Seasonal climate summary southern hemisphere (spring 2015): El Niño nears its peak

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Southern hemisphere circulation patterns and associated anomalies for the austral spring 2015 are reviewed, with an emphasis on Pacific climate indicators and Australian rainfall and temperature patterns. A strong El Niño persisted in the tropical Pacific Ocean with sea-surface temperature anomalies in excess of +2 °C in central and eastern parts, strongly negative outgoing longwave radiation near the Date Line, and the Southern Oscillation Index showing large negative departures. The positive Indian Ocean Dipole that had established in winter dissipated in late November, but was particularly influential on Australia’s climate during the months of September and October.

Australia’s spring rainfall was below average in the first two months, but improved later in the season: the northern half of Western Australia recorded above average November rainfall. Nevertheless, area-averaged rainfall in spring was below average for the country as a whole. For Australia, October was the warmest on record and had the highest mean temperature anomaly on record for any month since 1910. Spring temperatures were above average and Australia recorded its second-warmest spring on record, behind the record set in the previous year.

1. Introduction

This summary reviews the climate patterns for spring 2015, with particular attention given to the Australasian and Pacific regions. The main sources of information for this report are analyses prepared by the Bureau of Meteorology using data sourced from a range of centres and datasets.

2. Pacific and Indian Basin climate indices

2.1 Southern Oscillation Index

The Troup Southern Oscillation Index (SOI) for the period January 2011 to November 2015 is shown in Figure 1, together with a five-month weighted moving average. From winter 2014, SOI values were predominantly negative, the only exception being a weakly positive monthly value of +0.6 for February 2015. The positive value in late summer represents the short break between the near or marginal El Niño event in 2014 and the much stronger event in 2015 (though volatility in the SOI is common at this time of the year).

1 The Troup Southern Oscillation Index (Troup 1965) used in this article is ten times the standardised monthly anomaly of the difference in mean-sea-level pressure (MSLP) between Tahiti and Darwin. The calculation is based on a sixty-year climatology (1933–1992). The Darwin MSLP is provided by the Bureau of Meteorology, and the Tahiti MSLP is provided by Météo France inter-regional direction for French Polynesia.
Monthly SOI values for spring 2015 were -17.7 in September, -20.2 in October, and -5.3 in November, giving a seasonal average of -14.4. Spring mean sea level pressure (MSLP) values for Darwin were 1.9 hPa above average at 1012.4 hPa, and for Tahiti were 0.5 hPa below average at 1012.8 hPa. The positive MSLP anomalies at Darwin throughout the season were consistent with a drier than normal spring for many parts of Australia (see rainfall section).

Persistent negative values of the SOI are a key indicator of an El Niño. The negative SOI values observed in spring remained mostly in El Niño territory, as they had been since autumn, and were consistent with ocean patterns.

Figure 1 Southern Oscillation Index (SOI), from January 2011 to November 2015, together with a five-month binomially weighted moving average. The means and standard deviations used in the computation of the SOI are based on the period 1933–1992.

2.2 Composite monthly ENSO index (5VAR) and MEI

5VAR\(^2\) is a composite monthly ENSO index, calculated as the standardised amplitude of the first principal component of monthly Darwin and Tahiti MSLP\(^3\) and monthly NINO3, NINO3.4 and NINO4 sea-surface temperatures\(^4\) (SSTs). Persistent positive or negative 5VAR values of in excess of one standard deviation are typically associated with El Niño or La Niña events, respectively. Monthly 5VAR values for the period January 2011 to November 2015 are shown in Figure 2. The 2010-11 La Niña was one of the strongest such events, with monthly 5VAR values of −1.3 to −1.7 still evident in the first four months of 2011. After a lull in winter, a weaker La Niña redeveloped in spring and extended into summer 2012 (Tobin 2012, Cottrill 2012). Values came close to El Niño levels during winter of 2012 (Pepler 2013), but otherwise, 5VAR values were neutral for the years following. 2014 was a near-miss El Niño year (Hope et. al. 2015), which saw 5VAR values in positive territory from autumn onwards, but mostly values just shy of +1 standard deviation. After a dip during summer 2014-15, the 5VAR index increased steadily throughout the first half of 2015 to above +2 standard devia-

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\(^2\) ENSO 5VAR was developed by the Bureau of Meteorology and is described in Kuleshov et. al. 2009. The principal component analysis and standardisation of this ENSO index is performed over the period 1950–1999.  
\(^3\) MSLP data obtained from http://www.bom.gov.au/climate/current/soihtm1.shtml  
\(^4\) SST indices obtained from ftp://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/sstoi.indices
tions in May. Monthly values were +2.6, +2.5 and +2.1 for September, October and November respectively, consistent with a strong and mature El Niño event.

The Multivariate ENSO Index\(^5\) (MEI), produced by the Physical Sciences Division of the Earth Systems Research Laboratory (formerly known as the US Climate Diagnostics Centre), is derived from a number of atmospheric and oceanic parameters calculated as a two-month mean. As for 5VAR, significant positive anomalies are typically associated with El Niño, while large negative anomalies indicate La Niña. The 2015 August-September (+2.5), September-October (+2.2) and October-November (+2.3) values of the MEI were all strongly positive. The August-September value ranked the 2015-16 event as the third-highest event overall at any time of the year since 1950 based on this measure.

Figure 2 5VAR composite standardised monthly ENSO index from January 2011 to November 2015, together with a weighted three-month moving average.

3. **Outgoing long-wave radiation**

Outgoing long-wave radiation (OLR) in the equatorial Pacific Ocean may be used as a proxy for tropical convection and rainfall. Decreased OLR usually indicates increased convection and enhanced associated cloudiness and rainfall, and increased OLR usually indicates decreased convection. During El Niño, increased convection, or decreased OLR, often occurs near the Date Line as the main centre for convection moves east and the Walker Circulation is weakened or even reversed. The opposite is observed during La Niña.

