Weather and climate of the ACT 2007-11 and decadal trends

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ACT State of Environment Report 2010 - Weather

Summary

During the three-year period 2008-2010 the weather in the ACT was generally warmer than the long-term climate average (1961-1990), with drier conditions in 2008 and 2009 and wetter than average conditions in 2010. All weather indicators were consistent with these conditions.

At Canberra Airport rainfall was 54% above average in 2010, whereas 2008 and 2009 were drier than normal. The number of rain days was below average in 2008 and close to average in 2009 and 2010. This indicates that average rainfall intensity (the average amount of rainfall recorded on each rain day) was lower than normal in the dry year (2009) and higher than normal in the wet year (2010).

Above-average temperatures were recorded during this period both during the day (mean daily maximum temperatures) and at night (mean daily minimum temperatures). In terms of the mean daily temperature (the average of mean daily maximum and minimum temperatures) 2009 was the second hottest year since records began in Canberra in 1939/40; the hottest year was 2007. Although 2008 was the coolest year in the period 2003-2010, mean daily temperatures were 6% above the long-term average.

The number of hot days in summer in particular was considerably above average in 2009, with 69 days of 30°C or more. On the other hand, 2008 and 2010 had an average number of hot days in this category (30 and 31 days respectively). These results may reflect the impacts of ENSO events in the ACT region: El Niño events tend to be associated with drier, hotter conditions in spring and summer, and La Niña events with cooler, wetter conditions in those seasons. 2008/9 was an El Niño year and 2010/11 was a La Niña year.

Significant weather-related events that impacted on the ACT during the reporting period are listed below:

1. Dust storms were reported in Canberra on 15/4/2009 and 22/9/2009 with visibility reduced to 3 to 4 km.
2. A very strong La Niña event impacted on rainfall in the ACT region during 2010.
3. A small number of frost events occurred in 2009 and 2010.
4. A reduced number of fog events occurred in 2008 and 2009.
5. A particularly hot year was recorded in 2009.
6. There were four heavy rainfall days recorded over the period and three heavy rainfall events (over multiple days), with a significant flooding event in Queanbeyan that also impacted on the ACT in December 2010.
7. Canberra Airport recorded its wettest December day on record on 3 December 2010 (87.6 mm).

All data used in this analysis were sourced from the Bureau of Meteorology and came from official Bureau of Meteorology weather records. The Bureau of Meteorology installed a new observation site at Canberra Airport in September 2008, approximately 400 m from the long-running original site which was established in

1939. Data for 2008 were analysed from the original airport site and data for 2009 and 2010 were analysed from the new airport site. Research is currently being undertaken to determine the optimum method for combining the data from the two sites to form a continuous long-term record. Appendix A provides a comparative analysis of the data from the two sites over the period September 2008-November 2010, at which time the original site was closed.

Table 1: Weather Indices, Canberra Airport

Year	1961-1990 Average	2008	2009	2010
Annual Rainfall (mm)	623.2	530.4	431.4	959.6
Rainfall Anomaly (mm)		-92.8	-191.8	+336.4
Mean Daily Max Temperature (^oC)	19.5	20.4	21.7	20.3
Max Temperature Anomaly (^oC)		+0.9	+2.2	+0.8
Mean Daily Min Temperature (^oC)	6.5	7.1	7.5	7.3
Min Temperature Anomaly (^oC)		+0.6	+1.0	+0.9
Mean Daily Mean Temperature (^oC)	13	13.8	14.6	13.8
Mean Temperature Anomaly (^oC)		+0.8	+1.6	+0.8
3 pm Relative Humidity (%)	47.5	43	41.7	48.3
3 pm Relative Humidity Anomaly (%)		-4.5	-5.8	+0.8
Mean Daily Sunshine (Hrs)	7.6	8.1	7.9	7.7
Sunshine Anomaly (Hrs)		+0.5	+0.3	+0.1
Mean Daily Evaporation (mm)	4.6	4.8	4.9	4.1
Evaporation Anomaly (mm)		+0.2	+0.3	-0.5
Mean Hourly Wind Run (km)	8.2	8.0	8.4	7.7
Wind Run Anomaly (km)		-0.2	+0.2	-0.5

Table 2: Phenomena

Year	1961-1990 Average	2008	2009	2010
Days 35 ^oC or more	5	4	20	8
Days 30 ^oC or more	30	30	69	31
No. Frosts	99	85	58	53
No. Thunderstorms	23	22	20	18
No. Fog Days	44	28	26	62
No. Strong Wind Days	26	26	25	22
No. Rain Days**	105	94	103	106
Mean Daily Pressure	1016.7	1017.2	1016.8	1018.1

** A rain day is defined as a day on which 0.2 mm or more of precipitation has been recorded in the 24 hours to 9 am. This precipitation could include rainfall as well as dew, fog or frost.

The smaller number of fog days recorded in 2008 and 2009 reflect the lower than average rainfall and dry environmental conditions during these years; in contrast the number of fog days in the wet year of 2010 was the highest recorded since 1985. The small number of frost days in each of 2009 and 2010 reflect the lengthy period of above average minimum temperatures from September 2008 to March 2010.

It is likely that the number of days on which temperatures equalled or exceeded 30°C or 35°C in 2009, and the number of frost days in 2010, are records. This cannot be verified until the question of combining the records from the two airport observation sites has been resolved.

Rainfall

Monthly rainfall time series over the period July 2007- June 2011 in terms of annual rainfall, monthly time series, anomalies from the 1961-1990 monthly means and rainfall accumulation against the monthly mean are shown in Figure 1. The deficit between the actual rainfall accumulated over this period and the mean is 49.8 mm. The monthly rainfall data reflect the dry period 1 July 2007- January 2010 followed by the wet period February 2010 – February 2011.

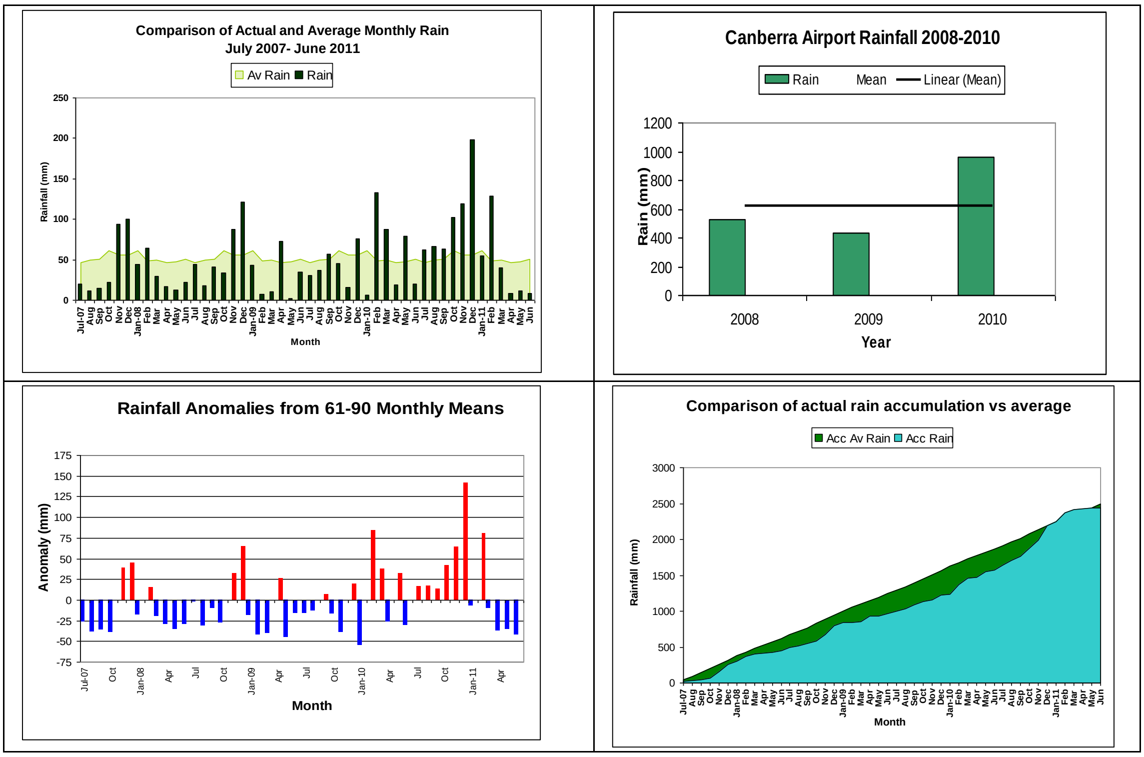


Figure 1: Rainfall at Canberra Airport, 2007-2011.

Long Term Trends

As the correlation between rainfall at Queanbeyan and at Canberra Airport is extremely high (Figure 2), the longer Queanbeyan rainfall record can be used as a proxy for rainfall at Canberra Airport for long term analyses. The long term time series of annual and seasonal rainfall at Queanbeyan for the period 1871-2010, shown in Figure 3, illustrate the overall decline in annual rainfall since the early 1990s which is due largely to reduced rainfall in spring and autumn. Similar trends are observed in other parts of south-eastern Australia. The decline was offset to some extent by relatively high rainfall in spring and summer 2010.

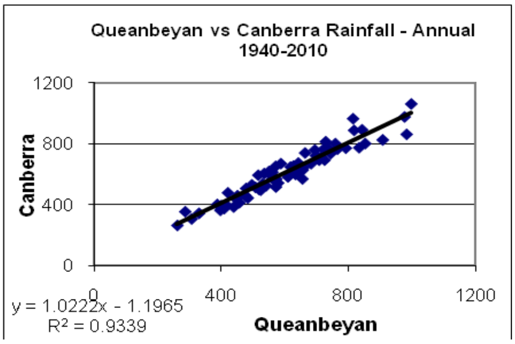


Figure 2: Comparison of annual rainfall at Canberra Airport and Queanbeyan.

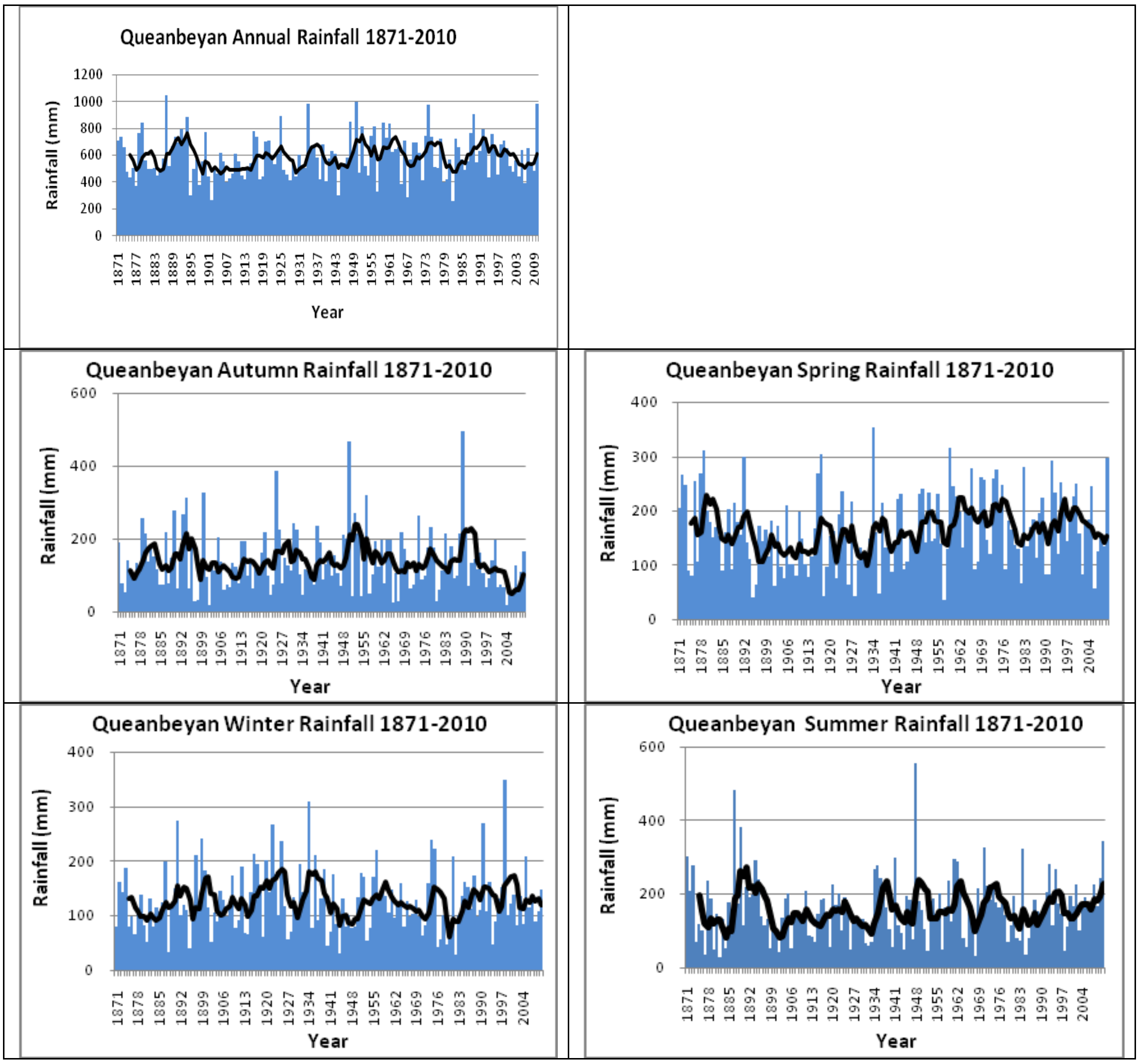


Figure 3: Time series of annual and seasonal rainfall at Queanbeyan with 5-year running mean.

The ACT region has now recorded below average rainfall for 7 of the last 10 years (2001-2010); 2010 is the only year with considerably above average rainfall (982 mm) during this decade. 2010 was the fourth wettest year on record at Queanbeyan (where the record is 1043.4 mm in 1887), and the wettest year since 1974 (975.6 mm).

