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Seasonal climate summary southern hemisphere (spring 2004): neutral conditions remain in the tropical Pacific and a warm spring across Australia

Lynette Bettio and Andrew B. Watkins
National Climate Centre, Bureau of Meteorology, Australia

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Atmospheric and oceanic conditions in the southern hemisphere are reviewed for the 2004 austral spring season. Particular emphasis is given to the Australian and Pacific regions. Similar to winter, sea-surface temperatures remained warm in the central to western Pacific. However, indices of the atmospheric evolution such as the Southern Oscillation Index were more indicative of a neutral El Niño-Southern Oscillation state. Over Australia, this lack of a clear El Niño signal was reflected in the seasonal rainfall deciles, which showed mixed signals with areas of average, below average and above average rainfall across the continent. Though El Niño events are not always associated with drought in Australia, historically they tend to result in drier conditions, especially over northeastern Australia. The most widespread climate signal in Australia during spring was the widespread maximum temperature anomalies, with nearly every part of Australia recording above average temperatures.

Introduction

There was much debate over the declaration of El Niño in winter and early spring 2004, which highlighted the need for an internationally agreed definition of an El Niño event (Collins 2005). This confusion arose due to the failure of El Niño-like conditions to appear across all indices. Though an El Niño event was declared by the United States National Oceanic and Atmospheric Administration (NOAA), which judges an event based solely on central equatorial Pacific sea-surface temperature (SST) anomalies, an El Niño event was not declared by Australia's National Climate Centre due to the lack of an El Niño-like signal in other indices of El Niño-Southern Oscillation (ENSO) evolution, and hence the lack of a truly coupled atmosphere/ocean event. Whilst warm SST anomalies were seen in the central Pacific, at the level of a weak El Niño event, subsurface temperatures remained average and atmospheric indices such as the Southern Oscillation Index (SOI) failed to reach El Niño levels, averaging only –5.3 for the season. The Multivariate ENSO Index (MEI) was on the borderline between neutral and El Niño conditions for the season.

Corresponding Author Address: Lynette Bettio, National Climate Centre, Bureau of Meteorology, GPO Box 1289, Melbourne, Vic. 3001, Australia.
Email:l.bettio@bom.gov.au

At the high latitudes, spring brought a reduced sea-ice extent off the Ross Sea and East Antarctica. In the Prydz Bay region, this was reflected by warmer than normal temperatures recorded at Australia's Davis base during October and November. Overall, however, the Antarctic sea-ice extent was above the recent mean value. Spring also brought a relatively small-sized Antarctic ozone hole, though the total amount of ozone destroyed was actually at record levels due to its extended duration.

Over Australia, rainfall was near average over much of the continent, with above average rainfall in parts of Western Australia and coastal New South Wales. Areas of southern WA, Tasmania and the Northern Territory received below average rainfall. Maximum temperature anomalies indicated warmer than normal conditions over nearly the whole of the continent. Areas of very much above average seasonal maximum temperature included the northern NT, southeastern WA and areas of coastal Queensland and NSW. An eastern Australian heatwave in September/October, following generally dry conditions, had a significant impact upon winter crops, reducing estimated yields. Australia-wide, spring 2004 was ranked the ninth warmest for daytime temperatures. Mean minimum temperature anomalies for spring showed more spatial variability than the maximum anomalies, with negative anomalies covering large areas of the NT, NSW and Victoria. Cooler than normal temperatures also occurred in northern and southern WA.

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)*

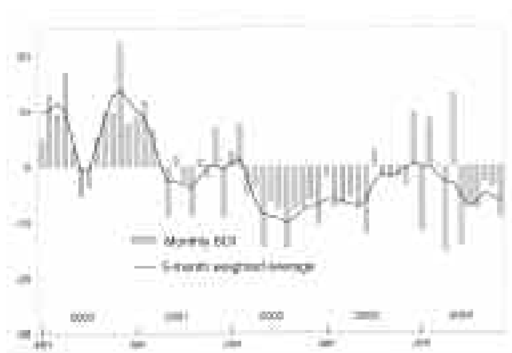
Winter 2004 saw the first three consecutive months with moderate negative SOI values since the demise of the 2002/03 El Niño event (Collins 2005). However, these negative SOI values weakened in spring, with values of –2.8, –3.7 and –9.3 recorded for September, October and November 2004 respectively (Fig. 1), resulting in a spring mean of –5.3. The weakness of these values represented the failure of the atmosphere to fully couple to the positive SST anomalies present in the central equatorial Pacific. Throughout the season, 30-day moving average approximate SOI values were always within one standard deviation of the mean (the Troup SOI has a standard deviation of 10) as were the 30-day moving average Tahiti minus Darwin sea-level pressure values, from which the SOI is based.

The continued positive monthly mean sea level pressure (MSLP) anomalies at Darwin during spring, +1.1 hPa, +0.5 hPa and +0.7 hPa for September, October and November respectively, were consistent with a weak warm event. However, monthly MSLP anomalies at Tahiti, +0.6 hPa, –0.1 hPa and –0.7 hPa for September, October and November respectively, oscillated about the mean. Thus, similar to winter, the weak negative SOI values recorded in spring were mainly due to positive anomalous pressures at Darwin, whilst significant negative pressure anomalies typical of an El Niño event were not observed at Tahiti.

Multivariate ENSO index

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

Fig. 1 Southern Oscillation Index, January 2000 to November 2004 inclusive. Means and standard deviations based on the period 1933-92.



*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.

October/November values of the MEI were +0.538 and +0.826 respectively. When ranked against historical values, these values sit on the boundary between neutral and El Niño conditions if a tercile split between La Niña, neutral and El Niño conditions is used. As discussed in the previous Seasonal Summary (Collins 2005), 'by mid-September the organisation (US Climate Prediction Center) had declared that a warm event had developed and was expected to continue until early 2005 (*Climate Diagnostics Bulletin - August*, CPC 2004)'. This declaration was not supported by Australia's National Climate Centre as a consistent pattern in all El Niño indicators failed to materialise; a clear indication that no coupled process was occurring. Rather, the SST anomalies were merely being supported by periodic westerly wind anomaly pulses from the Madden-Julian Oscillation.

