Hunter, Central and Lower North Coast

Regional Climate Change Project

2010

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

An Initiative of the Hunter & Central Coast Regional Environmental Management Strategy

Hunter & Central Coast Regional Environmental Management Strategy – a program of the Environment Division of Hunter Councils

Authors: Karen L. Blackmore (Hunter Councils) and Ian D. Goodwin, Climate Risk CORE, Macquarie University

Editors: Steve Wilson (Hunter Councils) and Meredith Laing (Hunter Councils)

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HCCREMS (Hunter Councils Inc. as legal agent)
PO Box 3137
THORNTON NSW 2322
Phone: 02 4978 4020
Fax: 4966 0588
Email: envirodirector@huntercouncils.com.au

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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 *western climatic zone* of the Lower North Coast, Central Coast and Hunter Region of NSW (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

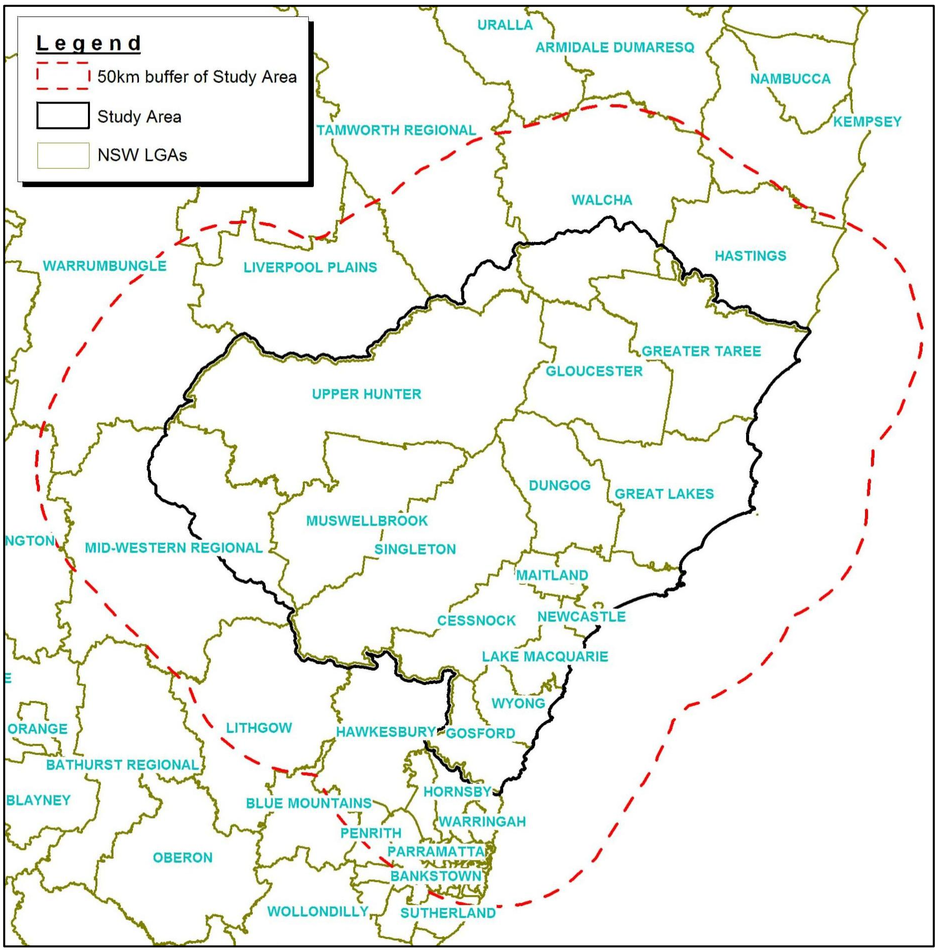

Figure 1 - LGAs in the study region

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 western climate zone of the study region, 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 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.

- An increase in average annual **minimum temperature** of 7^{o}C is projected to occur by 2080 A.D. This projected increase results from slight decreases in winter and spring and significant increases in summer and autumn.

- A statistically significant increasing trend in average annual **maximum temperature** of 1.1^{o}C is observed over the period from 1970-2007. Increases of 1.6^{o}C occurring in summer and 1.4^{o}C in spring over this period are also significant. An increase in average annual maximum temperature of 2.4^{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 increasing trend in annual **average temperature** of 0.6^{o}C is observed over the period from 1970-2007. Increases of 0.4^{o}C occurring in winter and 0.8^{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. These projected increases result from decreases in summer and spring and more significant increases in autumn and winter.

- A statistically significant increasing trend in autumn average **pan evaporation** of 0.3mm/24hr is observed over the period from 1970-2007. Despite this historic trend, no changes in pan evaporation are projected to occur by 2080 A.D.

- A stepwise shift in average **water balance** is projected to occur by 2040 A.D. Water balance for the period from 2020-2040 is projected to occur at the upper bound of experienced natural variability (i.e. wetter). From 2040-2080, water balance is projected to decrease to levels similar to those experienced during 1972-1996 (i.e. drier).

- A statistically significant decreasing trend in autumn average **wind speed** of 2.7km/hr is observed over the period from 1970-2007. Projected changes in average wind speed do not align with observed historic trends. An increase of 1.0km/hr is projected for autumn. No change in summer, a decrease of

0.3km/hr winter and a decrease of 1.3km/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 western 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 2.5 days in total is observed at Murrurundi 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 western 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

This project has included extensive research to identify the regional scale impacts of climate change. This research has been completed by the University of Newcastle and differs from other 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.

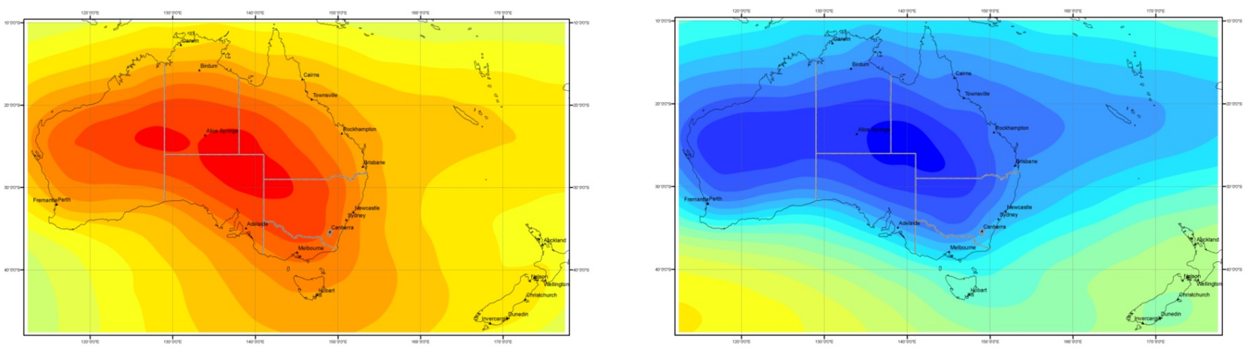

Figure 2 - Synoptic patterns are the air pressure systems commonly seen on weather maps

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 western zone.

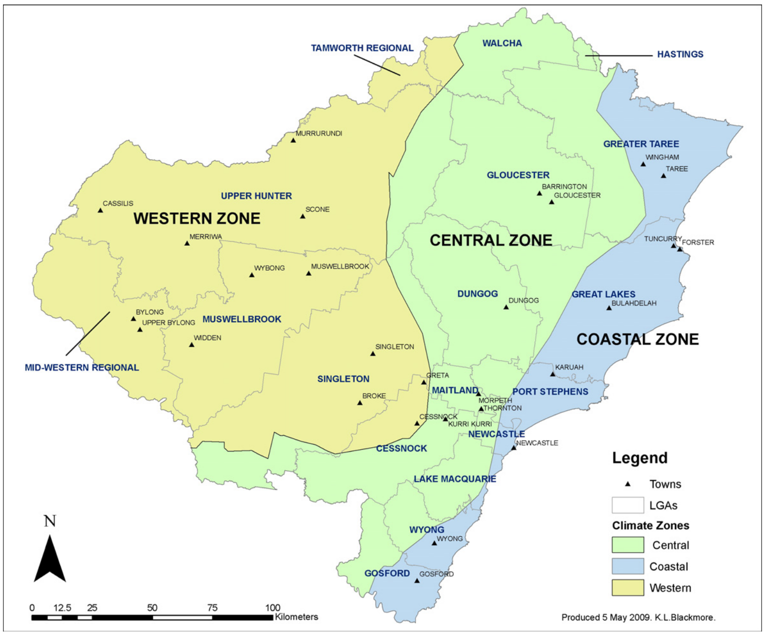

Figure 3 - The region's three climate zones identified in Stage 2 of the project

THE WESTERN CLIMATE ZONE

This report provides climate projections for the ‘western zone’ which primarily incorporates the Muswellbrook, Upper Hunter and Singleton local government areas (LGAs) as well as parts of the Cessnock LGA. Located in the zone are the major towns of Scone, Singleton, Muswellbrook, Merriwa and Murrurundi. The zone dips down through the Hunter Valley to include the town of Cessnock.

Covering a total area of approximately 18,250 square kilometers, the western zone tends to be warmer than the central and coastal zones (away from coastal influences) averaging 30.2^{o}C during summer. Key features of the zone include:

- Elevation ranges from approximately 1,300 meters above sea level (ASL) in the north of the zone to as little as 40 meters ASL in the east.
- The zone is subject to low minimum temperatures, averaging only 6.2^{o}C during winter, and frosts are common during autumn, winter and spring.
- The western zone receives the least rainfall of the region. Summer is the wettest season, averaging 78mm per month. Rainfall decreases during autumn and winter to approximately 48mm and 43mm per month respectively. Spring is slightly wetter with an average of 56mm 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 western 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)

Table 1 - Key climate variables and their units of measure

It is important to ensure that the data sets used in this study are of a sufficient length, cover a common time span, and are 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 western 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, 18 stations lie within the western climate zone (Table 2).

BOM_ID	NAME	YEAR OPENED	LATITUDE	LONGITUDE	ELEVATION
62036	ULAN POST OFFICE	1906	-32.280	149.743	420
62032	WOLLAR (BARRIGAN ST)	1901	-32.359	149.948	366
62009	CASSILIS (DALKEITH)	1874	-31.996	149.986	420
61075	MERRIWA (BOWGLEN)	1926	-32.228	150.216	380
62015	MERRIWA (MERRY VALE)	1890	-31.927	150.223	460
61002	BLACKVILLE (KRUI VALE)	1885	-31.847	150.341	610
61040	MERRIWA (GUMMUN PLACE)	1882	-32.139	150.358	260
61007	BUNNAN (MILHAVEN)	1900	-32.033	150.584	255
61016	DENMAN (PALACE STREET)	1883	-32.389	150.689	105
61065	ABERDEEN (ROSSGOLE)	1926	-32.140	150.729	543
61051	MURRURUNDI POST OFFICE	1870	-31.763	150.836	466
61079	WINGEN (MURRULLA)	1877	-31.868	150.881	335
61000	ABERDEEN (MAIN RD)	1894	-32.166	150.891	183
61086	JERRY'S PLAINS POST OFFICE	1884	-32.497	150.909	90
61026	GUNDY (MILLER ST)	1887	-32.012	150.997	259
61095	ROUCHEL BROOK (ALBANO)	1932	-32.194	151.093	305
61056	POKOLBIN (BEN EAN)	1905	-32.797	151.280	140
61050	SEDGEFIELD (BUNDAJON)	1903	-32.500	151.286	73

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 three stations lie within the western climate zone.

BOM_ID	NAME	DATE OPENED	LATITUDE	LONGITUDE	ELEVATION
61051	MURRURUNDI POST OFFICE	01/1870	-31.763	150.836	466
61086	JERRY'S PLAINS POST OFFICE	01/1884	-32.497	150.909	90
61089	SCONE SCS	01/1950	-32.063	150.927	216

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 (Scone and Cessnock) lie within the western climate zone.

BOM_ID	NAME	DATE OPENED	LATITUDE	LONGITUDE	ELEVATION
61089	SCONE SCS	01/1950	-32.063	150.927	216
61242	CESSNOCK (NULKABA)	01/1966	-32.809	151.349	62

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, four stations lie within the western climate zone. Although record keeping commences as early as 1870, consistent records are not available prior to 1973.

BOM_ID	NAME	DATE OPENED	LATITUDE	LONGITUDE	ELEVATION
61051	MURRURUNDI POST OFFICE	01/1870	-31.763	150.836	466
61086	JERRY'S PLAINS POST OFFICE	01/1884	-32.497	150.909	90
61089	SCONE SCS	01/1950	-32.063	150.927	216
61260	CESSNOCK AIRPORT AWS	06/1968	-32.789	151.338	61

Table 5 – Available humidity stations

AVERAGE WIND SPEED AND WIND GUSTS

Average wind speed data is available from three stations within the western climate zone (Table 6). Wind gust data is available from only one station (Williamtown) within the Hunter, Central and Lower North Coast region. Although this station is outside of the western climate zone, data from this recording station in included in this report to provide some information on wind direction as this parameter is not included with average wind speed records.

BOM_ID	NAME	DATE OPENED	LATITUDE	LONGITUDE	ELEVATION
61051	MURRURUNDI POST OFFICE	01/1870	-31.763	150.836	466
61086	JERRY'S PLAINS POST OFFICE	01/1884	-32.497	150.909	90
61089	SCONE SCS	01/1950	-32.063	150.927	216

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 period 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 in the region 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 western 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.

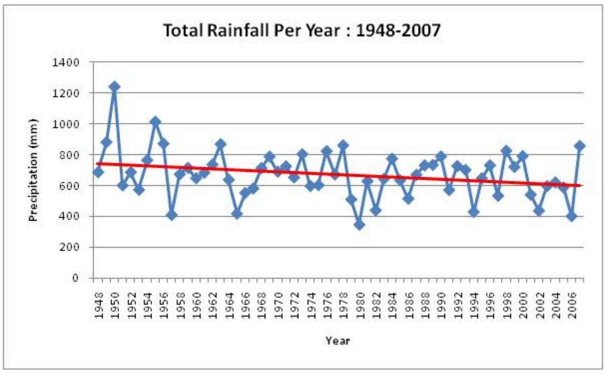

Figure 4 - Trend in total annual rainfall (1948-2007)

In the western zone, a statistically significant decreasing linear trend in average annual precipitation is evident over the period from 1948 to 2007 (Figure 4 on the previous page). This epoch spans a +ve and –ve phase of the IPO. Figure 5 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 than a decreasing linear trend over the period from 1948 to 2007, the average annual rainfall is approximately 77mm less (than 1948-1976) in the 1977 to 2007 period.

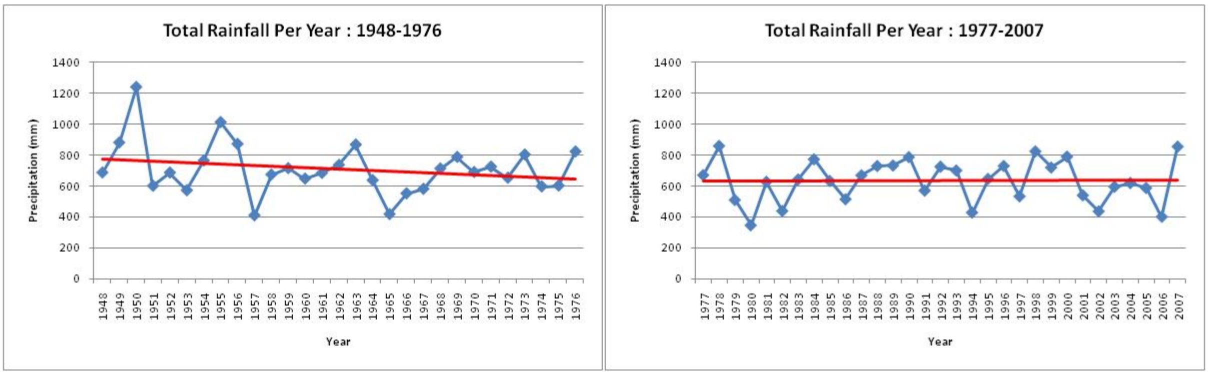

Figure 5 - Trend in total rainfall for *the* 1948-1976 and 19770-2007 time periods

Total Rainfall (1948-2007)			
Summer	**Autumn**	**Winter**	**Spring**
Drier: ~32mm* decrease	Drier: ~5mm decrease	Drier: ~10mm decrease	Wetter: ~2mm increase

Table 7 - Summary of historic changes in rainfall

Seasonally, a statistically significant decrease in average monthly precipitation has occurred during summer only (Table 7 above and Figure 6 over page). The monthly average summer rainfall has decreased by 0.6mm per annum (33mm in total) over the period 1948-2007.

