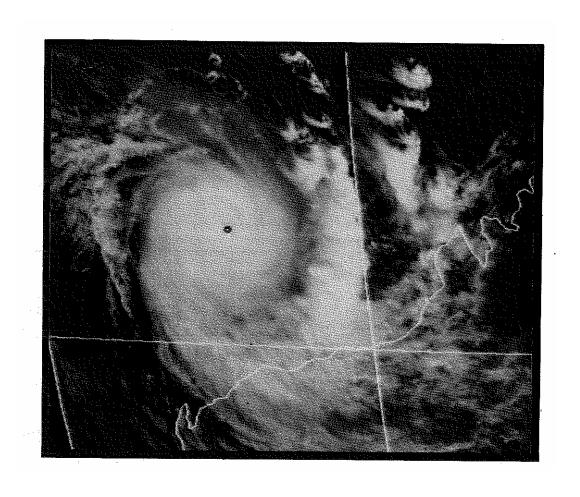
# REPORT ON CYCLONE ORSON

# **APRIL 1989**



# **FOREWARD**

Tropical cyclone *Orson* crossed the northwest Western Australia coast just west of Karratha during early morning of Sunday 23<sup>rd</sup> April 1989. It was one of the strongest cyclones to have affected Western Australia since records began and as it passed over the North Rank A gas platform its central pressure was measured at 905 hPa, the lowest pressure ever recorded in an Australian cyclone.

Fortunately, *Orson* made landfall in a sparsely populated area and, as a result, damage was not nearly as extensive as might have been the case. Warning services provided by the Bureau were very good with the affected area being under cyclone warning for about thirty hours before the strongest winds occurred. At least four Indonesian fishermen were drowned when their trawler sank near Ashmore Island but no other lives were lost.

A number of improvements to cyclone monitoring facilities have occurred over the past few years associated with a general upgrade of severe weather services approved by the Australian Government in September 1987. These improvements include hourly high resolution satellite facilities were of great assistance to forecasters monitoring the position of *Orson* and in predicting its future motion.

This report is concerned with the meteorological aspects of *Orson* and the impact of new technology on the monitoring of the system. It was prepared by Messrs B. Hanstrum and G Foley of the Western Australian Regional Office in collaboration with other staff of that office.

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June 1992

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# INTRODUCTION

At about 4.45am\* on the morning of Sunday 23 April 1989 tropical cyclone *Orson*, one of the most severe cyclones to approach the Australian mainland, crossed the coast at Cape Preston, approximately 70km to the west of Karratha. Five hours earlier the eye of the cyclone passed over the North Rankin A gas platform, where the minimum pressure recorded was 905 hPa, the lowest ever in an Australian cyclone.

The track of cyclone *Orson* and the location of the place names referred to in the text are shown in Fig. 1.

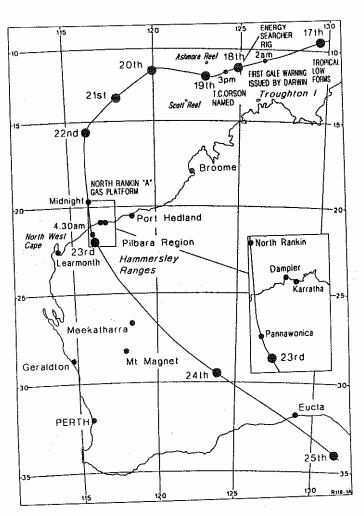


Fig. 1 Map showing track of cyclone Orson. Positions marked are at 9 am. Place names referred to in the text are also shown.

All times referred to in this report are Western Standard Time (WST) which is UTC plus eight hours.

Several Indonesian fishing vessels were reported sunk by the cyclone in the vicinity of Ashmore Island; at least four lives were lost. Fortunately the cyclone crossed the Australian coastline in a sparsely populated area and this reduced its economic impact. The main population centres along this section of the coast, Dampier and Karratha, sustained some damage but were located slightly east the zone in very destructive winds. The maximum wind gust at Dampier was 183 km/h, and at Mardie station located approximately 30 km to the west of the cyclone path, a maximum wind gust of 211 km/h was recorded. One casualty was the weather watch radar at Dampier which played a key role in plotting the cyclone's course towards the coast. The radar dome was destroyed by severe wind gusts at approximately 1.50am on 23 April.

Although weakening, *Orson* caused widespread roof and structural damage at Pannawonica as it passed over the town site (Fig.2). It subsequently decayed as it accelerated to the south-southeast later that day. The total damage cost was estimated to be in excess of \$20 million.

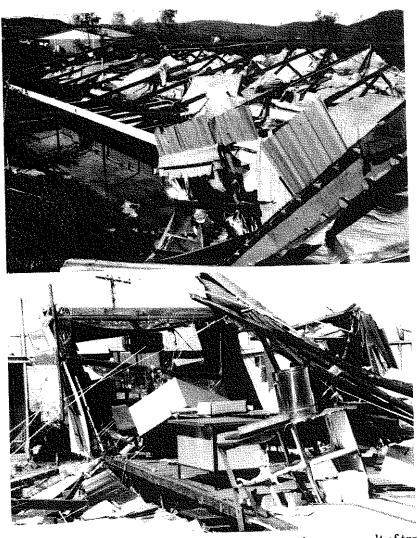


Fig. 2 Structural damage to buildings at Pannawonica as a result of tropical cyclone Orson. (Photographs courtesy of West Australian newspapers)

Fig.2 Structural damage to buildings at Pannawonica as a result of tropical cyclone *Orson*. (Photographs courtesy of West Australian newspapers)

A tidal anomaly of 3.1 meters was recorded at Dampier, but as the cyclone crossed the coast near the time of low tide, inundation of coastal areas was not significant.

Since the settlement of the Dampier/Karratha region in the mid 1960's, 19 tropical cyclones have passed within 200km of the area (Table 1). The only other storm of comparable magnitude to affect this area was tropical cyclone *Trixie* in February 1975, in which wind gusts of 259 km/h were recorded at Mardie station.

Table 1 Tropical cyclones passing within 200km of Karratha since 1965.

Cyclon	e Date		Direction of	n Landfall	Est. min	Max wind	Impact			
		11	noveme	nt	pressure					
		(1111)	110 , 01110		(hPa)	(km/h)				
(III u) (KIII/II)										
Joan	10/03/65	65(W)	Erratic	Mardie	965	N/A	Nil			
Shirley	02/04/66	75(W)	SSW	Karratha	965	111	Flood damage to rail construction			
Gladys	16/02/69	175(N)	W	X	987	N/A	Nil			
Shelia	3/02/71	45(E)	SSE	Roebourne	925	130	Minor damage			
Sophie							C			
Kerry	21/01/73	3 100(ENE	) SW '	Whim Creek	960	160	Minor damage			
Erica	31/12/73	65(NW)	SW	Exmouth	977	93	Nil			
Helen	01/03/74	175(NW)	SW	X	973	N/A	Nil			
Trixie	19/02/75	55(NW)	WSW	Onslow	925	259+	Widespread			
							damage			
Wally	24/02/76	110(E)	S	Geraldton	973	83	Nil			
Karen	07/03/77	( )	WSW	Exmouth	970	130	Minor damage			
Bruno	18/01/82	· /	W	X	976	N/A	Nil			
Ian	05/03/82	2 175(N)	WSW	Northwest	964	63-74	Nil			
				Cape						
Lena	07/04/83	( )	SE	Pt Hedland	980	N/A	Nil			
Chole	29/02/84	10(E)	SW	Cape	960	N/A	Moderate damage			
				Lambert						
Emma	12/12/84	55(W)	SE	Cape	966	N/A	Nil			
				Preston						
Gertie	31/01/85	Close	S	Cape	973	140	Minor damage			
~ .	10/01/01		~	Lambert		/.				
	19/01/8	( )	SW	Pt Hedland	950	N/A	Nil			
IIona	16/12/82	( )	SSE	Mardie	960	124	Minor damage			
Orson	23/04/89	9 65(W)	SSE	Cape	905	183	Moderate damage			
				Preston						

X Indicates the cyclone did not cross the coast.

