Seasonal climate summary southern hemisphere (autumn 2005): an exceptionally warm and dry autumn across Australia

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Southern hemisphere circulation patterns and associated anomalies are reviewed for the 2005 austral autumn season. Emphasis is given to the Pacific Basin climate indicators and Australian rainfall and temperature patterns.

Autumn, and especially April, was remarkable in Australia for the temperature anomalies across the continent during this period. Autumn 2005 was the warmest on record across Australia. Likewise, the Australian mean temperature in April was nearly 1°C above the previous April record, and well above the previous anomaly recorded for any month. Autumn also saw records set across Australia for maximum temperatures and a warmer than average season for minimum temperatures.

Both atmospheric and oceanic ENSO indicators were generally neutral throughout the season. With autumn being a key period for development of ENSO events, known triggers such as anomalously warm subsurface temperatures, present at the start of the season, were monitored closely. However, no ENSO event, either warm or cold, was initiated during the season with conditions persisting generally neutral into winter.

Introduction

Averaged across the country, autumn 2005 was the warmest since records began in 1950. No State recorded a negative (i.e. below average) mean temperature anomaly. South Australia and Western Australia recorded their highest autumn mean temperature on record. The Northern Territory recorded its second highest, New South Wales its third highest and Queensland its fourth highest. Though this was mainly driven by the large anomalies in the maximum temperature, which was the highest on record Australia-wide and in many states, minimum temperatures were also significantly higher than average over the western two-thirds of the country. Australia-wide it was the seventh warmest autumn on record in terms of minimum temperatures. This was all the more remarkable as Australia recorded its tenth driest autumn (of 106 years of records), dry conditions being generally associated with below-average minimum temperatures. This was especially evident in April, a remarkable month which, on a national scale, saw the most extreme temperature anomalies ever recorded for Australia.

The principal contributor to the abnormal warmth, especially in April, was persistent high temperatures in the northern half of Australia, associated with a relatively weak tropical wet season for 2004/05.

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However, temperatures were far warmer than would have been expected given the rainfall anomalies, reflecting global and regional long-term warming trends. Thus the record warmth was attributed to the combined effects of the long-term warming trend and the dry conditions over Australia.

Autumn also saw the end of what had been a very active tropical cyclone season in the South Pacific. Tropical cyclone *Ingrid*, which affected Australia in March, was the first tropical cyclone in the historical record to affect, as a severe tropical cyclone, the coastlines of three different States or Territories.

After the brief ENSO-like coupling and associated large drop in the Southern Oscillation Index (SOI) during February (Beard 2005), conditions returned to near normal in March. After a small positive SOI value in March, the SOI then decreased. Oceanic ENSO indicators persisted neutral to weak-warm throughout the season. With autumn a key period for the development for ENSO events, the positive sub-surface anomaly present on the thermocline at the start of the season was watched for its effect on equatorial sea-surface temperatures. However, after a brief surface warming in the eastern equatorial Pacific during late April-early May, an upwelling wave cancelled the positive anomalies and brought cooler conditions. Thus the ENSO pattern continued neutral into winter.

Data

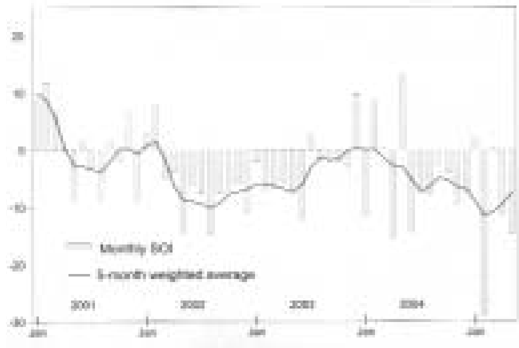
The main sources of information used for this summary were the *Climate Monitoring Bulletin* (Bureau of Meteorology, Melbourne, Australia) and the *Climate Diagnostics Bulletin* (Climate Prediction Center, Washington D.C., USA). Data sources are given in the Appendix.

Pacific Basin climate indices

The Southern Oscillation Index (SOI)*

The extreme negative SOI value of –29.1 of February 2005, the lowest since February 1983, did not persist into March. Instead the March value showed a strong rebound to a small positive value of +0.2, with a return to more normal patterns of convection over the Pacific. The approximate 30-day SOI peaked at +7.8 on 10 April. The SOI then showed a rapid fall and was strongly negative in the second half of the season, with April and May values of –11.2 and –14.5 respectively (see Fig. 1). The seasonal mean was –8.5.

Fig. 1 Southern Oscillation Index, January 2001 to May 2005 inclusive. A curve of five-month moving averages has been superimposed on the graph. Means and standard deviations based on the period 1933-92.



As discussed in Collins (2005) and Bettio and Watkins (2005), Australia's National Climate Centre did not classify 2004 as an El Niño year, despite the presence of weak warm sea-surface temperatures (SSTs) at El Niño levels, because of the lack of coupling between ocean and atmosphere, evident from the failure of the majority of indicators to reach El Niño levels for a sustained period. However, during late February and early March 2005, there was evidence of atmospheric coupling with the weak warm SSTs still present in the central Pacific (Beard 2005).This resulted in positive mean sea-level pressure (MSLP) anomalies in Darwin due to a weakening of the Australian monsoon, and record low MSLPs at Tahiti due to enhanced convection in this region (Beard 2005). However, by late March these anomalies had returned to closer to their average values, with a weaker positive anomaly (+0.7 hPa) at both Darwin and Tahiti. The return to a negative SOI value in April was mainly driven by the continued positive anomaly in Darwin (+1.4 hPa) as Tahiti recorded a zero anomaly. The SOI continued negative in May (–14.5) with a positive anomaly in Darwin (+1.2 hPa) and a negative anomaly at Tahiti (–0.6 hPa).

Multivariate ENSO index

This neutral-weak warm view of the El Niño conditions is supported by the Climate Diagnostics Center (CDC) Multivariate ENSO Index (MEI) (Wolter and

*The SOI used here is ten times the monthly anomaly of the difference in mean sea-level pressure between Tahiti and Darwin, divided by the standard deviation of that difference for the relevant month, based on the period 1933-1992.

Timlin 1993, 1998), an index derived from a number of atmospheric and oceanic parameters typically associated with El Niño and La Niña, with negative values indicating cooler conditions and positive values indicating warmer conditions. The March/April and April/May values of the MEI were +0.56 and +0.71 respectively. When ranked against historical values, these values indicate weak El Niño conditions.

Outgoing long wave radiation

The time series from January 2001 to May 2005 of monthly standardised outgoing long wave radiation (OLR) is shown in Fig. 2. These data were provided by the Climate Prediction Center, Washington D.C. (CPC 2005), and are a measure of the amount of long wave radiation emitted from an equatorial region centred about the date-line (5°S to 5°N, 160°E to 160°W). Negative (positive) values of the OLR index suggest cooler (warmer) black-body temperatures, which tend to be associated with an increase (decrease) in high cloud amount. (This may also signal increased (decreased) rainfall.) Studies have shown that during El Niño events, OLR is generally reduced (i.e. convection is generally enhanced) along the equator, particularly near and east of the date-line. During La Niña events, OLR is often increased (i.e. convection is often suppressed) over the same region (Vincent et al. 1998).

