The tropical circulation in the Australian/Asian region — November 1992 to April 1993

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A summary of the broadscale tropical circulation from 70°E to the date-line, for November 1992 to April 1993, is presented. Warm ENSO conditions persisted through the season, and there was an eastwards shift of the upward branch of the Walker circulation towards the date-line. Associated with this, rainfall across central and eastern parts of Australia was generally average to below average, and downmotion anomalies were evident over the southwest Pacific. The Asian northeast winter monsoon produced weaker than normal winds over east China and the South China Sea; however, the northeast trade winds extended strongly into the western Pacific during two periods. Each of these periods coincided with the eastward movement of a broadscale intraseasonal oscillation from the Indian Ocean to the western Pacific.

Introduction

This summary reviews the broadscale tropical circulation in the Australian/Asian region during the period November 1992 to April 1993. The area reviewed is the Darwin Regional/Specialised Meteorological Centre (RSMC) analysis domain: 40°S to 40°N, 70°E to 180°. The first section uses six-month average charts to describe the overall seasonal circulation and anomalies. The second section uses time series to portray variations of the tropical circulation within the season. The final section briefly summarises the occurrence of tropical cyclones in this six-month period.

Six-month mean charts were constructed using the tropical analysis scheme (TAS) of Davidson and McAvaney (1981), and anomalies were calculated relative to the six-year climatology of Lavery et al. (1991). The exception to this is mean sea-level pressure (MSLP) anomalies, for which the TAS chart was subjectively modified using monthly CLIMAT messages as discussed in Bate et al. (1993). Sea-surface temperature anomalies were calculated relative to the climatology of Reynolds (1983). All other data sources used are listed in the Appendix.

Broadscale seasonal features

Southern Oscillation

Figure 1 shows the ten-year behaviour of Troup's Southern Oscillation Index (SOI) and its five-month running mean. Values from January 1991 to April 1993 are listed in Table 1. The season was characterised by persistent moderate negative values of the SOI. This indicates a moderate re-emergence of the ENSO warm event that matured during the previous austral summer (Bate and Cheang 1995) then failed to decay completely during winter (Cleland et al. 1995).

Fig. 1 SOI time series for ten years to April 1993: monthly values (thin line); and five-month centred mean values (thick line).
Table 1. Monthly values of Troup's SOI for the period January 1991 to April 1993.

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<tr>
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<th>Feb</th>
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</table>

Sea-surface temperature (SST)

Figure 2 shows six-month SST anomalies across the region. Warm anomalies occurred across Indonesia and the equatorial Indian Ocean, as well as waters surrounding northern and southeastern Australia. Cold anomalies prevailed in the tropical northwest Pacific. Although not evident in Fig. 2, monthly analyses show that warm anomalies prevailed near the equator at the date-line with values exceeding +1°C early in the season. To the south, over the South Pacific convergence zone (SPCZ), small anomalies fluctuated above and below zero.

In the central and eastern Pacific, warm SST anomalies were predominant off the equator, however weak and even cold anomalies occurred on the equator. These cold anomalies contracted eastwards as the season progressed. While the overall pattern indicated warm ENSO conditions, the anomalies were generally weaker than is typical (Rasmusson and Carpenter 1982). Also, analysis of subsurface ocean temperatures shows a weaker pattern of warm anomalies across the equatorial Pacific than during the previous austral summer (Bell and Basist 1994).

Mean sea-level pressure and gradient-level wind

Figures 3 and 4 show the six-month mean and anomaly charts for MSLP and gradient-level (950 hPa) wind. A notable feature of Fig. 3(b) is the broad dominance of positive pressure anomalies, falling away to near or below zero anomalies at the tropical date-line. Similar to the previous austral summer, this pattern reflected the ENSO influence.

Fig. 2 Six-month SST anomaly (°C) November 1992 to April 1993; contour interval 1°C.

Fig. 3 Six-month MSL pressure (hPa) November 1992 to April 1993: (a) mean; (b) anomaly.
Fig. 4 Six-month 950 hPa wind field November 1992 to April 1993: (a) mean, isotachs (dashed) in m s$^{-1}$; (b) anomaly.

