Seasonal climate summary southern hemisphere (summer 2011–12): a mature La Niña, strongly positive SAM and active MJO

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Atmospheric and oceanic conditions in the southern hemisphere are reviewed for the austral summer 2011–12, with emphasis given to the Pacific Basin climate indicators and Australian rainfall and temperature patterns. In the Pacific Basin, the La Niña pattern that developed during spring 2011 strengthened in early summer before gradually decaying. It was the weaker of two consecutive, yet quite different, La Niña events following an extremely strong La Niña in 2010–11. A record strong positive Southern Annular Mode was present during December 2011 and January 2012 and an active Madden–Julian Oscillation affected the tropics for much of summer 2011–12, especially in February. Averaged across the country, Australia was wetter and cooler than usual, but there were large regional variations. Parts of the south and tropical north were drier and warmer than average, to some extent due to a less active than normal North Australian Monsoon. While New South Wales was exceptionally cool during the day and wetter than usual, Tasmania was exceptionally warm and drier than usual.

Introduction
This summary reviews the southern hemisphere and equatorial climate patterns for summer 2011–12, 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’s National Climate Centre and the Centre for Australian Weather and Climate Research (CAWCR).

Indo-Pacific Basin climate
Southern Oscillation Index
The Troup Southern Oscillation Index (SOI) is based on the mean sea-level pressure (MSLP) difference between Tahiti and Darwin. Sustained negative SOI values below around –8 generally indicate an El Niño event, while sustained positive values above around +8 are associated with La Niña periods. Fig. 1 shows SOI values from January 2008 to February 2012.

The SOI shifted from negative to positive in April 2010 following the rapid decay of the 2009–10 El Niño (Campbell 2011). Record or near-record high SOI values were attained in several months between September 2010 and April 2011 (Lovitt 2011, Imielska 2011, Tobin and Skinner 2012), coinciding with one of the strongest La Niña events on record (Beard et al. 2011). More neutral values in winter 2011 increased significantly in spring as another La Niña developed (Cottrill 2012). This La Niña peaked during summer 2011–12, with SOI values of +23.0, +9.4 and +2.5 for December, January and February respectively, and an average summer value of +11.6. The December SOI of +23.0 was exceptional for December, exceeded only in December 2010 (+27.1) and ranking equal second alongside December 1950 (records began in 1876). The December SOI of +23.0 was exceptional for December, exceeded only in December 2010 (+27.1) and ranking equal second alongside December 1950 (records began in 1876).

The individual pressure anomalies at Darwin and Tahiti contributed relatively equally to the SOI. MSLP was well below average in Darwin during December (anomaly −2.4 hPa) but gradually moved closer to average with anomalies of −0.4 hPa in January and +0.7 hPa in February. A strongly
positive Tahitian MSLP anomaly of +2.1 hPa in December gradually decreased with values of +1.5 hPa in January and +1.2 hPa in February.

Multivariate ENSO indices
Multivariate El Niño–Southern Oscillation (ENSO) indices are sometimes regarded as more complete indicators of ENSO than those based solely on one variable (such as pressure or sea surface temperature (SST)) as they bring several atmospheric and oceanic parameters together. One such index is the Climate Diagnostics Center’s Multivariate ENSO Index (MEI), a standardised anomaly index based on pressure, wind, sea and air temperatures, and cloudiness that is computed as a two-month mean (Wolter and Timlin 1993, 1998). MEI values have been calculated since 1950, and can be ranked from 1 to 63 with the lowest values indicating the strongest La Niña events and the highest values indicating the strongest El Niño events.

Fig. 2 shows the MEI between January 2008 and February 2012. Between July 2010 and April 2011 the MEI was at record or near-record low values corresponding to the very strong 2010–11 La Niña (Ganter 2011, Lovitt 2011, Imielska 2011, Tobin and Skinner 2012), reaching a minimum of –2.03 in August–September 2010. Values returned to near zero in mid-2011, indicating neutral ENSO conditions, before dropping again during spring. In summer 2011–12, the MEI dropped from –0.98 in November–December to a low of –1.05 in December–January before increasing to –0.70 in January–February. These values are ranked 14th, 11th and 18th respectively, suggesting a weak-moderate La Niña that started to decay in late summer. Values were much higher than the 2010–11 La Niña, suggesting the event was much weaker. Fig. 2 also shows that the two-year 2010–12 La Niña was stronger than the last two-year La Niña of 2007–2009.

Another multivariate ENSO index is 5VAR, a monthly index based on Darwin and Tahiti MSLP and monthly NINO3, NINO3.4 and NINO4 sea surface temperatures (Kuleshov et al. 2009). The 5VAR index (not shown) follows a similar pattern to the MEI with large negative values from spring 2010 to autumn 2011 briefly returning to near zero in winter 2011 before decreasing again during spring. Monthly values of –1.39, –0.98 and –0.59 for summer 2011–12 were higher than the previous summer (–1.94, –1.67, –1.62), indicating a weaker La Niña than that of 2010–11. 5VAR values peaked in December before weakening during the following months.

