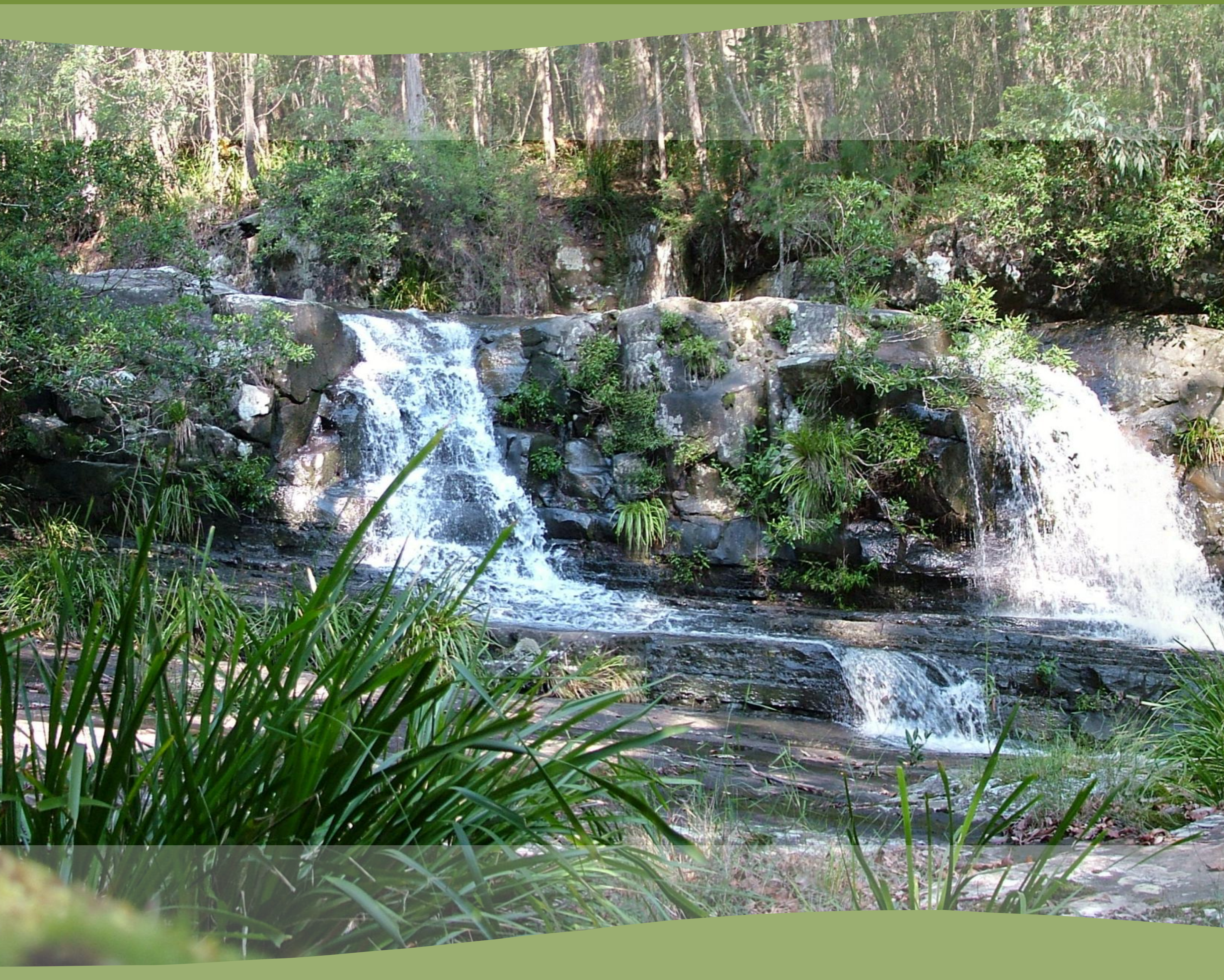
Hunter, Central and Lower North Coast

Regional Climate Change Project

2010

Historic and Projected Impacts of Climate Change on the CENTRAL Climatic Zone of the Hunter, Central and Lower North Coast



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Glossary

BOM	*BUREAU OF METEOROLOGY*
CSIRO	*COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANISATION*
GCM	*GLOBAL CLIMATE MODEL*
LGA	*LOCAL GOVERNMENT AREA*
HCCREMS	*HUNTER AND CENTRAL COAST REGIONAL ENVIRONMENTAL MANAGEMENT STRATEGY*
SLP	*SEA LEVEL PRESSURE*
ST	*SYNOPTIC TYPE*

INTRODUCTION

This report has been developed for the Hunter and Central Coast Regional Environmental Management Strategy (HCCREMS) to highlight the historic and projected climate changes in the *central climatic zone* of the Lower North Coast, Central Coast and Hunter Region (see Figure 3 on page 6). The results and analysis presented in this report are part of a regional climate change research and adaptation project implemented by HCCREMS and its 14 member councils (Figure 1). The key objectives of this project include:

- To identify the potential regional and sub regional impacts of climate change in the Hunter, Central and Lower North Coast region of New South Wales
- To use this information to raise awareness and understanding by local governments, industry and community in the region of the potential impacts of climate change on their activities
- To improve the awareness and capacity of these groups to accurately assess climate risk and to develop and implement appropriate adaptation strategies in response

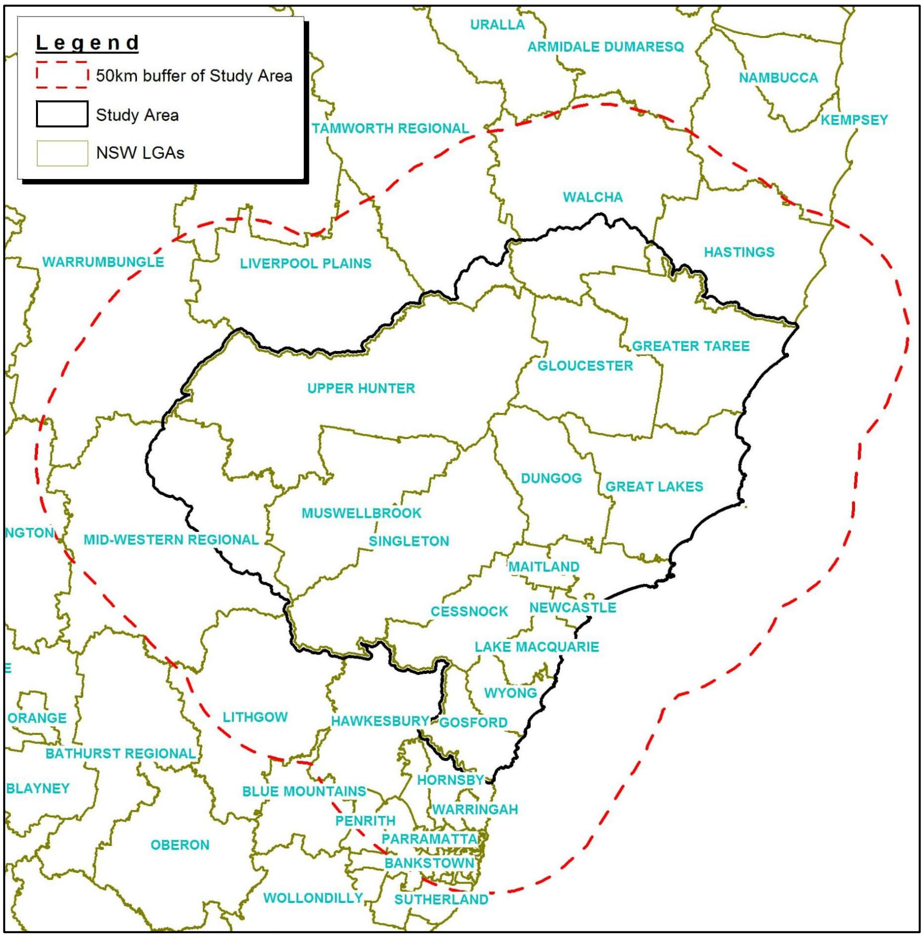


Figure 1 - LGAs in the study region

SUMMARY OF KEY FINDINGS

Historic and projected changes in key climate parameters have been presented in this report. The methodology adopted determines projected changes in these key climate parameters using a weather typing approach to statistical downscaling. This approach focuses on the analysis of changes in the synoptic drivers of weather in the region. Using historic data from BOM stations within the central climate zone, projections are "downscaled" to this zone and thus provide a sub-regional assessment of projected climate change.

Significant historic and projected changes in key climate parameters for the Central Zone of the study region have been identified. These include:

- A statistically significant decrease in average annual **precipitation** over the period from 1948-2007 is evident. However, this decrease appears to occur as a result of a stepwise shift in rainfall patterns resulting from the IPO. For the period from 2020-2080, no statistically significant change in precipitation is projected although rainfall patterns are expected to more closely resemble the slightly wetter and more variable rainfall patterns in summer and winter experienced during the 1948 to 1976 IPO period.

- A statistically significant increasing trend in average annual **minimum temperature** of 0.6^{o}C is observed over the period from 1970-2007. An increase of 0.9^{o}C occurring in spring over this period is also significant. An increase in average annual minimum temperature of 1.7^{o}C is projected to occur by 2080 A.D. This projected increase results from slight decreases in summer and spring and more significant increases in autumn and winter.

- A statistically significant increasing trend in average annual **maximum temperature** of 1.2^{o}C is observed over the period from 1970-2007. Increases of 1.0^{o}C occurring in winter and 1.7^{o}C in spring over this period are also significant. An increase in average annual maximum temperature of 2.1^{o}C is projected to occur by 2080 A.D. This projected increase results from a decrease in spring and more significant increases in autumn and winter. No change is projected for summer.

- A statistically significant increasing trend in annual **average temperature** of 0.9^{o}C is observed over the period from 1970-2007. Increases of 0.8^{o}C occurring in winter and 1.3^{o}C in spring over this period are also significant. An increase in average annual maximum temperature of 1.8^{o}C is projected to occur by 2080 A.D. This projected increase results from decreases in summer and spring and more significant increases in autumn and winter.

- A statistically significant decreasing trend in annual average **pan evaporation** of 0.8mm/24hr is observed over the period from 1970-2007. Decreases of 0.9mm/24hr occurring in autumn and 0.8mm/24hr in winter over this period are also significant. Despite these historic trends, no changes in pan evaporation are projected to occur by 2080 A.D.

- A statistically significant increasing trend in annual average **9am humidity** of 6% is observed over the period from 1977-2006. Increases of 6.0% occurring in summer, 5.6% in autumn and 6.8% in winter over this period are also significant. Projected changes in 9am humidity do not align with observed historic trends. Increases of 0.4% and 6.3% are projected for summer and spring respectively. Decreases of 3.4% and 2.2% are projected for autumn and winter. These changes balance out to produce an overall 0.3% increase by 2080 A.D. No significant changes, either historically or projected, are evident for 3pm humidity.

- A statistically significant decreasing trend in annual average **wind speed** of 6.5km/hr is observed over the period from 1970-2007. Decreases of 5.2km/hr occurring in summer, 5.8km/hr in autumn and 7.8km/hr in winter and 7.2km/hr in spring over this period are also significant. Projected changes in average wind speed do not align with observed historic trends. An increase of 1.2km/hr is projected for autumn. Decreases of 0.2km/hr in both summer and winter and a decrease of 2.2km/hr in spring are projected. These changes balance out to produce no overall annual change by 2080 A.D.

- A statistically significant increasing trend in summer average **wind gusts** of 6.3km/hr is observed over the period from 1970-2007. Wind gust projections are for changes in ST patterns in winter which should decrease the intensity of wind gusts in the central zone during this season. Conversely, changes in STs should produce more onshore wind gusts during summer. There is no indication from the ST patterns that the intensity of summer wind gusts will change.

- A statistically significant increasing trend in the number of **extreme heat events** of approximately 5 days in total is observed over the period from 1970-2007. Projected shifts in the frequency of occurrence of in STs suggest this trend likely to continue to 2080 A.D.

The climate change projections detailed in this report provide the next order of detail and insight over the previous CSIRO (2007) projections for the Hunter, Central and Lower North Coast Region of NSW, and it is now possible to assess the sensitivity and associated climate change risks for the central climate zone. It is important to note that the science of climate change impact projection will advance with the next generation of GCM's. Thus the development of detailed sub-regional climate change projections should be viewed as an ongoing endeavour.

METHODOLOGY

A key element of the project has included research to identify the regional scale impacts of climate change. This research has been completed by the University of Newcastle and differs from other research approaches in that projections of future climate are based on changes in the regions' "weather drivers". These drivers have been derived from the sea level pressure output of Global Climate Models (GCMs) and comprise 12 particular synoptic types that significantly influence the region's weather patterns. This is the first time this methodology has been applied in Australia. This approach contrasts to more common approaches that project changes in the climate based on the values of key climate variables such as rainfall and temperature generated by GCMs.

The research process itself has involved a comprehensive review of the region's climate history, analysis of variability, and identification of the relationship between these historic climate patterns and the 12 synoptic types. A detailed description of the full research methodology is included in Blackmore, K.L. & Goodwin, I.D (2009). Four distinct research stages were implemented. These include:

Stage 1: Identification of key regional synoptic patterns

Stage 2: Determining the relationship between synoptic types & climate variability in the region

Stage 3: Downscaling CSIRO global climate model (GCM) predictions for New South Wales to the region

Stage 4: Determining the potential impacts of climate change on the Study Region using statistical downscaling

Stage 1: Identification of key synoptic patterns

Data on key climate variables were obtained from the Bureau of Meteorology, including precipitation, temperature, humidity, evaporation, daily wind speed and wind gusts. Data for the period 1948 – 2007 was used for this process to comply with data quality and duration standards established for the project.

In addition, a detailed climatic data set was obtained from the US National Oceanic and Atmospheric Administration. This contained gridded 6 hourly, daily and monthly data for the full range of climate parameters, from the surface through the atmosphere. Monthly sea level air pressure data was then used to define the variety of synoptic types that drive climatic variability within the region. Figure 2 shows a sample of high (left) and low (right) pressure anomaly synoptic pattern.

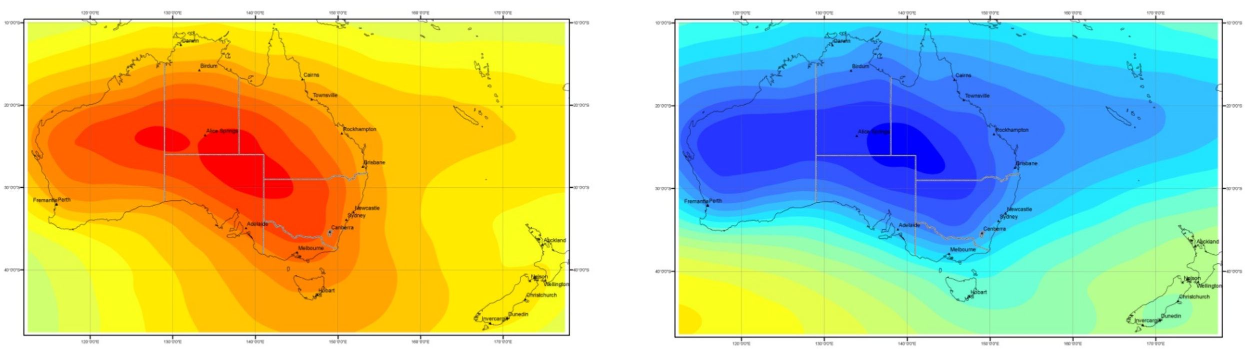


Figure 2 - Synoptic patterns are the air pressure systems commonly seen on weather maps

The final twelve synoptic types were then identified using a pattern recognition technique known as 'self-organising mapping'. This technique clusters like features together to produce a resultant "map" which arranges the clusters by similarity (i.e. clusters with similar features will appear close together on the map). This process enabled those synoptic patterns most associated with key weather patterns in the region to be identified.

Stage 2: Determining the relationship between synoptic types & climate variability

The 12 identified synoptic types generate a range of significant large-scale features that are known to influence the region's weather. They may induce clear seasonal trends in the location and intensity of features such as the subtropical anticyclone, the monsoonal trough, the circumpolar trough, the long wave trough, and ridge features in the Pacific and Indian Ocean. Data from Bureau of Meteorology recording stations within the region were related to each synoptic type to understand how these twelve patterns drive the region's climate variability.

This process confirmed that it is changes in the frequency of occurrence of these synoptic types between 1948 and 2007 that is responsible for the variability recorded in key climatic parameters during that period. Additionally, relationships between extreme events (high or low rainfall and temperature events) and synoptic types were also identified.

Stages 3 & 4: Determining potential impacts of climate change

Climate projections (based on the A2F1 emissions scenario) for the period 2020-2080 were assessed using data from the CSIRO Mk3.5 Global Climate Model (GCM). However, because Global Climate Models generate coarse-scale outputs, an additional process called Statistical Downscaling was also employed. This allowed the data to be meaningfully interpreted at a much finer geographical scale suitable for projecting likely climatic changes at both regional and subregional levels.

A weather typing approach to Statistical Downscaling was adopted for the research. This involved the Global Climate Model identifying projected changes in the frequency of the key synoptic types, with this data then being combined with an understanding of how the region's weather is impacted by these types. This allowed the researchers to project the likely changes in climate variables across the region, such as temperature, rainfall and evaporation at both sub regional and seasonal scales.

The actual climate variables for which an analysis has been completed were identified through consultation with regional stakeholders including councils, government agencies and the agricultural sector. This aimed to ensure that the outputs of the research were directly relevant to regional stakeholders and could be readily applied to risk assessment and adaptation planning activities.

LIMITATIONS

Regional climate impacts have been resolved throughout this study using a statistical downscaling approach, based principally on the projected monthly representation of the sea-level pressure field output from the CSIRO Mk3.5 GCM. The skill in projecting regional climate change impacts for the study area depends upon the model representation of the historical and future atmospheric circulation, together with the sensitivity of the Self Organised Mapping (SOM) approach to resolving change or shifts in the frequency of synoptic types.

The problem of sensitivity and predictive skill testing has been approached by training the methods on a calibration period from 1968 to 1990. This period spans a natural shift in the mean state of the climate, between a La Nina-like and an El Nino-like state, referred to as the Interdecadal Pacific Oscillation (IPO). The GCM's do not fully capture the range and shift in frequency of the key ST's determined from the analysis of the observed or instrumental sea-level pressure data (NCEP-NCAR Reanalysis data). Hence the GCM's do not fully capture the inherent interdecadal variability in the natural climate system that produces the climate shift and extremes that society, agriculture and the natural environment respond to.

Generally, the climate change projections for the 2020-2040, 2040-2060 and 2060-2080 are comparable, and do not display the interdecadal variability observed in the historical record. Hence, the projected climate variables should be interpreted as indicative of the shifts in climate relative to the specific historic period (i.e. +ve or –ve IPO phase). For example, if the shift is towards the interdecadal mean values experienced in the 1948-1976 period of persistent La Nina-like climate, then environmental management, planning and policy decisions should draw on the historical impacts during this period when formulating responses to the projected change. All statistically significant trends in this study are interpreted as being of moderate to high confidence, and accordingly, all non statistically significant trends as being indicative of low confidence projections.

CLIMATE ZONES

To facilitate the sub regional analysis and interpretation of projected climate change impacts, three sub regional *climate zones* (coastal, central and western) have been established for the region. An analysis of both historic and projected climate change has been provided for each of these. These zones are shown in Figure 3.

These zones were identified through a process known as climate zonation. This divides a region into distinct sub-regions or zones where climatic similarity is maximised within zones and minimised between zones. This purely statistical process was based upon key seasonal climate variables including summer, autumn, winter and spring precipitation and average minimum and maximum temperature.

This report provides a detailed analysis of historical climate variability and projected future climate change in the central zone.

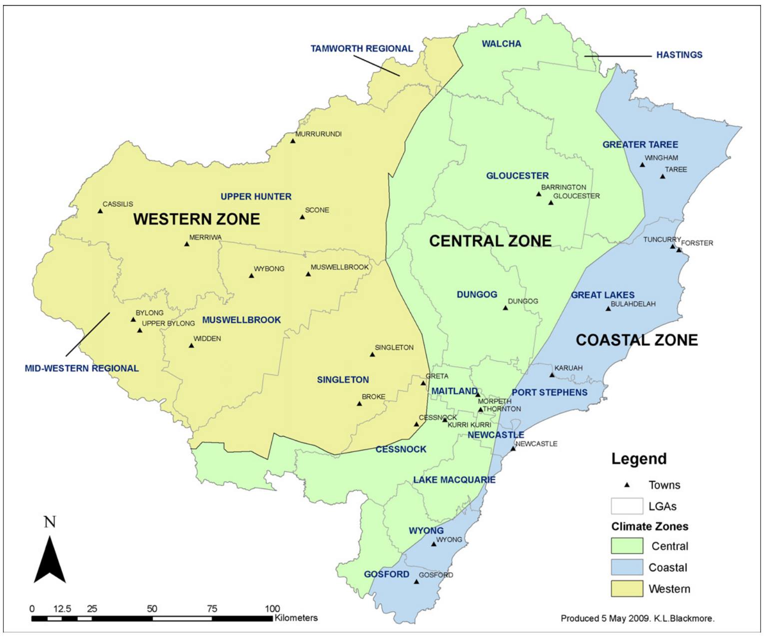


Figure 3 - The region's three climate zones identified in Stage 2 of the project

THE CENTRAL CLIMATE ZONE

This report provides climatic projections for the 'Central Zone' which incorporates the Dungog and Gloucester local government areas (LGAs) and parts of the Greater Taree, Great Lakes, Port Stephens, Newcastle, Maitland, Lake Macquarie, Wyong and Gosford LGAs. Located in the zone are the major towns of Gloucester, Dungog, and Maitland.