The National Oceanic and Atmospheric Administration’s (NOAA) Climate Prediction Center computes standardised monthly OLR anomalies for the region from 5°S to 5°N and 160°E to 160°W\(^6\). In 2015, the monthly OLR anomaly values

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\(^6\) Obtained from http://www.cpc.ncep.noaa.gov/data/indices/olr
for September, October and November were $-1.5$, $-1.4$ and $-1.3$ respectively, and the seasonal average for spring was $-1.4$, indicating strongly increased convection near the Date Line.

The spatial pattern of seasonal OLR anomalies across the Asia-Pacific region between $40^\circ$S and $40^\circ$N for spring 2015 is shown in Figure 3. However, there were suspected negative biases in the OLR anomalies over subtropical land areas in spring 2015 (estimated at around 5 Wm$^{-2}$) due to satellite decay (Wheeler pers. comm.). A map of the seasonal precipitation anomalies as calculated from NOAA’s Climate Anomaly Monitoring System-Outgoing longwave radiation Precipitation Index (CAMS_OPI) analysis\(^7\) for the Pacific region is shown in Figure 4 for comparison.

Keeping in mind the uncertainty in the OLR anomalies in the Australian region, negative OLR anomalies were observed over much of Western Australia and parts of north and central Queensland. Positive anomalies (indicating reduced convection) were confined to the coast in the far north of the Northern Territory and Cape York Peninsula, the eastern seaboard down into northern Tasmania, and southwest Western Australia. The positive anomalies extended from north of Australia through the Maritime Continent and Southeast Asia to the Philippines and Vietnam.

The OLR anomalies were generally reflected in the spring rainfall totals; patches of very much above average rainfall were observed in the northern half of Western Australia, while the country’s southeast received very much below average rainfall for the season (see Figure 24). Negative OLR anomalies over the equatorial Pacific around the Date Line and positive anomalies over the Maritime Continent were consistent with the conditions expected during an El Niño and were tied to severe drought, damaging upland frosts and widespread fires in this region. In comparison to some previous events, the southward extent of the positive OLR anomalies in the Australian region was rather constrained, though the analysis in this region is likely to have been affected by the suspected negative bias.

Figure 3 OLR anomalies for spring 2015 (Wm$^{-2}$). Base period is 1979–2000. The mapped region extends from $40^\circ$S to $40^\circ$N and $70^\circ$E to $180^\circ$E.

\(^7\) Obtained from the International Research Institute for Climate and Society https://iridl.ldeo.columbia.edu/maproom/Global/Precipitation/index.html#tabs-3
Indian Ocean Dipole (IOD)

The Indian Ocean Dipole (IOD) is an ocean-atmosphere phenomenon that influences Australian rainfall and temperature patterns, and can be represented by the Dipole Mode Index (DMI) (Saji et. al. 1999). The DMI is the difference in SST anomalies between a western node centred on the equator off the coast of Somalia (50°E to 70°E and 10°S to 10°N) and an eastern node near Sumatra (90°E to 110°E and 10°S to 0°S). Sustained values of the DMI below −0.4 °C indicate a negative IOD event, while sustained values above +0.4 °C indicate a positive IOD event. An IOD event typically starts from May or June and lasts to around November. A positive IOD event is often associated with below average rainfall in central and southeastern Australia in spring (Risbey et. al. 2009), and is more likely to occur alongside El Niño.

After neutral values earlier in autumn and winter, a positive IOD pattern rapidly established in winter 2015 and continued into spring (Figure 5). The event ended in late November when the DMI dropped below threshold levels (Figure 6) as broad positive SST anomalies extended across the Indian Ocean.
For spring, there was cooler than normal water in the tropical eastern Indian Ocean and warmer than normal water in the tropical western Indian Ocean, indicating a positive IOD event. Anomalies are relative to a 1961-1990 base period.

Weekly Dipole Mode Index (DMI) values from January 2012 to November 2015, together with a five-week binomially weighted moving average. Baseline period is 1961-1990.
5. **Madden-Julian Oscillation (MJO)**

The Madden-Julian Oscillation (MJO) is characterised by anomalies in tropical convection and winds, with these anomalies propagating eastwards from the Indian Ocean to the Pacific, and sometimes around the entire global equator, taking between 30 to 60 days to repeat its cycle (Madden and Julian 1971, 1972, and 1994). Impacts of the MJO can be felt in many regions of the globe, including outside the tropics (Donald et. al. 2004), and its frequency and strength vary from year to year (Wheeler and Hendon 2004).

When the MJO is active, it is associated with areas of both increased and decreased tropical convection, with effects transitioning from the northern hemisphere to the southern hemisphere from late austral spring. A description of the Real-time Multivariate MJO (RMM) index and the associated phases can be found in Wheeler and Hendon (2004).

During El Niño years, MJO convection anomalies tend to propagate further eastward over the warmer waters of the central and eastern Pacific Ocean, but the influence of ENSO on the MJO in other locations is either weaker or not well understood (Hendon et. al. 1999).

The phase-space diagram of the RMM for spring 2015 is shown in Figure 7, and the evolution of tropical convection anomalies along the equator with time is shown in Figure 8. There was only weak MJO activity during the first half of spring, but an active pulse of the MJO becomes evident over the Indian Ocean in the last week of October, moving over the Maritime Continent in November (shifting from phase two to four). Typically, phases two and three result in reduced rainfall over east to southeast Australia and easterly wind anomalies over eastern Australia (Wheeler and Hendon et. al. 2009). This likely reinforced the impacts of the positive IOD and El Niño in southeast Australia during spring. In Figure 8, the persistent negative OLR anomalies near the Date Line and the persistent positive anomalies over the Maritime Continent are a signature of El Niño. In late October, negative OLR anomalies between approximately 50°E and 80°E correspond with the strong MJO pulse in phase two (Figure 7).
Figure 7  Phase-space representation of the MJO index for spring 2015. Daily values are shown with September in red, October in green and November in blue. The eight phases of the MJO and the corresponding (approximate) locations of the near-equatorial enhanced convective are labelled.
6. Oceanic patterns

6.1 Sea surface temperatures (SSTs)

Figure 9 shows spring 2015 sea-surface temperature (SST) anomalies, obtained from NOAA’s Optimum Interpolation analyses (Reynolds et al. 2002). Negative (cool) anomalies are shown in blue, while positive (warm) anomalies are coloured red.

