The South Pacific and southeast Indian Ocean tropical cyclone season 2001-02

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The 2001-2002 tropical cyclone season in the South Pacific and southeast Indian Oceans was one of the quietest on record, in terms of both the number of cyclones that formed, and the impact of those systems on human affairs. In the southeast Indian Ocean basin, broadscale convection was generally suppressed and the overall number of depressions and tropical cyclones was below the long-term mean. Further east, broadscale convection was near or slightly above normal, but the proportion of tropical depressions and weak cyclones developing into severe cyclones was well below average. The below average activity represented a continuation of the trend of the previous few seasons. In the eastern Australian region, the four-year period up to 2001-2002 was by far the quietest recorded in the past 41 years.

Introduction

This paper is a continuation of the regular series of reviews of the Australia/South Pacific region tropical cyclone (TC) seasons. It concerns the region south of the equator, eastward from longitude 90°E through to 120°W in the South Pacific Ocean. Firstly, a general overview of the season is presented, including a summary of TC formation and comparisons with the climatology of the region. Then, some aspects of the large-scale flow patterns and anomalies are discussed with respect to TC formation observed during the season, in particular, the state of the El Niño Southern Oscillation (ENSO). Then, smaller scale waves and oscillations including the Madden-Julian Oscillation (MJO) and other shorter period equatorial wave modes are considered in reference to individual cyclogenesis events. Finally, each system that reached TC intensity during the season is individually described, including its best-track motion and intensity. The effects of these cyclones, such as damage and casualties caused by the system, are also summarised. Note that wind speeds and TC motion will be given in knots as well as metres per second. Even though the knot is not an SI unit, it is almost universally the unit of choice in tropical cyclone research, dialogue and literature.

Tropical cyclone occurrence

The 2001-2002 TC season in the southeast Indian and South Pacific basins was one of the quietest ever recorded since reliable satellite imagery became available some three or four decades ago. This was following on from the previous season, which was similarly inactive in the region. In fact, the total of fourteen* TCs that formed in the Australia and South Pacific region in

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* TC *Eddy* has been included in this summary, even though its centre did not enter the defined domain. It did however approach the western boundary to within about 20 km, and produced gales over the far western part of the domain.

2001-2002 was two more than the previous season, but in terms of the impact those systems had on human affairs, the current period was even quieter. Details of each TC in season 2001-2002 are summarised in Table 1, while the best tracks of each system are plotted in Fig. 1. A summary of the observed TC activity amongst the southern hemisphere basins, and a comparison with the local long-term means, is presented in Table 2. Various basin definitions have been defined and displayed here, primarily following the areas of responsibility of various warning agencies, which also closely resemble the domains used for past climatological and observational studies. Although the southwest Indian Ocean basin (SWI) does not form part of the domain of this review and is not considered in detail, it is interesting to compare the TC activity in this basin with that in the other southern hemisphere basins.

From Table 2, it is immediately apparent that there was a distinct longitudinal boundary of TC activity between the SWI and northwest Australian (AUW) basins, with below-average activity everywhere to the east of the boundary, and above-average activity to the west. In fact, inspection of the TC best tracks plotted in Fig. 1(a) would actually place this activity boundary a little further east at about 100°E. In total, a slightly above-average number of TCs developed over the SWI basin, whereas all basins to the east experienced a below-average number of cyclones.

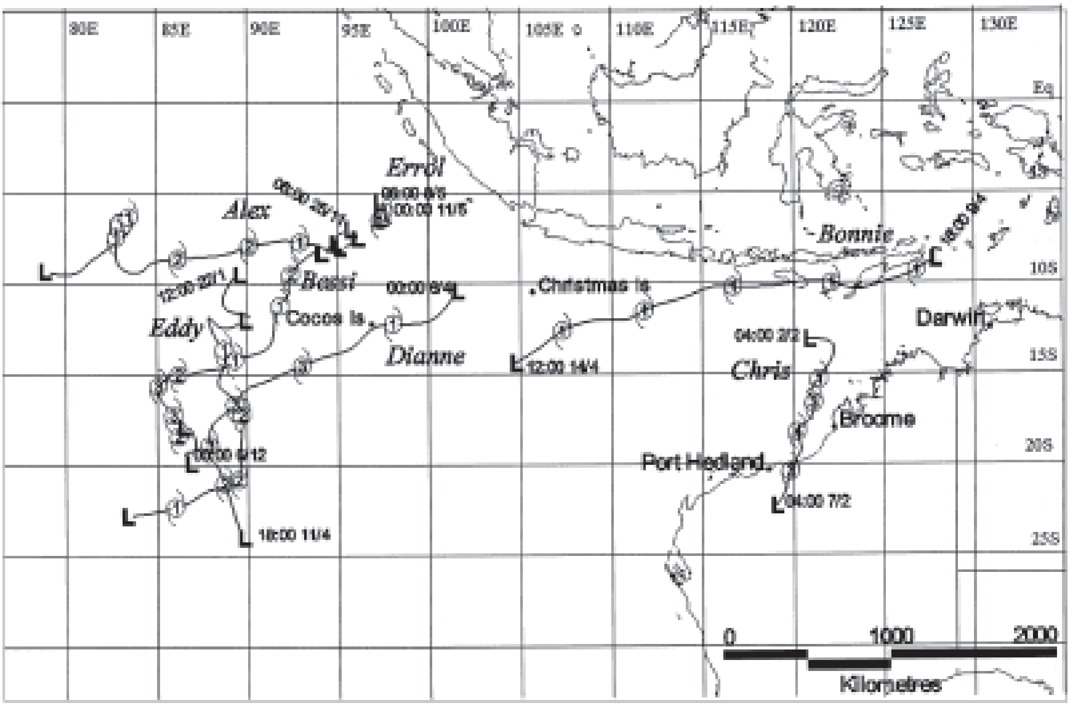
Table 1. Details of tropical cyclones in the South Pacific and southeast Indian Oceans during season 2001-02. Figures in parentheses in MSW column are category numbers on the Australian TC Scale. † Indicates end of TC phase the result of weakening over land after landfall. § The centre of tropical cyclone *Eddy* was never located east of 90ºE, but the system did produce significant weather over the far west of the domain of this summary.

	Low first identified			*System named*			
Name	*Date*	*Lat.*	*Lon.*	*Date*	*Time*	*Lat.*	*Lon.*
1. *Alex-Andre*	24 Oct	7.0ºS	97.5ºE	26 Oct	0600	8.1ºS	94.5ºE
2. *Bessi-Bako*	25 Nov	6.5ºS	95.7ºE	27 Nov	0000	8.3ºS	94.0ºE
3. *Trina*	18 Nov	21.5ºS	160.0ºW	30 Nov	0600	21.9ºS	159.4ºW
4. *Waka*	27 Dec	12.5ºS	177.5ºW	29 Dec	0600	11.3ºS	174.5ºW
5. *Vicky*	23 Dec	13.7ºS	157.1ºW	24 Dec	0600	12.6ºS	157.5ºW
6. *Bernie*	30 Dec	11.5ºS	137.5ºE	3 Jan	0400	14.7ºS	138.9ºE
7. *Eddy*§	22 Jan	9.5ºS	89.5ºE	24 Jan	1200	11.8ºS	87.9ºE
8. *Chris*	02 Feb	13.1ºS	120.8ºE	02 Feb	2200	15.0ºS	121.6ºE
9. *Claudia*	10 Feb	19.5ºS	155.7ºE	11 Feb	0600	20.5ºS	156.5ºE
10. *Des*	03 Mar	14.6ºS	154.2ºE	05 Mar	0600	19.3ºS	159.4ºE
11. *Dianne-Jery*	06 Apr	10.4ºS	101.5ºE	06 Apr	2100	12.2ºS	98.5ºE
12. *Bonnie*	07 Apr	7.2ºS	133.2ºE	09 Apr	1800	8.7ºS	127.8ºE
13. *Errol*	08 May	5.3ºS	97.3ºE	09 May	0000	6.0ºS	97.5ºE
14. Upia	25 May	7.5ºS	154.0ºE	25 May	1800	8.6ºS	153.4ºE

	Maximum intensity (knots)					*End of tropical cyclone phase*			
Name	*Date*	*Time (UTC)*	*Lat.*	*Lon.*	*MSW (knots)*	*Date*	*Time (UTC)*	*Lat.*	*Lon.*
1. *Alex-Andre*	28 Oct	0000	7.7ºS	89.7ºE	55(2)	30 Oct	1200	7.5ºS	82.7ºE
2. *Bessi-Bako*	2 Dec	1800	17.0ºS	85.8ºE	65(3)	5 Dec	0000	17.9ºS	86.4ºE
3. *Trina*	1 Dec	1200	21.1ºS	160.0ºW	35(1)	30 Nov	0000	21.5ºS	158.5ºW
4. *Waka*	31 Dec	1200	18.7ºS	174.0ºW	95(4)	2 Jan	0600	30.5ºS	167.5ºW
5. *Vicky*	24 Dec	1200	12.8ºS	157.6ºW	35(1)	24 Dec	1800	13.6ºS	157.3ºW
6. *Bernie*	3 Jan	1800	15.5ºS	139.0ºE	50(2)	4 Jan	1500†	16.5ºS	138.8ºE
7. *Eddy*§	26 Jan	0600	18.2ºS	89.7ºE	70(3)	28 Jan	0600	22.6ºS	84.4ºE
8. *Chris*	5 Feb	1900	19.8ºS	120.1ºE	110(4)	6 Feb	1300†	21.8ºS	22.3ºE
9. *Claudia*	12 Feb	0600	24.0ºS	167.9ºE	65(3)	13 Feb	1800	27.0ºS	171.0ºE
10. *Des*	5 Mar	1800	19.7ºS	161.3ºE	50(2)	7 Mar	0000	23.7ºS	166.5ºE
11. *Dianne-Jery*	8 Apr	1500	15.6ºS	90.2ºE	83(3)	11 Apr	1200	22.8ºS	89.0ºE
12. *Bonnie*	12 Apr	0600	10.2ºS	115.6ºE	48(2)	15 Apr	0600	13.5ºS	106.1ºE
13. *Errol*	9 May	0600	6.6ºS	97.6ºE	35(1)	9 May	1800	6.7ºS	97.7ºE
14. *Upia*	26 May	0600	9.1ºS	153.8ºE	40(1)	28 May	1800	10.1ºS	154.5ºE