During the individual months of autumn 2005, the OLR anomalies for the region showed some fluctuation about the mean. After the strongly negative February value (–2.3), the lowest value since the 1997/98 El Niño (Beard 2005), there was a rebound to average or slightly reduced convective activity in the region, with a positive value of +0.4 for March. This was indicative of an end to the ENSO-like coupling between the ocean and atmosphere that had occurred during February. Though convective activity then increased slightly, it was still far below the February level, with values of –0.4 for April and –0.1 for May.

There were two clearly-defined pulses of increased convective activity associated with the Madden-Julian Oscillation (MJO) during autumn. The MJO is characterised by waves of enhanced or suppressed convective activity propagating eastward across the Indian Ocean and northern Australian tropics to the western, or sometimes central, Pacific (Wheeler and Weickman 2001). It usually has a clear signal in the OLR field. As discussed, there was little convective activity during March, however April and May saw MJO-associated convection reach the date-line. The first pulse, initiated in late March, propagated over the maritime continent into the western Pacific, reaching the date-line by mid-April. This was reflected in enhanced convection over the Australian longitudes in early to mid April. The second pulse was initiated in the Indian Ocean in late April to early May and propagated rapidly east, reaching the date-line by mid-May.

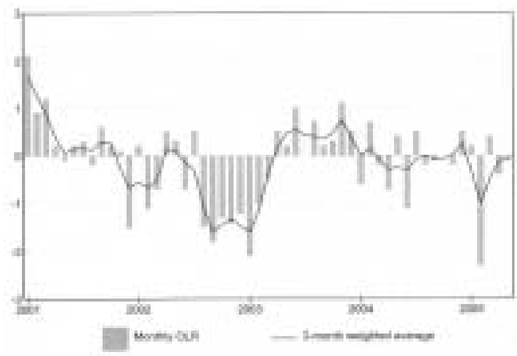


Fig. 2 Standardised anomaly of monthly outgoing long wave radiation averaged over 5°N-5°S and 160°E-160°W, for January 2001 to May 2005 inclusive. Negative (positive) anomalies indicate enhanced (reduced) convection and rainfall. Anomalies are based on a 1979-95 base period. After CPC (2005).

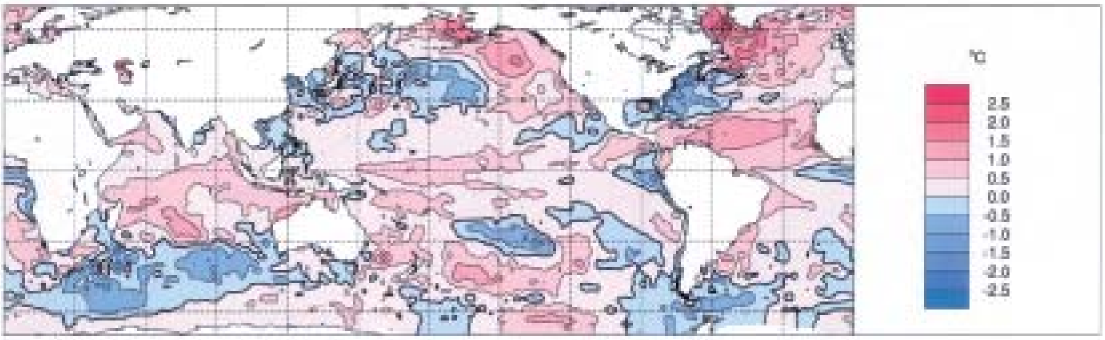
Ocean patterns

Sea-surface temperatures (SSTs)

Autumn 2005 SST anomalies are shown in Fig. 3, obtained from the NOAA Optimum Interpolation analyses (Reynolds et al. 2002). Positive (warm) anomalies are shown in red shades, and negative (cool) anomalies in blue shades.

Generally, the seasonal SST along the equator in the Pacific continued a weak cooling trend, which had emerged during the summer months, especially in the central Pacific. This constituted a further relaxation of the weak-warm conditions that were prevalent over the equatorial Pacific during the latter half of 2004 (Bettio and Watkins 2005). Beard (2005) found a marked decline in the spatial coverage of positive anomalies greater than 1°C in this area around the date-line in February. The NINO4 index reflected the decreasing trend, with values of +0.70°C, +0.50°C and +0.56°C for March, April and May respectively. The NINO3.4 index remained weakly positive, with values of +0.40°C, +0.35°C and +0.60°C for March, April and May respectively. The slight rise in both indices during May did not represent larger SST anomalies in the region; rather it represented an increase in the spatial area of anomalies between 0.5°C and 1.0°C along the equator.

Fig. 3 Anomalies of sea-surface temperature for autumn 2005 (°C).



Another feature of the SST anomalies along the equator was the area of negative anomalies in the far-eastern Pacific (Fig. 3). These first appeared in February, and continued into March and April. However, by May they had largely disappeared. This was reflected in the NINO1 and NINO2 indices which both showed weak negative values for March (–0.04°C and –0.37°C respectively) and April (–0.16°C and –0.23°C respectively), but then small positive anomalies for May (+0.13°C and +0.49°C respectively), with an especially rapid rise in the NINO2 area.

In the Australian region, autumn SSTs were generally slightly higher than normal to the north and to the east, especially in the region of the Tasman Sea, and also off the northwest coast of Australia. SSTs were generally lower than normal over the southern and southeast Indian Ocean near WA, and also in the waters around Tasmania.

Globally averaged, austral autumn SSTs were 0.42°C above the 1880-2002 mean (NCDC 2005), the second warmest March to May period on record (1998, coming out of an El Niño event, was the warmest). In the southern hemisphere, ocean temperatures were 0.38°C above average; the fifth warmest on record. In the northern hemisphere, the oceans were 0.53°C warmer than average, making it the warmest March-May period on record.

Subsurface ocean patterns

The Hovmöller diagram for the 20°C isotherm depth anomaly across the equator from January 2001 to May 2005, obtained from the Bureau of Meteorology Research Centre, is shown in Fig. 4. The 20°C isotherm depth is generally situated close to the equatorial ocean thermocline, the region of greatest temperature gradient with depth and the boundary between the warm near-surface and cold deep ocean water. Changes in the thermocline depth may act as a precursor to future changes at the surface.

