction is inherently more robust, as it uses ring-width chronologies from five species from eight geographically disparate locations and is of November–March temperature.

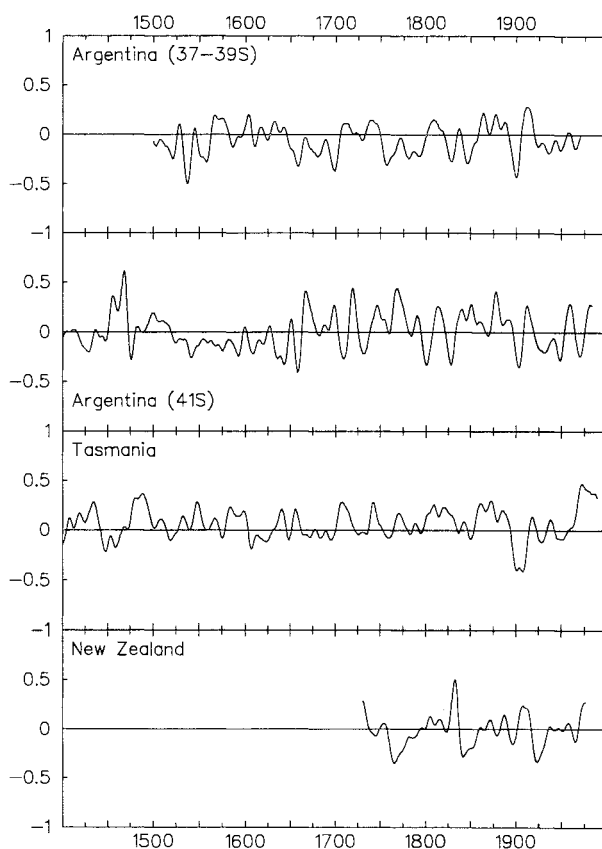


FIG. 7 — Reconstructed summer temperature anomaly series for Southern Hemisphere locations discussed in the text, referenced to the mean of each series for 1860–1959.

CONCLUSIONS

The observational records of climate allow the determination of trends throughout the Southern Hemisphere. Surface air temperatures have increased by 0.6°C since 1860, with the most marked increase since 1975. The land-only surface temperature trends are similar but show less warming, particularly since 1975. This is because the more frequent ENSO events in the tropical eastern Pacific Ocean cause large areas of above-average surface temperatures. Strong warming is seen in the land masses of Australia, Antarctica and southern Africa, but South American trends differ from the other land masses.

Warming in Oceania, is consistent with, if somewhat greater than the hemispheric trend. Surface air temperatures have generally increased by 0.4 to 0.8°C over the period 1951–90. Longer term temperature records show this temperature increase amounts to 0.7°C for the region southwest of the SPCZ since the beginning of the century, and a similar increase over most of Australia since 1910. The pattern of temperature increase of 0.48°C is observed for the Southern Hemisphere between the period 1881–1900 and the decade 1981–90 (Nicholls *et al.* 1996).

Over the forty-year period 1951–90 the DTR has decreased over most of Australia, while, at the same time, consistent increases in cloud cover have occurred in the northeastern interior. This DTR decrease is in contrast to the negligible trends observed in the first half of the twentieth century. However, the warming over the entire South Pacific has occurred with little reduction in the DTR and little trend in cloud cover. The subregions of the South Pacific show coherent behaviour between DTR, sunshine and cloud cover. Northeast of the SPCZ, both the DTR and sunshine show significant decreases, and cloud cover has increased. To the west, DTR has increased and cloud cover decreased.

The temperature and precipitation records confirm that interannual variability is very significantly affected by ENSO, consistent with relationships established in previous studies (Rasmusson & Carpenter 1983, van Loon & Shea 1987, Halpert & Ropelewski 1992, Folland & Salinger 1995, Salinger *et al.* 1995). The strongest signal is to be found over the tropical South Pacific and Australia. The ENSO phenomenon affects trends in precipitation in the South Pacific on decadal time-scales. However, on decadal time-scales ENSO has not affected the regional warming trend, particularly evident after 1950.

The observed twentieth-century changes in the Southern Hemisphere are not inconsistent with the pattern of change expected from anthropogenic activity (such as the enhanced greenhouse effect and increased aerosols in some areas of the globe). The regional evidence demonstrates that observed decreases in DTR occur, particularly in areas where cloud cover has increased. This has occurred in the northeast interior of Australia and in the Pacific to the northeast of the SPCZ. In other areas of the region, little reduction of the DTR is found. These observational studies support recent modelling studies (Hansen *et al.* 1995, Jones *et al.* 1994, Taylor & Penner 1994) that show dampening in the DTR over continental areas occurs with increases in greenhouse gases, cloud cover and sulphate aerosols.

Oceania is free of large sources of human emissions of sulphate aerosols, which provide backscatter to incoming solar radiation by day. One plausible mechanism leading to

increases in daily maximum and minimum surface temperatures is increased radiative forcing caused by increases in greenhouse gases.

The oceanic or rural nature of many of these climate sites mean they provide a very good climate-monitoring platform for this significant proportion of the Southern Hemisphere. Taken with the extensive data homogeneity testing and the clean nature of the climate records, remote from highly urbanised or industrial areas, particularly in the South Pacific, these sites provide higher certainties in the quantification of observed climate trends.

No coherent picture emerges of climate change over the last 500 years. The sparse dendroclimatic records from widely disparate locations show no common trends. Certainly, many more records are needed from the Southern Hemisphere before more unified time series of trends of climate can be assembled over this period. There is a need to bring together other proxy indicators from Antarctica (ice cores) and corals to obtain a better understanding of climate over the last 500 years. Only when these are available can questions about the "Little Ice Age", a term which is often used to describe a global, 400–500 year long, synchronous cold interval (Bradley & Jones 1993), be answered. The 20th-century observational climate records demonstrate that the multidecadal trends throughout the Southern Hemisphere are coherent.

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