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Seasonal climate summary southern hemisphere (autumn 2017): The Great Barrier Reef experiences coral bleaching during ENSO neutral conditions

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Austral autumn 2017 was classified as neutral in terms of the El Niño Southern Oscillation (ENSO), although tropical rainfall and sub-surface Pacific Ocean temperature anomalies were indicative of a weak La Niña. Despite this, autumn 2017 was anomalously warm for most of Australia, consistent with the warming trend that has been observed for the last several decades due to global warming. The mean temperatures for Queensland, New South Wales, Victoria, Tasmania and South Australia were all amongst the top ten. The mean maximum temperature for all of Australia was seventh warmest on record, and amongst the top ten for all states but Western Australia, with a region of warmest maximum temperature on record in western Queensland. The mean minimum temperature was also above average nationally, and amongst top ten for Queensland, Victoria and Tasmania. In terms of rainfall, there were very mixed results, with wetter than average for the east coast, western Victoria and parts of Western Australia, and drier than average for western Tasmania, western Queensland, the south-eastern portion of the Northern Territory, and the far western portion of Western Australia. Dry conditions in Tasmania and southwest Western Australia was likely due to a positive Southern Annular Mode, and the broader west coast and central dry conditions was likely due to cooler eastern Indian Ocean sea surface temperatures (SST) that limited the supply of moisture available to the atmosphere across the country. Other significant events during autumn 2017 were the coral bleaching in the Great Barrier Reef (GBR), cyclone Debbie, and much lower than average Antarctic sea-ice extent. Coral bleaching in the GBR is usually associated on broad scales with strong El Niño events, but is becoming more common in ENSO neutral years due to global warming. The southern GBR was saved from warm SST anomalies by severe tropical cyclone Debbie which caused ocean cooling in late March and flooding in Queensland and New South Wales. Antarctic sea ice extent was second lowest on record for autumn, with the March extent lowest on record.

1 Introduction

Austral autumn in 2017 followed a year of record high surface temperature in 2016 that was dominated by a strong El Niño at the beginning of the year, and transitioned to weak La Niña-like conditions by the end of 2016 and start of 2017 (National Oceanic and Atmospheric Administration 2017). In Australia for 2016, temperatures were very warm (fourth
warmest on record) driven by both El Niño and anthropogenic climate change (Bureau of Meteorology & CSIRO 2017). The Australian national average rainfall in 2016 was approximately 17% above average.

This summary reviews the climate patterns for Austral autumn 2017, 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 2013 to May 2017 is shown in Figure 1 (Troup 1965), together with a five-month weighted moving average to smooth out volatility (Wright 1989). Following positive SOI values for the second half of 2016, the first five months of 2017 alternated between positive and negative. The SOI values for March, April, and May were +5.1, -6.3, +0.5 respectively, giving a neutral seasonal average of -0.2. The five-month weighted moving average finished negative at -3.3 at the end of autumn. The monthly mean sea level pressure (MSLP) anomalies for both Darwin (provided by the Bureau of Meteorology) and Tahiti (provided by Météo France inter-regional direction for French Polynesia) were near to neutral in the three-month period (between -0.2 hPa and +0.8 hPa). The five-month weighted moving average was trending towards negative territory for the autumn period.

![Figure 1: Southern Oscillation Index (SOI), from January 2013 to May 2017, together with a five-month binomially weighted moving average. The Troup SOI 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).](image)

2.2 Composite monthly ENSO index (5VAR) and MEI

The 5VAR is a composite monthly El Niño Southern Oscillation (ENSO) index developed by the Bureau of Meteorology, calculated as the standardised amplitude of the first principal component of monthly Darwin and Tahiti MSLP (data obtained from http://www.bom.gov.au/climate/current/soihtm1.shtml) and monthly NINO3, NINO3.4 and NINO4 sea-surface temperatures (SST) from the National Centers for Environment Prediction (NCEP), obtained from ftp://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/sstoi.indices (Kuleshov et al. 2009). Persistent positive or negative 5VAR
values in excess of one standard deviation are typically associated with El Niño or La Niña events, respectively. The monthly 5VAR values for the period January 2013 to May 2017 are shown in Figure 2, along with the three-month moving average. The autumn period of March/April/May exhibited mildly positive values of +0.16, +0.75, and +0.72 respectively, which were all below the one standard deviation threshold for El Niño events.

Figure 2 5VAR composite standardised monthly ENSO index from January 2013 to May 2017, together with a weighted three-month moving average. The principal component analysis and standardisation of this ENSO index is performed over the period 1950–1999.