Fig. 1 **Best tracks of tropical cyclones in the 2001-2002 season: (a) southeast Indian Ocean/northwest Australian region, (b) northeast Australian region, and (c) South Pacific region. Numbers in the cyclone symbols indicate intensity category on the Australian scale, the symbol L denotes tropical low below TC intensity.**

(a)



(b)

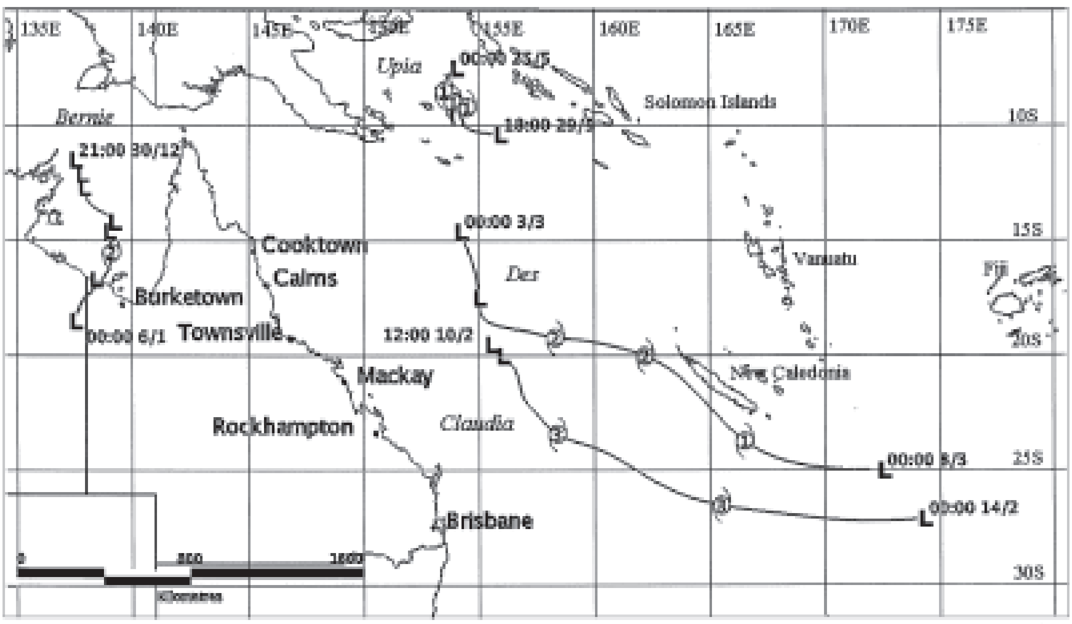
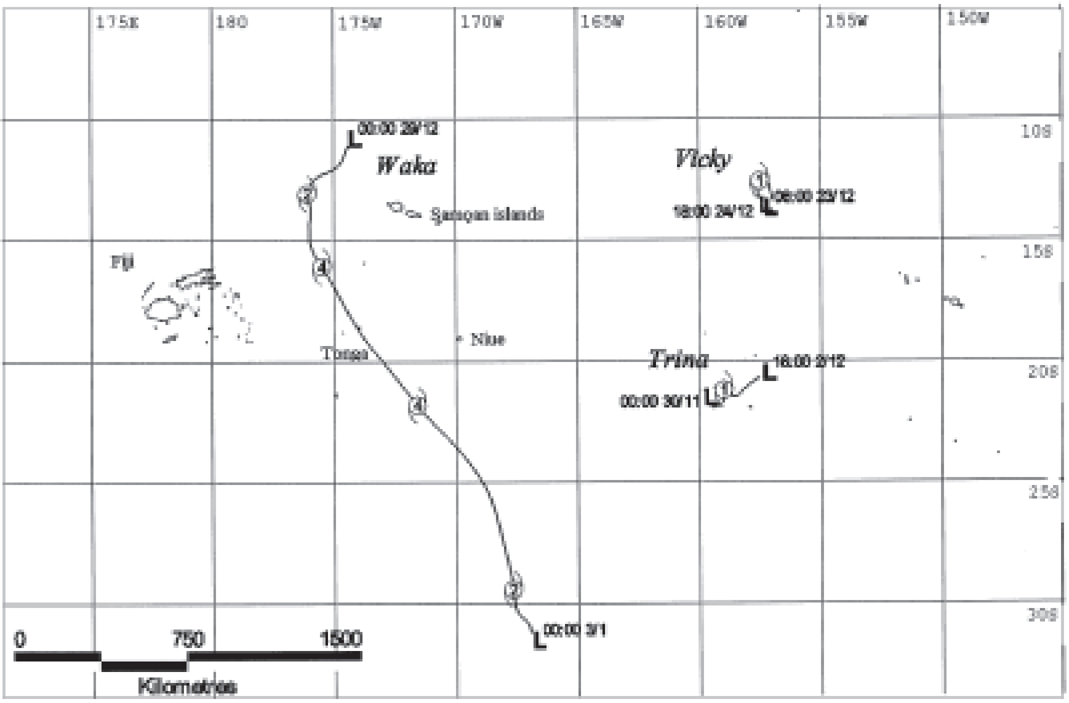


Fig. 1 Continued.

(c)



However, using Table 2 it can be seen that considering the total number of TCs only tells part of the story. A feature of the season was that many of the systems that did develop over the eastern basins tended to be short-lived and/or weak, in contrast with the SWI basin, where a high proportion of TCs went on to become intense systems. Thus, the westerly bias of TC activity can be seen even more clearly by considering other measures in common use that include intensity and longevity factors. One of these is a TC day, that is the total number of days during the season upon which one (or more) TCs were active in the basin. From Table 2, it can be seen that almost two-thirds of the TC days during the southern hemisphere season can be attributed to the SWI basin, one of the highest proportions on record. However, it is when severe tropical cyclones (STCs), possessing wind speeds greater than 64 knots (32 m s^{-1}), are considered that the almost unprecedented nature of this bias becomes evident. Three-quarters of the STCs in the southern hemisphere occurred in the SWI basin, the highest proportion on record, and this basin accounted for 78 per cent of the total STC days. Considering that the SWI spans a longitude range of about 70 degrees – about half the combined longitude range of the other basins – the heavily skewed nature of the TC activity is quite evident.

Gray et al. (1992) and Gray et al. (1994) introduced two other useful measures of TC activity that attempted to combine the intensity and duration, in order to summarise using a single parameter the potential for damage by a particular system, or of all systems in any one season. The first of these parameters was called the hurricane destruction potential (here referred to as the tropical cyclone destruction potential (TDP)), and for each individual system, this can be defined as

$$TDP_R = \sum_i \left[\frac{MSW_i - w_0}{v_0} \right]^2 \qquad \text{...1a}$$

where MSW_i is the maximum (10 minute) sustained winds for the ith six-hour period, v_0 is a velocity scale, here set to 100 knots (48 m s^{-1}), and w_0 is the wind threshold parameter defined by

$$w_0 = \begin{cases} MSW_i \text{ if } MSW_i \le 17 \text{ m s}^{-1} \\ 17 \text{ m s}^{-1} \text{ if } MSW_i \le 17 \text{ m s}^{-1} \end{cases}$$

Here 17 m s^{-1} (34 knots), the threshold of TC intensi-

Table 2. Occurrence of tropical cyclones within the southern hemisphere basins for season 2001-02. Upper line of each row gives the observation for the 2001-02 season, with the decile in which this observation fell in parentheses. Second line gives the long-term mean for each parameter in italics. Deciles have been omitted for cases where there were insufficient data to make them meaningful. Observations in the highest two and lowest two deciles have been marked in bold, with deciles 1 and 2 emphasised with the asterix, and deciles 9 and 10 with the dagger. Period used for climatology was 1971 to 2001.

	SWI west of 90°E	*AUW* 90°E -135°E	*AUE* 135°E-160°E	*AUS* 90°E-160°E	*SPA* east of 160°E	*SH*
TC	13 (7)	7 (4)	4 (4)	11 (3)	**5 (2)***	**25 (2)***
	11.5	*8.5*	*5.2*	*13.0*	*8.7*	*29.2*
STC	**9 (9)**†	**2 (1)***	1	**3 (2)***	**2 (2)***	**12 (2)***
	5.8	*4.3*	*2.1*	*6.4*	*4.1*	*14.8*
ITC	**6 (10)**†	1	0	1	1	8 (7)
	2.5	*1.8*	*0.7*	*2.5*	*1.6*	*6.2*
TCday	62.8 (5)	**20 (2)***	**5.5 (1)***	**25.5 (1)***	**11 (1)***	**98.8 (1)***
	57.7	*32.8*	*18.0*	*50.8*	*32.0*	*141.5*
STCday	**31.8 (10)**†	**4.3 (2)***	1.0	**5.3 (1)***	**4 (2)***	40.5 (4)
	19.7	*10.6*	*4.6*	*15.2*	*10.7*	*46.0*
ITCday	**14.3 (10)**†	1.8	0.0	1.8	1	17.0 (8)
	4.7	*2.5*	*1.0*	*3.5*	*2.5*	*10.7*
NTC (%)	**198 (10)**†	68 (3)	**32 (2)***	**58 (1)***	**57 (2)***	118 (5)
TDP	**150 (10)**†	**27 (2)***	**4 (1)***	**31 (1)***	**16 (1)***	196 (4)
	89.9	*51.1*	*24.7*	*75.8*	*48.9*	*216.0*

ty, is considered the minimum sustained wind speed that has the potential to do significant damage. The summation is over the lifetime of the system.

This parameter can then be summed over all TCs occurring during the season:

$$TDP = \sum_{n=1}^{N} TDP_n \qquad \text{...1b}$$

where N is the total number of TCs. As the potential for wind damage and storm surge increases as approximately the square of the wind speed, the idea behind this parameter is to provide a measure of damage potential, or how 'dangerous' a particular season is, compared with other seasons. Note that the scale factor v_0 is arbitrary and used only to keep the numbers small.