Covering a total area of approximately 15,400 square kilometers, the central zone is generally not influenced by ocean processes. The zone's higher elevations, relative to the coastal zone, result in cooler winter temperatures, including frosts. Key features of the zone include:

- Annual maximum temperatures average 23.6^{o}C (over the period from 1970-2007).
- Elevation ranges from approximately 1,535 meters above sea level (ASL) in the central-west of the zone to as little 5 meters ASL in the east.
- The central zone experiences frequent frosts in most areas with annual minimum temperatures averaging 12.0^{o}C.
- The central zone receives only slightly less rainfall than the coastal zone of the region. Summer is the wettest season, averaging 117mm per month. Rainfall decreases during autumn and winter to approximately 102mm and 69mm per month respectively. Spring rainfall is similar to winter with an average of 69mm per month recorded over the period from 1948 to 2007.

KEY CLIMATE PARAMETERS

This section provides details of the key climate parameter recording stations used to obtain data for the analysis of climate change in the central zone. The instrumental climate data sets used for this purpose were obtained from the National Climate Centre of the Australian Bureau of Meteorology (BOM). The data sets used represent the recordings from ground stations within the region, from the beginning of collection for the station until 31 December 2007. These data sets form the primary source of information used to study climate variability contained in this report and for the study of projected climate change impacts for the region. The particular climate variables acquired and analysed for this purpose are listed in Table 1.

Key Climate Variable	Units
Australian daily precipitation	Millimeters (mm)
Australian daily maximum and minimum temperatures	Degrees Celsius (°C)
Australian hourly temperature	Degrees Celsius (°C)
Australian hourly humidity	Percent (%)
Australian daily evaporation	Millimeters (mm)
Australian daily wind data	Kilometers per hour (km/hr)
Australian hourly wind gust data	Kilometers per hour (km/hr)
Daily cloudiness, visibility and sunshine hours data for BOM districts 60,61 and 62	Eighths, Kilometers(km), and Hours (hrs)
Six minute pluvial data for districts 60, 61 and 62	Millimeters (mm)

Table 1 - Key climate variables and their units of measure

It was important to ensure that the data sets used in the study were of a sufficient length, covered a common time span and were reasonably complete. Thus a data interrogation process was used to determine the completeness of each of the records. Each climate parameter time series was checked for missing data between the years of interest (1948 and 2007)[1] and this was converted to percentage completeness. It was determined that a good spatial coverage could still be maintained by restricting the final data set to stations with daily records that are at least 90% complete. Details of the stations in the central climate zone meeting these criteria are provided in Tables 2 – 6 on pages 9 and 10.

[1] The year 1948 was chosen as the lower bound as this corresponds to the first year for which the atmospheric data is available in the NCEP/NCAR dataset and therefore was also be the first year for which the synoptic typing was carried out.

DAILY PRECIPITATION

Of the 80 BOM precipitation stations meeting 90% complete criteria in the Hunter, Central and Lower North Coast region, 13 stations lie within the central climate zone (Table 2).

BOM_ID	NAME	DATE OPENED	LATITUDE	LONGITUDE	ELEVATION
61014	BRANXTON (DALWOOD VINEYARD)	01/1863	-32.639	151.417	40
61012	COORANBONG (AVONDALE)	01/1903	-33.085	151.463	10
61048	MULBRING (STONE STREET)	01/1932	-32.903	151.482	31
61082	WYEE POST OFFICE	03/1899	-33.175	151.485	20
61024	GRESFORD POST OFFICE	01/1895	-32.427	151.538	85
61096	PATERSON POST OFFICE	01/1901	-32.600	151.618	21
61151	CHICHESTER DAM	01/1942	-32.243	151.683	194
61031	RAYMOND TERRACE (KINROSS)	01/1894	-32.776	151.735	10
61017	DUNGOG POST OFFICE	01/1897	-32.402	151.758	55
61010	CLARENCE TOWN (GREY ST)	01/1895	-32.588	151.781	10
60015	GLOUCESTER POST OFFICE	01/1888	-32.006	151.960	105
61071	STROUD POST OFFICE	01/1889	-32.403	151.966	44
60021	KRAMBACH POST OFFICE	01/1910	-32.051	152.260	75

Table 2 – Available precipitation stations

DAILY MAXIMUM AND MINIMUM TEMPERATURE

Of the 17 BOM maximum and minimum temperature stations meeting 90% complete criteria in the Hunter, Central and Lower North Coast region, only two stations lie within the central climate zone.

BOM_ID	NAME	DATE OPENED	LATITUDE	LONGITUDE	ELEVATION
61288	LOSTOCK DAM	01/1969	-32.332	151.459	200
61250	PATERSON (TOCAL AWS)	11/1967	-32.630	151.592	30

Table 3 - Available maximum and minimum temperature stations

DAILY PAN EVAPORATION

From the seven BOM pan evaporation stations meeting 90% complete criteria in the Hunter, Central and Lower North Coast region, only two stations lie within the central climate zone.

BOM_ID	NAME	DATE OPENED	LATITUDE	LONGITUDE	ELEVATION
61288	LOSTOCK DAM	01/1969	-32.332	151.459	200
61250	PATERSON (TOCAL AWS)	01/1967	-32.630	151.592	30

Table 4 - Available pan evaporation stations

RELATIVE HUMIDITY

Of the 12 three (3) hourly humidity stations meeting 90% complete criteria in the Hunter, Central and Lower North Coast region, two stations lie within the central climate zone.

BOM_ID	NAME	DATE OPENED	LATITUDE	LONGITUDE	ELEVATION
61288	LOSTOCK DAM	01/1969	-32.332	151.459	200
61250	PATERSON (TOCAL AWS)	11/1967	-32.630	151.592	30

Table 5 – Available humidity stations

AVERAGE WIND SPEED AND WIND GUSTS

Average wind speed data is available from two (2) stations within the central climate zone (Table 6). Wind gust data is available from only one station (Williamtown) within the Hunter, Central and Lower North Coast region.

BOM_ID	NAME	DATE OPENED	LATITUDE	LONGITUDE	ELEVATION
61288	LOSTOCK DAM	01/1969	-32.332	151.459	200
61250	PATERSON (TOCAL AWS)	11/1967	-32.630	151.592	30

Table 6 - Available average wind speed stations

HISTORICAL CLIMATE VARIABILITY AND TRENDS

Historic climate records for each key climate variable have been analysed for increasing or decreasing linear trends. Regression analysis has been conducted for each climate variable to assess the statistical significance of linear trends. Regression analysis provides a measure of the statistical significance of the linear trend known as a “p-value”. Where the p-value is found to be less than 0.05, the linear trend is considered to be statistically significant. Linear trends found to be significant are reported in the text.

Historic climate records are marked by both annual and interdecadal variability. Interdecadal variability within the Australasian and South West Pacific regions is associated with the Interdecadal Pacific Oscillation (IPO). During the time period from 1948 to 2007 there have been two phases of this oscillation: IPO –ve phase (La Nina-like) from 1948 to 1976; and, IPO +ve phase (El Nino-like) from 1977 to 2007. The IPO periods represent shifts in the mean climate and are considered in the following analysis of climate variability and trends.

PRECIPITATION

The majority of the Hunter, Central Coast and Lower North Coast region’s rainfall occurs in the summer and autumn seasons. Variation in the seasonal distribution of precipitation is evident, with two distinct seasonal trends (i.e. wetter summer and autumn versus drier winter and spring). The precipitation pattern in the summer and autumn seasons dominates the annual pattern. The highest rainfall occurs in summer in the Barrington Tops, however all areas generally receive more than 70mm per month of summer rain. Summer monthly rainfall in the central and coastal areas averages over 120mm per month, whereas the west of the region averages around 80mm. The coastal effect is clearly evident in the autumn months, with the coastal region receiving average autumn monthly rainfall of over 125mm, compared to just over 50mm in the central parts of the region.

By July, precipitation further retracts to the coastal areas with an average of 90mm per month of winter rainfall; the western areas receive approximately 45mm. By spring the most even distribution of rainfall across the region occurs, with just over 20mm variation in averages across the region. Western areas receive ~ 55mm of winter rainfall compared to ~ 75mm on the coast. Thus the winter and spring seasons combine to define the region’s dry season.

In the central zone, a statistically significant decreasing linear trend in average annual precipitation is evident over the period from 1948 to 2007 (Figure 4). This time period spans a +ve and –ve phase of the IPO. Figure 5 (over page) shows separate graphs for each of these phases. A decrease is evident in the period from 1948 to 1976 (non significant) with no trend evident in the latter period. Rather, the average annual rainfall is approximately 112mm less (than 1948-1976) in the 1977 to 2007 period.

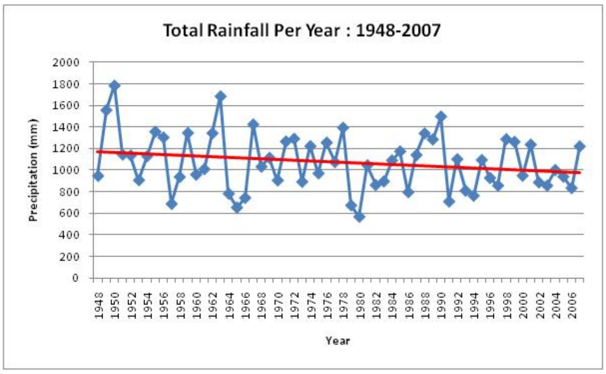


Figure 4 - Trend in total annual rainfall (1948-2007)

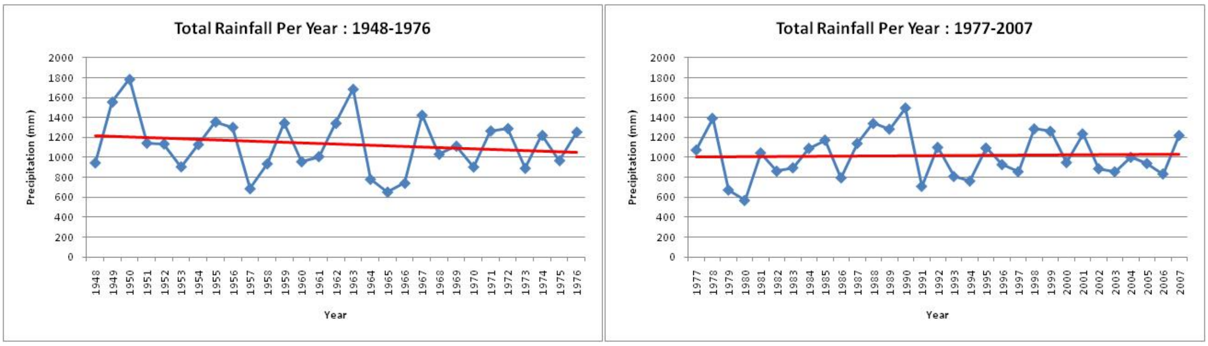


Figure 5 - Trend in total rainfall for the 1948-1976 and 1970-2007 time periods

Seasonally, statistically significant decreases in average monthly precipitation have occurred during summer and winter only (Table 7 and Figure 6). During summer and winter, the monthly average rainfall has decreased by 0.7mm per annum (43mm in total) over the period from 1948-2007.

Total Rainfall (1948-2007)			
Summer	**Autumn**	**Winter**	**Spring**
Drier: ~43mm* decrease	Wetter: ~9mm increase	Drier: ~43mm* decrease	Wetter: ~10mm increase

Table 7 - Summary of historic changes in rainfall

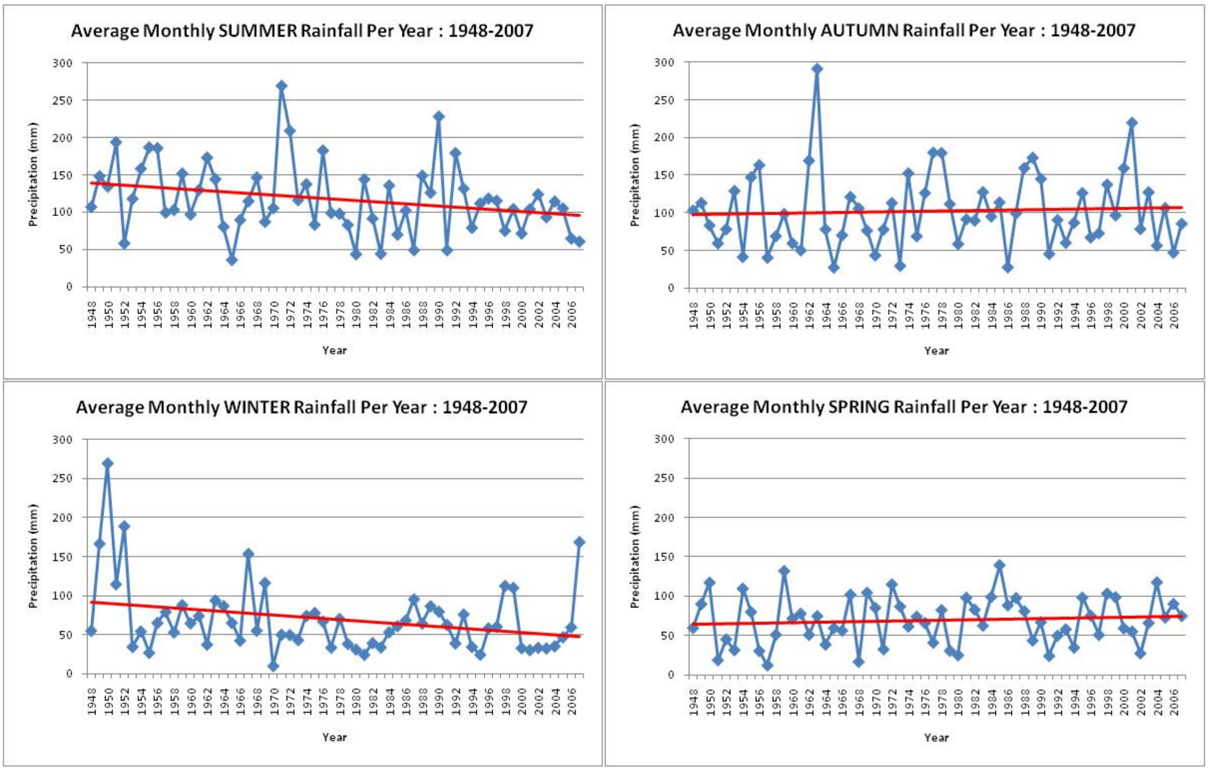


Figure 6 - Seasonal rainfall trends 1948-2007

TEMPERATURE

MINIMUM TEMPERATURE

The average annual minimum temperature recorded for the central zone from 1970 to 2007 is 12.0^{o}C. Over the period from 1970 to 2007, an increasing linear trend in average annual minimum temperature in the central zone is evident (Figure 7). This statistically significant trend is equivalent to an increase of approximately 0.6^{o}C over this entire period.

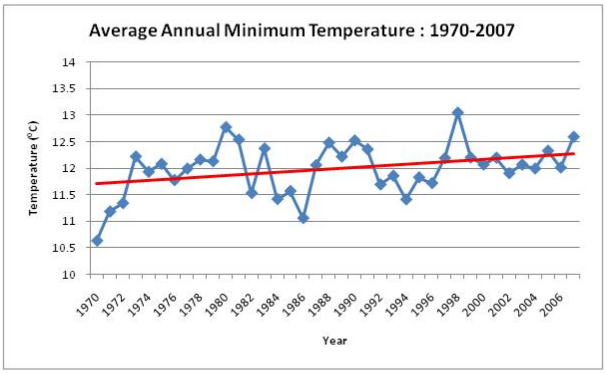


Figure 7 - Trend in average annual minimum temperature for the 1970-2007 time period

Minimum temperature (1970-2007)			
Summer	**Autumn**	**Winter**	**Spring**
Warmer: ~0.3°C increase	Warmer: ~0.5°C increase	Warmer: ~0.5°C increase	Warmer: ~0.9°C* increase

Table 8 - Summary of historic changes in minimum temperature

During summer, minimum temperatures average 18.2^{o}C in the central zone, decreasing to 14.0^{o}C during autumn and 7.6^{o}C during winter (Table 8 above and Figure 8 over page). Spring minimum temperatures average 12.6^{o}C. Average minimum temperatures show increases in all seasons over the period from 1970-2007 in line with the annual trend (Figure 7). The seasonal increases occurring in spring (~0.9^{o}C) are statistically significant.

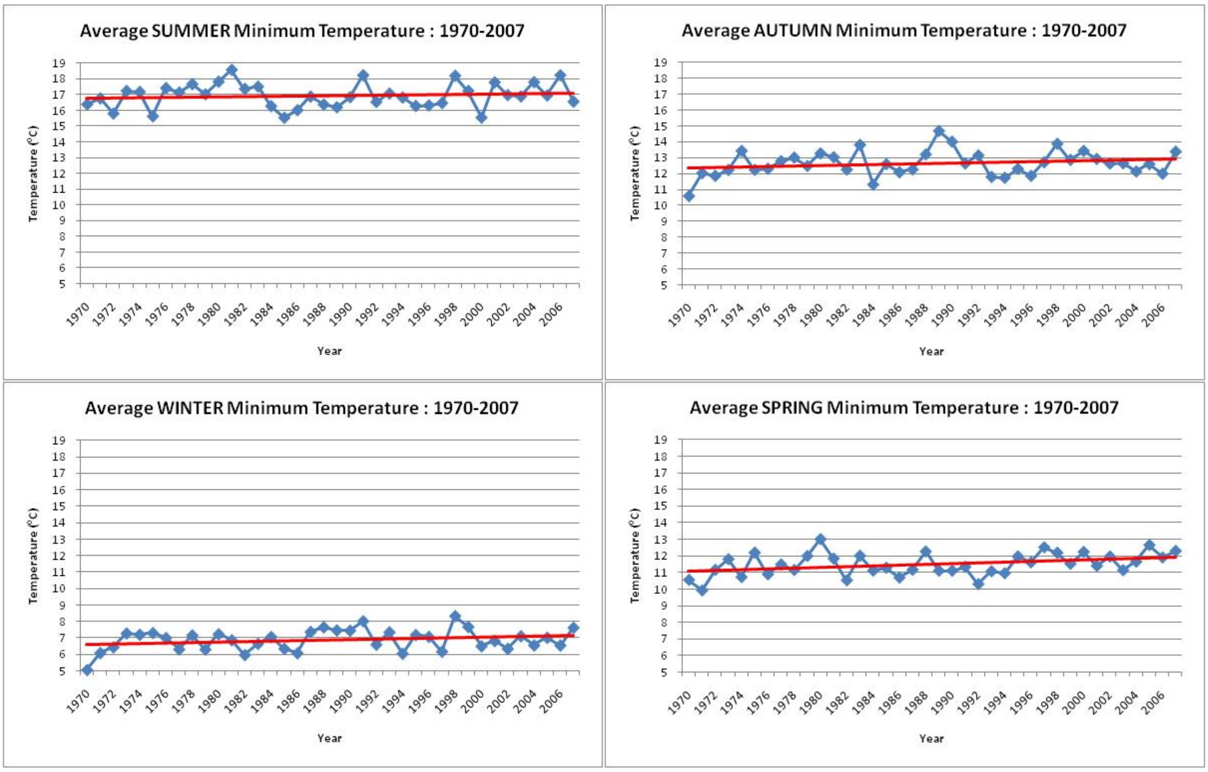


Figure 8 - Seasonal average minimum temperature trends 1970-2007

MAXIMUM TEMPERATURE

The average annual maximum temperature recorded for the central zone from 1970 to 2007 is 23.6^{o}C. Over the period from 1970 to 2007, an increasing linear trend in average annual maximum temperature in the central zone is evident (Figure 9). This trend is statistically significant and equivalent to an increase of approximately 1.2^{o}C over this entire period.

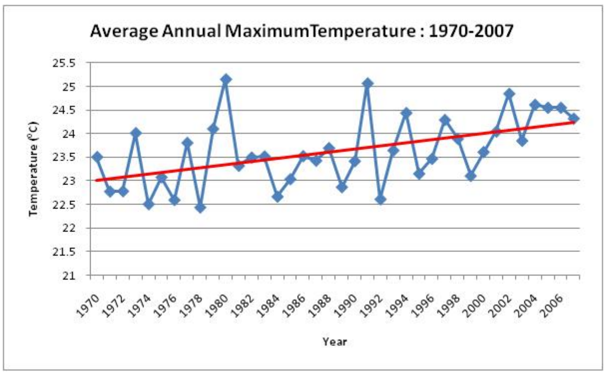


Figure 9 - Trend in average annual maximum temperature for the 1970-2007 time period

During summer, maximum temperatures average 29.0^{o}C in the central zone, decreasing to 23.6^{o}C during autumn and 17.6^{o}C during winter. Spring maximum temperatures average 24.3^{o}C. Average maximum temperatures show increases in all seasons over the period from 1970-2007 in line with the annual trend (Table 9 and Figure 10) however only the winter (~1.0^{o}C) and spring (~1.7^{o}C) seasonal increases are statistically significant.

