Back to
Papers

Tropical Cyclone Orson - A Severe Test For Modelling

B A HARPER, BE(Hons) PhD MIEAust CPEng
PPK Consultants Pty Ltd L B
MASON, BE(Hons) GradIEAust
and
L BODE, BSc(Hons) PhD Marine Modelling
Unit, James Cook University

SUMMARY Tropical Cyclone *Orson* in April 1989 was the most severe storm of its type yet recorded in the Australian region and amongst the most severe worldwide. The paper describes the storm event, the valuable engineering data obtained and explores the ability of present day numerical modelling techniques to hindcast its effects accurately. Conclusions are drawn as to those areas which most need special attention to improve predictive capabilities. Attention is focussed here on offshore rather than coastal effects.

1. INTRODUCTION

In spite of gradual developments in remote sensing techniques giving increased capability to detect and monitor the passage of tropical cyclones (hurricanes or typhoons) the instrumented close passage of such storms anywhere in the world still remains very much a rarity. In the Australian region this is compounded by our sparsely populated coastline, limited instrumentation resources and the temporal and spatial vagaries of these massive storms. When such a storm does stray into our fragile surveillance net it generates enormous interest. When that storm happens to be not only the most severe ever recorded in the Australian region but amongst the most severe worldwide, it forces a careful reappraisal of the accuracy of predictive techniques which have previously been (unavoidably) calibrated on much more common and relatively benign events. This paper examines the impact of severe Tropical Cyclone *Orson* in this light.

2. BACKGROUND

Tropical Cyclone *Orson* began as a poorly organised cloud area on 17 April 1989 in the eastern Timor Sea (Ref 1). In a late development to the season, it appears to have been the result of a "non-symmetrical twins" genesis whereby a northern hemisphere storm was simultaneously generated in the vicinity of Guam. It was officially named at 3pm WST on 18 April, at about the time several Indonesian fishing vessels sunk in the vicinity of remote Ashmore Reef with the loss of at least 4 lives. In the next 12 hr the storm moved steadily westwards (refer Figure 1) and the remote Automatic Weather Stations (AWS) at Scott Reef, Browse Island and Adele Island provided confirmation of gale force winds in the region.

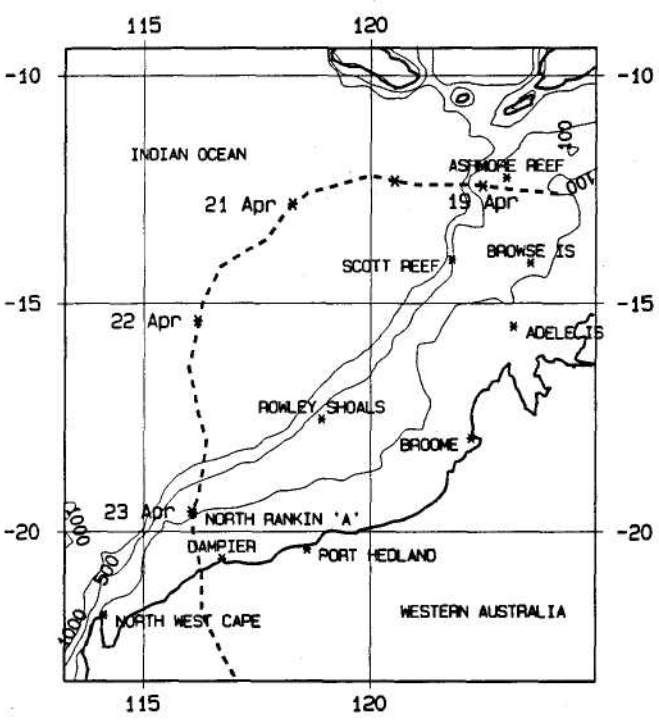

Figure 1 - Locality and Storm Track

Orson continued to intensify and formed an eye visible to satellite imagery from 20 April onwards. Over the following two days the storm began to recurve, shifting southwesterly and then southerly and continuing to both intensify and increase in forward speed. By this time, in spite of the vast oceanic region through which it traversed, the storm was headed directly for the small isolated man-made island which is the North Rankin 'A' (NRA) gas production platform some 130km offshore in 125 m depth, northwest of Dampier. Not long after midnight at 12:30am WST on 23 April the exact storm centre is estimated to have passed 4km west of the platform, which experienced the passage of the eye region for about 40 mins. The platform instrumentation recorded the lowest MSL central pressure on record in Australia of 905 hPa. The storm continued its southerly track and crossed the coast near Cape Preston four hours later. *Orson* was severity category 5 on a scale of 5.

