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The South Pacific and southeast Indian Ocean tropical cyclone season 2004-05

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Eighteen tropical cyclones formed in the combined southeast Indian Ocean and South Pacific Ocean basins during the 2004-05 season and they all, with the exception of the short-lived September cyclone *Phoebe*, developed between December and April. Four intense tropical cyclones developed east of 180°E in the South Pacific region during February and significantly affected South Seas islands from Tokelau in the north to Rarotonga in the south. Other cyclones/depressions impacted on the Port Moresby area of Papua New Guinea and across much of Northern Australia. Weakly negative to neutral ENSO conditions prevailed and mostly positive sea-surface temperature (SST) anomalies were observed over the region throughout the season. The genesis area for the four severe tropical cyclones, in the area to the east of 180°E, was also closely aligned with the most vigorous arm of the Hadley circulation in the western Pacific.

Introduction

This paper provides a summary of the tropical cyclone (TC) activity in the southeast Indian Ocean (east of 90°E) extending eastward to the South Pacific Ocean (west of 120°W) during the 2004-05 tropical cyclone season. This area is further divided into AUW (90°E – 135°E), AUE (135°E – 160°E), AUS (90°E –160°E) and South Pacific (SPA) (east of 160°E).

Information used in the preparation of this paper has been provided by the Australian Tropical Cyclone Warning Centres (TCWCs) at Darwin, Perth and Brisbane, the Fiji Meteorological Service and from the *Monthly Global Tropical Cyclone Summary*, September 2004 to June 2005, compiled by Gary Padgett, USA.

The distribution of tropical cyclones and their intensity (emphasis has been placed on significant impacts) during the period is set in the context of the broadscale circulation with particular reference to El Niño–Southern Oscillation (ENSO) and the Madden–Julian Oscillation (MJO). A more detailed account of the tropical circulation in the Australian/Asian region during the November 2004 to April 2005 period can be found in the summary by Shaik and Cleland (2005) and the *Darwin Tropical Diagnostic Statements* as indicated in the Reference section of this paper. Position verification statistics for the Australian region TCs have been included in Table 2. Wind speeds referred to in the text are ten-minute averages.

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Tropical cyclone occurrence

The TC season for the whole region extended from 2 September 2004 to 23 April 2005 and produced eighteen tropical cyclones. This is close to the average for the period 1970-71 to 2003-04 of 18.9 as shown by McInerney et al. (2006). Table 1 shows a summary of

Table 1. Tropical cyclones in the South Pacific and southeast Indian Ocean 2004-2005.

Name and maximum wind (10 minute average)	*Low first identified*	*Named as tropical cyclone*	*Maximum intensity*	*End tropical cyclone phase*
Phoebe 26 m s^{-1}	2.8 °S 87.7°E at 0600 UTC 30 Aug	8.0° S 91.2°E at 0000 UTC 02 Sep	8.9°S 91.8° E at 1200 UTC 02 Sep	9.9°S 91.7°E at 1200 UTC 04 Sep
Judy 21 m s^{-1}	16.0°S 146.0°W at 0600 UTC 22 Dec	19.5°S 145.2° W at 2100 UTC 24 Dec	20.4°S 145.5° W at 0300 UTC 25 Dec	28.5°S 146.5°W at 0000 UTC 27 Dec
Raymond 23 m s^{-1}	12.9°S 119.8°E at 0000 UTC 30 Dec	14.4°S 122.7°E at 1800 UTC 01 Jan	14.2°S 123.2° E at 0000 UTC 02 Jan	14.5°S 126.6°E at 1600 UTC 02 Jan
Kerry 39 m s^{-1}	11.7°S 172.9°E at 0000 UTC 05 Jan	13.3°S 171.5°E at 1800 UTC 05 Jan	18.0°S 159.2°E at 1200 UTC 09 Jan	24.5°S 159.3°E at 1800 UTC 13 Jan
Sally 23 m s^{-1}	9.0°S 99.0°E at 0600 UTC 06 Jan	13.7°S 100.4°E at 0400 UTC 08 Jan	14.6°S 99.6°E at 0000 UTC 09 Jan	16.3°S 98.0°E at 0100 UTC 10 Jan
Tim 23 m s^{-1}	13.5°S 112.4°E at 0000 UTC 22 Jan	15.1° 109.9° E at 1300 UTC 23 Jan	15.4°S 109.2°E at 2200 UTC 23 Jan	16.5°S 105.3°E at 0600 UTC 25 Jan
Lola 21 m s^{-1}	16.5°S 172.5°E at 2100 UTC 28 Jan	21.8°S 176.8°W at 1400 UTC 31 Jan	22.7°S 176.5°W at 1800 UTC 31 Jan	25.2°S 176.6°W at 0000 UTC 2 Feb
Meena 59 m s^{-1}	16.8°S 167.0°W at 1200 UTC 2 Feb	14.4°S 168.2°W at 0600 UTC 3 Feb	19.7°S 160.6°W at 1200 UTC 6 Feb	28.0°S 150.0°E at 0000 UTC 8 Feb
Harvey 44 m s^{-1}	14.0°S 135.8°E at 1200 UTC 3 Feb	14.0°S 139.7°E at 0000 UTC 6 Feb	16.5°S 137.7°E at 0800 UTC 7 Feb	16.9°S 137.1°E at 1830 UTC 7 Feb
Vivienne 23 m s^{-1}	14.5°S 118.0°E at 0000 UTC 4 Feb	15.7°S 116.1°E at 0400 UTC 8 Feb	16.4°S 116.5°E at 0600 UTC 8 Feb	15.7°S 116.6°E at 2200 UTC 8 Feb
Nancy 57 m s^{-1}	11.0°S 168.0°W at 2100 UTC 10 Feb	12.8°S 166.8°W at 1800 UTC 12 Feb	14.4°S 162.1°W at 1200 UTC 14 Feb	25.0°S 164.0°W at 0600 UTC 17 Feb
Olaf 64 m s^{-1}	9.3°S 178.0°W at 0300 UTC 13 Feb	9.2°S 177.5°W at 1500 UTC 13 Feb	12.8°S 171.1°W at 0600 UTC 16 Feb	31.0°S 161.2°W at 1800 UTC 19 Feb
Percy 64 m s^{-1}	8.3°S 179.0°W at 2100 UTC 24 Feb	8.5°S 178.4°W at 0000 UTC 25 Feb	16.2°S 165.3°W at 0600 UTC 02 Mar	25.8°S 152.8°W at 0000 UTC 5 Mar
Rae 21 m s^{-1}	16.0°S 167.4°W at 1700 UTC 4 Mar	21.0°S 164.5°W at 2100 UTC 5 Mar	21.5°S 164.0°W at 0000 UTC 6 Mar	23.9°S 161.4°W at 1200 UTC 6 Mar
Ingrid 62 m s^{-1}	11.5°S 140°E at 0000 UTC 4 Mar	12.7°S 148.0°E at 0200 UTC 6 Mar	11.6°S 135.9° E at 0000 UTC 12 Mar	15.3°S 128.4°E at 2100 UTC 16 Mar
Willy 41 m s^{-1}	11.8°S 120.2°E at 0600 UTC 8 Mar	13.8°S 118.0°E at 1600 UTC 9 Mar	18.2°S 111.2°E at 2200 UTC 11 Mar	21.1°S 106.0°E at 1200 UTC 14 Mar
Adeline 39 m s^{-1}	9.8°S 101.2°E at 0000 UTC 2 Apr	12.4°S 97.7°E at 1000 UTC 3 Apr	13.0°S 90.1°E at 1200 UTC 5 Apr	Moved west of 90°E
Sheila 21 m s^{-1}	16.3°S 173.5°W at 1800 UTC 21 Apr	18.4°S 168.8°W at 0600 UTC 22 Apr	19.3°S 166.4°W at 1200 UTC 22 Apr	26.0°S 157.0°W at 1200 UTC 23 Apr

each TC that occurred during the season. Figure 1 shows the tracks between 90°E and 150°E and further details can be found at the Bureau of Meteorology website at http://www.bom.gov.au/cgi-bin/silo/cyclones.cgi. Figure 2 shows a more detailed track of TC *Ingrid*. Figures 3, 4, 5 and 6 show details of the tracks in the area of greatest TC activity in the South Pacific region and Fig. 7 shows details of TC *Harvey* and the depression in the Papua New Guinea region.

Nine tropical cyclones developed in the AUS (90°E to 160°E) region – ten if the Papua New Guinea depression is considered as a TC. This number is similar to the previous season and somewhat below the long-term average of 12.8. Of these nine, only three made landfall on the Australian coast although severe TC *Ingrid* crossed land a number of times on its course across Northern Australia. As seven of these TCs formed in the AUW region (90°E-135°E), the shortfall was in the AUE region where only two TCs formed (*Ingrid* and *Harvey*) compared to 5.1 for the long-term average. TC occurrence in the South Pacific (East of 160°E) was about average with nine developing in the region although four (long-term average two) of these were classified as intense tropical cyclones (ITC) with maximum wind speeds >44 m s^{-1} (definition from McInerney et al. (2006)). Of the nine that formed east of 160°E only TC *Kerry* moved into the AUS region but it had weakened significantly before the remnant low came close to the south Queensland coast.

The number of TC days for all intensity categories for the AUS-SPA region was 62 compared to the long-term average of 78 days as shown by McInerney et al. (2006). The largest shortfall was in the AUS region where there were only 28 TC days for all severity categories compared to the long-term average of 68.4 days. However, there was an exception to the below average activity as there were 14 ITC days in the South

Fig. 1 Tracks of TCs from 90°E to 150°E – details of individual tracks can be found at http://www.bom.gov.au/cgi-bin/silo/ cyclones.cgi.

