Hunter, Central and Lower North Coast

Regional Climate Change Project

2010

Historic and Projected Impacts of Climate Change on the COASTAL 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

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Glossary

BOM	*BUREAU OF METEOROLOGY*
CSIRO	*COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANISATION*
GCM	*GLOBAL CLIMATE MODEL*
HCCREMS	*HUNTER AND CENTRAL COAST REGIONAL ENVIRONMENTAL MANAGEMENT STRATEGY*
LGA	*LOCAL GOVERNMENT AREA*
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 *coastal climatic zone* of the project study area (the Hunter, Central & Lower North Coast Region of New South Wales) (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; and
- To improve the awareness and capacity of these groups to accurately assess climate risk and to develop and implement appropriate adaptation strategies in response.

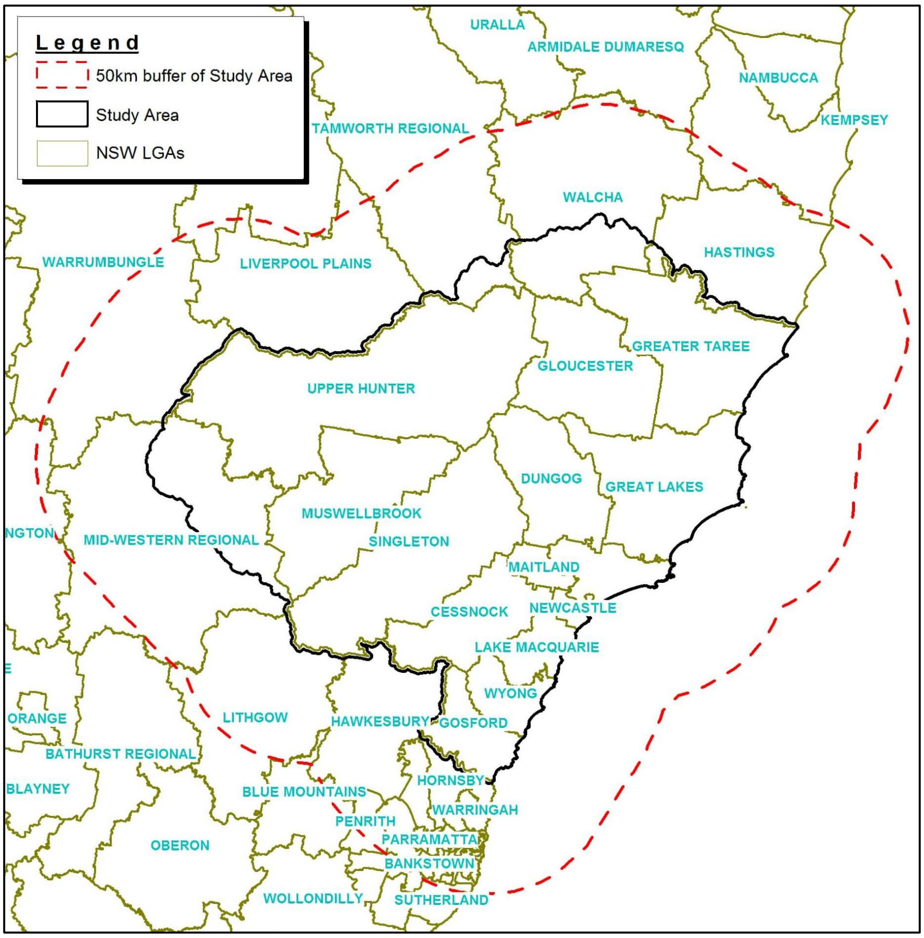

Figure 1 - LGAs in the study region

SUMMARY OF KEY FINDINGS

Historic and projected changes in key climate parameters are 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 coastal climate zone, projections are "downscaled" to this zone and thus provide a sub-regional assessment of projected climate change.

Statistically significant historic and projected changes in key climate parameters have been identified. These include:

- A 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. **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 increasing trend in average annual **minimum temperature** of 1.4^{o}C is observed over the period from 1970-2007. Increases of 1.2^{o}C occurring in winter and 1.0^{o}C in spring over this period are 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 decreases in summer and spring and more significant increases in autumn and winter.

- An increasing trend in average annual **maximum temperature** of 1.2^{o}C is observed over the period from 1970-2007. Increases of 0.9^{o}C occurring in winter and 1.4^{o}C in spring over this period are also significant. **An increase in average annual maximum temperature of 1.5^{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.**

- An 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 autumn, 1.2^{o}C winter and 1.0^{o}C in spring over this period are also significant. **An increase in average annual maximum temperature of 1.6^{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.

- An 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.

- **An increasing trend in the number of extreme heat events of approximately 3.3 days** in total is **observed over the period from 1970-2007 at Taree.** Projected shifts in the frequency of occurrence in **STs suggest this trend is 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 region. This now makes it possible to assess the sensitivity and associated climate change risks for the coastal 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.

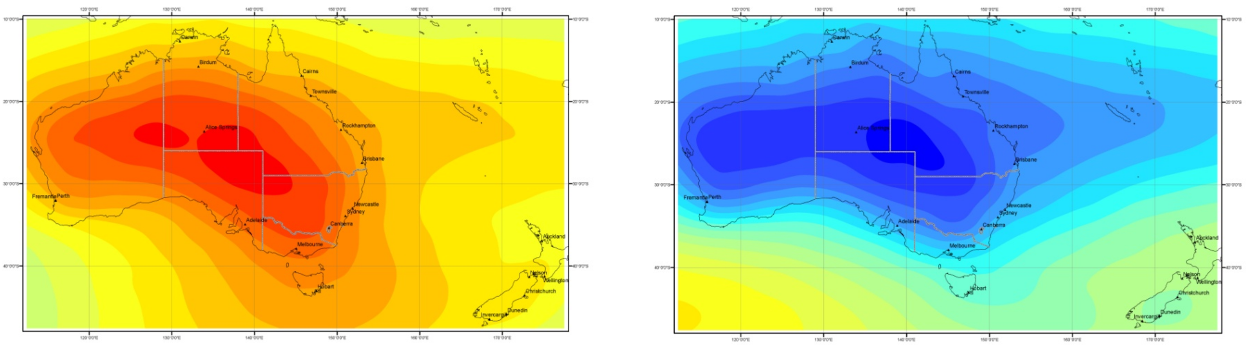

Figure 2 - Synoptic patterns are the air pressure systems commonly seen on weather maps

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 identified throughout this study using a statistical downscaling approach, based on principally 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 coastal zone.

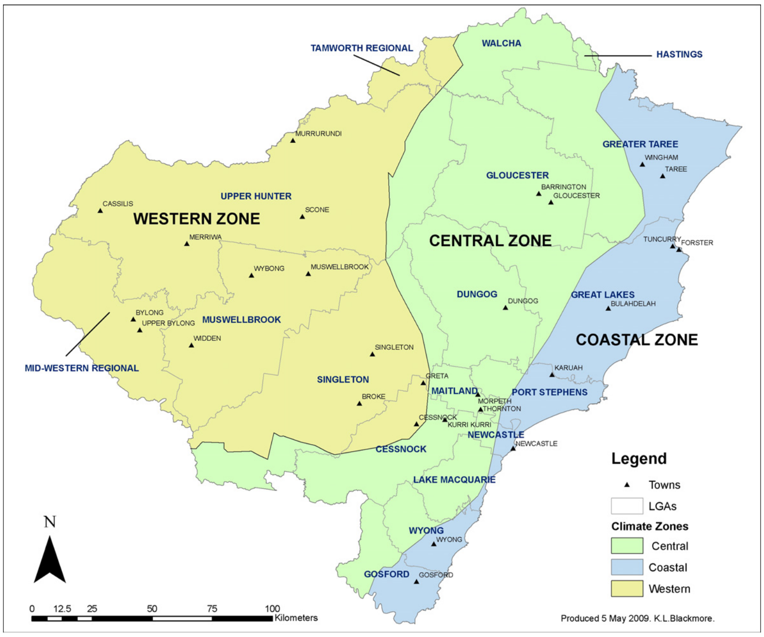

Figure 3 - The region's three climate zones identified in Stage 2 of the project

THE COASTAL CLIMATE ZONE

The coastal climate zone incorporates parts of the Greater Taree, Great Lakes, Port Stephens, Newcastle, Lake Macquarie, Wyong and Gosford local government areas (LGAs). Located in this zone are the major towns of Taree, Forster, Newcastle, Wyong and Gosford.

Covering a total area of approximately 6,165 square kilometers, the coastal zone is strongly influenced by ocean processes and coastal elevation, experiencing cooling coastal breezes during summer and warmer minimum temperatures during winter. Key features of the zone include:

- Annual maximum temperatures average 23.2^{o}C (over the period from 1970-2007).
- Elevation ranges from approximately 750 meters above sea level (ASL) in the north-west of the zone to as little as 0 meters ASL in the east.
- The coastal zone experiences infrequent frosts (which occur mainly in the western parts of the zone) with minimum annual minimum temperatures averaging 13.1^{o}C.
- The coastal zone receives the highest rainfall in the region. Autumn is the wettest season, averaging 126mm per month. Rainfall decreases during winter and spring to approximately 91mm and 79mm per month respectively. Summer is wetter with an average of 119mm per month recorded over the period from 1948 to 2007.

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 coastal 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 coastal climate zone meeting these criteria are provided in Tables 2 – 6 on pages 9 and 10.

DAILY PRECIPITATION

Of the 80 BOM precipitation stations meeting 90% complete criteria in the Hunter, Central and Lower North Coast region, 10 stations lie within the coastal climate zone (Table 2 over page).

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[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.

BOM_ID	NAME	YEAR OPENED	LATITUDE	LONGITUDE	ELEVATION
61087	Gosford (Narara Research Station) AWS	01/1916	-33.395	151.329	20
61083	Wyong (Wyong Golf Club)	01/1885	-33.272	151.432	37
61074	The Entrance (Eloora Street)	01/1943	-33.353	151.496	22
61055	Newcastle Nobbys Signal Station AWS	01/1862	-32.919	151.798	33
61072	Tahlee (Carrington House)	01/1887	-32.668	152.014	3
60002	Bulahdelah Post Office	01/1905	-32.413	152.208	10
60036	Wingham (Lanark Close)	01/1888	-31.862	152.344	66
60013	Forster – Tuncurry R.V.C.P	01/1896	-32.176	152.509	4
60017	Hannam Vale (Hannam Vale Road)	01/1926	-31.699	152.583	33
60023	Harrington (Oxley Anchorage Caravan Park)	01/1887	-31.871	152.683	6

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 coastal climate zone (Table 3).

BOM_ID	NAME	YEAR OPENED	LATITUDE	LONGITUDE	ELEVATION
61055	Newcastle Nobbys Signal Station AWS	01/1862	-32.919	151.798	33
61078	Williamtown RAAF	01/1942	-32.793	151.836	9
60030	Taree (Radio Station 2RE)	01/1881	-31.899	152.483	5

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 one station (Williamtown RAAF) lies within the coastal climate zone (Table 4).

BOM_ID	NAME	YEAR OPENED	LATITUDE	LONGITUDE	ELEVATION
61078	Williamtown RAAF	01/1942	-32.793	151.836	9

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, one station lies within the coastal climate zone (Table 5). Although record keeping commences as early as 1862, consistent records are not available prior to 1970.

BOM_ID	NAME	YEAR OPENED	LATITUDE	LONGITUDE	ELEVATION
61055	Newcastle Nobbys Signal Station AWS	01/1862	-32.919	151.798	33

Table 5 – Available humidity stations

AVERAGE WIND SPEED AND WIND GUSTS

Average wind speed data is available from two (2) stations within the coastal 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	YEAR OPENED	LATITUDE	LONGITUDE	ELEVATION
61055	Newcastle Nobbys Signal Station AWS	01/1862	-32.919	151.798	33
61078	Willamtown RAFF	01/1942	-32.793	151.836	9

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 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 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 coastal zone, a statistically significant decreasing linear trend in average annual precipitation is evident over the period from 1948 to 2007 (Figure 4). This epoch 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. Overall, the average annual rainfall is approximately 155mm less during the 1977 to 2007 period than during the 1948-76 period.

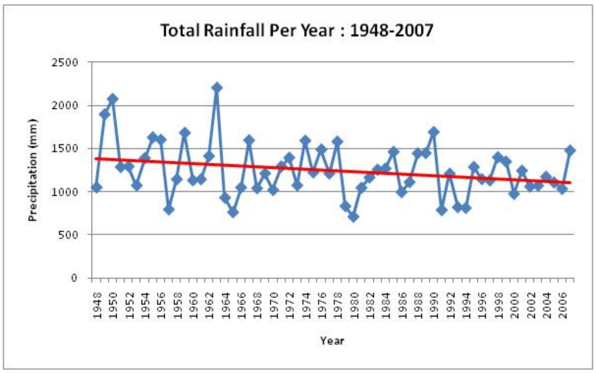


Figure 4 - Trend in total annual rainfall (1948-2007)

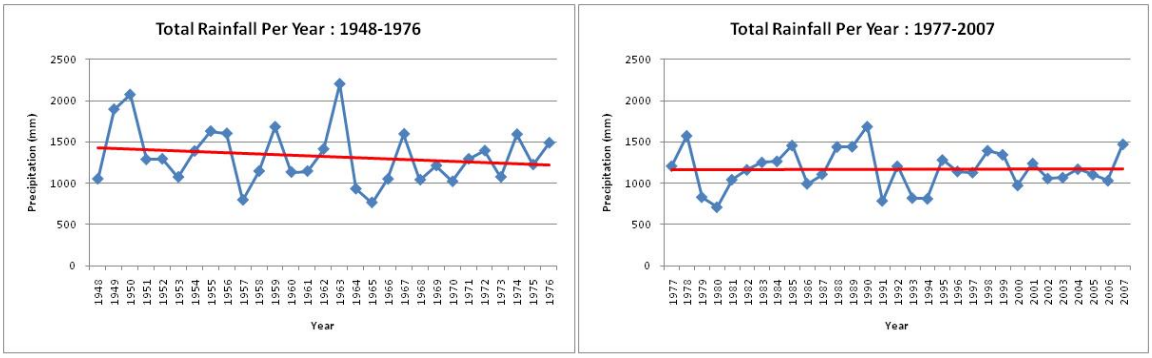


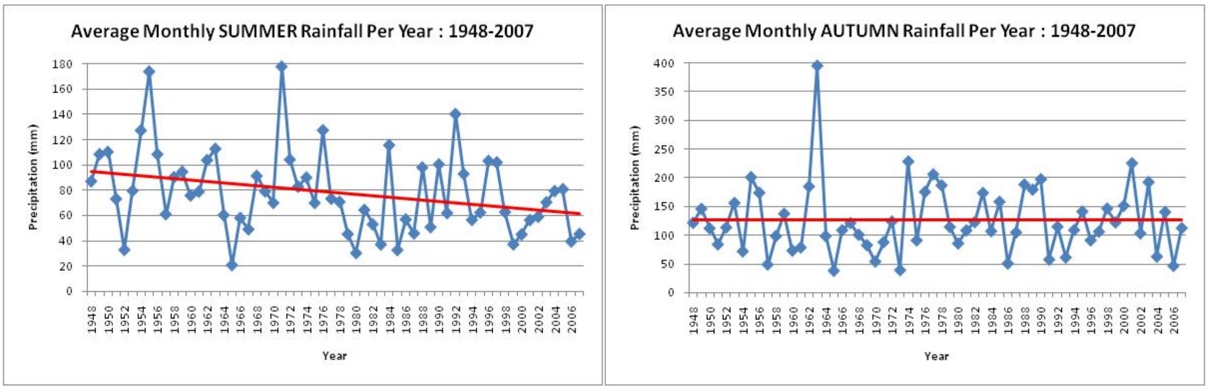
Figure 5 - Trend in total rainfall for the 1948-1976 and 19770-2007 time periods

Seasonally, statistically significant decreases in average monthly precipitation have occurred during summer and winter only (Table 7 and Figure 6). During summer, the monthly average rainfall has decreased by 0.8mm per annum (46mm in total) and in winter this decrease is approximately 0.9mm per annum (52mm in total) over the period from 1948-2007.

Total Rainfall (1948-2007)			
Summer	**Autumn**	**Winter**	**Spring**
Drier: ~46mm* decrease	No change	Drier: ~52mm* decrease	Wetter: ~4mm increase

* Statistically significant

Table 7 - Summary of historic changes in rainfall



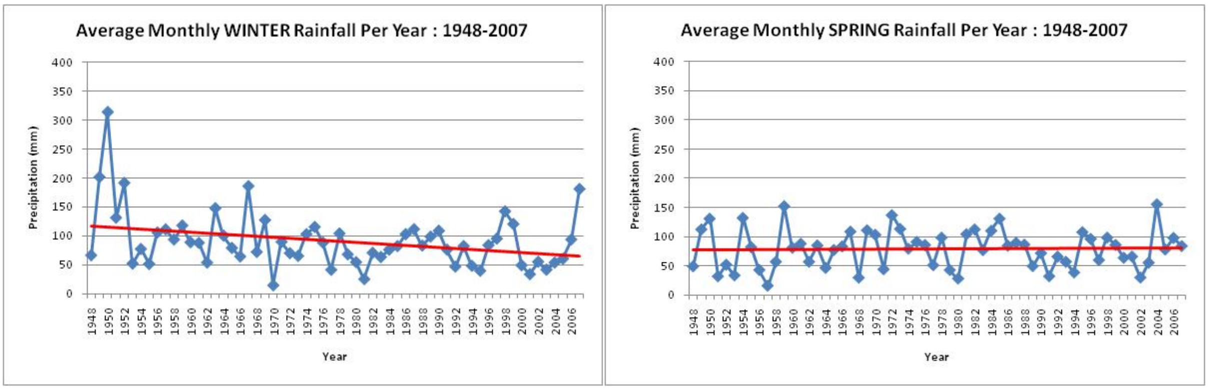


Figure 6 - Seasonal rainfall trends 1948-2007

TEMPERATURE

MINIMUM TEMPERATURE

The average annual minimum temperature recorded for the coastal zone from 1970 to 2007 is 13.1^{o}C. Over the period from 1970 to 2007, an increasing linear trend in average annual minimum temperature in the coastal zone is evident (Figure 7). This statistically significant trend is equivalent to an increase of approximately 1.4^{o}C over this entire period.

