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The South Pacific and southeast Indian Ocean tropical cyclone season 2005-06

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Fifteen tropical cyclones (TCs) formed in the South Pacific and southeast Indian Ocean during the 2005-06 TC season. This total was below the long-term average of 19 and is the seventh consecutive year of below average TC occurrence, although numbers were about average in the Australian region. Significantly there were five intense TCs, all in the Australian region. TC *Monica* reached a peak intensity of 69 m s^{-1} (135 kn) mean winds, the equal highest on record in the Australian region, as it crossed the Northern Territory coast. Most notably, TC *Larry* peaked in intensity at 56 m s^{-1} (110 kn) prior to crossing the Queensland coast, devastating the area around Innisfail. There were another four TCs that crossed the Australian coast. All of these crossed the Pilbara coast of northwest Australia, having a significant economic impact on the industry-rich region.

The season occurred during a neutral El-Niño Southern Oscillation (ENSO) phase, whilst sea-surface temperatures (SSTs) remained warmer than normal over much of the region. Active phases of the intraseasonal Madden-Julian Oscillation (MJO) coincided with the development of eleven of the fifteen TC events.

Introduction

This paper provides a summary of TC activity in the southeast Indian Ocean (east of 90°E) and the South Pacific Ocean (west of 120°W) during the 2005-06 cyclone season. The material has been gathered from information provided by the Australian Tropical Cyclone Warning Centres (TCWCs) in Perth, Darwin and Brisbane, the Port Moresby TCWC and the Fiji Regional Specialised Meteorological Centre (RSMC) in Nadi.

In addition to summaries of individual TCs 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 (2006). All mean wind speeds are ten-minute averages unless otherwise stated.

Tropical cyclone occurrence

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

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Table 1. Tropical cyclones in the South Pacific and southeast Indian Oceans 2005-06.

	Low first identified			*Initial tropical cyclone phase*			
Name	*Date*	*Lat. °S*	*Long.*	*Date*	*Time (UTC)*	*Lat. °S*	*Long.*
Bertie-Alvin	18 Nov	4.5	95.5° E	19 Nov	0600	6.6	94.2° E
Clare	6 Jan	11.3	129.1°E	7 Jan	1200	14.5	123.2° E
Tam	6 Jan	15.0	178.5°W	12 Jan	0000	14.5	178.5°W
Urmil	13 Jan	12.8	175.8°W	13 Jan	1800	14.6	174.4°W
Daryl	17 Jan	15.3	125.6°E	18 Jan	1800	15.8	123.1°E
Jim	25 Jan	17.7	146.7°E	27 Jan	1800	17.6	148.9°E
Vaianu	9 Feb	15.0	179.5°W	11 Feb	1200	17.4	174.9°W
Kate	22 Feb	10.7	143.5°E	22 Feb	1800	11.3	145.0°E
Emma	25 Feb	12.0	114.4°E	27 Feb	1200	18.3	115.2° E
Larry	14 Mar	12.5	158.0°E	17 Mar	1800	16.3	158.0°E
Wati	15 Mar	14.0	175.5°W	19 Mar	0600	15.7	164.5°E
Floyd	18 Mar	11.5	118.9°E	21 Mar	0000	12.2	116.4°E
Glenda	22 Mar	14.0	128.5°E	27 Mar	0000	14.9	124.4°E
Hubert	2 Apr	14.5	115.2°E	5 Apr	1200	16.8	116.3°E
Monica	16 Apr	9.5	152.5°E	17 Apr	0000	12.3	150.5°E

		Maximum intensity				*End tropical cyclone phase*			
Name	*Date*	*Time (UTC)*	*Lat. °S*	*Long.*	*Mean wind* $m\ s^{-1}$ *(kn)*	*Date*	*Time (UTC)*	*Lat. °S*	*Long.*
Bertie-Alvin[1]	22 Nov	1200	11.8	90.5° E	51 (100)	26 Nov	0600	13.9	86.6° E
Clare	9 Jan	0600	19.7	117.1° E	39 (75)	10 Jan	1500	23.3	116.2° E
*Tam**	12 Jan	1800	16.1	174.9°W	23 (45)	14 Jan	0600	30.5	166.5°W
*Urmil**	14 Jan	1200	19.8	172.8°W	31 (60)	15 Jan	0000	23.8	171.3°W
Daryl	19 Jan	1800	17.0	121.1°E	28 (55)	22 Jan	0000	20.2	114.8°E
*Jim**	30 Jan	1200	18.1	163.7°E	41 (80)	1 Feb	0600	28.0	174.4°E
*Vaianu**	13 Feb	1200	21.7	176.9°W	36 (70)	16 Feb	0600	28.0	167.6°W
Kate	23 Feb	0000	11.2	145.8°E	26 (50)	23 Feb	0600	11.3	146.8°E
Emma	27 Feb	1800	19.4	115.5°E	21 (40)	28 Feb	0300	21.3	115.9° E
Larry	19 Mar	1200	17.5	148.3°E	56 (110)	20 Mar	1200	18.7	142.2°E
Wati	23 Mar	1800	20.3	157.1°E	44 (85)	26 Mar	0000	34.0	166.6°E
Floyd	24 Mar	0000	15.1	108.2°E	54 (105)	26 Mar	1200	19.8	112.2°E
Glenda	28 Mar	0600	16.0	121.1°E	57 (110)	30 Mar	2100	22.7	115.1°E
Hubert	6 Apr	1200	18.8	115.3°E	26 (50)	7 Apr	1200	21.3	115.7°E
Monica	23 Apr	0600	11.4	137.4°E	69 (135)	24 Apr	1800	12.6	132.9°E

1 TC *Bertie* was renamed *Alvin* when it crossed 90°E.

* The end of tropical cyclone phase for *Tam, Jim, Urmil* and *Vaianu* is given when they became extratropical even though they still produced gale force winds.

activity in the 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.