Maximum temperature (1970-2007)			
Summer	**Autumn**	**Winter**	**Spring**
Warmer: ~1.6°C increase	Warmer: ~0.8°C increase	Warmer: ~1.0°C* increase	Warmer: ~1.7°C* increase

Table 9 - Summary of historic changes in maximum temperature

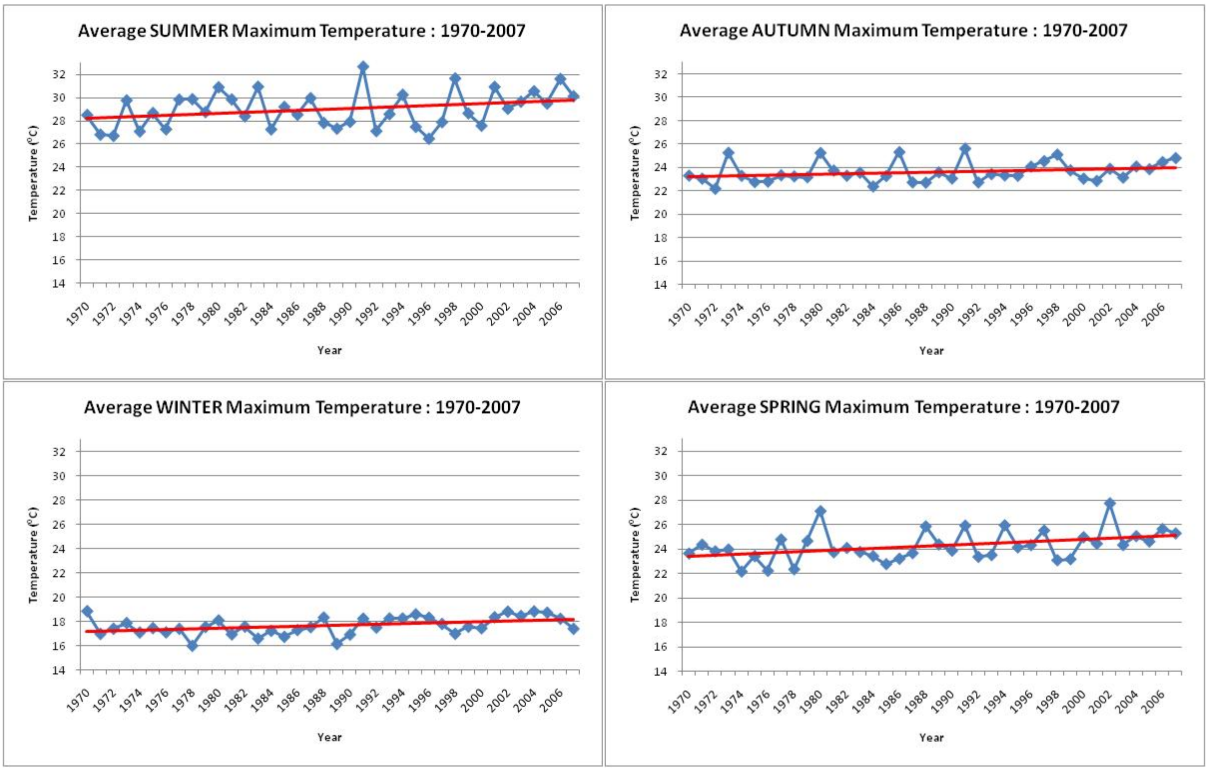


Figure 10 - Seasonal average maximum temperature trends 1970-2007

AVERAGE TEMPERATURE

The annual average temperature is calculated by adding the recorded average monthly maximum and minimum temperatures and dividing by two (i.e. (average monthly maximum temperature + average monthly minimum temperature) / 2). The recorded annual average temperature for the central zone from 1970 to 2007 is 17.8^{o}C. Over the period from 1970 to 2007, an increasing linear trend in annual average temperature in the central zone is evident (Figure 11). This trend is statistically significant and equivalent to an increase of approximately 0.9^{o}C over this entire period.

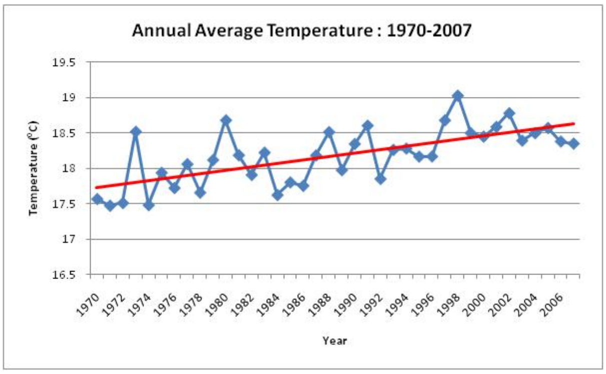


Figure 11 - Trend in annual average temperature for the 1970-2007 time period

Average temperature (1970-2007)			
Summer	**Autumn**	**Winter**	**Spring**
Warmer: ~0.1°C increase	Warmer: ~0.6°C increase	Warmer: ~0.8°C* increase	Warmer: ~1.3°C* increase

Table 10 - Summary of historic changes in average temperature

During summer, temperatures average 23.0^{o}C in the central zone, decreasing to 18.1^{o}C during autumn and 12.3^{o}C during winter. Spring temperatures average 17.9^{o}C. Average temperatures show increases in all seasons over the period from 1970-2007 in line with the annual trend (Table 10 above and Figure 12 over page). The seasonal increases occurring in winter (~0.8^{o}C) and spring (~1.3^{o}C) are statistically significant.

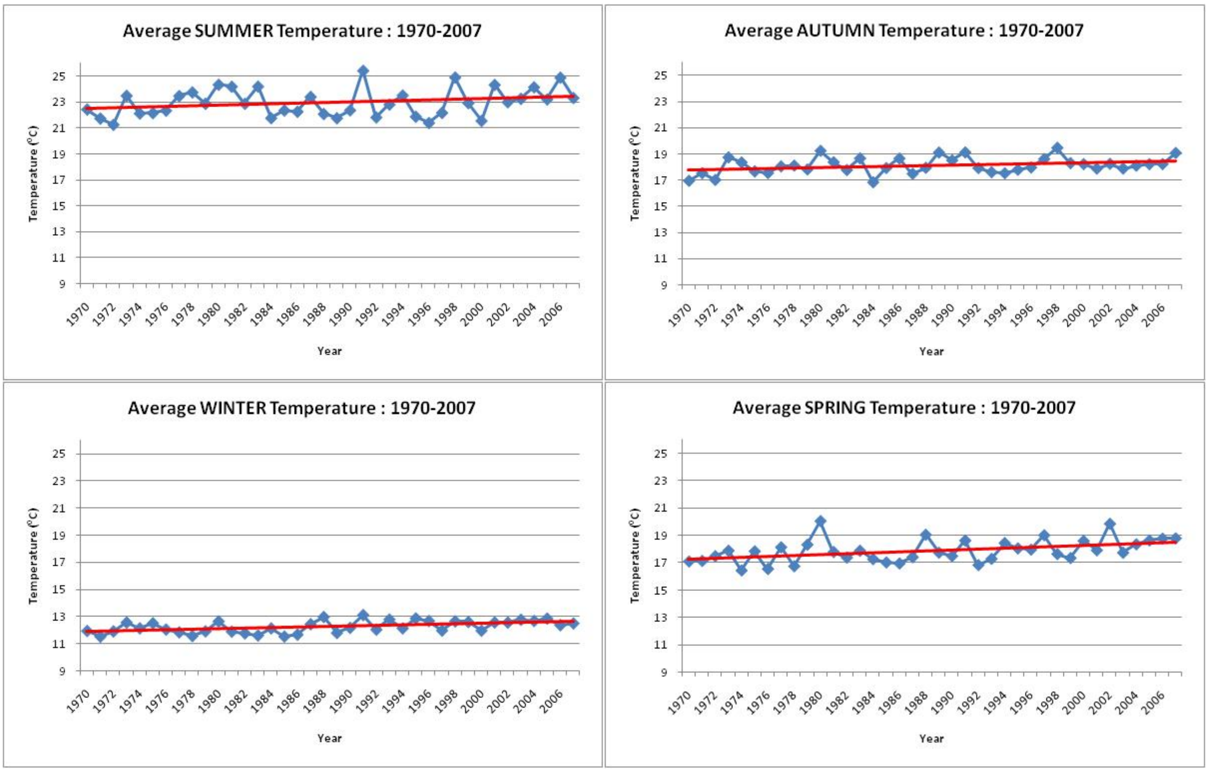


Figure 12 - Seasonal average temperature trends 1970-2007

DAILY PAN EVAPORATION

The recorded annual average pan evaporation for the central zone from 1974 to 2007 is 4.4mm/24hr. Over the period from 1970 to 2007, there has been a statistically significant decrease in pan evaporation of ~0.8mm/24hr (Figure 13).

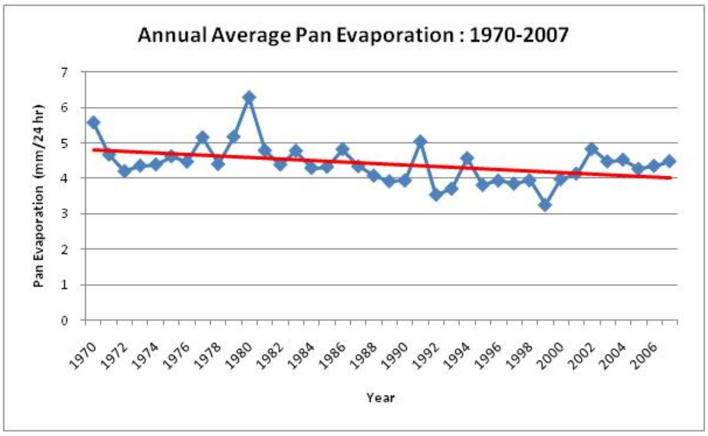


Figure 13 - Trend in annual average pan evaporation for the 1973-2007 time period

During summer, pan evaporation averages 6.2mm/24hr in the central zone, decreasing to 3.4mm/24hr during autumn and 2.8mm/24hr during winter. Spring pan evaporation averages 5.3mm/24hr. The decreasing trend in average annual pan evaporation is evident in each of the seasons (i.e. all seasons show a similar decreasing trend) (Table 11 below and Figure 14 over page). The decreases occurring in autumn (0.9 mm/24hr) and winter (0.8mm/24hr) are statistically significant.

Pan evaporation (1970-2007)			
Summer	**Autumn**	**Winter**	**Spring**
Wetter: ~0.4mm/24hr decrease	Wetter: ~0.9mm/24hr* decrease	Wetter: ~0.8mm/24hr* decrease	Wetter: ~0.7mm/24hr decrease

Table 11 - Summary of historic changes in average pan evaporation

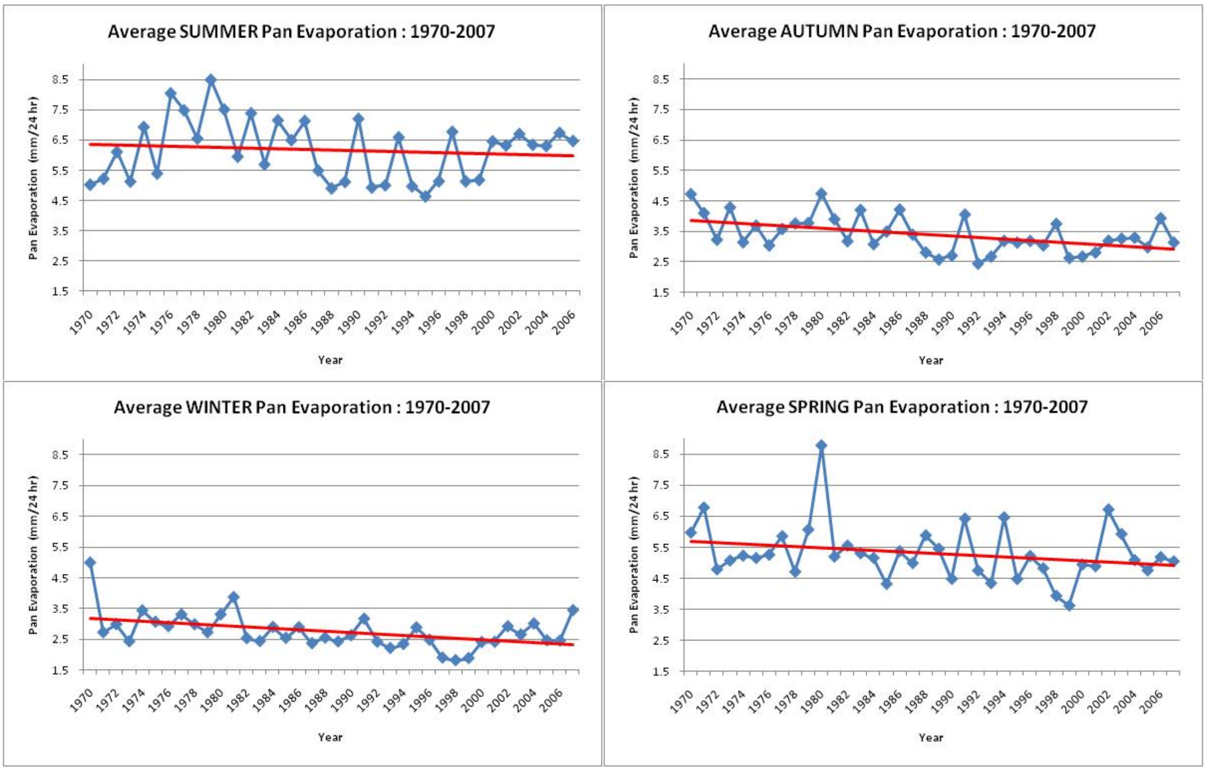


Figure 14 - Seasonal annual average pan evaporation trends 1970-2007

HUMIDITY

The annual average humidity recorded at 9am for the central zone from 1977 to 2006 is approximately 75.2%. Over the period from 1977 to 2006, an increasing linear trend in annual average 9am humidity in the central zone is evident (Figure 15). This statistically significant trend is equivalent to an increase of approximately 6% over this entire period.

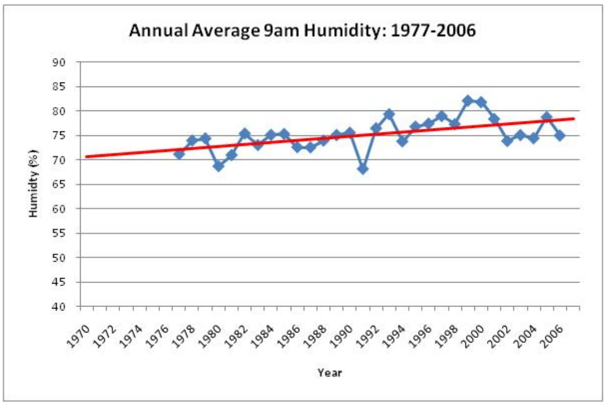


Figure 15 - Trend in annual average 9am humidity for the 1977-2006 time period

During summer, 9am humidity averages 76.3% in the central zone, increasing to 80.6% during autumn and 76.6% during winter. Spring 9am humidity averages 67.3%. Average 9am humidity shows increases in all seasons over the period from 1977-2006 in line with the annual trend (Table 12 below and Figure 16 over page). The summer, autumn and winter seasonal trends are statistically significant which aligns to the annual trend.

9am Humidity (1970-2007)			
Summer	**Autumn**	**Winter**	**Spring**
~6.0%* increase	~5.6%* increase	~6.8%* increase	~5.1% increase

Table 12 - Summary of historic changes in average 9am humidity

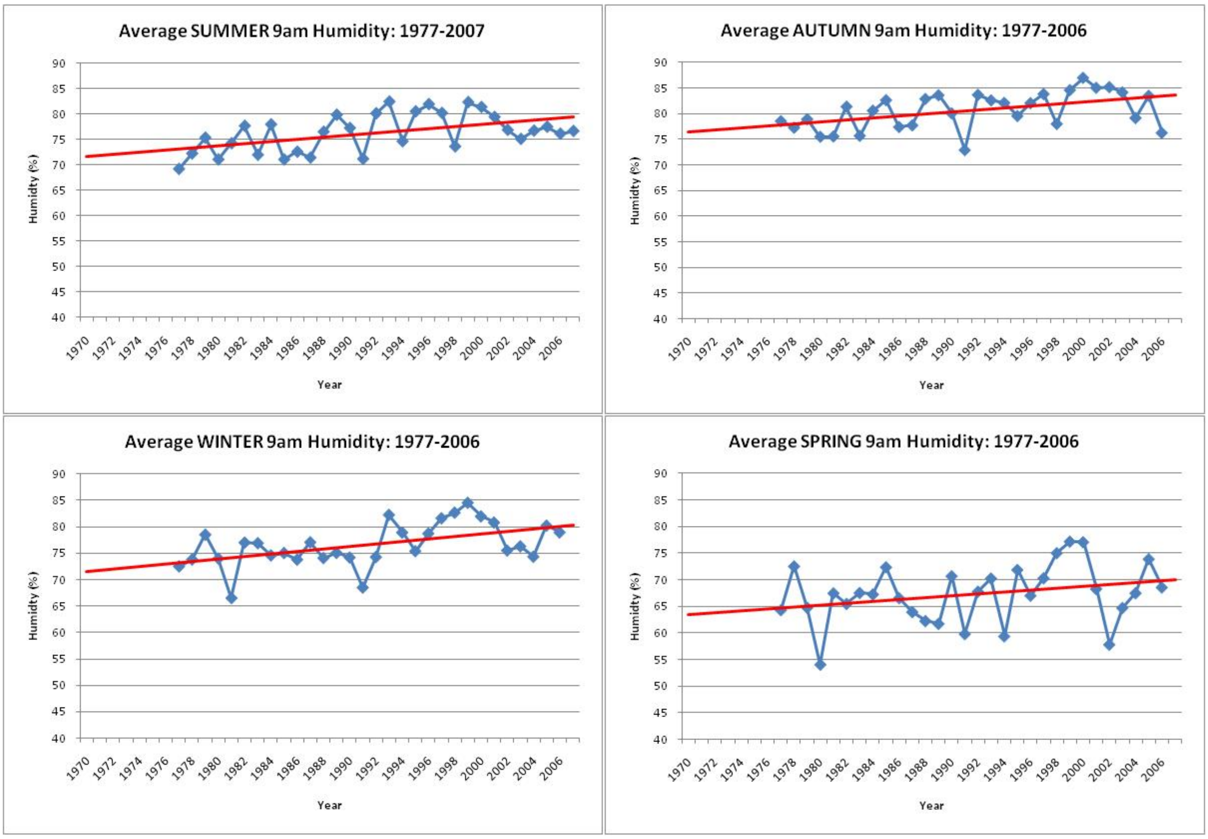


Figure 16 - Seasonal annual average 9am humidity trends 1970-2006

The annual average humidity recorded at 3pm for the central zone from 1970 to 2007 is approximately 52.7%. Over the period from 1970 to 2006, no trend in annual average 3pm humidity in the central zone is evident (Figure 17).

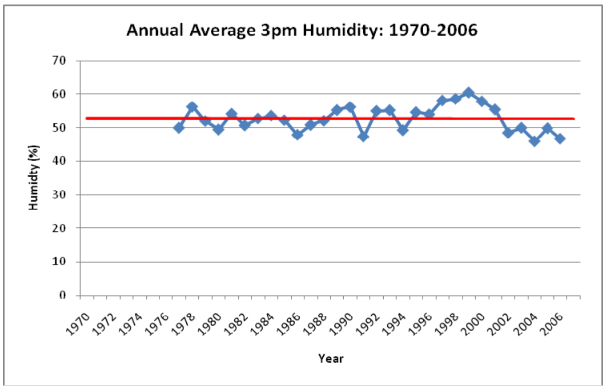


Figure 17 - Trend in annual average 3pm humidity for the 1970-2006 time period

During summer, 3pm humidity averages 51.9% in the central zone, increasing to 57.7% during autumn and 53.4% during winter. Spring 3pm humidity averages 47.5%. Average 3pm humidity shows little or no change in all seasons over the period from 1970-2007 in line with the annual trend (Table 13 and Figure 18).

3pm Humidity (1970-2007)			
Summer	**Autumn**	**Winter**	**Spring**
~0.1% increase	~1.4% decrease	~0.2% increase	~0.5% decrease

Table 13 - Summary of historic changes in average 3pm humidity

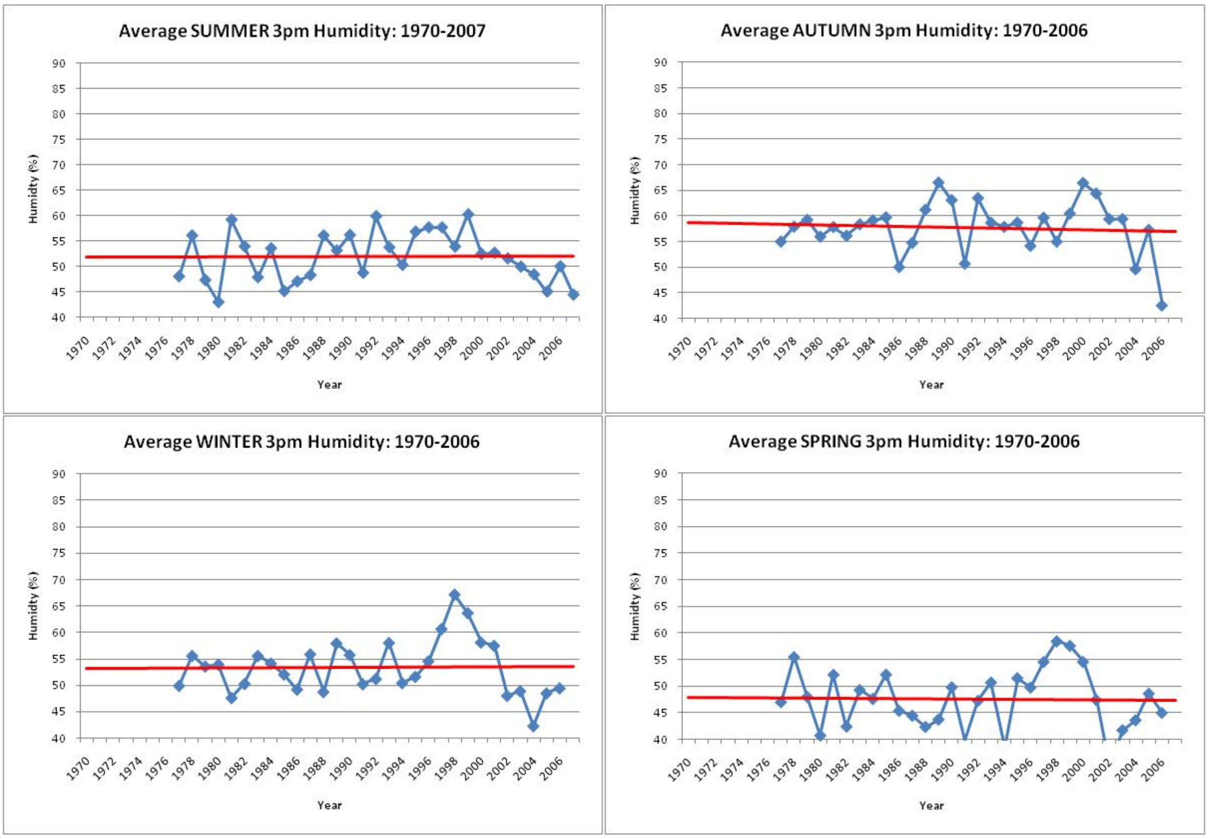


Figure 18 - Seasonal annual average 3pm humidity trends 1970-2006

WATER BALANCE

Simple water balance is calculated by subtracting the average daily pan evaporation (mm/24hr) from the average daily precipitation for each season. Evapotranspiration is not taken into account. Due to the need to include pan evaporation records in the calculations, water balance is calculated for the central zone using data from Paterson only.