The Multivariate ENSO Index (MEI), produced by the Physical Sciences Division of the Earth Systems Research Laboratory (formerly known as the US Climate Diagnostics Centre), is a standardised anomaly derived from a number of atmospheric and oceanic parameters calculated as a two-month mean (Wolter & Timlin 1993, 1998). As for 5VAR, significant positive anomalies are typically associated with El Niño, while large negative anomalies indicate La Niña. The 2017 February/March (-0.08), March/April (+0.74), and April/May (+1.44) values were increasing over the autumn period, similar to the 5VAR, although did not reach significant magnitudes. Contrary to this, rainfall patterns (section 2.3) and subsurface Pacific warming (section 4.2) were more indicative of a weak La Niña signal, and therefore the ENSO indicators pointing towards El Niño had little impact on the Australian climate for autumn 2017.

### 2.3 Tropical Convection and Rainfall

Outgoing long-wave radiation (OLR) is a good 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, OLR is often decreased near the Date Line indicating increased convection (and rainfall) as the Walker Circulation weakens and the warm pool and associated tropical rainfall is displaced to the east. The reverse is true during La Niña events.

Standardised monthly anomalies of OLR are computed for an equatorial region from 5°S to 5°N and 160°E to 160°W by NOAA's Climate Prediction Centre (obtained from http://www.cpc.ncep.noaa.gov/data/indices/olr). Monthly values for autumn were +1.1 Wm⁻², +0.4 Wm⁻², +0.1 Wm⁻² for March, April, May respectively, indicating that convection was sup-
pressed in that area during autumn. The overall autumn 2017 mean was +0.5, with countries in the region reporting
drought conditions e.g. Kiribati (Kiribati Meteorological Service 2017), and the northern Marshall Islands (UNOCHA
ROAP 2017). The spatial pattern of seasonal OLR anomalies across the Asia–Pacific region between 40°S and 40°N for
autumn 2017 are shown in Figure 3. Across Indonesia in locales of Sulawesi, Borneo, and West Sumatra, there were re-
ports of widespread floods and landslides during the autumn period (Davies 2017a). Rainfall associated with cyclone Deb-
bie can be seen crossing the Queensland border in Figure 4. The OLR and rainfall patterns in western Pacific and Indone-
sia are consistent with a weak La Niña, which is in contrast to what the 5VAR and MEI indicators were suggesting for this
period.

Figure 3 OLR anomalies for autumn 2017 (Wm⁻²). Base period is 1979–2000. The mapped region extends from 40°S
to 40°N and 70°E to 180°E.
2.4 Indian Ocean Dipole (IOD)

The Indian Ocean Dipole (IOD) describes the pattern of SST anomalies across the equatorial Indian Ocean. A positive phase of the IOD is characterised by cooler than usual water near Indonesia and warmer than usual water in the tropical western Indian Ocean. This pattern is usually associated with decreased convection, and hence less rainfall in the eastern Indian Ocean and across southern Australia during winter and spring. The opposite is true for a negative IOD phase.

IOD events can be represented by the Dipole Mode Index (DMI) (Saji et al. 1999). The DMI is the difference in SST anomalies between the Western Tropical Indian Ocean (WTIO) node centred on the equator off the coast of Somalia (50°E to 70°E and 10°S to 10°N) and the Southeastern Tropical Indian Ocean (SETIO) 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.

Following a strong negative IOD event that dominated much of 2016, the IOD was mostly weakly positive in autumn 2017. The peak IOD weekly value for this period was +0.38 °C (Figure 5), not quite breaching the threshold value of +0.4 °C for a positive IOD event. The SETIO node was dominated by cool anomalies (Figure 8), as was much of the eastern Indian Ocean. The western and central Indian Ocean saw mostly warm anomalies. This temperature gradient likely contributed to the dry conditions in western and central Australia as it limited the supply of moisture to the atmosphere across the country.
Madden-Julian Oscillation (MJO)

The Madden-Julian Oscillation (MJO) can be characterised as a burst of tropical cloud and rainfall which develops over the Indian Ocean and propagates eastwards over to the Pacific Ocean, and sometimes around the entire global equator (Madden & Julian 1971, 1972, 1994). The MJO typically takes 30 to 60 days to cross from the eastern Indian Ocean to the central Pacific, with six to twelve events per year.

The location of the convective phase of the MJO can be detected by looking for large-scale negative OLR anomalies near the equator, and is objectively monitored by the Real-time Multivariate MJO (RMM) index as described in Wheeler and Hendon (2004). 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 & 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, Zhang & Glick 1999).

The phase-space diagram of the RMM for autumn 2017 is shown in Figure 6, and the evolution of tropical convection anomalies along the equator with time is shown in Figure 7. At the beginning of autumn 2017, the MJO was in an active phase in the Indian Ocean (phase 3) but was soon indiscernible for most of March and April while over the maritime continent and therefore not having an impact on Australian climate. The MJO strengthened back to an active phase at the end of April into the western hemisphere and Africa (phase 8 and 1) until mid May.
Figure 6  Phase-space representation of the MJO index for autumn 2017. Daily values are shown with March in red, April in green and May in blue. The eight phases of the MJO and the corresponding (approximate) locations of the near-equatorial enhanced convective are labelled.