Consistent with a strong El Niño, SSTs across the central and eastern equatorial Pacific Ocean remained much warmer than normal during the austral spring (see Table 1).
Table 1  Monthly NINO SST anomalies for spring 2015, obtained from ftp://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/sstoi.indices.

It was also anomalously warm through much of the northeastern Pacific Ocean (west of North America), the North Atlantic Ocean, and in both the western and southeastern Indian Ocean. Around Australia, SSTs were warmer than normal along the coast of southeast Australia and along most of Western Australia’s coastline.

The SST anomalies in the Indian Ocean were quite remarkable during spring, setting new highs in the months of September and October (for the region 30°E-120°E, 0°S-60°S). Even waters to Australia’s north and west that are normally average or cooler than average during spring in an El Niño, were warmer than average.

Figure 9  Anomalies of global SST for austral spring 2015 (°C).

7.  **Equatorial Pacific sub-surface patterns**

The Hovmöller diagram for the 20 °C isotherm depth anomaly along the equator from January 2014 to November 2015, obtained from NOAA’s TAO/TRITON data is shown in Figure 10. The 20 °C isotherm depth is generally located close to the equatorial thermocline, which is the region of greatest temperature gradient with depth, and is the boundary between the warm near-surface mixed layer waters and cold deep-ocean waters. Therefore, measurements of the 20 °C isotherm depth make a good proxy for the thermocline depth. Positive (negative) anomalies correspond to the 20 °C isotherm being deeper (shallower) than average.

A deeper thermocline results in less near-surface cold water available for upwelling, and therefore a warming of surface temperatures. The converse is also true.

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1 Hovmöller plot obtained from http://www.pmel.noaa.gov/tao/jsdisplay/
The thermocline across the equatorial eastern Pacific Ocean remained deeper than normal throughout spring 2015, consistent with the strong El Niño. 2014 through 2015 saw a sequence of significant down-welling Kelvin Waves in the ocean, each being triggered in the west and travelling east as a positive anomaly. During the later stages of spring, a significant upwelling ("cool") Kelvin wave can be seen in the central Pacific, which acted to cool ocean water later in the year.

Figure 11 is a depth-longitude plot of monthly average temperatures around the equator (2°S to 2°N) for November 2015 and also shows that the thermocline was flatter than normal, consistent with the deepened thermocline in the east. The eastern Pacific anomalies peaked near +7 °C, providing strong support for the SST anomalies at the surface. These subsurface anomalies are consistent with the event being one of the strongest on record, arguably behind 1997-98 but similar to 1982-83.
Figure 11  Depth-longitude plot of monthly average temperatures at the equator (2°S to 2°N) for November 2015. (Plot obtained from the TAO Project Office).

Figure 12 shows a cross-section of monthly equatorial sub-surface analyses from August 2015 to November 2015. Red shading indicates positive (warm) anomalies, and blue shading indicates negative (cool) anomalies. Warm sub-surface anomalies persisted in the central and eastern equatorial Pacific Ocean throughout spring 2015. During November, cool anomalies increased in size and strength in the western equatorial Pacific, and at depths of around 150m these cool anomalies pushed across to the central Pacific Ocean. This pattern of slow erosion of anomalies at depth is consistent with the mature stages of an El Niño event and is a prelude to the eventual collapse of the anomalies further east.
Figure 12: Four-month sequence from August to November 2015 of vertical sea subsurface temperature anomalies at the equator for the Pacific Ocean. The contour interval is 0.5 °C. (Plot obtained from the Bureau of Meteorology).

8 Atmosphere patterns

8.1 Surface analysis

The mean sea level pressure (MSLP) pattern for spring 2015 is shown in Figure 13, computed using data from the 0000 UTC daily analyses of the Bureau of Meteorology’s Australian Community Climate and Earth System Simulator (ACCESS) model\textsuperscript{10}. MSLP anomalies are shown in Figure 14, relative to the 1979–2000 climatology obtained from the National Centers for Environmental Prediction (NCEP) II Reanalysis data (Kanamitsu et al. 2002). The MSLP anomaly field

\textsuperscript{9} This and other analyses available from http://www.bom.gov.au/oceanography/oceantemp/pastanal.shtml

\textsuperscript{10} For more information on the Bureau of Meteorology’s ACCESS model, see http://www.bom.gov.au/nwp/doc/access/NWPData.shtml
is not shown over areas of elevated topography (grey shading) as values are heavily influenced by how surface pressure is extrapolated to sea level.

The MSLP pattern in the austral spring was zonal around Antarctica, with the subtropical ridge forming a band of high pressure centres around 30°S. A high pressure centre was located over the Great Australian Bight (1021.4 hPa) as part of a band that extended west to another centre over the Indian Ocean (1022.6 hPa) and east to a centre off Australia’s east coast (1021.0 hPa). High pressure centres were also located in the southern South Atlantic Ocean (approximately 1020 hPa) and west of Chile over the southeastern Pacific Ocean (1023.0 hPa). The lowest pressures were found off West Antarctica around 150°W (972.4 hPa) in the core of the circumpolar trough.

![Spring 2015 MSLP (hPa). The contour interval is 5 hPa.](image-url)
There was a significant high pressure anomaly south of mainland Australia (+6.8 hPa), extending from south of the Great Australian Bight towards the east over Tasmania and into the Tasman Sea (see Figure 14). High pressure anomalies were observed across all of mainland Australia and up into the Maritime Continent. Large positive pressure anomalies (up to +9.6 hPa) were also located west of Chile at around 120°W. Low pressure anomalies were found throughout much of the central and eastern Pacific Ocean and surrounding Antarctica, with the largest negative anomaly being -8.2 hPa off the Ross Sea at about 60°S and 170°W.

The pressure anomalies in the Australian region were consistent with a substantial weakening and contraction of the spring time westerly winds. While pressures are often elevated and the subtropical ridge is displaced southwards during El Niño, the anomalies were displaced well south of what is usual. As a result, the strongest rainfall departure during spring occurred well south of the typical El Niño pattern, with particularly large rainfall anomalies in Tasmania and southern coastal parts of mainland Australia.