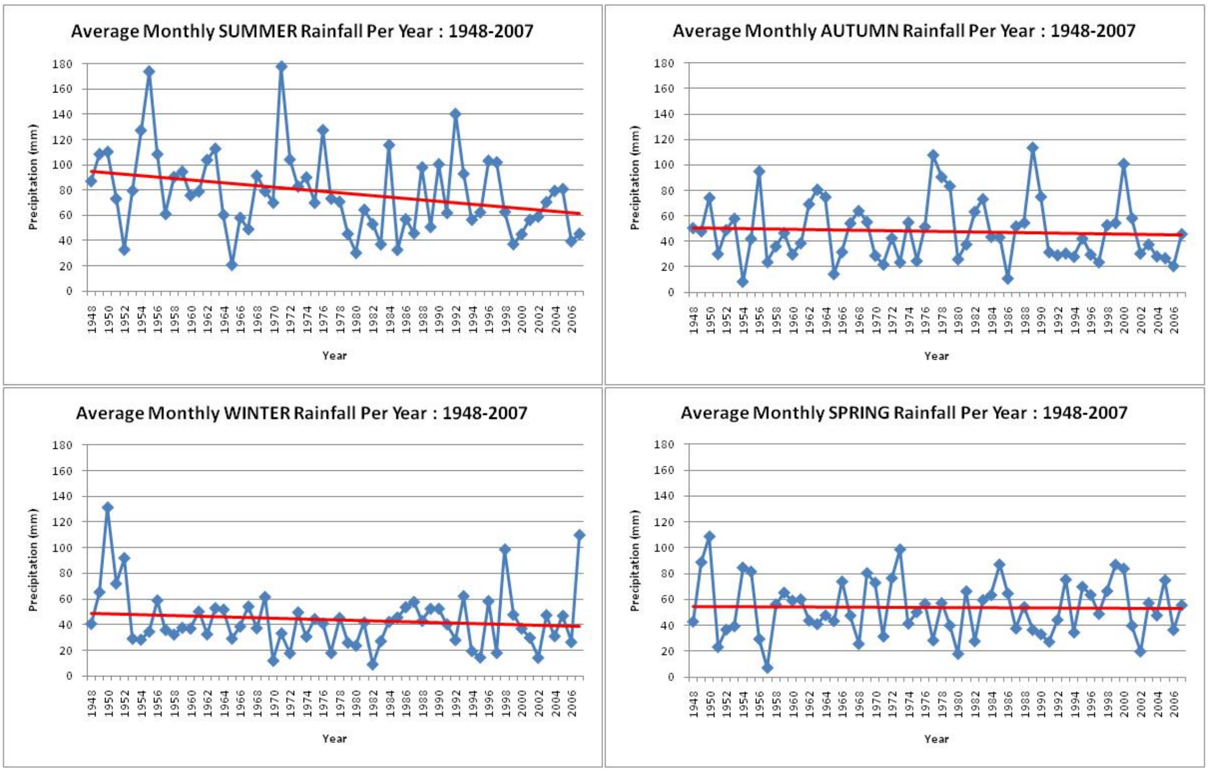

Figure 6 - Seasonal rainfall trends 1948-2007

TEMPERATURE

MINIMUM TEMPERATURE

The average annual minimum temperature recorded for the western zone from 1970 to 2007 is 8.8^{o}C. Over the period from 1970 to 2007, an increasing linear trend in average annual minimum temperature in the western zone is evident (Figure 7). This non-significant trend is equivalent to an increase of approximately 0.1^{o}C over this entire period.

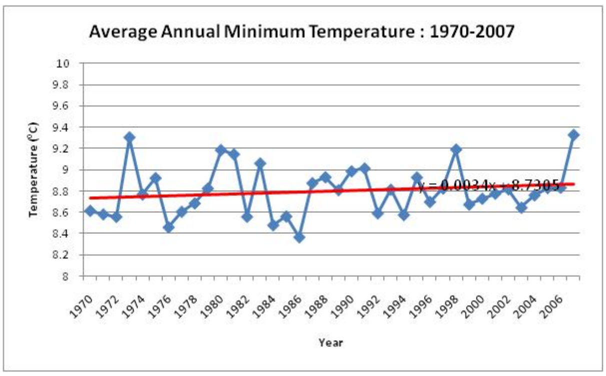

Figure 7 - Trend in average annual minimum temperature for the 1970-2007 time period

Minimum temperature (1970-2007)			
Summer	**Autumn**	**Winter**	**Spring**
Warmer: ~0.4°C increase	Warmer: ~0.2°C* increase	Cooler: ~0.1°C* decrease	Warmer: ~0.2°C* increase

Table 8 - Summary of historic changes in minimum temperature

During summer, minimum temperatures average 10.8^{o}C in the western zone, decreasing to 7.8^{o}C during autumn and 6.2^{o}C during winter. Spring minimum temperatures average 10.4^{o}C. Average minimum temperatures show slight increases in all seasons over the period from 1970-2007 in line with the annual trend (Table 8 above and Figure 8 below). These seasonal increases are not statistically significant.

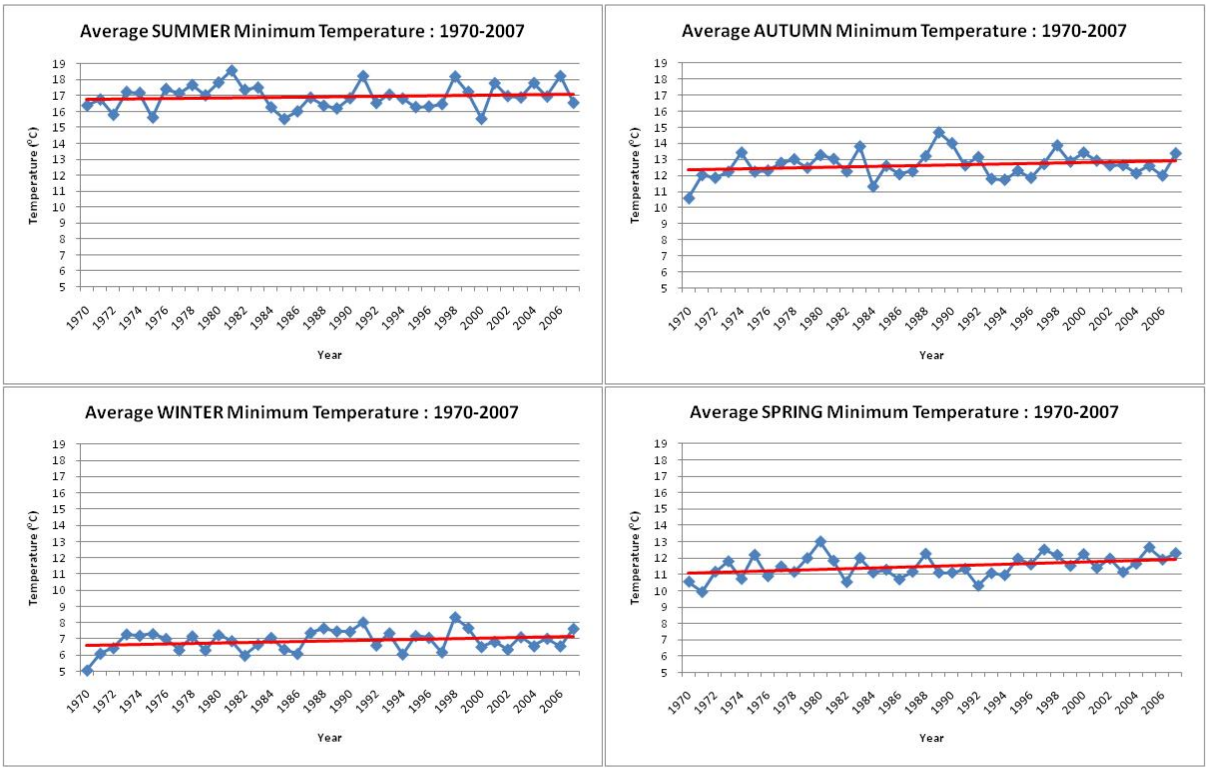

Figure 8 - Seasonal average minimum temperature trends 1970-2007

MAXIMUM TEMPERATURE

The average annual maximum temperature recorded for the western zone from 1970 to 2007 is 24.0°C. Over the period from 1970 to 2007, an increasing linear trend in average annual maximum temperature in the western zone is evident (Figure 9). This trend is statistically significant and equivalent to an increase of approximately 1.1°C over this entire period.

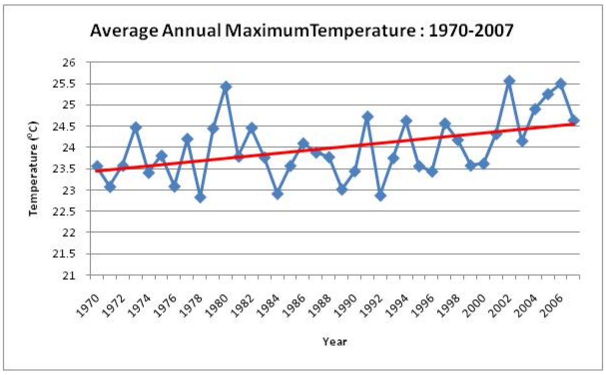

Figure 9 - Trend in average annual maximum temperature for the 1970-2007 time period

During summer, average maximum temperatures average 30.2°C in the western zone, decreasing to 24.1°C during autumn and 17.2°C during winter. Spring maximum temperatures average 24.5°C. Average maximum temperatures show increases in all seasons over the period from 1970-2007 in line with the annual trend (Table 9 below and Figure 10 over page) however only the summer (~1.6°C) and spring (~1.4°C) seasonal increases are statistically significant.

Maximum temperature (1970-2007)			
Summer	**Autumn**	**Winter**	**Spring**
Warmer: ~1.6°C* increase	Warmer: ~0.7°C increase	Warmer: ~0.8°C increase	Warmer: ~1.4°C* increase

Table 9 - Summary of historic changes in maximum temperature

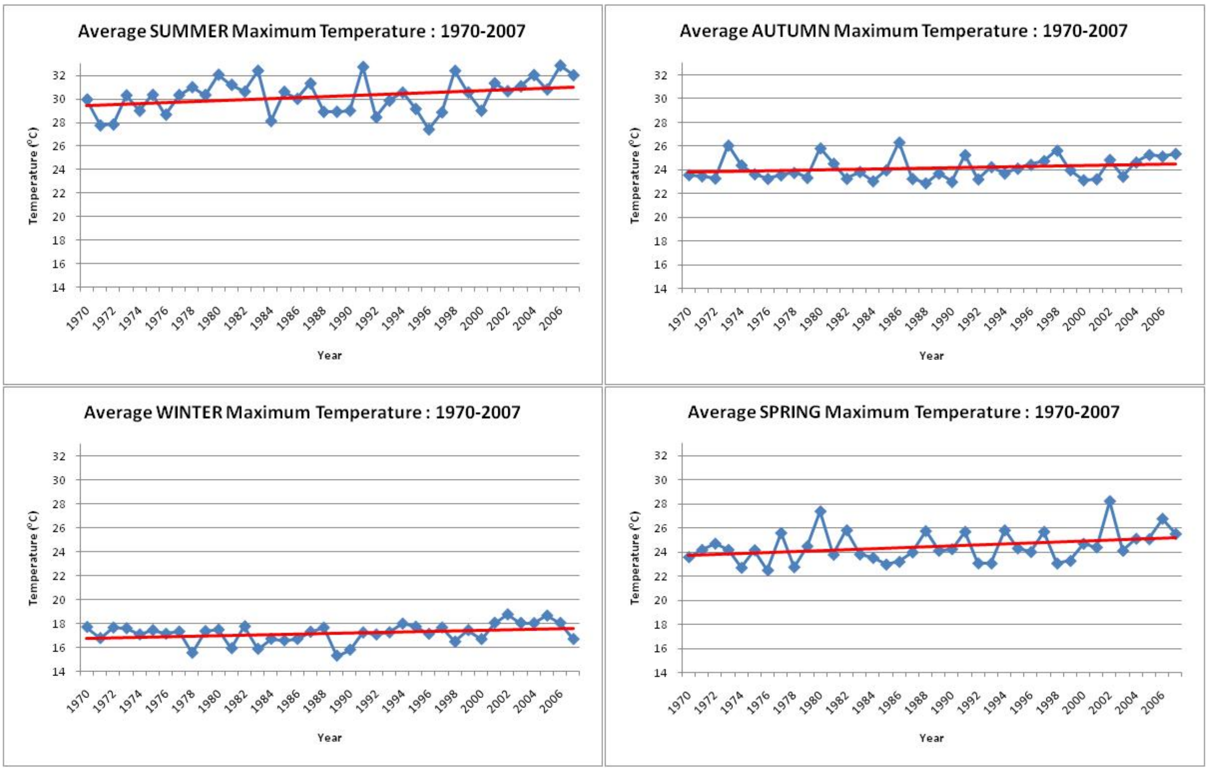

Figure 10 - Seasonal average maximum temperature trends 1970-2007

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 western zone from 1970 to 2007 is 17.0°C. Over the period from 1970 to 2007, an increasing linear trend in annual average temperature in the western zone is evident (Figure 11). This trend is statistically significant and equivalent to an increase of approximately 0.6°C over this entire period.

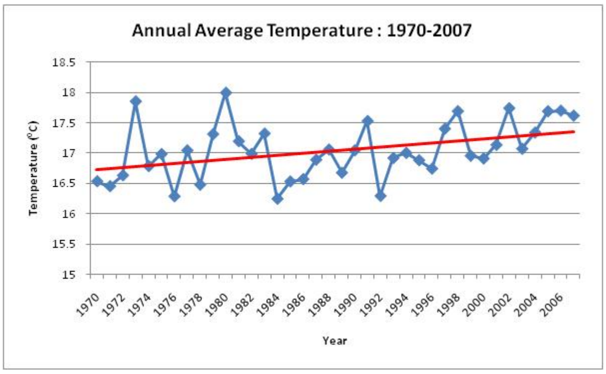

Figure 11 - Trend in annual average temperature for the 1970-2007 time period

Average temperature (1970-2007)			
Summer	**Autumn**	**Winter**	**Spring**
Warmer: ~0.9°C increase	Warmer: ~0.5°C increase	Warmer: ~0.4°C* increase	Warmer: ~0.8°C* increase

Table 10 - Summary of historic changes in average temperature

During summer, temperatures average 23.1°C in the western zone, decreasing to 17.3°C during autumn and 10.7°C during winter. Spring temperatures average 17.1°C. Average temperatures show increases in all seasons over the period from 1970-2007 in line with the annual trend (Table 10 and Figure 12) however none of these seasonal trends are statistically significant.

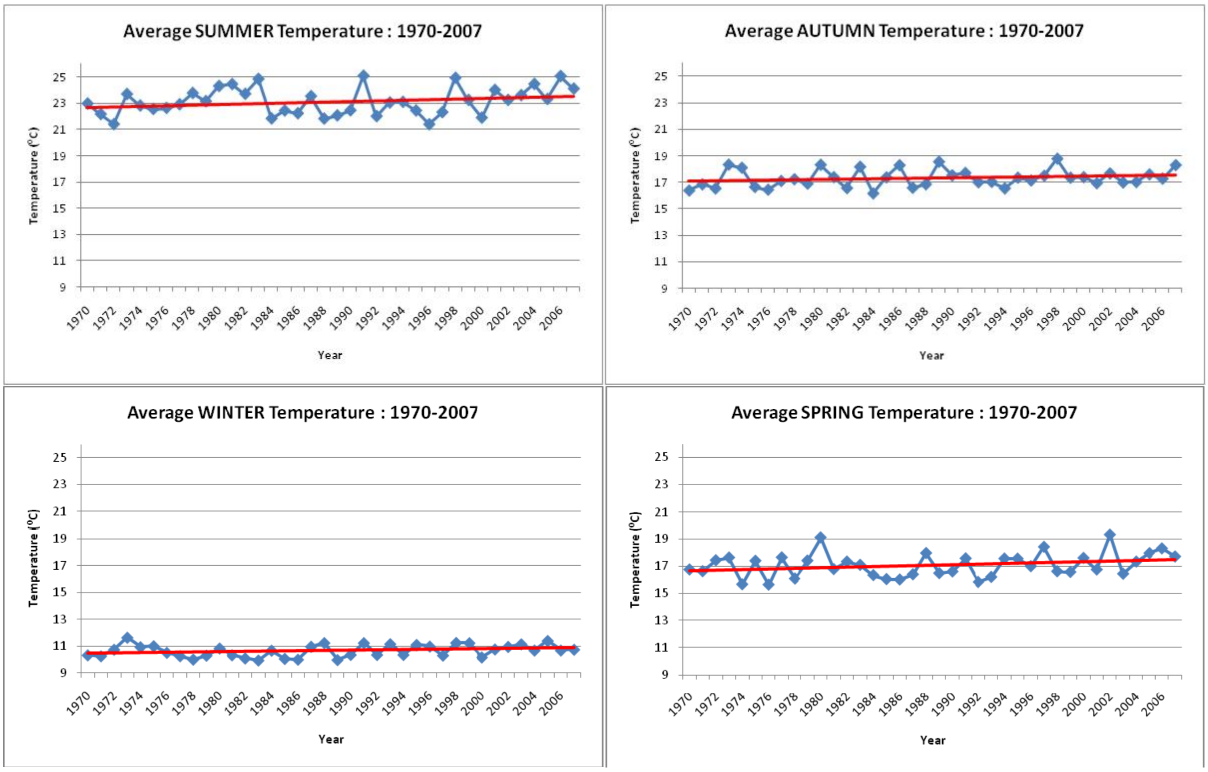

Figure 12 - Seasonal average temperature trends 1970-2007

DAILY PAN EVAPORATION

The recorded annual average pan evaporation for the western zone from 1973 to 2007 is 4.2mm/24hr. Over the period from 1973 to 2007, an increasing linear trend in annual average pan evaporation in the western zone is evident (Figure 13). This non-significant trend is equivalent to an increase of approximately 0.9mm/24hr over this entire period.