3. A WORTHY "DESIGN" STORM

immediately nicknamed "awesome *Orson"* by those who felt its fury firsthand, its legacy is a wealth of data which continues to yield valuable technical information. Fortunately for the north-western coastal settlements its direct impact was slight in terms of structural damage and there was no loss of life. NRA production platform, operated by Woodside Offshore Petroleum Pty Ltd, was also secure following the storm but suffered extensive superficial damage; the structure was designed to resist just such an event as *Orson.* However, the recollections of the 100 or so personnel who remained onboard after the last of the non-essential workers were evacuated by helicopter and emergency standby vessels headed for safer waters, presents a sobering picture (Ref *2) ...*

> ***"... the platform was literally rattling, knives and forks fell to the floor in the mess room and many good reputations floundered at the pool table as eight balls rollicked around the green cloth with seemingly little regard for the laws of physics. To our great relief the barometric pressure bottomed out at 905 hPa. The mad rattling and howling had stopped, leaving the platform swaying eerily underfoot ... a purple curtain shrouded the platform lit by neon flashes of lightning. Huge swells rushed around in all directions but not a breath of wind ... and then it started again. "***

Whilst the platform itself was intact it would be some weeks before the full effects of seabed scouring along the gas pipeline to shore would be assessed, resulting in remedial stabilisation works.

Orson's place in history is exemplified in Table 1 where a selection of past prominent storms shows that at 905 hPa it ranks amongst the most severe recorded — an obvious close cousin of the infamous *Hurricane Camille* which devastated the US Gulf Coast in 1969. The limited measurements available from some offshore platforms there (and the damage they suffered) served to underpin the standards for US (and much of the world's) offshore design practice over the past 24 years. Likewise the yield of data from *Orson* provides a valuable update and a critical second glimpse at the characteristics of such storms whose rarity places them towards the upper limit of any return period analysis — the class of the "design" storm.

4. THE YIELD OF INFORMATION

Throughout its development, *Orson* presented a relatively uncomplicated track to meteorologists. The available satellite imagery was particularly clear and valuable while coastal radar provided good coverage as it moved southwards. In addition to various ship reports and the critical information relayed from NRA, a number of sea and land-based anemometer sites contributed to a relatively good yield of useful meteorological data. Unfortunately no aircraft reconnaissance was available.

Table 1 - Some Notable Tropical Cyclones

Name	Central Pressure (hPa)	Year	Place
Tip	870	1979	NW Pacific
"Labour Day"	892*	1935	Atlantic
Allen	898	1980	Atlantic
Orson	905	1989	WA
Camille	905	1969	Atlantic
"Bathurst Bay"	914*	1899	QLD
Joan	915	1975	WA
Amy	915	1980	WA
Hugo	918	1989	Atlantic
Andrew	922	1992	Atlantic
Trixie	925	1975	WA
Carla	930	1961	Atlantic
"Mackay"	940	1918	QLD
Emily	945	1972	QLD
Tracy	950	1974	NT
Althea	952	1971	QLD

(*Est)

Whilst not immediately appreciated by those who weathered the storm on NRA, it was fortunate from an engineering point of view that the storm passed so close to the platform. The onboard monitoring systems provided continuous output and recording of atmospheric pressure, wind speed, air temperature and humidity — at least up until various sensors failed. Accelerometer signals and strain guages were also logged from a number of locations over the structure. Nearby the platform a Datawell Waverider monitored wave conditions and a string of four acoustic vector averaging current meters was deployed together with a bottom mounted tide recorder.

