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Seasonal climate summary southern hemisphere (winter 2001): near-normal conditions in the tropical Pacific continue

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Southern hemisphere circulation patterns and associated anomalies for the austral winter 2001 are reviewed, with emphasis given to the Pacific Basin climate indicators and Australian rainfall and temperature patterns. Spring 2000 and summer 2000/01 saw the development of a positive phase of the Southern Oscillation, the third such positive phase in as many years. By autumn 2001, the Southern Oscillation had returned to a neutral state, which persisted through the winter of 2001.

Winter rainfall across Australia was above average in a band stretching from the northwest across the centre into northwestern New South Wales. In contrast, winter rainfall was below average in the western half of Western Australia (prolonging the extant deficiencies there) and some coastal parts in the east of the continent. Seasonal maximum temperatures were consistent with the rainfall outcomes.

Introduction

The positive phase of the Southern Oscillation which developed during spring 2000 (Watkins 2001) and persisted through summer 2000/01 (Fawcett 2002), returned to a neutral phase by autumn 2001 (Pahalad 2002). This was the third successive positive phase of the Southern Oscillation in as many years, however the oceanic indicators failed to reflect the atmospheric activity to any great extent. Hence this positive phase could not be called a La Niña event. The neutral conditions which became established during autumn 2001 persisted into winter.

This summary reviews the southern hemisphere and equatorial climate patterns for winter 2001, with particular attention given to the Australasian and Pacific Regions. The main sources of information for this report are the Climate Monitoring Bulletin (Bureau of Meteorology, Australia) and the Climate Diagnostics Bulletin (Climate Prediction Center, Washington). Further details regarding sources of data are given in the Appendix.

Pacific Basin climate indices

The Troup Southern Oscillation Index*

The set of largely neutral monthly values (+6.7, +0.3, –9.0) for autumn 2001 (Pahalad 2002) of the Troup Southern Oscillation Index (SOI) was followed by +1.8 (June), –3.0 (July) and –8.9 (August). While the winter SOI values showed a falling trend (as also

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*The Troup Southern Oscillation Index (SOI) used in this article is ten times the standardised monthly anomaly of the difference in mean sea-level pressure between Tahiti and Darwin. The calculation is based on a sixty-year climatology (1933-1992).

occurred during the previous season), there was a substantial rise in the index between May and June. This ensured that the winter values remained within the same range of values as their autumn predecessors.

Interestingly, 30-day values of the un-normalised Tahiti-Darwin pressure difference (not shown) fell to be slightly more than one standard deviation below the mean late in August. For most of the season however, this pressure difference remained well within one standard deviation of the mean.

The neutral values of the SOI were reflected in the Climate Diagnostics Centre (CDC) Multivariate El Niño-Southern Oscillation (ENSO) Index (MEI) which remained very close to zero throughout the season, peaking at only +0.25 for the July/August two-monthly value. As the MEI is derived from a number of atmospheric and oceanic indicators, it reinforces the truly neutral state suggested by the winter values of the SOI.

The gradual decline of the SOI values through winter was the result of both increasing cyclonic anomalies north of Tahiti (see below) and increasing anti-cyclonic anomalies over Darwin, rather than a mean sea level pressure change at just one of the two stations.

Figure 1 shows the monthly SOI values from January 1997 to August 2001. A curve of five-month moving averages has been superimposed on the graph.

Outgoing long wave radiation

Figure 2, adapted from the Climate Prediction Center (CPC), Washington (CPC 2001), shows the monthly standardised anomaly of outgoing long wave radiation (OLR) from January 1997 to August 2001, together with a three-month moving average. These data, compiled by the CPC, 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 and 160°E to 160°W). Tropical deep convection in this region is particularly sensitive to changes in the phase of the Southern Oscillation (SO). During warm (El Niño) ENSO events, convection is generally more prevalent resulting in a reduction in OLR. This reduction is due to the lower effective black-body temperature and is associated with increased high cloud and deep convection. The reverse applies in cold (La Niña) events, with less convection in the region expected.

The monthly values +0.2 (June), +0.3 (July) and –0.2 (August) of this index were consistent with a neutral state of the Southern Oscillation. The negative monthly value for August was the lowest monthly value since May 1998 (also –0.2), which was itself the lowest monthly value since January 1998 (–0.4). The August value was in fact only the second negative value since winter 1998. In general, normal to slightly decreased high cloud amounts were observed right along the equator throughout the season.

