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The South Pacific and southeast Indian Ocean tropical cyclone season 2002-03

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Eighteen tropical cyclones formed in the South Pacific and southeast Indian Ocean during the 2002-03 tropical cyclone season. This total was just below the overall average and followed on from below-average activity in previous seasons. There was a marked shift in cyclone activity away from the Australian region towards the South Pacific, consistent with the prevailing moderate warm ENSO (El Niño) event. Only two cyclones occurred between 125° and 150°E whereas ten occurred east of 160°E. Of these ten systems, seven produced hurricane-force winds (sustained winds of at least 33 m/s). Furthermore three of these, *Zoe*, *Ami* and *Erica* caused significant damage to the eastern Solomon Islands, New Caledonia and Fiji, and Tuvalu respectively. *Zoe* and *Inigo* (NW Australia) both had estimated maximum sustained winds of 67 m/s, making them amongst the most intense systems ever experienced in the region. The 18 cyclones that formed spanned every month between December 2002 and June 2003 except for May.

The five active phases of the intraseasonal (Madden-Julian) oscillation (MJO) coincided with the development of thirteen of the eighteen cyclone events. Equatorial Rossby (ER) waves assisted in the genesis of four of these systems and with the development of a further four outside an active MJO phase. Only one cyclone (*Zoe*) was completely removed from an identified MJO or ER wave episode.

Introduction

This paper provides a summary of tropical cyclone (TC) activity in the southeast Indian Ocean (east of 90°E) and the South Pacific Ocean (west of 120°W) during the 2002-03 cyclone season. The material has been gathered from information provided by the Australian Tropical Cyclone Warning Centres (TCWCs) at Perth, Darwin and Brisbane, the Port Moresby TCWC and the Fiji Regional Specialised Meteorological Centre (RSMC) at Nadi.

In addition to summaries of individual tropical cyclones and overall occurrence, large-scale and intraseasonal features are discussed, particularly in relation to TC formation. For more details of the broadscale circulation within the Darwin RSMC area of responsibility (40°N-40°S, 70°E-180°E) see the seasonal summary by Shaik and Cleland (2004). All wind speeds are averaged over ten minutes unless otherwise stated.

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Tropical cyclone occurrence

There was a total of 18 tropical cyclones in the combined southeast Indian and South Pacific basins during the full year from July 2002 to June 2003. This was just below the long-term average (1970/71-2001/02) of 20 and followed on from below average seasons in 2001-02 (14) and 2000-01 (12). Details of each TC in the season are summarised in Table 1, while the best tracks for each system are plotted in Figs 3 to 6. A summary of the observed TC activity in the three subregions, western Australian (AUW, 90-135°E), eastern Australian (AUE, 135-160°E), South Pacific (160°E-120°W) and combined Australian and South Pacific (AUS-SPA), and a comparison with long-term means, is presented in Table 2. Data from the southwest Indian Ocean basin (SWI) obtained from La Reunion RSMC have been included in this table in order to compare TC activity across the entire southern hemisphere.

Table 1. Tropical cyclones in the South Pacific and southeast Indian Oceans 2002-03.

	Low first identified			*Initial tropical cyclone phase*			
Name	*Date*	*Lat. °S*	*Long.*	*Date*	*Time (UTC)*	*Lat. °S*	*Long.*
Yolande	3 Dec	17.0	179.0°W	5 Dec	0000	20.4	174.2°W
Zoe	23 Dec	8.0	176.0°W	25 Dec	2100	10.8	175.5°E
Unnamed 1	4 Jan	10.0	135.5°E	4 Jan	2100	11.4	135.6°E
Ami	9 Jan	8.0	176.0°W	12 Jan	0000	10.8	179.4°W
Beni	19 Jan	8.0	170.0°E	25 Jan	0000	13.2	161.2°E
Unnamed 2	21 Jan	12.5	125.3°E	24 Jan	1800	19.4	118.6°E
Cilla	24 Jan	16.0	174.0°E	27 Jan	0000	18.0	178.0°W
Fiona	3 Feb	11.8	117.4°E	5 Feb	0600	11.8	111.8°E
Dovi	5 Feb	11.0	163.0°W	5 Feb	2300	14.0	162.7°W
Graham	26 Feb	17.0	119.5°E	28 Feb	0000	17.7	121.2°E
Harriet	1 Mar	12.0	103.1°E	4 Mar	0600	14.8	113.0°E
Erica	1 Mar	21.0	147.5°E	4 Mar	0600	20.5	154.0°E
Eseta	8 Mar	13.0	176.0°E	10 Mar	0600	16.2	172.2°E
Craig	7 Mar	13.0	130.3°E	9 Mar	0300	10.8	128.9°E
Inigo	31 Mar	7.7	124.0°E	1 Apr	0600	9.6	121.0°E
Fili	13 Apr	13.5	178.0°W	14 Apr	1800	20.4	171.6°W
Gina	4 Jun	10.5	171.0°E	5 Jun	0600	11.3	169.1°E
Epi	5 Jun	7.9	152.9°E	5 Jun	0630	7.9	152.9°E

	Maximum intensity					*End tropical cyclone phase*			
Name	*Date*	*Time (UTC)*	*Lat. °S*	*Long.*	*Mean wind m/s (knots)*	*Date*	*Time (UTC)*	*Lat. °S*	*Long.*
Yolande	5 Dec	0600	21.0	173.2°W	18 (35)	5 Dec	1200	21.7	172.1°W
Zoe	28 Dec	0600	12.5	169.5°E	67 (130)	1 Jan	0000	20.3	175.1°E
Unnamed 1	5 Jan	1200	12.1	135.5°E	26 (50)	5 Jan	1800	12.4	134.9°E
Ami	14 Jan	1200	23.1	176.2°W	41 (80)	15 Jan	1200	29.1	163.3°W
Beni	29 Jan	1200	17.7	164.7°E	57 (110)	31 Jan	1800	24.3	163.5°E
Unnamed 2	25 Jan	0000	20.1	118.9°E	23 (45)	25 Jan	0600	20.6	119.3°E
Cilla	29 Jan	0000	22.3	167.5°W	21 (40)	29 Jan	1200	22.5	166.0°W
Fiona	9 Feb	0600	15.9	98.9°E	49 (95)	12 Feb	1800	21.6	92.0°E
Dovi	9 Feb	0000	20.2	168.5°W	57 (110)	11 Feb	0000	26.0	169.0°W
Graham	28 Feb	1200	18.8	121.3°E	21 (40)	1 Mar	1200	22.1	122.0°E
Harriet	8 Mar	1200	20.3	112.3°E	23 (45)	9 Mar	1800	25.1	107.6°E
Erica	13 Mar	1200	20.6	162.7°E	59 (115)	15 Mar	1200	30.0	179.0°E
Eseta	13 Mar	0600	22.2	175.3°W	52 (100)	14 Mar	1200	31.0	160.0°W
Craig	11 Mar	0000	11.6	132.2°E	28 (55)	12 Mar	2100	15.2	141.4°E
Inigo	4 Apr	0600	13.1	115.2°E	67 (130)	8 Apr	0300	20.6	115.6°E
Fili	15 Mar	0600	28.0	170.0°W	26 (50)	15 Apr	1200	29.4	170.6°W
Gina	7 Jun	1800	17.2	161.8°E	41 (80)	9 Jun	0600	16.5	162.0°E
Epi	5 Jun	0630	7.9	152.9°E	18 (35)	5 Jun	1800	7.5	155.0°E

Table 2. Occurrence of tropical cyclones (TC) within southern hemisphere basins for season 2002-03. Long-term means from 1970/71-2001/02 are shown in parentheses. STC indicates severe tropical cyclones (maximum wind speed >33m/s) and ITC indicates intense tropical cyclones (maximum wind speed >44m/s).