There were a total of 15 TCs in the combined southeast Indian and South Pacific basins during the full year from July 2005 to June 2006. This was below the long-term average (1970-71 to 2004-05) of 19.5. While the number of TCs in the Australian region (12) was close to the long-term average of 13.0, there were only five TCs in the South Pacific (average is 8.7). In the eastern Australian region five TCs were observed (long-term average 5.2), the first time five or more TCs have occurred in a season since 1999. Of particular significance is that, of the fifteen systems observed in the region as a whole, nine became severe, having winds of at least 33 $m\ s^{-1}$, five of these were intense, having

Table 2. Frequency of occurrence of tropical cyclones within southern hemisphere basins for season 2005-06. Long-term means from 1970-71 to 2004-05 are shown in parentheses. STC indicates severe tropical cyclones (maximum wind speed >33 m s^{-1}) and ITC indicates intense tropical cyclones (maximum wind speed >44 m s^{-1}).

	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	6 (12)	8 (8.5)	5 (5.2)	12 (13.0)	5 (8.7)	15 (19.5)	20 (29.2)
STC	4 (5.8)	5 (4.3)	4 (2.1)	8 (6.4)	3 (4.1)	9	11 (14.8)
ITC	2 (2.5)	4 (1.8)	2 (0.7)	5 (2.5)	0 (1.6)	5	7 (6.2)
TC days	28 (58.0)	28 (32.8)	17 (18)	42 (50.8)	15 (32)	64	92 (141.5)
STC days	8 (20.0)	11 (10.6)	11 (4.6)	21 (15.2)	5 (10.7)	25	33 (46)
ITC days	3 (4.7)	7 (2.5)	4 (1.0)	10 (3.5)	0 (2.5)	10	13 (10.7)

winds of at least 44 m s^{-1}, and all of these occurred in the Australian region. Furthermore, two of these, TCs *Larry* and *Monica* (Figs 1(a), 1(c), 5), crossed the coast as intense systems causing significant damage (see following section). TC *Monica* reached a maximum intensity of 69 m s^{-1}, making it the equal strongest cyclone (with TC *Orson* (1989)) since Australian records commenced. Four TCs, *Clare*, *Emma*, *Glenda* and *Hubert* (Fig. 4), crossed the northwest coast of Australia.

An indicator of intensity and longevity is the TC day, that is the total number of days when one or more TCs were active. There were 42 TC days in the 2005-06 season in the Australian region which was below the average of 50.8, and just 15 TC days east of 160°E, less than half the average of 32.0. Significantly, in the Australian region there were 21 severe TC (STC) days (days when there were one or more severe TCs) and 10 intense TC days (days when there were one or more intense TCs), considerably more than the averages of 15.2 and 3.5, respectively. So whereas one would expect to have an intense TC on about eight per cent of all TC days on average, the 2005-06 season saw a ratio of 24 per cent (10 of 42 days).

Of all the TCs, only *Bertie-Alvin* (November) (Fig. 3) occurred outside of the January to April period. Four TCs occurred between 7-22 January and four occurred between 17-30 March. The longest lasting TC was *Monica* (7.5 days), while TCs *Kate* and *Emma* (Figs 5, 4) lasted just 12 and 15 hours, respectively, at tropical cyclone intensity.

Impacts

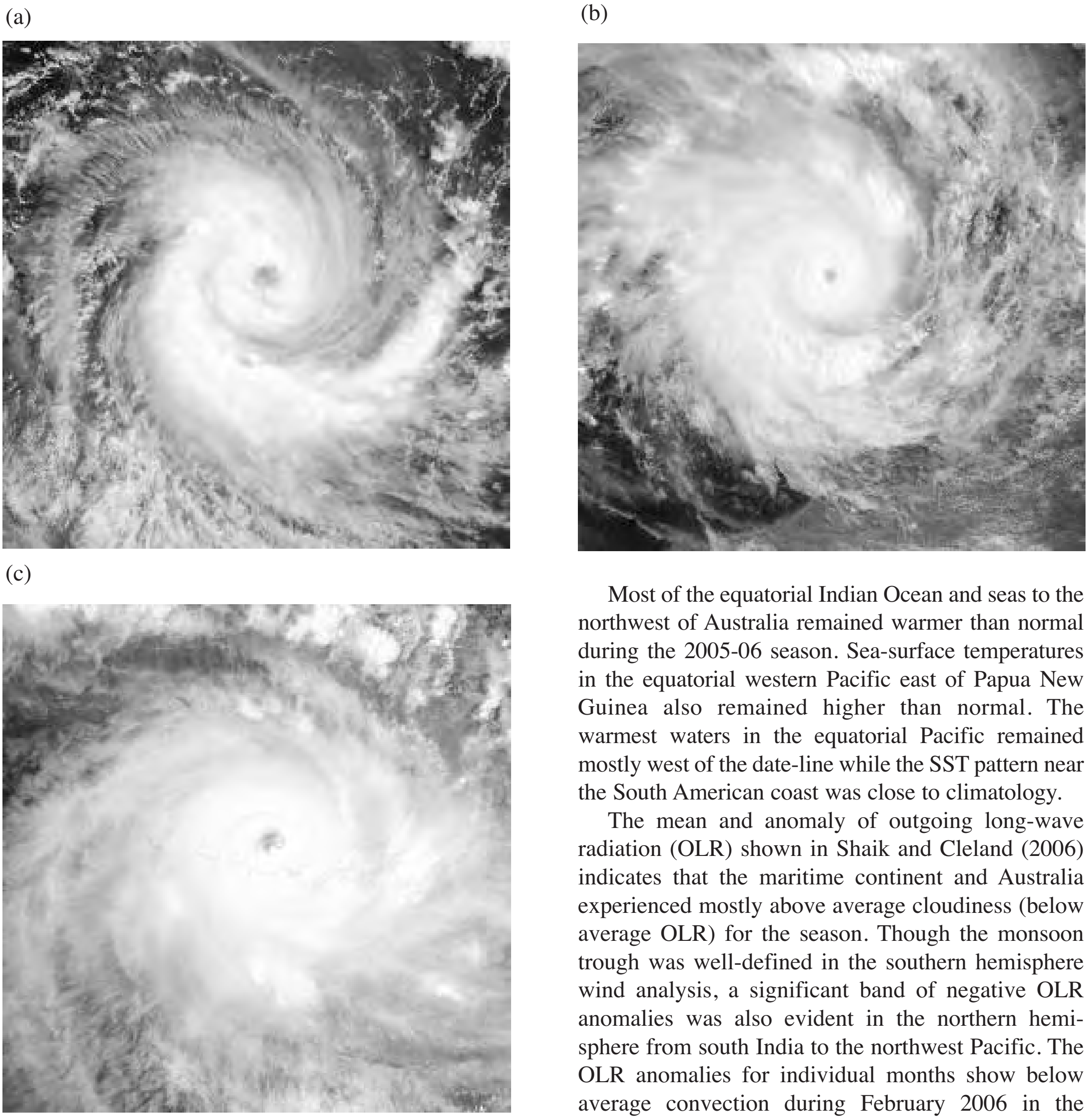
TC *Larry* was the first severe tropical cyclone to cross near a populated section of the east coast of Queensland since TC *Rona* in 1999. Extensive damage to infrastructure and crops in the area around Innisfail was estimated at upwards of $500 million. About 10 000 houses were damaged with the worst town affected being Silkwood where 99 per cent of the houses were damaged. Power was cut to the region owing to major transmission lines being downed. Flooding disrupted road and rail access for several days. Fortunately there were no fatalities or serious injuries.