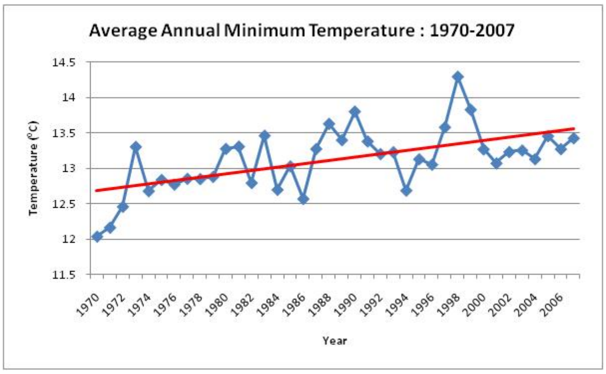


Figure 7 - Trend in average annual minimum temperature for the 1970-2007 period

During summer, minimum temperatures average 18.2^{o}C in the coastal zone, decreasing to 14.0^{o}C during autumn and 7.6^{o}C during winter. 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 (Table 8 below and Figure 8 over page). The seasonal increases occurring in autumn (~0.8^{o}C), winter (~1.2^{o}C) and spring (~1.0^{o}C) are statistically significant.

Average Minimum temperature (1970-2007)			
Summer	**Autumn**	**Winter**	**Spring**
Warmer: ~0.5°C Increase	Warmer: ~0.8°C* increase	Warmer: ~1.2°C* increase	Warmer: ~1.0°C* increase

* Statistically significant

Table 8 - Summary of historic changes in minimum temperature

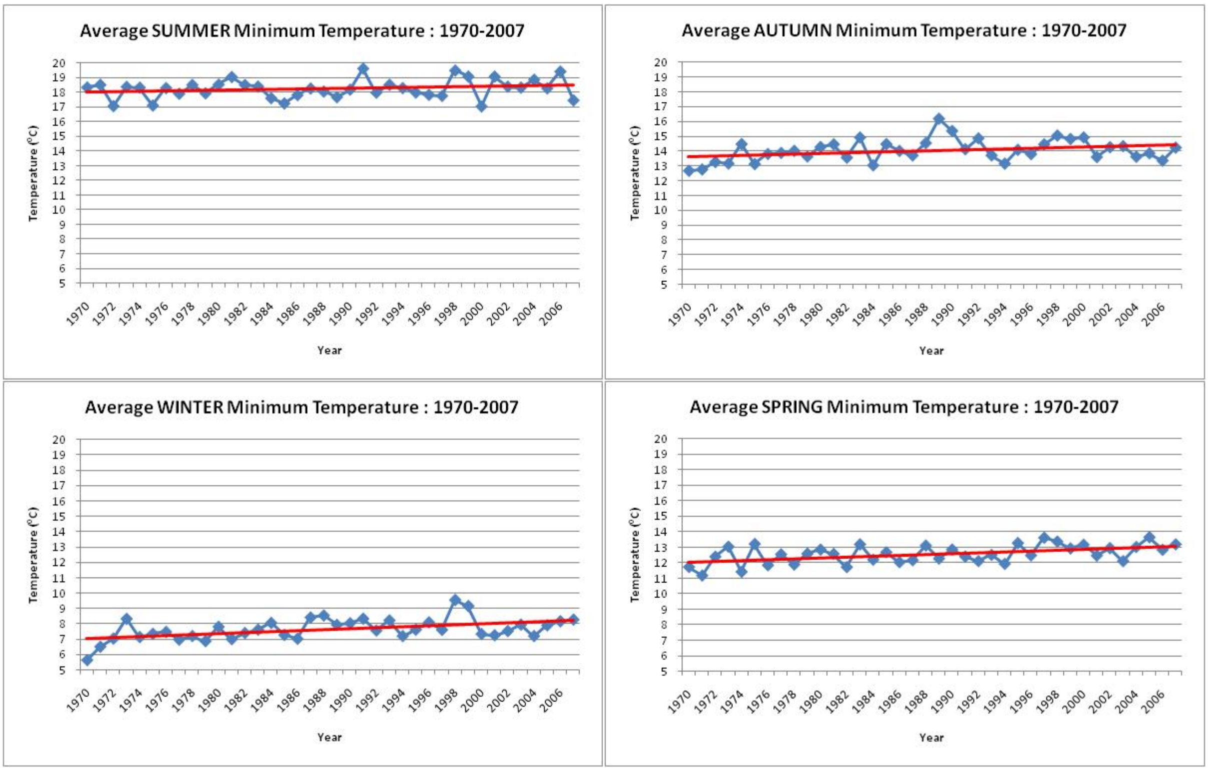


Figure 8 - Seasonal average minimum temperature trends 1970-2007

MAXIMUM TEMPERATURE

The average annual maximum temperature recorded for the coastal zone from 1970 to 2007 is 24.0^{o}C. Over the period from 1970 to 2007, an increasing linear trend in average annual maximum temperature in the coastal 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.

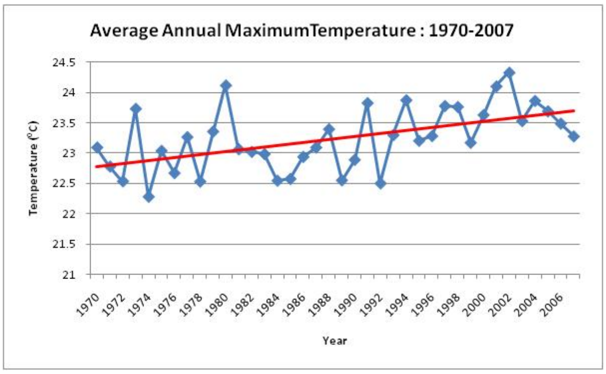


Figure 9 - Trend in average annual maximum temperature for the 1970-2007 time period

During summer, average maximum temperatures are 27.3^{o}C in the coastal zone, decreasing to 23.7^{o}C during autumn and 18.5^{o}C during winter. Spring maximum temperatures average 24.0^{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 (~2.0^{o}C) seasonal increases are statistically significant.

Average Maximum temperature (1970-2007)			
Summer	**Autumn**	**Winter**	**Spring**
Warmer: ~0.9°C increase	Warmer: ~0.5°C increase	Warmer: ~0.9°C* increase	Warmer: ~1.4°C* increase

*Statistically significant

Table 9 - Summary of historic changes in maximum temperature

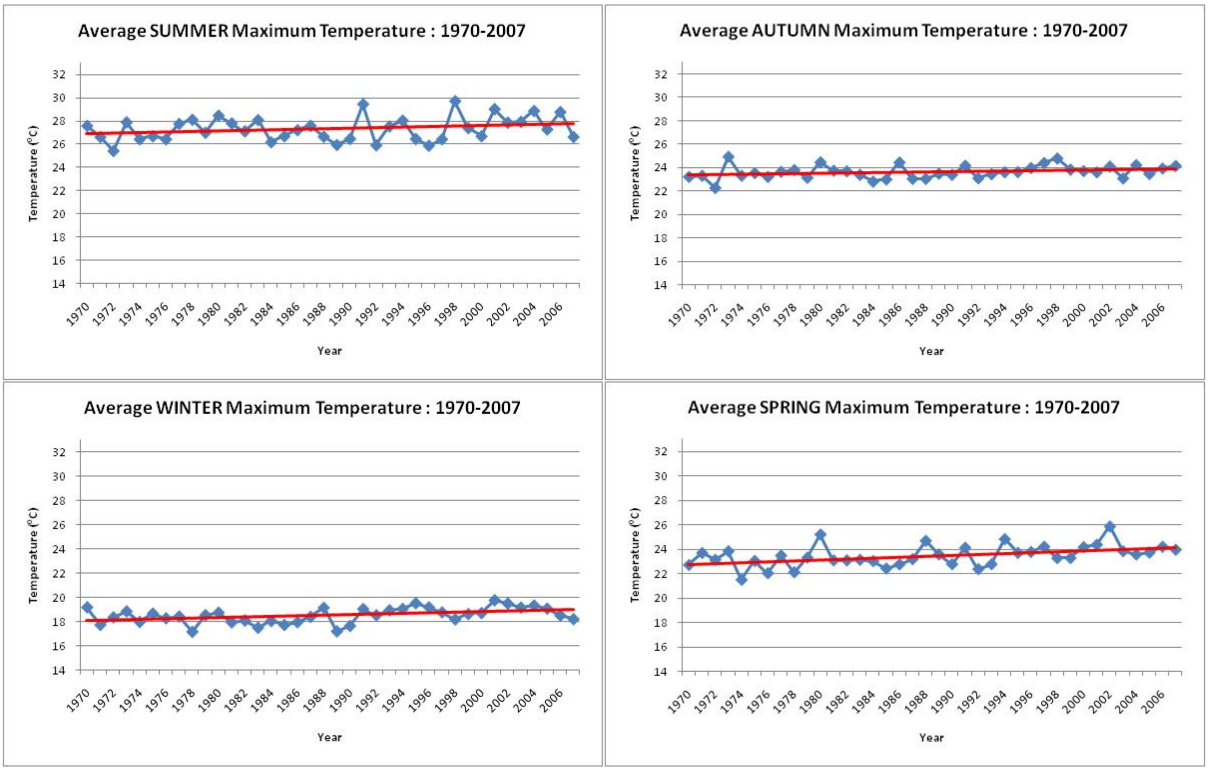


Figure 10 - Seasonal average maximum temperature trends 1970-2007

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 coastal zone from 1970 to 2007 is 18.2°C. Over the period from 1970 to 2007, an increasing linear trend in annual average temperature in the coastal zone is evident (Figure 11). This trend is statistically significant and equivalent to an increase of approximately 0.9°C over this entire period.

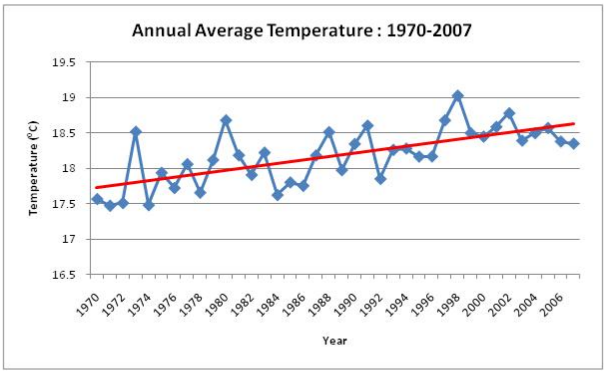


Figure 11 - Trend in annual average temperature for the 1970-2007 time period

During summer, temperatures average 22.8°C in the coastal zone, decreasing to 19.2°C during autumn and 13.2°C during winter. Spring temperatures average 18.6°C. Average temperatures show increases in all seasons over the period from 1970-2007 in line with the annual trend (Table 10 below and Figure 12 over page). The seasonal increases occurring in autumn (~0.7°C), winter (~1.0°C) and spring (~1.2°C) are statistically significant.

Average Minimum temperature (1970-2007)			
Summer	**Autumn**	**Winter**	**Spring**
Warmer: ~0.5°C Increase	Warmer: ~0.8°C* increase	Warmer: ~1.2°C* increase	Warmer: ~1.0°C* increase

*Statistically significant

Table 10 - Summary of historic changes in average temperature

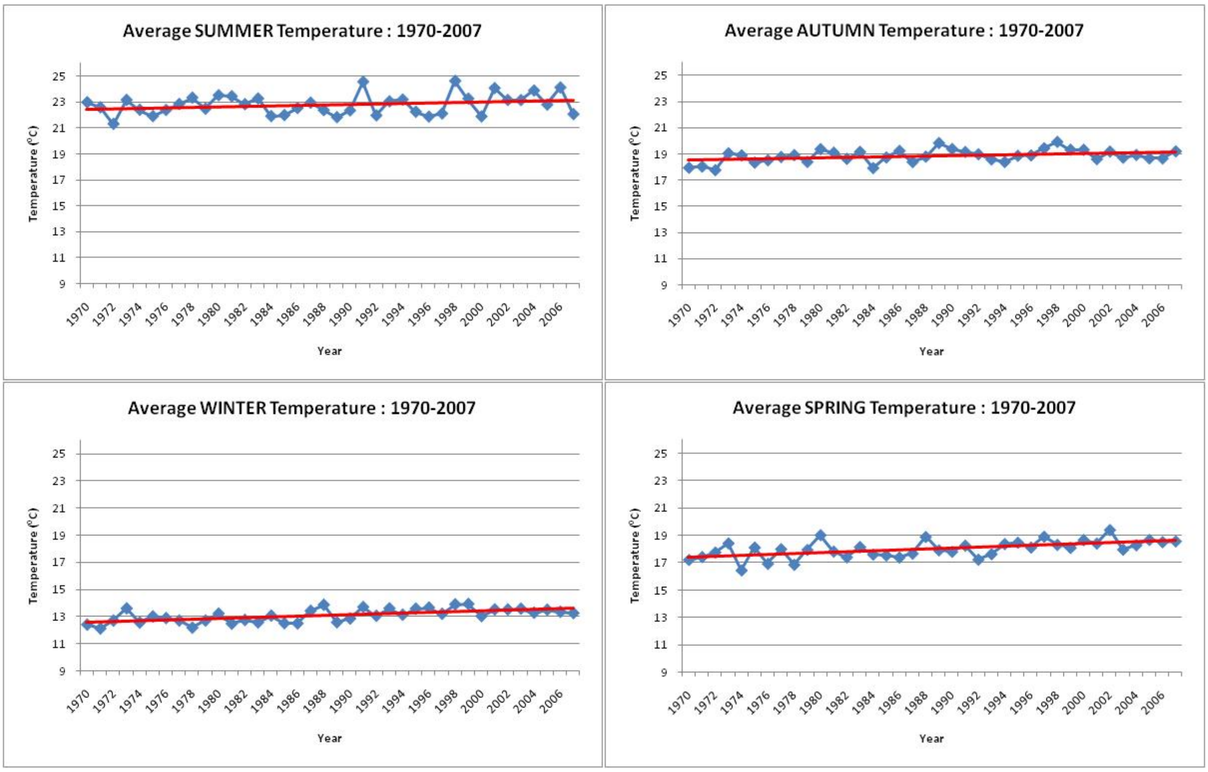


Figure 12 - Seasonal average temperature trends 1970-2007

DAILY PAN EVAPORATION

The recorded annual average pan evaporation for the coastal zone from 1974 to 2007 is 4.7mm/24hr. Over the period from 1974 to 2007, there has been no change in annual average pan evaporation (Figure 13).

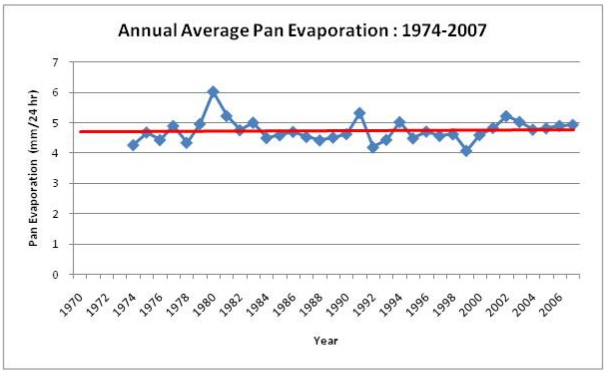


Figure 13 - Trend in annual average pan evaporation for the 1973-2007 time period

During summer, pan evaporation averages 6.8mm/24hr in the coastal zone, decreasing to 3.9mm/24hr during autumn and 3.2mm/24hr during winter. Spring pan evaporation averages 5.5mm/24hr. Average pan evaporation shows little or no change during summer and winter over the period from 1974-2007 in line with the annual trend (Table 11 below and Figure 14 over page). A slight increasing trend is evident during autumn paired with a slight decreasing trend during spring. These changes are not statistically significant and effectively offset each other to produce no overall annual change.