During February, quasistationary convection in the region of the date-line with westerly wind anomalies near, and to the west of, the convection produced a strong downwelling signature on the thermocline (Beard 2005). As seen in Fig. 4, this was the strongest in the series of regular disturbances since March/April 2004. Unlike those previous disturbances, the February wave showed some initial coupling to the overlying atmosphere, but that diminished in March. The downwelling Kelvin wave continued its eastward progression in early autumn, reaching the South American coast in April resulting in an initial rapid increase in SSTs. However, far eastern Pacific SSTs cooled almost as rapidly in late April and early May as a weak upwelling wave, propagating to the east in the wake of the strong downwelling, reached South America. Westerly wind anomalies in the western equatorial Pacific in April saw the initiation of another downwelling Kelvin wave. However, this was weak and had little effect on subsurface temperatures which remained cool.

The oceanic downwelling Kelvin wave is also observed in the cross-section of the equatorial Pacific temperature anomaly profile (Fig. 5), which shows temperatures down to 400 metres for the months from February to May 2005. Red shades indicate positive anomalies, and blue shades negative anomalies. In profile, the strong downwelling wave initiated in February is clearly evident. This wave strengthened on the thermocline and propagated eastward during March and April, although with a much reduced vertical extent in the latter as it was

Fig. 4 **Time-longitude section of the monthly anomalous depth of the 20°C isotherm at the equator for January 2001 to May 2005. Base period: 1979-89. Contour interval is 10 m.**

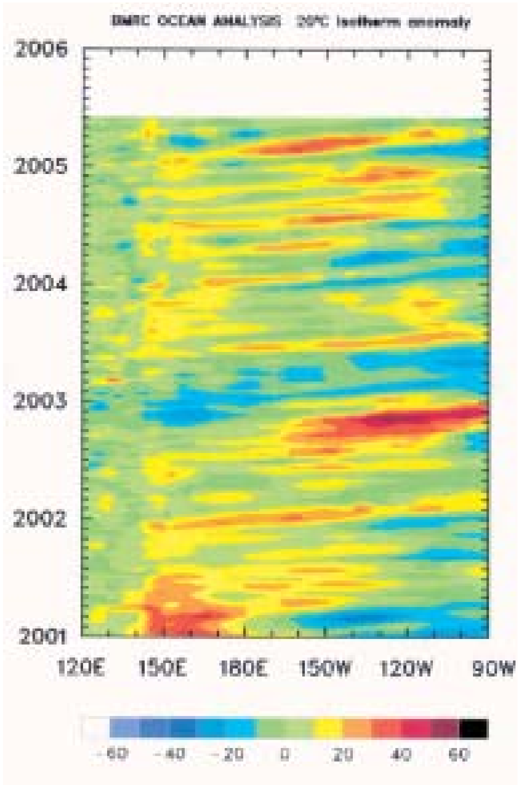
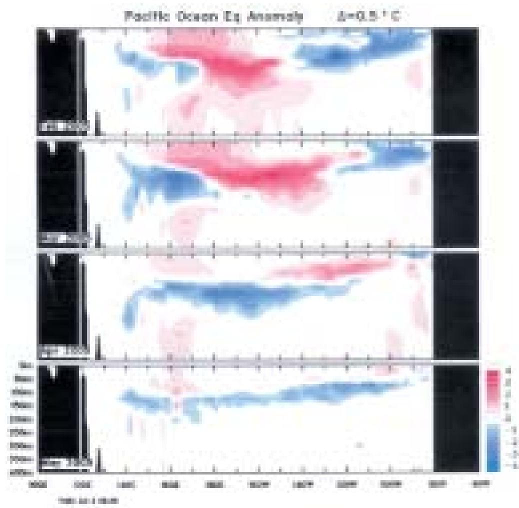


Fig. 5 **Four-month February to May 2005 sequence of vertical temperature anomalies at the equator. Contour interval is 0.5°C.**



undercut by negative anomalies (upwelling) propagating from the west. By May, positive anomalies were confined to a few small patches in the top 50 m of the eastern Pacific, with weak negative anomalies evident along nearly the entire thermocline.

Atmospheric patterns

Surface analyses

The southern hemisphere autumn 2005 mean sea-level pressure (MSLP) pattern, computed from the Australian Bureau of Meteorology's Global Assimilation and Prediction (GASP) model, is shown in Fig. 6, with the corresponding anomaly pattern provided in Fig. 7. These anomalies are the difference from a 22-year (1979-2000) climatology obtained from the National Centers for Environmental Prediction (NCEP) II Reanalysis data (Kanamitsu et al. 2002). The MSLP analysis has been computed using data from the 0000 UTC daily analyses of the Australian Bureau of Meteorology's GASP model. The MSLP anomaly field is not shown over areas of elevated topography (grey shading).

The autumn MSLP pattern (Fig. 6) displayed a very zonal structure in the mid to high latitudes. Weak long wave troughs were located at around 10°E, 100°E and 80°W. There was evidence of a blocking pattern in the central South Pacific, with negative pressure anomalies near 30°S and positive anomalies further to the south near 45°S.

In the tropical Pacific, MSLP anomalies (Fig. 7) were mostly small in magnitude, reaching minima of –1.3 hPa to the north and south of the equator. Though weak they give some indication of the positive SST anomalies in the region, which would have enhanced low-level warming and hence reduced pressures.

More substantial positive MSLP anomalies occurred over the Australian continent and surrounding regions during autumn, with an area of MSLP anomalies greater than 2.5 hPa covering much of eastern Australia. These generally higher pressures were also reflected in the increased OLR (decreased high cloud) observed during the season, which in turn contributed to the record-breaking warmth over Australia.

Fig. 6 Mean sea-level pressure for autumn 2005 (hPa).

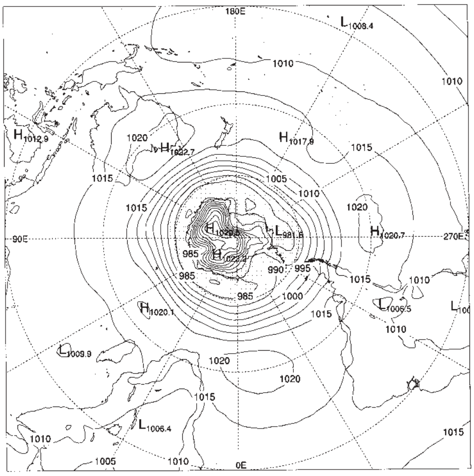
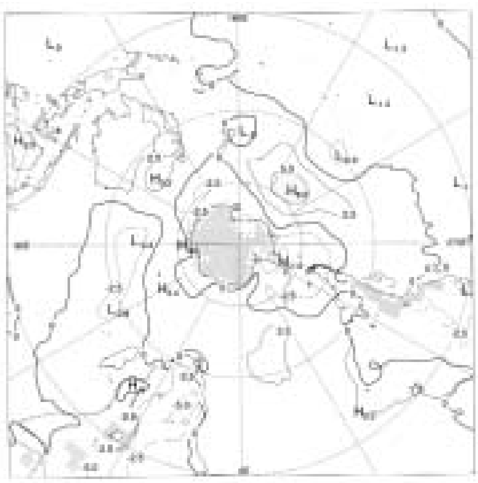


Fig. 7 Anomalies of the mean sea-level pressure from the 1979-2000 National Centers for Environmental Prediction Reanalysis II climatology, for autumn 2005 (hPa).