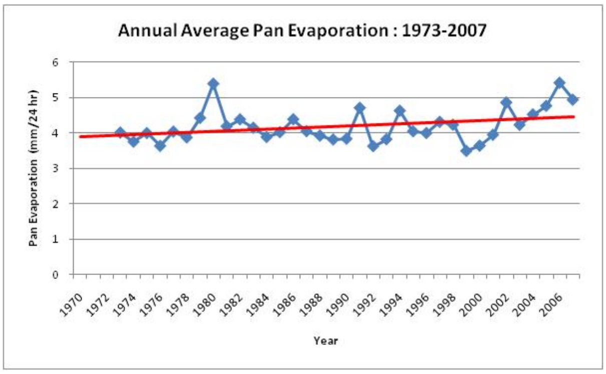

Figure 13 - Trend in annual average pan evaporation for the 1973-2007 time period

During summer, pan evaporation averages 6.5mm/24hr in the western zone, decreasing to 3.4mm/24hr during autumn and 2.1mm/24hr during winter. Spring pan evaporation averages 4.9mm/24hr. Average pan evaporation shows increases in all seasons over the period from 1972-2007 in line with the annual trend (Table 11 below and Figure 14 over page). The increase of approximately 1.0mm/24hr occurring during summer over the period from 1972-2007 is statistically significant.

Pan evaporation (1970-2007)			
Summer	**Autumn**	**Winter**	**Spring**
Drier: ~1.0mm/24hr increase	Drier: ~0.3mm/24hr* increase	No change	Drier: ~0.8mm/24hr increase

Table 11 - Summary of historic changes in average pan evaporation

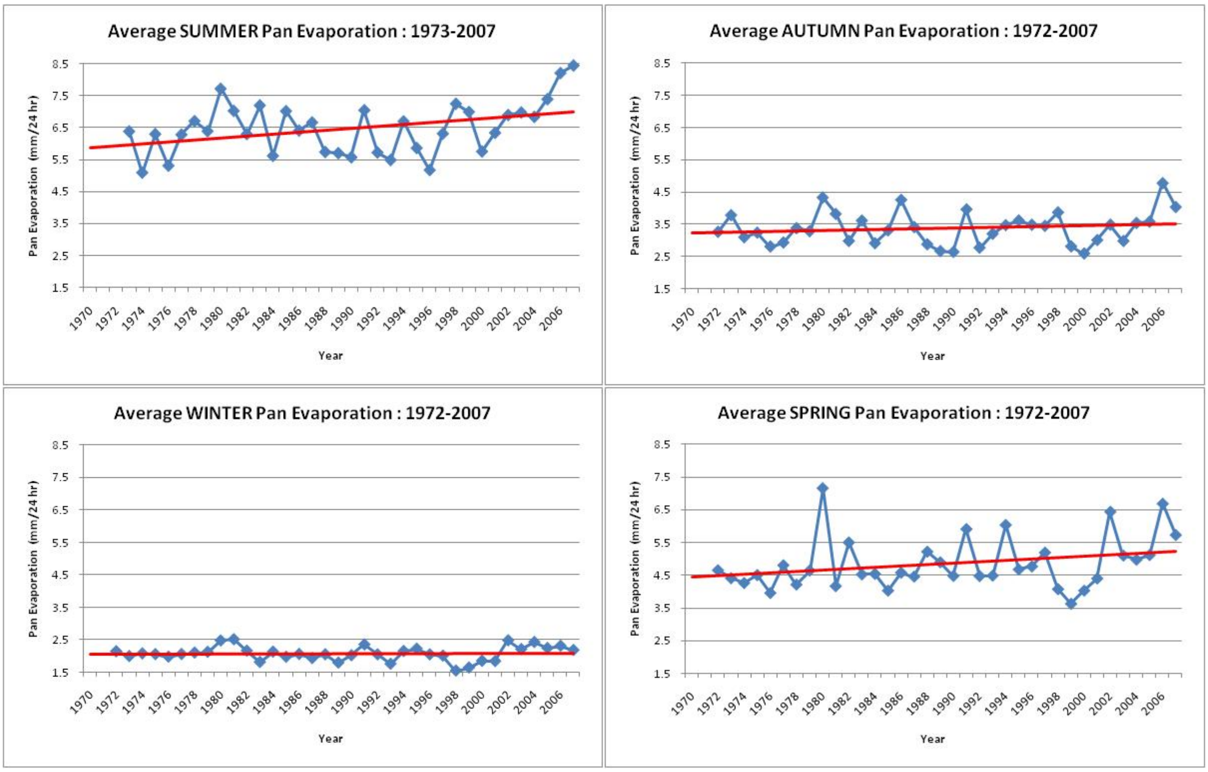

Figure 14 - Seasonal annual average pan evaporation trends 1972-2007

HUMIDITY

The annual average humidity recorded at 9am for the western zone from 1970 to 2007 is approximately 70.1%. Over the period from 1973 to 2006, a slight increasing linear trend in annual average 9am humidity in the western zone is evident (Figure 15). This non-significant trend is equivalent to an increase of approximately 1.4% over this entire period.

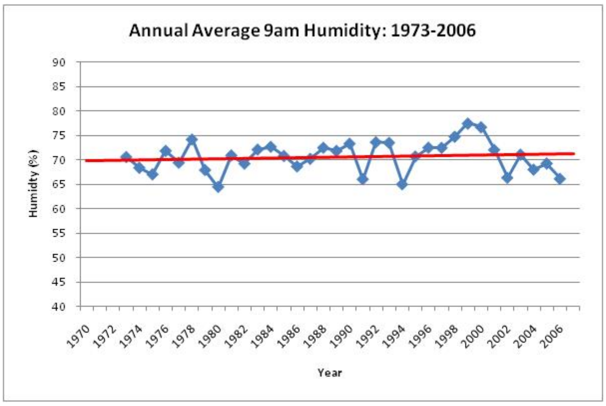

Figure 15 - Trend in annual average 9am humidity for the 1973-2006 time period

During summer, 9am humidity averages 68.7% in the western zone, increasing to 74.9% during autumn and 76.5% during winter. Spring 9am humidity averages 62.3%. Average 9am humidity shows increases in the summer, autumn and winter seasons over the period from 1973-2006 in line with the annual trend (Table 12 below and Figure 16 over page). A slight decreasing trend in 9am humidity is evident during spring. As with the annual trend, no seasonal trends are statistically significant.

9am Humidity (1970-2007)			
Summer	**Autumn**	**Winter**	**Spring**
~1.1% increase	~3.6% increase	~1.8% increase	~1.4% decrease

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

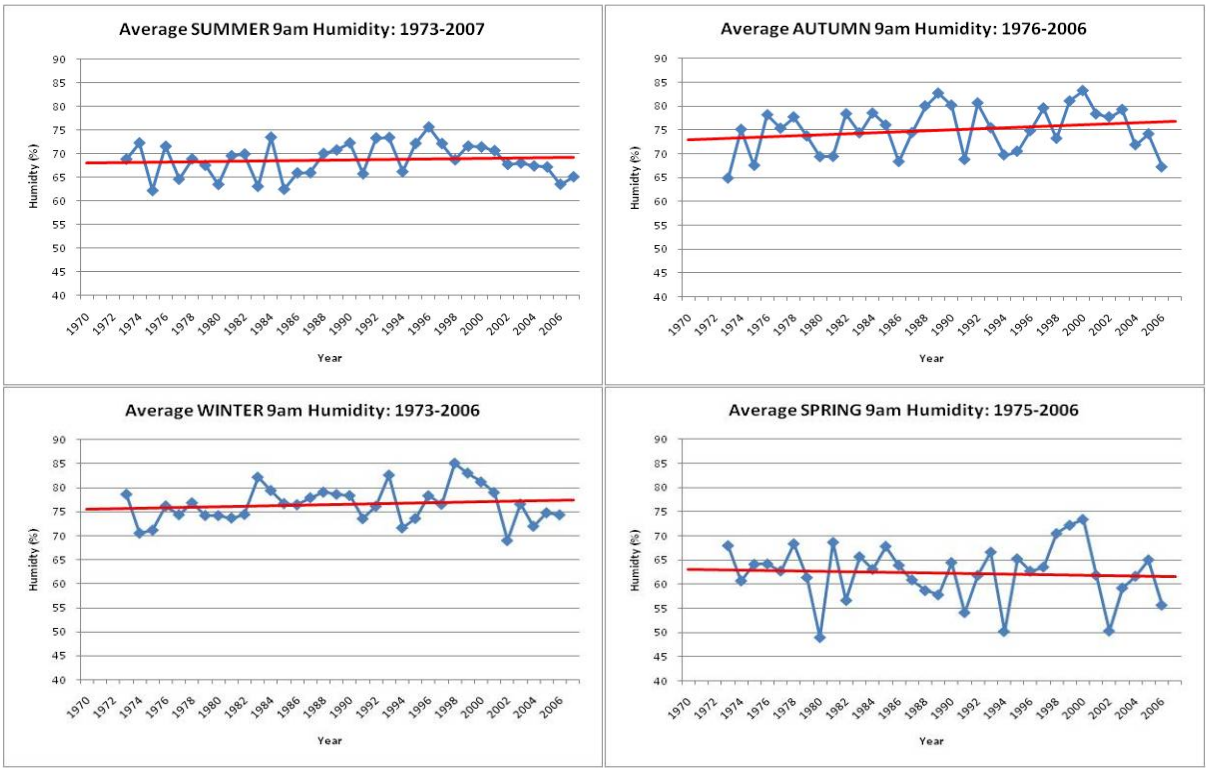

Figure 16 - Seasonal annual average 9am humidity trends 1973-2006

The annual average humidity recorded at 3pm for the western zone from 1970 to 2007 is approximately 41.8%. Over the period from 1973 to 2006, a slight increasing linear trend in annual average 3pm humidity in the western zone is evident (Figure 17). This non-significant trend is equivalent to an increase of approximately 1.4% over this entire period.

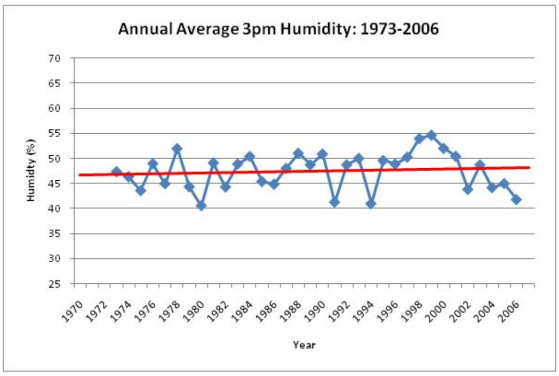

Figure 17 - Trend in annual average 3pm humidity for the 1973-2006 epoch

During summer, 3pm humidity averages 38.7% in the western zone, increasing to 39.7% during autumn and 47.5% during winter. Spring 3pm humidity averages 37.6%. Average 3pm humidity shows increases in the summer, autumn and winter seasons over the period from 1970-2007 in line with the annual trend (Table 13 and Figure 18). No change in 3pm humidity is evident during spring. As with the annual trend, no seasonal trends are statistically significant.

3pm Humidity (1970-2007)			
Summer	**Autumn**	**Winter**	**Spring**
~1.7% increase	~2.5% increase	~0.7% increase	No change

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

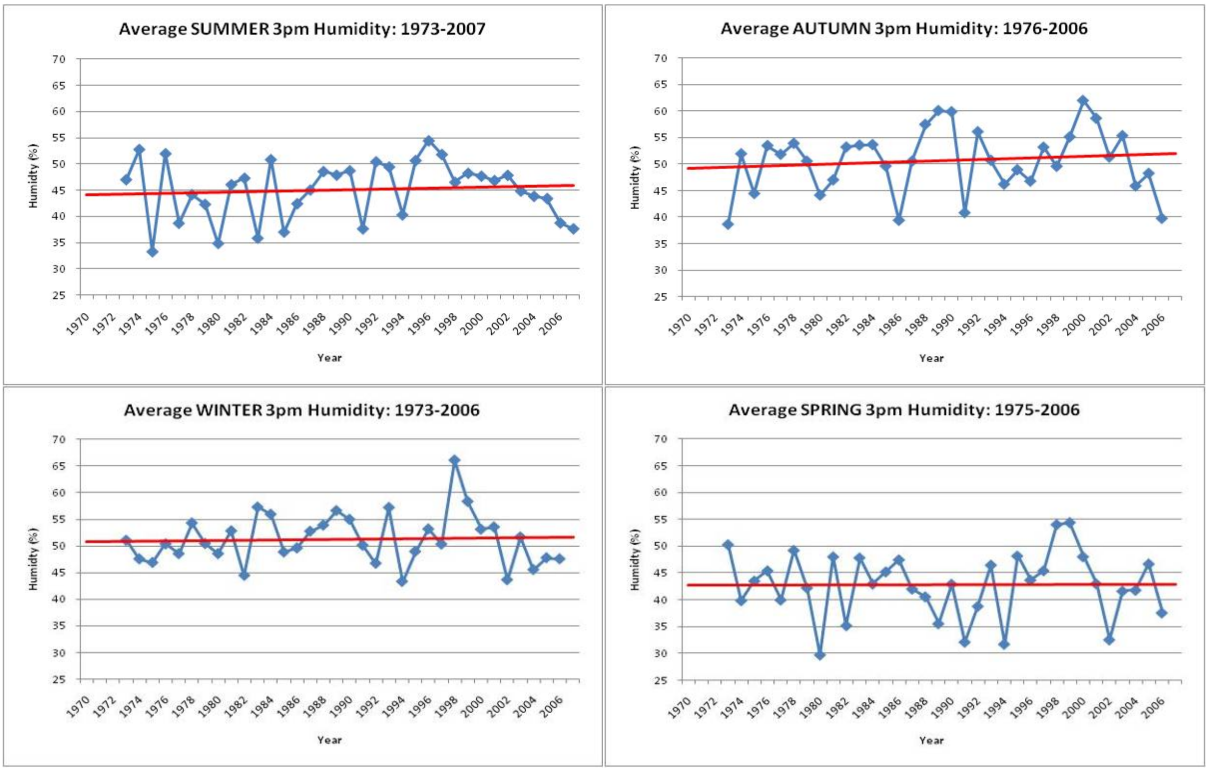

Figure 18 - Seasonal annual average 3pm humidity trends 1973-2006

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 western zone using data from Scone and Cessnock only.

The annual average water balance for the western zone from 1972 to 2007 is approximately -2.4mm/day. Over the period from 1972 to 2007, a decreasing linear trend in annual average water balance in the western zone is evident (Figure 19). This has resulted in a total decrease in average annual water balance of 0.7mm per day in the western zone from 1973-2007.

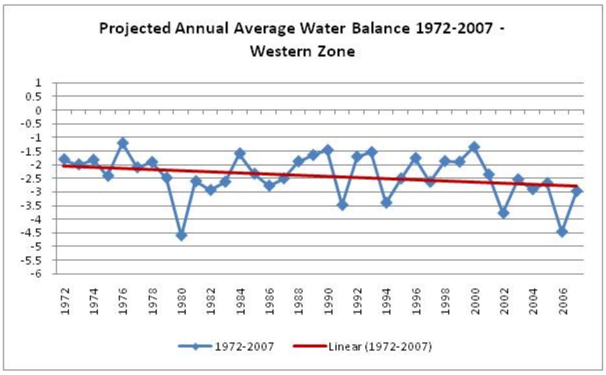

Figure 19 - Trend in water balance for the 1972-2007 epoch

During summer, water balance averages -4.2mm/day in the western zone, increasing to -1.8mm/day during autumn and -0.7mm/day during winter. Spring water balance averages -3.1mm/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.