Average Pan evaporation (1974-2007)			
Summer	**Autumn**	**Winter**	**Spring**
Drier: ~0.1mm/24hr increase	Drier: ~0.1mm/24hr increase	Wetter: ~0.1mm/24hr decrease	Drier: ~0.3mm/24hr increase

Table 11 - Summary of historic changes in average pan evaporation

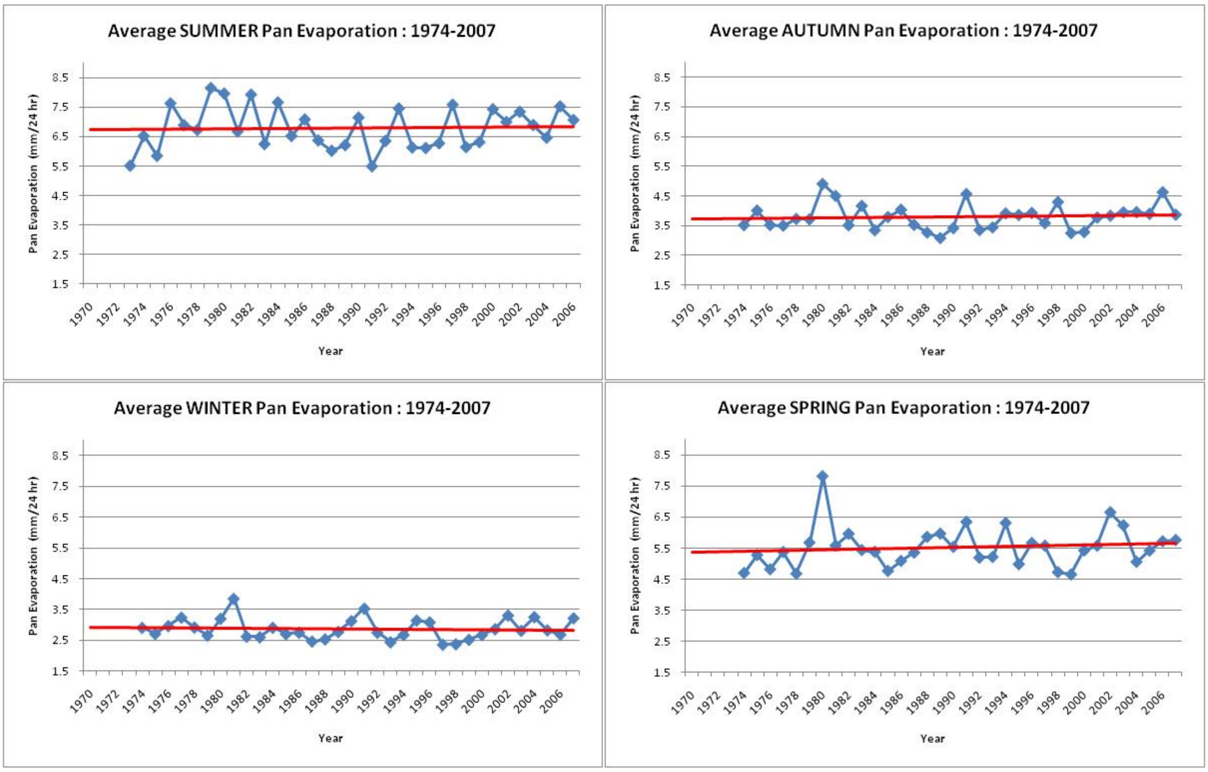


Figure 14 - Seasonal annual average pan evaporation trends 1972-2007

HUMIDITY

The annual average humidity recorded at 9am for the coastal zone from 1970 to 2007 is approximately 76.6%. Over the period from 1973 to 2006, a slight decreasing linear trend in annual average 9am humidity in the coastal zone is evident (Figure 15). This non-significant trend is equivalent to an increase of approximately 1.1% over this entire period.

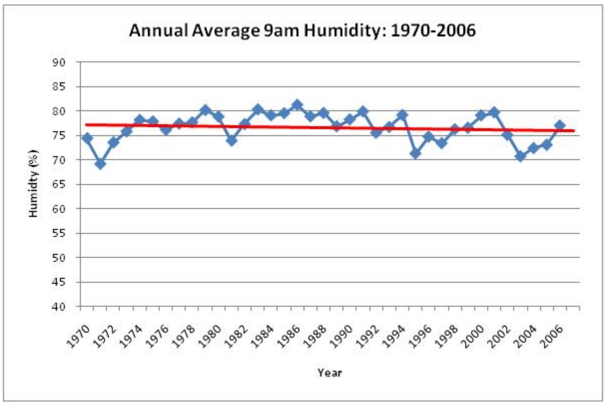


Figure 15 - Trend in annual average 9am humidity for the 1970-2006 time period

During summer, 9am humidity averages 80.0% in the coastal zone, decreasing to 79.4% during autumn and 76.3% during winter. Spring 9am humidity averages 71.0%. Average 9am humidity shows decreases in all seasons over the period from 1973-2006 in line with the annual trend (Table 12 below and Figure 16 over page). As with the annual trend, no seasonal trends are statistically significant.

Average 9am Humidity (1970-2006)			
Summer	**Autumn**	**Winter**	**Spring**
~2.1% decrease	~0.7% decrease	~0.2% decrease	~3.6% decrease

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

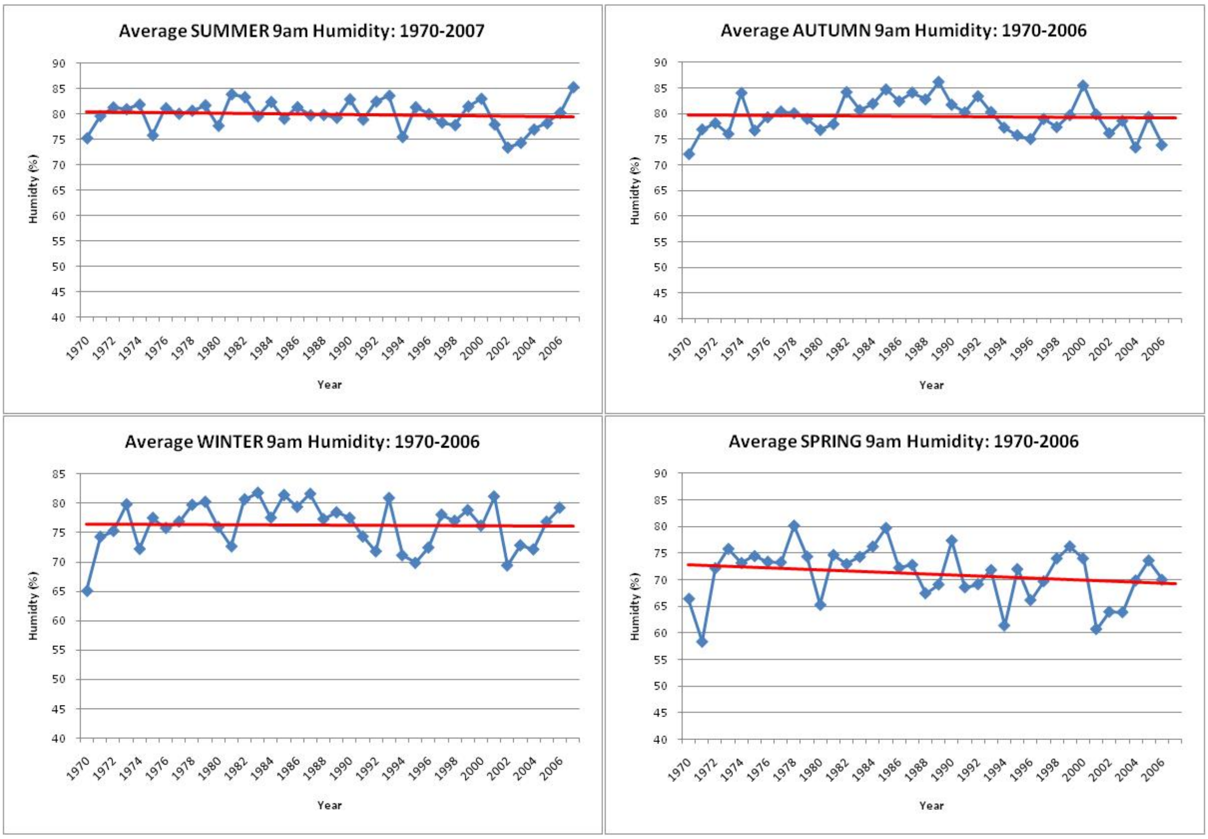


Figure 16 - Seasonal annual average 9am humidity trends 1970-2006

The annual average humidity recorded at 3pm for the coastal zone from 1970 to 2007 is approximately 67.0%. Over the period from 1970 to 2006, a slight increasing linear trend in annual average 3pm humidity in the coastal zone is evident (Figure 17). This non-significant trend is equivalent to an increase of approximately 2.6% over this entire period.

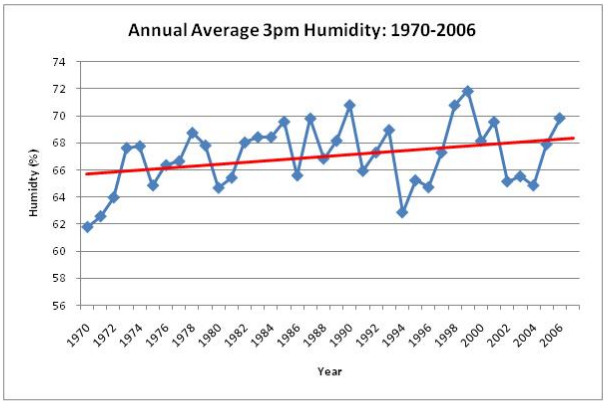


Figure 17 - Trend in annual average 3pm humidity for the 1970-2006 time period

During summer, 3pm humidity averages 74.3% in the coastal zone, decreasing to 69.0% during autumn and 59.8% during winter. Spring 3pm humidity averages 65.2%. Average 3pm humidity shows increases in all seasons over the period from 1970-2007 in line with the annual trend (Table 13 and Figure 18). As with the annual trend, no seasonal trends are statistically significant.

Average 3pm Humidity (1970-2006)			
Summer	**Autumn**	**Winter**	**Spring**
~1.8% increase	~3.7% increase	~2.9% increase	~1.1% increase

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

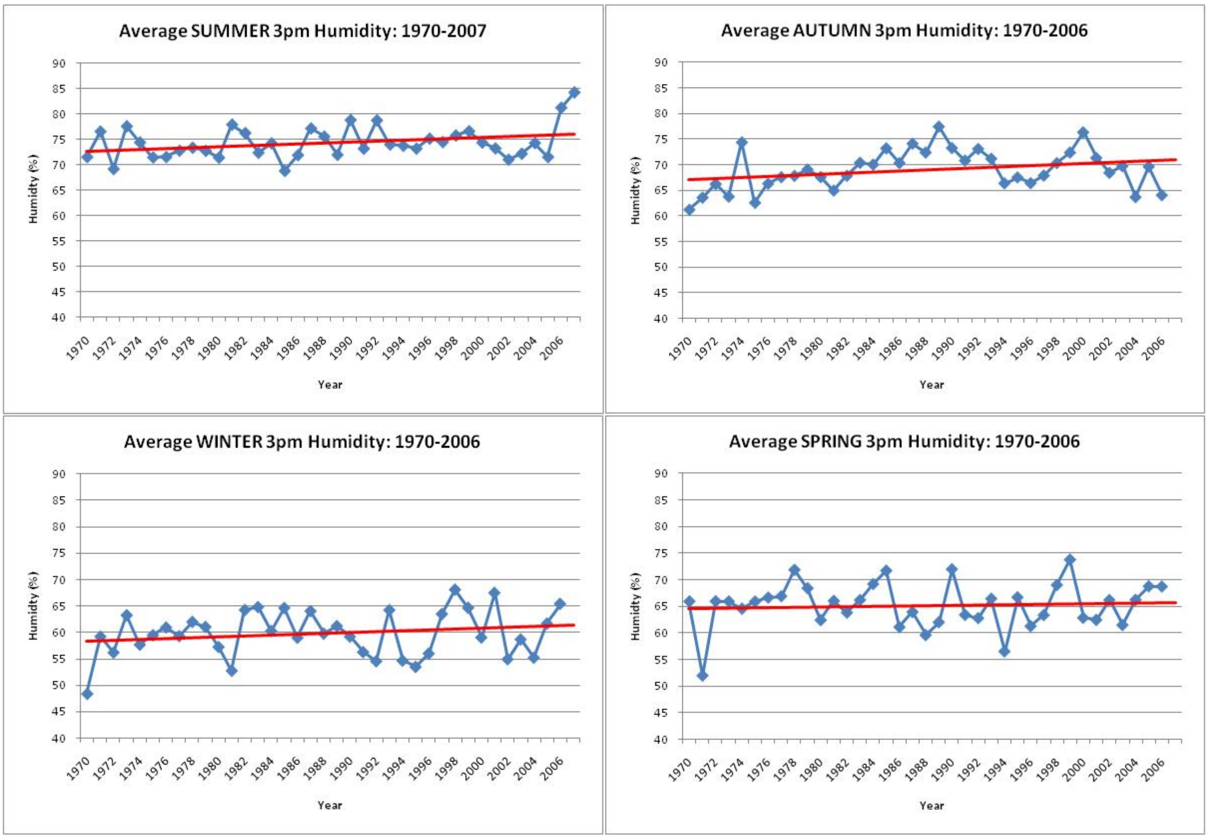


Figure 18 - Seasonal annual average 3pm humidity trends 1970-2006

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 coastal zone using data from Williamtown RAAF only.

The annual average water balance for the coastal zone from 1972 to 2007 is approximately -1.4mm/day. Over the period from 1974 to 2007, a decreasing (non significant) linear trend in annual average water balance has been evident (Figure 19). As a result, the coastal zone has experienced a total decrease in annual average water balance of 0.5mm per day over this period.

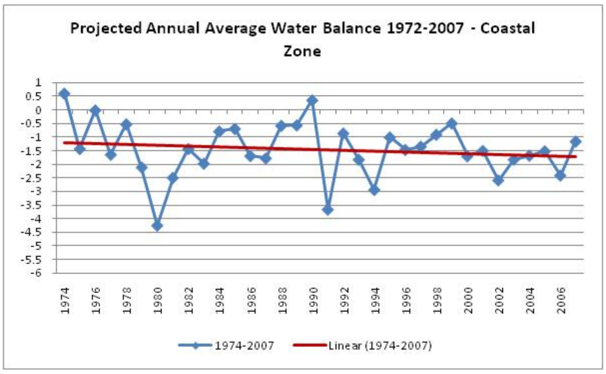


Figure 19 - Trend in water balance for the 1972-2007 time period

During summer, water balance averages -3.1mm/day in the coastal zone, decreasing to 0.5mm/day during autumn and -0.3mm/day during winter. Spring water balance averages -2.9mm/day. Average water balance shows decreases in summer, autumn and spring over the period from 1974-2007 in line with the annual trend (Table 14 below and Figure 20 over page). A slight increasing trend is evident during winter. As with the annual trend, no seasonal trends are statistically significant.

Average Water Balance (1974-2007)			
Summer	**Autumn**	**Winter**	**Spring**
Drier: ~0.5mm/d decrease	Drier: ~1.4mm/d decrease	Wetter: ~0.2mm/d increase	Drier: ~0.2mm/d decrease

Table 14 - Summary of historic changes in water balance

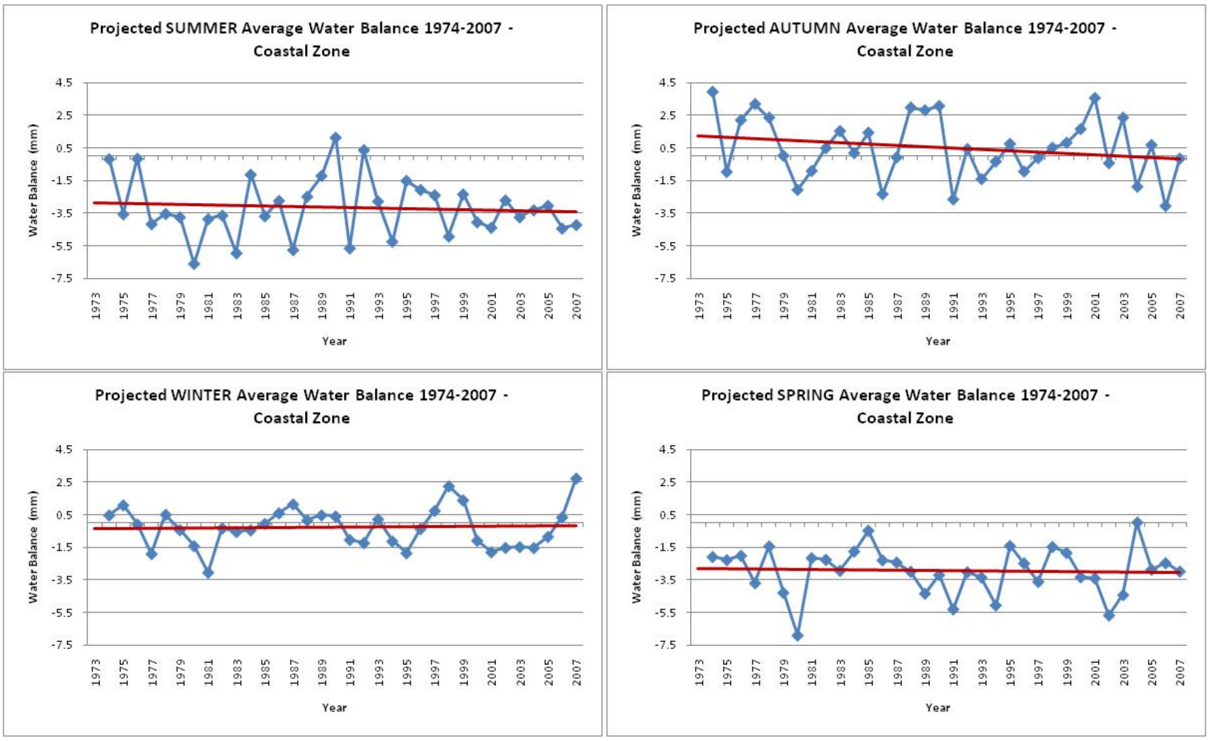


Figure 20 - Seasonal average water balance 1974-2007

AVERAGE WIND SPEED AND WIND GUSTS

The annual average wind speed for the coastal zone from 1970 to 2007 is approximately 19.8km/hr. Over the period from 1970 to 2007, a slight decreasing linear trend in annual average wind speed in the coastal zone is evident (Figure 21). This non-significant trend is equivalent to a decrease of approximately 0.14km/hr over this entire period.