Decadal trends in rainfall are shown in Figure 4 for the period 1871-2010. There is no clear change in rainfall outside natural variability over this period, except in autumn when a drying trend is evident over the last 40 years, with the most recent decade having the lowest autumn rainfall on record.

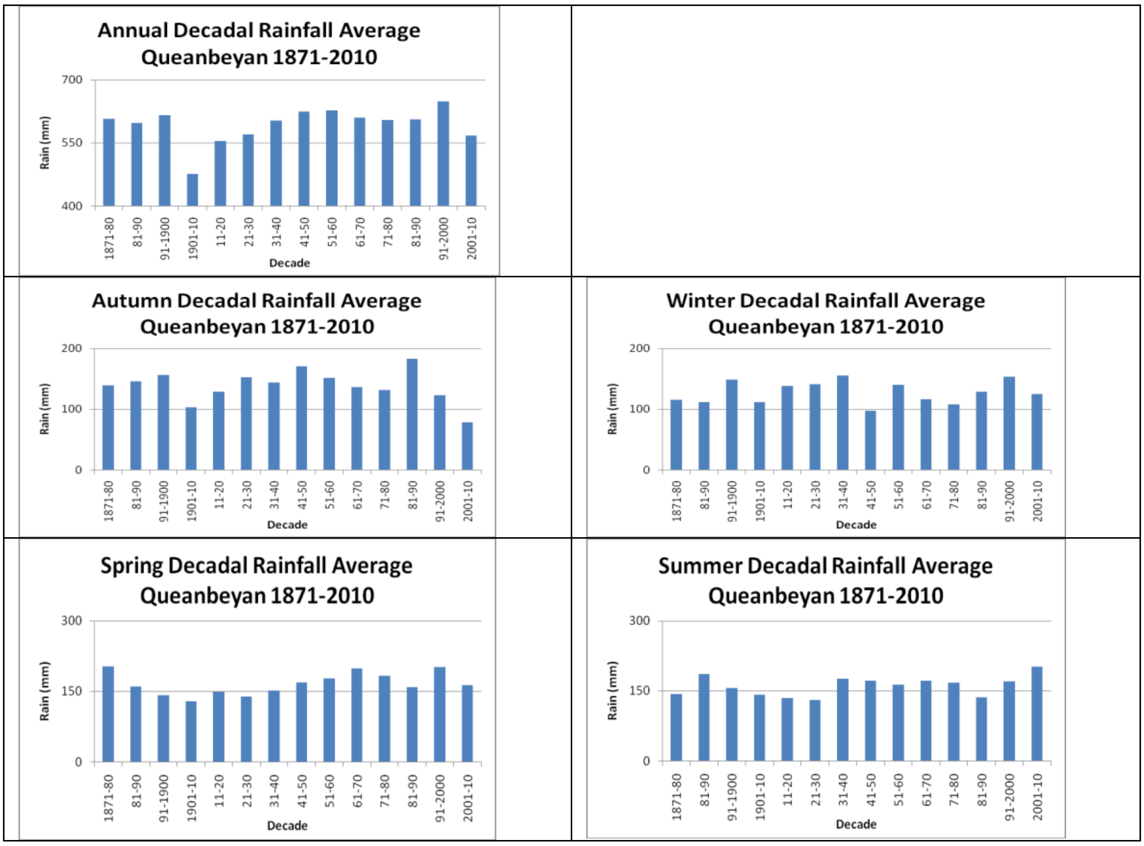


Figure 4: Decadal trends in annual and seasonal rainfall at Queanbeyan, 1871-2010.

Rainfall in the ACT region, particularly during winter and spring, tends to be affected by the El Niño Southern Oscillation (ENSO) phenomenon. The main measure used by the Bureau of Meteorology in determining an ENSO event is the Southern Oscillation Index (SOI), which is an index based on the air pressure differences at sea level between Darwin and Tahiti. Sustained strongly positive values (in the 80th percentile of all SOI values) indicate a La Niña event, and sustained negative values (20th percentile) mark an El Niño event. Table 3 lists the average winter/spring/summer SOI values in the period 2007-2010, and the correlations between winter and spring average SOI and rainfall at Queanbeyan is illustrated in Figure 5.

Table 3: Average SOI for 2007-2010

Year	Av Jun/Nov SOI	Av Sep/Nov SOI	Av Sep/Feb SOI
2007	3.4	5.6	11.1
2008	10.2	14.9	13.7
2009	-3.9	-5.8	-8.2
2010	16.8	19.9	21.5

Both 2008 and 2010 are identified as La Niña events. Although 2009 does not fit the definition of an El Niño year under these criteria, once the SOI values during summer and Pacific Ocean sea surface temperatures are taken into account it has been defined as an El Niño year.

Overall, the impacts of ENSO events in 2008 and 2009 on rainfall in the ACT were minimal. During the 2008 La Niña event rainfall was below average (with the exception of November and December), while in 2009, which was generally drier than average, there was close to average rainfall during winter and spring which minimized any overall impact from the El Niño event. Rainfall during 2010 did reflect the impact of the strong La Niña event with generally wet conditions in most months. This is considered the strongest La Niña event since 1917 and is one of the strongest on record. The impact of this event is evident when the Australian rainfall decile values are examined for this period; the extent of the heavy rainfall over most of Australia in 2010/11 is shown in Figure 6. The Jun/Nov SOI values for the 1876-2010 period and the monthly SOI values for the January 2007- June 2011 period are shown in Figure 7.

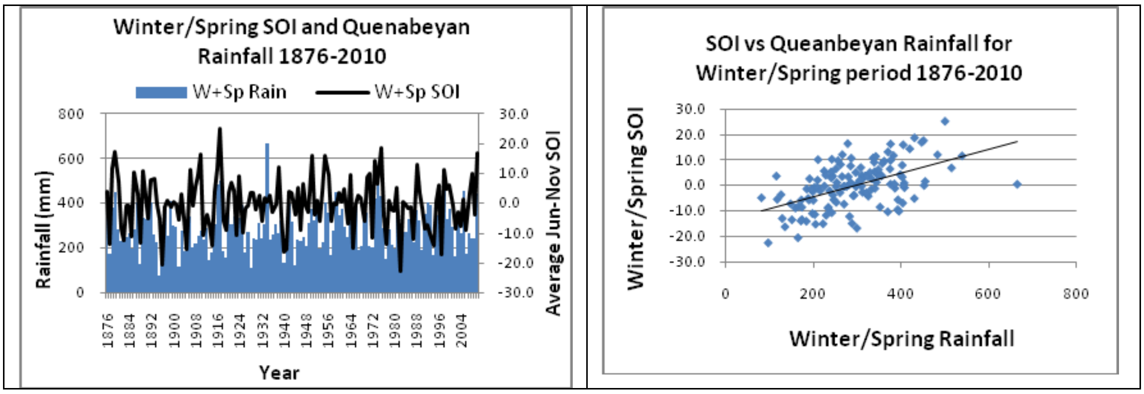
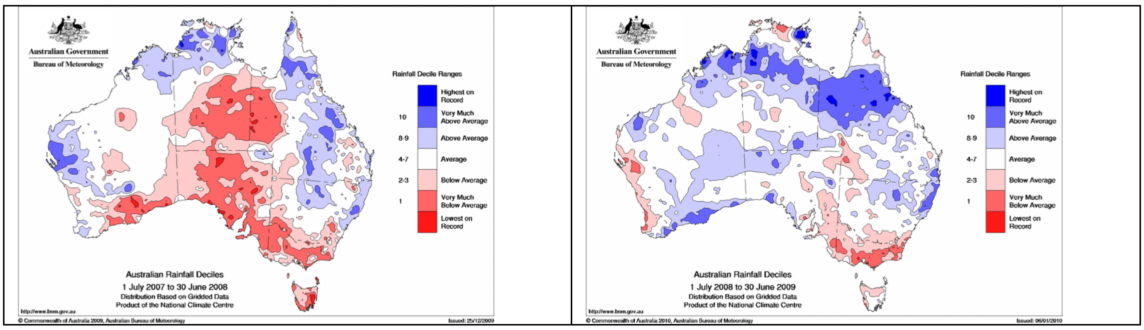


Figure 5: Comparisons of Winter + Spring rainfall at Queanbeyan with average June/November SOI.



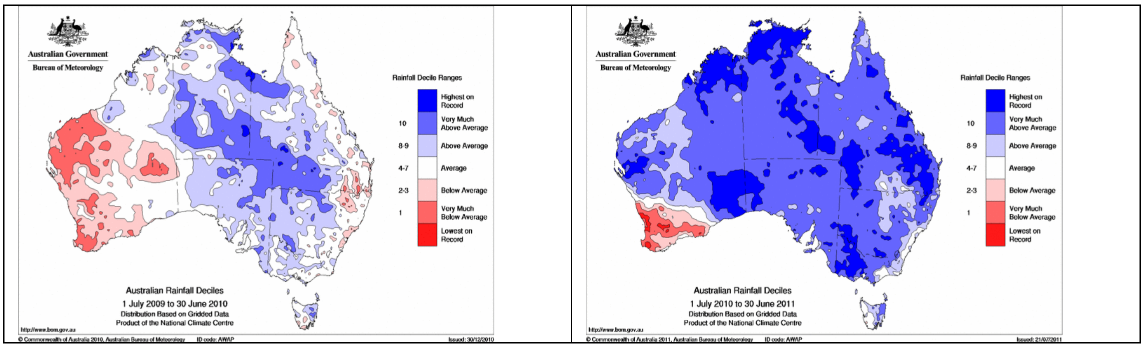
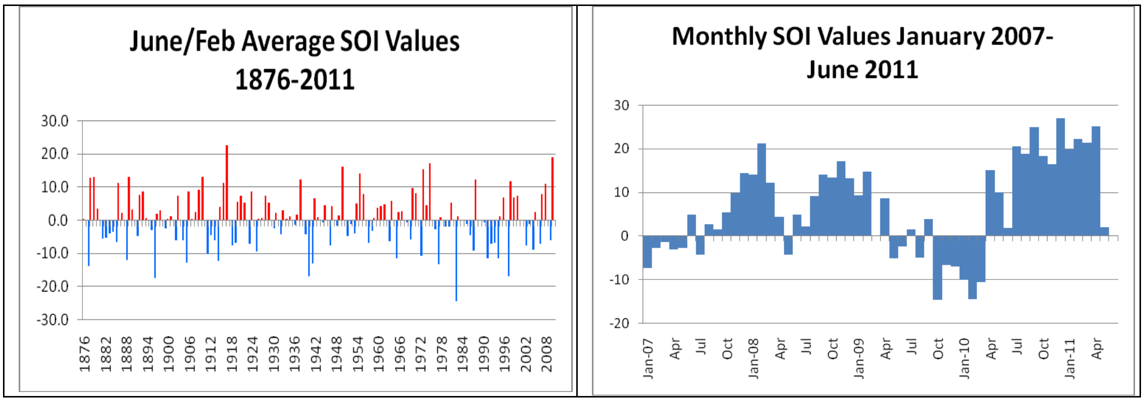


Figure 6: Australian rainfall decile values for the four 12-month periods July-June 2007/08, 2008/09, 2009/10 and 2010/11.

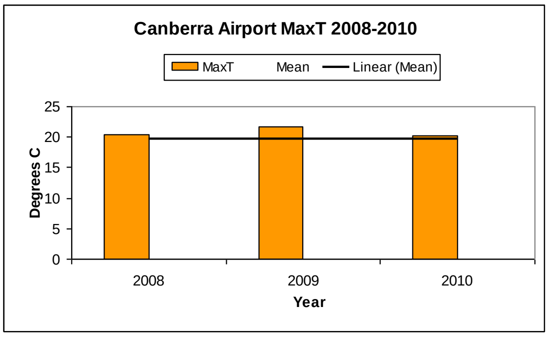


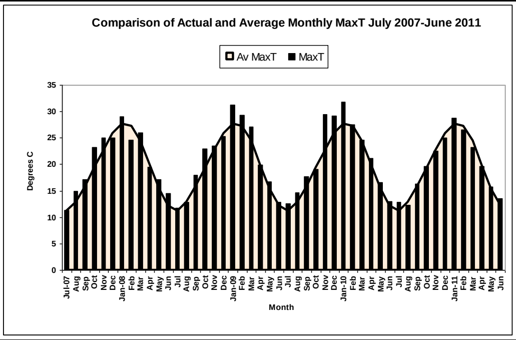
(a) (b)

Figure 7: (a) June-February SOI values, 1876-2011; (b) monthly SOI values, January 2007-June 2011.

Temperature

Monthly values of maximum temperatures, minimum temperatures and mean temperatures at Canberra Airport for the period July 2007 –June 2011 are shown in Figures 8, 9 and 10 respectively. Monthly temperatures have remained above the long term mean throughout the period. While maximum temperatures tended to be higher than average for most of 2009, they were close to average in 2010 and slightly above average in 2008. The slightly cooler than average conditions during January-March 2010 reflects the increased rainfall and cloud cover during this period. On the other hand, minimum temperatures were above average for most of the period, particularly during 2009. The period April-May 2010 was considerably cooler than average and a significant number of frosts were recorded during May 2010. The mean monthly temperature was above average throughout the reporting period.





