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Atmospheric Research 37 (1995) 87–99

ATMOSPHERIC
RESEARCH

Southwest Pacific temperatures: trends in maximum and minimum temperatures

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Accepted 17 November 1994

Abstract

Diurnal temperature trends are described for newly homogenised climate data sets for a large area of the South Pacific. The diurnal trends differ from those documented for Northern Hemisphere land areas, where decreases are observed in the diurnal temperature range as a result of increases principally in minimum temperature. The Southwest Pacific divides into four regions that share coherent diurnal temperature trends over the past five decades. Two regions southwest of the South Pacific Convergence Zone (SPCZ) display steady warming in mean temperature. The other two regions, located northeast of the SPCZ, cooled in the 1970's and warmed in the 1980's. The warming in three of the four regions can be attributed to increases in both mean daily maximum (mostly daytime) and mean daily minimum (mostly night time) temperature, with little change in the diurnal temperature range. In New Zealand, modification of the regional temperature trend occurs as atmospheric circulation interacts with the high orography, producing different local behaviour in trends of maximum and minimum temperature and diurnal temperature range. The present results come from sites where there can be no question of any urban influence. Most of the Southwest Pacific sites provide a very good climate monitoring platform for the surrounding oceans because of their island location.

1. Introduction

Global mean surface temperatures have increased by 0.3–0.6°C over the last 100 years, with the five warmest years being in the 1980's (Houghton et al., 1992). The diurnal character of the warming has been the subject of considerable analysis and debate. It has been observed from northern hemisphere land datasets that observed warming over the past several decades is primarily due to an increase in the daily minimum (night-time) temperatures with little contribution from daily maximum (daytime) temperatures (Karl et al., 1991). Recently, Karl et al. (1993) analysed monthly mean maximum and minimum temperatures from countries comprising 37% of the global landmass. Over the period 1951–1990, minimum temperatures warmed by 0.84°C compared to only 0.28°C for maximum

0169-8095/95/$09.50
SSDI 0169-8095(94)00071-9

temperatures. Over the same period average temperatures, estimated for the global land area, warmed by 0.33°C, compared to 0.56°C from those analysed by Karl et al. (1993). However, in the New Zealand region of the Southern Hemisphere, Salinger et al. (1993) note that warming over the past five decades can be attributed to increases in both mean maximum and mean minimum temperature. These results suggest that whilst changes in cloud cover and the presence of sulphate aerosols may play a direct role in the Northern Hemisphere, sulphate aerosols may be less important in the Southern Hemisphere.

New data has become available for the Southwest Pacific. The new high quality data presents new opportunities to examine diurnal changes in temperature behaviour. This study deals with temperature trends over the last five decades from the Southwest Pacific, a vast area of mainly ocean between 165°E to 145°W and 5°N to 55°S (21×10^6 km^2).

2. Data and methods

A number of methods were used to prepare the new high quality dataset for the Southwest Pacific. Firstly, temperature records were selected from climate stations whose records were of high quality and complete, at sites which were permanent and representative of the main geographical and circulation features of the region or island group. From these criteria 37 stations were selected for analysis of diurnal temperature trends. Six New Zealand sites were selected with high quality records and no known anthropogenic influences. Many more could have been chosen, but the density was kept comparable to that elsewhere in the Southwest Pacific. For the more detailed New Zealand study, data from 20 New Zealand sites were used. Station histories were prepared (Collen, 1992; Fouhy et al., 1992) from which the homogeneity of the temperature records could be assessed.

The next procedure was to carefully homogenise the temperature series that were as complete as possible from each of the selected climate sites. The methodology of Rhoades and Salinger (1993) was used as this provides a procedure for adjustment of temperature series for sites where no neighbour stations exist for comparisons. Many of the island sites in the South Pacific have no neighbour stations, especially in their earlier years of record. In all cases where adjustments have been made, the data from any earlier site was adjusted to that of the current temperature recording location.

To summarise the temporal temperature trends over such a vast area of the Pacific, two approaches were used to define areas that share coherent temperature anomalies. The first, cluster analysis using hierarchical agglomerative techniques (Willmott, 1978) was used to group stations into clusters based on degree of association from annual values of temperature. Principal component analysis was the second methodological approach employed (Salinger, 1980a, b). As the purpose was to investigate the spatial distribution of interannual temperature anomalies, the principal components were rotated orthogonally by the varimax criterion so as to produce components that delineate separate groups of highly intercorrelated stations.

