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The South Pacific and southeast Indian Ocean tropical cyclone season 1997-98

L.-C. Chappel and P.W. Bate
Bureau of Meteorology, Darwin

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Twenty-three tropical cyclones formed in the South Pacific and southeast Indian Ocean during the 1997-98 tropical cyclone season. Of these, fifteen formed in the South Pacific east of 160°E, making the season for this region the biggest in terms of cyclone number and intensity in twenty years. Ten of these cyclones formed east of the date-line, an area used to little cyclone activity. Cyclone numbers in the Australian region were slightly less than average. The season was characterised by strong El Niño conditions, which peaked in the early months and had begun to decline by the end. Cyclone occurrences were linked to active phases of the 30 to 60-day intraseasonal oscillation.

Introduction

This paper provides a summary of the tropical cyclone activity in the southeast Indian Ocean (east of 90°E) extending eastward to the South Pacific Ocean (west of 120°W) during the 1997-98 cyclone season. The material has been gathered from information provided by the Australian Tropical Cyclone Warning Centres (TCWC) in Perth, Darwin and Brisbane and the Fiji Regional Specialised Meteorological Centre (RSMC) in Nadi. Where not specified wind speeds referred to are sustained winds, or ten minute averages. Intensity of cyclones given is generally an estimated value obtained by using the Dvorak technique of satellite imagery interpretation (Dvorak 1984). No great accuracy should be implied by the quoted wind speeds, in most cases values have been supplied in a rounded value in knots, then converted to metres per second. Where references are made to climatology of Australian Region cyclones the area referred to covers 90°E to 160°E. Data for this climatology was obtained by the first author from a review of the cyclone season summaries of this series published in the *Australian Meteorological Magazine* over the past 20 years. References to the climatology of tropical cyclone occurrences in the Pacific refer to the area 160°E to 120°W.

Tropical cyclone occurrence is set in the context of the broadscale circulation with particular reference to El Niño Southern Oscillation (ENSO) and the intraseasonal oscillations. For more detail regarding the broadscale circulation in the southern hemisphere and tropical circulation within the Darwin RSMC area of responsibility (70°E to180°) see seasonal summaries such as Courtney (1998) and Cleland (1998b).

Tropical cyclone occurrence

Twenty-three tropical cyclones formed in the South Pacific and southeast Indian Ocean during the 1997-98 tropical cyclone season. This is slightly above the 20-year average of near nineteen over the area between 90°E and 120°W. Details of the life-cycle of these events between 90°E and 120°W are given in Table 1. Cyclone occurrences in the south Indian Ocean west of 90°E are not discussed in this summary.

A feature of the season was the eastward shift in genesis area of tropical cyclones in the South Pacific. The South Pacific convergence zone (SPCZ) is the genesis area for most tropical cyclones in the South

Corresponding author address: Lori-Carmen Chappel, PO Box 40050, Casuarina, NT 0811, Australia.
Email: L.Chappel@bom.gov.au

Table 1. Tropical cyclones in the South Pacific and the southeast Indian Oceans 1997-98.

	Low First Identified			Initial Tropical Cyclone Phase			
Name	*Date*	*Lat.*	*Lon.*	*Date*	*Time (UTC)*	*Lat.*	*Lon.*
1. *Lusi*	08 Oct	7.9°S	170.0°E	09 Oct	1200	8.6°S	169.6°E
2. *Martin*	27 Oct	7.0°S	160.0°W	31 Oct	1500	10.1°S	165.8°W
3. *Nute*	18 Nov	11.2°S	165.2°E	18 Nov	1200	12.0°S	163.4°E
4. *Osea*	22 Nov	9.5°S	157.0°W	24 Nov	0000	12.3°S	157.9°W
5. *Pam*	05 Dec	9.0°S	166.0°W	06 Dec	0600	11.5°S	162.7°W
6. *Sid*	24 Dec	13.2°S	130.1°E	26 Dec	0000	10.9°S	132.2°E
7. *Selwyn*	25 Dec	11.9°S	110.9°E	26 Dec	1600	13.4°S	111.5°E
8. *Ron*	01 Jan	8.9°S	165.5°W	02 Jan	0000	9.6°S	167.8°W
9. *Susan*	20 Dec	6.0°S	171.0°W	02 Jan	1200	11.9°S	174.4°E
10. *Katrina*	02 Jan	15.0°S	152.0°E	03 Jan	0600	16.4°S	151.9°E
11. *Les*	21 Jan	15.5°S	140.0°E	23 Jan	1800	14.2°S	139.8°E
12. *Tiffany*	22 Jan	15.0°S	124.5°E	24 Jan	1600	17.2°S	122.0°E
13. *Tui*	25 Jan	10.8°S	174.0°W	25 Jan	2100	13.0°S	172.7°W
14. *Ursula*	29 Jan	14.0°S	152.0°W	30 Jan	1800	16.0°S	148.0°W
15. *Veli*	30 Jan	13.1°S	165.8°W	01 Feb	0000	13.7°S	152.8°W
16. *Wes*	31 Jan	12.2°S	173.4°W	01 Feb	0600	11.7°S	168.4°W
17. *Victor*	08 Feb	13.3°S	126.1°E	10 Feb	1000	15.4°S	119.4°E
18. *May*	24 Feb	10.5°S	137.5°E	25 Feb	1800	15.6°S	138.3°E
19. *Yali*	18 Mar	12.2°S	165.9°E	19 Mar	1800	13.3°S	163.7°E
20. *Nathan*	20 Mar	11.2°S	143.4°E	21 Mar	0000	11.2°S	143.7°E
21. *Zuman*	29 Mar	13.7°S	171.2°E	30 Mar	1200	13.9°S	169.8°E
22. *Alan*	18 Apr	10.0°S	157.0°W	21 Apr	1800	11.2°S	158.0°W
23. *Bart*	29 Apr	15.4°S	142.1°W	29 Apr	1800	17.2°S	139.8°W

Pacific basin. Its usual location extends southeastward from near the Solomon Islands (160°E). During the 1997-98 season the SPCZ shifted about 40 to 50 degrees of longitude, with the northern part extending from near the Northern Cook Islands (160°W). Consequently ten cyclones formed east of the dateline. The genesis points of tropical cyclones in the South Pacific during strong El Niño events have been well documented to spread further eastwards into the western hemisphere than in the opposite La Niña phase (Revell and Goulter 1986; Hastings 1990). Another notable feature was two instances of tropical cyclone 'twins' on opposite sides of the equator early in the season. This phenomenon is linked with the atmospheric and oceanic anomalies associated with El Niño (Lander 1990).

Cyclone numbers in the Australian region (90°E to 160°E) for the 1997-98 season were just below the 20-year average. Nine cyclones formed in or moved into the Australian region compared with a seasonal average of eleven to twelve. All nine cyclones developed in the region 105°E to 165°E, the area used by McBride and Keenan (1982) and Nicholls (1992) for cyclone climatology studies and a comparison between cyclone numbers and the Southern Oscillation Index (SOI). According to McBride and Keenan (1982) the average number of cyclones developing, redeveloping and moving into this region is near twelve per season, based on the 20 years from July 1959 to June 1979. Nicholls (1992) showed that a relationship existed between the year to year difference in cyclone numbers and the corresponding differences in pre-season (July to September) SOI, as well as between the number of cyclones per season and the pre-season SOI. Based on this work a large drop in SOI from the previous season and a strongly negative pre-season SOI would both suggest a significant reduction in cyclone numbers in the Australian region. Although the 1997-98 pre-season SOI fell to -15 from +6 the previous season, cyclone numbers from 105°E to 165°E during the 1997-98 season were only three below the average and also three below the previous season's number.

The 1997-98 cyclone season in the South Pacific

Table 1. Continued.

	Maximum Intensity (m/s)					End Tropical Cyclone Phase			
Name	*Date*	*Time*	*Lat.*	*Lon.*	*Mean wind (m/s)*	*Date*	*Time (UTC)*	*Lat.*	*Lon.*
1. *Lusi*	11 Oct	0000	17.0°S	173.5°E	26	12 Oct	0600	23.8°S	178.2°E
2. *Martin*	03 Nov	1200	16.4°S	154.4°W	41	05 Nov	1200	26.0°S	141.3°W
3. *Nute*	19 Nov	1800	16.1°S	159.6°E	31	21 Nov	0000	20.6°S	158.5°E
4. *Osea*	26 Nov	0600	17.0°S	152.0°W	41	28 Nov	0600	21.4°S	148.0°W
5. *Pam*	08 Dec	1200	19.5°S	160.6°W	31	10 Dec	1200	24.9°S	155.4°W
6. *Sid*	28 Dec	1800	14.0°S	138.0°E	26	30 Dec	1200	16.4°S	138.8°E
7. *Selwyn*	28 Dec	0400	15.9°S	108.4°E	39	30 Dec	2200	16.4°S	99.9°E
8. *Ron*	05 Jan	1800	13.4°S	175.7°W	64	08 Jan	1200	25.3°S	169.7°W
9. *Susan*	05 Jan	1800	15.3°S	170.0°E	64	09 Jan	1800	30.5°S	173.0°W
10. *Katrina*	15 Jan	1200	14.0°S	149.7°E	46	24 Jan	0600	18.0°S	153.1°E
11. *Les*	24 Jan	2100	14.4°S	136.1°E	31	25 Jan	1200	14.4°S	134.4°E
12. *Tiffany*	26 Jan	1600	18.4°S	118.0°E	51	30 Jan	0400	19.5°S	107.7°E
13. *Tui*	26 Jan	1200	14.2°S	171.9°W	21	27 Jan	0600	14.6°S	172.3°W
14. *Ursula*	01 Feb	0000	22.5°S	138.5°W	28	01 Feb	2300	30.0°S	130.0°W
15. *Veli*	02 Feb	0600	19.0°S	146.0°W	28	03 Feb	1200	22.6°S	143.1°W
16. *Wes*	03 Feb	0600	15.5°S	159.7°W	23	04 Feb	0600	16.8°S	158.7°W
17. *Victor*	12 Feb	1000	15.4°S	111.7°E	41	14 Feb	2200	19.5°S	97.0°E
18. *May*	26 Feb	0600	16.5°S	138.8°E	21	26 Feb	1200	17.3°S	138.7°E
19. *Yali*	22 Mar	0600	18.7°S	168.2°E	36	25 Mar	0000	25.1°S	162.1°E
20. *Nathan*	21 Mar	0600	11.3°S	143.9°E	21	26 Mar	1800	14.6°S	158.4°E
21. *Zuman*	02 Apr	0000	15.7°S	164.7°E	41	05 Apr	1800	22.0°S	168.1°E
22. *Alan*	25 Apr	0600	15.5°S	153.1°W	23	26 Apr	0000	17.1°S	150.5°W
23. *Bart*	30 Apr	0600	18.5°S	138.4°W	23	1 May	0000	19.7°S	136.1°W