Figure 7  Time-longitude section of daily-averaged OLR anomalies, averaged for 15°S to 15°N, for the period March to May 2017. Anomalies are with respect to a base period of 1979–2010.
4 Oceanic Patterns

4.1 Sea Surface Temperatures (SSTs)

Sea surface temperature anomalies for autumn 2017 from Optimum Interpolation SST (Reynolds et al. 2002) are shown in Figure 8. The majority of the tropical Pacific had warm anomalies greater than 0.5 °C, with regions in the subtropics and eastern Pacific between 1 °C and 2 °C. The cooler anomalies in extratropical north and south Pacific and warm anomalies elsewhere is consistent with the warm phase of the Pacific Decadal Oscillation that has mostly persisted since 2014. Much of the eastern seaboard of Australia was warmer than average, and conversely, cool anomalies persisted in the southern half off the coast of Western Australia. The most significant warm anomaly in the Australian region was along the east coast of Tasmania extending into the Tasman Sea.

![Figure 8](image)
Figure 8 Anomalies of global SST for austral autumn 2017 (°C). Base period is 1981-2010.

The percentile rankings in terms of deciles are shown in Figure 9. The darkest green indicates the lowest SST on record since 1981, and dark orange is the highest on record. There are significant patches of highest on record within the western warm pool, which typically boasts the highest SSTs in the world. Regions of highest on record for autumn 2017 can be seen in the Pacific subtropics and central Indian Ocean, as well as in the far western Pacific Ocean. Warm waters off the coast of South America has been attributed to causing disastrous flooding rains in both Peru and Chile (Davies 2017b, 2017c). Around Australia, there are emerging regions of highest on record around Tasmania, and conversely, small regions of lowest on record off the southern Western Australia coast.
The NINO indices were positive for most of autumn 2017, with NINO4 in March the only exception having a slightly cool anomaly. The highest anomaly values were in the far eastern Pacific in the NINO1+2 region, although these exhibited a weakening trend over the autumn period, as did NINO3. Both NINO4 and NINO3.4 show warming trends across the autumn period. The NINO3 and NINO3.4 indices are both below the El Niño threshold of +0.8°C, although NINO1+2 values for the autumn period are the highest on record for the index in a year that falls outside of a basin-wide El Niño. For March, only the very strong El Niños of 1983 and 1998 have scored a higher NINO1+2 anomaly, with March 2017 even eclipsing the El Niño 2016 event. See Figure 10 for locations of the NINO boxes.

<table>
<thead>
<tr>
<th>Month</th>
<th>NINO1+2 Anomaly (°C)</th>
<th>NINO3 Anomaly (°C)</th>
<th>NINO4 Anomaly (°C)</th>
<th>NINO3.4 Anomaly (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>March</td>
<td>+1.89</td>
<td>+0.57</td>
<td>-0.06</td>
<td>+0.13</td>
</tr>
<tr>
<td>April</td>
<td>+0.93</td>
<td>+0.59</td>
<td>+0.15</td>
<td>+0.32</td>
</tr>
<tr>
<td>May</td>
<td>+0.78</td>
<td>+0.51</td>
<td>+0.29</td>
<td>+0.46</td>
</tr>
</tbody>
</table>

Table 1 Monthly NINO SST anomalies for autumn 2017, obtained from ftp://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/sstoi.indices.
4.1.1 Coral Bleaching

The term coral bleaching refers to the whitening of corals, indicating that the coral has been stressed by a significant change to its preferred environmental conditions which can lead to mortality if adverse conditions persist. In March 2017, the Great Barrier Reef (GBR) experienced its second consecutive mass coral bleaching event following the bleaching event of 2016 (Hughes et al. 2017; Hughes & Kerry 2017). The bleaching driver was elevated SSTs, with the Coral Sea experiencing the second highest autumn SST anomaly since 1900 using the ERSSTv5 dataset shown in Figure 11 (Huang et al. 2017). The only higher anomaly for autumn was in the previous year (2016) which also caused bleaching in the GBR.

![Figure 11](image-url)

Figure 11 Autumn sea surface temperature anomalies in the Coral Sea for the years 1900 to 2017 (ERSSTv5). Averaging region for the Coral Sea spans from latitude -4 °S to -26 °S, and longitude 142 °E to 174 °E.

Unlike the mass bleaching event in 2016 which was attributed to both climate change and amplified by the 2015/2016 El Niño event (Great Barrier Reef Marine Park Authority 2017), autumn 2017 was classified as ENSO neutral. The event is attributed to two main factors; global warming and local weather patterns. The positive warming trend in the Coral Sea is evident across the SST anomalies in Figure 11 and supported by IPCC (2013) that states 93% of global warming has occurred in the ocean between 1971 and 2010. In terms of local weather, a relatively low number of summer storms occurred over the Reef until late in the season, leading to increased surface heating and reduced mixing. The SST anomalies at their peak in mid-March (Figure 12a) were subsequently cooled after the crossing of Cyclone Debbie which made landfall near Airlie Beach (just north of Mackay). The SST anomalies in the northern half of the GBR, which was the primary region of bleaching impact, were largely unaffected by Cyclone Debbie. The final Degree Heating Day (DHD) metric that describes total thermal stress over the 2016/2017 austral summer period is shown in Figure 12b. Areas of highest stress are shown to be the central third of the GBR.
4.2 Equatorial Pacific sub-surface patterns