Outgoing long-wave radiation
Outgoing long-wave radiation (OLR) over the equatorial Pacific is a good measure of deep convection in the tropics, with increases in OLR indicating decreases in convection and vice versa. Convection in the equatorial region centred about the Date Line is sensitive to changes in the Walker Circulation. Studies such as Hoerling et al. (1997) have shown that during El Niño events, OLR is generally reduced (that is, convection is enhanced) along the equator, particularly near and east of the Date Line. During La Niña events, OLR is often increased (that is, convection is suppressed) along the equator near and west of the Date Line.

The Climate Prediction Center, Washington, computes a standardised monthly OLR anomaly over the equatorial Pacific near the Date Line averaged over 5°S to 5°N and 160°E to 160°W. Monthly values for summer 2011–12 were +1.7, +1.8 and +1.9 W m⁻² indicating suppressed convection in this area, consistent with La Niña conditions. These were

³Note that the method for calculating the MEI changed in March 2011, so the values here may be slightly different to those in earlier papers. Current MEI ranks are available at http://www.esrl.noaa.gov/psd/enso/mei/rank.html


⁵Standardised monthly OLR anomaly data available at http://www.cpc.ncep.noaa.gov/data/indices/olr
the peak values measured during the 2011–12 La Niña, but were lower than the record summer values of +2.1 to +2.4 W m⁻² that occurred during the 2010–11 La Niña (Imielska 2011). Unlike the SOI and MEI, OLR didn’t decrease in late summer 2011–12. This delay in the convective response has been a feature of most of the previous La Niña’s since the 1970s.

Summer 2011–12 average OLR anomalies across the Indian and Pacific oceans are displayed in Fig. 3. OLR anomalies across the equatorial Pacific show a typical La Niña pattern; strong positive anomalies are seen over the western and central areas, with the largest anomalies to the west of the Date Line, while negative anomalies dominate over the Maritime Continent and southwest Pacific. Over Australia OLR anomalies indicate suppressed convection in the north and enhanced convection in the south, which correlates well with the summer rainfall deciles (discussed later). Negative OLR anomalies in the eastern tropical Indian Ocean are consistent with a decline in the positive phase of the Indian Ocean Dipole (also discussed later).

A similar pattern is seen in the temporal evolution of tropical OLR anomalies in this region, shown in Fig. 4. Strong positive OLR anomalies persist near and west of the Date Line throughout summer 2011–12, but are not as strong as those in summer 2010–11. Several bands of enhanced convection (negative OLR anomalies) move from west to east throughout the summer period. These are indicative of the Madden–Julian Oscillation, as discussed in the next section.
Madden–Julian Oscillation

The Madden–Julian Oscillation (MJO) is the major source of intraseasonal variability in the tropics. An active MJO is characterised by an eastward-moving atmospheric anomaly near the equator that typically recurs every 30 to 60 days. It can often be detected by following areas of strong negative OLR anomalies (corresponding to increased convection and rainfall) along the equator; however MJO signals in convection are normally confined to the Indian and western Pacific oceans (Zhang 2005). The real-time Multivariate MJO (RMM) index developed by Wheeler and Hendon (2004) provides a more holistic method for monitoring the MJO, combining OLR data with 850 hPa and 200 hPa zonal winds to measure the state of the MJO each day. This index can be plotted in a phase-space diagram, as shown in Fig. 5 for summer 2011–12.

The MJO was active for much of summer 2011–12. After moving through phases two and three (Indian Ocean, as measured by the RMM—not shown) during late November 2011, it continued into phase four and five (Maritime Continent) in early December before weakening. A second burst of activity in late December and early January progressed through phases four to six (Maritime Continent and western Pacific), then in late January and throughout February a stronger burst moved anticlockwise from phase five through to phase three (from the Maritime Continent through the western Pacific and western hemisphere to the Indian Ocean). The activity was particularly strong in phase seven reaching a peak on 5–6 February. For phase seven (in the western Pacific), an amplitude

\[ \sqrt{(RMM1^2 + RMM2^2)} \]

this large has only been exceeded in December 1996 and March 1997.

Progress of the MJO can also be tracked in the OLR anomaly time-longitude section in Fig. 4. Strong negative OLR anomalies progressed through the Indian Ocean (40°E to 100°E) in late November then weakened as they moved over the Maritime Continent (100°E to 140°E) in early December, coinciding with the first burst of MJO activity. A similar pattern occurred with the second MJO burst in late December and early January, but was shifted slightly to the east as expected from the phase-space diagram. Negative OLR anomalies redeveloped around the Maritime Continent in late January as the third burst of the MJO began, and this time progressed further into the western Pacific (170°E). Negative anomalies became harder to distinguish beyond the Date Line (as expected), but re-emerged near Africa and in the Indian Ocean during mid-to-late February as the MJO reached this area. It is likely that La Niña had an influence on weakening the convective signal of the MJO before it reached the Pacific Ocean during December and January; this behaviour has been noted in the past (for example, Hendon et al. 1999, Wheeler 2008).

Oceanic patterns

Sea surface temperatures

Global SST anomalies for summer 2011–12 are presented in Fig. 6. The pattern is very similar to that for summer 2010–11 (Imielska 2011), and corresponds well with the OLR anomalies shown in Fig. 3.

