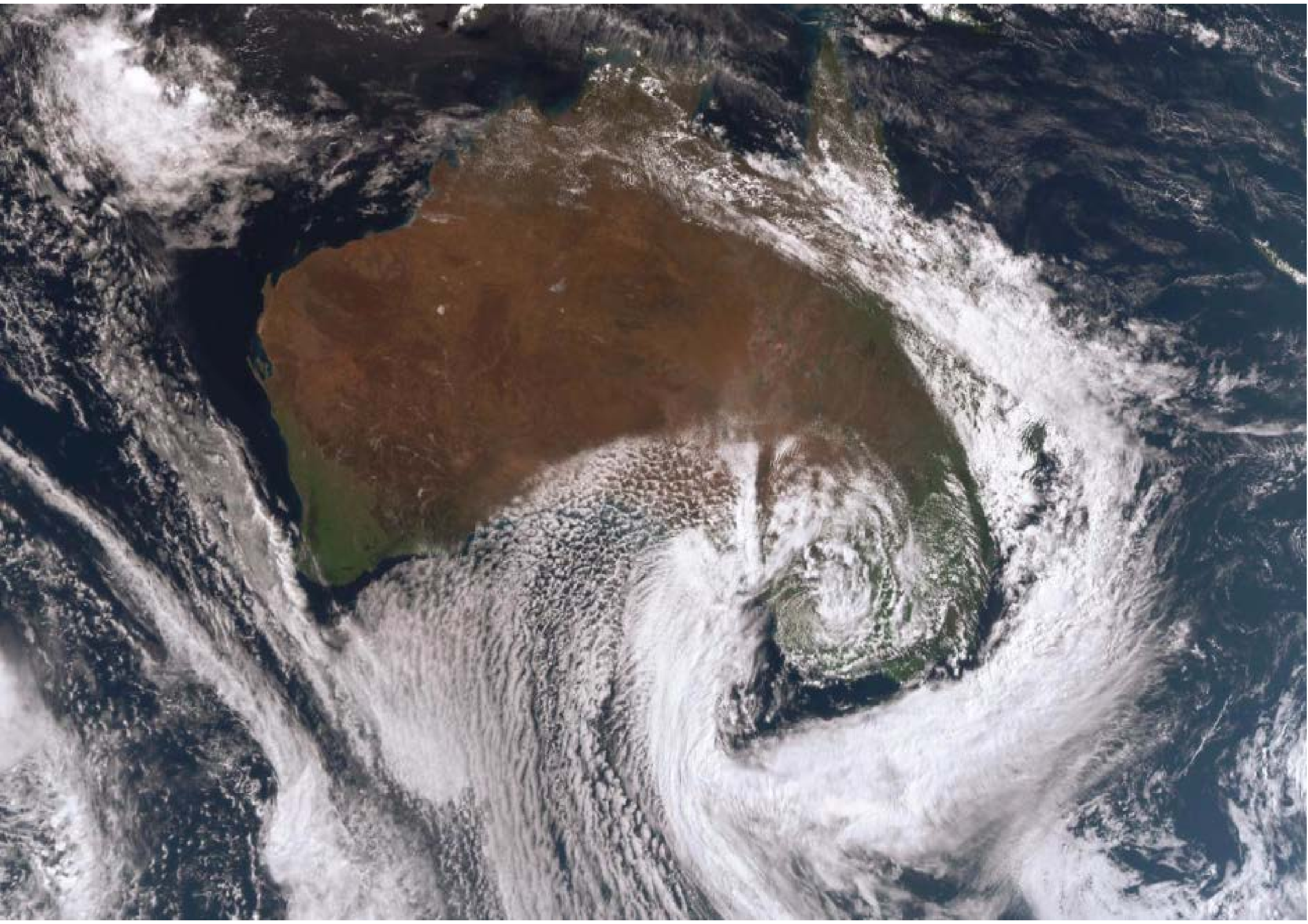
Australian Government
Bureau of Meteorology

# South Australia in 2016

Climate analysis for the Essential Services Commission of South Australia



Published by the Bureau of Meteorology

# 1 Introduction

2016 was a significant year for weather and climate events in South Australia. This report examines weather and climate events through 2016 with the aim of providing context for the significant impacts on South Australian infrastructure and power supply that occurred.

Figure 1-1 maps South Australian power infrastructure, and regions and station locations used in the analysis of conditions in 2016, and for longer term context.

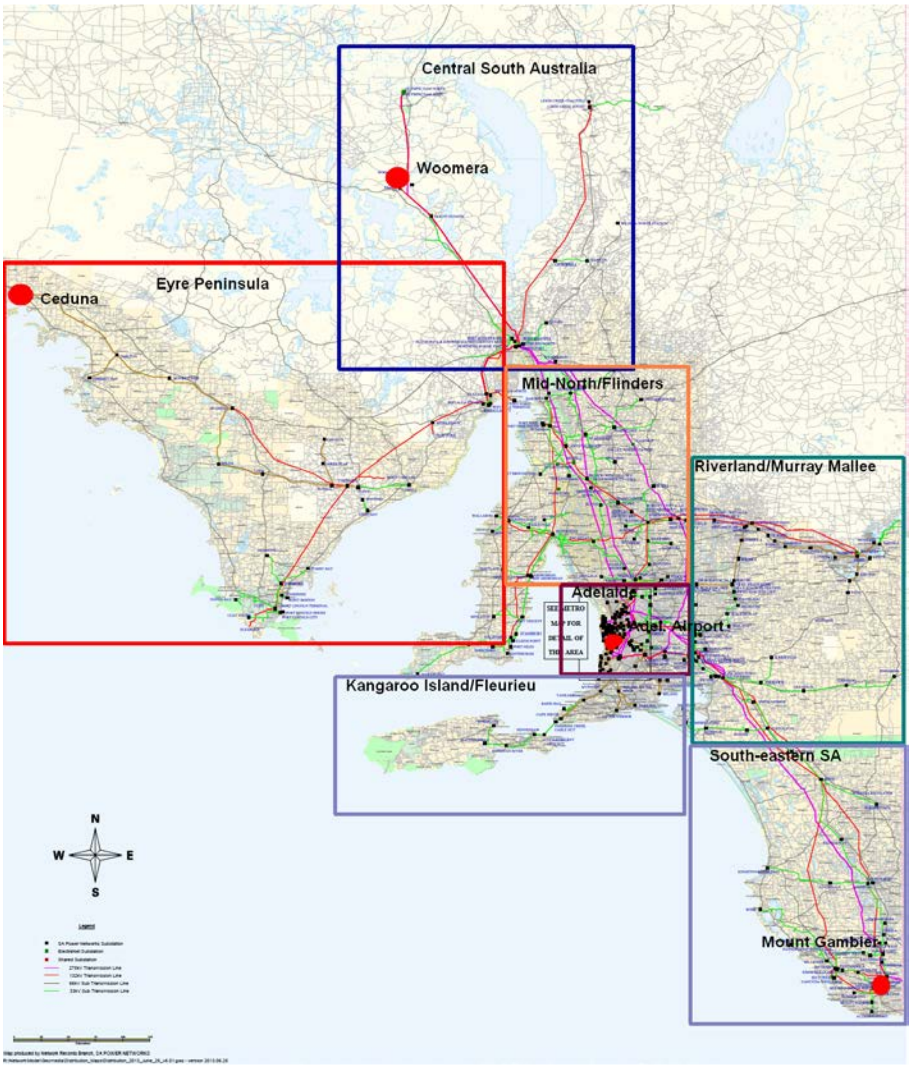



**Figure 1-1 South Australian power infrastructure including locations and regions for analysis**

## 1.1 Major climate influences impacting South Australia

Year to year variability in the climate of South Australia is influenced strongly by major patterns of variability in the Pacific and Indian Oceans to either side of the Australian continent. As well as this year to year variability, longer term trends are apparent from climate change.

### 1.1.1 El Niño Southern Oscillation

The El Niño Southern Oscillation (ENSO) pattern of variability in the Pacific Ocean can see in any particular year neutral or average conditions, or the development of El Niño or La Niña conditions.

La Niña events see cooling of ocean water in the central Pacific along the equator, and warmer than average waters near Australia. This results in increased cloud, and higher atmospheric moisture levels over Australia, typically leading to cooler and wetter than average conditions.

El Niño events see warmer than average water develop in the central Pacific and cooler than average water around northern Australia. This results in less cloud, decreased moisture availability, typically drier than average conditions, and warmer than average temperatures.

Both El Niño and La Niño typically start in winter, and once underway tend to impact South Australian climate for 6-9 months. The peak of changes in the oceans is usually observed in December, before events weaken back to neutral by autumn. Impacts for South Australia are typically strongest in spring, though there is a weak correlation with wetter conditions across central Australia in late summer and early autumn in the weakening phase of El Niño events. Both phases occur on average every 4-7 years. Notable recent years of El Niño influence are 2015, 2009, 2006, 2002. Notable recent La Niña events include 2011, and 2010.

More information on ENSO, and past El Niño and La Niña events is available at http://www.bom.gov.au/climate/enso/.

### 1.1.2 Indian Ocean Dipole

The northern Indian Ocean also experiences significant variability in ocean temperature patterns and atmospheric responses on a year to year basis that impacts South Australia.

The Indian Ocean Dipole (IOD) is a pattern of variability in ocean temperatures across the northern Indian Ocean. Positive phases, as in 2015, see the development of warmer than average water near Africa, and cooler than average water around north-western Australia. The cooler than average water reduces moisture availability and cloud formation, typically leading to reduced rainfall and warmer conditions.

Negative IOD phases see cooler than average ocean surface temperatures near Africa, and warmer than average temperatures around north-western Australia. This typically results in increased cloud and rainfall across Australia, and cooler than average conditions. The peak impact period on rainfall from IOD events is August to October.

These patterns each occur on average every 4-7 years, and when they occur typically start in June/July and continue into November before ending. Further information is available at http://www.bom.gov.au/climate/enso/#tabs=Indian-Ocean.