Water balance (1972 -2007)			
Summer	**Autumn**	**Winter**	**Spring**
Drier: ~1.4mm/d decrease	Drier: ~0.9mm/d decrease	Wetter:~1.1mm/d increase	Drier: ~0.8mm/d decrease

Table 14 - Summary of historic changes in water balance

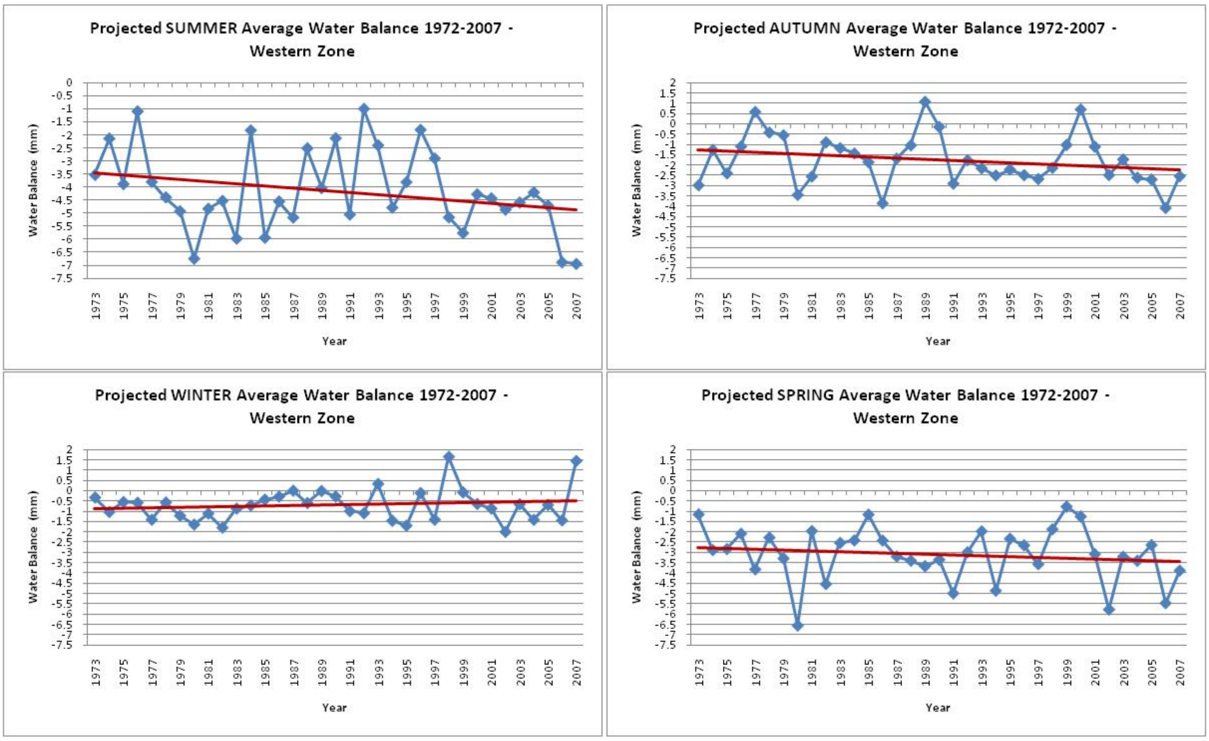

Figure 20 - Seasonal average water balance 1972-2007

AVERAGE WIND SPEED AND WIND GUSTS

The annual average wind speed for the western zone from 1970 to 2007 is approximately 9.3km/hr. Over the period from 1970 to 2007, a decreasing linear trend in annual average wind speed in the western zone is evident (Figure 21). This non-significant trend is equivalent to a decrease of approximately 1.9km/hr over this entire period.

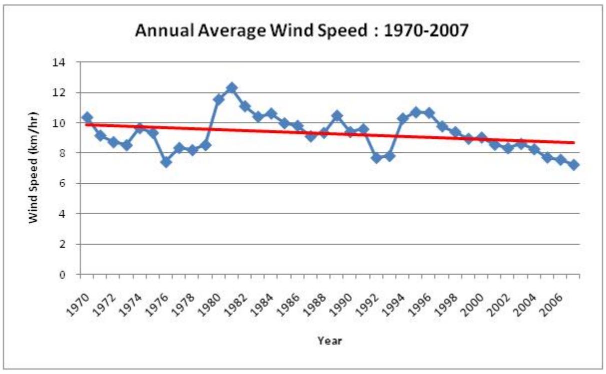

Figure 21 - Trend in annual average wind speed for the 1970-2007 time period

During summer, wind speed averages 9.5km/hr in the western zone, decreasing to 8.1km/hr during autumn and 9.1km/hr during winter. Spring wind speed averages 10.6km/hr. Average wind speed shows decreases in all seasons over the period from 1970-2007 in line with the annual trend (Figure 22 over page). The trend occurring during autumn (decrease of 2.7km/hr over the period from 1970-2007 – Table 15 below) is statistically significant.

Average Wind speed (1970-2007)			
Summer	**Autumn**	**Winter**	**Spring**
Calmer: ~1.0km/hr decrease	Calmer: ~2.7km/hr* decrease	Calmer: ~1.5km/hr decrease	Calmer: ~0.5km/hr decrease

Table 15 - Summary of historic changes in average wind speed

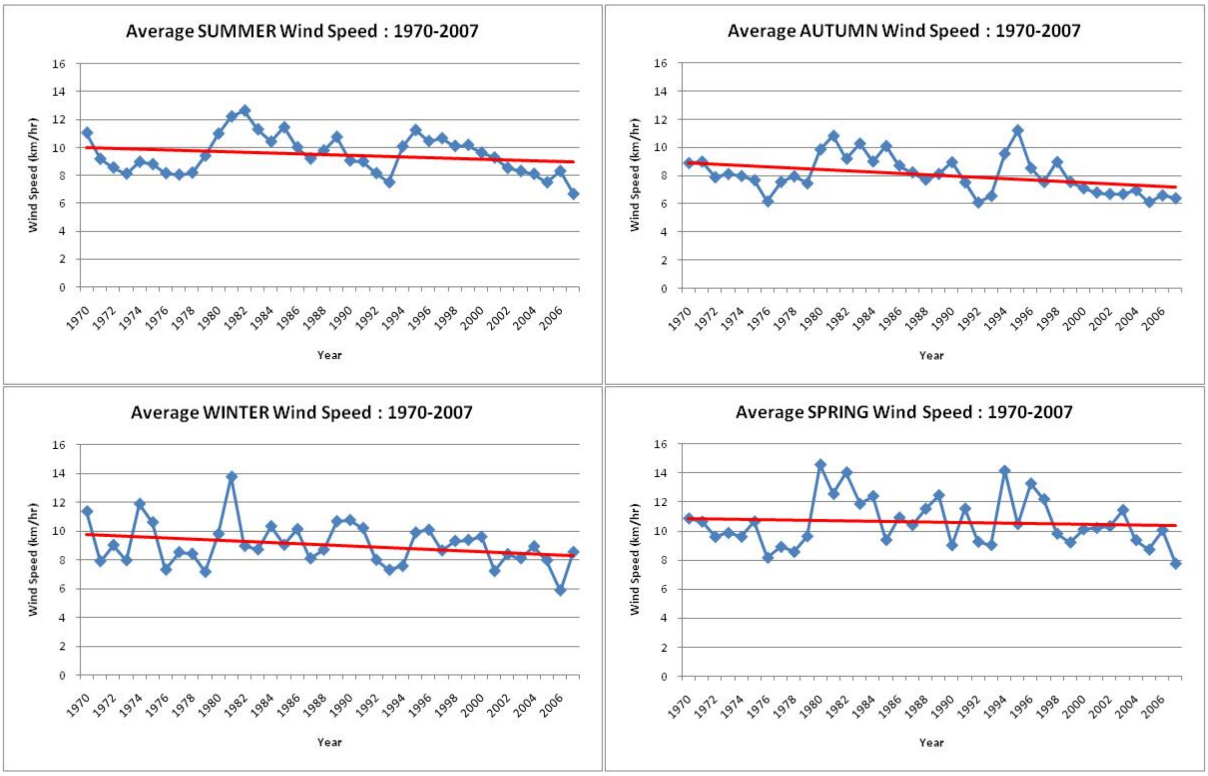

Figure 22 - Seasonal average wind speed trends 1970-2007

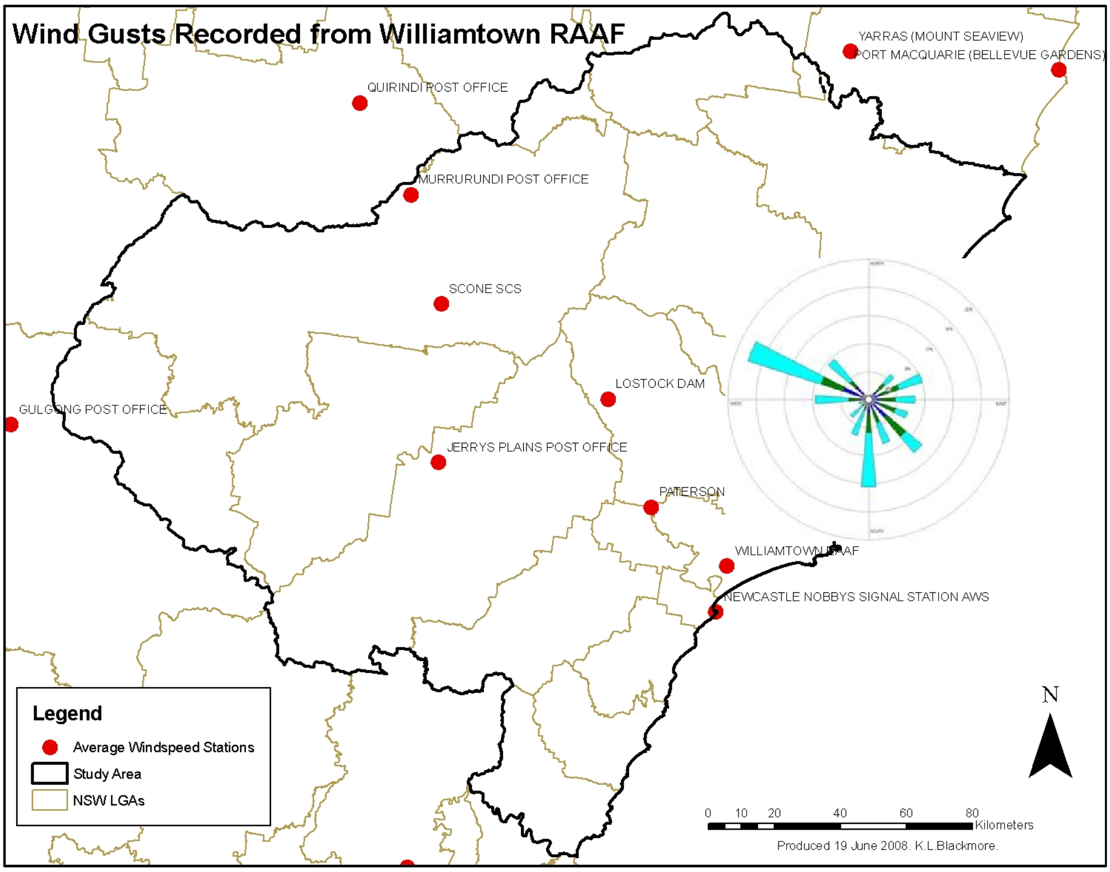

Figure 23 - Wind rose diagram of wind gusts recorded from Williamtwon RAAF.

Suitable (i.e. of a sufficient duration) maximum wind gust data is available from only one station in the study region (Williamtown). While this station is located in the coastal zone, it does provide indicative trends for the western 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.

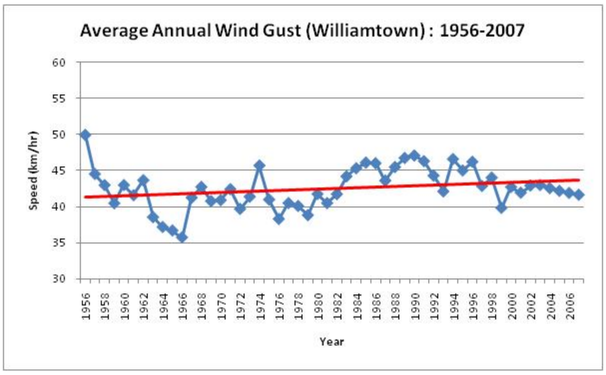

Figure 24 - Trend in average annual wind gusts recorded at Williamtown over the period over the period from 1956 to 2007

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 statistically significant ($P<0.05$).

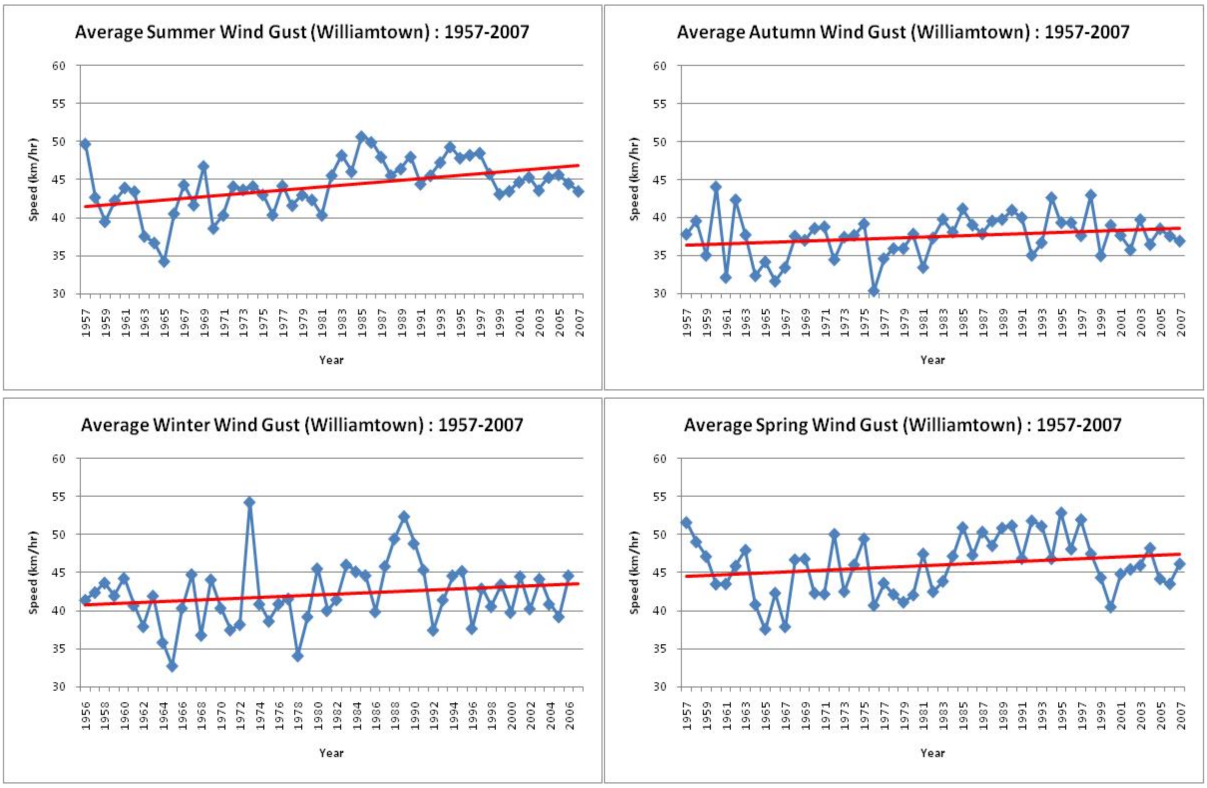

Figure 25 - Seasonal trends in average wind gusts (Williamtown): 1957-2007

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, two (2) representative stations within the western climate zone are selected for the analysis of extreme precipitation and temperature events (Figure 26).

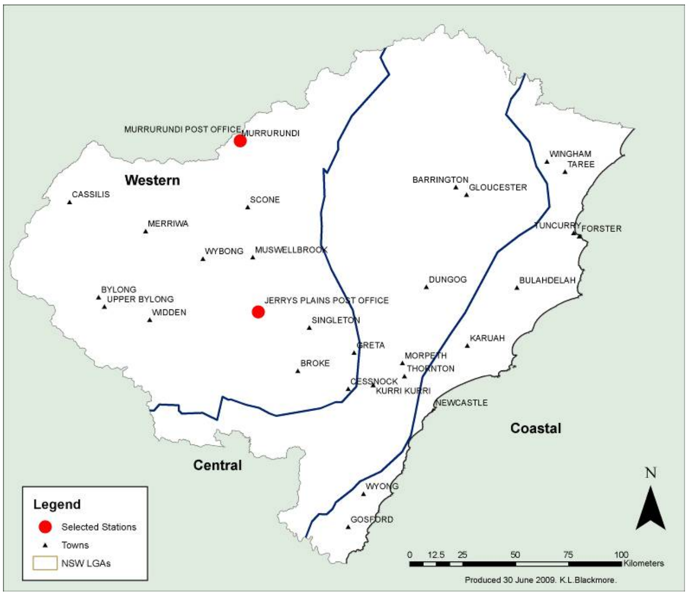

Figure 26 - Selected stations for analysis of extreme events

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 Murrurundi and Jerry's Plains 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.

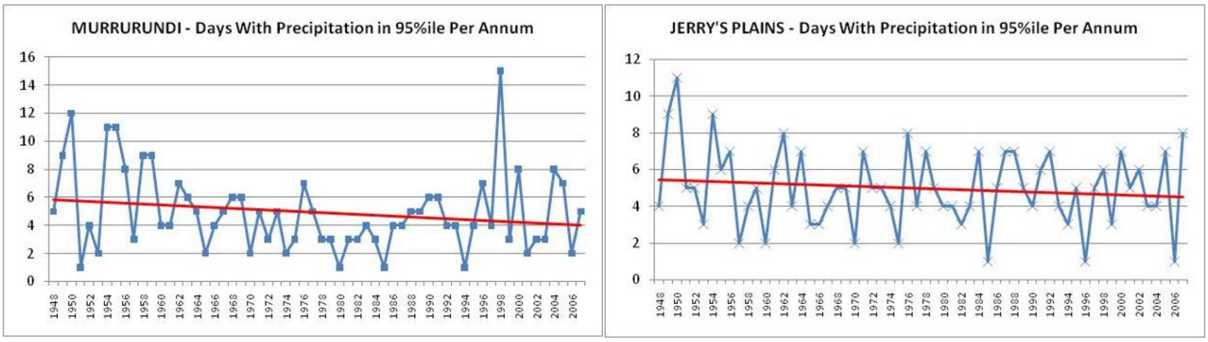

Figure 27 - Annual trend in days with rainfall in the 95th percentile (1948-2007)

Seasonally, the decreasing linear trends evident annually are reflected in the seasonal data Figure 28 (over page) with the exception of winter in Murrurundi and spring in Jerry's Plains. Both locations show a decreasing linear trend in days per annum with precipitation in the 95th percentile during summer and autumn. During winter, no change in these events is evident at Murrurundi. An increase in the frequency of these events is evident at Jerry's Plains during spring. As with the annual data, no seasonal trends are statistically significant.

