CHANGES IN CLIMATE EXTREMES OVER THE AUSTRALIAN REGION AND NEW ZEALAND DURING THE TWENTIETH CENTURY

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Abstract. Analyses of high quality data show that there have been some interesting recent changes in the incidence of some climate extremes in the Australian region and New Zealand.

For the Australia region:

- the percentage area of Australia experiencing extreme wet conditions has increased slightly while the area of extreme dryness has reduced slightly since 1910
- heavy rainfall has also increased in some areas during the same period, although not significantly
- the frequency of extreme warm days and nights has increased while extreme cool days and nights has decreased since 1961
- a decrease in the total number of tropical cyclones since the late 1960s is largely explained by variations in the El Niño Southern Oscillation phenomenon while the number of stronger cyclones has increased slightly
- extratropical cyclonic activity has decreased over much of the mid-latitude waters south of Australia since the mid-1960s but increased at higher latitudes further southwest

For New Zealand:

- warming from 1941 to 1990 has resulted in about 10 fewer days per year with temperatures less than 0°C and around 2 more days per year greater than 30°C in warmer locations
- the occurrence of moderate and severe drought decreased during the period 1951 to 1980 compared to the previous 30 year period
- changes in temperature extremes and drought frequency have been in response to changes in atmospheric circulation in the region

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1. Introduction

There have been fewer studies of regional changes in climatic extremes compared to studies of changes in climatic means although some recent regional assessments have been made (e.g. Karl, 1996 and other papers in this volume). Reasons for this include a lack of adequate data, since non-climatic factors (e.g. changes in station location) often bias extremes more than climatic means, and problems related to choosing appropriate thresholds to define extremes (Nicholls, 1995). Also, analyses of extremes require data at daily or better resolution and these data have not routinely been assembled into climatological databases. Plummer et al. (1997) discuss some further issues, such as historical changes in instrumentation and observation practices, which have affected Australian data.

Salinger et al. (1996) provide a thorough investigation into observed changes in mean climate, including atmospheric circulation, over the Australian, New Zealand and South Pacific regions. Annually, surface air temperatures increased by 0.4 to 0.8°C throughout most of this region from 1951 to 1993 and this is consistent with post-1910 trends from observations of both surface ocean and air temperatures (Folland et al., 1997). Longer-term series suggested an increase of about 0.7°C since the start of the century, broadly consistent with that observed for the Southern Hemisphere (Salinger et al., 1996). Recent decades have seen a decrease in the diurnal temperature range (DTR), i.e. the difference between daytime maximum temperatures and overnight minimum temperatures, over much of Australia and the central southwest Pacific. Summer precipitation has increased over eastern Australia this century while decreases have been observed over parts of southwestern Australia in winter. Increases in precipitation have occurred to the northeast of the South Pacific Convergence Zone (SPCZ) while decreases have occurred to the southwest of the SPCZ. Salinger and Mullan (1996) describe changes in the atmospheric circulation regime of the New Zealand/South Pacific region, occurring around 1950 and 1976.

Many critical climate impacts are a consequence of rarer extreme events rather than a result of changes in mean values. The climatic indices investigated in this study are closely related to the incidence of floods, droughts, heat waves, frosts and strong winds and so their variations are of prime interest to the climate impacts community. High temperatures can exacerbate drought conditions and increase the likelihood of fires. Low temperatures are expressed through frosts and heavy snowfalls in some parts of the Australian and New Zealand region. This study is a collection of preliminary analyses to gain an insight into changes in a range of climatic extremes over the Australian and New Zealand region. Some of the indices suggested here may not be the most appropriate for impact studies and future work is expected to follow the recommendations made at (and since – refer other papers in this volume) the recent CLIVAR/GCOS/WMO Workshop on Indices and Indicators for climate extremes.

2. Data

While most Australian data used in this study have been extracted from the Australian Bureau of Meteorology's climate database, they have undergone further quality analysis as described in Plummer et al. (1997). Homogeneous daily rainfall data from 1910 to 1995 have been obtained for 379 stations (Lavery et al., 1997). Daily maximum and minimum temperatures for the period 1961 to 1995 were from a 48 station network where monthly mean data satisfied homogeneity checks (Plummer et al., 1995; Torok and Nicholls, 1996). Unfortunately, daily temperature data are not widely available in digital form prior to the late 1950s. Manually drawn analyses prepared by the Bureau's National Meteorological Centre for the Australian region have been examined for changes in tropical cyclone activity from 1969/70 to 1995/96 and for extratropical cyclonicity from 1965 to 1993. While there are concerns about using manual or numerical analyses for climate change studies (e.g. Nicholls, 1995; Karl et al., 1995), there are grounds to suggest that the changes found here are reasonable.

Forty-one New Zealand stations with homogeneous temperature records and at least 40 years of data were selected for analysis. These stations were carefully adjusted for site changes and other disturbances consistent with the techniques described in Rhoades and Salinger (1993). Drought frequency over New Zealand was assessed in terms of changes in soil moisture deficit from water balance modelling (Coulter, 1973).

Indices and periods of data used in this study are summarised in Table I.

Region	Climate Extreme Index	Period Examined
Australia	Percentage wet & dry	1910-95
Australia	Rainfall intensity	1910-95
Australia	Temperature extremes	1961-95
Australia (105-160°E)	Tropical Cyclones	1969/70-95/96
Australia (30-55°S, 80°E-180°)	Extratropical cyclonic activity	1965-93
New Zealand	Temperature extremes	1941-90 but some longer records
New Zealand	Drought frequency	1921-80 but 1901-80s for some

Table I. Summary of indices used in this study. Note that changes in the New Zealand temperature extremes index are inferred from changes in mean maximum and minimum temperatures over the period shown (refer 3.2.1). Changes in drought frequency over New Zealand are based on water balance modelling.