Using the NCEP Reanalysis data since 1950, the average MSLP for an area covering southern mainland Australia between 30°S-40°S and 100°E-155°E has shown an increasing trend during the southern growing season (April to October), and extending into spring (see an example for winter and spring in Figure 15). Spring 2015 continued that trend of increasing average MSLP across southern mainland Australia: it was the highest average MSLP for winter and spring (June to November) since 1950 for southern Australia (an average of 1020.5 hPa); highest average for the southern growing season (April to October) since 1950 (average of 1021.4 hPa); and the third-highest average spring value since 1950 (average of 1019.3 hPa).
Winter and spring precipitation totals were calculated for southern coastal areas of Australia that receive more than half their annual precipitation (rainfall) total during those seasons (June to November). Higher average MSLP values in winter and spring across southern Australia are typically associated with reduced winter and spring rainfall in the southern coastal areas of mainland Australia and in Tasmania (see Figure 16). Those same areas of southern Australia have experienced severe rainfall deficiencies (see Figure 25) and drought in recent years. Rainfall in both the southern coastal areas of mainland Australia and in Tasmania during spring 2015 was well below average and consistent with this pattern of drier than normal conditions when the average MSLP is higher than normal across southern mainland Australia.

![Winter+spring average mean sea-level pressure for southern Australia](image)

**Figure 15** Winter and spring average mean sea level pressure (MSLP) for southern mainland Australia for 1950-2015.
9. **Mid-tropospheric analyses**

The 500 hPa geopotential height, an indicator of the steering of surface synoptic systems across the southern hemisphere, is shown for spring 2015 in Figure 17. The associated anomalies are shown in Figure 18. As with the MSLP anomalies, the spring 2015 500 hPa geopotential height field was dominated by zonal flow. The anomaly pattern shows positive geopotential height anomalies over the southern half of Australia (up to +93 gpm south of the Great Australia Bight). A band of negative geopotential height anomalies (as low as −88 gpm just to the north of the Ross Sea) encircled two other areas of positive anomalies that were in an area west of Chile around 120°W (+105 gpm) and over East Antarctica (+68 gpm).
Figure 17  Spring 2015 500 hPa mean geopotential height (gpm).
Southern Annular Mode (SAM)

The Southern Annular Mode (SAM, also known as the Antarctic Oscillation or AAO) describes the strength and extent of the southern hemisphere surface westerly winds (e.g. Marshall 2003 and references therein). Positive phases of the SAM are characterised by increased mass over the mid-latitudes and decreased mass over Antarctica (that is, anomalously high pressure over the mid-latitudes and anomalously low pressure over Antarctica), and an associated poleward contraction and strengthening in the belt of westerly winds that circles Antarctica. Conversely, negative phases of the SAM related to decreased mass (lower pressure) over the mid-latitudes, and increased mass over Antarctica, with an equatorward expansion of the mid-latitude westerly wind belt. A similar oscillation occurs in the northern hemisphere, the Northern Annular Mode or NAM (also known as the Arctic Oscillation or AO).

The Climate Prediction Center produces a standardised monthly SAM index. Daily and monthly values for the SAM index are shown in Figure 19. The September, October and November values for 2015 were +0.54, -0.17 and +0.70 respectively, with an overall spring value of +0.36. In spring, a positive SAM tends to be associated with increased rainfall over New South Wales, particularly along the East Coast. However, rainfall is generally decreased over western Tasmania (Hendon et al. 2007), suggesting that the positive SAM may have partially contributed towards the record low spring rainfall recorded in western Tasmania (see Figure 24).
Figure 19  Standardised AAO (SAM) index for June to November 2015. Each daily value has been standardized by the standard deviation of the monthly AAO index from 1979-2000.

The MSLP anomaly chart (Figure 14) shows anomalously low pressure around Antarctica, and higher pressure in parts of the mid-latitude region, particularly over the Australian region and west of South America. This is consistent with the overall positive seasonal value of the SAM during spring, and particularly suppressed rainfall in southern regions of Australia.

11. Winds

Figures 20 and 21 show spring 2015 low-level (850 hPa) and upper-level (200 hPa) wind anomalies respectively (winds computed from ACCESS and anomalies with respect to the 22-year NCEP climatology). Isotach contours are at 5 ms$^{-1}$ intervals. Low level winds (Figure 20) were close to average (within 5 ms$^{-1}$ of the long term average) in most regions, however there were areas of slightly stronger anomalies: westerly anomalies up to more than 7 ms$^{-1}$ across the central equatorial Pacific Ocean (indicating westerly wind bursts during the El Niño); and easterly anomalies above 5 ms$^{-1}$ across central Australia. The anomalies near Australia reflected a substantial weakening of the normal spring time westerlies, which are important for rainfall in southern Australia.
Figure 20 Austral spring 2015 850 hPa vector wind anomalies (ms$^{-1}$).

There were stronger anomalies in the upper level (200 hPa) winds as shown in Figure 21. Anomalies in the northern hemisphere were generally weak and mixed, but there were north-easterly anomalies above 10 ms$^{-1}$ in the equatorial Pacific Ocean around 115°W. In the southern hemisphere, westerly anomalies up to over 15 ms$^{-1}$ were seen in the mid latitudes over the central and eastern Pacific Ocean that continued in a band across South America into the western South Atlantic Ocean. There were also westerly anomalies above 10 ms$^{-1}$ in a band from about 45°S to 65°S that extended from south of Australia across the South Pacific Ocean to Chile, where they turned to a northerly direction. In the Australian region, the subtropical jet was weaker than normal, consistent with the large anticyclonic anomaly in the southeast. In contrast, upper level westerly winds further south where substantially strengthened.