	SWI West of 90°E	*AUW 90-135°E*	*AUE 135-160°E*	*AUS 90-160°E*	*South Pacific East of 160°E*	*AUS-SPA 90°E-120°W*	*Southern hemisphere*
TC	11 (12)	7 (8.5)	3 (5.2)	9 (13.0)	10 (8.7)	18 (19.8)	29 (29.2)
STC	7 (5.8)	2 (4.3)	1 (2.1)	3 (6.4)	7 (4.1)	9	16 (14.8)
ITC	3 (2.5)	2 (1.8)	0 (0.7)	2 (2.5)	5 (1.6)	7	10 (6.2)
TC days	52 (58)	29 (32.8)	11 (18)	33 (50.8)	40 (32)	60	112 (141.5)
STC days	22 (20)	11 (10.6)	1 (4.6)	12 (15.2)	19 (10.7)	26	48 (46)
ITC days	9 (4.7)	6 (2.5)	0 (1)	6 (3.5)	11 (2.5)	16	25 (10.7)

There was a marked shift in TC activity away from the Australian region towards the South Pacific region as shown in the best tracks and in Table 2. There were only nine TCs between 90 and 160°E compared with the long-term average of thirteen. Indeed only two cyclones, *Craig* and *Unnamed 1*, occurred between 125° and 150°E. Queensland was unaffected by any tropical cyclones, although a low that was to become TC *Erica* caused heavy rain over north Queensland in early March. In contrast there were more cyclones than normal across the South Pacific basin east of 160°E. Of particular significance is that seven of these ten systems became severe, having winds of at least 33 m/s. Five of these were intense having winds of at least 44 m/s, accounting for half of the intense TCs (ITC) across the entire southern hemisphere. Furthermore three of these, *Zoe*, *Ami* and *Erica* caused significant damage to land areas (see following section).

Another indicator of intensity and longevity is the TC day, that is the total number of days during the season upon which one or more TCs were active in the basin. There were just 33 TC days between 90 and 160°E well below the average of 50.8, but east of 160°E there were 40 TC days, eight more than average. Significantly there were 19 Severe TC (STC) days (days when there were one or more severe TCs) east of 160°E. Across the entire hemisphere there were 25 intense TC days (days when there were one or more intense TCs), more than double the average of 10.7.

The lower than average number of TCs in the Australian region and the eastward shift in TC activity are consistent with the prevailing warm ENSO (El Niño) event. These are well established links, as discussed in Nicholls (1985), Basher and Zheng (1995) and more recently by Kuleshov (2003).

Sixteen TCs occurred between December and April, while the remaining two, *Epi* and *Gina* were weak TCs occurring in early June 2003. Fifteen TCs occurred on 54 of the total of 112 days between 25 December 2002 and 15 April 2003.

Impacts

Of the eighteen cyclones that formed in the region, three (*Zoe*, *Ami* and *Erica*) caused significant damage to land areas, while eight others had some degree of impact on communities or human activity. TC *Zoe* was one of the most intense cyclones ever monitored in the South Pacific and was near peak intensity as it passed near the islands of Tikopia, Anuta and Fataka in the Temotu Province of the Solomon Islands in late December 2002. On Tikopia seventy per cent of housing was completely destroyed and the remainder partially damaged. All the crops were destroyed and the shoreline altered. Miraculously the 1300 residents survived by sheltering in craggy rocky overhangs. It was estimated that it would take at least three years for residents to regrow the required amount of food produce and at least 12 years to approach self-sufficiency in building materials.

Although initially forming off the North Queensland coast, TC *Erica*'s main impact was on the main island of New Caledonia on 14 March 2003. The cyclone was at peak intensity just prior to making landfall on the west coast about 200 kilometres northwest of Noumea. Two people died, thousands were left homeless and extensive damage was done to housing and infrastructure.

TC *Ami* was responsible for 14 deaths in Fiji and for an estimated damage bill of $F104 million ($AUS 72 million). Damage was worst in the Macuata, Cakaudrove and Lau Provinces. *Ami* also caused moderate housing damage and severe fruit tree damage on Niulakita island in Tuvalu.

Of the other cyclones, TC *Inigo* caused the loss of two Indonesian fishing vessels with five to eight people on board each; TC *Eseta* caused major crop damage on the Tongan island of Eua; TC *Beni* caused significant crop damage on the Rennell Islands. In Australia, flood damage was caused by TC *Craig*, TC *Graham* (one fatality), TC *Beni* (one fatality) and both the unnamed cyclones.

Broadscale features

The season was characterised by a moderate warm ENSO (El Niño) phase that weakened to near-neutral conditions during the austral autumn period. The Troup Southern Oscillation Index (SOI) remained moderately negative during the season, averaging –7.2 between November 2002 and June 2003, a slight increase from the May to October 2002 value of –9.7. The index remained negative through to June despite the demise of the El Niño. Dawkins (2004) suggests that the low values late in the period were partly due to the effects of an active Madden–Julian Oscillation (MJO) in May and a subsequent northeast shift of the South Pacific convergence zone (SPCZ).

Sea-surface temperatures (SSTs) were above average, being greater than 29°C across most of the tropics. The greatest anomaly was in the central Pacific as is typical of an El Niño pattern. The warm anomaly in this area increases the Tropical Cyclone Heat Potential as described in Goni and Trinanes (2003) and may be a contributing factor in why so many Pacific cyclones became severe. With the breakdown of the El Niño during the austral autumn the entire equatorial region of the Pacific cooled, but waters off northwest Australia remained warmer than average.

The mean and anomaly of outgoing long wave radiation (OLR) shown in Shaik and Cleland (2004) indicates there was greater than average convection about the date-line and less than average convection over the eastern Indian Ocean and Australian maritime continent as is typical during an El Niño. As a result most of the Australian continent experienced drier than normal conditions. Pressures were generally above average over most of the tropics except to the east of 170°E and in the central Indian Ocean where the anomalies were weakly negative. Additionally, the low-level winds showed easterly anomalies over northern Australian and particularly the Coral Sea reflecting an overall weaker monsoon trough in this area.

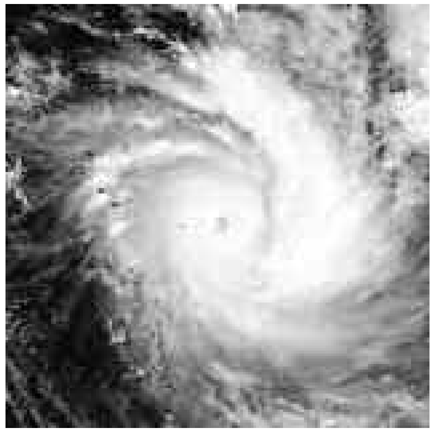
Seasonal features of OLR, velocity potential, surface pressure, lower and upper-level winds, and sea-surface temperature are discussed in detail in Shaik and Cleland (2004).