Fig. 1 **Southern Oscillation Index, from January 1997 to August 2001. Means and standard deviations used in the computation of the SOI are based on the period 1933-1992.**

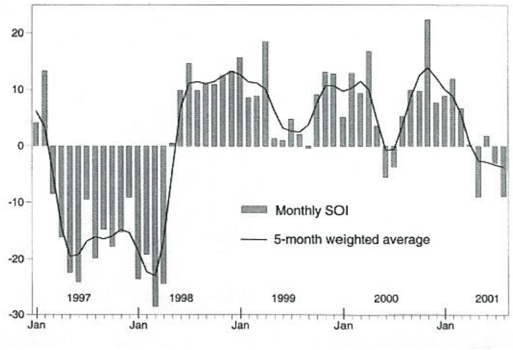
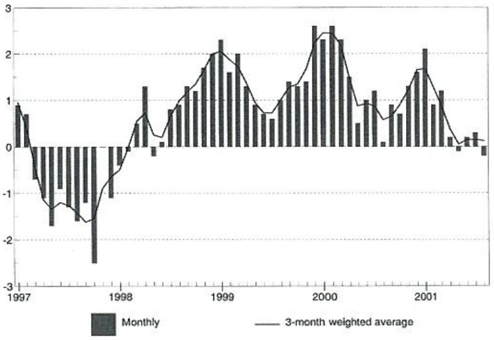
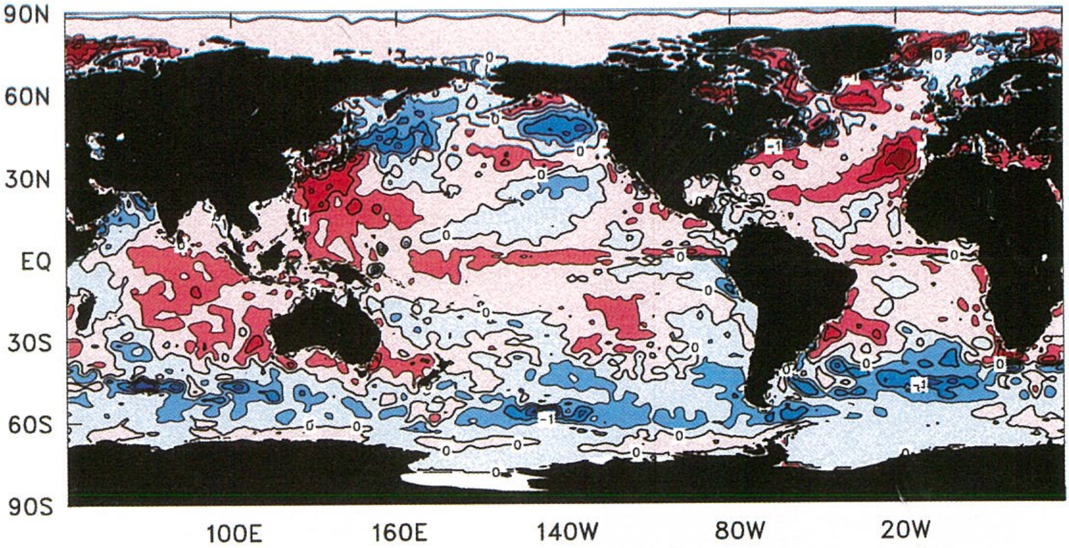


Fig. 2 **Standardised anomaly of monthly outgoing long-wave radiation averaged over the area 5°S to 5°N and 160°E to 160°W, from January 1997 to August 2001. Negative (positive) anomalies indicate enhanced (reduced) convection and rainfall in the area. Anomalies are based on the 1979-1995 base period. After CPC (2001).**



In the Pacific, increased OLR was experienced in regions near the Solomon Islands and to its southeast, stretching to the Cook Islands. This was a result of the slight southwest shift in the South Pacific convergence zone (SPCZ), a shift that had been observed for several months (Watkins 2001). Typically a southwest shift in the SPCZ is related to a positive phase of the SO, whilst a northeast positioning of the SPCZ is often associated with a negative SOI phase (J. Salinger, personal communication). The fact that winter 2001 experienced weakly negative SOI values with the SPCZ in contrast remaining in a position more typical of a positive SO phase highlights the seemingly inconsistent low SOI values and hence the neutral state of the ENSO system.

Fig. 3 **Anomalies of sea-surface temperature for winter (June, July, August) 2001 (°C). The contour interval is 0.5°C.**



OLR values over Australia during winter 2001 (not shown) were generally near normal, however August saw slightly decreased OLR (increased cloudiness) over much of the continent. Interestingly however, this did not correspond to higher rainfall totals (see below) - August was in fact slightly drier than normal over much of the continent.

Oceanic patterns

Sea-surface temperatures

Figure 3 shows the winter 2001 sea-surface temperature (SST) anomaly in degrees Celsius (°C). The contour interval is 0.5°C*. Positive anomalies are shown in red shades, while negative anomalies are shown in blue shades.

Winter sea-surface temperatures were generally above average in the western and central tropical Pacific Ocean, with a band of anomalies along the equator in the +0.5 to +1.0°C range between 165°E and 120°W. This was reflected in the monthly values of the NINO4 SST index as calculated by the National Meteorological and Oceanographic Centre (NMOC), Melbourne, which were +0.246°C (June), +0.503°C (July) and +0.461°C (August). Weekly values of this index (not shown) also as calculated by NMOC showed rising values from February 2001 onwards and through the winter months.