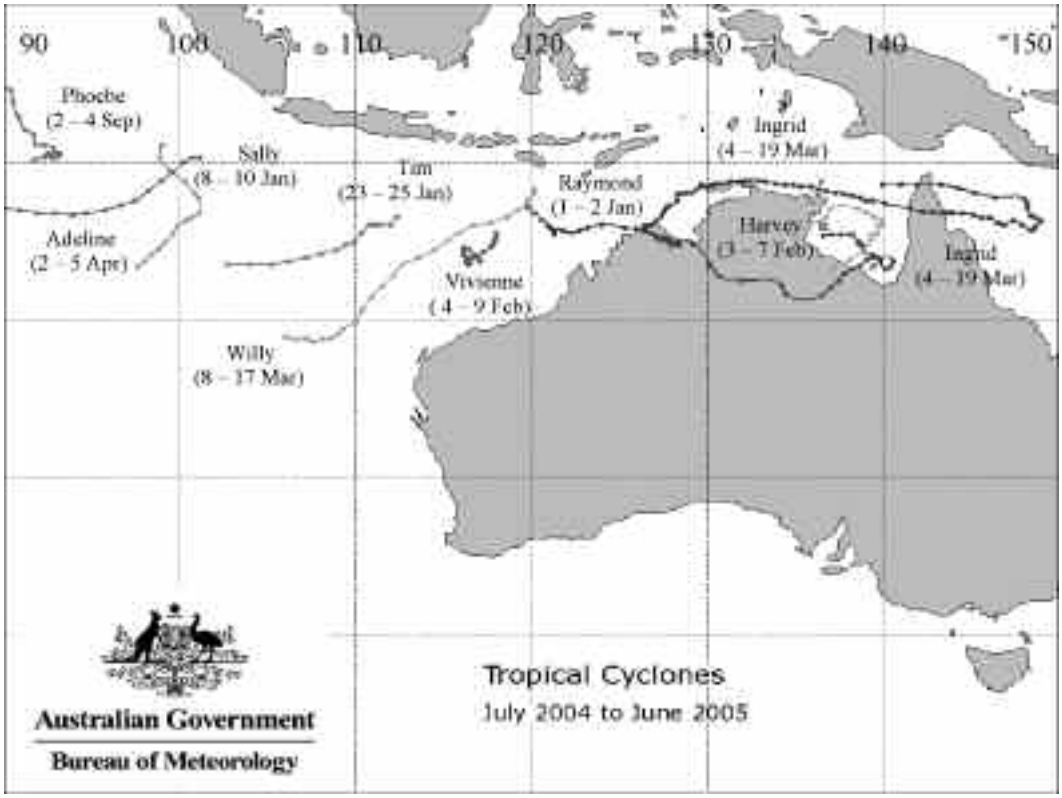


Fig. 2 Track of TC *Ingrid*.

Fig. 3 Tracks of TCs *Judy*, *Kerry* and *Percy*.