SST anomalies in the Pacific Ocean show a La Niña-like pattern that initially developed in winter 2010 (Ganter 2011). Negative anomalies extend through the central and eastern tropical Pacific with positive anomalies near northern Australia, in the northwest Pacific, and through parts of the southwest Pacific near and south of Fiji and Tahiti. These anomalies were strongest in December before gradually weakening (not shown). Anomalies were generally smaller in magnitude than in summer 2010–11, suggesting the 2011–12 La Niña was the weaker of the two.

SSTs in the tropical Pacific Ocean gradually warmed during summer 2011–12, shown by the increase in the standard monthly NINO indices and consistent with a weakening La Niña. The warming was greatest in the far east with NINO1+2 increasing from −1.01 to +0.28. The other NINO indices also increased: NINO3 from −0.89 to −0.17, NINO3.4 from −0.95 to −0.66 and NINO4 from −0.90 to −0.54.

The amplitude of the MJO is measured by \( \sqrt{(RMM1^2 + RMM2^2)} \) where RMM1 and RMM2 are described by Wheeler and Hendon (2004). Records began in June 1974.

The warming trend was similar to summer 2010–11, with all areas warming sharply in February. Both NINO3.4 and NINO4 cooled slightly in January before warming in February.

In the tropical Indian Ocean, SST anomalies returned to near normal after a positive Indian Ocean Dipole event during spring 2011 (Cottrill 2012). Further south in the Indian Ocean, anomalies were mostly neutral or positive except for an area around 30°S. Globally, the strongest positive anomalies occurred in the northern and southern Atlantic Ocean to the east of Argentina and Canada. SSTs around Australia were mostly warmer than usual except for an area off the coast of New South Wales.

**Subsurface patterns**

An ENSO event can be recognised in the ocean subsurface by a tilting of the thermocline in the equatorial Pacific. On average, the thermocline (area of distinct vertical temperature gradient between the warm near-surface water and the cooler water below) has a depth of about 150 metres in the western Pacific and rises to around 50 metres in the eastern Pacific.

A La Niña event magnifies this tilt, pushing the thermocline even deeper in the west and allowing it to become shallower in the east. The reverse is true during an El Niño event.

Fig. 7 shows a time-longitude plot of the depth anomaly of the 20 °C isotherm (used as a proxy for the thermocline) across the Pacific Ocean, both along the equator and at 5°N.
Positive (negative) anomalies indicate deeper (shallower) than average values. Upwelling (downwelling) Kelvin waves can be identified as eastward-propagating negative (positive) anomalies in Fig. 7(a), while relatively slow-moving Rossby waves appear as westward-propagating anomalies in Fig. 7(b).

The diagram shows a mature El Niño event in early 2010 with negative anomalies in the west and positive anomalies in the east. During 2010 an upwelling Kelvin wave moved eastwards across the equatorial Pacific Ocean (Fig. 7(a)), triggering the 2010–11 La Niña. The La Niña signal temporarily weakened in winter 2011 as a weak downwelling Kelvin wave reached the eastern Pacific (Tobin 2012). Simultaneously, an upwelling Rossby wave at around 5°N was travelling westwards in early 2011. In mid-2011, this Rossby wave reflected off the western Pacific boundary to re-emerge as another (weaker) upwelling Kelvin wave that reached the eastern Pacific later in the year. A mature La Niña during summer 2011–12 is indicated by the anomalously deep thermocline in the west and anomalously shallow thermocline in the east. Temperature gradients across the Pacific are similar or slightly weaker than the previous summer, indicating a weaker La Niña. Also evident during summer 2011–12 are the first signs of an upwelling Rossby wave in the eastern Pacific at 5°N (a reflection of the upwelling Kelvin wave at the equator) and the initial reflection of a downwelling Rossby wave as a Kelvin wave in the western Pacific at the equator.

Fig. 8 shows a cross-section of equatorial subsurface temperature anomalies by month from November 2011 to February 2012. The cool subsurface anomalies that developed in the central and eastern Pacific during winter and spring 2011 (Cotrill 2012) persisted during summer but weakened slightly in February. Warm anomalies in the western Pacific strengthened throughout the season, consistent with the thermocline deepening. The anomaly pattern closely matched that of summer 2010–11 (Imielska 2011) although the anomalies were slightly weaker and the cool anomalies didn’t extend as far into the central Pacific. The cool anomalies retreated quicker in February 2011 than in February 2012, suggesting the 2010–11 La Niña was faster to break down.

**Atmospheric patterns**

**Surface analyses**

The southern hemisphere summer 2011–12 MSLP pattern is shown in Fig. 9 and the associated anomaly pattern in Fig. 10. The MSLP pattern for summer 2011–12 shows a weak 3-wave pattern with troughs around 10°E, 110°E and 100°W. This 3-wave pattern was marked in December 2011 (not shown) but decayed during January and February. The subtropical ridge has centres of around 1021 hPa in the Indian Ocean, 1020 hPa in the Atlantic and eastern Pacific oceans and a weaker centre of 1018 hPa to the east of New Zealand, while the circumpolar trough has deep low centres below 980 hPa at around 0°E and 90°W with weaker centres near 110°E and 150°W.