In the far eastern tropical Pacific, the pattern was more varied with positive anomalies just north of the equator and a larger pattern of negative anomalies just south of the equator and extending some distance down the west coast of South America. These negative anomalies peaked during June around –1.5°C, after which they relaxed towards normal values. It is interesting to note that, just like the changes observed in the SOI values between the end of autumn and the end of winter, the three-month change between May (end of autumn) and August (end of winter) showed an anomalous cooling in the eastern Pacific of up to 2°C and an anomalous warming in the central to western Pacific of up to 1°C.

A much stronger pattern of warming was present in the tropical Indian Ocean during winter. Between southern India and Western Australia, there were widespread areas showing anomalies between +0.5 and +1.0°C, with a few patches having anomalies in excess of +1°C. The individual monthly patterns (not shown) were reasonably similar in this region, with the July pattern being slightly stronger than those of June and August. This pattern of warming extended around Australia's southern coastline and across the Tasman Sea to New Zealand. The positive anomaly in the Tasman Sea however showed a slow decrease in value over the course of the season.

An interesting feature of the SSTs in the mid to high southern latitudes is the band of negative anomalies mainly between 40°S and 60°S stretching all the way around Antarctica. Similar patterns were

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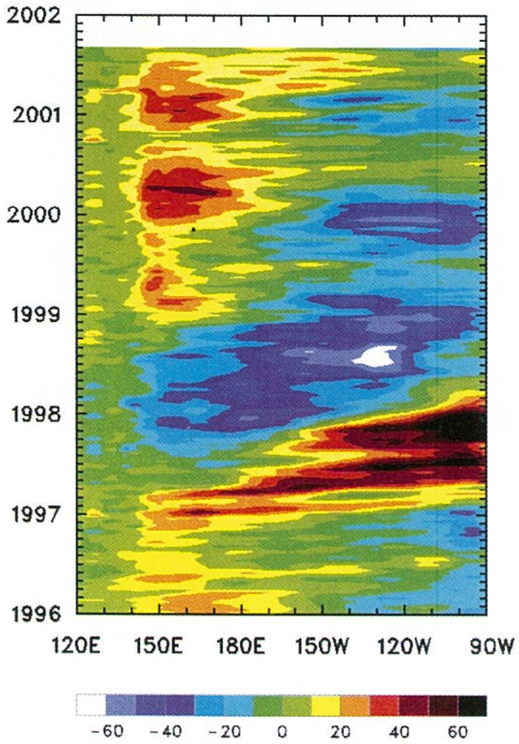
*Recent seasonal climate summaries in this journal have had this figure contoured at 1.0°C spacing.

Fig. 4 **Time-longitude section of the monthly anomalous depth of the 20°C isotherm at the equator from January 1996 to August 2001. The contour interval is 10 m.**



observed in the previous autumn (Pahalad 2002) and summer (Fawcett 2002). It is not entirely clear what may have caused such cool anomalies, but it is interesting to compare the locations of these SST anomalies with the anomalies in mean sea level pressure (see below). In regions to the northeast of the Weddell Sea, negative SST anomalies correspond to a large cyclonic (negative) anomaly (of up to 8.5 hPa) which would have drawn cold Antarctic continental air over this region. Arguably, a similar situation may have occurred north of the Amery Ice Shelf (East Antarctica). Colder than normal SSTs to the northeast of the Ross Sea are co-located with anomalously high (anti-cyclonic) pressure over the Amundsen Sea.

Subsurface patterns

Figure 4 shows a time-longitude diagram of the anomaly in metres of the depth of the 20°C isotherm along the equatorial Pacific Ocean between January 1996 and August 2001, as calculated by the Bureau of Meteorology Research Centre (BMRC). This isotherm is generally situated very close to the equatorial ocean thermocline, the region of greatest temperature gradient with respect to depth. The thermocline can also be regarded as the boundary between the upper ocean warm water and the deeper ocean cold water. An abnormally shallow thermocline in the eastern Pacific Ocean is characteristic of La Niña events. Positive anomalies correspond to the 20°C isotherm being deeper than average, and negative anomalies to it being shallower than average.

The winter months were characterised by a slightly deeper than normal 20°C isotherm (implying slightly warmer than average subsurface temperatures) across most of the equatorial Pacific. This was largely the result of westerly wind bursts during both May and early July which, due to their reduction of the strength of the trade winds (and hence in the magnitude of the upwelling along the equator), resulted in a deepening of the thermocline in the western Pacific. The resulting oceanic Kelvin waves traversed the equatorial Pacific during early June (from the first westerly wind burst) and during July and early August (from the second westerly wind event).

Neither oceanic Kelvin wave established truly coupled conditions, and hence by the end of winter negative 20°C isotherm anomalies had begun to emerge in the far east (implying slightly cooler than normal subsurface conditions for that region).

Interestingly, the subsurface pattern for winter 2001 showed some similarity to that of the first half of 2000, which had also seen some warming in the western Pacific subsurface. However the warmer western Pacific subsurface in 2000 did not remain throughout the year, with conditions becoming neutral by the spring (Watkins 2001). Likewise in winter 2001, warm subsurface water in the western Pacific lead to speculation about a potential transition to El Niño, but by the end of winter this had not eventuated.