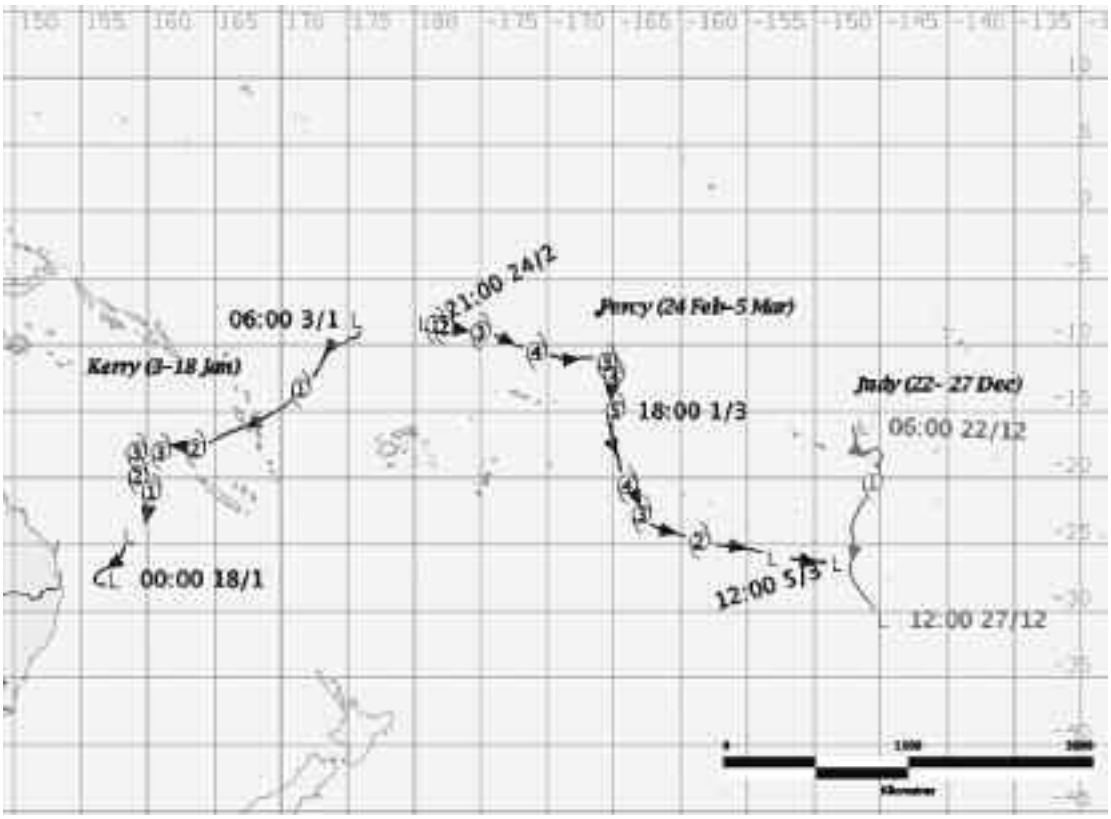


Fig. 4 **Tracks of TCs *Lola* and *Sheila*.**

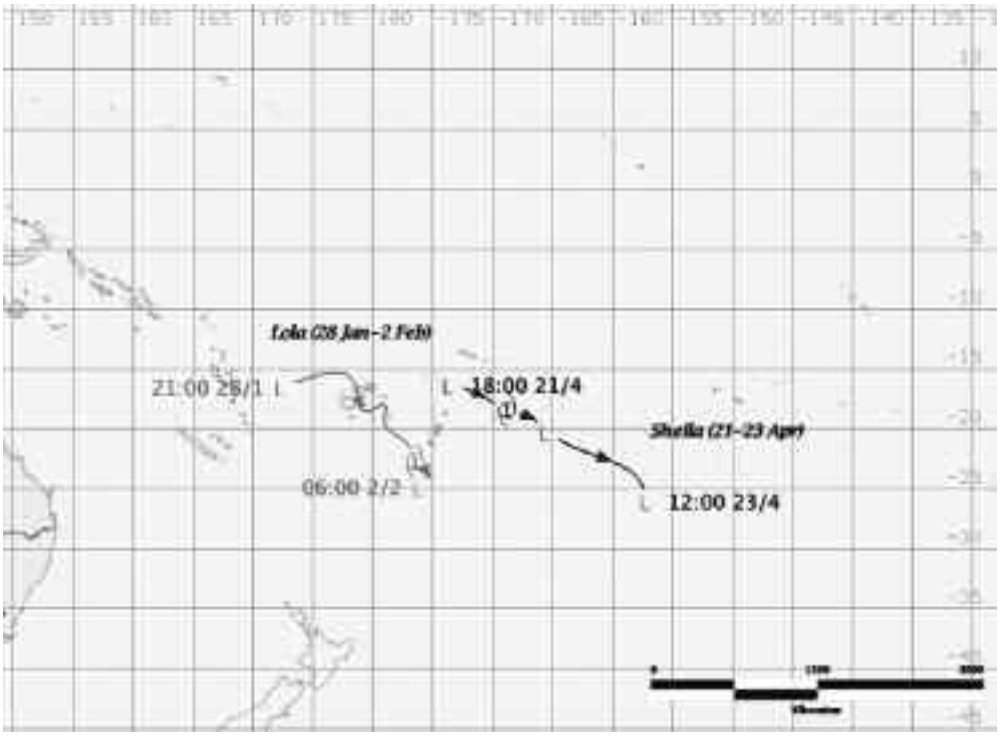


Fig. 5 **Tracks of TCs *Rae* and *Nancy*.**

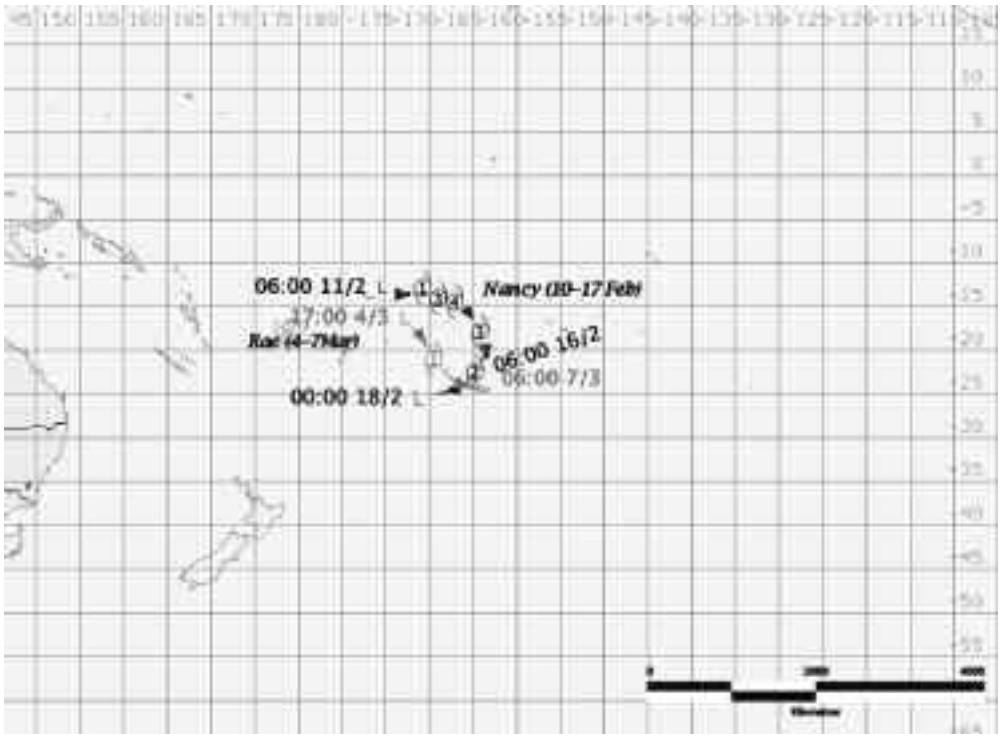


Fig. 6 Tracks of TCs *Olaf* and *Meena*.

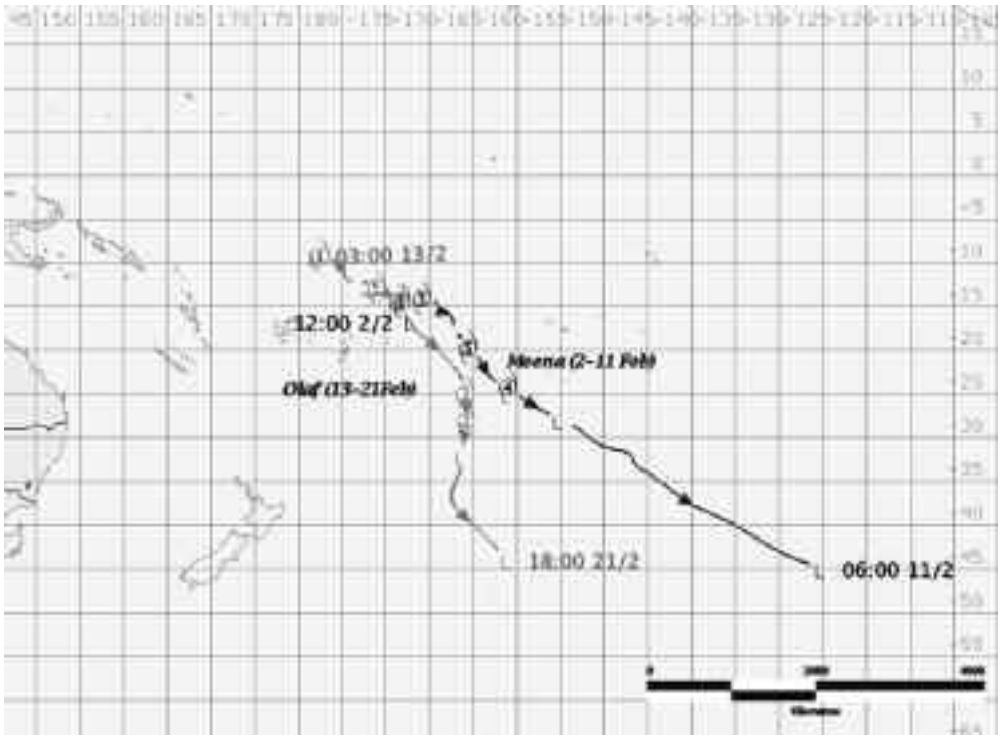
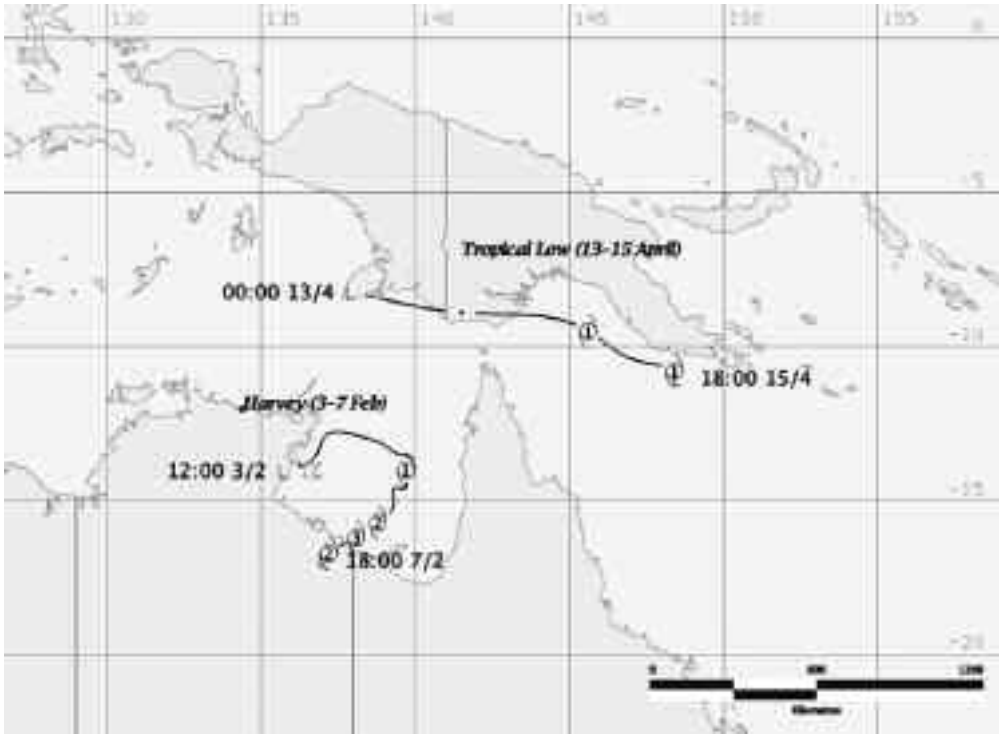


Fig. 7 Tracks of Papua New Guinea low and TC *Harvey*.



Pacific region resulting from four intense tropical cyclones (TCs *Meena*, *Nancy*, *Olaf* and *Percy*) that formed during February compared to 2.7 days for the long-term average. The last season when there were similar numbers of tropical cyclones in the southeast Pacific region in a season was in 1982-1983 when there were three – one less than in the 2004-05 season.

Impacts

Only five of the eighteen TCs for the season had major impacts on populated areas and four of these TCs *Meena*, *Nancy*, *Olaf* and *Percy* significantly affected South Seas islands from Tokelau in the north to Rarotonga in the south. TC *Meena*'s impact was felt most keenly in the Southern Cook Islands with Rarotonga being the most severely affected. The same general area was the target of TC *Nancy* only a week later with Aitutaki Atoll, Rarotonga and Mangaia being affected. TCs *Olaf* and *Percy* affected islands farther north, with TC *Olaf* battering some islands in American Samoa while TC *Percy* devastated the atolls of Tokelau, Swain's Island (belonging to American Samoa), Nassau and Pukapuka Atolls.

The destructive core of TC *Meena* weaved its way between island groupings without making a direct hit. However, areas near the coast experienced storm surge damage and there was widespread damage to gardens, sheds and trees but there were no reports of injury. TC *Meena*'s main impact was almost entirely due to the ocean swell impacting on fringing reefs and coastlines. The northern coast of Rarotonga, especially in the commercial district of Avarua, was pounded by huge waves early in the morning of 6 February. Waves were reported to be averaging 14 m in height. A strong storm surge and large waves also spread coral debris/rocks that contributed to the moderate damage that was reported to homes and businesses immediately on or near the shore from the eastern part of Avarua eastward along the east coast of the island. Government buildings on the east side including the Ministry of Police and Health were damaged by the tidal surge.

Similarly to *Meena*, the destructive core of TC *Nancy* weaved its way between the inhabited island groupings, and was considerably weakened prior to brushing Rarotonga. However, when compared to TC *Meena*, it was wind damage rather than sea surge damage that was notable, particularly to residential premises. On Aitutaki, TC *Nancy* uprooted trees, damaged roofs and flooded low-lying areas on the atoll. No injuries were reported among Aitutaki's 2000 residents. The northeastern side of Aitutaki was hit by huge waves, with the Samade Bar near the Ootu Peninsula experiencing flooding. Countless trees and branches brought down power lines and littered the roads, while a number of buildings including classrooms at Tereora College, Nikao Maori school, the Seventh Day Adventists' churches in Matavera, and the Portofino Restaurant in Maraerenga lost their roofs.