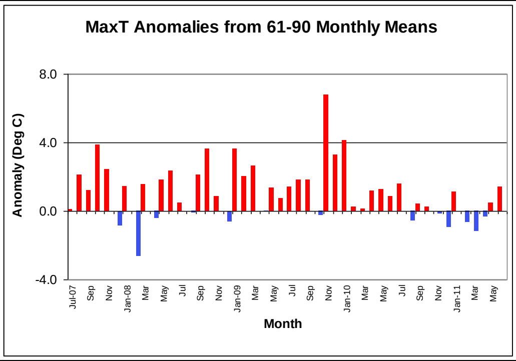
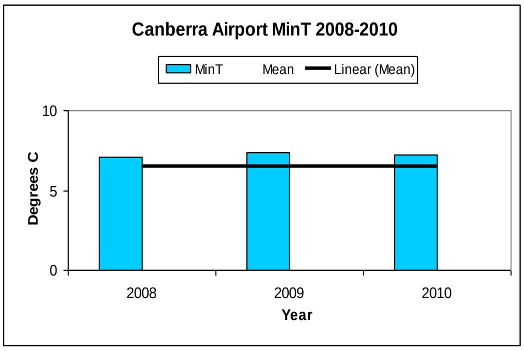
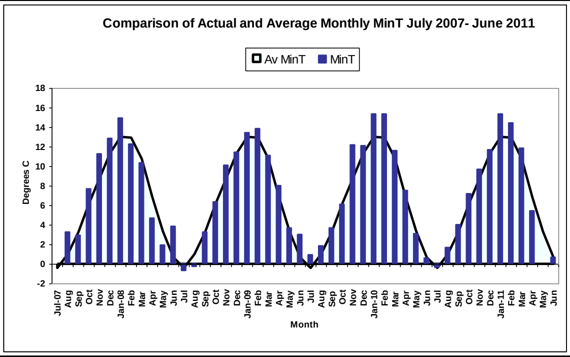


Figure 8: Monthly means of daily maximum temperatures at Canberra Airport, July 2007-June 2011.





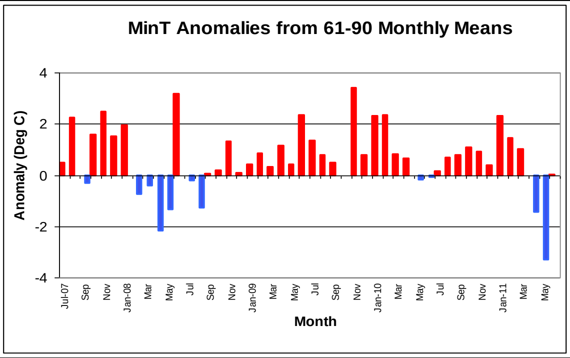
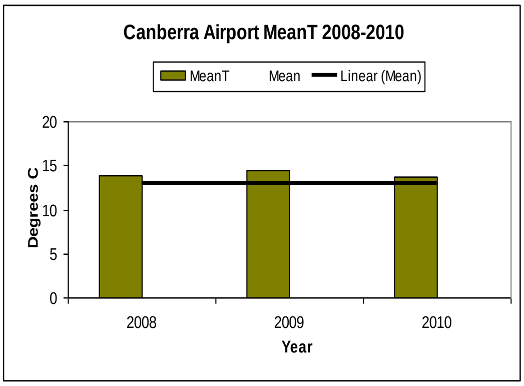


Figure 9: Monthly means of daily minimum temperatures at Canberra Airport, July 2007-June 2011.



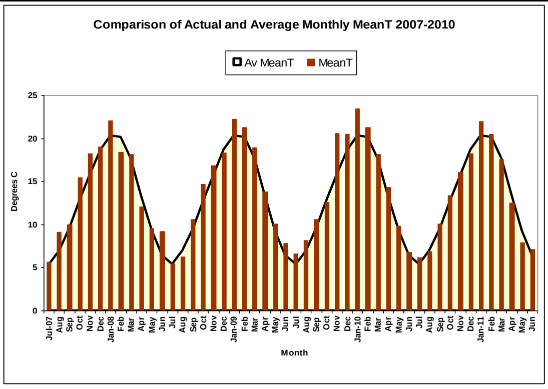
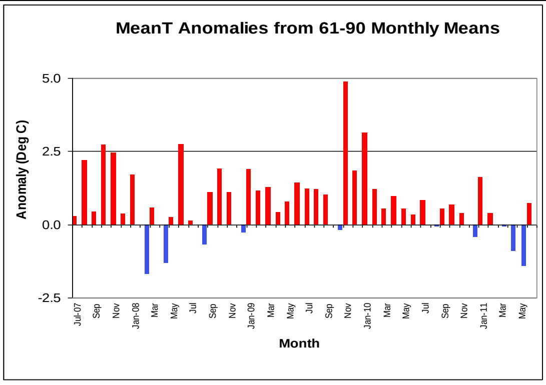
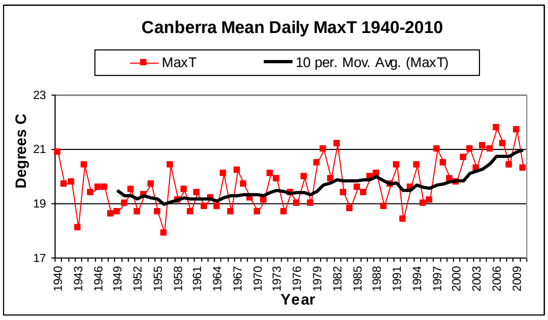


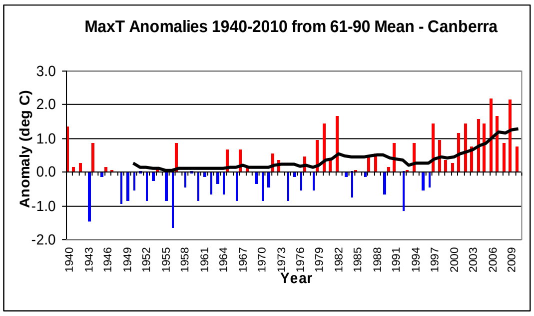
Figure 10: Monthly means of daily average temperatures (average MaxT+MinT) at Canberra Airport, July 2007-June 2011.



Long Term Trends

An analysis of long-term temperature data at Canberra Airport (Figures 11-13) indicates positive trends in annual maximum, minimum and mean temperatures, with most of the increase occurring during the last 15+ years. This increase is also clearly reflected in the graphs of temperature anomalies from the 1961-1990 long-term averages, and in the decadal trends. The increases in annual temperatures are consistent with the overall trends for Australia, although the Canberra anomalies are larger than that for Australia as a whole. Most recently, although 2010 was cooler than other recent years due to lower maximum temperatures resulting from the strong La Niña event and associated higher than average rainfall, it remained warmer than the 1961-1990 mean. Long-term trends, particularly in minimum temperatures, show that the region has continued to warm.





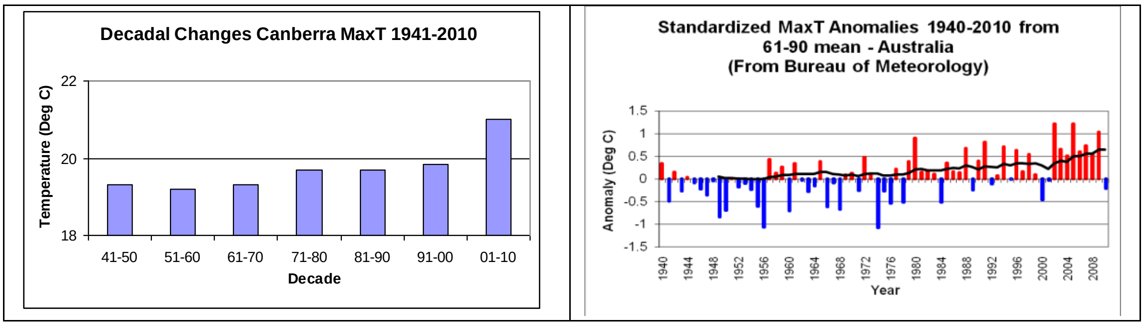


Figure 11: Long term trends in maximum temperatures for Canberra and Australia with 10-year running mean.

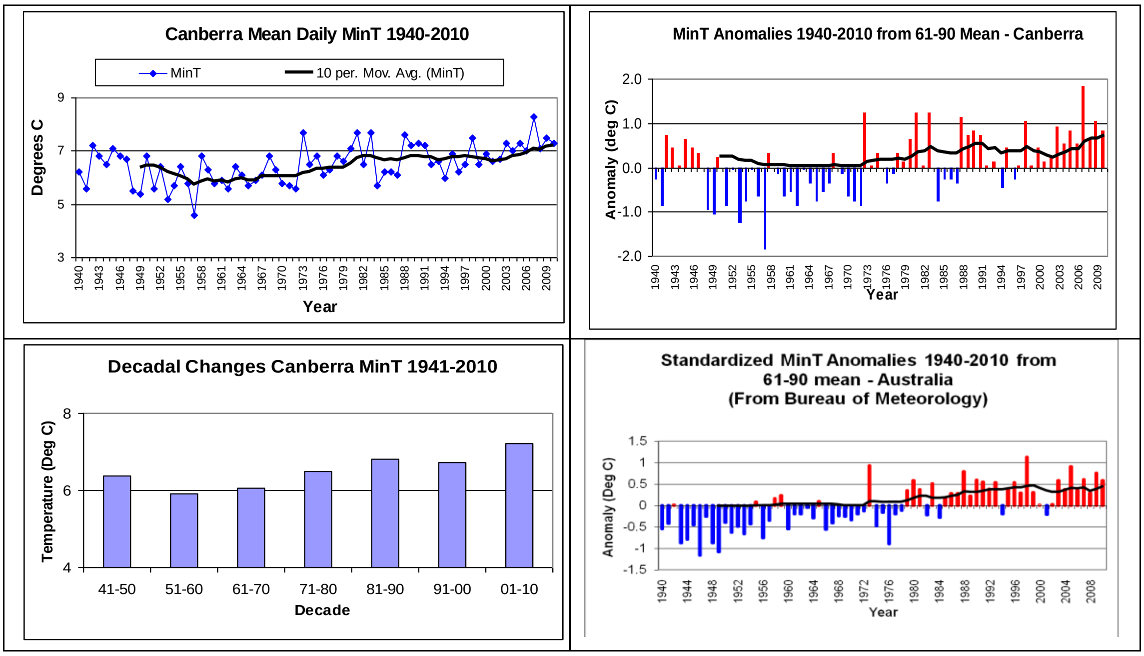
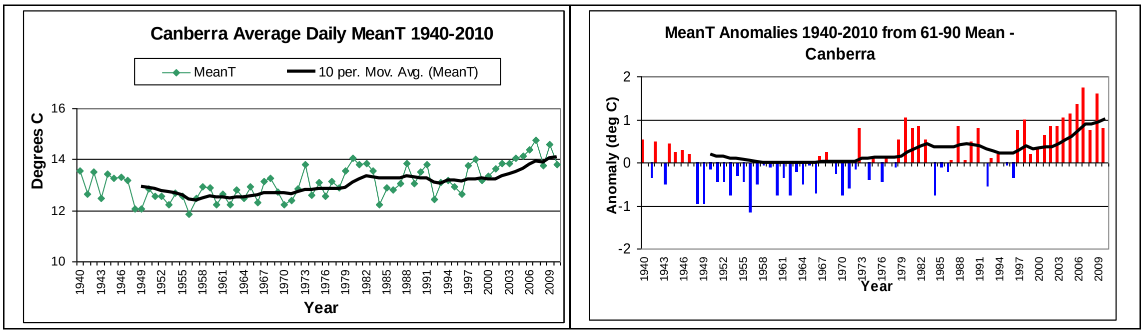


Figure 12: Long term trends in minimum temperatures for Canberra and Australia with 10-year running mean.



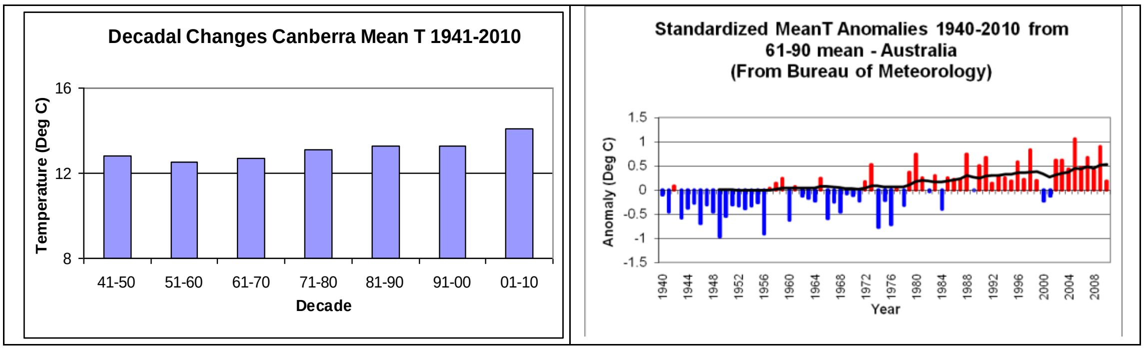


Figure 13: Long term trends in mean daily temperatures for Canberra and Australia with 10-year running mean.

Decadal averages of seasonal values of maximum and minimum temperatures at Canberra since 1941 are shown in Figures 14 and 15. The increases in both maximum and minimum temperatures have occurred across all seasons, most noticeably in spring and summer maximum temperatures in the most recent decade.