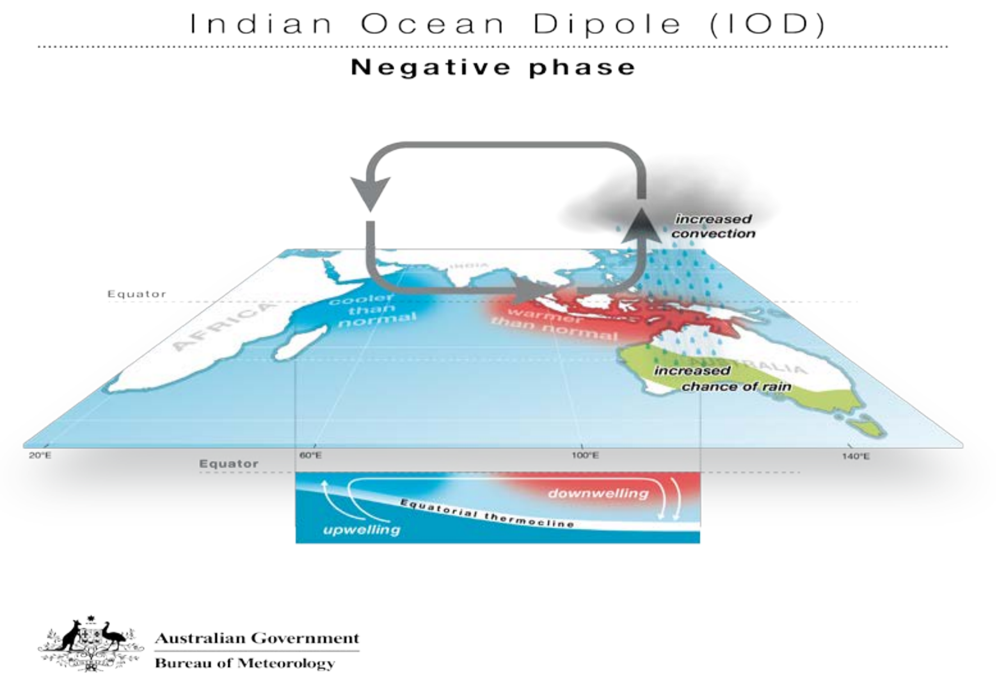



**Figure 1-2 Schematic of the Negative phase of the Indian Ocean Dipole**

### 1.1.3 ENSO and IOD impacts

ENSO events do impact the eastern states of Australian more strongly than South Australia, but are still an important influence on South Australia. The eastern states are impacted less by IOD, whereas this is an important influence on South Australia. IOD and ENSO events can occur individually in any year, or in combination with each other.

2015, for example, saw an El Niño event develop in May, combined with a Positive phase of the IOD. The impact of various combinations of climate influences on rainfall in the Adelaide region can be seen in Figure 1-3. Drier years are typically El Niño or Positive IOD years, or the two together. Wetter years tend to be La Niña or Negative IOD years, or the two together.

As well as impacting cloud, rainfall and temperature, various phases of ENSO and IOD are correlated with changes in weather patterns over South Australia. El Niño events tend to see weather systems contracted further south during June to September for instance. Negative IOD events see weather systems extending further north than usual over southern South Australia during June to August.

Outlooks of the expected climate influences are made available by the Bureau of Meteorology Climate Prediction services. Current outlooks for 2017 indicate a 50% risk (double the normal risk in any year) of an El Niño event developing. Modelling indicates a Positive IOD event is the most likely outcome for the remainder of 2017, though accuracy of modelling is poorest at this time of the year.

El Niño and Positive IOD is a combination of influences similar to 2015, but is showing less clear signs of development at this time in autumn 2017, than was observed through 2015. The likelihood of Negative IOD conditions in 2017 is low.

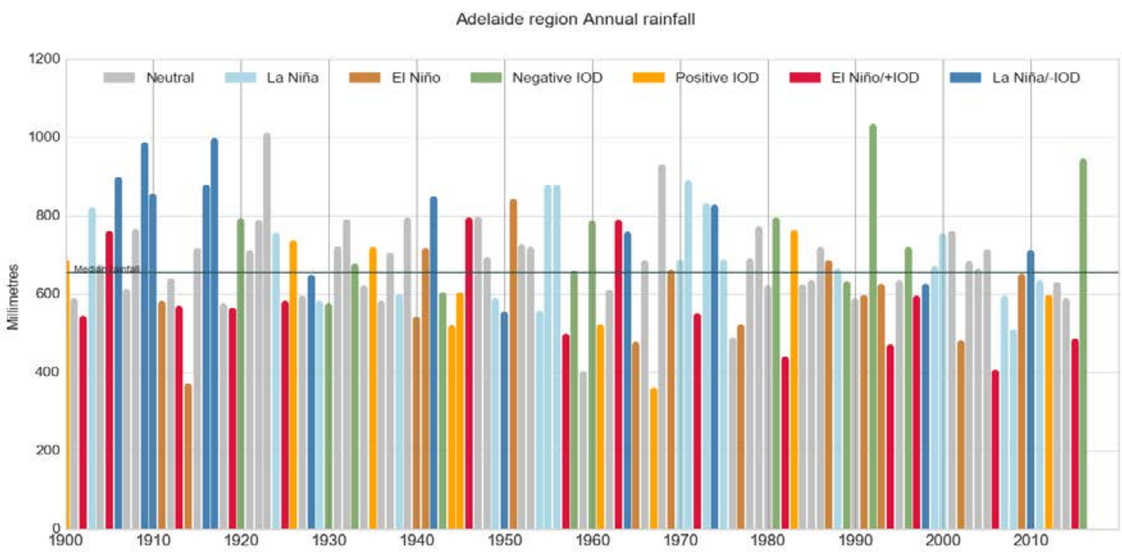



**Figure 1-3 Adelaide region annual rainfall under different combinations of climate influence**

### 1.1.4 Climate change and South Australia

As well as year to year variability, significant trends are apparent in South Australian climate in recent decades, in line with changes happening across Australia, and at the global level. There is a comprehensive body of work linking these changes to the impact of increased levels of greenhouse gases that are observed from human activity. For Australia, the *'Climate Change in Australia'* report (Climate Change in Australia, 2015) details the observed changes and future projections, while *'State of the Climate 2016'* provides a recent update.

For South Australia, background temperatures have risen by ~1.0 °C since the 1960's.Increases in temperature are contributing to increased bushfire risk, earlier fire seasons, and increased frequency and intensity of heatwave events in South Australia. Also, ocean temperatures have increased by similar amounts. This is important in terms of the contribution of the warmer ocean surfaces to increased atmospheric moisture levels. Research on the impacts of climate change has established that this is expected to contribute to more intense rainfall.

Sea level has risen by ~20 cm over the last 100 years, with rates of rise since the early 1990's of 4-5 mm / yr along South Australian coastlines. In response to a warmer planet, the tropics are expanding, leading to changes in weather patterns over Australia.

Rainfall has declined across southern South Australia in the April to October period since the 1980's as rain producing systems stay further south, while northern South Australia has seen an increase in tropically influenced rainfall over November to March.

## 1.2 2016 climate influences

For a general summary of the climate of 2016 in South Australia including short summaries of significant weather events through the year, and monthly maps of rainfall and temperature through the year, see the Bureau of Meteorology South Australia 2016 climate summary at http://www.bom.gov.au/climate/current/annual/sa/summary.shtml.

May 2015 saw the development of an El Niño event, accompanied by a Positive IOD event. This resulted in drier and hotter than average conditions in South Australia through the second half of 2015. The El Niño event peaked in December 2015.

As the 2015/2016 El Niño event weakened in early 2016, above average rainfall occurred across central Australia through January to March 2016. This rainfall was supported by very much warmer than average ocean temperatures which developed around north-western Australia from January 2016.

The Bureau of Meteorology declared the 2015/2016 El Niño had ended during May 2016. At the same time, climate modelling was suggesting the development of a Negative IOD event during 2016. During May 2016, IOD values became strongly negative indicating the start of a Negative IOD event, with the Bureau of Meteorology officially declaring this in early July. This event continued until mid-November 2016 before ending.

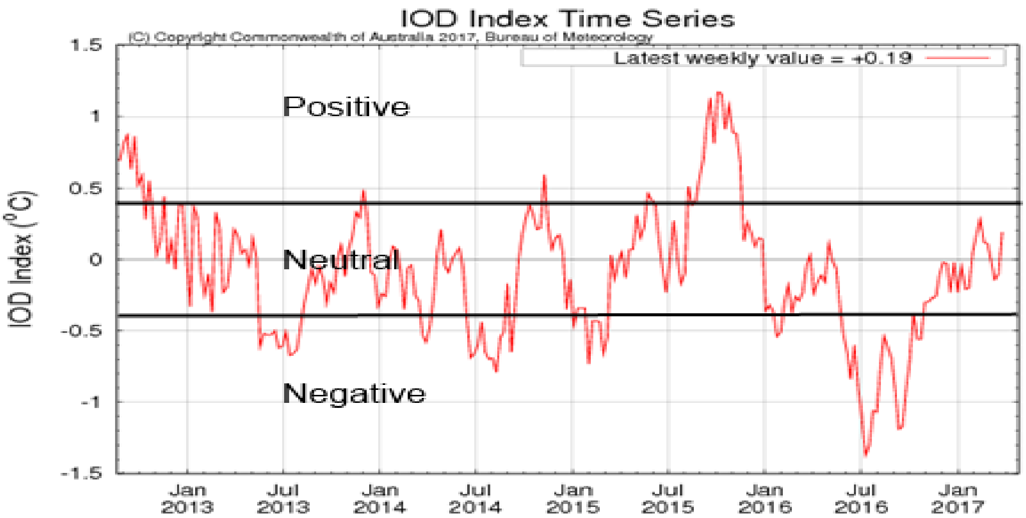



**Figure 1-4 Indian Ocean Dipole values 2013-2017**

The 2016 Negative IOD was a very strong event. The July 2016 values of -1.4 °C are the equal strongest observed in at least 50 years of events.