Intraseasonal modulation

Intraseasonal variability can be identified from time-longitude sections of OLR, 200 hPa velocity potential, and sea-level pressure anomaly, as well as station pressure series as shown in Shaik and Cleland (2004). Figure 2 shows a longitude/time plot of filtered outgoing long wave radiation (OLR) anomalies overlain

Fig. 1 Visible satellite images of (a) TC *Zoe* 2255 UTC 27 December 2002 (Terra satellite), (b) TC *Erica* 0255 UTC 13 March 2003 (Aqua satellite) and (c) TC *Inigo* 0625 UTC 5 April 2003 (Aqua satellite). Images courtesy of NASA.

(a)



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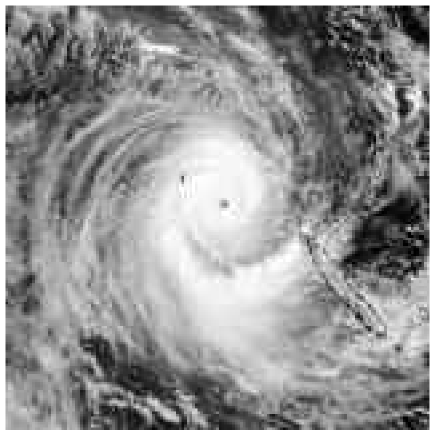

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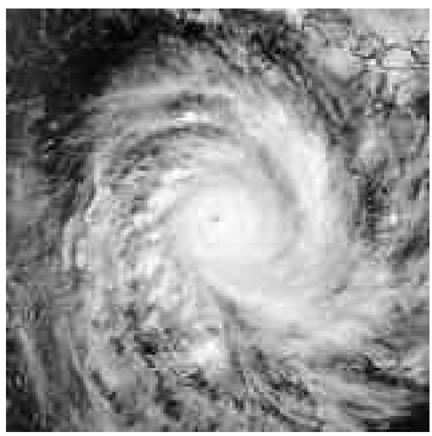
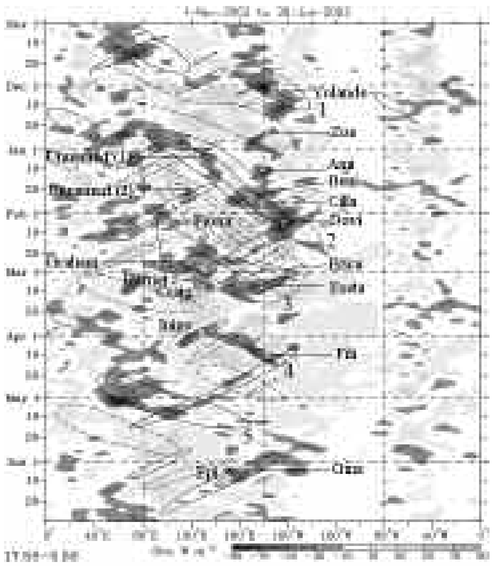


Fig. 2 Filtered anomalies of outgoing long wave radiation, averaged over latitudes 2.5°S to 17.5°S for November 2002 to June 2003. Contours sloping down to the right indicate MJO propagation, while contours sloping down to the left are for n=1 equatorial Rossby waves. Contour interval is 10 W m^{-2}. Locations of cyclogenesis events are indicated.



by contours indicating MJO periods (sloping down to the right) and Equatorial Rossby (ER) waves (number 1) (sloping down to the left). There are five identified active MJO phases, with a periodicity of about 30-40 days although some were quite weak and ill defined. The first active phase in November and early December assisted with the development of TC *Yolande* east of the date-line. The second MJO phase from late December through to early February was much stronger and during this phase the unnamed TC in the Arafura Sea and TCs *Ami*, *Beni*, *Cilla* and *Dovi* formed, the latter also coinciding with an ER wave. The third MJO phase was less coherent but nevertheless was associated with the development of TCs *Fiona*, *Graham*, *Erica*, *Eseta*, and *Harriet*; *Eseta* being assisted by an ER wave.

In late March/early April, a short-lived ER wave near 120°E was associated with the deep convection that influenced the development of TC *Inigo*. A weak MJO pulse (number 4) in April combined with an ER wave to spawn the twins TC *Fili* and typhoon *Kukira* in opposite hemispheres.

Although no TCs developed in the fifth MJO pulse in late April/early May, a strong ER wave led to the development of TCs *Gina* and *Epi* in early June.

Active phases of the MJO coincided with the development of thirteen of the eighteen cyclone events. ER waves assisted in the genesis of four of these systems and with the development of a further four outside an active MJO phase. Only one TC (*Zoe*) was completely removed from an identified MJO or ER wave episode. The strong association of the MJO pulse with cyclogenesis is consistent with the findings of Hall et al. (2001) who found that the links were stronger in El Niño years.

Note that TCs *Ami*, *Fiona*, *Harriet* and *Craig* have been included as cyclones forming within an MJO pulse although they lie just outside the envelope shown in Fig. 2.

Verification statistics

Position forecast verification statistics for each cyclone (Table 3) were derived by comparing the official warnings issued by the relevant warning centres with post-analysis best-track positions. Verification statistics for persistence forecasts (indicated by parentheses in Table 3) based on six-hour best-track movement vectors were also calculated to provide some indication of the steadiness of the track. Persistence tracks do not have an initial position error and thus cannot be directly compared with other forecast track types. For example, for TC *Graham* the forecast accuracy at 12 hours is 74 kilometres, about twice the figure for persistence, but much of the inaccuracy occurs at analysis time. The same is true for the second unnamed TC. Both of these systems were weak monsoonal systems having a centre that was difficult to locate in real time.

TCs with the most accurate forecasts included *Dovi* and *Inigo* that had 24-hour position accuracies of 76 and 84 kilometres respectively, and *Harriet* which had a 48-hour accuracy of just 139 kilometres. Overall the average 24-hour accuracy of 154 kilometres surpasses the 1999-2000 value of 157 kilometres described by Paterson and Bate (2001) as the best on record.

Tropical cyclones in the South Pacific and southeast Indian Oceans 2002-03

***Yolande* (Nadi) 29 November – 6 December 2002**

TC *Yolande* (Fig. 6) was a weak early season cyclone that lasted less than 24 hours east of Tonga. A low developed late in November over southern

Table 3. Position forecast verification statistics for official warnings issued by relevant warning centres. Forecast positions are verified against the official best track. Persistence errors (in brackets) based upon the best track are included to provide a baseline of the predictability of the track.

