The tropical circulation in the Australian/Asian sector — November 1986 to April 1987

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A synoptic overview is presented of the tropical circulation between 70°E and the dateline during the southern hemisphere summer months of November 1986 to April 1987.*
Analyses of upper and lower tropospheric flows, sea surface temperatures, and cyclone tracks during the period are discussed, together with rainfall data over the Australian region.
In the Darwin Regional Meteorological Centre area of responsibility, the weaker than normal monsoon circulation and below average northern Australian rainfall is linked to an El Niño warm event and negative values of the Southern Oscillation Index throughout the period.

Introduction

This climate summary discusses the tropical circulation in the Darwin Regional Meteorological Centre's (RMC) area of responsibility, that is, from 70°E to the dateline. The emphasis of the paper has been to identify circulation features that were significantly different from the long-term mean flows, seek out correlations between these anomalies and other measurable deviations from normal, and where possible, to specify the implications of the anomalies as they relate to regional climate.

The time-period used here is that of the southern hemisphere summer (from November 1986 until April 1987), with particular reference to January and February — the peak of the monsoon.

After a look at Southern Oscillation Index (SOI) values during this period, a broadscale overview of the monsoon circulation and its anomalies will be given, followed by discussions of sea surface temperature (SST) analyses, tropical cyclone tracks, and north Australian rainfall. In conclusion, these phenomena will be considered together in an attempt to find correlations between them.

Mean wind analyses were derived from the Bureau of Meteorology's automated tropical analysis scheme (Davidson and McAvaney 1981) which produces 12-hourly real-time univariate analyses from rawinsonde, aircraft and satellite-observed upper wind measurements. Climatological means were derived from those published by Atkinson and Sadler (1970), and Sadler (1975). The wind anomaly charts which are used herein were prepared from the above.

The SST anomaly analyses were produced manually from ship and satellite SST data compared with mean data from Reynolds (1983).

Monthly mean sea level (MSL) pressure data at standard land stations were extracted from routinely received messages, and pressure anomalies calculated; over data-sparse areas south of 10°S, the anomaly fields generated from Melbourne World Meteorological Centre objective MSL pressure analyses were employed and blended with these data.

In order to set the scene for subsequent discussions of anomalous flows, we should briefly describe the normal structure of the monsoon circulation in the Darwin RMC area of responsibility.

*The time intervals that these summaries cover have been changed to better represent the austral 'winter' and 'summer' seasons, viz. May-October and November-April.
Climatologically, the broad features of the large-scale flow over the tropical area of the Darwin RMC analysis domain during the southern hemisphere summer months may be briefly described by referring to the long-term mean 950 hPa chart (Fig. 1) and the long-term mean 200 hPa chart (Fig. 2) for February.

At the 950 hPa level in the southern hemisphere, the monsoon trough marks a clear shear zone between southeasterly trade flow from mid-latitudes and a moist northwesterly monsoonal stream from the northern hemisphere. The trough lies near 10°S over the Indian Ocean, then is displaced southwards over the Australian continent before maintaining a latitude of about 14°S over the Coral Sea. The monsoon northeasterlies in the northern hemisphere emanate from the subtropical ridge located between 20°N and 30°N.

In the upper troposphere (Fig. 2), the southern hemisphere ridge broadly overlies the low-level monsoon trough. Southeasterly ‘return flow’ emanates from this feature and represents the upper part of the Hadley cell. The northern (winter) hemisphere’s subtropical jet stream lies near 30°N and can be seen to be considerably stronger than its southern (summer) hemisphere counterpart.

Southern Oscillation Index

Berlage (1966) and Troup (1965) showed that pressure anomalies at Darwin and Tahiti are linked to the Southern Oscillation. The SOI is measured in the Darwin RMC utilising the following formula:

\[
\text{SOI} = (\Delta P \text{ (Tahiti)} - \Delta P \text{ (Darwin)}) \times 10/\sigma...
\]

where \(\Delta P\) (Tahiti) is the monthly MSL pressure anomaly at Tahiti, and \(\Delta P\) (Darwin) is that at Darwin; \(\sigma\) is the standard deviation of the long-term monthly mean pressure difference.