Figure 21 Austral spring 2015 200 hPa vector wind anomalies (ms$^{-1}$).
12. Antarctic Climate

For the first time in four years, Antarctic sea ice extent did not reach a (satellite era) record high during spring 2015 (Figure 22). Maximum Antarctic sea ice extent was close to normal at 18.83 million square kilometres on 6 October, 1.33 million square kilometres less than the record set in 2014 (from 35 years of satellite record). The date of maximum extent was the second-latest on record behind 12 October in 2002. El Niño is known to influence Antarctic sea ice extent (e.g. Kowk and Comiso 2002, Yuan 2004, Raphael et. al. 2015) and the spatial pattern of sea ice concentration anomalies in spring 2015 was similar to spring 1997, which was the last El Niño of similar strength.

![Antarctic sea ice extent](http://nsidc.org/data/seaice_index/archives.html)

For Australian Antarctic stations, average maximum temperatures were slightly warmer than normal at Mawson (a seasonal maximum temperature anomaly of +0.6 °C) and Davis (anomaly +0.3 °C), but slightly cooler than normal at Casey (anomaly -0.8 °C) and Macquarie Island (anomaly -0.3 °C). Minimum temperatures for spring were cooler than normal at all stations, ranging from 0.3 °C below the long-term average at Mawson to 1.6 °C below average at Casey.

13. Australian region

13.1 Rainfall

Rainfall during spring 2015 was 28 per cent below the long-term mean (1961-1990) for Australia as a whole. Rainfall totals (Figure 23) and deciles (Figure 24; deciles calculated using all springs from 1900 to 2015) show that rainfall was lower than average for the season over most of the eastern two thirds of Australia. Rainfall was very much below average (lowest ten per cent of records) for the west of the South West Land Division in Western Australia, southeastern South Australia and Victoria, and parts of the Top End of the Northern Territory. Rainfall was lowest on record for much of Tasmania, resulting in a very poor runoff season and an early start to the fire season in that State. After a drier than normal September across most of the country, above average rainfall during October and November across the northern half of Western Australia resulted in above average rainfall for the season in that region.

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12 These station-based temperature anomalies are calculated from all years of available data because not all stations have historical data for the standard base period of 1961-90.
The overall pattern of below average rainfall was consistent with the presence of an El Niño event, but the dry anomalies were shifted south of their average El Niño position (typically in Queensland and New South Wales). This highlights the significance of the large positive pressure anomalies near southern Australia and the confinement of the OLR signal to far northern Australia and the Maritime Continent.

A summary of seasonal rainfall ranks and extremes is shown in Table 2 for Australia and each State and Territory. Percentage areas of rainfall in different categories (e.g. highest and lowest on record) are shown for Australia and each State and Territory in Table 3. Spring 2015 was particularly dry in Tasmania, with almost 62 per cent of the State recording its driest spring on record and more than 91 per cent of the State below the fifth percentile. By comparison, rainfall was close to average for Western Australia at just one per cent below the long-term mean and no areas of the State recording driest spring on record.

No areas of Australia observed highest on record spring rainfall. Spring rainfall was in the highest decile (wettest 10 per cent of all years) over 1.2 per cent of Australia, mostly in the northern half of Western Australia but also small patches in the North Coast of New South Wales and southeastern Queensland. In contrast, 0.67 per cent of the country was driest on record and there were patches in the lowest decile (driest ten per cent of all years) in all States and Territories making up a total of 8.8 per cent of the country.

Drier than normal conditions dominated the first two months of spring and above average rainfall in parts of Australia during November was not sufficient to make up for these earlier deficiencies. It was the third-driest September on record nationally. October had below average rainfall for much of the country except in the northern half of Western Australia, and was particularly dry in southern South Australia, Victoria and Tasmania. November rainfall was mixed: below average rainfall in the southwestern corner of Western Australia, southern Victoria, most of Tasmania, central eastern and northern parts of the Northern Territory, and central and northern parts of Cape York Peninsula; above average rainfall for many other areas in all States and Territories.

The strong El Niño conditions also had a significant impact on rainfall in the Pacific Island Countries. With the South Pacific Convergence Zone (SPCZ) moving north and east during the El Niño, it was much drier than normal for many countries in the western Pacific: below average rainfall was recorded in Papua New Guinea, the Solomon Islands, Vanuatu, Fiji, southern Tonga, Niue and the Cook Islands. Countries further to the northeast such as Kiribati recorded above average rainfall for the season while Tuvalu was near average.

There were no tropical cyclones in the Australian region during spring 2015. The Australian tropical cyclone season is usually weaker and delayed during El Niño.

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Figure 23  Spring 2015 rainfall totals (mm) for Australia.

Figure 24  Spring 2015 rainfall deciles for Australia: decile ranges based on grid-point values over all springs from 1900 to 2015.
### Table 2: Summary of the seasonal rainfall ranks and extremes on a national and State basis for spring 2015.

<table>
<thead>
<tr>
<th>Region</th>
<th>Highest seasonal total (mm)</th>
<th>Lowest seasonal total (mm)</th>
<th>Highest daily total (mm)</th>
<th>Area-averaged rainfall (mm)</th>
<th>Rank of area-averaged rainfall (of 116 years)</th>
<th>% difference from mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>740.0 mm at Yarras (Mount Seaview) (NSW)</td>
<td>0.0 mm at several locations</td>
<td>148.0 mm at Marodian Homestead (Qld) on 15 November</td>
<td>52.5</td>
<td>34</td>
<td>−28</td>
</tr>
<tr>
<td>Queensland</td>
<td>504.2 mm at Happy Valley</td>
<td>0.0 mm at several locations</td>
<td>148.0 mm at Marodian Homestead on 15 November</td>
<td>58.3</td>
<td>39</td>
<td>−26</td>
</tr>
<tr>
<td>New South Wales</td>
<td>740.0 mm at Yarras (Mount Seaview)</td>
<td>0.0 mm at several locations</td>
<td>111.0 mm at Telegraph Point (Farrawells Road) on 15 November</td>
<td>106.1</td>
<td>51</td>
<td>−15</td>
</tr>
<tr>
<td>Victoria</td>
<td>308.8 mm at Falls Creek (Rocky Valley)</td>
<td>20.8 mm at Patho West</td>
<td>82.0 mm at Murrayville on 5 November</td>
<td>98.0</td>
<td>6</td>
<td>−46</td>
</tr>
<tr>
<td>Tasmania</td>
<td>497.4 mm at Mount Read</td>
<td>41.0 mm at Boothwell (Clyde River)</td>
<td>101.0 mm at Douglas River on 13 November</td>
<td>155.0</td>
<td>1</td>
<td>−58</td>
</tr>
<tr>
<td>South Australia</td>
<td>162.4 mm at Mount Lofty</td>
<td>0.0 mm at Innamincka Station</td>
<td>88.4 mm at Jamestown on 5 November</td>
<td>29.0</td>
<td>30</td>
<td>−43</td>
</tr>
<tr>
<td>Western Australia</td>
<td>229.8 mm at Drysdale River Station</td>
<td>0.0 mm at several locations</td>
<td>123.4 mm at Spring Valley on 7 November</td>
<td>40.6</td>
<td>73</td>
<td>−1</td>
</tr>
<tr>
<td>Northern Territory</td>
<td>301.6 mm at Mango Farm</td>
<td>0.0 mm at several locations</td>
<td>95.4 mm Nitmiluk Rangers on 31 October</td>
<td>38.5</td>
<td>33</td>
<td>−43</td>
</tr>
</tbody>
</table>

