The South Pacific and southeast Indian Ocean tropical cyclone season 1996-97

B.N. Hanstrum
Severe Weather Section, Regional Office, Bureau of Meteorology, Perth.

G. Reader
Regional Forecasting Centre, Regional Office, Bureau of Meteorology, Perth.

and

P.W. Bate
Climate and Consultancy Section, Regional Office, Bureau of Meteorology, Darwin.

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Tropical cyclone occurrences were above the long-term averages during the 1996-97 season. The weak La Niña phase which characterised 1996 declined and some early El Niño indicators emerged by the end of the season. These included the appearance of strong westerly equatorial wind anomalies near the date-line, increasing sea-surface temperature in the near-equatorial central and eastern Pacific, a fall of the Southern Oscillation Index to negative values and increased convective activity in the South Pacific convergence zone. The monsoon in the summer hemisphere was of average development or better, with strongest anomalies in the southwest Pacific. Three major cycles of the 30 to 60-day intraseasonal oscillation were diagnosed. The 26 cyclones that formed spanned every month (July 96-June 97) except August and September.

Introduction

This paper provides a summary of tropical cyclone activity in the southeast Indian Ocean (east of 80°E) and the South Pacific Ocean (west of 120°W) during the 1996-97 cyclone season. The material has been gathered from information provided by the Australian Tropical Cyclone Warning Centres (TCWCs) at Perth, Darwin and Brisbane, the Fiji Regional Specialised Meteorological Centre (RSMC) and La Reunion RSMC.

A moderate La Niña phase dominated the region during 1996. Averaged over the cyclone season (November-April), the summer monsoon was generally well developed between eastern Indian Ocean and Papua New Guinea longitudes. Later in the season, La Niña conditions began to break down, with indications emerging in March that an El Niño phase was beginning to develop; the South Pacific convergence zone became more active and convective activity to the west eased. Three major active cycles of the 30 to 60-day intraseasonal oscillation were diagnosed during the season. A brief overview of the major circulation features and climatic indices, based mainly

Corresponding author address: B.N. Hanstrum, Bureau of Meteorology, PO Box 1370, West Perth, WA 6872, Australia.

Table 1. Tropical cyclones in the South Pacific and southeast Indian Oceans 1996-97.

	Low first identified			Initial tropical cyclone phase			
Name	*Date*	*Lat.*	*Long.*	*Date*	*Time (UTC)*	*Lat.*	*Long.*
Lindsay	09 Jul	9.3°S	93.3°E	10 Jul	1000	12.0°S	92.0°S
Antoinette	15 Oct	5.5°S	93.5°E	17 Oct	1200	9.3°S	83.9°E
Melanie/ Bellamine	28 Oct	9.1°S	97.8°E	31 Oct	1600	9.0°S	93.6°E
Cyril	22 Nov	9.0°S	160.0°E	23 Nov	1200	14.8°S	160.5°E
Chantelle	23 Nov	6.8°S	94.2°E	26 Nov	0000	8.9°S	82.3°E
Elvina	08 Dec	11.7°S	92.1°E	10 Dec	0000	13.3°S	84.3°E
Nicholas	12 Dec	11.0°S	124.5°E	13 Dec	1600	14.2°S	123.5°E
Ophelia	13 Dec	9.1°S	107.9°E	15 Dec	0100	9.9°S	108.4°E
Fergus	23 Dec	11.6°S	160.9°E	23 Dec	1800	12.8°S	160.0°E
Phil I	22 Dec	11.0°S	139.0°E	25 Dec	1800	13.0°S	138.6°E
Phil II				28 Dec	0100	15.2°S	124.5°E
Rachel	01 Jan	13.3°S	133.4°E	02 Jan	2200	11.8°S	129.8°E
Drena	02 Jan	10.0°S	172.0°E	03 Jan	1200	14.7°S	164.1°E
Evan	09 Jan	15.5°S	172.5°W	12 Jan	1800	13.6°S	169.5°W
Pancho/ Helinda I	18 Jan	9.6°S	96.2°E	20 Jan	0100	9.8°S	96.2°E
Pancho/ Helinda II				27 Jan	1600	11.2°S	91.1°S
Freda	26 Jan	20.4°S	175.1°E	26 Jan	0800	21.5°S	175.8°E
Gillian	09 Feb	12.5°S	150.5°E	10 Feb	0000	14.2°S	149.9°E
Karlette	14 Feb	13.4°S	86.5°E	16 Feb	0000	15.0°S	82.3°E
Harold	16 Feb	13.7°S	157.8°E	16 Jan	1800	14.8°S	156.8°E
Ita	23 Feb	15.2°S	148.4°E	23 Feb	1800	16.2°S	149.0°E
Gavin	02 Mar	9.0°S	172.0°E	04 Mar	0000	9.6°S	173.7°E
Justin	06 Mar	17.0°S	153.5°E	06 Mar	1800	17.0°S	153.5°E
Hina	13 Mar	11.7°S	176.6°E	15 Mar	0000	12.8°S	179.3°W
Ian	16 Apr	16.8°S	173.2°E	17 Apr	0600	20.1°S	176.1°E
June	01 May	13.0°S	173.0°E	02 May	2100	13.5°S	173.7°E
Rhonda	10 May	11.1°S	84.5°E	11 May	0100	11.5°S	90.1°E
Keli	10 Jun	8.6°S	176.5°E	10 Jun	0600	9.4°S	177.5°W

Phil I, II refers to the first and second stages respectively of the lifecycle of *Phil.*
Pancho/Helinda I, II refers to the first and second stages respectively of the lifecycle of *Pancho/Helinda.*

on analyses averaged over the six months November 1996 to April 1997, follows. As this summary is primarily concerned with tropical cyclones, no figures depicting circulation aspects are included. For more detail regarding the tropical circulation within the Darwin RSMC area of responsibility (40°N-40°S, 70°E-180°E) see Bate (1997).

Tropical cyclone occurrence

Tropical cyclone occurrences during the 1996/97 season across the whole south Indian Ocean and South Pacific basins were above the long-term average, consistent with the general state of monsoon development. In the full year July 1996 to June 1997, 32 tropical cyclones occurred in the combined south Indian and south Pacific basins, compared with the mean of 27.3 (which includes some depressions of near tropical cyclone intensity) quoted by Etro and Bassi (1996). Of these, five occurred outside the months November to April, (the so-called 'cyclone season' in the southern hemisphere), well above the climatological mean of 2.2. The proportional geographical distribution of occurrences across the South Pacific Ocean (east of 165°E), Australian (105°E-165°E) and southern Indian Ocean (west of 105°E) regions were all above the long-term average. All of the Pacific cyclones (east of 165°E) occurred from January onward, consistent with the shift toward El Niño conditions. Of the south Indian Ocean cyclones, six occurred west of 80°E and are not discussed in this summary. Details on the lifecycle of the 26 events that formed between 80°E and 120°W are given in Table 1.

Table 1 (Continued). Tropical cyclones in the South Pacific and southeast Indian Oceans 1996-97.