3. Observed Trends in Climate Extremes Indices

3.1. AUSTRALIAN REGION

Area-weighted averages for the indices based on rainfall and temperature data were derived for Australia and its four quadrants (separated by 26°S and 135°E) using a modification of the Thiessen Polygon method (Lavery et al., 1997). Trends were calculated from simple linear regression and, unless otherwise stated, their statistical significance was assessed using the Kendall-tau non-parametric test (Kendall and Gibbons, 1990). Changes in data coverage do not generally have a large influence on the continental scale trends presented here because one of the major criterion for station selection was homogeneous and continuous observations. However, changes in data coverage over the sparse Australian interior made it necessary for the removal of four of the 379 stations used in the analysis of rainfall intensity (refer 3.1.2).

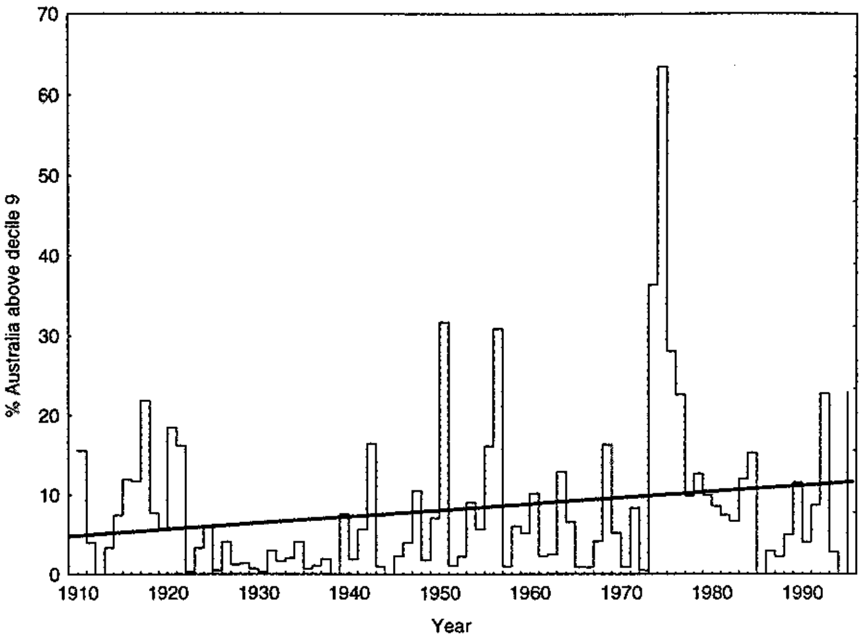
3.1.1. *Percentage of Australia extremely wet and dry*

Figure 1 shows that the percentage of Australia experiencing extreme dry conditions (below decile 1 or 10th percentile of annual total) has decreased slightly since 1910. Annual percentile values (Moore and McCabe, 1993) were computed from data over the period 1910 to 1995 for individual stations and area weightings were derived from the Thiessen Polygon method. Due to widespread high rainfall totals in the mid-1970s, a small increase in the area experiencing very wet conditions (above decile 9 or 90th percentile) was found. However, like the Australian average rainfall series (Nicholls and Lavery, 1992; Lavery et al., 1997), time series in Fig. 1 are dominated by high interannual and interdecadal variability so there is little to suggest that the extents of dry or wet conditions have been appreciably different during the past few decades compared to earlier this century. Neither of the trends are statistically significant at the 95% confidence level.

3.1.2. *Rainfall intensity*

Studies on trends in heavy rainfall intensity in Australia during the past century (Yu and Neil, 1993; Lough, 1993, 1997; Nicholls and Kariko, 1993; Suppiah and Hennessy, 1996) reveal results which are affected by the use of different definitions for heavy rain events and different statistical methods (Nicholls, 1995). In this paper, heavy rainfall was defined as the 99th percentile of daily data as calculated from the 1910 to 1995 period. This is the 4th highest value per year and the highest value per season. To supplement the analysis of changes in the intensity of heavy rainfall, changes in the frequency of heavy rainfall are presented for a threshold of 25.4 mm/day (1 inch). Heavy rainfall indices were computed at individual stations. Since stations are irregularly spaced, each station was weighted according to the area it represents. Stations with more-distant

(a)



(b)

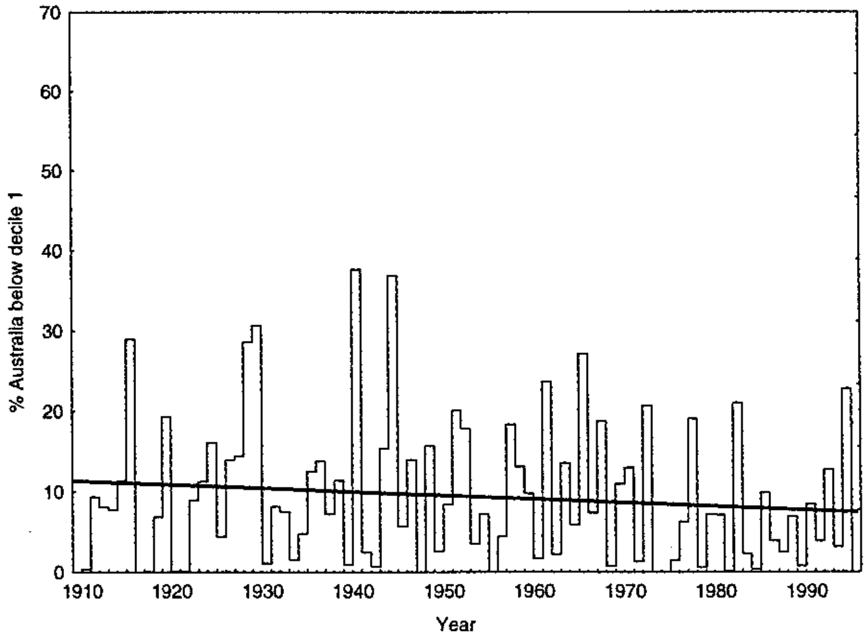


Figure 1. (a) Percentage of Australia experiencing extreme wet conditions (above decile 9, or 90th percentile, of annual total) and (b) extreme dry conditions (below decile 1, or 10th percentile) in each year from 1910 to 1995. Linear trend lines shown in bold.

neighbours represent larger areas and were given higher weight using a modification of the Thiessen Polygon method (Hennessy et al. 1998). Quadrant area-averages were then computed by summing weighted indices from each station. The significance of trends is determined from the non-parametric Kendall-tau test and the magnitude of trends is computed from linear regression analysis.

