

Seasonal climate summary southern hemisphere (winter 1999): a return to near-normal conditions in the tropical Pacific

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Circulation patterns and associated anomalies for the austral winter season 1999 are reviewed, with emphasis given to the tropical Pacific and Australian regions. As a whole, surface ocean and atmospheric indicators of the El Niño - Southern Oscillation displayed near neutral values during the winter of 1999, suggesting the moderate La Niña event whose intensity had peaked during the previous summer season had effectively ended. In the ocean subsurface, however, residual cool anomalies persisted through the season, and showed signs of strengthening and expansion in August, forewarning the re-establishment of Pacific cool conditions which was to occur later in the year.

In contrast to the near neutral phase of the El Niño - Southern Oscillation in the Pacific, winter 1999 was far from normal in the Australian region. The season as a whole was very anticyclonic, with seasonal pressure anomalies widely greater than +2 hPa, and approaching +5 hPa near Victoria. The positive pressure departures took the form of an anomalously strong and poleward shifted subtropical ridge, and were reflected in the low-level circulation as east to northeast wind anomalies over Australia. Seasonal rainfall totals and cloud amounts were widely below normal, particularly over southern parts, reflecting the prevalence of high pressure systems and a relative absence of substantial frontal passages. Seasonal mean maximum temperatures were mostly higher than normal with the Australia-wide value a near record, while the seasonal mean minimum temperature anomalies were mixed and of modest amplitude.

Introduction

The seasonal means of atmospheric and surface ocean indicators of the El Niño - Southern Oscillation (ENSO) revealed near-neutral conditions prevailed in

the Pacific basin during austral winter 1999. The Southern Oscillation Index (SOI) remained near zero, while the tropical Pacific sea-surface temperatures (SSTs), while on the cool side of climatology, were predominantly within 0.5°C of the mean. Low and upper-level wind anomalies in the Pacific basin were mixed, with the most notable features being anom-

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alous cross-equatorial flow in the eastern Pacific, and anticyclonic flow anomalies over Australia. Taken as a whole, conventional seasonal indicators suggested that the La Niña event which peaked in late 1998 (Beard 1999; Trewin 1999), and whose decline had accelerated through autumn 1999 (de Hoedt 2000) was over.

Belying the demise of the 1998/99 La Niña in conventional indices, analyses on the intra-seasonal time-scale and of the ocean subsurface suggested a more complex and transient situation. In the central and eastern tropical Pacific, residual cool anomalies persisted through winter in the subsurface, and indeed intensified and extended towards the surface during August. Concomitantly, the overlying Pacific Walker Circulation showed signs of re-invigoration late in winter, with the re-establishment of an anomalous convective dipole near the equatorial date-line. The developments late in the winter against a background of an otherwise near-neutral season, foreshadowed the return to moderate Pacific cool (La Niña) conditions which was to occur later in 1999.

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 mean value of the SOI for winter 1999 was +2.6, with values for the months June, July, and August of +1.0, +4.8, and +2.1, respectively. These values were in line with the value of the SOI observed in the May (+1.3) of the same year (de Hoedt 2000). Hence, on the basis of the monthly SOI series (Fig. 1) the La Niña of 1998/99, which was characterised by 11 months of persistently high SOI values, had effectively ceased by winter 1999.

The SOI values were the result of winter pressure readings at Darwin and Tahiti being influenced by a large anticyclonic anomaly whose centre lay near southeast Australia (Figs 6, 7), with positive departures at both sites. The monthly anomalies at Darwin were +0.5, +0.1, and +1.1 hPa for June, July, and August, respectively, while the equivalent values at Tahiti were +0.6, +0.9, and +1.5 hPa. The slightly positive monthly and seasonal SOI values reflected the greater amplitude of the anomalies at Tahiti compared to Darwin, and were not indicative of a pressure anomaly dipole, as is more typically associated with the SOI (Jones and Simmonds 1994).

Fig. 1 Southern Oscillation Index, January 1995 to August 1999 inclusive. Means and standard deviations based on the period 1933-92.

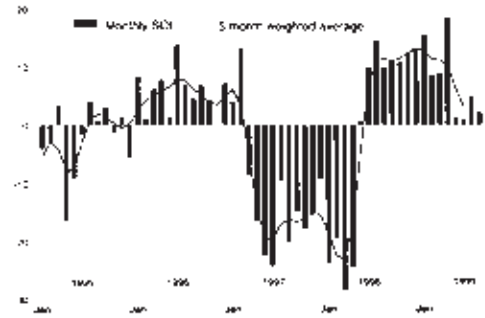
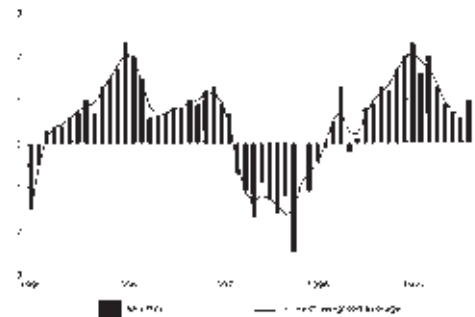


Fig. 2 Standardised anomaly of monthly outgoing long wave radiation averaged over 5°N-5°S and 160°E-160°W, for January 1995 to August 1999. Negative (positive) anomalies indicate enhanced (reduced) convection and rainfall. Anomalies are based on a 1979-95 base period of mean. After CPC (1999).