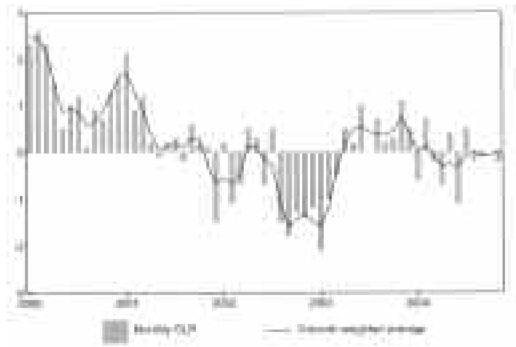
Outgoing long wave radiation

The time series from January 2000 to November 2004 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 dateline (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 spring 2004, the OLR anomalies for this region were –0.1, 0.0 and –0.2. Similar to winter, there was a lack of sustained negative values that would be expected during an El Niño event (e.g. spring of 2002 saw –1.8, –1.3 and –1.4 for September, October and November respectively (Watkins 2003)). As discussed previously, this represented a continued lack of coupling between the atmosphere and the ocean in the equatorial Pacific and indicated a lack of the widespread reorganisation of the climate system one might expect during an El Niño event.

Figure 3 shows the spatial pattern of OLR anomalies across the western and central tropical Pacific observed during the season. Similar to spring 2003, which also saw slightly warmer than average ocean conditions, an area of weakly suppressed convection extended east from near the date-line to the South

Fig. 2 Standardised anomaly of monthly outgoing long wave radiation averaged over 5°N-5°S and 160°E-160°W, for January 2000 to November 2004. Negative (positive) anomalies indicate enhanced (reduced) convection and rainfall. Anomalies are based on a 1979-95 base period. After CPC (2004).



American coast. In the far western equatorial Pacific, decreased OLR (increased convection) was apparent. This pattern is not what one would expect during a warm ENSO event. On the contrary, the pattern across the equatorial Pacific showed greater similarities to a cool ENSO event. In contrast, there was a widespread region of increased OLR (decreased convection) over the maritime continent, something more typical of an El Niño event.

The overall pattern of OLR for the South Pacific region saw decreased OLR (increased high cloud) over much of the western South Pacific (Fig. 3), which was reflected in the rainfall anomalies (not shown) in this region which were generally above average. The South Pacific convergence zone (SPCZ) was generally slightly south to southwest of its climatological position during the season. (During warm ENSO periods the SPCZ is ordinarily north and east of its average position, while during cool events it tends to be shifted south and west (Vincent 1993).)

Ocean patterns

Sea-surface temperatures (SSTs)

Spring 2004 SST anomalies are shown in Fig. 4, 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.

Fig. 3 **Anomalies of outgoing long wave radiation for spring 2004 (Wm^{-2}), based on a base period of 1979-98.**

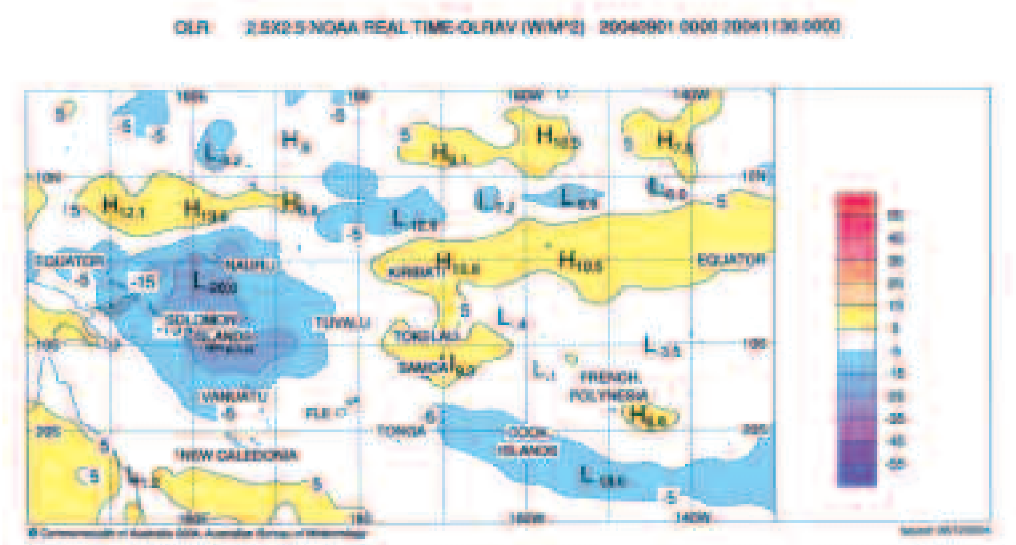
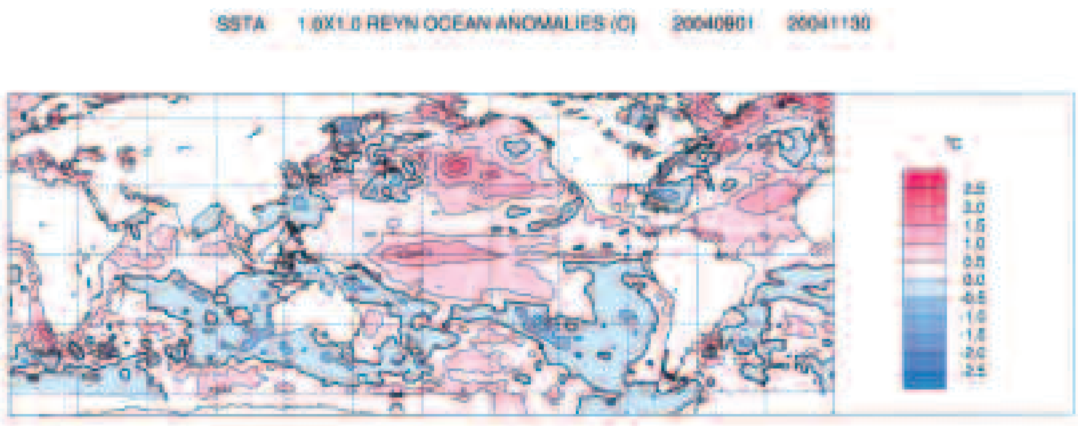


Fig. 4 **Anomalies of sea-surface temperature for spring 2004 (°C).**



Generally, seasonal SST anomalies along the equator remained similar to the pattern that emerged during winter (Collins 2005). Temperatures in the central equatorial Pacific remained warmer than normal, though only to the level of a borderline to weak El Niño event, with a slight expansion from winter. Anomalies were largely between +0.5°C and +1.5°C in the spring mean. Anomalies greater than 1°C remained confined to the equator between 160°E and 150°W. In the eastern equatorial region, the region that usually warms during a 'classical' El Niño event, SST anomalies exhibited some small warming, though remained close to average. Over the season in the far eastern Pacific, negative SST anomalies, which had dropped below –1°C in August, dissipated, with patches of warm anomalies (though not reflected in the spring mean) of between +1° and +2°C developing along the equator. In the eastern Pacific this warming was in response to warm subsurface water which propagated east and reached the surface during November. Also, westerly anomalies (weakened Trade Winds) helped warm equatorial Pacific SSTs during November.