The other composite parameter is the net tropical cyclone activity (NTC), which is defined as:

$$NTC = \left[\left(\frac{NS}{NS_{ave}} + \frac{STC}{STC_{ave}} + \frac{ITC}{ITC_{ave}} + \frac{NSD}{NSD_{ave}} + \frac{STCD}{STCD_{ave}} + \frac{ITCD}{ITCD_{ave}} \right) \Big/ 6 \right] \text{x } 100\% \qquad \text{...2}$$

where the first three terms refer to the number of TCs, STCs, and intense TCs respectively, and the last three terms refer to the corresponding number of days with a system active, and the subscript *ave* indicates the climatological average for each parameter. Here, an intense TC is defined as having sustained winds greater than 90 knots (46 m s^{-1}), the threshold of category 4 status on the Australian scale. In essence, the NTC presents the damage potential of total TC activity in a particular season as a percentage of the average damage potential in that basin. Both parameters have some 'cosmetic' strengths and weaknesses. The advantage of the TDP is that it may be used both for individual systems, and for seasonal averages. It is also constant for a particular system or season once v_0 has been selected. Furthermore, it can be used for interbasin comparisons, although an adjustment is often required due to different time averaging periods used, for example one-minute MSW is used in the North Atlantic basin. On the downside, its arbitrary nature makes it difficult to gain any intuitive meaning, although some idea can be gained by considering Fig. 2, where 24-hour accumulations of TDP for systems of constant intensity are shown. The physically reasonable bias towards more intense systems is made clear here. For example, a system bordering on category 3 and STC status would accumulate 0.36 units per day, whereas a strong category 5 system would generate about 3.0 units per day. A slightly more problematic drawback of this parameter is in the estimation of MSW. It must be remembered that the index was created to be used in the North Atlantic Basin where the aircraft reconnaissance program probably leads to a better estimation of the MSW_i factor in Eqn 1(a) than in other basins, where usually only satellite intensity estimates using the Dvorak method (Dvorak 1984) are available. The NTC is less sensitive to individual estimates of MSW, which is only used to categorise the intensity of a system rather than in the direct calculations. However in practice, errors in the estimation of MSW_i seem to cancel when averaged over entire basins and seasons, and overall, in terms of describing a whole season as in this review, choosing which of these indices to use is largely a matter of taste. For completeness, both will be described in this paper.

The utility of these composite parameters can be readily appreciated when they are used to describe the 2001-2002 season, as shown in Table 2. For clarity, the TDP for all southern hemisphere basins is also displayed as a box-and-whisker plot in Fig. 3. For all basins east of 90°E the NTC was well below 100 per cent, falling as low as 32 per cent in the eastern Australian basin. Note that although the overall number of TCs was in the middle quartile (and within one standard deviation of the mean) in all of these basins, the systems that did develop tended to be short lived and/or relatively weak. This factor is reflected in the very low NTC and TDP figures. In contrast, the SWI recorded an NTC of almost 200 per cent and a TDP of 150, both of which were the second highest on record. This again shows that although the overall level of activity was not far above the average, many of the TCs that did develop in that basin were long lived and became intense.

In the Australian region (between longitudes 90°E and 160°E), 11 TCs developed*, which is only about one less than the long-term average. However, only three of these systems became STCs, and only one – TC *Chris* – reached intense status (category 4 or 5 on the Australian scale). In addition, systems tended to be relatively short-lived, as shown in Table 2, where it can be seen that the total time with a TC active, about 25 and a half days, was only just over half the

Fig. 2 **One day accumulations of the tropical cyclone destruction potential index (TDP) for a system of constant intensity, indicated by 10-minute sustained winds. The dashed vertical lines and numbers indicate the Australian tropical cyclone intensity scale.**

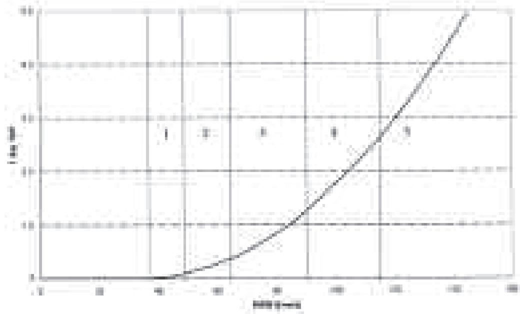
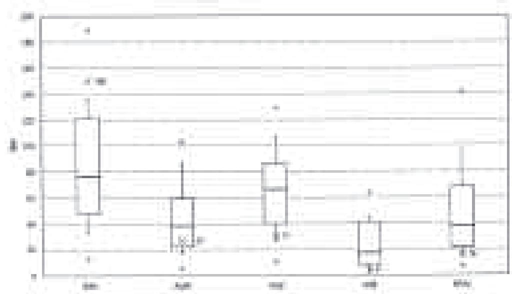


Fig. 3 **Box-and-whisker plot of tropical cyclone destruction potential (TDP) index in the southern hemisphere basins for season 2001-02 compared with climatology. The line in the middle of each box is the median, while the top and bottom of the boxes represent the third and first quartile respectively. Whiskers extend to the 9th and 1st deciles, while the plus signs indicate the highest and lowest on record. The cross represents the observation for season 2001-02 with the actual value also indicated.**



average, and in the decile one range. Similarly, the number of days with both STCs and intense TCs active were also about half the long-term means. Consequently, this also led to very low values of NTC and TDP. The TDP for the season was 31, which placed it in the decile two category, although it is interesting to note that TC *Chris* alone accounted for 20 of this total. The other two STCs in the season, *Claudia* and *Dianne*, both tracked near (and eventual-

* TC *Upia* has been included in the northeastern Australia (and therefore the Australian) basin, even though it formed and remained in the Papua New Guinea area of responsibility over its brief lifetime – here this basin is considered a subset of the northeastern Australia basin and is therefore included in the analysis.

ly over) the borders of the basin domain (*Claudia* in the east and *Dianne* in the west), and well away from the Australian continent

Looking more closely at the Western Australian basin, the current season continued a trend of declining activity over the past three years, from a peak in the 1998-1999 season. Referring to Table 2, the NTC of 68 per cent is indicative of a quiet season, and the TDP of 27 is in decile two. However for the mainland Western Australian coastline, even this is an overestimate of the season. Referring to Fig. 1(a), it can be seen that five of the seven systems tracked west of 100°E for most, if not all of their lifetimes, and so did not approach the Western Australian coast any nearer than about 2000 km. For this reason, and notwithstanding the impact of TC *Chris*, it can be said that this season was probably second only to the 1992-1993 season in terms of lack of TC activity for the mainland Western Australian coast in the past 40 years.

In the eastern Australian basin (AUE, 135°E to 160°E), it is fair to state that there was hardly a season at all. Four TCs formed, but only one, *Claudia*, intensified to STC status, and this occurred as the system was over the far eastern part of the basin, and was moving east-southeastwards out of the area. The number of TC days – five and a half – was in the lowest decile, and STC days totaled one, as *Claudia* intensified above the threshold about 24 hours before it moved out of the basin to the east. This was the fourth consecutive well-below normal season in the eastern Australian basin – all four years being either decile one or two in terms of TDP, and in most other measures as well. The current season had a TDP of four – since 1962, only the previous season (2000-2001) has had a lower TDP. Taken together, this four-year period has seen by far the lowest level of TC activity on record. Once again, although the overall number of TCs has been only slightly below average over this period, it is the almost total lack of systems intensifying as far as STC status that has been the real difference. In fact, along with *Claudia*, TC *Rona* in 1999 was the only other cyclone to do so throughout the four-year period, and it was also only of STC status in the basin for a total of one day. Thus, the STC days for the four-year period equalled two, compared to an expected value of about 16. The starkest illustration of the lack of activity though, is obtained through consideration of the TDP index. The total TDP for the four seasons was 16, very much below the four-year average of 91.1 and by far the lowest recorded over the past 41 years – the next lowest was 43 for the four-year period up to season 1970-1971. This four-year period has also been very quiet in the sense that only one STC, *Rona*, has made impact on the developed eastern Australian coast over the period. In fact, the 2001-2002 season did not feature a TC of any strength impacting, or even threatening, the east coast.

In the South Pacific basin (SPA, east of 160°E), six TCs were observed during the season, which is well below the long-term average (Table 2), continuing the recent trend of quiet years in this basin, the last above average season occurring in 1998-1999. With the overall number of TCs developing falling in the decile two range, at first this seems to go against the previous argument of the main characteristic being a near-average number of TCs with few becoming severe. However, it should be noted that there were many systems of tropical depression intensity observed in the SPA basin that did not reach TC intensity, eleven such systems being recorded in the basin during the season. The TCs that did form also tended to be weak and short-lived – TC *Waka* was the only exception. It can be seen that only two systems reached STC status, and one of these, TC *Claudia*, was only marginally and briefly above this threshold. Again, the best simple and overall summary of the season was provided by NTC and TDP figures, both of which were in the lowest decile, the TDP of 16 being one of the lowest on record for this basin.

Moving up in scale and considering the southern hemisphere as a whole, the season was close to average, and so followed the usual pattern of basin-scale variations tending to cancel on the larger scale. In terms of overall number of TCs, the season was slightly below average with 25 systems developing, compared with the mean of just over 28. However, a large proportion – about a third – of these developed into ITCs (most of them in the SWI basin as previously mentioned), which led to an NTC of 118 per cent, and a TDP slightly above average. This proportion of ITCs was in the highest decile, and has only been exceeded on four occasions in the past four decades.

The reasons for the lack of activity in the eastern basins, and enhanced activity in the west are difficult to quantify and will not be pursued in any great depth here, but some discussion of these observations is presented later in the paper.

Impacts

Of the 14 TCs that formed in the region during the season, only four – *Waka, Chris, Bonnie* and *Bernie* – had any significant impact on a landmass or on human affairs. As mentioned previously, this makes the 2001-2002 season one of the quietest on record in this sense. By coincidence, two of the cyclones that made a landfall – *Waka* and *Chris* – were also the most (and only) intense systems of the season, rating category 4 on the Australian scale. However, even then TC *Chris* affected a very unpopulated and undeveloped stretch of Western Australian coastline, and had the potential to be far more destructive had it impacted a more heavily settled area.