Tracks of cyclones in the Australian region during the period 1909 to 1981 (Lourensz 1981) revealed only six other cyclones which have crossed the Pilbara coast in April, an average of one every 11 years. Only one other event during this period occurred later than 20 April. Both the intensity of the storm and the lateness of the occurrence made the cyclone an unusual event.

The latest detailed report on a Western Australian tropical cyclone was complied following cyclone *Joan*, which crossed the coast near Port Hedland on 8 December 1975 (Bureau of Meteorology 1979). Since that time, technological advances have had a significant impact on tropical cyclone forecasting in the WA region. These include:

- The introduction of GMS imagery in 1978.
- The installation of a weather watch radar at Dampier in 1985.
- The development of global numerical prediction models and numerical track prediction techniques as a guide to cyclone movement.
- The introduction of Australian Region McIDAS (ARM), (Le Marshall et al. 1987) in February 1989.
- More rapid dissemination or warnings using AROS (Automated Regional Operational System).

# TRACK OF CYCLONE ORSON

Cyclone *Orson* began as a poorly organised tropical cloud area located using GMS imagery at 8am on 17 April, near 10°S 129°E. The first evidence that the low was intensifying came from the drilling rig Energy Searcher located near 12°S 125°E (see Fig.1.) Hourly observations from the rig showed the onset of southerly gales at midnight on 17 April. Theses were sustained for a period of two hours before moderating as the low moved eastward. The centre passed just to the north of the rig at 10am on 18 April. Winds from the northwest quadrant at this rig averaged 35 km/h in the subsequent 12 hours as the low moved away. The observations showed that, during this period, the strongest winds were displaced a considerable distance from the centre of the low, as would be expected in the incipient stage of cyclone development.

On the basis of the rig observations, the first gale warning to shipping was issued by Darwin Tropical Warning Centre at 2am on 18 April for the area within 120 nm of the low in the southern and western quadrants. Infrared satellite imagery during this time revealed an increase in the areal extent of the coldest cloud tops. By 2pm the visible image showed increased organisation in the low cloud structure and the first evidence of tight inner curvature in the low cloud lines. Tropical cyclone *Orson* was named at 3pm on 18 April.

In the next 12 hours the cyclone moved on a westerly track and passed south of another ship located near 12.3°S 123.5°E. At 2am on 19 April this ship reported a minimum pressure of 988 hPa as the cyclone passed by, confirming that ongoing development was occurring.

*Orson* continued to intensify and formed an eye which allowed good centre location at approximately 8am on 20 April. The eye remained visible on satellite imagery until 8pm on 22 April, by which time the cyclone was well within tracking range of the Dampier weather watch radar.

During 20 and 21 April the cyclone began to recurve, shifting to a southwesterly and then southerly course as it intensified. *Orson* continued to move southward towards the Pilbara coast on 22 April and began to increase it speeds of movement due to changes in the environmental steering flow resulting from the approach of a cold front towards the southwest of the continent.

The centre of the cyclone passed a few kilometres to the west of the North Rankin A gas platform at 12.30am on 23 April. Preceding the eye, peak wind gusts at the 10 m level were calculated to have reached 249 km/h (data provided by courtesy of Woodside Offshore Petroleum). The platform was in the eye of the cyclone for approximately 40 minutes, during which time the eye diameter was estimated from the Dampier radar to have been approximately 40km.

Orson crossed the coast near cape Preston at about 4.45am on 23 April. It passed over Pannawonica at approximately 6am and took on a southsouthwesterly, and then southeasterly track through the data sparse inland areas of the State, while moving at speeds of between 40 and 50 km per hour. It ceased generating gales at about 5pm when it was near 24.6°S 117.9°E but continued as a discernible low pressure circulation during 24 April as it moved into the Great Australian Bight where it slowed and filled.

#### GENESIS OF TROPICAL CYCLONE ORSON

Most cyclones in the Australian region form on the monsoon shear line (McBride and Keenan 1982). Enhancement of the low level flow on either side of this zone causes an increase in cyclonic shear vorticity which can lead to cyclogensis. The increased low level wind speed may result from either surges in the trade flow polewards of the circulation or increases in the monsoonal westerly flow on the equatorward side.

In the latter case tropical cyclogenesis may result from a cold surge towards the equator in the winter hemisphere, associated with anticyclogenesis behind polar fronts, leading to pressure rises od 1 to 2 hPa in the equatorial region and strengthening westerly winds (Love 1985). This process was observed by Love during genesis of approximately 80 per cent of southern hemisphere tropical cyclones.

It has been shown (Holland 1984) that in the Australian and Southwest Pacific region the upper level jet structure may also play an important part in the tropical cyclone development. Developing storms typically form close to but not under the area of low latitude subtropical jet westerlies between the upstream trough and downstream ridge axis. Divergence in the equatorward entrance region of the jet (with speed and

anticyclonic curvature increasing downstream) may assist in the development of the low.

On occasions cyclones are observed to form simultaneously on opposite sides of the equator. Simultaneous mirror image cyclone occur about once every two to three years, whereas simultaneous non-symmetrical storms (one north, the other south of the equator but at different longitudes), occur about once or twice each season in the spring and late autumn (Dean 1954). Lander (1987) has proposed a mechanism for the formation of such pairs, the precursor to which is an eastward propagating region of deep convection centred on the equator and associated with strengthening westerly winds over about a five-day period. The equatorial heat source that results leads to cyclonic circulations on either side of the equator in accord with the theoretical results of Gill (1980). Latent and sensible heat are imported toward the centre of the circulations resulting in further warming. This process is accentuated as winds strengthen further due to the lowering central pressure and results in twin cyclone information. It will be shown that *Orson* was the southern hemisphere portion of such a development.

# Synoptic aspects of genesis of cyclone Orson

The surface synoptic patterns which prevailed in the period prior to the genesis of cyclone *Orson* were characterised by the persistence of dual equatorial troughs centred along 10°N and 10°AS. In the southern hemisphere the embryonic *Orson* was the main cyclonic circulation located in the trough. This centre moved slowly westward from 8°S 125°E at 8am on 18 April. In the northern trough two circulations, initially to similar intensity, were located near 8°N 126°E and 8°N 149°E at 8am on 15 April. Over the succeeding days the western centre remained at a constant intensity whilst the eastern centre progressively deepened and was analysed as TC *Andy* (996 hPa) at 8am on 18 April, 6 hours prior to the naming of *Orson* in the southern hemisphere.

In the higher latitudes of the northern hemisphere a front moved eastwards across Japan from 15 to 17 April and was replaced by a weak pressure cell near 28°N 137°E by 8am on 18 April. The 1012 hPa isobar associated with the high was constrained to the north of 15°N by the presence of the near equatorial trough.

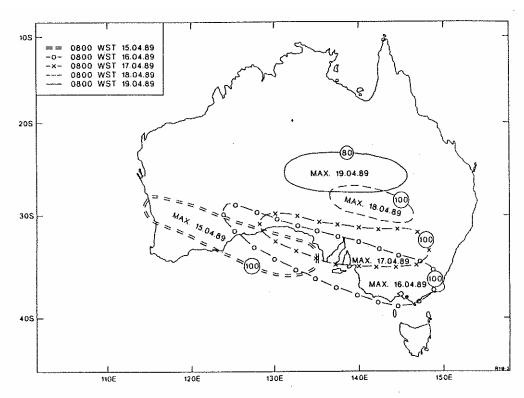


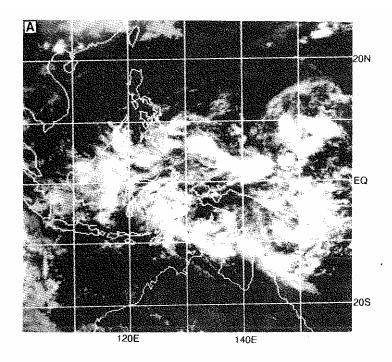
Fig. 3 Diagram showing the daily 8 am positions of the 250 hPa wind speed maximum in the period prior to genesis of cyclone Orson.

Fig.3 Diagram showing daily 8am positions of the 250 hPa wind speed maximum in the period prior to genesis of cyclone *Orson*.