Tropical cyclones

The sharp drop in the SOI during late January and February and strongly enhanced convection about the dateline were coincident with an active period of cyclone formation in the south Pacific, with five tropical cyclones recorded in this region (Beard 2005). Four tropical cyclones also crossed or threatened the Australian coastline during the summer of 2004/05.

The autumn period was associated with few tropical cyclones in the region. However, 6 March saw the formation of severe tropical cyclone *Ingrid* off the northeast coast of Queensland. It crossed the Queensland east coast south of Lockhart River at Category 4; moved across the Gulf into the Northern Territory and impacted on the small islands north of the Arnhem Land coast as a Category 5 cyclone; weakened slightly to Category 4 as it crossed Croker Island and the Cobourg Peninsula; was at Category 3 intensity as it traversed the Tiwi Islands north of Darwin; and finally reintensified to Category 4, before making a final landfall on the Western Australian Kimberley coast at that intensity (BoM 2005). Unusually, it was the first cyclone in the historical record to affect, as a severe tropical cyclone, the coastlines of three different States or Territories. Due to its small size, but great intensity, only regions within approximately 100 km of the coast were affected, leading to less extensive high rainfall totals than may have been expected. Tragically, large sea swells caused a boat to capsize near Kareema in Papua New Guinea, resulting in the loss of five lives.

Other tropical cyclones in the Australian region during autumn were tropical cyclones *Willy* and *Adeline-Juliet*. Neither of these cyclones made landfall, with *Willy* reaching category three status and tracking to the west of northwestern WA. Tropical cyclone *Adeline-Juliet* reached category five status, but tracked well away from the Australian landmass in the south Indian Ocean to the west of Christmas Island.

In the South Pacific, tropical cyclone *Rae,* the area's fifth cyclone in little more than a month, formed on 5 March, but soon weakened to a tropical depression by 7 March and moved east-southeast of the Cook Islands.

Mid-tropospheric analyses

The 500 hPa geopotential height (an indicator of the steering of surface synoptic systems) across the southern hemisphere is shown in Fig. 8, with anomalies in the 500 hPa field displayed in Fig. 9. Over Australia, 500 hPa heights were above average, with a local anomaly maximum of +48.8 m to the south of South Australia. Other features of note were two areas of below average 500 hPa heights: one situated at 40°S 90°E in the southern Indian Ocean (–48.3 m), the other located over the southern tip of South America (–57.0 m).

The analysis of the 500 hPa height shows strong positive anomalies near 50°S 140°W. This, combined with negative anomalies further to the north, is indica-

Fig. 8 Mean 500 hPa geopotential heights for autumn 2005 (gpm).

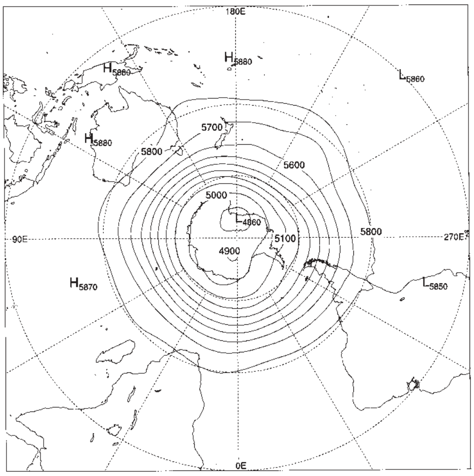
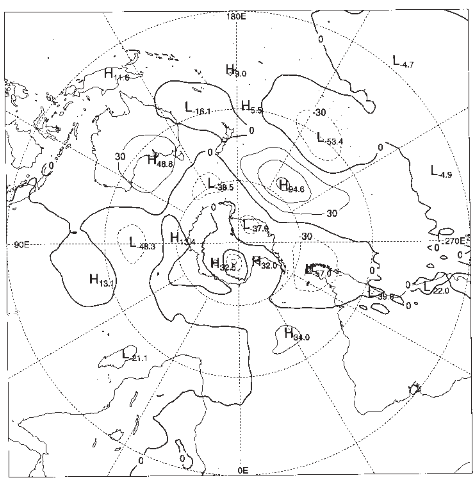


Fig. 9 Anomalies of the 500 hPa geopotential height from the 1979-2000 National Centers for Environmental Prediction reanalysis II climatology, for autumn 2005 (gpm).



Blocking

The time-longitude section of the daily southern hemisphere blocking index (BI)* is shown in Fig. 10, with the start of the season at the top of the figure. This index is a measure of the strength of the zonal 500 hPa flow in mid latitudes relative to that at lower and higher latitudes. Positive values of the blocking index are generally associated with a split in the mid-latitude westerly flow centred near 45°S and mid-latitude blocking activity.

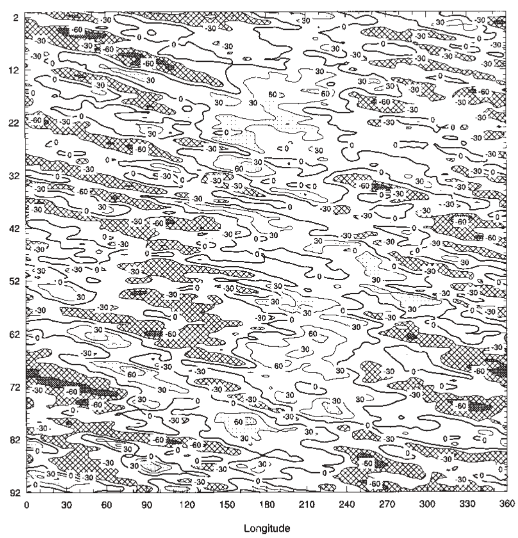
Positive daily BI values occurred between 140°E and 120°W during autumn, with several strong centres (BI > 60). The first event, starting mid-March, was centred around 150°W, and continued for a little over a week. The second event started around the beginning of May, again in this region, continued for a week before decaying then restrengthening for a few days at about 140°W. Further to the west (approximately 160°E) there was a smaller blocking event during mid-May.

Peak seasonal mean BI values were located around 140°W (Fig. 11), east of, and slightly greater than, the region of maximum climatological values. This was consistent with the 500 hPa anomalies mentioned above. The region from eastern Australia to the central Pacific (140ºE to 140ºW) is climatologically

tive of enhanced seasonal blocking in this region (Fig. 10). This is discussed further in the following section.

