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The South Pacific and southeast Indian Ocean tropical cyclone season 1991–92

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A summary is presented of the tropical cyclone season in the South Pacific and southeast Indian Oceans for 1991–92. Seasonal activity was strongly influenced by a mature El Niño episode with a significant number of cyclones forming well eastward of climatological genesis regions. A total of 17 cyclones formed between latitudes 70°E and 120°W and all but one had some impact on land.

Introduction

This article presents a summary of the 1991–92 tropical cyclone season for the southeast Indian Ocean and southwest Pacific basins. The summary is drawn from material provided by MetService New Zealand, the Fiji Meteorological Service and the Australian Bureau of Meteorology.

The cyclone season extended from 13 November 1991 to 1 May 1992, during which time 17 cyclones formed between 70°E and 120°W (see Table 1). Of these, a high proportion (12) achieved hurricane intensity. There were 82 days during the season on which a cyclone was present. Although long-term statistics for the area as a whole are not available, comparisons with figures for the regions 100°E to 120°W (WMO 1993) and 105°E to 120°W (Mautner and Guard 1992) suggest that cyclone numbers were close to or slightly greater than average.

Seasonal cyclone activity was strongly modulated by the influence of a mature ENSO warm phase. The focus of cyclogenesis was spread considerably eastward of its mean position, with eleven tropical cyclones forming between 165°E and 120°W. This is almost double the average of 5.7 (Mautner and Guard 1992). Furthermore, six of these cyclones developed east of the date-line.

The season was also characterised by a preponderance of cyclones affecting land. In particular, the islands of Vanuatu were a favoured area for cyclone activity throughout the season, with six cyclones, and three within a month, passing through the island chain. Tropical cyclone *Val* was the deadliest storm of the season, responsible for the loss of sixteen lives in the Samoan Islands. A further five people perished in cyclones *Wasa/Arthur* (Tahitian islands), *Betsy* (Vanuatu) and *Esau* (New Caledonia). Remarkably, only one cyclone (*Jane*) had no affect on any coastal or island community.

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Large-scale circulation features

Averaged over the southern hemisphere season, atmospheric patterns were typical of a mature El Niño event, the incipient stage of which was first noted last season (see, for example, Bannister and Smith (1993)). Across the central equatorial Pacific, persistent low-level westerlies in the vicinity of the date-line highlighted the weakness of the Walker circulation. Individual monthly sea-surface temperature and outgoing long wave radiation (OLR) charts provided further corroborative evidence of the current warm phase. Strong warm water anomalies dominated the eastern and central equatorial Pacific while cold water anomalies persisted in waters both east and north of the Australian continent. Over the central equatorial Pacific, OLR charts showed that tropical convection was primarily focused near and east of the date-line, particularly during the months of December, January and March. Available monthly rainfall figures for the region were well above average. In the extreme, March monthly totals were up to six times greater than average over the Line and Phoenix Islands. In contrast, rainfall over tropical Australia was generally average to below average.

Table 1. Tropical cyclones in the southwest Pacific and southeast Indian Oceans 1991–92.

	Low first identified			*Initial tropical cyclone phase*			
Name	*Date*	*Lat.*	*Long.*	*Date*	*Time (UTC)*	*Lat.*	*Long.*
Tia	13 Nov	9°S	162°E	16 Nov	0100	8.5°S	171.0°E
Graham	2 Dec	5°S	95°E	3 Dec	0000	6.2°S	94.3°E
Val	4 Dec	10°S	179°W	5 Dec	0700	8.9°S	176.6°W
Wasa/Arthur	3 Dec	10°S	160°W	5 Dec	1800	11.0°S	159.0°W
Betsy	5 Jan	9°S	170°E	6 Jan	1800	9.5°S	169.6°E
Mark	6 Jan	12°S	130°E	8 Jan	0600	14.0°S	138.1°E
Cliff	4 Feb	11°S	145°W	6 Feb	0600	11.8°S	141.6°W
Daman	11 Feb	9°S	173°W	15 Feb	0100	12.6°S	170.0°E
Harriet	24 Feb	11°S	102°E	25 Feb	0600	11.1°S	100.5°E
Esau	24 Feb	14°S	170°E	26 Feb	0700	15.7°S	167.1°E
Ian	27 Feb	12°S	114°E	27 Feb	1800	11.6°S	115.5°E
Fran	4 Mar	12°S	173°W	5 Mar	1800	13.5°S	176.7°W
Gene	15 Mar	14°S	165°W	16 Mar	2200	19.1°S	162.8°W
Hettie	24 Mar	12°S	148°W	25 Mar	1800	14.8°S	149.2°W
Neville	5 Apr	9°S	131°E	7 Apr	0200	10.7°S	132.7°E
Jane	7 Apr	8°S	98°E	8 Apr	1200	8.7°S	98.2°E
Innis	23 Apr	10°S	170°W	28 Apr	2100	11.3°S	172.4°E

	Maximum intensity					*End tropical cyclone phase*			
Name	*Date*	*Time (UTC)*	*Lat.*	*Long.*	*Mean wind ($m\ s^{-1}$)*	*Date*	*Time (UTC)*	*Lat.*	*Long.*
Tia	18 Nov	0000	12.2°S	169.3°E	40	20 Nov	1200	16.4°S	171.4°E
Graham	5 Dec	1200	10.1°S	96.0°E	65	9 Dec	1800	14.7°S	104.8°E
Val	7 Dec	1800	13.3°S	172.4°W	45	13 Dec	0600	30.0°S	163.0°W
Wasa/Arthur	10 Dec	0600	15.2°S	154.7°W	45	17 Dec	1200	18.0°S	131.9°W
Betsy	10 Jan	0000	18.3°S	162.7°E	45	14 Jan	0600	27.6°S	160.0°E
Mark	9 Jan	1800	13.3°S	141.1°E	30	10 Jan	1200	13.1°S	143.3°E
Cliff	6 Feb	1800	13.7°S	139.8°W	30	9 Feb	0600	28.0°S	131.5°W
Daman	17 Feb	0000	19.5°S	161.6°E	40	18 Feb	1800	29.6°S	156.0°E
Harriet	1 Mar	0000	14.9°S	90.6°E	60	8 Mar	1200	40.0°S	110.0°E
Esau	28 Feb	1800	14.1°S	159.8°E	50	5 Mar	1200	24.9°S	165.8°E
Ian	1 Mar	0900	16.7°S	117.1°E	60	3 Mar	1800	24.6°S	118.0°E
Fran	8 Mar	1800	17.4°S	170.8°E	50	16 Mar	0000	24.8°S	151.9°E
Gene	17 Mar	0000	19.4°S	162.7°W	25	19 Mar	0000	28.6°S	160.8°W
Hettie	27 Mar	0000	21.0°S	146.2°W	25	29 Mar	0600	30.0°S	132.7°W
Neville	8 Apr	1800	11.5°S	128.4°E	55	13 Apr	0200	12.6°S	125.1°E
Jane	15 Apr	0000	14.7°S	85.4°E	65	17 Apr	0100	17.1°S	82.6°E
Innis	30 Apr	0000	14.0°S	169.1°E	25	1 May	0000	17.0°S	169.3°E