Forecast lead time	*0 h*		*12 h*		*24 h*		*48 h*	
Name	*Accuracy (km)*	*Number*	*Accuracy (km)*	*Number*	*Accuracy (km)*	*Number*	*Accuracy (km)*	*Number*
Yolande	-	-	-	-	-	-	-	-
Zoe	13	26	75 (73)	22	134 (180)	18	-	-
*Unnamed 1**	-	-	-	-	-	-	-	-
Ami	6	12	95 (161)	8	293 (596)	4	-	-
Beni	14	30	94 (104)	26	165 (304)	22	-	-
Unnamed 2	54	4	146 (57)	3	209 (110)	6	-	-
Cilla	10	11	131 (130)	9	269 (220)	7	-	-
Fiona	27	30	71 (41)	31	128 (108)	29	256 (350)	12
Dovi	15	21	58 (80)	19	76 (160)	15	-	-
Graham	47	10	74 (35)	13	95 (103)	11	170 (399)	2
Harriet	24	23	88 (57)	23	116 (146)	26	139 (542)	10
Erica (Bne)	23	18	110 (78)	18	214 (193)	17	407 (446)	9
Erica (Fiji)	3	10	93 (107)	10	232 (308)	7	-	-
Eseta	9	16	106 (147)	12	240 (465)	10	-	-
Craig	17	14	103 (131)	15	139 (234)	12	284 (567)	4
Inigo	17	25	52 (36)	27	84 (97)	19	166 (278)	10
Fili	20	4	-	-	-	-	-	-
Gina	32	17	153 (165)	14	233 (359)	12	-	-
Epi	-	-	-	-	-	-	-	-
Weighted mean	17		78		154		239	

*Darwin TCWC issued land-gale warnings instead of TC warnings given the monsoonal nature of the system.

Tuvalu embedded in an active monsoon trough. By 3-4 December the system had moved to the south-southeast into an area of decreased vertical wind shear and reached tropical cyclone intensity at 0000 UTC 5 December. However, *Yolande*'s southeast track had moved it into an area of increased wind shear and the system was downgraded less than 12 hours later. The maximum winds were estimated at 18 m/s (35 knots) and no damage is known to have resulted.

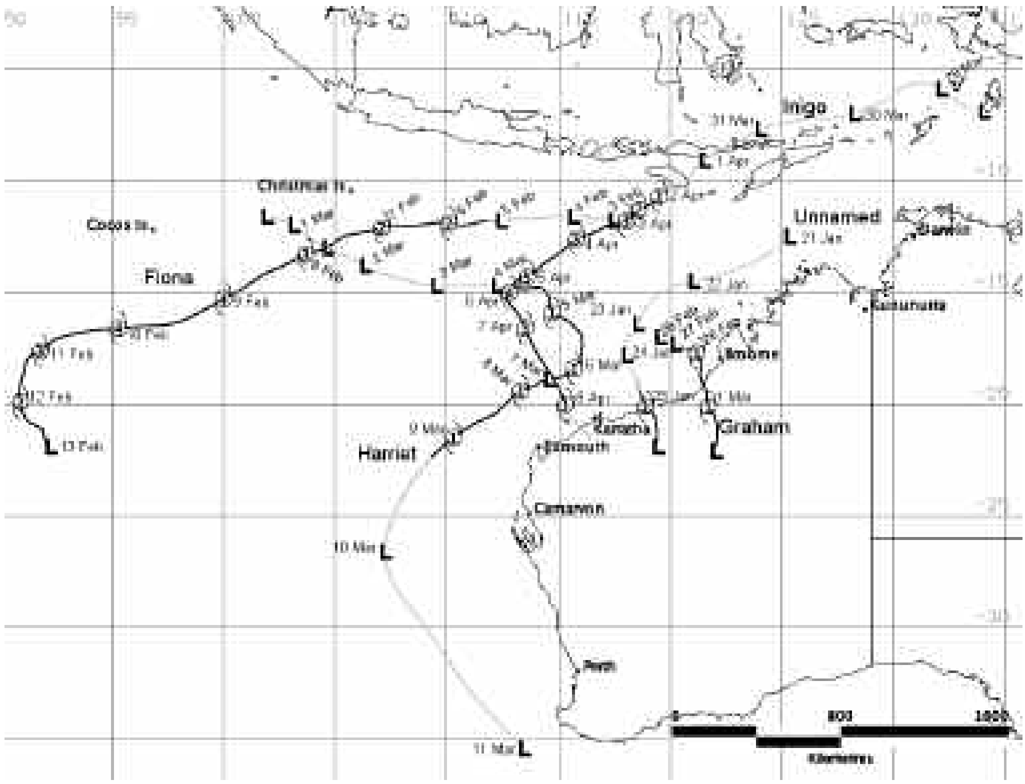
***Zoe* (Nadi) 23 December 2002 – 1 January 2003**

TC *Zoe* (Fig. 5) was one of the most intense cyclones ever seen in the southern Pacific Ocean with estimated winds reaching 67 m/s (130 knots) devastating the island of Tikopia in the Solomon Islands.

A tropical depression emerged from the South Pacific convergence zone on 23 December to the east of Tuvalu, being steered to the west-southwest under the influence of a mid-level ridge to the south. Convection increased and the low became more organised after crossing the date-line early on 25 December, assisted by strong upper diffluence. The low reached tropical cyclone intensity on 26 December and rapidly intensified under decreasing vertical wind shear and strong upper-level outflow in all quadrants. *Zoe*'s intensity was upgraded to hurricane-force on 27 December as an eye appeared on satellite imagery and then TC *Zoe* reached peak intensity at 0800 UTC 28 December near the Temotu Province of the Solomon Islands (see Fig. 1(a)). At this time *Zoe* virtually stalled before it tracked to the southeast on 29 December. It then accelerated in response to an approaching mid-level trough. Subsequently, the increased northwesterly flow gradually caused *Zoe* to weaken to below tropical cyclone intensity while located about 380 kilometres southwest of Nadi (Fiji) on 31 December.

TC *Zoe*'s main impact was on the islands of Tikopia, Anuta and Fataka when it was close to maximum intensity, passing within 30 kilometres of Tikopia totally destroying buildings and food crops. Miraculously the 3,700 residents of Tikopia and Anuta all survived.

Fig. 3 **Tracks of tropical cyclones *Fiona*, *Graham*, *Harriet*, *Inigo* and *Unnamed 2* in the northwest Australian region. Grey track indicates below tropical cyclone intensity and black indicates the tropical cyclone phase. Positions are at 0000 UTC unless otherwise stated. The number inside the cyclone symbol indicates the intensity category used in the Australian/South Pacific region.**