Tropical cyclone *Nancy* had a greater impact than TC *Meena* as it caused widespread destruction along the northern and eastern coasts of Rarotonga. Roads were flooded, trees uprooted and power lines were blown down by winds that gusted up to 185 km/h. Some buildings were destroyed, roofs were blown off some schools, and in some homes only a concrete slab remained. About seven houses and the Enua Manu pre-school lost their roofs, covers were blown off three community water tanks, 15 cooking shelters were demolished and the northern side of the island was pounded by heavy seas. At least two hotels on the island were closed temporarily for repair work. Considerable crop damage was also reported throughout the Southern Cook Islands associated with TC *Nancy*'s winds. Although the cyclone did not pass directly over Western Samoa, strong winds were reported to have damaged power lines on the western island of Savai'i. Extensive tidal damage was also reported in coastal areas. Faleolo International Airport in Apia was also closed during and after the cyclone.

Tropical cyclone *Olaf* caused very strong winds on the northern side of Tutuila the main island of American Samoa on 15 and 16 February, however no injuries or major damage occurred. On American Samoa's Manua'a islands, TC *Olaf* destroyed many homes close to the sea, flattened crops and littered the island with debris. Nearly all homes still standing had lost rooftops and the island was without electricity and running water, creating health concerns. The Manu'a group took the brunt of the cyclone. The Governor said the worst affected area was the village of Fitiuta on Ta'u Island which suffered 85-90 per cent destruction. Houses had been destroyed, trees snapped in two and a large section of road infrastructure wiped out. Twenty-three people were rescued from the sea as a result of the cyclone in the Samoan region, and two people were reported as missing from a fishing boat that sank.

Unlike TCs *Meena* and *Nancy*, which skirted the east coast of Rarotonga during the previous two weeks, TC *Olaf* affected the western side. Despite passing well to the west (approximately 230 km), there were reports of homes and businesses losing their roofs, and many more had been left without power or phone lines. About 30-40 per cent of homes on Rarotonga lost electricity and communications, but these services were quickly restored. The Cook Islands Emergency Operations Centre reported that approximately 60 houses on Rarotonga suffered dam-

age to their roofs. On the island of Palmerston, sea water was reported to have surged up to 100 m inland as TC *Olaf* passed by. There were no reports of death or injury on land from TC *Olaf*.

Tropical cyclone *Percy* severely affected the New Zealand-administered territory of Tokelau, damaging roads and power lines and spreading debris. The 1400 people of Tokelau were faced with a massive clean-up job in the wake of TC *Percy*, which has been described as the worst TC to hit the islands in living memory. The island's administrator, Neil Walters, was in Tokelau when the cyclone struck, coinciding with 'king tides' which swamped the islands in up to a metre of sea water. Nukunono, Atafu and Fakaofa atolls lost significant parts of their infrastructure, including damage from wind and floods to seawalls, hospital facilities, schools, an office building and a meeting-house while debris collected in the villages. Tokelau's three atolls lost most of their staple crops, especially the coconut crop used for food and drink, the swamp taro, banana and pawpaw crops, while most of the fish habitats were destroyed. The islands suffered beach erosion and many live coral formations were covered by sand and debris.

Swain's Island, a small outlying part of American Samoa midway between Hawaii and New Zealand, was out of contact for a week after TC *Percy* hit. Of the nine buildings on the island, only three survived, including the Government Building where the people took shelter during the storm. The island was largely flooded by the storm surge, with very heavy damage reported to gardens, trees and plants and with debris strewn throughout. According to Radio New Zealand International, nearly all of the 600 residents of Pukapuka and the 40 living on Nassau in the Northern Cook Islands lost their homes or suffered heavy damage from the cyclone, which hit after leaving damage in Tokelau and on Swains Island in northern American Samoa. Only ten buildings were left intact. Deputy Prime Minister and Finance Minister Sir Geoffrey Henry (Cook Islands) estimated that reconstruction costs from damage caused by the four cyclones, including TC *Percy*, during the month of February could be more than US$25 million.

Tropical cyclone *Lola* brought strong winds to parts of central and southern Tonga. Squally winds and localised heavy rains were reported from Ha'apai, Nomuka and Tongatapu Group, but there were no reports of significant structural damage. However, significant crop losses were reported with heavy windfalls of fruit, especially of mangoes, tava, breadfruit, avocados and bananas. Tongatapu, reported as having its first bumper crop mango season since 1998, was left with 'carpets of mangoes' under the trees.

The low that subsequently became TC *Rae* brought flooding rains to parts of Fiji and Samoa. Flooding in Fiji in the Suva and Nausori areas of Viti Levu was reported as causing several landslides and displacing several people.

Of the three TCs which made landfall on the Australian coast (TCs *Harvey*, *Raymond* and *Ingrid*) only TC *Ingrid* had a significant impact. TC *Ingrid* formed as a tropical low in the eastern Arafura Sea, moved east and strengthened to cyclone intensity in the Coral Sea, then moved back towards the west. TC *Ingrid* crossed the Queensland coast south of Lockhart River as a severe cyclone, continued on a westerly track across Cape York Peninsula and rapidly intensified again as it moved across the Gulf of Carpentaria. TC *Ingrid* reached ITC strength as it moved in a west-northwest direction, skirted the north coast of the Northern Territory, crossed a number of the larger islands before tracking southwest across the Timor Sea to make landfall on the Kimberley coast of Western Australia.

The first landfall of TC *Ingrid* near the sparsely populated Lockhart River resulted in a 55 kilometre wide strip of land being totally cleared of trees. The leaves had been stripped and the dismembered trunks had been pushed over near their bases. Queensland authorities reported an estimated peak water level of 4.0 m above Australian Height Datum (AHD) near Voaden Point (at the southern end of the Lockhart River Aboriginal Reserve). There were no reports of injury as a result of the Cape York crossing. However, five lives were lost in the Coral Sea near Kerema in Papua New Guinea as a boat capsized in the large swells generated by TC *Ingrid*. It was estimated that (AUS) $2 million worth of damage was caused in Queensland from TC *Ingrid*, with the Cook Shire Council estimating that damage of up to $1 million had occurred to shire roads and the Douglas Shire reporting up to $300 000 of road damage

Due to TC *Ingrid*'s longevity and proximity to the coast, many population centres in the Northern Territory were affected, however the effects were localised and confined mainly to island communities. Many coastal and island communities lost power and communications. Extensive tree damage and defoliation occurred at Elcho Island, North Goulburn Island, Croker Island, the Cobourg peninsula, the northeast tip of Melville Island and near *Ingrid*'s landfall point on the north Kimberley Coast. At Croker Island extensive damage occurred to several buildings. There was major damage to buildings and a school on the northern end of Elcho Island. A number of buildings also lost their roofs at Cape Don on the Cobourg Peninsula, in communities on the Tiwi Islands and at Kalumburu. Arafura Pearls reported suffering more

than $1 million damage to its pearling fleet, with seven vessels lost or missing and a 27 metre vessel that had run aground in Nhulunbuy harbour was damaged. The company reported that none of the crew or staff was injured in the cyclone. The Northern Territory Government estimated that TC *Ingrid* caused about Aus$5 million damage to Croker and the Tiwi Islands.

The resort of Faraway Bay (near the landfall point) in West Australia was reported as being wrecked by TC *Ingrid*. Two staff members escaped unharmed by sheltering in a sea container while TC Ingrid passed directly overhead. The storm tide accompanying the cyclone was reported as depositing boats about 100 m inland and several m above the usual high tide mark. Flooding was extensive in the Kimberley region, as the adjacent King Edward River became a massive swollen torrent. Floodwaters cut the Great Northern Highway near Kununurra and isolated some properties.

The remaining landfalling (or near landfalling) systems had lesser impact. TC *Harvey* made landfall in a remote part of the Northern Territory, and only a few settlements were affected. At Pungalina Station (130 km southeast of Borroloola) strong winds hit the homestead just before midnight and 60 mm of rain fell in a few hours. Many trees were uprooted or snapped, but there was no structural damage to any of the buildings. At Robinson River, there were some trees down and others stripped of foliage, with some minor structural damage to buildings. Extensive flooding was also reported, causing about $1 million damage to roads. The Robinson River rose 15 to 16 m and came within one metre of the power station.

Whilst not making landfall, TC *Kerry* produced long-period swell waves along the southern Queensland and New South Wales coasts. There were many rescues on the Gold and Sunshine Coasts and one surfer drowned. TC *Raymond* made landfall as a category one system on the north Kimberley coast of West Australia, near Mitchell Plateau with the main impact being the first heavy rain of the season to the Kimberley. On the afternoon on 3 January, a severe squall line formed on the periphery of the ex-TC. It produced widespread damage in Katherine South, with many trees being brought down.

The strong winds and heavy rain from the April tropical depression caused major disruptions to electricity, communication and airline flights in Port Moresby. Trees and power lines were brought down causing road blocks and the Burns Peak Repeater Site Tower collapsed, resulting in a disruption to communications. Fallen trees cut power lines along various parts of the city while the busy Port Moresby traffic was brought to crawling pace from heavy flooding of the roads.

Despite not reaching cyclone status, the Cape York and Coral Sea low in January brought heavy rains to the tropical coast of Queensland between Townsville and Mackay. Two cars collided with a truck near Yalboroo, south of Proserpine (Queensland) in heavy rain associated with the depression resulting in two deaths and injuries to three others. An unofficial but reliable source reported 642 mm of rain in 24 hours in a location just to the west of Townsville on 23 January. Falls of up to 200 mm were widespread in this region.

Broadscale seasonal features

Seasonally averaged mean sea-level pressure (MSLP) anomalies as shown by Shaik and Cleland (2005) were positive in the Australian region during the season. The positive anomalies over Australia were consistent with the persistent dry conditions over much of the continent. The pattern of MSLP anomalies over this region was similar to the November 2003 to April 2004 season and also to what could be expected in a weak El Niño event.