	Maximum intensity				*End tropical cyclone phase*				
Name	*Date*	*Time (UTC)*	*Lat.*	*Long.*	*Mean wind (m/s)*	*Date*	*Time (UTC)*	*Lat.*	*Long.*
Lindsay	10 Jul	1600	12.3°S	92.0°E	18	11 July	0700	12.4°S	92.2°E
Antoinette	19 Oct	1800	12.5°S	68.6°E	32	21 Oct	1200	13.1°S	58.4E
Melanie/ Bellamine	07 Nov	0000	12.0°S	79.0°E	24	10 Nov	0000	22.0°S	79.0°E
Cyril	.24 Nov	0000	16.1°S	160.7°E	23	26 Nov	0000	19.8°S	162.1°E
Chantelle	27 Nov	1200	8.8°S	77.3°E	26	28 Nov	1800	5.5°S	75.0°E
Elvina	10 Dec	1800	13.3°S	81.8°E	23	13 Dec	0000	13.3°S	77.4°E
Nicholas	14 Dec	0700	15.5°S	123.5°E	26	15 Dec	0100	17.7°S	123.5°E
Ophelia	16 Dec	0400	12.0°S	110.8°E	28	17 Dec	1000	13.7°S	115.5°E
Fergus	28 Dec	0000	19.0°S	168.0°E	41	29 Dec	1800	29.5°S	175.3°W
Phil I	26 Dec	0600	13.3°S	136.1°E	23	26 Dec	0900	13.3°S	135.8°E
Phil II	28 Dec	1900	15.3°S	121.3°E	30	31 Dec	1300	17.8°S	114.6°E
Drena	06 Jan	0000	16.5°S	158.6°E	46	09 Jan	1200	30.0°S	169.0°E
Rachel	06 Jan	1900	19.1°S	119.3°E	36	08 Jan	1900	25.1°S	119.6°E
Pancho/ Helinda I	21 Jan	1000	12.2°S	94.5°E	57	26 Jan	1600	12.7°S	90.6°E
Pancho/ Helinda II					57	04 Feb	0400	18.2°S	87.0°E
Evan	15 Jan	0000	21.5°S	165.7°W	36	17 Jan	0000	34.5°S	170.5°W
Freda	27 Jan	1800	24.9°S	177.0°E	28	29 Jan	0600	26.8°S	180.0°E
Gillian	11 Feb	0600	16.7°S	148.9°E	20	11 Feb	1100	17.3°S	148.7°E
Harold	18 Feb	1800	18.4°S	156.7°E	31	20 Feb	1800	24.5°S	164.3°E
Karlette	22 Feb	0000	20.9°S	62.5°E	31	25 Feb	0000	34.0°S	58.6°E
Ita	24 Feb	1200	19.3°S	147.3°E	23	24 Feb	1800	20.0°S	146.7°E
Gavin	08 Mar	1200	20.0°S	176.1°E	51	10 Mar	2300	32.8°S	176.4°E
Justin	17 Mar	1800	12.3°S	154.8°E	43	22 Mar	0900	17.0°S	145.2°E
Hina	16 Mar	1200	22.5°S	174.4°W	33	19 Mar	0000	35.0°S	156.0°W
Ian	18 Apr	0000	21.3°S	179.4°E	23	19 Apr	0000	23.0°S	173.0°W
June	04 May	0000	15.4°S	176.4°E	26	05 May	0600	17.6°S	176.9°E
Rhonda	14 May	0400	15.9°S	96.8°E	54	16 May	0400	24.1°S	108.3°E
Keli	12 Jun	0600	10.6°S	179.7°W	41	15 Jun	0600	19.5°S	162.5°W

Large-scale circulation features

Averaged over the six months November 1996 to April 1997, anomaly fields of lower level wind and sea-level pressure were generally not strong in the tropics. West of the dateline this was also the case at upper levels, implying a circulation similar to the long-term average. The monsoon in the southern hemisphere was of average development or better, with strongest anomalies in the southwest Pacific. Westerly anomalies appeared to the north of the trough in this region in December, and by April had strengthened considerably as equatorial easterlies reversed - typical of incipient El Niño conditions. In the southern Indian Ocean the monsoon trough was near-normal strength but a little poleward of its mean latitude. The subtropical ridge was generally near its average location and strength.

At upper levels, six-month averaged charts indicated a subtropical ridge of near-normal strength and location west of the date-line. Equatorial westerlies across the Pacific were stronger than average, evidence of a well-developed Walker circulation. This situation persisted until quite late in the season, divergent upper easterlies suggestive of an early El Niño phase appearing along the equator near and east of the date-line in April and subsequently strengthening.

Climatic indices

The season was characterised by a decline in the weak to moderate La Niña event which dominated 1996 and early signs of El Niño development in the later months. After maintaining mostly moderate positive values until February 1997, the Southern Oscillation

Index (SOI)* fell quickly, indicating an eastward shift of the Walker circulation upward branch. By April the SOI had reached its lowest value since September 1994 and by June it was at its lowest value for that month since 1905.

Sea-surface temperature (SST) averaged over the season was generally a little warmer than normal through most tropical parts west of the date-line. Weak to moderate negative anomalies characterised the southwest Pacific, Tasman Sea and parts of the southern Indian Ocean. In the Pacific east of the date-line, SST along the equator was generally slightly cooler than average until March when warmer conditions began to extend eastward.

Broadscale convection is inferred from time sections and monthly maps of outgoing long wave radiation anomaly (OLR) from satellite data. The strongest tropical convection was concentrated mainly from the eastern Indian Ocean to Papua New Guinea longitudes until February. For much of this period, convective activity was below normal both west of about 90°E and east of about 160°E. March marked the beginning of the eastward shift of major convection anomalies, consistent with SOI behaviour. OLR anomalies became generally positive (below normal convection) over much of the eastern Indian Ocean and northern Australia and Indonesia, while convective activity increased further east in the South Pacific convergence zone.

Intraseasonal modulation

The 30 to 60-day intraseasonal oscillation (ISO) inferred from time-longitude sections of 200 hPa velocity potential, OLR, sea-level pressure anomaly as well as station pressure series was clearly defined from late October to March. Three major active phases occurred during this period, most strongly affecting the 70°E-180° longitude range from mid-October to early November, late November to late December and early February to early March. The dominant period of the oscillation during the bulk of the season was about sixty days. Periods of enhanced convection also occurred in January and April, but were not as strongly defined as the other peaks. The April phase was less evident across Indonesian longitudes. The majority of tropical cyclone genesis events were associated with active phases of the ISO.

* The SOI used here is defined as ten times the normalised monthly difference in pressure anomaly between Tahiti and Darwin, based on the reference period 1933-1992.

Verification statistics

Position forecast verification statistics for each cyclone (Table 2) were derived by comparing the official warnings issued by the relevant warning centres with post-analysis best-track positions. For comparison, verification statistics for persistence forecasts based on 12-hour best-track movement vectors were also calculated. Overall, initial position accuracy was slightly worse than in previous seasons, principally due to the large inaccuracies associated with the positioning of *Lindsay, Melanie, Phil* and to a lesser extent *Cyril*. In all of these cases vertical wind shear caused the difficulty with centre location. In the case of *Phil* the middle-level centre tracked away to the west while the surface centre circulation slowed. The forecast position errors for these cyclones reflected the difficulties with centre location.