Cross sectional monthly sub-surface temperature anomalies along the equator, encompassing latitudes 2 °S to 2 °N, is shown in Figure 13. The first two months of autumn 2017 had a persisting warm anomaly west of the date line, and a cold anomaly as low as -3 °C stretching eastward from the date line to 100 °W that looked similar to what occurs during a La Niña event. However, the month of May saw a significant weakening in this anomaly, resulting in largely neutral conditions throughout most of the equatorial Pacific, with small patches of sub-surface warming in the west and a remaining small cool anomaly close to the surface in the far east.
The equatorial thermocline is a region below the surface where the temperature gradient between warm near surface water and cold deep-ocean waters is greatest. The 20 °C isotherm depth is generally located close to this equatorial thermocline. Therefore, measurements of the 20 °C isotherm make a good proxy for the thermocline depth. Positive anomalies correspond to a deeper-than-average thermocline and vice versa, where shifts in the depth of the 20 °C isotherm provide an indication of subsequent temperature changes in SSTs; a deeper thermocline results in less cold water available for upwelling, and therefore warming of surface temperatures. The time-longitude (Hovmöller) diagram for the 20 °C isotherm depth anomaly along the equator for January 2015 to May 2017, obtained from the TAO Project Office, is shown in Figure 14.

The 20 °C isotherm was elevated in western Pacific at the commencement of autumn 2017. By the end of autumn 2017, the 20 °C isotherm was mostly in a neutral position in both the far eastern and western Pacific, and slightly suppressed in the central Pacific. By the end of autumn 2017, both subsurface SST anomalies and isotherm location was close to neutral in much of the Pacific, ending the La Niña-like pattern observed over the summer/autumn period.
Sea level anomalies for autumn 2017 are shown in Figure 14 and reference a datum of mean sea surface height from 1993 to 2017. Both the southern Pacific Ocean and Indian ocean had mostly positive sea level anomalies. Around Australia, anomalies were also positive, with the highest anomalies experienced in the Gulf of Carpentaria and off the coast of New South Wales. Flooding associated with the remnants of cyclone Debbie end of March 2017 at Tweed River and Brunswick River (Maddox 2017) were exacerbated by high tides and anomalously high sea levels along the east coast.
Figure 15  Sea level anomalies are a combination of data from TOPEX/Poseidon, Jason-1, Jason-2 and Jason-3 satellites. Inverse barometer effect not removed; seasonal signal not removed, global trend not removed; glacial isostatic adjustment removed. Data obtained from CSIRO Sea Level, Waves and Coastal Extremes: http://www.cmar.csiro.au/sealevel/sl_data_cmar.html

5 Atmospheric Patterns

5.1 Surface Analysis

The mean sea level pressure (MSLP) pattern for autumn 2017 is shown in Figure 15, computed using data from the 0000 UTC daily analyses of the Bureau of Meteorology's Australian Communicate Climate and Earth System Simulator (ACCESS) model (Puri et al. 2013). The MSLP anomalies are shown in Figure 16, relative to the 1979-2000 climatology obtained from NCEP II Reanalysis data (Kanamitsu & others 2002).

The subtropical ridge formed a band of high pressure that was situated below 30 °S, extending across the Indian Ocean with maximum pressure of 1022.8 hPa. Anomalies show that the high pressure bands were close to climatology for autumn 2017 in the Indian Ocean and across southern Australia. The band of anomalously higher pressure in the Southern Ocean and lower pressure over Antarctica is indicative of a weak positive Southern Annular Mode (See section 5.3). Other high pressure centres associated with the subtropical ridge were located over South Africa (1020.5 hPa) and off the west coast of Chile (1022.2 hPa). The largest significant low pressure was located at the circumpolar trough off Antarctica between 180°E and 270°E, with anomalous pressures of -12.5 hPa. Across the Australian continent, anomalies were generally weak and close to neutral.
Figure 16 Autumn 2017 mean sea level pressure (MSLP; hPa). The contour interval is 5 hPa. The MSLP anomaly field is not shown over areas of elevated topography (grey shading) as the extrapolation to sea level can result in unrealistic structures.

Figure 17 Autumn 2017 mean sea level pressure (MSLP) anomalies (hPa), from a 1979–2000 climatology.
5.2 Mid-tropospheric Analysis

The 500 hPa geopotential height, an indicator of the steering of surface synoptic systems across the southern hemisphere, is shown for autumn 2017 in Figure 17, with associated anomalies shown in Figure 18. The anomaly patterns show average geopotential height across mainland Australia, with positive anomalies across Tasmania extending to a high of +69 gpm approximately over Macquarie Island. These positive heights south of Australia (along with positive MSLP anomalies) reduced the strength of prevailing westerly winds across southern Australia, contributing to a drier south west Western Australia and Tasmania during autumn. The most significant anomalies in the southern hemisphere is the low of -121 gpm that coincides with the location of the lowest MSLP anomaly in Figure 16, and a high of +103 gpm over the Antarctic Peninsula.