In the southern hemisphere, fronts to the south of Australia were migratory south of 35°S 129°E by 8am on 16 April and remained in this area until 18 April. In the upper levels a jet maximum in excess of 100 knots, initially located over the southwest of the continent at 8am on 15 April, moved northeastward over succeeding days to be over central Australian by 8am on 19 April (Fig.3). There was no evidence of any significant high level trough in the westerlies protruding northward towards low latitudes.

Of the genesis mentioned, the model described by Langer (1987) appears the most plausible. *Orson* developed in step with tropical cyclone *Andy* in the northern hemisphere. Both lows formed approximately equidistant from the equator, separated by twenty degrees of longitude; Lander's so called 'non symmetrical twins' case. The pair developed in phase while their separation increased. Satellite photographs in the pre-genesis period (see for example Fig.4(a)), showed the clustering of convection about the equator between longitudes 120°E and 150°E as described in stage 1 of Lander's model. It is postulated that the heat energy released by this convection played a key role in the formation of both *Orson* and *Andy*, as they moved apart and intensified (Figs4(a), (b) and (c)).

The 'cold surge' formation mechanism described by Love (1985) was not observed in this case. The northern hemisphere equatorial trough acted as a barrier to the southward moving surge in the wake of the front which traversed Japan.



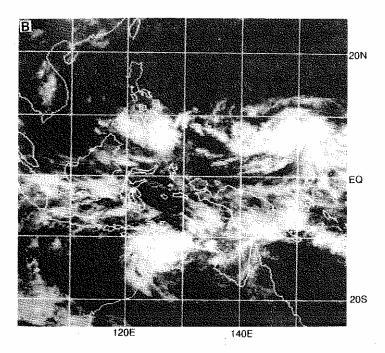
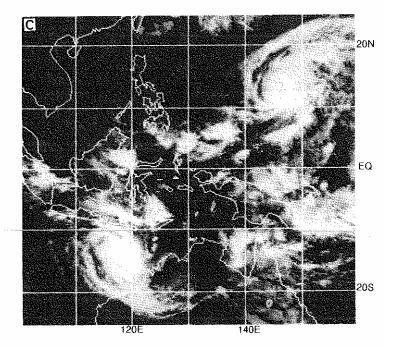


Fig. 4 Unenhanced infrared satellite photographs (remapped Mercator projections) from GMS-3 at: (a) 8 am 14 April, (b) 8 am 17 April and (c) 8 am 21 April.

Fig. 4 Continued.



The superposition of the divergent zone associated with the high level jet over central Australia may have enhanced the development process, but it was seen to be a secondary rather than primary influence.

# An objective method for accessing cyclogenesis potential

The potential for tropical cyclogenesis can be assessed on a daily basis using the method described in McBride and Zehr (1981). The method was developed from composite wind data of tropical lows over the Atlantic and Western Pacific. Assuming a symmetric disturbance, their findings can be synthesised into one parameter for the potential for development of a tropical low into a tropical cyclone:

Daily Genesis Potential (DGP) = 
$$\int 900 \text{ hPa} - \int 200 \text{ hPa}$$
  
=  $\Delta u + \Delta u$ 

when applied over 0-6 degrees radius, where  $\int$  is the relative vorticity at the level indicated;  $\Delta u$  is the meridional gradient of the zonal component of shear; and  $\Delta u$  is the zonal gradient of the meridional component of shear.

The important condition for cyclone development is not just a high value of DGP (absolute values generally greater than  $20 \times 10^{6} \, \mathrm{s}^{1}$ ), but rather that  $\Delta u$  and  $\Delta u$  Separately both have high values, so that there is zero shear near the centre with uniformly high vertical shear surrounding the system in all directions. Mc Bride and Zehr found that average DGP values were three times higher in developing lows than non-developing lows.

At least three out of four of the following objective criteria must be satisfied for 36 hours prior to cyclone development:

- (i)  $\Delta u$  greater than 8 x 10 6 s 1
- (ii)  $\Delta u$  greater than 8 x 10 6 s 1
- (iii) There exists a line of zero vertical shear in the meridional wind.
- (iv) There exists a line of zero vertical shear in the zonal wind.

A trial of the technique was conducted by the Northern Territory Severe Weather Section for tropical lows in the Australian region during 1987-1988 season. From a total of six developing and 17 non-developing tropical lows it was found that the cyclogenesis parameter could discriminate to some extent between developing and non-developing systems but the suggested cyclogensis thresholds were also exceeded foresight of the non-developing lows (Garden, personal communication). The Australian DGP values and  $\Delta u$  values for developing cyclones were generally higher than the McBride and Zehr results whereas  $\Delta u$  values were lower. The small sample size and the paucity of the data over ocean areas could offer an explanation for the apparent differences.

In the case of tropical cyclone *Orson* the DGP,  $\Delta u$  and  $\Delta u$  all attained a maximum on the morning prior to genesis. DGP values exceeded 20 x 10 6 s 1 on the four days prior to genesis, and attained a maximum value of 41.2 x 10 6 s 1. The  $\Delta u$  was generally lower (maximum value 8.1 x 10 6 s 1), more consistent with the values obtained in the pre-genesis period in the Australian region trial. On each of the four days leading up to the cyclone genesis three out of four of McBride and Zehr's conditions were met.

# MOVEMENT OF TROPICAL CYCLONE ORSON

# Climatology of April tropical cyclones over the eastern Indian Ocean region

Cyclone tracks over the northwest Australian region in April for the period from 1965-1988 (fig.5), show that the most cyclones either recurve or move southeastward. The only cyclone to affect the Pilbara coast during this period was cyclone *Lena*, which crossed the coast near Port Hedland on 4 April 1983. Even though cyclone activity near northwest Australia is comparatively rare in April, the track of *Orson* followed the suggested climatological trend.

# Movement of Orson in relation to the broadscale steering environment

The surface pressure analyses together with 500 hPa and 250 hPa streamline analyses covering the Australian and eastern Indian Ocean region were examined in order to relate the observed movement to changes in the environmental wind field at various levels. The track could be broken into three stages corresponding to westward movement, recurvature and southward acceration. These stages can be seen in Fig.6.

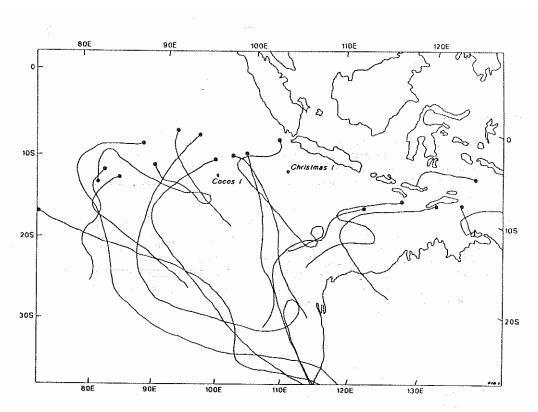


Fig. 5 Tracks of tropical cyclones over the eastern Indian Ocean in April during the period 1964-1965 to 1988-1989.

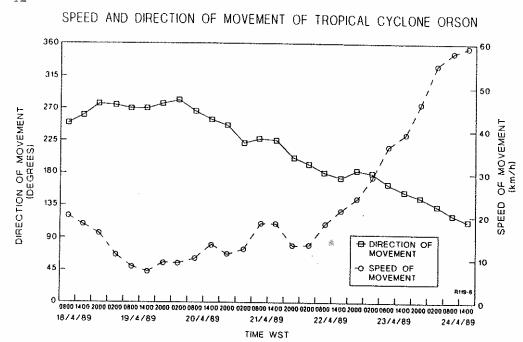


Fig. 6 Graph showing: (i) speed of movement (km/h) of tropical cyclone Orson (dashed line) and (ii) direction of movement (degrees) of Orson (solid line) versus time.

#### Westward movement

During this phase *Orson* appeared to be steered by the easterly flow on the equatorward side of the subtropical ridge axis evident through the middle and upper troposphere (Fig 7(b)/(c)). The anticyclone at 250 hPa was located approximately 1100 km to the east-southeast of the cyclone, over the northern Territory.

Over southern Australian a generally westerly flow prevailed at this time and a jet stream with speed maximum near 100 knots was located over the south of Western Australia. There was little evidence of meridionality in the patterns at high levels nor at the surface (Fig. 7(a)), where a narrow ridge covered latitudes between 30°S and 40°S, from the central Indian Ocean across to southeastern Australia. A very broad surface trough was evident over higher latitudes of the Indian Ocean spanning longitudes 45°E to 140°E.