The ranking in the 2nd last column goes from 1 (lowest) to 116 (highest) and is calculated over the years 1900 to 2015 inclusive.
<table>
<thead>
<tr>
<th>Region</th>
<th>Lowest on record (%)</th>
<th>Severe deficiency (%)</th>
<th>Decile 1 (%)</th>
<th>Decile 10 (%)</th>
<th>Highest on record (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>0.67</td>
<td>4.2</td>
<td>8.8</td>
<td>1.2</td>
<td>0.00</td>
</tr>
<tr>
<td>Queensland</td>
<td>0.00</td>
<td>0.7</td>
<td>4.2</td>
<td>0.1</td>
<td>0.00</td>
</tr>
<tr>
<td>New South Wales</td>
<td>0.00</td>
<td>0.2</td>
<td>1.4</td>
<td>0.3</td>
<td>0.00</td>
</tr>
<tr>
<td>Victoria</td>
<td>1.05</td>
<td>28.5</td>
<td>47.6</td>
<td>0.0</td>
<td>0.00</td>
</tr>
<tr>
<td>Tasmania</td>
<td>61.98</td>
<td>91.8</td>
<td>93.7</td>
<td>0.0</td>
<td>0.00</td>
</tr>
<tr>
<td>South Australia</td>
<td>0.13</td>
<td>2.1</td>
<td>6.3</td>
<td>0.0</td>
<td>0.00</td>
</tr>
<tr>
<td>Western Australia</td>
<td>0.03</td>
<td>1.7</td>
<td>3.9</td>
<td>3.5</td>
<td>0.00</td>
</tr>
<tr>
<td>Northern Territory</td>
<td>0.55</td>
<td>9.3</td>
<td>19.7</td>
<td>0.0</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Table 3 Percentage areas in different categories for spring 2015 rainfall. ‘Severe deficiency’ denotes rainfall at or below the 5th percentile. Areas in decile 1 include those in ‘severe deficiency’, which in turn includes areas which are ‘lowest on record’. Areas in decile 10 include areas which are ‘highest on record’. Percentage areas of highest and lowest on record are given to two decimal places because of the small quantities involved; other percentage areas are to one decimal place.
### Table 4: Summary of the seasonal maximum temperature ranks and extremes on a national and State basis for spring 2015.

Summarized in the last column goes from 1 (lowest) to 106 (highest) and is calculated over the years 1910 to 2015 inclusive.\(^\text{14}\)

<table>
<thead>
<tr>
<th>Region</th>
<th>Highest seasonal mean maximum (°C)</th>
<th>Lowest seasonal mean maximum (°C)</th>
<th>Highest daily temperature (°C)</th>
<th>Lowest daily maximum temperature (°C)</th>
<th>Area-averaged temperature anomaly (°C)</th>
<th>Rank of area-averaged temperature anomaly (of 106 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>39.9 °C at Fitzroy Crossing (WA)</td>
<td>9.7 °C at kunanyi (Mount Wellington Pinnacle) (Tas)</td>
<td>46.8 °C at Roebourne (WA) on 15 November</td>
<td>−3.6 °C at Thredbo (Top Station) (NSW) on 23 September</td>
<td>2.08</td>
<td>105</td>
</tr>
<tr>
<td>Queensland</td>
<td>37.6 °C at Century Mine</td>
<td>23.3 °C at Applethorpe</td>
<td>45.0 °C at Urandangi on 26 November and at Winton on 28 November</td>
<td>14.8 °C at Applethorpe on 23 September</td>
<td>1.37</td>
<td>99</td>
</tr>
<tr>
<td>New South Wales</td>
<td>31.9 °C at Mungindi</td>
<td>9.9 °C at Thredbo (Top Station)</td>
<td>44.5 °C at Menindee on 19 November and at Mungindi on 26 November</td>
<td>−3.6 °C at Thredbo (Top Station) on 23 September</td>
<td>2.86</td>
<td>103</td>
</tr>
<tr>
<td>Victoria</td>
<td>27.6 °C at Mildura</td>
<td>11.1 ° at Mount Baw Baw</td>
<td>42.5 °C at Mildura on 19 November</td>
<td>−1.9 °C at Mount Baw Baw on 22 September</td>
<td>2.98</td>
<td>105</td>
</tr>
<tr>
<td>Tasmania</td>
<td>20.1 °C at Bushy Park</td>
<td>9.7 °C at kunanyi (Mount Wellington Pinnacle)</td>
<td>33.6 °C at Friendly Beaches on 6 October and at Campania on 9 November</td>
<td>−2.0 °C at kunanyi (Mount Wellington Pinnacle) on 22 September</td>
<td>1.35</td>
<td>105</td>
</tr>
<tr>
<td>South Australia</td>
<td>33.1 ° at Oodnadatta</td>
<td>18.4 °C at Neptune Island and Cape Willoughby</td>
<td>45.8 °C at Ceduna on 18 November</td>
<td>7.8 °C at Mount Lofty on 2 September</td>
<td>2.71</td>
<td>103</td>
</tr>
<tr>
<td>Western Australia</td>
<td>39.9 °C at Fitzroy Crossing</td>
<td>20.0 °C at Albany</td>
<td>46.8 °C at Roebourne on 15 November</td>
<td>10.7 °C at Rocky Gully on 1 September</td>
<td>2.41</td>
<td>106</td>
</tr>
<tr>
<td>Northern Territory</td>
<td>38.5 °C at Ngukurr</td>
<td>30.2 °C at McCluer Island</td>
<td>44.0 °C at Elliot on 29 November</td>
<td>20.0 °C at Kulgera on 3 and 7 September</td>
<td>1.34</td>
<td>99</td>
</tr>
</tbody>
</table>