Tropical cyclones in the South Pacific and southeast Indian Oceans 1996-97

***Lindsay* (Perth TCWC): 9 to 13 July 1996 (Fig. 1)**
Lindsay began as an area of deep persistent convection in the near equatorial trough to the west of Sumatra. A low formed in the Bay of Bengal to the north of the trough during 7 and 8 July. This caused a surge of equatorial westerlies to the north of the near equatorial trough. *Lindsay* became first discernible as a low-level circulation on 9 July near 9°S 94°E. It initially tracked to the southwest around the shoulder of a weak mid-level anticyclone to its southeast. *Lindsay* then moved south and intensified to briefly reach cyclone status during the night of 10/11 July, before being sheared apart overnight on 11 July as it came under the influence of strong upper-level northwesterlies. The remnants of *Lindsay* slowly moved southeast over the next couple of days before being absorbed into a broad trough area on 13 July near 15°S 95°E.

***Antoinette* (La Reunion RSMC): 15 to 24 October 1996 (Fig. 1)**
Antoinette formed to the southwest of Sumatra in an area of persistent convection within the near equatorial trough. Located beneath an upper ridge axis and with moderate low-level inflow from a high pressure system in the Indian Ocean, it was first analysed by Darwin RSMC as a cyclone on 17 October. It was named by La Reunion Tropical Cyclone Centre on 18 October. Situated equatorward of the mid-level ridge, *Antoinette* moved rapidly on a west-southwest track, crossing 80°E on 18 October. Tropical cyclone strength was maintained until 24 October.

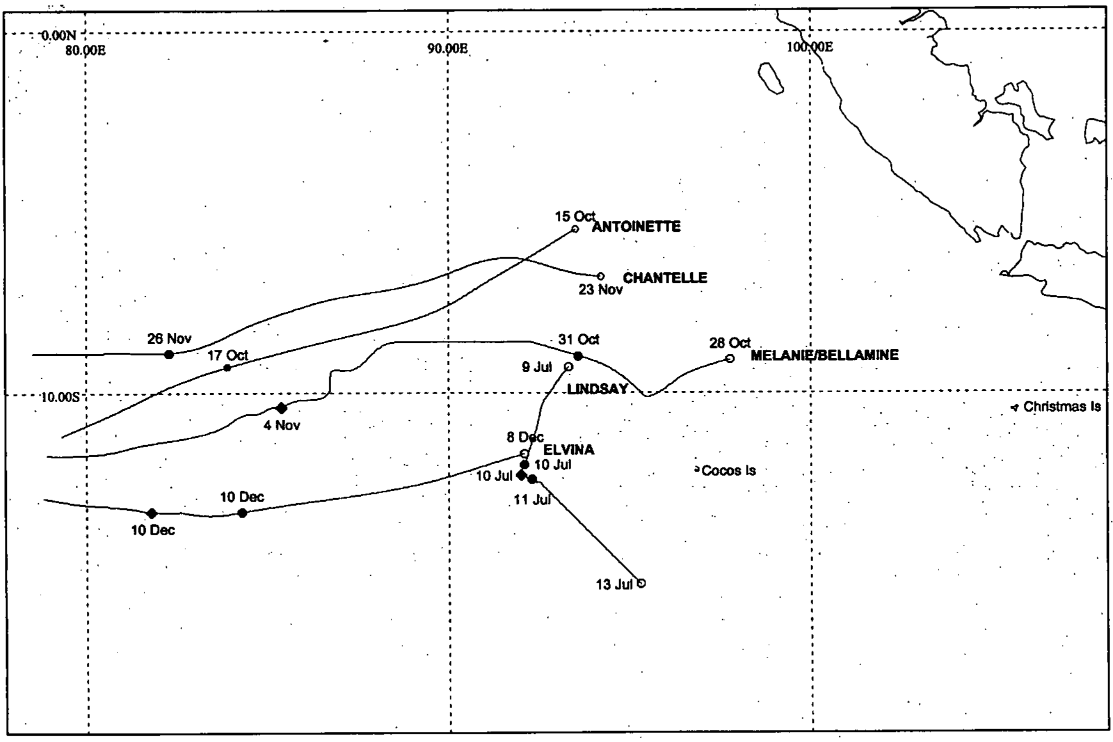
Table 2. Position forecast verification statistics for official warnings issued by relevant warning centres. Forecast positions are verified against the official best track. Persistence errors (in brackets) are included for comparison. Warnings for cyclones marked with an asterisk were issued by La Reunion RSMC.

Forecast Lead Time	*0 hr*		*12 hr*		*24hr*		*48 hr*	
Name	*accuracy (km)*	*number (km)*	*accuracy (km)*	*number (km)*	*accuracy*	*number*	*accuracy*	*number*
Lindsay	121	9	201 (124)	7	353 (221)	6		
*Antoinette**								
Melanie	96	21	131 (133)	16	266 (178)	9	335 (268)	4
Cyril	63	12	218 (248)	9	413 (465)	7		
*Chantelle**								
*Elvina**								
Nicholas	36	17	74 (50)	12	96 (51)	14		
Ophelia	36	18	104 (78)	13	201 (134)	16		
Fergus	30	22	121 (137)	20	195 (293)	18	399 (-)	8
Phil	110	38	222 (270)	29	297 (422)	35	434 (564)	9
Rachel	25	31	95 (85)	24	174 (111)	31	332 (204)	9
Drena	21	23	92 (105)	20	204 (282)	19	416 (1099)	9
Evan	46	27	138 (157)	11	269 (415)	11		
Pancho	50	57	89 (97)	38	165 (158)	54	338 (307)	16
Freda	9	8	65 (48)	6	132 (105)	4		
Gillian	23	9	78 (74)	9	109 (144)	7	76 (-)	4
*Karlette**								
Harold	42	18	129 (162)	15	252 (323)	13	407 (812)	11
Ita	24	4	-	0	-	0		
Gavin	21	23	89 (137)	21	157 (371)	19		
Justin	36	63	87 (93)	61	149 (157)	58	318 (336)	55
Hina	28	16	105 (109)	8	269 (334)	8		
Ian	13	9	134 (153)	5	206 (175)	1		
June	11	12	90 (113)	8	152 (214)	4		
Rhonda	57	33	151 (150)	23	302 (197)	31	531 (271)	6
Keli	32	21	185 (172)	17	435 (427)	13		
Total		491		372		378		131
Weighted mean	43		121		214		351	

Melanie/Bellamine **(Perth TCWC/La Reunion RSMC): 28 October to 12 November 1996 (Fig. 1)**
During the formation stage of *Melanie* a monsoon low was apparent near 10°N 100°E giving rise to an enhanced equatorial westerly flow. Initial development was slow as it was located on the northwest flank of the upper ridge and encountered considerable northeasterly shear. *Melanie* reached cyclone strength on 31 October to the northwest of the Cocos Islands. During most of its lifetime *Melanie* remained north of the mid-level ridge and moved in a generally westerly direction, apart from a period during 3 November when a mid-level trough to the south of the cyclone caused a more southwesterly track. *Melanie* intensified further as it moved westwards out of the Perth TCWC region early on 2 November and was renamed *Bellamine* by La Reunion RSMC. Peak intensity was reached on 7 November with maximum mean winds of 47 m/s, just after the system crossed west of 80°E. *Bellamine* weakened below cyclone strength on 10 November near 22°S 79°E.