MSLP was generally higher than normal in a band between 40°S and 50°S, with strong negative anomalies further to the south peaking at ~8.9 hPa just west of 0°E. This pattern suggests an intense circumpolar trough and a southwards contraction of the subtropical ridge, and has strong similarities with the loading pattern of the Southern Annular Mode (discussed below). North of 40°S anomalies were mixed, with generally positive anomalies in the Australian region and over the Atlantic Ocean and negative anomalies elsewhere. The MSLP anomaly pattern was markedly different to that of summer 2010–11, when the circumpolar trough was much weaker and the subtropical ridge was stronger and further north in the eastern Pacific Ocean (Imielska 2011).

**Mid-tropospheric analyses**

The southern hemisphere summer 2011–12 500 hPa geopotential height, which gives an indication of the steering of surface synoptic systems, is shown in Fig. 11 with the associated anomalies in Fig. 12. The weak 3-wave pattern evident at the surface is more distinct at this level. Again, the 3-wave pattern was strong in December (not shown) but decayed during January and February. The anomaly pattern closely matches the MSLP anomaly pattern with a band of positive anomalies around 40°S to 50°S, strong negative anomalies around Antarctica, and mixed anomalies to the north. A band of negative anomalies extends over southern Australia, which was not evident at the surface. This pattern is quite different to summer 2010–11, when positive anomalies covered much of the southern hemisphere south of 30°S (Imielska 2011).
Southern Annular Mode
The Southern Annular Mode (SAM, also known as the Antarctic Oscillation or AAO) describes the variation of atmospheric pressure between the polar and mid-latitude regions of the southern hemisphere. Positive phases of SAM are characterised by increased pressure over the extratropics, decreased pressure over Antarctica and a poleward contraction of the mid-latitude band of westerly winds and associated storm tracks. Conversely, negative phases of SAM indicate decreased pressure over the extratropics, increased pressure over Antarctica, and an equatorward expansion of these westerlies.

A standardised monthly SAM (or AAO) index is produced by the Climate Prediction Center, Washington. After remaining negative for much of winter and spring 2011 (Tobin 2012, Cottrill 2012), this index shifted strongly positive in December 2011 (+2.57) and January 2012 (+1.58) before dropping to near neutral in February (–0.28). Both the December and January values were the highest respective monthly values on record (since 1979), and the value in December had only ever been exceeded once before, in May 1989 (also a La Niña period). The average summer value of +1.29 was not quite a record due to the large drop in February, but was the second-highest on record for summer behind 2007–08. Studies (for example, L’Heureux and Thompson 2006) have shown a correlation in summer between La Niña events and positive SAM, however these values can not be

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8Analyses are computed using data from the 0000 UTC daily analyses of the Bureau of Meteorology’s Australian Community Climate and Earth System Simulator (ACCESS) model. Anomalies are based on a 1979–2000 climatology obtained from the National Centers for Environmental Prediction (NCEP) II Reanalysis data (Kanamitsu et al. 2002).

9SAM (AAO) index values are derived from daily 700 hPa height anomalies south of 20°S and are available at http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/aoa/aoa.shtml
entirely attributed to the La Niña event. For example, during the strong La Niña of 2010–11 the highest monthly SAM index during summer was only +1.07 (Imielska 2011). Several studies have noted a trend towards positive SAM over time (for example, Marshall 2003).

Indications of a positive SAM during summer 2011–12 are also present in the MSLP and 500 hPa geopotential height anomaly patterns (shown in Fig. 10 and Fig. 12 respectively). Both show a contraction of the mid-latitude westerlies towards Antarctica and bear a strong resemblance to the loading pattern for the positive phase of the SAM (Carvalho et al. 2005).

Hendon et al. (2007) investigated the relationship between the SAM and Australian temperature and rainfall patterns. They found that a positive SAM in summer is correlated with decreased rainfall in western Tasmania and increased rainfall over much of the remainder of southeastern and central Australia, as well as reduced temperatures over large parts of continental Australia except for the tropics. This is broadly consistent with the rainfall and temperature patterns observed in summer 2011–12 (discussed below).

**Blocking**

The blocking index, defined as $BI = 0.5 \left( (u_{25} + u_{30}) - (u_{40} + 2u_{45} + u_{50}) + (u_{55} + u_{60}) \right)$ where $u_x$ is the westerly component of the 500 hPa wind at latitude $x$, is a measure of the strength of the zonal 500 hPa flow in the mid-latitudes (40°S to 50°S) relative to that of subtropical (25°S to 30°S) and high (55°S to 60°S) latitudes. Positive values of the index are generally associated with a split in the mid-latitude westerly flow near 45°S and mid-latitude blocking activity, and most commonly occur in the Australian and western Pacific latitudes (Risbey et al. 2009, Coughlan 1983).

Fig. 13 gives the summer 2011–12 blocking index for each longitude along with climatological values and shows that the blocking index for this season was above average across the southern hemisphere apart from an area in the central Atlantic Ocean (between approximately 25°W and 5°E). This is consistent with the MSLP anomalies in Fig. 10 and the southwards shift of the subtropical ridge. The only area of positive blocking occurred between 150°E and 225°E (135°W), corresponding to the area extending from eastern Australia into the centre of the Pacific Ocean (and in contrast to summer 2010–11 when the blocking index was below average in these longitudes). Fig. 14, a time-longitude section of the daily southern hemisphere blocking index for summer 2011–12, shows several blocking events affected this region with few events elsewhere. The most significant blocking occurred in late January and early February when a high pressure ridge formed around 50°S and several cut-off lows developed to the north. Another event affected a similar area late in February.