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Outgoing long wave radiation

Figure 2 shows a time series of monthly standardised outgoing long wave radiation (OLR) anomalies for the period January 1995 to August 1999. These data were provided by the Climate Prediction Center, Washington D.C. (CPC 1999), and are a measure of the OLR emitted from an equatorial region centred on the date-line. Positive values of this index indicate an increased

* 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 1933-92.

effective black-body temperature in the index zone, and tend to be associated with decreased cloudiness and rainfall. Tropical convection in this indicator zone is particularly sensitive to changes in the phase of the Southern Oscillation (Hoerling et al. 1997): during warm (El Niño) events convection is generally enhanced resulting in a reduction in the OLR, and the reverse applies during cold (La Niña) events.

Early winter witnessed a continued decline in OLR anomalies from the high values of the previous summer. The observed relaxation of the OLR values towards zero is consistent with the return of the Pacific Walker Circulation to near normal, in response to the decline of the oceanic phase of the 1998/99 Pacific cool event. With the decline of La Niña conditions, the SSTs underlying the index zone warmed substantially from summer 1998/99 to near normal by winter 1999, and this warming was reflected in the return of convective activity to near normal.

The August value of the OLR index showed a rebound from July, implying a reduction in tropical convection near the date-line. In isolation it would not be possible from this jump to support the conclusion of a resurgent Pacific cool event, particularly when viewed against the historical intraseasonal variability of the OLR index. However, the high spatial organisation of the contributing anomalies in August which covered most of the central tropical Pacific (not shown), combined with the re-intensification of cool ocean anomalies, forewarned the re-emergence of La Niña conditions which was to occur later in 1999.

Ocean patterns

Sea-surface temperature (SST) patterns

For the most part, the distribution of SST anomalies during winter (Fig. 3) was similar to that observed in the previous (autumn) season (de Hoedt 2000), but with generally reduced magnitudes. Indeed, quite possibly the most significant feature of the anomaly chart for winter is the quite general absence of significant anomalies of any sign, with only small parts of the globe showing departures from climatology of greater than 1°C. Winter 1999 marks the first season since the onset of the strong El Niño in 1997, and the subsequent La Niña conditions in 1998, in which global SSTs have not shown widespread large amplitude anomalies.

On the more regional scale, SSTs continued to be cooler than climatology across most of the tropical Pacific, but with departures greater than 1°C limited to near the Peruvian coast. The weak cool anomalies in the tropical Pacific were the surface reflection of more substantial (residual) anomalies at depth (Fig. 5). Based on the small magnitude of the seasonal SST anomalies across most of the tropical Pacific, and the return of the NINO3 and NINO4 indices to near zero (not shown), the La Niña which developed in 1998 had effectively ended by winter 1999.

In the Australian region, SSTs continued to be mostly warmer than normal, but with anomalies greater than 1°C confined to relatively small regions near the south and west coasts. Elsewhere, the north-

Fig. 3 Anomalies of sea surface temperature for Winter 1999 (°C).