The number of stations passing the quality control processes (Hennessy et al. 1998) increased from 266 in 1910 to 370 in 1988, then declined to 236 in 1995. Most changes to the data network occur within areas already having good coverage, and so network variations have little effect on regional trends. Four stations (Giles, Forrest, Rabbit Flat and Rawtinna) in data-sparse parts of central and western Australia were introduced between 1931 and 1970, each having a noticeable effect on continental and regional trends. To eliminate such effects, these four stations were removed from the analysis.

The heaviest rainfall occurs in summer and autumn in northern Australia (Fig. 2a). Southern Australia generally has a uniform seasonal distribution of heavy rainfall but the southwest has a winter peak in less-intense rainfall. It is important to interpret seasonal and regional changes relative to this climatology.

The 99th percentile intensity has experienced negligible change over the period 1910-1995 for the continent overall. While increases in the 99th percentile occur in more quadrants and seasons than decreases (Fig. 2b), none of the changes are significant at the 5% level (although the 24% increase in the southeast in autumn is significant at the 6% level). Non-significant changes judged to be of hydrological importance include increases of about 20% in the northwest in winter and southwest in summer, and decreases of about 20% in the northeast in winter and in the southwest in autumn. In a related study looking at smaller spatial scales, Hennessy et al. (1998) found a significant 31% increase in the 99th percentile from 1910-1995 in New South Wales (in southeastern Australia) in autumn and a significant 13% decrease in southwest Western Australia in winter.

For Australia overall, there has been a non-significant 5% increase in the annual number of days with a rainfall total over 25.4 mm (Fig. 2d). Small increases have occurred in summer and autumn with decreases in winter and spring. Regionally and seasonally, increases in frequency are more prominent than decreases. None of these changes are significant, but the increases in the southeast in summer and autumn may be hydrologically important. For Australia, Groisman et al. (1998, this volume) found a non-significant increase in the number of summer days with totals over 50.8 mm (2 inches) of 1.1% per decade relative to the 1910-1996 mean, and a significant increase of 4.6% per decade was found for coastal regions of New South Wales and Victoria in southeastern Australia.

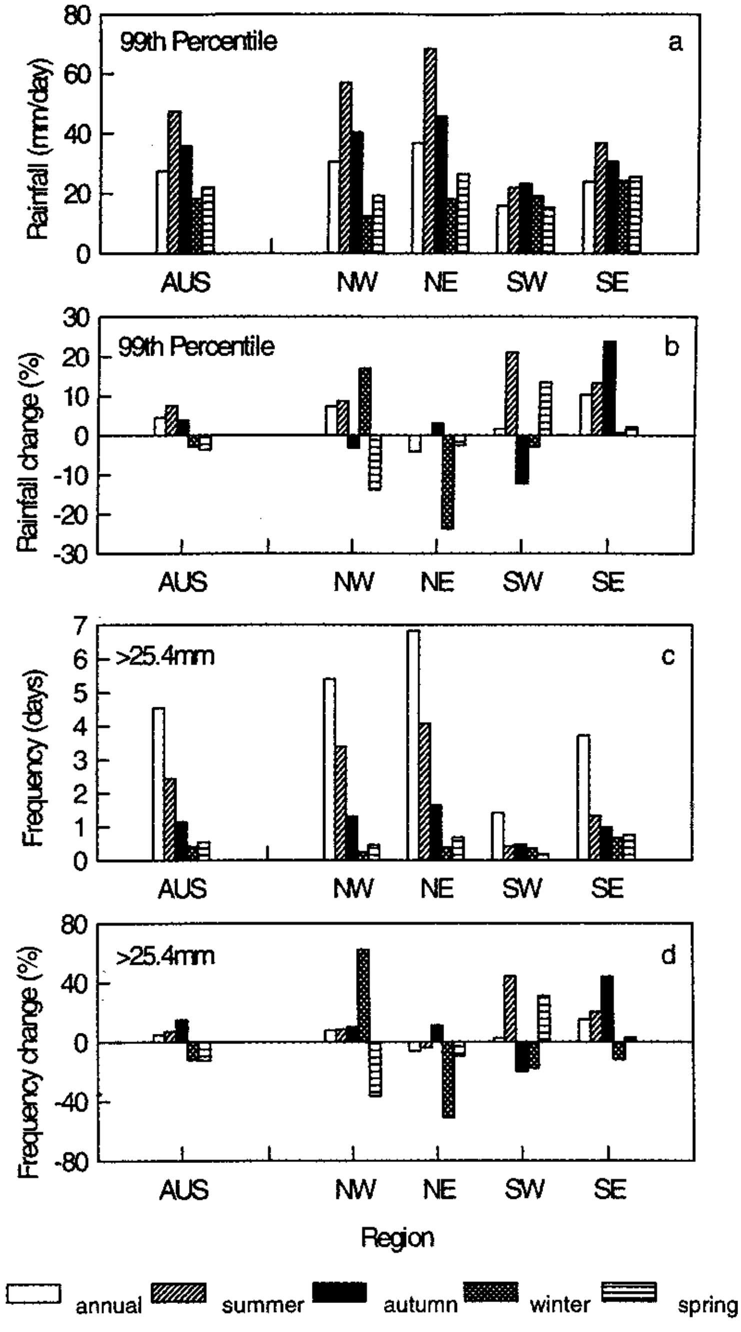


Figure 2. Australian (AUS) heavy rainfall indices. (a) 1910-1995 average 99th percentile intensity, (b) percentage changes in the 99th percentile, (c) 1910-1995 average frequency of days of at least 25.4 mm, and (d) percentage changes in days of at least 25.4 mm. Changes are expressed as a percentage of the 1910 regression value. The quadrants northwest (NW), northeast (NE), southwest (SW) and southeast (SE) are of similar size and are separated by latitude 26°S and longitude 135°E.