A plausible reason for that speculation (along with falls in the SOI at the ends of both autumn and winter) can be seen in Fig. 5 which shows a sequence of equatorial Pacific vertical temperature anomaly profiles for the four months ending August 2001, also obtained from the BMRC. In the figure, red (blue) shades indicate subsurface waters which are warmer (cooler) than average. As a result of the oceanic Kelvin waves described above, a coherent warm anomaly, from May through to July, propagated eastward and intensified, but the pattern largely collapsed in August. A cool anomaly expanded in the far east from July to August.

Fig. 5 Four month May to August 2001 sequence of vertical temperature anomalies at the equator for the Pacific Ocean. The contour interval is 0.5°C.

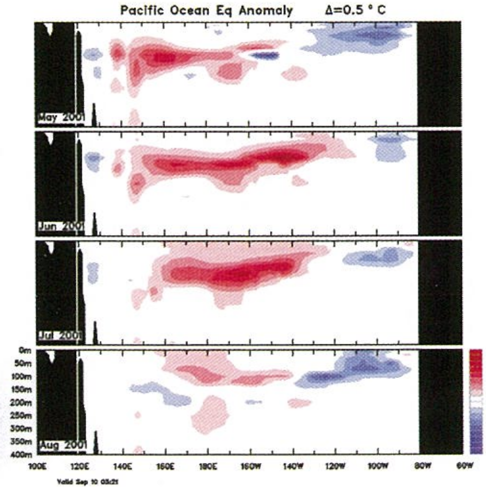


Fig. 6 Winter 2001 mean sea-level pressure (hPa). The contours are spaced at 4 hPa intervals between 980 hPa and 1028 hPa.

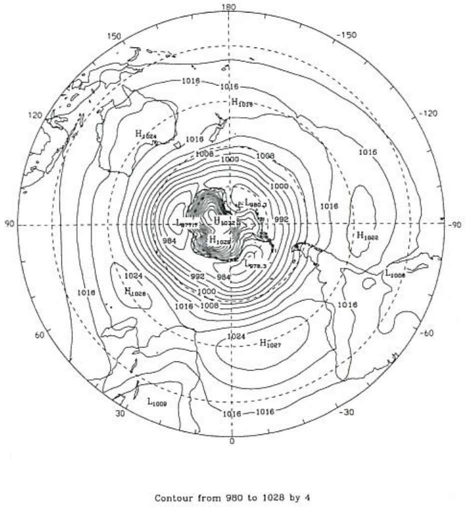
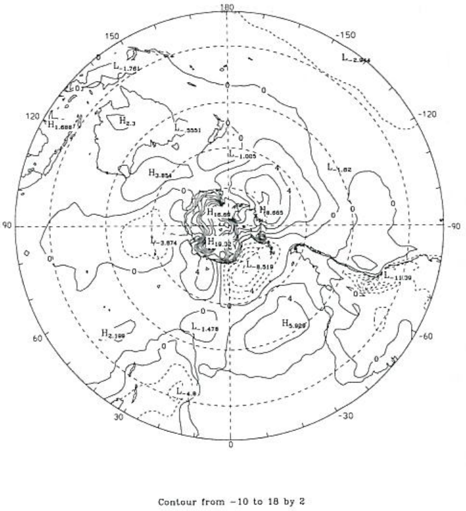


Fig. 7 Winter 2001 mean sea-level pressure anomaly (hPa). The contours are spaced at 2 hPa intervals between −10 hPa and +18 hPa.



Atmospheric patterns

Surface analyses

The winter 2001 mean sea-level pressure (MSLP) across the southern hemisphere is shown in Fig. 6, with the associated anomalies shown in Fig. 7. These anomalies are the departures from an eleven-year (1979-1989) climatology obtained from the European Centre for Medium-range Weather Forecasts (ECMWF). The MSLP analysis itself has been computed using data obtained from the Bureau of Meteorology's Global Assimilation and Prediction (GASP) model daily 2300 UTC analyses.

The low pressure anomaly over high elevation parts of South America and the high pressure anomaly over the Antarctic plateau are persistent features, and appear to be the result of a systematic difference between the GASP and ECMWF models and the way they extrapolate down to mean sea level. Therefore, the low pressure over parts of South America should not be treated as a meteorological consequence of the current state of the El Niño-Southern Oscillation.

The Antarctic circumpolar trough showed three substantial minima, located at 90°E, 150°W and 20°W. The latter two minima represented departures from climatology, the one at 150°W being some 9 hPa weaker than normal, while the one at 20°W was some 9 hPa stronger than normal. Such substantial anomalies appear contrary to the sea ice concentration anomalies over the winter 2001 pack (not shown), with the reduced mean sea level pressures occurring over higher concentration sea ice, and increased pressures over slightly lower sea-ice concentrations. Modelling studies have suggested that ordinarily the opposite would be expected (Watkins and Simmonds 1995). One can only surmise that these large pressure anomalies were a result of either a shift in the timing or spatial distribution of the Antarctic Semi-Annual Oscillation (van Loon 1967), or 'downstream' effects from the sea-ice concentration anomalies.