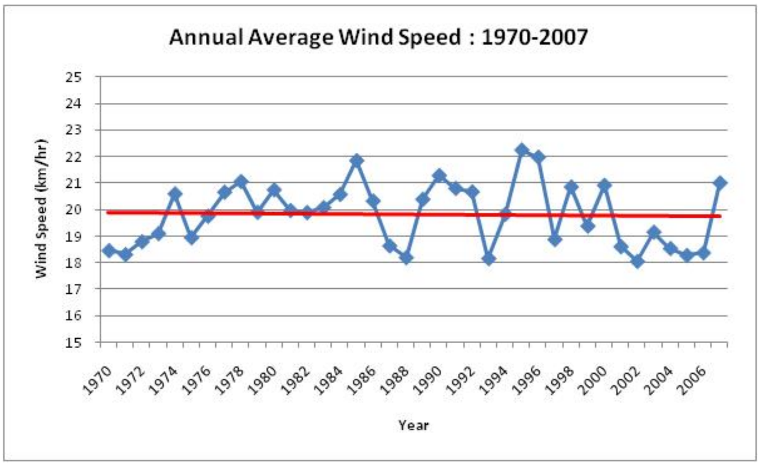


Figure 21 - Trend in annual average wind speed for the 1970-2007 time period

During summer, wind speed averages 20.3km/hr in the coastal zone, decreasing to 17.7km/hr during autumn and increasing again to 20.1km/hr during winter. Spring wind speed averages 21.1km/hr. Average wind speed shows increases in summer and autumn and decreases during winter and spring over the period from 1970-2007 (Table 15 below and Figure 22 over page). As with the annual trend, no seasonal changes are statistically significant.

Average Wind speed (1970-2007)			
Summer	**Autumn**	**Winter**	**Spring**
Windier: ~1.4km/hr Increase	Windier: ~0.6km/hr increase	Calmer: ~2.0km/hr decrease	Calmer: ~0.4km/hr decrease

Table 15 - Summary of historic changes in wind speed

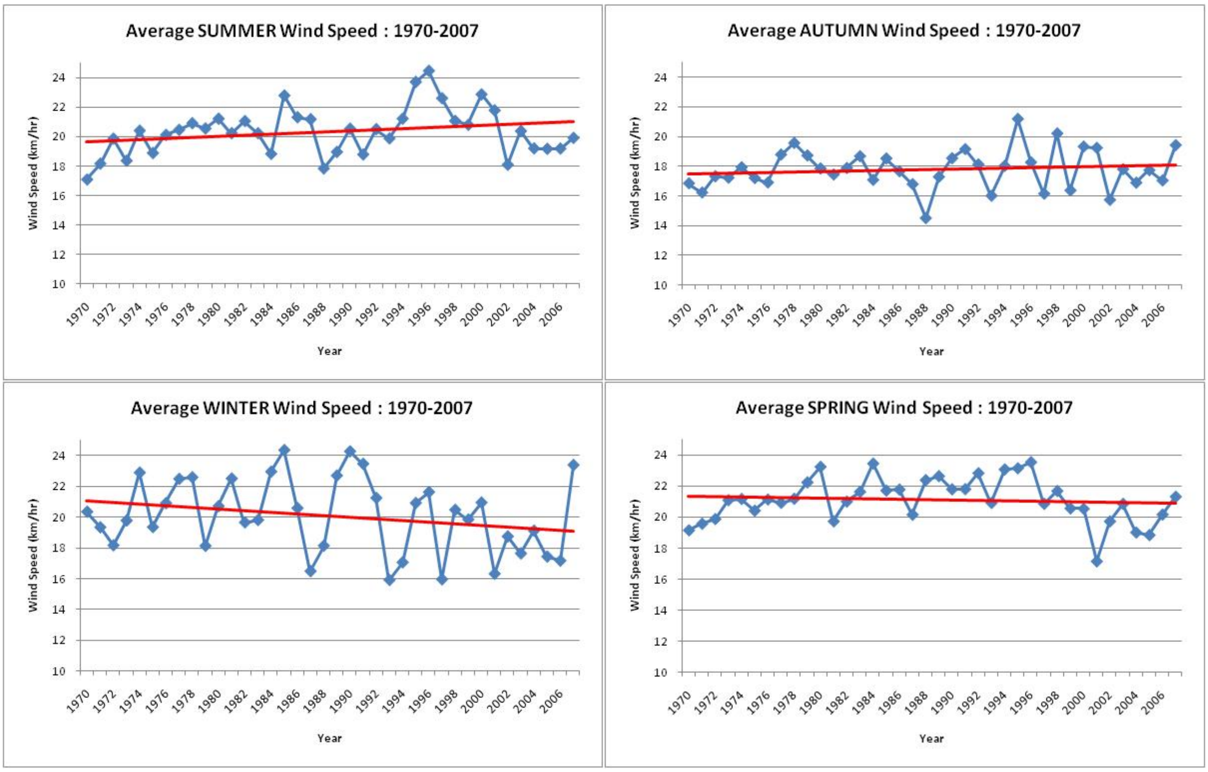


Figure 22 - Seasonal average wind speed trends 1970-2007

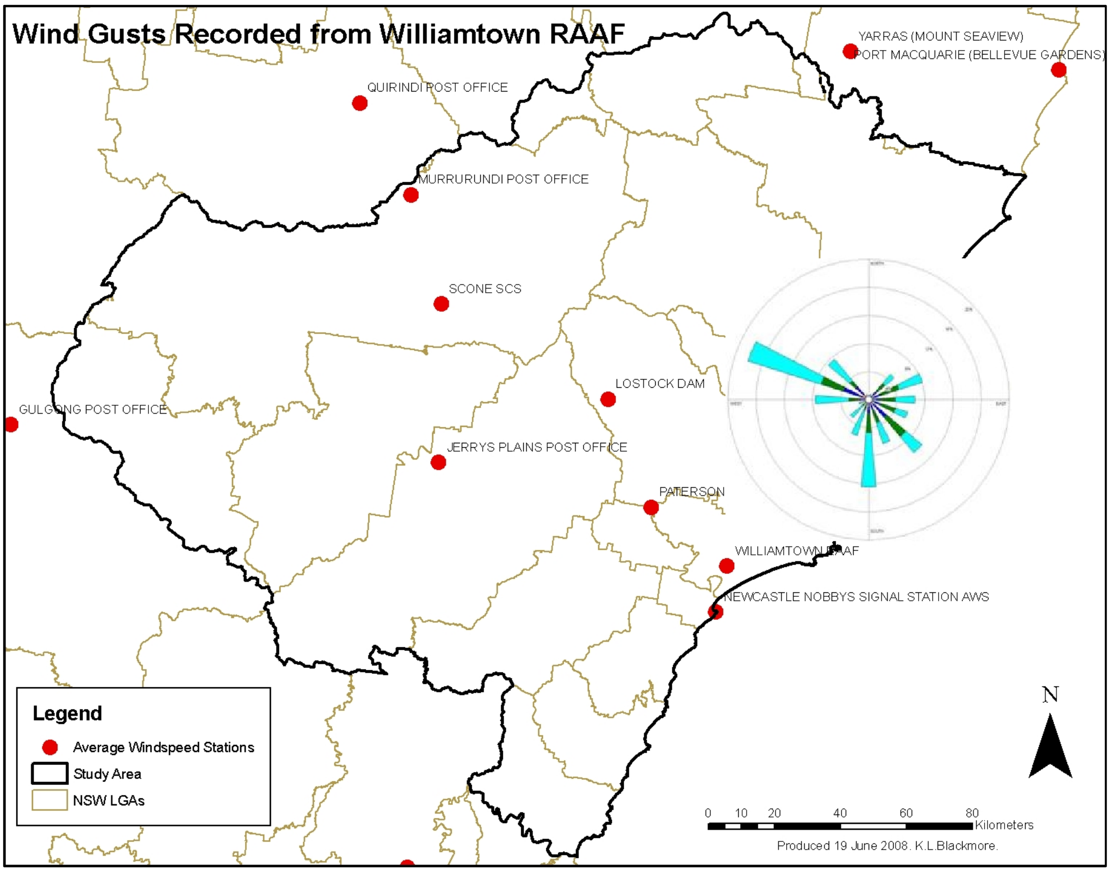


Figure 23 - Wind rose diagram of wind gusts recorded from Williamtown RAAF.

Suitable (i.e. of a sufficient duration) maximum wind gust data is available from only one station in the coastal zone (Williamtown). Although wind gust station data records from Williamtown RAAF began on 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.

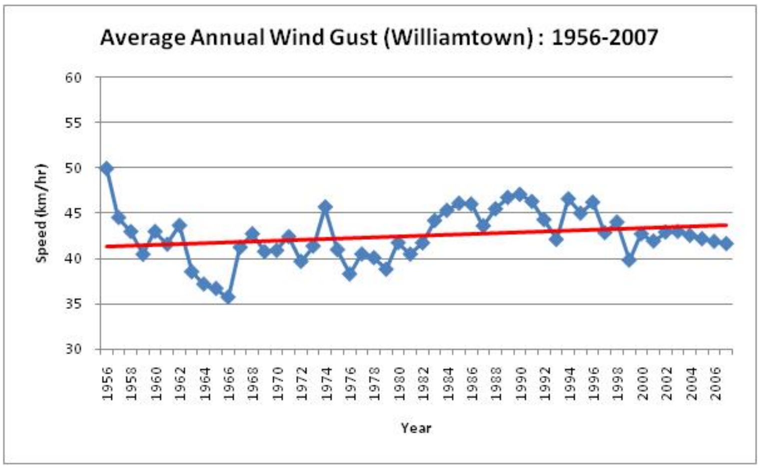
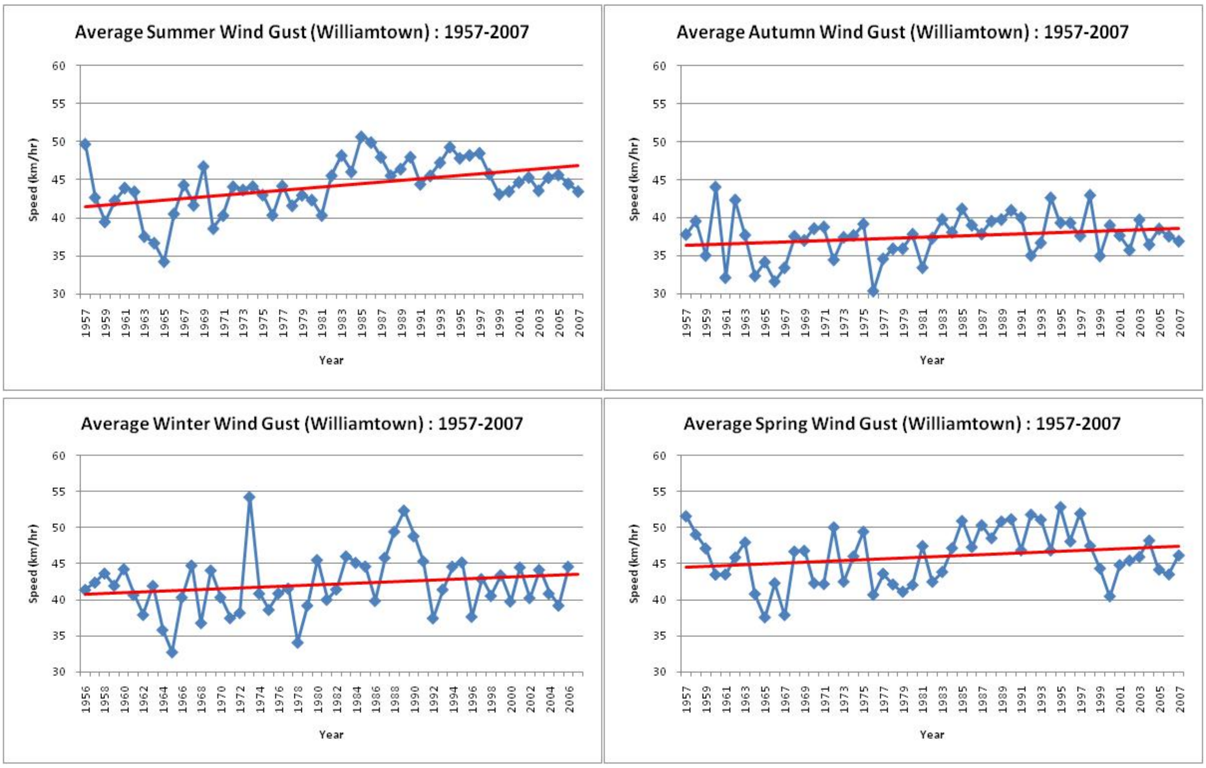


Figure 24 - Trend in average annual wind gusts recorded at Williamtown over the period over the period from 1956 to 2007

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 (P<0.05).



Average Summer Wind Gust (Williamtown) : 1957-2007

Average Autumn Wind Gust (Williamtown) : 1957-2007

Average Winter Wind Gust (Williamtown) : 1957-2007

Average Spring Wind Gust (Williamtown) : 1957-2007

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°C (number of extreme heat days); and
- daily minimum temperature below 0°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, three (3) representative stations (Wingham, Taree and Newcastle (Nobby's Head)) within the coastal zone are selected for the analysis of extreme precipitation and temperature events (Figure 26).

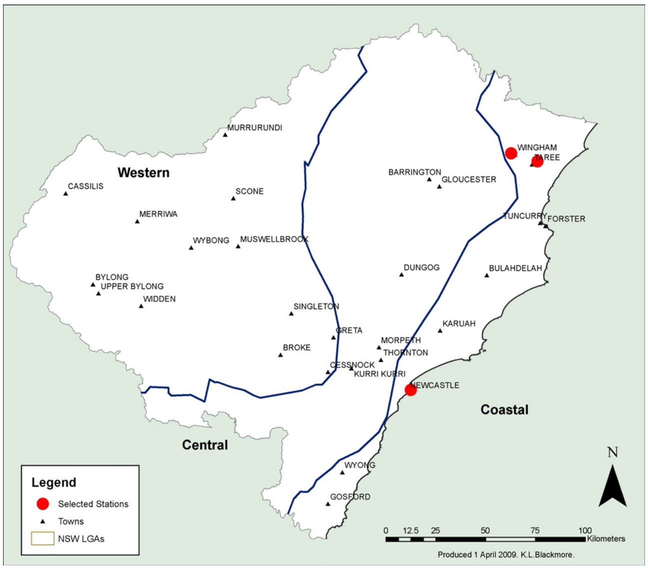


Figure 26 - Selected stations for analysis of extreme events

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. Newcastle shows no trend however Wingham shows a decreasing linear trend in the frequency of occurrence of these events over the period from 1948 to 2007. This trend is not statistically significant.