The "single-site" temperature series are displayed as differences from the means of the reference period 1951–1980. These data series are combined to form time series of annual anomalies for each of the emergent temperature regions. The regional anomalies in maximum, minimum and diurnal temperature range are smoothed using a selected gaussian filter

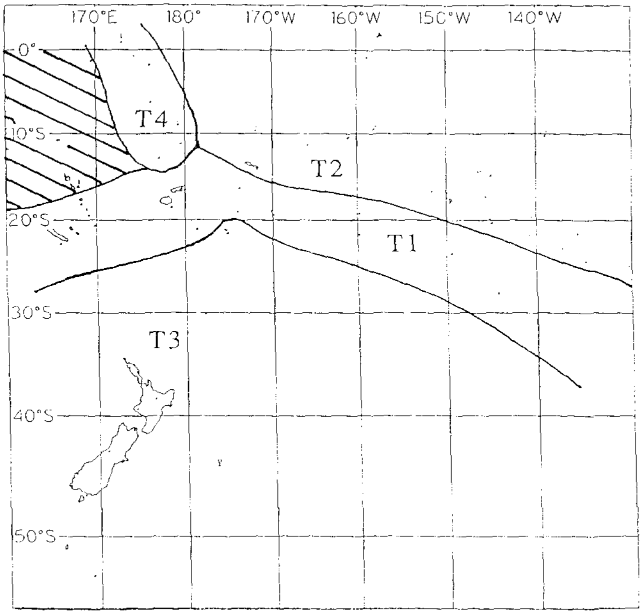


Fig. 1. The Southwest Pacific, showing regions of coherent temperature trends. Regions: *T1* – South east Trades, *T2* – Central Pacific, *T3* – New Zealand, *T4* – ITCZ and SPCZ.

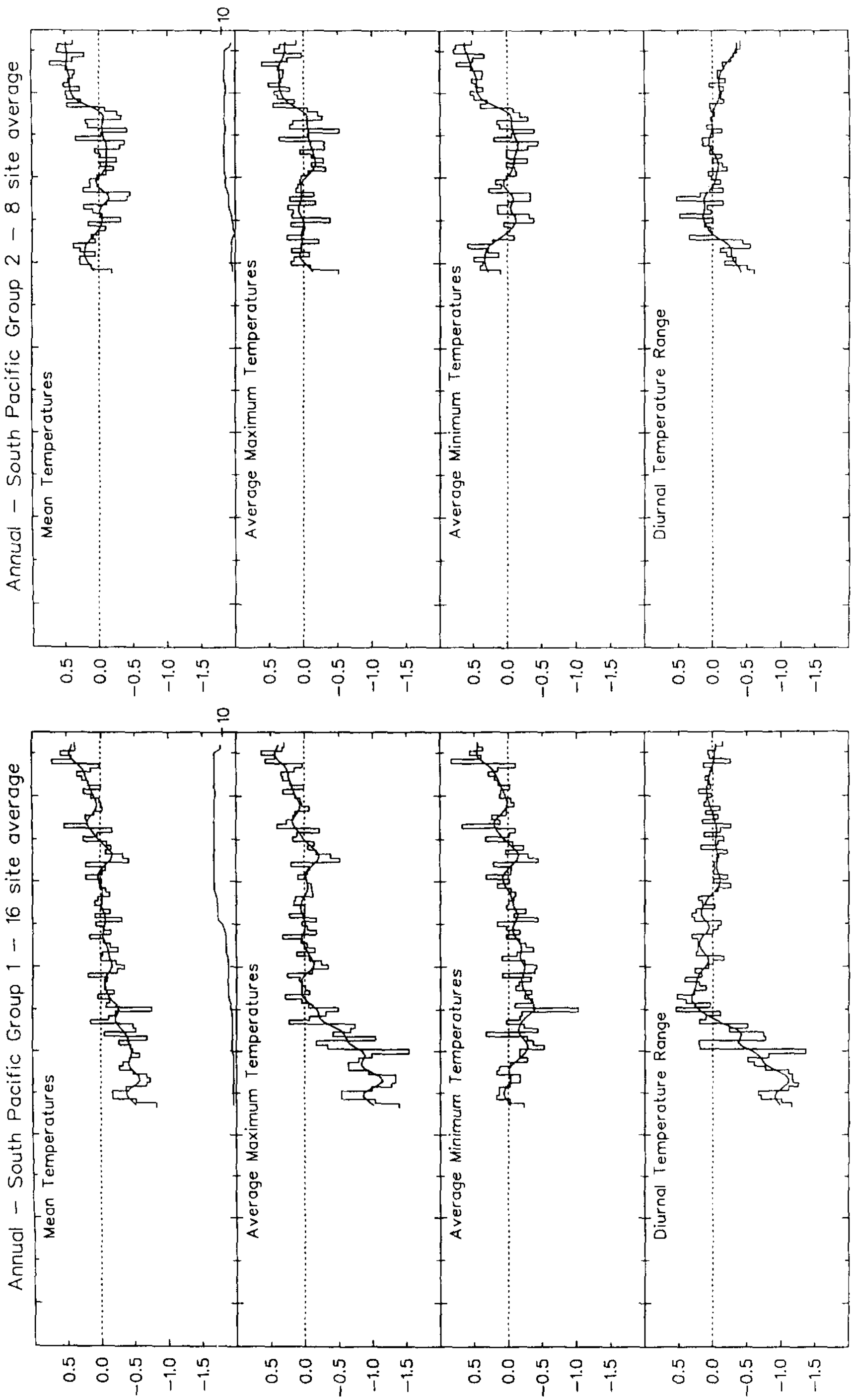
(Jones et al., 1986) which suppresses periods of less than 10 yr, in order to facilitate trend detection. As well, changes in temperature, using a linear trend, are calculated for each of the regions over the period 1941–1990.