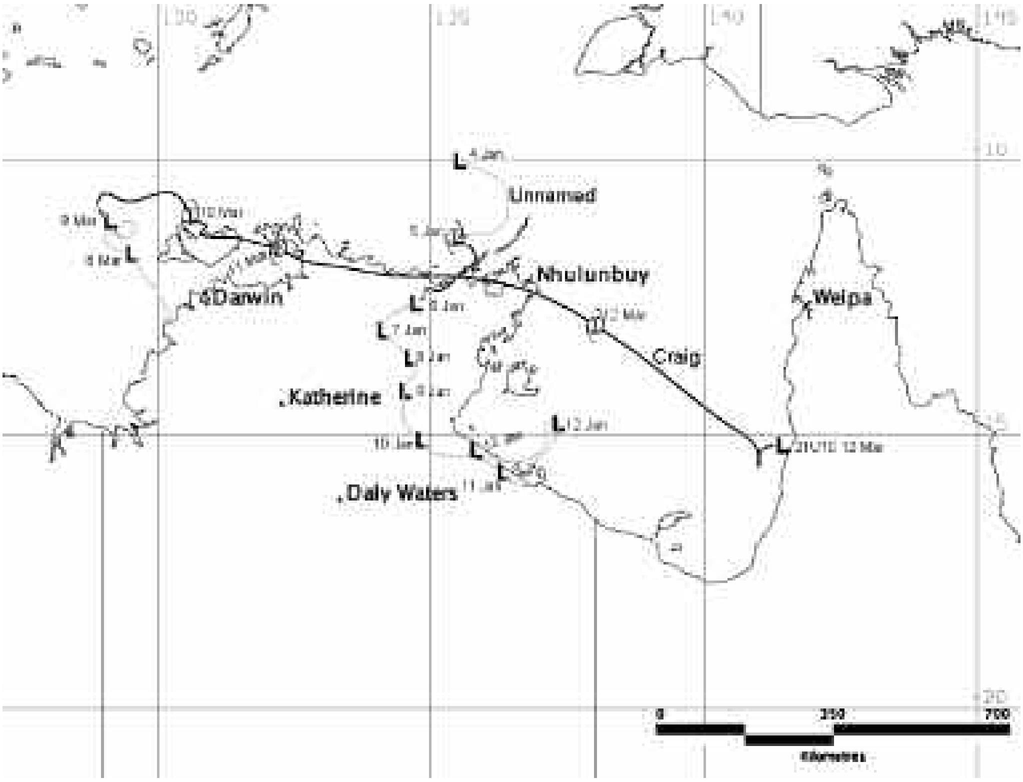
Unnamed tropical low 1 (Darwin) 2 – 6 January 2003 (Fig. 4)

A low formed on the monsoon trough in the Arafura Sea during an active MJO phase early in January. Strong monsoonal flow combined with favourable low shear and upper divergence encouraged rapid development of the low on 4 January and it reached tropical cyclone intensity at 2100 UTC. The core region was only about 30 kilometres in radius and a band of near gale-force northwesterly winds extended to a radius of 280 kilometres in the northeastern sector. The system drifted southwards, passing over Elcho Island in the afternoon before crossing the mainland coast. It then weakened below tropical cyclone intensity as it moved southwestwards over Arnhem Land on 6 January.

Radar images showed a C-shaped structure with a radius of about 20 kilometres persisting for many hours. This radar signature indicates that the heaviest precipitation, and likely the strongest winds, were in the offshore flow on the western side of the eyewall. This is consistent with a damage assessment that indicated maximum winds occurred in the offshore southerly flow. This is also consistent with preliminary modelling studies of landfalling tropical cyclones that show the increased surface roughness of the land gives rise to stronger inflow and increased advection of angular momentum, resulting in a wind maximum in the offshore flow (J. Kepert, personal communication).

Monsoonal gales associated with the broader circulation persisted in the Arafura Sea and Gulf of Carpentaria. The low was maintained over land resulting in heavy rainfall throughout much of January. Redbank Mine, near the Queensland border recorded 1100 mm of rain between 8-17 January. Many rivers across eastern Northern Territory were in flood, particularly the McArthur River which extended about six kilometres across near Borroloola on 16 January. At Elcho Island tree damage was extensive, and falling trees also caused minor damage to structures and vehicles.

Fig. 4 Tracks of tropical cyclones *Craig* and *Unnamed 1* in the northern Australian region. Symbols as in Fig. 3.



Unnamed tropical low 2 (Perth) 22 – 25 January 2003 (Fig. 3)

A low over the Timor Sea developed as it moved to the southwest steered by a mid-level ridge over the continent. The low then took a more southerly course as a strong trough approached from the Indian Ocean eventually crossing the coast just east of Port Hedland on 25 January. The unnamed low exhibited monsoonal features throughout its lifetime and produced gale-force winds at two offshore sites indicating that the system briefly reached tropical cyclone intensity.

As was the case when the initial unnamed low moved over Elcho Island, the maximum winds occurred in the western quadrants in close proximity to land. Radar imagery also showed a similar asymmetric bias to the western semi-circle feature of the initial unnamed low.

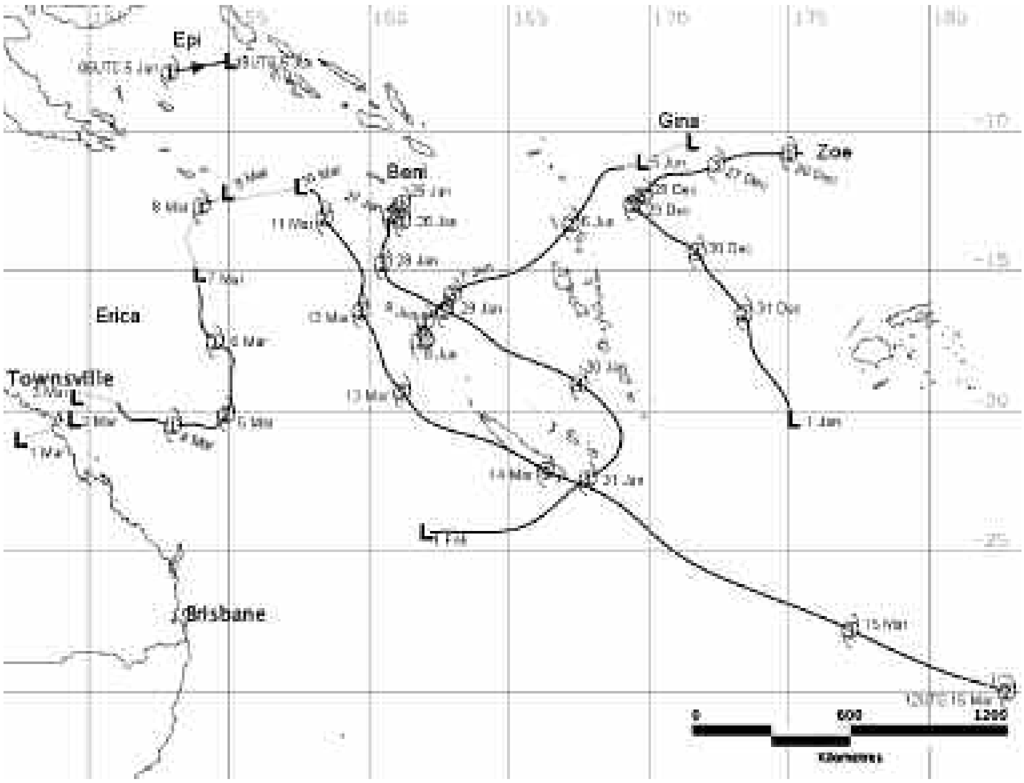
Heavy rain south of the centre in the vicinity of Port Hedland caused the Yule River to break its banks, cutting the Northwest Highway. Port Hedland recorded 110.2 mm in six hours and several sites registered accumulated falls in excess of 200 mm (Pardoo 222.2 mm in two days). There was no known wind damage.

***Ami* (Nadi) 9 – 15 January 2003**

Severe TC *Ami* (Fig. 6) which reached a maximum intensity of 41 m/s (80 knots) caused considerable damage to northern Fiji.