3.1.3. *Temperature extremes*

Warming has occurred over Australia during the second half of this century, particularly at night (Torok and Nicholls, 1996). Changes in the frequency of days and nights exceeding extreme warm threshold values and falling below extreme cool thresholds were analysed from 1961 to 1995. For each station, seasonal and annual time series of the percentage frequency of periods for which temperatures exceeded their (warm) 90th percentile threshold and fell below their (cool) 10th percentile were derived. Percentiles for individual stations were calculated from data over 1961 to 1990. Periods examined were single days/nights and three consecutive days/nights (i.e. occurrences of three consecutive days/nights where an extreme threshold was reached on every day/night). Percentages of periods were calculated, instead of counts of the period, to provide reasonable seasonal and annual values of the index when a (pre-defined) small number of missing observations were encountered. Similar to the rainfall analyses, these individual station time series were spatially averaged for Australia and each of its quadrants using the Thiessen Polygon approach.

There has been an increase in the frequency of warm days and nights (Fig. 3(a)) and a decrease in cool days and nights (Fig. 3(b)). The strongest trends were found for decreases in the frequency of cool nights (3% decrease over Australia annually and 5% in winter) while reductions in the number of cool days were relatively small. Since the stations used in this analysis were from small towns or remote locations, it is unlikely that trends are greatly affected by urbanisation. The most marked changes occurred over the northern quadrants, and daytime extremes have shown the greatest change in autumn. However, changes were weaker than trends in the number of days with temperatures exceeding the median. Trends in the frequencies of consecutive extremes (shown as the lower two series in both Fig. 3(a) and Fig. 3(b)) and more-extreme events (defined by the 95th and 5th percentile thresholds, not shown), although of similar sign, were also weaker than trends in the single and less-extreme (90th, 10th percentile) events, respectively. Of the eight annual time series in Fig. 3, the only changes not statistically significant at the 95% confidence level (at least) were the decreases in periods (both 1 and 3 days) with maximum temperature below the 10th percentile. Consistent with trends in the cooler extremes, there has been a significant decrease in the occurrences of minimum temperatures below 0°C and a trend towards an earlier date of last frost, over inland eastern Australia during this century (Stone et al., 1996).

3.1.4. *Tropical cyclones*

Trends in tropical cyclone activity in the Australian region (105-160°E) were examined from the 1969/70 season - considered to be the first reliable season due to the availability of satellite pictures - to 1995/96. Tropical cyclone numbers in the region are influenced by the El Niño Southern Oscillation (ENSO) phenomenon (Nicholls, 1992).