Figure 18 Autumn 2017 500 hPa mean geopotential height (gpm).
Figure 19  Autumn 2017 500 hPa mean geopotential height anomalies (gpm), from a 1979–2000 climatology.

5.3 Southern Annular Mode

The Southern Annular Mode (SAM) is a mode of variability that is characterised by the north-south oscillation of westerly winds that circles Antarctica. An index of SAM is the zonal pressure difference between the latitudes 40 °S and 65 °S (Marshall 2003). During a positive SAM phase, westerly winds contract closer to Antarctica, and a negative phase moves westerly winds towards the equator. Figure 19 shows the SAM index as described in Marshall (2003) from 2015 to the end of autumn 2017 (data obtained from https://legacy.bas.ac.uk/met/gjma/sam.html). SAM was mostly positive from 2015 to mid-2016 and was negative for six consecutive months from October 2016 to March 2017. During April and May 2017 SAM returned to the positive phase, which has been shown to reduce rainfall in the far south west corner of Western Australia in autumn (Hendon, Thompson & Wheeler 2007).
Figure 20  Autumn 2017 500 hPa mean geopotential height anomalies (gpm), from a 1979–2000 climatology.

6  Winds

Low-level (850 hPa) and upper-level (200 hPa) wind anomalies are shown in Figure 20 and Figure 21 respectively. Isotach contours are at 5 ms\(^{-1}\) intervals. In the southern central Pacific there was an anomalous feature that exists in both low (high of 6.6 ms\(^{-1}\)) and upper level winds (high of 12.8 ms\(^{-1}\)) that is associated with the very strong low-pressure system off the coast of Antarctica (shown in MSLP anomaly Figure 16). In Australia, the anomalies shown in the low-level are enhanced easterlies across the north and weakened westerlies from the Tasman Sea to the Southern Ocean going over Tasmania. In the upper level, mainland Australia was dominated by an anti-cyclonic system that enhanced the subtropical jet in the southern half and weakened it in the northern half.

Figure 21  Autumn 2017 850 hPa vector wind anomalies (ms\(^{-1}\))
Australian Region

7.1 Rainfall

A rainfall summary for Australia nationwide and each state and territory is listed in Table 2. Rainfall was slightly below average in autumn 2017 over Australia but varied regionally across the country significantly. Victoria, NSW, and Western Australia were slightly above the mean, Queensland was slightly below the mean, and the remainder of the states and territories were well below the mean by an order of 20 to 30 percent. Central Australia experienced very much below average rainfall, primarily in the southern Northern Territory, as did in smaller regions in the far west of Queensland.

The coastline of Queensland had above average rainfall from approximately Townsville all the way south along the Queensland and NSW coast to the Victorian border. Western Victoria was mostly above average. Southern Western Australia had very much below average rainfall in the west, however the remainder of the state was either average or above average. Severe tropical cyclone Debbie brought heavy rainfall and floods to parts of eastern Queensland and northeastern New South Wales at the end of March. The two highest daily totals for Queensland and New South Wales shown in Table 2 (Mt Jukes and Chillingham respectively) for autumn 2017 were associated with cyclone Debbie. Heavy rain in Queensland on 18 and 19 May also contributed to high seasonal totals between the Gulf Country and the tropical and central coasts, with some locations setting monthly rainfall records for May in part due to this event.

Rainfall deciles indicate where rainfall amounts rank in terms of the 1900 to 2017 record, which are allotted into ten percentile bins (Figure 24). Above average rainfall was also observed in western Victoria and adjacent parts of New South Wales border country and southeastern South Australia; an area of central South Australia; the coastal Top End in the Northern Territory; and areas of Western Australia's between the southern Kimberley and southern interior, and along a broad strip extending from the eastern Pilbara coast to the western Eucla coast.

Rainfall for the season was below average for much of western and southwestern Queensland, extending across the southern half of the Northern Territory; on each of the Yorke, Eyre, and Fleurieu peninsulas in South Australia; across the west of Western Australia from the far western Pilbara to the south coast around Esperance. In Western Australia the South West Land Division recorded its 11th-driest autumn on record, and driest autumn since 2012, and was the driest autumn for at least two decades at many locations. In Tasmania, western and southern regions were below average.
Figure 23  Autumn 2017 rainfall totals (mm) for Australia.