commenced very early when *Lusi* formed east of the Solomon Islands at the start of October. This is the earliest cyclone to develop in the South Pacific in the last twenty seasons. The previous season had only ended four months earlier in June with *Keli* east of the dateline. The first cyclone of the Australian and South Pacific cyclone season occurs on average in late November and is most likely to form west of 125°E in the southeast Indian Ocean (author's analysis).

The 1997-98 cyclone season in the South Pacific was the most active season to have occurred in the last 20 years. The season was a record for both cyclone number and intensity of cyclones, as well as the length of season. A total of fifteen cyclones formed in the area between 160°E and 120°W, and another, *Katrina,* from Brisbane's area of responsibility, was in the area for a few days. Of the fifteen cyclones which formed, eight reached hurricane force. The average number of cyclones developing in this area is seven to eight, of which four reach hurricane strength. The season was the longest ever at 208 days, two days longer than the previous season, which was also a remarkably long season.

Tropical cyclone impacts

Three of the nine cyclones to form in the Australian region crossed the Australian coastline: *Sid, Les* and *May*. All three crossed the coast of the Gulf of Carpentaria at storm force intensity or below with minimal impact on the nearby communities. *Tiffany* developed near the coast and near gale-force winds affected the Pilbara coast of Western Australia as it moved parallel to the coast. The monsoon depression remnants of *Les* also produced gale-force winds on the Kimberley coast of Western Australia. However it was not the tropical cyclones which produced the major impact on the Australian continent, but flooding resulting from remnant lows. An active monsoon interacting with the remnants of *Sid* and *Les* produced heavy rain which resulted in the devastating flooding of Townsville in North Queensland and Katherine in the Northern Territory respectively. Major flooding also occurred in Queensland south of the Gulf of Carpentaria as a result of heavy rainfall produced by the remnants of *May*. Flooding also occurred over the Kimberley region from ex-*Les*.

Most island nations of the western South Pacific suffered some impact from one or more of the cyclones which developed in the region during the 1997-98 cyclone season. Wind damage caused much destruction of the lightweight traditional houses common in the Pacific. However, the most severe damage in many cases was a result of phenomena associated with the cyclone other than wind. Storm surge, coastal damage from heavy swells and landslides and mudslides resulting from heavy rainfall devastated many areas. A storm surge associated with *Martin* destroyed almost every building on Manihiki Atoll, Northern Cook Islands, and approximately 20 fatalities occurred on the island. Torrential rainfall from *Alan* caused landslides resulting in substantial loss of life and property in parts of the Society Islands, and was categorised as one of the worst natural disasters in French Polynesia in the last 20 years.

Large-scale circulation features

Averaged over the six months November 1997 to April 1998, positive pressure anomalies dominated much of the region; pressures were significantly lower than average only in the low latitude eastern Pacific. The subtropical ridge was much stronger than the long-term mean in both the southeast Indian and southwest Pacific oceans, with greater than 4 hPa anomalies analysed in the latter.

The intertropical convergence zone (ITCZ) was not well defined west of longitude 130°E. In the Indian Ocean the monsoon trough was very poorly developed; averaged over the six months, the mean low latitude flow was easterly in this region, rather than the climatological monsoon westerlies. Over the Indonesia/Papua New Guinea region, monsoonal westerlies were still weaker than average. Further east the anomaly pattern was reversed, with westerly equatorial anomalies indicating a weakened easterly wind field, and an enhanced SPCZ east of about 170°E. Equatorial westerly wind anomalies were strongest during the early part of the season, and contracted eastward during the latter half. A band of southeasterly anomalies affected a large area extending to the east-southeast from the Solomon Islands.

In the upper troposphere, divergent equatorial easterly anomalies were noted east of the date-line, typical of El Niño and providing the upper branch of an enhanced Hadley circulation. As with low-level flow, this anomaly pattern contracted eastward during the season. To the west, the upper ridge was mostly 2° to 5° of latitude equatorward of the climatological location, and low-latitude easterlies were generally below average strength. Velocity potential analyses based on the seasonal wind fields indicated that diagnosed broadscale tropical upmotion was generally weak over most of the region west of the date-line, but was enhanced further eastward.

Climate indices

During the southern hemisphere winter of 1997 El Niño conditions had become established (Cleland 1998a). This strong El Niño event persisted throughout this summary period, reaching maturity during the summer months (Courtney 1998). Troup's Southern Oscillation Index (SOI) remained at -15 or below for all months except December (-9), while the mean SOI for the six months November 1997 to April 1998 was -20. Although the SOI remained strongly negative, by April there were other indications, such as the weakening of Pacific sea temperature and broadscale atmospheric anomaly patterns, that the event was in decline.

Warm sea-surface temperature (SST) anomalies dominated most of the region, including virtually all of the near-equatorial band, all of the tropical Indian Ocean and much of the southwest Pacific. The only exception was a swathe of weak to moderate cool anomalies which extended toward the east-southeast from the vicinity of the Solomon Islands – the southern arm of the 'cool v' which typically surrounds the eastern Pacific El Niño warm anomaly. While the Pacific warm anomalies are typical of El Niño, over western parts it is likely that the warm anomaly was influenced by increased insolation and reduced surface mixing, a consequence of the weak monsoon. Warm anomalies in the central Pacific peaked during the period October to December 1997, then gradually eased during the next four months.

Broadscale tropical convection, as indicated by outgoing long wave radiation (OLR), was generally suppressed (positive OLR anomalies) throughout the period over the region west of the date-line. In contrast, convection was enhanced close to, and east of this longitude. Increased convective activity became apparent during March and April 1998 over parts of the southern Indian Ocean and western parts of Australia, possibly resulting partly from the very warm SST that developed in the tropical Indian Ocean during the period of suppressed convection. In addition, active conditions were noted over northern Australia during much of December 1997 and over a region encompassing northeast Queensland and the adjacent southwest Pacific region in January and March 1998.

Intraseasonal modulation

Intraseasonal activity is inferred from time-longitude sections of 200 hPa velocity potential, OLR, and sea level pressure anomaly, station pressure series and daily satellite imagery. Averaged through the entire season the strongest convection was apparent between about the date-line and 140°W. However, periods of moderate activity progressed across much of the longitude range at roughly 30-day intervals. This appears to be the most dominant intraseasonal mode, though other frequencies made it difficult to isolate. The 30 to 60-day intraseasonal (Madden-Julian) oscillation (ISO) was evidently active at the higher frequency end of the range during the period, at least for the four months December to March when activity was strongest. Most tropical cyclones developed during these active phases.

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 analysed best-track positions. For comparison, verification statistics for persistence forecasts based on operational track movement vectors were

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.

	Forecast Lead Time											
	0 h		*12 h*			*24 h*			*48 h*		
Name	*error (km)*	*number*	*error (km)*		*number*	*error (km)*		*number*	*error (km)*		*number*
1. *Lusi*	29	18	145	(163)	10	211	(312)	8			
2. *Martin*	45	19	169	(184)	15	320	(357)	10			
3. *Nute*	31	15	128	(145)	11	215	(209)	7			
4. *Osea*	42	25	114	(138)	17	222	(255)	15			
5. *Pam*	14	23	88	(118)	16	137	(205)	12			
6. *Sid*	37	11	97	(118)	8	222	(299)	4			
7. *Selwyn*	43	21	82	(109)	16	146	(160)	12	299	(-)	6
8. *Ron*	22	29	84	(83)	24	163	(169)	21			
9. *Susan*	10	23	73	(76)	19	180	(231)	15			
10. *Katrina*	27	90	94	(105)	86	161	(205)	82	286	(440)	56
11. *Les*	35	8	82	(67)	5	166	(144)	5			
12. *Tiffany*	19	27	65	(67)	25	111	(126)	20	214	(-)	9
13. *Tui*	36	10	175	(175)	5	352	(339)	4			
14. *Ursula*	44	13	164	(157)	7	331	(390)	6			
15. *Veli*	45	11	180	(197)	7	211	(182)	2			
16. *Wes*	39	20	131	(139)	13	244	(277)	12			
17. *Victor*	54	24	140	(138)	22	242	(221)	19	489	(-)	9
18. *May*	30	13	123	(111)	2	-	-	-			
19. *Yali*	27	25	126	(141)	17	253	(328)	16			
20. *Nathan*	27	25	96	(131)	21	187	(307)	17	315	(666)	9
21. *Zuman*	16	30	86	(99)	25	166	(203)	22			
22. *Alan*	59	24	117	(143)	9	205	(327)	7			
23. *Bart*	26	9	163	(87)	6	94	(144)	1			
Total		512			386			320			89
Weighted Average											
1997-98	31		106	(117)		189	(229)		303	(471)	
Australian Region											
10-year average											
1987/88 - 1996/97	45		115			201			381		

also calculated. Warning responsibility for two cyclones in the Coral Sea (*Nute* and *Katrina*) was shared between Brisbane TCWC and Nadi RSMC. Forecasts issued by Nadi RSMC were verified when the cyclone's initial position was east of 160°E; and west of 160°E Brisbane forecasts were verified.