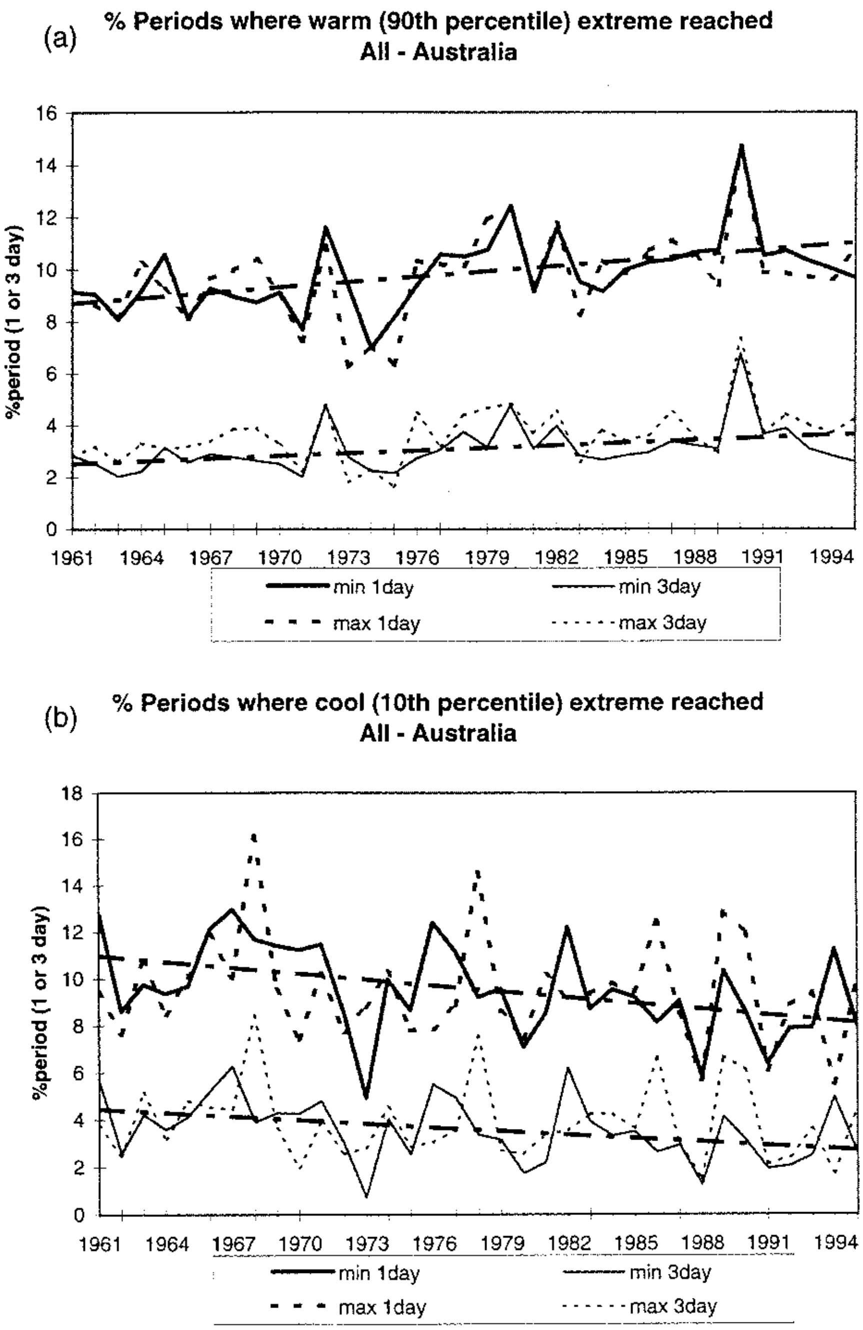


Figure 3. Percentage of periods where (a) warm - 90th percentile, and (b) cool - 10th percentile extreme temperatures reached over Australia. Periods are for both 1 day (bold lines - top two in each graph) and 3 days (lower two). Variations in periods of extreme maximum (broken lines) and minimum temperatures (solid) are shown. Linear trends (bold dashed-dot lines) are only shown for the minimum temperatures to give a comparison between 1 day and 3 day events.

Figure 4 shows that while the total number of cyclones has decreased, the number of stronger cyclones (minimum central pressure, MCP, ≤ 970hPa) has increased (Nicholls et al., 1998) although neither trend is statistically significant at the 95% confidence level. The total number of cyclone days has also increased slightly. Much of the decline in the weaker cyclones (MCP > 990hPa) occurred suddenly in the mid-1980s and this, with a concomitant change in relationship between cyclone numbers and the Southern Oscillation Index (SOI - a measure of the state of ENSO) around this time, suggest this decrease may be artificial. Improved understanding of weaker systems has resulted in them being less likely to be analysed as tropical cyclones (Nicholls et al., 1998). From regression analysis, the decrease in cyclones with MCP between 970hPa and 990hPa is largely due to a negative trend in the SOI over the past few decades.

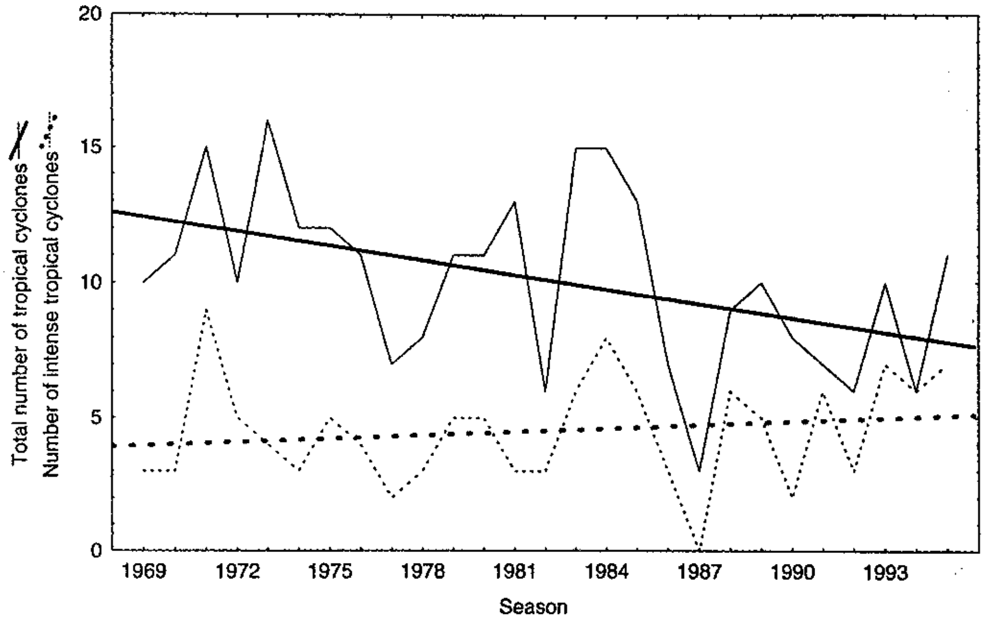


Figure 4. Total number of tropical cyclones (solid lines) and the number of intense systems (MCP ≤ 970hPa, dotted lines) in the Australian region (105-160°E). Linear trends are shown in bold. The abscissa gives the year in which the cyclone season starts (e.g. the 1969/70 season is plotted against "1969").

3.1.5. *Extratropical cyclonic activity*

Recent work found an increase in east-coast cyclones since the late 1950s (Hopkins and Holland, 1997). These systems are intense cyclonic systems that develop occasionally on the middle and southern parts of Australia's east coast. From updated analyses of mean sea level pressure (MSLP) charts (Leighton and Deslandes, 1991), changes in extratropical cyclonicity were examined over the Australian region (30-55°S, 80°E-180°) from 1965 to 1993. Cyclonicity is defined as the time (in hours) during which cyclone centres occupy a 5° lat/lon grid-box during a given period. An extratropical cyclone centre could be an identifiable closed circulation with or without an associated front or a wave low which developed into a closed circulation. Note that variations in this index do not necessarily suggest changes in the intensity of extratropical cyclones and a decrease may be associated with either fewer or faster moving systems. However, good correlations with other climatic variables over parts of southern Australia in recent decades (e.g. rainfall) suggest that this index may provide a useful indicator of changes in baroclinic activity in the extratropics. Some of the earlier years analysed may be suspect due to satellite pictures not being available.