Monthly values of the SOI between January 1982 and April 1987 are shown in Fig. 3. This figure includes the El Niño warm event of 1982 which can be compared with the late 1986/early 1987 period.

Although little persistent variation from zero occurred between May 1983 and October 1986, the SOI became negative from November 1986. This reduction of the SOI resulted from changes

Fig. 1  Climatological mean 950 hPa streamline analysis for February, after Atkinson and Sadler (1970).
in the Walker circulation (see Bjerknes 1969; Troup 1961; Bjerknes 1970) in response to the onset of an El Niño warm event. The associated lower and upper-level tropospheric wind anomalies over the tropical west Pacific, will be discussed later in this climate summary.

The tropical circulation during the southern hemisphere 1986/87 summer

Low-level (950 hPa) flow

Figure 4 shows 950 hPa vector wind anomaly charts for the months November 1986 to April 1987, while Fig. 5 shows an average field of these over the six-month period.
Fig. 4 950 hPa vector wind anomaly charts for November 1986 to April 1987.

These charts show an anticyclonic anomaly shear line over the Indian Ocean at 5°S (Fig. 4(a)) which moves to its extreme southerly position at 18°S in February (Fig. 4(d)) before moving northwards again. This shear line persisted throughout the period and approximately followed the position of the monsoon trough (see Fig. 7). The large area of westerly anomalies south of the shear line implies that the southeasterly trade winds were weaker than normal, which continues the trend of the preceding austral winter season (Kingston et al. 1987) while the generally easterly anomalies to the north of the shear line suggest a weaker than normal northwesterly monsoon. This indicates that the monsoon trough had less cyclonic vorticity than normal.

Figures 4(c) and (d) which correspond to January and February, show a weakening of these easterly anomalies. McBride and Nicholls (1983) have studied the relationship between rainfall in the Australian region and the Southern Oscillation. After analysing 42 years of rainfall data, they found that El Niño warm events were significantly correlated with measurable changes in rainfall distribution over the Australian continent. They also noted that the broadscale anomaly pattern due to El Niño effects partially broke down during the southern hemisphere months of December to February, but strengthened again in March and April. This appears to have been the case in 1986/87. Rainfall data presented later in this paper will support this.

The 950 hPa wind anomalies over the western Pacific Ocean reflect changes to the Walker circulation consistent with the onset of an El Niño warm event. The zonal Walker circulation as described by Bjerknes (1969) is thermally driven by SSTs along the equatorial Pacific belt and normally has an upward leg near 160°E. The Walker circulation responds to El Niño produced SST changes in the equatorial Pacific by shifting eastwards (see Bjerknes 1970; Julian and Chervin

Fig. 5 950 hPa vector wind anomaly chart averaged over the November 1986 to April 1987 period.
The associated eastward displacement of the Walker circulation’s upward leg reduces convective activity between 160°E and 180° while enhancing convection just east of the dateline (Krueger and Gray 1969). This has the effect of shifting the South Pacific Convergence Zone (SPCZ) eastward. Figure 5 clearly shows westerly wind anomalies in the west Pacific equatorial region, and is consistent with greater than normal low-level convergence just east of the dateline. The effect of this on tropical cyclone genesis in the southwest Pacific between November 1986 and April 1987 will be discussed later.

Figure 5 shows broad anomalous southwest to northwesterly flow anomalies over the South China Sea and the Bay of Bengal, implying a weaker than normal northeasterly trade flow in these regions.

The persistent anomalous easterly flow immediately south of the equator between 80°E and 150°E is consistent with a weaker than normal northwesterly monsoonal stream.

Figure 6 shows MSL pressure anomaly charts for the months November 1986 to April 1987.

Large areas of positive pressure anomalies persisted over tropical oceanic regions west of 160°E. The patterns are consistent with a weaker than normal monsoon flow west of 160°E.