#### Recurvature

The first signs of recurvature became evident at 2am on 21 April when the cyclone changed direction from west-southwest (Fig.6). *Orson* had moved into a region of increasing northerly flow in the middle and higher levels (Figs. 8(b)/(c)). This was particularly noticeable in the wind profiles at Broome and Port Hedland.

Comparison of the high level analyses with the composite analyses of George and Gray (1976), indicate close similarities between this situation, and their recurving case at both 12 hours and 36 hours prior to recurvature.

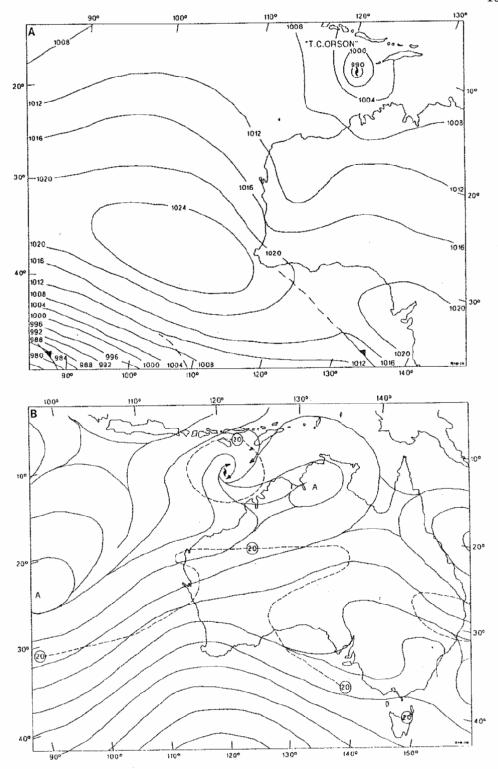
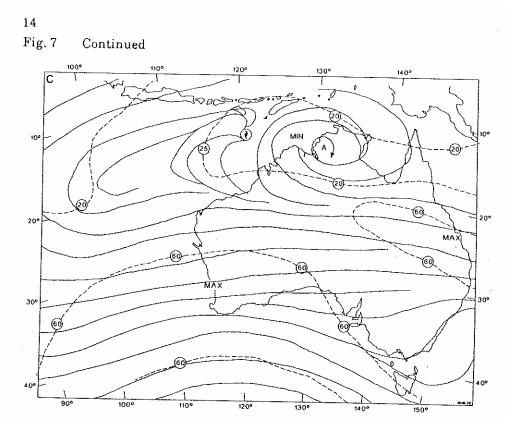


Fig. 7 Charts showing: (a) Mean sea level surface pressure analysis; (b) 500 hPa streamline analysis and (c) 250 hPa streamline analysis at 8 pm on 19 April.



The broad surface trough in the central Indian Ocean (Fig. 8(a)) intensified to form a major cold front which became mobile and caused large pressure falls over the eastern Indian Ocean.

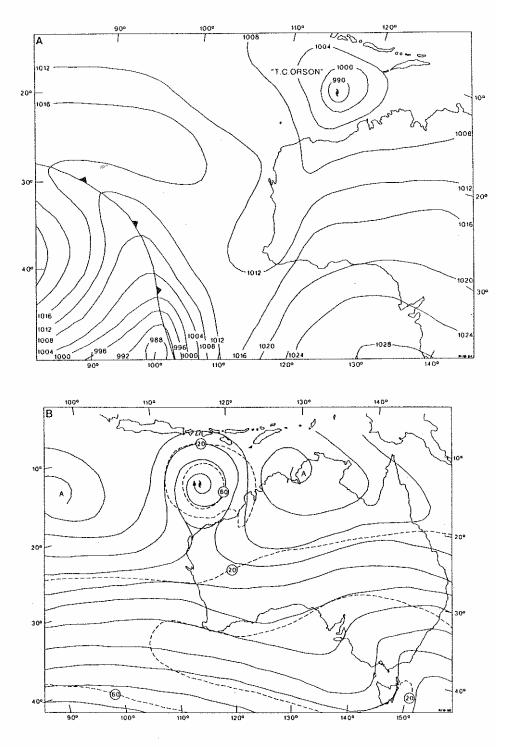
#### Acceleration

Acceleration of *Orson* began at 8am on 22 April (Fig. 6), at a time when the broadscale pattern over the Australian region was undergoing a major readjustment. The zonal pattern over at high levels which had prevailed over the previous days rapidly transformed into one of the high meridionality (Figs. 9(b)/(c). A sharpening trough had become evident in the eastern Indian Ocean some 2200 km to the southwest of *Orson* and a developing cut off low was located over southeastern Australia. At the surface the cold front had moved eastwards along 35°S at 14 km/h and was located approximately 1800 km to the southwest of *Orson* at 8pm on 22 April (Fig.9(a)).

# Forecast guidance for movement of tropical cyclone Orson

There is an increasing amount of forecast guidance available in the operational environment to assist forecasters with track prediction. A statistical-analogue method termed TOPEND provides guidance on cyclone motion twice daily during cyclone events giving 12, 24 and 48 hour predicted positions. The technique is run by NMC in Melbourne using previous track positions.

It has been suggested (Chan and Lam 1989; Morris and hall 1989) that global models, which were developed with no predilection towards tropical cyclones, do show some skill in medium range forecasts of cyclone motion.



 $Fig.\,8\qquad As in \,Fig.\,7 \,but \,for\,8 \,pm \,on\,21 \,April.$ 

Fig. 8 Continued.

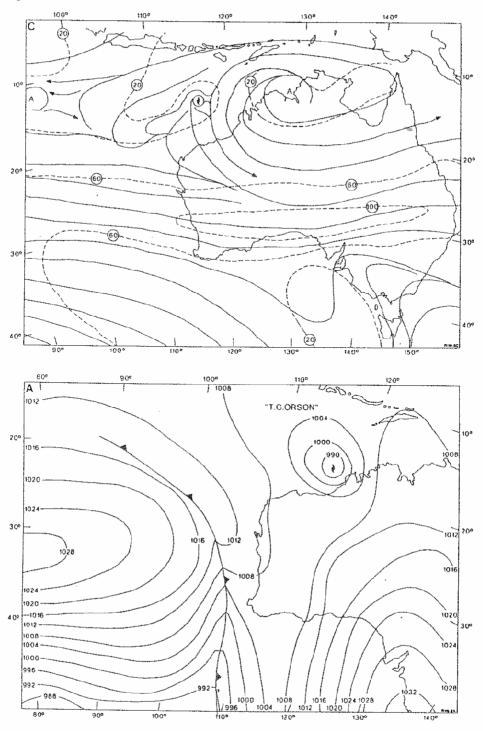
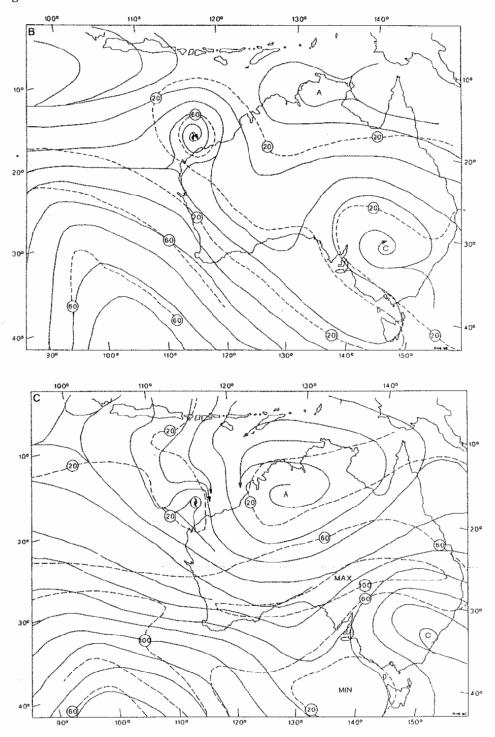


Fig. 9 As in Fig. 7 but for 8 pm on 22 April.

Fig. 9 Continued.