Ocean temperatures around north-western Australia reached record warmest levels through the IOD event in 2016. Ocean temperatures have undergone a significant warming trend of ~1.0 °C since the 1960's. That the ocean waters in this area were at record temperatures likely contributed to enhancing the Negative IOD event in 2016.

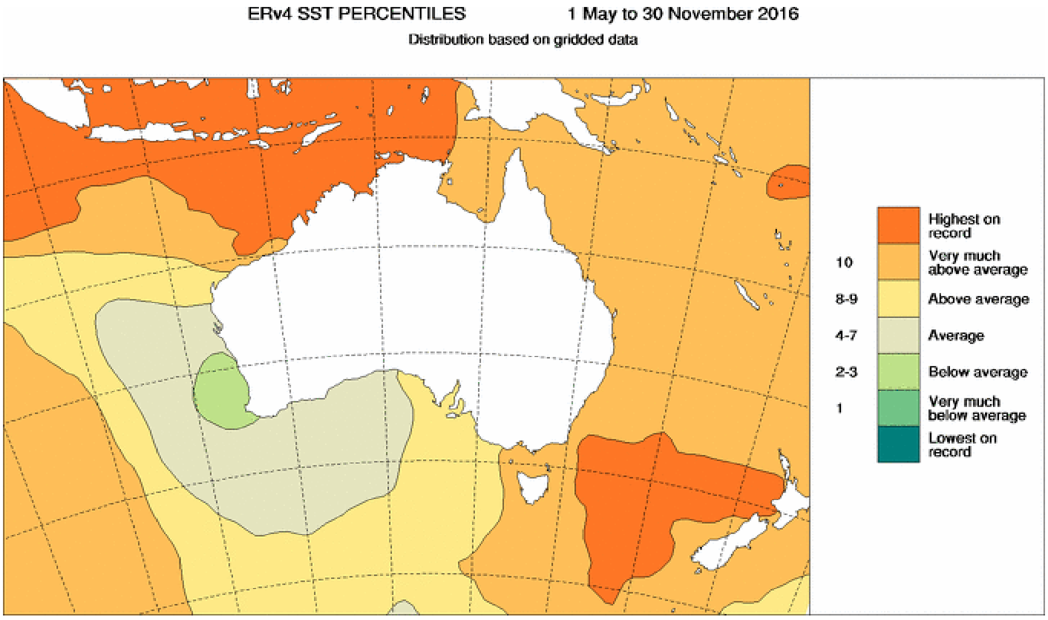



**Figure 1-5 Australian region ocean temperatures (ERv4 sst dataset) May-November 2016**

# 2 2016 in overview

## 2.1 Temperature

Overall temperatures across South Australia in 2016 were not particularly notable. This is in contrast to 2015 where El Niño conditions contributed to record October and December 2015 temperatures for South Australia.

Maximum temperatures were significantly warmer than average in April 2016, and the warmest April since 2013. Maximum temperatures were cooler than average for September 2016. But otherwise maximum temperatures were generally near average through the year across South Australia. Heatwave conditions in February 2016 did impact northern and eastern Australia, and into north-eastern pastoral areas of South Australia, but did not impact most of South Australia.

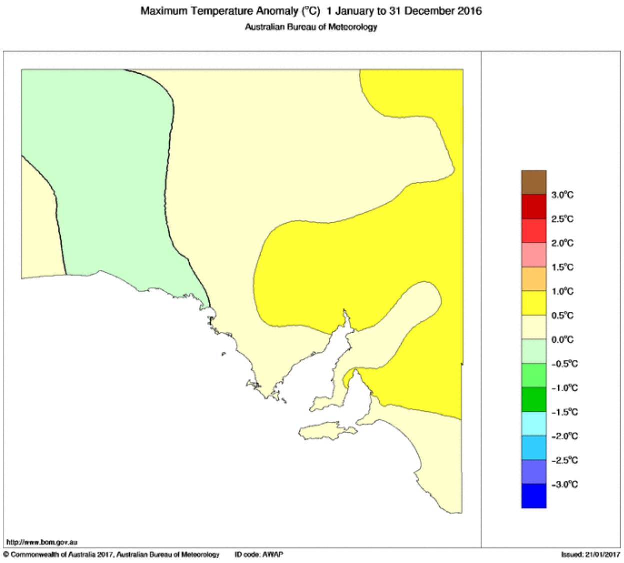



**Figure 2-1 Difference from average of maximum temperatures in 2016**

Minimum temperatures varied strongly through 2016. A run of months with above average frequency of warm nights occurred across the pastoral districts of South Australia through March to July, and also in December.

Cooler than average nights were experienced across the state from September to November. Overall minimum temperatures were close to average across southern South Australia for 2016, with very much warmer than average minimum temperatures resulting for the year in pastoral areas.

## 2.2 Rainfall

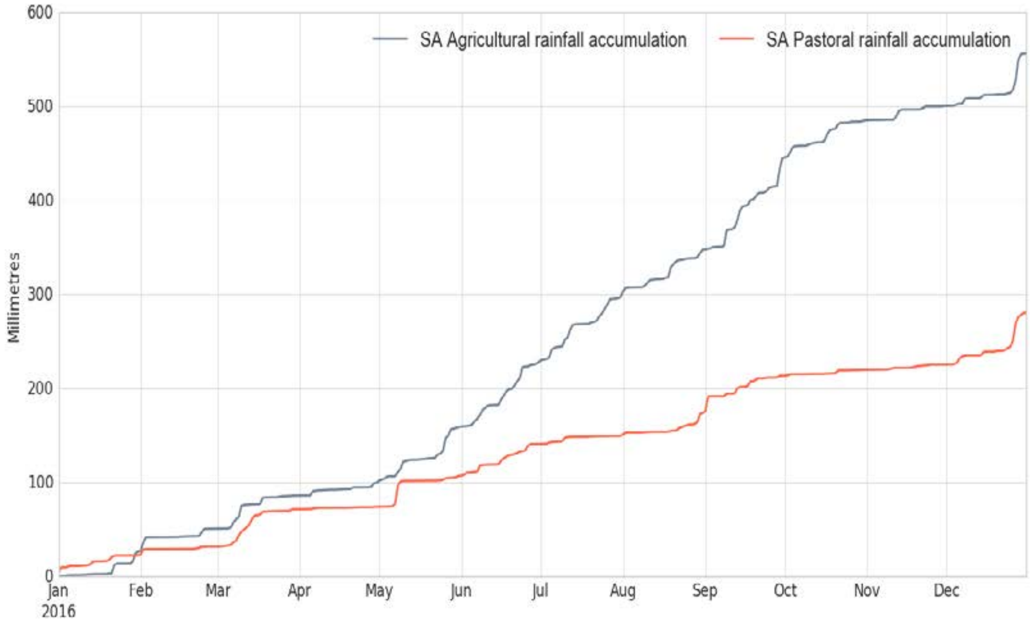



**Figure 2-2 Rainfall accumulation through 2016 in South Australian agricultural and pastoral areas**

The influence of the Negative IOD through May to November 2016 is evident in the sustained rain across much of the state for that period seen in Figure 2-2.

2016 started with well above average sea surface temperatures around much of Australia. A burst of Madden Julian Oscillation (MJO) tropical activity towards late January saw a significant though patchy rainfall event develop across the state.

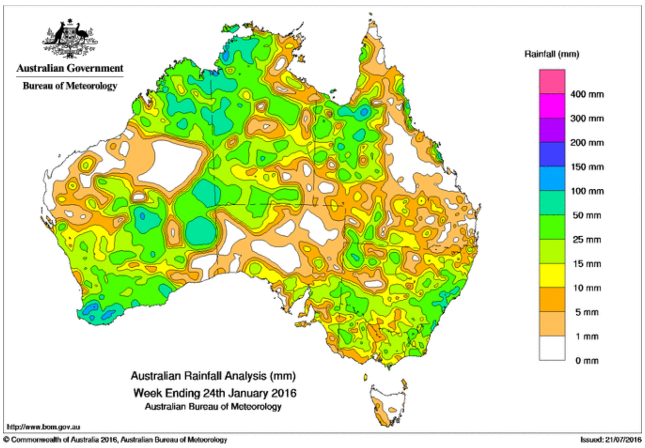



**Figure 2-3 Rainfall totals in the week ending 24/1/2016**

Another burst of MJO tropical activity in the second week of March 2016 contributed to a widespread rainfall event across much of the state.

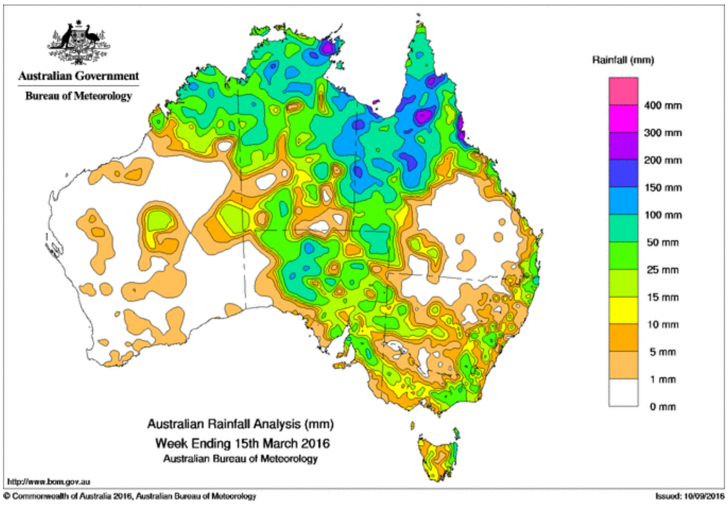



**Figure 2-4 Rainfall totals for the week ending 15/3/2016**

In the third week of May 2016 another burst of Madden Julian Oscillation tropical activity moved across northern Australia. This contributed to significant rainfall across south-eastern Australia through to the end of the month.