Figure 24  Autumn 2017 rainfall deciles for Australia: decile ranges based on grid-point values over all autumns from 1900 to 2017.
<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 total (mm)</th>
<th>Rank of area-averaged rainfall</th>
<th>Difference from mean (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>1891.0 at Mount Jukes (QLD)</td>
<td>zero at several locations</td>
<td>635.0 at Mt Jukes (QLD) on 30 March</td>
<td>113.3</td>
<td>69</td>
<td>6.0% below mean (= 120.50)</td>
</tr>
<tr>
<td>Queensland</td>
<td>1891.0 at Mount Jukes</td>
<td>zero at several locations</td>
<td>635.0 at Mt Jukes on 30 March</td>
<td>156.5</td>
<td>73</td>
<td>4.1% below mean (= 163.14)</td>
</tr>
<tr>
<td>New South Wales</td>
<td>1383.5 at Chillingham</td>
<td>zero at Glenbrook Bowling Club</td>
<td>507.0 at Chillingham on 31 March</td>
<td>154.8</td>
<td>93</td>
<td>8.4% above mean (= 142.74)</td>
</tr>
<tr>
<td>Victoria</td>
<td>451.2 at Wyelangta</td>
<td>55.8 at Avoca (Homebush)</td>
<td>103.2 at Woomelang on 21 April</td>
<td>164.3</td>
<td>81</td>
<td>4.8% above mean (= 156.81)</td>
</tr>
<tr>
<td>Tasmania</td>
<td>640.8 at Mount Read</td>
<td>59.6 at Bridgewater (Treatment Plant)</td>
<td>147.6 at Cornwall on 21 May</td>
<td>262</td>
<td>21</td>
<td>23.0% below mean (= 340.42)</td>
</tr>
<tr>
<td>South Australia</td>
<td>229.0 at Lucindale Post Office</td>
<td>3.6 at Mount Dare</td>
<td>98.8 at Lucindale Post Office on 21 March</td>
<td>42.95</td>
<td>58</td>
<td>23.7% below mean (= 56.32)</td>
</tr>
<tr>
<td>Western Australia</td>
<td>393.4 at Port Hedland Airport</td>
<td>zero at several locations</td>
<td>193.0 at Yeeda on 13 March</td>
<td>94.7</td>
<td>66</td>
<td>5.0% above mean (= 90.23)</td>
</tr>
<tr>
<td>Northern Territory</td>
<td>1015.7 at Lake Evella</td>
<td>zero at several locations</td>
<td>384.0 at Point Fawcett on 5 March</td>
<td>102.5</td>
<td>49</td>
<td>26.5% below mean (= 139.34)</td>
</tr>
</tbody>
</table>

Table 2 Summary of the seasonal rainfall ranks and extremes on a national and state basis for autumn 2017. The ranking in the 2nd last column goes from 1 (lowest) to 118 (highest) and is calculated over the years 1900 to 2017 inclusive.

7.2 Drought

Rainfall deficiencies are used to indicate areas of drought, and are assessed by determining regions in the lowest 10% of records (serious deficiency), lowest 5% (severe deficiency), and lowest on record. Deficiencies for autumn 2017 are shown in Figure 25. The most prominent region of rainfall deficiency was along the west coast of Western Australia, spanning from Gascoyne, through the Mid West and into the Wheatbelt. Small regions of lowest on record were experienced near the coast from Carnarvon to Shark Bay. The Northern Territory also had a region of serious to severe deficiency south of Tennant Creek reaching across the borders into Queensland and South Australia. Serious rainfall deficiencies also emerged in pockets of the southern South West Land Division in Western Australia and on the Eyre Peninsula in South Australia. In Tasmania, rainfall deficiencies covered the western highlands region.
7.3 Temperature

A subset of the full temperature network was used to calculate the spatial averages and rankings for Australia, and all states and territories shown in Table 3 (maximum temperature) and Table 4 (minimum temperature). This dataset is known as ACORN-SAT (see http://www.bom.gov.au/climate/change/acorn-sat/ for details) and extends from 1910 to present. The mean maximum temperature for autumn 2017 was +1.21 °C above average for Australia, ranking 7th warmest out of 108 autumn periods on record. All states except New South Wales and Western Australia ranked in the top ten autumns for maximum temperature. Regions in western Queensland and into the Northern Territory were highest on record. National mean minimum temperatures were +0.42 °C above average, although only Queensland, Victoria, and Tasmania were within the top ten autumns for minimum temperature.

Maximum temperatures for autumn were above to very much above average for most of the Northern Territory, along the eastern border of Western Australia south of the Kimberley, across all of South Australia, most of Queensland, inland New South Wales, all of Victoria, and very much above average for all of Tasmania, and an area of Western Australia between the western Pilbara and Central Wheat Belt. There was a region of warmest on record for autumn in western Queensland, reaching across the border into the Northern Territory.

Mean minimum temperatures were also above to very much above average for most of eastern Australia, the east of South Australia, and the northern half and far southeast of the Northern Territory. Minimum temperatures were mostly near average for Western Australia during autumn, although they were cooler than average for an area spanning the southwestern Northern Territory and the adjacent eastern interior and southeastern Kimberley in Western Australia. There was a small region of very much below average minimum temperatures on the Western Australia coast west of the South Australia border, and additional pockets of below average minimum temperatures north east of the wheat belt and near Karratha.
Figure 26  Autumn 2017 maximum temperature anomalies (°C) from analysis of ACORN-SAT data.