TC *Waka* was by far the most destructive cyclone of the season, passing close to or through several island groups in the south Pacific. It had its strongest impact on the eastern island groups of the Kingdom of Tonga, which it struck while near peak intensity, and became the most damaging cyclone, in monetary terms, to affect the area in the past two decades. It was also the only system of the year to be directly responsible for loss of life (one fatality recorded on the Tongan island of Ha'apai).

The fact that one hybrid or subtropical type cyclone in July 2001 was alone responsible for eight deaths in the eastern Australian region (compared with a single known fatality due to TCs over the AUW, AUE and SPA regions combined), places the official TC season in some perspective. At the same time, it also highlights the hitherto somewhat neglected importance of these hybrid systems—a matter that will not be pursued further here, but the reader is referred to, for example, Callaghan (2001) for further discussion.

Two other TCs did strike habited landmasses during the season, although both were weak category 1 systems when they did so. TC *Bernie* struck a sparsely populated section of the Gulf of Carpentaria coast near the Queensland/Northern Territory border as a minimal TC, and produced little damage and only slight inconvenience due to flooding of roads. The other was TC *Bonnie*, which passed over two major islands of the Indonesian archipelago, Timor and Sumba. Although *Bonnie* was weak, both of these islands are at a low enough latitude to make TC impacts quite rare, and both are relatively mountainous landmasses. Thus the cyclone still had the potential to be quite dangerous through heavy rainfall leading to damaging flooding and landslides. However, in this case *Bonnie* was quite a compact system and was moving quickly enough throughout the landfall periods – averaging 12 to 15 knots (6 to 8 m s^{-1}) – to keep rainfall accumulations below disastrous levels.

Broadscale seasonal features

As mentioned earlier, an outstanding feature of the southern hemisphere season on the broadscale was the sharp longitudinal dividing line of TC activity and characteristics at about 100°E. Any discussion of the broadscale features of the period needs to address the reasons for the tendency of systems to be weak and short-lived to the east of 100°E – in both the South Pacific and the eastern Indian Oceans – and conversely the propensity for TCs to become intense and long-lived to the west of 100°E, in the southwest Indian Ocean basin. This is not straightforward, in part because cyclogenesis and intensification processes are still not completely understood. However, it is well known that several necessary conditions are required for cyclogenesis to take place (first identified by Gray (1975)). Briefly, these include sea-surface temperatures above about 26°C, high relative humidity through a large depth of the troposphere, conditionally unstable stratification, and dynamic conditions consisting of broadscale cyclonic low-level vorticity of the environment and weak vertical wind shear through the depth of the troposphere. Tropical cyclogenesis also must start with a pre-existing disturbance, and so a below-average season can be brought about either by a reduced number of candidate disturbances, or a reduced ratio of these disturbances intensifying into tropical cyclones, presumably due to the unfavourable nature of one or more of the conditions just mentioned.

In the present season, the evidence points to a combination of these two reasons producing the well-below average season over the Australian and south Pacific basins. On the broad scale, the flow had many characteristics of a weak El Niño pattern, even though the Southern Oscillation Index was near zero and indicative of neutral conditions in the main (Shaik and Bate 2003). In the AUW basin, convection was generally somewhat suppressed during the season, a typical pattern in neutral to weakly El Niño conditions. Although the number of TCs in the basin as a whole was close to average, it should be remembered that all but two of these occurred west of 100°E, over the far western part of the area. Over the remainder of the basin, including to the immediate northwest of the Australian coast where there is a climatological peak in TC activity (e.g. McBride and Keenan (1982)) the season was unusually devoid of activity of any strength. Further east, in the AUE and SPA basins, broadscale convective activity was close to average or even enhanced over eastern parts, and the number of candidate disturbances was also close to average, so the real reason for the quiet season was the very small proportion of these disturbances developing into severe TCs. As Shaik and Bate (2003) showed, anomalies of outgoing long wave radiation (OLR) – a proxy for deep convection – and 200 hPa velocity potential (their Figs 4 and 5) indicated an eastward shift of enhanced deep convection, and the upward part of the Hadley circulation, towards the date-line. This is reminiscent of the circulation pattern observed during El Niños, although the displacement in the current season was not as far east as in a full warm event. However, this eastward shift of the upward branch of the Hadley Circulation also led to an eastward displacement of the subtropical jet maximum to Tasman Sea longitudes. As a result, a dominant characteristic of the 2001/02 season was the regular formation of large amplitude mid-latitude troughs through the Australian and south Pacific longitudes, particularly through the Tasman Sea and southern Coral Sea. This led to relatively frequent spells of moderate to strong vertical shear, and introduced pulses of dry mid-level air into deep tropical latitudes, penetrating north of 10°S at times. Monthly anomalies of 700 hPa relative humidity were persistently negative through the AUE and SPA basins as far east as the dateline. This may have been the primary inhibiting factor preventing tropical disturbances or depressions intensifying into TCs in the AUE and SPA basins.

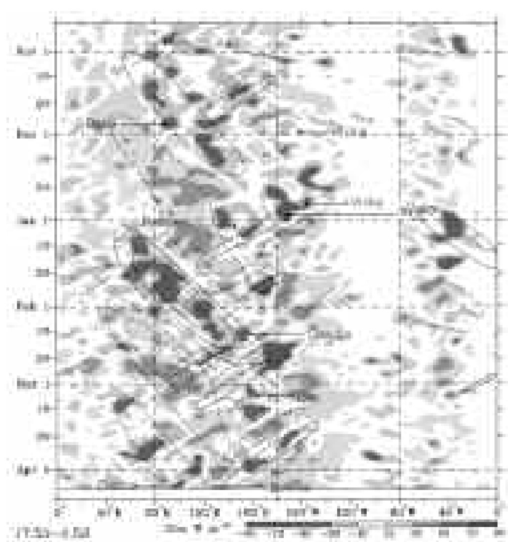
Intraseasonal patterns

It has been known for some time that TC formation does not occur at a steady rate through the course of a season, rather TCs tend to form in clusters. Studies in the past decade have linked this clustering to intraseasonal oscillations in cloudiness and wind fields observed in the tropics. In particular, the relationship between TC genesis and the MJO is now well documented for most TC basins, including the southern hemisphere basins considered here (e.g. Hall et al. (2001); Liebmann and Hendon (1994)). More recently, studies have been undertaken attempting to identify theoretical equatorial wave modes such as equatorial Rossby (ER) waves, mixed-Rossby gravity (MRG) waves and Kelvin waves, mostly using some form of real-time filtering of the patterns of deep convection (Wheeler and Weickmann 2001; Yang et al. 2003). The further step of establishing links between TC genesis and these theoretical equatorial wave modes has also been undertaken in a few studies (Frank and Roundy 2004; Dickinson and Molinari 2002). These show promising results, and possibly may lead to better short to mid-range forecasting of TC genesis in future, although there is much work left to be done before any relationships are established firmly enough to be used in a real-time operational sense. In this review, TC formation locations will be presented relative to diagnosed equatorial wave modes active at the time near the cyclogenesis location, although no attempt will be made to explain these observations in any theoretical sense.

The propagation of the MJO was relatively strong and regular during the 2001-2002 season. A longitude/time plot of filtered outgoing long wave radiation (OLR) anomalies during the main part of the TC season is displayed in Fig. 4, from which it can be seen that the main part of the cyclone season (November to April) was punctuated by three major active phases of the MJO. Hereafter, these active phases of the MJO will be referred to, in sequence, as A1, A2 and A3 respectively. In addition, one other active pulse, A4, reached Australian and south Pacific longitudes slightly outside the main TC season (not shown), passing through the region during May.

With the help of filtered data such as shown in Fig. 4, it was found that the genesis of almost all TCs in the 2001-2002 season could be broadly associated with one of these equatorial wave modes, if the formation of a TC in the vicinity of diagnosed active wave modes can be termed an association. The only clear exception was *Trina*, which developed in late November, prior to the arrival of A1, and in an area of generally suppressed tropical convection. However, *Trina* developed at a relatively high latitude from an upper-level disturbance of extratropical origin, and so could not be expected to be directly related to the MJO or other equatorial wave modes. Besides *Trina*, no TC developed outside the broad envelope of enhanced convection associated with an MJO pulse, although the cases of *Bernie* and, particularly, *Alex* are a little uncertain.

Fig. 4 Filtered anomalies of outgoing longwave radiation, averaged over latitudes 2.5°S to 17.5°S. Contours sloping down to the right indicate MJO propagation, while contours sloping down to the left are for n=1 equatorial Rossby waves. Contour interval is 10 W m-2. Locations of cyclogenesis events are indicated.



The periodicity of the MJO was quite regular during the season (Fig. 4), although the period of about 60 to 70 days was a little longer than average. The first active phase, A1, approached the western boundary of the area in late October/early November, and TCs *Alex* and *Bessi* developed from cloud clusters within the envelope of enhanced convection over the Indian Ocean to the southwest of Java. This pulse then propagated eastwards across the Arafura Sea area to the north of Australia and the warm pool in the first week of December, reaching the western south Pacific in early to mid-December. Once in the Pacific, the envelope of enhanced convection expanded somewhat, as is often observed. As this expansion took place, a series of ER waves developed, and TCs *Waka* and *Vicky* formed in the vicinity of one of these waves in the south Pacific east of 160°E. In addition, TC *Bernie* formed in the Gulf of Carpentaria and may also have been associated with the cyclonic member of an ER mode.

The second active phase A2 produced the strongest signal in OLR of any of the active pulses, and was associated with the formation of three TCs: firstly *Eddy* in the central Indian Ocean, then *Chris* off the northwest Australian coast, and finally *Claudia* in the central Coral Sea. It could be argued that the formation of TC *Des*, also in the Coral Sea, may have been associated with the final stages of A2 as well, although this is not entirely clear from Fig. 4. It is also possible that even more genesis events may have been associated with A2 had it not occurred during the peak of the Australian monsoon season, with the monsoon trough located over land through the Australian longitudes. Climatologically, there is a slight minimum in TC formation in the Australian region in about mid-January, which has been generally attributed to this reason. This is also supported by the fact that during this period, a deep monsoon depression formed within the MJO envelope, however it remained on land over the Top End of Australia for its lifetime. Satellite imagery suggested that this depression had many of the peripheral features of a TC, but lacked the inner core structure due to its position over land. In a similar pattern to A1, a series of equatorial Rossby waves became active as A2 reached the date-line area in the central Pacific and the envelope of enhanced convection expanded and ceased its propagation. TC *Des* formed in the Coral Sea, in the vicinity of these ER waves.