Central Forecast Office of the United Kingdom Meteorological Office in Bracknell commenced an advisory service during the 1988-1989 cyclone season, providing forecasts of cyclone position at 0, 12, 24, 48, 72, 96, and 120 hours from analysis time. The predicted tracks given for *Orson* are shown in Fig. 10 and indicate that, while the model projected a general westerly trend in the early advices, by 8am (0000 UTC) on 20 April, the forecasts were indicating a change to a more southerly track.

While the general track guidance was good, the model failed to resolve the degree of acceleration of the cyclone in its latter stages and this tended to increase the model's absolute forecast errors.

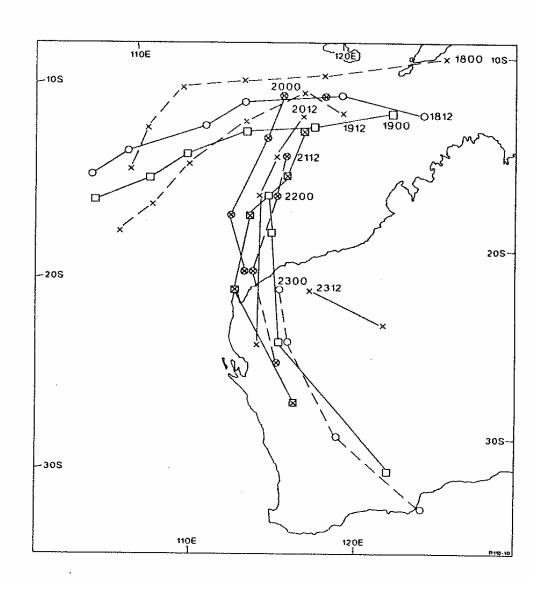


Fig. 10 Forecast cyclone positions at 24-hour intervals from UK global model advices. Forecasts are issued every 12 hours and extend out to 120 hours. Times shown (DDgg) are the analysis times (UTC) for each model run.

The two models are compared with official TCWC operational forecasts and TOPEND in Table 2. The TCWC forecasts are of course not independent of the output of these models as all available guidance is input to the official forecast.

Table 2 Comparison of centre location and forecast position errors in km at 12, 24 and 48 hours for official TCWC forecasts, TOPEND and UK global model advices. Official TCWC forecast errors have been stratified for occasions when the centre location was determined using satellite imagery (with and without an eye being visible) and radar imagery.

	TCWC forecas					
	Satellite (without eye)	Satellite (with eye)	Radar	TCWC	Topend	UK
Centre location	42	14	7	25	N/A	N/A
12 hr forecast	103	51	65	70	95	88
24 hr forecast	179	138	N/A	153	190	178
48 hr forecast	N/A	407	N/A	407	472	368

#### SATELLITE IMAGERY

The evolution of the cloud field associated with tropical cyclone *Orson* was monitored principally using satellite imagery from the Japanese geostationary satellite GMS-3. Since the launch of GMS-1 in 1978, satellite imagery has generally been available at 3-hourly intervals. However following the introduction of PC-ARM (Le Marshall et al. 1987) into the WA region in February 1989, hourly images at very high resolution have become available. These images were used with obvious benefit to monitor the development and movement of *Orson*.

Cyclone *Orson* began as a poorly organised area of convective cloud over the ocean to the northwest of Darwin on the morning of 17 April 1989. the cloud mass moved west and increased in the area in the following 24 hours, but at 8am on 18 April visible satellite imagery revealed little evidence of a significant low level circulation. However during the day rapid organisation of the cloud field took place, signalling the genesis of tropical cyclone *Orson*. By 2 pm on 18 April there was evidence of tight inner curvature in the low cloud lines near 12.6°S 124.1°E, approximately 220km off the Kimberly coastline. Infrared enhanced imagery three hours after genesis (Fig1 11(a)) shows the deep convective cloud band associated with the developing cyclone.

The cloud pattern continued to develop and an eye became evident by 8am on 20 April. An example of visible imagery showing the eye pattern when the cyclone was near peak intensity is presented in Fig1 11(b). The eye pattern was maintained until just prior to landfall, following which the structure and aerial extent of the cloud field progressively diminished.

The main technique used for estimating tropical cyclone intensity from satellite imagery in the Perth Tropical Cyclone Warning Centre is that of Dvorak, 1984. Infrared Dvorak enhanced satellite images during intensification and decay of *Orson* are shown at generally 12-hour intervals in Fig. 12.

Orson developed from a 'curved band' cloud pattern as defined by Dvorak and is shown as a T 3.0 in infra-red imagery at 5pm on 18 April in Fig. 11(a), three hours after the cyclone was named. From that time onwards the cyclone developed steadily. An estimated intensity of T 3.5 was reached at 11am on 19 April, and T 4.5 was attained by 8am on 20 April. By midday (Fig 12(c)) the 'eye pattern' was first observed at 8am on 20 April. By midday (Fig. 12(c)) the 'eye pattern' analysis gave a T number estimate of 5.0. Intensification of the cyclone continued and T number estimates of the intensity were placed at 6.0 or 6.5 on various images (Figs 12 (d)-(g), Fig.11 (b)) up until 2am on 23 April, when the eye pattern was lost just prior to landfall.

As *Orson* passed North Rankin A gas platform its current intensity (CI) number was evaluated as T 6.5 which would give an estimated central pressure of 914 hPa and accompanying maximum wind gusts of 292 km/h. This compares with a lowest pressure reading measured at North Rankin of 905 hPa and estimated maximum wind gusts of 255 km/h at the 10 m level.

The cloud structure accompanying the weakening cyclone as it moved over land is shown in Figs 12(h)/(i).

Intensity estimates using the Dvorak method were generally seen to provide useful guidance during cyclone *Orson*.

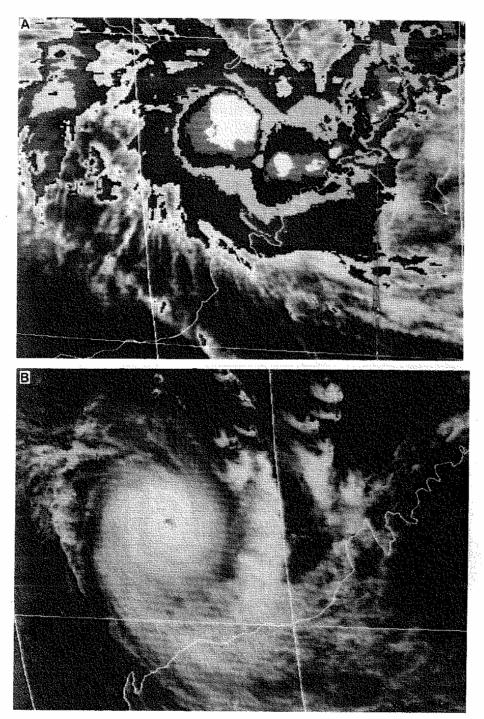


Fig. 11 GMS-3 satellite photographs showing: (a) Infrared Dvorak enhanced image at 5 pm on 18 April, 3 hours after genesis of tropical cyclone Orson and (b) Visible image at 11 am on 22 April showing Orson close to peak intensity.

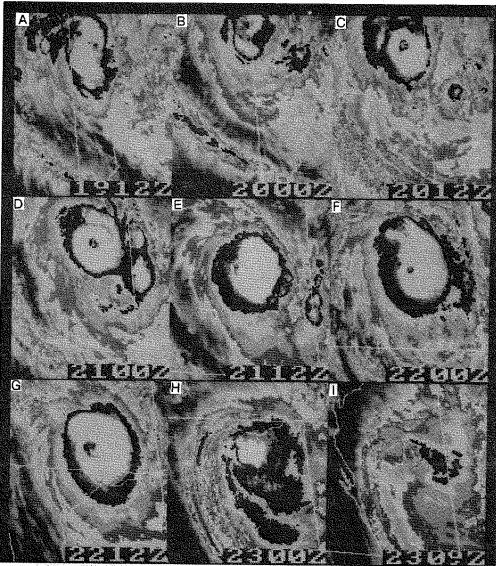


Fig. 12 Dvorak enhanced infrared GMS-3 satellite imagery at generally 12-hourly intervals commencing 8 pm on 19 April showing the intensification and decay of cyclone *Orson*.