Low pressure anomalies over northwest China suggest that the Siberian high was weaker than normal. This, together with the high pressure anomalies across the northwest Pacific near 10° to 20°N, caused the northeast winter monsoon over eastern China, the South China Sea and surrounding land areas to be weaker than normal (Figs 4(a) and 4(b)).

Cross-equatorial surges from the northeast winter monsoon provide an important inflow to the northwest monsoon over northern Australia. However, there are other mechanisms which, in this season, more than compensated for the weakness in the northeast monsoon. High pressure anomalies over the Indian Ocean combined with weak low pressure anomalies over southern Australia to produce a stronger than normal onshore southwesterly airstream, an effect that was particularly strong during February. Also, high pressure anomalies east of the Philippines produced a stronger than normal northeast to northwest cross-equatorial flow through longitudes 120°E to 140°E.

Upper-level wind and cross-equatorial circulation

Figures 5 and 6 show the six-month mean and anomaly charts for 200 hPa wind and an equatorial cross-section of meridional wind. The anomalously strong and diffuent upper easterlies over the equatorial western Pacific in Fig. 5(b) are indicative of warm ENSO conditions. In combination with the gradient-level anomalies they portray a shift of the upward branch of the Walker circulation towards the date-line, centred on and north of the equator.

To the south, in the mid-latitude westerly winds, troughs favoured central Australia and the southwest Pacific (Fig. 5(a)) rather than the more normal east Australian coast. A similar weakness in the east coast trough is evident at 500 hPa (chart not shown).

The westerly trough and jetstream were weaker than normal over northern China. This weakened cold outbreaks in the area, which is associated with the weakness of the Siberian high and northeast winter monsoon described earlier.

Figure 6(a) depicts a broadly normal Hadley circulation, comprising low-level northerly flow and upper southerly return flow. The anomaly chart (Fig. 6(b)) highlights the weakened meridional circulation near the date-line, where both low-level northerlies and upper southerlies were weaker than normal. The converse was true in the longitude belt 120° to 140°E, where the strengthened circulation assisted the north Australian monsoon.

Likewise, the westerly wind anomalies in the equatorial western Pacific (Fig. 4(b)) were indicative of warm ENSO conditions, and had persisted for several seasons. The gradient-level wind anomalies show that the near-equatorial trough (NET) in the northwest Pacific was stronger than normal and extended further east to the date-line than in the climatological mean (not shown). The SPCZ was slightly further north than normal. Southerly anomalies through the SPCZ indicate that the cross-equatorial flow penetrated southwards around the trough much less than normal. High pressure and anticyclonic wind anomalies were situated to the south and southwest.
Fig. 5 Six-month 200 hPa wind field November 1992 to April 1993: (a) mean, isotachs (dashed) in m s⁻¹; (b) anomaly.

Fig. 6 Equatorial cross-section of six-month meridional wind November 1992 to April 1993: (a) mean; (b) anomaly.

Broadscale vertical motion
Figures 7 and 8 show the six-month mean and anomaly charts for the divergent component of the wind in the lower troposphere (950 hPa) and the upper troposphere (200 hPa) respectively. The purpose of these charts, as described in Stringer et al. (1994), is to infer regions of deep tropospheric upmotion.

The mean charts show typical broadscale features. These include general upmotion across the equatorial belt centred south of the equator, where upper divergence overlies lower convergence, surrounded by general downmotion across the subtropics, particularly in the northern (winter) hemisphere.

The anomaly charts show generally mixed and weak patterns across Australia, with little correlation between the lower and upper levels. However, low-level divergence anomalies and upper convergence anomalies near 130°E to 140°E north of the equator point to downmotion, which is consistent with the strengthened Hadley circulation through these longitudes noted earlier.

The weakness of the Siberian high and the northeast winter monsoon is illustrated by low-
level convergence anomalies across eastern China and surrounding sea areas, together with divergence anomalies from the Malay Peninsula to Borneo.