3. South Pacific diurnal trends

Clustering and principal component analysis yield four regions which behave coherently for temperature trends (Fig. 1). These regions group according to the main climatological features of the South Pacific. Two regions lie northeast of the South Pacific Convergence Zone (SPCZ), one where the Intertropical Convergence Zone (ITCZ) and SPCZ merge and the other in the central Pacific region of divergent easterly winds. The two southwest of the SPCZ include the southeast trade wind region, and the New Zealand region.

3.1. Southeast trades (region T1)

This region comprises a large part of the South Pacific around 20°S. All stations are located in the sub tropics to the southwest of the SPCZ in the Southeast Trade Wind belt, and include the territories of New Caledonia, Vanuatu, Fiji, northern Tonga, Niue, the Southern Cook Islands and the southwestern islands of French Polynesia. Annual temperature series are shown in Fig. 2 and the temperature changes, estimated by fitting a linear trend over the 1941–1990 period, given in Table 1. These show a warming trend of 0.45°C,


Annual – South Pacific Group 2 – 8 site average
Mean Temperatures
Average Maximum Temperatures
Average Minimum Temperatures
Diurnal Temperature Range
Annual – South Pacific Group 1 – 16 site average
Mean Temperatures
Average Maximum Temperatures
Average Minimum Temperatures
Diurnal Temperature Range
0.5
0.0
–0.5
–1.0
–1.5
10
1860
1880
1900
1920
1940
1960
1980