This increasing trend in the eastern equatorial Pacific, and steady trend in the central equatorial Pacific, is reflected in the NINO indices. In the eastern equatorial Pacific, the NINO 1+2 value for September of –0.42°C rose to +0.31°C by November. In the central equatorial Pacific the NINO 3, 3.4 and 4 values remained steady with values of +0.33°C, +0.83°C and +1.11°C in September, and +0.51°C, +0.79°C and +1.21°C in November. During the spring season the NINO 4 region was the only region consistently above one standard deviation from the mean. The NINO 3.4 region was the only other region to show a monthly mean value greater than one standard deviation from the monthly mean, this occurred in September, however later months remained within one standard deviation from the mean.

In the South Pacific, positive anomalies (greater than +0.5°C) extended from the equatorial anomalies into the South Pacific to approximately 20°S.

Sea-ice anomalies around the Antarctic (not shown) reflected, to some degree, warmer than normal conditions in the Pacific and Indian Oceans. Large negative concentration anomalies occurred in the outer sea-ice pack northeast of the Ross Sea and off east Antarctica during September and October, though a slow retreat in November meant that some positive anomalies occurred off Wilkes Land. However, November also saw substantially lower than normal concentrations in the sea-ice pack off the Amery Ice Shelf/Prydz Bay region. Interestingly, this corresponded with above average temperatures at nearby Davis base, which recorded maximum temperatures 1.6 and 1.4°C above normal in October and November respectively. Likewise, minimum temperatures at the base were also 1.5°C and 1.7°C above normal for the same months.

Elsewhere, negative anomalies were also present at the ice edge north of the Weddell Sea, while large positive concentration anomalies (i.e. more sea-ice than normal) were recorded in the vicinity of the mean sea-ice edge off Dronning Maud Land and in the outer Bellingshausen Sea. Also notable was the emergence of negative anomalies in the vicinity of the Weddell polynya region during November.

In total, the Antarctic sea-ice area (using the NASA Team algorithm (Cavalieri et al. 1984)), defined as the area within the 15 per cent concentration boundary, reached its annual (monthly) peak extent of 18.76 million km^2 in September, with values of 18.2 and 16.3 million km^2 for October and November respectively. The September 2004 peak areal extent is somewhat larger than the 1987-2003 mean value of 18.32 million km^2, and was second only to the 2000 September average value of 18.79 million km^2 in the short 1987-2004 time series.

In the Australian region, spring SSTs were generally slightly cooler than normal, except in and to the north of, the Tasman Sea, where SSTs were slightly warmer than normal. The area of warm anomalies in the Tasman Sea included a small area of anomalies greater than +0.5°C. A small area of negative anomalies less than –0.5°C was present off the southern Western Australian coast.

Globally averaged, 2004 austral spring SSTs were 0.48°C above the 1880-2003 mean (NCDC 2004), the third warmest September to November period on record (the 2003 spring was the second warmest, 1997 – an El Niño year – being the warmest). In the Southern Hemisphere oceans were 0.42°C above average; the sixth warmest on record. In the Northern Hemisphere oceans were 0.59°C above average making it the second warmest spring behind 2003.

Subsurface ocean patterns

The Hovmöller diagram for the 20°C isotherm depth anomaly across the equator from January 2001 to November 2004, obtained from the Bureau of Meteorology Research Centre, is shown in Fig. 5. 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.

The latter half of 2004 saw a succession of subsurface Kelvin waves propagate east in response to Madden-Julian Oscillation-related westerly wind bursts, resulting in a weak warming trend in the eastern equatorial Pacific. Following the strong Kelvin wave which peaked in July but failed to develop into a sustained deepening of the thermocline (Collins 2005), a westerly wind burst in late August initiated a downwelling oceanic Kelvin wave, which crossed the equatorial Pacific during August and September and reached the eastern Pacific by late September/early October. This resulted in a +20 m anomalous thermocline depth, somewhat further east but not as strong as the July peak. Again this anomaly failed to develop into a sustained deepening of the thermocline. This was followed in October by another Kelvin wave, which reached the eastern Pacific in November. Similar to the previous Kelvin waves this wave failed to cause a coupling with the overlying atmosphere, therefore the subsurface temperatures were seen to slowly cool once the Kelvin wave passed.

Fig. 5 **Time-longitude section of the monthly anomalous depth of the 20°C isotherm at the equator for January 2001 to November 2004. Base period: 1979-89. Contour interval is 10 m.**

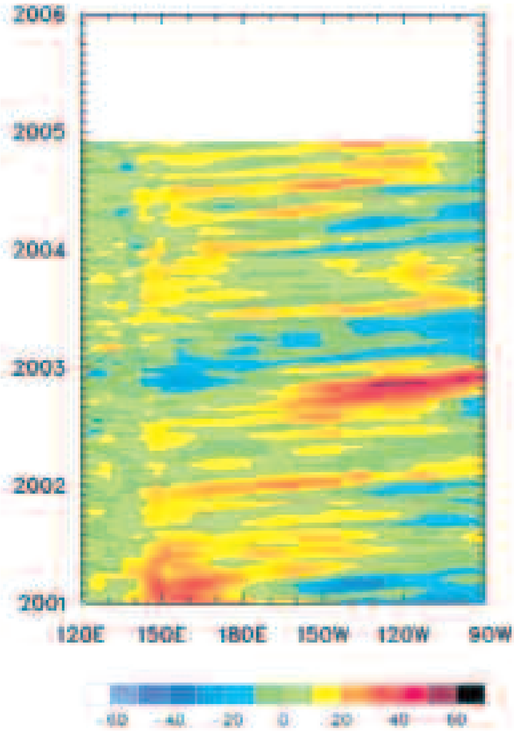
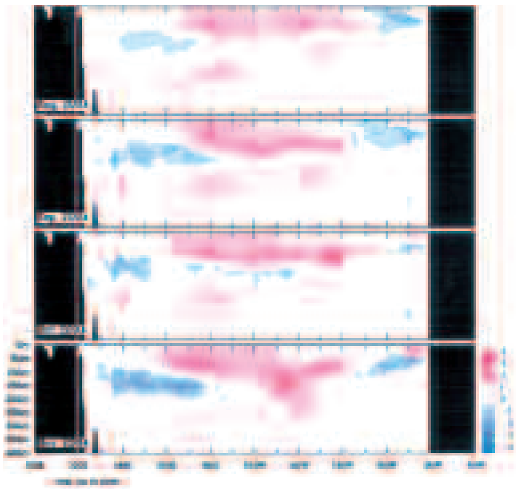