In the western Pacific near the date-line, much stronger than normal upmotion is shown near and north of the equator. To the south, however, there are strong downmotion anomalies over a broad area from the Solomon Islands southwards.

**Intraseasonal variations**

**Broadscale variations**

Figure 9 shows the location of major regions of deep tropical convection (low values of outgoing long wave radiation (OLR)), and their evolution with time. The overall seasonal pattern was strongly modulated by several intraseasonal oscillations. The most active region of deep convective activity early in the season was the equatorial Indian Ocean. During December this activity propagated eastwards to the western Pacific following the typical life cycle for intraseasonal oscillations as described, for example, by Knutson and Weickmann (1987) and Rui and Wang (1990).

There was a suppressed period over the Indian Ocean during early January in the wake of this oscillation event. Equatorial westerlies redeveloped in mid-January, and the divergent circulation and active tropical weather again propagated eastwards to northern Australia then the western Pacific during late January to early February.

The typical life cycle broke down after this event, with a broadscale monsoon circulation and cyclogenesis events continuing in the southwest Pacific throughout February and March. The Indian Ocean remained generally suppressed, apart from an active period in early March which didn’t display any eastward propagation.

Finally, in early April, a further intraseasonal oscillation event developed over the Indian Ocean and propagated eastwards to the western Pacific. Being late in the season, the deep convec-
Fig. 9  Time longitude section of five-day running mean OLR (W m⁻²) November 1992 to April 1993, averaged over: (a) 5°N to 15°N; (b) 5°S to 5°N; (c) 15°S to 5°S. Day 306 = 1 November.

Australasian northwest summer monsoon
Figure 10 gives a detailed picture of seasonal rainfall across northern Australia. Above average falls were confined to parts of the northern tropics, where specific heavy rainfall events occurred. These events included severe tropical cyclone Nina, which moved eastwards across Cape York in late December, and two deep tropical lows which moved westwards over land to the south of Darwin as described later.

Fig. 10  Decile values of six-month district average rainfall November 1992 to April 1993 for Australian districts north of 26°S.

Average to below average rainfall occurred over central and eastern Australia. This reflected the lack of southward penetration of rain events such as rain-bearing tropical lows or decaying tropical cyclones.

The evolution of the Australian monsoon may be described with reference to Darwin station data. Figure 11 shows the six-month time series of 850 hPa zonal and meridional wind, as well as daily rainfall. Onset of the monsoon over northern Australia, as defined by Holland (1986), was close to average in late December 1992, while the finish of the monsoon at the start of March 1993 was about a week earlier than average.

Apart from the break period during mid-January, the monsoon westerly wind was anomalously strong. The peaks at the end of December and at the end of January were each associated with the passage of a broadscale intraseasonal oscillation. The first of the deep tropical lows mentioned earlier developed during the second peak, and the wind turned from southwest to northwest as the low passed to the south of Darwin. The second deep tropical low developed later in February, causing a more localised strong northwesterly wind at Darwin.

The return of southeasterly winds was stronger and earlier than average. Hence Darwin received much lower than normal rainfall during March and April, as did tropical Australia in general.
Fig. 11 Darwin (12°S, 131°E) station data November 1992 to April 1993: (a) daily rainfall (bars), smoothed 850 hPa zonal wind (line) and its climatology (smooth line); (b) smoothed 850 hPa meridional wind (line) and its climatology (smooth line). Winds were smoothed by averaging four observations each day, then taking a three-day running mean; climatology 1950–1988.

There was a regular sequence of northeast surges during the three months December to February. Many occurred well to the east of their normal location and aren’t represented by pressure gradient peaks in Fig. 12; hence the monsoon over east China and the South China Sea was anomalously weak. During this period there was a strong correlation between the longitude of northeast surges and the longitude of the two intraseasonal oscillation events noted earlier. From late November to late December, surges occurred progressively further eastwards, and in early January a northeast trade wind surge occurred near the date-line. The pattern was then repeated with strong surges in the South China Sea in mid January, then progressively further east of the Philippines in late January to mid February.