A substantial area of decreasing cyclonicity extends northwest-southeast over waters south of Australia but increases have occurred further southwest (Fig. 5). Although the overall field significance of these changes have not been assessed (as, for example, in Wigley and Santer (1990)), locally statistically significant changes at the 95% confidence level (from a Students t-test) are shown shaded in Fig.5. This pattern of change is consistent with increases in winter MSLP (Allan and Haylock, 1993) which are linked to decreases in rainfall over southwestern Australia during the past three decades or so (Wright, 1974a, 1974b; Pittock, 1983; Nicholls and Lavery, 1992; Suppiah and Hennessy, 1998).

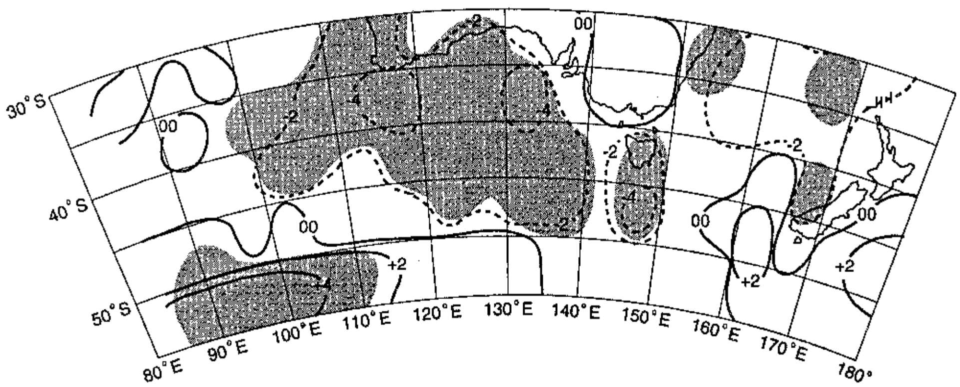


Figure 5. Annual variations in extratropical cyclonicity over the Australian region. Linear trends are in hours per year and shaded areas denote trends statistically significant at the 95% confidence level.

3.2. NEW ZEALAND

3.2.1. *Temperature extremes*

To examine the sensitivity of temperature extremes over New Zealand to changes in monthly and annual mean temperatures, temperature extremes were regressed against mean temperature data (Salinger, 1997). The New Zealand analysis was based on changes in specific temperature thresholds rather than changes in percentiles (as in 3.1.3). Temperate and sub-tropical grasses and crops are grown in New Zealand and the juxtaposition of the subtropical/temperate division is strongly determined by temperatures above and below certain thresholds. Additionally, the thermal regime in New Zealand is more moderate to that of Australia, with a relatively small difference in mean temperature between the warmest and coolest months. Therefore the sensitivity of temperature extremes to mean temperature changes is higher than for extremes in continental climates (Salinger, 1988). Regressions were performed for average maximum temperature compared with the number of days reaching 30°C or more and for average minimum temperature compared with the number of days of 0°C or below. In both cases, separate regression equations were calculated for monthly (combining all 12 months) and annual data although similar results were found for both. The regressions of monthly and annual numbers of days with average maximum and average minimum temperatures were then verified against the actual number of days. For days of 0°C or below, regressions were calculated for all 41 stations. For days of 30°C or above, only 18 stations were used since many had no (or very few) days above 30°C.

The relationship between changes in the number of cold days and changes in the average annual minimum temperature showed a robust response as shown by the large values for the percentage of variance explained (Table II). For much of the North Island a 1°C warming decreased the number of air frost days (i.e. temperatures below 0°C - ground frosts can occur when the air temperature is slightly above 0°C) by between 8 and 12 per year, and for inland areas by 20 days per year. In the South Island, the response was between 7 and 11 days in the north and west, 11 to 18 days in the east and south, and from 15 to 27 days per year for inland areas. The largest sensitivity of the number of air frost days to annual minimum temperature change was in the inland areas - where the highest incidence occurs. In most cases regression relationships were strong, explaining between 45 and 70 percent of the variance. The New Zealand average for all sites analysed was 14 fewer air frost days per year for a 1°C increase in average annual minimum temperature.

The change in the length of the frost free period (i.e. the number of days between the last spring frost, and first autumn frost) was investigated at 24 locations. Cold sites with a large range in minimum temperature, such as inland South Island areas, showed a change in frost-free period of about 15-25 days per °C change in average annual minimum temperature. Warmer sites with a small annual temperature range exhibited a larger sensitivity. Throughout the North Island the length of the frost-free period increased by at least 30 days for every 1°C increase in average minimum temperature. Time series of trends at two sites, Ruakura and Rotorua, which have not had site changes are shown in Fig. 6. These show a clear reduction (statistically significant above the 99% confidence level) in annual frequency of air frosts, particularly during the 1950s.

Presently, warmer locations only average between 1 and 9 days with

(a) Specific sites

	< 0°C		> 30°C	
	No. Days	Variance explained	No. Days	Variance explained
North Island				
Ruakura	-8	49	1	47
Gisborne	-5	34	3	17
Hastings	-11	62	2	11
Palmerston North	-8	48	-	-
South Island				
Nelson	-7	20	-	-
Winchmore	-18	71	2	12
Ophir	-22	74	2	8
Invercargill	-18	53	-	-

(b) Districts

	< 0°C	
	No. Days	Variance explained
Inland North Island	-20	67
Rest of North Island	-8 to -12	33 to 63
North and west of South Island	-7 to -11	20 to 44
Inland South Island	-15 to -27	46 to 74
Eastern South Island	-11 to -18	46 to 71
New Zealand	-14	

Table II. Changes in the annual number of days below 0°C per °C change in average annual minimum temperature, and above 30°C per °C change in average annual maximum temperature for (a) specific sites and (b) districts in New Zealand.