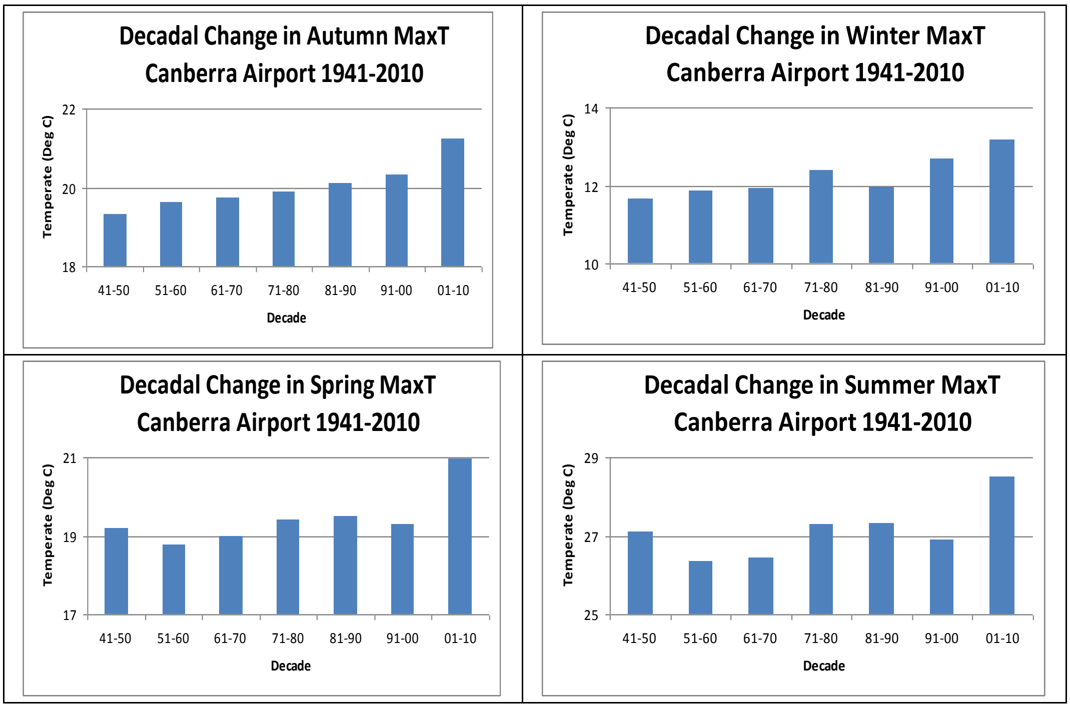
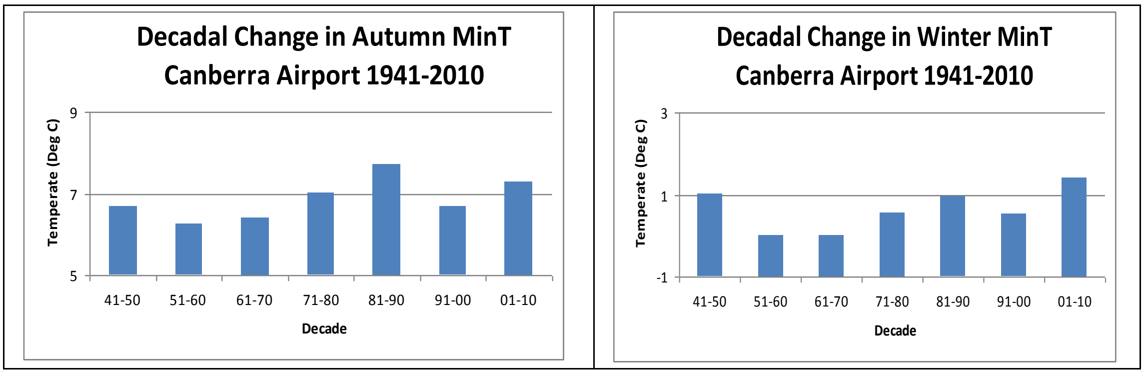


Figure 14: Trends in seasonal maximum temperatures at Canberra Airport.



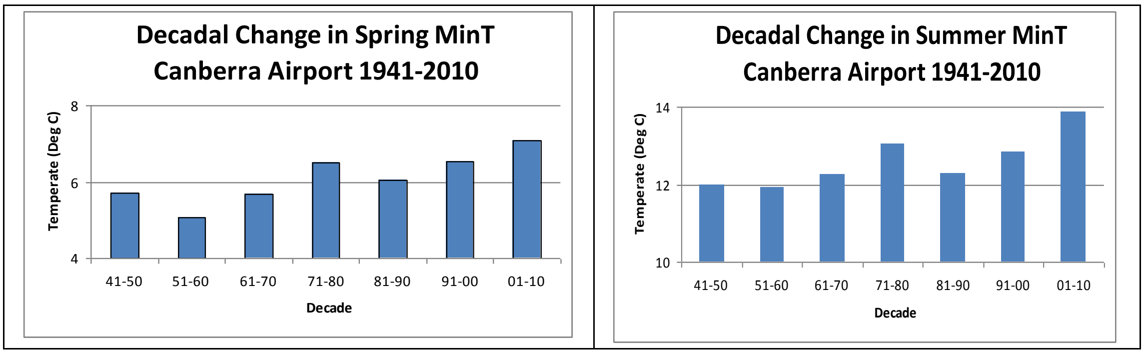
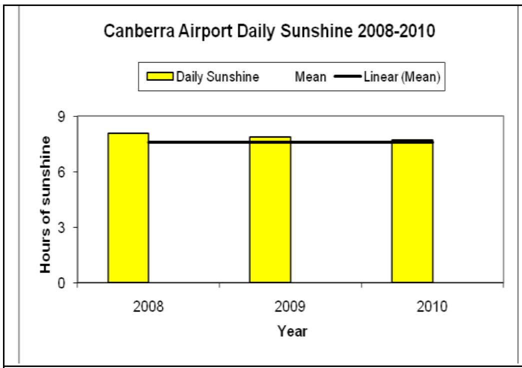
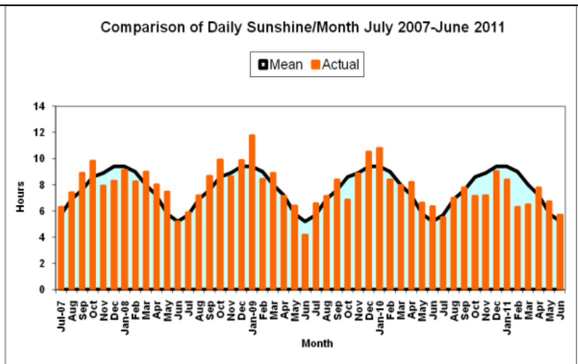


Figure 15: Trends in seasonal minimum temperatures at Canberra Airport.

Sunshine

Mean daily sunshine hours in the period 2008-2010 at Canberra Airport are shown in Figure 16. While 2008 and 2009 were sunnier than normal, 2010 had close to average sunshine hours despite being a very wet year. On a monthly basis, while the summers of 2008/09 and 2009/10 were considerable sunnier than average, the period October 2010-Mar 2011 had fewer sunshine hours. This is consistent with the wetter conditions and associate increased cloud cover during these months.





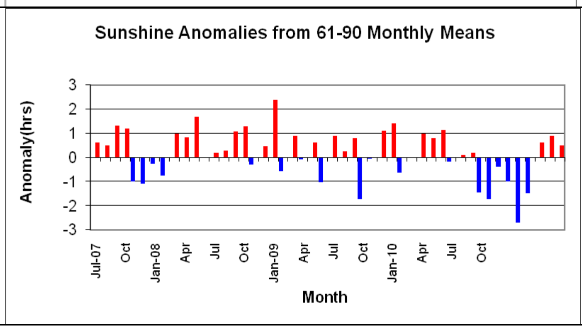


Figure 16: Mean daily sunshine hours at Canberra Airport, 2008-2010.

Long Term Trend

Annual and decadal values of mean daily sunshine hours over the longer term (1981-2010) are illustrated in Figure 17. Annual sunshine hours have generally increased during this period, which is consistent with the overall increase in daytime maximum temperatures during the same period. The dip towards average conditions in 2010 reflects the impact of the La Niña event on rainfall and associated cloudiness. The upward trend in decadal average sunshine hours is also consistent with the warm and dry conditions experienced in Canberra during the last decade.

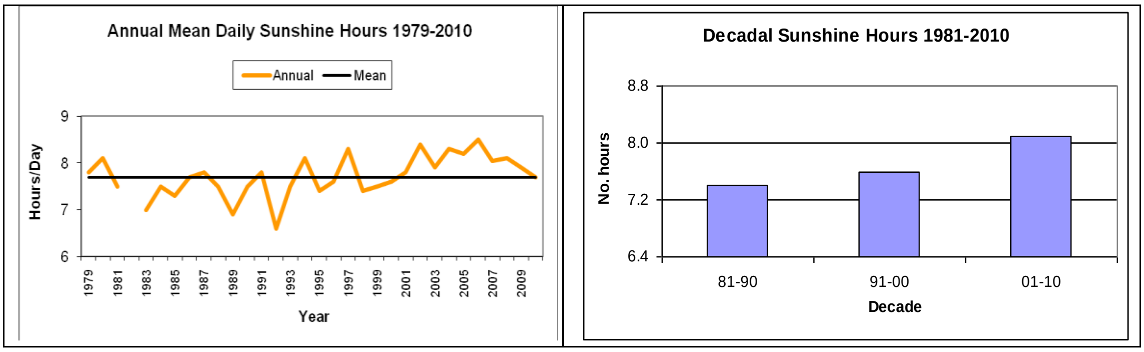
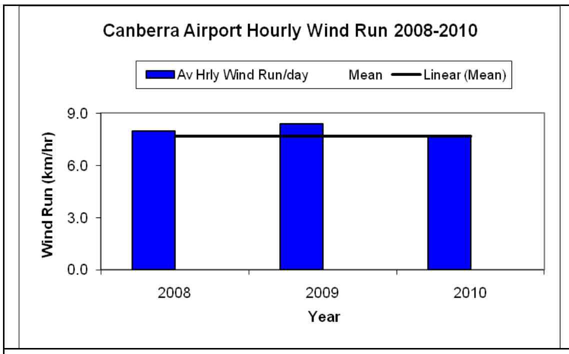
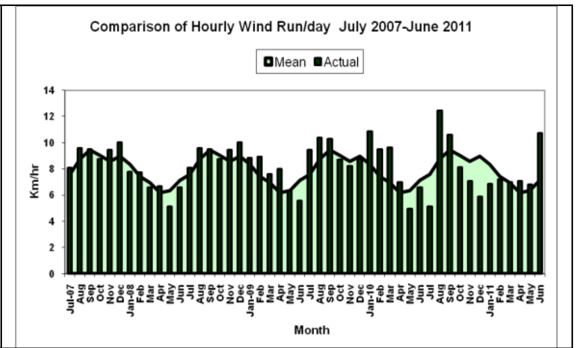


Figure 17: Long term trends in mean daily sunshine hours, Canberra Airport, 1979-2010.

Wind

Wind run is a measure of the wind speed at a place, recorded at 2 m above the surface as hourly values that are presented here as monthly averages (Figure 18). While wind speeds in 2008 and 2010 were near average, 2009 had higher wind speeds. However, wind speeds were lower in the period May 2010-February 2011 except during August-September 2010.





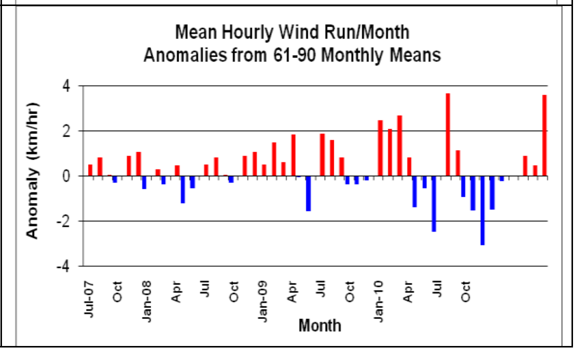


Figure 18: Trends in mean hourly wind run at Canberra Airport, 2008-2010.

Long Term Trend

Trends in wind run at Canberra Airport in the period 1970-2010 are illustrated in Figure 19. There is no apparent overall trend in wind run on an annual basis. Decadal average wind run was approximately the same in the earliest decade analysed (1971-1980) as in 2001-2010, but was lower in the 1990s.

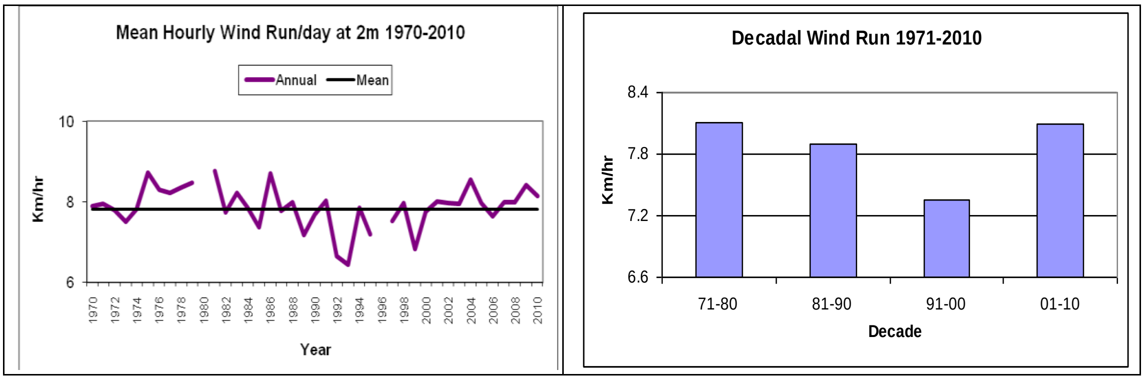
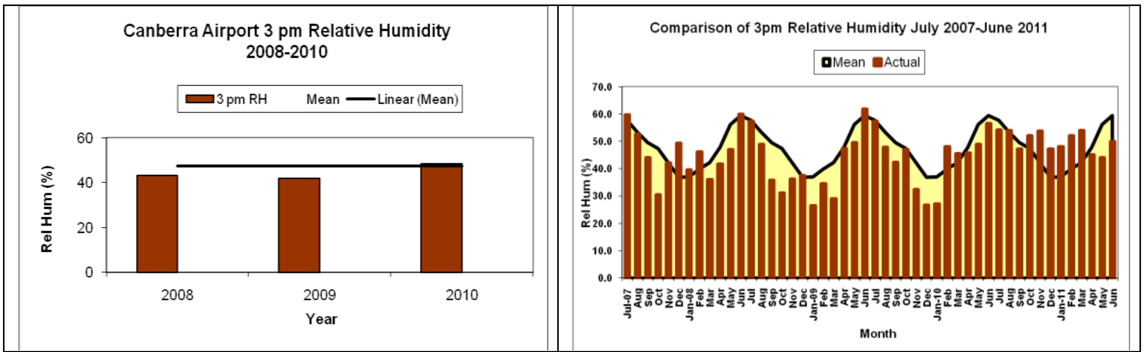


Figure 19: Long term trends in mean daily wind run at Canberra Airport, 1970-2010.

Relative Humidity

Monthly averages of relative humidity at 3 pm over the period 2008-2010 are illustrated in Figure 20. As relative humidity is temperature dependent and changes during the day, the 3 pm value has been selected as it is measured at the time closest to when the maximum temperature is usually observed; this is when the greatest difference between temperature and humidity tends to occur. While relative humidity in 2008 and 2009 reflects the drier than average conditions experienced in those years, humidity in 2010 was slightly above average which is consistent with the higher rainfall during that year. The monthly time series clearly shows the dry and wet spells that occurred during the reporting period.