Low-level westerly anomalies were evident across most of the near-equatorial Pacific leading to seasonally averaged westerlies around Papua New Guinea (PNG). This gave rise in the anomaly fields to an apparent divergence over Indonesia and convergence over the northern tropical Pacific around 160°E. Low-level winds over northern Australia showed easterly anomalies of nearly 5 m s^{-1} over large areas, indicative of the poor monsoon season over the region. At upper levels, the flow produced a divergence effect northeast of PNG and convergent effect north of Indonesia. The centres of maximum low-level convergence and upper-level divergence were displaced well to the east of their climatological locations and is consistent with above average convection east of 160°E and below average convection over the Maritime Continent. The seasonal mean flow showed a strong long-wave trough located west of Western Australia.

Sea-surface temperatures for the six months November to April were chiefly within ±0.5°C of the long term mean for the Coral Sea and the Gulf of Carpentaria. Most of the equatorial Indian Ocean and seas to the northwest of Australia remained warmer than normal. SSTs in the equatorial western Pacific east of Papua New Guinea and in the northwest Pacific also remained warmer than normal. These warm temperature anomalies have been more or less a feature of the past three seasons. The warmest waters in the equatorial Pacific remained mostly west of the date-line while the SST pattern near the South American coast was close to climatological values.

Intraseasonal variations

Broadscale areas of active convection formed over the near-equatorial central Indian Ocean during the latter half of each month since July 2004, which could be attributed to MJO active phases. One of these was observed in the Indian Ocean in late August to early September and contributed to the development of TC *Phoebe*. The periodicity of these active events remained around 30-35 days for the season. In addition to these major events, there were several weak convective pulses and others were evident in the eastern half of the region and may well be related to the progress of near-equatorial Rossby waves through the region.

Verification statistics

Position forecast and analysis verification data for each TC in the Australian region was calculated by comparing best-track positions with real time analyses and forecasts. These are summarised in Table 2. Initial position analysis errors and 12 and 24-hour forecast position errors were all less than the long-term mean errors.

Tropical cyclones in the South Pacific and southeast Indian Ocean 2004–2005

TC *Phoebe* (Perth) 2–4 September (Fig. 1)
A low developed near 2.8°S 87.7°E at 0600 UTC on 30 August within an unseasonably active monsoon band, coincident with a burst in the MJO. The low moved to the southeast over the next few days, and suffered from significant 850-250 hPa shear exceeding 20 kn throughout its lifetime. On 31 August an area of deep convection developed to the west-southwest of the low-level circulation centre. This convection was to be persistent for the following four days, although the low–level centre remained exposed for almost all of that time. The low was named TC *Phoebe* on 2 September when the low-level centre moved closer to the edge of the deep convection. At this time TC *Phoebe* was centred about 800 km west-northwest of the Cocos Islands. TC *Phoebe*'s intensity fluctuated over the following two days but weakened as the system moved over cooler ocean waters when near 10°S on 4 September. TC *Phoebe* remained over open waters throughout its lifetime and there were no known impacts.

TC *Raymond* (Perth) 1–2 January (Fig. 1)
On 30 December satellite imagery depicted rotating deep convection over a possible weak low-level cloud centre and by at 0400 UTC on 31 December the developing low was located approximately 400 km north-northwest of Broome. The low began to track slowly northeastward on 1 January and as the day progressed the tropical low commenced a slow east-southeastward drift as convection began to increase over the low-level centre. At 1800 UTC on 1 January, Perth upgraded the low to TC *Raymond* when located near 14.4°S 122.7°E and moving towards the east. The easterly motion continued and accelerated as the day progressed. By 1600 UTC on 2 January TC *Raymond* had moved inland just west of Kalumburu in the Kimberley region and had been downgraded to a tropical low. The remnant low continued to move eastwards across the Northern Territory as it weakened, eventually reaching the Gulf of Carpentaria.

Table 2. Position verification statistics for each cyclone were derived by comparing the official warnings issued by the relevant Tropical Cyclone Warning Centres with post analysis 'best track' positions.

	Initial position		*12 h forecast*		*24 h forecast*		*48 h forecast*	
Tropical cyclone name	*Error (km)*	*No.*	*Error (km)*	*No.*	*Error (km)*	*No.*	*Error (km)*	*No.*
Ingrid	12	55	74	50	73	47	124	40
Phoebe	57	9	116	9	210	8	267	5
Raymond	31	12	131	12	487	12	844	2
Sally	36	12	103	11	195	9	-	-
Tim	34	9	71	7	75	5	-	-
Vivienne	22	17	52	17	86	15	114	7
Willy	29	23	59	21	78	19	162	15
Kerry	45	22	70	22	137	22	333	21
Harvey	7	10	58	6	77	4	-	-
Adeline	43	13	98	13	149	12	335	7
Total		182		168		153		97
Weighted Mean	27		79		137		212	

TC *Sally* (Perth) 8–10 January (Fig. 1)

On 6 January an area of convection developed roughly 920 km west-southwest of Jakarta, Indonesia. At 0400 UTC on 7 January the low was positioned approximately 370 km east-northeast of the Cocos Islands. A day later at 0400 UTC on 8 January the system was named TC *Sally* when located about 370 km east-southeast of the Cocos Islands and moving west-southwest at 6 kn. TC *Sally* moved on a slow south-westerly track throughout its life as a tropical cyclone, guided by a large mid-level ridge situated to its south-east. TC *Sally* reached peak intensity of 45 kn on 9 January but weakened quickly due to the combined effects of dry air and increased vertical shear. TC *Sally* was downgraded to a tropical low at 0100 UTC on 10 January, and the final position of the low at 0600 UTC on 10 January was 16.7°S 97.7°E about 460 km south-southwest of the Cocos Islands. No known damage or casualties were attributed to TC *Sally*.

TC *Tim* (Perth) 23–25 January(Fig. 1)

An area of convection associated with a low pressure centre was evident as early as 22 January in the area of 13.5°S 112.4°E and being in a low shear/strong upper outflow environment began to develop fairly rapidly on 23 January. The low was upgraded to TC *Tim* and at 1300 UTC on 23 January it was located about 690 km southeast of Christmas Island, moving southwestward at 6 kn. Throughout its short life TC *Tim* moved on a slow west-southwesterly course as it was steered by an anticyclone lying to its southeast. TC *Tim*'s rapid development did not continue, and after reaching peak intensity with maximum winds of 45 kn at 2200 UTC on 23 January, TC *Tim* began to weaken and gales were last observed associated with the system at 0000 UTC on 25 January when located approximately 740 km south-southwest of Christmas Island.

TC *Kerry* (Nadi – Brisbane) 3–17 January (Fig. 3)

The low that was to become TC *Kerry* was first identified as a westward-moving depression to the north of Fiji on 3 January. At this time the relatively disorganised cloud mass was located in a favourable environment for further development as the environmental shear was weak and SSTs were around 30°C. Convection developed rapidly close to the low-level circulation and the island of Funafuti, (8.5°S 179.2°E), to the north and east of the developing system, reported very heavy rainfall totals for the 24 hours ended 0000 UTC on 4 January.

Gales around the centre became evident early on 4 January and the low was named *Kerry* at 1800 UTC on 5 January when located about 580 km northeast of Port Vila, Vanuatu, and moving southwest at about 11 kn. TC *Kerry* picked up forward speed as it approached Vanuatu, crossing the central part of the island nation between 1800 UTC and 0000 UTC on 7 January. Interaction with the larger islands also ensured TC *Kerry* remained a relatively weak system. During its passage through Vanuatu there were no reports of major damage and no reported casualties.

Once clear of Vanuatu, TC *Kerry* continued to move west-southwest at around 20 kn. The process of intensification commenced as it moved west and closer to the upper-level ridge axis, the centre passing close to the Isles Surprises (New Caledonia territory). TC *Kerry* developed to reach severe intensity by 1200 UTC on 7 January when 550 km northwest of Noumea. At 0600 UTC on 8 January when near 18.3°S 160.0°E Severe TC *Kerry* moved into Brisbane's area of responsibility. Peak intensity of 955 hPa and maximum winds of 80 kn were attained when the centre was located roughly 880 km northwest of Noumea.

Tropical cyclone *Kerry* commenced a slow track to the south-southeast, progressively weakening under strong vertical wind shear associated with an approaching upper-level trough. A strong surface ridge eventually pushed a considerably weakened TC *Kerry* to the west-southwest on 13 January toward Australia's south Queensland coastline. By this stage, the upper-level structure of the cyclone had been completely disrupted due to strong vertical wind shear with the low-level circulation centre exposed. TC *Kerry* lost tropical cyclone status near 24.5°S 159.3°E, or about 740 km east-northeast of Brisbane, at 1800 UTC on 13 January.

The remaining exposed low-level circulation of ex-TC *Kerry* proved to be a remarkably resilient feature, moving southward to approximately 148 km off the southern Queensland coast only to be pushed northwards again several days later. The low-level centre was still evident in high-resolution visible satellite imagery on 20 January a week after losing tropical cyclone status. The system eventually decayed completely to the east of Queensland's Sunshine Coast near 25.5°S 157.0°E.

TC *Vivienne* (Perth) 4–9 February (Fig. 1)

On 4 February, a weak low had formed near 14.5°S 118.0°E with associated convection and with strong low-level inflow. The low-level circulation centre was located in an environment of low to moderate vertical shear with very favourable divergence aloft and increasing 850 hPa vorticity. The system at this time was drifting slowly to the south-southwest. By 0000 UTC on 8 February the low-level circulation centre had moved under the deep convection and at 0400 UTC on 8 February the low was named TC *Vivienne* when located approximately 700 km west-northwest of Broome and essentially stationary.