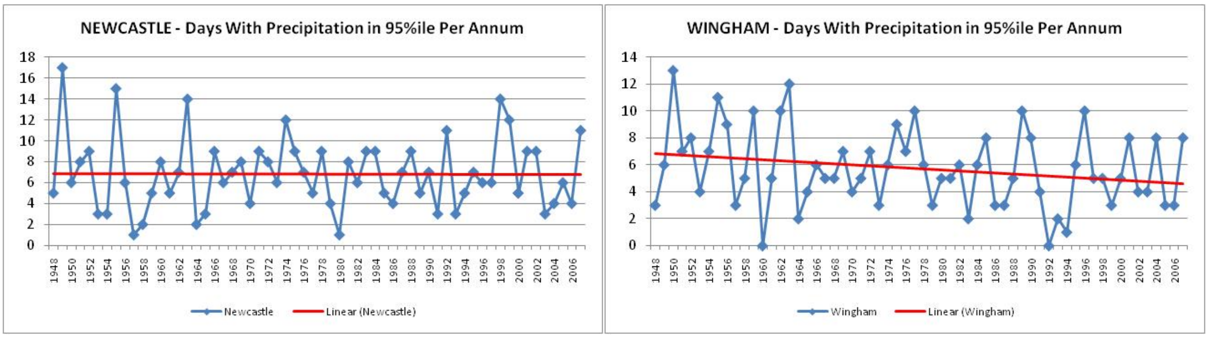
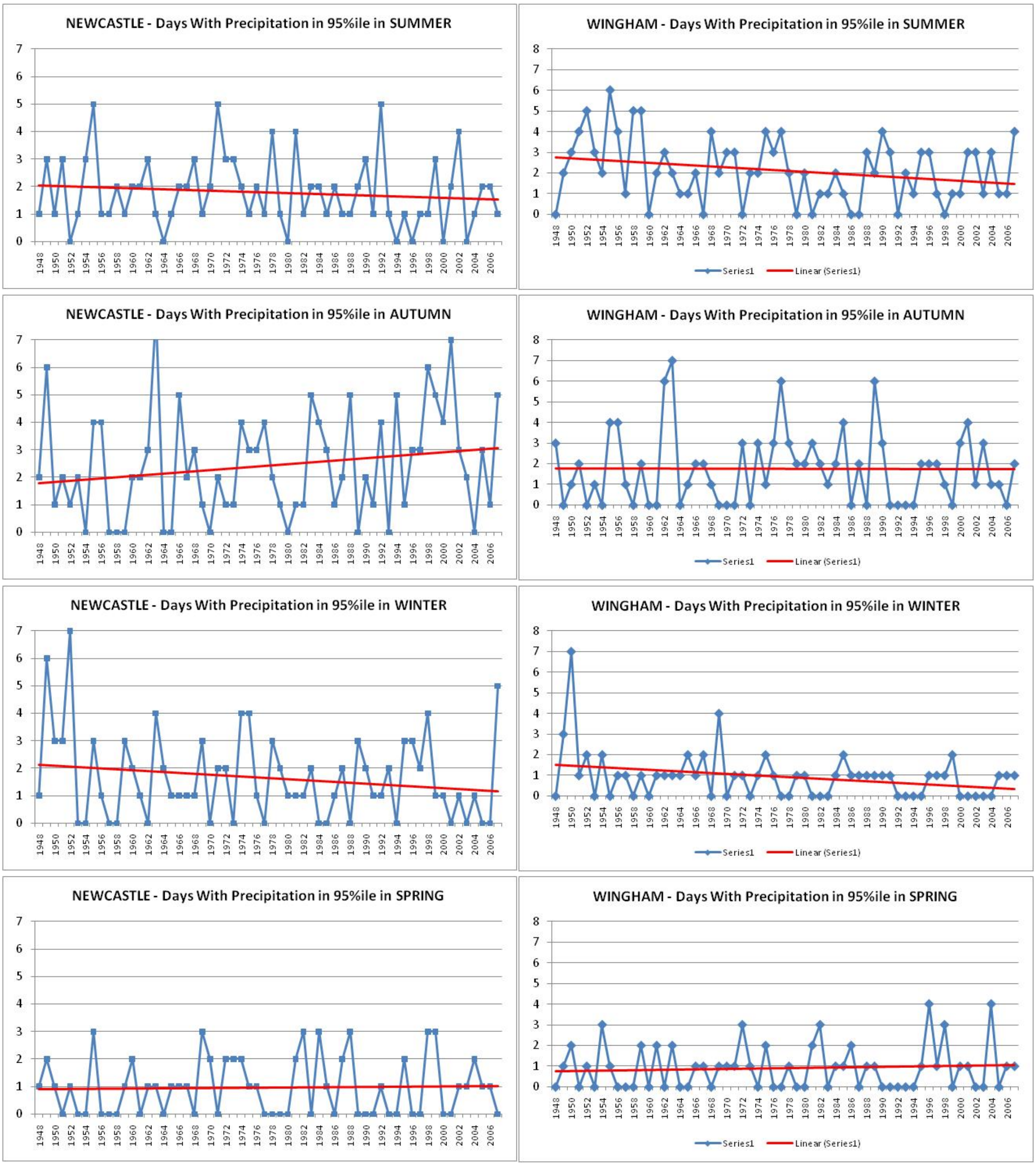


Figure 27 - Annual trend in days with rainfall in the 95th percentile (1948-2007)

Seasonally, the decreasing linear trends evident annually are reflected in the seasonal data (Figure 28 over page) with the exception of autumn in Newcastle and spring in Wingham. Both locations show:

- a decreasing linear trend in days per annum with precipitation in the 95th percentile during summer and winter.
- At Newcastle, no change in these events is evident during spring but an increase has occurred during autumn.
- At Wingham, a slight increase in the frequency of these events is evident during spring with no change evident during autumn.

As with the annual data, no seasonal trends are statistically significant.



NEWCASTLE - Days With Precipitation in 95%ile in SUMMER

WINGHAM - Days With Precipitation in 95%ile in SUMMER

NEWCASTLE - Days With Precipitation in 95%ile in AUTUMN

WINGHAM - Days With Precipitation in 95%ile in AUTUMN

NEWCASTLE - Days With Precipitation in 95%ile in WINTER

WINGHAM - Days With Precipitation in 95%ile in WINTER

NEWCASTLE - Days With Precipitation in 95%ile in SPRING

WINGHAM - Days With Precipitation in 95%ile in SPRING

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

EXTREME HEAT DAYS

A slight decreasing trend (non significant) in days per year with maximum temperature greater than or equal to 37°C over the period from 1970-2007 is evident at Newcastle. An increasing linear trend is evident at Taree. This increase is statistically significant. On average, Taree records between 3 and 4 days per annum with temperatures greater than or equal to 37°C. Over the period from 1970 to 2007, an increase of approximately 3.3 days in total is evident (Figure 29).

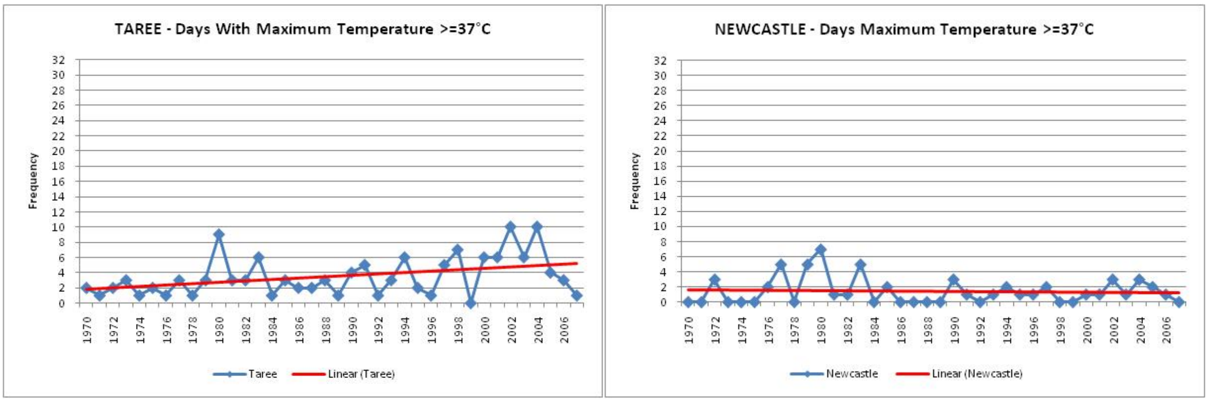


Figure 29 - Annual trend in extreme heat days at Taree and Newcastle

FROSTS

Local variability in frost events (days per annum with minimum temperature less than or equal to 0°C) exists in the coastal zone. No frost events were recorded at Newcastle over the period from 1970 to 2007, and only 0 to 4 events per annum at Taree, with the exception of 1971 – 1972 when significantly more events were recorded (Figure 30). A decreasing linear trend in frost events is evident at Taree but this trend is not statistically significant. Due to the limited number of occurrences per annum, seasonal analysis of frost events in the coastal zone is not possible.

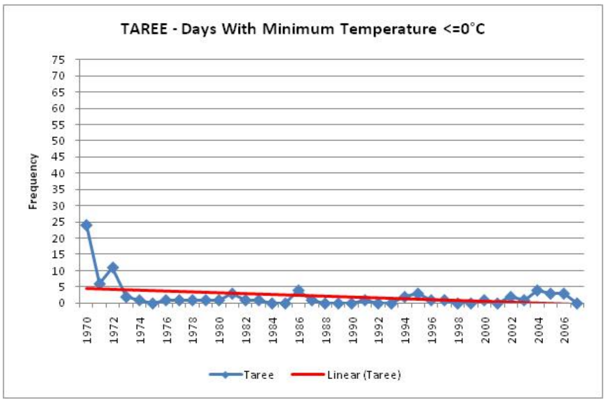


Figure 30 - Annual trend in frosts at Taree

PRECIPITATION PROJECTIONS

An understanding of future changes can be obtained by contrasting projected values to those recorded historically. 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 for the region's coastal 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 coastal 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 coastal zone with a slight increase projected for spring.

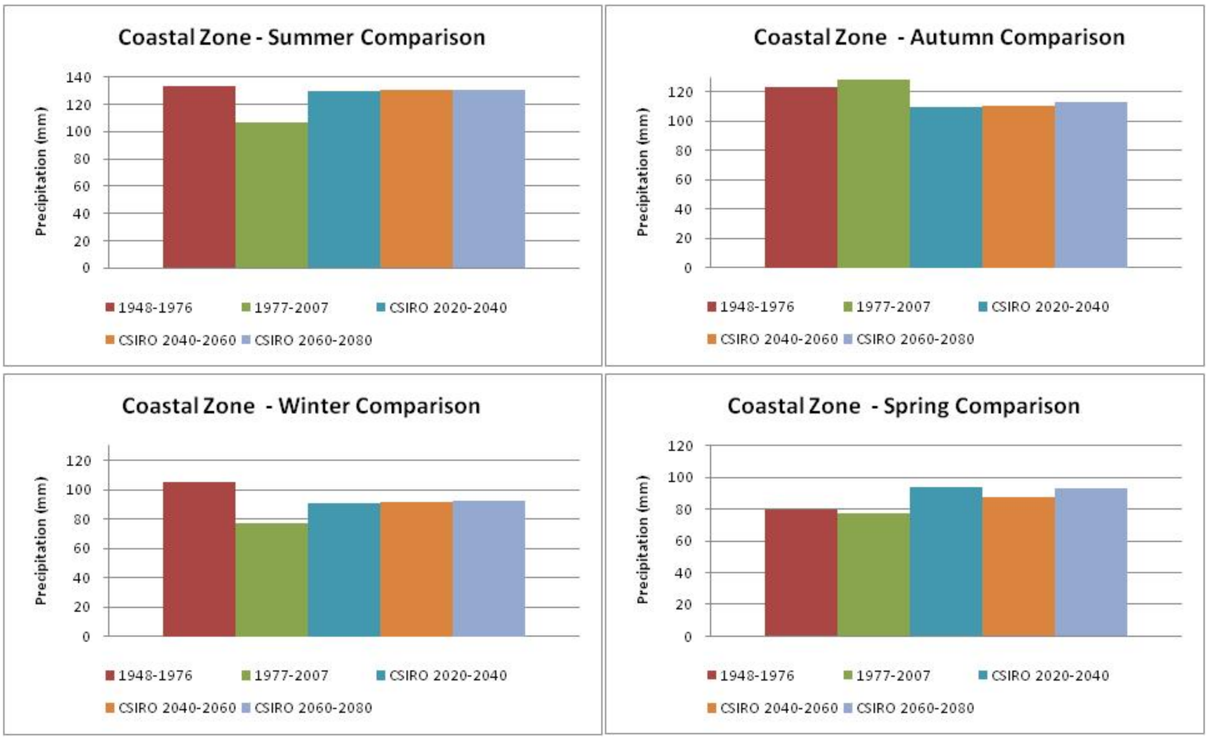


Figure 31 - Seasonal comparison of precipitation for historic interdecal time periods and future time horizons

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. With the exception of autumn, projected precipitation patterns are similar to those recorded during the 1948 to 1976 time period. An approximate 9% decrease in autumn precipitation, relative to the 1948 to 1976 time period, is projected.

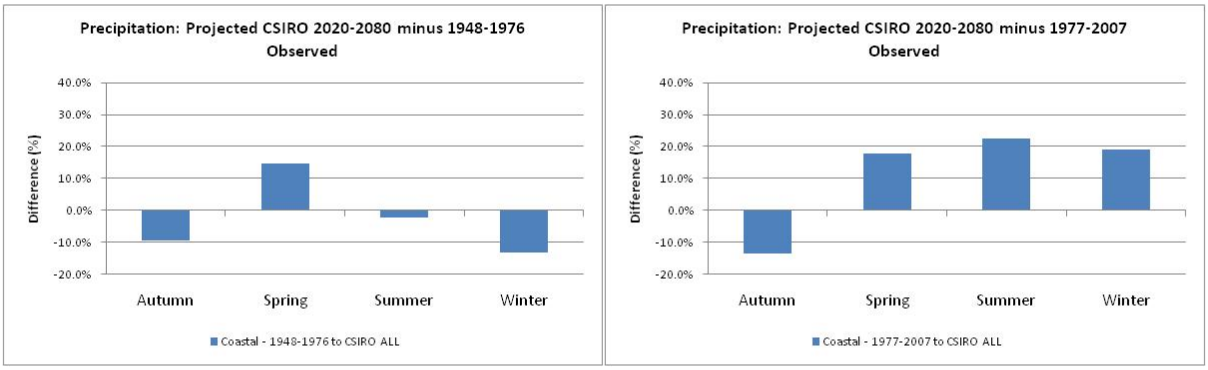


Figure 32 - Projected changes in precipitation relative to historic interdecal time periods

Season	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	134	-3	-2%	107	24	22%
Autumn	123	-12	-9%	129	-17	-14%
Winter	**106**	**-14**	**-13%**	77	15	19%
Spring	**80**	**12**	**15%**	78	14	18%

Bold text = Statistically significant trend

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

<table>
<tr><td colspan="4">Projected Precipitation (2020 – 2080)
<i>Projected changes are relative to the 1948-1977 period</i>
<i>(ie La Nina –ve phase)</i></td></tr>
<tr><th>Summer</th><th>Autumn</th><th>Winter</th><th>Spring</th></tr>
<tr><td>No significant change</td><td>No significant change</td><td>Drier:
~13% decrease</td><td>Wetter: ~15% increase</td></tr>
</table>

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 33 over page). In addition to showing projected linear trends (green line), total annual precipitation for the calibration period (1968-1996) is superimposed onto the projected data.

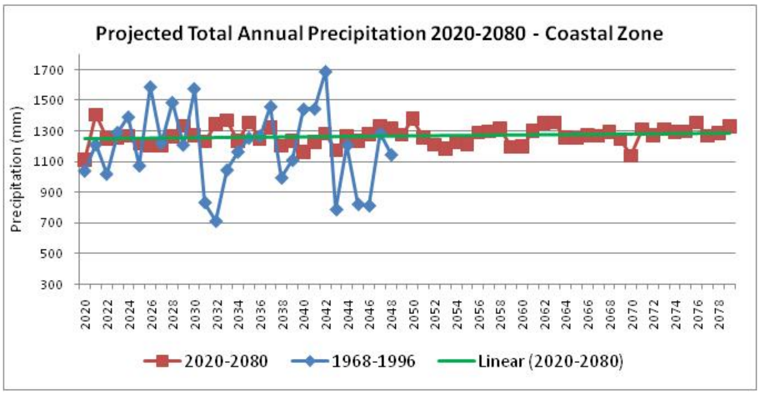


Figure 33 - Projected total annual precipitation for 2020-2080 showing a linear trend

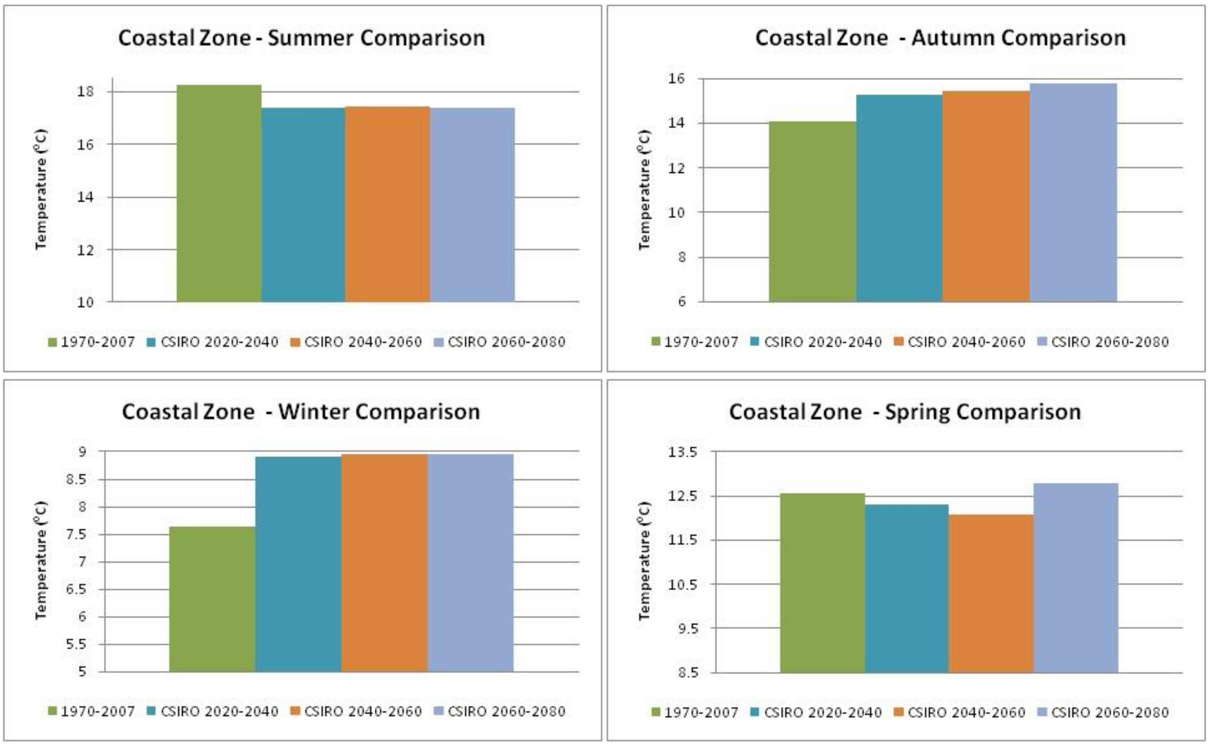
Projections for the coastal zone, although still within the bounds of natural variability, show a tendency toward the upper bound. The statistical significance of the linear trend for precipitation for the 2020-2080 time period was tested using regression analysis. An increase of approximately 32mm over 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 coastal 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
- 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.