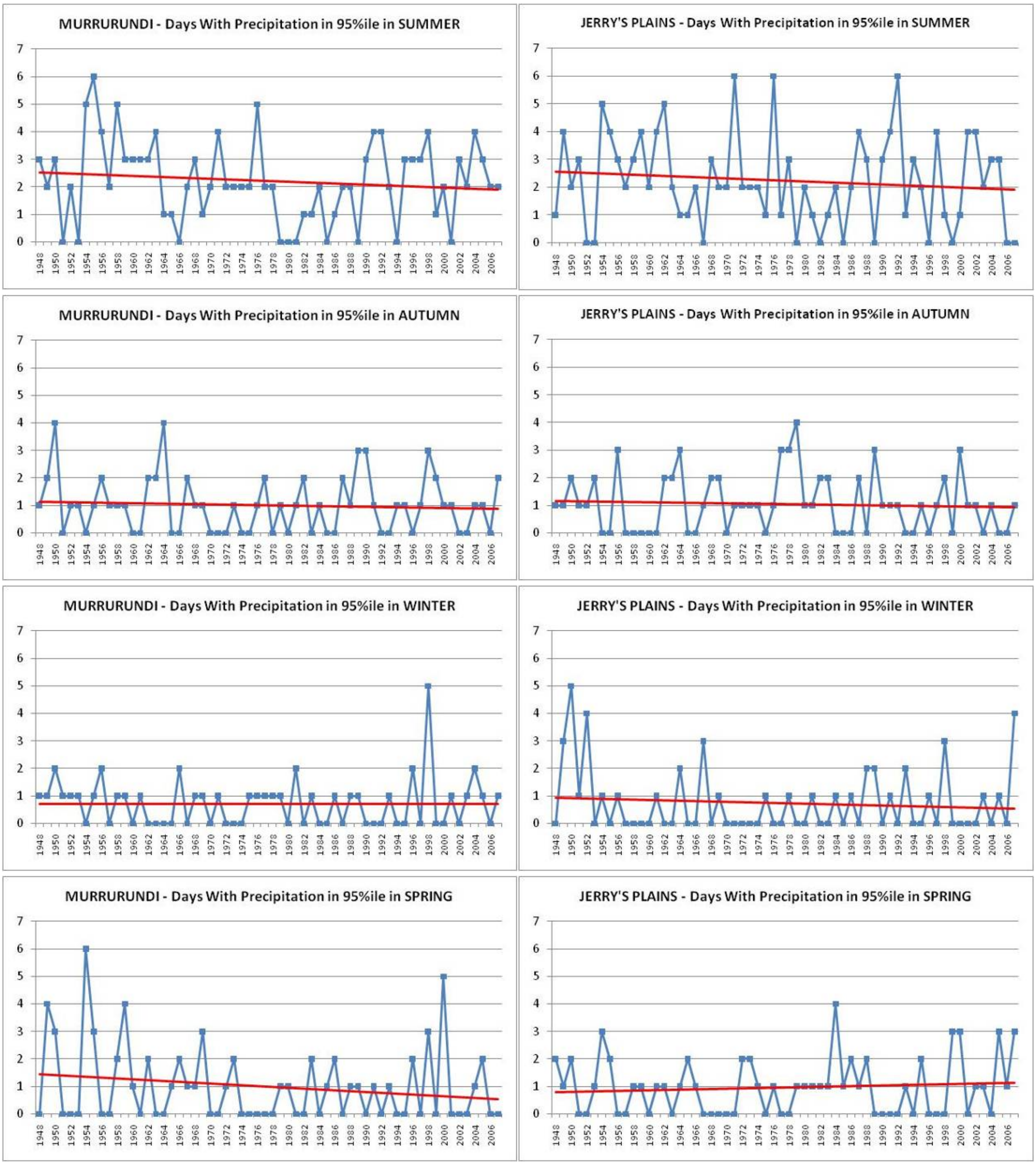

Figure 28 - Seasonal trend in days with rainfall in the 95th percentile (1948-2007)

EXTREME HEAT DAYS

An increasing linear trend in days per year with maximum temperature greater than or equal to 37ºC is evident at both Murrurundi and Jerry's Plains (Figure 29). The increase recorded at Murrurundi is statistically significant. On average, Murrurundi records between 2 and 3 days per annum with temperatures greater than or equal to 37ºC. Over the period from 1970 to 2007, an increase of approximately 2.5 days in total is evident.

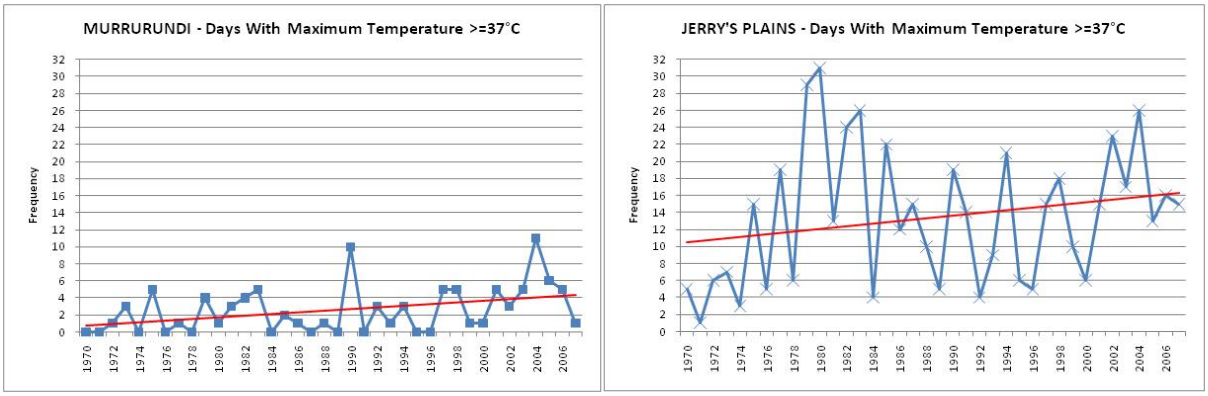

Figure 29 - Annual trend in extreme heat days at Murrurundi and Jerry's Plains

FROSTS

Local variability in frost events is evident in the histograms of days per annum with minimum temperature less than or equal to 0ºC for Murrurundi and Jerry's Plains (Figure 30). On average, Murrurundi averages 42 days per year with minimum temperature less than or equal to 0ºC compared to 9.5 at Jerry's Plains. An increasing linear trend in the frequency of these events over the period from 1970 to 2007 is evident at Murrurundi. A slight decrease in frequency is evident at Jerry's Plains. Neither of these trends are statistically significant.

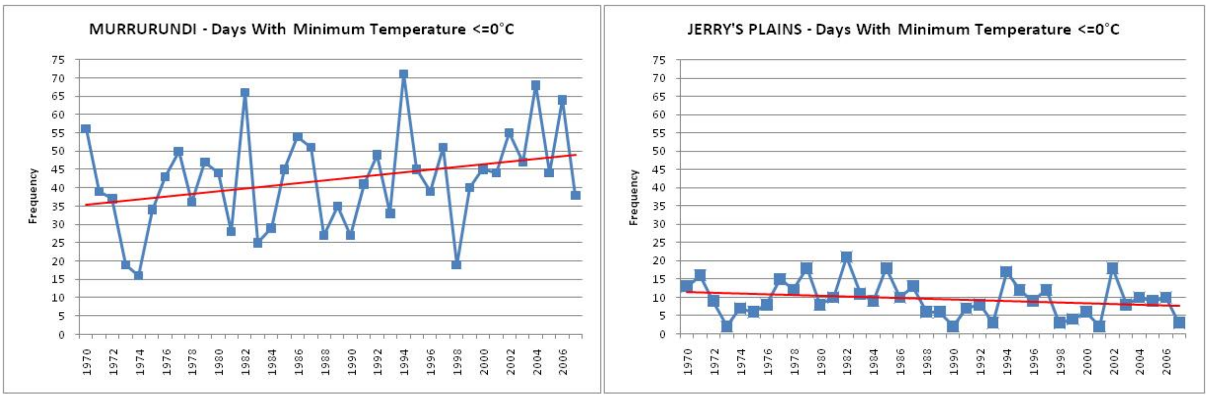

Figure 30 - Annual trend in frosts at Murrurundi and Jerry's Plains

The days per annum with minimum temperature less than or equal to 0ºC for autumn, winter and spring at Murrurundi are shown in Figure 31. The increasing linear trend is evident in all three seasons although as per the annual data, these trends are not statistically significant. Analysis of these seasonal trends is not included for Jerry's Plains due to the small number of events per annum.

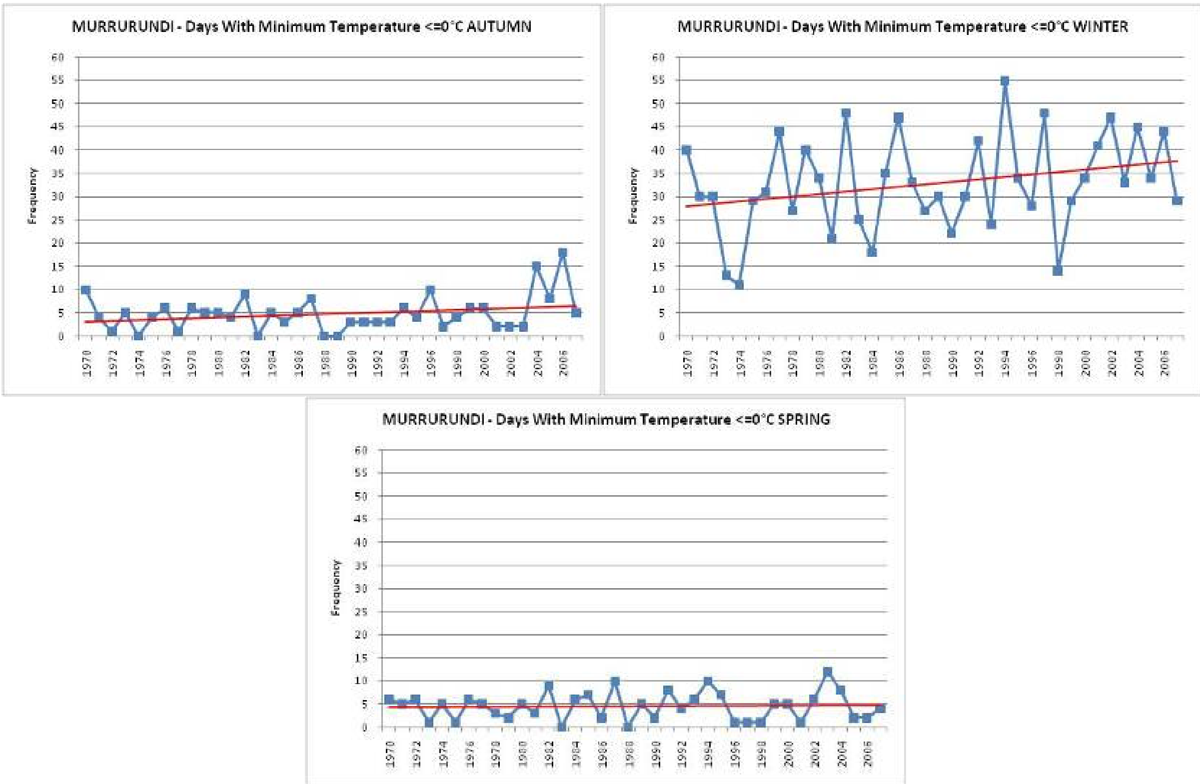

Figure 31 - Trend in frost at Murrurundi for autumn, winter and spring

PROJECTED CHANGES IN CLIMATE

PRECIPITATION PROJECTIONS

An understanding of future changes can be obtained by contrasting projected values to those recorded historically. Figure 32 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 for the region's western climate zone. 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 western 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. An increase in precipitation is projected for autumn in the western zone with little or no change projected for spring.

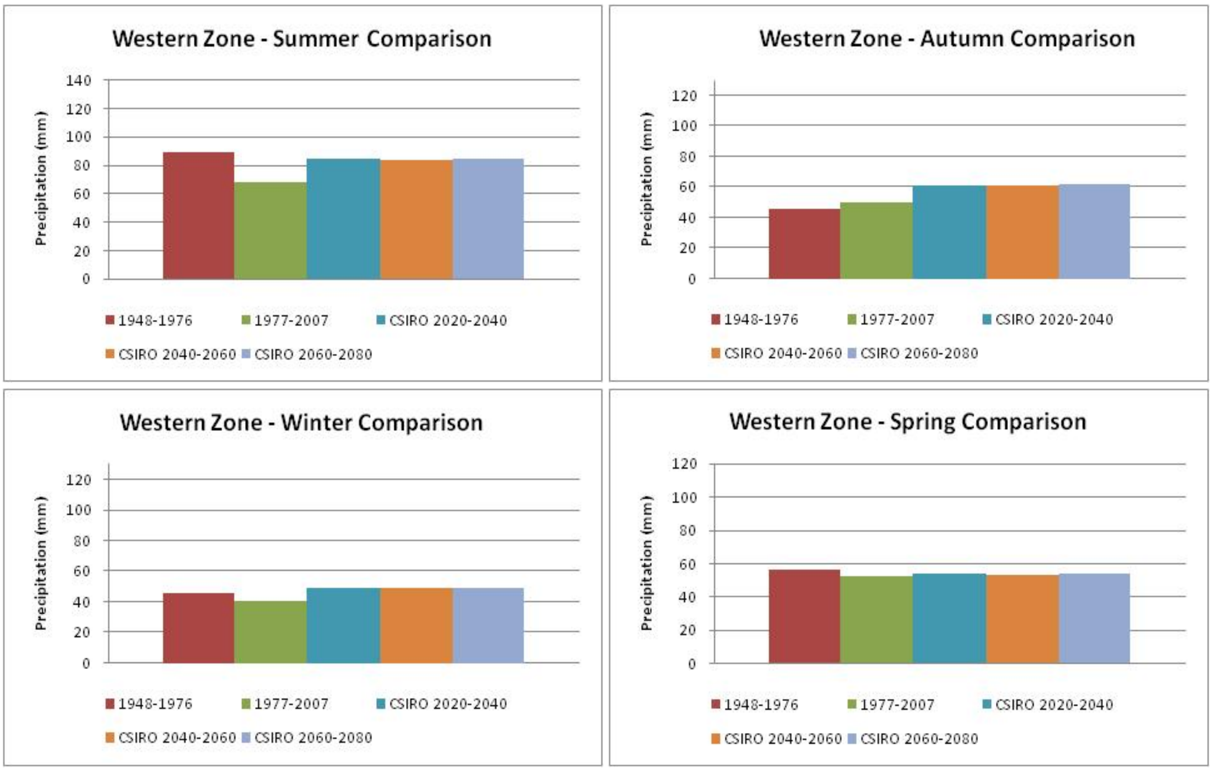

Figure 32 - Seasonal comparison of precipitation for historic interdecal time periods and future time horizons

Estimates of the magnitude of seasonal shifts, relative to the interdecadal periods, are presented in Figure 33 and Table 16 & 17. 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. With the exception of autumn, projected precipitation patterns are similar to those recorded during the 1948 to 1976 time period. An approximate 33% increase in autumn precipitation, relative to the 1948 to 1976 time period, is projected.