---

\(^{14}\) A subset of the full temperature network is used to calculate the spatial averages and rankings shown in Table 4 (maximum temperature) and Table 5 (minimum temperature); this dataset is known as ACORN-SAT (see http://www.bom.gov.au/climate/change/acorn-sat/ for details). These averages are available from 1910 to the present. As the anomaly averages in the tables are only retained to two decimal places, tied rankings are possible.
<table>
<thead>
<tr>
<th>Region</th>
<th>Highest seasonal mean minimum (°C)</th>
<th>Lowest seasonal mean minimum (°C)</th>
<th>Highest daily minimum temperature (°C)</th>
<th>Lowest daily temperature (°C)</th>
<th>Area-averaged temperature anomaly (°C)</th>
<th>Rank of area-averaged temperature anomaly (of 106 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>26.4 °C at Troughton Island (WA)</td>
<td>1.4 °C at kunanyi (Mount Wellington Pinnacle) (Tas)</td>
<td>33.2 °C at Teller (WA) on 23 November</td>
<td>−8.3 °C at Thredbo (Top Station) (NSW) on 24 September</td>
<td>1.22</td>
<td>104.5 (tied)</td>
</tr>
<tr>
<td>Queensland</td>
<td>24.6 °C at Horn Island</td>
<td>9.4 °C at Applethorpe</td>
<td>30.4 °C at Sweers Island on 29 November</td>
<td>−1.9 °C at Stanthorpe on 24 September</td>
<td>1.11</td>
<td>100</td>
</tr>
<tr>
<td>New South Wales</td>
<td>16.8 °C at Cape Byron</td>
<td>1.8 °C at Thredbo (Top Station)</td>
<td>28.3 °C at Fowlers Gap on 20 November</td>
<td>−8.3 °C at Thredbo (Top Station) on 24 September</td>
<td>1.71</td>
<td>104</td>
</tr>
<tr>
<td>Victoria</td>
<td>12.4 °C at Gabo Island</td>
<td>3.4 °C at Mount Baw Baw</td>
<td>22.6 °C at Swan Hill on 19 November</td>
<td>−6.8 °C at Mount Buller on 23 September</td>
<td>1.10</td>
<td>102</td>
</tr>
<tr>
<td>Tasmania</td>
<td>10.9 °C at Swan Island</td>
<td>1.4 °C at kunanyi (Mount Wellington Pinnacle)</td>
<td>17.9 °C at Friendly Beaches on 6 October</td>
<td>−6.4 °C at Liawenee on 17 October</td>
<td>0.43</td>
<td>91 (tied with two other years)</td>
</tr>
<tr>
<td>South Australia</td>
<td>17.0 °C at Mooma</td>
<td>7.3 °C at Naracoorte</td>
<td>29.1 °C at Oodnadatta on 30 November</td>
<td>−3.6 °C at Keith (Munkora) on 23 September</td>
<td>1.68</td>
<td>106</td>
</tr>
<tr>
<td>Western Australia</td>
<td>26.4 °C at Troughton Island</td>
<td>7.5 °C at Wandering</td>
<td>33.2 °C at Teller on 23 November</td>
<td>−2.7 °C at Eyre on 8 September</td>
<td>1.44</td>
<td>105</td>
</tr>
<tr>
<td>Northern Territory</td>
<td>25.9 °C at McCluer Island</td>
<td>13.9 °C at Arltunga and Alice Springs</td>
<td>30.4 °C at Tennant Creek on 29 November</td>
<td>0.8 °C at Alice Springs on 25 September</td>
<td>0.35</td>
<td>74.5 (tied)</td>
</tr>
</tbody>
</table>

Table 5 Summary of the seasonal minimum temperature ranks and extremes on a national and State basis for spring 2015. The ranking in the last column goes from 1 (lowest) to 106 (highest) and is calculated over the years 1910 to 2015 inclusive.
### Table 6

<table>
<thead>
<tr>
<th>Region</th>
<th>Lowest on record</th>
<th>Decile 1</th>
<th>Decile 10</th>
<th>Highest on record</th>
<th>Lowest on record</th>
<th>Decile 1</th>
<th>Decile 10</th>
<th>Highest on record</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>0.00</td>
<td>0.0</td>
<td>76.5</td>
<td>17.52</td>
<td>0.00</td>
<td>0.0</td>
<td>64.5</td>
<td>14.42</td>
</tr>
<tr>
<td>Queensland</td>
<td>0.00</td>
<td>0.0</td>
<td>49.2</td>
<td>0.00</td>
<td>0.00</td>
<td>0.0</td>
<td>50.8</td>
<td>0.83</td>
</tr>
<tr>
<td>New South Wales</td>
<td>0.00</td>
<td>0.0</td>
<td>87.0</td>
<td>11.60</td>
<td>0.00</td>
<td>0.0</td>
<td>98.3</td>
<td>2.61</td>
</tr>
<tr>
<td>Victoria</td>
<td>0.00</td>
<td>0.0</td>
<td>100.0</td>
<td>22.54</td>
<td>0.00</td>
<td>0.0</td>
<td>91.4</td>
<td>0.00</td>
</tr>
<tr>
<td>Tasmania</td>
<td>0.00</td>
<td>0.0</td>
<td>100.0</td>
<td>0.92</td>
<td>0.00</td>
<td>0.0</td>
<td>30.9</td>
<td>0.00</td>
</tr>
<tr>
<td>South Australia</td>
<td>0.00</td>
<td>0.0</td>
<td>99.6</td>
<td>5.56</td>
<td>0.00</td>
<td>0.0</td>
<td>96.2</td>
<td>35.17</td>
</tr>
<tr>
<td>Western Australia</td>
<td>0.00</td>
<td>0.0</td>
<td>86.0</td>
<td>45.53</td>
<td>0.00</td>
<td>0.0</td>
<td>79.2</td>
<td>28.75</td>
</tr>
<tr>
<td>Northern Territory</td>
<td>0.00</td>
<td>0.0</td>
<td>64.9</td>
<td>0.00</td>
<td>0.00</td>
<td>0.0</td>
<td>6.8</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Percentage areas in different categories for spring 2015 using ACORN-SAT data. Areas in decile 1 include those which are ‘lowest on record’. Areas in decile 10 include those which are ‘highest on record’. Percentage areas of highest and lowest