Fig. 6 **Four-month August to November 2004 sequence of vertical temperature anomalies at the equator. Contour interval is 0.5°C.**



The oceanic downwelling Kelvin wave is also observed in the cross-section of the equatorial Pacific temperature anomaly profile (Fig. 6), which shows temperatures down to 400 metres for the months from August to November 2004. Red shades indicate positive anomalies, and blue shades negative anomalies. For all of the period, positive anomalies are present in the central Pacific to a depth of approximately 150 m. Negative anomalies present near the surface in the eastern pacific during August and September contracted to the east during October but reappeared in November. Negative anomalies around the depth of the thermocline in the western Pacific strengthened during November and extended to the date-line.

Overall, the subsurface anomalies throughout the equatorial Pacific were generally within ±2.0°C of their long term mean. When it is considered that the spring 2003 (neutral year) subsurface temperatures reached +4°C by November (with a maximum local anomaly of +5.3°C) (Watkins 2004), and that in comparative terms the peak of the El Niño event in 1997/98 saw subsurface anomalies reach in excess of +8°C, spring 2004 can only be classified as neutral to weakly warm in the subsurface.

Atmospheric patterns

Surface analyses

The southern hemisphere spring 2004 mean sea-level pressure (MSLP) pattern, computed from the Australian Bureau of Meteorology's Global Assimilation and Prediction (GASP) model, is shown in Fig. 7, with the corresponding anomaly pattern provided in Fig. 8. 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 spring MSLP pattern (Fig. 7) displays a very zonal structure with a weak wavenumber four pattern. The Antarctic circumpolar trough showed four areas where mean pressures were below 980 hPa; 30°E, 60°E to 120°E, 180°E to 90°W and 45°W.

Fig. 7 Mean sea-level pressure for spring 2004 (hPa).

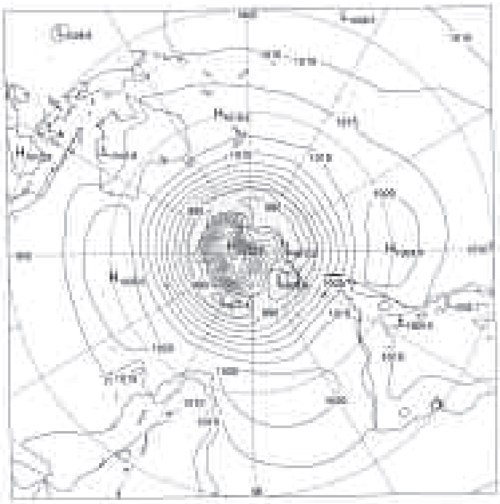


Fig. 8 Anomalies of the mean sea-level pressure from the 1979-2000 National Centers for Environmental Prediction Reanalysis II climatology, for spring 2004 (hPa).

In the tropical Pacific (Fig. 8), MSLP anomalies were mostly small in magnitude (reaching minima of –1.8 and –2.1 hPa, compared to the 2002 El Niño spring values which were down to –3.9 hPa), but nonetheless negative. This is not surprising given the positive SST anomalies (Fig. 4), which would have enhanced low-level warming and hence reduced pressures. However, the weakly negative pressure anomalies are further evidence of the failure of the atmosphere to fully respond to the relatively larger positive anomalies in SST.

More substantial positive MSLP anomalies occurred over the Australian continent and surrounding regions during spring, with a maximum of +3.5 hPa over eastern South Australia. These generally higher pressures were also reflected in the increased OLR (decreased high cloud) observed during the season and in the generally above average maximum and minimum temperature deciles.

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. 9, with anomalies in the 500 hPa field displayed in Fig. 10.

The analysis of the 500 hPa height shows positive anomalies near 240°E, 50°S. This, combined with negative anomalies to the north, is indicative of an increased tendency for blocking in this region (Fig. 11). This is further discussed in the following section.

As with the MSLP anomaly field, anomalies of the 500 hPa height were not particularly strong (Fig. 10). At the mid to high latitudes, the major 500 hPa height anomalies were generally centred over the same locations as their MSLP counterparts. Combined, this suggests a largely barotropic atmospheric structure.

Blocking

The time-longitude section of the daily southern hemisphere blocking index (BI)* is shown in Fig. 11. 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.

The BI values during spring 2004 showed several relatively strong blocking events (BI > 60). The first event is a continuation of a strong event started in August 2004. This event, centred around 210°E, continued into the first week of the season and weakly into the second week. A small, strong blocking event, centred on the date-line, occurred in the first week of October. The largest blocking event during the season took place through late October and early November. Positive daily BI values occurred between 90°E and 270°E with several strong centres (BI > 60).

* 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.

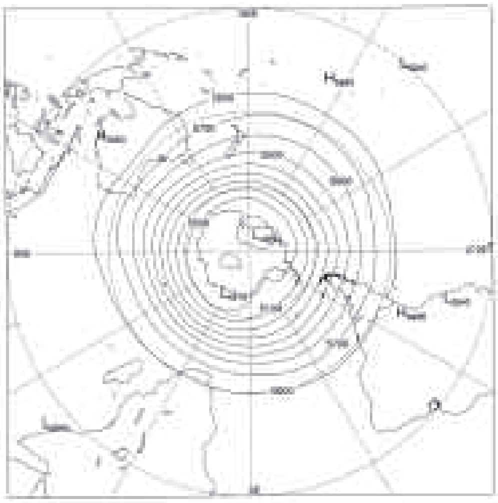


Fig. 9 **Mean 500 hPa geopotential heights for spring 2004 (gpm).**

Fig. 10 **Anomalies of the 500 hPa geopotential height from the 1979-2000 National Centers for Environmental Prediction reanalysis II climatology, for spring 2004 (gpm).**

Peak seasonal mean BI values were located around 210°E (Fig. 12), east of, and slightly greater than, the region of maximum climatological values. BI values greater than climatology were also observed around 110°E. The region from eastern Australia to the central Pacific (140ºE to 140ºW) is climatologically favoured for blocking (Trenberth and Mo 1985; Sinclair 1996). As shown in Fig. 9, this region primarily east of the date-line, was the most notable region of split flow at the 500 hPa level.