The orderly transition of the monsoon trough across the longitudinal domain of the summer hemisphere was observed to progress westward from the central equatorial Pacific in November, reaching the central Indian Ocean in December – a month later than normal. Over Australian-Indonesian longitudes, the trough was generally weak and ill-defined, remaining north of the Australian continent throughout most of the season.

Over the Pacific, the monsoon trough extended well east of its climatological mean position, with equatorial low-level westerlies in the southern hemisphere penetrating as far eastward as 150°W during January. Strong cross-equatorial return flow at high levels provided further evidence of an active Hadley circulation in this region.

In contrast, the monsoon trough was comparatively weak over the Indian Ocean, particularly in the east, where the cross-equatorial contribution to the monsoon was generally weaker and shallower than normal. Three active phases of the monsoon occurred during the season, two in February and one in April.

Onset of the Australian summer monsoon, as defined by Holland (1986), was observed in early December, although the westerly stream was primarily of southern hemisphere origin and inactive. During February, however, a prolonged active phase of the monsoon developed, during which time there were two distinct pulses in activity. The end of the active phase was signalled in March by the rapid return of a broadscale easterly wind regime.

As expected during an El Niño warm phase, there was a significant eastward shift in the major areas of cyclogenesis towards the central Pacific. A total of eleven tropical cyclones formed between 165°E and 120°W, six of them east of the date-line.

Climatic indices

Troup's Southern Oscillation Index (SOI), defined as the normalised Tahiti minus Darwin pressure difference multiplied by ten, was generally negative throughout the season. While monthly values varied between −26 in November and +1 in May, the centred five-month running mean remained strongly negative, reaching a minimum value of −19 in February. Individual monthly mean sea level pressure (MSLP) charts from the Climate Analysis Center, Washington, revealed the classic trans-Pacific pressure anomaly dipole associated with the El Niño. Over tropical latitudes, MSLP anomalies were predominantly negative east of the date-line and positive elsewhere, particularly over north Australia and Indonesia.

Intraseasonal modulation

In contrast to last season, the Madden-Julian Oscillation (MJO) was regular and well defined throughout the 1991–92 southern cyclone season. A strong burst in high-level divergence over the near-equatorial Indian Ocean, first noted in late November, signalled the initiation of MJO-related convection in the southern hemisphere. Further pulses were observed spreading eastward across the Indian Ocean *en route* to the central Pacific during late December, February and early April. Tropical cyclogenesis events were frequently associated with these pulses.

Verification statistics

Position forecast verification statistics for official warnings issued by the relevant Tropical Cyclone Warning Centres are presented in Table 2. All forecasts were verified against the official best track. For comparison, verification statistics for persistence forecasts based on 12-hour movement vectors are also included. Warning responsibility for cyclones in the Coral Sea was often shared between Brisbane Tropical Cyclone Warning Centre (TCWC) and Nadi TCWC. For these systems, forecasts issued by Nadi TCWC were verified when the cyclone's initial position was east of 160°E; for cyclones west of 160°E, Brisbane forecasts were used.

Compared with the 1990–91 season, improvements in the initial position (0-hour) error and 12-hour forecast error of 18 per cent and 12 per cent respectively were achieved. Slight improvements were also made in the 36 and 48-hour forecasts, although the sample was significantly smaller. Surprisingly, initial position errors were not closely correlated with intensity. In particular, cyclones with the smallest initial position errors (*Tia* and *Mark*) were amongst the weaker storms, whilst the most intense cyclone in 1991–92 (*Jane*) was also one of the most poorly located. Clearly, where cyclones formed in data-sparse regions and/or on the limbs of satellite imagery (*Jane, Wasa/Arthur*), centre location was difficult.

The largest forecast position errors were usually associated with weak, poorly fixed and fast-moving cyclones such as *Cliff* and *Hettie*. 'Well-behaved' cyclones – those that did not undergo sudden changes in forward speed or direction of movement – exhibited the smallest forecast errors (e.g. *Neville*).

Tropical cyclones in the southwest Pacific and southeast Indian Oceans 1991–92

***Tia* (N): 16 to 20 November 1991**

A weak tropical depression was first observed over the Solomon Islands on 13 November. The depression intensified slowly in an environment of weak vertical shear. As the depression moved eastwards, upper outflow characteristics became more favourable for development and the system was named tropical cyclone *Tia* at 0100* 16 November. Around 1200, *Tia* slowed down, undertook a small anticlockwise loop, and then commenced a southwestward track in response to a developing northerly steering current. From this point, *Tia* rapidly intensified, with mean winds reaching storm force by 1800 16 November, and hurricane force by 0000 17 November.

Tia passed about 55 km to the west of Anuta Island around 1800 17 November and close to nearby Tikopia about 0000 18 November. Maximum intensity was achieved at about this time with mean winds near the centre estimated at 40 m s^{-1} and movement towards the south-southwest at about 5 m s^{-1}.

During the next 24 hours, *Tia* entered an area of strengthening upper-level northerly flow and began to curve towards the south, passing about 150 km east of the Banks Islands in the Vanuatu group around 1200 18 November. The cyclone then started to turn towards the southeast under the influence of increasingly strong upper-level

*All times in Universal Coordinated Time (UTC).

Table 2. Position forecast verification statistics for official warnings issued by relevant TCWCs: Nadi (N); Brisbane (B); Darwin (D); Perth (P). Forecast positions verified against official best-track data. Square brackets denote best-track 12-hour persistence forecast.