# RADAR ANALYSIS

The remotely controller radar at Dampier was commissioned in December 1985 as a consequence of concerns that a tropical cyclone approaching the Karratha coastline from the north may not be adequately resolved by the existing radar facilities at Port Hedland and Learmonth. Observations from the Dampier radar proved to be of invaluable assistance in tracking *Orson* as it approached the coast. The recently installed RAPIC (Radar PICture) system enabled forecasters in the TCWC to view high quality radar images. Features of this system include the ability to schedule images (the minimum time between images being ten minutes), a facility which enables looping of sequential images, a zoom facility and navigational mapping of the cursor. The system greatly increased the confidence of meteorologists in the centre location and movement prediction as the cyclone approached the coast.

The eye of the cyclone was first observed at 3.30pm on 22 April approximately 350km from Dampier on a bearing of 354 degrees. Radar surveillance from Dampier was maintained at 10-minute intervals until the radar dome was destroyed by severe wind gusts about 1.50am on 23 April. After this time radar images from Port Hedland (200km to the east of Dampier) and Learmonth (270km to the west-southwest) were used to track the cyclone as it crossed the coast near Cape Preston, approximately equidistant from the two stations.

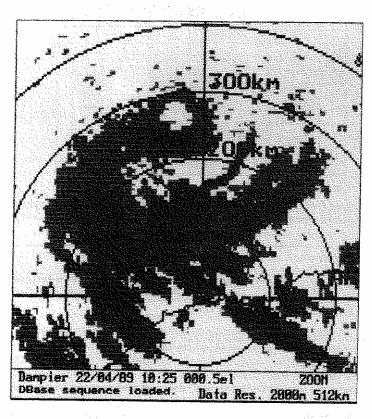


Fig. 13 Radar image at 6.25 pm (1025 UTC) on 22 April showing the 'inner' and 'outer' eye structure of cyclone Orson.

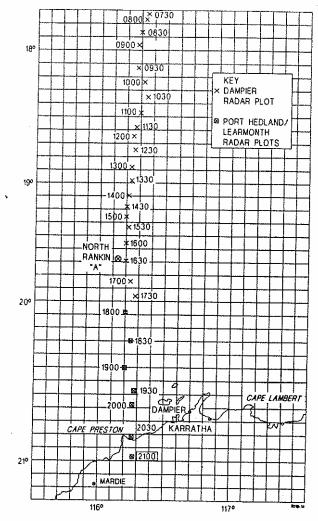


Fig. 14 Track of tropical cyclone Orson from radar positions. (Times at 30 minute intervals in UTC)

It was discovered when an assessment of the damage to the Dampier radar was being undertaken that the power supply and the communications links to the facility both failed shortly after the radar dome was destroyed. The failure of either of these services would have meant the loss of radar information from Dampier even if the radar dome had survived.

The eye wall region returned strong signals during the entire period of observations, allowing good operation centre location. Post-analysis of radar imagery revealed two possible positions for the cyclone centre. At times there appeared to be an 'inner eye' within the centre of the 'outer' or most obvious eye (Fig. 13). The inner eye was not always well defined and seemed to merge with the southern and western parts of the 'outer eye'. Track positions at 10-minute intervals (Fig. 14) are four the 'outer' eye for which the average eye diameter for the period of observations was 40km. the 'inner' eye when discernible was approximately 10 to 15 km in diameter.

A comparison of the radar track with observations from North Rankin A gas platform revealed that, although the centre as depicted on radar was seen to pass to the east of the platform, the surface observations indicated that the centre, as defined by the wind field, passed just to the west.

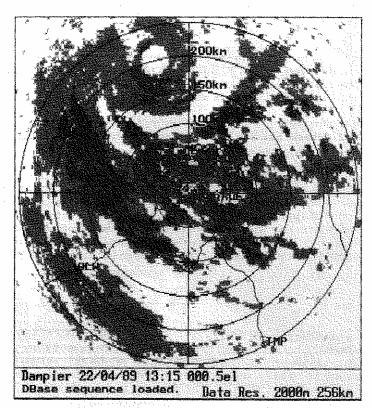


Fig. 15 Radar image of tropical cyclone Orson at 9.15 (1315 UTC) on 22 April, approximately 8 hours prior to landfall. Note the most intense echoes on the southern flank of the storm and the spiral rain bands impinging on the northwest coast.

# OBSERVED PHYSICAL CHARACTERISTICS OF CYCLONE ORSON

#### Wind

The 10 minute mean winds recorded at North Rankin A gas platform are shown in Fig. 16. The anemometers were located at 36.4m above MSL. The highest recorded 10 minute wind average speed at this level was 224 km/h which occurred at 11.40pm on 22 April, on the southern side of the eye wall. No maximum three second wind gust data were available during the period of maximum recorded winds.

The maximum gust measured was 275 km/h during the period between 11.20pm and 11.30pm. Gust factors for the five previous hours were consistent and averaged 1.25

The eye diameter measured by radar in conjunction with North Rankin A anemograph trace suggested the radius of maximum winds was in the range 20 to 30 km.

Winds decreased rapidly as the eye region moved over the platform and a minimum 10 minute mean wind of 14 km/h, was recorded at 12.30 am on 23 April. The anemometers sustained major damage as winds increased on the northern side of the eye wall and no further data were available.

Over land the maximum wind gusts measured were 183 km/h at Dampier (56 km to the east of track) and 211 km/h at Mardie station (30 km to the west of track).

The rapid speed of movement of *Orson* meant the most localities were only exposed to destructive winds for a relatively short period of time. For example, both Mardie station and vessels anchored in King Bay reported winds in excess of 90 km/h for a period of approximately 5 hours. This compares with a period of about 10 hours of destructive winds at Port Hedland during Tropical Cyclone *Joan* (Bureau of Meteorology 1979). This relatively short duration of destructive winds may have lessened the potential for structural damage in towns of Dampier and Karratha.

#### **Pressure**

The minimum pressure recorded during cyclone *Orson* was at the North Rankin A gas platform where the barometer fell to 905 hPa at 11.50pm on 22 April. A recreation of the pressure profile base on 10 minute readings is shown in Fig. 16. The rate of pressure fall was extremely rapid in the hour prior to the passage of the eye, dropping from 960 to 905 hPa. The pressure remained below 910 hPa for one hour before rapidly rising to 960 hPa in the next two hours. This suggests that the pressure gradient around the eye was greater on the southern side of the centre.

A barograph trace was available from Dampier, 56 km to the east of the point of landfall (Fig.17.) The lowest mean sea level pressure recorded was approximately 969 hPa at 4.30am on 23 April. Given the magnitude of the pressure gradient measured near

North Rankin A gas platform this reading is consistent with the central pressure of *Orson* at landfall being near 920 hPa.

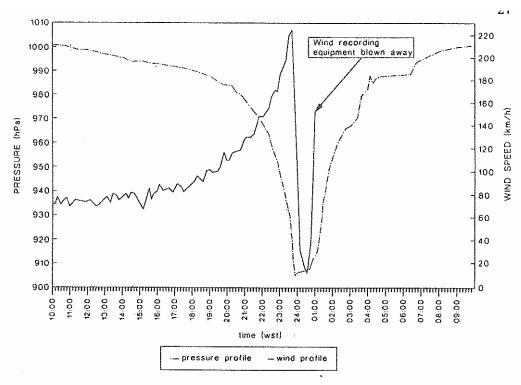


Fig. 16 Mean Sea Level pressure profile (dashed line) and 10-minute mean wind speed profile reduced to 10 m level (solid line) at North Rankin A gas platform during cyclone Orson. Units are hectopascals (pressure) and kilometres per hour (wind speed). (Data supplied courtesy of Woodside Offshore Petroleum.)

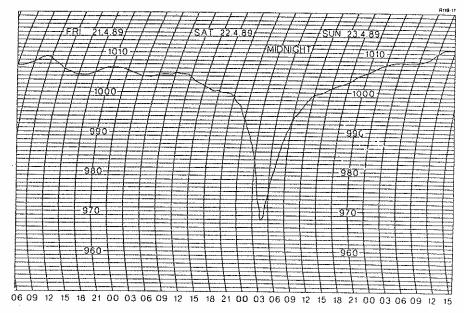


Fig. 17 Barograph trace at Dampier during cyclone Orson.