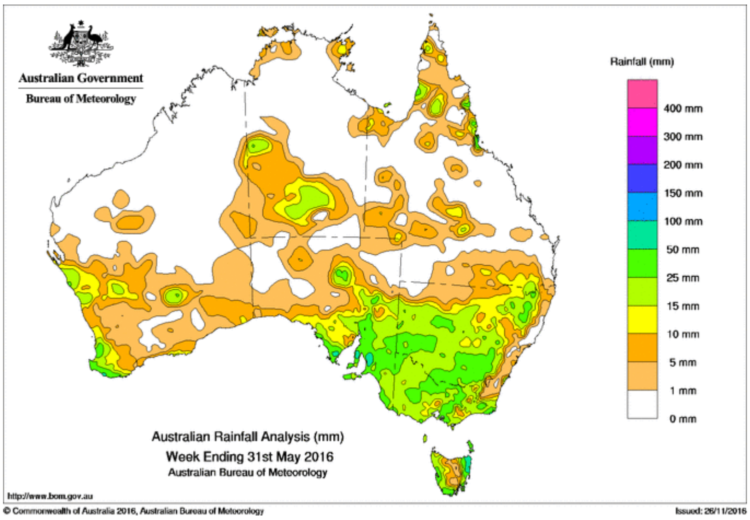



**Figure 2-5 Rainfall totals for the week ending 31/5/2016**

## 2.3 Significant weather systems in 2016

2016 saw a number of significant events impact South Australia. Several significant low pressure weather systems moved across South Australia during the period of the Negative Indian Ocean Dipole event – May to November 2016. This weather pattern is typical of the lower than average surface pressure seen in Negative IOD years, as seen in Figure 2-7. This is from a US National Centers for Environmental Prediction (NCEP) climate reanalysis dataset.

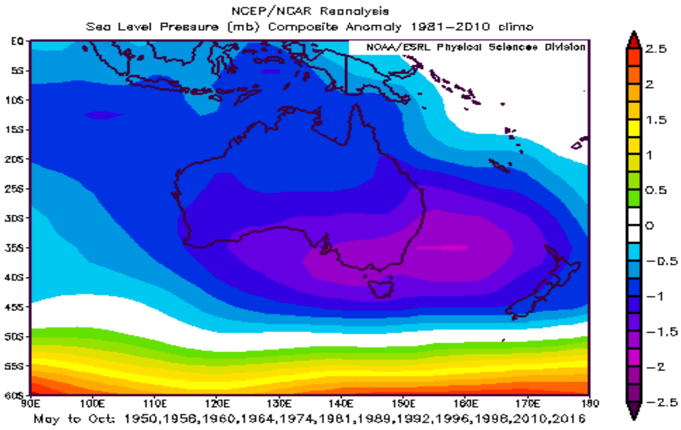



**Figure 2-6 Difference from average of mean sea level pressure in the Australian region in Negative IOD years (NCEP Reanalysis dataset 1948-2017)**

Figure 2-7 highlights the main events generating thunderstorm and lightning activity across various regions. It must be remembered that the size of the regions used varies considerably so comparing numbers between regions is not useful. This figure highlights the variability within a region across the year.

The main events seen are the January, March and December rain events, and the early November and storms. The weather system in July impacted the Eye Peninsula and Central region. All regions experienced some degree of thunderstorm activity with the late September weather system.

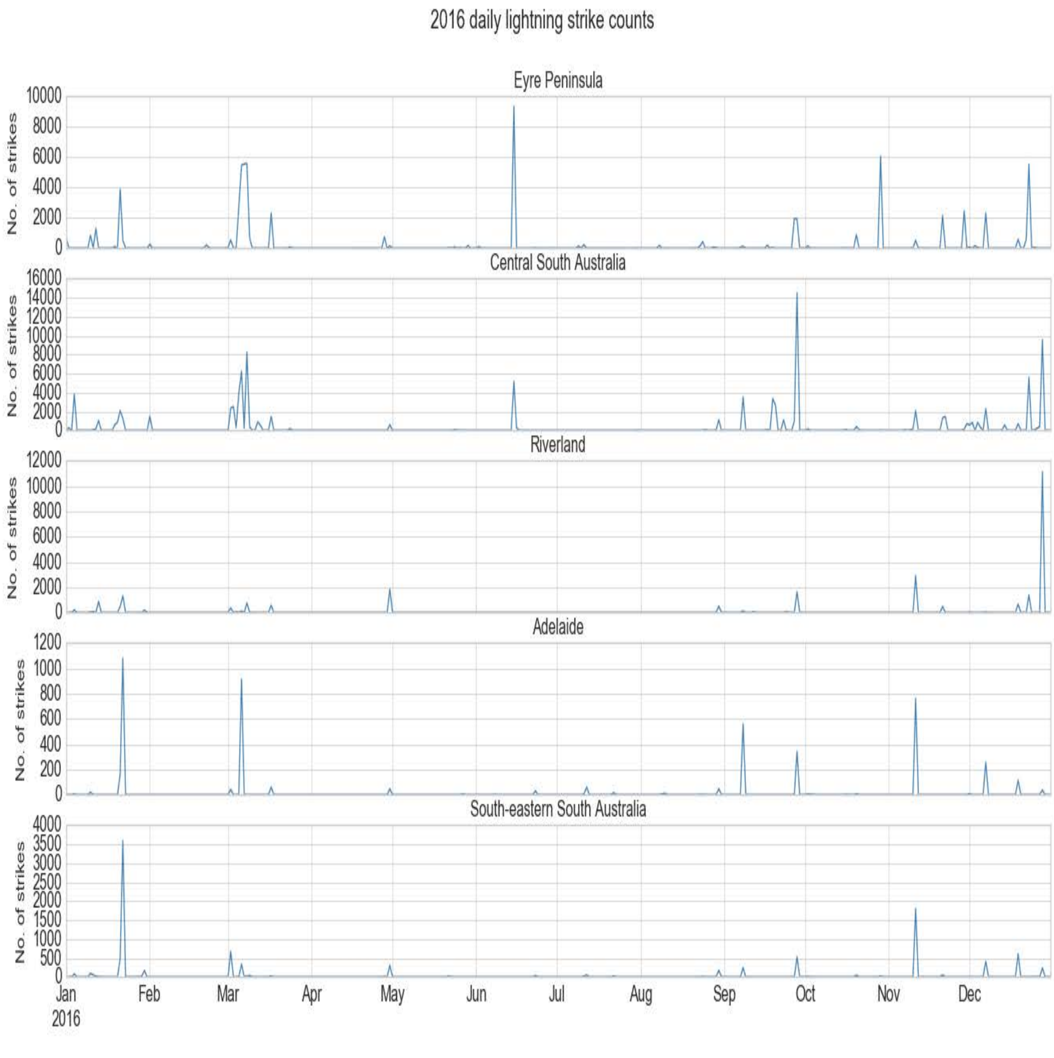



**Figure 2-7 2016 daily lightning strike counts across SA regions**

### 2.3.1 May 2016 weather system

An intense low pressure system developed in the Great Australian Bight in the second week of May 2016.

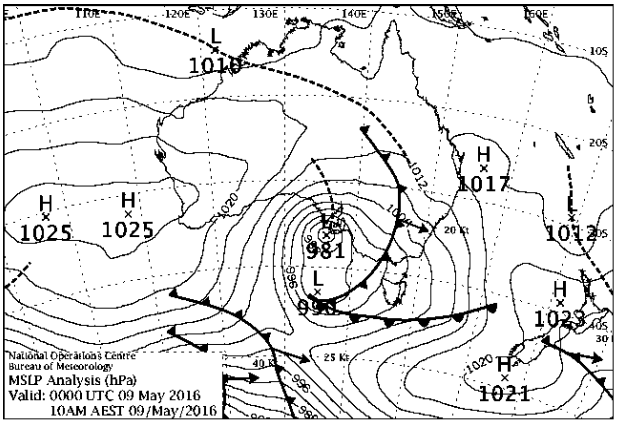



**Figure 2-8 Weather chart of mean sea level pressure for 9:30am (ACST) 9th May 2016**

Central air pressure was lowest on record for May for Adelaide Airport, and 10 minute averaged winds were in excess of 40 km/h for most of the day across the Adelaide region on the 9th.

The combination of intense low pressure, persistently strong onshore winds and high astronomical tides during the day led to record sea levels observed along South Australia coastlines at several locations, including Outer Harbor at Port Adelaide. Background sea level rise over recent decades likely contributed to the observed record sea levels.

Significant damage of coastal infrastructure, and localised coastal flooding occurred around South Australian gulfs in this event.

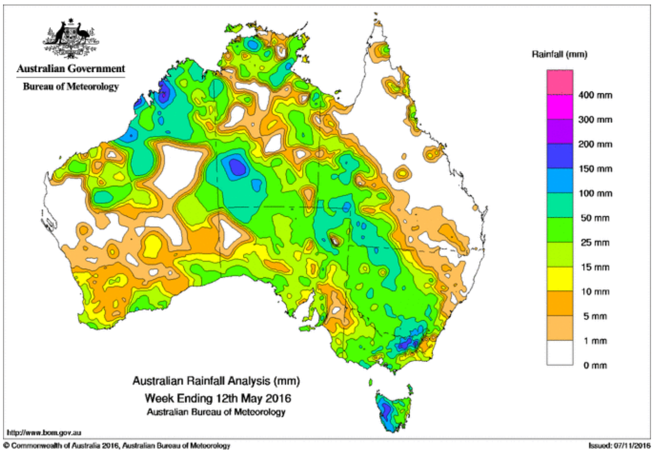



**Figure 2-9 Rainfall totals analysis for the week ending 12th May 2016**

### 2.3.2 9-13 July

The intensity of the low pressure system is reflected in the daily wind run values seen Figure 2-17. They are highest or close to highest for 2016 - windiest day of the year or close to it - at several locations along southern South Australia.

For Adelaide Airport, average July daily wind run is 374 km. The total for the airport of 1019 km is 270% of the July average daily wind amount.