Forecast lead time	*0 h*		*12 h*		*24 h*		*36 h*		*48 h*	
Name	*error (km)*	*number*	*error (km)*	*number*	*error (km)*	*number*	*error (km)*	*number*	*error (km)*	*number*
Tia (N)	19	41	127 [149]	17	283 [247]	15				
Graham (P)	35	24	93 [117]	21	171 [167]	9			389 [155]	6
Val (N)	45	33	121 [116] [116]	29	239 [279] [279]	18				
Wasa/Arthur (N)	56	44	125 [190]	38	166 [186]	9				
Betsy (N) (B)	41	31	115 [138]	29	215 [198]	14	327 [555]	10	443 [922]	8
Mark (B) (D)	19	12	71 [82]	11	132 [151]	8	211 [150]	6	323	4
Cliff (N)	52	11	219 [159]	9	416 [247]	7				
Daman (N) (B)	20	19	138 [156]	17	276 [332]	14				
Harriet (P)	46	23	91 [76]	18	176 [97]	7				
Esau (B) (N)	20	33	78 [75]	31	160 [139]	28	275 [533]	7	371 [813]	6
Ian (P)	21	21	85 [93]	19	148 [222]	8			413 [399]	6
Fran (N) (B)	20	48	73 [73]	45	158 [166]	40	272 [304]	16	375 [433]	16
Gene (N)	54	14								
Hettie (N)	70	10	193 [245]	8	416 [139]	6				
Neville (D)	43	25	56 [75]	22						
Jane (P)	67	22	126 [148]	20	291 [269]	6			465 [929]	5
Innis (N)	29	8	57 [77]	6	150	4				
Total		419		340		193		39		51
Weighted Mean	37		104		210		277		396	

northwesterlies. The influence of strengthening environmental vertical wind shear caused *Tia* to begin weakening; by 0600 19 November, mean winds had eased to storm force, and 12 hours later, to gale force. The system became slow-moving about 370 km east of Port Vila at 0000 20 November. It then turned to the northwest and had weakened below cyclone intensity by 1200 20 November. The low-level circulation subsequently crossed the earlier part of its track just east of Vanuatu at a point where it had been generating hurricane-force winds two days previously.

Apart from some small islands, no major inhabited areas lay in the path of *Tia*. However, hurricane-force winds wrought much damage on the two eastern-most islands of the Solomon group, namely Tikopia and Anuta. No deaths were reported. On Tikopia, more than 1000 people were left homeless and ninety per cent of dwellings were destroyed. Seven of eight church buildings were also destroyed, along with all but one classroom building. Food crops were ruined, with all coconut trees either blown down or uprooted. High seas caused extensive flooding to low-lying areas, salinating food crops and destroying the island's water supply system.

In Vanuatu, damage was minimal and confined mainly to fruit trees on the Banks and Torres Islands. On Mota, one man was slightly injured by flying corrugated iron and a church building was flattened.

***Graham* (P): 3 to 9 December 1991**

Tropical cyclone *Graham* was the first cyclone of the year to be named by Perth TCWC and the first of three cyclones to have an impact on Cocos Island.

Late in November, an active pulse in the MJO developed over equatorial waters in the southern Indian Ocean. Convergence into the area was further assisted by a low-level cross-equatorial surge from the northern hemisphere. By 0000 2 December, a low pressure system had developed near 5°S 95°E tracking south-southwest.

Intensification of the low was rapid and at 0000 3 December, tropical cyclone *Graham* was named whilst located about 750 km northwest of Cocos Island. Within 24 hours, satellite imagery was indicating the development of an eye. Shortly thereafter, *Graham* commenced a gradual recurvature towards the southeast under the influence of a deep-layer anticyclone to the east. Maximum intensity was reached at 1500 5 December with mean winds estimated to be 65 m s^{-1}.

Tropical cyclone *Graham* made its closest approach to Cocos Island at 2300 5 December whilst located 150 km to the north-northeast. Although gales were reported on the island for a short period, damaging winds did not occur. The lowest MSLP recorded was 1004 hPa, indicative of the compact nature of the circulation.

As the cyclone tracked away from Cocos Island, it encountered strengthening upper-level westerly winds ahead of an advancing trough and began to shear. By 0000 8 December, the low-level circulation centre was fully exposed on the northwest side of the deep convection. *Graham* weakened below cyclone intensity at 1800 9 December although it wasn't until 10 December that the system was completely stripped of its central convection.

***Val* (N): 5 to 13 December 1991**

The tropical depression that subsequently developed into tropical cyclone *Val* was first observed southeast of Tuvalu on 4 December 1991, forming in association with a low-level westerly wind surge on the northern side of the South Pacific convergence zone (SPCZ). The depression tracked northeast over the next two days and steadily intensified. At 0700 5 December, the system was named tropical cyclone *Val*. Shortly thereafter, steering-level northwesterly winds increased and *Val* assumed a southeastward track towards Samoa.

Val continued intensifying, reaching hurricane force by 0000 7 December. Peak intensity was achieved about 18 hours later, as *Val* made landfall on Savaii in Western Samoa. Mean surface winds were estimated at 45 m s^{-1} at this time with gales extending 280 km from the centre. Weakening upper-level winds caused *Val* to slow down after crossing Savaii and the system subsequently performed a small clockwise loop southwest of the island. The effect of this was to considerably prolong the damaging impacts of heavy seas and destructive winds upon Samoa.

Upon completing the loop, tropical cyclone *Val* tracked eastward, passing directly over Tutuila in American Samoa around 0200 10 December. At Pago Pago, mean winds of 35 m s^{-1} and a lowest MSLP of 944 hPa were recorded.

After devastating the Samoas, *Val* accelerated toward the southeast, tracking to the west of the southern Cook Islands. The system also began weakening as environmental upper wind shear increased. By 0600 12 December, winds had eased below hurricane force. Shortly after crossing latitude 25°S, Val commenced extratropical transition, and by 0600 13 December, could no longer be classified as a tropical cyclone. Nevertheless, storm-force winds persisted around the periphery of the centre as it tracked due south during the next three days. Near 50°S, the vortex was finally captured and sheared apart by strong environmental westerlies associated with the circumpolar trough.

Val was amongst the most destructive cyclones on record to have affected the Samoas, and the second devastating cyclone in three years (*Ofa* 1990 was the earlier one). On Western Samoa, fifteen people perished, 95 per cent of homes were destroyed or badly damaged, and preliminary damage estimates put the bill at nearly $US200 million*. One life was lost on American Samoa and damage was estimated at over $US50 million.

***Wasa/Arthur*† (N): 5 to 17 December 1991**

Wasa/Arthur was the first of three cyclones to affect French Polynesia during 1991–92 and the first major cyclone there since 1982–83. Unsurprisingly, both the 1991–92 and 1982–83 seasons coincided with major El Niño episodes.