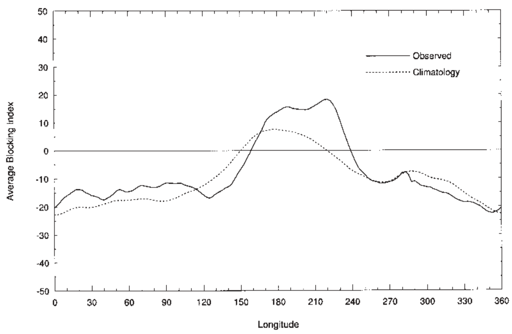
At the mid to high latitudes, the major 500 hPa height anomalies (Fig. 9) were generally centred over the same locations as their MSLP counterparts. Combined, this suggests a largely barotropic atmospheric structure.

Fig. 10 Autumn 2005 daily blocking index: time-longitude section. Day 1 is 1 March.



* The blocking index is defined as BI = $0.5[U_{25} + U_{30} - (U_{40} + 2U_{45} + U_{50}) + U_{55} + U_{60}]$ where U_x is the westerly component of the 500 hPa wind at latitude x.

Fig. 11 Mean southern hemisphere blocking index for autumn 2005 (bold line). The dashed line shows the corresponding long-term average. The horizontal axis shows the degrees east of the Greenwich meridian.



favoured for blocking (Trenberth and Mo 1985; Sinclair 1996). As shown in Fig. 8, this region primarily east of the date-line, was the most notable region of split flow at the 500 hPa level.

Low and upper-level winds

Autumn 2005 low-level (850 hPa) and upper-level (200 hPa) wind anomalies (from the 22 year NCEP II climatology) are shown in Figs 12 and 13 respectively. Isotach contours are at 5 m s^{-1} intervals, and in Fig. 12 the regions of the globe where the land rises above the 850 hPa height are shaded grey. At the low levels, the wind anomalies (Fig. 12) generally reflected the MSLP anomalies (Fig. 7). Notable wind anomalies in the southern hemisphere included the strong circulation pattern associated with the aforementioned MSLP and 500 hPa anomalies located near 50°S, 140°W. This feature was also evident in the upper levels (Fig. 13).

In the Australian region, the low-level anomalous winds (Fig. 12) were mostly weak and were generally from the northerly quarter in the west of the country. The most notable circulation feature in the region was the cyclonic anomaly over the southern Indian Ocean, which contributed somewhat to the anomalous northerly flow over WA. Elsewhere around Australia, the low-level anomalies were weak. At the upper levels Australia was dominated by cyclonic anomalies to the south and the northeast of the continent. This resulted in winds from the southeast quarter dominating much of the flow over the country.

Low-level wind anomalies across the tropical Pacific were generally fairly weak in autumn, although, similar to the previous autumn (Trewin 2005), there was some evidence of anomalous southerly (cross-equatorial) flow in the eastern Pacific. At the 200 hPa level on and just to the north of the equator, there were some areas of easterly anomalies which peaked at over 5 m s^{-1} around 150°W. Coupled with the surface anomalies, this was indicative of some weakening of the Walker Circulation, though not the widespread suppression which would occur if the atmosphere was strongly coupled to the anomalously warm ocean temperatures.

After the strong westerly wind anomalies present in the western Pacific in February, an indicator of a short-lived coupled ENSO-mode in this region (Beard 2005), the wind anomalies across the equatorial Pacific returned to near-average by mid-March (not shown). A westerly wind burst during April raised fears that the consequent downwelling wave might trigger an El Niño event (see above), but the associated ocean temperature anomalies soon decayed. A weaker westerly wind burst in late May failed to generate any significant response in the subsurface.

Australian region

Rainfall

The distribution of Australian rainfall totals for autumn 2005 is shown in Fig. 14, whilst Fig. 15 shows the associated decile ranges based on gridded rainfall data for all autumns from 1900 to 2005.

During autumn, the highest rainfall totals were on the northern edges of the continent. These were largely a result of heavy falls due to tropical cyclone *Ingrid* in March. In comparison with the historical record, the only extensive area of above-average rainfall was in the western part of WA from Port Hedland southwards (Fig.14). Some parts of the southern inland parts of WA received more than double their average autumn rainfall, and a number of stations set autumn records. However, autumn 2005 was mainly characterised by below average to very much below average rainfall over most of the country, with a number of areas, including large parts of Victoria and Tasmania, receiving the lowest on record autumn totals (Fig. 15). The national area-average of 66.8 mm, was the tenth lowest on record and 46 per cent below normal. Both Victoria and South Australia had their driest autumn on record. The Victorian area average of 46.7 mm was particularly exceptional, as it was well below the previous record of 65.3 mm set in 1991. NSW had its second driest autumn on record. Table 1 summarises seasonal rainfall ranks and extremes on a national and State basis.

Fig. 12 Autumn 2005 850 hPa vector wind anomalies with contours of vector magnitude overlayed. The contour interval is 5 m s^{-1}, with values above 5 m s^{-1} stippled.

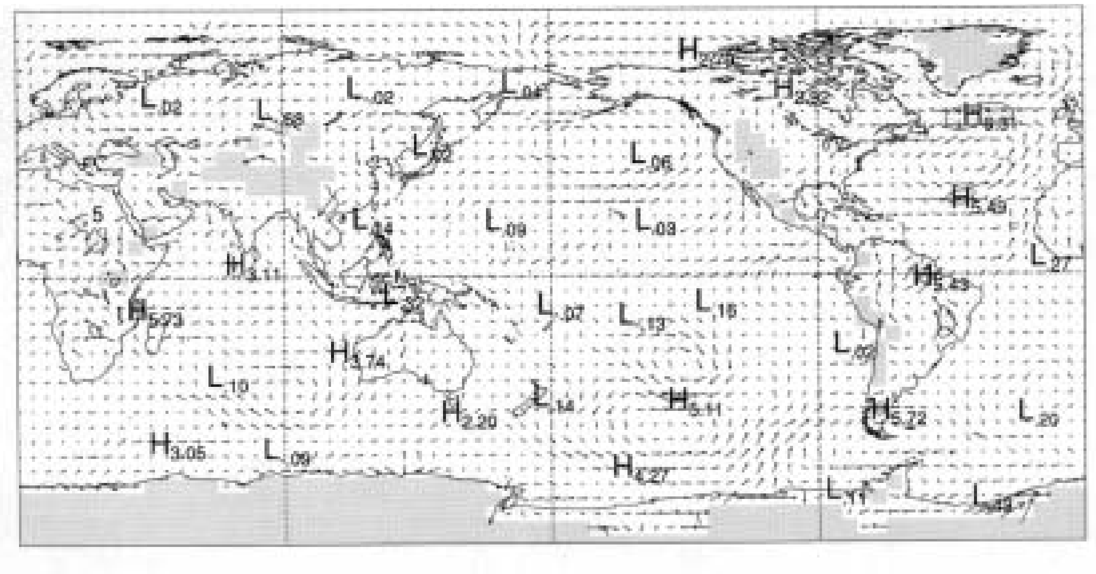
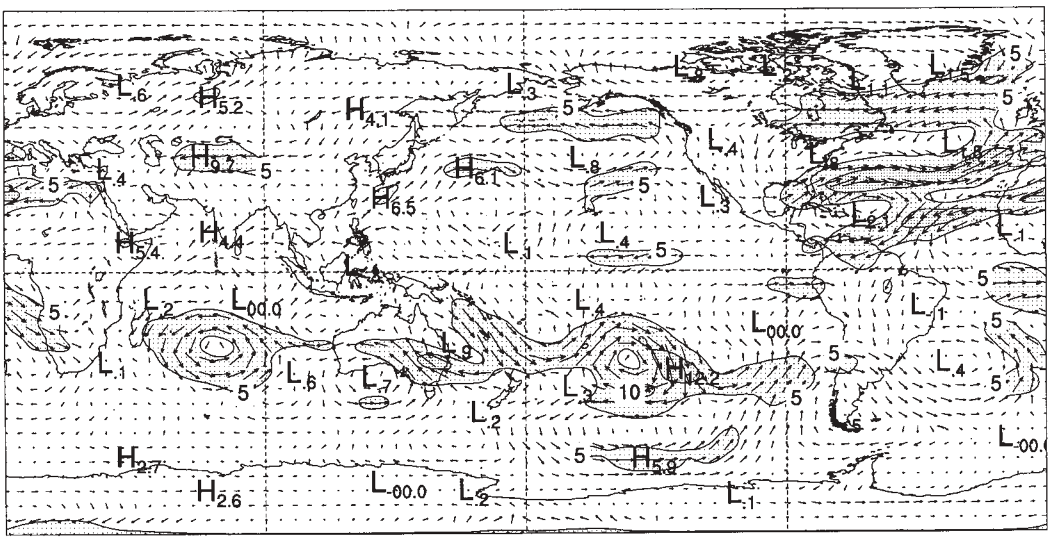