Cyril **(Nadi RSMC): 22 to 26 November 1996 (Fig. 3)**
Around the middle of the month the near-equatorial trough established itself in the southwest Pacific. Two low-level circulations formed within the trough, which was situated beneath the upper ridge axis. As convective organisation increased, one of these developed to become *Cyril* on 23 November. *Cyril* was located on the southern side of a northwest/southeast

Fig.1 **Tracks of tropical cyclones *Elvina, Antoinette, Melanie/Bellamine, Chantelle* and *Lindsay*. Open circles denote start and finish of the tropical low phase, filled circles indicate the start and end of the tropical cyclone phase. Filled diamond indicates the time at which the maximum intensity was reached.**



oriented mid-level subtropical ridge with a large amplitude trough over eastern Australia, consequently steering was from the north-northwest over much of this system's life. As *Cyril* moved southwards from beneath the upper ridge it became increasingly sheared and this hindered development. On the night of 24 November upper westerlies sheared the convection away from the low-level circulation. Further southward movement increased the vertical shear, further exposing the low-level circulation and leading to the weakening of *Cyril* to below cyclone strength on 26 November.

Chantelle (La Reunion RSMC): 23 to 28 November 1996 (Fig. 1)

Toward the end of the month another southern Indian Ocean low formed within the near-equatorial trough to the southwest of Sumatra. Situated equatorward of the mid-level sub-tropical ridge, the system tracked westwards and developed in an area of upper divergence and low-level inflow. It was named *Chantelle* on 26 November. The low continued to track westwards, crossing 80°E on 26 November. It continued to develop, reaching its maximum intensity late on 27 November. An increase in upper-level shear subsequently exposed the low-level circulation and rapidly weakened the system to below tropical cyclone strength on 28 November.

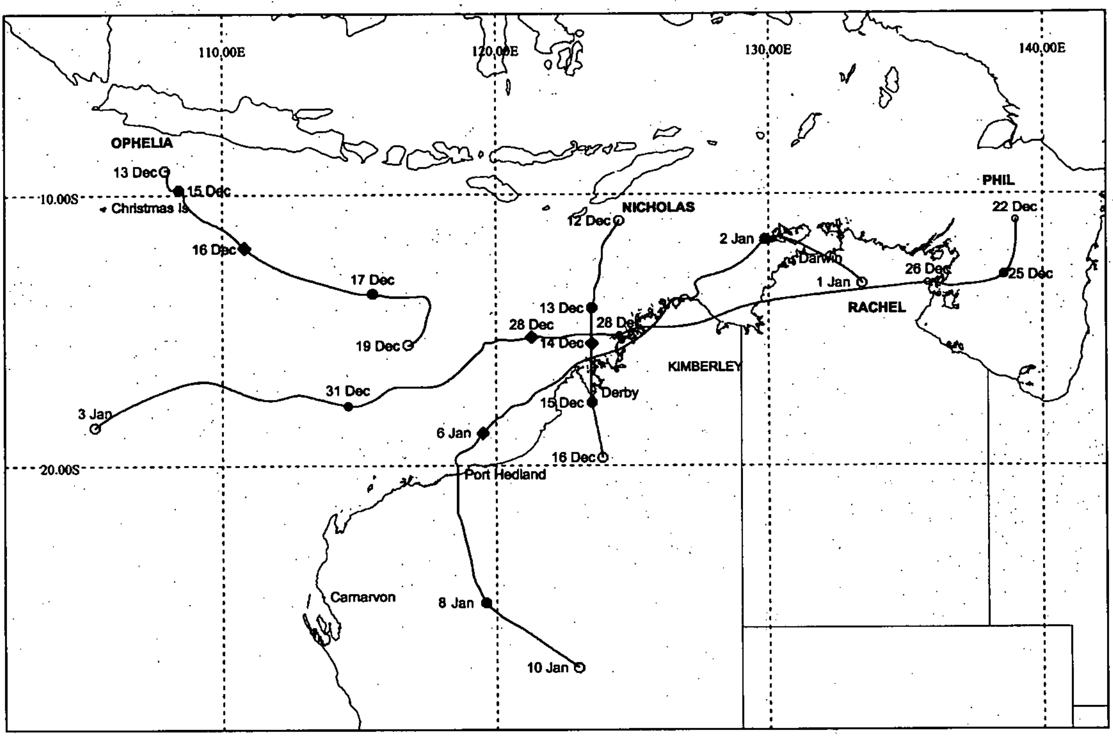
Elvina (La Reunion RSMC): 8 to 13 December 1996 (Fig. 1)

Elvina formed north of an upper ridge in the southern Indian Ocean from a circulation within an active monsoon trough. It moved steadily west, turning in its final stage to the southwest towards a weakness in the subtropical ridge. For its duration *Elvina* was strongly affected by significant easterly vertical shear which hindered its development. Maximum intensity was reached overnight on 10 December, after which vertical shear caused the system to weaken.

Nicholas (Perth TCWC): 12 to 15 December 1996 (Fig. 2)

Nicholas was the first cyclone to form off the northwest Australian coast during the season. It began as a weak low on the monsoon trough near Gove on 9 December.

Fig. 2 Tracks of tropical cyclones *Nicholas, Phil, Ophelia* and *Rachel*. Symbols as in Fig. 1.



Initial development was associated with a broadscale cross-equatorial surge. A low-level centre emerged within the broad monsoonal circulation during the early morning of 14 December. Shear over the genesis region was low due to the proximity of the upper ridge axis. The low then moved steadily south due to a major 500 hPa trough to the southwest of the cyclone and a high to the southeast. Cyclone strength was reached early on 14 December off the northwest Kimberley coast. As the cyclone neared the coast it weakened due to upper shear and interaction with the land. It continued south and weakened further over the inland west Kimberley during the day. It finally dissipated as a surface circulation during the afternoon of 16 December. Gale to storm-force winds were experienced by pearling boats near the northwest Kimberley coast. There was no damage over land although heavy rain over the north Kimberley caused local flooding.

Ophelia (Perth TCWC): 13 to 17 December 1996 (Fig. 2)

Ophelia formed from an area of convection within the monsoon trough to the east of Christmas Island during an active phase of the intraseasonal oscillation. It formed between two tropical cyclones, *Nicholas* and *Elvina*, beneath the axis of the upper ridge. It intensified rapidly to cyclone intensity by the morning of 15 December. The intensification phase was short-lived however. As *Ophelia* was a small cyclone it was susceptible to vertical wind shear. Shear resulted from northwest flow in the mid-levels superposed by north-northeast flow in high -levels. By 17 December a low-level centre became exposed on the northern flank of the main cloud mass. The track of *Ophelia* was somewhat unusual in that it moved towards the southeast for most of its lifetime, under the influence of northwest steering flow. The cyclone had no impact on Christmas Island or northwest Australia.