Verification results for the 1997-98 tropical cyclone season were on average an improvement on the previous season's statistics and also on the ten-year Australian region average (1987-88 to 1996-97). The official TCWC and RSMC forecasts were generally better than the persistence forecasts also. Forecast accuracy for *Tiffany*, *Pam*, *Selwyn*, *Ron*, *Katrina*, *Les* and *Zuman* was particularly good with errors at 24 hours in the range 110 to 170 km. The forecast accuracy for *Tiffany* for 24 hours was near 110 km, a result of good initial position fixes from the intensity and small size of the cyclone, and of the relatively persistent track. *Katrina's* forecast positions were also good despite the track changing directions many times. Most of these cyclones with the exception of *Ron, Katrina* and *Zuman* had a uniform track, though operational forecasts still performed better than persistence. Of these cyclones *Pam*, *Selwyn* and *Les* did not reach hurricane strength but did have relatively uniform tracks.

Tropical cyclones in the South Pacific and southeast Indian Ocean 1997-98

1. *Lusi* (Nadi RSMC): 8 – 12 October 1997 (Fig. 1)

The development of *Lusi* in early October brought a very early start to the cyclone season. *Lusi* reached storm force intensity as it traversed the South Pacific for three days but had little effect on any islands.

Early in October active near-equatorial troughs were evident either side of the equator in the western Pacific east of 160°E with anomalous westerly flow in between. The climatological pattern at this time of year indicates easterly winds. An area of active convection south of the equator formed into a tropical depression on 8 October, about 1000 km east of the Solomon Islands. The system moved south closer to the upper ridge, and with the resulting improved outflow developed into a tropical cyclone on 9 October. At similar longitudes in the northern hemisphere typhoon *Ivan*, then super typhoon *Joan* followed the development of *Lusi* by several days. Over the next few days *Lusi* moved south-southeast steered by an approaching mid-latitude trough and passed between Vanuatu and Fiji. *Lusi* reached peak intensity of 26 m/s two days after development while 350 km west of Fiji. Increasing vertical wind shear and cooler sea surface temperatures caused *Lusi* to weaken. The cyclone was downgraded to a depression on 12 October. *Lusi* brought gales and some heavy rainfall to some of the southwestern islands in the Fiji group.

2. *Martin* (Nadi RSMC): 27 October – 5 November 1997 (Fig. 2)

Martin was the first tropical cyclone for the season to reach hurricane intensity. *Martin* developed west of the Northern Cook Islands and travelled southeast, causing a destructive storm surge over Manihiki Atoll before weakening and passing southwest of Tahiti.

A weak tropical disturbance developed north of the Northern Cook Islands on 27 October. Convection remained disorganised for several days as the system was being affected detrimentally by strong upper-level northeast winds. On 31 October the system began to show a marked improvement in organisation and began developing rapidly. *Martin* was named about 500 km west of Manihiki, Northern Cook Islands. The cyclone moved to the southeast over the following days, passing about 150 km south of Manihiki Atoll. *Martin* reached maximum intensity of 41 m/s on 3 November while passing near the westernmost islands of the Society group (Bellingshausen, Mopelia and Scilly) where eight deaths were reported. Early on 4 November the cyclone began to weaken steadily and accelerate to the southeast, passing more than 250 km to the southwest of Tahiti.

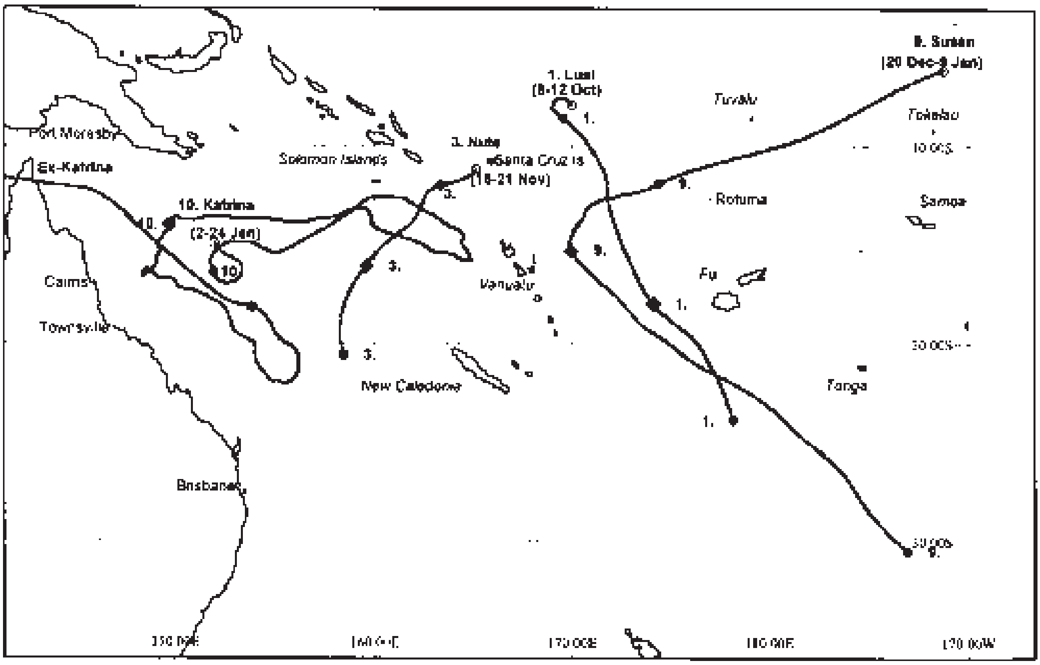
Martin was quite destructive at Manihiki Atoll. When the centre was closest to the island, the automatic weather station reported a lowest pressure of 994hPa, sustained winds of 20 m/s, and a highest gust of 29 m/s. However, this was the last meteorological report from the station before it was destroyed by storm surge. There were 10 known fatalities on Manihiki with 10 more persons reported missing (and presumed drowned). Almost every building on the island was destroyed by the storm surge.

3. *Nute* (Nadi RSMC and Brisbane TCWC): 18 – 21 November 1997 (Fig. 1)

During the second half of November an active phase of the intraseasonal oscillation produced two cyclones in the southwest Pacific: *Nute* west of the date-line then *Osea* east of the date-line. *Nute* developed south of the Solomon Islands during November and traversed an island-free area of the western South Pacific for several days before decaying between New Caledonia and the Queensland coast without causing any damage.

A tropical depression within the South Pacific convergence zone was located about 100 km southwest of Santa Cruz Island in the Solomons on 18 November. The depression was steered to the southwest by the middle level ridge to the south of the system. *Nute*

Fig. 1 Tracks of early season tropical cyclones *Lusi*, *Nute*, *Susan* and *Katrina* in the western South Pacific. Open circles denote start and finish of the tropical low phase (finish not always included), filled circles indicate the start and end of the tropical cyclone phase. A filled diamond indicates the time at which the maximum intensity was reached. Cyclone number, name and dates are located near the start of tropical low phase. Numbers near a cyclone track point correspond to the cyclone numbers in tables 1 and 2.



developed rapidly initially in an area of increasing upper divergence and favourable sea surface temperatures. Maximum winds reached 31 m/s on 19 November and intensity remained steady until 20 November when the system began to weaken rapidly. An approaching mid-latitude trough resulted in shearing of the cyclone, entrainment of dry air and a recurvature to the southeast. *Nute* dissipated on 21 November west of New Caledonia.

4. *Osea* (Nadi RSMC): 22 – 28 November 1997 (Fig. 2)

Osea developed near the Northern Cook Islands during November as *Nute* further to the west was decaying. *Osea* travelled to the southeast reaching hurricane intensity and caused extensive damage to the northernmost Society Islands, before passing just west of Tahiti.