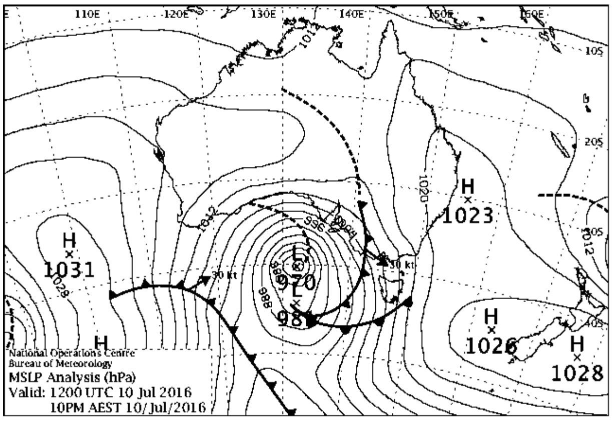



**Figure 2-10 Weather chart of mean sea level pressure for 9:30pm (ACST) 10th July 2016**

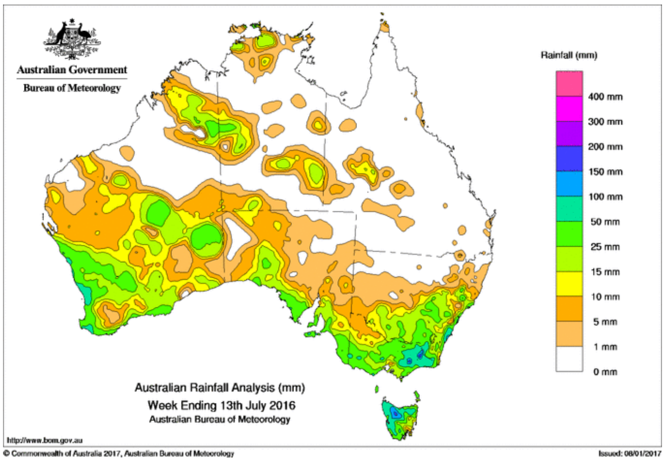



**Figure 2-11 Rainfall totals analysis for the week ending 13th July 2016**

### 2.3.3 22-25 July

This period saw a succession of cold fronts moving over southern Australia, seeing a period of sustained strong winds. Significant rainfall totals accumulated, particularly over the Mount Lofty and Flinders Ranges in the persistent onshore airstream.

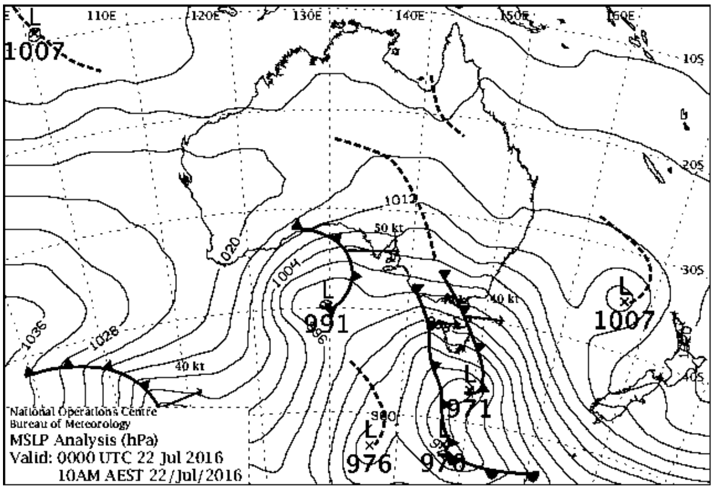



**Figure 2-12 Weather chart of mean sea level pressure for 9:30am (ACST) 22nd July 2016**

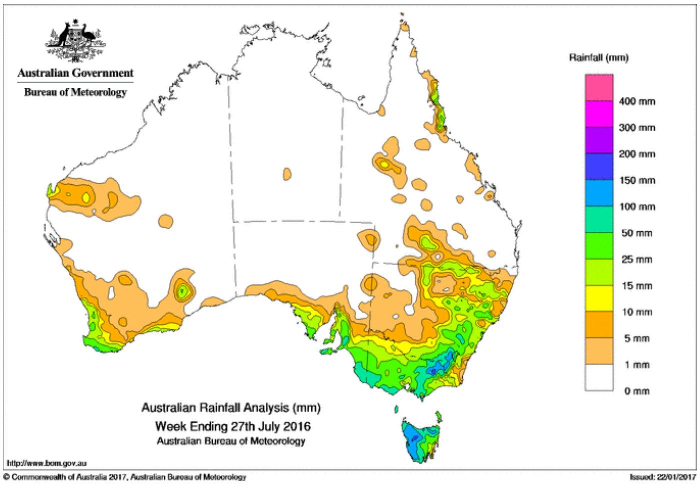



**Figure 2-13 Rainfall totals analysis for the week ending 27th July 2016**

## 2.3.4 28-30 September

September 2016 saw well above average rainfall accumulate through the month from a succession of cold frontal systems. This followed above average rainfall in the months since April.

The last week of September 2016 saw an intense low pressure system develop in the Great Australian Bight. As this moved towards Adelaide, a trough of low pressure developed ahead of the low during the 28th September, and extended across Eyre Peninsula. This trough triggered widespread severe thunderstorm activity along a long line from the southern pastoral area southwards to Adelaide over the afternoon of the 28th September. A number of reports of severe damage and tornado activity were received through the afternoon.

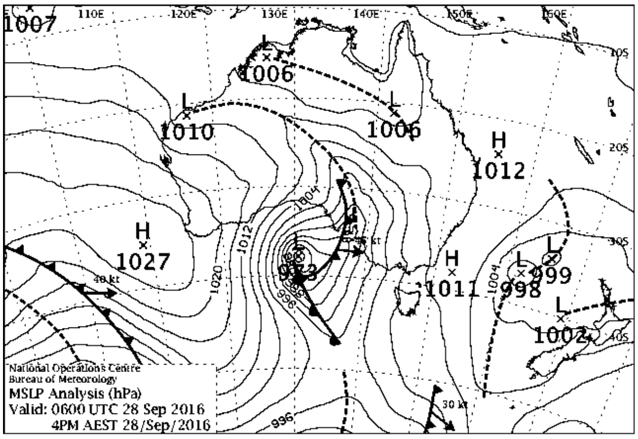



**Figure 2-14 Weather chart of mean sea level pressure for 3:30pm (ACST) 28th September 2016**

Post-event damage analysis indicates 5-7 tornadoes were generated to the north of Adelaide by the line of severe thunderstorm activity through the afternoon of the 28th September 2016. Damage tracks from two tornadoes were identified as crossing the path of powerlines, impacting power infrastructure triggering power outages, ultimately ending in a widespread power outage across much of South Australia. The Bureau of Meteorology report on this event, in Further Reading, contains more detail on this event, and details impacts on power infrastructure.

The low pressure system moved over southern South Australia overnight on the 28th and into the 29th September producing sustained gale force winds at several locations, and producing storm surges at several areas along southern South Australian coastlines.

This event clearly had very significant impacts. Lines of severe thunderstorm of this scale are not frequent, but have been seen before in South Australia. Tornado activity is a typical feature of South Australia severe weather, with on average approximately 2-3 tornadoes, usually of lesser wind strength and impact compared to 2016, reported in South Australia each year.

This type of local scale weather event is not well captured by observation systems. While damage tracks indicate wind gusts in the tornado paths were likely in excess of 200km/h, the highest reported wind speed from weather stations across South Australia was much lower.

This, and the increased capture of such events in the digital era, means it is not straightforward to quantify the frequency of events of this type from observational data.

The persistent onshore airstream saw further rainfall accumulate over southern South Australia, and regions in the Mount Lofty Ranges saw flooding, including in the Onkaparinga and Gawler River catchments.

### 2.3.5 7-10 November

The second week of November saw a low pressure system develop over central Australia that generated widespread severe thunderstorm activity over the eastern half of South Australia. Rainfall totals were not particularly large, but significant hail damage was reported across Adelaide, with large hail occurring in the Riverland, impacting crops.

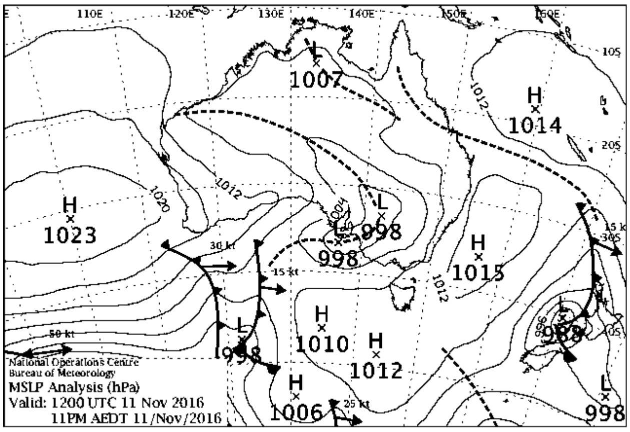



**Figure 2-15 Weather chart of mean sea level pressure for 10:30pm (ACDT) 11th November 2016**

### 2.3.6 27- 29 December

Warmer than average ocean temperatures persisted through December 2016. A burst of tropical activity late in the month contributed to a widespread rainfall event. Wet soils from earlier rainfall saw flash flooding in the Adelaide region. Significant thunderstorm and severe winds were observed.