As A2 degenerated near the date-line near the end of February, A3 had developed in the central Indian Ocean, and began to approach the western margin of the domain. While this active pulse was moving through the region, TCs *Dianne* and *Bonnie* formed over the Indian Ocean and Arafura Sea respectively.

The fourth active pulse, A4, developed over the western Indian Ocean during mid-April, and propagated eastwards to the Indonesian region by the first week of May (not shown in Fig. 4). Equatorial Rossby wave activity was detected in satellite imagery and wind fields, emerging from the area of enhanced convection. At this time of year, such situations often lead to the formation of 'twin' TCs, each member of the pair forming at roughly the same longitude on opposite sides of the equator. In this particular case, two sets of twin TCs formed, the first pair over the central Indian Ocean at the start of May (TC *Kesiney* in the southern hemisphere and TC *02A* in the northern hemisphere), and the second pair further east about a week later. TC *Errol* was the southern member of this second set of twins, while TC *02B* formed in the Bay of Bengal. For a brief period, all four systems were active simultaneously, the first time such an event has been observed in the Indian Ocean. Around two weeks later, A4 had propagated through the warm pool region to the northeast of Australia, and once again an ER wavetrain became active within the region of enhanced convection. Within the southern member, TC *Upia* developed over the Solomon Sea to the east of Papua New Guinea.

Verification

Position forecast verification data for each TC was calculated by comparing best-track positions with real-time forecasts. These are summarised in Table 3, with a weighted mean of results over the past ten seasons presented for comparison purposes. As mentioned previously, one of the features of the season in the Australian region was the generally short-lived and weak nature of the few TCs that did form. Because of this short-lived nature, there were relatively few forecasts required for lead times of 48 hours or greater. This was particularly the case in the AUE basin, where there was only one forecast data-point for the 36-hour lead time, and none at all for 48 hours. Thus the results in Table 3 for the 48-hour, and to a lesser extent the 24-hour, lead times should be treated with caution due to the small size of the dataset.

With this caveat in mind, it can be seen that overall, position forecasts were on par with, or better than, the weighted mean of the past ten seasons. This represents a good result, given that the majority of systems during the season remained weak and poorly organised for much of their lifetimes. Initial position errors were close to the ten-year mean, with the highest errors associated with weak systems, as is normally the case. In the cases of *Bessi*, *Bonnie* and *Errol*, the high values of initial position error are probably a

Table 3. Position forecast veification statistics for official warnings issued by warning centres in Perth, Darwin, Brisbane and Nadi. Forecast positions are verified against the official best-track. *Des* (a) refers to warnings issued by Brisbane, while *Des* (b) is for warnings issued by Nadi.

	0 hour		*12 hour*		*24 hour*		*48 hour*	
Name	*error (km)*	*number*	*error (km)*	*number*	*error (km)*	*number*	*error (km)*	*number*
1. *Alex*	30	9	87	6	178	4	n/a	0
2. *Bessi*	81	22	143	14	175	16	275	2
3. *Trina*	29	12	52	7	99	5	n/a	0
4. *Vicky*	38	7	n/a	0	n/a	0	n/a	0
5. *Waka*	13	15	73	11	238	7	n/a	0
6. *Bernie*	34	8	39	6	70	4	n/a	0
7. *Chris*	21	22	72	16	98	21	106	3
8. *Claudia*	19	5	125	3	n/a	0	n/a	0
9. *Des* (a)	53	3	198	3	352	2	n/a	0
9. *Des* (b)	20	7	85	3	n/a	0	n/a	0
10. *Dianne*	44	11	98	5	186	4	n/a	0
11. *Bonnie*	66	34	111	24	155	27	190	5
12. *Errol*	63	25	129	17	194	19	269	5
Total		180		101		109		15
Weighted Average	46		101		159		211	
Mean (10 yr)	44	2188	106	1782	180	1711	339	586

reflection of their development amongst widespread convection associated with active MJO pulses, and the fact that they remained weak through their lifetimes. Although developing in a similar environment, the initial errors for *Waka* and *Chris* are much less, due to the fact that they developed into severe TCs and became much easier to locate as a consequence. It is also interesting to note that the initial errors for the small and compact systems *Claudia* and *Trina* were lower than average.

Tropical cyclones in the South Pacific and southeast Indian Ocean 2001-2002

Alex-Andre (Perth TCWC): 24 October to 31 October 2001

The 2001-2002 season had a much earlier than normal beginning with the formation of TC *Alex* over the Indian Ocean near Cocos Island in late October. In fact, *Alex* formed a week before the cyclone season in the southeastern Indian Ocean officially opened, although TCs have been observed on rare occasions in all months of the year in this area. Sea-surface temperatures (SSTs) were anomalously high over the eastern Indian Ocean for much of 2001. During September and October, these anomalies peaked at over +1.4°C around the Cocos Island area where SSTs were 27 to 28°C and capable of sustaining TC genesis. In late October, an area of enhanced convection associated with a weak MJO was propagating through this area of anomalously high SSTs. An area of persistent deep convection formed in this area during 24 and 25 October and gradually began to organise over the following two days. The disturbance was located under a weak extension of the upper ridge axis, in an environment of weak to moderate vertical shear. Convection continued to organise on 26 October, and the system was named TC *Alex* at 0600 UTC (all subsequent references to time will be in UTC unless otherwise noted), while located about 550 km northwest of Cocos Island.

The system formed (and remained) at fairly low latitude, moving generally westward under the influence of the low to mid-level ridge to the southeast. *Alex* remained equatorward of the upper ridge and in an area of moderate vertical shear. Consequently its development was somewhat retarded and it remained a relatively weak cyclone, reaching a maximum intensity of 55 knots (28 m s^{-1}, category 2) at about 2100 27 October while crossing the 90°E meridian and moving westwards into the La Réunion area of responsibility. Thereafter, the cyclone weakened under the influence of persistent vertical shear, and eventually dissipated over open waters and still at low latitude, about 700 km east-southeast of Diego Garcia. TC *Alex-Andre* did not make any close approaches to land, and no reports of damage or casualties at sea are known.

Bessi-Bako (Perth): 25 November to 6 December 2001

Towards the last week in November, a large area of enhanced convective activity associated with an active phase of the MJO (A2) was moving slowly eastwards through the central Indian Ocean. The cloud cluster that was to become TC *Bessi* developed within this region, approximately 670 km southwest of Sumatra. Moderate vertical wind shear affected the system at this early stage, and retarded its development slightly until the environment became more favourable by 27 November. At 0600 27 November, the Tropical Cyclone Warning Centre (TCWC) in Perth upgraded the low to TC *Bessi*, when the system was located approximately 630 km northwest of Cocos Island.

Bessi was initially steered westward under the influence of the subtropical ridge to its southeast, however the track gradually curved to the south as a passing mid-latitude trough weakened this steering ridge. As the track change occurred, the storm reached an initial peak intensity of 60 knots (31 m s^{-1}, high category 2) at 0400 28 November, possibly assisted by a favourable interaction with the trough. At this time, the cyclone was centred approximately 675 km west-northwest of Cocos Island. Soon after this however, *Bessi* began to weaken as the approaching trough increased the vertical shear over the system. By 0300 29 November, the cyclone was moving south south-eastward at 8 knots (4 m s^{-1}). At this time satellite imagery revealed a partially exposed low-level circulation centre, with the associated deep convection displaced from the centre, and the estimated sustained winds had decreased to 40 knots (category 1). The passing trough had insufficient amplitude to ‘dig’ the cyclone out of the tropics, and during 29 November, the new ridge building in behind began to steer the system onto a westerly track once more. At 1800 29 November, the cyclone was tracking south-southwestward, still in an environment of moderate shear. At about 0600 on 30 November, the cyclone was moving on a westward track at 13 knots (7 m s^{-1}) as it moved west of longitude 90°E, and was renamed tropical storm *Bako* by La Réunion warning centre. The system continued to move rather erratically, but generally westward and southward, further into the La Reunion area of responsibility, and briefly attained a secondary peak intensity of 65 knots (33 m s^{-1}, category 3) while located about 1300 km west-southwest of Cocos Island. The storm subsequently weakened and underwent extratropical transition on 5 December. TC *Bessi-Bako* remained over open ocean far from land for its entire lifetime, and no reports of damage or casualties were recorded.

Trina (Regional Specialised Meteorological Centre (RSMC) Nadi): 29 November to 3 December 2001

During the 2000-2001 season, the first South Pacific TC did not make its appearance until February. In contrast, the current season got underway quite early with the development of TC *Trina* near Rarotonga in late November. *Trina* was initially a hybrid system, which steadily increased its tropical characteristics after forming at relatively high latitude. It was a short-lived and weak cyclone, only marginally of named strength throughout its lifetime. The system was first identified as a baroclinic, upper-level cut-off low west of Rarotonga, which gradually developed down to the surface. During 28 and 29 November, the system became positioned over the tail end of a weak low-level shear line and began to take on more tropical characteristics as deep convection began forming near the centre. The system was then slow-moving, and in a poor environment for further development, being located only about 45 km southwest of Rarotonga, over marginally warm SSTs of around 26 to 27°C and under moderate to strong vertical wind shear. During 30 November, the system drifted northeastwards, closer to Rarotonga, and deep convection began to increase in curvature and cloud tops cooled somewhat. As is often the case with high-latitude TCs in the southern Pacific Ocean, the pressure gradient on the southern (poleward) side was strongly enhanced by an intense surface anticyclone to the south, leading to mean winds of gale intensity over the southern quadrants. Following a new TC naming policy introduced for the 2001-2002 season by the Tropical Cyclone Committee for the South Pacific and South-East Indian Ocean (RAV/TCC), the system was named TC *Trina* by RSMC Nadi. The new policy only require gales to be estimated or observed ‘near’ the centre in one quadrant, whereas the previous policy required gales in all quadrants, i.e., completely surrounding the circulation. Note should be made that under the previous policy, the system probably would not have been named at this time (and with its subsequent failure to intensify any further, its unlikely that it would have been named at all).