**Winds**

Low-level (850 hPa) and upper-level (200 hPa) wind anomalies for summer 2011–12 are shown in Fig. 15 and Fig. 16 respectively. At the 850 hPa level in the southern hemisphere, the strongest anomalies occurred in the central to western Pacific Ocean and indicate enhanced easterly trade winds in this area, consistent with a La Niña event. Westerly anomalies are indicated in the eastern Pacific, which is unusual for a La Niña although similar patterns have been observed in recent years (Wheeler 2008, Mullen 2009, Imielska 2011). Examining anomaly maps for individual months (not shown) reveals the westerly anomalies in the eastern Pacific were mainly due to strong anomalies in February when the La Niña was weakening. Strong westerly anomalies are also present in the tropical Indian Ocean; these anomalies were strongest in December then gradually weakened by February, consistent with the phases of the MJO discussed earlier (Wheeler and Hendon 2004).
Further south at 850 hPa, easterly anomalies encompass much of the globe between 30°S and 50°S with westerly anomalies surrounding Antarctica. This suggests a polewards shift of the mid-latitude westerlies and is consistent with a positive SAM. Strong southeasterly anomalies are present over South America between Uruguay and Bolivia, while anomalies in the Australian region are relatively weak. Of note are the easterly anomalies across the top end of Australia, associated with a weaker than normal monsoon (discussed later).

In the upper levels, the strongest wind anomalies in the southern hemisphere also reflect a La Niña event and positive SAM. Strong westerly anomalies in the tropical Pacific suggest a strengthened Walker Circulation, associated with La Niña events, and stronger than normal westerlies around Antarctica suggest a poleward shift of the polar front jet, consistent with a positive SAM. Stronger than usual westerlies are also seen in the central Indian Ocean and across central parts of Australia and indicate a strengthened subtropical jet in these areas. The enhanced jet in the Indian Ocean has particular significance, with its right exit region near southwest Western Australia suggesting enhanced convection and increased rainfall in this area (as was observed—see below). Easterly anomalies over Tasmania and the Great Australian Bight suggest weakened westerlies, and a cyclonic wind anomaly is present across the east coast of South America. All of these upper level wind anomalies were mainly due to strong anomalies in December 2011, which is consistent with the strongest 3-wave pattern, SAM, and SOI all occurring in December.
Australian region

Rainfall

Fig. 17 (rainfall totals) and Fig. 18 (rainfall deciles) show that most of Australia had above average rainfall during summer 2011–12. Only parts of the tropical north, western Victoria and adjacent southeast South Australia, and Tasmania, were drier than usual. New South Wales and southern Queensland were particularly wet; New South Wales recorded its sixth wettest summer on record (records commenced in 1900) with over 50 per cent of the State receiving rainfall in decile 10 or above (Table 1, Table 2). This contributed to the above average rainfall in the Murray Darling Basin, which recorded its fifth wettest summer with rainfall 75 per cent above normal. Parts of Western Australia were also much wetter than usual.

Several heavy rainfall events contributed to the wetter than normal conditions. In Western Australia, most of the rain occurred early in the summer with two major rain events in southern areas during December breaking several records (see Special Climate Statement 35, Bureau of Meteorology 2011); this coincided with the right exit region of the subtropical jet lying near southwest Western Australia. Further significant rain fell in localised regions of Western Australia with tropical cyclones in January (see below) and slow-moving thunderstorms near Perth on 20 January. Significant falls in northern New South Wales and southern Queensland in late January and early and late February resulted in moderate to major flooding, isolating Moree (New South Wales) in early February. This rainfall coincided with a positive blocking index between 150°E and 225°E (135°W), as mentioned earlier. The heavy rainfall in late February continued into early March and also affected northeastern South Australia and northern Victoria, producing major flooding not seen for several decades in southeastern New South Wales and northern and Gippsland regions of Victoria (see Special Climate Statement 39, Bureau of Meteorology 2012).

For the whole of summer 2011–12 Australia’s area-averaged rainfall was 246 mm, which is 18 per cent above average and the 22nd highest summer total on record. This continued a sequence of mostly wet seasons since summer 2009–10 that combined to give Australia its wettest two calendar years on record in 2010–11 (see Special Climate Statement 38, National Climate Centre 2012c). The individual years 2010 and 2011 were the third and second wettest on record for Australia respectively. La Niña patterns generally produce above average rainfall across Australia (Risbey et al. 2009), and this was the main driver of above average rainfall during this period. Seven of the ten wettest Australian summers have coincided with La Niña events, with the remaining three occurring during neutral ENSO years.

Although summer 2011–12 was wetter than usual, its area-averaged rainfall of 246 mm was over 100 mm below the 367 mm average from summer 2010–11. It was the driest summer since 1988–89. This was mainly due to the below average rainfall in the far north; because Australia’s highest summer rainfalls occur in the far north, significantly wetter or drier than usual conditions in this area have a large effect on the national area-averaged total. The drier than usual conditions in the far north resulted from a lack of monsoon activity, which may be related to the MJO. After a typical onset of the monsoon in the third week of December, an unusually long break occurred during the first three weeks of January and again during most of February. Darwin Airport registered its equal-longest January dry spell, with ten consecutive dry days from the 4th to the 13th, inclusive.