Fig. 13 Autumn 2005 200 hPa vector wind anomalies with contours of vector magnitude overlayed. The contour interval is 5 m s^{-1}, with values above 5 m s^{-1} stippled.



During March, most of the eastern two-thirds of Australia recorded below to very much below average rainfall. Areas of average to above average falls were typically due to the passage of a single event. As mentioned previously, some of the most substantial rain events of the season were those caused by tropical cyclone *Ingrid*. Substantial 24-hour falls (to 9 am on the indicated day) included 192 mm at Gove Airport (NT) on 12 March, 438 mm at Truscott (WA) on 16 March (including 341.2 mm in four hours) and 445 mm at Emma Gorge (WA) on 17 March. Very heavy rain fell over parts of southwestern WA at the end of

Fig. 14 Autumn 2005 rainfall totals over Australia (mm).

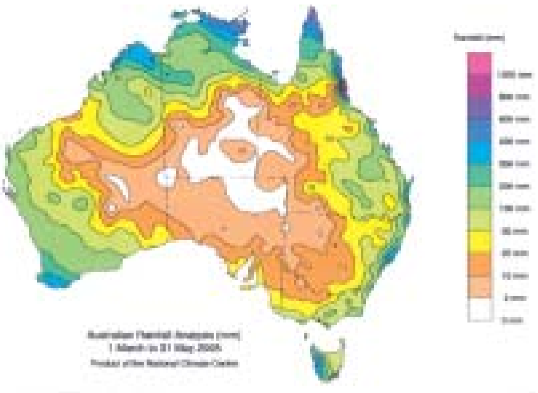


Fig 15 Autumn 2005 rainfall deciles for Australia: decile range based on grid-point values over the autumn periods from 1900 to 2005.

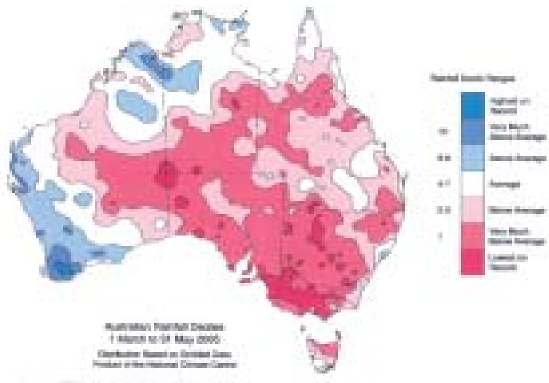


Table 1. Seasonal rainfall ranks and extremes on a national and State basis for autumn 2005.

	Highest seasonal total (mm)	*Lowest seasonal total (mm)*	*Highest 24-hour fall (mm)*	*Area-averaged rainfall (aar) (mm)*	*Rank of aar **
Australia	2795 at Bellenden Ker, Top Station (Qld)	0 at several locations (NT, SA, Qld, NSW)	445 at Emma Gorge, 17 March (WA)	67.15	10
WA	572 at Truscott	4 at Giles	445 at Emma Gorge, 17 March	80.92	47
NT	758 at Cape Wilberforce	0 at several locations	410 at Cape Wilberforce, 12 March	85.88	3
SA	77 at Lake Leake	0 at several locations	23 at Mount Schank, 5 March	8.32	lowest
QLD	2795 at Bellenden Ker, Top Station	0 at several locations	340 at Happy Valley on 12 March	75.01	11
NSW	698 at Hawkes Nest	0 at several locations	233 at Hawkes Nest, 23 March	45.9	2nd lowest
VIC	278 at Wyelangta	2 at several locations	49 at Point Hicks, 22 March	46.77	lowest
TAS	974 at Mount Read	38 at Whitemark	60 at Strathgordon, 25 May	187.61	10

* The rank goes from 1 (lowest) to 106 (highest) and is calculated on the years 1900 to 2005 inclusive.

the month when an amplifying cold front interacted with a pre-existing trough lying through the west of the State. The highest total for the three days from 31 March to 2 April was 218.2 mm at Albany Airport.

Though April was mainly remarkable for the number of temperature records broken, it was also a very dry month nationally, ranking eighth driest out of the 106 years since records began. NSW had its sixth driest April on record. Much of the eastern and northern parts of Australia received average to very much below average rainfall. The exception to the below average rainfalls across the continent was in western and southern WA, with a small area of southwestern WA receiving highest on record rainfall for the month (mainly due to the previously discussed rain event at the start of the month).

May was another dry month over much of Australia, with no rain falling over large areas of the NT, northeastern WA and northern SA, though much of this area is seasonally dry. In southern SA, NSW and in Victoria and northern Tasmania large areas received falls in the lowest 10 per cent of years on record. The only large areas to receive above average falls in May were parts of central and southern inland Queensland and (once again) in southern and western parts of WA. In Queensland, the rainfall was mainly attributable to the one rain event, an upper trough system that brought some local heavy falls during the week ending the 17 May such as 134 mm at Springfield and 121 mm at Karoola Park.