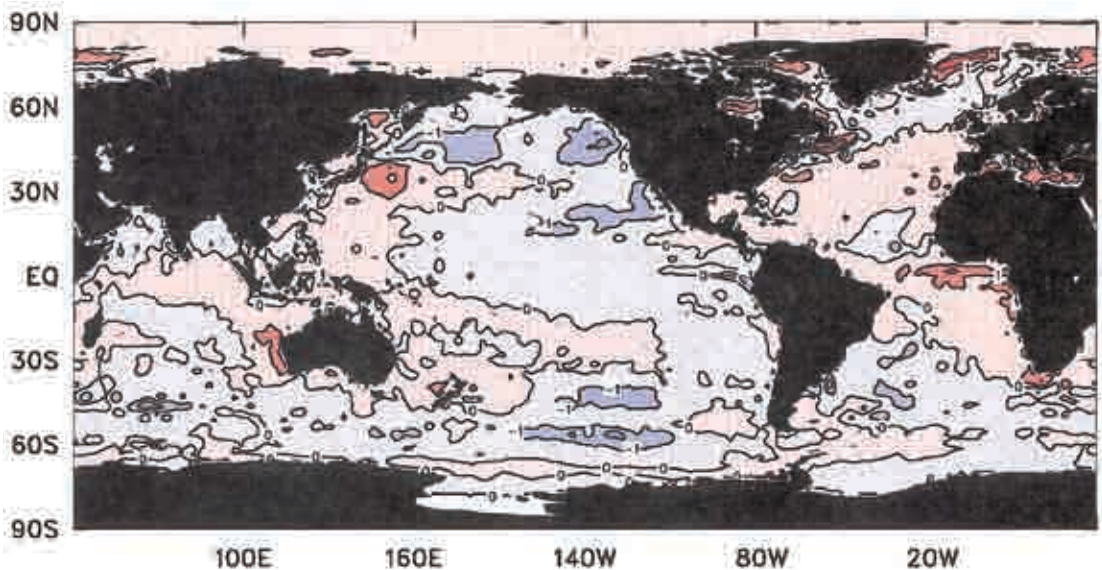
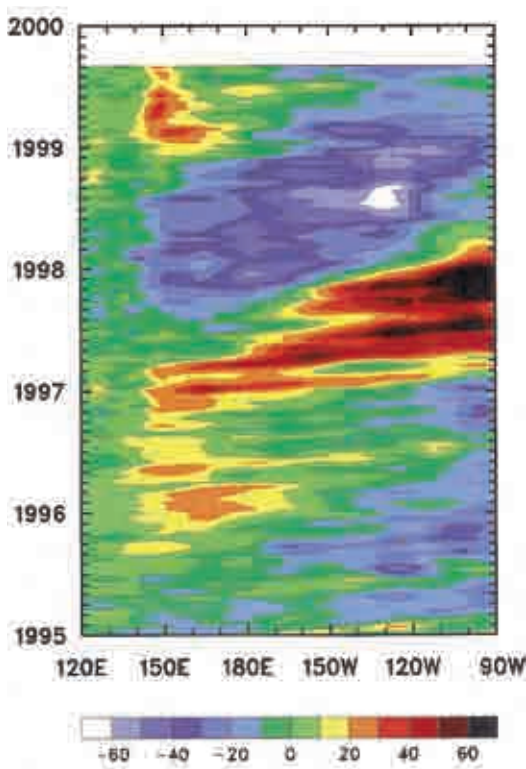


Fig. 4. Time-longitude section of the monthly anomalous depth of the 20°C isotherm at the equator for January 1995 to August 1999. Contour interval is 10 m.

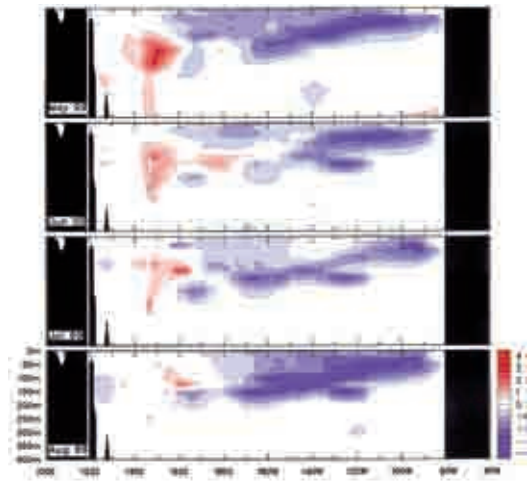


east Pacific continued to be cooler than normal and the ocean near the Kuroshio current warmer than normal, continuing a pattern evident since mid 1998 (Beard 1999). The observed pattern of anomalies bears a strong resemblance to the SST Interdecadal Pacific Oscillation (Power et al. 1999), suggesting a possible role of low frequency oceanic variability in this ocean dipole structure.

Subsurface ocean patterns

To highlight the evolution of the subsurface ocean, Fig. 4 shows the Hovmöller diagram of the anomaly of the 20°C isotherm for January 1995 through August 1999. This isotherm is generally situated very close to the equatorial ocean thermocline, the region of greatest temperature gradient with depth, or the boundary between the warm near-surface and cold deep-ocean water. The Hovmöller diagram clearly shows the rapid establishment of the 1997/98 El Niño through a series of warm (thermocline depressing) pulses during early 1997 associated with eastward propagating oceanic Kelvin waves (Beard 1998). The

Fig. 5 Four-month May to August 1999 sequence of vertical temperature anomalies at the equator. Contour interval is 0.5°C.



La Niña which developed through 1998 (Courtney 1998), is evident as an eastward spreading of reduced thermocline depth, which was associated with undercutting, erosion and eventual replacement of the very warm Pacific subsurface waters associated with the preceding El Niño. On the basis of the subsurface, the La Niña which developed through 1998 was fully mature by spring 1998, and declining by early 1999 (Trewin 1999; de Hoedt 2000).