Table 2 summarises the peak atmospheric and ocean conditions recorded by these sensors. The severity of the storm took its toll however — the waverider lost radio contact prior to the peak of the storm and broke its mooring. Of the twin anemometers, one survived only to the first passage of the radius to maximum winds while the other failed as the eye wall passed once more. Three of the four internally recording current meters survived together with the tide recorder, but the entire mooring was dragged several kilometres off station. Estimates of the peak wave height were fortunately gained as a result of maintenance works which were being planned beneath the production deck level (+ 23 m MSL). This work required extensive temporary support scaffolding and access stairways and these acted as crude but effective passive wave staffs, giving an estimated maximum single wave height of approximately 20 m. In addition to the instrumented yield, a video record was also obtained of the storm build-up and subsequent minor damage to the structure.

Table 2 - Peak Measured Parameters at NRA

Waves:	Hs	8.8	m
	Tp	7.7	s
	Tz	9.1	s
Winds:	Vmean	45.6	ms^{-1}
(+10m MSL)	V3sec	55.9	ms^{-1}
Currents:	U-15m	1.21	ms^{-1}
	U-70m	0.78	ms^{-1}
	U-100m	0.68	ms^{-1}

5. THE HINDCAST CHALLENGE

When a storm such as *Orson* seemingly threatens a major man-made facility like NRA the natural question asked of the ocean engineer is *"How well do your predictive models work for this storm?".* It is axiomatic in the development of simplified models of the real world that simplifying assumptions must be made, but it is storms such as *Orson* which provide the vital opportunity to test the range of validity of model assumptions and extrapolations out to the actual level of serious structural threat.

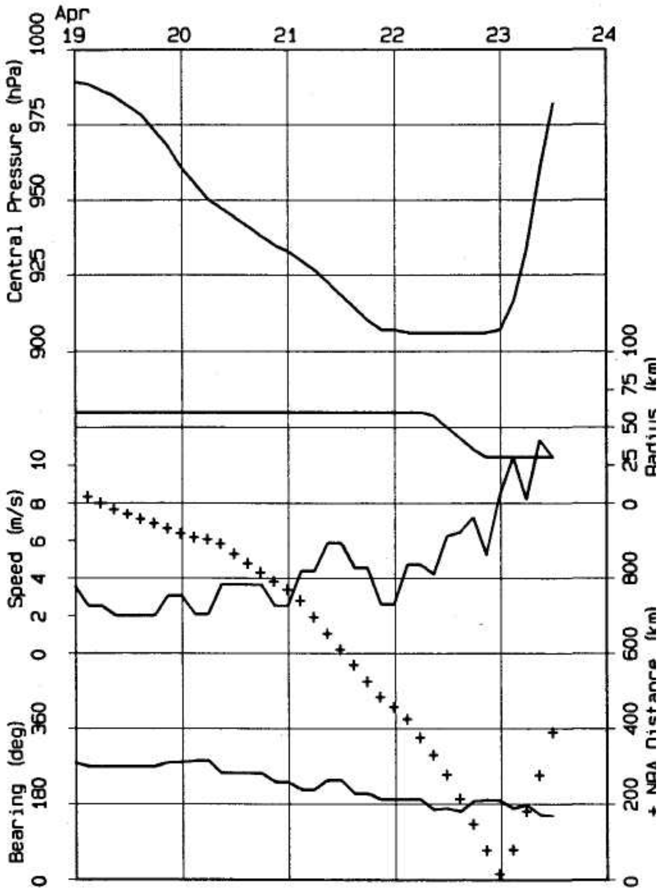

Figure 2 - Storm Parameter History

5.1 The Pitfalls

One of the initial drawbacks relates to the quality and quantity of measured data — there remain some alarming deficiencies in the data set, mainly due to instrument failure. These are issues which result ultimately in subjective judgements — even ignoring the total lack of any other supporting offshore data in the region.

The major traditional unknown in the Australian region is the meteorological detail of the storm. Again, the remote coast and wide oceanic region works quite naturally against a closely knit array of meteorological stations of the type afforded in more bounded and populated regions such as the Gulf of Mexico. The absence of aerial reconnaissance also means that much greater reliance is placed on satellite imagery.