The annual average water balance for the central zone from 1973 to 2007 is approximately -1.6mm/day. Over the period from 1973 to 2007, an increasing linear trend in annual average water balance in the central zone is evident (Figure 19). As a result, the central zone has experienced a total increase in annual average water balance of 0.3mm per day between 1973-2007.

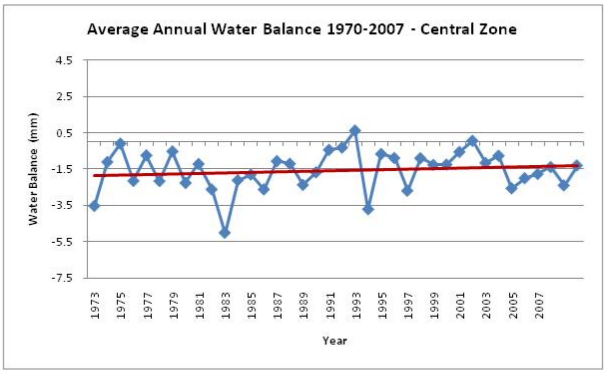


Figure 19 - Trend in water balance for the 1972-2007 time period

During summer, water balance averages -2.4mm/day in the central zone, increasing to -0.02mm/day during autumn and -0.9mm/day during winter. Spring water balance averages -2.9mm/day. Average water balance shows decreases in all seasons over the period from 1972-2007 in line with the annual trend (Table 14 below and Figure 20 over page). As with the annual trend, no seasonal trends are statistically significant.

Average Water balance (1972 -2007)			
Summer	**Autumn**	**Winter**	**Spring**
Wetter: ~0.6mm/d increase	Wetter: ~0.3mm/d increase	Wetter: ~1.1mm/d increase	Wetter: ~0.9mm/d increase

Table 14 - Summary of historic changes in average water balance

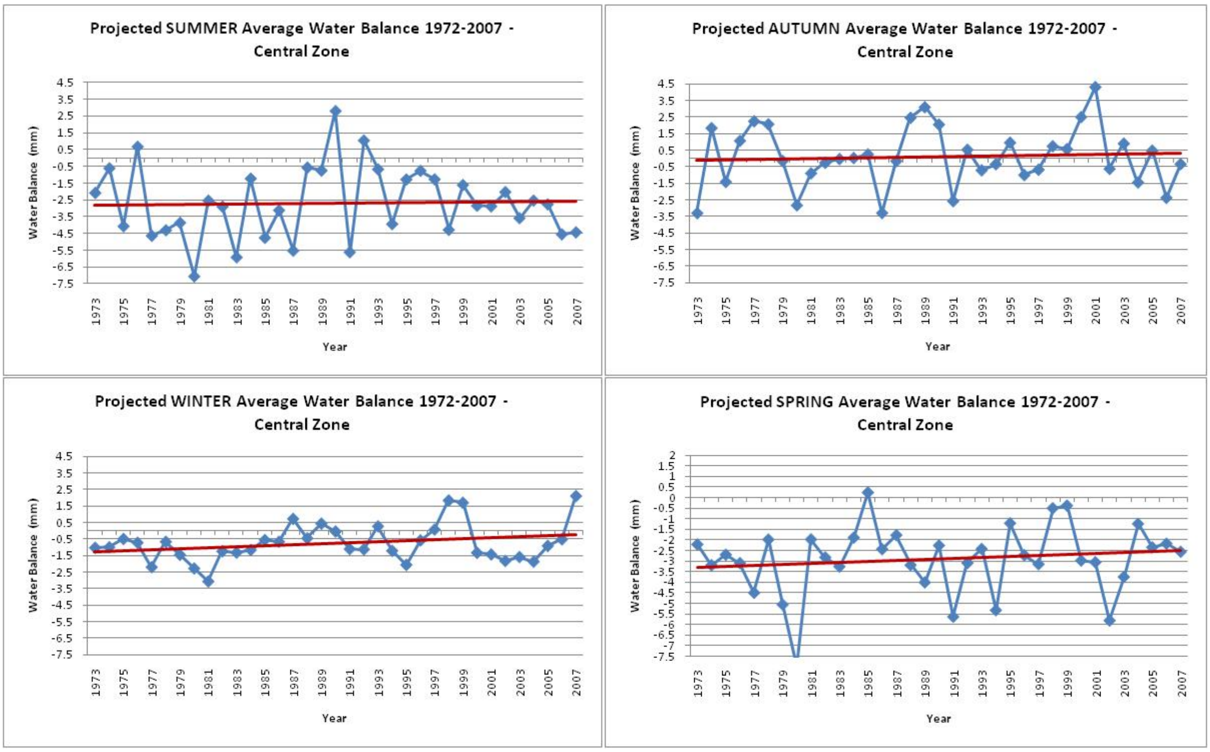


Figure 20 - Seasonal average water balance 1972-2007

AVERAGE WIND SPEED AND WIND GUSTS

The annual average wind speed for the central zone from 1970 to 2007 is approximately 9.8km/hr. Over the period from 1970 to 2007, a decreasing linear trend in annual average wind speed in the central zone is evident (Figure 21). This statistically significant trend is equivalent to a decrease of approximately 6.5km/hr over this entire period.

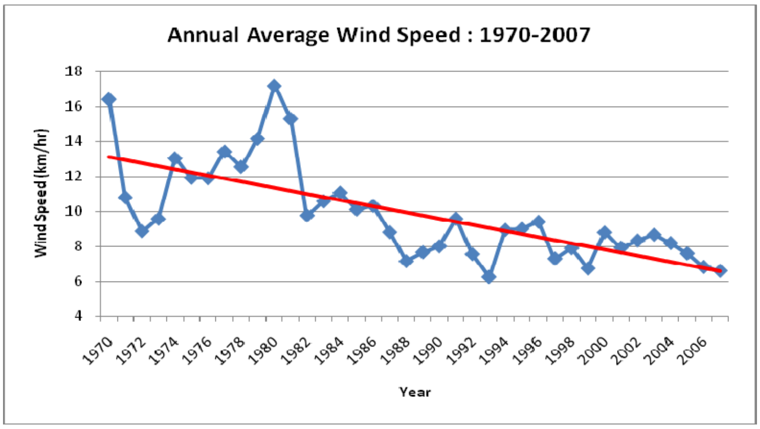


Figure 21 - Trend in annual average wind speed for the 1970-2007 time period

During summer, wind speed averages 8.2km/hr in the central zone, decreasing to 7.8km/hr during autumn and increasing to 12.1km/hr during winter (Table 15 below and Figure 22 over page). Spring wind speed averages 11.2km/hr. Average wind speed shows decreases during all seasons over the period from 1970-2007. As with the annual trend, these seasonal changes are statistically significant.

Wind speed (1970-2007)			
Summer	**Autumn**	**Winter**	**Spring**
Calmer: ~5.2km/hr* decrease	Calmer: ~5.8km/hr* decrease	Calmer: ~7.8km/hr* decrease	Calmer: ~7.2km/hr* decrease

Table 15 - Summary of historic changes in wind speed

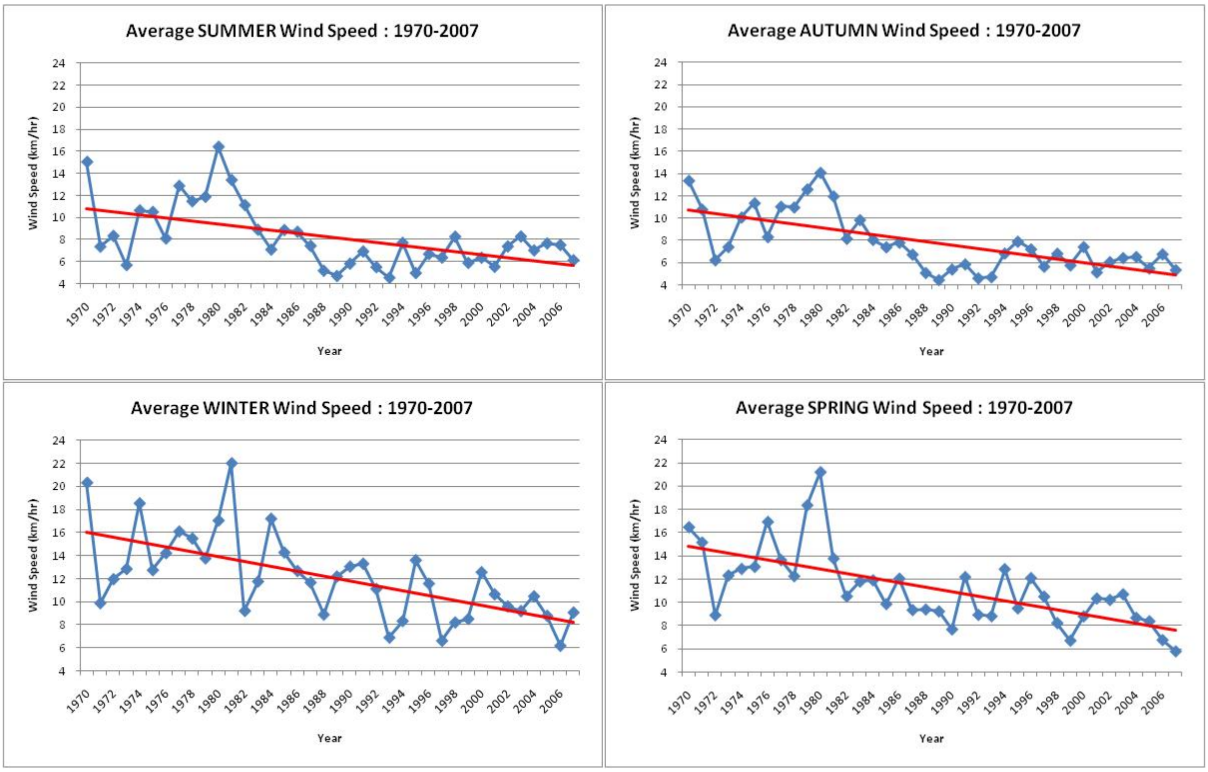


Figure 22 - Seasonal average wind speed trends 1970-2007

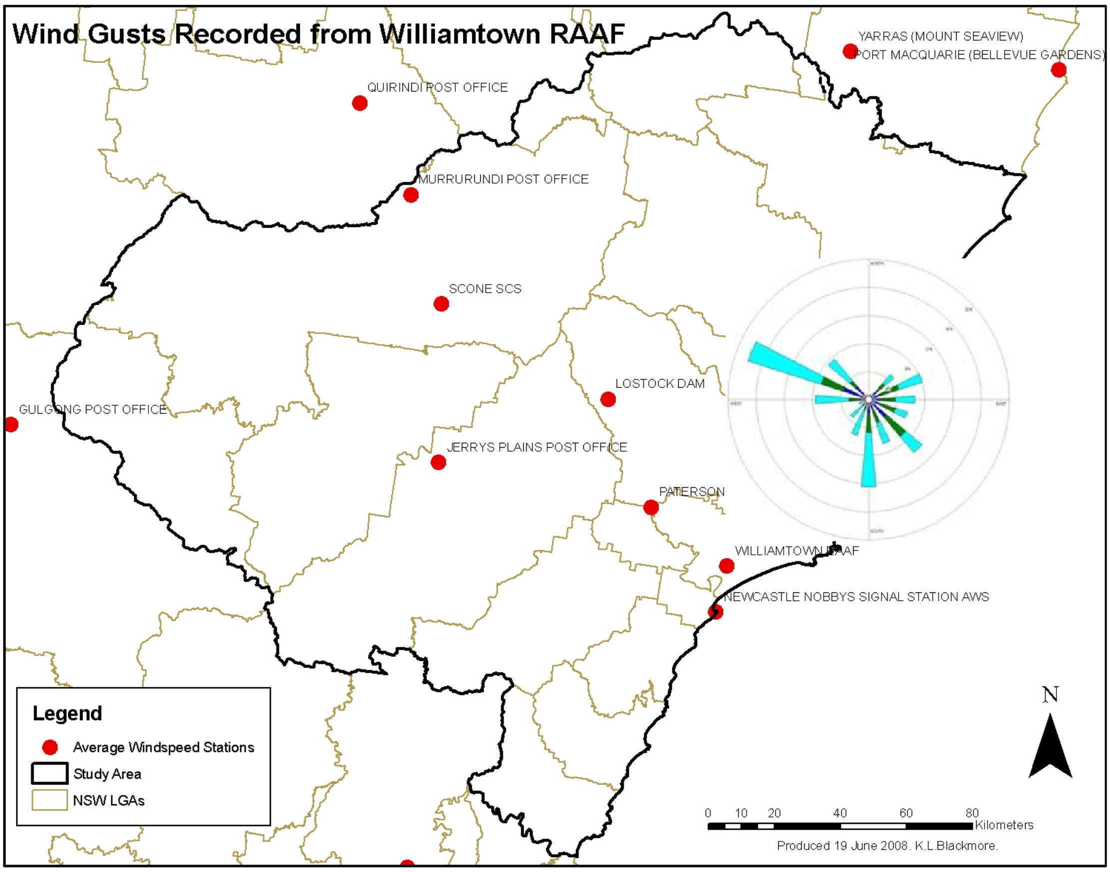


Figure 23 - Wind rose diagram of wind gusts recorded from Williamtwon RAAF.

Suitable (i.e. of a sufficient duration) maximum wind gust data is available from only one station in the region (Williamtown). While this station is located in the coastal zone, it does provide indicative trends for the central zone. Although wind gust station data records from Williamtown RAAF begin 1/10/1942, consistent recording of data does not commence until 1/10/1956. Historic wind gust patterns include:

- Maximum wind gusts average 44km/hr during summer from a south easterly direction.
- Autumn and spring wind gusts tend southerly (average of 37.5km/hr and 45.7km/hr respectively).
- Winter winds tend south westerly with average gusts at 42km/hr.

The strong westerly wind gusts are dominant in the region. The wind rose diagram in Figure 23 (previous page) clearly shows the dominance of the westerly wind gusts.

Annual average wind gusts recorded at Williamtown over the period from 1956 to 2007 average 42km/hr and show a slight increasing trend of approximately 2.4km/hr (Figure 24). This increasing trend is not statistically significant.

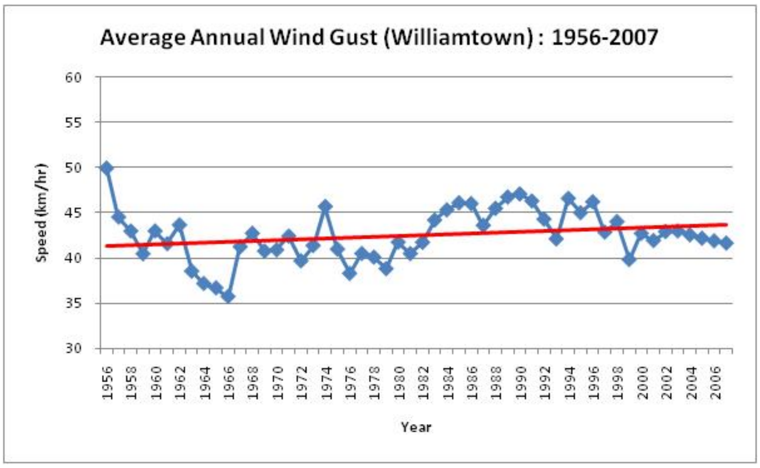


Figure 24 - Trend in average annual wind gusts recorded at Williamtown over the period over the period from 1956 to 2007

Seasonal trends in wind gusts are shown in Figure 25 over page. All seasons show an increase in average recorded wind gusts over the period from 1957 to 2007. This increase is most pronounced during summer and only the increase in summer was found to be statistically significant.

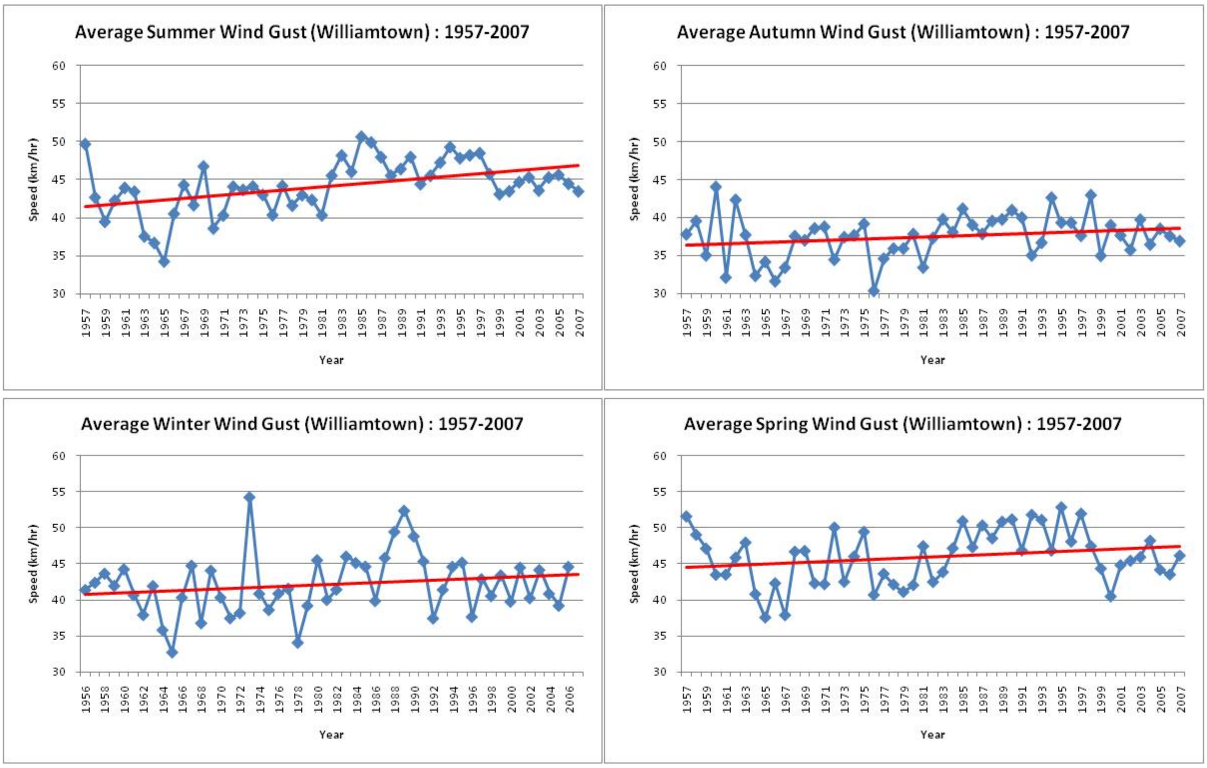


Figure 25 - Seasonal trends in average wind gusts (Williamtown) : 1957-2007

EXTREME EVENTS

Extreme weather events such as major storms, flooding rains or extreme temperature days, are a key concern for the community. Their occurrence is a significant source of risk, whether in terms of personal injury, loss of life, economic damage, social disruption or environmental damage. Accordingly, extreme events in the 95th percentile (that is, events in the top 5%) at individual Bureau of Meteorology recording stations have been analysed to project likely changes in their future occurrence.

For the purpose of this climate profile, extreme events are defined as:

- daily precipitation readings occurring in the 95th percentile;
- daily maximum temperature above 37^{o}C (number of extreme heat days); and
- daily minimum temperature below 0^{o}C (number of frost days).

In the case of precipitation, the percentiles are calculated from daily records with precipitation recorded (i.e. above 0mm). The data used for this analysis is provided by the BOM. Data from January 1948 to December 2007 are analysed for precipitation whereas data from January 1970 to December 2007 are analysed for temperature. This difference occurs as a result of the length of available records.