A shallow depression was first observed on 3 December embedded in the monsoon trough over the northern Cook Islands. The system steadily intensified and by 1900 5 December had achieved tropical cyclone status. At this stage, *Wasa/Arthur* was located approximately 250 km southwest of Penrhyn Island and moving slowly northwest. Weak vertical wind shear in the environment of *Wasa/Arthur* assisted rapid development, with hurricane-force winds developing within thirty hours. During this period, the cyclone underwent a slow clockwise loop towards the southwest.

At 0000 8 December, *Wasa/Arthur* turned

*All damage estimates in original dollars.

†Although this cyclone was given two separate names by Nadi TCWC, *Arthur* formed from the ex-*Wasa* depression and is therefore regarded as a single system that underwent a regeneration.

sharply to the southeast, assuming a course that took it through the Society Islands during the following three days. Maximum intensity was achieved during this time, with maximum mean winds reaching 45 m s^{-1}. *Wasa/Arthur* passed within 280 km to the southwest of Tahiti on 11 December, and directly over Tubuai at 1200 12 December. Sustained winds of 29 m s^{-1} were recorded at Tubuai with a lowest MSLP of 976 hPa. The cyclone was already filling by this time, and shortly thereafter environmental wind shear and cool sea-surface temperatures weakened the system below cyclone strength.

Gales persisted on the southeastern side of the depression, however, and it turned toward the northeast, re-entering warm waters near the Tuamotu archipelago a day later. By 1800 13 December, the system had reorganised sufficiently to be named again as a cyclone, this time as *Arthur* by the Nadi TCWC. Winds associated with the system increased to marginal storm force on 1200 14 December as the cyclone passed about 150 km from Mururoa. The cyclone maintained this intensity for the next 24 hours as it tracked through the northern islands of the Actaeon group before slowly weakening. Around 0000 16 December, *Wasa/Arthur* took on a more easterly track before finally dissipating as a cyclone late on 17 December.

Most of the damage associated with *Wasa/Arthur* occurred during the first cyclone phase whilst the system was moving through the Society Islands. The worst affected islands were Bora Bora and Tubuai, where over 360 homes were destroyed, a variety of crops were ruined, and many public buildings and works damaged. Two deaths were reported with the cyclone – in a mudslide on Moorea during torrential rain 24 hours after the cyclone's closest point of approach.

***Betsy* (N) and (B): 6 to 13 January 1992**

Tropical cyclone *Betsy* was the second cyclone to affect Vanuatu during 1991–92 and was considerably more damaging than its predecessor, tropical cyclone *Tia*. Unusually for the time of year, *Betsy* formed as a southern hemisphere twin to typhoon *Axel* in the northern hemisphere. (*Axel* tracked westward and was subsequently associated with the spin up of tropical cyclone *Mark* in the Gulf of Carpentaria.)

Between 3 and 5 January, strong to gale-force westerly winds developed on the northern side of the southern hemisphere monsoon trough. Enhanced convection associated with the westerly burst gradually became more organised within the trough west of Tuvalu, and by 1800 5 January, a deep tropical depression was evident. The depression continued intensifying as it drifted slowly west and at 1900 6 January was named tropical cyclone *Betsy*. During the next 12 hours, *Betsy* steadily deepened and tracked south-southeast at around 5 m s^{-1}. Mean winds associated with the cyclone reached storm force at 2100 7 January and the system turned to the southwest in response to increasing deep-layer mean easterlies. This brought the cyclone on a direct course for the central Vanuatu Islands.

By 1800 8 January, mean winds associated with tropical cyclone *Betsy* had reached hurricane force. Six hours later, the destructive core of the cyclone struck the islands of Ambrym and Malakula in central Vanuatu. On Malakula, sustained winds of 33 m s^{-1} were recorded between 0400 and 0500 9 January and the MSLP dropped to 959 hPa. At this point, *Betsy* possessed a large ragged eye with a diameter of over 110 km. *Betsy* continued to intensify after leaving Vanuatu, and reached maximum intensity (mean winds estimated to 45 m s^{-1}) at around 0000 10 January whilst 200 km to the north of New Caledonia.

By 0600 11 January, satellite imagery indicated that *Betsy* was losing organisation, with the large eye (diameter of 165 km) rapidly shrinking and becoming elongated and ragged. Around 1200 11 January, *Betsy* recurved sharply to the south under the influence of an approaching upper trough. Environmental shearing increased over the next few days, and by 13 January *Betsy* had dissipated as a tropical cyclone. The extratropical remnants continued drifting southeast and then east, passing close to the northern coast of New Zealand on 17 January.

Tropical cyclone *Betsy* wrought considerable damage in Vanuatu and was responsible for the deaths of two people. The worst affected island was Efate, where an estimated three-metre storm surge washed away kilometres of coastal road, parts of villages and the entire resort of Takara. Elsewhere on Efate, houses lost roofing, major crop damage was reported north of Vila, and power lines were brought down. On Pentecost Island and Espiritu Santo, many houses were destroyed or damaged and roads were blocked by mud slides.

***Mark* (B) and (D): 8 to 10 January 1992**

Like *Betsy*, tropical cyclone *Mark* formed within the monsoon trough in response to enhanced equatorial westerly flow between the trough and typhoon *Axel* in the northwest Pacific. The incipient depression was first analysed in the Timor Sea to the west of Melville Island on 6 January. The system tracked rapidly eastwards across the northern 'Top End' of Australia, entering the Gulf of Carpentaria at 1200 7 January. Once over water, satellite imagery indicated that the system slowly organised and by 0600 8 January, whilst approaching the central Gulf of Carpentaria, it was named. Tropical cyclone *Mark* was the only cyclone to be named by Brisbane TCWC during 1991–92.

Upon naming, *Mark* slowed and adopted a slightly northeastward track in response to enhanced ridging to the south. This track was

Fig. 1 Tracks of cyclones *Val* (3), *Wasa/Arthur* (4), *Cliff* (7), *Gene* (13) and *Hettie* (14). Note: Cyclones are numbered according to the order in which they formed during the season.

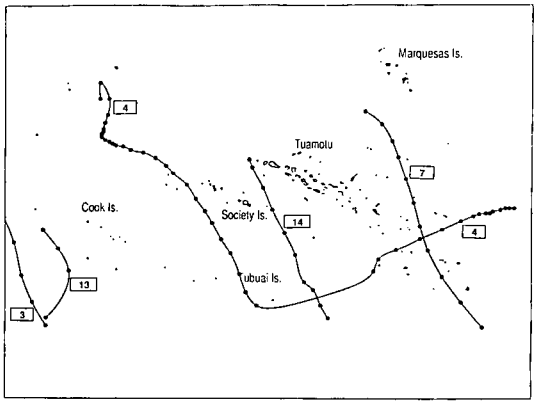


Fig. 2 Tracks of cyclones *Val* (3), *Wasa/Arthur* (4), *Fran* (12) and *Gene* (13).