Fergus (Brisbane TCWC/Nadi RSMC): 23 to 29 December 1996 (Fig. 3)

On 23 December 1996 a stationary tropical low lay just to the southwest of Rennell Island (the southernmost island in the Solomons Group). This depression deepened under the influence of a complicated upper ridge and a retrogressing upper trough, and was named *Fergus* late on 23 December. Initially, *Fergus* moved in a loop, then, under the influence of an approaching upper trough, moved in a southeasterly direction. The system began to deepen and reached a maximum wind speed of 41 m/s on 28 December. During this period the system moved between and parallel to Vanuatu and the Loyalty Islands. The system subsequently moved in a more southerly direction, undergoing extratropical transition. The remnants of the cyclone finally crossed the northern coast of the North Island of New Zealand on 30 December causing wind damage and flooding in the vicinity of the Bay of Plenty. No deaths were reported though extensive property and crop damage was reported on Rennell Island.

***Phil* (Darwin/Perth TCWCs): 22 to 31 December 1996 (Fig. 2)**

Phil formed in the monsoon trough and under an upper ridge in the Gulf of Carpentaria on 26 December. It moved west-southwest and made its landfall on the east coast of the Northern Territory. *Phil* moved rapidly westward across the Northern Territory during that day and temporarily weakened over land. Re-intensification to cyclone intensity occurred on 28 December off the northwest Kimberley coast. It intensified rapidly during the day due to fresh monsoonal flow to the north and a southeast surge to the south. On 29 December it was experiencing vertical wind shear and its subsequent structure on satellite imagery was poor. A ship passed close to the centre early on the morning of 30 December and experienced winds up to 26 m/s. Throughout its lifetime it travelled on a west-southwesterly path due to a mid-level ridge to the south. It was downgraded to below cyclone strength late on 31 December.

***Drena* (Brisbane TCWC/Nadi RSMC): 2 to 9 January 1997 (Fig. 3)**

A low was first identified in the monsoon trough with a deep ridge to the south. Low-level inflow and an upper divergent easterly flow aided the development and it moved in a west-southwesterly direction, passing through the northern part of Vanuatu and into the Coral Sea before being named *Drena* on 3 January. *Drena* continued in a west-southwest direction while slowly intensifying. Interaction with a deep short wave trough caused re-curvature to the southeast. A maximum intensity of 46 m/s was reached as it crossed the mid-level ridge axis. While further southeast the cyclone weakened due to increased shear ahead of the upper trough. As the system accelerated to the southeast it weakened further and became cold-cored on 9 January. On its passage south, considerable wind damage was reported in New Caledonia and along Coromandel Peninsula and Taranaki in New Zealand.

***Rachel* (Darwin /Perth TCWCs): 1 to 8 January 1997 (Fig. 2)**

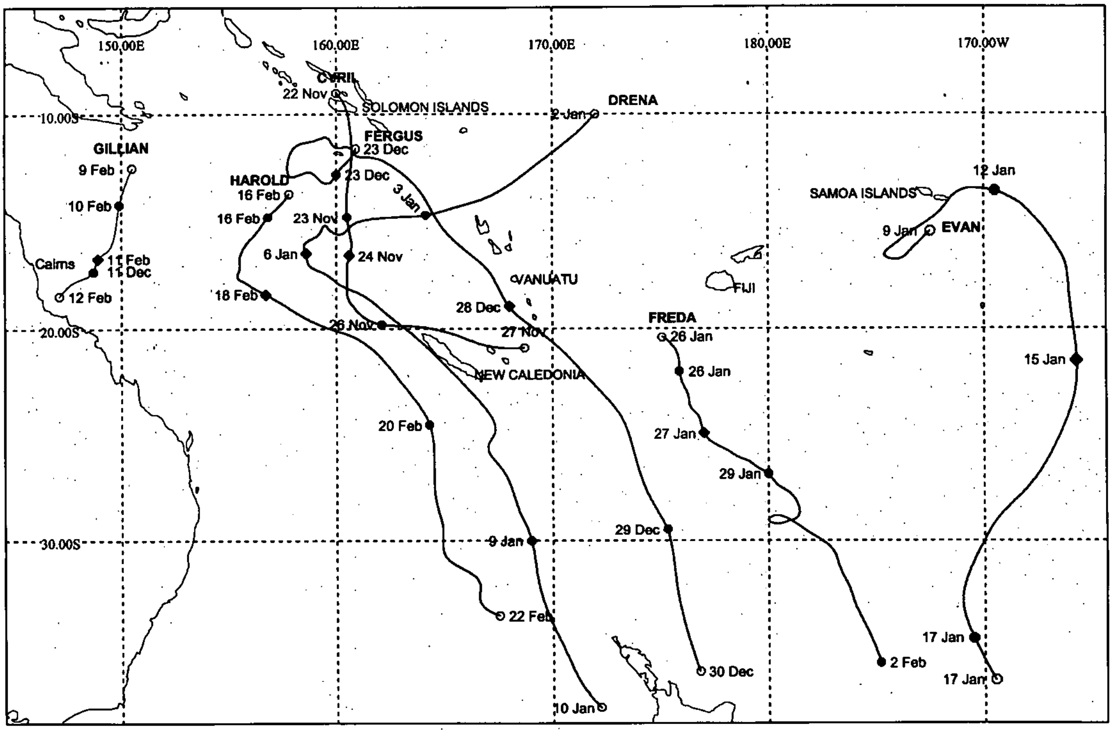
A tropical low was first analysed within the monsoon trough over northern Australia on 31 December. Convective activity was focussed around a well-developed middle-level circulation. A low-level easterly surge associated with a developing ridge over southern Australia pushed the tropical low northwest towards Melville Island on 2 January. Outflow over the system was enhanced by interaction with an upper trough and *Rachel* was named on 3 January (CST). The cyclone moved southwest and intensified, then weakened as it moved across the northern Kimberley, before moving out to sea again on 5 January near Cape Leveque and subsequently re-intensifying. The intensification was slow due to its proximity to land as it moved down the coast. The cyclone continued the southwest track under the influence of a trough to the southeast and a high north of the NT until midday on 7 January. It then slowed and abruptly changed course towards the south as a meridional ridge developed to the east of the cyclone. The eye of the cyclone passed directly over Port Hedland at 0830 UTC with reported average winds of 33 m/s. The cyclone then continued to move southward, weakening as it passed over the Hamersley ranges overnight and was downgraded to below cyclone strength. Damage to property at Port Hedland was mostly minor. Power was lost in parts of the town and numerous trees were blown over.

***Pancho/Helinda* (Perth TCWC/La Reunion RSMC): 18 January to 4 February 1997 (Fig. 4)**

Tropical cyclone *Pancho/Helinda* was a long-lived cyclone with a highly convoluted track. It formed to the southwest of Sumatra during an active phase of the northwest monsoon. There was moderate cross-equatorial northwest flow on the northern side of the low and the genesis region was beneath the upper ridge axis. The cyclone was named on 20 January when it was north-northwest of the Cocos Islands. Initially the cyclone was in a weak steering environment in the deep monsoonal trough and only moved slowly south. A weak ridge axis built up to the south of the cyclone causing it to move in a more southwesterly direction and to quickly intensify with a maximum wind of 54 m/s reached on 22 January.