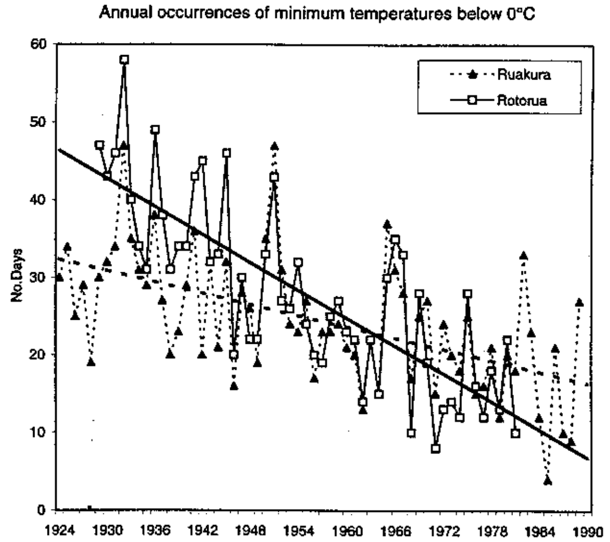


Figure 6. Annual frequency of days below 0°C (air frosts) at two New Zealand sites (Ruakura and Rotorua). Linear trends are shown in bold.

temperatures above 30°C. Therefore, the results of similar analyses were much weaker than those for temperatures below 0°C (the regression variance explained ranged from 8 to 47 percent; Table II). Typically the response was for an increase in the number of days above 30°C by between 1 and 4 days for every 1°C increase in average maximum temperature. The average for those sites that showed a response was 2.4 days/°C. Time series for two sites, Hastings and Ashburton, are shown in Fig. 7. These sites have experienced a non-statistically significant increase in the frequency of days above 30°C since 1950.

New Zealand average mean air temperatures have increased by 0.7°C over the period 1941 to 1990 (Salinger, 1997). On this basis, there would be a trend, on average, to 10 fewer days (ranging from 4 to 19 depending on the site) with temperatures less than 0°C. In the east of the North Island, and inland and eastern areas of the South Island, this temperature trend equates to an increase in incidence of days above 30°C of around 2 days from 1941 to 1990.

3.2.2. *Drought frequency*

Using water balance modelling, an index of drought or dry periods is provided by summations of the number of days within a year at wilting point (ND). This assumes that water is lost from the soil at the potential evapotranspiration rate, until all the readily available water capacity is exhausted. At this point the model assumes that evapotranspiration ceases until rainfall on any one day exceeds the mean daily evapotranspiration for the calendar month in which the day falls. When the readily available water capacity is exhausted, the soil is assumed to be at wilting point, and plant growth is assumed to stop. The number of days at wilting point is thus an index of agricultural drought.

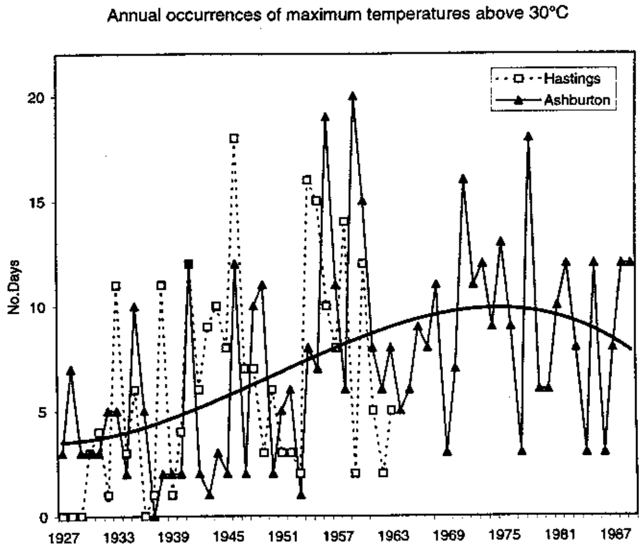


Figure 7. Annual frequency of days above 30°C at two New Zealand sites (Hastings and Ashburton). Linear trend, for Ashburton only, is shown in bold.

This model, developed by Coulter (1973), has been successfully applied and tested in the New Zealand situation for many years. Porteous et al. (1994) calibrated the performance of this model for pasture sites with two weekly measurements of soil moisture from neutron probe measurements over a two year period at four sites. This study found that predicted deficit regressions against measured deficit explained between 88 and 97% of the variance in model runs. They concluded that this model can be applied with confidence to many pastoral agricultural applications such as drought assessments. Barringer et al. (1995) also validated this model in predicting wilting point deficits with four years of neutron probe data and concluded that this model accurately predicted the gross trends in soil moisture deficit, giving reasonable estimates of the timing and magnitude of deficits. New Zealand has mountainous orography, giving strong precipitation gradients, and young soils of varying depths. This gives a rather complex mixture of soils with different field capacities. Evapotranspiration shows small variability compared with rainfall, and the rainfall gradients. Because of these factors, the water balance model has been successfully applied in New Zealand. For this study, the readily available water capacity was set at 75 mm as this is representative of many New Zealand soils.

Wilting point (ND) summations were performed for the period 1921 to 1980 for stations from representative climate regions (Salinger, 1997). ND summations with return periods of 1 in 20 years and 1 in 10 years were classified as 'severe' and 'moderate' droughts, respectively. These return periods are useful in identifying the inconstancy in the frequency of extreme events. The summations were compared between periods 1921-1950 and 1951-1980, because the westerly circulation over New Zealand had weakened in the latter period.

'Moderate' and 'severe' droughts from water balance return period analysis are listed in Table III. The results suggest a trend to fewer serious droughts in many New Zealand districts for the 1951-80 period compared with the previous 30 years. From matched pairs Students t-tests, this decrease was found to be statistically significant above the 99% confidence level. Reductions were particularly apparent in the north and east of the North Island and in the south of the South Island. These changes were associated with a change in atmospheric circulation with more east to northeast airflow in the latter period compared to south to southwest airflow from 1921 to 1950 (Salinger and Mullan, 1996). More frequent airflow from the east and northeast gives higher rainfall in the drier, more drought prone lower rainfall areas of New Zealand. Examples of time series used to derive drought frequency are shown in Fig. 8.