Figure 7 shows actual and mean positions of the monsoon trough and the northwest Australian heat trough between November 1986 and April 1987. The long-term mean positions were taken from Sadler et al. (1987a, 1987b). The positions of the heat trough were close to the mean but the positions of the monsoon trough were generally north of the mean. Thus, in addition to the weaker than normal nature of the monsoon trough during the 1986/87 southern hemisphere summer, it did not progress as far south as climatological means would predict.

**Upper tropospheric (200 hPa) flow**

Figure 8 shows a 200 hPa vector wind anomaly analysis, averaged over the period from November 1986 to April 1987. Five features stand out from this chart.

The northern hemisphere mid-latitude westerlies were stronger than normal, and westerly wind anomalies prevailed over the tropical Indian Ocean. A cyclonic anomaly persisted near 20°S in the southern Indian Ocean where the southern hemisphere subtropical ridge would normally lie (see Fig. 2). Anomalous easterly flow was evident over the tropical western Pacific Ocean and a pair of anticyclonic anomalies were centred near 20°N and 20°S east of the dateline.

Arkin (1982) has studied upper tropospheric analyses taken from 11 years of data from the United States National Meteorological Center’s operational tropical analyses, and showed that composites prepared during El Niño events revealed anomalous anticyclonic circulations in the central Pacific. In addition, anomalous
easterlies were evident over the tropical west Pacific during the southern hemisphere winter following SST warming along the South American coast. He also found a significant strengthening of the northern hemisphere jet stream during these El Niño years. Selkirk (1984), in a similar study, related the anticyclonic anomalies over the central Pacific to greater than normal upmotion in the region in response to warmer SSTs. The proposed enhanced meridional Hadley circulation over the central Pacific is consistent with the southeast to southwesterly anomalies seen over the northwest Pacific in our Fig. 8. Furthermore, the enhanced poleward angular momentum transport in this region is probably responsible for the stronger than normal northern hemisphere subtropical jet stream.

In Indian Ocean longitudes on the other hand, the upper tropospheric part of the monsoon circulation was weaker than normal. The cyclonic anomaly over the southern Indian Ocean in Fig. 8 is coincident with the upper ridge. This fact, together with the almost non-existent low-level monsoon trough in this area and the westerly upper wind anomalies over the Bay of Bengal, suggest a very poorly developed monsoon circulation in these longitudes.

**Sea surface temperatures**

Figure 9 shows a SST anomaly analysis for the six-month period from November 1986 to April 1987. This anomaly analysis was derived from ship and satellite SST data compared with mean SST data from Reynolds (1983).
It is worthy of note here that Kingston et al. (1987) inferred that widespread positive SST anomalies evident in the tropical waters between 70°E and 180° between April and September 1986 were part of the precursor conditions for an El Niño warm event.

Tropical cyclones

Figure 10 shows the unofficial cyclone tracks during the November 1986 to April 1987 period, whilst Table 1 gives the monthly distribution of cyclones within the various ocean basins.

Following the below average tropical cyclone activity in the northwest Pacific during July to September 1986, the latter part of the season was unusually active with 13 tropical storms and typhoons occurring between October 1986 and

<table>
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<th>North-West Ocean Region</th>
<th>Indian Ocean Region</th>
<th>Australian Ocean Region</th>
<th>South Pacific Ocean Region</th>
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<td>0</td>
<td>0</td>
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<td>1</td>
<td>0</td>
</tr>
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</table>

Table 1. Monthly distribution of cyclones within the various ocean basins.

Fig. 10 Unofficial cyclone tracks during the November 1986 to April 1987 period. Legend: TS (tropical storm); TY (typhoon) — northern hemisphere; TC (tropical cyclone); STC (severe tropical cyclone) — southern hemisphere.
January 1987 compared with the 1959-1985 average of 8.2 (Joint Typhoon Warning Center 1985). Four cyclones occurred in December for the first time since 1959. A feature of the broadscale flow pattern during this period was a continued displacement of the mean monsoon trough about 5 to 10 degrees northward of its normal position. The upper ridge was similarly displaced. In July and September this may have contributed to a decrease in cyclone genesis by placing the preferred cyclone genesis area over a cooler ocean surface and closer to the stronger vertical shear of the mid-latitude upper westerlies. However the normal December position of the monsoon trough lies between the equator and 5°N, where a poleward displacement of the trough may be expected to favour cyclone genesis due to an increased Coriolis parameter and a more favourable juxtaposition of the surface trough with the upper ridge. In addition, the SST cold anomaly present in the northwest Pacific in September had by November been replaced by a warm anomaly.