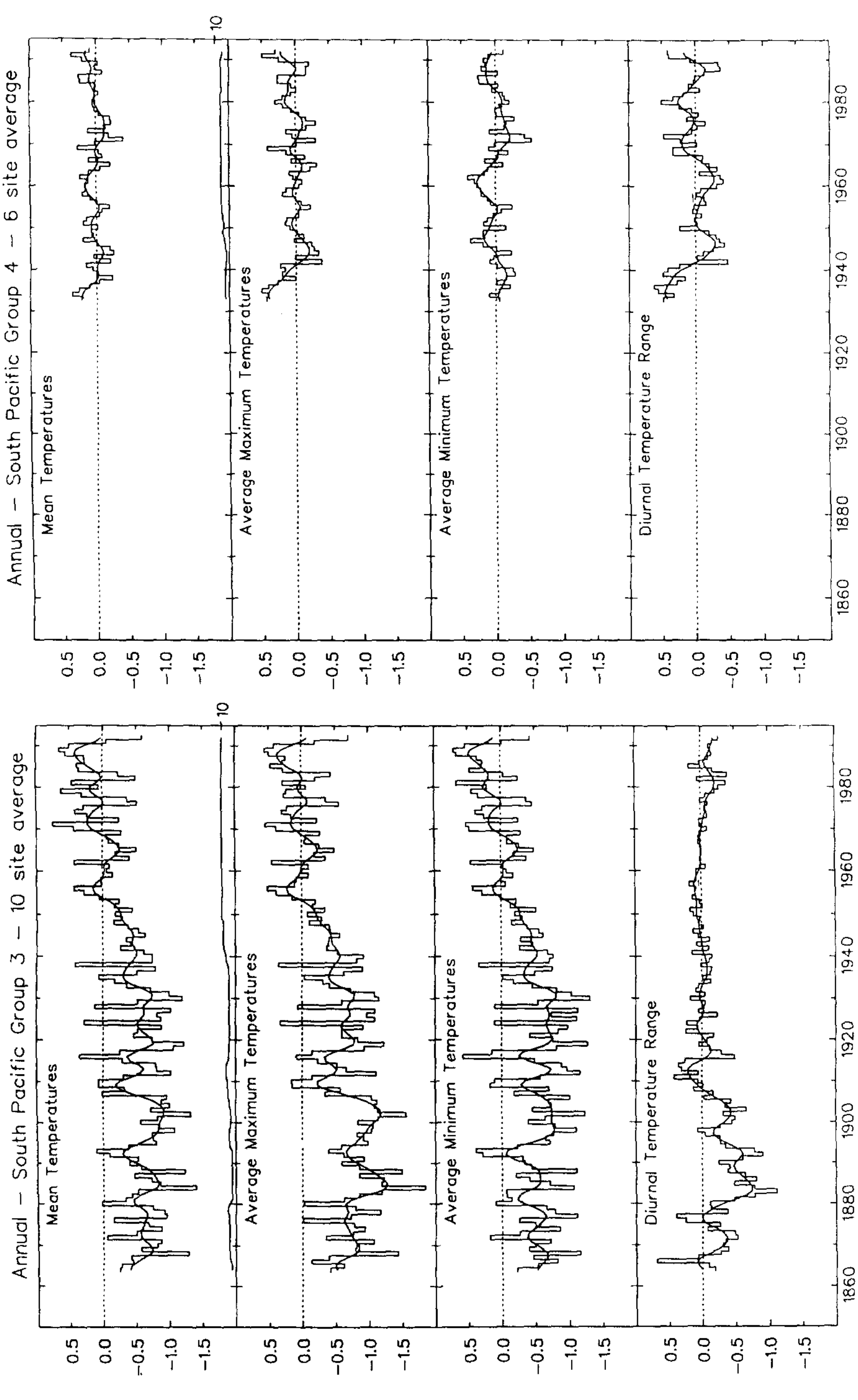


Fig. 2. Aggregated temperature trends and annual anomalies in the Southwest Pacific for regions T1 – T4, expressed as departures from the 1951–1980 period. Trends in mean, maximum and minimum temperature and the diurnal temperature range are shown.

Table 1
Seasonal and annual changes in temperature (°C), using a linear trend, for the four regions of the South Pacific for the five decades 1941–1990. Asterisks indicate significance at the 5% level. (ANN = annual, DJF = December, January, February; MAM = March, April, May; JJA = June, July, August; SON = September, October, November)

Southeast Trades (Region T1)	Mean	Max	Min	Range
DJF	0.46*	0.43	0.49*	−0.06
MAM	0.45*	0.36	0.52*	−0.16
JJA	0.36	0.33	0.35	0.02
SON	0.44	0.33	0.52	−0.19
ANN	0.45*	0.37	0.47*	−0.10
Central Pacific (Region T2)				
DJF	0.41	0.34	0.43	−0.09
MAM	0.43	0.26	0.52	−0.26
JJA	0.40	0.39	0.35	0.04
SON	0.49	0.37	0.53	−0.16
ANN	0.43	0.34	0.45	−0.11
New Zealand (Region T3)				
DJF	1.00	0.77	1.19*	−0.24*
MAM	0.64	0.61	0.56	0.05
JJA	0.70	0.66	0.71	−0.05
SON	0.67	0.35	0.90	−0.55*
ANN	0.77*	0.62*	0.86*	−0.24*
ITCZ and SPCZ (Region T4)				
DJF	0.01	0.21	−0.08	0.29
MAM	−0.02	0.11	−0.09	0.20
JJA	0.05	0.24	−0.14	0.38
SON	0.01	0.06	−0.05	0.11
ANN	0.02	0.16	−0.09	0.25

which includes a 0.37°C increase in mean daily maximum temperature and 0.47°C increase in mean daily minimum temperature, leading to a slight decrease in the diurnal temperature range, by 0.10°C. The increases in daily mean and minimum temperatures are significant. Seasonal temperature trends over the five decade period are similar to the annual trend. Apart from the austral winter period (JJA), minimum temperatures increase slightly more than maximum temperatures, with the diurnal temperature range decreasing slightly. Significant increases in mean and minimum temperatures occur for the austral summer and autumn seasons. A slight decrease in the diurnal temperature range is recorded in all seasons apart from winter.