On the intraseasonal time-scale, Fig. 4 reveals rather complex behaviour in the decline of the 1998/99 La Niña. The return towards neutral conditions substantially reflected two warm pulses consistent with the west to east propagation of oceanic Kelvin waves, the second and more substantial of which occurred from May through July. To further highlight this evolution, Fig. 5 shows the sequence of vertical temperature anomaly sections at the equator for each of the four months, May 1999 through August 1999. This suggests an oceanic Kelvin wave propagating from near 140°E in the vicinity of the thermocline (150-200 metres depth) towards the east, and being manifested as a rapid warming of near-surface waters in the central and eastern Pacific in June through July. Indeed, this event was sufficient to temporarily raise central Pacific SSTs to locally above normal values during July, and can be clearly seen as the pulse of increased thermocline depths in the 20°C Hovmöller diagram (Fig. 4). Following the passing of the Kelvin wave and its apparent failure to couple with the atmosphere, August saw a re-establishment of widespread cool anomalies in the central and eastern Pacific.

Surface analyses

The winter mean sea-level pressure (MSLP) across the southern hemisphere is shown in Fig. 6, with the associated anomalies from climatology given in Fig. 7. These anomalies are the difference from an eleven-year (1979-89) climatology obtained from the European Centre for Medium Range Weather Forecasts (ECMWF). For the most part the winter 1999 pressure distribution resembled climatology for the season (Hurrell et al. 1998), with highest pressure associated with the Antarctic high and subtropical ridge. Over the Southern Ocean, the pressure field was dominated by the circumpolar trough whose axis lay near or poleward of 60°S, with the most noteworthy departure from zonal symmetry being a substantial (and rather anomalous) four-wave pattern embedded in the mid/high latitude westerlies.

The anomalous MSLP during winter shows a tendency for elevated pressures over and near the Antarctic. While the combination of high topography and a strong surface inversion over the Antarctic complicates interpretation, the mid tropospheric heights (Fig. 9) and Southern Ocean wind observations (Figs 11, 12), support the observation of an enlarged and intensified polar anticyclone. Further north, the MSLP was widely below normal across the Southern Ocean in a belt centred near 45°S, with an embedded zonal four-wave pattern. The minima in the anomalous four-wave pattern lay near 90, 180, 270, and 360°E, each being associated with marked cyclonic curvature in the seasonal mean westerlies in their vicinity.

Positive pressure anomalies dominated the Australian region during each of the winter months, giving rise to seasonal departures greater than +2 hPa across much of the country. These anomalies were largely a result of anomalously strong and persistent anticyclones about southeast Australia and the Tasman Sea, and an associated absence of significant low and frontal passages. The associated anomalous pressure gradient was reflected in a strong anomalous anticyclonic circulation extending over most of Australia (Fig. 11). Consequently, the season saw a weakening of the climatological westerlies in the south, and an enhancement of the easterlies in the north, with an anomalous northerly wind component across most of Australia south of the tropics.

Mid tropospheric analyses

Figures 8 and 9 show the distribution of mean and anomalous 500 hPa geopotential height across the southern hemisphere for winter 1999. The mean chart is dominated by the climatological circumpolar vor-

Fig. 6 Mean sea-level pressure for winter 1999 (hPa).

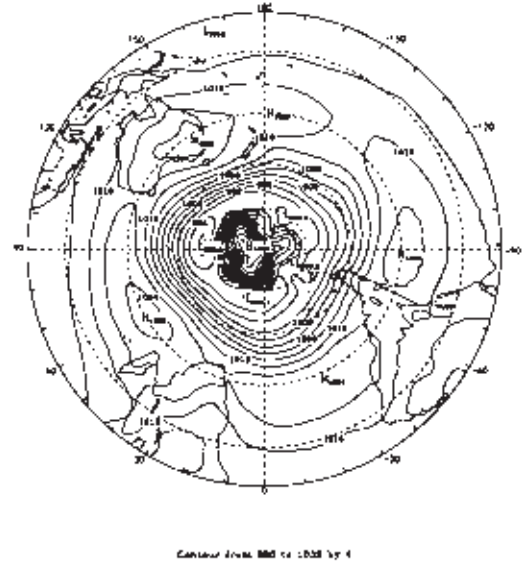
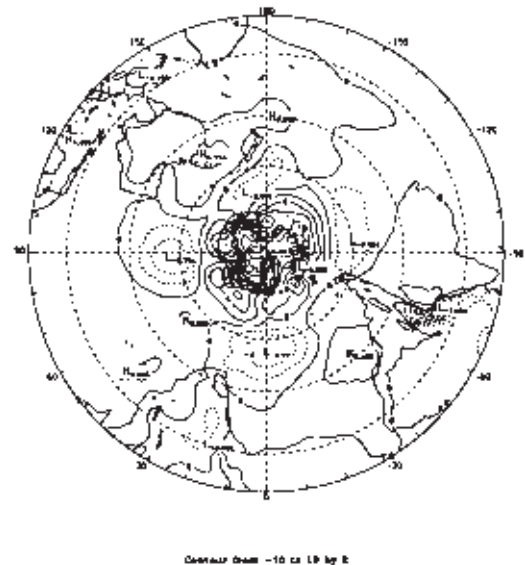