In the southern hemisphere, six cyclones occurred in the Australian region (90°E-160°E), less than half the 10-year seasonal mean of 13.4 (Kingston 1986). Five of these six disturbances were generated during the period between 17 January and 23 February which corresponds to the breakdown of the El Niño induced wind anomalies during these months. The greatest departure from normal seasonal cyclone activity was in the Coral Sea (between the Queensland coast and Newmea) where no cyclone genesis occurred for the first time in at least 50 years. An inspection of the MSL pressure anomaly charts (Fig. 6) reveals that large positive anomalies persisted over eastern Australia and the Coral Sea throughout the six-month period. There were seven cyclone genesis events in the South Pacific east of 160°E including one east of the dateline, compared with an average of 5.9 (Gray 1979). Five cyclones spun up in the mid Indian Ocean (between 70°E and 90°E).

Tropical cyclone activity in the southern hemisphere during the November to April period appears to have been strongly influenced by the moderate El Niño warm event. One of the effects of this phenomenon was the suppression of cyclogenesis in the Australian region (Nicholls 1985) and a coincident increase of activity in the mid South Pacific (Julian and Chervin 1978).

Nicholls (1985) has produced a formula which links the expected number of cyclone days in the Australian region between 105°E and 165°E during a given southern hemisphere summer, to the Darwin 9 am MSL pressure (in units of hPa) averaged over the preceding months of July, August and September:

\[
\text{Cyclone Days} = 224.5 - [11.6 \times (P - 1000)]
\]

This formula predicts 61 cyclone days in the Australian region for the 1986/1987 season. In fact, only 32 cyclone days occurred.

The cause of this disparity lies in the increase of the SOI during November. The Darwin pressure was close to average during the July to September period. The negative movement of the SOI only began in November in the Australian region, with a coincident increase in the Darwin pressure relative to the long-term mean. (Normally, these changes would occur in the southern hemisphere autumn and would therefore be included in the Nicholls prediction.) One could hypothesise that the lower than expected number of cyclone days was due to the establishment of the El Niño warm event, and the consequent shifting of the upwards branch of the Walker circulation from near 160°E to the central Pacific. Indeed, the greater than normal number of cyclones east of 160°E add support to this suggestion.

Rainfall over northern Australia

Area weighted, monthly district average rainfall for the period November 1986 to April 1987 inclusive is presented in histogram form in Fig. 11. The districts comprise all those within continental Australia north of 20°S (see Fig. 12 for locations). For comparison, climatic average rainfall values are also presented.

It can be seen from Fig. 11 that rainfall during November and December was below average; January and February was above average (although January only marginally); and below average totals were recorded in March and April.

A further broad presentation of continental rainfall is shown in Table 2 which lists the cumulative rainfall and decile ranges for the respective districts (no weighting applied) during the same period.

Fig. 11 Area weighted monthly district average rainfall over continental Australia north of 20°S between November 1986 and April 1987.
Table 2. 1 month, 2 months, ......, 6 months cumulative district average rainfall (mm) for all districts north of 20°S over the Australian continent (see Fig. 12 for locations). The rainfall period commences November 1986 and concludes April 1987. Respective decile ranges are shown in parentheses.