Five tropical cyclones affected the Australian region during summer 2011–12; however only three passed over the Australian continent. The first, tropical cyclone
Grant, affected the top end of the Northern Territory in late December and resulted in heavy falls near Katherine. The highest daily total of 385 mm at Edith Falls Ridge on 27 December was also the highest daily total for summer 2011–12 in Australia. On 12 January, tropical cyclone Heidi crossed the Pilbara coast near Port Hedland (Western Australia), bringing very heavy falls to the east Pilbara and west Kimberley with totals reaching over 300 mm near the cyclone path (including at Mulga Downs). Lastly, tropical cyclone Iggy moved near the Western Australian coast in late January and combined with an active monsoon in the north of the State to bring daily falls of over 100 mm to parts of the Pilbara and Kimberley between 26 and 29 January 2012. The remnants of tropical cyclone Iggy brought heavy falls to southwest Western Australia around 3 February.

### Temperature

Averaged across the whole of Australia, maximum temperatures for summer 2011–12 were 0.55 °C below average and ranked 11th coolest, based on summers since 1950–51 (Table 3). There was considerable variation across the country (Fig. 19, Fig. 20). Large parts of New South Wales, southern Queensland and Western Australia were cooler than usual. New South Wales had its second lowest

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**Table 1.** Summary of the seasonal rainfall ranks and extremes on a national and State basis for summer 2011–12. The ranking in the last column goes from 1 (lowest) to 12 (highest) and is calculated over summers from 1900–01 to 2011–12. Values as at 25 September 2012.

<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</th>
<th>% difference from 1961–1990 mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>1999 at Upper Springbrook</td>
<td>3 at Geraldton Town</td>
<td>385 at Edith Falls Ridge, 27 December</td>
<td>246</td>
<td>91</td>
<td>+18</td>
</tr>
<tr>
<td>Queensland</td>
<td>1999 at Upper Springbrook</td>
<td>32 at Roseberth Station</td>
<td>337 at Cooroy, 25 February</td>
<td>392</td>
<td>85</td>
<td>+21</td>
</tr>
<tr>
<td>New South Wales</td>
<td>1623 at Upper Rous River</td>
<td>55 at Wentworth (Springwood)</td>
<td>290 at Meerschaum Vale, 26 January</td>
<td>272</td>
<td>107</td>
<td>+59</td>
</tr>
<tr>
<td>Victoria</td>
<td>547 at Falls Creek (Rocky Valley)</td>
<td>18 at Sea Lake (Marston Downs)</td>
<td>223 at Pennroyal Creek, 10 February</td>
<td>136</td>
<td>74</td>
<td>+14</td>
</tr>
<tr>
<td>Tasmania</td>
<td>501 at Mount Read</td>
<td>49 at Cressy House</td>
<td>114 at Deal Island, 11 February</td>
<td>182</td>
<td>19</td>
<td>–25</td>
</tr>
<tr>
<td>South Australia</td>
<td>298 at Marree (Clayton)</td>
<td>11 at Moomba</td>
<td>121 at Marree (Clayton), 29 February</td>
<td>82</td>
<td>91</td>
<td>+32</td>
</tr>
<tr>
<td>Western Australia</td>
<td>1045 at Cape Leveque</td>
<td>3 at Geraldton Town</td>
<td>300* at Mulga Downs, 13 January</td>
<td>193</td>
<td>90</td>
<td>+29</td>
</tr>
<tr>
<td>Northern Territory</td>
<td>1446 at Lake Evella</td>
<td>53 at Manners Creek</td>
<td>385 at Edith Falls Ridge, 27 December</td>
<td>286</td>
<td>51</td>
<td>–9</td>
</tr>
</tbody>
</table>

*The gauge overflowed and the true total would have been higher.

**Table 2.** Percentage areas in different categories for summer 2011–12 rainfall. ‘Severe deficiency’ denotes rainfall at or below the fifth percentile. Areas in ‘decile 1’ include those in ‘severe deficiency’, which in turn include those which are ‘lowest on record’. Areas in ‘decile 10’ include those 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 to one decimal place.

<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>0.00</td>
<td>0.1</td>
<td>0.7</td>
<td>18.3</td>
<td>0.37</td>
</tr>
<tr>
<td>Queensland</td>
<td>0.00</td>
<td>0.0</td>
<td>0.3</td>
<td>19.8</td>
<td>1.28</td>
</tr>
<tr>
<td>New South Wales</td>
<td>0.00</td>
<td>0.0</td>
<td>0.0</td>
<td>54.3</td>
<td>0.24</td>
</tr>
<tr>
<td>Victoria</td>
<td>0.00</td>
<td>2.9</td>
<td>5.0</td>
<td>6.5</td>
<td>0.00</td>
</tr>
<tr>
<td>Tasmania</td>
<td>0.00</td>
<td>0.0</td>
<td>9.8</td>
<td>0.0</td>
<td>0.00</td>
</tr>
<tr>
<td>South Australia</td>
<td>0.00</td>
<td>0.1</td>
<td>0.4</td>
<td>10.8</td>
<td>0.00</td>
</tr>
<tr>
<td>Western Australia</td>
<td>0.00</td>
<td>0.0</td>
<td>0.1</td>
<td>18.4</td>
<td>0.17</td>
</tr>
<tr>
<td>Northern Territory</td>
<td>0.00</td>
<td>0.0</td>
<td>1.9</td>
<td>2.2</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Table 3. Summary of the seasonal maximum temperature ranks and extremes on a national and State basis for summer 2011–12. Rankings in the last column are from 1 (lowest) to 62 (highest) based on summers between 1950–51 and 2011–12. Values as at 25 September 2012.