On 23 January it came under the influence of an amplifying mid-level trough to its southwest. The cyclone moved in a south-southeasterly direction, weakening as it came under the influence of increasing vertical shear. It stalled near 90°E and weakened to below cyclone strength then began moving northwards on 26 January. The system then moved into the strong monsoon northwesterly flow, re-intensified

Fig. 3 **Tracks of tropical cyclones *Gillian, Harold, Cyril, Fergus, Drena, Freda* and *Evan*. Symbols as in Fig. 1.**

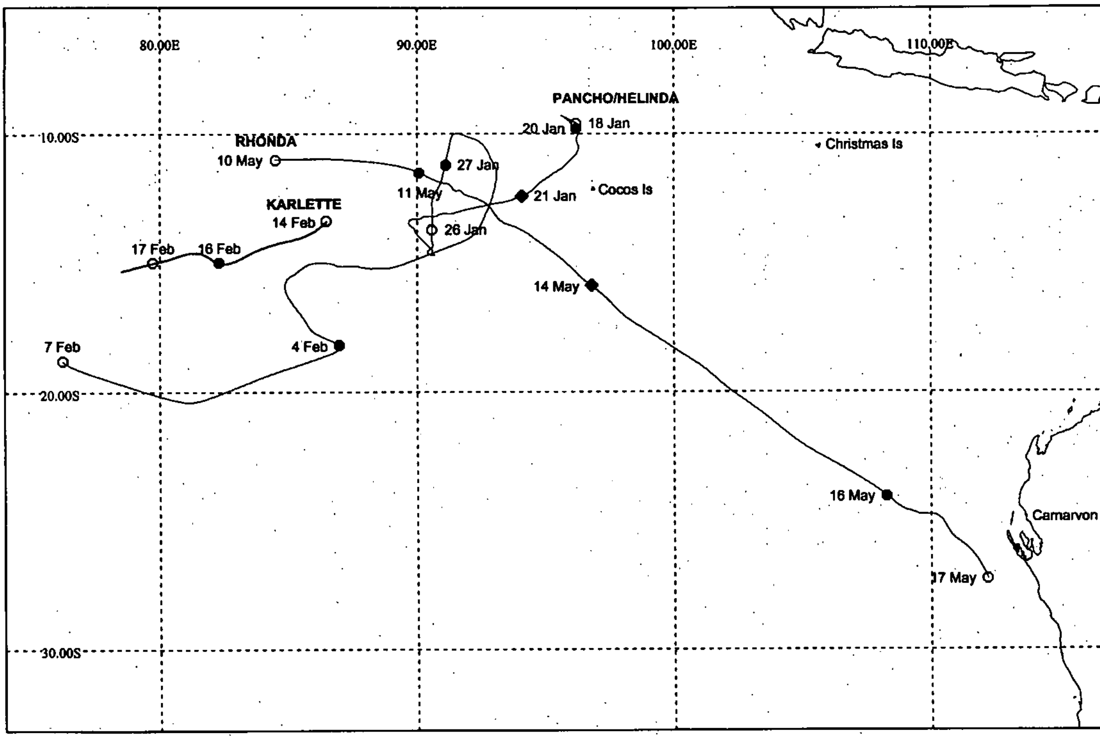


and commenced a southeast track. During this period a new mid-level high pressure system was building to the south of the cyclone. Gradually during 29 January the cyclone moved southwards from the monsoon-influenced steering regime and began a southwest track as it came under the influence of the mid-level ridge to its south. *Pancho/Helinda* remained under the influence of this steering regime in early February and reached a second maximum in intensity. On 3 February another mid-level amplifying trough approached from the southwest and steered the cyclone towards the southeast, weakening the system to below cyclone strength during 4 February. The remnants of *Pancho/Helinda* then drifted to the west in the low-level easterly flow.

***Evan* (Nadi RSMC): 9 to 17 January 1997 (Fig. 3)**
A disturbance initially near Samoa, moved into an area of enhanced upper diffluent flow and warm seas. This triggered an increase in organisation, and subsequent intensification. Tropical cyclone intensity occurred late on 12 January as it began to curve towards the southeast. Further rapid development occurred and only 12 hours later it reached storm-force intensity. By 0000 UTC 14 January *Evan* reached hurricane-force intensity with a cloud-filled eye visible on satellite imagery. Evan then gradually began to accelerate, turned southwards and reached peak intensity of 36 m/s on 15 January. Weakening was then apparent due to the effects of strong vertical shear and cooler seas. The system weakened below cyclone strength on 17 January east of New Zealand.

***Freda* (Nadi RSMC): 26 to 29 January 1997 (Fig. 3)**
As the monsoon trough became more active in the southern hemisphere towards the end of January, this system developed in the southwest Pacific. Initially a depression embedded in the monsoon trough, development was hindered by upper-level westerlies shearing the convection away from the low-level circulation. A moderation of the vertical shear and favourable low-level inflow led to an increase in organisation and the system intensified to cyclone strength, despite its high latitude, on 26 January. *Freda* moved to the south-southeast and continued to intensify as outflow improved. On 29 January the system began to lose its warm core and became an extratropical system. Gales were estimated to have continued until 1 February.

Fig. 4 Tracks of tropical cyclones *Pancho/Helinda, Rhonda,* and *Karlette.* Symbols as in Fig. 1.



***Gillian* (Brisbane TCWC): 9 to 12 February 1997 (Fig. 3)**

A tropical depression located within the monsoon trough in the Coral Sea formed rapidly into cyclone *Gillian* on 10 February. Its movement was towards the south-southwest under the influence of a marked upper-level trough lying to the south of the system and a north/south oriented mid-level ridge to the east. As it approached the Tropical Upper Tropospheric Trough (TUTT) cell over northeast Australia, shear increased and weakened the system. By 12 February *Gillian* had weakened to become a tropical depression. The remnants of the cyclone continued to move in a southwesterly direction and crossed the coast in the vicinity of Townsville with little discernible effect.

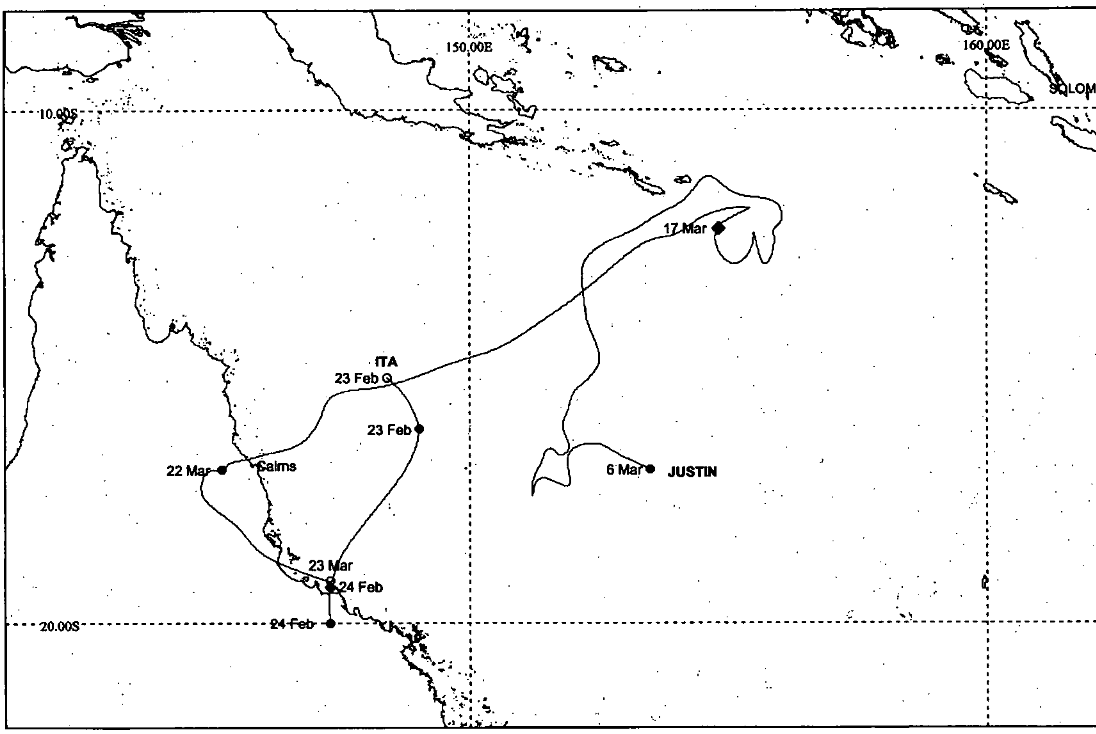
***Harold* (Brisbane TCWC): 16 to 22 February 1997 (Fig. 3)**