The failure of the autumn rains (see Fig. 15) in southern Australia (except WA) resulted in widespread short-term rainfall deficiencies over SA, NSW, Victoria and Tasmania. For the period January to May 2005, rainfall deficiencies were also evident in a band stretching from northwestern WA across the centre of the continent down to coastal SA and across to southern Queensland and northern NSW. The autumn period of rainfall deficits was set against a background of extended average to below average falls. Since the drought of 2002/03, there has been no prolonged period of widespread above average falls to fully remove rainfall deficiencies. Bureau of Meteorology data indicate, for example, that the Murray-Darling Basin region was in the midst of its worst multi-year period of rainfall deficiencies since the 1940s. The effects of these rainfall deficits were in many cases compounded by some of the highest autumn temperatures on record (see below).

Temperature

Seasonal maximum and minimum temperature anomalies for autumn 2005 are shown in Figs 16 and 17, respectively. These are calculated with respect to the 1961-90 period, and use all temperature observation stations for which a 1961-90 normal is available. A high quality subset of the network is used to calculate the spatial averages and rankings shown in Tables 2 and 3 and discussed elsewhere in this summary.

In 2005 Australia experienced its warmest autumn since records began in 1950. The all-Australian mean temperature anomaly of +1.62°C was more than half a degree above the previous record of +1.10°C (1958). As well, both daytime maximum and overnight minimum temperatures were well above normal, with maximum temperature anomalies (+2.21°C, highest on record) being particularly extreme.

The record-breaking warm autumn is further illustrated by the extensive area of above average temperatures on the deciles map for mean temperature (Fig. 18, calculated from 1950 to 2005 analyses using the high quality station network, rather than the full network of Fig. 16 and Fig. 17). Far north Queensland was the only part of the country to record below average (i.e. deciles 1 to 3) mean temperatures during this period, with much of Australia recording very much above average (decile 10) or highest-on-record mean temperatures.

Maximum temperature anomalies greater than 1°C covered most of the country during autumn (Fig. 16). Exceptions to this were mainly coastal areas of northern and eastern Australia. There were very few areas that had a negative temperature anomaly for the season. These included western Tasmania, coastal areas of northeastern Queensland and a small area along the coast in eastern Victoria. Within the area of greater than +1°C anomalies, a large area of greater than +2°C anomalies covered large parts of WA, NT, SA, Queensland, NSW and the northwestern corner of

Fig. 16 Autumn 2005 maximum temperature anomalies for Australia based on a 1961-90 mean (°C).

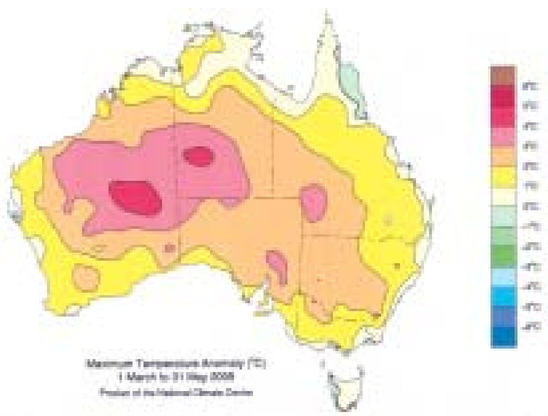


Fig. 17 Autumn 2005 minimum temperature anomalies for Australia based on a 1961-90 mean (°C).

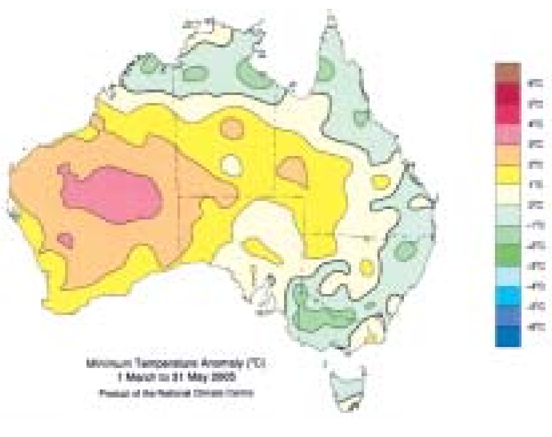


Table 2. Seasonal maximum temperature ranks and extremes on a national and State basis for autumn 2005.

	Highest seasonal mean (°C)	*Lowest seasonal mean (°C)*	*Highest daily recording (°C)*	*Lowest daily recording (°C)*	*Anomaly of area-averaged mean (°C) (aam)*	*Rank of aam **
Australia	37.9 at West Roebuck (WA)	8.8 at Mount Read (Tas)	46.9 at Roebourne, 1 March (WA)	–1.1 at Mount Hotham, 28 May (Vic)	+2.21	highest
WA	37.9 at West Roebuck	21.6 at Albany	46.9 at Roebourne, 1 March	10.7 at Manjimup, 31 March	+2.35	highest
NT	36.4 at Elliott	30.3 at Arltunga	43 at Walungurru, 1 and 2 March	18.0 at Arltunga, 28 May	+2.48	highest
SA	31.8 at Marree	17.6 at Mount Lofty	44.1 at Moomba, 1 March	8.2 at Mount Lofty, 28 May	+2.75	highest
QLD	35.5 at Century Mine	22.4 at Applethorpe	44.5 at Birdsville, 1 March	14.9 at Warwick, 11 May	+1.69	2nd highest
NSW	30.2 at Wanaaring	10.2 at Thredbo (Top Station)	44.5 at Tibooburra, 1 March	–0.4 at Thredbo (Top Station), 28 May	+2.11	highest
VIC	25.8 at Mildura	9.6 at Mt Hotham	40.8 at Mildura and Ouyen, 1 March and Swan Hill, 14 March	–1.1 at Mt Hotham, 28 May	+1.52	highest
TAS	19.2 at Launceston	8.8 at Mount Read	33.8 at Ouse, 13 March	–0.4 at Mount Wellington, 25 May	+0.45	45

* The temperature ranks go from 1 (lowest) to 56 (highest) and are calculated on the years 1950 to 2005 inclusive.

Table 3. Seasonal minimum temperature ranks and extremes on a national and State basis for autumn 2005.