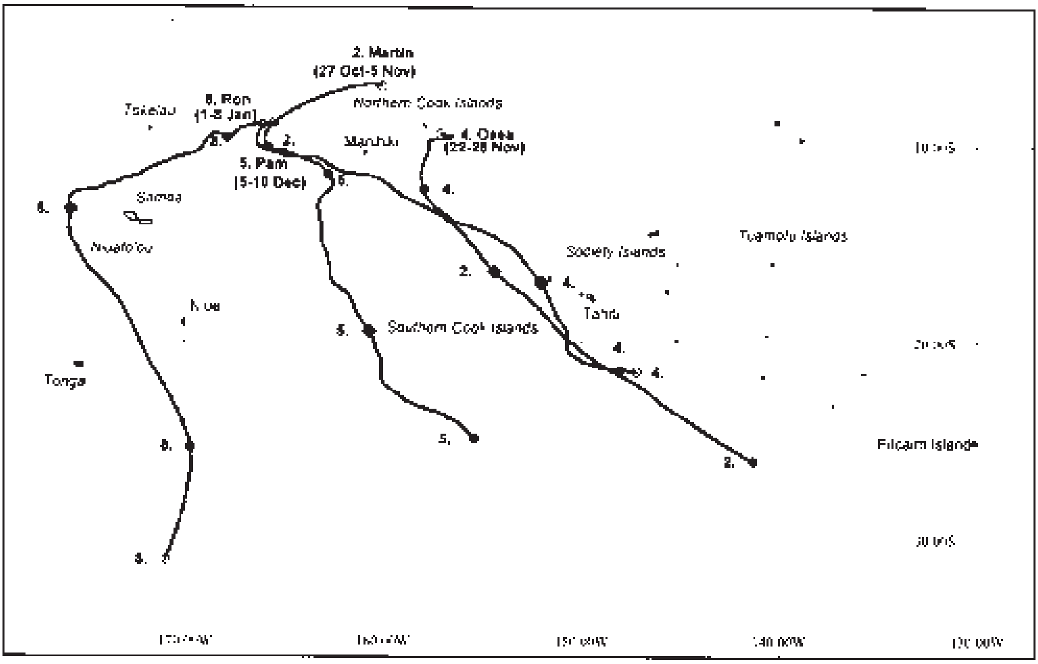
Osea began as a tropical depression northeast of Manihiki Atoll, Northern Cook Islands on 22 November. The depression remained weak and drifted very slowly southward for the next two days, before it was named, about 400 km southeast of Manihiki. *Osea* began to intensify and moved a little faster on a southeast course. Hurricane intensity was reached on 25 November as *Osea* was passing the northwestern most islands of the Society group (about 550 km west-northwest of Tahiti) with peak winds of 41 m/s occurring during 26 November. From then the cyclone began to weaken steadily. On 28 November, *Osea* was downgraded to a depression south of Tahiti.

Osea was quite destructive to some of the northwestern Society Islands. More than 700 homes were destroyed or badly damaged on Maupiti, Bora-Bora, and Raiatea. On Maupiti (population 1100) about 95 per cent of the infrastructure (including the town hall, two schools, and an airfield) were destroyed. On Bora-Bora (population 4500) roughly 30 per cent of the infrastructure was destroyed. There was no loss of life reported from *Osea*.

5. *Pam* (Nadi RSMC): 5 – 10 December 1998 (Fig. 2)

Pam developed east of the date-line at the same time super typhoon *Paka* was developing across the equator in the North Pacific. *Pam* travelled to the south and southeast over several days, not quite reaching hurricane intensity and weakening before its centre passed near Rarotonga on the Southern Cook Islands.

Fig. 2 **Tracks of early season tropical cyclones *Martin*, *Osea*, *Pam* and *Ron* in the South Pacific east of the date-line. Symbols as in Fig. 1.**



Convection in the tropics was focussed to the east of the date-line in early December. A tropical depression developed between Samoa and the Northern Cook Islands on 5 December. An equatorial westerly wind burst at this time produced cyclone twins either side of the equator. *Paka* formed in the North Pacific about 3 December and *Pam* and was named on 6 December as it slowly drifted to the south-southeast. *Pam* started moving a little faster to the south-southeast, with the automatic weather station on Aitutaki Atoll, Southern Cook Islands, reporting winds of 17 m/s on 7 December, indicating a reasonably large radius of gales. At this time the centre was about 370 km west-northwest of the atoll. The cyclone reached maximum intensity of 31 m/s on 8 December about 150 km southwest of Aitutaki. *Pam* passed about 75 km southwest of Rarotonga on 9 December. By this time the storm was beginning to weaken as it turned to a southeast course. Rarotonga reported maximum sustained winds of 20 m/s with peak gusts of 33 m/s. By 10 December *Pam* was rapidly weakening and losing its tropical characteristics.

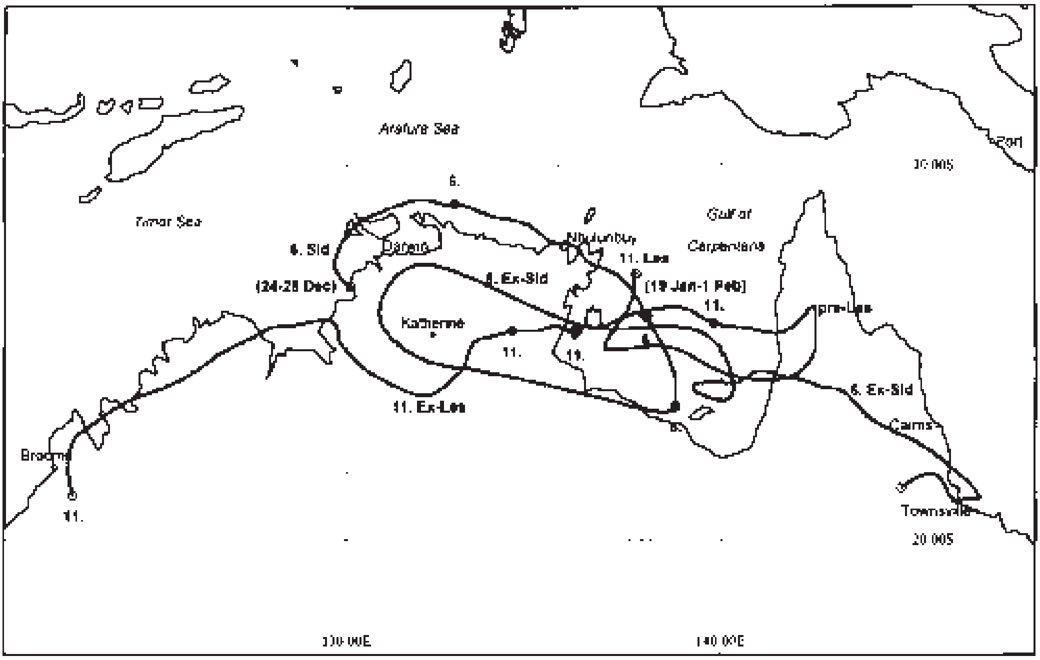
Damage on Rarotonga was light, mainly consisting of fallen trees and power lines. A few houses lost their roofs. There was some flooding of low-lying roads due to both heavy seas and rain. During the passage of *Pam* 149 mm of rainfall was recorded in a six-hour period. There were no reports of casualties due to the cyclone.

6. *Sid* (Darwin TCWC): 24 – 28 December 1997 (Fig. 3)

An active phase of the intraseasonal oscillation late in December and early January resulted in the formation of five cyclones: *Sid, Selwyn, Ron, Susan* and *Katrina*, across the Australian and southwest Pacific Ocean tropical cyclone basins. *Sid* was the first of these to develop as a cross-equatorial surge resulted in the formation of the monsoon trough near northern Australia. *Sid* developed very close to the Northern Territory's north coast near Darwin before moving east along the coast, then south into the Gulf of Carpentaria before decaying. The remnant low produced record and devastating flooding two weeks later around Townsville in North Queensland.

A low pressure system over the northwest of the Northern Territory moved just offshore into the Timor Sea. Interaction with monsoon westerlies then steered the low eastward along the coast with *Sid* forming on 26 December in the Arafura Sea, 70 km from the

Fig. 3 Tracks of mid-season tropical cyclones *Sid* and *Les* over northern Australia. Symbols as in Fig. 1.



Northern Territory coast. Further intensification was restricted by the proximity to the coast. The cyclone reached the edge of the Gulf of Carpentaria on 27 December after passing close to the town of Nhulunbuy. It then took a south-southeast course into the Gulf of Carpentaria as the system came under the influence of a high amplitude middle level ridge in the Coral Sea. *Sid* briefly intensified early on 28 December in the central Gulf reaching a maximum sustained wind speed of 26 m/s. It then weakened below cyclone intensity under the influence of upper level shearing as it approached the southern Gulf coast late on 28 December.

As *Sid* passed the township of Nhulunbuy and Groote Eylandt trees were uprooted and powerlines were damaged at both locations. Two craft dragged their moorings and one was washed against rocks at Nhulunbuy Yacht Club.

Over the week and a half following *Sid's* decay the remnants meandered about the Top End of the Northern Territory and Gulf of Carpentaria without redeveloping into a cyclone. The low finally moved into Queensland in early January.

Whilst remaining near stationary near Townsville the low acted as a focal point within the monsoon trough, bringing heavy rainfall to North Queensland and causing major flooding. Townsville recorded 549 mm of rain in the 24-hour period ending 2300 UTC 10 January, with another 245 mm falling during the next two days. Included in the first days rainfall was a total of 120.6 mm in one hour and 205.2 mm in two hours. The flooding resulted in the loss of one life when a man was drowned after his car was washed off a creek crossing in Townsville. In Townsville around 100 houses had substantial over-floor flooding with hundreds more sustaining property flooding. Numerous cars were damaged by flooding, and up to 50 per cent of the houses in Townsville lost power at some stage. Damage to local Government infrastructure was high. On Magnetic Island just offshore from Townsville, a landslide caused major damage to a tourist complex. The small communities of Black River and Bluewater north of Townsville suffered extensive damage from flash-flooding. Forty-eight houses were affected in this area with the majority rendered uninhabitable. Fourteen of these were totally destroyed with eight washed away. One hundred houses experienced over-floor flooding in the towns Halifax and Ingham north of Townsville. There was also extensive damage to the rural sector. Wave action and storm surge inflicted severe damage and erosion to coastal areas around Townsville with damage from these effects quoted as reaching A$19m. The sea reached a level just below highest astronomical tide level at 2220 UTC 10 January and the Townsville wave recording station recorded a maximum significant wave height of 5.41 metres at 0500 UTC 10 January. Seven vessels sank in Townsville harbour. The total damage bill was estimated to be well in excess of A$100m.