Coastal Zone - Summer Comparison

Coastal Zone - Autumn Comparison

Coastal Zone - Winter Comparison

Coastal Zone - Spring Comparison

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 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.

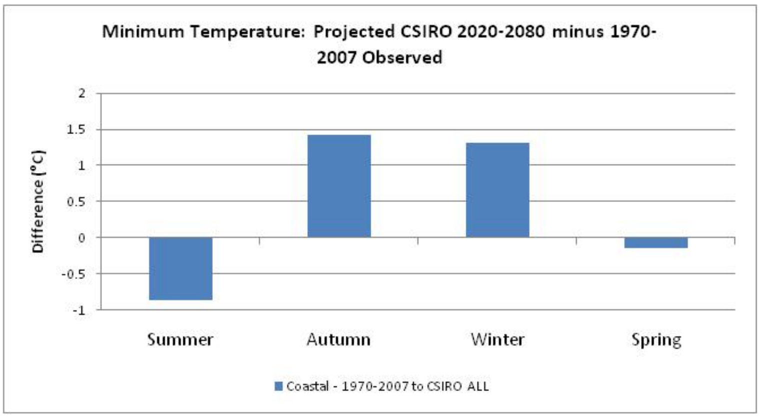


Figure 35 - Projected changes in minimum temperature relative to historic interdecal time periods

Projected Minimum Temperature (2020-2080) *Projected changes are relative to the 1970-2007 period*			
Summer	**Autumn**	**Winter**	**Spring**
Cooler: ~0.9°C decrease	Warmer: ~1.4°C increase	Warmer: ~1.3°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 projected 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 (ie 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).

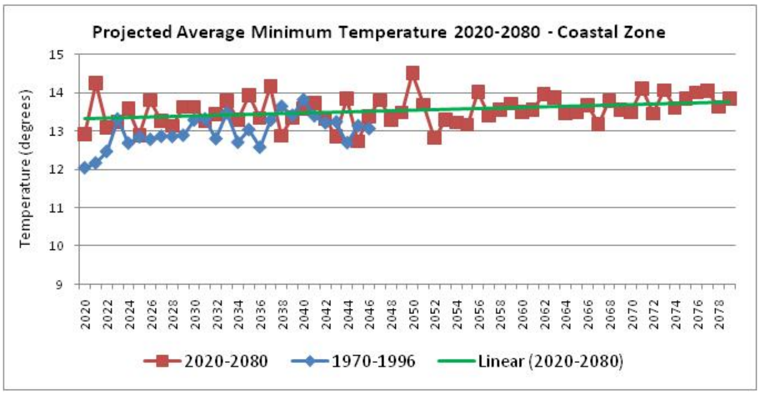


Figure 36 - Projected total average minimum temperature for 2020-2080 showing linear trend

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. 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.
- Similar increases during winter within each of the projected time periods
- A general increasing trend during autumn, however some variation occurs across the three time horizons
- 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 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.

Estimates of the magnitude of seasonal shifts in maximum temperature, relative to the 1970-2007 time period, are presented in Figure 38 over page and Table 19 on page 40. 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.

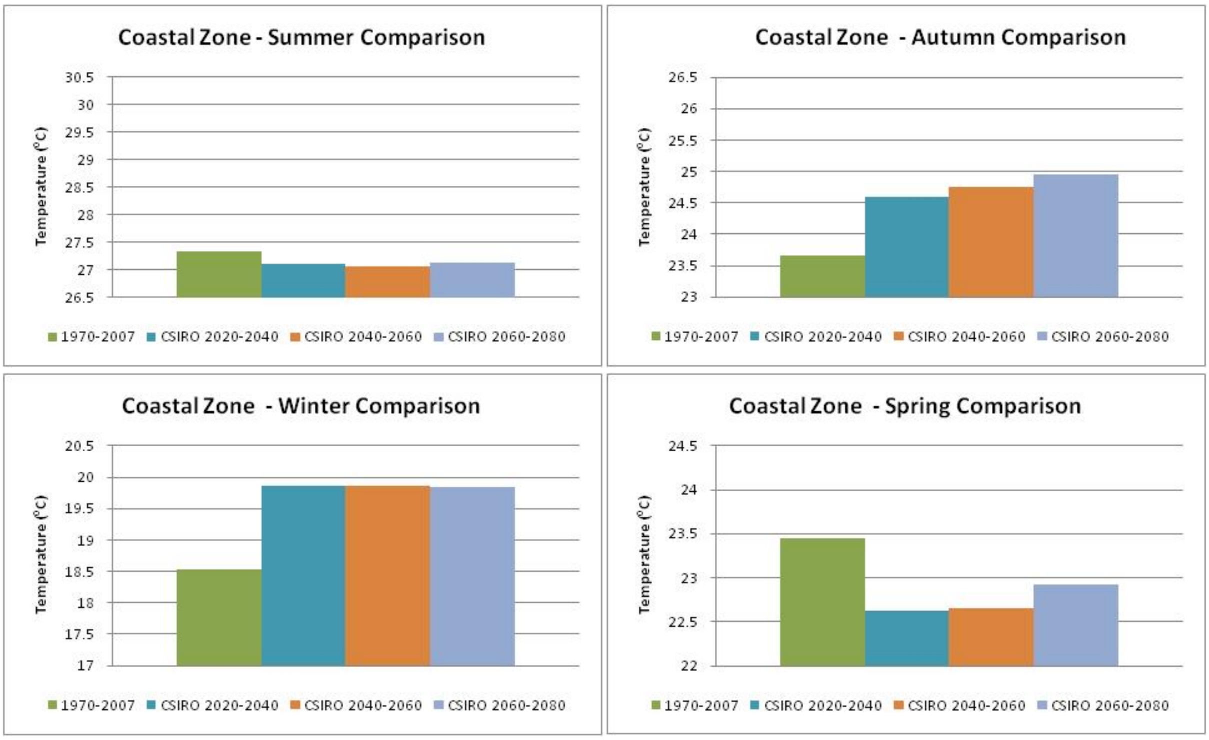


Figure 37 - Seasonal comparison of maximum temperature for historic interdecal time periods and future time horizons

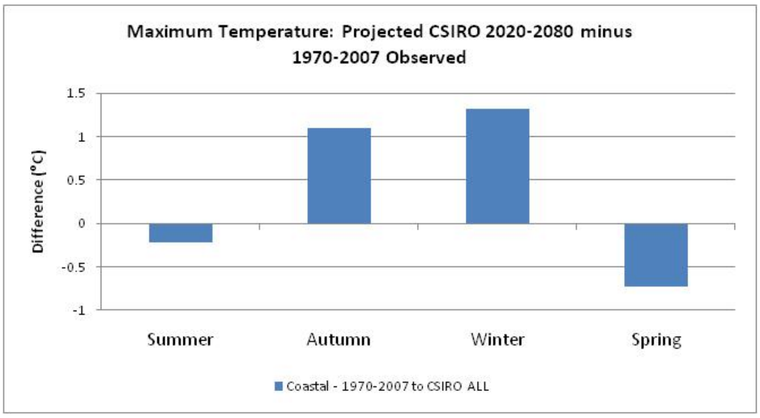


Figure 38 - Projected changes in maximum temperature relative to historic interdecal time periods

Projected Maximum Temperature (2020-2080) *Projected changes are relative to the 1970-2007 period*			
Summer	**Autumn**	**Winter**	**Spring**
Cooler: ~0.2°C decrease	Warmer: ~1.1°C increase	Warmer: ~1.3°C increase	Cooler: ~0.7°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 39. In addition to showing the projected 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°C. This trend is statistically significant at the 5% level (P<0.05).

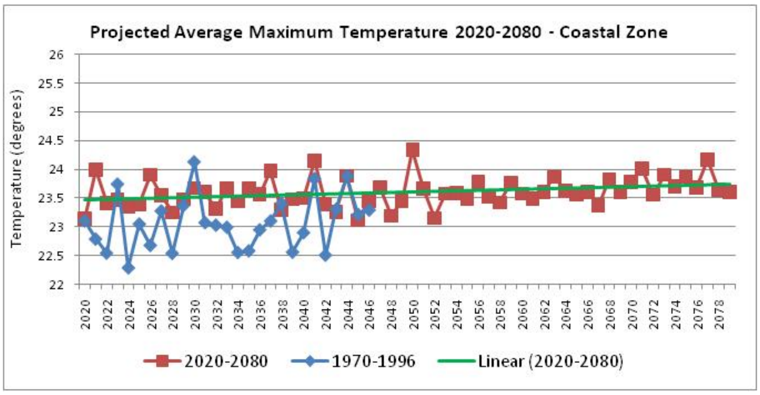


Figure 39 - Projected total average maximum temperature for 2020-2080 showing linear trend

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 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' coastal 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 general increasing trend during autumn, however some variation occurs across the three time horizons
- Some variation for spring is also 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.

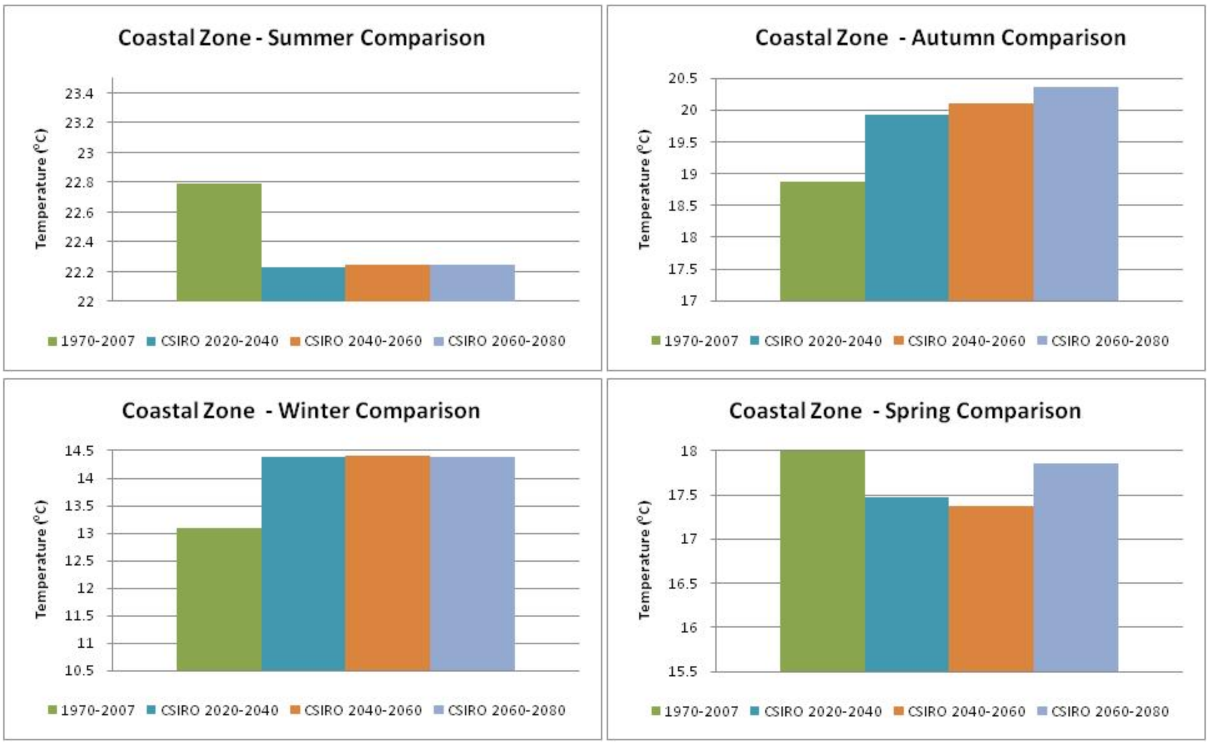


Figure 40 - Seasonal comparison of average temperature for historic interdecal time periods and future time horizons

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. 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.

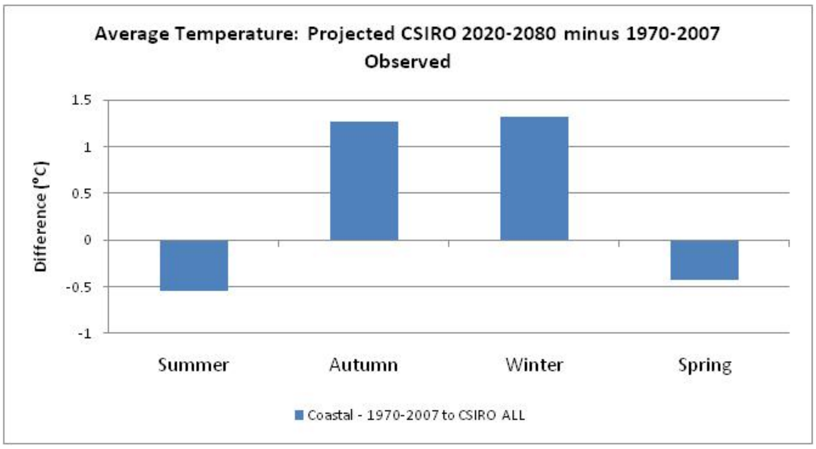


Figure 41 - Projected changes in average temperature relative to historic interdecal time periods

Projected Average temperature (2020-2080) *Projected changes are relative to the 1970-2007 period*			
Summer	**Autumn**	**Winter**	**Spring**
Cooler:~0.5°C decrease	Warmer: ~1.3°C increase	Warmer: ~1.3°C increase	Cooler: ~0.4°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 projected linear trends (green line), average temperature for the period from 1970-1996 is superimposed onto the projected data. Projected values for all zones 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 0.1^{o}C. This trend is statistically significant at the 5% level ($P<0.05$).

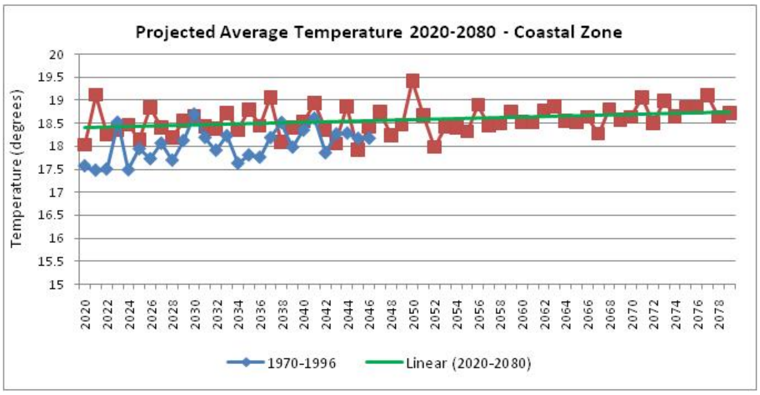


Figure 42 - Projected annual average temperature for 2020-2080 showing linear trend

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.