At Mardie station, approximately 30 km to the west of the cyclone path the lowest MSL pressure was 965 hPa, recorded at 6am on 23 April.

#### Rainfall

The rainfall isohyets for the three-day period from 9am on 21 April to 69mm on 24 April are shown in Fig. 18. The rainfall totals associated with *Orson's* passage over land were modest in comparison with other major tropical cyclone events. In TC *Joan*, for example, rainfall amounts were estimated to have exceeded 600 mm in places over the Hamersley Ranges. For *Orson* the maximum fall reported was only 146 mm at Pannawonica. The lower rainfall totals accompanying *Orson* were most likely the result of its higher speed of movement. The average speed of cyclone *Joan* in the 24 hours following landfall was 14 km/h whereas for *Orson* it was 43 km/h. During *Joan* rain fell over a 60-hour period. At Pannawonica during *Orson* the rainfall duration was 19 hours.

Falls along the Pilbara coastal region showed a markedly asymmetrical distribution about the cyclone track, with rainfall biased towards the eastern side. There was also a much stronger isohyetal gradient on the western side of the track. Learmonth, located approximately 220 km to the west of track, reported blowing dust and no rainfall whereas Port Hedland, 300 km to the east of track, recorded 59 mm. This distribution is consistent with moist onshore flow and convergence to the east of the cyclone track as compared with drier offshore flow over areas to the west.

As is common with cyclones which cross this section of the coastline, rain extended over most places in the southern half of the state as the cyclone decayed and moved southward. The only exceptions were the eastern border areas and the coastal and adjacent inland areas between North West Cape and Geraldton where no rain fell. The sharp rainfall cut off to the west of the track (evident along the west Pilbara coast) extended southward to about Mount Magnet. However further south the rainfall area extended to the west coast where a maximum in excess of 25 mm was observed in the Perth area. The rain area formed in situ as the result of baroclinic processes operating between the southward moving warm corded system and the approach of a marked cold trough towards the west coast.

The only usable pluviograph record in the path of the cyclone was from Pannawonica. The hourly rainfall rates have been plotted relative to the cyclone centre positions to show the rainfall intensity distribution alongside a major peak (maximum intensity 49 mm/h) corresponding to the passage of the northern side of the cyclone centre. The minor peaks (located approximately 180 km to the north and south of the centre), probably correspond to decaying spiral rain bands. As the cyclone was filling no diminution of rainfall was evident in the eye which was covered by cloud at this time (Fig. 12(h)).

#### Storm surge

The degree of threat from storm surge along the Pilbara coast is closely linked to the height of the astronomical tide at the time of landfall because the large tidal range in the area. A change in the tidal height and hence the surge height.

Tide levels were falling as *Orson* approached the coast on the morning of 23 April, making the threat of inundation from the surge less immediate. The predicated tide at Dampier at the time of landfall was 1.6 metres, substantially less than the highest astronomical tide (HAT) level of 5.1 metres. The contribution from *Orson* to the tidal level was observed to be 3.1 metres, making the total tide

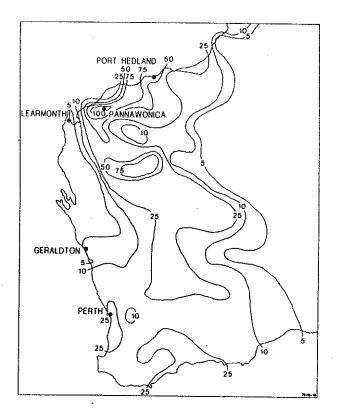


Fig. 18 Rainfall isohyets (mm) for the period from 9 am on 21 April to 9 am on 24 April.

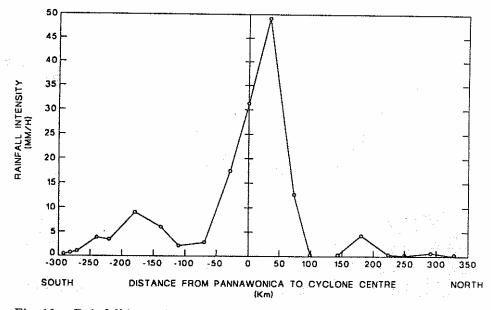


Fig. 19 Rainfall intensity (mm/h) at Pannawonica relative to the location of tropical cyclone Orson. Positive (negative) values refer to distances north (south) of Pannawonica.

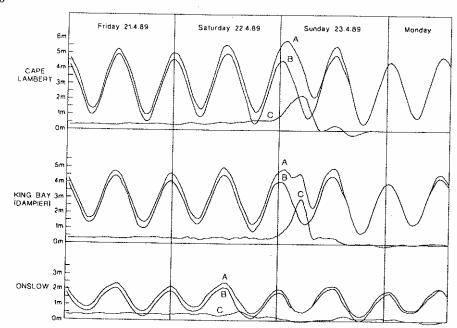


Fig. 20 Observed tide levels at Cape Lambert, King Bay (Dampier) and Onslow (curve 'A') during cyclone *Orson*, compared with predicted tide levels (curve 'B'). Curve 'C' is the tidal anomaly. Tide heights are in metres. (Data supplied courtesy of Marine and Harbours Department Karratha)

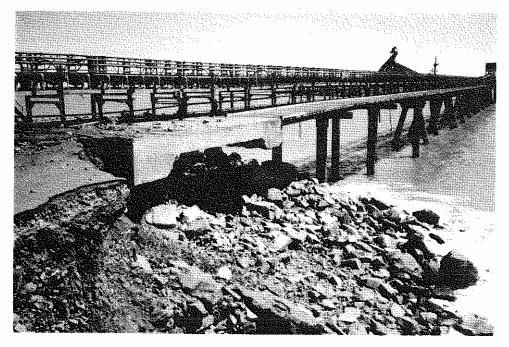


Fig. 21 Erosion of rock fill sea walls at the Hamersley Iron Loading Facility at the Dampier port. (Photograph courtesy of Hamersley Iron Pty Ltd)

Height 4.7 metres. Tide gauge recordings at Cape Lambert, Dampier and Onslow are shown in Fig.20 along with predicted tidal levels and the resultant anomalies.

Although little in the way of inundation was reported, the action of the driving seas and the contribution of the tidal anomaly caused significant erosion of rock fill sea walls at the Hamersley Iron loading facility at the Dampier port. Areas of fill up to 10 metres wide and 20 metres deep were gouged out of the walls at the height of the cyclone (Fig.21).

#### Wave heights

Data transmission from a wave height recording instrument situated at North Rankin A gas platform failed a few hours before the peak of cyclone *Orson*. However, examination of damage to the base of the platform indicated a peak significant wave height of 12 m and a maximum wave height in excess of 20 m.

#### Theoretical wind profile

An analytical wind pressure field model for tropical cyclones (Holland 1980) has been widely used in the Australian region. Given two synoptic pressure observations at known distances form the eye, an estimate of the central pressure and the ambient pressure (usually the pressure value of the first anticyclonically curved isobar), the wind field can be described at any point within the cyclone environment.

Two observations taken from the North Rankin A gas platform centred on 10.30pm on 22 April were used to derive the wind field. The cyclone was located at distances of 31 km and 65 km from the platform with the eye accurately located by radar. The resultant wind field is shown in Fig. 22. One of the most notable features was the asymmetry of wind distribution about the centre largely due to the high translational speed of the storm. The centre of the wind field was displaced slightly to the west, consistent with radar fixes and with the observational data from North Rankin A.

## Theoretical storm surge

The technique used in the Perth TCWC for calculating storm surge from tropical cyclones has been that of Jelesnianski (1966, 1967) and Nickerson (1971). In this technique, bathymetry parameters for the appropriate stretch of coast under

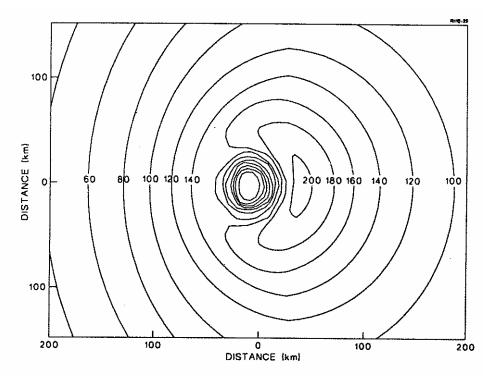


Fig. 22 Derived horizontal wind profile (km/h) for cyclone Orson using the method of Holland (1980).