<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</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>39.5 at Marble Bar</td>
<td>13.0 at Mount Wellington</td>
<td>49.4 at Roebourne, 21 December</td>
<td>0.6 at Mount Hotham, 11 January</td>
<td>-0.55</td>
<td>11</td>
</tr>
<tr>
<td>Queensland</td>
<td>38.7 at Birdsville</td>
<td>24.2 at Applethorpe</td>
<td>47.5 at Birdsville, 7 January</td>
<td>13.0 at Applethorpe, 6 December</td>
<td>-0.74</td>
<td>Equal 16</td>
</tr>
<tr>
<td>New South Wales</td>
<td>34.0 at Tibooburra Post Office</td>
<td>14.4 at Thredbo AWS</td>
<td>42.8 at Wanaaring, 7 January</td>
<td>1.3 at Thredbo AWS, 11 January</td>
<td>-1.71</td>
<td>2</td>
</tr>
<tr>
<td>Victoria</td>
<td>31.6 at Walpeup and Ouyen</td>
<td>13.6 at Mount Hotham</td>
<td>43.0 at Dartmoor, 2 January</td>
<td>0.6 at Mount Hotham, 11 January</td>
<td>+0.34</td>
<td>Equal 38</td>
</tr>
<tr>
<td>Tasmania</td>
<td>25.2 at Ouse</td>
<td>13.0 at Mount Wellington</td>
<td>39.4 at Hobart Airport, 25 February</td>
<td>2.5 at Mount Wellington, 4 December</td>
<td>+1.73</td>
<td>60</td>
</tr>
<tr>
<td>South Australia</td>
<td>36.7 at Moomba, Marree Comparison and Oodnadatta</td>
<td>21.7 at Cape Willoughby</td>
<td>46.2 at Ceduna, 1 January</td>
<td>12.8 at Mount Lofty, 29 February</td>
<td>-0.06</td>
<td>Equal 25</td>
</tr>
<tr>
<td>Western Australia</td>
<td>39.5 at Marble Bar</td>
<td>23.0 at Albany</td>
<td>49.4 at Roebourne, 21 December</td>
<td>16.5 at Mount Barker, 13 December</td>
<td>-0.64</td>
<td>14</td>
</tr>
<tr>
<td>Northern Territory</td>
<td>38.8 at Rabbit Flat</td>
<td>31.8 at Black Point</td>
<td>44.3 at Yulara, 25 December</td>
<td>21.0 at Yulara, 29 February</td>
<td>0.00</td>
<td>35</td>
</tr>
</tbody>
</table>

Table 4. As for Table 3, but for minimum temperatures.

<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</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>27.1 at Troughton Island</td>
<td>5.0 at Perisher Valley and Mount Wellington</td>
<td>33.2 at Wittenoom, 22 December</td>
<td>-4.5 at Mount Hotham, 5 December</td>
<td>-0.32</td>
<td>15</td>
</tr>
<tr>
<td>Queensland</td>
<td>26.5 at Sweers Island</td>
<td>14.0 at Applethorpe</td>
<td>32.8 at Birdsville, 21 January</td>
<td>7.9 at Stanthorpe and Applethorpe, 12 January</td>
<td>-0.78</td>
<td>8</td>
</tr>
<tr>
<td>New South Wales</td>
<td>21.0 at Tibooburra Post Office</td>
<td>5.0 at Perisher Valley</td>
<td>29.6 at Bourke, 8 January</td>
<td>-4.3 at Thredbo AWS, 5 December</td>
<td>-0.52</td>
<td>Equal 16</td>
</tr>
<tr>
<td>Victoria</td>
<td>16.4 at Mildura</td>
<td>5.9 at Mount Hotham</td>
<td>26.3 at Cape Otway, 26 February</td>
<td>-4.5 at Mount Hotham, 5 December</td>
<td>+1.00</td>
<td>53</td>
</tr>
<tr>
<td>Tasmania</td>
<td>15.0 at Swan Island</td>
<td>5.0 at Mount Wellington</td>
<td>23.6 at Tasman Island, 26 February</td>
<td>-3.7 at Liawenee, 2 December</td>
<td>+1.04</td>
<td>59</td>
</tr>
<tr>
<td>South Australia</td>
<td>22.3 at Oodnadatta</td>
<td>11.8 at Keith (Munkora)</td>
<td>31.1 at Oodnadatta, 20 January</td>
<td>2.4 at Naracoorte, 5 December</td>
<td>+0.27</td>
<td>33</td>
</tr>
<tr>
<td>Western Australia</td>
<td>27.1 at Troughton Island</td>
<td>13.3 at Rocky Gully</td>
<td>33.2 at Wittenoom, 22 December</td>
<td>3.1 at Eyre, 11 February</td>
<td>-0.16</td>
<td>22</td>
</tr>
<tr>
<td>Northern Territory</td>
<td>26.9 at Cape Don</td>
<td>19.5 at Artunga</td>
<td>30.5 at Jervois, 7 January</td>
<td>10.4 at Artunga, 9 February</td>
<td>-0.63</td>
<td>10</td>
</tr>
</tbody>
</table>

*A high-quality subset of the temperature network is used to calculate the spatial averages and rankings shown in Table 4 (maximum temperature) and Table 5 (minimum temperature). These averages are available from 1950 to the present.*
Table 5. As for Table 2, but for maximum and minimum temperatures.