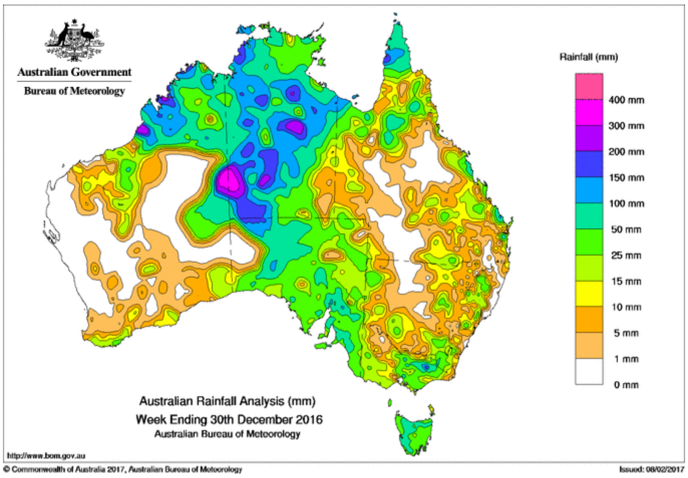



**Figure 2-16 Rainfall totals for the week to 31/12/2016**

## 2.4 Wind through 2016

The influence of the Negative Indian Ocean Dipole conditions from May to November is clear in the increased daily wind run values seen at all stations in Figure 2-17, particularly at Adelaide Airport. The late September event stands out at all sites as probably the most significant wind event, but early May, and July also are significant.

The influence of the Negative IOD is also evident in the daily maximum wind gusts seen in Figure 2-18. Horizontal lines respectively represent a 70km/h and 90km/h threshold. There are many instances at Adelaide Airport through May to November of wind gusts reaching in excess of 70km/h. Wind gusts reach 90km/h in early May, through July and in the late September event.

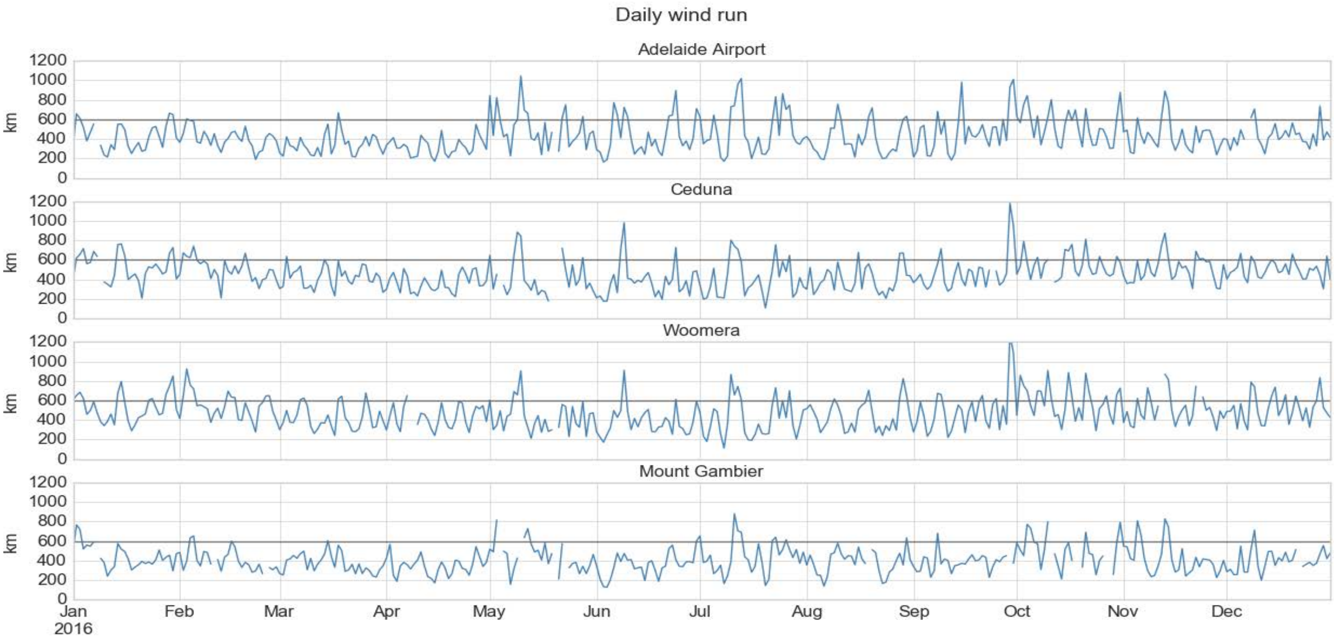



**Figure 2-6 Daily wind run values for South Australian stations**

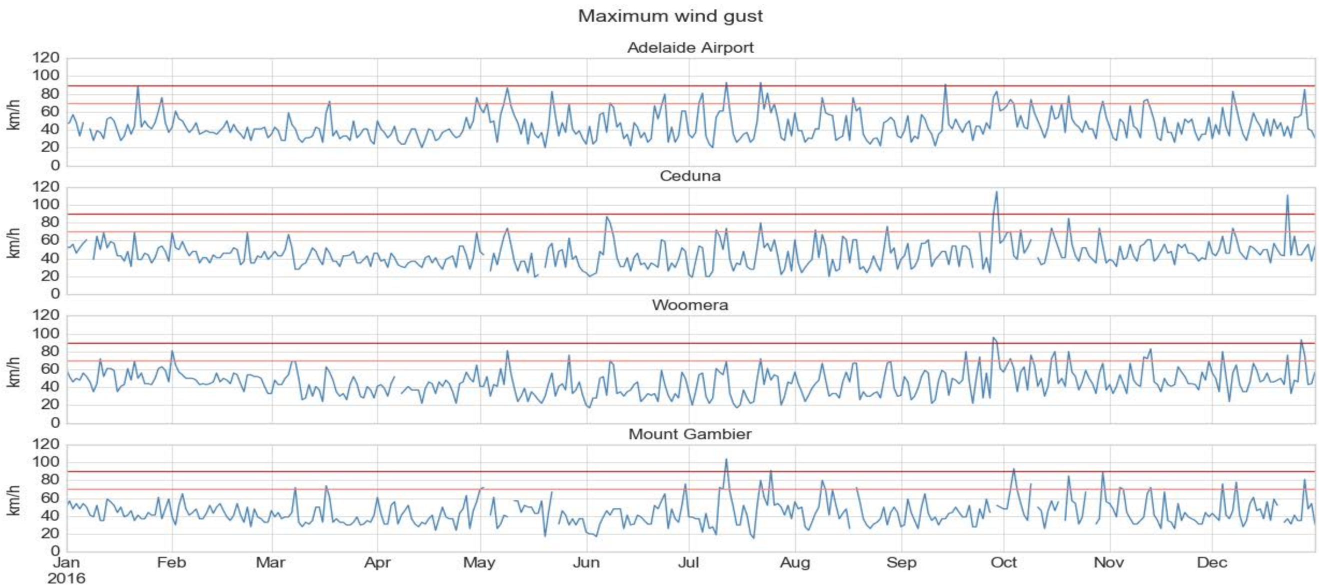



**Figure 2-7 Daily maximum wind gusts for South Australian stations**

# 3 2016 events in longer term context

## 3.1 Rainfall

Rainfall across 2016 was very much above average over almost all of the state, with a number of long term stations in the Mount Lofty Ranges and Mid-North with records in excess of 100 years reporting record annual rainfall. Mt Bold Reservoir, with a rainfall record of 77 years, also recorded a highest annual rainfall total.

In excess of 90 stations around the state recorded highest annual rainfall totals in the last 20 years. For the South Australian agricultural area in which most power infrastructure is located, rainfall for April to November was highest since 1992. For Adelaide, 2016 was the second wettest year on record after 1992, in a rainfall record commencing in 1839.

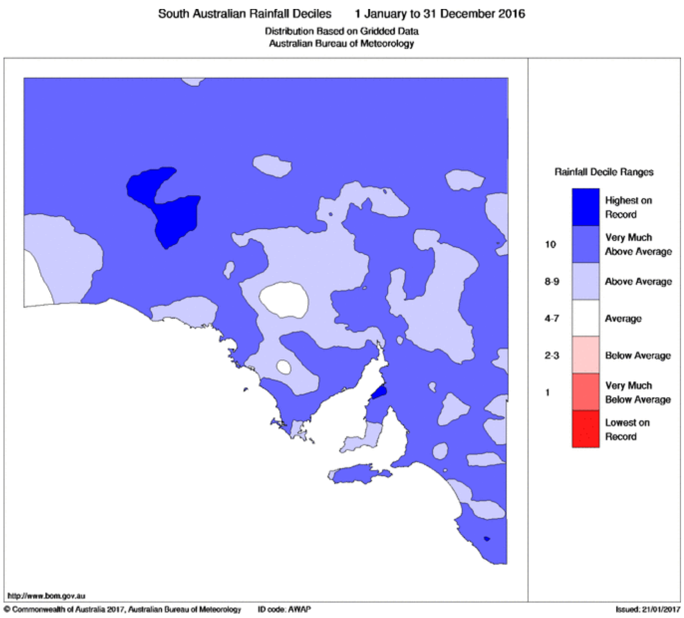



**Figure 3-1 Annual rainfall analysis for South Australia in 2016**

Several stations in South Australia with 70 to 80 year length records had highest on record daily rainfall totals in 2016, mainly from the late December event.

## 3.2 Wind

A number of different wind related parameters are presented for various sites around South Australia in Figures 3-1 to 3-4. These sites were chosen as being reasonably representative of different regions of the state, and all have longest established consistently measured wind records in the state.

The parameters presented are the highest wind gust recorded in each year, the accumulation across the year of daily wind run values, the maximum daily wind run value in each year. Discussion with SA Power Networks has revealed that wind gusts between 70 to 90 km/h contribute to power line outages, with wind gusts in excess of 90 km/h leading to very significant impacts on power lines. Numbers of events annually in each criterion are also presented.

The wind data presented is from automatic weather stations installed in the mid-1990s. Some earlier data is available from different types of instruments for wind gusts, but has been established to give higher wind gust readings than the instruments installed from the 1990s, so the earlier data has not been included.

While looking across this relatively short data record might appear to suggest a trend, the length of record from comparable instruments is not long enough to establish if this might or might represent a significant trend, or is year to year variability.

Bearing the above in mind, 2016 was a significant year in terms of winds experienced across South Australia. All sites presented saw record or close to record amounts of wind, as represented by the wind run accumulation. The daily wind run data presented in Figure 2-10 established this occurred mainly through May to November during the Negative Indian Ocean Dipole event.