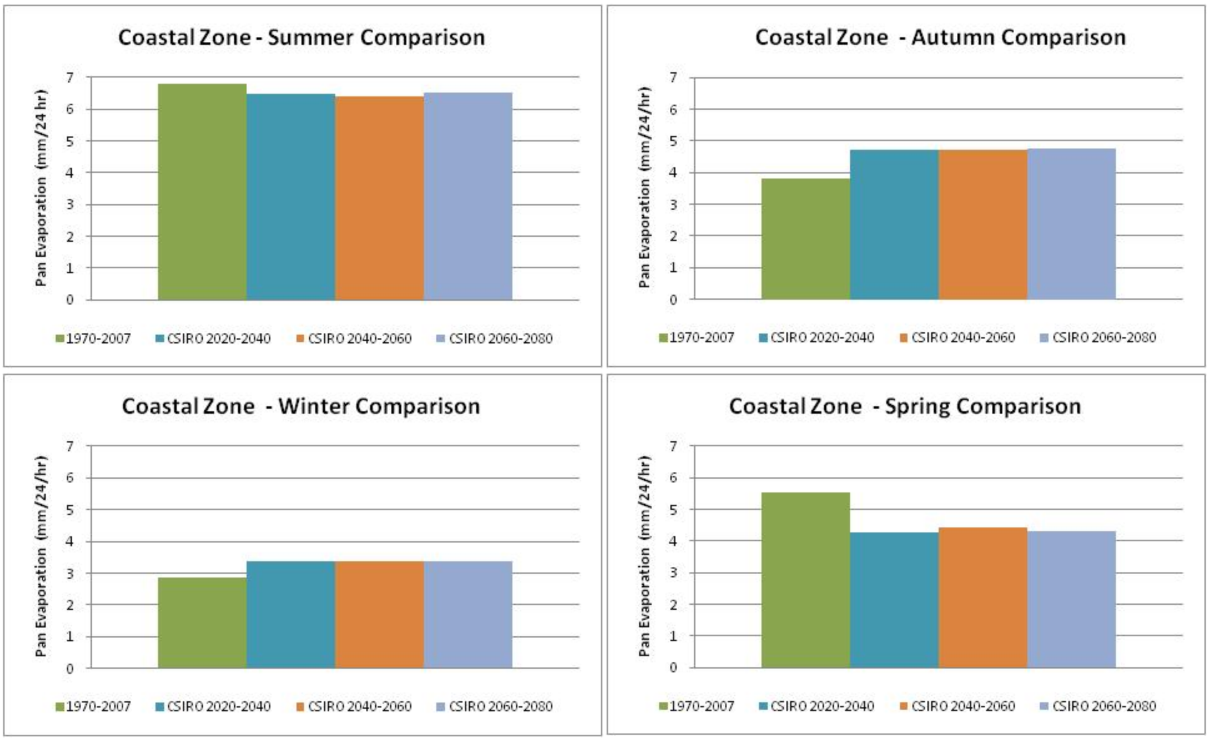


Figure 43 - Seasonal comparison of pan evaporation for historic interdecal time periods and future time horizons

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. Seasonal shifts appear to balance out to produce no projected change in annual pan evaporation.

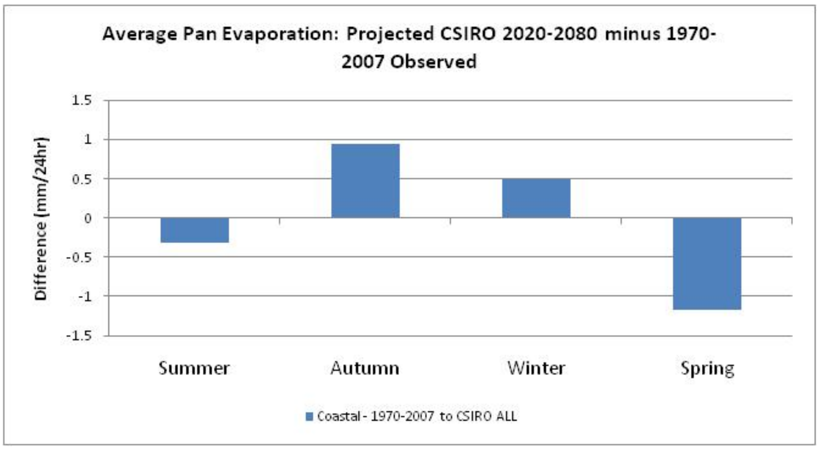


Figure 44 - Projected changes in average pan evaporation relative to historic interdecal time periods

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

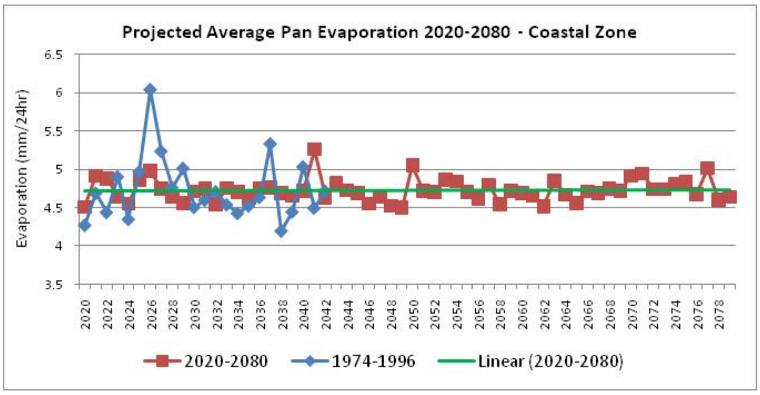


Figure 45 - Projected annual average pan evaporation for 2020-2080 showing linear trend

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

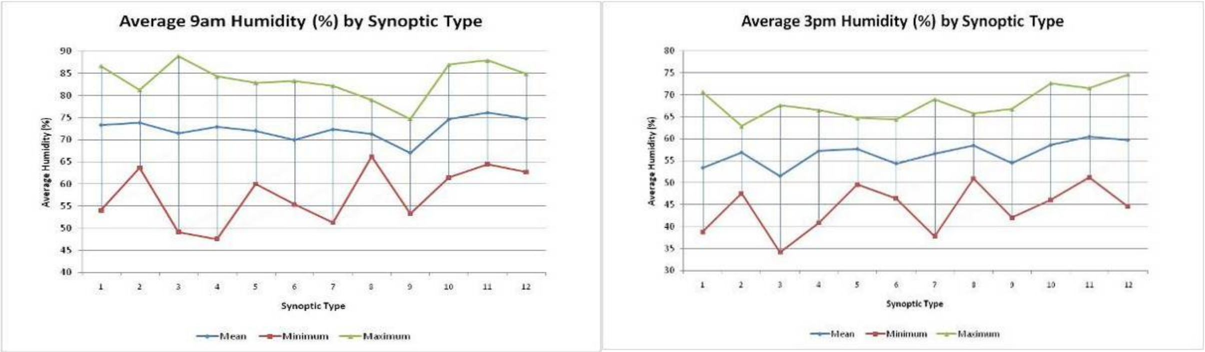


Figure 46 - 9am and 3pm humidity by CSIRO ST

Relationships between the CSIRO ST's 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).

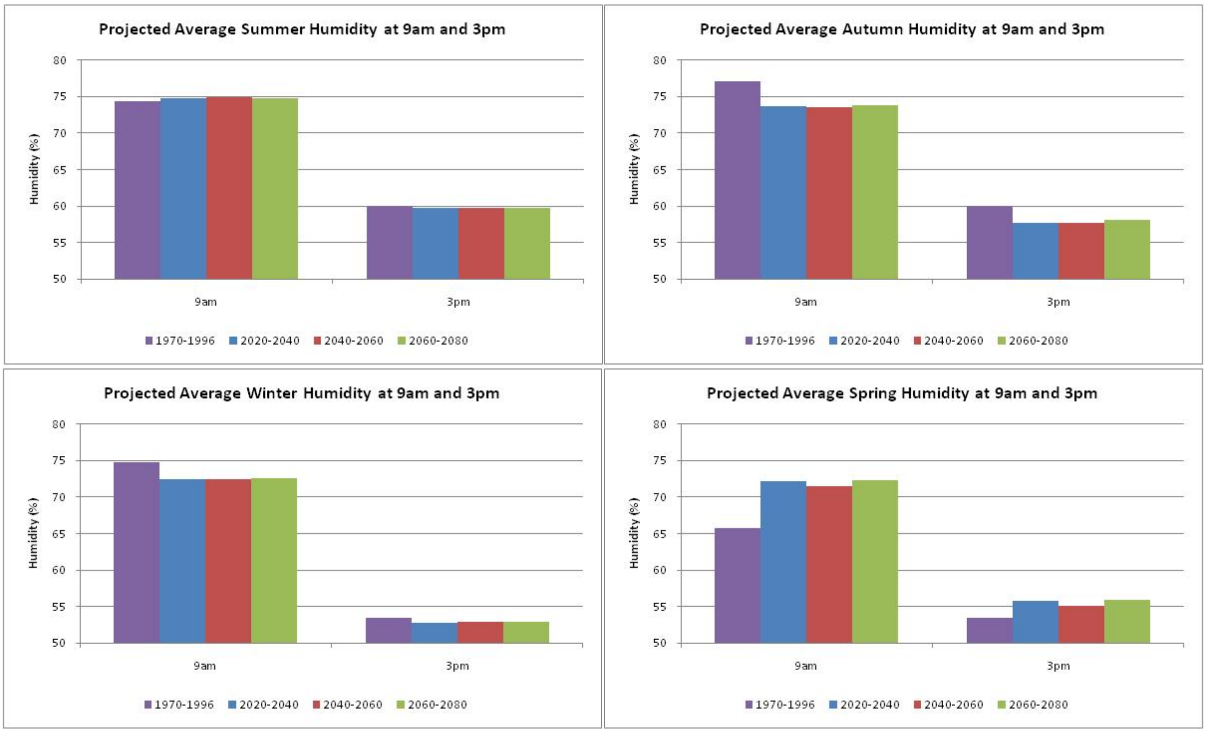


Figure 47 - Seasonal comparison of 9am and 3pm humidity for historic time period and future time horizons

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.

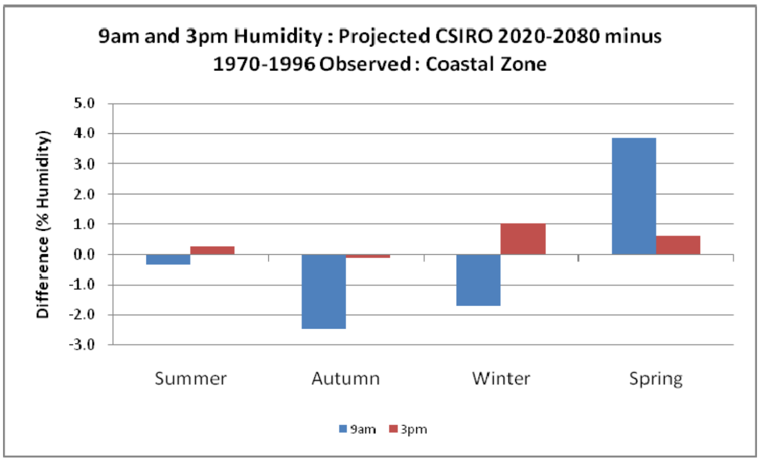


Figure 48 - Estimates of projected humidity shifts relative to the 1970-1996 period

Average humidity (2020-2080) *Projected changes are relative to the 1970-1996 period*				
	Summer	**Autumn**	**Winter**	**Spring**
9am Humidity	Less Humid: ~0.3% decrease	Less Humid: ~2.5% decrease	Less Humid: ~1.7% decrease	More Humid: ~3.9% increase
3pm Humidity	More Humid: ~0.3% increase	Less Humid: ~0.1% decrease	More Humid: ~1.0% increase	More Humid: ~0.6% 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 projected 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.

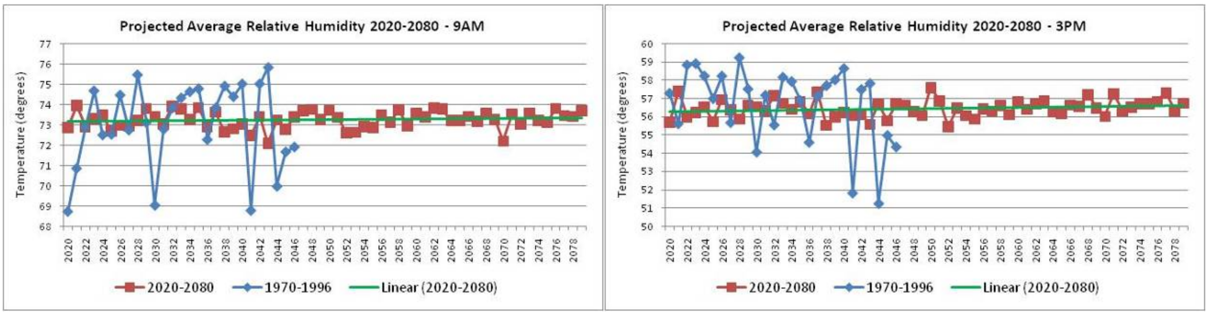


Figure 49 - Projected average annual 9am and 3pm relative humidity for 2020-2080 showing linear trends

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).

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) (Figure 50 over page). Projections (relative to the 1970-2007 time period) include:

- little or no change in average water balance during summer.
- decreases across all time horizons during Autumn
- a slight increase during winter across all time horizons
- decreases during spring in all time horizons relative to the 1970-2007 period.

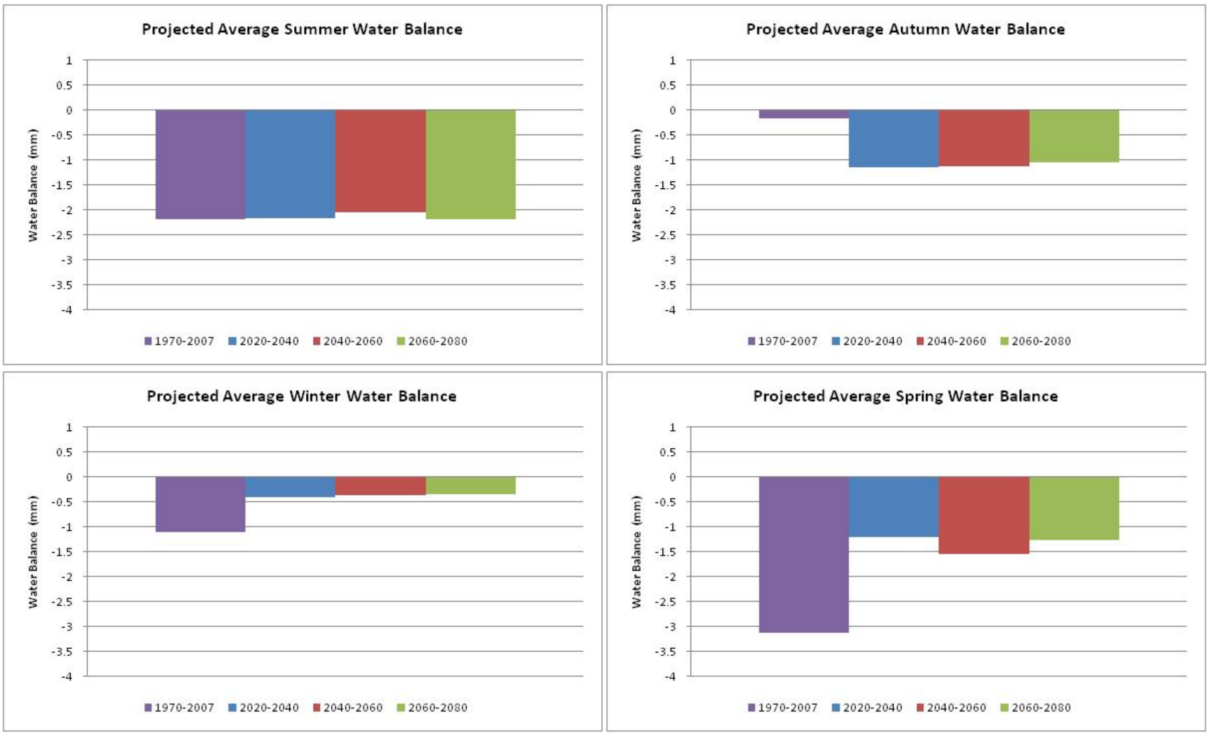


Figure 50 - Seasonal comparison water balance for historic interdecal time periods and future time horizons

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.

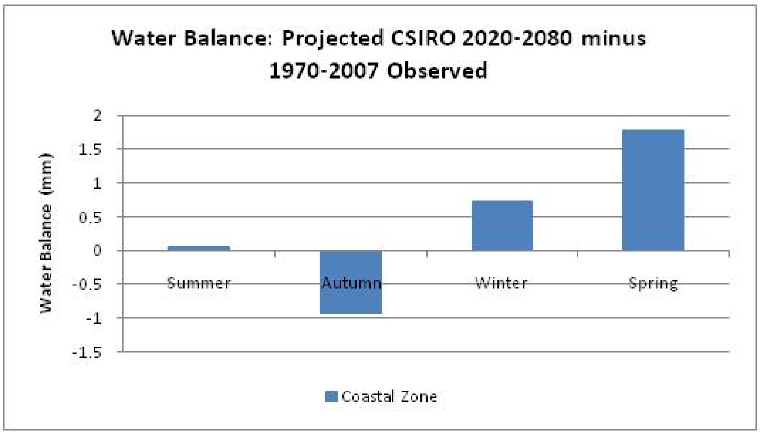


Figure 51 - Projected changes in average water balance relative to historic interdecal time period

Water Balance (2020-2080) *Changes are reported in average mm per day relative to 1970-2007.*		
Season	**Decrease**	**Increase**
Summer		~0.1 mm
Autumn	~0.9 mm	
Winter		~0.7 mm
Spring		~1.8 mm

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 projected linear trends (green line), average annual water balance for the period from 1970-1996 is superimposed onto the projected data. Projected values for all zones show no propensity to extend beyond the bounds of natural variability experienced during the period from 1970-1996. Average water balance shows no change over the period from 2020-2080 in the coastal zone.