7. *Selwyn* (Perth TCWC): 26 December 1997 – 3 January 1998 (Fig. 4)

Selwyn formed about 650km east-southeast of Christmas Island in the Indian Ocean from an area of convection within the monsoon trough. It developed at the same time *Sid* was developing near the Northern Territory coast. *Selwyn* moved to the southwest, briefly reaching hurricane intensity before decaying 600 km southeast of Cocos Island.

Selwyn formed on 26 December in a low shear area beneath the axis of the upper ridge. There was moderate low-level cross-equatorial northwest flow to the north of both *Selwyn* and *Sid*. Initially movement was slow. The cyclone was then steered southwest as it moved around the shoulder of the mid-level high to its southeast. A well-developed eye formed on 28 December prior to *Selwyn* reaching a maximum sustained wind speed of 39 m/s. The cyclone then moved south of the upper ridge axis and encountered strengthening mid-level northwest winds together with increasing low-level southeast winds on its southern side. The cloud field around the cyclone became elongated along a northwest-southeast axis. *Selwyn* became sheared and a low-level centre was exposed on the northern flank of the cloud mass on 29 December. It then began a west-northwest track. *Selwyn* finally decayed below tropical cyclone strength on 30 December, with the remnant low continuing its westward track.

Selwyn was a reasonably small cyclone during its lifetime and thus was able to intensify rapidly in its development stage but was also susceptible to vertical wind shear. Apart from increasing swell along the northwest coast of Western Australia the cyclone had no direct impact on the Australian mainland or island communities

8. *Ron* (Nadi RSMC): 1 – 8 January 1998 (Fig. 2)

Tropical cyclone *Ron*, with the concurrent *Susan*, were the two most intense cyclones to form in the South Pacific in recent years. Both generated estimated maximum sustained winds of 64 m/s. The last previous tropical cyclone to possibly reach this intensity in the South Pacific was tropical cyclone *Hina* in March 1985. *Ron* was a relatively small cyclone but caused major damage to northern parts of the Tongan group as it crossed.

A depression was identified east of the date-line on 1 January when the system was centred about 850 km northeast of Samoa. Tropical cyclone intensity was reached on 2 January. *Ron* drifted slowly towards Samoa, passing to the north. Intensification proceeded at a fairly rapid rate and the peak intensity of 64 m/s was reached on 5 January when *Ron* was centred about 450 km north-northwest of Apia, Western Samoa, three days after initial development. The cyclone maintained this strength for about 36 hours. During 5 January *Ron* recurved on a south-southeast course. On 6 January the cyclone passed very close to the island of Niuafo'ou, Tonga, where considerable damage occurred. Niuafo'ou reported sustained winds of 31 m/s with a pressure of 983.7 hPa. The lowest pressure observed on the island during *Ron's* passage was 972.4 hPa with estimated maximum winds from 35-40 m/s. *Ron* was a relatively compact cyclone. A 10-min average wind speed of only 9 m/s with gusts to 16 m/s was reported from Wallis Island at 0000 UTC 5 January, then located about 180 km southeast of the centre.

After passing Niuafo'ou *Ron* began to weaken steadily as it started to accelerate to the southeast. The storm passed between central Tonga and Niue on 7 January and, by 9 January, had been absorbed by the much larger circulation of tropical cyclone *Susan*.

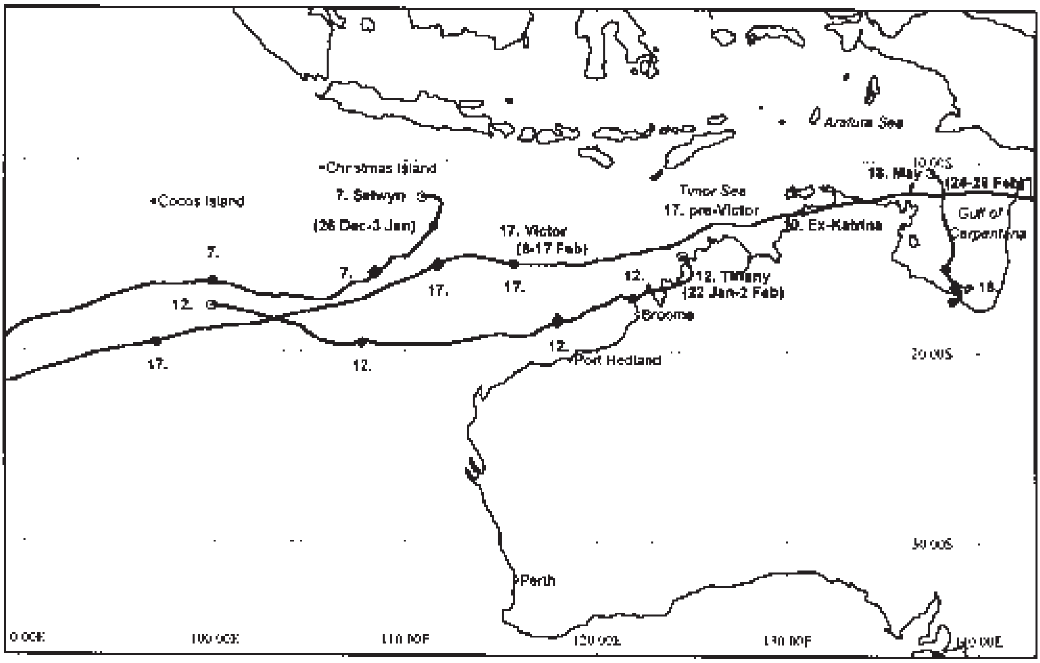
The greatest damage from *Ron* occurred on the Tongan island of Niuafo'ou (population 735). About 67 per cent of the buildings were either damaged or destroyed. Many of these were Tongan fales (thatched houses). Agricultural losses were also severe. Between 80 and 90 per cent of coconut and breadfruit trees were damaged, and losses of food crops such as taro, kape, manioc, and bananas were estimated at 95 per cent. The *Tonga Chronicle* reported that it would take about five years for crop production to return to pre-cyclone levels. The cost of rehabilitation (houses, food, water, etc.) is estimated at $T1,100,000. Fortunately no deaths were reported.

Some damage was also reported on the Tongan islands of Niuatoputapu, Tafahi, and Vava'u but was generally not as severe as on Niuafo'ou.

9. *Susan* (Nadi RSMC): 20 December 1997 – 9 January 1998 (Fig. 1)

While being quite an intense and rapidly developing cyclone, *Susan* resulted in a relatively minor impact on the South Pacific. Recurvature near peak intensity spared Vanuatu a direct hit, and the main effect of the cyclone was coastal damage on Fijian islands from heavy seas and swell as the cyclone passed to the west.

Fig. 4 Tracks of tropical cyclones *Selwyn*, *Tiffany*, *Victor* and *May* over the Indian Ocean and northern and western Australia. Symbols as in Fig. 1.



Tropical cyclone *Susan* developed from a disturbance which had been tracked since around 20 December when it was just north of Tokelau (north of Western Samoa). Over the next two weeks the system drifted very slowly to the west-southwest. The tropical disturbance finally developed into *Susan* on 2 January during a particularly active period of convection in the southwest Pacific. At this stage the disturbance was located west of the date-line near the island of Rotuma. *Susan* developed in a low shear environment with northeasterly steering. It was initially located north of the upper ridge, but with a good outflow which increased as it moved west-southwest. *Susan* intensified rapidly to hurricane strength within 36 hours of initial development. On 5 January the storm came within about 400 km of Port Vila, Vanuatu as it reached an estimated peak intensity of 64 m/s and central pressure of 900 hPa. The cyclone posed a severe threat to Vanuatu, but recurved in time to spare the country a direct hit. A mid-latitude trough approaching from the west steered and accelerated Susan toward the southeast. On 7 and 8 January *Susan* passed close enough to Fiji to cause gales in the westernmost islands of the group.

After passing by Fiji *Susan* continued accelerating on a southeast course which converged with that of *Ron*. Cyclone *Ron* was absorbed into *Susan's* larger circulation by 9 December and the combined system became extratropical shortly afterwards about 1300 km east-northeast of Auckland, New Zealand. Winds remained well above hurricane force as *Susan* made the transition to a vigorous extratropical cyclone.

One fatality resulted from *Susan*. A woman was killed by a falling coconut tree on Ambrym Island, Vanuatu. Overall, damage from *Susan* was minor. However, high seas, a heavy swell and storm surge inundated a village on Kadavu, Fiji and partly destroyed beach-fronts, roads, jetties and bridges on the island. Beqa Island was also affected by high seas and swell. Some damage due to tornadic winds in a cyclone feeder band occurred at shops in Lautoka, a port city in western Viti Levu, Fiji.

10. *Katrina* (Nadi RSMC and Brisbane TCWC): 2 – 24 January 1998 (Fig. 1 and Fig. 4)

Katrina was an erratic and extremely long-lived cyclone which spent three weeks in the Coral Sea and South Pacific Ocean between the Queensland coast and

Vanuatu. After its decay the remnants of Katrina moved westward over Cape York Peninsula, past the Northern Territory and into the Indian Ocean where it developed into tropical cyclone *Victor* during February. *Victor* was then re-named *Cindy* as it moved into La Reunion RSMC in the central Indian Ocean. *Katrina* developed in early January during an active phase of the intraseasonal oscillation after *Sid* had weakened to the west and *Ron* and *Susan* were developing to the east.