The official Bureau of Meteorology intensity and track values have been used in this assessment together with available estimates of radius to maximum wind based on radar. The time development of these are presented in Figure 2 together with the storm distance from NRA.

5.2 Representation of the Surface Wind and Pressure Fields

Following extensive studies of some 28 separate tropical cyclones across 74 anemometer sites, both offshore and onshore, in the North West Shelf (NWS) region (Ref 3), detailed calibrations have shown the Holland (Ref 4) model has the ability to reliably represent the surface wind and pressure profiles of such storms. In addition to the base use of such a model, which is greatly simplified and largely empirical, there are a number of other issues which need to be considered. These include the influence on the vortex of storm forward speed, which contributes to its asymmetry, frictional inflow angles and the development of the atmospheric boundary layer in tandem with the sea surface roughness.

The results of applying such a model at NRA are shown in Figure 3a, which compares the calibrated Holland wind field model with the recorded 10 minute mean wind speeds (adjusted to +1 Om MSL), as well as direction and MSL atmospheric pressure. While this shows a quite spectacular matching at a single point, the corresponding accuracy at seven other anemometer sites is also impressive. Considering that these fits are based on objective Bureau estimates (interpolated half-hourly) and were obtained through the tuning of a single parameter (the wind profile peakedness) **and** the partial tuning of radius to maximum winds, it is reasonable to conclude that this is an area of prediction which, if properly carried out, could be regarded as highly accurate in spite of the model assumptions made.

Figure 4 presents a plan view of the estimated wind speed pattern in *Orson* at a time when it was approaching NRA, at a spatial resolution of 10km. A peak mean wind speed of 55.2 ms' is indicated, located approximately 40 km NE of NRA at this time.

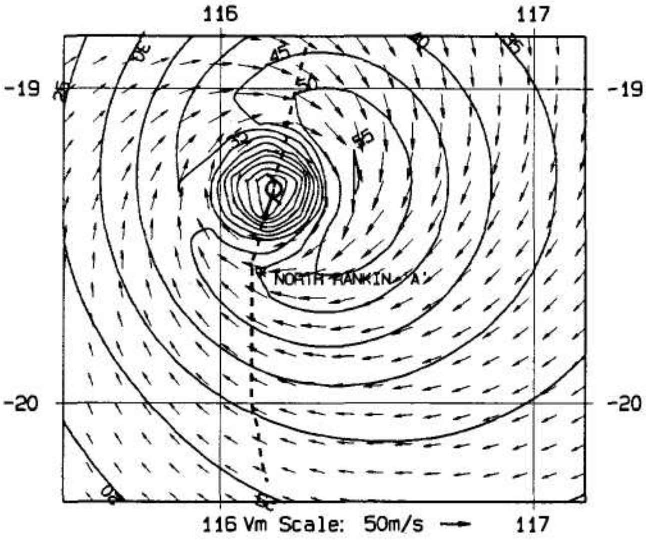

Figure 4 - Predicted +10m MSL Mean Wind Field

5.3 Modelling the Surface Wave Field

This has always been a challenging area for modellers and especially so because of the rapidly changing fetch lengths and directions associated with the moving vortex and the spatially and temporally changing wind strength. Only with the development of discrete spectral models in the late 1970s did this problem become tractable, and even then it was somewhat limited in a practical sense by the available computing power. The 2nd generation model after Sobey and Young (Ref 5) has been used successfully on the NWS since 1981 in a variety of deep and shallow water studies.

For the present example the model was run in a three stage nested numerical grid system of 60 km, 30 km and then 10 km spatial resolution. This provides the essential balance between widespread early fetch development and fine scale wind speed and direction gradients close to the storm centre. Each separate grid result was used as boundary information for the finer subgrid in a series of decoupled simulations. A directional resolution of 22.5° and a 10 band frequency resolution were used, with a final solution timestep of 15 minutes. There was no tuning of wave model parameters.