TC *Monica* caused widespread tree damage and moderate damage to infrastructure along the Arnhem Land coast. Maningrida community, just 35 km east of the coastal crossing point, received substantial damage with several houses damaged by fallen trees. The cyclone weakened rapidly as it moved inland, however Jabiru still experienced some damage, mostly due to fallen trees. As the low tracked inland, heavy rainfall caused major flooding in the Adelaide River catchment, as well as moderate flooding in the Daly, Katherine and Victoria River catchments.

Although TCs *Clare* and *Glenda* (Figs 4, 1(b)) caused mean winds in excess of 33 m s^{-1} at the northwest Australian towns of Onslow and Dampier, respectively, only minor structural damage occurred. During TC *Clare*, power and telecommunications were disrupted in many areas of the Pilbara and flooding cut road access for an extended period. Overall, the succession of TCs near the northwest coastline (*Clare*, *Daryl*, *Emma*, *Floyd*, *Glenda* and *Hubert* (Fig. 4)) caused lost production from the oil, gas and mining industries as well as evacuations of offshore installations costing hundreds of millions of dollars.

During the early stages of TC *Kate* wave action demolished a jetty and caused beach erosion in the Torres Strait Islands. Heavy rainfall associated with TC *Jim* (Fig. 5) caused flooding in north Queensland, the Solomon Islands, New Caledonia and Fiji. The remainder of the observed TCs produced no known direct impacts on island communities in the South Pacific.

Fig. 1 **Visible satellite images of: (a) TC *Larry* 0025 UTC 19 March 2006 (Terra satellite); (b) TC *Glenda* 0200 UTC 28 March 2006 (Terra satellite); and (c) TC *Monica* 0430 UTC 24 April 2006 (Aqua satellite). Images courtesy of NASA.**



Broadscale features

The seasonally averaged diagnostics generally supported a neutral ENSO phase although there were some La Niña-like characteristics in some indicators during the season. Large fluctuations in the monthly SOI were evident, with the values oscillating between –3 and +15, whilst the mean SOI for the season was +6.6. The five-month centred mean of SOI remained between +1 and +9.

Most of the equatorial Indian Ocean and seas to the northwest of Australia remained warmer than normal during the 2005-06 season. Sea-surface temperatures in the equatorial western Pacific east of Papua New Guinea also remained higher than normal. The warmest waters in the equatorial Pacific remained mostly west of the date-line while the SST pattern near the South American coast was close to climatology.

The mean and anomaly of outgoing long-wave radiation (OLR) shown in Shaik and Cleland (2006) indicates that the maritime continent and Australia experienced mostly above average cloudiness (below average OLR) for the season. Though the monsoon trough was well-defined in the southern hemisphere wind analysis, a significant band of negative OLR anomalies was also evident in the northern hemisphere from south India to the northwest Pacific. The OLR anomalies for individual months show below average convection during February 2006 in the southern hemisphere indicating weak monsoon conditions. Each other month of the season saw negative OLR anomalies (enhanced cloudiness) over large parts of northern Australia.

Velocity potential analyses showed good vertical alignment of axes of maximum low-level convergence and upper-level divergence, indicating well-organised upmotion of a vigorous Hadley circulation in the western Pacific. The position of both lower and upper-level axes and the centres of maximum low-level convergence and upper-level divergence were close to their respective climatological mean latitudes and close to the peak convection area during the season.

Seasonally averaged MSLP showed weak positive pressure anomalies over the RSMC region as the subtropical ridges in both hemispheres were close to their respective mean locations. The weak MSLP anomalies over the region were consistent with the near-neutral ENSO conditions during the season.

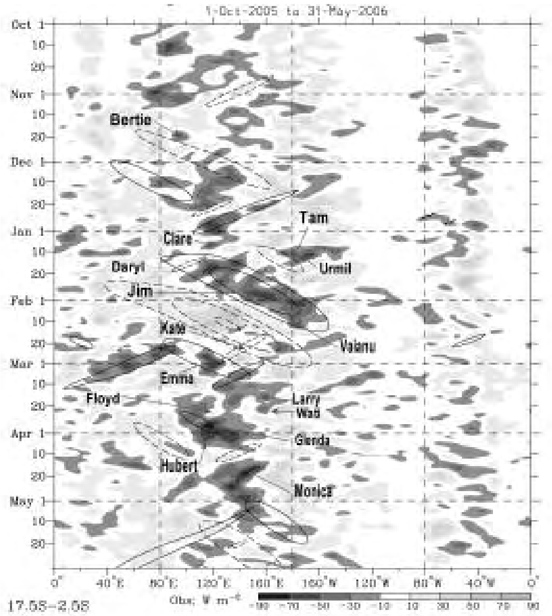
Shaik and Cleland (2006) discuss seasonal features in further detail.