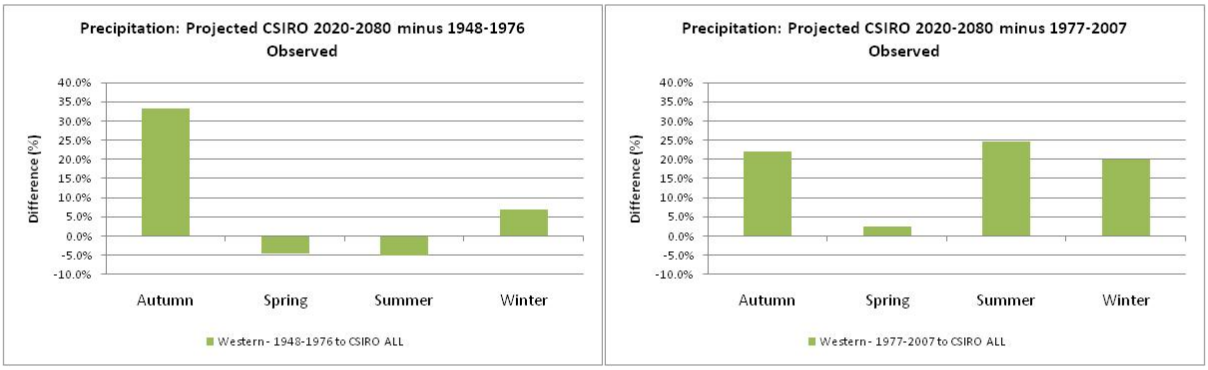

Figure 33 - Projected changes in precipitation relative to historic interdecal time periods

Season	Observed 1948-1976	Projected Change (2020-2080) Relative to 1948-1976 (mm)	Projected Change (2020-2080) Relative to 1948-1976 (%)	Observed 1977-2007	Projected Change (2020-2080) Relative to 1977-2007 (mm)	Projected Change (2020-2080) Relative to 1977-2007 (%)
Summer	89.1	-4.4	-5%	68.0	16.7	25%
Autumn	45.8	15.3	33%	50.1	11.0	22%
Winter	46.0	3.2	7%	41.0	8.2	20%
Spring	55.8	-2.6	-5%	51.9	1.3	2%

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

Rainfall (2020 – 2080) *Projected changes are relative to the 1948-1977 period* *(ie La Nina –ve phase)*			
Summer	**Autumn**	**Winter**	**Spring**
No significant change	Sig. wetter: ~33% increase	No significant change	No significant change

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 projected period from 2020 to 2080 are considered (Figure 34). In addition to showing linear trends (green line), total annual precipitation for the calibration period (1968-1996) is superimposed onto the projected data.

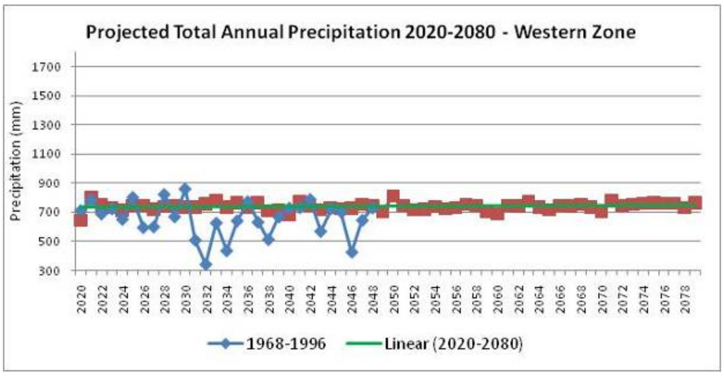

Figure 34 - Projected total annual precipitation for 2020-2080 showing a linear trend

Projections for the western zone, although still within the bounds of natural variability, 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 less than 50mm 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 35 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 western 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 during autumn, however some variation occurs across the 3 time horizons
- a decrease in average minimum temperature during winter
- 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 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 fails to return minimum temperatures to the levels experienced during the historic time period.

Figure 35 - 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 36 and 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.

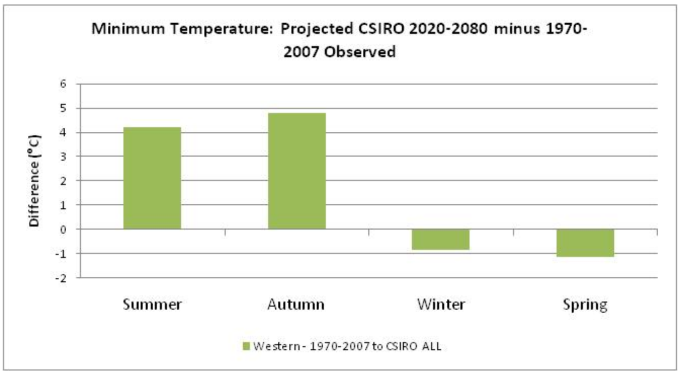

Figure 36 - Projected changes in minimum temperature relative to historic interdecal time periods

Minimum temperature (2020-2080) *Projected changes are relative to the 1970-2007 period*			
Summer	**Autumn**	**Winter**	**Spring**
Warmer: ~4.2°C increase	Warmer: ~4.8°C increase	Cooler: ~0.8°C decrease	Cooler: ~1.2°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 37 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 ($P<0.05$).

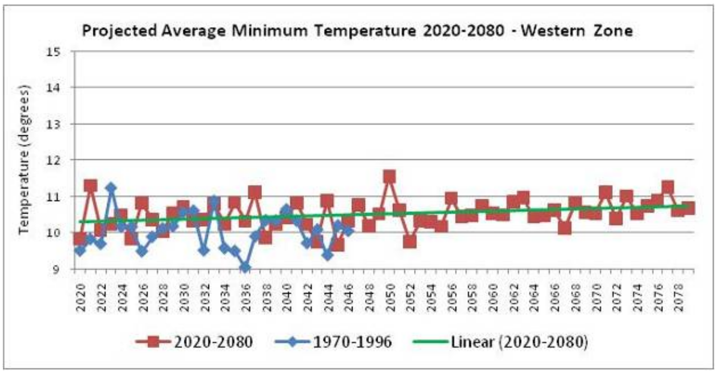

Figure 37 - Projected total average minimum temperature for 2020-2080 showing linear trend

MAXIMUM TEMPERATURE PROJECTIONS

Figure 38 (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 western 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:

- a decrease in average maximum temperature during summer relative to the 1970-2007 time period.
- a 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.
- decreases during spring (relative to 1970-2007), however some variation occurs across the three time horizons. A decrease is projected for the 2020-2040 time horizon 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.

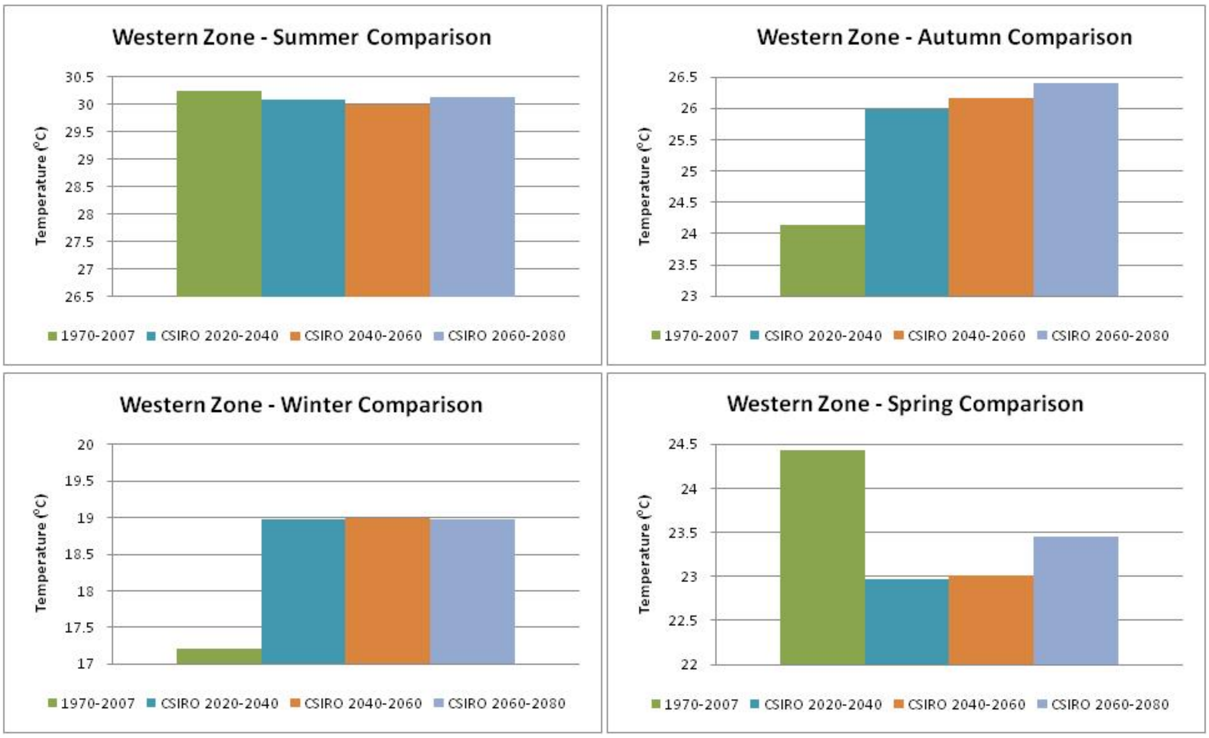

Figure 38 - Seasonal comparison of maximum temperature for historic interdecal time periods and future time horizons

Estimates of the magnitude of seasonal shifts in maximum temperature, relative to the 1970-2007 time period, are presented in Figure 39 (below) and Table 19 (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.

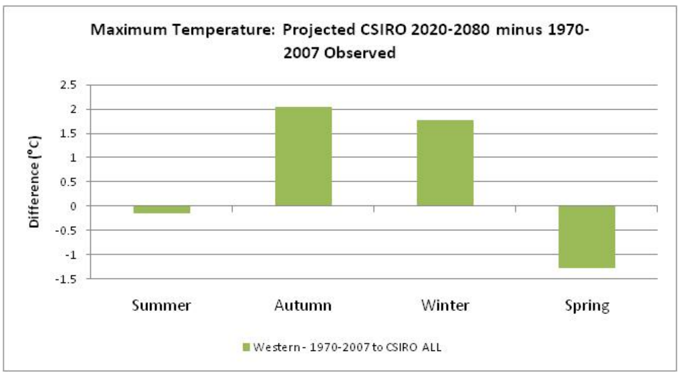

Figure 39 - Projected changes in maximum temperature relative to historic interdecal time periods

Maximum temperature (2020-2080) *Projected changes are relative to the 1970-2007 period*			
Summer	**Autumn**	**Winter**	**Spring**
Cooler: ~0.2°C decrease	Warmer: ~2.0°C increase	Warmer: ~1.8°C increase	Cooler: ~1.3°C decrease

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

Changes in average maximum temperature for the projected period from 2020 to 2080 are shown in Figure 40. 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. This trend is statistically significant at the 5% level (P<0.05).

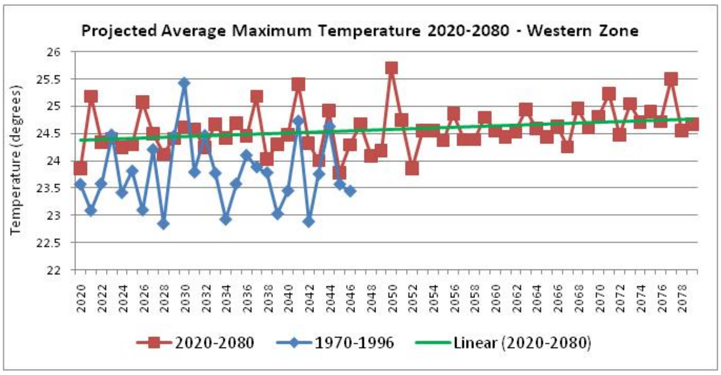

Figure 40 - Projected total average maximum temperature for 2020-2080 showing linear trend

AVERAGE TEMPERATURE PROJECTIONS

Average temperature is calculated from the minimum and maximum temperature values (i.e. (Minimum Temp + Maximum Temp) / 2). Figure 41 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 regions' western 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
- an increase in average temperature during winter
- a general increasing trend during autumn with some variation across the three time horizons.
- variation during spring 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.

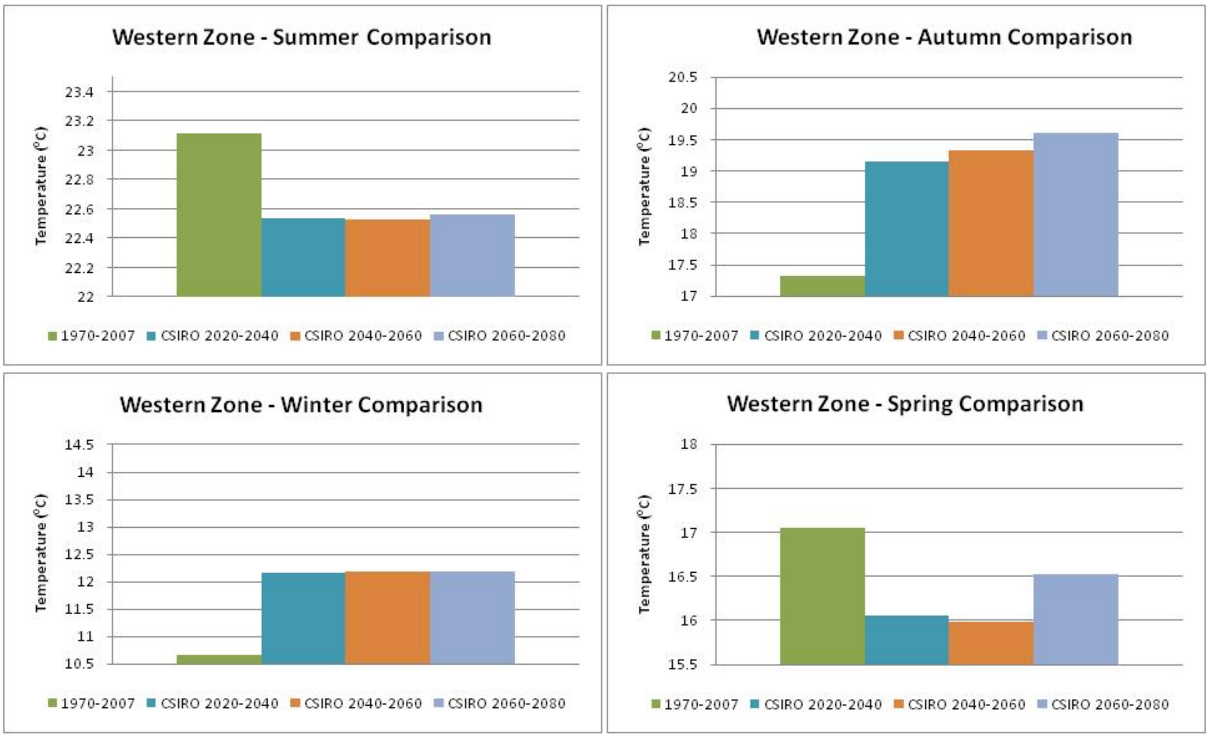

Figure 41 - Seasonal comparison of average temperature for historic interdecal time periods and future time horizons

Estimates of the magnitude of seasonal shifts in average temperature, relative to the 1970-2007 time period, are presented in Figure 42 and Table 20. 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.

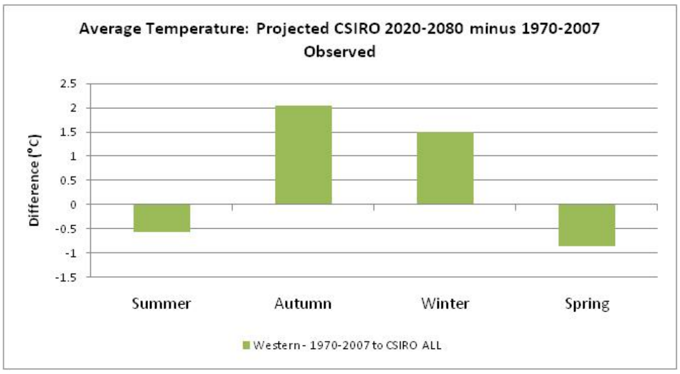

Figure 42 - Projected changes in average temperature relative to historic interdecal time periods

Average temperature (2020-2080) *Projected changes are relative to the 1970-2007 period*			
Summer	**Autumn**	**Winter**	**Spring**
Cooler:~0.6°C decrease	Warmer: ~2.0°C increase	Warmer: ~1.5°C increase	Cooler: ~0.9°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 43 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 western climate zone shows 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. This trend is statistically significant at the 5% level ($P<0.05$).

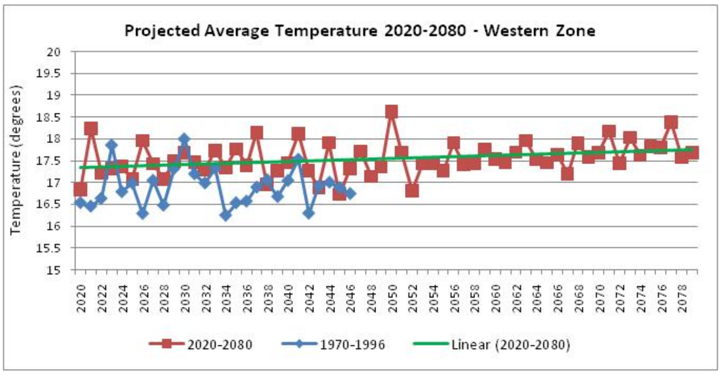

Figure 43 - Projected annual average temperature for 2020-2080 showing linear trend

PAN EVAPORATION PROJECTIONS

Figure 44 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 western climate zone.