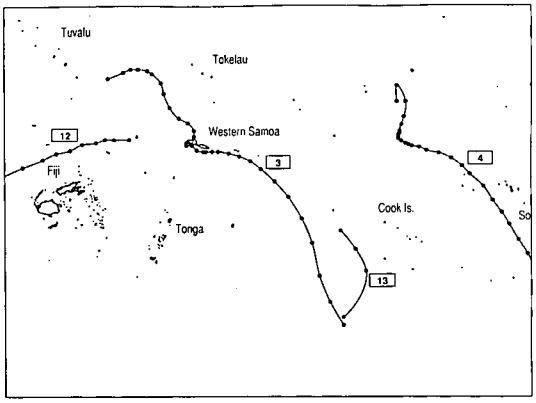


Fig. 3 Tracks of cyclones *Tia* (1), *Val* (3), *Betsy* (5), *Daman* (8), *Esau* (10), *Fran* (12) and *Innis* (17).

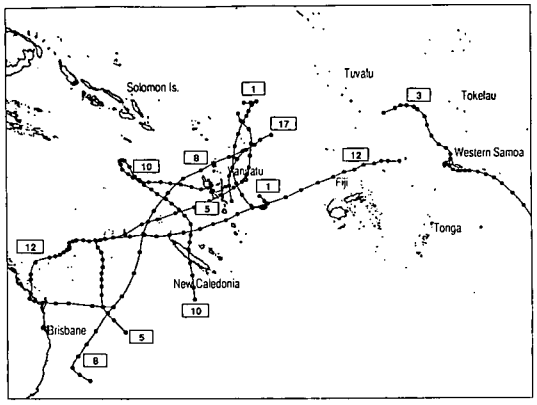


Fig. 4 Detail of tracks of cyclones *Tia* (1), *Betsy* (5), *Daman* (8), *Esau* (10), *Fran* (12) and *Innis* (17) over Vanuatu.

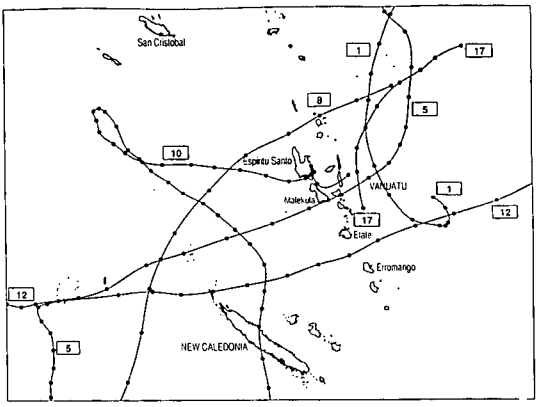


Fig. 5 Tracks of cyclones *Mark* (6) and *Neville* (15).

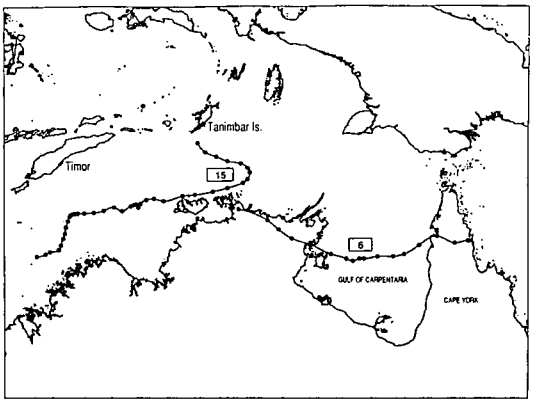
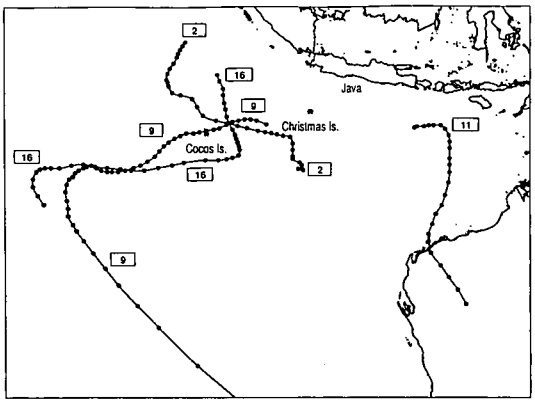


Fig. 6 Tracks of cyclones *Graham* (2), *Harriet* (9), *Ian* (11) and *Jane* (16).



maintained for the next 40 hours and at 2100 9 January, *Mark* crossed the western coast of Cape York Peninsula just south of Weipa. Maximum sustained winds at landfall were estimated at 28 m s^{-1} with a central pressure of 980 hPa. Tropical cyclone *Mark* weakened as it crossed the peninsula and was downgraded to a tropical depression at 1200 10 January.

The town of Weipa sustained widespread minor damage with falling trees largely responsible for damage to houses and power lines. Wave action caused an estimated $A3.5 million damage to the Kaolin loading facility at Weipa port.

***Cliff* (N): 6 to 9 February 1992**

Early in February 1992, a vigorous monsoon convergence zone had become established in the central South Pacific, extending from the northern Cook Islands southeastward as far as Pitcairn Island. Late on 4 February, an area of low pressure developed within the convergence zone to the north of the Society Islands and began moving east. Assisted by a favourably located upper trough, the low consolidated southwest of the Marquesas Islands, and by 0600 6 February, tropical cyclone *Cliff* was born. *Cliff* was the furthest eastward forming cyclone of the season.

Cliff intensified quite quickly and within 12 hours had reached maximum intensity, with sustained winds estimated at 30 m s^{-1} near the centre. The cyclone was moving southeastward at this time ahead of an advancing upper trough, a direction it maintained for the remainder of its lifetime. For 24 hours, until about 1800 7 February, *Cliff* maintained intensity, passing 55 km to the west of the small island of Tatakoto. Around 0600 8 February, whilst weakening in response to strengthening upper-level northwesterlies, the cyclone tracked through the Actaeon Group. Accelerating to the southeast, *Cliff* weakened below cyclone intensity at about 0600 9 February, under the dual influence of strong environmental shearing and cool seas.