A low first appeared on 10 January east of Tuvalu in an active monsoon trough. Initial development was inhibited by vertical wind shear but this decreased on 11 January. Favourable upper-level diffluence associated with the near-equatorial ridge helped the system to develop and it reached tropical cyclone intensity on the following day. The system had tracked steadily to the southwest at about 12 km/h but slowed and turned towards the south under the influence of an upper-level trough located to the southwest, during 12 January. This placed the system in a favourable environment of low wind shear and good outflow aloft. TC *Ami* reached hurricane intensity at 0600 UTC 13 January with a ragged eye becoming apparent as it accelerated southwards. TC *Ami* passed over the northern Fijian islands of Vanua Levu and Taveuni before moving southeastwards through the Lau Group, reaching peak intensity at 0600 UTC 13 January about 100 kilometres south-

Fig. 5 Tracks of tropical cyclones *Zoe*, *Beni*, *Erica*, *Gina* and *Epi* in the western South Pacific. Symbols as in Fig. 3.



southwest of Lakeba. The system then weakened as it accelerated further to the southeast, becoming sheared and moving over cooler waters. TC *Ami* interacted with a frontal boundary to its southwest on 15 January, undergoing complete extratropical transition.

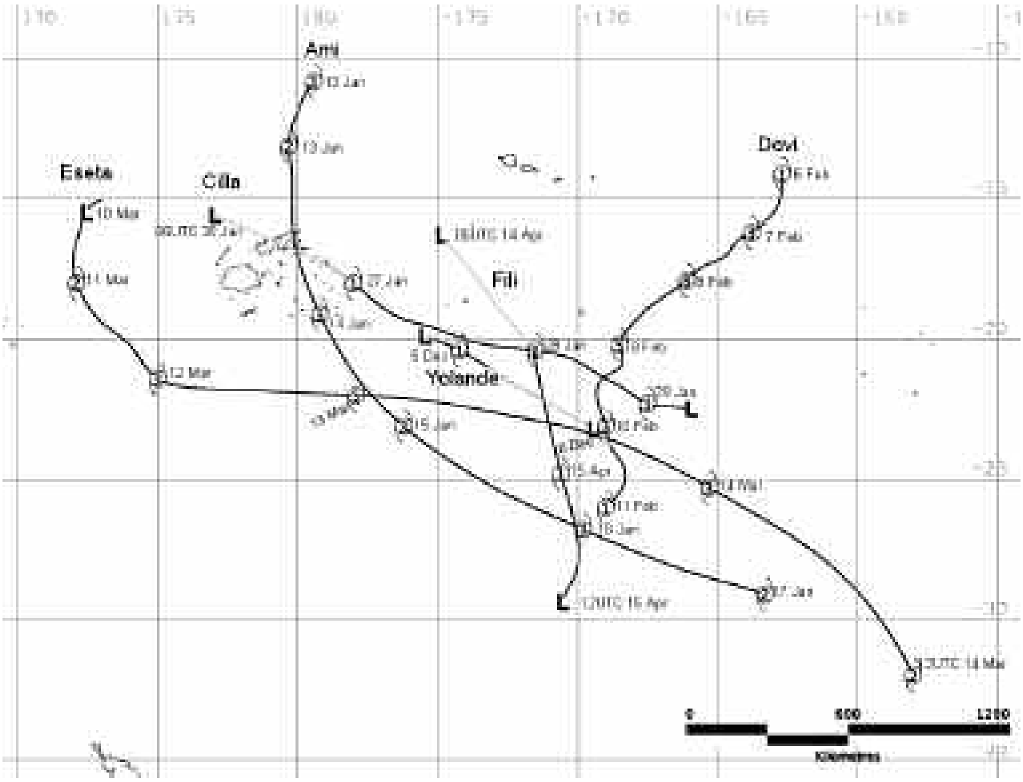
A total of 14 people died in Fiji and damage was estimated at $F104 million ($AUS 71 million), mainly in the northern and eastern districts of Macuata, Cakaudrove and Lau that bore the full impact of TC *Ami*. Severe river flooding in Labasa caused serious damage and high waves and storm surges caused coastal inundation in many areas along *Ami*'s path. Some Tongan islands also suffered substantial tree damage.

Beni **(Nadi and Brisbane) 20 January – 5 February 2003 (Fig. 5)**

An active monsoon trough within the South Pacific convergence zone spawned a low northeast of the Santa Cruz Islands (Solomon Islands) on 20 January. The low moved to the west-southwest and developed in a favourable environment of low shear and moderate diffluent flow aloft and sea-surface temperatures of about 30°C. However, from 22-23 January, further development was suppressed by strengthening wind shear exposing the low-level circulation east of the deep convection. The low resumed development on 24 January as it moved beneath the upper-level ridge and tropical cyclone intensity was reached at 0000 UTC 25 January about 160 kilometres southeast of Rennell Island (Solomon Islands). For the following two days TC *Beni* meandered in a clockwise loop, developing only slowly, and exhibited a partially exposed low-level circulation and deep convection on its western flank.

TC *Beni* developed steadily as it tracked southwards and then southeastwards influenced by a mid-level ridge to the east and an approaching trough to the west. By 1800 UTC 28 January TC *Beni* reached hurricane intensity as a ragged eye appeared and the circulation became more organised. Maximum intensity of 57 m/s (110 knots) occurred around 0600 UTC 29 January while *Beni* was located about 200 kilometres north of the northwestern tip of New Caledonia and 450 kilometres west of Vila, Vanuatu.

Fig. 6 Tracks of tropical cyclones *Yolande*, *Ami*, *Cilla*, *Dovi*, *Eseta* and *Fili* in the central South Pacific. Symbols as in Fig. 3.



The mid-level trough that was accelerating TC *Beni* southeastwards also increased the shear weakening the cyclone as it passed between New Caledonia and Vanuatu on 30 January. A strengthening ridge to the south turned TC *Beni* through the south to the southwest around New Caledonia. The shear increased to 15-20 m/s exposing the low-level circulation and TC *Beni* was eventually downgraded to a tropical depression by 1200 UTC 31 December while located southwest of New Caledonia.

The remnants of TC *Beni* were steered to the west then northwest over the southern Coral Sea with periodic peripheral gales to the south which eventually affected southeastern Queensland by 2 February. Convection developed near the circulation due to warm air advection into the area and with gales recorded to the south of the centre *Beni* was again analysed as a tropical cyclone on 4 February about 200 kilometres east of Mackay. However, as the convection and gales became displaced from the centre *Beni* was downgraded within 12 hours before making landfall on 5 February.

During TC *Beni*'s slow movement near the Rennell Islands, gales caused significant damage to crops and to buildings constructed of semi-permanent materials. Heavy swell and coastal inundation over parts of Vanuatu and New Caledonia caused some damage but both countries were fortunate that *Beni* passed between them. Heavy rainfall was recorded over eastern Queensland as *Beni* made landfall, with some areas near Gladstone recording over 500 mm. One person died as a result of the flooding.

Cilla (Nadi) 25 – 30 January 2003

A low formed northwest of Fiji on 25 January within the monsoon trough that also spawned TC *Beni* further to the northwest. While *Beni* moved slowly south of the Solomon Islands, this low moved to the east-southeast. On 26 January the low passed to the north of Fiji with deep convection tending to be displaced from the circulation centre. The following day deep convection became more aligned with the circulation and the low was named TC *Cilla* (Fig. 6) while located some 450 kilometres east of Fiji. *Cilla* continued on its east-southeast track but during the 28 January began exhibiting some baroclinic features and the partial exposure of the low-level circulation suggested that the system was struggling against an unfavourable sheared environment. At 0000 UTC 29 January the circulation remained under deep convection and a banding pattern indicated gales were still occurring. However, convection subsequently weakened under increasing shear and *Cilla* was downgraded with mean winds below gale force at 1200 UTC some 600 kilometres west of Rarotonga (Cook Islands).