Across the equatorial Pacific, MSLP values for the season were below average, as may have been expected with slightly above average SSTs in the same region. In the south Pacific region, MSLP anomalies were generally close to normal despite the slight southwest shift in the SPCZ.

Over Australia, MSLP values were above average, consistent with the weakly negative average SOI for the season (the cause of which, in part, was the anomalously high pressure for Darwin). In addition to the 2 hPa anomaly over the Northern Territory, a 4 hPa anomaly was located immediately to the south of the continent in the Great Australian Bight. A weak negative pressure anomaly (–0.6 hPa) off the New South Wales coast was associated with the anomalously warm SSTs in this region, which persisted for much of the season. This anomalous cyclonic region and its associated warm onshore flow may well have contributed to the later arrival of the snow season in the Snowy Mountains.

Mid-tropospheric analyses

The mean 500 hPa geopotential height patterns for winter 2001 are shown in Fig. 8, with anomalies shown in Fig. 9. Flow was in general zonal, with (arguably) a wavenumber 3 to 4 pattern evident (Fig. 8). The season showed anomalous ridging extending from the southwest Indian Ocean across Antarctica into the southern Pacific, complemented by a broad positive anomaly over Australia and a positive anomaly of smaller areal extent but greater amplitude off the east coast of South America.

The major axes of the mid-level flow tended to reflect the major axes of the corresponding winter 2001 MSLP pattern. Likewise, the 500 hPa anomaly pattern also reflected the anomalies in the surface pressure, suggesting a largely barotropic atmospheric structure.

Blocking

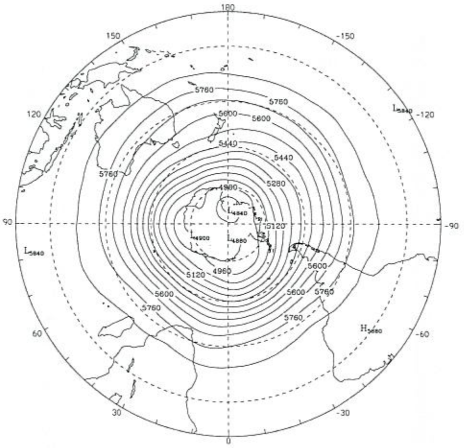
Figure 10 is a time-longitude section of the daily southern hemisphere mid-level Blocking Index (BI),

$$BI=1/2[(u_{25}+u_{30})-(u_{40}+2u_{45}+u_{50})+(u_{55}+u_{60})]\ .$$

Here, u_λ indicates the 500 hPa level zonal wind component at eight degrees of southern hemisphere latitude ranging from 0° at the equator to +90°S at the South Pole. The blocking index measures the strength of the 500 hPa flow at the mid-latitudes (40°S to 50°S) relative to that at subtropical (25°S to 30°S) and high (55°S to 60°S) latitudes.

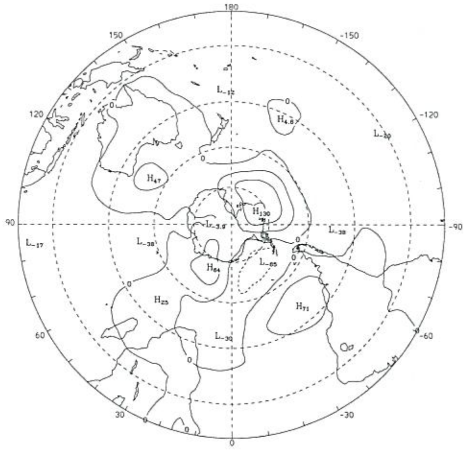
Taken across the entire season in the form of a seasonal mean (Fig. 11), southern hemisphere blocking was fairly close to average, particularly in Australian longitudes. The corresponding monthly figures (not shown) also showed blocking levels which were close to average at most longitudes (Bureau of Meteorology 2001).

Fig. 8 **Winter 2001 500 hPa mean geopotential height (m). The contours are spaced at 80 geopotential metre intervals from 4880 gpm to 5840 gpm.**



Contour from 4880 to 5840 by 80

Fig. 9 **Winter 2001 500 hPa mean geopotential height anomaly (m). The contours are spaced at 40 gpm intervals from –40 gpm to +120 gpm.**



Contour from -40 to 120 by 40

One feature of interest however lies near the dateline around 50°S (Fig. 9). This manifests itself as subtle splitting of the mid-level westerly flow over

Fig. 10 **Winter 2001 daily blocking index: time-longitude section. The horizontal axis measures degrees of longitude east of the Greenwich meridian. Day one is 1 June.**