On 16 February tropical cyclone *Harold* formed in an area of upper divergence with an upper anticyclone to the north and a TUTT to the west. The system moved in a southwesterly direction in response to a mid-level ridge to the southeast. *Harold* continued to move in a southwesterly direction until 17 February when the mid-level ridge weakened. It subsequently began to recurve to the southeast under the influence of an amplifying upper-level trough lying to the southwest during 18 February. The maximum wind speed attained was 31 m/s on 18 February. *Harold* continued to move southeast and accelerated while weakening and shearing under the influence of the upper northwesterly flow. The system had degenerated to a low early on 22 February. No damage was reported.

***Karlette* (La Reunion RSMC): 16 to 25 February 1997 (Fig. 4)**

This system developed within a well-defined monsoon trough in the southern Indian Ocean. A strong westerly flow to the north of the trough and a strong southeasterly flow to the south provided favourable low-level inflow and horizontal shear for development. With favourable divergence in the upper levels the system developed into a tropical cyclone on 16 February. *Karlette* was located to the north of the ridge axis through all levels and easterly vertical shear hindered development as it tracked westwards

Fig. 5 **Tracks of tropical cyclones *Justin* and *Ita*. Symbols as in Fig. 1.**



through the Indian Ocean. For a brief period on 17 February, when it crossed west of 80°E, and on 20 February, *Karlette* was analysed as a tropical depression. As the system moved further west, shear decreased and re-intensification occurred. It remained a tropical cyclone until 25 February.

Ita (Brisbane TCWC): 23 to 24 February 1997 (Fig. 5)

Tropical cyclone *Ita* rapidly developed off the north Queensland coast in markedly divergent upper flow east of an upper low on 23 February. The system moved in a southerly then southwesterly direction towards the coast. However, northerly upper flow between an upper low over Queensland and an anticyclone in the Coral Sea increased. Development was inhibited and the lowest central pressure of 994 hPa occurred just prior to crossing the coast southeast of Townsville on 24 February, where it dissipated quickly. Little wind damage was reported, however, moderate flooding was reported in coastal rivers and creeks. A tornado occurred at Yukan about 13 km south of Sarina on 24 February.

Gavin (Nadi RSMC) 2 to 10 March 1997 (Fig. 6)

Early in the month, as the monsoon trough became better organised and convection increased in the southwest Pacific, *Gavin* formed from a depression to the northeast of Vanuatu. In an environment of good low-level inflow and upper divergence, warm SST and low shear, *Gavin* intensified rapidly, being named on 4 March. An upper trough to the southwest and an upper ridge to its north combined to steer the system to the southeast. As the trough amplified, *Gavin* turned towards the south-southwest, passing close to Fiji and bringing destructive winds (51 m/s) to the islands. The first intensity maximum was reached at this time. Worst hit was the western part of the main island, Viti Levu, with reports of at least 18 lives lost and thousands of people made homeless. In terms of damage, *Gavin* was the most destructive cyclone to affect Fiji since *Kina* (26 December 1992 - 5 January 1993). The damage bill was estimated at F$33.4 million (1997 dollars). After interaction with the Fijian islands, *Gavin* proceeded on a southward course and continued to intensify, reaching its maximum strength on 9 March. Progress south brought an increase in vertical wind shear and a decrease in sea-surface temperature, causing the cyclone to slowly lose intensity. It made the transition to an extratropical depression late on 10 March and remained a powerful weather system as it passed to the northeast of New Zealand. Gales continued, but eventually ceased on 13 March.

***Justin* (Brisbane TCWC): 6 to 24 March 1997 (Fig. 5)**
Tropical cyclone *Justin* was a long-lived and destructive cyclone that affected Papua New Guinea, Queensland and the Coral Sea. Two tropical depressions embedded in a very active monsoon trough in the Coral Sea developed on 5 March. Over the next two days the lows merged and the deep convection and gales wrapped in towards the centre. On 7 March, *Justin* was named and then moved slowly west in response to a weak mid-level ridge. *Justin* intensified and with a broad area of gale-force winds extending out to at least 600 kilometres from the system centre, began buffeting Queensland's offshore islands. *Justin* intensified further on 9 March. Estimated maximum wind gusts of 42 m/s close to the centre and winds to 22 m/s along exposed parts of the central Queensland coast and islands blew down trees and produced minor damage to some houses. The system generated heavy seas and swells that extended onto the Queensland coast and islands between Cairns and Lady Elliot Island. The heavy seas, coinciding with high tides, produced massive beach erosion and inundation of foreshore areas between Cairns and Innisfail. A large pressure gradient between *Justin* and a high over Indonesia produced destructive storm-force winds over Papua New Guinea. Two people were killed in Madang when crushed by falling trees, and many lives were lost over waters to the south and east of Papua New Guinea.