Fig. 7 Anomalies of the mean sea-level pressure from the 1979-89 ECMWF climatology, for winter 1999 (hPa).



tex, with a mixed three/four-wave in the mid-latitudes. For the most part, the mid tropospheric troughs in the westerlies lie near to or slightly west of their surface counterparts (Fig. 6), as is typical of southern hemisphere mid latitude weather systems.

Fig. 8 Mean 500 hPa geopotential height for winter 1999 (gpm).

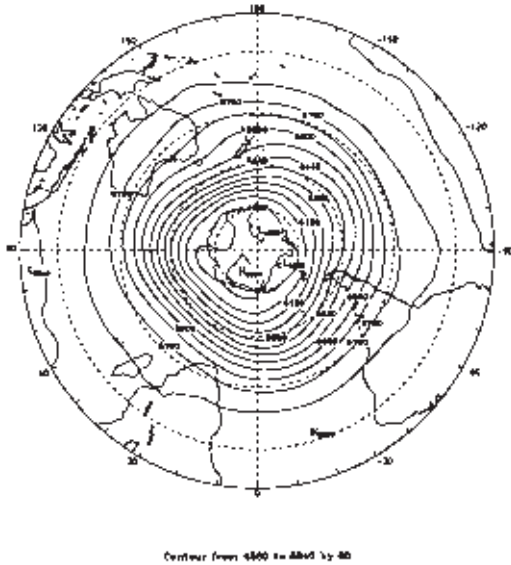
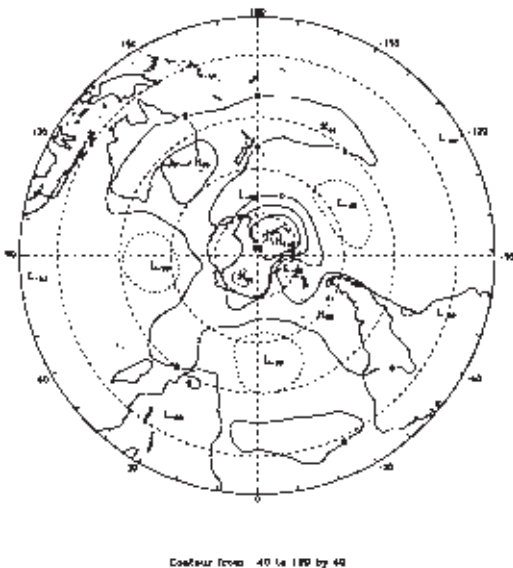


Fig. 9 Anomalies of the 500 hPa geopotential height from the 1979-89 ECMWF climatology, for winter 1999 (gpm).



The 500 hPa anomaly chart is similar to the equivalent figure for the MSLP (Fig. 7), with each major surface anomaly having a counterpart at the upper-level. The surface anticyclonic anomaly over southern Australia, and the cyclonic anomalies near

45°S in the Indian and Atlantic sectors have comparable magnitudes at the upper level with only small horizontal displacements, implying these to be substantially barotropic. The surface pressure anomalies near 45°S, 180°E and 45°S, 270°E correspond less closely with their mid-tropospheric counterparts. Notably, the 500 hPa anomaly minimum near 270°E, is substantially stronger and northwest of its surface counterpart, signifying a substantial baroclinic component, while that near 180°E is much less developed at the upper level.

Blocking

Figure 10 shows the time-longitude section of the daily southern hemisphere blocking index (Wright 1993), which measures the strength of the zonal 500 hPa flow in mid latitudes relative to that at subtropical and high 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. Blocking in winter 1999 was chiefly focussed in the climatologically favoured New Zealand sector (see, Trenberth and Mo (1985)), with greatest activity occurring from mid July through to mid August. Elsewhere, blocking activity was limited to relatively brief episodes, with the blocks themselves being relatively mobile.