The interaction between the northeast winter monsoon and the southern hemisphere northwest summer monsoon is not well understood. Stringer (1993) pointed out that active periods of the northeast monsoon occur on shorter time-scales than active periods of the northwest monsoon. It was suggested that cold surges which produce cross-equatorial momentum are not an intrinsic part of the Australian monsoon; rather they play a role in strengthening an existing broadscale westerly wind burst south of the equator. The above observations suggest, however, that there may be a feedback between equatorial westerly bursts and the location of east Asian mid-latitude westerly troughs and cold surges.

The rest of the season through March and April saw a mobile synoptic pattern over northern China which is evident in Fig. 12 as a steady sequence of only moderate pressure gradient peaks. None of these produced a substantial northeasterly surge.

Tropical cyclones

During November 1992 to April 1993, 23 tropical cyclones (TCs) (defined as having maximum ten-minute mean winds greater than 17 m s⁻¹, or named systems) were analysed by Darwin RSMC. Operational tracks from DTDS are shown in Fig. 13. Table 2 lists the TCs in order of occurrence, within the various basins, showing duration and estimated maximum intensity details. For TCs in the northern hemisphere, these details were obtained from the best-track data of Mautner and Guard (1993) and Etkin and Morse (1994), after applying a factor of 0.88 to convert maximum winds from one-minute mean to the Australian convention of ten-minute mean. For TCs in the southern hemisphere, operational data were used with some adjustments to maximum winds based on post-event advice (Bergin, per-
Fig. 12 Pressure gradient indices of the Asian northeast winter monsoon November 1992 to April 1993. Thick line = Hong Kong (22°N, 114°E) to Singapore (01°N, 104°E); thin line = Wuhan (31°N, 114°E) to Hong Kong.

Table 2. Tropical cyclones within the Darwin RSMC area November 1992 to April 1993. (T) = typhoon; (ST) = super-typhoon; (STC) = severe tropical cyclone.

<table>
<thead>
<tr>
<th>TC name</th>
<th>Dates at TC intensity in Darwin RSMC area</th>
<th>Maximum 10-min mean wind (m s⁻¹)</th>
<th>Estimated minimum MSLP (hPa)</th>
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<tr>
<td>Northwest Pacific (including South China Sea)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Dan (T)</td>
<td>25 Oct–3 Nov</td>
<td>50</td>
<td>933</td>
</tr>
<tr>
<td>Elsie (ST)</td>
<td>30 Oct–7 Nov</td>
<td>66</td>
<td>892</td>
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<td>Forrest (T)</td>
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<tr>
<td>Gay (ST)</td>
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<td>872</td>
</tr>
<tr>
<td>Hunt (T)</td>
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<td>Irma</td>
<td>12 Mar–17 Mar</td>
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<td>984</td>
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<tr>
<td>North Indian Ocean (including the Bay of Bengal)</td>
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<td>984</td>
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<tr>
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<td>11 Nov–17 Nov</td>
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<td>972</td>
</tr>
<tr>
<td></td>
<td>30 Nov–3 Dec</td>
<td>23</td>
<td>987</td>
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<td>South Indian Ocean (70°E–105°E)</td>
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<td>Ken</td>
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<td>Edwinia (STC)*</td>
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<tr>
<td>Jourdanne (STC)</td>
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<td>930</td>
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<tr>
<td>Australian (105°E–165°E)</td>
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<td>39</td>
<td>958</td>
</tr>
<tr>
<td>Nina (STC)#</td>
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<td></td>
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<tr>
<td>Lena</td>
<td>24 Jan–2 Feb</td>
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<tr>
<td>Oliver (STC)</td>
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<td>South Pacific Ocean (165°E to 180°)</td>
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<td>Oli@</td>
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<tr>
<td>Prema (STC)</td>
<td>27 Mar–1 Apr</td>
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* moved out of Darwin RSMC area before reaching peak intensity
# moved out of Darwin RSMC area after reaching peak intensity
@ moved into Darwin RSMC area after reaching peak intensity
sonal communication), and minimum pressures were estimated using the relationship of Atkinson and Holliday (1977).