A tropical low within the active monsoon trough in the Coral Sea was named *Katrina* on 3 January as an upper ridge provided the system with good outflow. The pre-*Katrina* low had been looping in the Coral Sea, then commenced an eastward movement after development as a result an increase in the deep westerly monsoon flow to the north of the system. *Katrina* passed about 120 km to the south of Rennell Island, southern Solomon Islands on 7 January, reaching hurricane intensity on 9 January just prior to reaching the most easterly point of its track. The cyclone came within 220 km of Vanuatu's northernmost island Espiritu Santo on 9 January before recurving back to the west due to weakening of the monsoon westerlies and the development of an anticyclone to the south. *Katrina*'s intensity peaked at a sustained wind speed of 42 m/s on 10 January, before temporarily weakening as the cyclone moved west-northwest and the upper ridge moved to the south, reducing upper outflow. The storm passed for a second time about 280 km south of Rennell Island on 11 January.

Katrina began deepening again on 14 January as the upper ridge moved north over the system once again and improved upper-level outflow. The maximum intensity with sustained winds of 46 m/s was reached during 15 and 16 January within 500 km of the north Queensland coast. The cyclone at this point started moving south-southwest, and weakened while executing a clockwise loop before moving off to the east-southeast as the northwest monsoon flow increased. *Katrina* moved southeast parallel to the Queensland coast for several days with fluctuating intensity, before turning once again to the northwest and weakening as a mid-latitude trough sheared the system. The cyclone finally weakened to a tropical depression on 24 January. The remnants of *Katrina* continued to move west towards the coast and finally moved north and weakened substantially east of Cairns. A weak circulation persisted for a further two weeks and drifted westwards across north Australian and into the Indian Ocean.

One fatality was reported in Vanuatu when a man fishing from a reef was swept away by rough seas. In the Solomon Islands, 200 homes were destroyed on southern Guadalcanal and 450 homes destroyed on the islands of Rennell and Bellona.

11. *Les* (Darwin TCWC and Perth TCWC): 19 Jan – 1 Feb 1998 (Fig. 3)

Les was the first of a group of six cyclones to develop across the Australia and South Pacific regions during an active phase of the intraseasonal oscillation in late January and early February. *Les* developed rapidly in the Gulf of Carpentaria and was near hurricane strength just prior to landfall on the Arnhem Land coast. Little damage was caused by the cyclone at landfall, however heavy rainfall and devastating floods in the Katherine region were produced by the remnant depression as it moved inland over the Top End of the Northern Territory. The remnants of *Les* continued moving west and produced gale-force winds on the Kimberley coast of Western Australia as the monsoon depression intensified temporarily near the coast before moving further inland.

A deep westerly monsoon surge interacted with a low embedded in the monsoon trough in the Gulf of Carpentaria on 20 January. The surge eased after several days. By this stage the low-level centre had been pushed over Cape York Peninsula. The low started developing a more organised structure during 22 January, with rainbands over the land and sea either side of the peninsula around the centre. Upper-level return equatorial easterly flow was well developed with a 25 m/s jet over Papua New Guinea and Indonesia. At this time a strengthening high pressure ridge in the low to middle levels over Queensland initially pushed the low north along the Peninsula, then westward, returning it to the Gulf of Carpentaria. Deep convection persisted near the low's centre as it moved in the Gulf of Carpentaria and *Les* formed early on 24 January, about 12 hours after moving over the sea. The cyclone intensified rapidly with favourable upper outflow, attaining near hurricane strength 24 hours after initial development. Les showed signs of eye formation before its intensification was temporarily retarded as the core crossed the south coast of Groote Eylandt. Some re-intensification occurred in the eighty km of sea between Groote Eylandt and the mainland. A peak wind gust of 47 m/s was recorded by a bulk ore carrier in *Les's* path in this area. At this time the gale radius extended to 110 km, storm force winds to 35 km and the radius of calm winds to about 7 km. *Les* passed over the town of Numbulwar on the mainland coast early on 25 January.

There were several roofs blown off old houses, trees blown down and power outages at Numbulwar and the communities on Groote Eylandt. Local flooding was reported as well as a one metre rise in sea level above high tide at Alyangula, the Groote Eylandt port.

The westward steering continued to dominate over the next five days as the post-cyclone low crossed the Top End of the Northern Territory, Joseph Bonaparte Gulf then the north Kimberley coast. As ex-*Les* crossed the Top End of the Northern Territory during the period 25 to 29 January record rainfall fell in the catchment of the Katherine River. In the 72 hours to 2330 UTC 27 January 400 to 550 mm of rainfall was recorded, causing the most significant flood on record in the Katherine and Daly rivers. Thousands of residents in the towns of Katherine, and the communities of Mataranka, Palumpa, Peppimenarti, Daly River and Beswick were evacuated. Three people drowned. The flood covered an area of about a thousand square km, affected 1100 dwellings and flooded every business and government office in the central business district of Katherine. About 640 business owners, primary producers, and contractors were affected. Road traffic was severely disrupted with highways washed out in many places across the region. Darwin was cut off from the remainder of the country by road and many travellers and goods were stranded for at least five days. Telecommunications were also severely disrupted with one of the two fibre optic cables connecting the Top End with the remainder of Australia being cut. Repairs to flood damaged buildings and infrastructure in Katherine were estimated to have cost more than A$100m.

As the ex-*Les* low continued westward it crossed into the Joseph Bonaparte Gulf on 29 January before once again moving over land on the north Kimberley coast. Gales were observed along the Kimberley with the low having the structure of a well-developed monsoon low with gales at a large distance from the centre. Flooding and damage to trees and power lines occurred in the Kimberley communities of Kalumburu and Oombulgurri. The low followed the west Kimberley coast, causing some minor tree damage at Broome and around 200 mm of rain in two days before moving inland and weakening over the Pilbara region of West Australia.

12. *Tiffany* (Perth TCWC): 22 January – 2 February 1998 (Fig. 4)

Tiffany formed off the northwest Kimberley coast of Western Australia as *Katrina* intensified in the Coral Sea and *Les* formed in the Gulf of Carpentaria.

Tiffany formed during an active monsoon period when cross-equatorial flow into the Australian region coincided with a strong southeast surge in the low-level flow south of the system. A low over the Kimberley coast developed into a cyclone almost as soon as it moved offshore. It subsequently intensified rapidly into a small but intense cyclone in a region of low wind shear and moved generally west or west southwest, remaining offshore from the Pilbara coast at a distance of approximately 200 km. Maximum intensity of 51 m/s was reached overnight on 26 January while 230 km north-northwest of Port Hedland. Approximately nine hours after maximum intensity was reached, as estimated from satellite images using the Dvorak technique, the eye of the cyclone passed over a buoy. A minimum central pressure of 958 hPa was observed followed an hour later by an observed maximum mean wind speed of 47 m/s. The central pressure was higher than would be observed for an average sized cyclone off the West Australian coast, but is consistent with the pressure drop observed from the surrounding environment in a small cyclone. *Tiffany* had a radius of gales between 100 and 130 km, storm-force winds occurred within 50 km of the centre and hurricane-force winds extended outwards a distance of only 30 km. The gale radius had an asymmetric distribution towards the southern side due to a strong high pressure system to the south. This resulted in strong winds in the Port Hedland area well outside the core of strong winds associated with the cyclone centre.

Tiffany caused strong to near gale-force winds on exposed areas of the Pilbara coast and storm-force winds at North Rankin offshore gas platform during 27 January but had no other effect on coastal Western Australia. The cyclone weakened as it continued to move westwards and finally decayed below tropical cyclone strength in the Indian Ocean about 700 km south-southeast of Cocos Island.

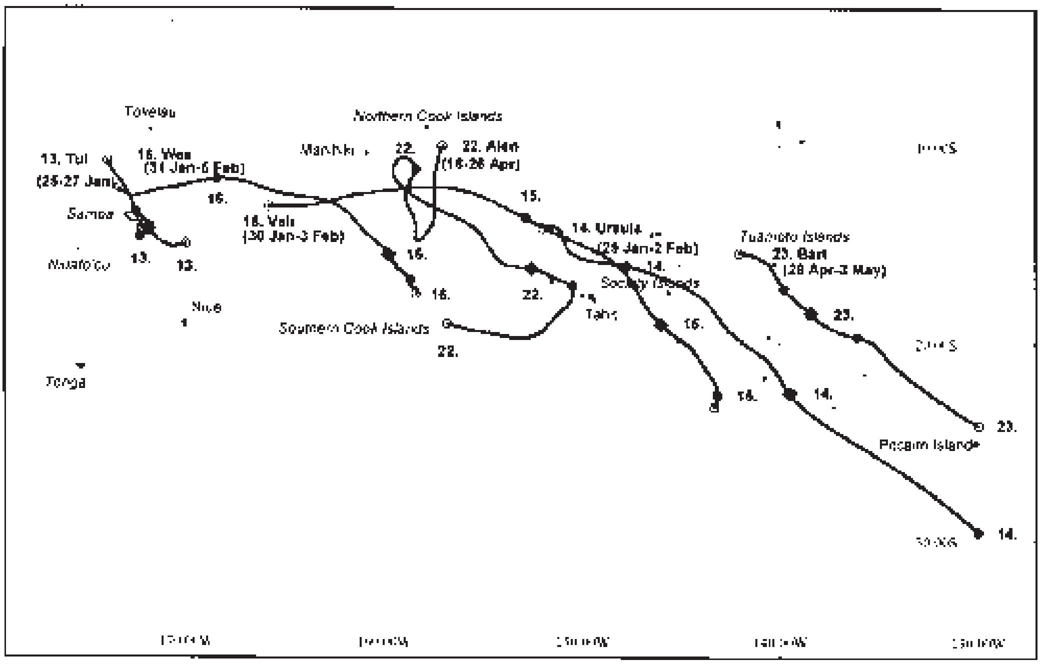
13. *Tui* (Nadi RSMC): 25 – 27 January 1998 (Fig. 5)

Tui was a short-lived and relatively weak cyclone in the South Pacific near Samoa. It was the first of four cyclones to develop in the Fiji area of responsibility during another active phase of the intraseasonal oscillation, shortly after *Les* and *Tiffany* developed in the Australian region. These cyclones were *Tui*, *Ursula*, *Veli* and *Wes*, all of which were relatively weak and developed east of the date-line.