3.2. The central Pacific (region T2)

This extensive area in the central South Pacific includes all stations located between the ITCZ and SPCZ in an area of divergent easterly winds, and includes Samoa, Tokelau, eastern Kiribati, northern Cook Islands and the northeastern part of French Polynesia. This region shows a temperature warming trend of 0.43°C over the five decade period (Fig. 2), comprising of an increase of 0.34°C in mean daily maximum temperature and 0.45°C in mean daily minimum temperature, with a slight decrease in the diurnal temperature range of 0.11°C. These same trends in the fitted linear regressions (Table 1) are apparent in all

Table 2
Seasonal and annual changes in temperature (°C), using a linear trend, for the six response regions of New Zealand the five decades 1941–1990. Asterisks indicate significance at the 5% level. (ANN = annual, DJF = December, January, February; MAM = March, April, May; JJA = June, July, August; SON = September, October, November)

Western North Island	Mean	Max	Min	Range
DJF	1.19	0.84	1.53	−0.69
MAM	0.73	0.64	0.73	−0.09
JJA	0.71	0.65	0.72	−0.07
SON	0.87	0.39	1.31*	−0.92
ANN	0.78*	0.64	1.11*	−0.47*
Eastern North Island				
DJF	1.15	0.60	1.66*	−1.06*
MAM	0.79	0.68	0.84	−0.16
JJA	0.76	0.53	0.97	−0.44
SON	0.87	0.34	1.38*	−1.04*
ANN	0.89*	0.59	1.23*	−0.64
West Coast				
DJF	1.15	1.45	0.81	0.64
MAM	0.95	1.00	0.83	0.17
JJA	0.78	0.63	0.88	−0.25
SON	0.84	1.05	0.60	0.45
ANN	0.92*	1.03*	0.80	0.23
Eastern South Island				
DJF	0.93	0.72	1.06	−0.34
MAM	0.69	0.79	0.47	0.32
JJA	0.75	0.82	0.57	0.25
SON	0.47	0.19	0.71	−0.52
ANN	0.74*	0.67	0.70	−0.03
Inland Central				
DJF	0.90	1.05	0.76	0.29
MAM	0.73	0.75	0.70	0.05
JJA	0.44	0.35	0.52	−0.17
SON	0.36	0.39	0.31	0.08
ANN	0.61	0.67	0.61	0.06
Southland				
DJF	0.93	0.18	1.58*	−1.40*
MAM	0.93	0.48	1.20*	−0.72
JJA	1.01*	0.81	1.13*	−0.32
SON	0.73	−0.01	1.29*	1.30*
ANN	0.91*	0.43	1.31*	−0.88*

the seasons apart from the austral winter. Similar increases occur in trends in both daily maximum and minimum temperature, and no change in the diurnal temperature range.

3.3. New Zealand (region T3)

This region comprises a large southern area including Campbell Island (53°S) in the south, New Zealand, Chatham Islands (44°S, 176°W) to the east, and as far north as Nuku'alofa (21°S) in southern Tonga. Most of the area is influenced by the southern latitude westerlies and subtropical anticyclonic belt. Mean temperatures increase sharply in this region, amounting to a significant warming of 0.77°C (Table 1 and Fig. 2) from 1941–1990. Significant increases in the fitted linear trend occur for both annual mean daily maximum and minimum temperatures of 0.62°C and 0.86°C respectively. At the same time there is a significant, but small decrease in the diurnal temperature range of −0.24°C. Similar trends are seen in the austral summer season, and the decrease in diurnal temperature range is more marked in spring (−0.55°C). Little trend in the diurnal temperature range occurs in autumn and winter, where the temperature increase in both daily maximum and minimum temperatures is comparable.

3.4. Meeting of ITCZ and SPCZ (region T4)

The fourth region comprises the area of western Kiribati and Tuvalu, close to where the SPCZ merges with the ITCZ. No trend is discernible in mean temperatures over the 1941–1990 period (Fig. 2). Fitted linear trends show a slight increase in daily maximum temperatures and decrease in daily minimum temperatures leading to a slight, but non-significant increase in diurnal temperature range of 0.25°C. The seasonal trends in daily maximum and minimum temperature and diurnal temperature range are similar to the annual trends.

4. New Zealand diurnal trends

For the two islands of New Zealand itself, the warming over the past five decades can be attributed to increases in both mean daily maximum and mean daily temperature. However, New Zealand is a long narrow country extending from 34 to 46°S, with axial ranges trending southwest/northeast. The interaction of the regional circulation and orography causes local differentiation of climatic anomalies. Salinger (1979) has identified six "response areas", areas that share coherent temperature anomalies (Fig. 3).