Variables with high spatial variability such as precipitation may result in only localised extreme events. Thus analysis on a regional level distorts results in that extreme localised events may be missed. For this reason, four (4) representative stations (Gresford, Paterson, Lostock Dam and Tocal) within the central climate zone are selected for the analysis of extreme precipitation and temperature events (Figure 26). Precipitation and temperature are often not available from the same stations. Thus the stations at Gresford and Paterson are used to examine precipitation whereas Lostock Dam and Tocal are used for temperature. It should also be noted that these stations are located relatively close together in the context of the entire central zone. Although areas within the zone are climatically similar, variability does occur and as such, the selected stations may not be representative of the full range of climatic conditions within the zone.

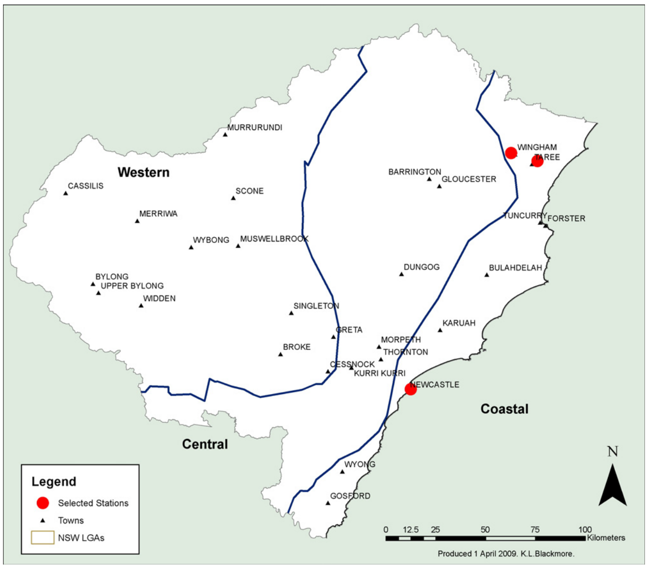


Figure 26 - Selected stations for analysis of extreme events

PRECIPITATION (HIGH RAINFALL EVENTS)

The number of days per year with precipitation events in the 95th percentile of all rain events over the period from 1948 to 2007 is shown in Figure 27. Both Gresford and Paterson show a decreasing linear trend in the frequency of occurrence of these events over the period from 1948 to 2007. These trends are not statistically significant.

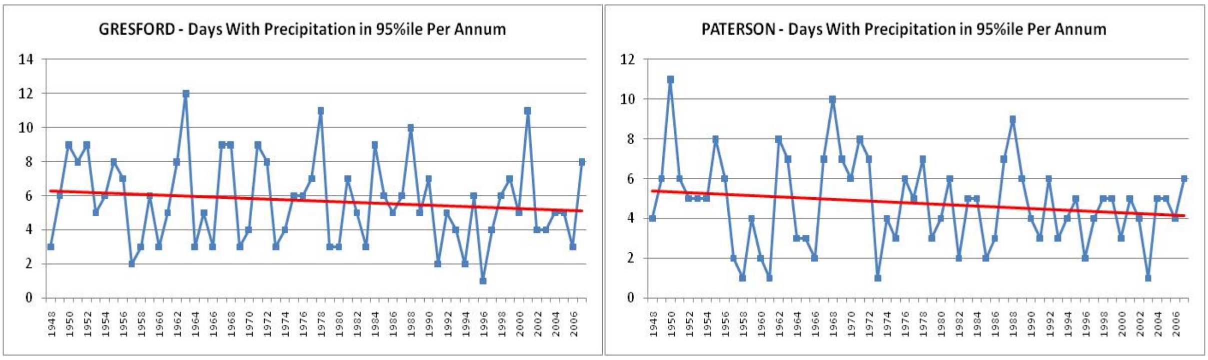


Figure 27 - Annual trend in days with rainfall in the 95th percentile (1948-2007)

Seasonally, the decreasing linear trends evident annually are reflected primarily in the summer and winter seasonal data (Figure 28 over page). A slight increase in the frequency of occurrence of 95th%ile rainfall events is evident during autumn and spring. As with the annual data, no seasonal trends are statistically significant.

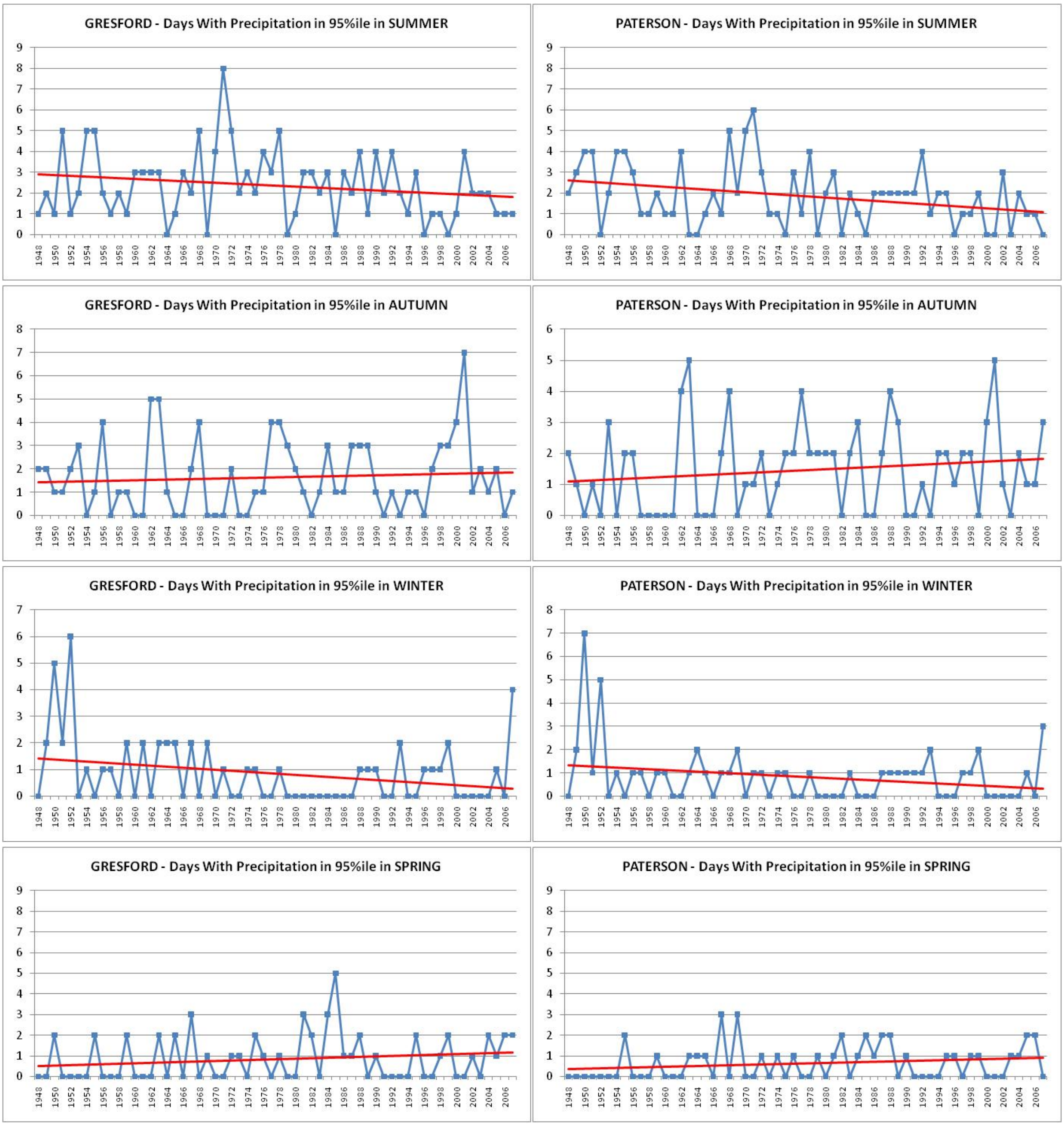


Figure 28 - Seasonal trend in days with rainfall in the 95th percentile (1948-2007)

EXTREME HEAT DAYS

An increasing linear trend in days per year with maximum temperature greater than or equal to 37^{o}C over the period from 1970-2007 is evident at Lostock Dam and Paterson (Figure 29). On average, Lostock Dam and Paterson record 7 to 8 and 5 to 6 days per annum with temperatures greater than or equal to 37^{o}C respectively. The increase in extreme heat days evident at Paterson is statistically significant.

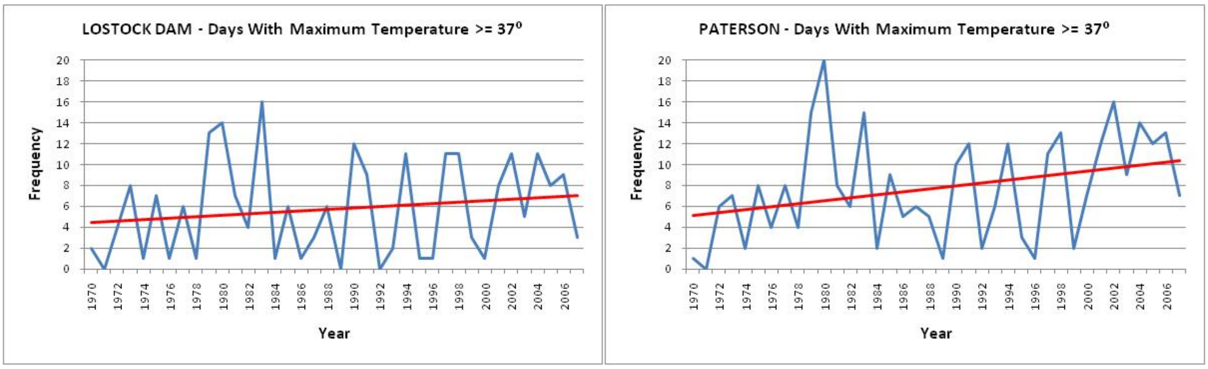


Figure 29 - Annual trend in extreme heat days at Lostock Dam and Paterson

FROSTS

Local variability in frost events (days per annum with minimum temperature less than or equal to 0^{o}C) exists in the central zone. Frost events were recorded in only two years at Lostock Dam over the period from 1970 to 2007, and 0 to 10 events per annum at Paterson (Figure 30). A decreasing linear trend in frost events is evident at Paterson and this trend is statistically significant. It should be noted however that this trend is primarily due to an increased frequency in frost events during 1970 and 1971. Removing these two years from the time series would result in no trend. Due to the limited number of occurrences per annum, seasonal analysis of frost events recorded at stations in the central zone is not possible.

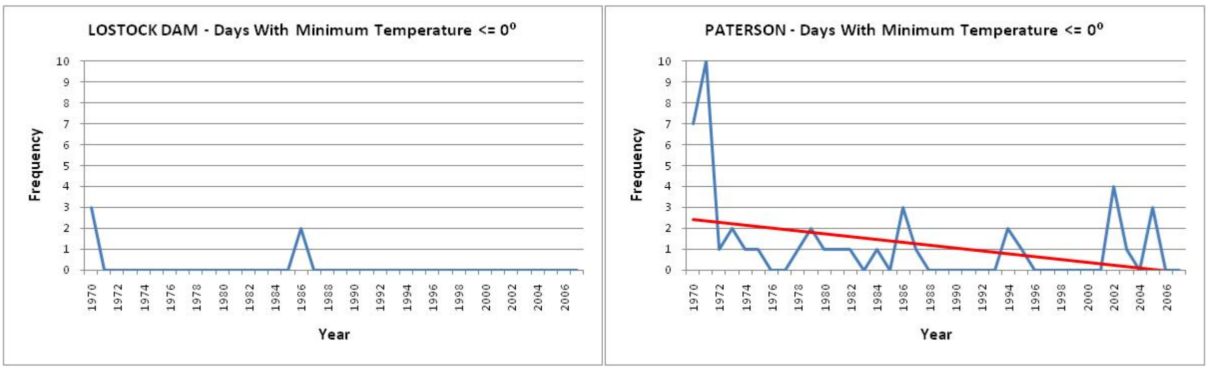


Figure 30 - Annual trend in frosts at Lostock Dam and Paterson

PRECIPITATION PROJECTIONS

An understanding of future changes can be obtained by contrasting projected values to those recorded historically. This section provides projections for each of the climate parameters for the central zone. Figure 31 shows projected seasonal average precipitation for the 2020-2040, 2040-2060 and 2060-2080 time horizons together with average recorded values for the 1948-1976 and 1977-2007 time periods. Little variation in projected values is evident over the three projected time horizons (i.e. 2020-2040, 2040-2060 and 2060-2080 projections are all similar). Projections for summer show an increase in precipitation on the 1977-2007 seasonal average in the central zone. The projected change in this season shows a future pattern similar to that recorded in the 1948-1976 interdecadal shift. Similar results are shown for winter, with an increase in precipitation more in line with the actual records for the 1948-1976 time period. A decrease in precipitation is projected for autumn in the central zone with a slight increase projected for spring.

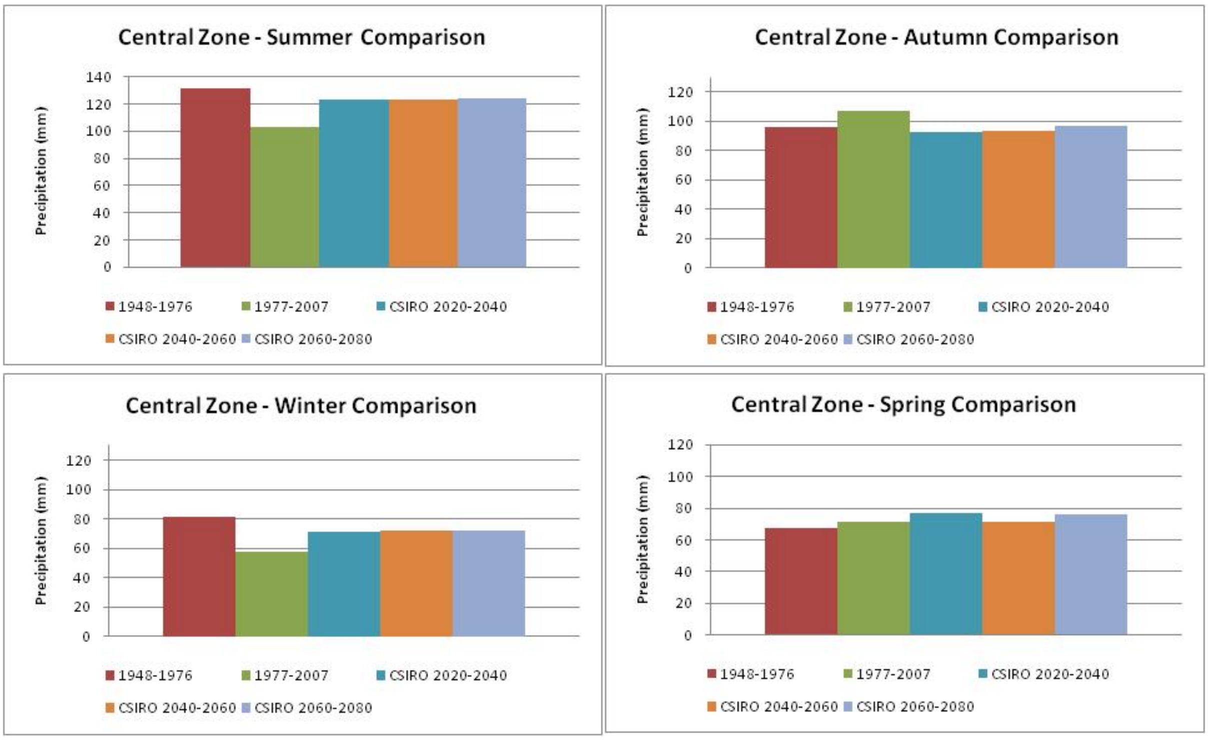


Figure 31 - Seasonal comparison of precipitation for historic interdecal time periods and future time horizons

Estimates of the magnitude of seasonal shifts, relative to the interdecadal periods, are presented in Figure 32 and Table 16 & 17 over page. Seasonal averages for the interdecadal periods (1948-1976 and 1977-2007) are calculated from BOM data and compared with projected seasonal averages calculated from the CSIRO Mk3.5 STs for the period from 2020 to 2080 (CSIRO ALL). This time period is used for the projected data (rather than the three individual time horizons) as analysis shows little variation between the projected periods. Projected precipitation patterns are similar to those recorded during the 1948 to 1976 time period with greatest deviations occurring during spring and winter. An approximate 12% decrease in winter precipitation and an 11% increase during spring, relative to the 1948 to 1976 time period, are projected.

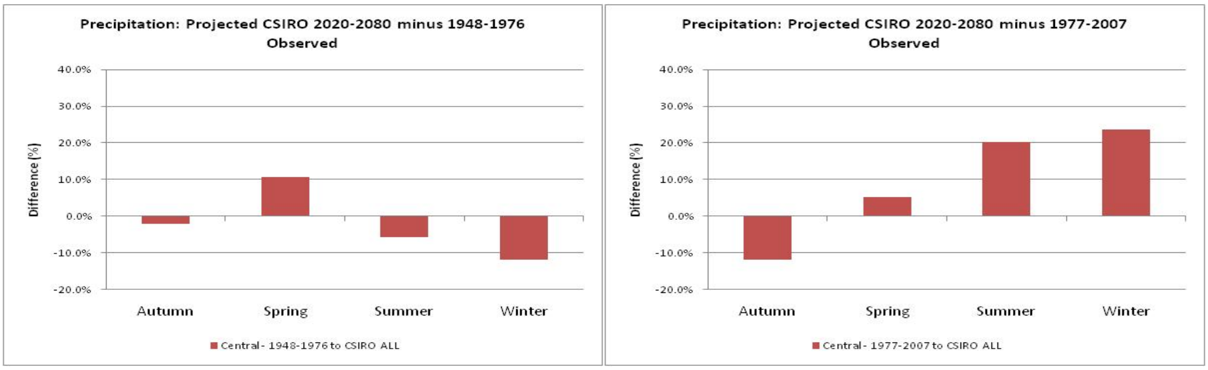


Figure 32 - Projected changes in precipitation relative to historic interdecal time periods

Season	Zone	Observed 1948-1976 (mm)	Projected Change (2020-2080) Relative to 1948-1976 (mm)	Projected Change (2020-2080) Relative to 1948-1976 (%)	Observed 1977-2007 (mm)	Projected Change (2020-2080) Relative to 1977-2007 (mm)	Projected Change (2020-2080) Relative to 1977-2007 (%)
Summer	Central (2)	132	-7	-6%	103	21	20%
Autumn	Central (2)	96	-2	-2%	107	-13	-12%
Winter	**Central (2)**	**81**	**-10**	**-12%**	58	14	24%
Spring	**Central (2)**	**67**	**7**	**11%**	71	4	5%

Table 16 - Projected changes in total seasonal precipitation relative to IPO periods

Precipitation (2020 – 2080) *Projected changes are relative to the 1948-1976 period* *(ie La Nina –ve phase)*			
Summer	**Autumn**	**Winter**	**Spring**
No significant change	No significant change	Drier: ~12% decrease	Wetter: ~11% increase

Table 17 - Summary of projected changes in precipitation (2020-2080)

The twenty year time periods analysed for each of the projected time horizons do not provide a sufficient length of record for the testing of the statistical significance of linear trends (due to the variability in the data). As such, changes in precipitation for the total projected period from 2020 to 2080 are considered (Figure 33 over page). In addition to showing linear trends (green line), total annual precipitation for the calibration period (1968-1996) is superimposed onto the projected data.

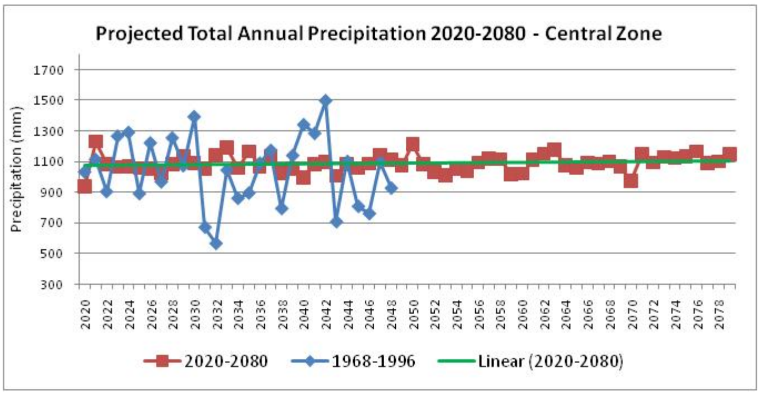


Figure 33 - Projected total annual precipitation for 2020-2080 showing a linear trend

Projections for the central zone, although still within the bounds of recorded natural variability for the 1968-1996 time period, show a tendency toward the upper bound. The statistical significance of the linear trend for precipitation for the 2020-2080 time period was tested using regression analysis. An increase of approximately 31.0mm over the entire period (2020-2080) is projected and the results from the regression analysis indicate that the increase is not statistically significant (i.e. $P>0.05$).

TEMPERATURE PROJECTIONS

MINIMUM TEMPERATURE PROJECTIONS

Figure 34 shows projected seasonal average minimum temperature for the 2020-2040, 2040-2060 and 2060-2080 time horizons together with average recorded values for the 1970-2007 time period for the central climate zone. Little variation in projected values for summer and winter is evident over the three time horizons (i.e. 2020-2040, 2040-2060 and 2060-2080 projections are all similar). Projections include:

- an increase in average minimum temperature during summer relative to the 1970-2007 time period
- a general increasing trend is evident during autumn, however some variation occurs across the three time horizons
- a marked increase during winter relative to the 1970-2007 average values.
- Some variation for spring is also evident across the three time horizons. A decrease is projected for the 2020-2040 time horizon (relative to the 1970-2007 time period) followed by a further decrease in 2040-2060. Projections show an increase in minimum temperature, relative to the preceding time horizons, in the 2060-2080 period. This shift returns minimum temperatures to the level slightly higher than those experienced during the historic time period.