Figure 27  Autumn 2017 maximum temperature deciles from analysis of ACORN-SAT data: decile ranges based on grid-point values for all autumns from 1910 to 2017.
Figure 28  Autumn 2017 minimum temperature anomalies (°C) from analysis of ACORN-SAT data.

Figure 29  Autumn 2017 minimum temperature deciles from analysis of ACORN-SAT data: decile ranges based on grid-point values for all autumns from 1910 to 2017.
<table>
<thead>
<tr>
<th>Region</th>
<th>Highest seasonal mean maximum (°C)</th>
<th>Lowest seasonal mean maximum (°C)</th>
<th>Highest daily maximum 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>35.9 at Century Mine (QLD)</td>
<td>9.5 at Mount Hotham (VIC)</td>
<td>44.6 at Mandora (WA) on 5 March</td>
<td>-3.7 at Thredbo AWS (NSW) on 31 May</td>
<td>1.21</td>
<td>102</td>
</tr>
<tr>
<td>Queensland</td>
<td>35.9 at Century Mine</td>
<td>21.2 at Applethorpe</td>
<td>44.0 at Urandangi Aerodrome on 28 March</td>
<td>13.5 at Applethorpe on 27 April</td>
<td>1.54</td>
<td>102</td>
</tr>
<tr>
<td>New South Wales</td>
<td>29.5 at Mungindi Post Office</td>
<td>9.5 at Thredbo AWS</td>
<td>44.0 at Wilcannia Aerodrome AWS on 27 March</td>
<td>-3.7 at Thredbo AWS on 31 May</td>
<td>1.01</td>
<td>97</td>
</tr>
<tr>
<td>Victoria</td>
<td>25.4 at Mildura Airport</td>
<td>9.5 at Mount Hotham</td>
<td>38.0 at Walpeup Research on 2 March</td>
<td>-3.3 at Mount Hotham on 31 May</td>
<td>1.21</td>
<td>101</td>
</tr>
<tr>
<td>Tasmania</td>
<td>20.2 at Launceston (Ti Tree Bend)</td>
<td>9.8 at Kunanyi (Mount Wellington Pinnacle)</td>
<td>33.2 at Bushy Park (Bushy Park Estates) on 14 March</td>
<td>-0.6 at Kunanyi (Mount Wellington Pinnacle) on 30 May</td>
<td>0.95</td>
<td>101</td>
</tr>
<tr>
<td>South Australia</td>
<td>30.2 at Moomba Airport</td>
<td>18.4 at Mount Lofty</td>
<td>44.5 at Ceduna Amo on 26 March</td>
<td>8.5 at Mount Lofty on 28 May</td>
<td>1.46</td>
<td>102</td>
</tr>
<tr>
<td>Western Australia</td>
<td>35.7 at Mandora</td>
<td>20.3 at Shannon</td>
<td>44.6 at Mandora on 5 March</td>
<td>11.5 at Manjimup on 21 May</td>
<td>0.73</td>
<td>84</td>
</tr>
<tr>
<td>Northern Territory</td>
<td>35.1 at Mcarthur River Mine Airport</td>
<td>30.3 at Yulara Airport</td>
<td>42.0 at Curtin Springs on 26 March</td>
<td>18.2 at Arltunga on 31 May</td>
<td>1.66</td>
<td>102</td>
</tr>
</tbody>
</table>