After being named, the exposed low-level circulation centre drifted under the upper-level trough axis and into a weak steering regime, and during 1 December, the low-level circulation centre had partly slipped under the deep convection. However, prevailing shear and cool SSTs prevented any further intensification, and the system was downgraded to tropical depression status on 2 December when located about 70 km northwest of Mangaia. The depression lingered in the area for another day or two, with a small area of gales persisting well-removed from the centre to the southwest, before finally dissipating as a significant system on 3 December.

Although *Trina* remained a very weak system throughout its lifetime, it did produce some significant flood damage on the island of Mangaia, where four days of heavy rains resulted in the worst flooding on the island for 50 years. Minimal wind and storm surge damage was also reported from Rarotonga, especially over the southeastern side of the island, and parts of the island were submerged under two metres of water. Some of the press releases indicated that winds gusted above hurricane force, which is considered inconsistent with a minimal TC such as *Trina*, these reports being attributed to wind gusts associated with strong thunderstorms in the outer circulation of the storm.

Waka (Nadi, RSMC Wellington): 19 December 2001 to 5 January 2002

While the South Pacific TC season was generally very uneventful, TC *Waka* was the major exception, and was the only TC to strongly affect settled areas and produce significant levels of widespread damage. Several islands of the Kingdom of Tonga bore the brunt of *Waka* and suffered heavy damage.

During the second half of December, the tail end of the MJO pulse A1 had led to a classic transition season structure stretching from the warm pool to well east of the date-line, with active monsoon troughs in both hemispheres and an associated westerly wind burst along the equator. By 19 December, a typical equatorial Rossby wave structure had developed; with twin vortices centred at about 165°E embedded in the monsoon troughs in either hemisphere. Super typhoon *Faxai* developed from within the northern hemisphere component, while the southern hemisphere twin was much slower to develop, but eventually became TC *Waka* about a week later. The initial lack of development was probably due to moderate vertical shear over the system, but by 27 December the disturbance had moved generally southeastwards to a location about 1100 km northeast of Nadi, and into a more favourable environment for intensification. During 29 December, RSMC Nadi named the system and it continued to intensify rapidly into 30 December as the environment improved further. The cyclone was steered generally southwards as a mid-level steering ridge developed to the southeast, bringing it close to Wallis Island on 30 December. An approaching upstream trough also began to affect *Waka* at this time, initially improving outflow over the system and aiding in its intensification, while at the same time producing an accelerating curve to the south-southeast. This track brought *Waka* over the island of Niuafo'ou on the 31 December as a category 3 system with sustained winds of about 80 knots (41 m s^{-1}) and it intensified further. The island recorded wind gusts to 100 knots (52 m s^{-1}) and a lowest pressure of 964.0 hPa as *Waka* passed overhead. The cyclone was reaching its peak intensity of 100 knots (52 m s^{-1}, category 4) late on 31 December as it passed almost directly over the island of Vava'u of the Kingdom of Tonga. Microwave imagery from the Special Sensor Microwave/Imager (SSMI) at 0915 31 December clearly depicted the island under the southern eyewall of *Waka*, with a well-defined, circular eye about 60 km in diameter over water to the immediate north-northwest. The following imagery pass some nine hours later at 1754 31 December showed the centre to the southeast of Vava'u, with convection beginning to be sheared to the southeast of the centre, and the eyewall fracturing and opening up to the northwest. By this time, it was clear that *Waka*'s initially favourable interaction with the mid-latitude trough had become unfavourable as the vertical shear increased over the system. On Vava'u, winds gusted to 120 knots (62 m s^{-1}) and the pressure fell to 960.0 hPa with the passage of *Waka*, although it is interesting to note that the highest wind gusts were recorded at about 1500 31 December and from the southwest after the passage of the eye over the island and from the portion of the eyewall that was apparently weakening and dissipating. After passing through the Vava'u group, *Waka* continued to accelerate to the southeast and began to weaken as vertical shear increased further and the cyclone moved over progressively cooler SSTs. The system was declared extratropical on 2 January, and became a vigorous extratropical cyclone well south of the Cook Islands.

Cyclone *Waka* was directly responsible for the only fatality of the season, on the island of Ha'apai in the Kingdom of Tonga, as well as extensively damaging several island groups during its passage. The majority of the damage occurred in the Vava'u group of Tonga, in what was the worst TC induced disaster to strike the Kingdom since TC *Isaac* in 1982. Total damages were estimated at 104.2 million Tongan Pa'anga – about A$73 million (source: reliefweb), with estimates running at about 60 per cent of buildings partially or extensively damaged. Damage to crops and agriculture was also severe, and led to food shortages over the subsequent months. On Niuafo'ou and Wallis, damage to property and infrastructure was significantly lighter, but agricultural losses were similarly significant.

***Vicky* (Nadi): 22 to 26 December 2001**

TC *Vicky* was a very short-lived and weak system, retaining TC status for a period of only 18 hours. The system was quite small, and was exposed to moderate to strong vertical shear throughout its short lifetime. The cyclone developed from a cloud cluster embedded in a zone of generally enhanced convection associated with the same ER wave that led to the formation of *Waka*. It was initially identified on 22 December, located to the south of the upper ridge axis, and in an area of moderate southwesterly shear. Despite this, the system still began to display a slight improvement in organisation over the next two days, with persistent, strong convection on the northern side of the low-level circulation centre trying to wrap into the centre. With the environment expected to improve slightly, the system was eventually named *Vicky* during 24 December, while located 900 km north-northeast of Rarotonga. However, a migratory mid-latitude trough almost immediately reinforced the vertical shear, and the cyclone was quickly downgraded to a depression once more. The system subsequently began to drift southwards into an even more hostile environment, and lost all tropical characteristics soon after. The remains of the circulation entered the mid-latitude westerlies and re-intensified into a vigorous tropical cyclone well to the south of French Polynesia. No reports of damage attributable to *Vicky* were received.

***Bernie* (Brisbane RFC): 30 December 2001 to 6 January 2002**

The initial tropical disturbance that developed into TC *Bernie* was first identified over the northern Gulf of Carpentaria, and may have been associated with the same equatorial Rossby or Mixed Rossby-Gravity wave activity that led to the formation of super typhoon *Faxai* and TCs *Waka* and *Vicky* further east. *Bernie* also had a northern hemisphere twin – tropical storm *Tapah*, although it remained a very weak system. Deep convection gradually began to organise about the depression that was to become *Bernie* during 1 and 2 January, as it moved slowly south-southeast into the central Gulf. The environment continued to be moderately favourable for further development with light to moderate vertical wind shear and fair outflow aloft, and on 3 January the system was named *Bernie*, located about 225 km north-northwest of Mornington Island and almost stationary. During 4 January, the cyclone adopted a slow southwesterly motion under the influence of a building low to mid-level ridge to the southeast. The development of the system was retarded by the vertical shear in the environment, and the effect of this was clearly seen in animated satellite imagery, with deep convection confined mainly to the southern and western sides, and did not wrap around the centre of the circulation. However, the system still managed to undergo a modest amount of intensification, and eventually reached a peak of 50 knots (26 m s^{-1}, category 2) late on 4 January. This intensity was maintained as the centre passed within about 45 km of Mornington Island, still moving south-southwestwards towards the Gulf coast. *Bernie* made landfall at about 1300 4 January near Massacre Inlet, about 170 km west-northwest of Burketown, or 220 km east-southeast of Port McArthur. After crossing the coast, the system continued to track south-southwest as it slowly weakened into a rain depression over far northwestern Queensland.

The damaging effects of TC *Bernie* were relatively minor, and almost totally due to very heavy rainfall and resultant flooding, although there was also some beachfront erosion and damage due to wave action. As an example of the heavy rainfall, 335 mm was recorded at Mornington Island in the 24 hours to 9 am local time 4 January 2002. On the mainland, all roads around the settlements at Burketown and Doomadgee were closed for some time due to flooding. Virtually no structural wind damage was recorded.

***Eddy* (La Reunion): 22 to 28 January 2002**

Tropical cyclone *Eddy* has been included in this summary, even though the centre was never actually east of 90°E, and thus was officially in the SWI basin for its entire lifetime. However, the centre of the cyclone did approach the basin boundary to within about 20 km at times, and certainly would have produced gales over far western parts of the AUW basin.

The convective envelope associated with the active MJO pulse A2 was located over the central to eastern Indian Ocean during mid January. A persistent area of cycling convection associated with a weak low-level circulation centre developed about 900 km west-northwest of Cocos Island on 18 January. Located to the north of the upper ridge axis in an area of moderate vertical shear, the disturbance changed little over the following four days, remaining virtually stationary and showing few signs of organisation. However, conditions for intensification were improving by 23 January, with the disturbance slipping closer to the upper ridge, leading to weaker shear and improving outflow aloft. The system responded by developing more organised banding features, and was named *Eddy* at 1200 24 January, located about 970 km west of Cocos Island.

At this time, TC *Eddy* was located in a relatively weak steering regime, with a low amplitude trough migrating to its south, and a weak ridge pushing equatorwards through the Indonesian region. In response, the cyclone followed a rather slow and erratic, but generally southerly track. A slight amplification in the trough at about 1200 25 January nudged the system onto a more southeasterly track for a short time. By this stage, a banding eye was becoming visible in IR imagery. At about this time, an SSM/I pass revealed a band of deep convection wrapping completely around the circulation centre, and the cyclone peaked in intensity a short time later. By 1800, the south-southeasterly track had brought the cyclone to within about 20 km of the AUW basin, but the influence of the trough weakened as it pushed further east, and *Eddy* resumed its southerly track, just to the west of the basin boundary. Around 24 hours later, a new ridge had begun to build to the south of *Eddy*, and the cyclone curved towards the southwest and accelerated. By this time, the system was responding to the effects of increasing vertical shear and lower SSTs, with convection being restricted to the southeastern side of the storm. The weakening trend continued over the following days, as the system continued on its southwesterly track over open waters of the southern Indian Ocean.

Eddy remained over open waters far from land throughout its lifetime, and no damage or casualties occurred.