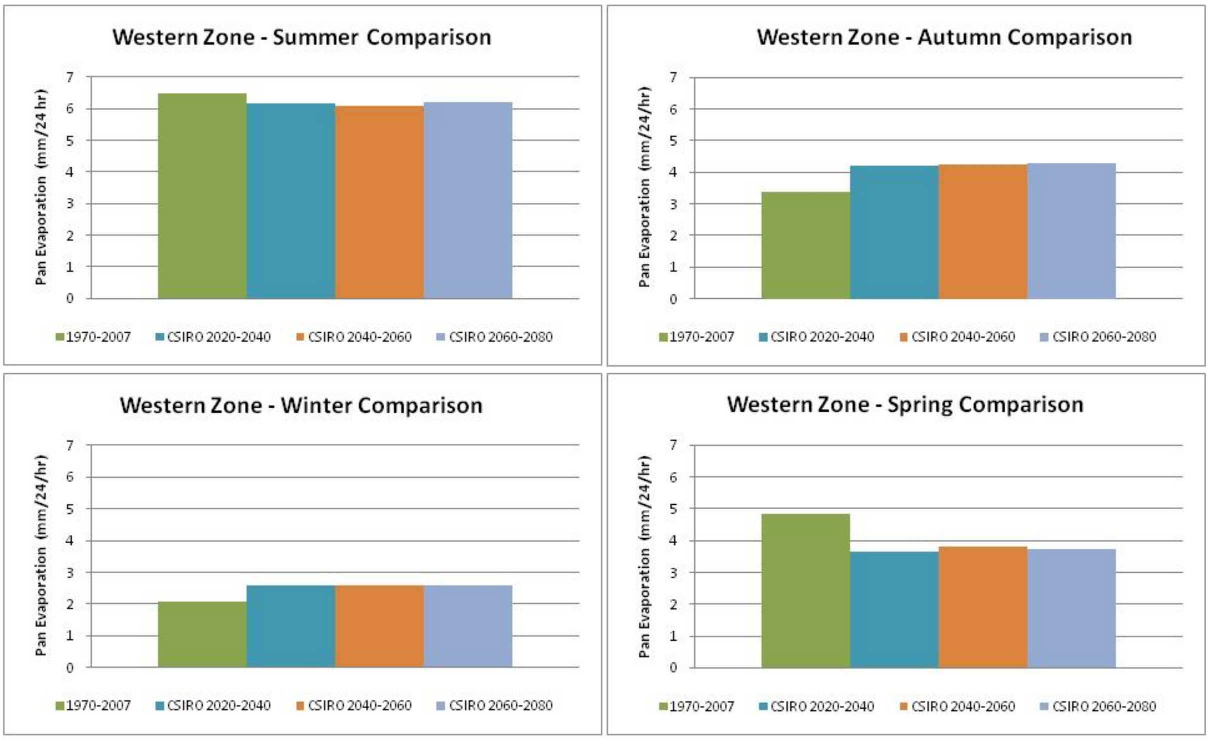

Figure 44 - Seasonal comparison of pan evaporation for historic interdecal time periods and future time horizons

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 45 below and Table 21 over page. Seasonal shifts appear to balance out to produce no projected change in annual pan evaporation.

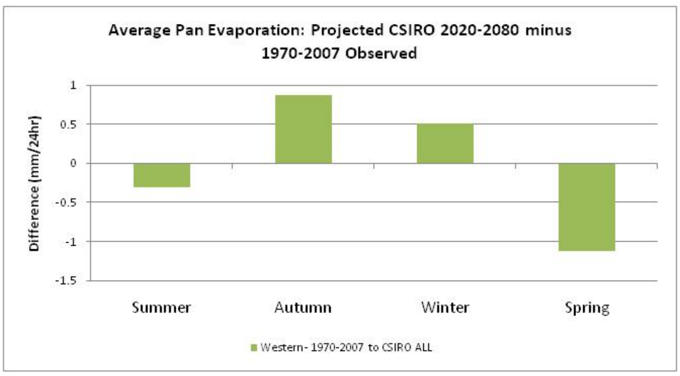

Figure 45 - Projected changes in average pan evaporation relative to historic interdecal time periods

Average pan evaporation (2020-2080) *Projected changes are relative to the 1970-2007 period*			
Summer	**Autumn**	**Winter**	**Spring**
Wetter:~0.3mm/24hr decrease	Drier: ~0.9mm/24hr increase	Drier: ~0.5mm/24hr increase	Wetter: ~1.1mm/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 46). 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.

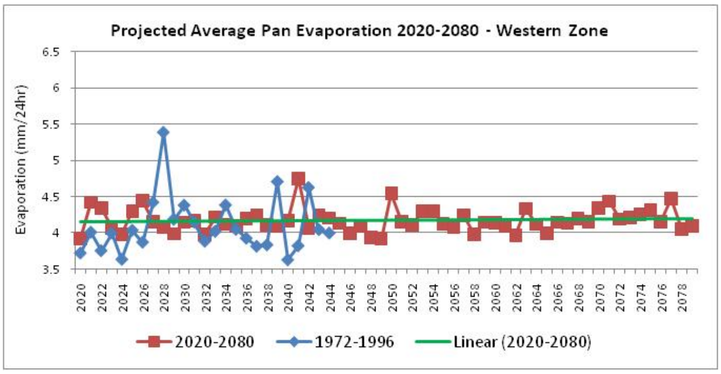

Figure 46 - Projected annual average pan evaporation for 2020-2080 showing linear trend

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 region 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 47 shows the average, minimum and maximum humidity range for each of the CSIRO STs.

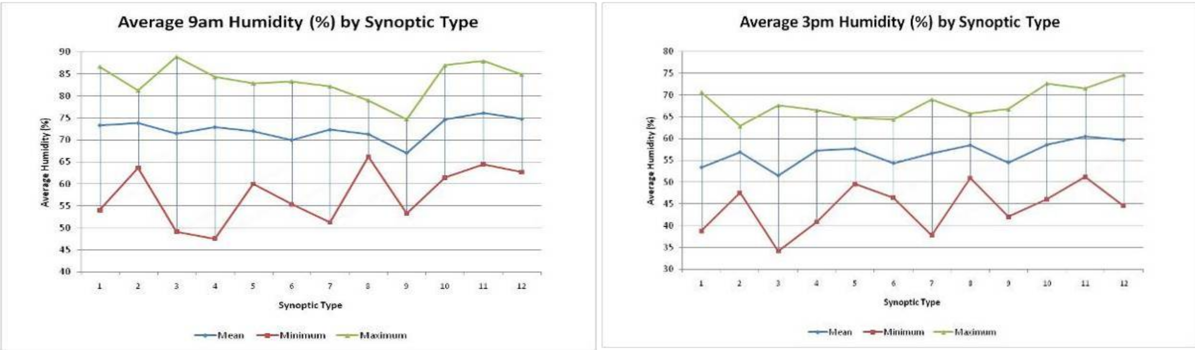

Figure 47 - 9am and 3pm humidity by CSIRO ST

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 48 (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).

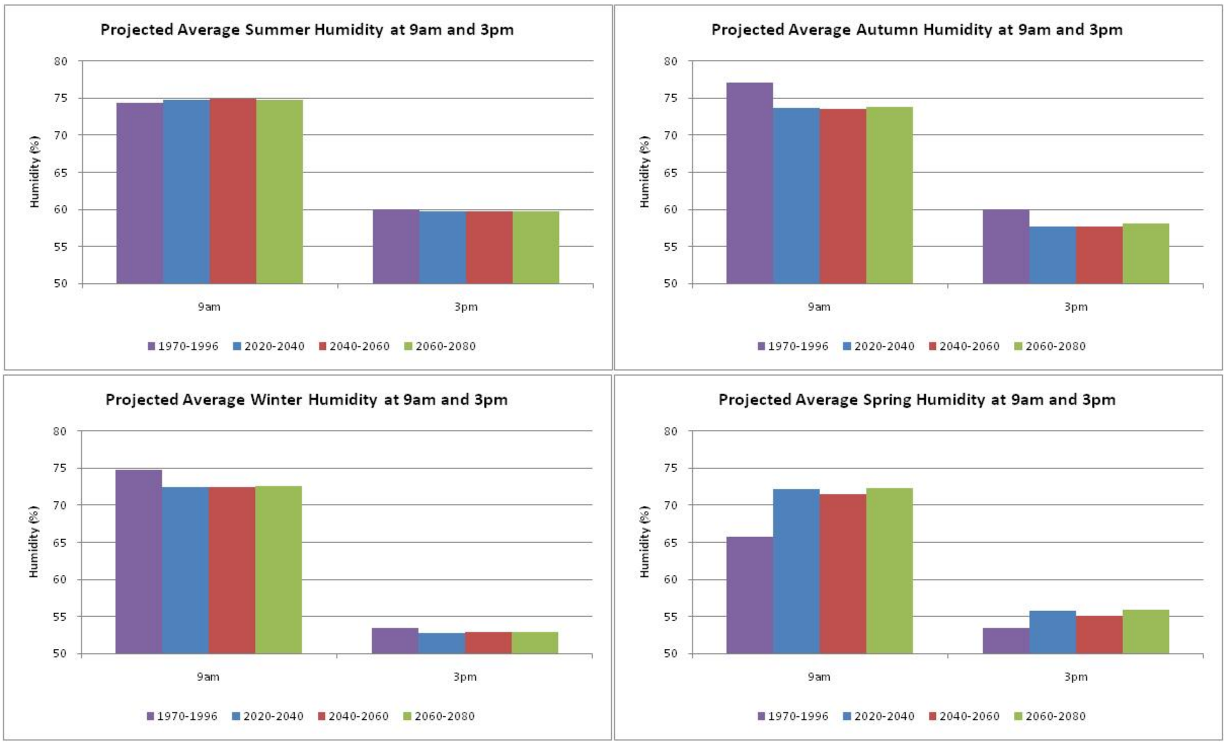

Figure 48 - Seasonal comparison of 9am and 3pm humidity for historic time period and future time horizons

Estimates of the magnitude of seasonal shifts, relative to the 1970-1996 period, are presented in Figure 49 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.

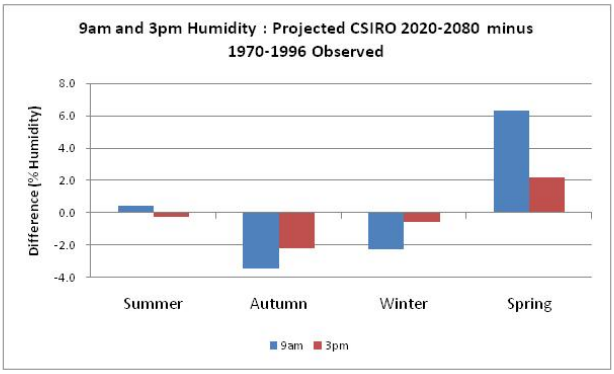

Figure 49 - Estimates of projected humidity shifts relative to the 1970-1996 period

Average humidity (2020-2080) ***Projected changes are relative to the 1970-1996 period***				
	Summer	**Autumn**	**Winter**	**Spring**
9 am Humidity	More Humid: ~0.4% increase	Less Humid: ~3.4% decrease	Less Humid: ~2.2% decrease	More Humid: ~6.3% increase
3 pm 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 50. 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.

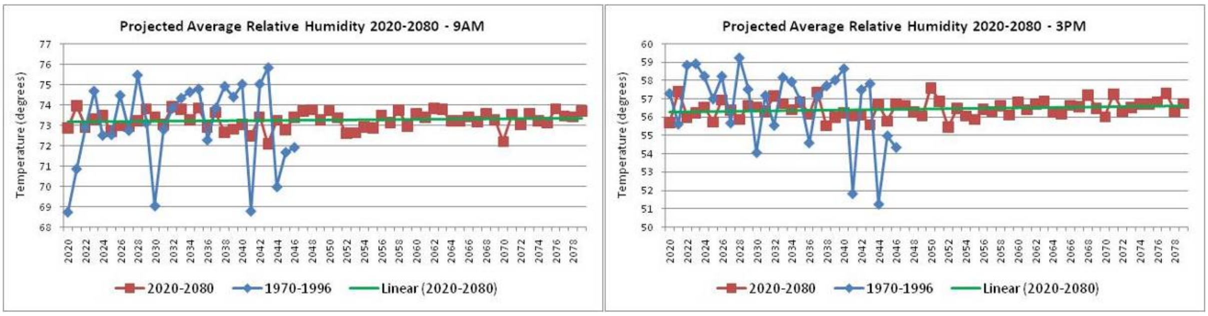

Figure 50 - Projected average annual 9am and 3pm relative humidity for 2020-2080 showing linear trends

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).

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 51). Projections include:

- An increase in average water balance during summer
- An initial slight increase during autumn from 2020-2030, followed by a decrease in both 2040-2060 and 2060-2080
- A slight increase during winter for 2020-2030 followed by decreases in 2040-2060 and 2060-2080.
- Increases in average water balance during spring in all time horizons relative to the 1970-2007 period. The strongest increase is projected to occur during the 2020-2030 time period, followed by a decrease (relative to the 2020-2030 time period) then a slight increase.

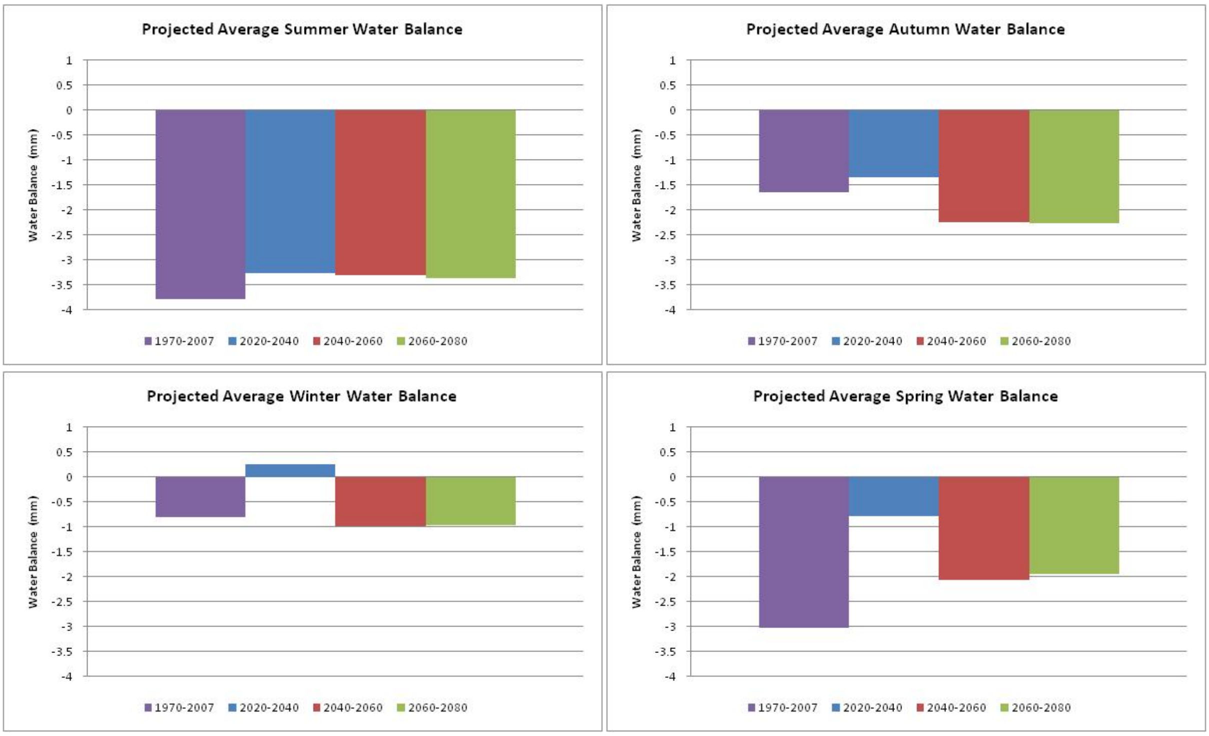

Figure 51 - Seasonal comparison water balance for historic interdecal time periods and future time horizons

Estimates of the magnitude of seasonal shifts, relative to the 1970-2007 time period, are presented in Figure 52 and Table 23. 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.

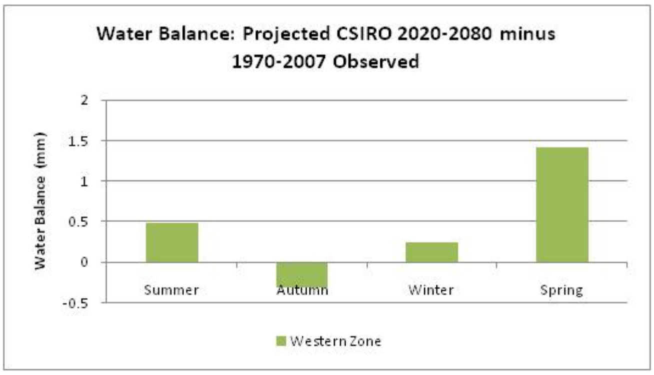

Figure 52 - Projected changes in average water balance relative to historic interdecal time period

Average water balance (2020-2080) *Projected changes are relative to the 1970-2007 period*			
Summer	**Autumn**	**Winter**	**Spring**
Wetter:~0.5mm/24hr increase	Drier: ~0.3mm/24hr decrease	Wetter: ~0.2mm/24hr increase	Wetter: ~1.4mm/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 53 over page. 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 western climate zone shows a 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 western zone. This trend is statistically significant at the 5% level ($P<0.05$).