Table 3: Summary of the seasonal maximum temperature ranks and extremes on a national and state basis for autumn 2017. The ranking in the last column goes from 1 (lowest) to 108 (highest) and is calculated over the years 1910 to 2017 inclusive. 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 minimum 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>27.4 at Browse Island (WA)</td>
<td>1.3 Perisher Valley AWS (NSW)</td>
<td>30.2 at Oodnadatta Airport (SA) on 27 March</td>
<td>-8.5 at Thredbo AWS (NSW) on 3 May</td>
<td>0.42</td>
<td>88.5</td>
</tr>
<tr>
<td>Queensland</td>
<td>25.9 at Coconut Island</td>
<td>10.3 at Applethorpe</td>
<td>29.8 at Boulia Airport on 29 March</td>
<td>-2.7 at Warwick on 31 May</td>
<td>0.98</td>
<td>99</td>
</tr>
<tr>
<td>New South Wales</td>
<td>17.1 at South West Rocks (Smoky Cape Lighthouse)</td>
<td>1.3 at Perisher Valley AWS</td>
<td>27.8 at Fowlers Gap AWS on 27 March</td>
<td>-8.5 at Thredbo AWS on 3 May</td>
<td>0.87</td>
<td>95</td>
</tr>
<tr>
<td>Victoria</td>
<td>14.2 at Wilsons Promontory Lighthouse</td>
<td>3.3 at Mount Hotham</td>
<td>23.2 at Echuca Aerodrome on 16 March</td>
<td>-6.3 at Mount Hotham on 3 May</td>
<td>0.95</td>
<td>99</td>
</tr>
<tr>
<td>Tasmania</td>
<td>13.4 at Hogan Island</td>
<td>2.5 at Liawenee</td>
<td>21.1 at Launceston (Ti Tree Bend) on 16 March</td>
<td>-4.6 at Liawenee on 4 May</td>
<td>0.72</td>
<td>100</td>
</tr>
<tr>
<td>South Australia</td>
<td>16.2 at Moomba Airport</td>
<td>8.8 at Keith (Munkora)</td>
<td>30.2 at Oodnadatta Airport on 27 March</td>
<td>-2.8 at Yunta Airstrip on 31 May</td>
<td>0.36</td>
<td>77</td>
</tr>
<tr>
<td>Western Australia</td>
<td>27.4 at Browse Island</td>
<td>8.4 at Jarrahwood</td>
<td>30.0 at Legendre Island on 7 March</td>
<td>-0.2 at Jarrahwood on 1 May</td>
<td>-0.10</td>
<td>59</td>
</tr>
<tr>
<td>Northern Territory</td>
<td>26.0 at Mccluer Island</td>
<td>12.8 at Alice Springs Airport</td>
<td>30.0 at Centre Island on 30 March</td>
<td>-2.0 at Arltunga on 11 May</td>
<td>0.3</td>
<td>80</td>
</tr>
</tbody>
</table>

Table 4 Summary of the seasonal minimum temperature ranks and extremes on a national and State basis for autumn 2017. The ranking in the last column goes from 1 (lowest) to 108 (highest) and is calculated over the years 1910 to 2017 inclusive. As the anomaly averages in the tables are only retained to two decimal places, tied rankings are possible.
8 Southern Hemisphere

Temperatures in the southern hemisphere were the warmest on record for land and ocean in autumn 2017 according to the National Aeronautics and Space Administration (NASA) dataset (Hansen et al. 2010), second warmest on record for land and ocean in the National Oceanic and Atmospheric Administration (NOAA) dataset (Smith & Reynolds 2005), and third warmest in the United Kingdom Meteorological Office Hadley Centre/Climatic Research Unit, University of East Anglia (HadCRU) dataset (Morice et al. 2012). The differences in ranks between the three datasets reflect the different methods they use for assessing temperatures over data-sparse land measurements and is typically greater in the southern hemisphere than the northern due to the lower data density.

Land temperatures in autumn 2017 were mostly warmer than average in the southern hemisphere, with the only significant exception being the south-west coast of Western Australia (Figure 30). Both southern Africa and eastern Australia had significant expanses of up to +1 °C warmer than the 1981-2010 average. South America was mostly up to +0.5 °C warmer than average. New Zealand's North Island experienced temperatures up to +1.2 °C above the 1981-2010 average, with even higher temperatures in the Bay of Plenty and Auckland (NIWA 2017).

![Figure 30 Mean temperature anomalies (°C) from a 1981-2010 base period for March to May 2017 (source: National Centers for Environmental Information).](image)

Seasonal precipitation percentages with reference to normal from 1951 to 2000 are shown for autumn 2017 in Figure 31. Above-average seasonal precipitation was observed across the west coast of, and southern, South America, with severe flooding reported in Argentina, Peru, and Chile (Davies 2017b, 2017c; World Meteorological Organization 2018). Flooding along the west coast of South America is typical in the late phase of El Niño, although autumn 2017 was defined as ENSO neutral. Sea surface temperatures off the Peruvian coast were +1.89 °C warmer than average in the NINO1+2 region (Table 1) which is indicative of a "coastal El Niño" (Takahashi & Martínez 2017). Drier-than-average conditions were notable across northeastern South America and central and western Australia. New Zealand's North Island experi-
enced more than 150% of the normal autumn rain, with several locations recording their wettest autumn on record (NIWA 2017).

Figure 31 Precipitation as a percentage of the 1951-2000 average for March to May 2017 (source: Global Precipitation Climatology Centre).

8.1 Antarctic Climate

Sea ice extent in the Antarctic was 3rd lowest on record since 1978 for the autumn 2017 period. Sea ice extent in March 2017 was lowest on record for that month. The significantly low sea ice extent follows near average conditions in autumn 2016, and a period of record high sea ice extent in the four years from 2011 to 2015, with record highs ending in spring 2015 (Martin 2016). The SAM index is a known commodity in determining Antarctic sea ice extent, with negative SAM phases linked to lower sea ice extents (Hall & Visbeck 2002). This is confirmed to be the case for the period leading up to and including the start of autumn 2017, when a negative SAM from October 2016 to March 2017 led to the record low for March.
Figure 32 Antarctic sea ice extent. Average is calculated from 1981 to 2010. Data from National Snow and Ice Data Center (http://nsidc.org/data)

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