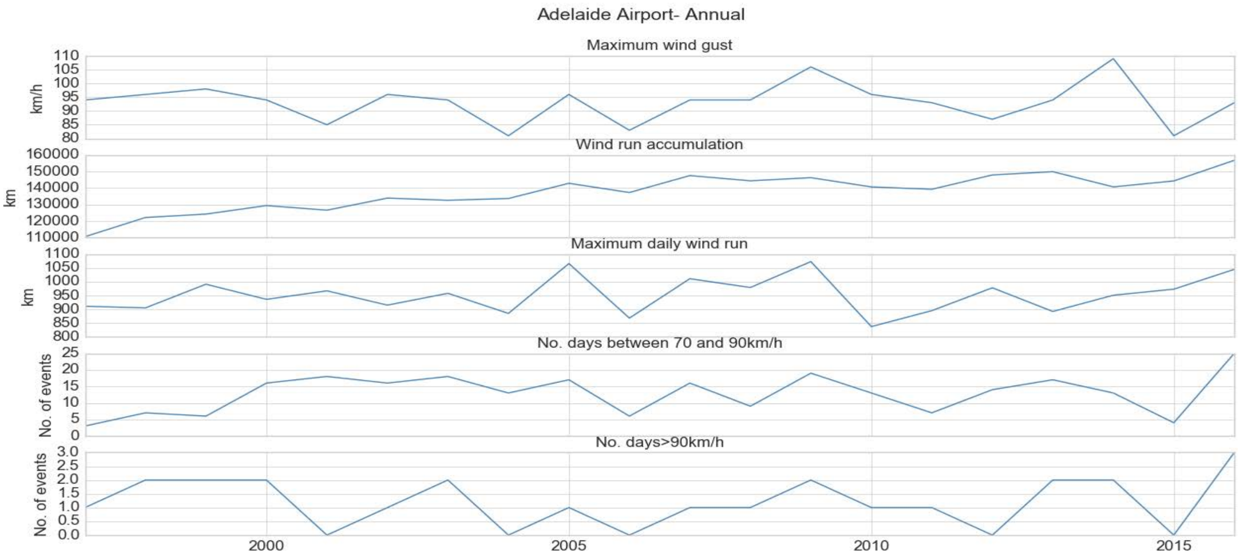



**Figure 3-2 Annual wind for Adelaide Airport**

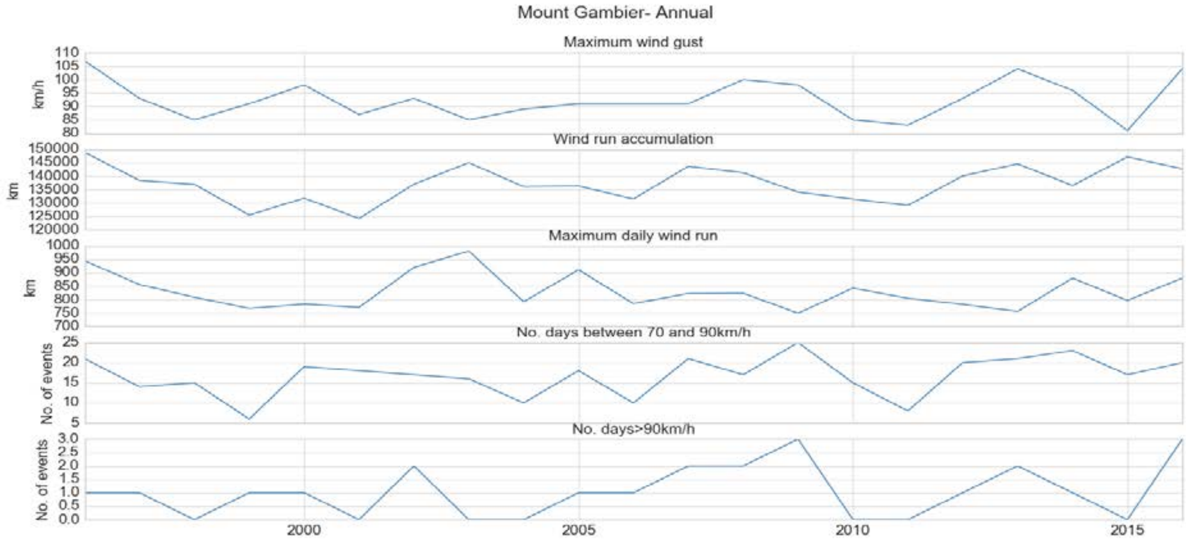



**Figure 3-3 Annual wind for Mount Gambier Aerodrome**

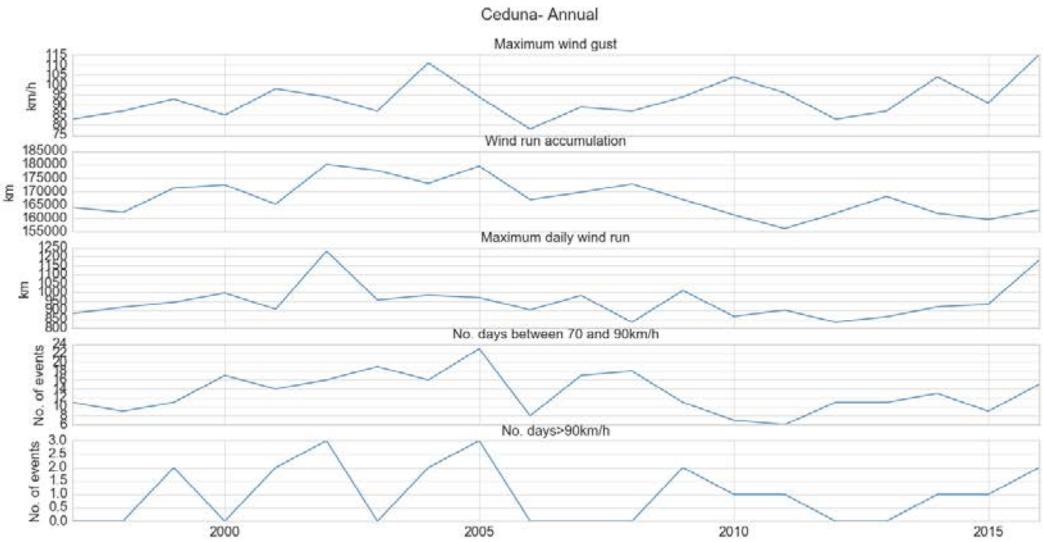



**Figure 3-4 Annual wind for Ceduna Aerodrome**

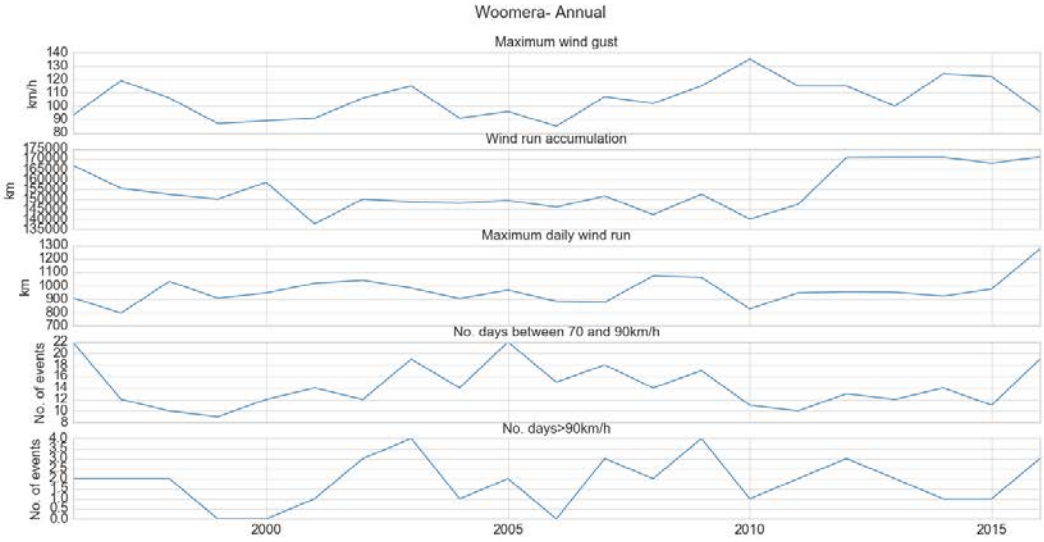



**Figure 3-5 Annual wind for Woomera station**

Figure 2-17 indicates that the windiest day of the year was typically related to the 28th -29th September low pressure system. The daily wind run values observed through this event are highest or close to highest in the dataset available for wind-run, starting in the mid-1990s.

While the maximum wind gust recorded at each site was generally not at record levels, the numbers of events with gusts between 70-90km/h and in excess of 90 km/h were the highest recorded, or close to this, at all of the sites presented.

## 3.3 Thunderstorm and lightning activity

Thunderstorm activity is often associated with extreme wind gusts as seen in section 3.1. Lightning activity produced in thunderstorms can also strike power infrastructure and cause outages. This section examines lightning strikes across various regions across South Australia on an annual basis to place 2016 in context, as best possible. The regions used are seen in Figure 1-1.

The lightning strike data analysed here are from the GPATS system, collected since late 1999. This is from detectors deployed across Australia which triangulate the radio wave signal generated by lightning strikes. A significant increase in the number of detectors deployed occurred in 2005. This led to a notable increase in the numbers of strikes detected. Because of this, the data from 2005 onwards is presented in this report, as being a consistent dataset to use for year to year comparison.