Threat must be determined along a forecast storm track. A number of separate variables must be determined in order to arrive at a complete profile. The procedure is cumbersome under ideal conditions but becomes untenable under the landfall position is uncertain and several alternative sites must be considered. The method is not applicable for gulfs or bays.

The estimate of the storm surge obtained by using post-operational best track data with this method yielded a maximum surge height of 4.4 meters and a height of 3.3 metres at King Bay, 56 km east of the point of landfall.

Recently a depth-averaged, numerical storm-surge model has been developed for use in forecast offices in real-time by Hubbert et al. (1990). The surface pressures and winds which drive the model are derived from the analytical –empirical model of Holland (1980) which requires as input the cyclone positions, intensities and radii of maximum winds. Output consists of the derived cyclone wind and pressure fields, ocean elevations and ocean currents. A surge time series may be displayed for any point in the domain.

The model was run in non-real-time using best track positions and intensities for cyclone *Orson*, and gave a peak surge value at King Bay of 3.0m (Fig. 23), which compared very favourably with the observed tidal anomaly of 3.1 m (Fig. 20). The model is expected to become operational in the Perth TCWC in the 1990-1991 tropical cyclone season.

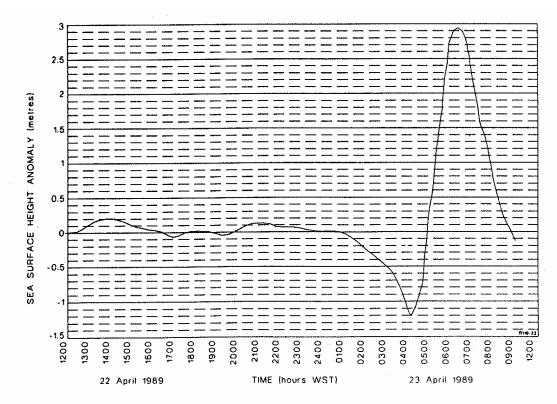


Fig. 23 Modelled sea surface height anomaly (m) at King Bay during tropical cyclone Orson.

#### WARNINGS TO THE PUBLIC

The tropical cyclone warning system in use in communities in northwest Australia is highly developed and well understood by counter disaster organisations. This has been achieved through many years of close liaison between the Bureau of Meteorology and both local communities and industry, as well as through a concerted and sustained public education program.

Communities in the northwest of Australia base their response to a tropical cyclone threat on a three tiered, colour coded alert system (blue, yellow, and red alerts in increasing order of priority).

Stage blue (the initial stage) was declared by the Karratha local counter disaster committee at 10pm on 21 April. Stage yellow came into force at 5pm on 22 April. As the decision to go to stage yellow was announced on late Saturday afternoon, it was made clear that the next phase (stage red) would be declared at midnight, in an attempt to minimise any potential communications difficulties.

The Australian tropical cyclone warning system has been described in the Bureau of Meteorology publication, Public Weather Services handbook (Bureau of Meteorology 1990).

The areas covered by watch/warning messages of cyclone *Orson* are shown in Figs 24(a)-(1). *Orson* was in the process of recurving towards the coast when the first

cyclone watch message was issued at 10am on 21 April (see Fig. 24(a)). By 7pm the most portable area to be affected had been determined and a cyclone warning message was issued (see Fig.24(c)). At 10am on 22 April, the warning area remained unchanged, but the watch area was relocated to include a portion of the west coast as the cyclone travelled further south (Fig.24(d)).

The first mention of landfall was made at 7pm on 22 April as 'close to Karratha', but this was subsequently revised to be 'between Katharra and Mardie' by 9pm.

Once the cyclone had crossed the coast and began to move inland over a sparsely populated area, problems with adequately defining the warning area emerged. Unlike when the coastline can be used to fix the boundaries of the warning area, defining the cyclone warning area over land poses greater problems, due to the small number of settlements with familiar names.

After landfall, the rain echo pattern on radar displays became less distinct and concomitantly, the cyclone lost its eye characteristics on satellite imagery. This made accurate centre location difficult, a task exacerbated by the sparse synoptic network.

As part of the documentation phase, questionnaires were sent to the station owners in the general path of cyclone *Orson*. Of the 21 responses returned to the Bureau, 18 stated they were satisfied with the cyclone warnings, despite the operational difficulties encountered. The dissatisfied station owners saw the TCWC's reversion to three-hourly warnings from one-hourly warnings (issued when there is a confident estimate of the centre location on radar) as a degradation of the warning service to pastoralists. The overall forecasting performance associated with the cyclone *Orson* event attracted a minimum of public criticism.

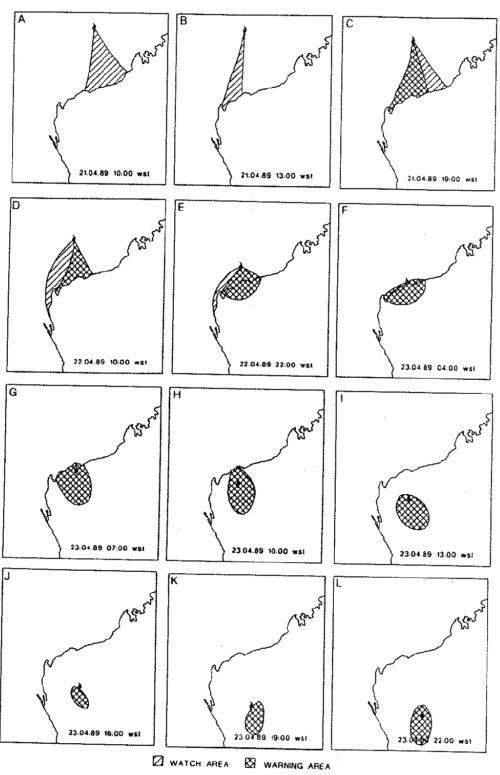


Fig. 24 Cyclone watch/warning areas issued for cyclone Orson: (a)-(f) prior to landfall, and (g)-(l) following landfall.

#### CONCLUSIONS

*Orson* was one of the most powerful cyclones to affect the West Australian coast. The barometric pressure of 905 hPa recorded as the eye passed over the North Rankin A gas platform is the lowest pressure ever recorded in an Australian cyclone. It was a relatively fast moving cyclone and was travelling at about 25 km/h as it crossed the coast.

Fortunately, *Orson* made land fall in a sparsely populated area and, as a result damage was relatively minor. The only lives lost were those of about four Indonesian fishermen in the vicinity of Ashmore Island. As landfall occurred near low tide, inundation of the coast due to storm surge was not a significant problem.

Orson followed a relatively uncomplicated track and for the greater part of its life had an eye which could be identified from satellite imagery. High quality imagery from GMS-3 was available at hourly intervals throughout the event and this was a great value to forecasting staff. The major forecasting problem was predicting the commencement of recurvature.

Orson was monitored by the Dampier radar from 3.30pm an 21 April, some 13 hours before landfall, until the radar suffered significant wind damage at about 1.50am the following morning. During this period high quality radar images were available to forecasters in the TCWC and these were updated every 10 minutes. After the loss of the Dampier facility, similar data were available from both Port Hedland and Learmonth. These data played a vital role in enabling forecasters to accurately locate the cyclone and predict its movement during the critical hour's immediately preceding landfall.

Warning services were good. The first watch for the effected area was issued about 36 hours before the gales developed and the first warning provided about 30 hours leadtime.

The loss of the radar facility at Dampier about three hours before landfall was not critical to the warning process as it was possible to accurately monitor the cyclone using both the Port Hedland and Learmonth radars. However, there are many locations along the West Australian coast where the loss of a radar facility would have resulted in no radar information near the eye of a cyclone being available. It is therefore very important that action be taken to ensure that similar equipment failures do not occur in future. In particular, all radar domes should be checked for structural integrity and all power supplies and communication systems should be checked to ensure that they are able to perform adequately under extreme conditions.

# ACKNOWLEDGMENTS

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