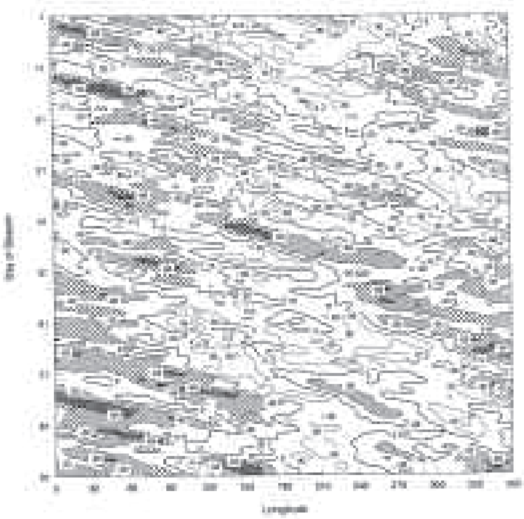


Fig. 11 **Spring 2004 daily blocking index: time-longitude section. Day 1 is 1 September.**

In contrast, the BI index in the region between 30°W and 70°E was lower than climatology, indicating enhanced zonal flow in this region. Figure 11 reveals several episodes of strong zonal flow occurred during spring in this region. Two of the strongest episodes occurred in the second week of September and in mid-November.

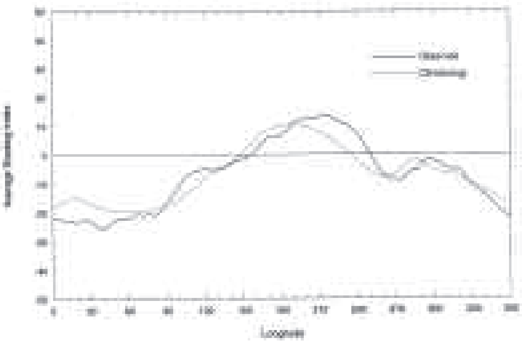
Winds

Spring 2004 low-level (850 hPa) and upper-level (200 hPa) wind anomalies (from the 22 year NCEP II climatology) are shown in Figs 13 and 14 respectively.

At the low levels, the wind anomalies (Fig. 13) generally reflected the MSLP anomalies (Fig. 8). Largest anomalies tended to occur in the mid to high latitudes. However, one of the largest anomalies, 5 m s^{-1}, occurred in the northern Australian region. This was in contrast to most of the tropical Pacific sector which displayed close to normal winds. Close to the South American coast there was a weak enhancement of the Trade Winds in the southern hemisphere, thus facilitating the upwelling of cooler deep water, with negative SST anomalies apparent in this area (Fig. 4).

As previously mentioned, low-level wind anomalies across the tropical Pacific were fairly weak in spring, as they had been in winter, not exhibiting the strong suppression of the trade winds that one would expect from a fully coupled El Niño event. However, between about 5°N and 10°N the trade winds were suppressed right across the Pacific from 180°E to the Americas. Upper-level winds were close to average across the equatorial Pacific, although immediately south of the equator there were easterly anomalies

Fig. 12 Mean southern hemisphere blocking index for spring 2004 (bold line). The dashed line shows the corresponding long-term average. The horizontal axis shows the degrees east of the Greenwich meridian.



shading to southeasterly anomalies in the eastern half. Coupled with the anomalies at the surface 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. As stated in Collins (2005), the lack of an El Niño signature in the atmospheric anomalies was one of the reasons the National Climate Centre did not declare 2004 an El Niño year.

In the Australian region, as mentioned previously, the most significant low-level wind anomaly was the 5 m s^{-1} anomaly over northern Australia. This put much of Australia in anomalous northerly flow, which may have contributed to the above average maximum temperature over most of Australia for the season (Fig. 18).

Ozone hole observations

The austral spring is the time of the maximum extent of the Antarctic ozone hole and the time of lowest annual ozone levels. In the absence of sunlight, the wintertime polar vortex in the lower stratosphere cools to below –78°C enabling polar stratospheric ice clouds to form. Chlorine and bromine compounds react in the ice clouds to produce chemical species that, when combined with the incoming UV radiation as the sunlight returns in spring, destroy ozone (WMO 1998). As the stratosphere warms in spring (and hence ice clouds can no longer form) this process weakens. Ozone levels then return to near normal by early summer. The compounds that lead to the ozone breakdown are largely anthropogenic, but now appear to be in decline (WMO 1998).

Figure 15 shows the mean ozone measurements for spring 2004 from the Total Ozone Mapping Spectrometer (TOMS) instruments. Typically, the ozone hole is taken as the area of total column ozone with a value of less than 220 Dobson units (DU). The minimum value recorded by satellite in 2004 was about 90 DU at the start of October. The mini-

Fig. 13 Spring 2004 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.

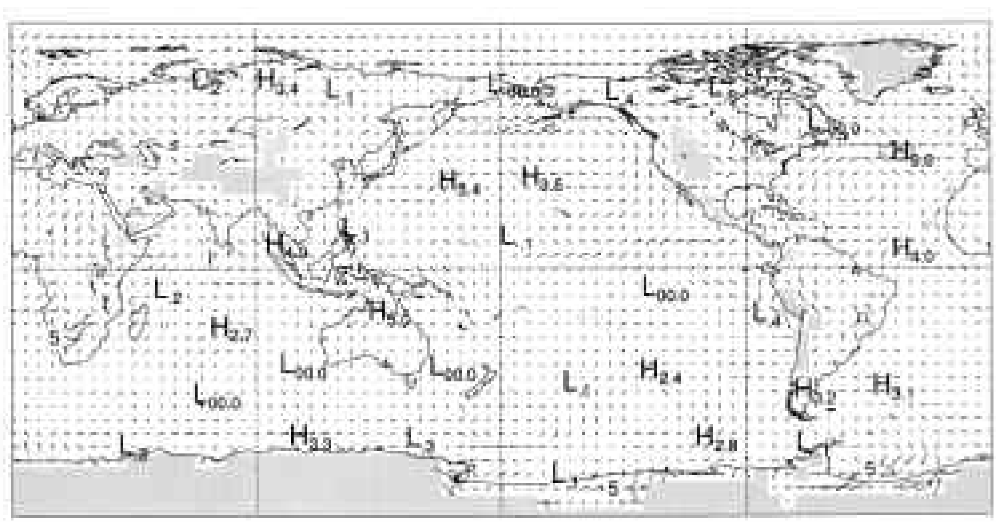


Fig. 14 **Spring 2004 200 hPa vector wind anomalies with contours of vector magnitude overlayed. The contour interval is 5 m s^{-1}, with values above 5 m s^{-1} stippled.**