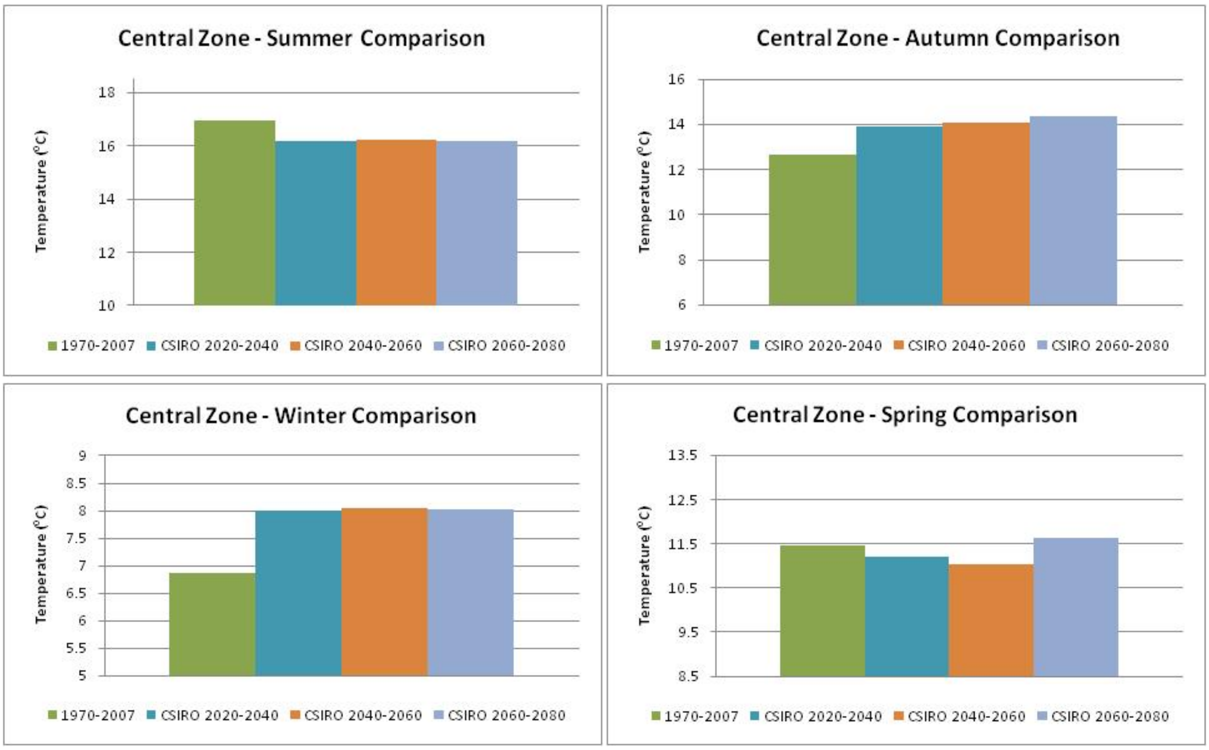


Figure 34 - Seasonal comparison of minimum temperature for historic interdecal time periods and future time horizons

Estimates of the magnitude of seasonal shifts in minimum temperature, relative to the 1970-2007 time period, are presented in Figure 35 & Table 18. Seasonal averages for the period from 1970-2007 are calculated from BOM data and compared with projected seasonal averages calculated from the CSIRO Mk3.5 STs for the period from 2020 to 2080 (CSIRO ALL). Note that these results should be considered in the context of the changes in the autumn and spring values for the projected time horizons discussed above. Additionally, consistent historic records are not available to cover the preceding two IPO phases (i.e. –ve La Nina–like phase for 1948-1976 and +ve El Nino-like phase for 1977-2007). Thus, the time period from 1970-2007 covers a predominantly El Nino-like historical period.

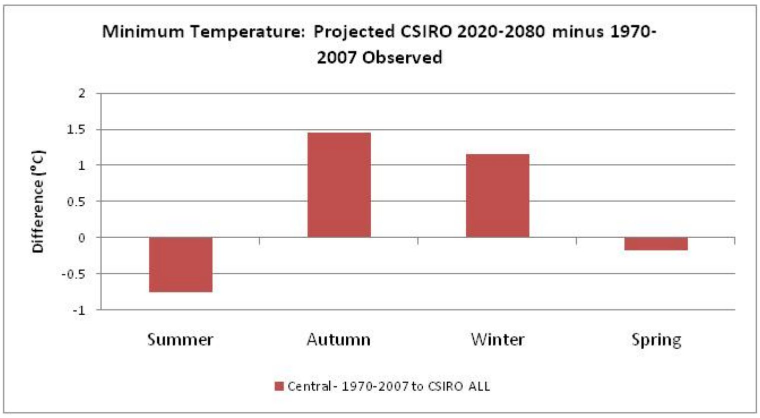


Figure 35 - Projected changes in minimum temperature relative to historic interdecal time periods

Minimum temperature (2020-2080) *Projected changes are relative to the 1970-2007 period*			
Summer	**Autumn**	**Winter**	**Spring**
Cooler: ~0.8°C decrease	Warmer: ~1.5°C increase	Warmer: ~1.2°C increase	Cooler: ~0.2°C decrease

Table 18 - Summary of projected changes in minimum temperature (2020-2080)

Changes in average minimum temperature for the projected period from 2020 to 2080 are shown in Figure 36 over page. In addition to showing the linear trend (green line), average annual minimum temperature for the period from 1970-1996 is superimposed onto the projected data. Projected values show a propensity to extend beyond the bounds of natural variability experienced during the period from 1970-1996. Higher average annual minimum temperatures than those previously experienced are projected. Average minimum temperatures show an increasing trend over the period from 2020-2080. This trend is statistically significant at the 5% level ($P<0.05$).

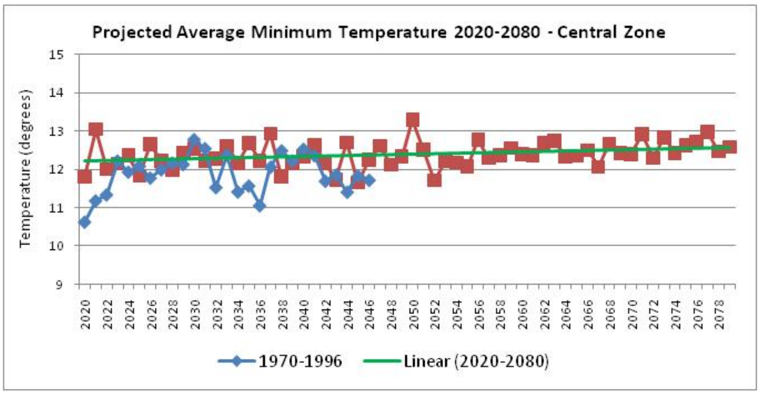


Figure 36 - Projected total average minimum temperature for 2020-2080 showing linear trend

MAXIMUM TEMPERATURE PROJECTIONS

Figure 37 (over page) shows projected seasonal average maximum temperature for the 2020-2040, 2040-2060 and 2060-2080 time horizons together with average recorded values for the 1970-2007 time period for the central climate zone. As with average minimum temperature, little variation in projected values for summer and winter is evident over the three time horizons (i.e. 2020-2040, 2040-2060 and 2060-2080 projections are all similar). Projections include:

- little or no change in average maximum temperature during summer relative to the 1970-2007 time period.
- an general increasing trend during autumn, however some variation occurs across the three time horizons
- increases during winter with each of the projected time periods recording similar values.
- Some variation for spring is evident across the three time horizons. A decrease is projected for the 2020-2040 time horizon (relative to the 1970-2007 time period) followed by increases (relative to the 2020-2040 time horizon) in the 2040-2060 and 2060-2080 time periods. Thus spring projections are for an initial decrease in average maximum temperature followed by moderate increases. These increases fail to return average maximum temperature to the levels experienced during the historic time period.

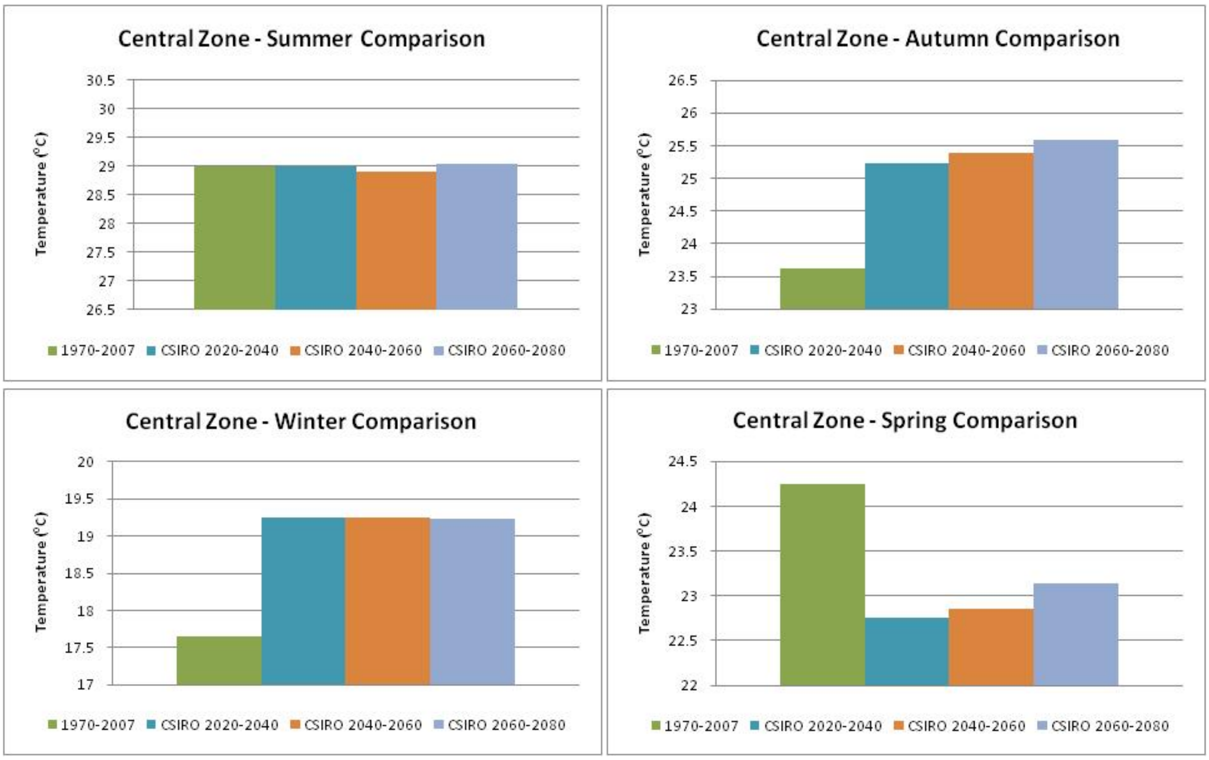


Figure 37 - Seasonal comparison of maximum temperature for historic interdecal time periods and future time horizons

Maximum temperature (2020-2080) *Projected changes are relative to the 1970-2007 period*			
Summer	**Autumn**	**Winter**	**Spring**
Minimal change	Warmer: ~1.8°C increase	Warmer: ~1.6°C increase	Cooler: ~1.3°C decrease

Table 19 – Summary of projected changes in maximum temperature (2020-2080)

Estimates of the magnitude of seasonal shifts in maximum temperature, relative to the 1970-2007 time period, are presented in Table 19 above and Figure 38 over page. Seasonal averages for the period from 1970-2007 are calculated from BOM data and compared with projected seasonal averages calculated from the CSIRO Mk3.5 STs for the period from 2020 to 2080 (CSIRO ALL). Note that these results should be considered in the context of the changes in the autumn and spring values for the projected time horizons discussed above. Additionally, consistent historic records are not available to cover the preceding two IPO phases (i.e. –ve La Nina–like phase for 1948-1976 and +ve El Nino-like phase for 1977-2007). Thus, the time period from 1970-2007 covers a predominantly El Nino-like historical period.

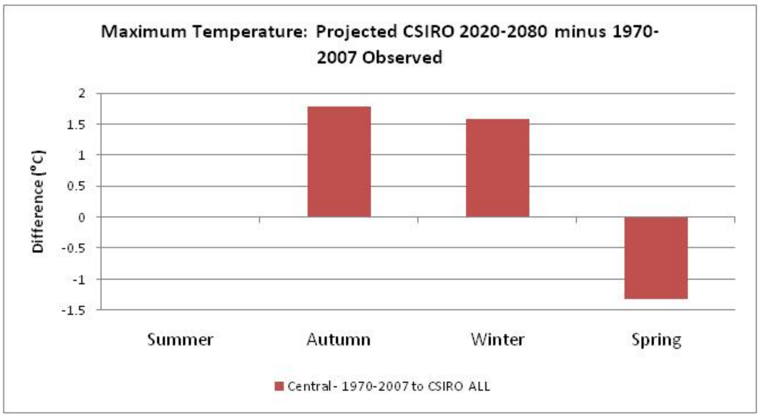


Figure 38 - Projected changes in maximum temperature relative to historic interdecal time periods

Changes in average maximum temperature for the projected period from 2020 to 2080 are shown in Figure 39. In addition to showing the linear trend (green line), average annual maximum temperature for the period from 1970-1996 is superimposed onto the projected data. Projected values show a propensity to extend beyond the bounds of natural variability experienced during the period from 1970-1996. Higher average annual maximum temperatures than those previously experienced are projected. Average maximum temperatures show an increasing trend over the period from 2020-2080 of approximately 0.3^{o}C. This trend is statistically significant at the 5% level ($P<0.05$).

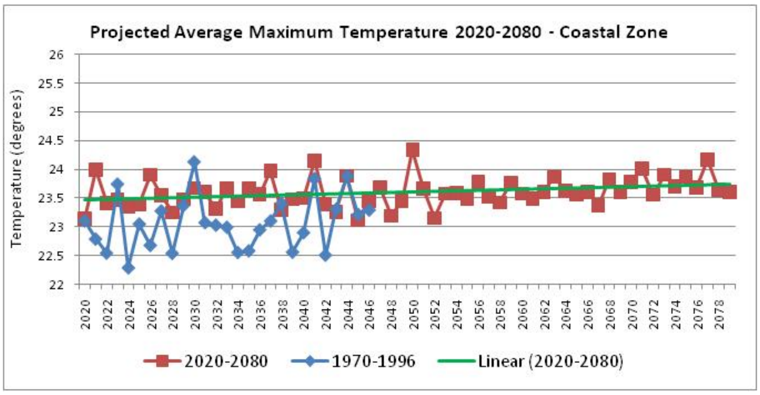


Figure 39 - Projected total average maximum temperature for 2020-2080 showing linear trend

AVERAGE TEMPERATURE PROJECTIONS

Average temperature is calculated from the minimum and maximum temperature values (i.e. (Minimum Temp + Maximum Temp) / 2). Figure 40 shows projected seasonal average temperature for the 2020-2040, 2040-2060 and 2060-2080 time horizons together with average recorded values for the 1970-2007 time period for the regions' central climate zone. Following the average minimum and maximum temperature patterns, little variation in projected values for summer and winter is evident over the three time horizons (i.e. 2020-2040, 2040-2060 and 2060-2080 projections are all similar). Projections include:

- a decrease in average temperature during summer relative to the 1970-2007 time period, whereas winter projections show increases.
- a generally increasing trend during autumn with some variation across the three time horizons.
- Some variation for spring is evident across the three time horizons. A decrease is projected for the 2020-2040 and 2040-2060 time horizons (relative to the 1970-2007 time period) followed by an increase (relative to the 2040-2060 time horizon) in the 2060-2080 time period. Thus spring projections are for initial decreases in average temperature followed by a moderate increase. This increase fails to return average temperature to the levels experienced during the historic time period thus an overall decrease in spring average temperature is projected.

Figure 40 - Seasonal comparison of average temperature for historic interdecal time periods and future time horizons

Estimates of the magnitude of seasonal shifts in average temperature, relative to the 1970-2007 time period, are presented in Figure 41 and Table 20 over page. Seasonal averages for the period from 1970-2007 are calculated from BOM data and compared with projected seasonal averages calculated from the CSIRO Mk3.5 STs for the period from 2020 to 2080 (CSIRO ALL). Note that these results should be considered in the context of the changes in the autumn and spring values for the projected time horizons discussed above. Additionally, consistent historic records are not available to cover the preceding two IPO phases (i.e. –ve La Nina–like phase for 1948-1976 and +ve El Nino-like phase for 1977-2007). Thus, the time period from 1970-2007 covers a predominantly El Nino-like historical period.

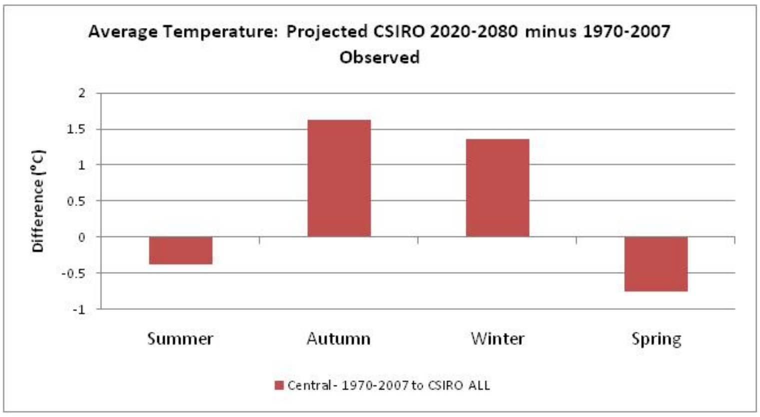


Figure 41 - Projected changes in average temperature relative to historic interdecal time periods

Average temperature (2020-2080) *Projected changes are relative to the 1970-2007 period*			
Summer	**Autumn**	**Winter**	**Spring**
Cooler:~0.4°C Decrease	Warmer: ~1.6°C increase	Warmer: ~1.4°C increase	Cooler: ~0.8°C decrease

Table 20 – Summary of projected changes in average temperature (2020-2080)

Changes in annual average temperature for the projected period from 2020 to 2080 are shown in Figure 42 over page. In addition to showing linear trends (green line), average temperature for the period from 1970-1996 is superimposed onto the projected data. Projected values for the central zone show a propensity to extend beyond the bounds of natural variability experienced during the calibration period from 1968-1996. Higher average temperatures than those previously experienced are projected. Average temperatures show an increasing trend over the period from 2020-2080 of approximately 0.3^{o}C. This trend is statistically significant at the 5% level ($P<0.05$).

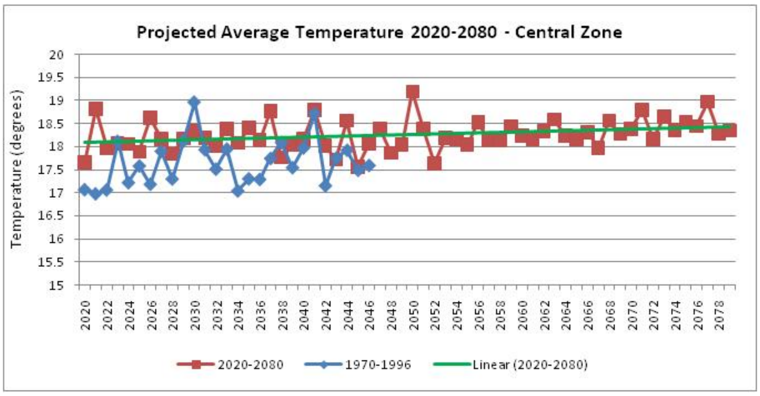


Figure 42 - Projected annual average temperature for 2020-2080 showing linear trend

PAN EVAPORATION PROJECTIONS

Figure 43 shows projected seasonal average pan evaporation for the 2020-2040, 2040-2060 and 2060-2080 time horizons together with average recorded values for the 1970-2007 time period for the region's central climate zone.

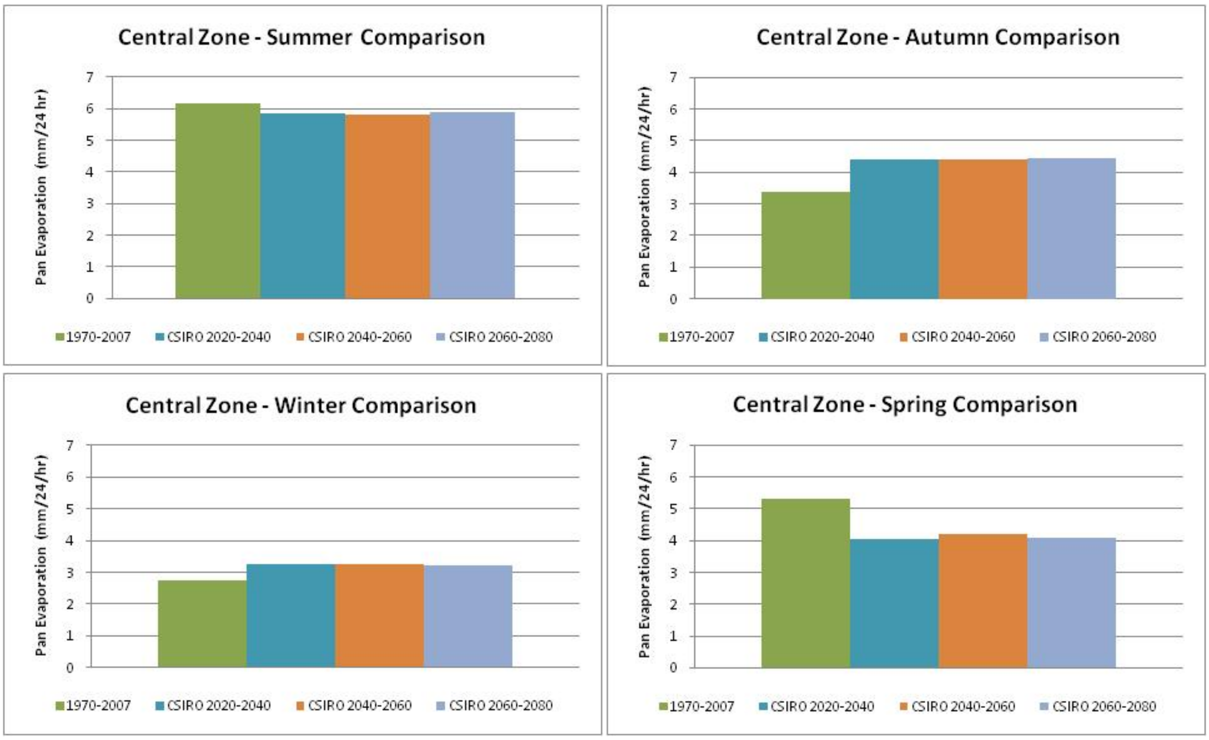


Figure 43 - Seasonal comparison of pan evaporation for historic interdecal time periods and future time horizons

Little variation in projected values is evident over the three projected time horizons (i.e. 2020-2040, 2040-2060 and 2060-2080 projections are all similar). Projections for summer show a decrease in pan evaporation on the 1970-2007 seasonal average. Similar results are shown for spring, with a decrease in pan evaporation also projected, albeit larger. Increases in pan evaporation are projected for autumn and winter.