No damage is known to have resulted from *Cilla*.

Fiona (Perth) 3 – 11 February 2003

A tropical low that developed east of Christmas Island on 3-4 February was enhanced by an eastward propagating MJO pulse and reached tropical cyclone intensity on 5 February. Low vertical wind shear and strong upper divergence favoured subsequent intensification. TC *Fiona* (Fig. 3) moved westwards passing south of Christmas Island under the influence of a mid-level ridge to the south and peaked in intensity about 460 kilometres south-southeast of Cocos Islands on 9 February with mean winds estimated to be 49 m/s (95 knots) and gusts to 130 knots. Thereafter the system weakened due to cooler and drier air wrapping into the system from the south. The approach of a vigorous mid-latitude trough on 10 February eroded the mid-level ridge to the south and caused the system to recurve to the south-southeast on 11-12 February. An environment of increasing vertical wind shear caused dissipation by 13 February.

TC *Fiona* did not affect any island communities or cause any known damage.

Graham (Perth) 27 February – 1 March 2003

A low formed in a deep and persistent monsoon trough reaching tropical cyclone intensity about 300 kilometres to the west-northwest of Broome on 27 February. A northward movement of the upper-level ridge over the low and a strengthening of the low-level monsoon flow contributed to cyclogenesis. Although vertical wind shear remained low, TC *Graham* (Fig. 3) retained monsoonal characteristics throughout its lifetime. After initially moving east-southeast and intensifying slowly the system then turned south on 28 February as a deep trough moved into the Great Australian Bight. *Graham* reached maximum intensity of 21 m/s (40 knots) late on 28 February, before crossing the 80 Mile Beach 115 kilometres northeast of Wallal at about 2000 UTC 28 February and dissipating over land.

Significant rainfall exceeding 150 mm was recorded as *Graham* crossed the coast. Telfer and Mandora registered 24-hour falls of 175 mm and 164 mm respectively. A man was killed while attempting to cross a flooded creek near Fitzroy Crossing in the Kimberley.

Dovi (Nadi) February 5 – 12 2003

TC *Dovi* (Fig. 6) was another intense tropical cyclone in the South Pacific for the season, being one of the strongest systems on record east of the date-line.

A low formed within the South Pacific convergence zone on 5 February in the vicinity of the northern Cook Islands some 800 kilometres east-northeast of American Samoa. The system developed quite rapidly in an environment of low to moderate wind shear and favourable outflow to the north and east and was named TC *Dovi* at 0000 UTC 6 February. A mid-level ridge to the east steered *Dovi* to the south-southwest, a course that was sustained throughout much of its life. Being underneath the upper-level ridge and in low wind shear, the system intensified, reaching hurricane strength late on 6 February and developed a distinct eye the following day. TC *Dovi* reached a maximum intensity of 57 m/s (110 knots) at 1800 UTC 7 February while located some 600 kilometres south-southeast of American Samoa.

TC *Dovi*'s continued southward movement steered it away from the upper-level ridge into an environment of stronger shear and cooler SSTs that combined to weaken the system over subsequent days. By 1400 UTC 10 February the low-level circulation was displaced northwest of the deep convection and eventually *Dovi* became extratropical as it passed south of 25°S well west of the Cook Islands.

Apart from some damage to banana plantations on Palmerston Island (18°S 163°W) *Dovi* did not cause any significant damage.

Harriet (Perth) 28 February – 14 March 2003

A low which developed on 28 February southwest of Christmas Island on an active monsoon trough tracked steadily to the east-southeast under the influence of a low to mid-level ridge displaced to the north by TC *Graham*. However, development was constrained by moderate wind shear and the lingering effects of ex-TC *Graham* over continental Australia. Nevertheless near gale-force monsoon west to northwesterlies extended several hundred kilometres to the north of the low.

An increased organisation of deep convection on 4 March indicated cyclone intensity was reached but this was short lived as convection weakened the following day completely exposing the low-level centre. By this time the mid-level trough over Australia weakened and the strengthening mid-level ridge to the south and east steered the system to the south and then southwest towards the upper ridge. The reduced vertical wind shear allowed re-intensification to occur on 7-8 March and maximum intensity was reached at 1200 UTC 8 March. TC *Harriet* (Fig. 3) remained a small system with the radius to gales only reaching 70 kilometres at maximum intensity. *Harriet* weakened on 9 March under increasing shear and became captured by a large amplitude mid-latitude trough before accelerating to the south-southeast on 11 March. The low passed about 250 kilometres to the west of the southwest Capes of Western Australia near 0000 UTC 11 March and although not affecting the lower west coast directly, it did contribute to strong winds and high temperatures fanning one of the largest bushfire in recent decades in Western Australia near Walpole on the south coast.

Erica **(Brisbane and Nadi) 2 – 16 March 2003**

Long-lived TC *Erica* (Fig. 5) formed over Queensland but developed into the strongest tropical cyclone on record to affect New Caledonia since TC *Beti* which devastated the country in 1996. A monsoon low that had drifted over continental Australia during the second half of February finally emerged into the Coral Sea near the Whitsunday Islands early on 3 March. Gale to storm-force winds occurred on the coast around Cairns associated with a tight topographically induced pressure gradient on the northern side of the low.

Once offshore the low reached tropical cyclone intensity under decreasing wind shear, reaching maximum winds of 28 m/s (55 knots) at 1800 UTC 4 March. TC *Erica* changed from an easterly to a more northerly track as a low to mid-level ridge developed to the south and west. *Erica* encountered increasing wind shear and was downgraded to below gale-force intensity at 0000 UTC 7 March, temporarily reintensifying on 8 March as it moved to the northeast. A strengthening of the monsoon set the low on an easterly course south of the Solomon Islands for the next few days.

The low recommenced intensification on 10 March with a more favourable environment of low wind shear coinciding with an active MJO phase. A slow-moving upper trough over eastern Australia accelerated TC *Erica* to the southeast and it reached hurricane-force intensity at 1800 UTC 11 March, peaking at 59 m/s (115 knots) at 0600 UTC 13 March when located about 500 kilometres west-northwest of Noumea, New Caledonia (see Fig. 1(b)). The following day *Erica*'s core closely paralleled the southwest coast of the main island of New Caledonia, crossing over the southern end of the island. The system was rapidly accelerating toward the east-southeast and beginning to rapidly weaken under increasing shear. *Erica* underwent extratropical transition as it moved rapidly into the mid-latitudes passing well to the east of New Zealand on 16-17 March.

Erica's main impact was on the main island of New Caledonia, where the west coast and Noumea suffered extensive damage. Two people died and more than one hundred were injured. Maximum gusts of 67 m/s were recorded at Koniambo and Vavouto while Noumea recorded a 56 m/s gust. Some damage also occurred in the Cairns district of North Queensland when *Erica*, at pre-TC stage, moved offshore.

Eseta **(Nadi TCWC) 9 – 14 March 2003**

Two weak lows formed in the monsoon trough during an active MJO period in the vicinity of and northeast of Vanuatu. The environment remained favourable for several days and TC *Eseta* (Fig. 6) was named at 1800 UTC 10 March. *Eseta*'s initial south-southeasterly track swung more to the east-southeast as a mid-level ridge became located northeast of the system.