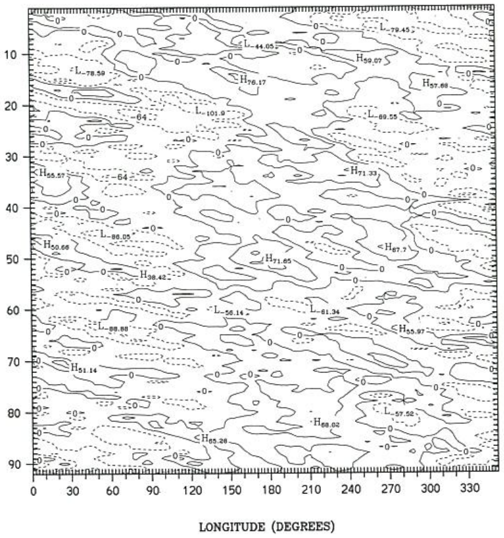
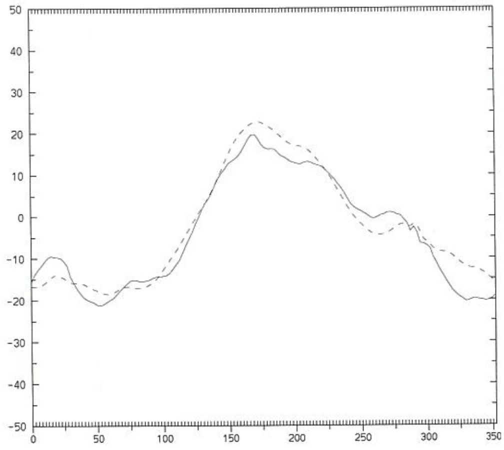


Fig. 11 **Mean southern hemisphere blocking index for winter 2001 (bold line). The dashed line shows the corresponding long-term average. The horizontal axis shows degrees east of the Greenwich meridian.**



the Tasman Sea (where a similar split occurred in winter 2000 (Beard 2001)), with an additional small cyclonic anomaly at the surface. This feature occurred in the middle of the region climatologically favoured for blocking during winter (Trenberth and Mo (1985), see also the maximum in the climatological blocking index in Fig. 11). It appears however to be located a little further poleward than the average thereby resulting in a seasonal blocking index in that area which was slightly below the climatological value.

Winds

Low-level (850 hPa) and upper-level (200 hPa) wind anomalies for winter 2001 are shown in Figs 12 and 13 respectively.

The low-level winter wind anomalies (Fig. 12) were southerly to southeasterly across the eastern half of the equatorial Pacific, turning to easterly at around 10°N. Anomalies over the western tropical Pacific were much weaker, the winds there being close to the average. Such a pattern of enhanced trade winds further suggests that, despite the falling SOI during winter 2001, the general atmospheric state was remaining closer to neutral, or even slightly cool ENSO (La Niña-like), conditions. Anticyclonic anomalies in the mid to high latitudes of the South Pacific (Fig. 7) would have contributed in some part (via increased easterly anomalies in the subtropics) to the small southwesterly shift of the SPCZ. The 850 hPa wind anomalies also suggest that the Intertropical convergence zone was also slightly enhanced.

Upper-level wind anomalies (Fig. 13) near the equator, primarily in the central to eastern Pacific, tended to display westerly characteristics. In conjunction with the easterly anomalies at the surface, this may suggest an enhanced Walker circulation, again a sign of conditions more reminiscent of a cool ENSO phase rather than a warm one.

The western tropical Indian Ocean showed anomalous southwesterly cross-equatorial (monsoonal) flow in the low levels, with anomalous northeasterly return flow in the upper levels. There also were indications of low-level anomalous southerly cross-equatorial flow with anomalous northerly return flow in the upper levels for the tropical areas immediately to Australia's north.

Low-level wind anomalies over Australia were generally weak and variable in direction (Fig. 12), as were the upper-level anomalies over the northern half of the continent (Fig. 13). Upper-level anomalies over the southern half were southerly to easterly, and in the southwest formed part of an anomalous anti-cyclonic circulation which may have contributed to a weakening of the subtropical jet. At low levels this anti-cyclonic circulation would have contributed to the very low rainfall totals observed in the continent's southwest during June (see below).