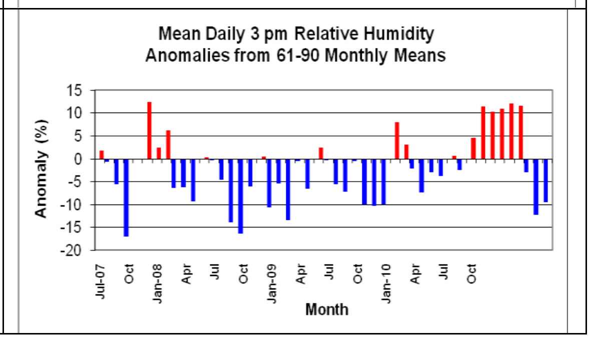


Figure 20: Mean 3 pm relative humidity at Canberra Airport, 2008-2010.

Long Term Trend

The general decrease in relative humidity in recent years (Figure 21) is also consistent with the lack of rainfall experienced over this period, while the increase in 2010 reflects the wetter conditions then. The relatively wet period during the 1970s and 1980s and the dry period during the last decade are particularly evident in the decadal averages.

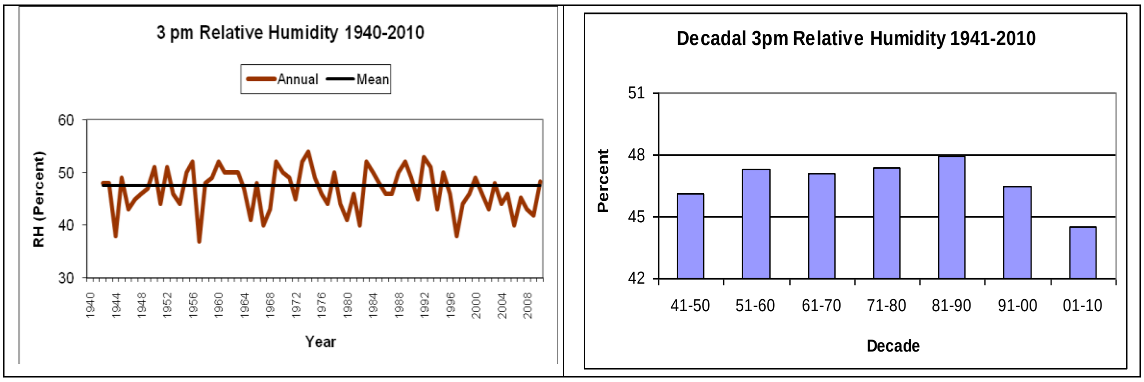


Figure 21: Long term trends in mean 3 pm relative humidity at Canberra Airport, 1940-2010.

Evaporation

Annual and monthly averages of daily potential evaporation measurements at Canberra Airport during the period 2008-2010 are presented in Figure 22. The effects of the drier and warmer conditions experienced during 2009 are evident in higher than average evaporation, and the wetter period in 2010 in lower than average evaporation. In the monthly time series the low evaporation/wetter periods in the summers of 2007/08 and 2010/11 contrast with the high evaporation/drier periods in 2008 and 2009. Potential evaporation is influenced by a range of factors including solar radiation, temperature, humidity and wind speed, all of which need to be considered in a thorough analysis of this variable.

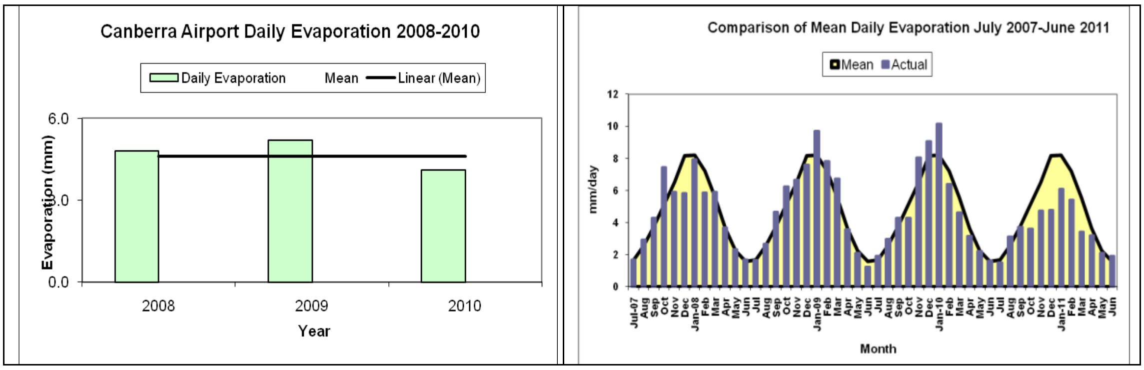
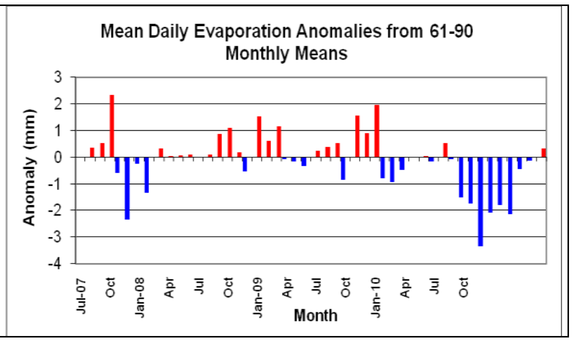


Figure 22: Mean daily evaporation at Canberra Airport, 2008-2010.	

Long Term Trend

During the longer period 1967-2010 there appears to be little overall trend in potential evaporation, although there is an increase over several years in the 2000s reflecting both the below average rainfall and increase in temperature during this period. In 2010 the lower potential evaporation values reflect the wetter, lower temperature conditions.

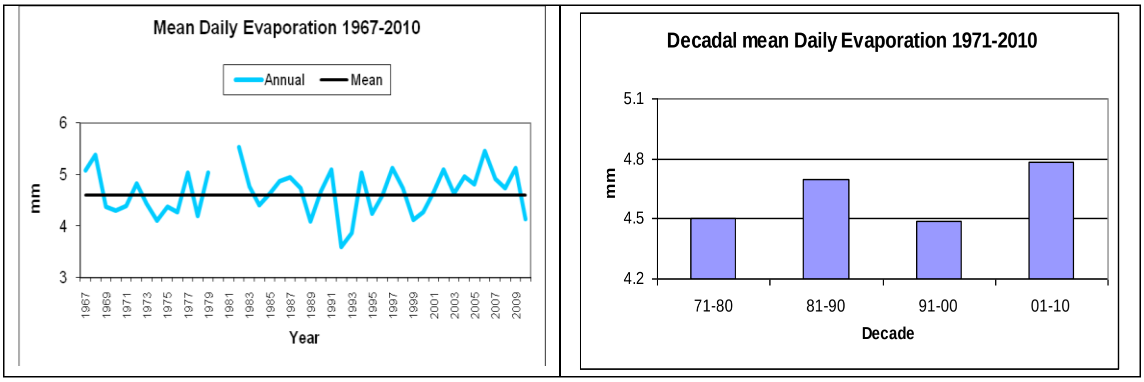
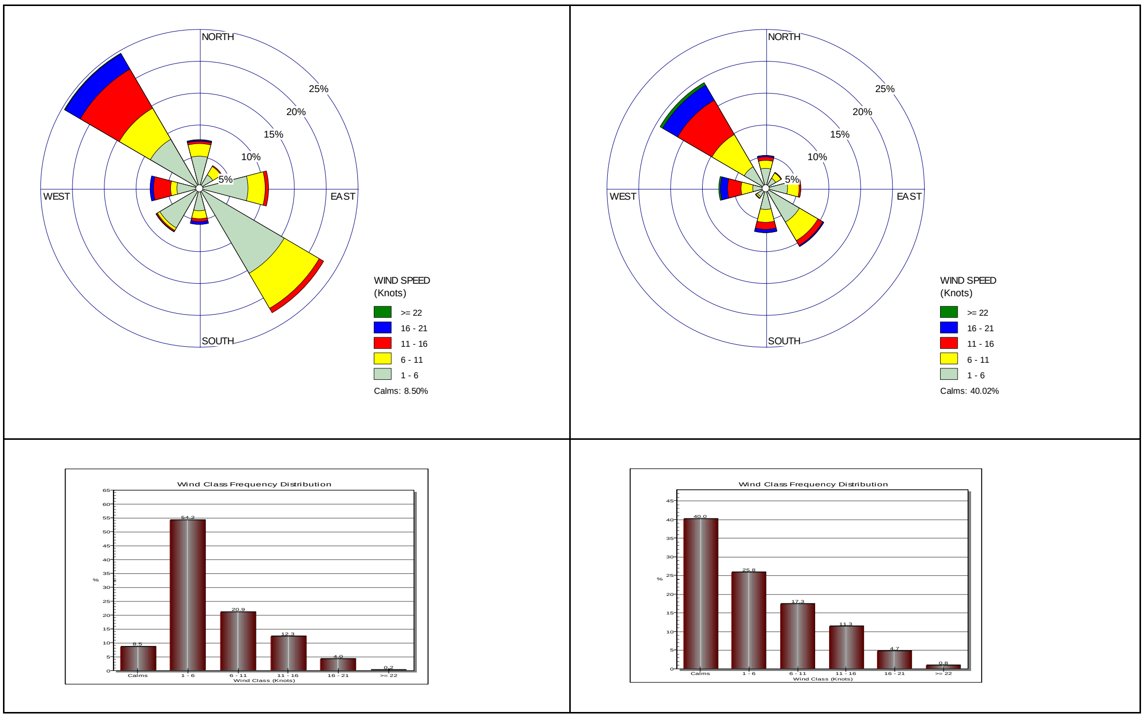


Figure 23: Long term trends in mean daily evaporation at Canberra Airport, 1967-2010.

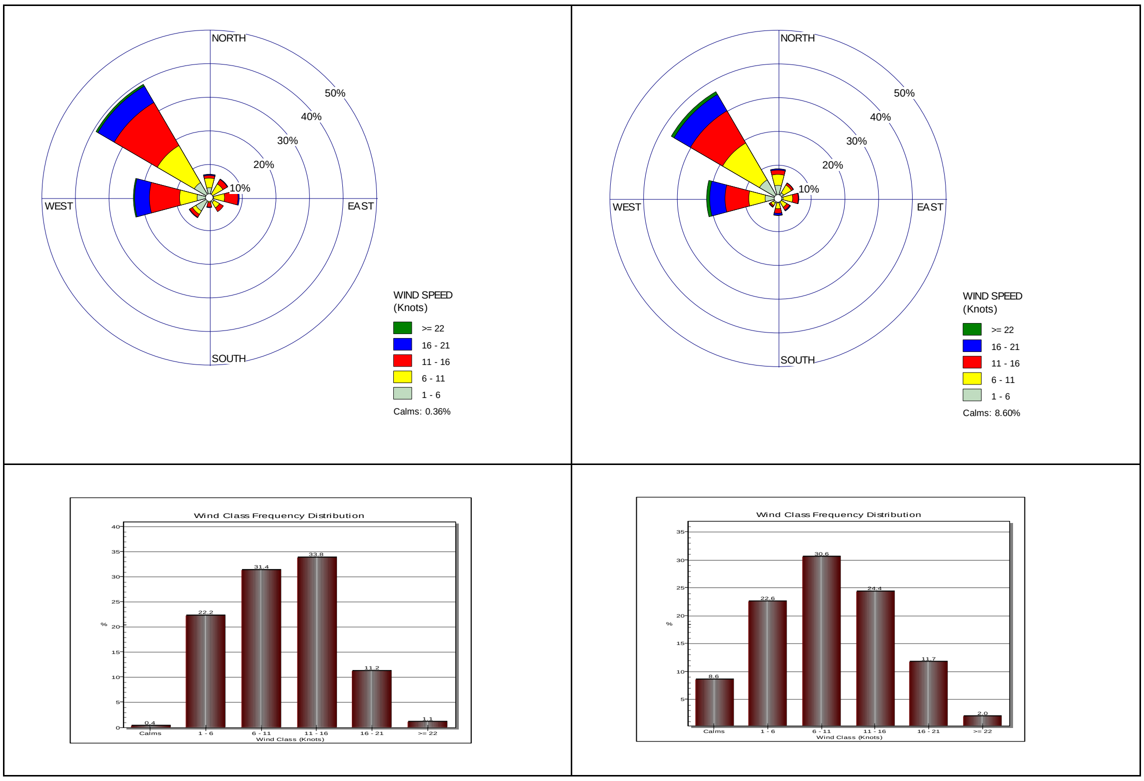
Wind Data

Wind roses are a way of presenting data for both wind speed and direction on the same chart. They are circular plots that show the wind direction (direction from which the wind is blowing) and wind speed ranges. The percentage of wind from a particular direction is indicated by the total length of each segment aligned with that direction. The wind speed ranges are expressed as percentages of the total wind, indicated by the relative size of each coloured segment in the wind rose. The wind frequency chart sets out the total percentage of wind in defined wind speed ranges. The two diagrams below show the 9 am and 3 pm wind data from Canberra Airport for the reporting period, together with the long term data at the site. Note that for the 2007-2011 period wind speed is expressed in knots, whereas the long term averages are expressed in km/h; the wind ranges have been scaled so that the wind roses are directly comparable.



a. July 2007-June 2011 b. March 1939-June 2011

Figure 24: Wind data for 9 am for the period July 2007–June 2011 in comparison with 9 am data for the period March 1939-June 2011.



a. July 2007-June 2011 b. March 1939-June 2011

Figure 25: Wind data for 3pm for the period July 2007 – June 2011 in comparison with 3pm for period March 1939-June 2011

Overall the winds during the last three years were close to the long term averages, although at 9 am there was a significant decrease in the numbers of calm events (reduced to 9.5% from 42%) and an increase in winds from both the W/NW and E/SE directions. At 3 pm almost no calm conditions were recorded, and there was an increase in westerly winds in comparison to the long term average.