	MODERATE		SEVERE	
	1921 - 50	1951 - 80	1921 - 50	1951 - 80
Northern North Island	3.4	1.2	0.8	0.6
Western North Island	2.5	2.3	1.0	1.0
Eastern North Island	3.2	1.8	1.7	0.8
Western South Island	2.3	3.0	1.0	0.8
Northern South Island	3.5	1.5	1.5	1.0
Eastern South Island	2.0	1.5	1.5	0.5
Southern South Island	4.7	2.0	2.3	0.2

Table III. Moderate and severe drought frequency for districts of New Zealand. Values are frequencies as defined by the 1 in 10 (moderate) and 1 in 20 (severe) year return period for moderate (severe) events.

4. Discussion and Conclusions

This study provides evidence that there have been some interesting changes in climate extremes over the Australian and New Zealand region during the twentieth century. However, several data series span only a few decades and, for some indices, the El Niño Southern Oscillation phenomenon contributes much of the observed variability. Further work is required to investigate the influence of this phenomenon on these observed changes. Perhaps the most apparent and consistent change in the region has been a decrease in the number of cold nights in recent decades. Although regionally there have been some exceptions, there is little evidence to suggest a trend towards drier conditions over Australia or New Zealand. Nevertheless, further work is necessary to provide optimum information on variations in climatic extremes. In the future, indices of direct relevance to climate sensitive sectors need to be developed, as do indices for more problematic data types such as occurrences of strong winds and thunderstorms. Further, a large

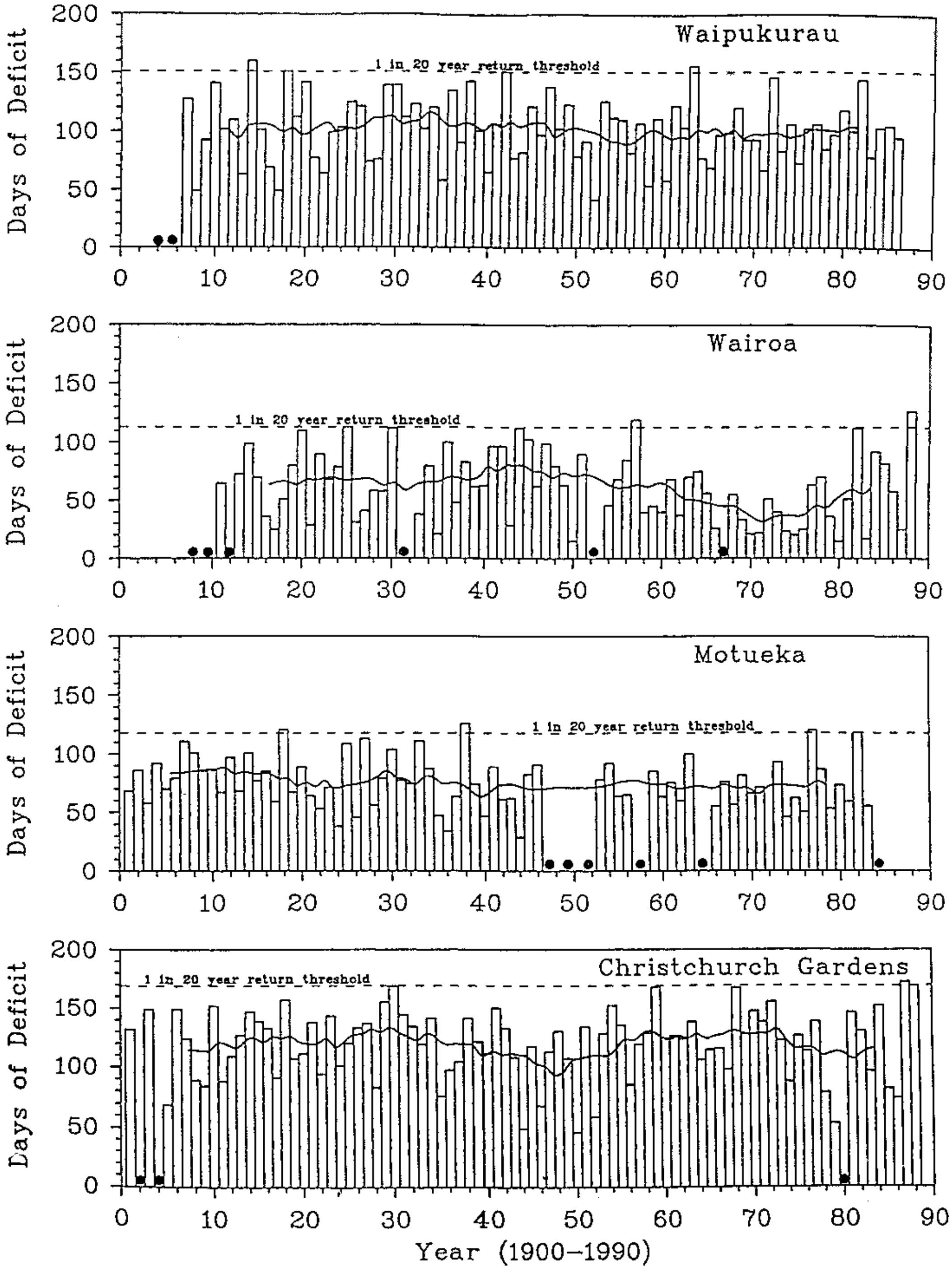


Figure 8. Annual number of days of deficit (ND, explained in text), for soils with an available water capacity of 75 mm, for locations in eastern areas of New Zealand. A dot represents missing data.

volume of daily and hourly historical data are still to be digitised and archived.

Clearly, future long-term climate monitoring will require adherence to a number of guiding principles so that data homogeneity and continuity are maintained (Karl et al., 1995). These should ensure that influences on the climate record caused by changes in instruments, observing practices, observation locations, sampling rates, etc. are known prior to implementing such changes.

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