Intraseasonal modulation

Intraseasonal variability can be identified from time-longitude plots of OLR, 200 hPa velocity potential and sea-level pressure anomaly as shown in Shaik and Cleland (2006). Figure 2 shows a time versus longitude plot of filtered outgoing long-wave radiation (OLR) anomalies overlain by contours indicating MJO periods (sloping down to the right) and Equatorial Rossby (ER) waves (number 1) (sloping down to the left). The plot indicates five active phases of the MJO progressing through the Darwin RSMC. The first phase (weak and incoherent) occurred in early to mid-December 2005, with a period of about 40-45 days. The first major active phase occurred from mid-January to mid-February, with subsequent events in late February to March, late March to early April and during May. The period of these events remained close to 30-35 days.

About mid-October 2005, convective activity increased around the near-equatorial central Indian Ocean. The area of enhanced convection extended eastward, so that most central Darwin RSMC longitudes experienced above average convection during much of November, and TC *Bertie* developed during this period. TCs *Clare*, *Daryl*, *Jim* and *Vaianu* can be associated with the active MJO phase that progressed across the region from mid-January to mid-February. TC *Emma* developed during the progression of the next active phase during late February to early March, while TCs *Floyd*, *Glenda* and *Hubert* occurred during the active phase from late March to early April. Although not shown on the OLR anomalies, TC *Monica* developed when an MJO episode entered the Australian region in late April. The development of TCs *Larry* and *Wati* came at the very end of the March MJO event. Active phases of the MJO coincided with the development of eleven of the fifteen cyclone events, whereas the other four, TCs *Bertie*, *Tam*, *Urmil* and *Kate* appeared not to be associated with an identified MJO or ER wave episode. TCs *Tam* and *Urmil* developed in the South Pacific ITCZ while TC *Kate* developed from a weak tropical low embedded in the monsoon trough.

Fig. 2 **Filtered anomalies of outgoing long-wave radiation, averaged over latitudes 2.5°S to 17.5°S for November 2005 to June 2006. 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.**



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. TC *Glenda* had a remarkable 24-hour and 48-hour accuracy of just 45 km and 61 km respectively while TCs *Clare*, *Kate* and *Monica* also had 24-hour accuracy of less than 100 km. Overall the average 24-hour accuracy of 111 kilometres surpasses the 2003-2004 value of 118 km (McInerney et al. 2006).

Tropical cyclones in the South Pacific and southeast Indian Oceans 2005-06

TC *Bertie* (Perth) 19-26 November 2005 (Fig. 3)

A tropical low developed within the monsoon trough on 18 November. The low steadily increased in organisation and was named TC *Bertie* at 0600 UTC 19 November over open waters near 6°S 94°E. For the

Table 3. Position forecast verification statistics for official warnings issued by relevant warning centres. Forecast positions are verified against the official best track.

Forecast lead time	*0 h*		*12 h*		*24h*		*48 h*	
Name	*Accuracy (km)*	*Number*	*Accuracy (km)*	*Number*	*Accuracy (km)*	*Number*	*Accuracy (km)*	*Number*
Bertie-Alvin	48	17	76	17	96	16	143	13
Clare	24	16	56	12	79	12	141	6
Tam	29	16	193	5	119	4	-	-
Urmil	29	8	79	9	125	7	-	-
Daryl	33	23	74	20	93	18	195	10
Jim (Bne)	37	11	110	8	157	7	310	3
Jim (Fiji)	9	8	87	4	-	-	-	-
Vaianu	33	19	65	12	118	10	268	3
Kate	64	8	134	6	85	4	-	-
Emma	71	10	152	9	254	9	482	2
Larry	35	16	76	14	112	12	182	8
Wati (Bne)	18	18	85	16	184	14	400	10
Wati (Fiji)	47	18	-	-	-	-	-	-
Floyd	29	32	72	31	120	29	253	18
Glenda	19	23	50	20	45	18	61	8
Hubert	31	17	82	15	116	15	174	5
Monica	18	38	57	37	86	37	153	294
Total		298		235		209		115
Weighted mean	31		78		111		201	

next couple of days TC *Bertie* tracked to the south-southwest around the western periphery of a low to mid-level anticyclone centred between northwestern Australia and Sumatra. TC *Bertie* intensified from 0000 UTC 20 November as it moved into an area of low vertical wind shear, reaching maximum intensity of 51 m s^{-1} (100 kn) between 1200 UTC 22 November and 1200 UTC 23 November. At this time TC *Bertie* was moving to the south, just east of the 90°E border.

Weakening began late on 23 November prior to crossing west of 90°E into La Reunion's area of responsibility and being renamed TC *Alvin*. The cyclone then took a west-northwest track into an area of high vertical wind shear and consequently weakened rapidly after 0000 UTC on 25 November. There was no known impact from TC *Bertie*.

TC *Tam* (Fiji) 6-15 January 2006 (Fig. 6)

TC *Tam* was first identified as a tropical low approximately 400 km north-northeast of Fiji as early as 6 January 2006. By 0600 UTC 12 January the low was upgraded to tropical cyclone status and named TC *Tam* by RSMC Nadi; its centre roughly 650 km northeast of Fiji, moving east at 8 m s^{-1}. TC *Tam* was steered to the southeast by deep environmental northwesterlies while deep convection formed a cold overcast over the low-level circulation centre. TC *Tam* reached a peak intensity of 23 m s^{-1} (45 kn) at 0000 UTC 13 January (near 17.0°S/173.2°W) approximately 400 km southwest of Pago Pago, American Samoa.

Thereafter, TC *Tam* continued to maintain deep convection close to the low-level circulation centre despite vertical shear increasing over the system. By 1200 UTC 13 January, TC *Tam*'s convective tops were being blown off to the southeast by the increasing upper-level wind shear. Decreasing sea-surface temperatures, strong upper-level shear and overall acceleration to the south resulted in TC *Tam* being declared extratropical approximately 1600 km southwest of Rarotonga by 1200 UTC 14 November. There was no known damaging impact from TC *Tam*.