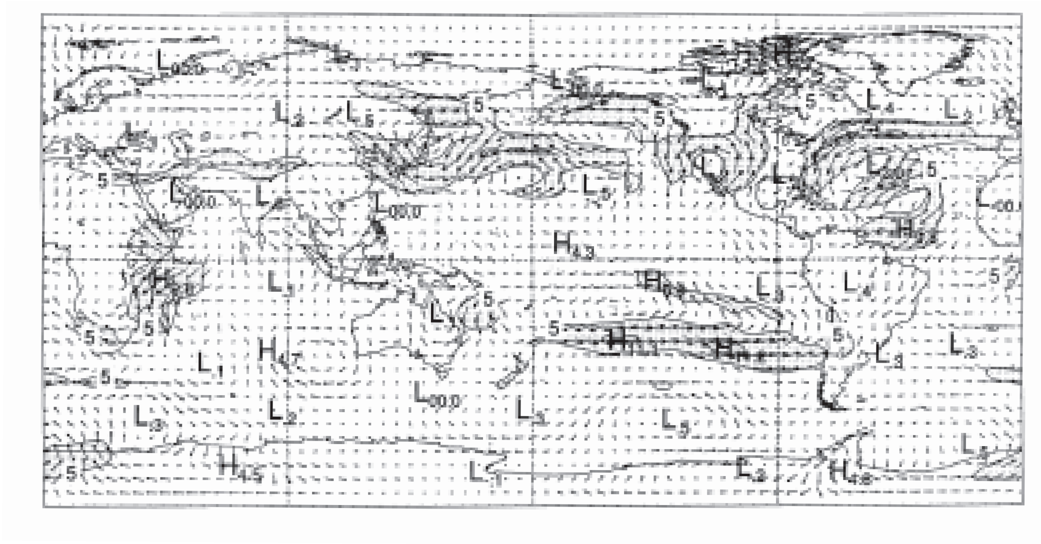
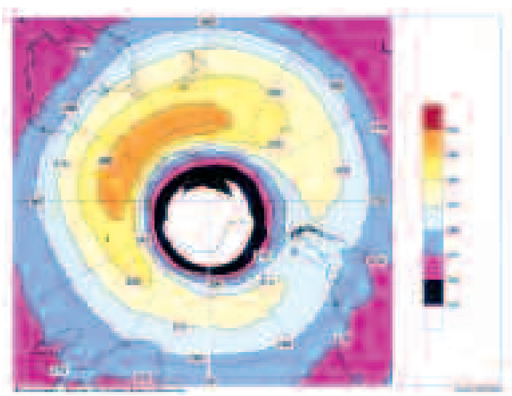


Fig. 15 **Spring 2004 total ozone (Dobson Units) from TOMS**



mum value recorded by ground observation was 133 DU at Halley Bay. The lowest observed values to date are 88 DU by satellite and 98 DU at Halley Bay, both in 1994.

The southern polar vortex reached a size of around 35 million km^2 during September, a size near average for recent years, while temperatures in the lower stratosphere cold enough for polar stratospheric clouds to form ended about 2 to 3 weeks earlier than most recent years.

As a result, the 2004 ozone hole was relatively small, with the areal extent comparable to that of the small hole in 2002, with values generally well below that of the 1994-03 mean. Peak values were around 20 million km^2, with the hole becoming elongated enough during 10 to 12 September, and again during 19 to 24 September, for the hole to pass over the tip of South America, the Falkland Islands and over South Georgia. After peaking in mid September, the hole lost more than 50 per cent of its area in the following five weeks. However, and quite unusually, the ozone hole then increased in area by more than 30 per cent over the following three weeks, before experiencing a rapid decrease in area until the ozone hole disappeared on 17 November.

Despite being smaller in size than past ozone holes, the longer life of the hole meant that the total mass of ozone destroyed in the region of the ozone hole (called the 'ozone mass deficit') was in fact higher than for most years in the past decade during September, and for November was at record amounts, with over 55 million tonnes of ozone lost.

Although the 2004 ozone hole was again relatively weak (as was the hole of 2002) this is not considered an indication of a return to a normal chemical composition of the stratosphere, rather, it is expected that it may be at least another decade before ozone levels trend towards pre-ozone-hole values.

Australian region

Rainfall

The distribution of Australian rainfall totals for spring 2004 is shown in Fig. 16, whilst Fig. 17 shows the associated decile ranges based on gridded rainfall data for all springs from 1900 to 2004.

The highest rainfall totals during spring 2004 were in alpine Victoria, western Tasmania and coastal NSW (Fig. 16). Compared with the historical record, rainfall was above average along coastal and north-eastern NSW and southeastern Queensland (Fig. 17). Rainfall was also average to above average over northern SA and most of WA, excepting southwestern parts which received below to very much below average rainfall. Other parts to receive below average rainfall included much of the Northern Territory, northern and central Tasmania and small areas of coastal South Australia.

Substantial rain fell over much of coastal NSW in the period 18-22 October, with flooding in some coastal river valleys. Sydney had 122 mm in the period 18-21 October, and 234 mm for the period 1-25 October, about three times the October mean. Heaviest falls for the week 15-21 October were 384 mm at Bowra Sugarloaf, 348 mm at Old Bar and 333 mm at Tweed Heads. The heavy rain also affected the far southeast of Queensland on 18-19 October with up to 200 mm being reported in the Gold Coast region.

Several significant rain events also occurred in rapid succession between 27 October and 13 November in and to the east of Melbourne resulting in flooding on several rivers, reaching its peak over the weekend 13-14 November. Three deaths resulted from this event. Melbourne received 164 mm of rain in the 19 days from 27 October to 14 November, about three times its monthly average for November or October.

Heavy rains, generally associated with thunderstorms and causing flash-flooding, also occurred in parts of southeastern Queensland in early November. At Gold Coast Seaway, 150 mm fell on 7 November followed by 147 mm on the 8 November. Two people drowned in a vehicle in a flooded creek near Biggenden, west of Bundaberg, on 5 November.

Table 1 summarises seasonal rainfall ranks and extremes on a national and state basis. Spring area-averaged rainfall totals were close to average over Australia as a whole. Likewise many of the States were ranked close to the median. Exceptions to this were Tasmania and Northern Territory, which both received total rainfall which placed them in the lowest tercile.