Although tropical cyclone *Cliff* affected several islands of French Polynesia, no reports of personal injury or property damage have been received.

***Daman* (N) and (B): 15 to 18 February 1992**

Tropical cyclone *Daman* began life on 11 February as a shallow depression embedded in the monsoon trough near Tokelau. Initial movement of the circulation was towards the west-southwest under the influence of an easterly steering flow. A few days later, in response to an intensification of the subtropical ridge to the south, the low began to accelerate, passing through the Tuvalu Islands during 14 February.

From this point, the system began to steadily develop and at 0100 15 February, whilst located approximately 300 km northeast of the Banks Islands in Vanuatu, *Daman* was named. Twelve hours later, the cyclone brushed the northern tip of Vanua Lava before passing to the northwest of Vanuatu's largest island, Espiritu Santo, and heading out into the open waters of the Coral Sea.

At around 0600 16 February, the track of tropical cyclone *Daman* began curving to the southwest, and then south-southwest, under the influence of a strengthening northerly component in the steering level flow. At 0000 17 February, *Daman* reached its maximum intensity with mean winds estimated at 40 m s^{-1}.

The system began weakening shortly thereafter as environmental shear increased, and by 1800 18 February, near latitude 30°S, *Daman* lost its tropical cyclone characteristics. Soon afterwards, the low-level extratropical depression became fully embedded in mid-latitude westerlies and was advected rapidly eastwards, bringing gale-force winds to parts of the North Island of New Zealand. At Manakau Heads near Auckland, a maximum gust of 57 m s^{-1} was recorded during the evening of 21 February.

Although *Daman* passed through the northern islands of Vanuatu, it was a relatively weak cyclone at this stage. The majority of *Daman's* life, in particular while it was at its most intense, was spent over the open waters of the Coral Sea. Accordingly, no reports of injury resulting from this cyclone have been reported. However, gales associated with the ex-cyclone depression were responsible for fallen power lines and significant tree damage around the streets of Auckland.

***Harriet* (P): 25 February to 8 March 1992**

The low that subsequently became *Harriet* was first observed on 24 February embedded in the monsoon trough approximately 550 km east of Cocos Island. The low developed quite rapidly in association with a surge in the low-level cross-equatorial flow, and at 0600 25 February, the system was named. Initial movement of tropical cyclone *Harriet* was west-southwest towards the Cocos Island group, passing just south of North Keeling Island at 0000 27 February. Maximum mean winds were estimated to be 30 m s^{-1} at this stage and a peak gust of 45 m s^{-1} was recorded on Cocos Island, the second strongest on record (1952–92).

Continuing organisation of the cloud pattern occurred over the next 72 hours, and at 0000 1 March maximum intensity was achieved. At its most intense, *Harriet* was estimated to have sustained winds of 60 m s^{-1} and a central pressure of 930 hPa.

Harriet slightly weakened over the next three days whilst maintaining a steady westward course. An amplifying frontal system approaching from the west caused *Harriet* to recurve to the south during 4 March and begin to weaken under the effects of increasing environmental wind shear. By 0000 6 March the front was located about 15 degrees of latitude to the southwest of

Harriet and an acceleration of the cyclone towards the southeast took place. Forward speed of movement of tropical cyclone *Harriet* increased to more than 30 m s^{-1}. The circulation centre passed 700 km to the southwest of Cape Leeuwin in southwest Western Australia during the evening of 8 March, shortly before losing warm-core characteristics.

Tropical cyclone *Harriet* was the second and most damaging cyclone during 1991–92 to affect the Cocos Islands. It caused minor residential property damage, mainly to roofing, and significant losses were sustained on horticultural land. Overall damage costs were estimated at $A60 000. There were no reports of injury.

***Esau* (N) and (B): 26 February to 5 March 1992**

Tropical Cyclone *Esau* was the fourth cyclone to affect the Vanuatu group during the 1991–92 season, closely following *Daman* a week and a half earlier. *Esau* was also the second cyclone to affect the Solomon Islands.

Tropical cyclone *Esau* developed from a shallow depression which formed about 370 km northeast of northern Vanuatu on 24 February. The depression was part of an active monsoon trough extending from northern Australia through Vanuatu and eastwards to Samoa.

The system initially drifted southwestward towards northern Vanuatu under the influence of a northeasterly steering flow, making a clockwise loop over the island of Espiritu Santo as it underwent further organisation. Tropical cyclone *Esau* was named at 0700 26 February whilst located just east of Espiritu Santo, and by 1800 it had moved southwest, clear of the Vanuatu group.

Esau then accelerated on a westward track on the northern side of an intense subtropical ridge. With decreasing vertical shear, the cyclone intensified at a steady rate; by 28 February sustained winds had reached hurricane force near the centre, which was located about 550 km west of Espiritu Santo. Between 1800 28 February and 1200 29 February, the system attained peak intensity of 50 m s^{-1} and executed a second, larger, clockwise loop. At this stage in its development, *Esau* exhibited a distinctly symmetrical cloud signature with a well-defined eye. At the northernmost point of its trajectory, *Esau* was about 260 km south of Bellona and Rennell Islands in the Solomon group and these islands were within the estimated radius of gale-force winds.

From 1 March, tropical cyclone *Esau* started to move steadily southeastwards and weaken under the influence of a northwest steering flow ahead of a developing upper trough. The system moved away from the Solomon Islands and returned to within 450 km of southern Vanuatu on 4 March before turning south towards New Caledonia. By this stage, the eye had filled with cloud and the overall cloud structure had become distorted. Sustained winds close to the centre were estimated to be 40 m s^{-1} when it struck central parts of New Caledonia overnight on 4 March, crossing the coast not far from Ponerihouen. Passage over a mountainous island barrier and increasing vertical wind shear combined to further weaken the cyclone. On 5 March, winds decreased below hurricane force as the cloud signature became much less organised and upper clouds became sheared off to the south of the low-level centre. With further southward movement, the system underwent extratropical transition over the cooler waters of the Tasman Sea and eventually passed over the North Island of New Zealand with much reduced intensity.

Tropical cyclone *Esau* directly affected three countries in its path through the southwest Pacific. Gale-force winds at Bellona and Rennell Islands in the Solomon group destroyed several houses and caused some food crop damage due to flooding. On New Caledonia, which bore the brunt of hurricane-force winds, one woman was drowned. In addition, buildings were damaged and roads blocked.