Table 3 compares cyclone occurrences in each basin to the long-term mean. Note that occurrences differ from those in Table 2 because they include: depressions of intensity 13 m s\(^{-1}\) or more; cyclones west of 70°E and east of the date-line; and a slightly longer summation period in the southern hemisphere.

There were more cyclones than normal in the north Indian Ocean. They all occurred during November and December, which has been noted above as an active period of deep tropical convection in that region assisted by surges from the northeast winter monsoon. Occurrences were near normal over the northwest Pacific.

In the southern hemisphere, occurrences were above average in the Pacific Ocean and slightly below average in the Indian Ocean and Australian region. This distribution is similar to but less extreme than that of the previous season (Bate and Cheang 1995), and symptomatic of the continuing warm ENSO conditions. In particular, the total of nine tropical cyclones in the South Pacific had only been exceeded three times in the previous twelve years, during the warm ENSO years 1982–83 (12 cyclones), 1986–87 (11 cyclones) and 1991–92 (13 cyclones). Other years had totals ranging from one to seven cyclones (Etro and Morse 1994). As in the previous year, about half of the South Pacific tropical cyclones occurred east of the date-line.

**Summary**

The season was characterised by persistent moderate negative values of the SOI and positive SST anomalies at the equator near and east of the date-line, indicating a continuation of the warm ENSO conditions which had matured during the previous austral summer. A shift of the upward branch of the Walker circulation towards the date-line was evidenced by the combination of low pressure, low-level westerly wind and convergence, and upper-level easterly wind and divergence anomalies there. The eastward shift in deep tropical convection was evidenced by the persistent low OLR values and above average TC occurrences near the date-line.

One consequence of the warm ENSO conditions was average to below average rainfall across central and eastern parts of Australia. Also associated with ENSO were the low-level anticyclonic, upper cyclonic, and downwind motion anomalies over the southwest Pacific from the Solomon Islands southwards.

The Asian northeast winter monsoon produced weaker than normal winds over east China and the South China Sea, a result of the weaker than normal Siberian high. However, the northeast trade winds extended strongly into the western Pacific during two periods, namely early January and the first half of February. Each of these periods coincided with the eastward movement of a broadscale intraseasonal oscillation from the Indian Ocean to the western Pacific.

The Australian northwest summer monsoon was not significantly affected by the weakness of cross-equatorial surges from the South China Sea. Compensating factors included the strength of the

![Tropical cyclone tracks November 1992 to April 1993. Solid line = severe tropical cyclone/typhoon; dashed line = tropical cyclone/storm.](image)

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<tr>
<td>North Indian Ocean</td>
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<td>Australia (105–165°E)</td>
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<td>9.3</td>
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onshore southwesterly airstream over northwest Australia, and a stronger than normal cross-equatorial flow through longitudes 120°E to 140°E.

Acknowledgments
The author would like to thank Rob Porteous for drafting the figures, and Sam Cleland for assistance in obtaining the six-month district average rainfall totals for northern Australia.

Appendix
Data sources used in this summary were:
Darwin RSMC grid-point analysis data from the Tropical Analysis Scheme and Australian region grid-point analysis data from the National Meteorological Centre, Melbourne.
Darwin RSMC weekly manual SST analyses of in situ (ship/buoy) data, converted to grid-point format at 5"×5" resolution, six-month means calculated for each grid-point.
Darwin Tropical Diagnostic Statement, October 1992–April 1993, issued monthly by Bureau of Meteorology, GPO Box 735, Darwin, NT 0801, Australia.
District average rainfall and rainfall deciles from the database maintained by National Climate Centre, Bureau of Meteorology, Melbourne.
Monthly CLIMAT messages received via the Global Telecommunications System.
Weekly Tropical Climate Note, November 1992–April 1993, experimental product prepared weekly for internal use by Bureau of Meteorology, GPO Box 735, Darwin, NT 0801, Australia.

References