4.1. North Island

The North Island axial ranges are lower than in the South Island, giving less differentiation between the western and eastern response areas (Fig. 4). The warming trend over the period 1941–1990 (Table 2) is 0.78 and 0.89°C for the Western North Island and Eastern North Island areas respectively. In the western area the warming includes a 0.64°C increase in mean daily maximum temperature and 1.11°C increase in mean daily minimum temperature, leading to a decrease in the diurnal temperature range of 0.47°C. The increases of daily maximum and minimum temperature in the eastern area, by 0.59 and 1.23°C, gives a similar diurnal temperature range decrease of 0.64°C. The seasonal trends are most pronounced in the austral spring and summer seasons, when significant decreases occur in the diurnal temperature range.

4.2. South Island

The South Island, with more accentuated relief, shows a much more diverse response in changes to the diurnal temperature range (Fig. 4). A similar trend to the North Island

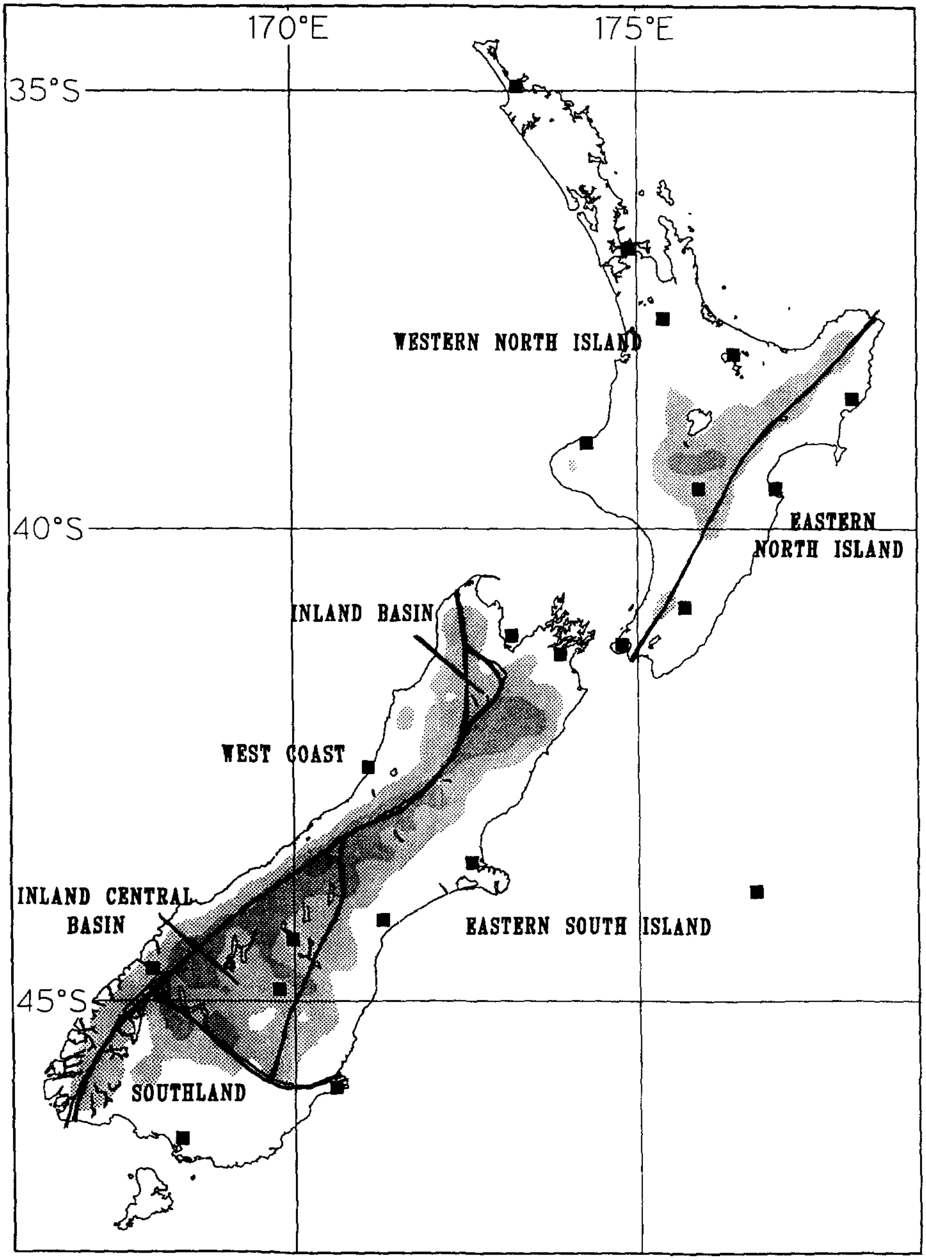


Fig. 3. New Zealand temperature response areas and stations used in this study (after Salinger, 1979).

response areas occurs in the South Island response area of Southland, where over the 1941–1990 period the mean temperature increases by 0.91°C, made up of an increase of 0.43°C in daily maximum, 1.31°C in daily minimum temperature, and a 0.88°C decrease in the diurnal temperature range. As in the North Island areas, the largest decrease in diurnal temperature range occurs in the austral spring and summer.