TC *Clare* (Perth) 7-10 January 2006 (Fig. 4)

A tropical low formed in the Arafura Sea on 4 January then moved slowly westward into the Timor Sea. The track became more west-southwest and the low was upgraded to cyclone intensity at 1200 UTC 7 January when Browse Island recorded gales. TC *Clare* then intensified further reaching peak intensity at 39 m s^{-1} (75 kn) at 0600 UTC 9 January.

Fig. 3 Track of TC *Bertie-Alvin*, in the Indian Ocean 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.

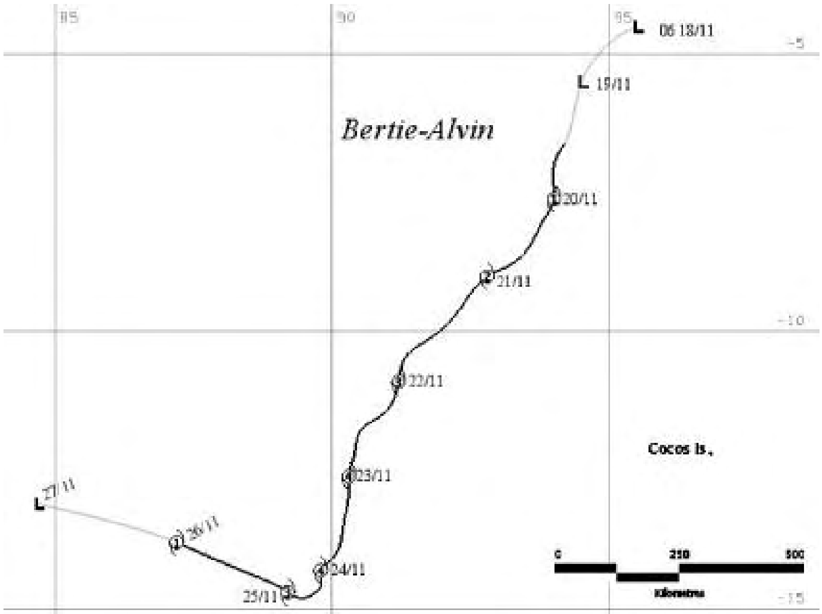
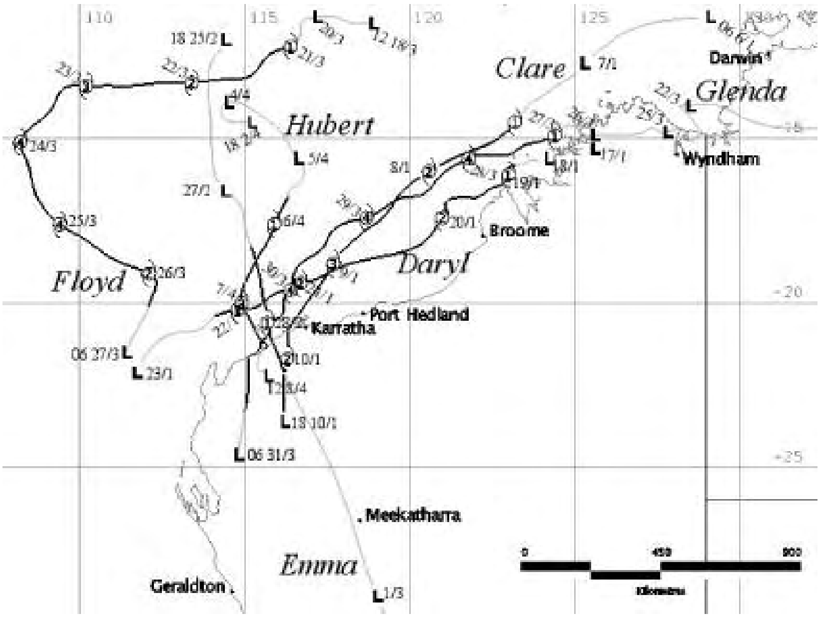


Fig. 4 Tracks of TCs *Clare*, *Daryl*, *Emma*, *Floyd*, *Glenda* and *Hubert* in the northwestern Australian region. Symbols as in Fig. 3.



The track became increasingly south-southwesterly as *Clare* approached the Pilbara coast. Radar and infrared imagery showed weakening prior to crossing the Pilbara coast between Dampier and Mardie early on 10 January. Slightly cooler sea-surface temperatures of 28°C may have contributed to the weakening prior to coastal crossing. Dampier experienced very destructive winds for a period as the eye wall passed over the town. Downed power lines and flooding disrupted power and telecommunication to many parts of the Pilbara including Dampier and Karratha.

Following landfall, the cyclone weakened rapidly as it continued moving further inland through the western Pilbara and northern Gascoyne. The remnant low continued to move south producing heavy rain and some flooding through the Gascoyne and inland parts of the Southwest Land Division in the following days.

TC *Urmil* (Fiji) 13-15 January 2006 (Fig. 6)

A tropical low was first identified at 1800 UTC 13 January approximately 400 km west of Pago Pago, American Samoa moving to the southeast at 5 m s^{-1}. TC *Tam* was located to the southeast of the low at this time and moving rapidly to the southeast and weakening. The system rapidly intensified in TC *Tam*'s wake under favourable conditions.

By 2100 UTC on 13 January, the tropical low had achieved cyclone status and was named TC *Urmil* approximately 370 km west-southwest of Pago Pago as it accelerated to the southeast. TC *Urmil* reached peak intensity at 1200 UTC on 14 January about 310 km northeast of Tongatapu. However, the TC was running into ever-increasing vertical shear and was soon losing its organisation with cloud tops near its centre decreasing in spatial extent and warming significantly. At 0000 UTC 15 January, TC *Urmil*'s deep convection was displaced about half a degree to the south of the exposed low-level circulation centre. The cyclone was subsequently downgraded to an extratropical depression six hours later approximately 1200 km west-southwest of Rarotonga in the Cook Islands. There was no known damaging impact from TC *Urmil*.