***Ian* (P): 27 February to 3 March 1992**

Ian was the second cyclone to be spawned during late February from an active southeast Indian Ocean monsoon trough. *Ian* was the first cyclone since *Orson* in April 1989 to cross the Western Australian coast.

Within two days of the formation of *Harriet*, another depression had developed in the monsoon trough further east, approximately 300 km south of the southeastern tip of Java. Unlike *Harriet*, however, this system tracked eastwards in its early stages in response to a high amplitude upper trough located to the west. Enhanced upper divergence associated with sharpening of the trough assisted further development and at 1800 27 February, tropical cyclone *Ian* was named. Shortly afterwards, the upper trough weakened in association with an intensifying anticyclone over northwest Western Australia. *Ian* consequently came under the influence of a deep-layer northerly steering current and it recurved to the south.

Ian continued to intensify within a favourable upper environment and by 0900 1 March had reached maximum intensity with mean winds estimated at 60 m s^{-1}. Although *Ian* began weakening as it approached the Western Australian coast, it was still a severe cyclone as it tracked directly over the Monte Bellos Islands and Barrow Island, where gusts to 57 m s^{-1} were recorded. *Ian* subsequently crossed a relatively uninhabited stretch of coastline approximately 75 km east of Onslow at 2145 2 March and weakened over land. Throughout *Ian*'s lifetime, ship observations, hourly satellite imagery and radar data ensured a high confidence in position location. In addition, the cyclone passed close to or over several reliable observation sites enabling the collection of a high-quality data set.

Impacts from tropical cyclone *Ian* were generally confined to the offshore islands. In the Monte Bellos group, a mining campsite was extensively damaged and a landing stage on Barrow Island sustained minor damage due to a 1.6 m storm surge.

Fran (N) and (B): 5 to 16 March 1992

Tropical cyclone *Fran* was the fifth cyclone, and the third within four weeks, to affect Vanuatu during 1991–92. *Fran* was also the second cyclone to cross the Queensland coast.

Fran originated from a shallow low that was first identified on 4 March embedded in the monsoon trough north-northwest of Western Samoa. Organisation of the cloud signature was quite slow at first, but by 1800 5 March there were indications that sustained winds near the centre had reached gale force and the system was named. *Fran* was moving in a general west-southwest direction at this stage, a track that the cyclone maintained with remarkable persistence until shortly before reaching the Queensland coast over a week later.

Tropical cyclone *Fran* passed between Wallis and Futuna Islands shortly after achieving cyclone intensity. Considerable rainfall was recorded on the islands, with Wallis Island reporting over 540 mm in 12 hours alone. *Fran* was intensifying rapidly at this stage and by 0000 7 March, shortly after crossing the date-line, hurricane-force winds had developed. During the next 24 hours, whilst steadily deepening, the cyclone tracked across waters to the north of Fiji and towards the central islands of Vanuatu. Maximum intensity was achieved just before reaching the island chain.

Fran passed between Efate and its southern neighbour Erromango between 0000 and 1200 9 March, with a highest gust of 40 m s^{-1} recorded at Bauerfield on Efate. In the higher and more exposed parts of the capital, Vila, gusts of up to 50 m s^{-1} were estimated to have occurred. The passage of *Fran* through Vanuatu caused it to weaken slightly, but upon reentering open water to the west, the cyclone slowly reintensified. *Fran* passed north of New Caledonia around 0000 10 March before assuming a more westward track which kept the centre north of the 20th parallel of latitude for the next two and a half days.

By 1200 12 March, *Fran* had reached its secondary maximum intensity – estimated mean winds of 40 m s^{-1} – whilst located approximately 650 km from the Queensland coast. The cyclone had slowed by this stage and it subsequently assumed a somewhat erratic southwest track towards the coast. Over the next three days *Fran* weakened, with satellite imagery indicating a steady decrease in the degree of organisation. The cyclone finally crossed the Queensland coast near the Town of Seventeen Seventy at 1700 15 March, with an eye diameter of approximately 80 km and maximum sustained winds estimated at 28 m s^{-1}. *Fran* subsequently moved inland and weakened to a tropical depression before recurving to the southeast and moving back over water. The ex-cyclone depression tracked over Norfolk Island before ultimately being captured by a westerly trough north of New Zealand.

The effects of tropical cyclone *Fran* were felt over a large area of the southwest Pacific. At Wallis and Futuna Islands, damage to trees, telephone and power lines was experienced, several boats were sunk and some buildings lost roofs. The heaviest impacts were felt in Vanuatu; in Erromango, houses were destroyed, considerable crop damage occurred and a storm surge was reported at Erromango wharf. In Efate, over 130 houses lost roofs. Finally, in southeast Queensland, winds and flooding caused minor property damage and heavy crop losses along the coast, particularly in the Bundaberg district. Insurance losses were estimated to be $A2.5 million.

Gene (N): 16 to 19 March 1992

Tropical cyclone *Gene* was the fifth cyclone to develop east of the date-line during the 1991–92 season, and like the systems before it, formed within an active SPCZ that extended well eastward of its climatological mean position.

For some days preceding the formation of *Gene*, an intense tropical depression was embedded within a broad low pressure area north of the Samoan group of islands. A vigorous westerly flow prevailed over a large area to the north. During 15 March, as the depression drifted eastward towards the northern Cook Islands, a second circulation developed within the low pressure area and consolidated. During 16 March, the low – now the dominant system – assumed an accelerating southeastward track and deepened further, passing approximately 60 km to the west of Palmerston Island at 1200 16 March. By 2200, satellite imagery indicated that cyclone intensity had been achieved and *Gene* was named.

Tropical cyclone *Gene* attained maximum intensity shortly after naming, with sustained winds estimated at 25 m s^{-1}. Maintaining this intensity, *Gene* tracked within 170 km of Rarotonga shortly before turning to the southwest. *Gene* had accelerated to 10 m s^{-1} by this stage and began to weaken as it encountered cooler waters. Passing south of 25°S, *Gene* recurved toward the southeast and by 0000 19 March, had lost its tropical cyclone characteristics.

The most extensive damage associated with tropical cyclone *Gene* occurred in the northern Cook Islands, where heavy seas induced by gale-force winds on the northern periphery of the cyclone produced coastal inundation.

***Hettie* (N): 25 to 29 March**

Tropical cyclone *Hettie*, like *Gene*, formed in the latter part of March during an active phase of the SPCZ, well east of the date-line. *Hettie* was the third cyclone of 1991–92 to affect French Polynesia.