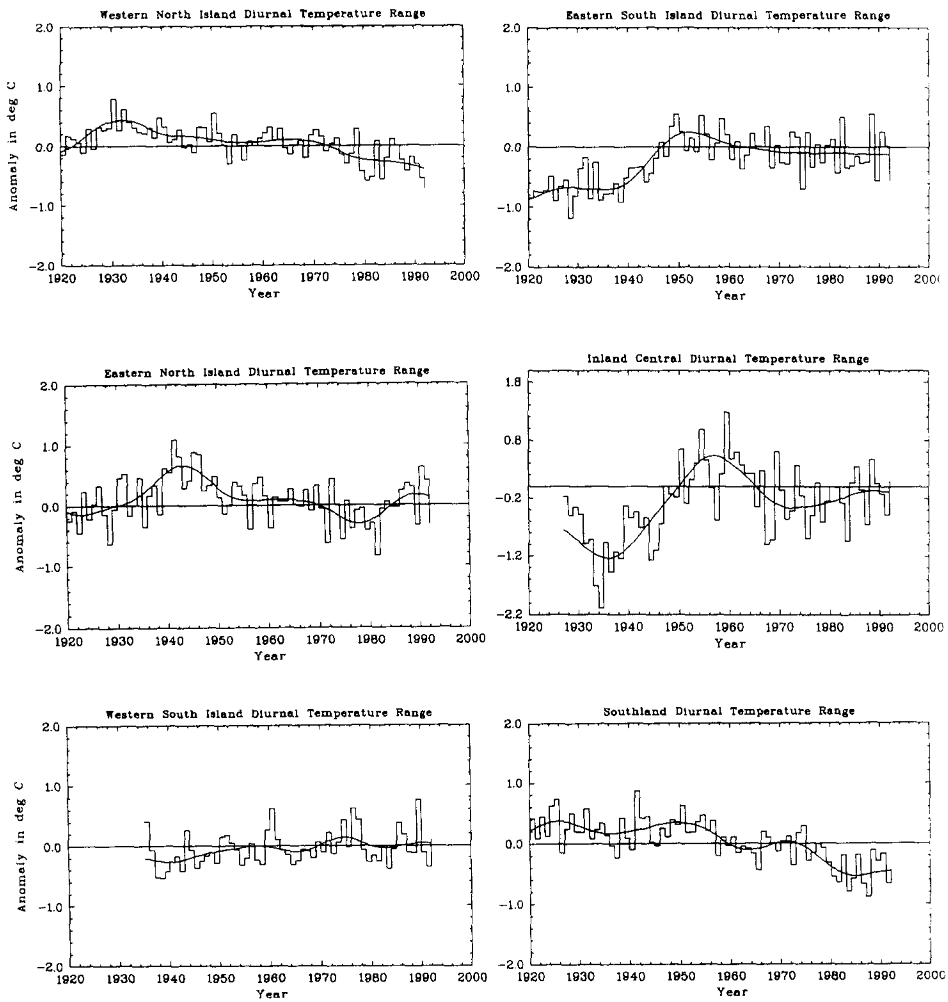


Fig. 4. Trends and annual anomalies in the diurnal temperature range for the six New Zealand response areas used in this study, expressed as departures from the 1951–1980 period.

In other South Island areas, the increase in mean temperature over the 1941–1990 period is similar (0.6–0.9°C), but trends in diurnal temperature behaviour differ (Fig. 4). In the West Coast area, the daily maximum temperature increase (1.06°C) is more than that for the daily minimum temperature (0.80°C) leading to a slight increase in the diurnal temperature range (0.23°C). All seasons, apart from winter, show similar trends to the annual in the diurnal temperature range and maximum and minimum temperatures. The two eastern South Island response areas (Eastern South Island and Inland Central) show no trend in the diurnal temperature range because both daily maximum and minimum temperatures increase by similar amounts (Table 2). These warm by about 0.7°C for Eastern South Island and 0.65°C in the Inland Central area. However, Eastern South Island displays the decrease in diurnal temperature range evident in other areas in spring and summer. In contrast, there is an increase in autumn and winter.