Eseta reached hurricane force by 0000 UTC 12 March having a ragged eye, located some 450 kilometres south-southeast of Fiji. At this time intensification was rapid and peak intensity of 52 m/s (95 knots) winds was reached only 18 hours later. The system was then moving at 10 m/s along the southern periphery of the mid-level ridge. Weakening was rapid as TC *Eseta* encountered strengthening wind shear during 13 March as a mid-latitude low developed north of New Zealand. *Eseta* passed just to the south of the main Tongan Island group causing significant damage to crops on the small island of Eua before completing its demise south of the Cook Islands. There was little other damage reported apart from flash flooding in western parts of Fiji as TC *Eseta* passed to the south.

Craig **(Darwin TCWC) 7 – 12 March 2003**

A low developed in a weak monsoon trough just west of Darwin on 7-8 March. Strengthening monsoon flow to the north, a reduction of vertical wind shear and increased upper-level outflow combined to improve organisation and tropical cyclone intensity was reached at 0300 UTC on 9 March when TC *Craig* (Fig. 4) was located west of the Tiwi Islands. Despite moving over the northeastern end of Melville Island, TC *Craig* intensified further as it moved eastwards as the mid-level ridge weakened to the south and a peak intensity of 28 m/s (55 knots) was reached at 0000 UTC 11 March prior to landfall at the base of the Cobourg Peninsula about 90 kilometres southeast of Cape Don. A sharp upper trough extended into the tropics to the southwest producing deep-layer westerly winds that accelerated TC *Craig* to 10-15 m/s as it skirted the northern coast. Despite weakening due to land interaction and increased shear *Craig* retained its structure with the strongest winds on the western flank of the 75 kilometre diameter core.

Craig entered the Gulf of Carpentaria near Nhulunbuy at about 2000 UTC 11 March and briefly re-intensified, although the strongly asymmetric wind and rainfall features persisted under the influence of the upper trough. Later on 12 March the system slowed and became near stationary near Kowanyama on encountering a strengthening low-level ridge over Cape York. TC *Craig* weakened rapidly under strong vertical wind shear and entrainment of deep dry air from the western flank of the upper trough over eastern Australia.

There were reports of mostly minor damage to vegetation along affected parts of the coastline, power lines were cut by falling trees and many roads were closed. Two cargo vessels were damaged in high seas off Melville Island and storm surges to 2.5 metres were estimated on Cobourg Peninsula and Goulbourn Island.

***Inigo* (Perth) 30 March – 8 April 2003**

Late in March a westward-moving low developed in the Banda Sea north of the upper ridge in an area of easterly shear. On 31 March, the low turned towards the southwest and moved over the eastern end of the island of Flores. Strong upper divergence enhanced convection near the system centre, causing heavy rainfall in Flores and Timor, but the development of a strong low-level circulation appeared to be impeded by interaction with the islands. Early on 1 April, the low moved into the Savu Sea and commenced a period of rapid intensification as northeasterly shear decreased slightly, reaching tropical cyclone intensity as TC *Inigo* (Fig. 3) at 0600 UTC.

The cyclone's development was arrested temporarily as it passed over Sumba, an island about 75 kilometres wide having a mountain range to 300 metres. However, once clear of the island it recommenced rapid intensification from 1800 UTC 1 April under a favourable environment of low wind shear and strong upper-level divergence. TC *Inigo* reached hurricane-force intensity at 1200 UTC 2 April and maximum intensity at 0600 UTC 4 April with maximum mean winds of 67 m/s (130 knots) (see Fig. 1(c)). The radius of gales was estimated at 280 kilometres and the the radius of hurricane-force winds at 55 kilometres. A persistent mid-level ridge off northern Australia continued to steer TC *Inigo* on its southwest course.

TC *Inigo* began to weaken later on 5-6 April, encountering increasing vertical wind shear with the approach of a mid-latitude trough. The weakening process accelerated on 6-7 April as TC *Inigo* recurved to the south-southeast toward the northwest Australian coast. TC *Inigo* weakened below gale-force intensity just prior to crossing the coast near Mardie station west of Karratha at 0500 UTC 8 April. Convection was limited to a small area near Mardie where 149 mm fell in two hours.

During its development phase, however, the low crossed over parts of eastern Indonesia producing heavy rain that caused landslides and flooding to Flores and neighbouring islands. At least 50 people were killed and many thousands of homes and buildings destroyed particularly on Flores Island. The towns of Ende and Larantuka were flooded and mudslides destroyed Ndona town. Seven villages were also flooded by the Oessao River in east Kupang district, West Timor.

Two Indonesian fishing vessels, with about five to eight crew each, were reported missing several days after Inigo passed over their position near 12°S.

***Fili* (Nadi and Wellington) 13 – 15 April 2003**

A low developed northeast of Fiji on 13 April in an area favoured by upper-level divergence. Convection became more organised as the system moved quite rapidly to the southeast across the northern islands of Tonga. Gale-force intensity was reached at 1200 UTC 14 April when the system was about 350 kilometres northeast of Tongatabu. TC *Fili* (Fig. 6) was accelerating to the south-southeast into an environment of strengthening northwesterly shear ahead of an upper-level trough and became extratropical on 15 April. No damage is known to have resulted from TC *Fili*.

***Gina* (Nadi) 4 – 9 June 2003**

TC *Gina* (Fig. 5) was an unusually late season severe tropical cyclone in the South Pacific. A low was first identified well to the northeast of Vanuatu on 3 June moving to the west-southwest under the influence of a mid-level ridge to the south. Favourable upper-level outflow assisted further development and cyclone intensity was reached at 0000 UTC 5 June near the Santa Cruz Islands some 900 kilometres east-southeast of Honiara. TC *Gina* steadily intensified and reached hurricane intensity on 7 June with an eye becoming more distinct. The peak intensity of 41 m/s (80 knots) was reached at 1200 UTC 7 June about 600 kilometres west-northwest of Port Vila, Vanuatu. Thereafter TC *Gina* moved into a region of stronger shear and cooler SSTs as a short wave trough caused it to recurve to the southeast. By 0000 UTC 9 June TC *Gina* was well sheared and gradually dissipated west of Vanuatu.

In its early stages of formation *Gina* was reported to have affected the island of Tikopia, which was devastated by TC *Zoe* in December. A yacht sailing from Queensland to Vanuatu foundered on 8 June and the crew was rescued by an Indonesian ship.

***Epi* (Port Moresby) 5 – 6 June 2003**

TC *Epi* (Fig. 5) was a very short-lived cyclone, lasting less than 12 hours over the Solomon Sea, having formed in an area of persistent convection that extended from Papua New Guinea toward the north of Fiji. Satellite imagery showed the development of a large curved band giving the indication of a rapidly developing cyclone at 0600 UTC 5 June. However, cloud features weakened around 1400 UTC when strong northeasterly upper-level winds developed over the centre. Initially TC *Epi* appeared to be moving slowly west. However, it paused and then moved eastwards indicating possible interaction with a strengthening low to the southeast that developed into TC *Gina* and contributed to *Epi*'s demise.

There was no known damage from TC *Epi*.

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