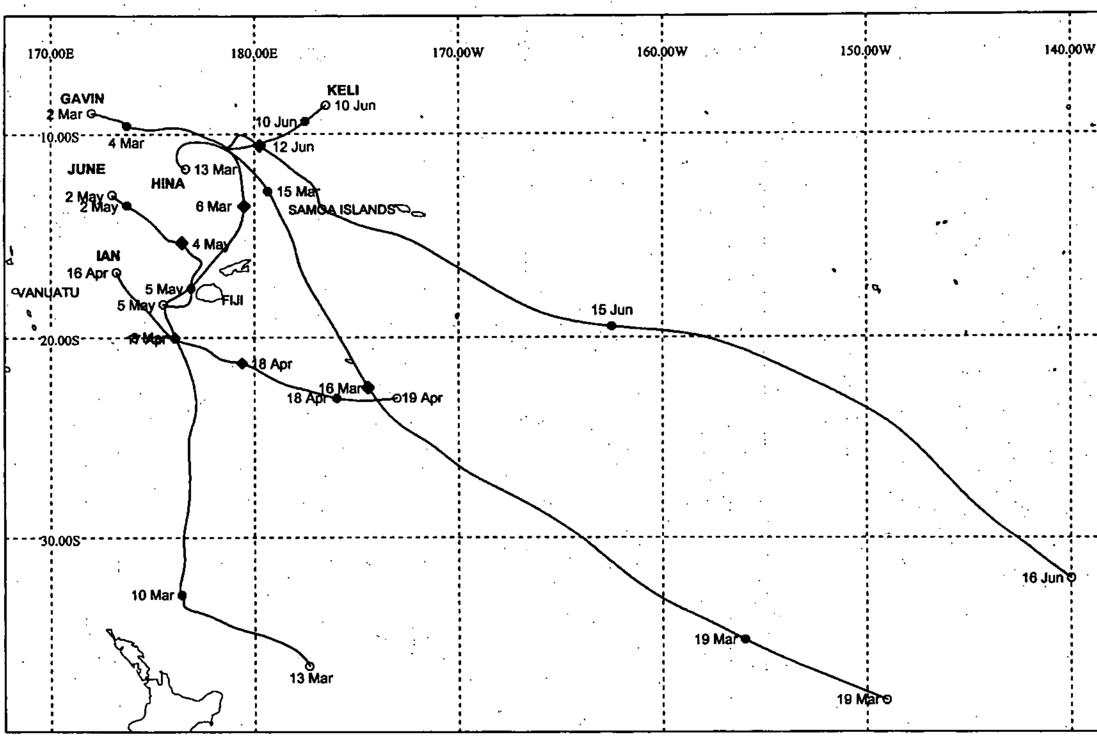
Over the next four days *Justin* drifted slowly northward, in a weak steering environment, passing close to Willis Island and producing more than 1000 millimetres of rain (exceeding the rainfall record for the station). The time spent by the cyclone in a small area lowered the SST and this, together with an increase in easterly vertical shear, weakened the system. On 13 March it was downgraded to a tropical low. *Justin* continued to drift slowly north, moved into warmer waters and re-intensified to tropical cyclone strength on 14 March. The cyclone continued a general northeast track before recurving and moving southward early on 16 March. *Justin* rapidly intensified and on 17 March reached maximum intensity (41 m/s) with a well-defined eye. The high pressure area over Indonesia six days earlier had moved over northern Papua New Guinea and as a consequence a very strong pressure gradient developed between this high and *Justin*. Winds over Papua New Guinea were destructive causing widespread damage. About 30 people were killed and 12000 were left homeless. A further five people died after their yacht sunk in the Coral Sea.

The cyclone began to be influenced by the mid-level ridge to its south and again tracked southwest toward the north Queensland coast. However, by 20 March, *Justin* had weakened due to increased upper easterly flow and movement over cold water associated with its previous path. The cyclone re-intensified as upper shear decreased and reached warmer water before crossing the coast on 22 March northwest of Cairns. The area sustained generally minor structural damage, but crop losses were high. Two people lost their lives. *Justin* moved further inland and weakened below cyclone strength. As it passed through the subtropical ridge it began to move southeast. Once again over water it re-intensified on 23 March, before strong upper northwest winds sheared convection away from the low-level circulation and the system dissipated. The proximity of the cyclone to the coast and torrential rain caused significant flooding and crop damage.

***Hina* (Nadi RSMC): 15 to 19 March 1997 (Fig. 6)**
Tropical cyclone *Hina* began as a shallow depression which developed along the Monsoon Trough in the vicinity of Rotuma around 12 March. On 13 March, the system began moving slowly northward, then east and finally southeast. Favourable developmental conditions led to intensification and *Hina* was named on 15 March. Shortly afterwards, *Hina* suddenly began accelerating and curved more south-southeastwards, passing over southern Tonga on 16 March. *Hina* was the worst tropical cyclone to hit the Kingdom of Tonga since *Isaac* in 1982 and took less than two hours to inflict considerable damage on the islands. Over 600 people were left homeless. Power lines and telecommunication systems were badly damaged, with structural damage to buildings reported. There was also extensive damage to agriculture and vegetation. Despite the seriousness of the damage, not one casualty was reported. The estimated cost of the damage in Tonga was reported to be around $18.2 million Tongan Pa'anga (approx. USD $15.2 million). *Hina* continued to move quickly southeast, finally dissipating over the southern Pacific on 19 March.

***Ian* (Nadi RSMC): 16 to 19 April 1997 (Fig. 6)**
A persistent trough was located in the South Pacific convergence zone region, convection increased, aided by an active intraseasonal oscillation pulse and a weak circulation formed on 13 April adjacent to the Solomon Islands. It moved eastwards over the next two days and on 15 April it began to slip south between Vanuatu and Fiji. As the upper ridge devel-

Fig. 6 Tracks of tropical cyclones *Gavin, Hina, Keli, June* and *Ian*. Symbols as in Fig. 1.



oped and convection increased, tropical cyclone intensity was reached on 17 April. With an upper subtropical ridge to the north, *Ian* moved off towards the southeast, attaining maximum intensity early on 18 April. As the cyclone accelerated eastward, increasing westerly shear began to destroy it and it weakened below tropical cyclone intensity on 19 April, east of the date-line.

***June* (Nadi RSMC): 1 to 5 May 1997 (Fig. 6)**
The development of June in the southwest Pacific was assisted by a westerly wind surge to its north and a strong high pressure system in the Tasman Sea, providing substantial low-level horizontal wind shear. This was in contrast to the climatological wind pattern of low-level easterly winds throughout the near-equatorial western Pacific. Upper outflow was favourable and June developed quickly as it moved to the southeast. Tropical cyclone intensity was reached on 3 May. As the system moved further south, the environment was not as favourable, with upper-level westerlies producing strong vertical wind shear. Hence *June* began to weaken as its steering became influenced by the strong easterly mid-level flow associated with the high pressure system to the southeast and it dissipated on 5 May over water after causing little damage.

***Rhonda* (Perth TCWC): 10 to 17 May 1997 (Fig .4)**
Rhonda formed from an area of persistent convection near 10°S 80°E in an active phase of the ISO. It reached cyclone strength on 11 May 1997. *Rhonda* remained south of the mid to upper-level ridge axis and tracked in an east-southeasterly direction on the northeast flank of a mid-level trough for its entire lifetime. Good upper outflow allowed *Rhonda* to intensify to 54 m/s during 14 May when south of Cocos Island. As the system moved further south upper shear increased and *Rhonda* then weakened quickly before dissipating and being absorbed into a cut-off low pressure system near the west coast of Western Australia during 17 May.

***Keli* (Nadi TCWC): 10 to 15 June 1997 (Fig. 6)**
Tropical cyclone *Keli* was the final cyclone of the 1996-97 season. *Keli* formed on June 10 from a depression just east of the date-line, that had been active for a few days. It crossed the date-line westwards on June 11, then slowed and reached its maximum intensity (41 m/s) a day later. The system did a

small loop and returned east of the date-line, where it weakened the following day due to increased vertical wind shear. *Keli* was downgraded to a tropical depression on 15 June when it was located about 370 km west of Rarotonga.

Acknowledgment

The cyclone tracks in this summary were prepared by Mr Kevin Smith from the Severe Weather Section, Regional Office, Bureau of Meteorology Perth using the Australian Tropical Cyclone Workstation.

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