Chris (Perth): 2 to 6 February 2002

TC *Chris* was easily the most intense and potentially destructive cyclone of the 2001-2002 season in the Australian region. This system provided a reasonable example of the short lead-times to major TC impacts that often occur in the Australian basin. About 60 hours after being named as a minimal TC, the cyclone made landfall as a high-end category 4 system in the Pilbara region of Western Australia. In fact, *Chris* had a rather slow translation speed through its lifetime – with faster moving storms, even shorter lead-times to landfall are sometimes seen in this part of the world. Fortunately, *Chris* struck one of the many sparsely populated and undeveloped sections of this region, and the damage sustained was much less extensive than is possible with a system of this intensity. The cyclone was reaching its peak intensity and still intensifying as it approached the coast.

By the last week of January 2002, widespread deep convection was beginning to break out over the eastern south Indian Ocean and Timor Sea with the approach of the second major MJO pulse of the season. On 1 February, a convective cloud cluster had developed about 700 km northwest of Port Hedland. Over the next two days, the system slowly increased in organisation in an environment of moderate vertical shear, but reasonably good outflow aloft, and SSTs above 29°C. The depression was also following a slow, southerly track, into a much more favourable area of lighter vertical shear under the upper ridge axis, and at 0300 3 February it was named TC *Chris*, located about 300 km north-northwest of Broome. The main steering influences on the cyclone were quite weak, with a low-amplitude trough translating over southern Western Australia being replaced by a weak, cradling high to the south, and another weak anticyclone building equatorwards to the east of the system. This setup led to a slow southerly motion of TC *Chris* towards the Pilbara coast, averaging about 7 knots (3 m s^{-1}), although several short-term deviations from this track were noted, in particular a step to the southwest occurring at about 0800 4 February. This was possibly due to subtle fluctuations in the strength of the ridge to the east; however, it may also have been due to some structural changes in the developing system. Satellite imagery depicted a burst of strong convection breaking out to the immediate south and west of the ragged eye feature at this time, and radar imagery from Broome seemed to indicate a reorganisation of the eyewall structure to the west in response. Apart from these small deviations, *Chris* maintained its generally slow south-southwesterly motion up to and beyond landfall on Eight Mile Beach between Wallal and Pardoo, 160 km east-northeast of Port Hedland, at about 1700 5 February. The environment was favourable for rapid intensification and *Chris* became a severe category 3 TC (sustained winds 64 knots, 33 m s^{-1}) at about 0400 4 February, when located 180 km northwest of Broome, or 320 km north of Wallal. Further strengthening took place as the cyclone approached the coast, reaching a maximum intensity of 110 knots (57 m s^{-1}) and estimated central pressure of 915 hPa on landfall. This placed the system near the borderline between categories 4 and 5. Although quite an intense cyclone, *Chris* was a reasonably small system, with the radius of winds above 64 knots (33 m s^{-1}) never greater than 30 km, and the radius of gales at landfall no more than 130 km.

After crossing the coast, the cyclone continued on its south-southwesterly track at about 15 km/h while weakening rapidly over land. This track took the centre close to the town of Marble Bar at about 0700 6 February, as a category 2 system with sustained winds of 60 knots (31 m s^{-1}) and central pressure 975 hPa. *Chris* was downgraded to a tropical depression at 1900 6 February, when located between the towns of Newman and Tom Price.

As mentioned previously, it is fortunate that *Chris* struck a relatively undeveloped stretch of coastline and overall the impact was minimal for a system of its intensity. However, the Pardoo Roadhouse suffered severe wind damage as the cyclone came ashore about 30 km to the east. Unfortunately, there were no wind-recording instruments near the path of *Chris* at landfall, and by the time it passed close to Marble Bar about 14 hours later, it had weakened considerably; a maximum sustained wind of 45 knots with a gust to 64 knots (23 gusting 33 m s^{-1}) being recorded at this station. A damage survey of the affected coastline and adjacent inland estimated a maximum storm surge of about 3.5 metres (about 4.0 metres with wave run-up), at a location 20 km east of the landfall point. These estimates were consistent with expected surges taking into account the intensity and size of the storm, and the angle and speed of approach.

Claudia (Brisbane, Nadi, Wellington): 11 to 15 February 2002

About a week after the formation of TC *Chris* over the Timor Sea, widespread convection began to increase over the Coral Sea with the eastward progression of the MJO phase A2. At the same time, low-level westerlies increased along the equator in these longitudes, and low-level vorticity generally increased over the area. On 9 February, an area of persistent convection developed in this area initially located about 1100 km east-northeast of Cairns. The disturbance was located downstream of a persistent upper trough through eastern Australia and the Tasman Sea, and was steered towards the southeast by this system. Initially the depression underwent little development, due in part to moderate vertical shear, but by 11 February the disturbance had moved into a much more favourable environment under the upper-ridge axis, with outflow being enhanced by the upstream trough and with much weaker wind shear. Additionally, a surge in the low-level trades reached the system at about the same time, and these factors provided the impetus for rapid development. The system was named *Claudia* at 0600 11 February while located about 800 km east of Mackay and moving southeastwards at about 10 knots (5 m s^{-1}). Soon after this time, the ship Tasman Crusader recorded sustained winds of 45 knots (23 m s^{-1}) from its position about 60 km north of the centre. About eight hours later, *Claudia* made its closest approach to Cato Island automatic weather station, which recorded sustained winds of 30 knots (15 m s^{-1}) while the centre was 250 km to the south-southeast, although this was well outside the main circulation of the cyclone. In fact, *Claudia* could be classified as a midget system, and in common with many systems of this size, it continued to develop rapidly as it moved southeastwards over open water, becoming a category 3 severe TC at about 0000 12 February, only 18 hours from being named as a minimal TC. A ragged eye was evident in IR imagery at this time, and microwave imagery from a good Tropical Rainfall Measuring Mission (TRMM) satellite pass at 0600 depicted a strong, almost complete eyewall, although partially open southwest of the centre. The cyclone was reaching its peak intensity at about this time, with sustained winds of 65 knots (34 m s^{-1}, marginal category 3) and central pressure 965 hPa. However, from this time onwards, the system began to weaken as it encountered ever-increasing vertical shear and cooler SSTs. At 0000 13 February, *Claudia* was located about 400 km south of Noumea, or 370 km northwest of Norfolk Island, and moving rapidly to the east-southeast at about 20 knots (11 m s^{-1}). At 0600, IR imagery showed that deep convection was weakening near the centre of the cyclone, and becoming confined to the southeastern quadrant due to the persistent northwesterly shear. As is often the case with small systems, *Claudia* both strengthened and weakened at a rapid rate, and by 1800 13 February, IR imagery depicted a shallow depression devoid of deep convection, while a Quikscat pass at this time also indicated rapid weakening of the system and failed to indicate any area of gales associated with it. Thus, the system had weakened over open waters from a marginally severe tropical cyclone, to a shallow depression with sustained winds no higher than 25 knots (12 m s^{-1}) in less than 24 hours. The remains of TC *Claudia* continued on an east-southeastward track for several days, eventually crossing the date-line on 14 February before merging with a frontal system well south of Tonga. No reports of casualties or damage attributable to *Claudia* were received.

Des (Brisbane, Nadi): 4 to 7 March 2002

Des was a relatively weak and short-lived TC, which formed in a similar area to where TC *Claudia* had developed just under a month previously. *Des* also followed a similar track, although a little further east, and did at one time pose a moderate threat to New Caledonia and its capital Noumea.

By late February, the active area of convection associated with the MJO pulse A2 had reached the date-line, and had become stationary, at least in the OLR and convection signal (Fig. 4). An ER wavetrain was identified on the western periphery of the convectively enhanced MJO envelope, and the cyclonic members in both hemispheres had become convectively active. Super typhoon *Mitag* had formed near the northern cyclonic member of the ER wavetrain in late February, and by 3 March an area of convection had consolidated near the southern cyclonic member, over the Coral Sea about 250 km east-southeast of Port Moresby, Papua New Guinea.

Similarly to the case of *Claudia*, the developing system was located downstream of a slow-moving upper trough system lying over eastern Australia and through the southern Tasman Sea, with a high-amplitude ridge pushing equatorwards to its east, providing a steady northwesterly steering flow. The disturbance showed a gradual increase in organisation of its cloud system over the following 24 hours. By 1200 4 March, the system was located about 950 km east of Townsville, and a similar distance west-northwest of Noumea, moving east-southeastwards at about 12 knots (6 m s^{-1}). At this stage, some negative features in the environment were retarding the development of the system. SSTs were only marginal at around 27°C, and the area was under moderate vertical shear. However, animated IR imagery was indicating that the upper trough through the Tasman Sea was beginning to provide a narrow outflow channel to the south and southeast of the system's centre, and this became a positive influence on development over the following 24 hours. The system was named *Des* at 0900 5 March whilst located about 375 km west of the northern tip of the main island of New Caledonia, or 700 km west-northwest of Noumea, and moving east-southeastwards at 8 knots (4 m s^{-1}). At this stage, the cyclone was becoming a threat to the developed west coast of New Caledonia, particularly given some potential for rapid development sometimes seen in these situations, and demonstrated by *Claudia* a few weeks previously. In fact, the cyclone did intensify further during the next 12 hours, eventually reaching a peak of 50 knots (26 m s^{-1}, category 2) at 1800, when located 600 km west-northwest of Noumea. At this time, the mid-level steering ridge to the northeast of the system intensified and developed equatorward, leading to a gradual veering of the steering flow over the cyclone. This led to TC *Des* taking a gradual turn to the southeast, and spared New Caledonia from a direct impact. A Quikscat pass at 0600 6 March helped to place the centre about 60 km offshore from the northwest coast of New Caledonia, and indicated winds of 40 to 50 knots (20 to 25 m s^{-1}) along this section of coast. At this time, TC *Des* was moving southeastwards, parallel to the coast, at about 15 knots (8 m s^{-1}). In an environment that was only marginally favourable for intensification, the proximity of the rugged mountains of New Caledonia was probably the major influence that led to the weakening of the cyclone over the next 12 hours. By 1800, the cyclone had decreased in organisation with sustained winds dropping to 40 knots (21 m s^{-1}, category 1), the centre was moving clear of the island, after approaching within about 120 km of Noumea and the cyclone was being steered into a strongly sheared environment. The weakening trend continued and by 0600 7 March, the system was completely devoid of deep convection, and was downgraded to depression status.