As the position of the anemometer at Canberra Airport has not changed during this period, these results indicate that there has either been a change in weather patterns or that the instrumentation currently used for wind measurement may be more sensitive in light wind conditions than previous instruments. Further investigation is required to determine the reasons for the observed changes in wind speeds.

Seasonal Wind Roses

Wind rose data and frequency of occurrence at 9 am and 3 pm for each month, grouped by season, are presented for the period 2007-2011 in comparison with the 1939-2011 period in Figures 26-29.

Summer: there has been a reduction in calm conditions in all three months. In December, there has been an increase in NW winds and E/SE winds at 9 am and W/NW and NE winds at 3 pm. In January, the increase has been in W/NW winds and E/SE winds at 9 am and in W and NE winds at 3 pm. In February the increase has been in SE winds at 9 am and E/SE winds at 3 pm.

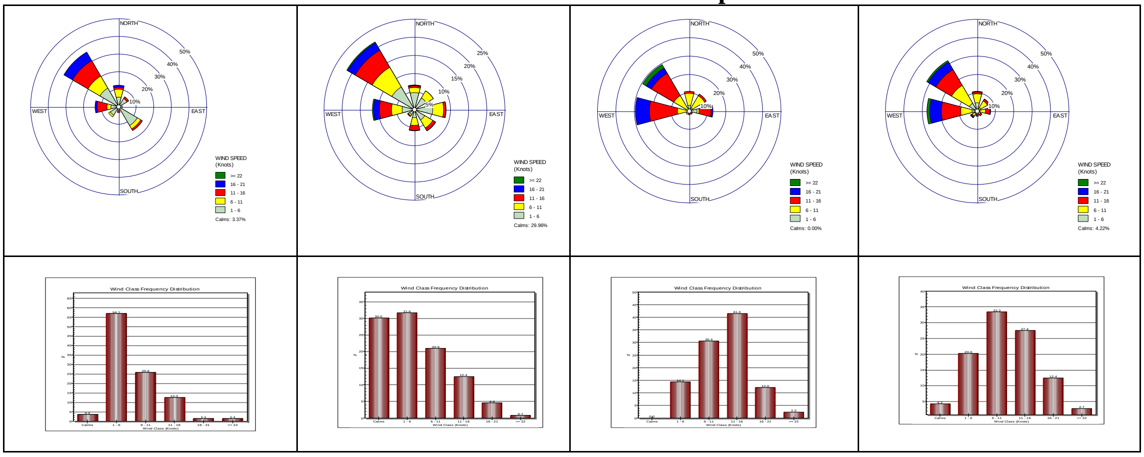
Autumn: there has been a general decrease in calm conditions. In both March and April there has been a significant increase in SE winds at 9 am and W and E/NE winds at 3 pm. In May the increase has been in SW winds and SE/E winds at 9 am and in NW/SW winds at 3 pm.

Winter: a reduction in calm conditions is observed. In June winds increased from the N/NW and E/SE at 9 am and NE/SE at 3 pm. In July the increase was from NW/SW at 9 am and E/SE at 3 pm. In August the increase was from W/NW and E/SE at 9 am and W at 3 pm.

Spring: in September the winds increased from the NW and from the SE at 9 am, and from the W/NW and East at 3 pm. Winds decreased from the S/SE. In October the winds increased from NE/SE and SW at 9 am and from the N and W and E/NE at 3 pm. In November winds decreased from the NW and increased in all other directions at 9 am, and increased from the E/NE and W at 3 pm.

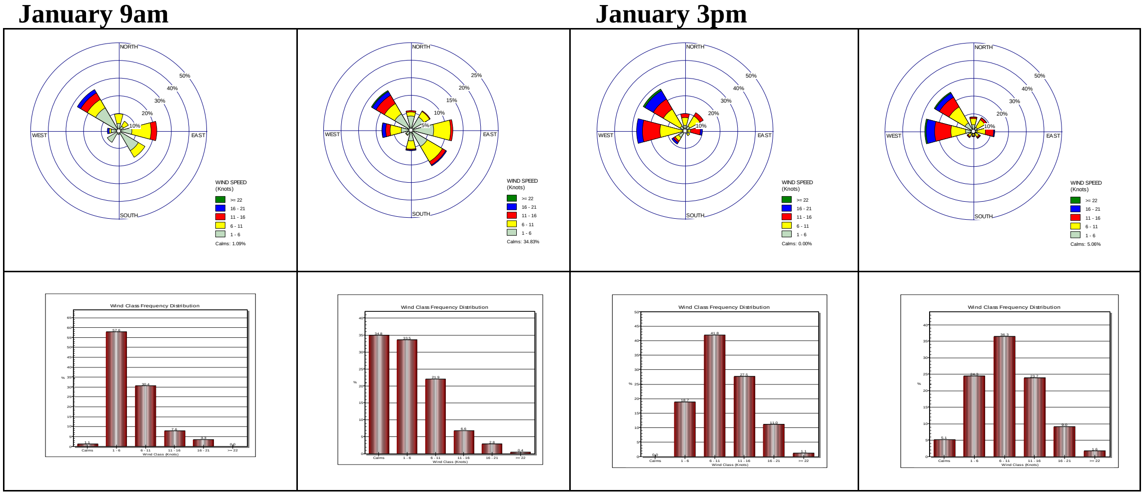
Seasonal Wind Rose Data – Summer

December 9am **December 3pm**



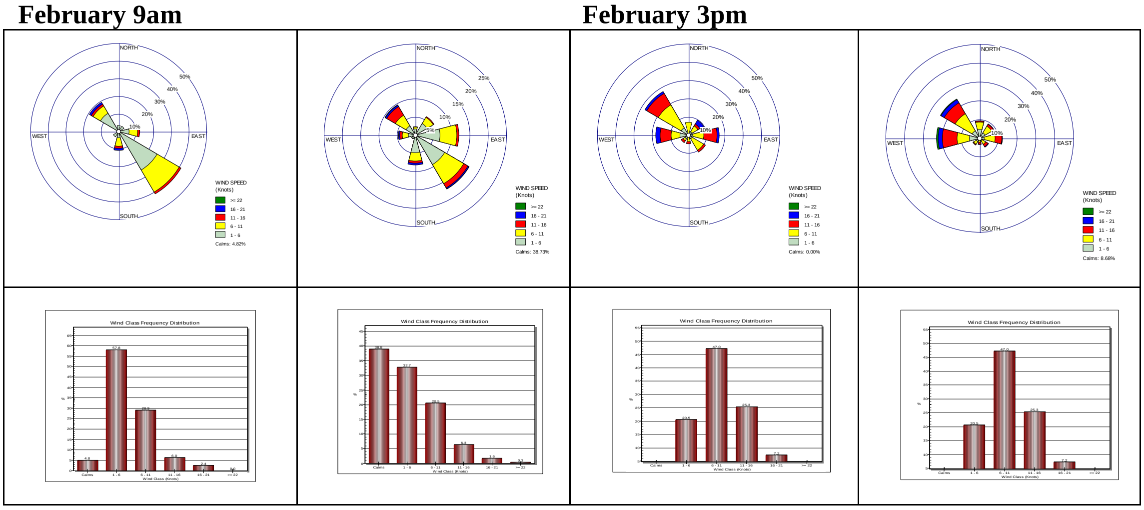
2007-2011 1939-2011 2007-2011 1939-2011

January 9am **January 3pm**



2007-2011 1939-2011 2007-2011 1939-2011

February 9am **February 3pm**

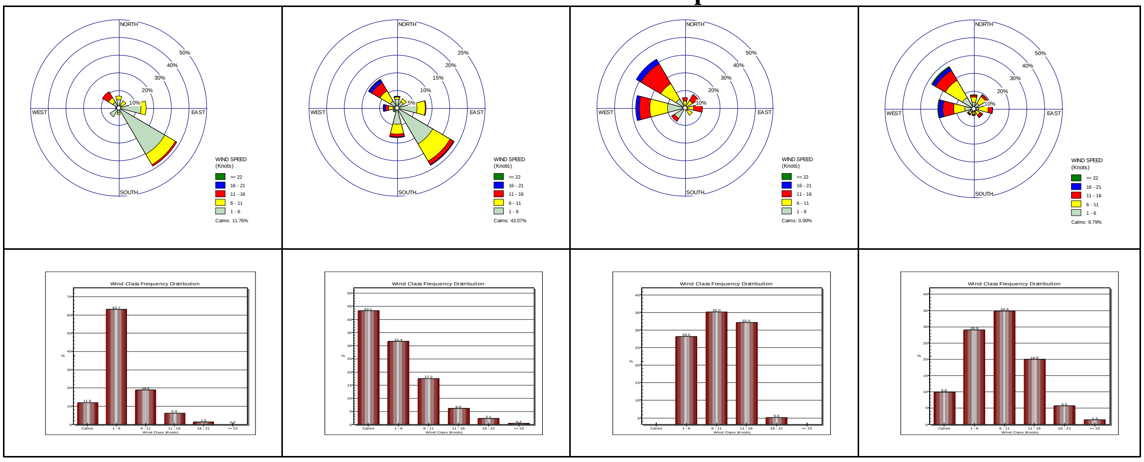


2007-2011 1939-2011 2007-2011 1939-2011

Figure 26: Summer wind roses for 2007-2011, compared to 1939-2011.

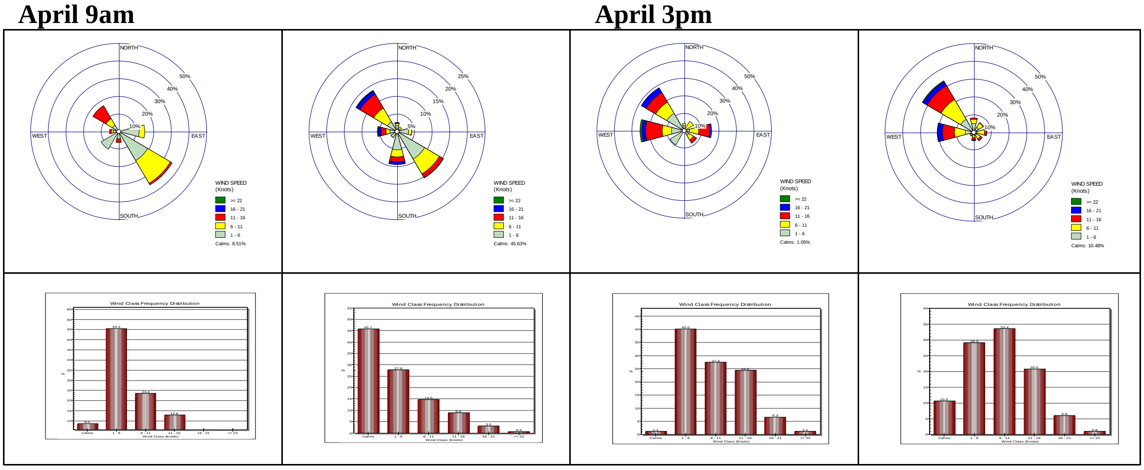
Seasonal Wind Rose Data – Autumn

March 9am **March 3pm**



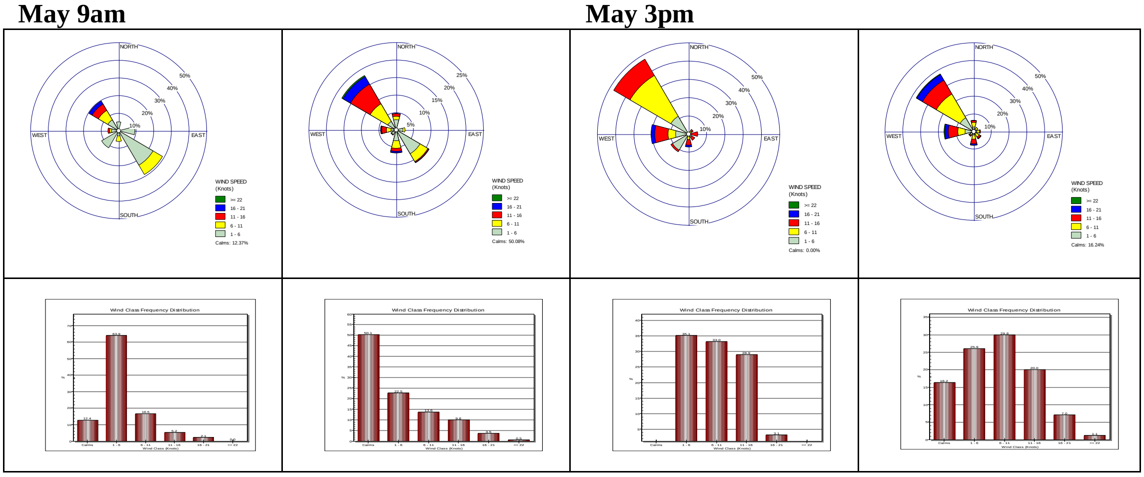
2007-2011 1939-2011 2007-2011 1939-2011

April 9am **April 3pm**



2007-2011 1939-2011 2007-2011 1939-2011

May 9am **May 3pm**

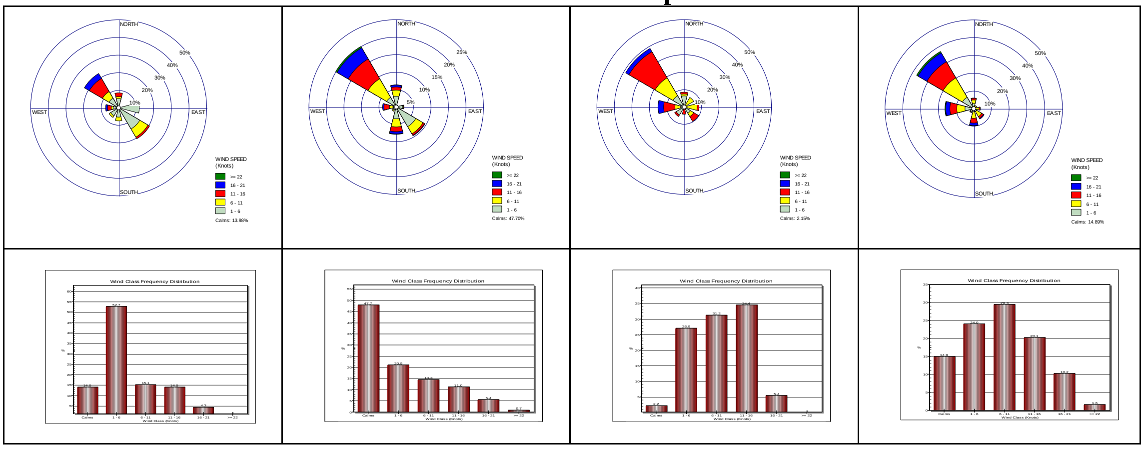


2007-2011 1939-2011 2007-2011 1939-2011

Figure 27: Autumn wind roses for 2007-2011, compared to 1939-2011.