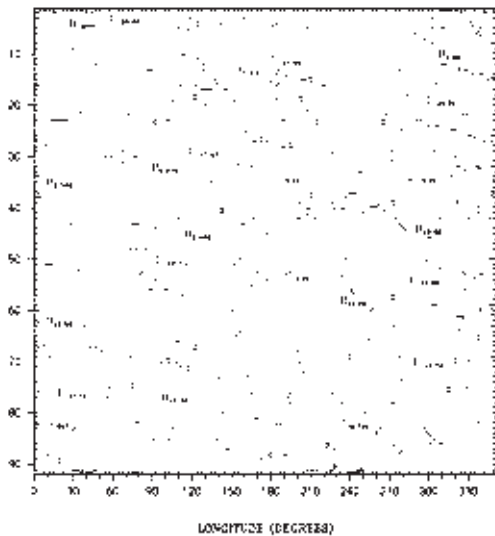
In the seasonal mean, anomalies of southern hemisphere blocking activity (not shown) substantially reflected the anomalies of 500 hPa geopotential height (Fig. 9). The seasonal blocking index values were above average between 120 and 210°E, reflecting the frequent occurrence of slow moving anticyclones in the Australian sector. Elsewhere blocking activity was mostly below normal, but with the magnitude of associated departures being quite small.

Low and upper-level winds

The low (850 hPa) and upper (200 hPa) wind anomalies from the eleven-year ECMWF climatology are shown in Figs 11 and 12, respectively. Low-level wind anomalies in the central and eastern tropical Pacific Ocean were dominated by anomalous cross-equatorial flow into the north equatorial convergence zone, with return flow anomalies evident aloft. Further west, the trade winds were stronger than normal in the North Pacific, associated with anomalously active convective activity across southeast Asia, while the trades in the southwest Pacific were near normal.

In the southern extratropics, the most important anomalies in the 850 hPa winds for winter 1999, were

Fig. 10 Winter 1999 daily blocking index: time-longitude section. Day 1 is 1 June.



associated with the increased strength of the Antarctic high, and the zonal four-wave anomaly pattern in the mid latitude westerlies. There were substantial cyclonic flow anomalies in the vicinity of 45°S centred on the longitudes of 90, 270 and 360°E with a weaker centre near 180°E. On the south side of the circumpolar trough, the polar easterlies were substantially stronger than normal near the Antarctic coast, being reflected in strong easterly wind anomalies.

At the 200 hPa level the extratropical wind anomalies showed many similarities with those at the lower level, implying a substantial (equivalent) barotropic component in the associated height anomalies. The mid-latitudes were dominated by cyclonic anomalies near 90, 250, and 360°E, the upper centre in each case being near or slightly west of its 850 hPa equivalent.

Over Australia, the upper wind field was dominated by the aforementioned large anticyclonic anomaly, with particularly marked east to southeast wind anomalies through south and central parts of the continent. The strong upper southeasterly flow anomalies are counter to the upper winds which tend to be associated with Australian northwest cloud bands (Downey et al. 1981; Wright 1997), and indicate a substantially weakened subtropical jet stream over Australia. It is noteworthy that winter 1999 was characterised by very few substantial northwest cloudbands across Australia. The relative absence of these climatologically important features was reflected in marked OLR anomalies (not shown) and below normal rainfall over southern parts of the country (Fig. 14).

Australian region

Figure 13 shows the distribution of rainfall totals for winter 1999, while Fig. 14 shows the associated decile ranges based on a 100-year reference period (1900-99). For the most part, the distribution of winter rainfall followed climatology with substantial falls limited to the south and east coasts. Highest seasonal rainfall totals occurred in far southwest Western Australia, western Tasmania, and on the northern New South Wales coast, where seasonal totals locally approached 1000 mm.

The rainfall decile ranges for winter reveal that totals were widely below, to very much below, normal over southern Australia, focussed in a band from central Western Australia through southern Victoria. The relatively low rainfall over southern parts reflected a lack of substantial frontal passages and northwest cloudband activity, due to a poleward shift of the subtropical ridge and a weakening and stabilisation of the tropospheric westerlies. Equatorwards of the subtropical ridge, persistent low-level easterlies and showery conditions resulted in above to very much above normal seasonal rainfall on the New South Wales and southeast Queensland coasts, while elsewhere deciles were mixed. The patterns of observed rainfall in each of the three months broadly followed the seasonal pattern, with below normal totals widespread in the south, above normal falls along parts of the east coast, and mixed falls over the continental interior.

June 1999 witnessed generally average to below-average rainfall across Australia, with above-average falls largely confined to a band from the east coast near Brisbane, stretching northwest to near Broome. Rainfall in the south was largely associated with weakening frontal systems moving out of a dominant Indian Ocean long wave trough, with only one instance of significant cyclogenesis during the month. On the east coast persistent moist easterly flow and the passage of a number of upper troughs resulted in rainfall totals locally in the highest decile.

