Seasonal climate summary southern hemisphere (autumn 1987): a season of continuing ENSO anomalies

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An analysis of the southern hemisphere climate and circulation for the autumn months March to May 1987 is presented. Emphasis is given to the Australian region which is roughly bounded by the equator, Antarctica, 90°E and the dateline. Anomalies associated with an El Nino Southern Oscillation (ENSO) warm episode in the Pacific Ocean are discussed, together with related broadscale features around the hemisphere.

Introduction
This climate summary follows in a similar format to the 1986/1987 summer summary (Gaffney and Casey 1987). The data used were derived from the archived southern hemisphere grid-point analyses produced by the World Meteorological Centre, Melbourne and from monthly mean data prepared from real-time data archives in the National Climate Centre, Melbourne and issued in monthly Climate Monitoring Bulletins.

Seasonal summaries of the Australian/Asian tropical area are published regularly (see e.g. Kingston et al. 1987), and so the tropical circulation is not discussed in detail here. More comprehensive tropical data for individual months can be obtained from the Darwin Tropical Diagnostic Statements# and Climate Analysis Center (CAC) (1987 a, b, c).

Overview
An ENSO warm event, which had been developing since the spring of 1986, was in progress in the Pacific Ocean and appeared to be approaching its peak phase. Sea surface temperature (SST) anomalies along the Peruvian coast which peaked at values of over +4°C during March fell to around +2°C by May. An area of maximum SST departures in the eastern Pacific of around +2°C which had developed during the summer began to migrate westward towards the central Pacific and expand during the autumn period.

Associated with the SST anomalies, pressures were below average in the central Pacific and were abnormally high in the far western Pacific, particularly over eastern and northern Australia. As measured by the Tahiti minus Darwin pressure difference anomaly, the Southern Oscillation Index (SOI) as shown in Table 1 fell to around two standard deviations below average and remained near that figure throughout autumn. The SOI as used at the National Climate Centre, Melbourne is 10 times the Tahiti minus Darwin monthly mean MSL pressure difference anomaly divided by the standard deviation of those differences for the relevant month over the period 1882 to 1985.

Westerly wind anomalies in the lower levels of the troposphere and easterly anomalies in the upper levels were observed in the equatorial central and western Pacific, signifying a reversal of the Walker circulation over the western part of the basin.

Anomalous enhanced convective activity was evident along the equator to the east of the dateline and

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*Obtainable from the Bureau of Meteorology, GPO Box 1289K, Melbourne 3001, Australia.

#Obtainable from Northern Territory Regional Office, Bureau of Meteorology, PO Box 735, Darwin 5794, Australia.
the location of the South Pacific Convergence Zone (SPCZ) was shifted east of its mean autumn location. Tropical convective activity north of Australia and over the ocean continent was generally suppressed throughout the season and an early retreat of the northwest monsoon from northern Australia was observed in March.

Figures 1 and 2 show respectively the three-month mean and anomaly charts at 500 hPa for the autumn period. The mean chart shows a fair degree of zonal symmetry although high latitude troughs are discernible in the mid-Pacific, Atlantic and western Indian Oceans.

The general mid-troposphere circulation features in the Pacific region showed a marked change from early autumn to the latter part of the season. In March, negative height anomalies spanned the mid-latitude Pacific, and a large positive height anomaly was situated at higher latitudes in the central Pacific. Through April and May, strong positive anomalies

Fig. 1 Mean autumn (March, April, May) 500 hPa height analysis (dam).

Fig. 2 Autumn (March, April, May) 500 hPa height anomaly analysis (dam).

Fig. 3 March 500 hPa height anomaly analysis (dam).

Fig. 4 April 500 hPa height anomaly analysis (dam).
became established at middle latitudes in the eastern and western parts of the basin, and a strong negative anomaly replaced the positive anomaly at higher latitudes (compare Fig. 3 with Figs 4 and 5). The pattern in March showed general similarities in the Pacific region to composites of previous summer ENSO anomalies (compare Fig. 3 with Fig. 6). The pattern which developed through late autumn displayed a strong positive-negative-positive anomaly pattern across the Pacific which appeared to progress gradually eastward. This pattern was similar to composites of previous winter ENSO warm phase anomalies (see Fig. 7) in regard to the alternation of anomalies across the mid-latitude Pacific, but was displaced well to the east of the composite pattern.

March

Three upper-level long-wave troughs were evident on the monthly mean 500 hPa chart; to the south of Australia, in the eastern Pacific and in the south Atlantic as shown in Fig. 8. The major wave analysis at 55°S as shown in Table 2 indicates that planetary wave

Fig. 5  May 500 hPa height anomaly analysis (dam).