Fig. 12 **Winter 2001 850 hPa vector wind anomalies (m s^{-1}).**

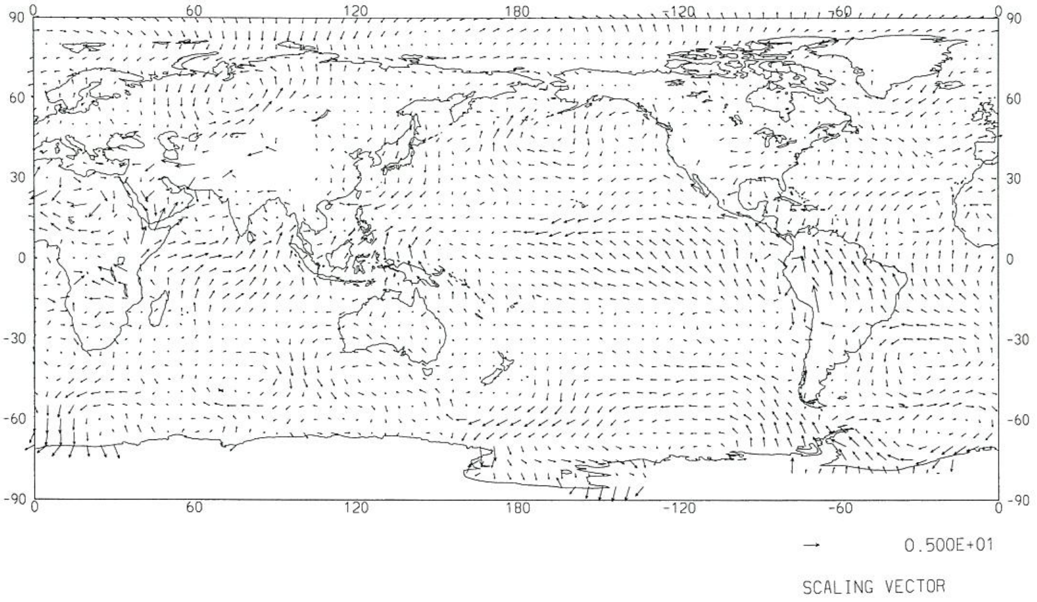
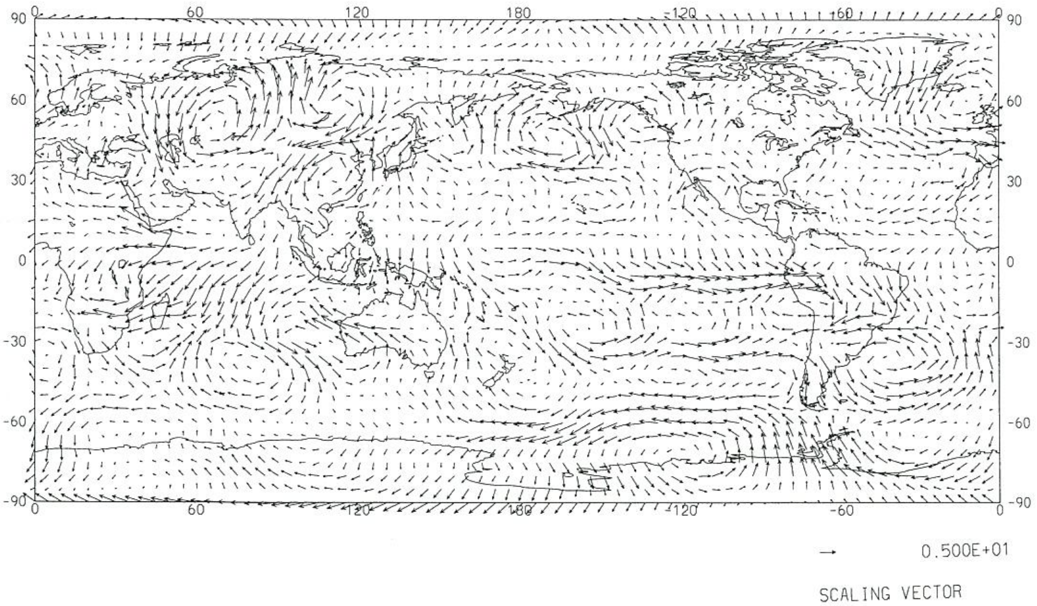


Fig. 13 **Winter 2001 200 hPa vector wind anomalies (m s^{-1}).**



Australian region

Rainfall

Figure 14 shows the winter rainfall totals for Australia, while Fig. 15 shows the winter rainfall deciles, where the deciles are calculated with respect to gridded rainfall data for all winters from 1900 to 2001.

Rainfall was above to very much above average for winter in a large area extending from northwest Australia to the centre of the continent where record high falls occurred. These high rainfall totals in the centre occurred in June and July; by August the pat-

Fig. 14 Winter 2001 rainfall totals (mm) in Australia.

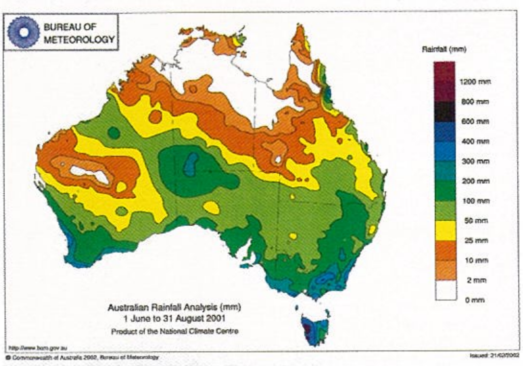
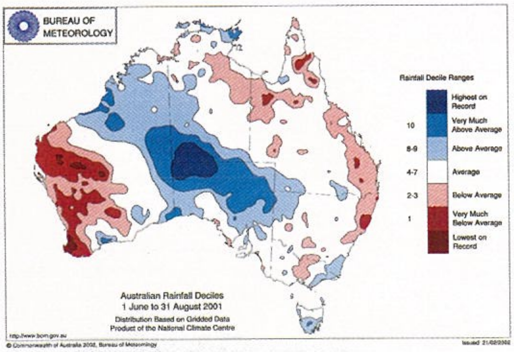