5. Discussion

The results show that temperature trends in the Southwest Pacific and their diurnal characteristics group into four relatively coherent zones. These are strongly related to the strength and position of the main climatological features affecting the region. Temperature region T1 lies just to the southwest of the SPCZ in the southeast trade wind belt on the northern side of the zone of migratory anticyclones of the Southwest Pacific. Region T2 lies between the ITCZ and SPCZ and is dominated by divergent easterly winds from the semi-permanent anticyclones of the southeast Pacific. Temperature region T3 includes the zone of migratory anticyclones of the Southwest Pacific and westerlies on their southern flanks. Region T4 occurs where the ITCZ and SPCZ merge.

The importance of orography in differentiating the regional trend into local diurnal temperature trends is clearly illustrated by the impact of New Zealand's orography on the warming signal over the period 1941–1990. New Zealand lies between the migratory anticyclones of the Southwest Pacific to the north and the southern westerly circulation to the south. The mean airflow which prevails is from the west southwest (Maunder, 1971). The axial ranges trend southwest/northeast which produce regions which are exposed and sheltered to the flow.

In the North Island the axial ranges are lower. As a result only two temperature response areas occur: Western North Island to the west of the axial ranges and Eastern North Island to the east. The lower relief gave smaller west/east differences in diurnal temperature behaviour. The results from the South Island show that the higher axial ranges, which are at least 1000 m over a distance of 700 km, produce more pronounced local temperature response areas. Four response areas occur. The two regions most exposed to the mean airflow, West Coast and Southland, demonstrated larger increases in mean temperature (about 0.9°C) from 1941–1990 than the other two. However, the largest increase was in daytime temperatures in the former and night time temperatures in the latter leading to a diurnal temperature range increase in West Coast and a decrease in Southland. The two more sheltered regions, Eastern South Island and Inland Central demonstrated similar increases in both day and night time temperatures, and no change in the diurnal temperature range.

It has been suggested that increases in temperature, especially mean daily minimum can be a result of the unremoved portions of the urban heat islands in temperature records. However, the data used in this study come mainly from island locations where there can be no suggestion of urban influences. The records have been rigorously screened, and the clean nature of the temperature records remote from highly urbanised or industrial areas mean that they depict real trends in surface diurnal temperature behaviour.

Mechanisms (Houghton et al., 1992) have been suggested for the decrease in diurnal temperature range observed in many northern hemisphere land records. These include an enhancement of night-time warming due to increases of greenhouse gases and clouds, and a counteraction of greenhouse-gas induced warming by day due to increases in clouds, cloud albedo and backscattering of solar radiation by sulphate aerosol. Some of these mechanisms will not apply in the South Pacific. Increases in concentrations of greenhouse gases and changes in cloudiness could be plausible mechanisms for the overall increase in both daily maximum and minimum temperatures. However, as the Southwest Pacific region is free of large sources of sulphate aerosols and production of other air pollutants which could increase the turbidity of the atmosphere; increased backscattering of solar radiation by sulphate aerosols and other air pollutants is unlikely to counteract any warming by day. The results are consistent in that there is little change in the diurnal temperature range over the 1941–1990 period.

6. Conclusions

In summary, this study shows that generally, both daily maximum and minimum air temperatures have increased throughout the South Pacific region in the last five decades. Of the four regions that share similar trends in diurnal temperature behaviour, mean daily maximum temperatures increase in all of them, whilst mean daily minimum air temperatures have increased in only three of the four regions. As a consequence changes in the diurnal temperature range are only small. For New Zealand, an increase in both daily maximum and minimum air temperatures is observed. However, modification of the overall regional temperature trends occurs in the diurnal temperature behaviour with the interaction between atmospheric circulation and New Zealand's orography. This interaction gives local response areas with different trends in maximum and minimum temperature. In one response area the diurnal temperature range increases, in three areas the range decreases and in two areas there is no trend in the diurnal temperature range.

The Southwest Pacific results suggest that increased concentrations of greenhouse gases and changes in cloudiness could be plausible mechanisms for the overall increase in night-time temperatures. The increase observed in day-time temperatures suggests that the mechanism of backscattering of solar radiation by sulphate aerosols and other air pollutants is unlikely. Finally, the oceanic nature of most of the sites mean that they provide a very good platform from which to monitor climate trends for the surrounding oceans.

Acknowledgements

This research was supported by the New Zealand Foundation for Research Science and Technology Contract CO1308.

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