### 14. Drought

During spring 2015, rainfall deficiencies increased in extent or severity in all affected regions.

The 17-month period between July 2014 and November 2015 saw severe rainfall deficiencies (lowest five per cent of historical records) across southern and central South Australia, the western half of Victoria, parts of northern and central Queensland, northern and western parts of Tasmania, and in the far southwest of Western Australia (Figure 25). On much longer timescales, the large anomalies that commenced in 1997 in southeast Australia continued to worsen. In many spots, it was only during the peak of the 2010 to 2012 La Niña that rainfall has significantly exceeded the long-term average.
15. Temperature

Figure 26 and Figure 28 show the maximum and minimum temperature anomalies (relative to 1961-1990) for spring 2015. Figure 27 and Figure 29 respectively show the corresponding temperature deciles for maximum and minimum temperatures during spring 2015, calculated using monthly temperature analyses of the ACORN-SAT data from 1910 to 2015. National and State ranks and extremes are shown in Table 4 and Table 5, while a summary of maximum and minimum temperature deciles is shown in Table 6.

Spring daytime and night time temperatures were warmer than average for most of Australia. Only the Kimberley, the Top End and northern Cape York Peninsula experienced cooler than average nights. Nationally, maximum temperatures were the second-warmest on record for spring and minimum temperatures were the equal second-warmest on record (anomalies of +2.08 °C and +1.22 °C respectively) behind 2014 and 1998 respectively. The national mean temperature was the second-warmest on record for spring at 1.65 °C above the long-term average, with only 2014 (+1.67 °C) being higher. The last three springs have been unprecedented in Australian historical temperature records with the spring record broken in 2013, broken again in 2014, and very close to the hottest on record in 2015.

In terms of mean temperatures, Victoria and Western Australia had their warmest spring on record with anomalies of +2.04 °C and +1.93 °C respectively. New South Wales, Tasmania and South Australia all had their second-warmest spring on record (anomalies of +2.29 °C, +0.90 °C and +2.19 °C respectively), while Queensland (+1.24 °C) was seventh-warmest. Northern Territory was the only State or Territory that did not record an area-averaged spring mean temperature that ranked in the top-10 for all years, but was still much warmer than average with a positive anomaly of +0.85 °C.

Each of the individual months of spring 2015 experienced different temperature patterns: maximum temperatures in September were very much warmer than average across the west of Western Australia while minimum temperatures were
cooler than average for a broad strip that extended from the Kimberley and Top End through the centre to southeast South Australia, western Victoria and New South Wales; October saw exceptional warmth for both maxima and minima across the southern half of Australia, and was record-warm for the nation as a whole, recording the highest mean temperature anomaly for any month (+2.89 °C); November saw above average temperatures across virtually all of Australia for both maxima and minima and was equal second-warmest on record for Australia as a whole (anomaly of +1.87 °C). In the first ten days of October, extreme heat was observed in the southern half of Australia and set new records for early-season warmth (see Bureau of Meteorology 2015). This heat followed on from Australia’s third-driest September on record (see previous section), with large areas in the southwest and southeast of the country having below average soil moisture conditions.

Australian spring temperatures have been warming rapidly since 1950, and recent analyses (Lewis et. al. 2016) have shown that this warming trend dominates the setting of high temperature records at large spatial scales. Adding to the warming trend in 2015 was an established El Niño in the equatorial Pacific Ocean and the positive Indian Ocean Dipole (IOD). For example, Melbourne has recorded 12 of its 16 early-season spring heat events during El Niño years (Bureau of Meteorology, 2015).

Australia’s second-warmest spring on record coincided with the globe’s warmest austral spring on record according to each of the major global datasets. The global temperature anomaly for the austral spring 2015 was reported as +0.96 °C by US Goddard Institute of Space Studies15, +0.53 °C by Japan Meteorological Agency16, +0.96 °C by US National Climatic Data Centre17 and +0.83 °C by UK Met Office Hadley Centre18.

Figure 26 Spring 2015 maximum temperature anomalies (°C) from analysis of ACORN-SAT data.

18 Seasonal anomaly calculated by Bureau of Meteorology http://www.bom.gov.au/web01/ncc/www/clh_chg/timeseries/global_t/0911/global/latest.txt, original data developed by Climatic Research Unit (University of East Anglia) in conjunction with the Hadley Centre (UK Met Office), base period 1961 to 1990 https://crudata.uea.ac.uk/cru/data/temperature/
Figure 27  Spring 2015 maximum temperature deciles from analysis of ACORN-SAT data: decile ranges based on grid-point values for all springs from 1910 to 2015.

Figure 28  Spring 2015 minimum temperature anomalies (°C) from analysis of ACORN-SAT data.
Acknowledgements

The author would like to thank Matthew Wheeler for sharing his knowledge about the MJO and producing the RMM MJO plot, David Jones for information about the MSLP trends, Simon McGree for his discussion about the SPCZ and impacts on rainfall in the Pacific Island Countries, and members of the Climate Monitoring section at the Bureau of Meteorology, including Alex Evans, Blair Trewin and Robert Smalley, for their input and support. Thank you also to Yanhui Brockley and Catherine Ganter for reviewing early drafts of this manuscript and providing helpful comments.

References