These seasonal increases and decreases in pan evaporation (for the entire 2020 to 2080 projected period), relative to the 1970-2007 observations, are shown in Figure 44 and Table 21 over page. Seasonal shifts appear to balance out to produce no projected change in annual pan evaporation.

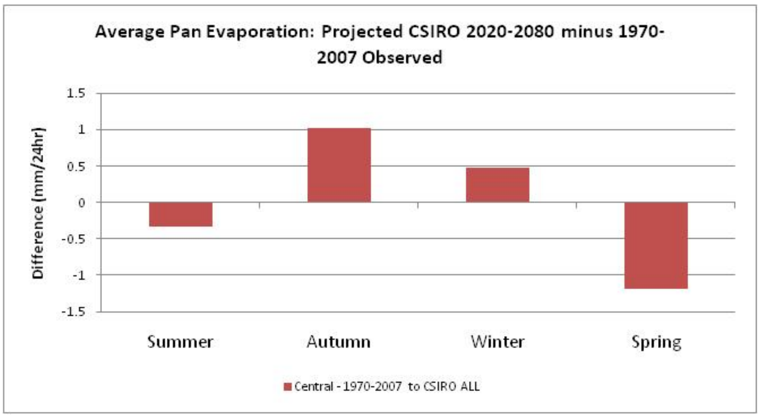


Figure 44 - Projected changes in average pan evaporation relative to historic interdecal time periods

Average pan evaporation (2020-2080) *Projected changes are relative to the 1970-2007 period*			
Summer	**Autumn**	**Winter**	**Spring**
Wetter: ~0.3mm/24hr decrease	Drier: ~1.0mm/24hr increase	Drier: ~0.5mm/24hr increase	Wetter: ~1.2mm/24hr decrease

Table 21 – Summary of projected changes in average pan evaporation (2020-2080)

Changes in average annual pan evaporation for the projected period from 2020 to 2080 are considered using linear trends and regression analysis (Figure 45). In addition to showing linear trends (green line), average annual pan evaporation for as much of the calibration period (1972-1996) as is covered by the BOM data is superimposed onto the projected data.

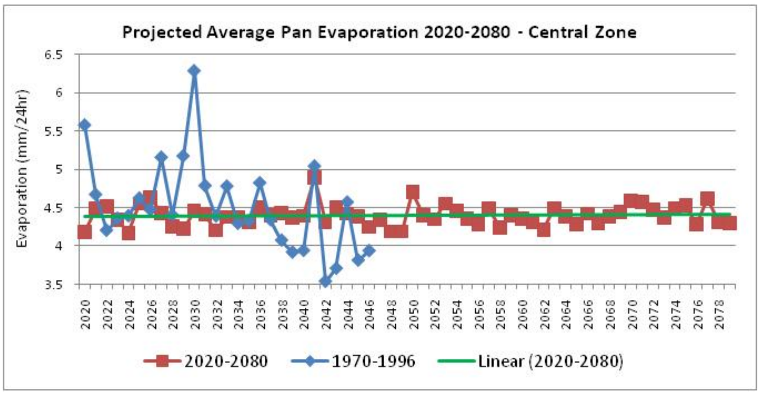
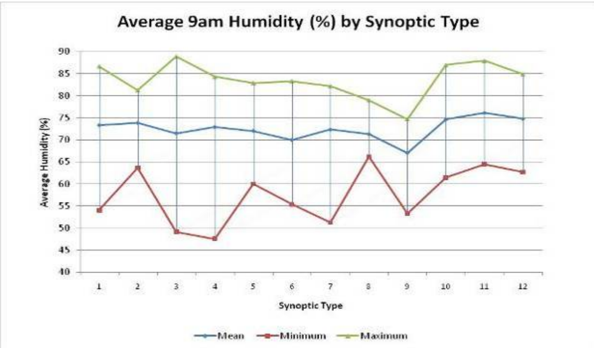


Figure 45 - Projected annual average pan evaporation for 2020-2080 showing linear trend

The projected data lies well within the bounds of natural variability recorded during the calibration period. The statistical significance of the linear trend for average annual pan evaporation for the 2020-2080 time period was tested using regression analysis. No change is projected.

RELATIVE HUMIDITY

Previous analysis identified that an insufficient number of appropriate BOM relative humidity recording stations are present in the central zone to enable spatial distribution patterns to be produced (Blackmore & Goodwin 2008). As such, relative humidity at 9am and 3pm is analysed by CSIRO ST averaged for the entire region rather than individual zones. Figure 46 shows the average, minimum and maximum humidity range for each of the CSIRO STs.



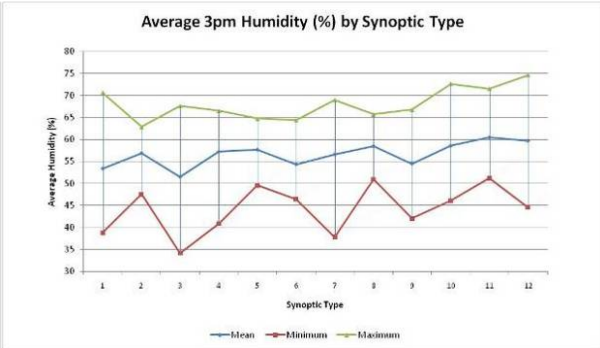


Figure 46 - 9am and 3pm humidity by CSIRO ST

Relationships between the CSIRO synoptic types and relative humidity in the region include:

- Average 9am and 3pm humidity is higher during summer, although only marginally.
- The dominant summer STs (11 and 12) are associated with average humidity of approximately 75% at 9am and 60% at 3pm whereas the dominant winter types (1 and 3) are associated with average humidity of approximately 72% at 9am and 52% at 3pm.
- Substantial differences in the humidity range associated with each CSIRO ST are notable. In particular, STs 2 and 8 show low variability at both 9am and 3pm; ST5 also shows low variability at 3pm. These relationships suggest that changes in the frequency of occurrence of STs for the projected time horizons will have limited or no impact on average humidity due to the limited differentiation in this climate variable by CSIRO ST. However, differences in the frequency of occurrence of STs 2, 5 and 8 may impact on the variability of relative humidity in the region.

Figure 47 (over page) shows projected seasonal average humidity recorded at 9am and 3pm for the 2020-2040, 2040-2060 and 2060-2080 time horizons together with average recorded values for the 1970-1996 time period. No discernable change in humidity at either 9am or 3pm is projected to occur during summer. A slight decrease in both 9am and 3pm humidity is projected for autumn and winter, whereas a slight increase is projected for spring. Little variation in projected values is evident over the three projected time horizons (i.e. 2020-2040, 2040-2060 and 2060-2080 projections are all similar).

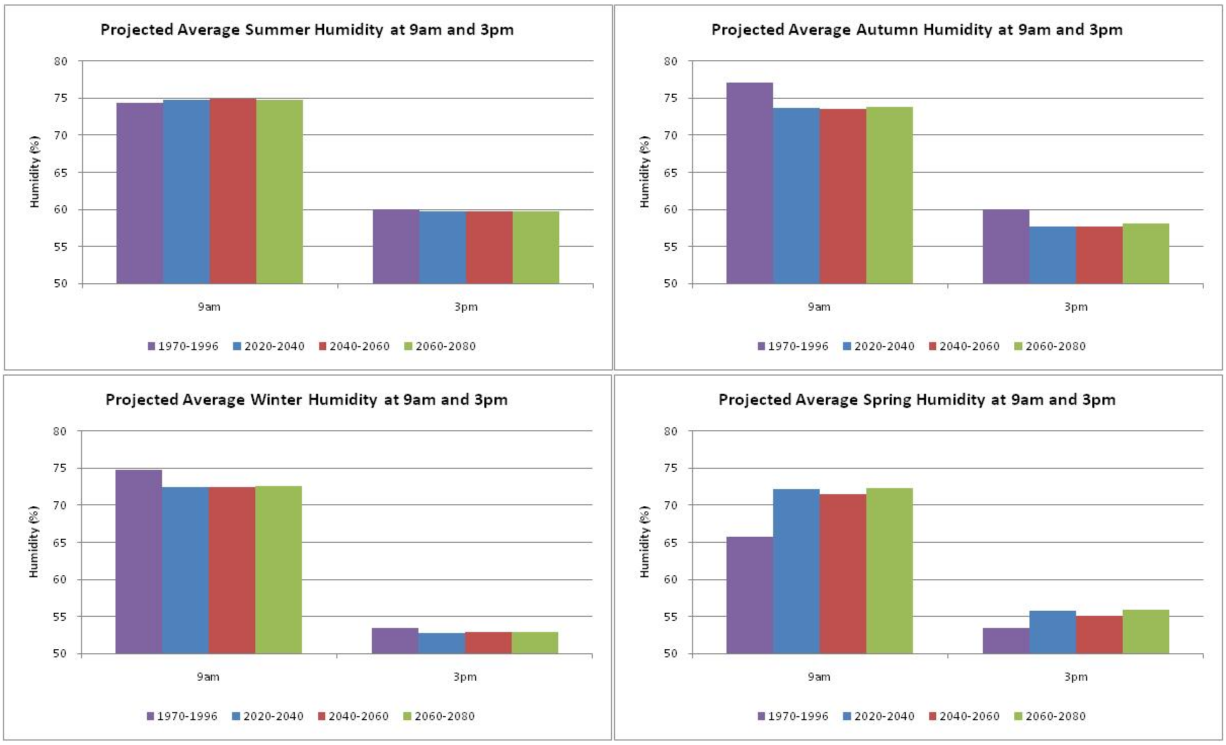


Figure 47 - Seasonal comparison of 9am and 3pm humidity for historic time period and future time horizons

Estimates of the magnitude of seasonal shifts, relative to the 1970-1996 period, is presented in Figure 48 below and Table 22 over page. Seasonal averages for the historic time period (1970-1996) are calculated from BOM data and compared with projected seasonal averages calculated from the CSIRO Mk3.5 STs for the period from 2020 to 2080 (CSIRO ALL). A negative change signifies a decrease in humidity over the projected time horizon (relative to the historic time period) whereas a positive change signifies an increase.

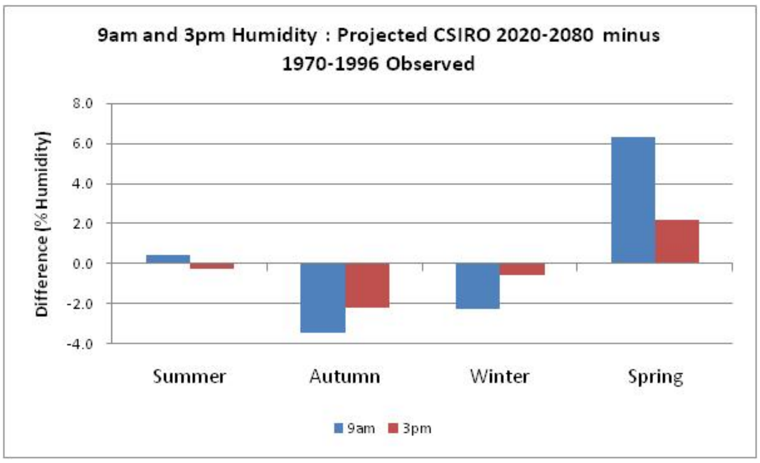


Figure 48 - Estimates of projected humidity shifts relative to the 1970-1996 period

Average temperature (2020-2080) *Projected changes are relative to the 1970-2007 period*				
	Summer	**Autumn**	**Winter**	**Spring**
9am Humidity	More Humid: ~0.4% increase	Less Humid: ~3.4% decrease	Less Humid: ~2.2% decrease	More Humid: ~6.3% increase
3pm Humidity	Less Humid: ~0.2% decrease	Less Humid: ~2.2% decrease	Less Humid: ~0.6% decrease	More Humid: ~2.2% increase

Table 22 - Summary of projected changes in 9am and 3pm humidity

Changes in relative humidity for the projected period from 2020 to 2080 are considered in Figure 49. In addition to showing linear trends (green line), average annual relative humidity for the period from 1970-1996 is superimposed onto the projected data. There is no evident increase in average annual relative humidity projected and projected values are within the bounds of natural variability experienced during the 1970-1996 time period.

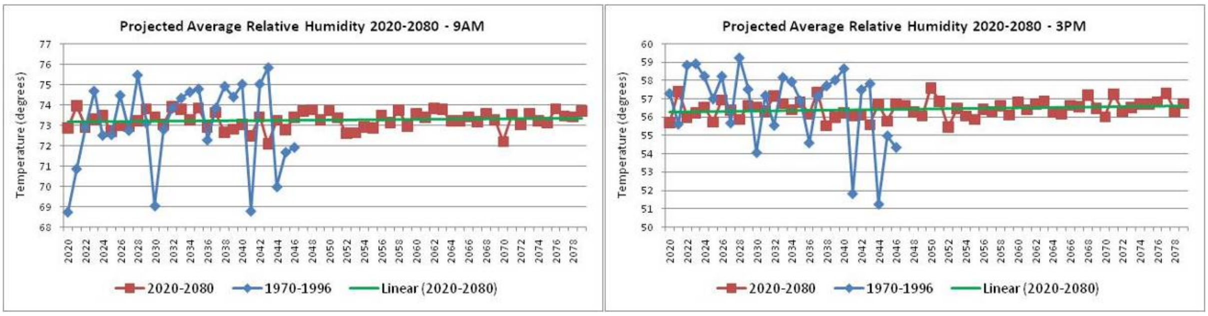


Figure 49 - Projected average annual 9am and 3pm relative humidity for 2020-2080 showing linear trends

WATER BALANCE

Water balance was calculated by subtracting the average daily pan evaporation (mm/24hr) from the average daily precipitation. These calculations were used to derive both seasonal and annual projections of water balance. Water balance values from this simple equation are presented as average daily millimeters (mm). An increase in (or positive value) water balance is associated with moister conditions whereas a decrease (or negative value) in water balance is associated with drier conditions.

Little variation in projected values for summer is evident over the three time horizons (i.e. 2020-2040, 2040-2060 and 2060-2080 projections are all similar) (Figure 50 over page). Projections (relative to the 1970-2007 time period) include:

- an increase in water balance (i.e. moister) during summer
- a decrease in water balance (i.e. drier) during autumn
- a slight increase during winter for 2020-2080.

- increases during spring in all time horizons. The strongest increase is projected to occur during the 2040-2060 time period.

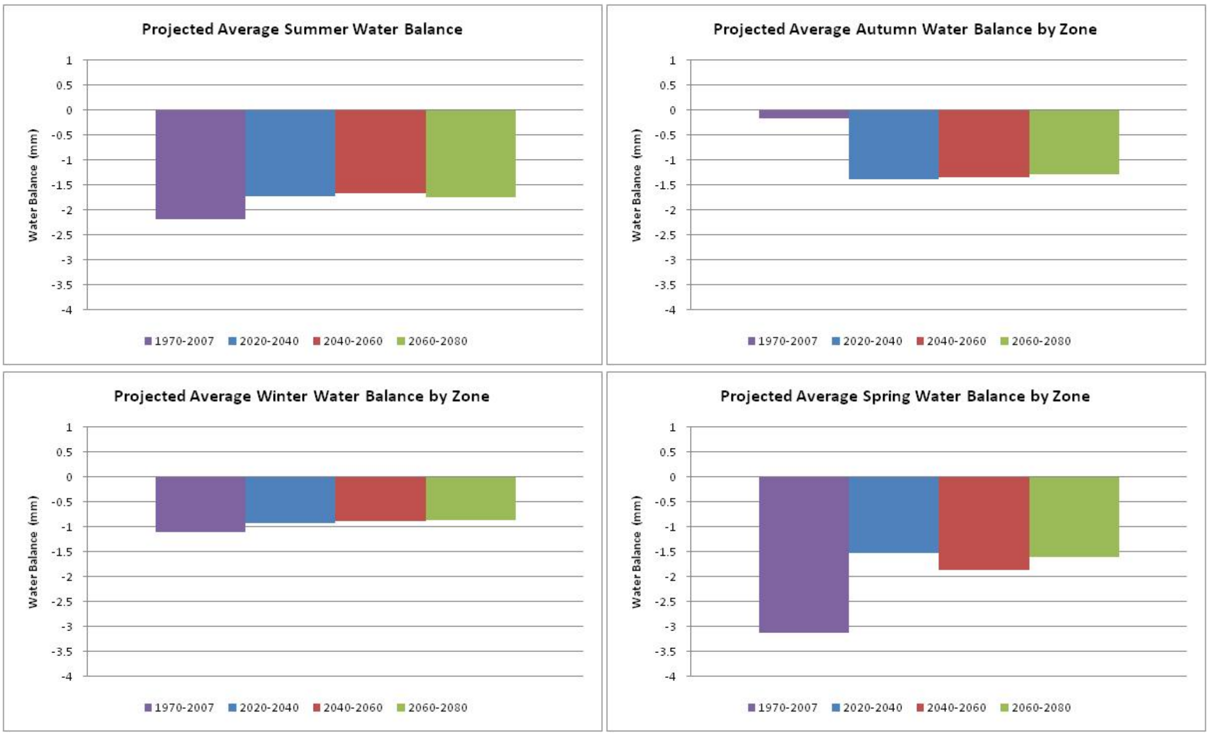


Figure 50 - Seasonal comparison water balance for historic interdecal time periods and future time horizons

Estimates of the magnitude of seasonal shifts, relative to the 1970-2007 time period, are presented in Figure 51 below and Table 23 over page. Seasonal averages for the period from 1970-2007 are calculated from BOM data and compared with projected seasonal averages calculated from the CSIRO Mk3.5 STs for the period from 2020 to 2080 (CSIRO ALL). Note that these results should be considered in the context of the changes in the projected time horizons discussed above. Additionally, consistent historic records are not available to cover the preceding two IPO phases (i.e. –ve La Nina–like for 1948-1976 and +ve phase El Nino-like for 1977-2007). Thus the time period from 1970-2007 covers a predominantly El Nino-like historic period.

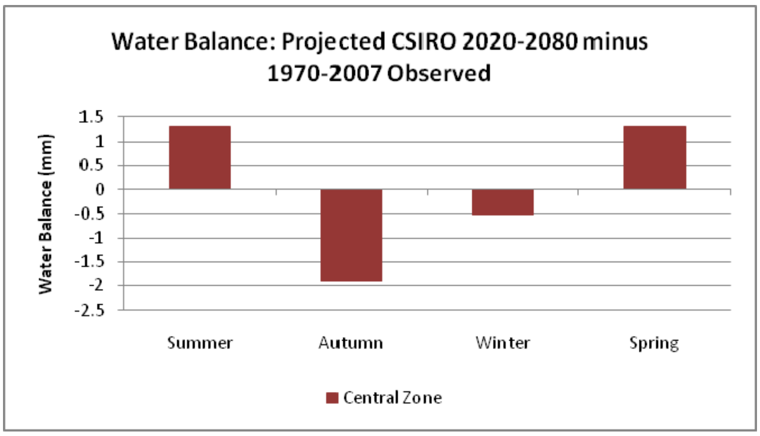


Figure 51 - Projected changes in average water balance relative to historic interdecal time period

Average water balance (2020-2080) *Projected changes are relative to the 1970-2007 period*			
Summer	**Autumn**	**Winter**	**Spring**
Wetter: ~1.3mm/24hr increase	Drier: ~1.9mm/24hr decrease	Drier: ~0.5mm/24hr decrease	Wetter: ~1.3mm/24hr increase

Table 23 - Summary of projected changes in water balance

Changes in average annual water balance for the projected period from 2020 to 2080 are shown in Figure 52. In addition to showing linear trends (green line), average annual water balance for the period from 1970-1996 is superimposed onto the projected data. Projected values for the central zone show no propensity to extend beyond the bounds of natural variability experienced during the period from 1970-1996. Average water balance shows a decreasing trend (ie drier) over the period from 2020-2080 in the central zone. This trend is statistically significant at the 5% level (P<0.05).