TC *Daryl* (Perth) 19-23 January 2006 (Fig. 4)

A weak surface low over the north Kimberley drifted westwards moving off the coast near Kuri Bay at 0000 UTC 18 January and reached tropical cyclone intensity north of Cape Leveque some eighteen hours later. TC *Daryl* moved towards the southwest guided along the northwestern periphery of a mid-level ridge centred over Australia. TC *Daryl*'s intensity remained fairly constant for the next couple of days as it moved in a west-southwesterly direction parallel to the Western Australian coastline.

TC *Daryl* peaked in intensity at 28 m s^{-1} (55 kn) at 1800 UTC 19 November when convection increased in the western and northern quadrants. However ongoing moderate easterly shear and relatively cool SSTs of less than 28°C following the recent passage of TC *Clare* arrested any further intensification. On 21 January convection decreased and the upper and lower-level circulations began to decouple as TC *Daryl* continued to move west-southwestward parallel to the coastline. Early on 22 January the low-level circulation centre was fully exposed with cycling deep convection located along the western periphery of the system and TC *Daryl* weakened below cyclone intensity at 0600 UTC. Although there was no direct impact to coastal areas, the offshore oil and gas industry suffered economic losses associated with reduced production and evacuations.

TC *Jim* (Brisbane/Fiji) 28 January-1 February 2006 (Fig. 5)

TC *Jim* was named at 0000 UTC 28 January when 370 km east of Innisfail and moving further out to sea. As TC *Jim* continued to deepen and move offshore in a general east to east northeasterly direction, sporadic gale force winds were experienced well to the south of the centre in the Whitsunday Islands region of Queensland. Lihou Reef recorded easterly gales as TC *Jim* passed to the north during 28 January.

TC *Jim* continued to intensify in a low shear environment and reached hurricane force intensity before moving into the Fiji area of responsibility. The peak intensity of 41 m s^{-1} (80 kn) was attained about 780 km northwest of Noumea, New Caledonia, at 0600 UTC 30 January. This intensity was maintained for a further 24 hours as TC *Jim* moved to the east-southeast at 10 m s^{-1}. TC *Jim* turned to the southeast, passing approximately 175 km parallel to the northeastern coastline of New Caledonia and gradually weakened as upper-level shear increased over the cyclone. Heavy rainfall associated with TC *Jim* caused flooding extending to north Queensland, the Solomon Islands, New Caledonia and Fiji.

TC *Vaianu* (Fiji) 11 February-16 February 2006 (Fig. 6)

Early in February an active area of convergence developed across the southeast Pacific from the Solomon Islands through to Tonga. On 9 February an eastward-moving tropical low developed approximately 150 km north-northeast of Vanua Levu. At 1200 UTC 11 February, the low reached tropical cyclone intensity and was named TC *Vaianu* approximately 165 km southwest of Niuatoputapu. By this stage the system had swung back to a southwesterly path being steered by a mid-level ridge to the southeast. The cyclone continued to track to the southwest over the open ocean to the west of the Tongan group of islands while slowly strengthening as the upper-level wind shear relaxed.

Fig. 5 **Tracks of TCs *Jim*, *Kate*, *Larry* and *Monica* in the northeastern Australian region. Symbols as in Fig. 3.**

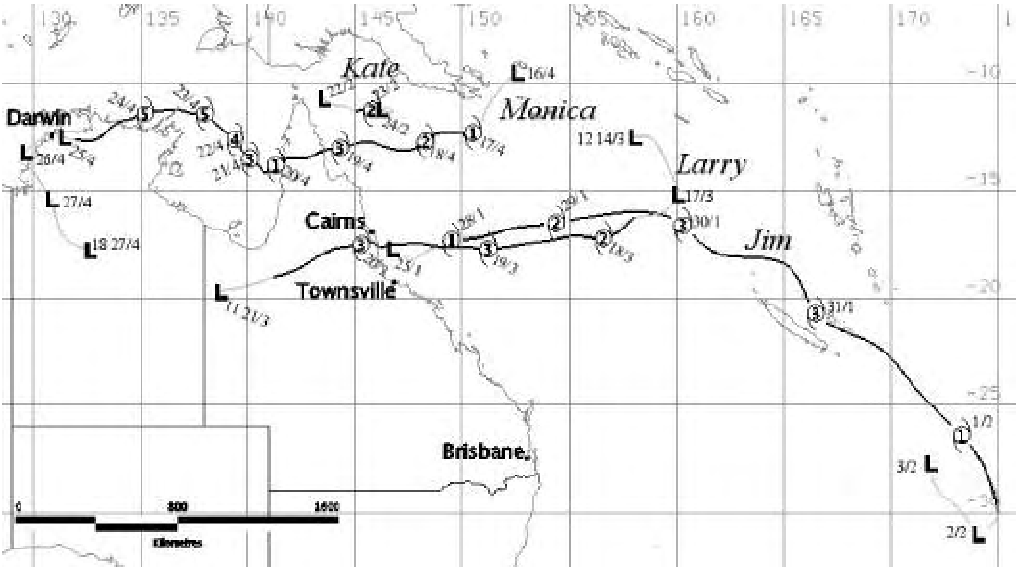
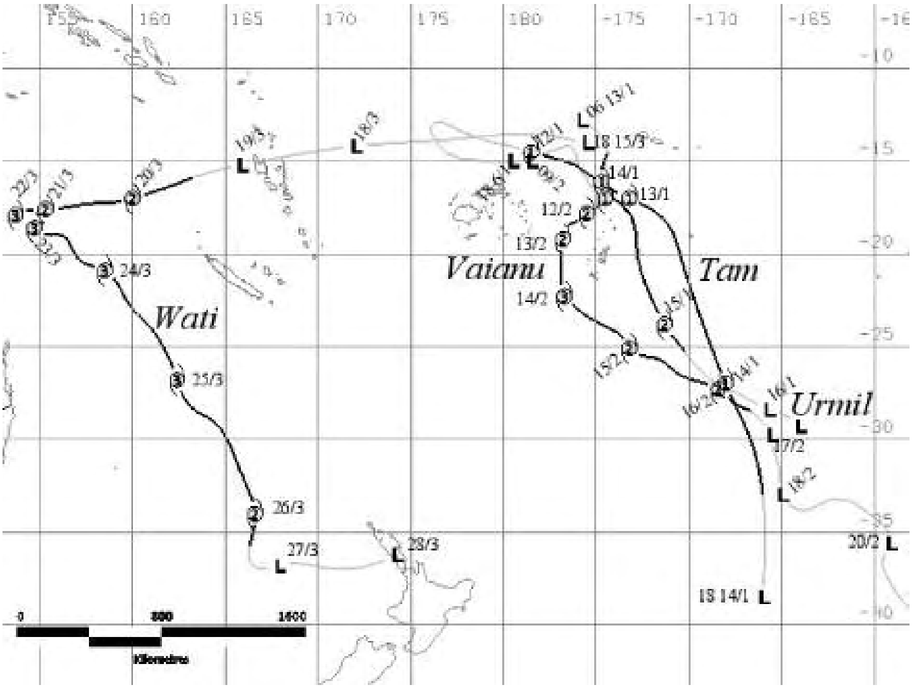