Fig. 6  Composite summer (December, January, February) 500 hPa height anomalies for 1972, 76/77 and 82 ENSO events (dam).

Fig. 7  Composite winter (June, July, August) 500 hPa height anomalies for 1972, 76/77 and 82 ENSO events (dam).

Fig. 8  March 500 hPa mean height analysis (dam).
number one was the dominant contributor to the overall mean monthly amplitude, both on a daily basis and to the monthly mean pattern and remained nearly stationary throughout the month as can be inferred from the high constancy value. Wave numbers three and four however, contributed most to the overall daily variance from in situ changes in amplitude. All major waves at high latitudes were close to their climatological mean locations for March as can be seen from the mean phase angles.

Positive SST anomalies of 1° to 2°C extended through most of the tropical Pacific east of the dateline with maximum values off the west coast of South America (Climate Analysis Center 1987a). Positive anomalies were also evident in the Indian Ocean.

Darwin mean monthly MSL pressure was 1010.7 hPa, 3.1 hPa above average, while that at Tahiti was 1011.6 hPa (-0.1) which gave a SOI of -16 (Table 1). This was the second highest March pressure in the 106 year Darwin record; the maximum of 1010.8 hPa was recorded in 1905.

In the Australian region, sea surface temperatures were close to average although an area of positive anomalies of around 2°C was situated along the east coast (Fig. 9). Cold waters were present to the south of the continent.

Negative outgoing long-wave radiation (OLR) anomalies (Climate Analysis Center 1987a) indicative of enhanced convective activity, were observed throughout the equatorial central and eastern Pacific, over northeast Brazil and in the Indian Ocean south of the equator. Positive OLR anomalies were notable over Indonesia, New Guinea and northern Australia. Nevertheless, the locations of the OLR mean maxima, apart from the anomalies in the western Pacific, were close to their March climatological mean locations (as derived from NOAA 1985).

### Table 2. Statistics of major southern hemisphere long waves at 55°S based on WMC, Melbourne 500 hPa analyses, March 1987.

<table>
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<tr>
<th>Zonal Wave Number</th>
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<td>Amplitude of Monthly Mean</td>
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<td>Mean of Daily Amplitude</td>
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<td>Anomaly</td>
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<td>% of Total Daily Variance</td>
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<td>Average (1976-85)</td>
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<td>70</td>
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Total Variance – all waves 99.7
Anomaly (1976-85) 0.2

### Fig. 9 March mean SST anomaly in °C. Climatology based on United States Navy (1969).

### Fig. 10 Time-longitude section at 55°S of daily Blocking Index values. Day 1 is the first of March.
Little progression in these systems was seen as might be expected from the dominance of the standing wave pattern.

A well-developed upper-level anticyclonic couplet, noted by Rasmussen and Wallace (1983) as typical of warm phase ENSO events, straddled the equator to the east of the dateline producing upper-level easterly flow anomalies along the equator in the western Pacific (Climate Analysis Center 1987a). A similar pattern was also seen in the western Indian Ocean.

Low-level easterly wind anomalies prevailed south of the equator from northern Australia westward into the eastern Indian Ocean, signalling the early retreat of the north Australian monsoon.

March rainfall was markedly below average over most of northern Australia and some districts recorded their lowest ever rainfall for the month of March (Fig. 11). Notably above average rains were received in southeastern Australia in a band extending from South Australia to the New South Wales coast.

Both maximum and minimum temperatures in March were below average over a large area of southern Australia as seen in Figs 12 (a) and (b), primarily due to frontal systems associated with transient lows in the long-wave trough to the south of the continent.

April

Major long-wave upper-level troughs were evident to the west of Australia, in mid-Pacific, off the west coast of South America and in the eastern South Atlantic as shown in Fig. 13. All of these except the trough near South America were anomalously strong.

The 500 hPa anomaly chart (Fig. 4) showed a well-developed circumpolar trough and stronger than average subtropical ridge with major centres in the Indian Ocean, over southeast Australia, in the eastern Pacific and in the South Atlantic. The anomaly pattern at middle to high latitudes across the Pacific was almost the reverse of that of March.

An area of SST anomalies of around +2°C was situated in the far eastern tropical Pacific with positive anomalies of 1° to 2°C extending through most of the equatorial Pacific east of the dateline (Climate Analysis Center 1987b). The positive anomalies on the South American coast began to decrease.

Pressures remained below average in the central tropical Pacific region due to the warmer SSTs and were above average over northern and eastern Australia. Darwin mean monthly MSL pressure was 1011.5 hPa (+ 2.0) while that at Tahiti was 1010.9 hPa (-1.0) which gave a SOI of -22. The five-month running mean centred on February was -15.