The pattern of rainfall during July was very similar to June, being dominated by large slow-moving anticyclones near the southeast. Above average falls were largely confined to the east coast, being associated with persistent moist onshore flow, with occasional enhancement by upper troughs. Dry conditions occurred in many south coastal parts, with large areas experiencing rainfall in the lowest 10 per cent of observations. The tendency for below-average rainfall continued through much of South Australia and parts of Western Australia in August. While it was a very anticyclonic month in the southeast with pressure anomalies of greater than +6 hPa, the passage of a major low pressure complex in early August, and a second weak-

Fig. 11 Anomalies of the vector wind at the 850 hPa level from the 1979-89 ECMWF climatology, for winter 1999 (m s^{-1}).

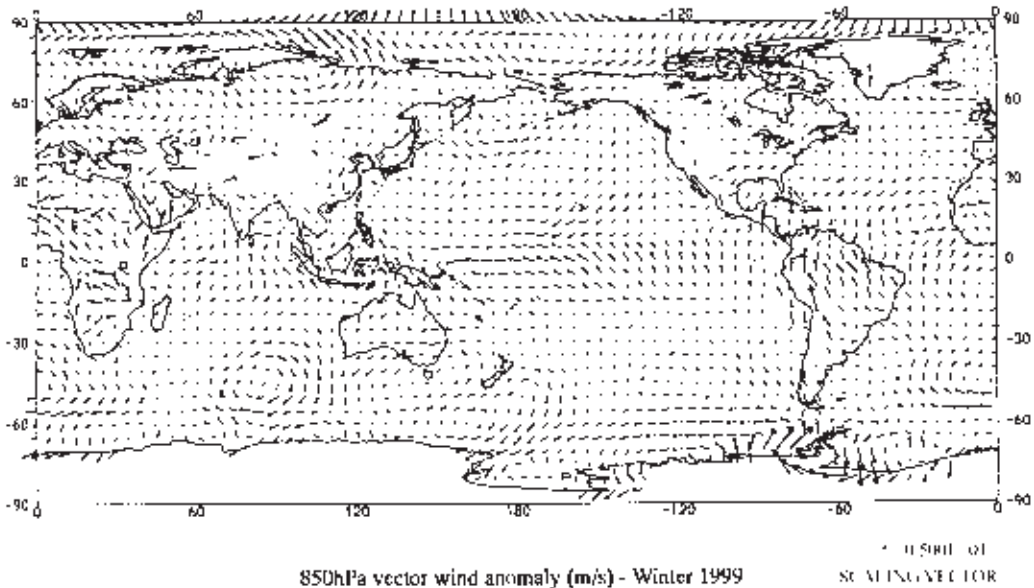
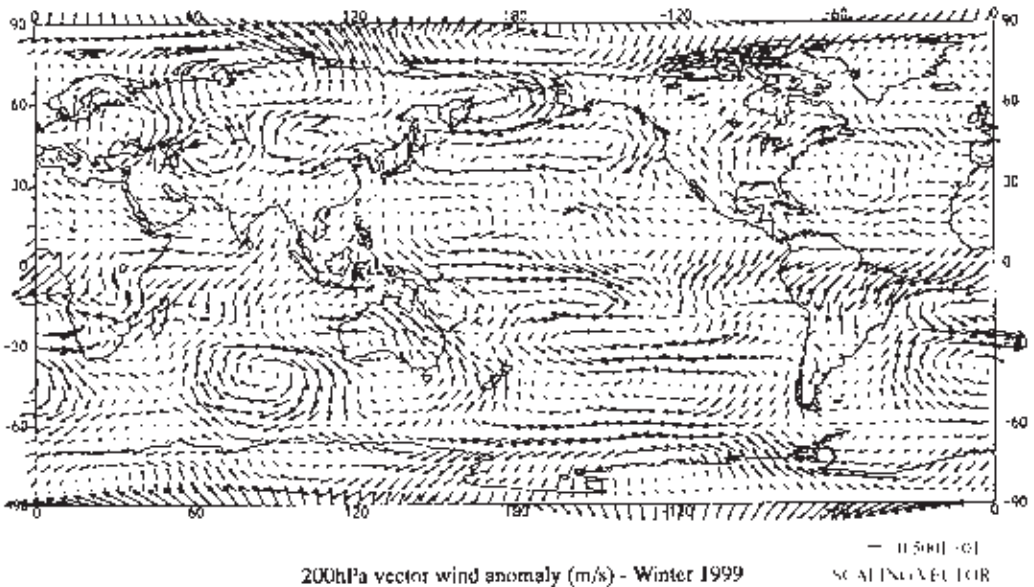


Fig. 12 Anomalies of the vector wind at the 200 hPa level from the 1979-89 ECMWF climatology, for winter 1999 (m s^{-1}).



er cut-off later in the month meant that most parts of Victoria received average to above-average monthly rainfall. On the east coast, rainfall totals continued to be average to above average, in response to persistent easterlies, with falls locally in decile 10 near Coffs Harbour, and in parts of far north tropical Queensland.