The depression from which *Tui* developed was first identified northwest of Samoa on 25 January, and named within 90 km of Apia, Western Samoa, a day later. The system moved slowly south-southeastward for most of its life. After crossing Western Samoa *Tui* intensified slightly, reaching a peak intensity of 21 m/s when located to the south-southwest of Pago Pago, American Samoa. *Tui* then weakened a little more than 24 hours after initial development and remained in the vicinity of Samoa for several more days.

The system passed over the island of Savai'i, Western Samoa causing relatively minor damage but unfortunately causing one death. A young boy died when he stepped into a puddle of water electrified by a power line brought down by wind.

Fig. 5 **Tracks of mid to late season tropical cyclones *Tui, Ursula, Veli, Wes, Alan* and *Bar*t over the South Pacific east of the date-line. Symbols as in Fig. 1.**



14. *Ursula* (Nadi RSMC): 29 January – 2 February 1998 (Fig. 5)

Ursula developed near the Society Islands immediately following *Tui's* decay, and reached storm force intensity as it moved southeastwards towards Pitcairn Island.

A developing depression was located north of Tahiti following *Tui's* decay to the west. The system moved slowly to the southeast and reached cyclone intensity on 30 January while northeast of Tahiti. Over the next few days *Ursula* moved on a southeasterly course, accelerating considerably as it was caught in the west-northwesterly flow. The cyclone passed through the middle of the Tuamotu Archipelago and then towards the open central South Pacific Ocean. *Ursula* became extratropical on 2 February south of Pitcairn Island. Very few tropical cyclones move as far east in the South Pacific as did *Ursula*, which passed about 500 km to the west of Pitcairn Island. The greater than normal tropical cyclone activity in this region is most likely attributed to the warmer sea surface temperatures and lower than average atmospheric pressures in the region associated with El Niño.

Both *Ursula* and *Veli*, which followed several days later, had an impact on islands of the Tuamotu group. More information on the damage caused by both these cyclones is contained in the section on *Veli*. Damage resulting from *Ursula* was due to pre-cyclone swell rather than winds.

15. *Veli* (Nadi RSMC): 30 January – 3 February 1998 (Fig. 5)

A tropical depression south of the Northern Cook Islands on 31 January began moving east-southeast, and was named *Veli* the following day while north of the Society Islands. The cyclone then followed a similar path to *Ursula* a few days previously, through the middle of the Tuamotu Archipelago. Unlike the earlier cyclone, *Veli* did not get caught up in the mid-latitude westerlies, but drifted slowly southward and weakened.

Ursula and *Veli* caused damage to three islands in the Tuamotu group: Mataiva, Rangiroa, and Makatea. Mataiva was the worst struck with 39 houses damaged, bridges down and roads washed away. Makatea had five houses damaged and operations at the airstrip on Rangiroa were disrupted by wash-up of coral and sand. Fortunately there was no loss of life.

16. *Wes* (Nadi RSMC): 31 January – 5 February 1998 (Fig. 5)

Wes was a weak tropical cyclone in the South Pacific which traversed Samoa and the Cook Islands.

A weak circulation, possibly the remains of *Tui*, remained in the vicinity of Samoa for several days. A reorganisation coupled with a monsoon westerly surge resulted in *Wes* developing on 1 February northeast of Samoa. *Wes* initially continued moving on an easterly course, passing about 95 km south of Nassau, Northern Cook Islands and moving further east very close to Suwarrow Atoll. After this point, *Wes* slowed and began to move in a southeasterly direction. *Wes* weakened on 4 February as it became quasi-stationary near the Southern Cook Islands before being downgraded to a tropical depression. *Wes* did not affect any inhabited islands and caused no damage on Suwarrow Atoll.

17. *Victor* (Perth TCWC): 8 – 17 February 1998 (Fig. 4 and Fig. 1)

Victor formed in the Indian Ocean, most likely from the remnants of *Katrina* which decayed in the Coral Sea two weeks previously. The cyclone was very small in size, reached severe intensity, but caused no major impact, spending its lifetime over the ocean.

An identifiable low pressure system tracked westward late in January and early February across northern Cape York Peninsula, the northern Gulf of Carpentaria, along the north coast of the Northern Territory and across the Kimberley region of West Australia. The low was weak and poorly structured as it passed to the north of the Kimberley coast during 8 February, however its deep convection and vertical organisation improved markedly on 9 February as it moved west southwest away from the influence of land under a region of low vertical wind shear. The cyclone was named the following day. *Victor* continued to move westward with the motion being dominated by an intense mid-level subtropical ridge to its south. Hurricane intensity was reached on 12 February with a peak mean wind speed of 41 m/s. *Victor* continued moving west-southwest but then progressively weakened as a result of increasing vertical wind shear. Low-level easterly winds increased as *Victor* moved southwards of the upper ridge axis into an area of weak north to northwesterly flow. By 15 February the system was fully sheared with an exposed low-level centre apparent on satellite imagery.

Victor was briefly renamed by La Reunion as tropical cyclone *Cindy* as it passed west of longitude 90°E. The time period from the formation of the low from which tropical cyclone *Katrina* formed in the Coral Sea, through until it could no longer be identified as a low in the central Indian Ocean was at least 50 days.

Victor was a very small system with an estimated radius of gales of only 75 km, and an estimated radius of maximum winds of 10 km. It was surrounded by very high environmental pressures of around 1012 hPa. The combination of these two factors resulted in relatively high central pressure for the corresponding wind speed.

18. *May* (Brisbane TCWC): 24 – 26 February 1998 (Fig. 4)

May developed in the southern Gulf of Carpentaria and existed at minimal cyclone intensity for less than 24 hours before crossing the coast.

A relatively unorganised low pressure system in the eastern Arafura Sea on 21 February moved slowly into the Gulf of Carpentaria during 23 and 24 February under the influence of a westerly monsoon surge. Southeasterly low-level flow into the system from 23 February improved organisation. The low developed into a tropical cyclone on 25 February as upper-level outflow also improved. *May* moved south southeast in a northwest monsoonal steering flow. The cyclone crossed the coast near Mornington Island less than 24 hours after development and weakened into a tropical depression as it moved inland.

Wind associated with *May* damaged 44 buildings on Mornington Island at a cost of A$ 375 745. The remnants of *May* remained in the southern Gulf country until early March, producing heavy rain resulting in extensive flooding and property damage. The highest rainfall was recorded at Burketown with 1065 mm over the seven-day period commencing 26 February. Severe flooding to major flood level occurred in the lower reaches of the Nicholson, Albert, Gregory and Leichhardt and lower Flinders Rivers.

19. *Yali* (Nadi RSMC): 18 – 27 March 1998 (Fig. 6)

Yali was a severe cyclone in the South Pacific which caused much damage to the southern islands of Vanuatu.

A well-defined low pressure system was identified between Vanuatu and the Solomon Islands on 18 March and drifted to the southwest while slowly strengthening. Monsoon northwest flow increased to the north of the system and *Yali* was named on 19 March in an environment of favourable upper outflow and low vertical wind shear. The cyclone commenced moving towards the southeast under the influence of a monsoon surge and travelled parallel to the Vanuatu island chain for several days while intensifying to hurricane strength. *Yali's* centre passed about 100 km west of Port Vila during 22 March but no strong winds were reported at the capital. Peak intensity of 36 m/s was attained shortly after this time and just prior to passing over the southernmost Vanuatu islands of Tanna and Aneityum.

By 23 March *Yali* had reached its easternmost position. The upper ridge to its north had intensified, increasing shear and suppressing convection. Consequently the cyclone began to weaken to below hurricane force. At the same time a mid-level intensifying anticyclone to the south began to influence the system, turning it towards the southwest. *Yali* continued to move southwest and weaken. The wind field at this time was becoming quite asymmetric with gales extending much further to the south than the north. Matthew Island, about 250 km southeast of the centre, reported easterly winds of 20 m/s on 23 March. The main convection at this time was about 250 km south of the centre.

The weakening cyclone passed just south of New Caledonia late on 23 March as it continued on its southwest track. By 25 March an upper cut-off low had captured the cyclone with a cold air cloudfield working around the west and north sides of the circulation. *Yali* had now lost its tropical characteristics.

Yali underwent an extratropical transition over the Tasman Sea as it came under the influence of a double jet structure, and strong cyclonic vorticity advection in the middle levels. The system deepened rapidly and moved quickly towards New Zealand where considerable damage was caused including one death.