Fig. 6 **Tracks of TCs *Tam*, *Urmil* and *Vaianu* and *Wati* in the South Pacific region. Symbols as in Fig. 3.**



Peak intensity of 36 m s^{-1} (70 kn) was reached at 1200 UTC 13 February approximately 205 km west-southwest of Tongatapu, and this intensity was sustained for a further 24 hours as TC *Vaianu* swung onto a southward track midway between Ono-i-lau (in Fiji's Lau Archipelago) and Tongatapu.

The cyclone eventually recurved to the south-east, being steered by a mid-level ridge located to the northeast and by a broad 250 hPa trough to the west. The storm gradually weakened due to increasing wind shear and cooler SSTs. TC *Vaianu* lost TC status whilst undergoing extratropical transition about 1165 km southwest of Rarotonga at 1200 UTC 16 February, but remained a powerful low pressure system for several days thereafter while tracking generally to the east over open ocean. There was no known damaging impact from TC *Vaianu*.

TC *Kate* (Brisbane) 22-24 February 2006 (Fig. 5)

TC *Kate* was a short-lived cyclone in the far northwest Coral Sea, originating from a weak tropical low embedded in the monsoon trough near Torres Strait. On 22 February, the low rapidly intensified as it tracked eastwards reaching tropical cyclone intensity at 1800 UTC. TC *Kate* peaked at 26 m s^{-1} (50 kn) at 0000 UTC 23 February but weakened soon after as the low-level circulation remained stationary while the deep convection moved eastwards. During the early stages of TC *Kate*'s existence, wave action washed away a jetty and caused beach erosion in the Torres Strait Islands.

TC *Emma* (Perth) 27-28 February 2006 (Fig. 4)

A low developed within an active monsoon trough in the vicinity of 12°S, 114°E, well to the north of Exmouth on 25 February. On 27 February convection became more sustained to the south and east but quite removed from the centre. The system tracked to the south-southeast and attained TC intensity at 1200 UTC 27 February. It then crossed the Pilbara coast near Mardie the following morning and weakened below TC intensity by early afternoon.

The low then accelerated to the south-southeast passing near Esperance on the south coast at 1300 UTC 1 March. Despite a ragged satellite signature and with convection well to the south, the pressure fell to 988 hPa at Meekatharra and 993 hPa at Esperance, suggesting minimal weakening of the circulation. Surface friction and stabilisation of the boundary layer are thought to have kept surface winds below gale force. Heavy rainfall occurred as the remnant low moved across inland Western Australia.

TC *Larry* (Brisbane) 17-20 March 2006 (Figs 1(a), 5)

A tropical low developed over the eastern Coral Sea and reached TC intensity during the early hours of 18 March and proceeded on a general westerly course towards the Queensland coast. TC *Larry* rapidly intensified in the following 48 hours reaching hurricane force intensity at 1200 UTC 18 March and peaking at 56 m s^{-1} (110 kn) at 1200 UTC 19 March as it moved steadily westwards towards the coast.

The eye of the cyclone made landfall near Innisfail around daybreak on Monday 20 March. A marked variation in wind gusts was observed, both in a spatial sense and across elevated terrain. This was clearly evidenced by varying levels of damage across relatively small distances. TC *Larry* remained at hurricane force intensity as it moved over the Atherton Tablelands. It maintained TC strength until 1400 UTC 21 March.

Extensive damage to infrastructure and crops in the area around Innisfail was estimated at upwards of $500 million. About 10 000 houses were damaged. Flooding disrupted road and rail access for several days. For more details about TC *Larry* see Bureau of Meteorology (2007).

TC *Wati* (Fiji/Brisbane) 19-25 March 2006 (Fig. 6)

A westward-moving tropical low was first identified east of the northern tip of Vanuatu on 17 March. The low reached TC intensity at 1200 UTC 19 March being named TC *Wati* by the RSMC Nadi about 580 km north-northwest of Noumea, New Caledonia.

As TC *Larry* weakened overland, TC *Wati*'s radial outflow improved and the system intensified under weak vertical wind shear. By 1800 UTC 21 March, the cyclone reached hurricane force intensity about 800 km east of Innisfail. Although Queensland communities were preparing for a second major cyclone impact within a week, a major short-wave trough extending northwards from near New Zealand induced a recurvature in TC *Wati*'s track toward the southeast parallel to the Queensland coast. Peak intensity of 44 m s^{-1} (85 kn) occurred at 1800 UTC 23 March approximately 900 km east of Proserpine. Soon afterward, TC *Wati* commenced extratropical transition due to increasing vertical wind shear. The cyclone accelerated to the southeast as it slowly lost both its embedded centre and its convective organisation due to the increasing northwesterly wind shear.