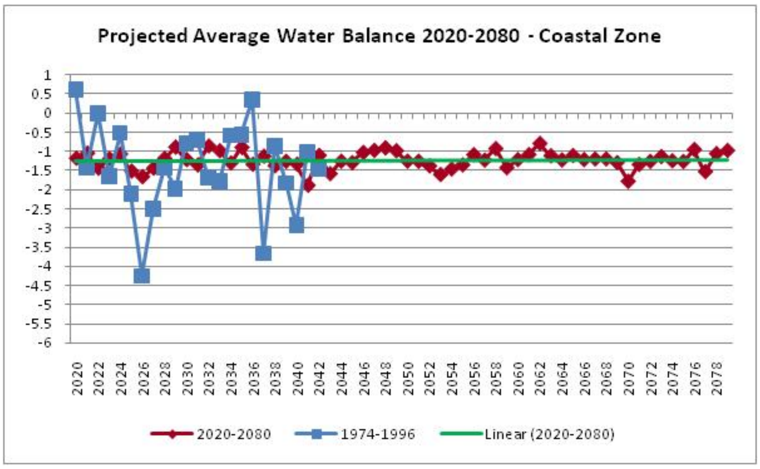


Figure 52 - Projected annual average water balance for 2020-2080 showing

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 coastal 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.

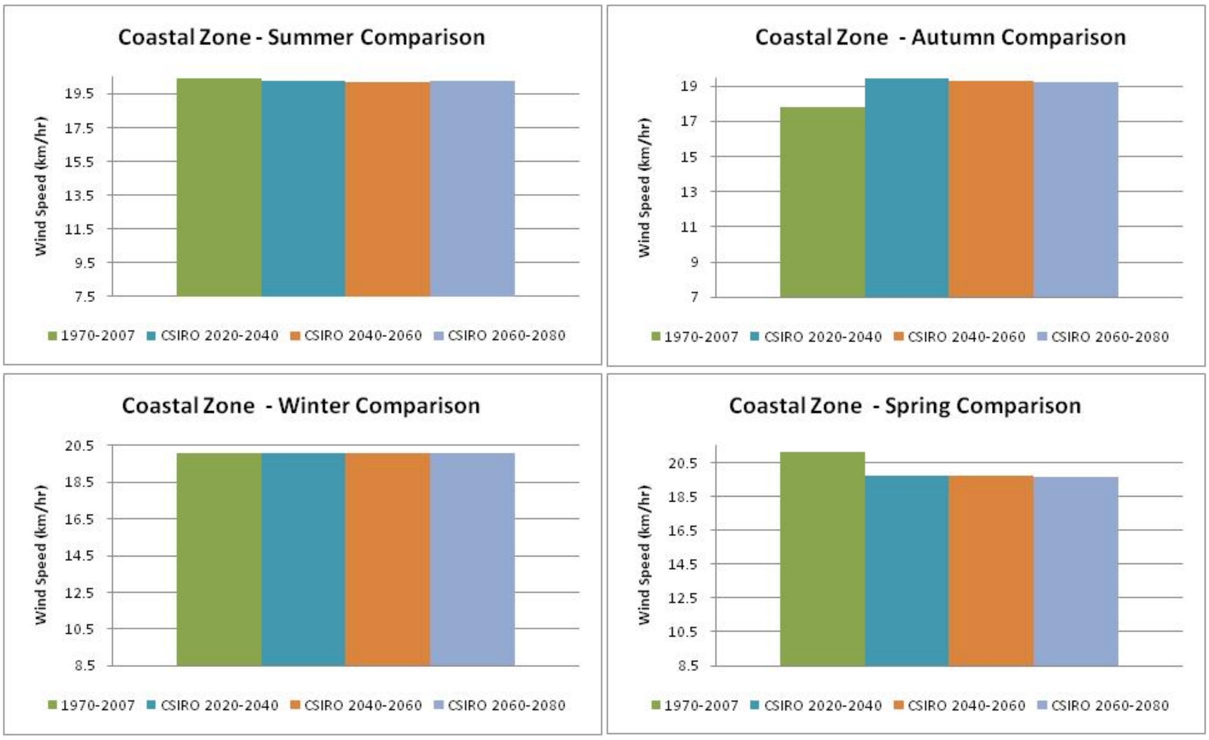


Figure 53 - Seasonal comparison of average wind speed for historic interdecal time period and future time horizons

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).

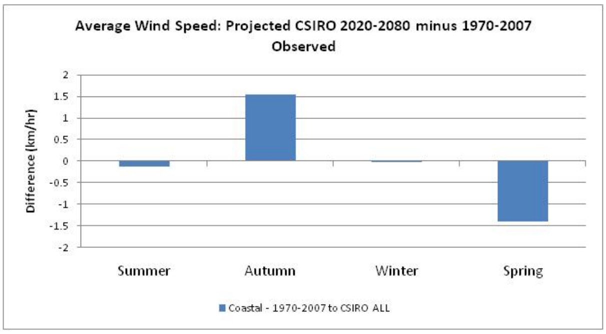


Figure 54 - Projected changes in average wind speed relative to historic interdecal time period

Wind Speed (2020-2080)

Changes are reported in average km/hr relative to 1970-2007.

Season	Decrease	Increase
Summer	~0.1km/hr	
Autumn		~1.5km/hr
Winter		Minimal change
Spring	~1.4km/hr	

Table 24 - Summary of projected changes in wind speed

As can be seen from Table 24, increases during autumn will be balanced by decreases occurring in spring and thus should result in no overall change in annual average windspeed.

Changes in annual average wind speed for the projected period from 2020 to 2080 are shown in Figure 55. In addition to showing projected linear trends (green line), average annual wind speed for the period from 1970-1996 is superimposed onto the projected data. Projected values for the coastal 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 significant change in annual average wind speed is projected.

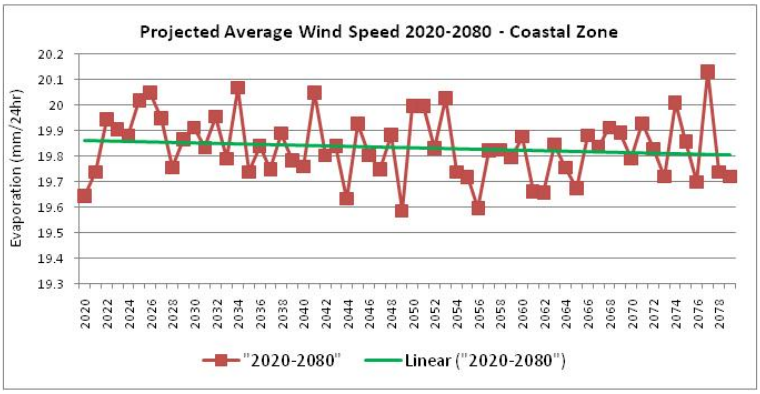


Figure 55 - Projected annual average wind speed for 2020-2080 showing linear trend

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.

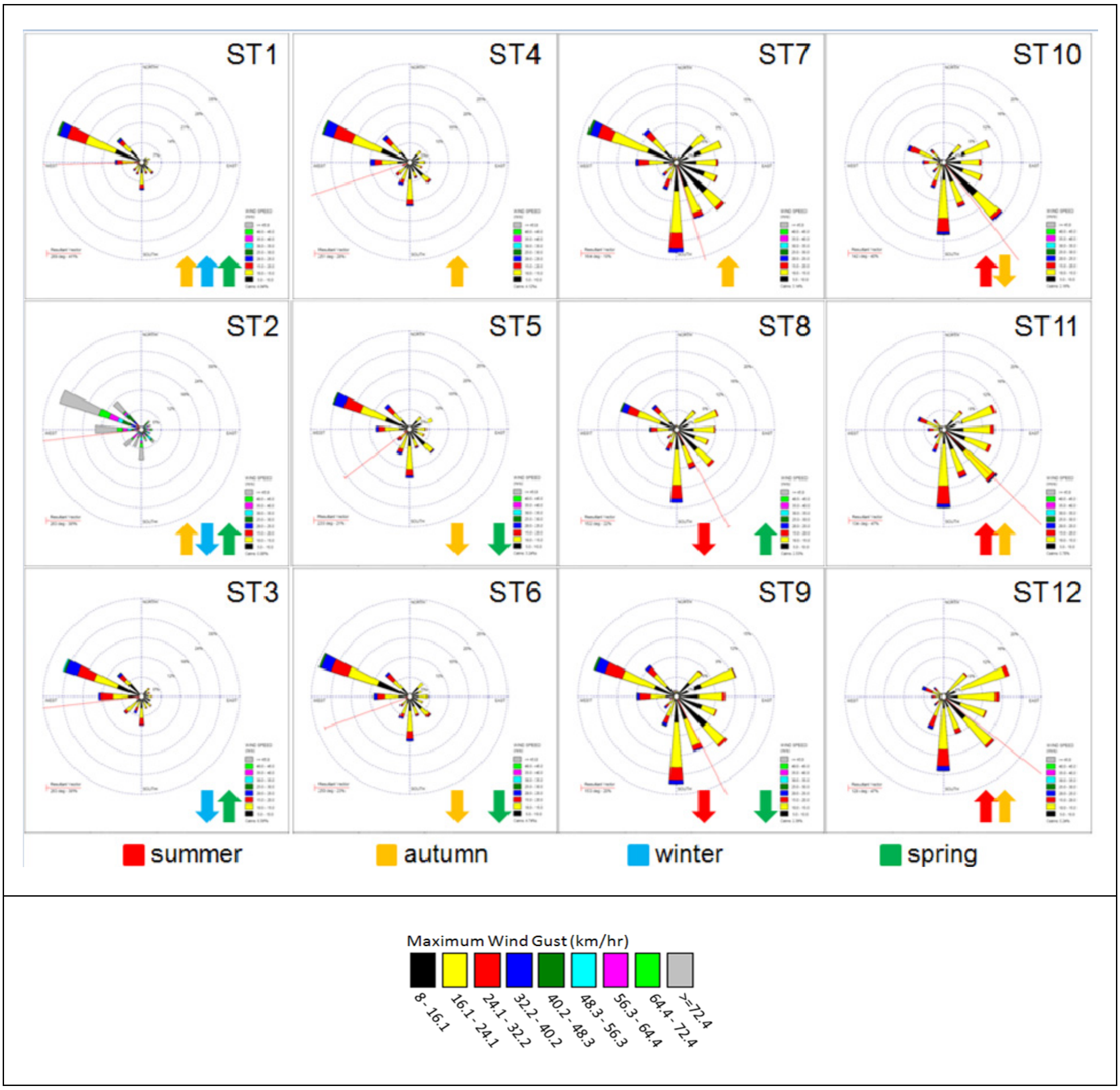


Figure 56 - Regional maximum wind gust patterns for CSIRO STs

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°C (number of extreme heat days); and
- Daily minimum temperature below 0°C (number of frost days).

As identified previously, two (2) representative stations within the coastal 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 11 occurs in the region, this ST produces a rainfall event in the 95%ile in Wingham 3.25% 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.

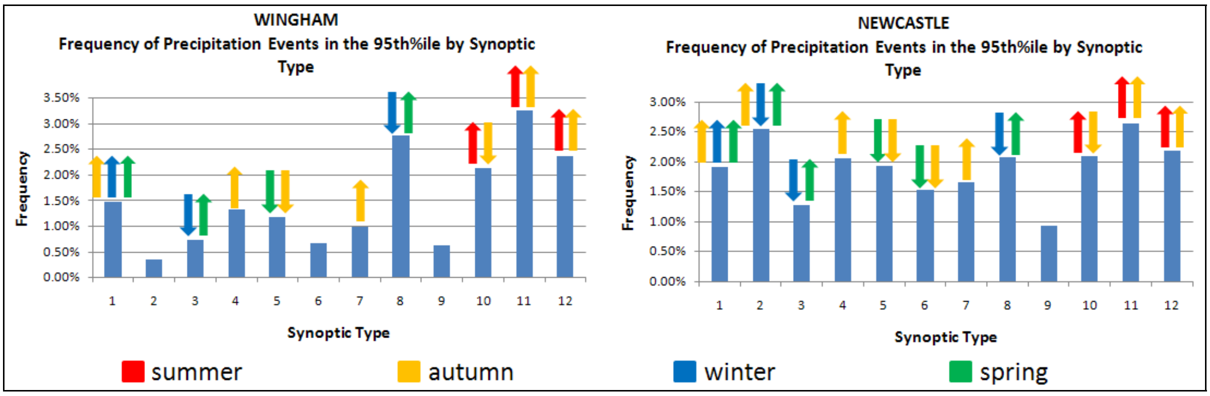


Figure 57 - Frequency of precipitation events in the 95%ile by ST for selected stations with arrows indicating seasonal shifts

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

- During summer and autumn, ST 11 is most likely to produce a high rainfall event in the coastal zone (Newcastle and Wingham). The frequency of occurrence of both 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.
- 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 and increases during spring suggest a corresponding shift to occur in high rainfall events during these seasons.

MAXIMUM TEMPERATURE (EXTREME HEAT DAYS)

A clear relationship between ST12 and extreme heat days (EHDs) exists for both stations (Figure 58). This relationship is strongest in the far north of the region (Taree) where ~58% 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.

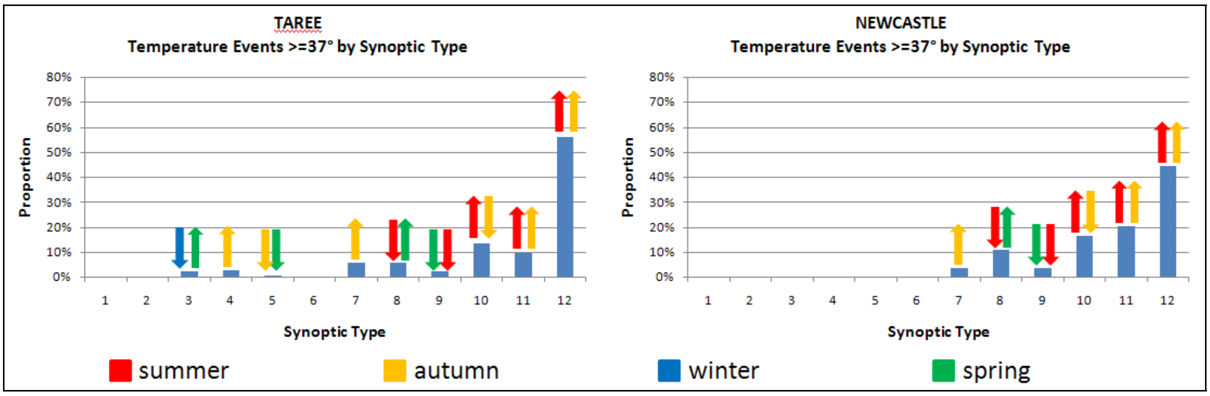


Figure 58 - Frequency of temperature events >=37^{o}C by ST for selected stations with arrows indicating seasonal shifts

MINIMUM TEMPERATURE (FROSTS)

Frost events (temperatures below or equal to 0^{o}C) occur only at the Taree station in the coastal zone (Figure 59). An association between minimum temperature events of less than or equal to 0^{o}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 a slight decrease or 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^{o}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^{o}C) in the projected period (2020-2080) during autumn.

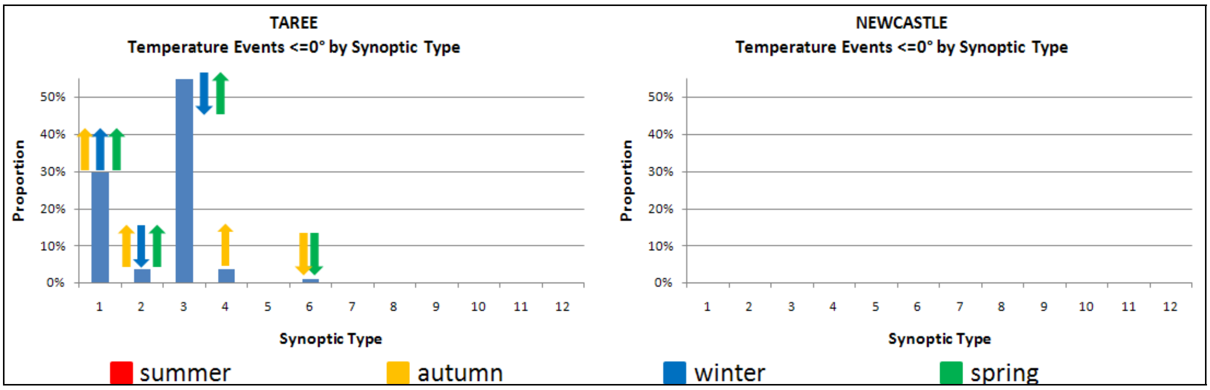


Figure 59 - Frequency of minimum temperature events <=0^{o}C by ST for selected stations with arrows indicating seasonal shifts

REFERENCES

Blackmore, in prep.

Blackmore, K.L. & Goodwin, I.D. (2008) *Climate Variability of the Hunter, Lower North Coast and Central Coast Region of NSW*. Consultancy report by Newcastle Innovation for the Hunter and Central Coast Regional Environment Management Strategy (HCCREMs). HCCREMS. p.92.

Blackmore, K.L. & Goodwin, I.D. (2009) *Climatic Change Impact for the Hunter, Lower North Coast and Central Coast Region of NSW*. Consultancy report by Newcastle Innovation for the Hunter and Central Coast Regional Environment Management Strategy (HCCREMs). HCCREMS. p.99

IPCC (2007a). Summary for Policymakers. In: *Climate Change 2007: The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller, Eds., Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC (2007b). *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, p.976.

Verdon, D & Goodwin, I.D. (2008). *Progress Report 1 to HCCREMS on Stage 1 of the Regional Climate Change Study*. Consultancy report by Newcastle Innovation for the Hunter and Central Coast Regional Environment Management Strategy (HCCREMs). HCCREMS. p.29.

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