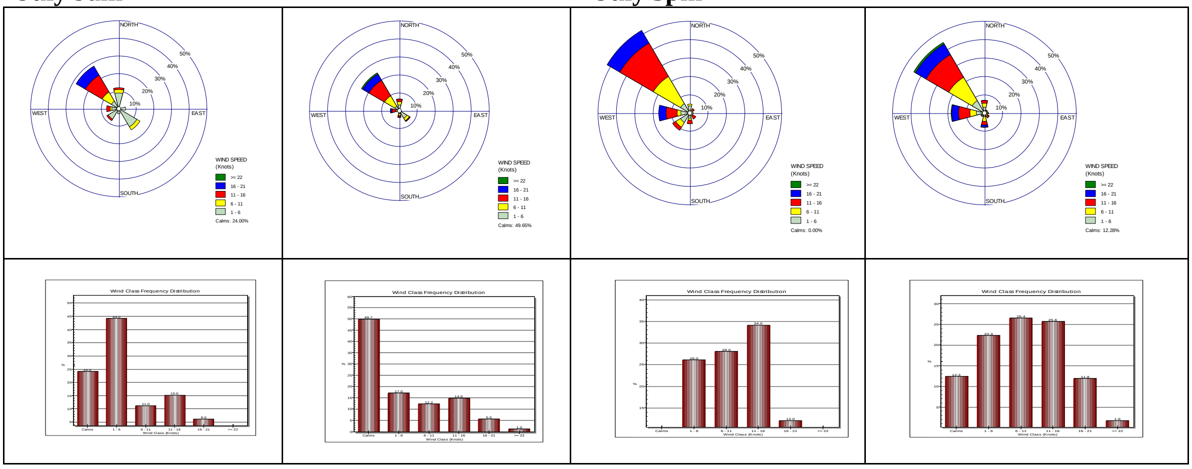
Seasonal Wind Rose Data – Winter

June 9am **June 3pm**



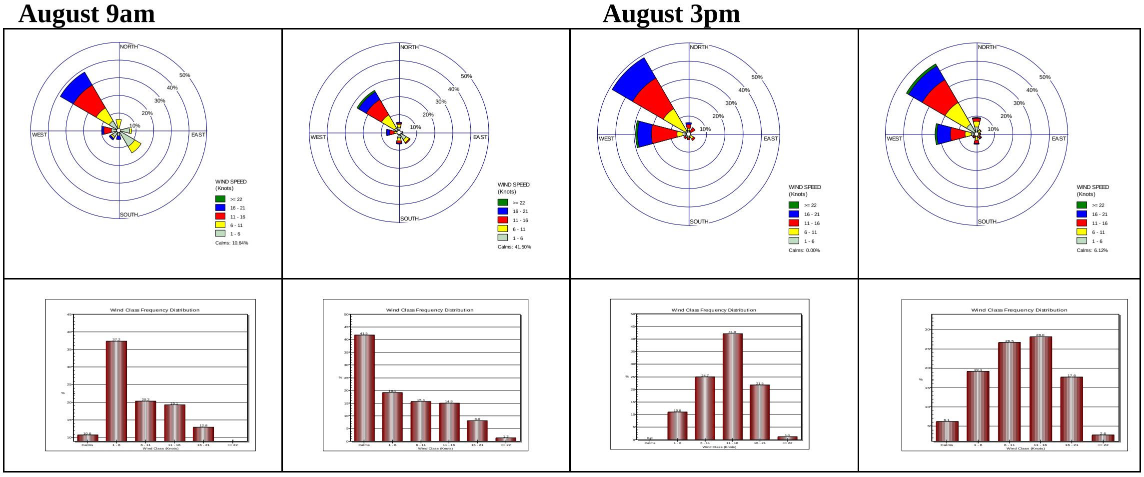
2007-2011 1939-2011 2007-2011 1939-2011

July 9am **July 3pm**



2007-2011 1939-2011 2007-2011 1939-2011

August 9am **August 3pm**

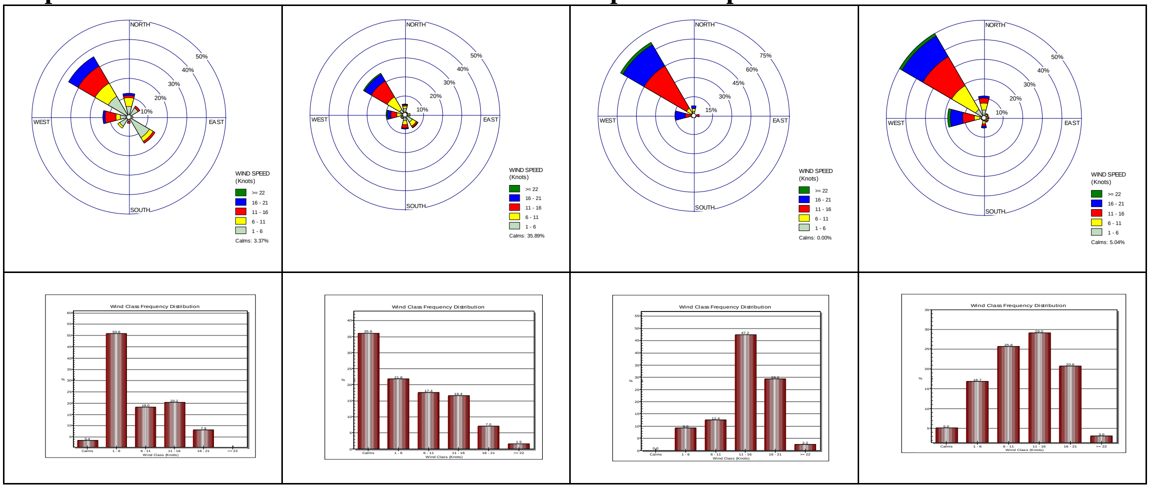


2007-2011 1939-2011 2007-2011 1939-2011

Figure 28: Winter wind roses for 2007-2011, compared to 1939-2011.

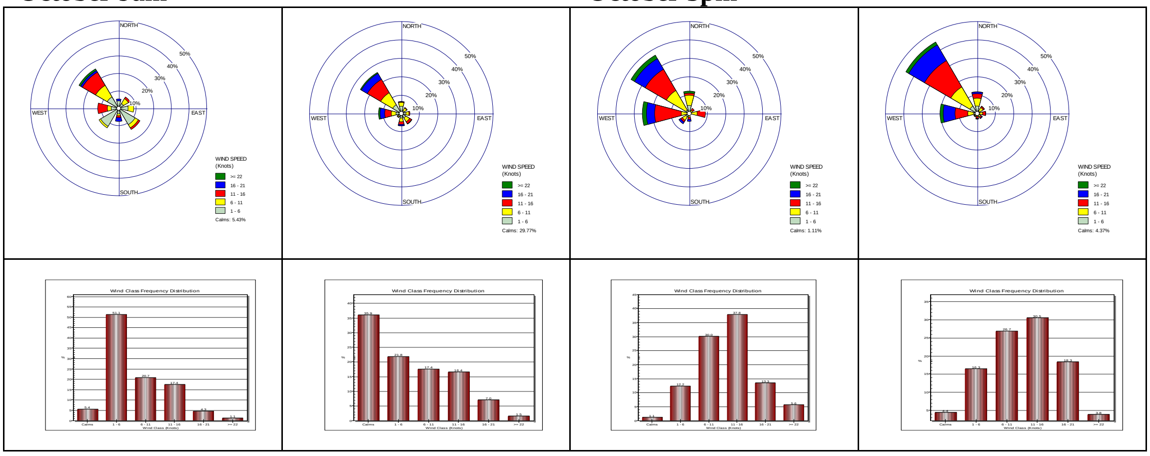
Seasonal Wind Rose Data – Spring

September 9am | **September 3pm**



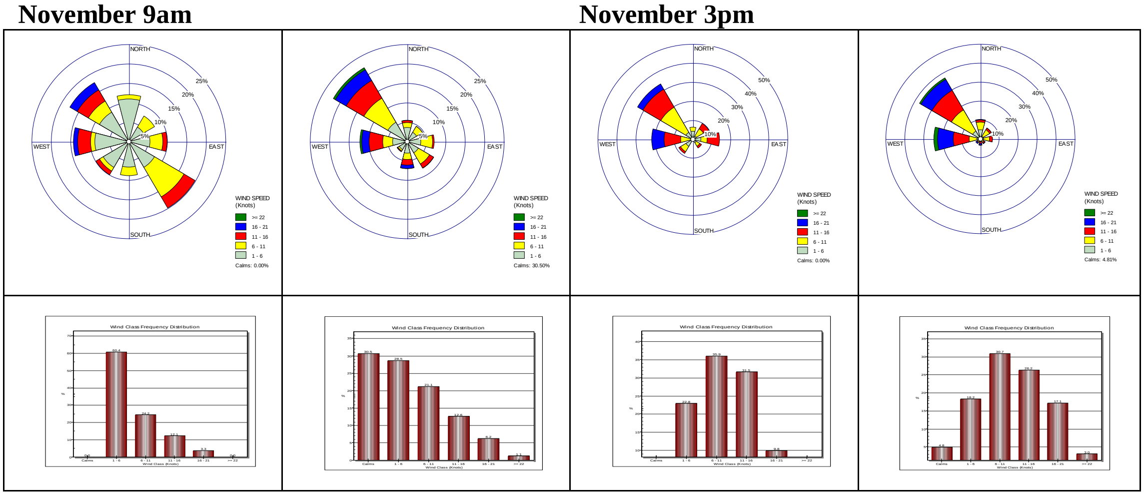
2007-2011 | 1939-2011 | 2007-2011 | 1939-2011

October 9am | **October 3pm**



2007-2011 | 1939-2011 | 2007-2011 | 1939-2011

November 9am | **November 3pm**



2007-2011 | 1939-2011 | 2007-2011 | 1939-2011

Figure 29: Spring wind roses for 2007-2011, compared to 1939-2011.

Significant Weather Events July 2007-June 2011

1. Dust Storms

Two dust storms were recorded in the ACT during 2009, on 15/4/2009 and 22/9/2009. During these events visibility was reduced to 3-4 km. Both were a result of markedly dry conditions over inland Australia preceding the passage of a significant cold front from the west. The dust was raised by strong W/NW winds ahead of the front and carried over the ACT and region as the frontal weather system moved eastward (Figures 29 and 30).

15/4/2009

A fast moving front moving over southern Australia picked up dust from western NSW in the strong W/NW airstream

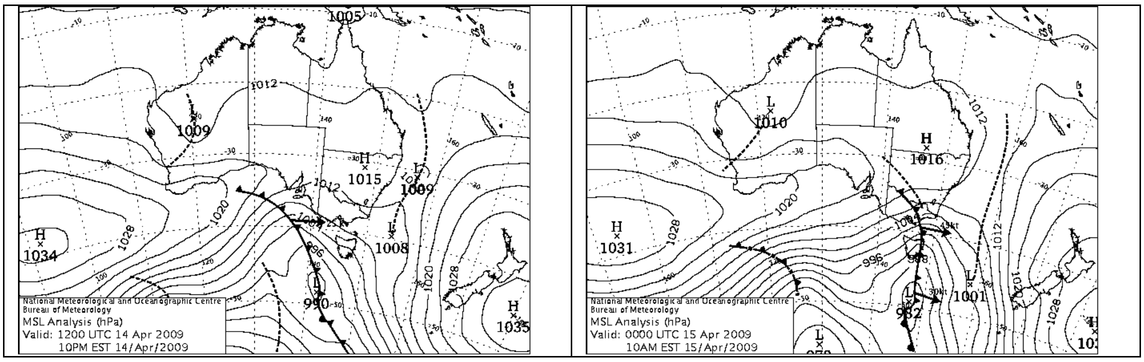


Figure 30: Surface synoptic charts for 9 pm on 14/4/2009 and 9 am on 15/5/2009.

22/9/2009

A deep low pressure system with a front extending to the north picked up dust from northern SA and SW Queensland and advected it over most of eastern and southern NSW and ACT in a NWly airstream.

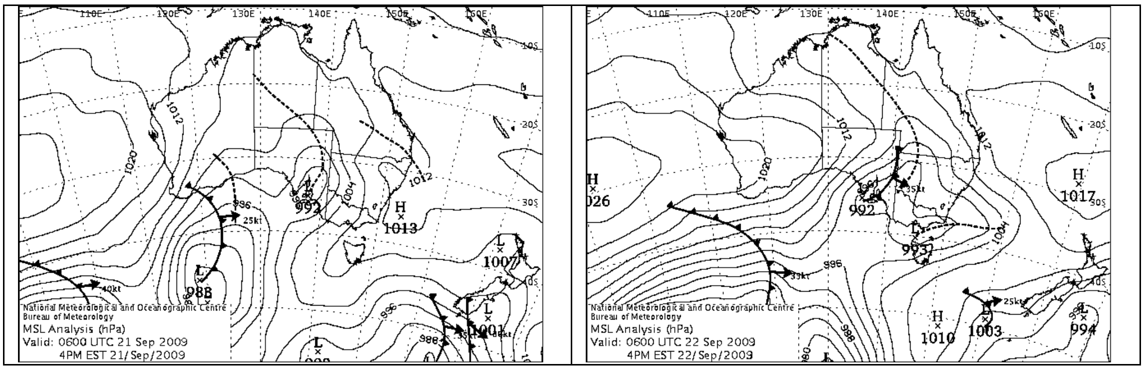


Figure 31: Surface synoptic charts for 3 pm on 22/9/2009 and 22/9/2009.