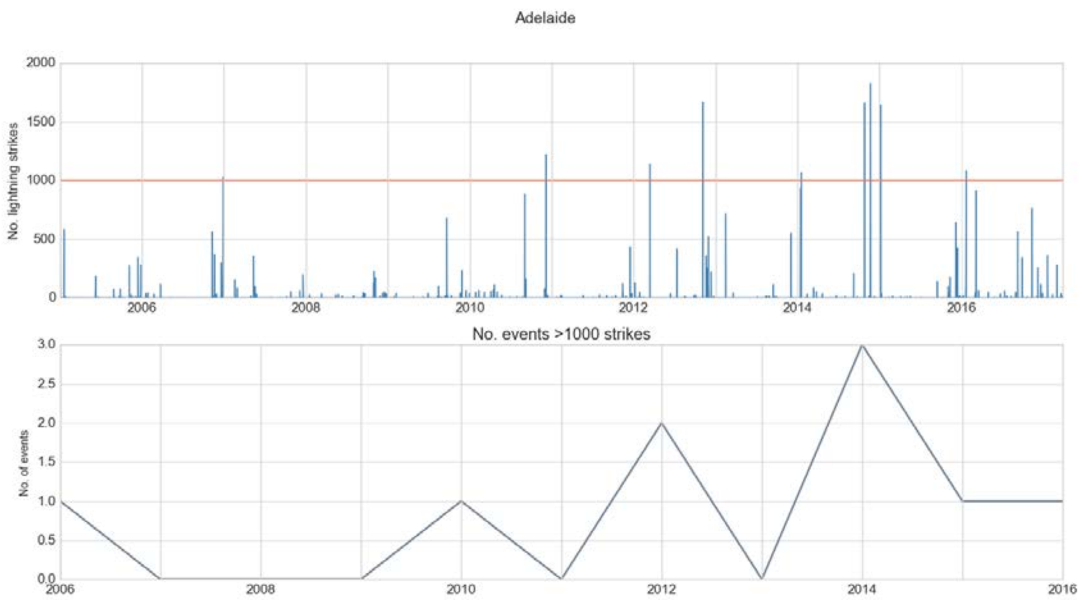



**Figure 3-6 Lightning strike numbers across Adelaide region**

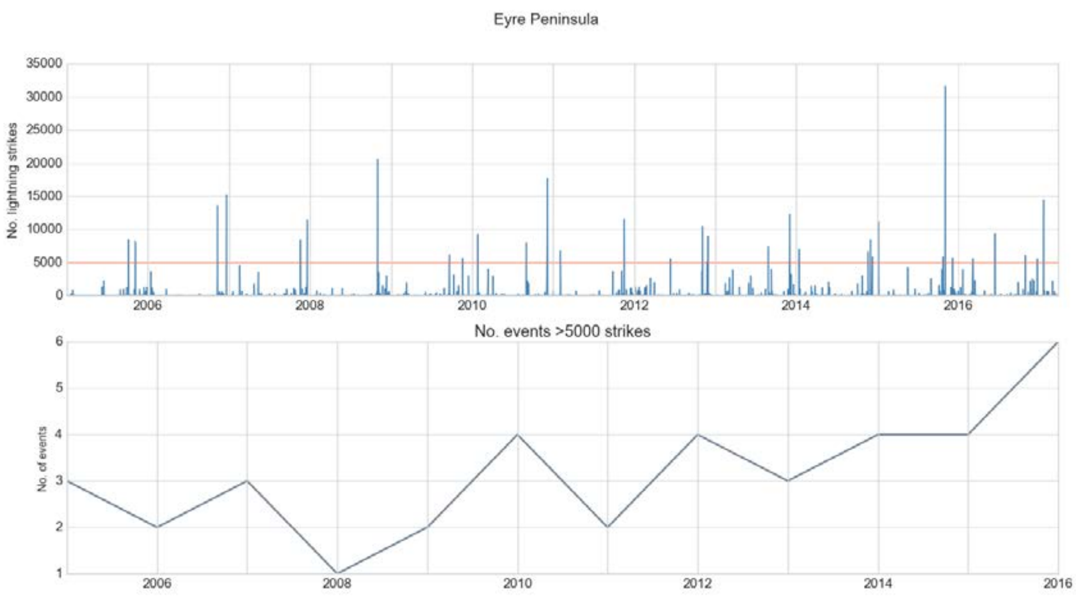



**Figure 3-7 Lightning strikes across Eyre Peninsula region**

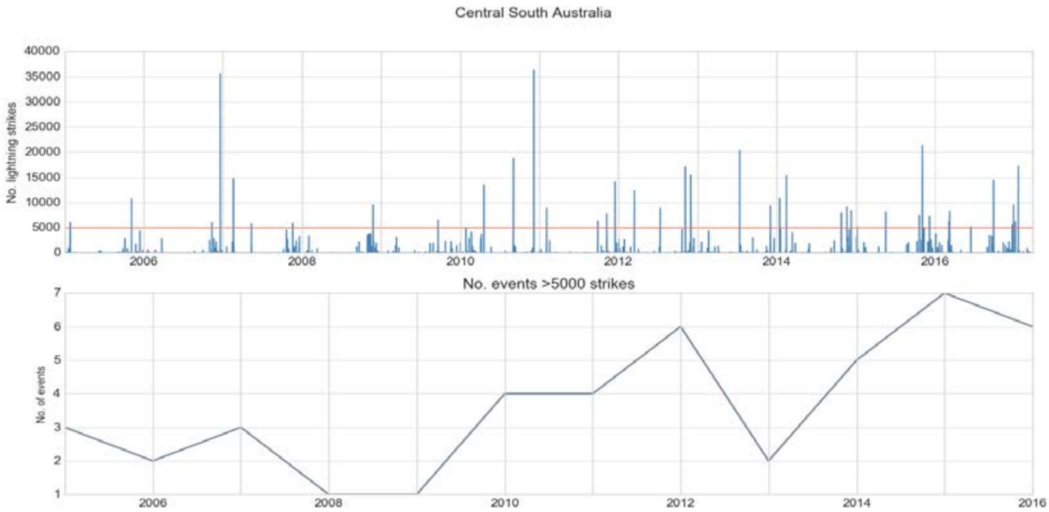



**Figure 3-8 Lightning strikes across Central South Australian region**

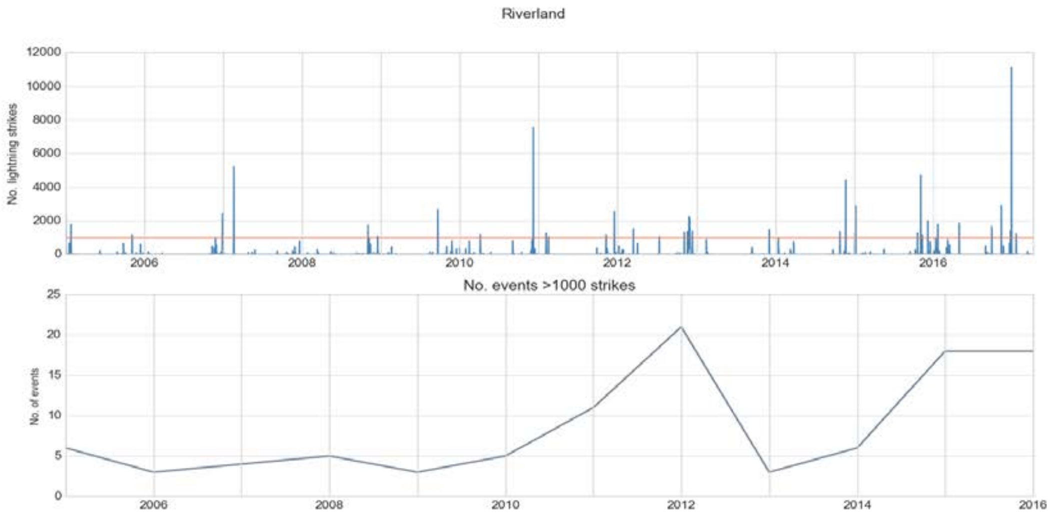



**Figure 3-9 Lightning strikes across Riverland region**

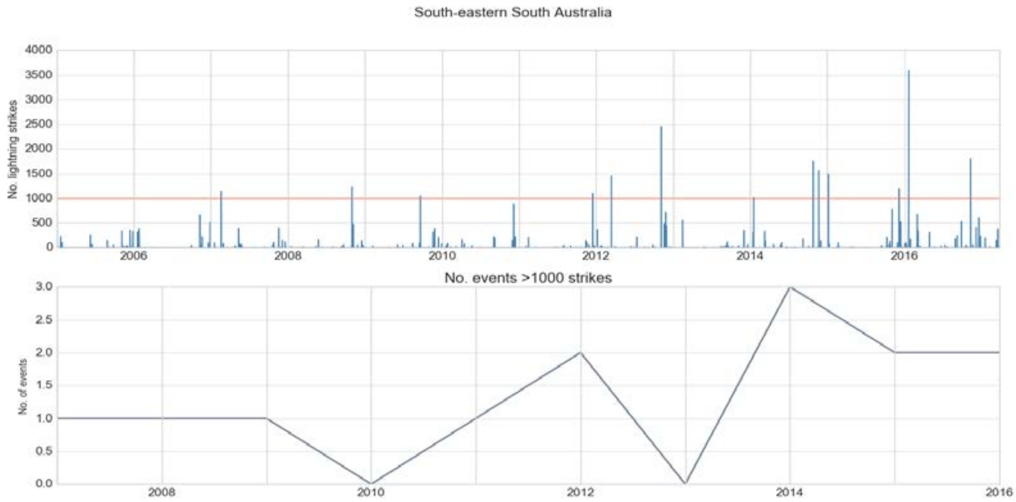



**Figure 3-10 Lightning strikes across South-eastern SA region**

Figures 3-6 to 3-10 all show an increase in recorded lightning strike numbers since 2010. The lower graph indicates numbers of days in each year with large numbers of strikes for that region. All regions show record levels or close to record numbers of strikes occurring in 2016.

# Further reading

Severe thunderstorm and tornado outbreak: South Australia 28 September 2016

Bureau of Meteorology 2016

http://www.bom.gov.au/announcements/sevwx/sa/Severe_Thunderstorm_and_Tornado_Outbreak_28_September_2016.pdf

South Australian 2016 climate summary

http://www.bom.gov.au/climate/current/annual/sa/summary.shtml

Climate Change in Australia

https://www.climatechangeinaustralia.gov.au/en/publications-library/technical-report/

State of the Climate 2016

http://www.bom.gov.au/state-of-the-climate/