Hettie was a slow developer that originated from a shallow low pressure system first identified on 24 March north of the Society Islands in French Polynesia. During 25 March, the system showed signs of development and the convective cloud signature improved in organisation. By 1800 25 March, gales associated with the circulation were estimated to have developed around the centre to a radius of 100 km, and *Hettie* was named.

The cyclone moved towards the south-southeast throughout its lifetime under the influence of a persistent northwesterly environmental steering flow. Near gale-force winds were experienced in the Windward group of the Society Islands as the centre of *Hettie* passed approximately 60 km to the west. The cyclone continued to slowly intensify, reaching maximum intensity of 25 m s^{-1} during 27 March whilst some 150 km southwest of Hereheretue.

Shortly afterwards, the cyclone began weakening under the dual influences of increasing vertical wind shear and cooler sea-surface temperatures. By 0600 29 March, Hettie had completed extratropical transition and was subsequently captured by an eastward-moving frontal system.

The only damage reported as a result of tropical cyclone *Hettie* was some minor property and crop damage in parts of Hereheretue.

***Neville* (D): 7 to 13 April 1992**

Tropical cyclone *Neville* was the only cyclone to form in the Darwin TCWC area of responsibility during 1991–92 and was the most intense cyclone since *Kathy* in 1984.

A major pulse in the MJO during the early part of April led to the genesis of a tropical depression near the Tanimbar Islands on 4 April. At first, the depression drifted slowly southeast in an environment of low shear and highly favourable high-level divergence. At 0600 6 April, the circulation was sufficiently developed vertically, and far enough south to come under the influence of a deep easterly steering current generated by the subtropical ridge over inland Australia; at 0200 7 April, the depression recurved to the southwest and was named. Tropical cyclone *Neville* maintained a general westerly or southwesterly track for the remainder of its lifetime.

Tropical cyclone *Neville* was a compact cyclone that intensified rapidly, despite the relative proximity of land. Shortly after crossing the northwestern tip of Melville Island, and only 24 hours after naming, sustained winds close to *Neville's* centre had reached hurricane force. The cyclone continued deepening as it tracked into the central Timor Sea, reaching maximum intensity around 1800 8 April. Mean winds at this stage were estimated to be 55 m s^{-1}.

Shortly after reaching maximum intensity, tropical cyclone *Neville* slowed in response to the passage of a higher latitude middle-level trough. After undergoing a small anticlockwise loop, *Neville* resumed its track to the southwest and began to slowly weaken. By 0600 10 April, the eye of the cyclone was no longer visible on satellite imagery and weak shearing effects were beginning to distort the overall cloud signature. At 0800 11 April, sustained winds associated with *Neville* eased below hurricane force and the cyclone slowed to a near standstill. The dual effects of weak vertical shearing and upwelling of cool water under the near-stationary cyclone caused the circulation to continue to weaken, and by 0200 13 April, *Neville* had dissipated. The residual low-level circulation was apparent on visible satellite imagery over the following two days as it drifted away to the southwest and spun down.

Damage associated with tropical cyclone *Neville* was confined to the northwest 'Top End' coast of the Northern Territory and Bathurst and Melville Islands. Widespread tree damage occurred and a safari camp on Melville Island was destroyed.

***Jane* (P): 8 to 17 April 1992**

Tropical cyclone *Jane* was the last cyclone to occur in the Australian region for 1991–92 and was also, along with tropical cyclone *Graham*, the most intense. Remarkably, *Jane* appears to be the only cyclone of the 1991–92 season that had no effect on any coastal or island community.

During 7 April, visible satellite imagery indicated the formation of a tropical low in the monsoon trough near 7°S 99°E, approximately 600 km northeast of Cocos Island. The low continued to intensify on a general south-southeastward course, achieving cyclone intensity at 1200 8 April. At 0000 10 April, *Jane* made its closest point of approach to Cocos Island, passing approximately 250 km to the east. The cyclone possessed a compact structure at this stage so that although sustained winds were estimated to be in excess of 35 m s^{-1}, gales were not recorded on Cocos Island.

As *Jane* tracked further southward it came under the influence of a deep-layer easterly steering flow generated by the subtropical ridge to the south. Between 0400 and 1800 11 April, the cyclone turned onto a westward track which it maintained for nearly five days. In the absence of inhibiting influences, *Jane* continued to deepen and at 1200 13 April, a well-defined eye appeared on satellite imagery. Twenty-four hours later, maximum intensity was reached with sustained winds estimated at 65 m s^{-1}.

Over the next 24 hours, tropical cyclone *Jane* began to weaken in response to increased vertical wind shear associated with an advancing mid-latitude trough. By 0600 15 April, the eye had become cloud-filled, and at 0000 16 April, the cyclone began to recurve to the southeast and rapidly weaken. By 0100 17 April, *Jane* had weakened below cyclone intensity.

Although tropical cyclone *Jane* was a very intense system, it spent its lifetime over open water and no reports of damage or injury were received.

***Innis* (N): 28 April to 1 May 1992**

Tropical cyclone *Innis*, the last cyclone for the 1991–92 season, was a small, weak and short-lived system. *Innis* was the sixth and least damaging cyclone to affect Vanuatu during the season.

Tropical cyclone *Innis* formed from a depression that first developed on 23 April between Tokelau and the northern Cook Islands, embedded in an active SPCZ. The depression subsequently tracked westward under the influence of a strengthening anticyclone east of New Zealand. The system slowly developed over the following days and decelerated as it approached the eastern Solomon Islands. By 2100 28 April, the system was named tropical cyclone *Innis*, with satellite imagery displaying curved banding and a well-formed cluster of central convection.

The cyclone intensified further, acquiring a symmetrical cloud signature on 29 April under a small upper outflow centre. *Innis* achieved its maximum intensity of about 25 m s^{-1} at 0000 30 April whilst located about 180 km east of Santa Maria Island in Vanuatu. At this point, the influence of an amplifying upper trough in the Coral Sea west of Vanuatu was producing northeast to northwest upper winds in the vicinity of *Innis* and the cyclone turned further to the south and the southeast. The centre passed within about 90 km of Pentecost Island in central Vanuatu before turning away and tracking out over open water.

With increasing vertical shear over the cyclone, it weakened rapidly from 0600 30 April, and had dissipated as a cyclone by 0000 1 May. The ex-cyclone depression subsequently accelerated to the southwest and was fully captured by the upper trough south of Fiji during 2 May.

Although gale-force winds affected parts of the eastern Solomon Islands and central Vanuatu, no injury or damage was reported.

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Appendix

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