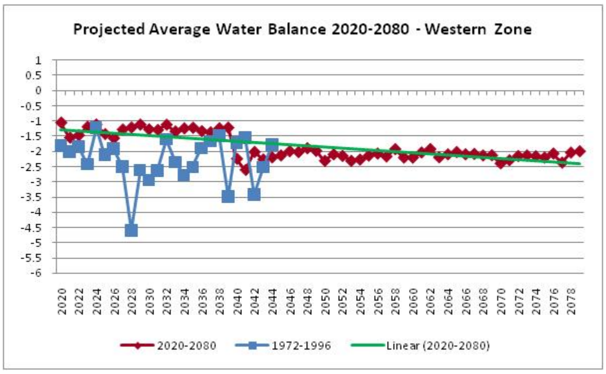

Figure 53 - Projected annual average water balance for 2020-2080 showing linear trend

Although the decreasing linear trend is statistically significant, the projected time series clearly shows a stepwise change in water balance occurring around 2040 A.D. Water balance for the period from 2020-2040 is projected to occur at the upper bound of experienced natural variability (i.e. wetter). From 2040-2080, water balance is projected to decrease to levels similar to those experienced during 1972-1996 (i.e. drier).

AVERAGE WIND SPEED AND WIND GUSTS

Figure 54 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' western 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.

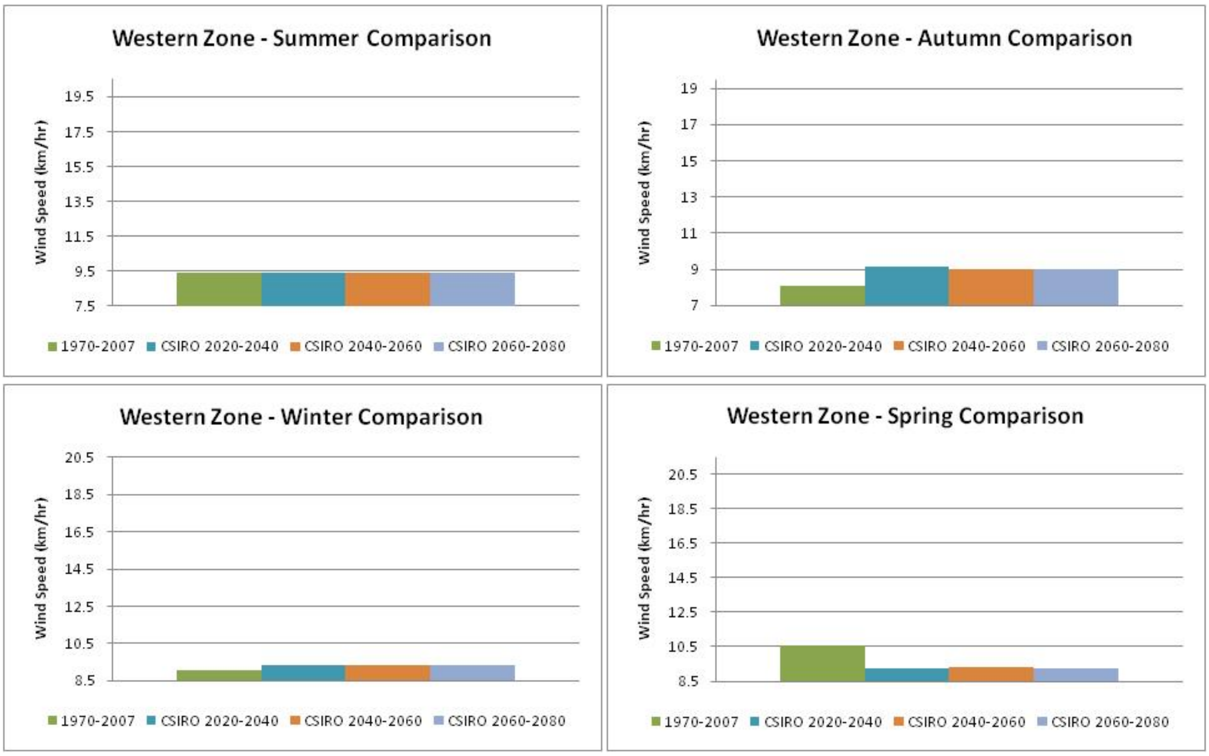

Figure 54 - Seasonal comparison of average wind speed for historic interdecal time period and future time horizons

Estimates of the magnitude of seasonal shifts, relative to the 1970-2007 time period, are presented in Figure 55 (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).

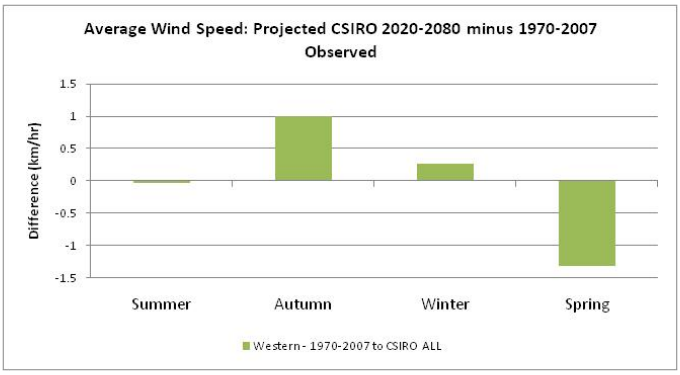

Figure 55 - Projected changes in average wind speed relative to historic interdecal time period

Wind Speed (2020-2080) *Changes are reported in average km/hr relative to 1970-2007.*		
Season	**Decrease**	**Increase**
Summer	Minimal change	
Autumn		~1.0km/hr Western Zone
Winter		~0.3km/hr Western Zone
Spring	~1.3km/hr Western Zone	

Table 24 - Summary of projected changes in wind speed

Increases occurring during autumn are balanced by decreases occurring in spring and thus should result in no overall change in annual average wind speed.

Changes in annual average wind speed for the projected period from 2020 to 2080 are shown in Figure 56. 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 western 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.

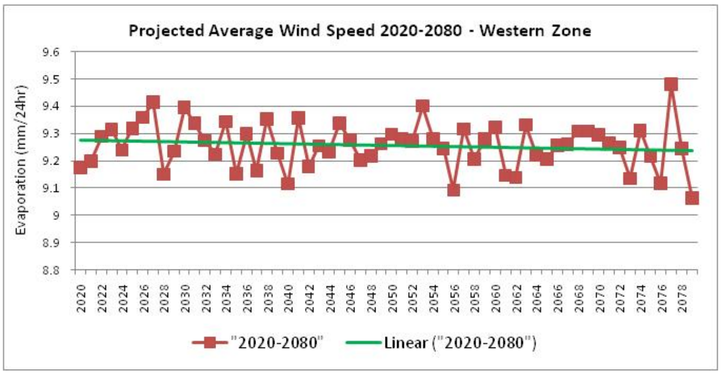

Figure 56 - Projected annual average wind speed for 2020-2080 showing linear trend

Wind gust rose diagrams showing the relationship between the CSIRO ST's and wind gust are shown in Figure 57 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.

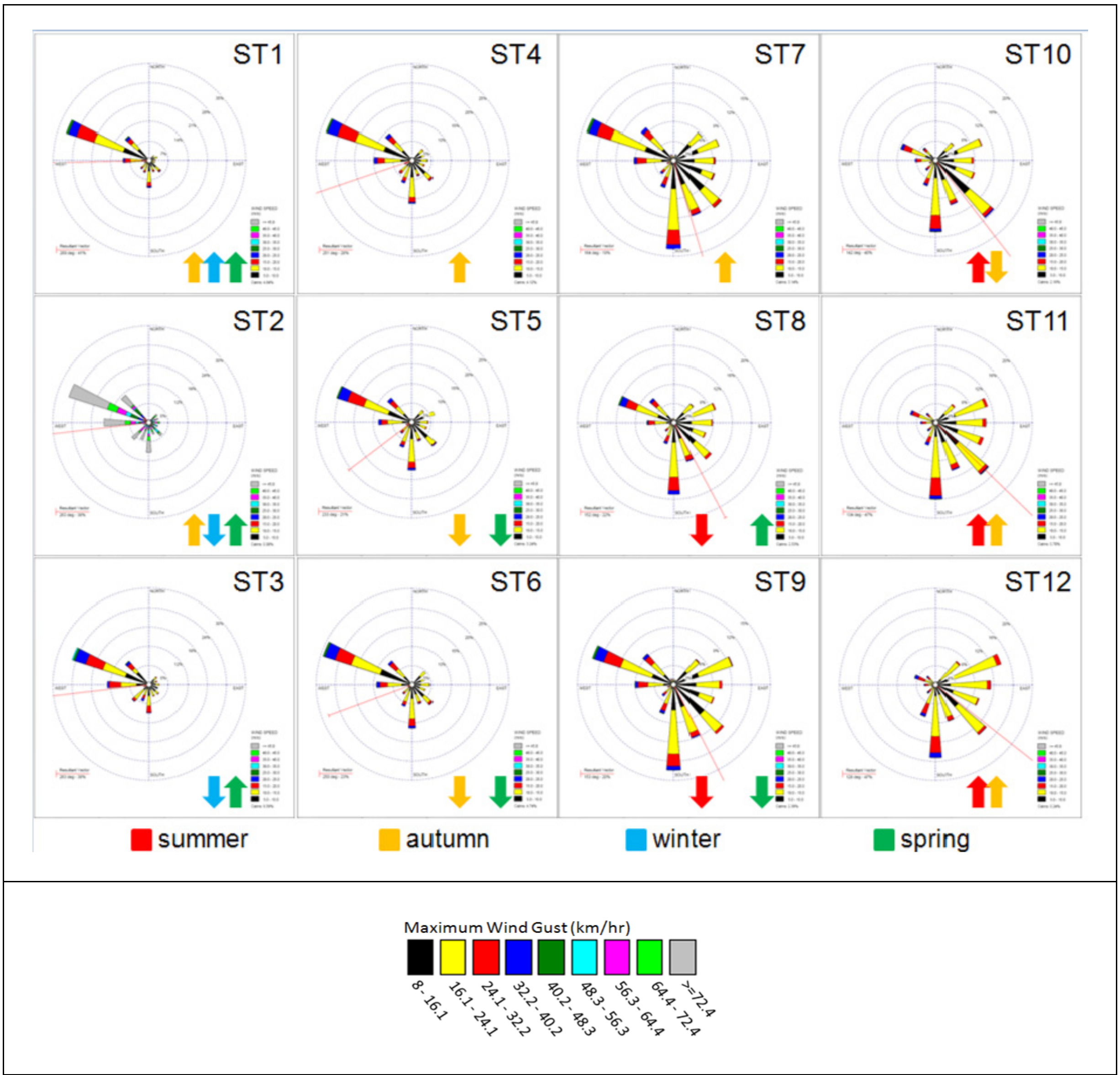

Figure 57 - Regional maximum wind gust patterns for CSIRO STs

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).

As identified previously, two (2) representative stations within the western 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 58 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 Murrurundi 2.65% 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.

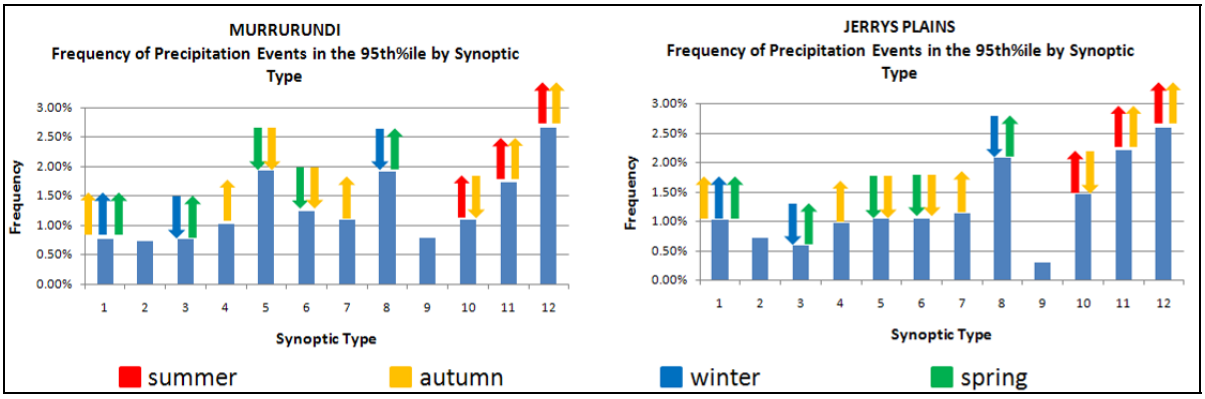

Figure 58 - Frequency of precipitation events in the 95%ile by ST for selected stations with arrows indicating seasonal shifts

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

- During summer and autumn, STs 11 and 12 are most likely to produce a high rainfall event in the western zone (Jerrys Plains and Murrurundi). The frequency of occurrence of both of these STs 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 8 is associated with a relatively high frequency of extreme rainfall events during winter and spring. Projected decreases in the frequency of occurrence of this type during winter suggest a decrease in extreme rainfall events during winter is likely. Although an increase in the frequency of ST8 during spring is projected, this change is directly offset by a projected decrease in frequency of ST5 and thus no change is spring is projected.

MAXIMUM TEMPERATURE (EXTREME HEAT DAYS)

A clear relationship between ST12 and extreme heat days (EHDs) exists for both stations (Figure 59). This relationship is strongest in the far west of the region (Murrurundi) where ~72% 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.

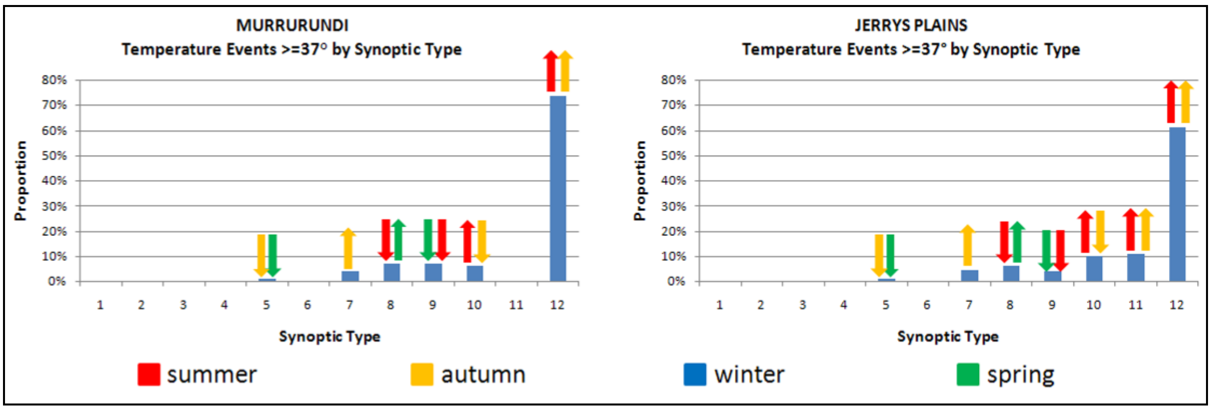

Figure 59 - Frequency of temperature events >=37^{o}C by ST for selected stations with arrows indicating seasonal shifts

MINIMUM TEMPERATURE (FROSTS)

Frost events (temperatures below or equal to 0°C) occur at each station in the western zone (Murrurundi and Jerrys Plains) (Figure 60). An association between minimum temperature events of less than or equal to 0°C and STs 1 and 3 are evident. Winter projections suggest increases in ST1 will be offset by decreases in STs 2 and 3, thus minimal change is expected during this season. However projected increases in the frequency of occurrence of STs 1, 2 and 3 during spring 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 4 are also likely to produce an increase in minimum temperature events (<=0°C) in the projected period (2020-2080) during autumn.

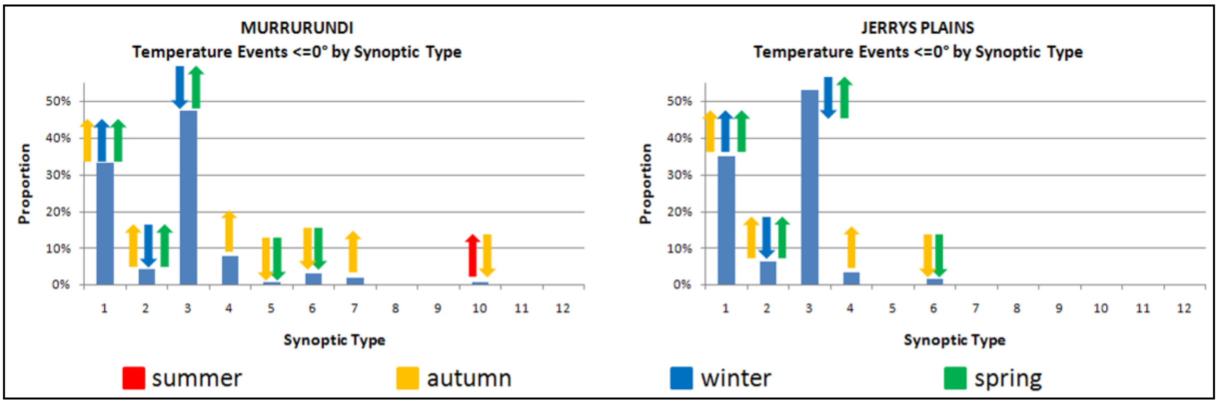

Figure 60 - Frequency of minimum temperature events <=0°C by ST for selected stations with arrows indicating seasonal Shifts

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