By 0600 UTC 25 March TC *Wati* had undergone complete extratropical transition approximately 900 km east of Cape Moreton. The storm remained a powerful 988 hPa extratropical system at this time with winds estimated to 26 m s^{-1} (50 kn) and then passed as close as 300 km to the west-southwest of Norfolk

Island before sliding southwards and then almost due east over the North Island of New Zealand. The system was finally absorbed in the mid-latitude westerlies to the east of New Zealand on 28 March. There was no known damaging impact from TC *Wati*.

TC *Floyd* (Perth) 21-27 March 2006 (Fig. 4)

A tropical low developed on 18 March south of the Indonesian island of Sumba and moved to the west-southwest, gradually strengthening. The low is estimated to have reached TC intensity around 2100 UTC on 20 March while located about 875 km west-northwest of Cape Leveque. Moderate easterly shear on 21 March gradually eased and TC *Floyd* developed rapidly later on 22 March, reaching hurricane force intensity at 0000 UTC 23 March while located about 1090 km north-northwest of Exmouth.

TC *Floyd* reached maximum intensity of 54 m s^{-1} (105 kn) at 0000 UTC 24 March, approximately 1000 km northwest of Exmouth. The cyclone at the time was making a turn to the south due to the approach of a mid-latitude trough. TC *Floyd* slowly weakened as it moved on a southeasterly track towards the northwestern coastline of Western Australia. Microwave imagery showed that *Floyd* underwent an eyewall replacement cycle on the 24th, culminating around 0000 UTC 25 March. The storm reached a point about 300 km northwest of Exmouth at 1200 UTC 26 March, then encountered cooler SSTs and strong upper-level winds and consequently weakened to below TC intensity six hours later.

TC *Glenda* (Perth) 27-31 March 2006 (Figs 4, 1(b))

A weak low developed in the Gulf of Carpentaria during the middle of March and slowly progressed westwards over the Northern Territory. On 24 March it moved across the Joseph Bonaparte Gulf north of Wyndham, then accelerated across the Kimberley overnight. On 26 March vertical wind shear eased and by about 1200 UTC the system moved off the coast and developed rapidly. TC intensity was attained at 0000 UTC 27 March.

Glenda developed rapidly reaching peak intensity of 57 m s^{-1} (110 kn) at 0600 UTC 28 March about 230 km northwest of Broome. The strongest convection was on the western side of the system, a pattern that continued throughout much of TC *Glenda*'s lifetime. Eye definition diminished overnight due to an increase in easterly shear though an eye returned on the 29th, albeit weaker, and was short lived becoming obscured overnight. Winds on the southern side of TC *Glenda* were enhanced by a synoptic-scale easterly surge resulting from a strong ridge to the south of Western Australia. By this stage TC *Glenda* was moving to the southwest towards the west Pilbara coast.

TC *Glenda*'s radar signature became weaker on the 30th indicating some weakening prior to making landfall at 1400 UTC on 30 March near Onslow. Trees were uprooted and power lines brought down but damage to property was generally of a minor nature. TC *Glenda* rapidly weakened as it moved further inland and decreased below TC intensity by 0000 UTC 31 March. Floodwaters cut road access for several days across the region.

TC *Hubert* (Perth) 5-7 April 2006 (Fig. 4)

A low formed well north of the Pilbara coast early in April along the monsoon trough but was subject to moderate easterly shear. On 5 April wind shear began to ease sufficiently and the system developed to TC intensity at 1200 UTC. A strong ridge south of Western Australia combined with the system to cause strong easterly winds across the Pilbara and accentuated winds in the southern semicircle of TC *Hubert*.

TC *Hubert* reached peak intensity of 26 m s^{-1} (50 kn) at 1200 UTC 6 April as it moved southwards towards the west Pilbara coast. Visible satellite imagery showed the low-level circulation centre moving under an increasing area of deep convection. TC *Hubert* crossed the Pilbara coast just west of Mardie at 1200 UTC on 7 March but no damage was reported.

TC *Monica* (Brisbane) 17-25 April 2006 (Figs 5, 1(c))

A tropical low was analysed in the far northern Coral Sea on 16 April. The low moved towards the southwest under the influence of a weakening ridge to the south, and reached TC intensity on 17 April as it began a more westward track toward Cape York Peninsula. The system intensified to hurricane force strength before making landfall 40 km south of Lockhart River on the afternoon of 19 April. The system weakened over land, before entering the Gulf of Carpentaria as a weak TC early the following day.

TC *Monica* began to intensify rapidly as it tracked to the northwest over the Gulf of Carpentaria reaching 56 m s^{-1} (110 kn) intensity at 0600 UTC 22 April then attaining maximum intensity of 69 m s^{-1} (135 kn) 24 hours later about 120 km to the northeast of Nhulunbuy. This equalled the highest intensity attained by any cyclone in the Australian region, held by TC Orson (1989). At this time, *Monica* had an eye diameter of around 30 km but the effects of the very destructive core were confined close to the eye wall. The Cape Wessel AWS recorded a mean wind of 36 m s^{-1} (70 kn) prior to failing as TC *Monica*'s maximum winds approached to an estimated 15 km from the station. The convective structure of TC *Monica* maintained its intense nature until it made landfall at 0900 UTC 24 April at Junction Bay, 35 km west of Maningrida (see Fig. 5).

After moving over land, *Monica* weakened rapidly under increasing shear, but it appears the entrainment of mid-level dry air was the most important factor in the rapid decline. Just 12 hours after landfall, the system had weakened to below TC intensity and passed to the north of Darwin as a tropical low during the afternoon of 25 April.

Fortunately TC *Monica* crossed Cape York Peninsula at a remote location, avoiding the local townships of Lockhart River and Coen. However, along the Arnhem Land coast there was widespread tree damage and moderate damage to infrastructure, extending as far west as the township of Jabiru. Maningrida community received substantial damage as the TC passed just to the north of the township, with several houses damaged by fallen trees. The uninhabited coastal crossing point suffered severe vegetation damage, with 50-70 per cent of all trees felled, and there was evidence of a 5-6 m storm surge zone in Junction Bay.

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