Temperatures

The mean maximum and minimum temperature anomalies for winter 1999 calculated with respect to the 30-year reference period 1961-90 are shown in Figs 15 and 16, respectively. The combination of

Fig. 13 Rainfall totals over Australia for winter 1999 (mm).

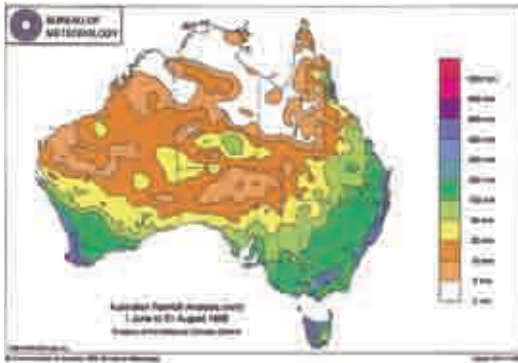
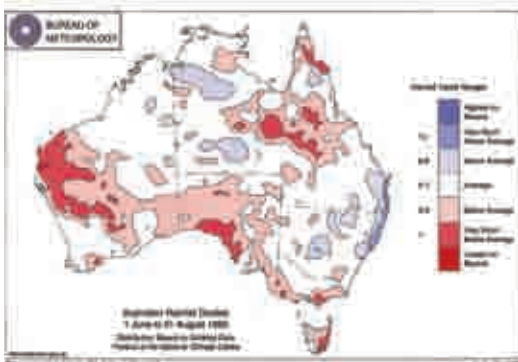


Fig 14 Deciles of rainfall over Australia for winter 1999, based on 100-year 1900-99 base period.



below average rainfall and cloudiness, and anomalous poleward flow in the low levels, meant that most parts of Australia experienced above average daytime temperatures for winter. The greatest departures from climatology occurred through the southern interior of the continent, where anomalies were widely greater than $+1^{\circ}\text{C}$, and locally reached $+2^{\circ}\text{C}$ in South Australia. Anomalies for the mean minimum temperature were rather mixed, reflecting the dual influence of above average daytime temperatures and an increased diurnal temperature range. In general, the minimum temperatures were mostly near normal in the south and west, and above normal in the northeast, with most associated anomalies being of modest amplitude.

Based on quality-controlled station data the all Australian mean maximum temperature anomaly for

Fig. 15. Winter 1999 maximum temperature anomalies ($^{\circ}\text{C}$) for Australia based on a 1961-90 mean.

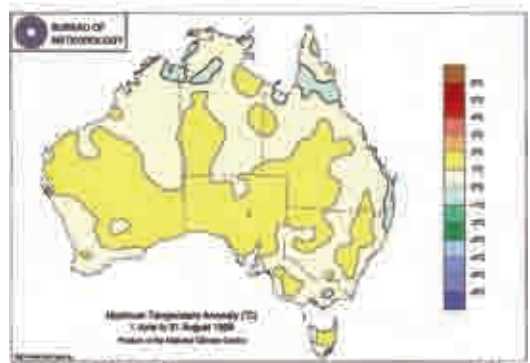
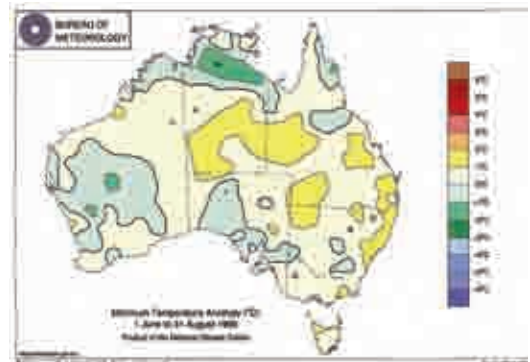


Fig. 16. Winter 1999 minimum temperature anomalies ($^{\circ}\text{C}$) for Australia based on a 1961-90 mean.



the season was $+0.94^{\circ}\text{C}$ above normal, being the second highest winter value since national records commenced in 1950 (record $+0.96^{\circ}\text{C}$ in 1996). The equivalent value for the minimum temperature was a near-normal $+0.35^{\circ}\text{C}$, with the anomalously large diurnal temperature range reflecting the shift towards anticyclonic conditions across most of the country.

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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 1289K, Melbourne, Vic., 3001, Australia.

Climate Prediction Center, *Climate Diagnostics Bulletin*. Obtainable from: Climate Prediction Center, National Weather Service, Washington D.C., USA, 20233.