Fig. 15 Winter 2001 rainfall in Australia: decile range values based on grid-point values over the winters 1900 to 2001.



tern had flipped to below and even very much below average rainfall for much of central Australia, as well the majority of Queensland and northern New South Wales. In contrast to the wet conditions in the centre, the far west of Western Australia was significantly drier than average, with several regions recording lowest on record winter totals. The low winter rainfall totals in those parts of Western Australia exacerbated existing rainfall deficiencies, so that areas south of Perth experienced lowest on record December to August totals. This prolonged dry period resulted in Perth water storages dropping to only 25 per cent of capacity by late July, but closer to normal rainfall totals in this region during August managed to raise this value slightly by the end of winter.

Winter totals were also below average within about 100 km of the east coast in a band stretching from near Sydney northward to central Queensland. Near average falls predominated elsewhere, although there were small areas that departed from this picture (for example, southern Tasmania).

Fig. 16 Winter 2001 maximum temperature anomalies (°C) for Australia based on a 1961-1990 mean.

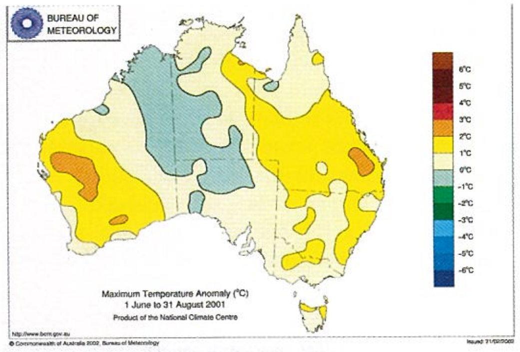
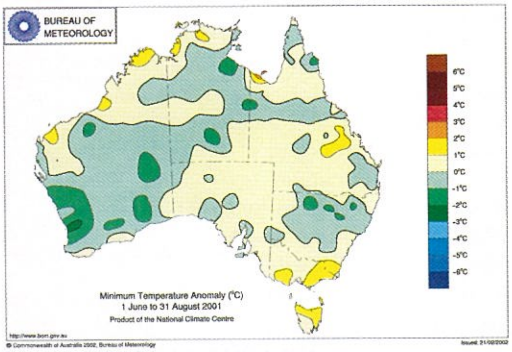


Fig. 17 Winter 2001 minimum temperature anomalies (°C) for Australia based on a 1961-1990 mean.



In area-averaged terms, June 2001 was South Australia's wettest June of the post-1890 period, in part contributing to its overall winter average being the fifth wettest of this period.

Temperatures

Figures 16 and 17 show the maximum and minimum temperature anomalies respectively for winter 2001. The anomalies have been calculated with respect to the 1961-1990 period.

Winter maximum temperatures were slightly below average in a band stretching from the far north of Western Australia down into northern South Australia, which relates closely to the region of above normal winter rainfall.

For most of the rest of the country however, the anomalies for maximum temperature were positive with large areas of anomalies between +1 and +2°C in Western Australia and eastern Australia. A few patches in WA, the NT and Queensland recorded seasonal anomalies between +2 and +3°C. With the exception of the cooler than normal strip through central Australia, this pattern of generally warmer than normal maximum temperatures appears consistent with the SOI/maximum temperature relationship shown by Jones and Trewin (2000). Their study suggests that during periods of negative SOI, positive anomalies in maximum temperature may be expected in most regions of Australia south of the Tropic of Capricorn.

In area-averaged terms, Queensland experienced its warmest winter of the post-1950 period (equal warmest with winter 1973), as calculated using a high-quality data set maintained by the National Climate Centre. This dataset is rather smaller than that used to construct Fig. 16.

For the seasonal minima (Fig. 17), 1°C departures of either sign from average were much more localised, with anomalies across the country generally less than 1°C in magnitude. A large part of Western Australia experienced a colder than average winter, particularly around Geraldton and Perth. In contrast, Tasmania and almost all of Victoria experienced a warmer than average winter.

As for maximum temperature, and despite the seemingly random (and small magnitude) nature of the minimum temperature anomaly distribution, the pattern of winter 2001 minimum temperature anomalies shows a fair degree of correlation with the pattern of SOI/minimum temperature relationships shown by Jones and Trewin (2000). This similarity to what may have been expected with a negative SOI, when added to the fact that a similarly strong (if not stronger) correspondence occurred for winter 2001 maximum temperature and rainfall, is fascinating. This is especially so when it is considered that despite a falling SOI, most indicators including arguably the SOI itself would suggest that the winter 2001 season was truly a neutral phase of the El Niño-Southern Oscillation phenomenon.

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Appendix

Data sources used for this review were:

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

Climate Prediction Center (CPC), *Climate Diagnostics Bulletin.* Obtainable from the Climate Prediction Center (CPC), National Weather Service, Washington D.C., 20233, USA.