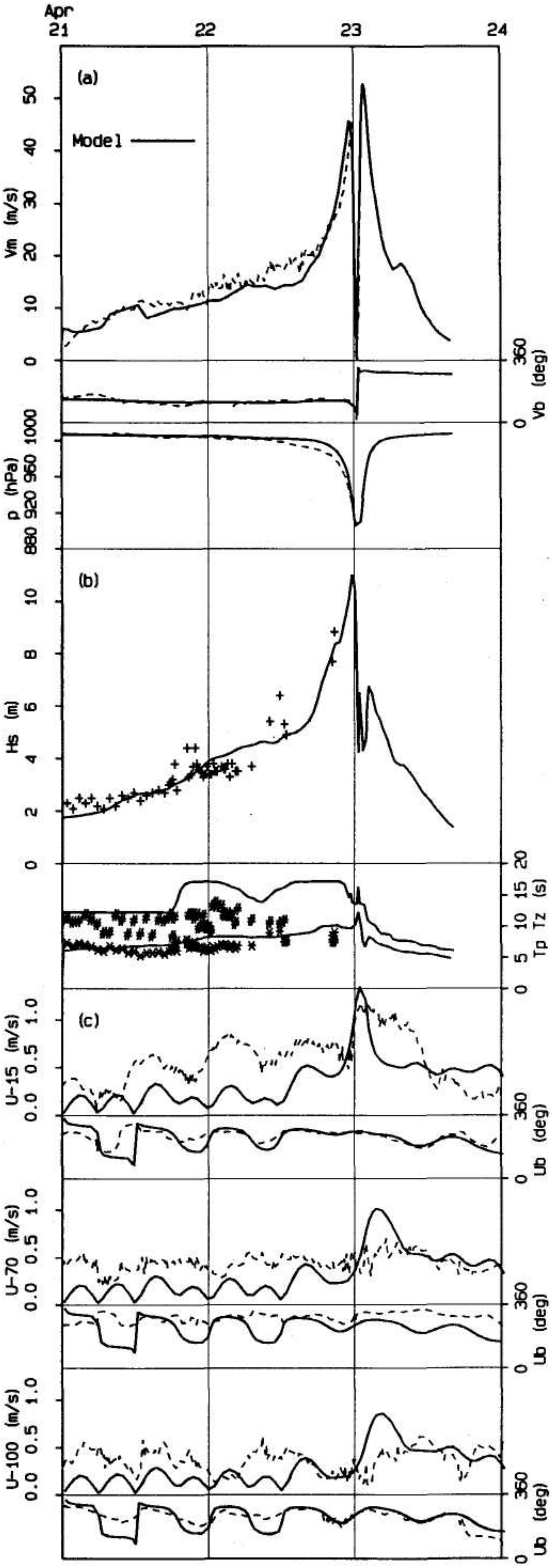

Figure 3 - Time History Comparisons

The results from the wave model at the NRA location are presented in Figure 3b together with the measured wave data until the time of buoy failure. In spite of the lack of data at the peak, the faithfulness of the comparison is compelling in the case of significant wave height Hs. Of further interest is the estimated maximum wave height which, based on a peak Hs of 11 m, suggests an Hmax of 18 to 19 m (Ref 3). Allowing for wave runup and short-crested interactions within the jacket structure, this compares well with the estimate of 20 m based on damage assessment. Also shown are the time histories of measured and modelled peak spectral period Tp and mean zero crossing period Tz. Here the model appears less accurate, generally overpredicting each parameter, although Tp (the higher) is sensitive to the model frequency resolution. Space here does not permit examination of the spectral wave forms nor the statistical makeup of individual waves but the data has considerable potential benefit for design.

Figure 5 presents the plan view of Hs contours, mean energy direction and Tp consistent with the wind field of Figure 4. This view shows the very high gradients of wave height at this time, which exemplifies the accuracy of the combined wind and wave model in reproducing the measured responses. A complex trailing "wake" region is also predicted. The model predicts a peak Hs of almost 15 m at this time, again some 40 km NE of NRA.