The anomalous upper anticyclonic couplet straddling the equator to the east of the dateline remained well developed (Climate Analysis Center
sustaining the reversed Walker circulation of upper easterlies and low-level westerlies in the western and central tropical Pacific.

Negative OLR anomalies continued in the western Pacific with the SPCZ very active into higher latitudes and still displaced east of its mean April location by about 20° of longitude.

Blocking Index values around most of the hemisphere were below average with a general increase in the mid-latitude zonal strength due to the stronger circumpolar trough and subtropical ridge. Systems were more progressive than in the preceding month as may be seen in Fig. 10. Exceptions were a brief period in the second week of April when an almost stationary high became established in the Indian Ocean and another around the 18th when a strong anticyclone formed near the dateline and drifted slowly eastward into the Pacific. Both these episodes were brief and appeared to be associated with a reorganisation of the major planetary wave structure.

A Fourier analysis of the major planetary waves at 55°S as shown in Table 3 indicated that each of the major wave numbers from one to four were either below or close to average in monthly mean amplitude. Wave number two contributed most to the daily variance and along with wave number one exhibited a low constancy figure. An analysis of the daily phase angles and amplitudes (not shown) saw wave number one nearly stationary and of almost constant amplitude until mid-month when it weakened and then underwent several fluctuations in amplitude and shifts in location. Wave number two varied in amplitude and showed periods of progression and retrogression throughout the month.

Anomalies in sea surface temperatures in Australian waters were again mostly small, except for an area of warm water off the Western Australian coast near Northwest Cape (Fig. 14). The region of above average sea surface temperatures off the east coast was weaker than in March, but extended further south.

Fig. 13 April 500 hPa mean height analysis (dam).

Table 3. Statistics of major southern hemisphere long waves at 55°S based on WMC, Melbourne 500 hPa analyses, April 1987.

<table>
<thead>
<tr>
<th>Zonal Wave Number</th>
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<td>Amplitude of Monthly Mean</td>
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<td>-2.0</td>
<td>-0.5</td>
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<td>Mean of Daily Amplitude</td>
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<td>6.6</td>
<td>5.4</td>
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<tr>
<td>Anomaly</td>
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<td>-2.2</td>
<td>1.1</td>
<td>-1.4</td>
<td>-2.4</td>
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<td>% of Total Daily Variance</td>
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<td>Anomaly</td>
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<td>Average (1976-85)</td>
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<td>52 bi-mod</td>
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Total Variance – all waves 99.3
Anomaly (1976-85) – 0.2

Fig. 14 April mean SST anomaly in °C. Climatology based on United States Navy (1969).

Fig. 15 April decile range values of Australian rainfall based on district averages.
Rainfall (Fig. 15) was below to very much below average over a large area of southeastern Australia associated with the positive height anomalies that had been situated over that region. Above average daytime maximum temperatures (Fig. 16(a)) and cooler overnight minima (Fig. 16(b)) were experienced in areas of southeastern Australia due to the clearer skies associated with subsidence in the ridge. Maximum and minimum temperatures were generally warmer through a large area of the interior and the west because of low-level easterly wind trajectories drying and warming over the land surface.

May

The height anomalies in the Pacific region showed similar features to those of April. The relative stability of this pattern was an indication of the growing influence of the ENSO event in maintaining planetary scale circulation features. There was a general eastward progression of the higher latitude anomaly patterns from the previous month.

At middle to high latitudes major long-wave troughs were situated in the central Pacific, South Atlantic and central Indian Oceans as can be seen in Fig. 17. The troughs in the central Pacific and Indian Oceans were both anomalously strong as can be seen in Fig. 5. At subtropical latitudes troughs were discernible over eastern Australia and to the east of New Zealand. The general flow began to exhibit more zonal asymmetry with an increase in the middle to high latitude westerly flow through the Indian Ocean and Australasian region.

An analysis of the major planetary waves at 55'S indicated that the total variance of all waves was generally close to average (Table 4). Wave numbers two and three were the dominant monthly mean amplitudes and these two waves also provided the largest percentage of the daily variance anomaly. Both waves remained nearly stationary through most of the month but did show some periods of progression during those times when they were increasing in amplitude.

Positive sea surface temperature anomalies in the eastern and central equatorial Pacific remained similar to the previous two months but with some increase in area and westward migration of the maximum departures (Climate Analysis Center 1987c, Fig. 9). Anomalies on the Peruvian coast which had reached values of over 4°C above average in February and March fell to around +2°C by May.

The upper-level anticyclonic circulation anomalies in the western Pacific continued to produce upper-level easterly wind anomalies and compensatory low-level westerly wind anomalies along the equator in the vicinity of the dateline.