Some of the southernmost islands of Vanuatu (Aniwa, the northern and western portions of Tanna, and the southern and western sides of Erromango) suffered severe damage from *Yali*. About 60-70 per cent of the crops and 30 per cent of the houses were badly damaged by winds with some damage to roads on Tanna. Both Tanna and Aniwa had suffered from a drought before the cyclone so stocks of food were already quite low. Only minor damage was reported elsewhere in Vanuatu.

20. *Nathan* (Brisbane TCWC): 21 – 27 March 1998 (Fig. 6)

Nathan was a weak cyclone which spent six days in the Coral Sea at minimum cyclone intensity.

A favourable upper pattern resulted in the rapid development of a low embedded in the monsoon trough just east of northern Cape York Peninsula on 21 March. *Yali* had just developed to the east near Vanuatu during the previous day. Movement was initially slow and erratic within an environment of weak steering. *Nathan* intensified to its maximum intensity of 21 m/s six hours after initial development and remained near this intensity for several days as middle level shear restricted further intensification. The cyclone tracked southeast parallel to a relatively unpopulated area of the far North Queensland coast, then away from the coast to the east, as *Yali* dragged the monsoon trough to the south. Mid-level shear resulted in the displacement of the low-level circulation away from the deep convection on 26 March and *Nathan* eventually weakened to a tropical depression on 27 March. Ex-*Nathan* moved in a general westward direction until it dissipated close to the coast in the vicinity of Princess Charlotte Bay, just south of where it formed. No damage or casualties were reported.

21. *Zuman* (Nadi RSMC): 29 March – 6 April 1998 (Fig. 6)

Zuman was a severe cyclone in the South Pacific which resulted in major damage on one of the northern islands of Vanuatu, but weakened before passing close to New Caledonia.

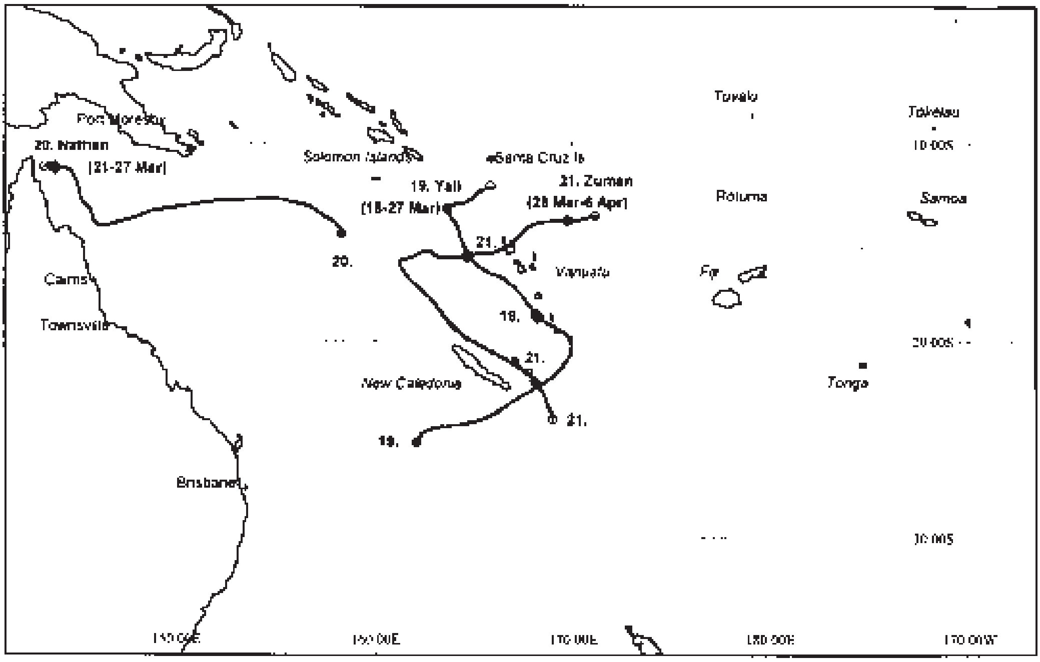
A tropical depression was first noted northeast of Vanuatu late in March. The system moved slowly west towards the northern islands of Vanuatu, with motion influenced by a middle level subtropical ridge to the south. *Zuman* developed quickly on 30 March under the upper ridge with good outflow. This occurred shortly after *Yali* and *Nathan* dissipated, during a relatively inactive period of broadscale convection.

Rapid intensification occurred as *Zuman* turned to the southwest on 31 March, crossing the north of the island of Espiritu Santo, Vanuatu, on 1 April with sustained winds estimated at 41 m/s. The cyclone weakened slightly while crossing the island but soon recovered from the effects of having been over land. Winds remained near peak intensity through to 3 April before the cyclone recurved to the southeast and began to weaken in the shearing northwest flow ahead of a mid-latitude trough. The upper ridge also moved to the north restricting outflow over the system. *Zuman* weakened as it brushed the eastern coast of New Caledonia. Winds had decreased to about 20 m/s on 5 April by the time the storm was at its closest point to Noumea (200 km to the east) and the system was downgraded to a depression shortly afterwards.

The remains of the original vortex induced a depression along a cloud band which tracked southwards towards New Zealand. This secondary system produced several short bursts of heavy rain in the far northern and northeastern parts of North Island, New Zealand before slipping away toward the Chatham Islands and eventually into the higher latitudes of the South Pacific Ocean.

The island of Espiritu Santo, Vanuatu, sustained heavy damage from *Zuman's* impact with the eastern and northeastern parts of the island affected most

Fig. 6 Tracks of late season tropical cyclones *Yali, Nathan* and *Zuman* in the western South Pacific. Symbols as in Fig. 1.



severely. The most serious damage was to dwellings and coconut trees, seriously affecting the island's major industry, copra. All semipermanent houses in Hog Harbour were partly or completely destroyed. Other towns hard hit were Port Olry and Luganville. No reports of fatalities were received.

22. *Alan* (Nadi RSMC): 18 – 26 April 1998 (Fig. 5)

Alan, although categorised as a weak tropical cyclone, resulted in substantial loss of life and property. The cyclone travelled through the central South Pacific east of the date-line in an area which lies outside the primary tropical cyclone belt during most seasons.

An erratic moving tropical disturbance had been tracked since 17 April east of the Northern Cook Islands. The depression began to organise as it commenced moving slowly north. The system was upgraded to tropical cyclone *Alan* on 20 April when it was located about 300 km east-southeast of Manihiki Atoll, Northern Cook Islands. It began to move west, then to the southeast whilst becoming slightly sheared, but remained as a weak tropical cyclone.

Alan presented forecasting challenges after its initial development. It was difficult to locate and its intensity and intensity changes were difficult to estimate. Northwesterly steering continued to dominate and during 23 April the cyclone appeared sheared and only a moderate low-level circulation existed. *Alan* was most likely still at cyclone strength and from 1800 UTC 24 April the cyclone underwent a rapid intensification. This was thought to have resulted from an approaching middle-level trough and increased upper-level divergence on the equatorward side of the subtropical jet. *Alan* reached peak intensity of 23 m/s on 25 April as it approached and moved very near or over the Leeward Islands of the Society group. The cyclone weakened shortly afterwards and decreased below cyclone intensity on 26 April before reaching Tahiti.

Alan passed the Bora Bora Meteorological Station at 0800 UTC 25 April. A maximum wind gust of 41 m/s was recorded. However, the corresponding pressure observation of near 1002 hPa indicated a relatively weak system. Squalls within the convective feeder band of the cyclone may have caused a stronger wind gust than that expected in a gale-force intensity cyclone. Also, the extent of the damage on the island of Huahine together with a sharp dip on the Uturoa barograph trace suggests the possibility of a tornado spawned in one of the convective feeder bands of the cyclone.

Damage from *Alan* was mostly confined to the Leeward Islands of the Society group. The islands most affected were Bora Bora, Tahaa, Raiatea and Huahine. About 750 houses were destroyed and churches, schools and clinics were damaged throughout these islands as a result of storm winds and landslides. Water and electricity were cut off and there were many fallen trees. Huahine was the worst affected. Mudslides blocked access to roads and on Tahaa two bridges collapsed due to landslides. Eight people died and 30 were injured, mostly as a result of mudslides caused by the torrential rains associated with *Alan*. Although weak, *Alan* has been categorised as one of the worst natural disasters experienced in French Polynesia.

23. *Bart* (Nadi RSMC): 29 April – 3 May (Fig. 5)
Bart developed east of the date-line in the South Pacific, farther east than any previous cyclone in the 1997-98 season. It was a weak cyclone, but still caused fatalities as it passed over the Tuamotu Archipelago in the central South Pacific.

A depression was first identified east-northeast of Tahiti, in the midst of the Tuamotu Islands. It was part of a very large area of lower-than-normal pressure which contained the remnants of *Alan*. *Bart* was named on 29 April east of Tahiti near the island of Hau, Tuamotu. The cyclone initially began moving to the south-southeast, but a blocking ridge to the south strengthened on 30 April and caused the cyclone to slow down. *Bart's* winds peaked at 23 m/s at this point, before weakening steadily due to wind shear in the low to middle levels. Satellite imagery on 1 May showed that the main convective area had been sheared about 100 km to the southeast of the exposed low-level centre. The system was downgraded to a depression just after this time. Ex-*Bart* began to accelerate again in more of an east-southeasterly direction, finally weakening near the southeastern Tuamotu Islands, about 100 km north of Pitcairn Island on 3 May. Up to 10 fatalities occurred when a boat capsized.

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Appendix

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