However, TC *Vivienne*'s life as a tropical cyclone was very brief and at 1039 UTC on 8 February satellite microwave observations indicated that the low-level circulation centre had become fully exposed and visible imagery revealed that the deep convection had weakened significantly. TC *Vivienne* was declassified as a cyclone at 2200 UTC on 8 February. During its brief life as a tropical cyclone TC *Vivienne* moved very little and no associated damage or casualties are known to have resulted.

TC *Harvey* (Brisbane and Darwin) 3–7 February (Figs 1, 7)

On 3 February a tropical low developed on the monsoon trough in the western Gulf of Carpentaria to the north of Groote Eylandt. By 5 February this low had moved into the central Gulf approximately 230 km west-southwest of Weipa, Queensland. Under favourable conditions of low shear, high SSTs and good poleward upper-level outflow, it commenced the process of intensification. The system was named TC *Harvey* at 0000 UTC on 6 February when near 14.0°S 139.7°E, commenced moving in a south-southwesterly direction, and intensified rapidly into a severe cyclone in the hours just prior to making landfall 93 km north-northwest of Wollogorang (Northern Territory) at 0600 UTC on 7 February.

TC *Harvey* lost cyclone status at 1830 UTC on 7 February when approximately 110 km west-northwest of Wollogorang and was soon captured by the approaching surface trough to the southwest and steered rapidly across inland Queensland, passing into the Coral Sea off the central Queensland Coast near Mackay on 10 February.

TC *Ingrid* (Brisbane, Darwin and Perth) 4–19 March (Figs 1, 2)

On 3 March an area of low pressure gradually consolidated to the northeast of Cape Wessel, Northern Territory and commenced moving toward the east-southeast. The developing tropical low crossed the northern tip of Cape York Peninsula and moved into the far northwestern Coral Sea. By 0500 UTC 5 March it was near 11.9°S 145.0°E (approximately 185 km east of Cape Greenville, Queensland and moving eastward at 10 kn. The low was located in a favourable environment for further development with low vertical wind shear and favourable diffluence aloft and when over water the SSTs were generally about 30 °C.

The low was upgraded to tropical cyclone status and named TC *Ingrid* at 0200 UTC on 6 March when near 12.7°S 148.0°E, approximately 460 km east of Lockhart River, Queensland, as gales wrapped around the low-level circulation centre. The cyclone intensified at a rapid rate and slowed its forward momentum as a high-pressure ridge built to the south across the Coral Sea. In a little over 24 hours, TC *Ingrid* was a severe tropical cyclone located 410 km east-northeast of Cooktown with gales extending little more than 55 km from the centre and hurricane force winds of up to 75 kn confined to near its centre. Soon afterward TC *Ingrid* recurved to the southwest and commenced movement towards the far northern Queensland tropical coast in response to the strengthening of a mid-level ridge located to the south of the system. The first of TC *Ingrid*'s three periods of category 5 intensity occurred in the northwestern Coral Sea. At 14.0°S 147.9°E, approximately 330 km east-northeast of Cooktown, *Ingrid* reached an estimated central pressure of 930 hPa and with maximum winds of 115 kn near the centre.

In satellite imagery, TC *Ingrid* developed a very symmetrical eye with an impressive but tight outflow pattern. However, the cyclone weakened on its approach to northern Cape York due to unfavourable wind shear and a weakening in poleward outflow due to the passing of a mid-latitude trough. TC *Ingrid* re-strengthened slightly just prior to landfall at 13.2°S 143.5°E, 28 km south of Old Lockhart River Mission and 55 km south-southeast of New Lockhart River. At this time, TC *Ingrid* was a compact 955 hPa cyclone with destructive winds extending 55 km from the centre and very destructive gusts of up to 130 kn extending only 20 km from the centre.

TC *Ingrid* continued to track across Cape York Peninsula on a westerly track at 8-12 kn, gradually weakening, but maintaining tropical cyclone status prior to crossing back to sea in the Gulf of Carpentaria near Aurukun (13.3°S 141.8°E) at 0900 UTC on 10 March. TC *Ingrid* had maintained a fairly well intact structure while crossing land and quickly re-intensified as it moved west-northwest over the very warm waters of the Gulf. The cyclone maintained a path to the west-northwest at 10 kn, passing approximately 28 km north of Nhulunbuy (Gove) at 1800 UTC on 11 March where wind gusts reached 60 kn. The cyclone was tracked by the Nhulunbuy (Gove) radar, which depicted a compact cyclone with a tightening wind core that signified the cyclone was intensifying. TC *Ingrid* brushed the northeastern tip of the Northern Territory at Cape Wilberforce and continued on a general west-northwesterly path, crossing through the southern part of the Wessel Island chain and passing 46 km north of Elcho Island at 0000 UTC on 12 March. TC *Ingrid* regained category 5 status at about this time with an estimated central pressure of 938 hPa and maintained an oscillating west-northwestward path at 10 kn parallel to and approximately 55-75 km off the Arnhem coastline. TC *Ingrid* main-

tained a very compact destructive core with hurricane force winds extending little more than 18 km from the centre and gales to 110 km. As such, the very destructive core was for the most part maintained offshore. Radar imagery indicated a very small and intense system with an eye diameter near 9 km: cloud-top temperatures surrounding the eye were estimated at –76°C to –80°C.

TC *Ingrid* turned to the west as it approached Coburg Peninsula and reached its second major peak in intensity of 925 hPa and average winds of 120 kn, passed to the south of the southern tip of Croker Island at 1800 UTC on 12 March before moving over Coburg Peninsula at 0000 UTC on 13 March. The cyclone weakened due to interaction with land and unfavourable shear, with the eye disappearing briefly from satellite and radar imagery. TC *Ingrid* maintained a 5 kn westward path over the northern part of the Tiwi Islands, passing firstly over Melville Island as a category 3 (950 hPa, maximum average winds of 90 kn) cyclone before moving into the Timor Sea at 1800 UTC on 13 March. Once again the cyclone strengthed as it moved clear of the Tiwi Islands and in response to favourable upper-level outflow conditions in all directions and high SSTs. Satellite imagery and the Darwin radar depicted an intensifying cyclone with deep convection increasing around the eyewall. TC *Ingrid* continued to be a very compact cyclone as it moved initially to the west-southwest and then on a southwesterly path at 7 kn in response to a weakening in the middle-level ridge to the south. The main jet stream moving to the southeast of the system across into Queensland further enhanced the intensification process as TC *Ingrid* regained category 5 status at 0000 UTC on 15 March: an intensity that was maintained until landfall.

At 1200 UTC on 15 March, TC *Ingrid* made final landfall, crossing the north Kimberley coast about 55 km northeast of Kalumburu and 215 km northwest of Wyndham. The Wyndham radar depicted the compact core of TC *Ingrid* making landfall at Faraway Bay. The cyclone maintained a southwesterly course overland, slowing to 3 kn before recurving to the east-southeast around the upper-level ridge to the south. As expected for a small system, the cyclone weakened fairly rapidly over the rugged terrain of the north Kimberley region and was finally downgraded at 2100 UTC on 16 March (near Kununurra, Western Australia) as it moved at 6 kn into the Northern Territory as a rain depression.

TC *Willy* (Perth) 8–17 March (Fig. 1)

A tropical low was first identified near 11.8°S 120.2°E at 0600 UTC on 8 March. Infrared satellite imagery indicated an increase in deep convection, and at 1013 UTC on 8 March a microwave pass depicted a well-organised low-level centre located in an environment of moderate vertical shear and moderate upper-level divergence The low at 0100 UTC on 9 March was centred 830 km north of Port Hedland and deep convection was increasing around the low-level centre as it moved slowly to the west. Shortly thereafter, at 1600 UTC on 9 March the low was named TC *Willy* with minimal 35 kn winds around the centre.

For several days, TC *Willy* moved rather slowly along a west-southwest to southwest track off the coast of Western Australia being steered by a ridge lying to the southeast. The cyclone was located in a favourable environment with dual outflow channels and strengthened steadily, reaching severe tropical cyclone status with 65 kn winds by 2200 UTC on 10 March while located approximately 650 km north-northwest of Onslow. TC *Willy* continued to intensify, reaching its peak intensity with an estimated minimum central pressure of 960 hPa around 2200 UTC on 11 March. The cyclone was then centred roughly 555 km northwest of Onslow. TC *Willy* maintained this intensity for about 24 hours before commencing a fairly rapid decline in intensity and was downgraded to a tropical low at 1000 UTC on 14 March while located approximately 880 km west-northwest of Carnarvon, Western Australia. During its weakening phase TC *Willy* adopted a westerly track in response to a low to mid-level ridge building equatorward of the system. The low continued to drift westward for two to three days well west of the Australian coastline.

TC *Adeline* (Perth) 2–5 April (then moved west of 90°E) (Fig. 1)

A tropical low was located at 9.8°S 101.2°E at 0000 UTC on 2 April. The system was basically stationary and convection was becoming increasingly organised over the low-level centre and upper-level analysis indicated favourable divergence aloft. Initially moving westward, the low assumed a southwesterly track on 3 April in the general direction of the Cocos Islands. The system continued to exhibit increasing deep convection and improving outflow. At 1000 UTC on 3 April the low was named TC *Adeline*, when located about 46 km east of the Cocos Islands. As TC *Adeline* passed just to the south of the Cocos, its track shifted to the west. The system continued to steadily intensify to and it reached severe tropical cyclone status before moving west of longitude 90° E and into the Mauritius area of responsibility at about 1200 UTC on 5 April. The Meteorological Service of Mauritius renamed the cyclone TC *Juliet* and continued referring to it as TC *Juliet*/ex- TC *Adeline* for a couple of days. No fatalities or damage are known to have resulted from TC *Adeline-Juliet*.