Although *Des* did make a relatively close approach to the New Caledionian coast, no reports of damage or casualties were received. On the Australian mainland, the presence of the cyclone was felt through large swells buffeting the northern NSW and southern Queensland coasts, peaking at five to six metres (peak heights) on coastal wave-rider buoys. Generally this swell was beneficial, bringing perfect waves for an international surfing contest on the Gold Coast in southern Queensland, however the conditions proved dangerous for the general public and lifesavers made many rescues and closed a large number of beaches.

Dianne-Jery (Perth): 6 to 11 April 2002

During the first week of April, the active MJO pulse A3 was reaching the eastern south Indian Ocean region, leading once again to an active monsoon and a low-level westerly wind burst at low southern latitudes through this area. At the same time, a strong subtropical ridge was producing solid southeast trade flow over the Timor Sea. A circulation centre could be discerned embedded in the monsoon trough on 2 April, and by 4 April scattered deep convection was beginning to become associated with this circulation. At this time, the disturbance was located about 400 km east-northeast of Cocos Island, moving west-southwestwards at about 30 km h^{-1}. A fresh burst of southeast trade flow impinging on the southern side of the vortex during 6 April provided the necessary impetus for a fresh burst of convection to wrap around the centre, and cyclogenesis to take place. Soon after being named, the system passed close by to the south of Cocos Island, as a category 1 system with sustained winds of 45 knots (23 m s^{-1}). The cyclone continued to intensify at a near climatological rate in a favourable environment of weak vertical shear, and reasonable outflow, and tracked steadily west-southwestwards under the influence of a deep layer ridge to the southeast. By 1600 8 April, the system was displaying a ragged eye feature in satellite imagery, but with strong banding features. Maximum sustained winds at this point were estimated to be 75 knots (39 m s^{-1}), making the cyclone a severe category 3. At about this time, TC *Dianne* was crossing the 90ºE meridian into the La Reunion area of responsibility, and was renamed TC *Jery*. At the same time, an approaching mid-latitude trough began to have an influence on the cyclone, initially weakening the steering ridge to the south and allowing the system to make a turn to the south-southwest. As is often the case in such a scenario, the cyclone initially intensified further, undergoing a favourable interaction with the approaching trough. *Jery* reached a maximum intensity of 83 knots (43 m s^{-1}, strong category 3) at 0000 9 April, maintaining this intensity until about 1200 9 April, before beginning to weaken as the unfavourable aspects of the trough interaction began to take effect. The system began to track southwards and then south-southeastwards from 0000 10 April. By 1200 10 April, the system had lost most of its deep convection and was becoming asymmetric, signaling that extratropical transition was taking place. The system was declared extratropical at 1200 11 April, some 1400 km southwest of Cocos Island, and maintained gales well removed from the centre for several more days.

Dianne was quite weak and still in its developing stages as it made its close approach to Cocos Island, and remained over open waters thereafter. No significant damage or casualties were recorded.

Bonnie (Darwin, Perth): 9 to 15 April 2002

During the first week of April, the MJO pulse A3 had led to a large-scale enhancement of convection throughout the eastern Indian Ocean and Timor and Arafura Seas to the north of Australia. An ER wave-train was also active in the Arafura Sea, through the eastern periphery of this active envelope. A few days after the formation of TC *Dianne*, an area of enhanced convection developed near the southern cyclonic Rossby gyre, initially located about 600 km northeast of Darwin, and moving slowly to the west. The depression was located slightly north of the upper ridge, and upper wind analyses from Darwin and Cooperative Institute for Meteorological Satellite Studies (CIMSS) satellite products indicated weak to moderate vertical shear over the area, with fair outflow aloft. In the low to mid-levels, a solid ridge was located through central Australia, although a low amplitude, migratory trough had weakened the ridge slightly to the south of the disturbance, leading to a steady west-southwest track. A new ridge was beginning to build to the southwest of the system as the trough passed eastwards through the Great Australian Bight.

The disturbance continued to gradually organise over the next 24 to 48 hours, although overall development was slow in the marginally favourable environment. By 0000 10 April the circulation had moved generally southwestwards to be near the eastern tip of the island of Timor. By this time, the centre was quite compact on IR imagery, and banding features were observed wrapping in towards the centre, and the system was upgraded to TC *Bonnie*.

The cyclone continued to track to the west-southwest, almost parallel to the southern coast of Timor, remaining slightly offshore. However, by 1200 10 April, TC *Bonnie* took a slight turn towards the west in response to the new ridge building into central Western Australia, taking it over the southern tip of the island. As well as the persistent wind shear, the close proximity to land had hampered its development up to this stage, and *Bonnie* passed over southern Timor as a category 1 cyclone, with sustained winds estimated at about 40 knots (20 m s^{-1}). After moving clear of the island, the westward track continued, briefly bringing the system over open waters of the Timor Sea, and once clear of land, the system gradually intensified, with banding features becoming prominent in satellite imagery once more. This track took TC *Bonnie* towards the island of Sumba, and it made landfall on the eastern coast at about 0600 11 April as a category 1 system with sustained winds estimated at 40 knots (20 m s^{-1}). The cyclone took about four hours to pass over Sumba, and the encounter led to a weakening of the system, but once clear of the island, the westerly track took *Bonnie* over open waters once more, and there was a possibility of re-intensification. Satellite imagery did confirm some slight strengthening of the cyclone over the following 24 hours. However, by 1800 12 April, increasing vertical wind shear was becoming a retarding factor, and *Bonnie* reached its peak intensity of 50 knots (25 m s^{-1}, weak category 2) at this time, before gradually weakening over the following days.

The cyclone took a gradual turn to a west-southwestward track on 12 April, further away from the island of Java and the influence of land, but at the same time into an area of increasing wind shear. Deep convection decreased around the system during 13 April and satellite imagery depicted a partially exposed low-level circulation centre by 1200. IR imagery and an SSM/I pass at 2316 13 April indicated that deep convection had increased once more and a banding feature had developed, suggesting a slight re-intensification of the system. However, this proved to be short-lived, and the system continued its decline on 14 April, with only sporadic, disorganised bursts of convection near the weakening low-level circulation. The system dissipated entirely over the following day or two.

The centre of *Bonnie* made landfall on the islands of Timor and Sumba, but the system was quite weak (category 1) during both impacts. Heavy rainfall would have been the main threat to the islands, however no damage or casualty reports were received.

Errol (Perth): 8 to 15 May 2002

TC *Errol* was a weak, late season system that only attained minimal TC intensity for a period of about 18 hours. As discussed earlier, most of the interest in this system centred on the large-scale situation leading to its formation.

The disturbance that became *Errol* was first identified during 8 May, located about 750 km north of

Cocos Island, and near the southern cyclonic member of an ER wave. Although late in the season, SSTs in the area were still 27 to 28°C and capable of supporting TC development. The system was located to the north of the upper ridge, and vertical shear over the area was moderate. However, the disturbance began to organise rapidly during 9 May, with cycling convection consolidating about the circulation centre. Although hampered by the vertical shear, the system had become organised enough by 0400 9 May for it to be upgraded to TC *Errol*. Initially, the system was steered by the low to mid-level ridge to its southeast, but this feature weakened and moved eastwards, and left TC *Errol* in a weakly steered environment, and consequently the motion was slow and erratic. The largest changes in position at this stage were associated with outbreaks of deep convection near the centre. This also kept the system to the north of the upper ridge axis, and development continued to be severely hampered by moderate vertical shear. In fact, the cyclone weakened to below TC strength early on 10 May. At 1602 11 May, a 37 GHz TRMM microwave scan indicated that the weak system may have been multi-centred. On 12 May, the depression took up a south-southeasterly track as the mid-level ridge built back to its east. The system remained strongly sheared, with sporadic deep convection and no real reintensification was observed. The depression passed near the east of the Cocos Islands in the early hours of 15 May local time, and thereafter continued to accelerate to the south-southeast, eventually becoming extratropical over open waters.

The system was weak as it moved rapidly past the Cocos Islands, and no damage or casualties were caused by TC *Errol*.

***Upia* (Port Moresby): 25 to 29 May 2002**

Upia was the first TC to form in the Papua New Guinea area of responsibility for nine years, the previous system being TC *Adel* in May 1993. *Upia* was a brief and weak system, attaining minimal TC strength over the Solomon Sea for a period of about one day.

Once again, it appears this cyclone developed near the cyclonic member of an ER wavetrain. On 23 May, a persistent area of convection developed in the central Solomon Sea in a broad area of low-level cyclonic vorticity associated with the Rossby gyre. Although the disturbance was north of the upper ridge axis, vertical shear was relatively light, with reasonable upper diffluence. Deep convection continued to cycle near the centre and the system overall became gradually more organised and compact throughout 24 May, with a banding feature developing in IR imagery and wrapping into the centre. By 1800 24 May, the system had clearly attained minimal TC strength, as indicated by animated satellite imagery and a Quikscat pass at 1920 which depicted a belt of 35 to 40 knot (18 to 22 m s^{-1}) winds on the southern side of the system. Throughout 25 May, the system drifted slowly southwards under the influence of a weak ridge to the east, but this motion became slow and erratic by 0000 27 May. However, by this time 200 hPa analyses indicated that the centre had slipped south of the upper ridge axis, and the cyclone was experiencing moderate northwesterly shear. Throughout 27 May, satellite imagery depicted deep convection almost entirely confined to the southeast of the low-level circulation centre. By this time, the system had weakened below TC strength, supported by a Quikscat pass at 0710, which failed to indicate any gales near the centre of the system. During 28 May, the system recommenced its south to southeastward motion, but remained weak. A Quikscat pass at 1942 27 May indicated the depression had weakened further. Eventually, ex-*Upia* merged with a broad tropical trough over the southern Solomon Sea.

No reports of damage or casualties were generated by TC *Upia*.

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Some post analysis of wind and height fields was undertaken using reanalysis data from the NOAA-CIRES Climate Diagnostics Center, Boulder, Colorado, web site at: http://www.cdc.noaa.gov.

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