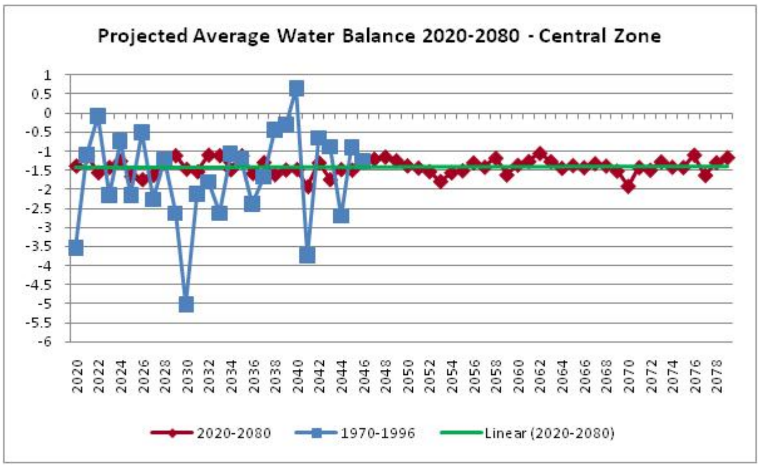


Figure 52 - Projected annual average water balance for 2020-2080 showing linear trend

AVERAGE WIND SPEED AND WIND GUSTS

Figure 53 shows projected seasonal average wind speed for the 2020-2040, 2040-2060 and 2060-2080 time horizons together with average recorded values for the 1970-2007 time period for the regions' central climate zone. Note that average wind speed data from BOM recording stations does not include directional information. Little variation in projected values is evident over the three time horizons (i.e. 2020-2040, 2040-2060 and 2060-2080 projections are all similar). Projections for summer and winter show little or no change in average wind speed relative to the 1970-2007 time period. Projections for autumn show an increase in average wind speed whereas spring projections show a decrease.

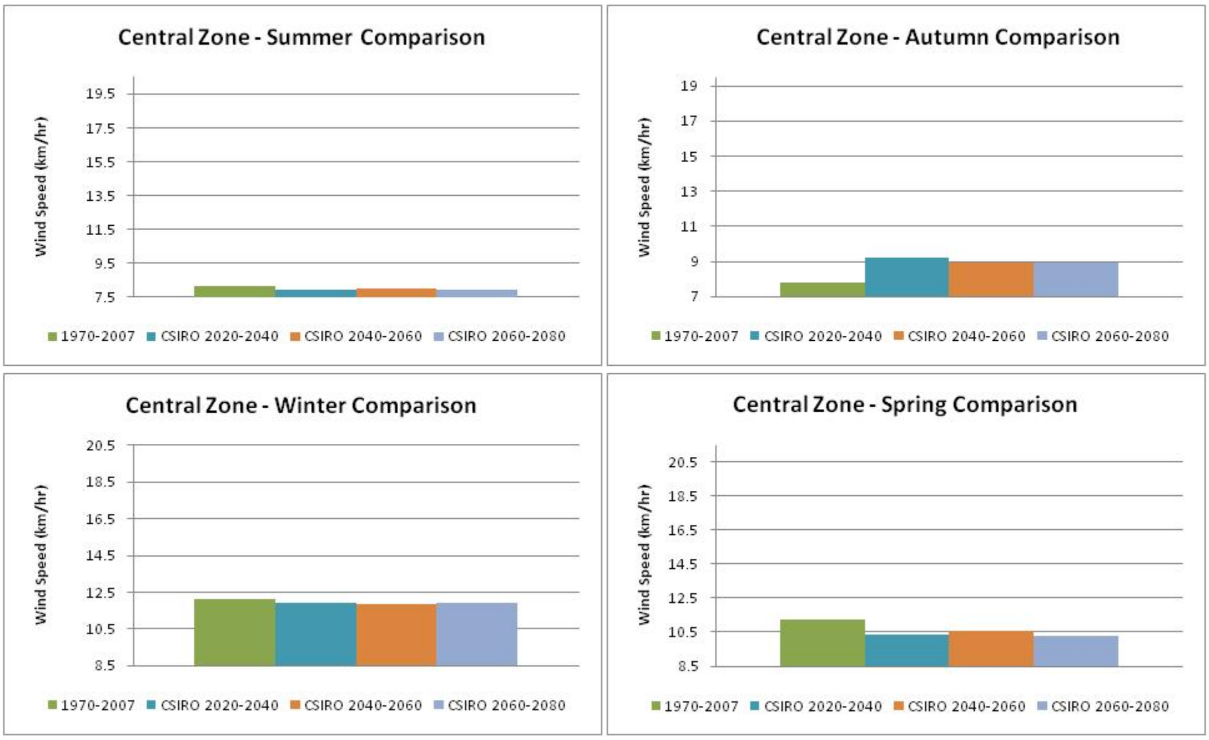


Figure 53 - Seasonal comparison of average wind speed for historic interdecal time period and future time horizons

Estimates of the magnitude of seasonal shifts, relative to the 1970-2007 time period, are presented in Figure 54 below and Table 24 over page. Seasonal averages for the period from 1970-2007 are calculated from BOM data and compared with projected seasonal averages calculated from the CSIRO Mk3.5 STs for the period from 2020 to 2080 (CSIRO ALL).

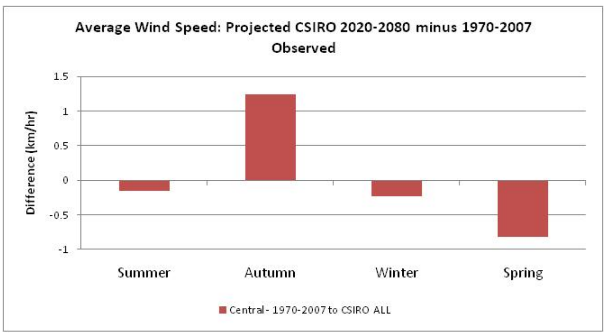


Figure 54 - Projected changes in average wind speed relative to historic interdecal time period

Wind Speed (2020-2080) *Changes are reported in average km/hr relative to 1970-2007.*		
Season	**Decrease**	**Increase**
Summer	~0.1km/hr	
Autumn		~1.2km/hr
Winter	~0.2km/hr	
Spring	~0.8km/hr	

Table 24 - Summary of projected changes in wind speed

Changes in annual average wind speed for the projected period from 2020 to 2080 are shown in Figure 55. In addition to showing linear trends (green line), average annual wind speed for the period from 1970-1996 is superimposed onto the projected data. Projected values for the central climate zone do not extend beyond the bounds of natural variability experienced during the period from 1970-1996. As suggested by the seasonal shifts in average wind speed, no change in annual average wind speed is projected.

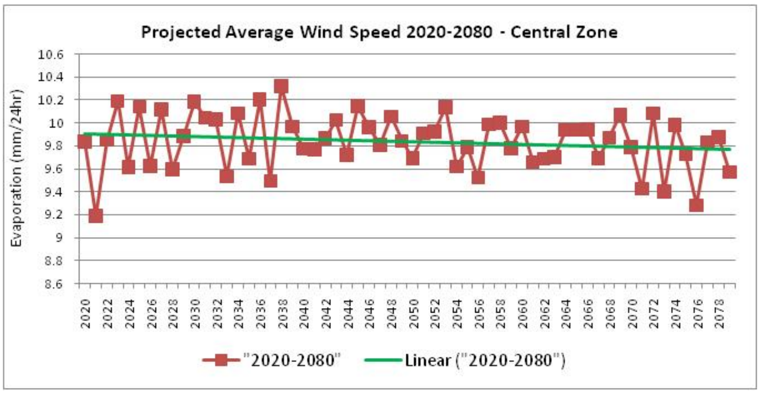


Figure 55 - Projected annual average wind speed for 2020-2080 showing linear trend

Wind gust rose diagrams showing the relationship between the CSIRO ST's and wind gust are shown in Figure 56 over page. This identifies that:

- ST 2 is associated with the highest wind gusts in the region. These gusts occur during winter and are from a predominately westerly direction.
- STs 1 through to 6 all produce predominately westerly winds.
- STs 7, 8 and 9 are associated with wind gusts from multiple directions, however strongest gusts occur from both the west and the south.
- ST10 is associated with gusts predominantly from the south and south east.
- STs 11 and 12 are associated with easterly on-shore gusts as well as those from the north east, south east and southerly directions.

Projected changes in wind gust for the 2020-2080 period (relative to 1970-2007) include:

- Decreases in the frequency of occurrence of STs 2 and 3 during winter should decrease the intensity of wind gusts during this season.
- Increases in STs 11 and 12 should produce more onshore wind gusts during summer.

There is no indication from the ST patterns that the intensity of summer wind gusts will change.

Further details on projected changes in wind gust relative to each synoptic type are summarised in Table 25 over page.

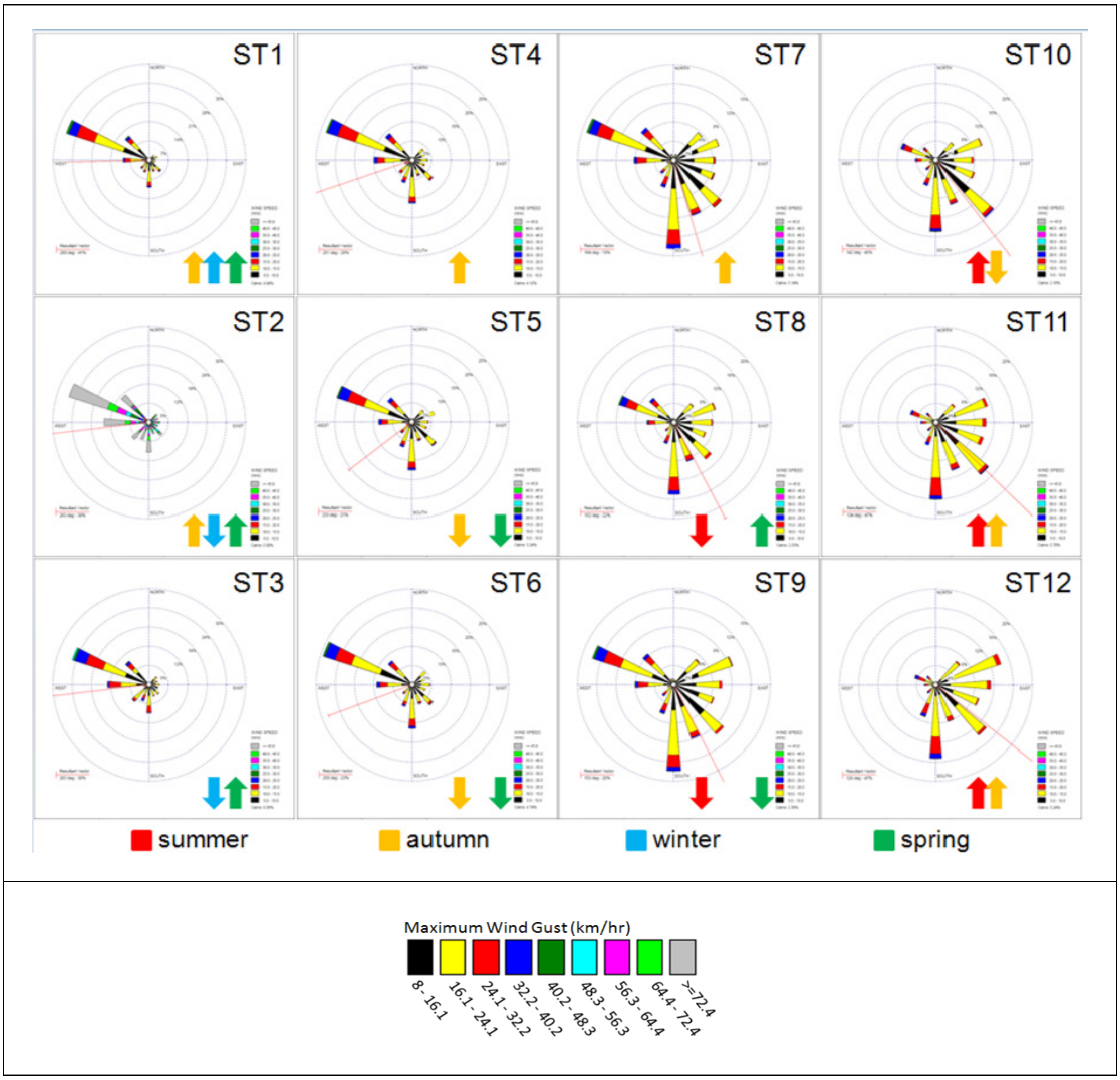


Figure 56 - Regional maximum wind gust patterns for CSIRO STs

ST	Dominant Wind Direction	Change Projected
1	North-Westerly	Increase in autumn, winter and spring
2	North-Westerly	Increase in autumn and spring, decrease in winter
3	North-Westerly	Decrease in winter, increase in spring
4	North-Westerly, Southerly	Increase in autumn
5	North-Westerly, Southerly	Decrease in autumn and spring
6	North-Westerly, Southerly	Decrease in autumn and spring
7	Southerly, North-Westerly	Increase in autumn
8	Southerly, North-Westerly	Decrease in summer, increase in spring
9	Southerly, North-Westerly	Decrease in summer and spring
10	Southerly, South-Easterly	Increase in summer, decrease in autumn
11	Southerly, South-Easterly, Easterly	Increase in summer and autumn
12	Southerly, North-Easterly, South-Easterly	Increase in summer and autumn

Table 25 - Summary of projected wind gust changes for each synoptic type

EXTREME EVENT PROJECTIONS

As identified previously, for the purpose of this climate profile, extreme events are defined as:

- Daily precipitation readings occurring in the 95th percentile;
- Daily maximum temperature above 37^{o}C (number of extreme heat days); and
- Daily minimum temperature below 0^{o}C (number of frost days).

Two (2) representative stations within the central climate zone have been selected for the analysis of extreme precipitation and temperature events. This reflects the high spatial variability associated with extreme events (particularly precipitation) which can result in them being very localised. Analysis on a regional level can therefore distort results in that extreme localised events of this nature may be missed.

PRECIPITATION (HIGH RAINFALL EVENTS)

High rainfall events can occur under any of the 12 STs however a greater likelihood of precipitation events in the 95th percentile (95th%ile) occurs under some STs. The frequency of precipitation events in the 95th%ile by ST for the two selected stations is shown in Figure 57 over page. The frequency is shown as the percentage of 95th%ile rain events associated with each ST. For example, when ST 12 occurs in the region, this ST produces a rainfall event in the 95%ile in Gresford approximately 30% of the time. Additionally, red, orange, blue and green upward and downward arrows are used to indicate dominant seasonal shifts in the ST. For example, the orange upward arrow on ST 7 indicates that an increase in frequency of this ST during autumn is projected.

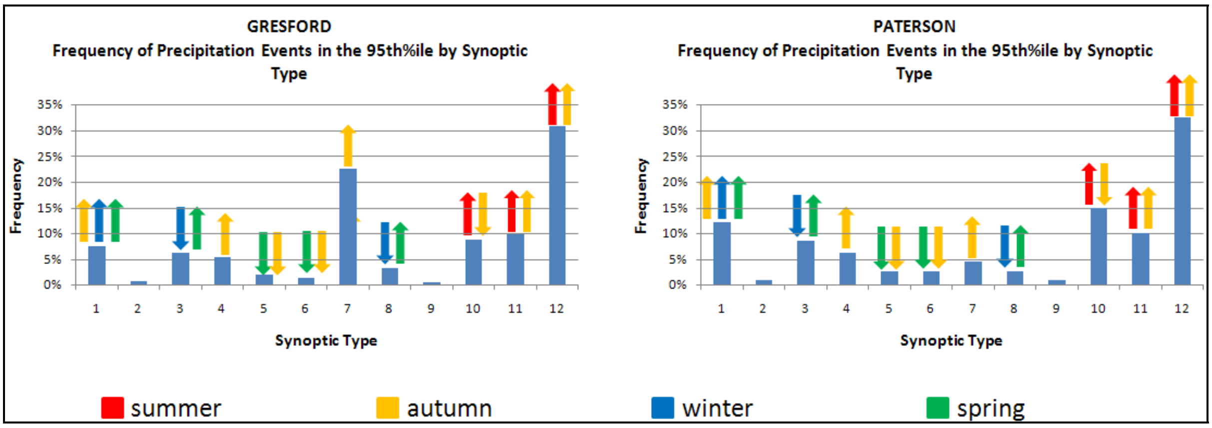


Figure 57 - Frequency of precipitation events in the 95%ile by ST for selected stations with arrows indicating seasonal shifts

Projections for the 2020-2080 period for extreme rainfall events include:

- During summer and autumn, ST 12 is most likely to produce a high rainfall event in the central zone (Gresford and Paterson). The frequency of occurrence of this ST is projected to increase during the period from 2020-2080. This would suggest an increase in the frequency of occurrence of high rainfall events in summer and autumn during the projected period.
- ST 7 is also associated with a relatively high frequency of extreme rainfall events during autumn in Gresford. Projected increases in the frequency of occurrence of this type during autumn at Gresford are thus expected to result in a further increase in extreme rainfall events.
- Minimal changes are anticipated to occur during winter and spring.

MAXIMUM TEMPERATURE (EXTREME HEAT DAYS)

A clear relationship between ST12 and extreme heat days (EHDs) exists for both stations (Figure 58). At Lostock Dam and Paterson, ~70% of all EHDs (daily temperature greater than or equal to 37^{o}C) occur when ST12 is the dominant monthly type. Projected increases in this ST during summer and autumn are likely to result in increased frequency of EHDs in the region during the period from 2020-2080.

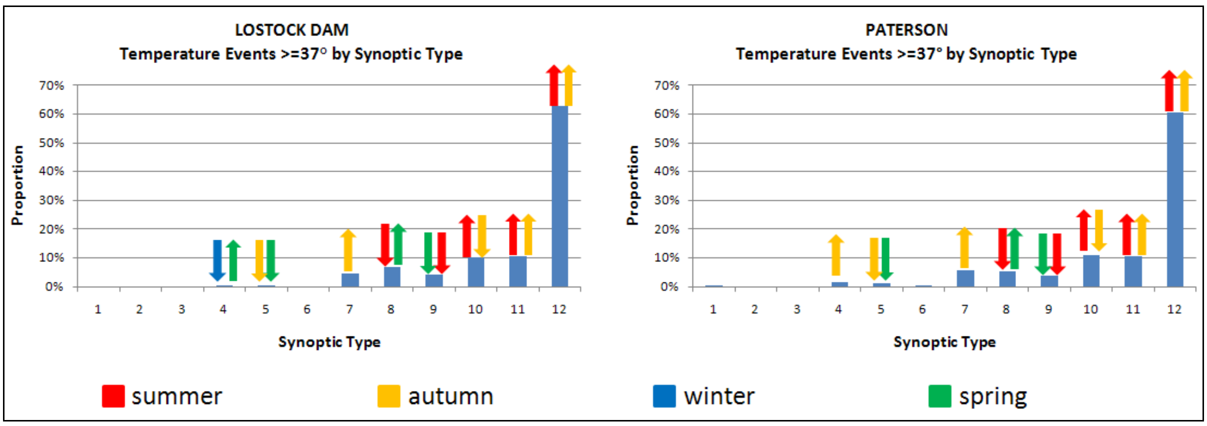


Figure 58 - Frequency of temperature events >=37^{o}C by ST for selected stations with arrows indicating seasonal shifts

MINIMUM TEMPERATURE (FROSTS)

Frost events (temperatures below or equal to 0°C) occur at both stations in the central zone (Lostock Dam and Paterson) (Figure 59). An association between minimum temperature events of less than or equal to 0°C and STs 3 is evident. Winter projections suggest decreases in ST3 will produce fewer frost events during this season. However projected increases in the frequency of occurrence of STs 1, 2 and 4 during autumn are likely to see an increase in the frequency of minimum temperature events (<=0°C) during this season. Increases in the frequency of occurrence of STs 1, 2 and 3 are also likely to produce an increase in minimum temperature events (<=0°C) in the projected period (2020-2080) during spring.

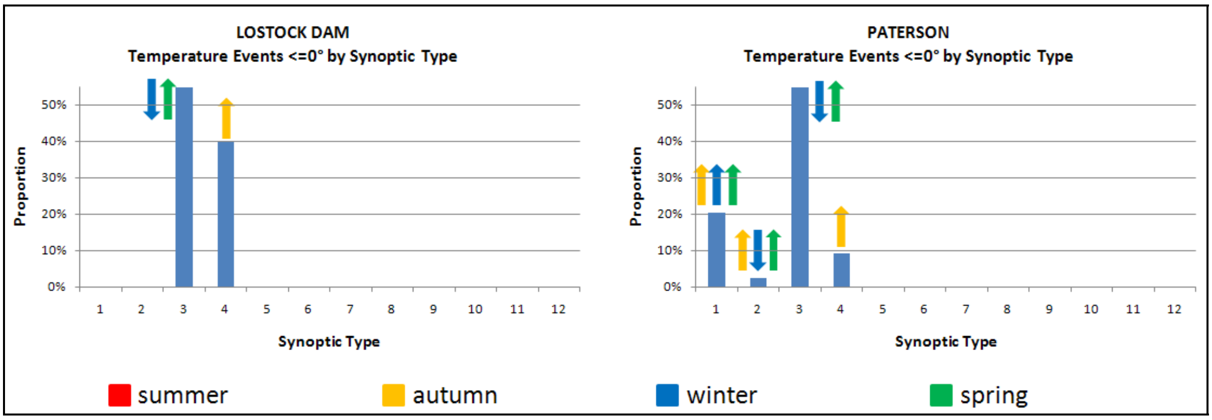


Figure 59 - Frequency of minimum temperature events <=0°C by ST for selected stations with arrows indicating seasonal shifts

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