Above average to very much above average spring rainfall in northeastern NSW and central to southeast Queensland removed rainfall deficiencies that had developed since April 2004. There was also a decrease in deficiencies over inland NSW for the period since January 2004, although some patches remained. Rainfall deficiencies also persisted in parts of central to coastal Queensland and southern WA.

Fig. 16 **Spring 2004 rainfall totals over Australia (mm).**

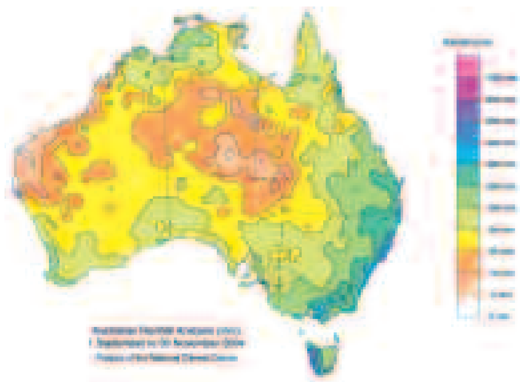
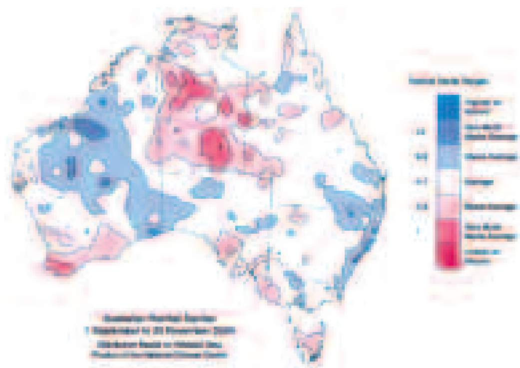


Fig. 17 **Spring 2004 rainfall deciles for Australia: decile range based on grid-point values over the spring periods from 1900 to 2004.**



Temperature

Mean maximum and minimum temperature anomalies for spring 2004 are shown in Figs 18 and 19, 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.

Table 1. Seasonal rainfall ranks and extremes on a national and State basis for spring 2004.

	Highest seasonal total (mm)	*Lowest seasonal total (mm)*	*Highest 24-hour fall (mm)*	*Area-averaged rainfall (aar) (mm)*	*Rank of aar **
Australia	1099 at Mount Read (Tas)	0 at several locations (WA, NT, Qld)	344 at Orama (NSW), 20 October	63	51
WA	227 at Karri Valley	0 at several locations	85 at Theda, 10 November	38	64
NT	243 at Woodycupaldiya	0 at several locations	107 at Wildman River Plantations, 21 November	38	23
SA	253 at Piccadilly	3 at Innamincka	62 at Ashton, 8 September	46	53
QLD	669 at Springbrook	0 at several locations	238 at Mt Tambourine, 7 November	72	50
NSW	780 at Promised Land	16 at Fort Grey	344 at Orama, 20 October	135	63
VIC	686 at Rocky Valley	45 at Morkalla North	113 at Rocky Valley, 9 September	169	53
TAS	1099 at Mount Read	76 at Tunbridge	75 at Mount Read, 13 September	254	28

* The rank goes from 1 (lowest) to 105 (highest) and is calculated on the years 1900 to 2004 inclusive.

Maximum temperatures averaged over the spring season were mostly average to above average, apart from small regions of below average temperatures on the coastal fringes (Fig. 18). Negative departures were less than –1°C and included regions around Carnarvon in WA, the north WA coast extending into the NT, the northeast NT coast and some small patches in Queensland. Maximum temperature anomalies exceeded +1°C over large areas of Australia and +2°C over a small region in southeast Queensland. According to gridded analyses of the high-quality maximum temperature network from 1950 to the present (not shown), more than half of the country recorded above average (deciles 8 and 9) temperatures, with scattered very much above average (decile 10) areas around the coast. These decile 10 areas included the southern SA/WA border region, the Top End of the NT, the south and central coasts of Queensland, southern coastal NSW and the far northeast of Tasmania. Table 2 shows that all States recorded higher than normal area-averaged spring maximum temperatures, with the greatest departures being +1.03°C for SA and +0.98°C for NSW. This follows a winter in which all States also had higher than normal area-averaged maxima. When ranked, the spring anomalies indicate that SA and Queensland had their eighth warmest spring daytime temperatures since 1950. Australia wide, it was the tenth warmest spring for daytime temperatures.

For the individual spring months the highest departures from normal occurred during October. Almost all of the country recorded above average (deciles 8 and 9) to very much above average (decile 10) monthly maximum temperatures, with a band running from southeast to northwest across central and southern WA recording highest on record October maxima. The Australia-wide mean maximum temperature was the second highest for October in the post-1950 period (+2.15°C), behind October 1988 (+2.69°C). The corresponding figure for WA was the highest on record. September's maximum temperatures were generally near average (deciles 4 to 7), with areas of below average (deciles 2 and 3) maximum temperatures across the tropics. The only areas of above average temperatures were through NSW and southern Queensland. November's maximum temperatures were generally average, with some areas of above average temperatures in all States and territories, but only a small area of below average temperatures in the west.

These high seasonal mean values were at least partly the result of two notable spring heatwaves in eastern Australia, one from 27-29 September and one from 11-13 October. The September event mostly affected inland New South Wales, with a State record for September (39.6°C) set on the 28 at Wanaaring. The October event was more widespread, with monthly records set at 34 locations in New South Wales, Victoria and South Australia. This included a Victorian State record for October of 40.2°C at Mildura and Walpeup on the 12th, and a Sydney October record of 38.2°C on the 13th. For Victoria, this was the third monthly record set in a 13-month period, following on from the new Victorian record for September set in 2003 (37.4°C, beating 35.6°C set in 1965) and a new record for February set in 2004 (46.7°C; previous record 45.6°C set in 1968).

Table 2. Seasonal maximum temperature ranks and extremes on a national and State basis for spring 2004.