Fig. 17 May 500 hPa mean height analysis (dam).
Warm water off the northwest coast of the Australian continent was more extensive than in April with positive anomalies of around 2°C (Fig. 18). Ocean temperatures in the tropical western Pacific were below average. Above average sea surface temperatures just east of Tasmania appeared to be the result of advection in the Tasman current of the positive anomalies noted in previous months along the east coast.

Rainfall in May was generally average to above average over most of eastern Australia (Fig. 19). Above average rainfalls were confined to the coastal strip from eastern South Australia to western Victoria and the northern New South Wales-Queensland border region. May rainfall over the northwest and interior of the continent was generally below average. Totals were close to average over the remainder of the west apart from below average rain in a small area in the far southwest.

Rainfall for the autumn season was very much below average in the northwest of Australia (Fig. 20).

**Table 4. Statistics of major southern hemisphere long waves at 55°S based on WMC, Melbourne 500 hPa analyses, May 1987.**

<table>
<thead>
<tr>
<th>Zonal Wave Number</th>
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<th>3</th>
<th>4</th>
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<tr>
<td>Amplitude of Monthly Mean</td>
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<td>Anomaly</td>
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<td>1.3</td>
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<td>Mean of Daily Amplitude</td>
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<td>7.0</td>
<td>9.1</td>
<td>7.4</td>
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<td>% of Total Daily Variance</td>
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<td>Average (1976-85)</td>
<td>213</td>
<td>152</td>
<td>38</td>
<td>58</td>
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</table>

Total Variance – all waves 72.4
Anomaly (1976-85) – 2

Enhanced convective activity as derived from OLR anomalies was again noticeable along the equator near the dateline. The maximum was still displaced eastward from its long-term mean location, but had begun to show a shift westward in concert with the usual seasonal movement observed at this time of year.

Darwin mean monthly MSL pressure in May was 1012.6 hPa (+1.6) while that at Tahiti was 1011.5 (-1.2) giving a SOI of -20 and a five-month running mean centred on March of -16.

Blocking activity in the Australian region and near South America was above average for the month. A particularly intense cut-off low developed in the Great Australian Bight around the 11th of the month as a block developed near Western Australia and progressed steadily eastward. The blocking system reached maximum strength near eastern Australia in mid-month and then gradually dissipated as it moved into the western Pacific late in the month. A blocking episode near South America developed during the middle of the month showing two distinct maxima around the 17th and 25th and was stationary.

**Fig. 18 May mean SST anomaly in °C. Climatology based on United States Navy (1969).**

**Fig. 19 May decile range values of Australian rainfall based on district averages.**

**Fig. 20 Autumn (March, April, May) decile range values of Australian rainfall based on district averages.**
As shown in Figs 21(a) and (b), both daytime maximum and overnight minimum temperatures over Australia were below average by about 2°C over a large area of the west and interior of the continent as a result of cold advection around the anticyclonic anomaly to the southwest of Western Australia. Maxima and minima over the tropical north were about 1°C above average.

Concluding remarks
The austral autumn is the usual transition period when the southern hemisphere Hadley cell becomes the dominant circulation in the tropics. The SPCZ reaches its furthest eastward extent, then begins to move back towards the west, and the Pacific Inter-Tropical Convergence Zone (ITCZ) moves north.

Some of these changes were observed to occur on the usual time scale. However the SST, pressure and height anomalies characteristic of an ENSO warm event were more influential in determining the general circulation features. The enhanced convective activity along the equator in the vicinity of the dateline and in the SPCZ appeared to have been responsible for an above average strength southern hemisphere Hadley cell in the Pacific region. This in turn appeared to produce a large amplitude short wavelength structure across the Pacific basin which, as can be seen in the composite ENSO anomaly charts (Fig. 7), is a typical feature of winter ENSO warm events.

The mean autumn circumpolar trough deepened while the subtropical ridge through the Indian Ocean and Australian longitudes intensified, producing an increase in the middle to high latitude zonal flow in that region.

Blocking activity was generally above average early in the season and the location of the hemispheric maximum was shifted east of its mean location. Blocking episodes during the latter part of the season were either brief or of a progressive nature.

SST anomalies in the far eastern tropical Pacific peaked simultaneously with the maximum in the seasonal cycle in April and then began to show a spread westward and latitudinally into the central tropical Pacific as the ENSO episode developed towards a peak phase. Low-level westerly anomalies and upper easterly anomalies were evident in the western Pacific which were associated with low-level cyclonic circulations in the vicinity of the SPCZ and upper-level anticyclonic anomalies either side of the equator to the east of the dateline.

Acknowledgment
The authors wish to thank Dr David Karoly for providing the programs and data for the preparation of the composite ENSO material.

References
Environmental Research Laboratories, NOAA, USA.