2. Rainfall Events

Table 3 lists the definitions used for this analysis while Tables 4 and 5 provide a summary of the significant and heavy rain days and rain events for the period.

Table 3: Definitions of Significant and Heavy rain days and Events

Definitions	**Rainfall**
Significant rain day	25 mm or more
Heavy rain day	50 mm or more
Heavy rain events where day 1 = 10 mm or more	
4 consecutive days	75 mm or more
5 consecutive days	100 mm or more
6 consecutive days	125 mm or more
7 consecutive days	150 mm or more

Table 4: Summary of significant and heavy rain days for the period July 2007-June 2011

Canberra Airport	**Jul-Dec 2007**	**2008**	**2009**	**2010**	**Jan-Jun 2011**	**Total**
Significant rain days	2	2	3	9	2	18
Heavy rain days	0	1	0	2	1	4

Table 5: Heavy rain events and rain days for the period July 2007-June 2011

Canberra Airport July 2007- June 2011		
Heavy Rainfall events	**No. Days**	**Rainfall**
13/2-16/2/2010	4	111.2
13-16/10/2010	4	84.6
29/11-5/12/2010	7	191
3/2-6/2/2011	4	100.2
Heavy Rainfall days	**Total**	**Thunderstorm?**
3/12/2010	87.6	Y
13/12/2008	55.4	N
14/02/2008	55.2	N
3/02/2011	50	Y

*Record daily total for December

There was a considerable increase in significant and heavy rain days during 2010, reflecting the impact of the La Niña event. The high rainfall total in 2010 was the result of rainfall on a relatively small number of rain days (there was only a slight increase in rain days in 2010), which means that the rainfall tended to be heavier during those rain days. The heavy rainfall event of 29/11-5/12/2010 was significant in that it led to flooding in the ACT and Queanbeyan; this was the heaviest flooding experienced there since 1974 (the last strong La Niña event). The high rainfall recorded to 9 am on 3 December 2010 meant that this was the wettest December day recorded at Canberra Airport; it was associated with a thunderstorm that also produced hail.

3. Heat Waves and Hot events

The overall numbers of days of 30°C or more and days of 35°C or more are listed in Table 1. The definitions of heat waves and hot events used for this analysis are as follows:

Heat Wave: At least three consecutive days of 33.5°C or more or at least three days of 33.5°C or more separated by one day of between 31.5°C to 33.4°C.

Hot Event: At least two consecutive days of 31.5°C or more.

These threshold temperatures reflect the 90th percentile level of summer maximum temperatures (33.5°C) and the 80th percentile level (31.5°C) for Canberra respectively.

During the summers of 2007/8-2010/11 nine heat waves (37 days) and 20 hot events (60 days) were recorded at Canberra Airport. A summary of these events is shown in Table 6.

There was one particularly long hot period of 12 days experienced between 28/1/2009 and 8/2/2009, during which the maximum temperature dropped below 33.5°C on only two occasions, with neither of these days being below 31°C. As can be seen in Table 6 the summer of 2009/10 was particularly hot, whilst 2010 was considerably cooler than has been experienced in recent times.

Table 6: Heat Waves and Hot Events for Canberra Airport 2007/8-2010/11

Summer Period	2007/08	2008/09	2009/10	2010/11	Total
Heat Wave Events	2	4	3	1	10
Heat Wave days	8	15	11	4	38
Hot Events	5	4	8	4	21
Hot Event days	17	8	30	9	64

Longest Heat Wave 5 consecutive days (twice)

Longest Heat Event 13 consecutive days >31.4°C (9 heat wave days + 4 hot days)

During this period (27/1/2009-8/2/2009) there were 10 days of 33.5°C or more and 3 single days between 31.5°C and 33.4°C

Summer with largest number of events	2009/10
Summer with the largest number of hot days	2009/10
Summer with largest number of heat wave days	2009/10
Summer with the least number of heat wave days	2010/11

Long term trends

Given the small numbers of heat waves overall, the analysis of these trends is limited to full decadal data; the last two summers have not been included in the decadal trends, but are included in the analysis of impacts of ENSO on heat events. Figure 32 provides a decadal analysis of heat waves in Canberra. There have been increases in both heat wave events and the number of heat wave days in the most recent decade (2001-2010). Table 7 shows the considerable influence of ENSO events on Canberra high temperature events, with El Niño years being considerably hotter with more heat waves, while La Niña years are cooler with very few heat waves occurring. There are almost three times as many heat waves in El Niño years than La Niña years.

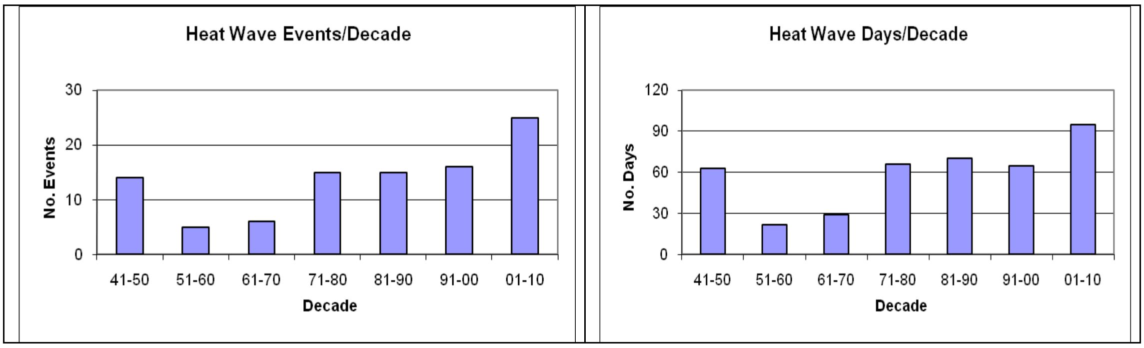


Figure 32: Decadal trends in heat wave events and heat wave days in Canberra, 1941-2010.

Table 7: Comparison of heat waves in Canberra between ENSO and non-ENSO events (based on the 20th and 80th percentile Jun/Nov SOI and Sept/Nov SOI values)

Period 1939-2010	El Nino	La Nina	Non Enso	Total
No. Years	17	16	39	72
No. Heat wave events	32	11	56	99
No. Heat wave days	143	44	232	419
Longest Sequence	10 days (twice)	6 days (once)	8 days (twice)	
Most HW events in 1 year	6	3	5	
Most HW days in 1 year	27	12	21	

Appendix A: Comparison of the Canberra Airport Observation Sites

In September 2008 the Bureau of Meteorology established a new site at Canberra Airport in response to the possible impact on the old site from development that had occurred during 2006-2008 around it. The old site was subsequently closed in November 2010. The new site is located around 400m further to the south.

This analysis is based on the two years of overlapping data that was downloaded from the Bureau of Meteorology website.

Results:

1. Rainfall

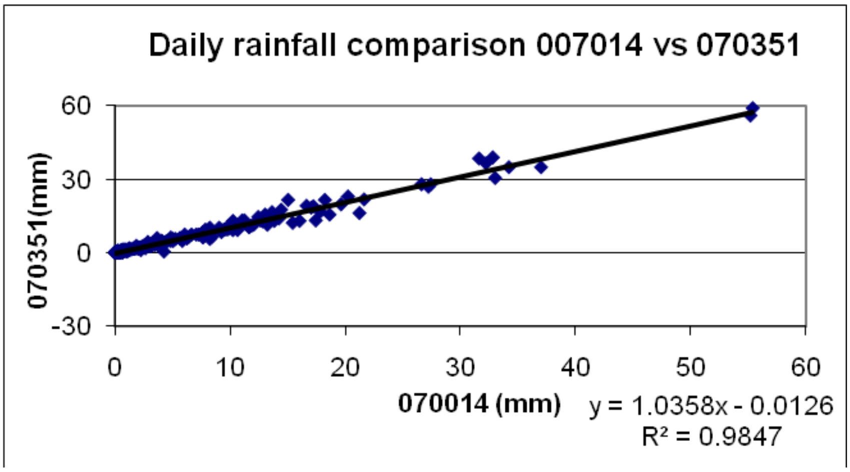


Figure 1: Comparison of 24 hour daily rainfall totals between the old (070014) and new (070351) observation sites at Canberra Airport

Table 1: Comparison between specified daily rainfall ranges of the two sites at Canberra Airport

Range	70014	70351	Difference	%Diff	Average/event
<1mm	32.2	32	-0.2	-1%	0
1-9.9mm	402.6	410.2	7.6	2%	0.1
10-19.9mm	471.2	484	12.8	3%	0.4
+>20mm	455.6	474.2	18.6	4%	1.3
Total	1361.6	1400.4	38.8	3%	

Table 2: Comparison between events of 0.2mm and no rain between the 2 sites at Canberra Airport

		70014	
		No Rain	0.2mm
70351	No Rain	538	30
	0.2mm	9	17

Development around the old site at Canberra Airport appears to be impacting on daily rainfall in two ways. There are many more days of 0.2mm being recorded at the old site. This change may be related to increased dew developing as a result of changes in overnight temperatures or in the fact that overnight watering of grass in the development occurred . There is also increasing rainfall amounts being observed at the new site for totals above 10mm with increasing amounts for higher totals. This could be due to possible wind flow effects and/or sheltering as a result of the development around the old site impacting on rainfall.

2. Temperatures

a. Comparison of Canberra Airport Sites

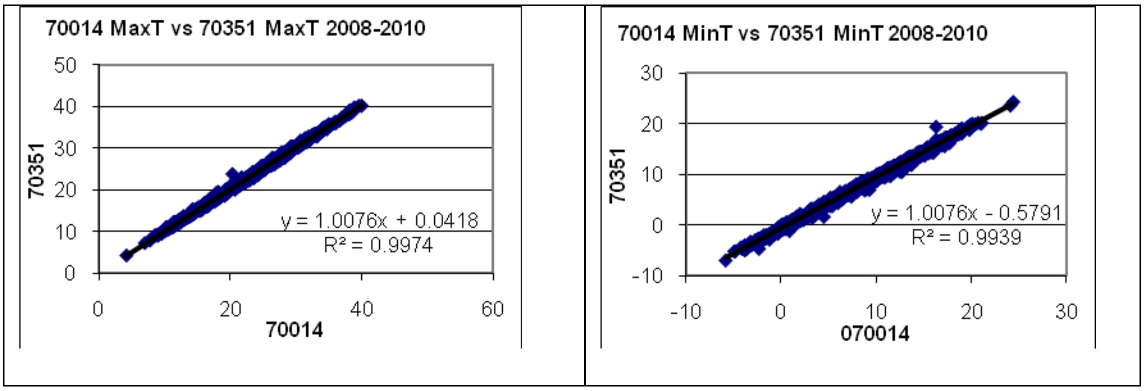


Figure 2: Comparison of the daily maximum and minimum temperatures between the old site (070014) and new site (070351) at Canberra Airport

Figure 2 indicates that there is an extremely high degree of correlation between both maximum and minimum temperatures between the old and new sites at Canberra Airport and as a result we can determine correction factors that can be applied to the data to ensure that the observations are comparable.

Table 3: Difference between the daily maximum and minimum temperatures at Canberra Airport (Old Site-New Site) by specified range

MaxT	Range	Average Difference
	<29.4	-0.2
	=>29.5	-0.4
MinT	Range	Average Difference
	<5	0.6
	5-14.9	0.5
	=>15	0.4

This comparison indicates that the new site is warmer for maximum temperatures above 29.4°C and cooler for minimum temperatures across all temperature ranges with a greater difference occurring for lower temperatures. Applying these differences to the data sets enables adjusted data sets to be developed that can allow us to continue to use the site for climate analysis.

Table 4: Adjusted occurrences of the numbers of days where maximum and minimum temperatures have been above or below specified temperatures using differences from Table 3

		70014	70351	Adjusted 70351
MaxT	Days=>30C	94	102	94
	Days=>33.5C	39	42	39
	Days=>35C	23	26	23
	Days=>36.5C	17	18	16
		70014	70351	Adjusted 70014
MinT	Days<=-3C	21	32	32
	Days<=0C	84	102	113
	Days<=2.2C	154	184	177

As can be seen in Table 4 the application of these correction values to the new site (070351) indicates that only very minimal changes have occurred in maximum temperatures whilst the application of the correction values for minimum temperatures at the old site (070014) has resulted in a considerable increase across all temperature ranges and more in line with the new site.

Summary:

Rainfall analysis suggests that there were more days of 0.2mm being recorded at the old site compared to the new site while the new site recorded around 3-4% more rainfall in heavier rainfall events. Suggested causes for these differences may include the impact of watering of grass in the development close to the old site in the development or the impact of an increase in dew point due to the change in minimum temperatures. Increased rainfall may be due to wind effects in a more exposed area at the new site or sheltering at the old site from buildings to the east.

Temperature analysis between the old and new sites indicates that they are very highly correlated to the extent that correction factors can be derived which can be applied to the data sets to ensure they are comparable and as such the site can be continued to be used as a climate reference station. The main areas where correction factors are required are for the maximum temperatures of 29.5°C or more where the new site appears to be on average 0.4°C warmer and for all minimum temperatures where the new site appears to range between 0.6C and 0.4°C cooler than the old site with the larger difference applying to colder temperatures and the smaller difference to warmer temperatures.

The Bureau of Meteorology considers that the lower minimum temperatures being recorded at the new site is in fact just returning these temperatures to those that were experienced prior to development so any adjustment only needs to be applied to the old site from the commencement of development to September 2008 (B.Trewin (pers comm.)). For maximum temperatures, however, as the new site does appear to be warmer, adjustments should continue to be made for temperatures of 29.5°C or more to maintain consistency across the 2 sites for climate trend purposes.