	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	39.4 at Fitzroy Crossing (WA)	7.1 at Mt Hotham	45.6 at Ivanhoe (NSW), 30 November	–2.7 at Thredbo (Top Station) (NSW), 12 September	+0.80	46
WA	39.4 at Fitzroy Crossing	18.7 at Cape Leeuwin	45.3 at Fitzroy Crossing 14 November and Port Hedland, 15 November	10.6 at Jacup, 9 September	+0.69	43
NT	37.9 at Bradshaw	30.3 at McCluer Island	44.3 at Rabbit Flat, 18 November	17.0 at Kulgera, 12 September	+0.73	40
SA	30.9 at Oodnadatta	15.1 at Mount Lofty	45.5 at Maree and Oodnadatta, 30 November	4.4 at Mount Lofty, 11 September	+1.03	48
QLD	36.8 at Century Mine	22.6 at Applethorpe	44.8 at Birdsville, 30 November	13.0 at Applethorpe, 12 September	+0.85	48
NSW	29.7 at Mungindi	7.3 at Thredbo (Top Station)	45.6 at Ivanhoe, 30 November	–2.7 at Thredbo (Top Station), 12 September	+0.98	43
VIC	20.5 at Mildura	7.1 at Mt Hotham	40.2 at Mildura and Walpeup, 12 October	–2.3 at Mt Hotham, 11 September	+0.59	41
TAS	18.4 at Bushy Park	7.7 at Mount Wellington	31.5 at Hobart, 18 November	–0.4 at Mount Read, 15 October	+0.51	43

* The temperature ranks go from 1 (lowest) to 55 (highest) and are calculated on the years 1950 to 2004 inclusive.

Table 3. Seasonal minimum temperature ranks and extremes on a national and State basis for spring 2004.

	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	25.4 at McCluer Island (NT)	0.0 at Thredbo (Top Station) (NSW)	31.0 at Marble Bar (WA), 29 November	–11.4 at Charlotte Pass (NSW), 1 September	+0.31	39
WA	24.8 at Wyndham	6.6 at Wandering	31.0 at Marble Bar, 29 November	–4.5 at Kellerberrin, 11 September	+0.54	46
NT	25.4 at McCluer Island	14.0 at Alice Springs	30.5 at Timber Creek, 29 October	–1.0 at Kulgera, 13 September	–0.23	22
SA	15.4 at Moomba	6.4 at Yongala	29.0 at Arkaroola, 13 October	–3.8 at Yongala, 5 September	+0.67	44
QLD	24.4 at Horn Island	8.4 at Applethorpe	30.2 at Camooweal, 13 November	–4.0 at Applethorpe, 13 September	+0.27	34
NSW	16.7 at Byron Bay	0.0 at Thredbo (Top Station)	30.7 at Tibooburra, 30 November	–11.4 at Charlotte Pass, 1 September	+0.26	33
VIC	11.6 at Gabo Island	0.8 at Mt Hotham	24.2 at Mildura, 30 November	–7.2 at Mt Hotham, 12 September	-0.01	35
TAS	10.4 at Swan Island	0.5 at Mount Wellington	16.1 at Friendly Beaches, 12 October	–6.3 at Mount Wellington, 12 September	+0.20	42

* The temperature ranks go from 1 (lowest) to 55 (highest) and are calculated on the years 1950 to 2004 inclusive.

Fig. 18 Spring 2004 maximum temperature anomalies for Australia based on a 1961-90 mean (°C).

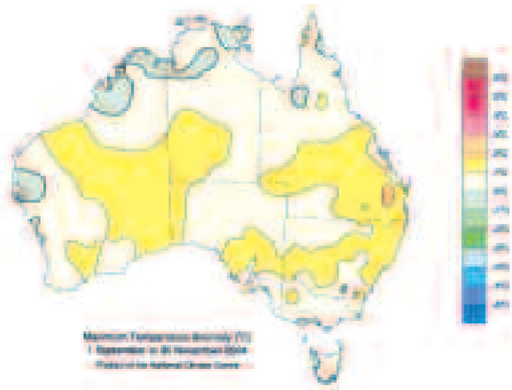
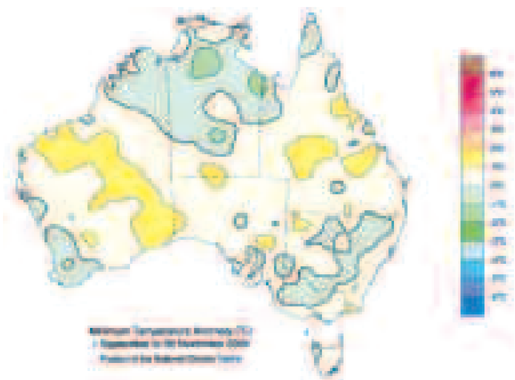


Fig. 19 Spring 2004 minimum temperature anomalies for Australia based on a 1961-90 mean (°C).



In conjunction with a dry spell and with windy conditions accompanying the October heatwave, significant moisture was drawn from winter crops that were approaching harvest. This led to significant crop losses in parts of Victoria and South Australia.

Mean minimum temperature anomalies for spring (Fig. 19) showed more variability than the maximum anomalies, with positive anomalies covering large areas of WA, SA and Queensland, with some areas in WA and Queensland between +1°C and +2°C. Cooler than average anomalies occurred in northern and southern WA and parts of Victoria, NSW and NT. These anomalies were generally between zero and –1°C, except for some small areas in the NT between –1°C and –2°C. Table 3 shows that the mean minimum Australia-wide temperatures for the season were warmer than average. WA showed the highest ranked seasonal mean, and none of the area-averaged means were ranked in the lowest (cooler than average) tercile of rankings.

Gridded analyses of the high-quality network (not shown) indicate very much above average to highest on record seasonal minimum temperatures in southeast Western Australia, with a wider area from northwest WA extending down to cover most of SA experiencing above average (deciles 8 and 9) seasonal minimum temperatures. In contrast, the Top End of the NT recorded very much below average (decile 1) to lowest on record spring temperatures.

As with the maximum temperatures, October saw widespread above to very much above average minimum temperatures, with scattered areas of highest on record October outcomes being seen across parts of WA and western SA. Mean minimum temperatures for October were the highest on record for WA and the third highest for Australia and South Australia for the post-1950 period.

Low minimum temperatures resulted in a major late-season frost event in the southwest of Western Australia on 11-12 September, with many locations setting September records. The lowest temperature recorded was –4.5°C at Kellerberrin, an all-time record for the station and the second lowest on record for Western Australia in September. This frost occurred at a critical time for grain crops and significant losses occurred. This was followed on 18 November when unusually low temperatures again occurred in this area, with –1.1°C recorded at Wandering, making it the latest date on which a subzero temperature has occurred in Western Australia. November minimum records were also set at Perth Airport (3.2°C) and Perth City (5.0°C).

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Appendix

The main sources for data used in this review were:

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- Climate Prediction Center, *Climate Diagnostics Bulletin*. Obtainable from: Climate Prediction Center, National Weather Service, Washington D.C., USA, 20233.
- World Meteorological Organization, *Antarctic Ozone Bulletin*. Obtainable from: http://www.wmo.ch/web/arep/gawozobull03.html; sighted (8/7/2005).