<table>
<thead>
<tr>
<th>Districts</th>
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<th>4</th>
<th>5</th>
<th>6</th>
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<tr>
<td></td>
<td>Nov</td>
<td>Dec</td>
<td>Month</td>
<td>Month</td>
<td>Month</td>
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<tr>
<td>1</td>
<td>86(9)</td>
<td>149(4)</td>
<td>452(5)</td>
<td>827(7)</td>
<td>835(4)</td>
<td>893(4)</td>
</tr>
<tr>
<td>2 *</td>
<td>1(L)</td>
<td>28(1)</td>
<td>292(7)</td>
<td>509(8)</td>
<td>530(7)</td>
<td>533(6)</td>
</tr>
<tr>
<td>3</td>
<td>27(9)</td>
<td>35(3)</td>
<td>249(7)</td>
<td>487(8)</td>
<td>494(6)</td>
<td>502(5)</td>
</tr>
<tr>
<td>14GA</td>
<td>96(5)</td>
<td>193(1)</td>
<td>562(3)</td>
<td>897(6)</td>
<td>979(2)</td>
<td>1010(2)</td>
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<tr>
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<td>73(1)</td>
<td>272(2)</td>
<td>864(8)</td>
<td>965(5)</td>
<td>1156(6)</td>
</tr>
<tr>
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<td>373(7)</td>
<td>701(9)</td>
<td>714(6)</td>
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<td>235(3)</td>
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</table>

* Lowest on record

Three features are highlighted by Table 2. There was a marked increase in rainfall for district 14DE during January, and a marked increase in rainfall for district 27 during February. In addition, a consistent increase in decile ranges over most districts was observed during February.

The first and second features are associated with the development and inland passage of tropical cyclones Irma (January) and Jason (February). The third can be related to brief but active monsoon bursts over the second half of January and during February.

In order to more precisely describe rainfall over tropical Australia, a time-series of area weighted, weekly district average rainfall was prepared. The time-series covers the period from 29 October 1986 to 6 May 1987 inclusive and the districts used are the same as above. Figure 13 shows the rainfall presented in histogram form and clearly identifies a seven-week period of enhanced rainfall from 14 January to 4 March 1987 inclusive. This period corresponds to the reduced effect of the El Niño warm event upon the monsoon circulation mentioned earlier in this summary.

Within the enhanced rainfall spectrum, three distinct peaks can be identified: during the weeks ending 21 January, 4 February and 25 February 1987. These peaks coincide with surges in the low-level northwesterly monsoonal stream.

Further evidence of the general below average rainfall trend over tropical Australia and adjacent oceans can be gleaned from Table 3 which lists monthly mean rainfall, actual rainfall and decile ranges at Cocos Island and Willis Island (see Fig. 12 for locations).

Inspection of the table reveals that both stations suffered rainfall deficiencies during most of the November 1986 to April 1987 period.

Summary

A number of significant departures from the seasonal mean flow have been documented for tropical and adjacent subtropical areas between 70°E and 180°E for the period from November

Table 3. Monthly mean rainfall, actual rainfall and decile range at Cocos Island and Willis Island for the period November 1986 to April 1987 inclusive.

<table>
<thead>
<tr>
<th>Month</th>
<th>Cocos Island</th>
<th>Willis Island</th>
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<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Actual</td>
</tr>
<tr>
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<td>104</td>
<td>46</td>
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<tr>
<td>December 1986</td>
<td>120</td>
<td>54</td>
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<tr>
<td>January 1987</td>
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<tr>
<td>February 1987</td>
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<tr>
<td>April 1987</td>
<td>255</td>
<td>72</td>
</tr>
</tbody>
</table>

* Telegraphic reports only

Fig. 13 Area weighted weekly district average rainfall over the same area as Fig. 11.

Fig. 12 Location map showing the rainfall districts referred to in the text.
1986 to April 1987.
Perhaps the clearest message given by all the preceding data, is that a moderate El Niño warm event was occurring during the period.
The monsoon circulation was shown to be weaker than normal between 70°E and 160°E and an eastward displacement of the Walker circulation’s upwards leg to just east of the dateline was evident. Below average rainfall at Cocos and Willis Islands adds support to this.
SST anomaly patterns for the period are similar to those produced by Rasmussen and Carpenter (1982) from composites of SST data measured during El Niño warm event years.
Tropical cyclone activity in the southern hemisphere summer was below average in all areas except near the dateline.

References