<table>
<thead>
<tr>
<th>Region</th>
<th>Maximum temperature</th>
<th></th>
<th>Minimum temperature</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lowest on record</td>
<td>Decile 1</td>
<td>Decile 10</td>
<td>Highest on record</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>3.23</td>
<td>17.8</td>
<td>1.9</td>
<td>0.00</td>
</tr>
<tr>
<td>Queensland</td>
<td>0.83</td>
<td>19.8</td>
<td>0.0</td>
<td>0.00</td>
</tr>
<tr>
<td>New South Wales</td>
<td>28.50</td>
<td>62.7</td>
<td>0.0</td>
<td>0.00</td>
</tr>
<tr>
<td>Victoria</td>
<td>0.00</td>
<td>0.0</td>
<td>0.0</td>
<td>0.00</td>
</tr>
<tr>
<td>Tasmania</td>
<td>0.00</td>
<td>0.0</td>
<td>34.4</td>
<td>0.00</td>
</tr>
<tr>
<td>South Australia</td>
<td>0.00</td>
<td>1.0</td>
<td>0.0</td>
<td>0.00</td>
</tr>
<tr>
<td>Western Australia</td>
<td>0.00</td>
<td>19.5</td>
<td>2.1</td>
<td>0.00</td>
</tr>
<tr>
<td>Northern Territory</td>
<td>0.00</td>
<td>0.4</td>
<td>5.2</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Fig. 19. Australian summer 2011–12 maximum temperature anomalies°C.

Fig. 20. Australian summer 2011–12 maximum temperature deciles.

Fig. 21. Australian summer 2011–12 minimum temperature anomalies°C.

Fig. 22. Australian summer 2011–12 minimum temperature deciles.
summer average maximum temperature, with some areas almost four degrees cooler than usual and over 28 per cent of the State having its coolest summer on record (Table 5). December was especially cool with maxima in the northeast reaching six degrees below average (not shown). Conversely, Tasmania, parts of Victoria, the west coast of Western Australia and far northern areas of Western Australia and the Northern Territory were warmer than usual. Tasmania had its third warmest summer since 1950–51 with over a third of the State in the top ten per cent of records. Darwin’s average summer maximum temperature of 32.8 °C was the third highest on record for summer. The spatial pattern of maximum temperatures matches closely the pattern expected in a La Niña year (Jones and Trewin 2000), apart from the warm anomalies in the far north. This is likely related to the long breaks in the monsoon experienced during summer 2011–12. Six of the ten lowest Australian maximum temperatures averaged over summer have coincided with La Niña events, with the remaining four occurring during neutral ENSO years.

Minimum temperatures averaged across Australia for summer 2011–12 were also cooler than usual with an anomaly of –0.32 °C and a summer ranking of 15th coolest for summer 2011–12 were also cooler than usual with an occurring during neutral ENSO years.

Minimum temperatures averaged across Australia for summer 2011–12 were also cooler than usual with an anomaly of –0.32 °C and a summer ranking of 15th coolest (Table 4). This was Australia’s coolest summer minimum temperature since 2001–02, but the single number conceals a large spatial variation. Fig. 21 and Fig. 22 show that although large parts of inland Australia were cooler than usual, the south and far north had above average minima. Tasmania was especially warm with the whole State falling within decile 10, and recorded its fourth highest summer average minimum on record. Victoria had its tenth warmest summer average minimum, while Queensland had its eighth coolest (lowest since 1974–75), and the Northern Territory its tenth coolest (lowest since 1978–79). The pattern of minimum temperatures was also consistent with a La Niña event apart from the warm minima in southern Western Australia (likely related to the above average rainfall in this area) and northern Northern Territory.

Mean temperatures for the season were similarly ranked, with Tasmania having its second warmest and New South Wales its fourth coolest summer mean temperature.

There were several significant temperature events during the season. A notable cold snap affected southeast Australia on 11–12 January as an active cold front crossed the area. Several records were broken and Mount Hotham reached only 0.6 °C, setting a new record low maximum temperature for Australia in January (see Special Climate Statement 36, National Climate Centre 2012a). This was also the coldest day for the whole summer. In contrast, a heatwave occurred in the Pilbara (Western Australia) from 20 to 25 December with numerous sites observing daily maxima over 47 °C and several record-high December temperatures. Temperatures peaked at 49.4 °C at Roebourne on 21 December; this was Australia highest recorded temperature since 1908 and the second highest December temperature on record (see Special Climate Statement 37, National Climate Centre 2012b). Another notable hot spell occurred in Tasmania on 25–26 February. Parts of southeast Tasmania exceeded 36 °C on both these days, which is exceptional for this time of the year.

Acknowledgments
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