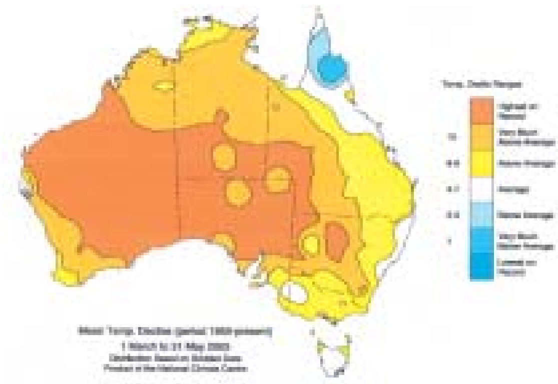
	Highest seasonal mean (°C)	*Lowest seasonal mean (°C)*	*Highest daily recording (°C)*	*Lowest daily recording (°C)*	*Anomaly of area-averaged mean (°C) (aam)*	*Rank of aam **
Australia	27.4 at Troughton Island (WA)	1.4 at Thredbo Village (NSW)	33.3 at Marble Bar (WA), 1 March	–9.0 at Woolbrook, 29 May (NSW)	+1.03	50
WA	27.4 at Troughton Island	10.8 at Jarrahwood	33.3 at Marble Bar, 1 March	–2.0 at Eyre, 28 May	+2.06	highest
NT	25.8 at McCluer Island	13.5 at Alice Springs	30.0 at Walungurru, 2 March and Dum In Mirrie , 11 March	0.5 at Kulgera, 31 May	+1.19	50
SA	16.2 at Moomba	7.0 at Keith	28.7 at Moomba, 2 March	–2.7 at Yongala, 30 May	+1.06	50
QLD	25.4 at Coconut Island	9.1 at Applethorpe	29.8 at Ballera Gas Field, 2 March	–4.5 at Stanthorpe, 28 May	+0.23	37
NSW	17.3 at Byron Bay	1.4 at Thredbo Village	27.6 at Tibooburra, 2 March	–9.0 at Woolbrook, 29 May	–0.09	30
VIC	14.0 at Gabo Island	3.3 at Mt Hotham	23.8 at Aireys Inlet, 10 April	–5.0 at Mt Hotham, 26 May	–0.80	18
TAS	12.4 at Swan Island	1.6 at Liawenee	19.4 at Flinders Island Airport, 10 April	–7.1 at Liawenee, 17 May	–0.18	28

* The temperature ranks go from 1 (lowest) to 56 (highest) and are calculated on the years 1950 to 2005 inclusive.

Victoria. Most of the central inland of WA and the southern NT recorded anomalies of greater than +3°C, with small areas of between +4°C and +5°C in both these regions.

Table 2 shows that all States recorded higher-than-normal area-averaged autumn maximum temperatures, with most recording their highest on record. The most extreme anomalies were in SA (+2.75°C)

Fig. 18 Autumn 2005 mean temperature deciles for Australia: decile range based on grid-point values over the autumn periods from 1950 to 2005.



and the NT (+2.48°C). When ranked, all States except Queensland and Tasmania had their highest on record autumns. Queensland had its second-highest on record and Tasmania its twelfth.

For the individual autumn months the standout month was April which saw the most extreme temperature anomalies ever recorded for Australia. The Australian mean temperature was 2.58°C above the 1961-90 average, more than 0.8°C above the previous April record (+1.73°C in 2002), and well above the largest anomaly previously recorded for any month (+2.32°C in June 1996). National average maximum and minimum temperatures also set records, whilst State-averaged mean temperatures set records in every State except Tasmania, which recorded near-average temperatures. April was also remarkable for its consistent heat, with many places (including Alice Springs, Canberra and Wagga Wagga) exceeding their long-term average maximum on nearly every day of the month. There were also more than 100 daily high-temperature records set in April, and there were many records set for the latest-ever date of a temperature above 40, 35 and 30 degrees in autumn.

March and May both recorded large areas of average to very much above average maximum temperatures, though not as extensive as in April. May, in particular, had two areas of highest on record temperature anomalies (not shown), one stretching from northwestern WA to the SA/NT border, the other covering most of eastern SA, southern NSW and northern Victoria. Australia-wide daytime maximum temperatures for May recorded an anomaly of +1.95°C, second only to 2002 (+2.21°C). NSW and Victoria had their highest May maximum temperatures on record, whilst SA and WA had their second highest. Though March did not have any highest-on-record maximum temperatures for the month, Queensland recorded its second highest and WA the fourth highest. Nationwide, the March anomaly was +1.57°C, the fifth highest on record.

Minimum temperature anomalies for autumn (Fig. 17) were not as extreme as the maxima, but were still positive over most of the country. In particular, WA anomalies, except for in the far north, were above +1°C in nearly all areas, with a large area between +2°C and +3°C. Furthermore, anomalies exceeded +3°C in central parts of that State. Anomalies greater than +1°C were recorded in the southern NT, western and northern SA, western Queensland, the northwestern corner of NSW and a small area in eastern Victoria. Nationwide there was a minimum temperature anomaly of +1.03°C, making it the seventh warmest autumn on record.

Table 3 also shows that WA was ranked highest on record, with an area-averaged anomaly of +2.06°C. Three States (NSW, Victoria and Tasmania) showed negative anomalies, though only Victoria was ranked in the lowest tercile (the ranking of 18 out of 56 made this near the boundary between tercile 1 and tercile 2).

Gridded analyses of the high quality network (not shown) indicate very much above average (decile 10) seasonal minimum temperatures in most areas of WA south of 18°S, with much of this area being highest on record (including adjacent parts of far western SA). Most of SA and the NT were above average (deciles 8 to 9), with patches of very much above average (decile 10). In contrast most of the eastern States were average (deciles 4 to 7), with areas of below average to very much below average (deciles 1 to 3) in northern and southeastern Queensland, the central coast of NSW and in northern and eastern Victoria.

April, similar to what was observed for the maximum temperatures, was the standout month in terms of records, with the highest on record Australia-wide mean minimum temperature. SA, WA and the NT all had their highest on record April minimum temperatures, with Queensland and NSW experiencing their fourth highest. It is particularly notable that record high minimum temperatures were set in a month which was also abnormally dry. Dry conditions are generally associated with below-average minimum temperatures, particularly for inland and southern Australia. As with the maximum temperatures, April saw widespread above to very much above average minimum temperatures, with areas of highest on record April minimum temperatures being seen across large areas in WA, the

NT, SA, western Queensland and far northwest NSW. The only areas that had below average minimum temperatures were northern Queensland and southwestern WA.

March and May, particularly in the western/central regions also saw large areas of above to very much above average minimum temperatures. However, for both these months there were also large areas of below average temperatures; a large area covering NSW, Victoria and eastern SA during March, and across northern Queensland and parts of Victoria and NSW during May. March and May, though not setting nationwide minimum temperature records, did break some individual State ones. March minima were the highest on record in WA and the fourth lowest on record for Victoria, while in May they were the second highest on record in WA.

Acknowledgments

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Appendix

The main sources for data used in this review were:

- National Climate Centre, *Climate Monitoring Bulletin - Australia*. Obtainable from: National Climate Centre, Bureau of Meteorology, GPO Box 1289, Melbourne, Vic., 3001, Australia.

- National Climate Centre, South Pacific Seasonal Outlook Reference Material. Obtainable from: National Climate Centre, Australian Bureau of Meteorology, GPO Box 1289, Melbourne, Vic. 3001, Australia.

- Climate Prediction Center, *Climate Diagnostics Bulletin*. Obtainable from: Climate Prediction Center, National Weather Service, Washington D.C., USA, 20233.http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/CDB_archive.html