TC *Judy* (Nadi and Wellington) 24–27 December (Fig. 3)

A slow-moving low pressure system was located approximately 500 km east of Tahiti, on 21 December to the northwest of deep convective cloud in an area where the SSTs were approximately 28°C. Over the next 36 hours the deep convection began to wrap around the low-level centre. By 2100 UTC on 24 December, gales had developed close to the centre and the system was named TC *Judy*, when located approximately 510 km east-southeast of Tahiti. At this time TC *Judy* was moving towards the south-southwest at about 5 kn with a central pressure of 993 hPa. A few hours later it reached its peak intensity with a central pressure near 989 hPa. A large area of gales was located in the southern semi circle. By 0000 UTC on 27 December, increasing vertical wind shear and cooler SSTs halted further development and TC *Judy* eventually merged with a low pressure system to the south about 1390 km south-southeast of Tahiti.

TC *Meena* (Nadi) 2–8 February (Fig. 6)

An area of low pressure was first identified moving westward on 1 February. After some consolidation, this area of low pressure became quasi-stationary with a surface low analysed near 15.0°S 168.0°W, approximately 330 km east of Pago Pago, American Samoa. The low was within a favourable environment for continued development, being located just south of the upper-level (250 hPa) outflow in a region of strong diffluence. The upper-level outflow in the northern region was enhanced by strong cross-equatorial wind flow, but restricted elsewhere. The low was upgraded to tropical cyclone status and named TC *Meena* at 0600 UTC on 3 February when near 14.4°S 168.2°W, about 278 km east of Pago Pago. TC *Meena* then commenced a slow eastward path. By 1200 UTC on 4 February, organisation had improved sufficiently for to have developed hurricane force winds. At this time TC *Meena* was located approximately 509 km east of Pago Pago.

The cyclone turned to the southeast at 10 kn and slowly accelerated in this direction, being steered along the western periphery of a stationary low to mid-level ridge to the southeast. TC *Meena* intensified rapidly in the following 12 hours while passing 140 km to the east of Palmerston Island and 185 km to the west of Aitutaki. A well defined eye was evident in satellite pictures. The upper-level outflow remained good in all quadrants and was enhanced in the southeast sector by a jet entrance region. By 1200 UTC on 6 February, peak intensity of 915 hPa and average winds of 115 kn were reached and maintained for the following six hours, TC *Meena*'s very destructive core was centred only about 185 km northwest of Rarotonga as it reached peak intensity and the eye subsequently passed between Rarotonga and Managaia Island and passing 75 km northeast of Rarotonga.

Thereafter, equatorward outflow decreased with steady erosion in the deep convection in TC *Meena*'s western semicircle. The fairly rapid weakening process was enhanced by increasing vertical wind shear and cooling SSTs and TC *Meena* was was declared extratropical at 0000 UTC on 8 February when near 28.0°S 150.0°W, or approximately 1020 km south of Tahiti.

TC *Nancy* (Nadi) 10-17 February (Fig. 5)

A broad area of low pressure was first identified stretching from Tuvalu across the central South Pacific to the north of Samoa as early as 10 February. Two centres of low pressure were identified with the eastern low developing into a tropical depression (TD-09F) near 11°S 168°W, approximately 220 km north-northeast of Pago Pago, American Samoa, at 2100 UTC on 10 February. The depression's convection was concentrated around the centre with improving organisation and was located just west of an upper-level outflow in a low shear environment where SSTs were about 30° C.

At 1800 UTC on 12 February the low was upgraded to cyclone status and named TC *Nancy* when at 12.8°S 166.8°W, approximately 550 km east-northeast of Pago Pago. Initial motion was to the northeast at about 5 kn. TC *Nancy* was located in a region of strong diffluence with good outflow to the north and south and commenced the process of intensification. At 0000 UTC on 14 February the cyclone was located near 14.0°S 164.0°W, about 740 km east of Pago Pago, and was moving to the southeast at 4 kn under the influence of a mid-level ridge to the east. The cyclone had undergone rapid intensification in the previous 12 hours and had developed hurricane force winds.

Peak intensity of 935 hPa was reached at 1200 UTC on 14 February when near 14.4°S 162.1°W, approximately 185 km south-southeast of Suwarrow Atoll as the cyclone moved to the east-southeast at 12 kn. A gradual turn to the south-southeast and south ensued in the following 36 hours as TC *Nancy* crossed over the uninhabited atoll of Manuae, situated almost midway between Aitutaki and Atiu. Rapid weakening became evident as a result of increasing vertical wind shear associated with a sharpening upper-level trough to the southwest. Hurricane intensity was lost at 0600 UTC on 16 February as the low-level circulation centre moved away from the main area of convection.

By this time, TC *Nancy* had turned to a southwesterly path at 10-12 kn as a result of interaction with strengthening TC Olaf situated to the northwest and

passed approximately 130 km to the east and south of Rarotonga. Continued interaction with TC *Olaf* resulted in TC *Nancy*'s convective centre being completely displaced toward the southwest away from the low-level circulation centre. By 0600 UTC on 17 February TC *Nancy* had transformed into an extratropical low near 25.0°S 164.0°W, or approximately 555 km southwest of Rarotonga.

TC *Olaf* (Nadi) 10–19 February (Fig. 6)

By 10 February a broad area of low pressure had become established in the central South Pacific stretching from Tuvalu to north of Samoa. This area of disturbed weather spawned two centres of low pressure with the western low developing into a tropical depression (TD-08F) around 2100 UTC on 10 February when located roughly 925 km northeast of Fiji. By 0600 UTC on 13 February the low had consolidated near 9.2°S 177.6°W, approximately 850 km northwest of Apia, Western Samoa in a region of strong diffluence south of the 250 hPa outflow with SSTs of around 30° C.

The low was named TC *Olaf* at 1500 UTC on 13 February as winds reached 35 kn near the centre which was located near 9.2S° 177.5°W. At this time, the cyclone was almost stationary and commenced a phase of fairly rapid intensification under favourable conditions of low environmental shear and strong diffluence aloft. Twelve hours later, at 0600 UTC on 14 February TC *Olaf* had strengthened into a hurricane with 75 kn winds. By 0000 UTC on 15 February the cyclone had become very intense with peak winds estimated at 120 kn and a central pressure of 930 hPa and had commenced a steady east-southeasterly movement at 8 kn. TC *Olaf* gradually turned southeastward, accelerating to 10 kn as it was steered by the equatorial northwesterlies. By 0600 UTC on 16 February, TC *Olaf* had intensified further with satellite imagery depicting a well-defined and warming eye and convective tops cooling to –80°C. Peak intensity of 915 hPa was reached at this time near 12.8°S 171.1°W, approximately 130 km north-northeast of Apia and 170 km north-northwest of Pago Pago. The cyclone subsequently reassumed a southeasterly track at around 15 kn and reached a point near 19.7°S 164.3°W, approximately 700 km east-southeast of Niue. During this period, TC *Olaf*'s eye passed approximately 28 km to the east of Ta'u, American Samoa, where a barometric pressure of 931 hPa was recorded at 1654 UTC on 16 February.

After 0000 UTC on 18 February, increasing shear south of 20°S ahead of an approaching upper-level trough and dry air intrusion eroding convection in the cyclone's southwest quadrant heralded a fairly rapid weakening of TC *Olaf* as the system continued to accelerate to the southeast through south-southeast and south at up to 20 kn. Convection became displaced to the southeast of the low-level circulation centre at 0000 UTC on 19 February when TC *Olaf* was approximately 600 km south-southwest of Rarotonga. TC *Olaf* finally lost tropical cyclone status at 1800 UTC hours on 19 February near 31.0°S 161.5°W. The extratropical remains of TC *Olaf* continued to track at up to 25 kn in a general southeasterly direction into the open ocean, re-intensifying as a powerful 968 hPa extratropical system two days later.

TC *Percy* (Nadi) 24 February–5 March (Fig. 3)

A discrete area of convection developed to the east of Tuvalu on 23 February with an area of low pressure soon forming into a tropical depression (TD-10F) by 2100 UTC on 24 February. Being located in a favourable outflow environment in all quadrants with SSTs around 31°C, the depression underwent rapid development. Deep convection rotated around the low-level circulation centre and by 0000 UTC on 25 February the low was named TC *Percy* when located near 8.5°S 178.4°W, or approximately 220 km east of Fongafale, Tuvalu. TC *Percy* was embedded in deep monsoonal westerly winds, and as a consequence was being steered to the east-southeast at 14 kn.

Early development was described as being explosive with TC *Percy* developing hurricane force winds by 1800 UTC on 25 February when located near 9.0°S 175.0°W, about 740 km northwest of Pago Pago, American Samoa. *Percy* passed midway between Fakaofa and Swains Island, reaching its first peak in intensity of 925 hPa at 0000 UTC on 27 February when near 10.8°S 169.6°W, approximately 400 km north-northeast of Pago Pago. TC *Percy* then moved eastward and decelerated as it ran into the middle-level ridge located to its east. Hereafter, the cyclone's structure became somewhat asymmetric under the influence of increasing northeasterly vertical wind shear and a slight weakening trend persisted for the following 18 hours.