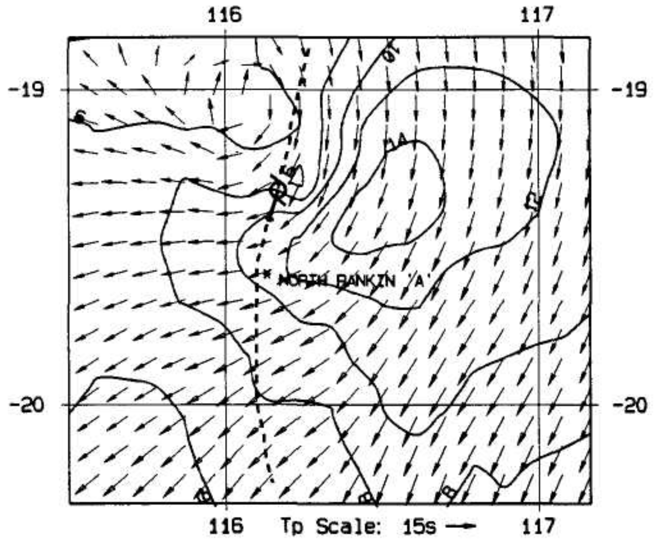

Figure 5 - Predicted Significant Wave Height Field

5.4 Modelling the Current Field

The NWS is known to exhibit complex current behaviour; the tidal influence is strong, background drift (including the Leeuwin Current) is pronounced and the intense solar radiation develops a strongly stratified vertical structure in summer months. The combination of the above in association with the shelf geometry is known to excite strong and persistent internal tides which are imperfectly correlated with the surface tide. This makes even separation of the various current components a difficult analysis task. The superposition of severe wind forcing from a tropical cyclone induces even more complex dynamic behaviour which can be very site specific. The consequences for structural design of fixed jackets and flexible risers are that vertical current profiles can be highly variable in space and time and near-bottom currents affecting pipeline stability can become very severe.

Currents have been modelled here using a three-dimensional (3D) free surface hydrodynamic model based on the extension of an existing 2D model (Ref 6) which uses an implicit splitting scheme, thus permitting long time steps. It uses sigma depth coordinates (terrain following) and has a homogeneous density structure. The latter assumption precludes representation of the complex internal (baroclinic) tides in this case but their *accurate* prediction is considered beyond present state-of-practice. Other features of this model include quadratic bottom friction, nonlinear horizontal advective momentum terms and a constant vertical eddy viscosity. The horizontal resolution is 5 km; ten levels are specified in the vertical. In addition to the surface forcing derived from the Holland model, the coexisting astronomical tide has also been included and accurately calibrated against both coastal and offshore elevation data. The model results are compared with the measured data in Figure 3c. This illustrates the difficulties in computing extreme storm currents, particularly where pre-existing internal tides followed by vigorous surface mixing contribute significantly to the motion. The first obvious difference between data and the model near the sea surface (U-15) is the peaked nature of the model response. The data also show a 0.2 ms^{-1} background drift and a definite ramping-up in the measured currents (modulated by tidal oscillations) in the two days preceding the storm. As well as a sharper response, the peak modelled currents exceed the measured values. To a large extent this is controlled by the selection of the constant vertical eddy viscosity of 0.1 $\mathrm{m}^2\mathrm{s}^{-1}$ which parameterises the vertical flux of horizontal momentum through the water column due to turbulence. The narrowness of the modelled peak response may be linked to the slight but general underprediction of wind speed during 22 April translating into a loss of surface stress.

At the deeper meters, the only evidence of the storm passage is a general increase in current strength and the generation of an inertial oscillation. This latter effect is linked to the relaxation of colder near-bottom waters which have been forced up the shelf slope by Ekman pumping and are evident in the velocity data for several days following the storm. The extreme complexity of these motions ensures that the prospects of modelling them accurately will continue to remain a major challenge.