Between 1800 UTC on 27 February and 0000 UTC on 28 February, TC *Percy* passed to the southwest of and close to Pukapuka and Nassau Islands as a 940 hPa cyclone with maximum average winds of 85-90 kn. At this point, the cyclone recommenced intensification and a second peak intensity was achieved at 0000 UTC on 2 March when located near 16.2°S 165.3°W, or roughly 510 km south of Nassau with a central pressure estimated at 900 hPa. Satellite imagery showed a cloud-free eye with a concentric eyewall and this intensity was maintained for a further 18 hours while moving to a position approximately 200 km west of Palmerston Island.

Weakening commenced thereafter as the eye began to cool and fill. In a pattern established with the intense

cyclones of the previous weeks, a fairly rapid degeneration process followed as the cyclone passed south of 20°S as a result of an increase in vertical shear over the system and a restriction in outflow over the northern quadrant. TC *Percy* was directed to the southeast by an approaching upper-level trough, and eventually turned eastward after passing 24°S when captured by a deep trough approaching from the west. By 1200 UTC on 4 March when located near 24.7°S 158.6°W the low-level centre was detached to the northwest of the deep convection. Hurricane intensity was lost at this time and rapid weakening ensued as the cyclone entered a belt of stronger westerlies. TC *Percy* accelerated to the east at 20 kn, eventually becoming extratropical at 0000 UTC on 5 March when near 26.0°S 153.0°W, or approximately 425 km south of Rimatara.

TC *Lola* (Nadi) 27 January–2 February (Fig. 4)

The storm was first identified as a low in the intertropical convergence zone near the islands of Vanuatu on 27 January. The low-level centre moved steadily toward the east at 5 kn into an environment of active surface convergence, good upper-level diffluence at 250 hPa, decreasing westerly shear and SSTs of approximately 30°C. On its approach to the northern islands of Fiji, the low accelerated and commenced a southeastward motion of 15 kn, passing over Vanua Levu in Fiji's Northern Division on 30 January. An area of gales moved with the depression and rough seas were reported. However, there was no significant damage associated with the system in Fiji. At this time, the low exhibited an asymmetrical shape. However, by 1400 UTC on 31 January the previously exposed low-level centre had moved underneath the developing convection region.

With a central pressure estimated at 992 hPa, the low was upgraded to tropical cyclone status near 21.8°S 176.8°W and was named TC *Lola* when approximately 195 km west-southwest of Tongatapu. TC *Lola* continued to track to the southeast with slight intensification, however dry air intrusion from the southwest quadrant and strong westerly winds aloft hindered any further development. The low-level circulation centre was re-exposed and TC *Lola* was downgraded at 0000 UTC on 2 February when located near 25.2°S 176.6°W, about 460 km south-southwest of Tongatapu. The remnant depression slowed down in response to the ridge of high pressure to the south and persisted as a westward-moving and fully exposed depression for several days.

TC *Rae* (Nadi) 28 February–8 March (Fig. 5)

The initial easterly-moving tropical depression (TD-12F) can be traced back to near 11.5°S 178.5°E at 2100 UTC on 28 February. At this time, convection remained detached from the circulation centre with active convection evident only in the northern and eastern quadrants. SSTs were around 30°C and the low remained under an upper-level (250 hPa) outflow with relatively weak environmental shear. However, early development appeared to be suppressed partly due to the proximity of TC *Percy* to the east. It was not until 1815 UTC on 4 March that convective organisation rapidly improved with the development of a spiralling band pattern. The system was steered by the monsoon westerlies to the south-southeast at 10 kn into an area of reduced vertical wind shear relative to the system and a region of good outflow to the north, enhanced by the jet entrance region to the south. At 2100 UTC on 5 March the low was named TC *Rae* as convection erupted close to the low-level circulation centre and gales encircled in all quadrants. At the time of naming, TC Rae was located near 21.0°S 164.5°W, approximately 370 km west-southwest of Rarotonga, moving to the south-southeast at 13 kn, this direction being maintained for the rest of TC *Rae*'s short life. Peak intensity of 990 hPa and average winds of 40 kn were briefly attained shortly after naming. Soon thereafter weakening commenced as TC *Rae* began to run into the subtropical ridge located to the southeast. At 1200 UTC on 6 March when located near 23.9°S 161.4°W, approximately 335 km south of Mangaia, TC *Rae* was downgraded from cyclone status as major convection became detached from the centre and lay on the southern side of the low-level centre. Strong shear from the mid-latitude westerlies and dry air entrainment from the south rapidly weakened TC *Rae* into an extratropical system. However, gales were maintained for the next couple of days between the stalling ex-cyclone and the high-pressure ridge to the south due to the increased pressure gradient.

TC *Sheila* (Nadi) 21–23 April (Fig. 4)

The initial tropical depression (TD-15F) that developed into TC *Sheila* was one in a series of low-pressure centres that were part of a persistent monsoonal trough extending from north of the Solomon Islands to Fiji from as early as 16 April. The series of depressions were located over SSTs of about 28-29°C. However, strong upper-level northwesterly shear of 25-30 kn at the 250 hPa level inhibited development of these systems until 21 April when the low-level circulation centre became concurrent with the convection close to its centre. Strong surface westerly winds were established on the northern side, while a high-pressure system over New Zealand provided a good southeasterly surge to the south, providing the impetus for further development.

The low moved to the southeast at 20 kn, running down the axis of the South Pacific convergence zone as it was steered by northwesterlies at middle levels.

In doing so the depression moved along with the upper-level flow and consolidated sufficiently to attain cyclone status, being named TC *Sheila* at 0600 UTC on 22 April near 18.4°S 168.8°W, approximately 120 km northeast of Niue. TC *Sheila* reached peak intensity at 1200 UTC on 22 April near 19.3°S 166.4°W but continued to be a sheared cyclone with the low-level circulation centre soon becoming exposed on the western edge of the convection area as winds at 250 hPa increased to 45 kn. Tropical cyclone status was lost at 1800 UTC on 22 April when located near 20.2°S 165.4°W, approximately 445 km east-southeast of Niue, only 12 hours after being named. The remnant extratropical low merged with a frontal system to the south soon after. There were no reports of incidents associated with *Sheila*.

Tropical disturbances

Papua New Guinea low 14–15 April (Fig. 7)
A tropical low first became apparent in the far northern Arafura Sea on 12 April where it continued to develop. By 2230 UTC on 14 April the low had deepened to 995 hPa when positioned near 9.3°S 144.0°E, approximately 260 km northeast of Cape York, Queensland, and 295 km west of Port Moresby, Papua New Guinea. The low moved eastward at approximately 10 kn and deepened to 993 hPa as the system developed deep convective banding over its western quadrants. At 0300 UTC on 15 April the low was 100 km southwest of Port Moresby and producing very rough seas and gales of 35-40 kn (and possibly to 50 kn) within 110 km of the centre. The low approached and interacted with the southeastern landmass of Papua New Guinea as it moved into a region of increasing upper shear. This weakened the system and by 1854 UTC on 15 April gales were no longer observed with the system located near 11.0°S 148.6°E, approximately 230 km southeast of Port Moresby. The low later weakened further under strong northeasterly wind shear.

Tropical low (TC-10S) 13–19 January
The tropical low identified as TC-10S was quite likely a redevelopment of the remnants of former TC *Raymond* (Fig.1). The ex-TC *Raymond* vortex travelled eastward across the Northern Territory and moved into the Gulf of Carpentaria on 8 January. The cloud system associated with TC *Raymond* tended to dissipate after landfall and there was an insignificant satellite signature from 5 to 7 January. However, convection flared up significantly in the Gulf of Carpentaria on 8 January, and the cloud mass subsequently tracked westward across the Top End of the Northern Territory on 10 January with the low-level vortex. On 12 January the centre temporarily moved back over land near Kalumburu with convection becoming cyclic, but by 1600 UTC on 13 January, the low had moved back over water about 220 km north of Yampi Sound. Deep convection was persisting over the low-level circulation, vertical shear was low, divergence aloft was favourable, and 850 hPa vorticity was increasing. The tropical low continued to move westward away from the Australian coastline. By 1800 UTC on 16 January the centre had become partially exposed east of decreasing convection. The low never reached tropical cyclone status, but gales did exist well removed from the centre in the southwestern quadrant until 0000 UTC on 17 January when it was located many hundreds of km southeast of Christmas Island.

Cape York and Coral Sea low 19–25 January
A tropical low first became apparent to the northeast of the tip of Cape York Peninsula (Queensland, Australia) on 19 January. The low moved south-southwest and overland on Cape York near Iron Range late on 19 January before it was able to reach tropical cyclone status. The low maintained an inland path down the middle of Cape York Peninsula, whilst still showing its impressive presence on satellite imagery. By 23 January, the main centre was located near Georgetown (18.3°S 143.6°E). At this time the low became elongated, stretching towards the northeast coast of Queensland. A large band of heavy rain developed near Townsville in an area of backing winds with height (warm air advection) and a new centre rapidly formed in this region near Lucinda (18.5°S 146.3°E). This centre quickly moved out to sea. (NOTE: The new and perhaps 'multi-centred' hybrid low was effectively a reorganisation of the initial system and for purposes of this report is treated as a single system). The low never regained its initial tropical characteristics, and by 25 January was drawn into a developing trough to the south and accelerated to the southeast, parallel to but well off the Queensland and northern New South Wales coastlines.

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Data sources

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