Figure 6 displays the modelled *surface* currents analogous to the previous plan views of winds and waves. It can be seen that NRA is again about 40 km from the predicted peak value of 2.5 ms"\

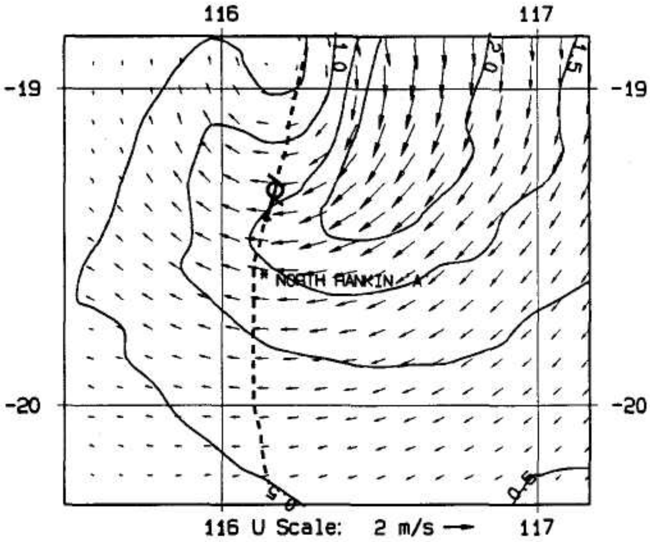

Figure 6 - Predicted Surface Current Field

6.0 CONCLUSIONS

Tropical Cyclone *Orson* and its close approach to NRA represents one of the most valuable offshore data sets available for the development and calibration of numerical models of winds, waves and currents. The data exist as a result of the practical commitment by industry, the foresight of the engineering profession and an element of luck. Long term ocean data collection is an expensive and painstaking activity which demands constant, justification, especially in times of fiscal restraint. However, the reward is incalculable in terms of not only the rare yields such as *Orson* but the steady accumulation of high quality physical data. In pace with increasingly challenging offshore design needs, models need to grow in sophistication and accuracy and the value of long-term high-quality data sets is then realised. This is the message for management.

The failure of a number of industry standard instruments gives much cause for concern. Moorings may need special attention beyond manufacturer specification in these very steep seas; power supply failures both offshore and onshore resulted in significant data losses. These systems require special consideration in their design and maintenance to ensure survival.

In terms of modelling, the major challenge for deepwater sites presently relates to the prediction of extreme currents. Higher order turbulence closure schemes need to be adopted to replace simplified eddy viscosity parameterisations. There is still room for improvement in the representation of wind fields, especially in association with significant synoptic influences. The oceanic boundary layer and resulting surface stress require more effort; the separate coupling through wave and current models is a critical element which has historically travelled separate development paths but now needs addressing. Finally, all modelling continues to benefit from the availability of increased computational power allowing more complex algorithms and finer resolutions.

Increasing confidence in the accuracy of deterministic modelling of this type can open the way to more sophisticated treatment of the stochastic processes which comprise the overall environmental loading risk on engineering structures. The application of joint-probability analysis of winds, waves and currents is now becoming a justifiable basis for the reduction of design loadings; further model developments should ensure its routine application.

7.0 ACKNOWLEDGEMENTS

The authors wish to thank the management of Woodside Offshore Petroleum Pty Ltd and the North West Shelf Joint Venture Participants for permission to publish the measured data in this paper. The Participants in the NWS Venture are Woodside Petroleum Ltd (through subsidiaries), BHP Petroleum (North West Shelf) Pty Ltd, BP Developments Australia Ltd, Chevron Asiatic Limited, Japan Australia LNG (MIMI) Pty Ltd and Shell Development (Australia) Pty Ltd. Special thanks also to Stan Stroud, Chief Ocean Engineer for Woodside Offshore Petroleum Pty Ltd, and Bureau of Meteorology personnel Gary Foley, Supervising Meteorologist Perth, and Greg Holland, Principal Research Scientist BMRC, for their cooperation.

8.0 REFERENCES

1. Bureau of Meteorology, "Report on Cyclone Orson - April 1989", June, 1992.

2. Woodside Offshore Petroleum Pty Ltd, "Woodside News", Vol 4, No 3, June 1989, p5.

3. Harper B A, "Wanaea Hindcast Preliminary Studies", Report prepared for Woodside Offshore Petroleum Pty Ltd, PPK Consultants Pty Ltd, 1992.

4. Holland G J, "An Analytic Model of the Wind and Pressure Profiles in Hurricanes", Monthly Weather Review, Vol 108, 8, Aug 1980, pp 1212-1218.

5. Sobey R J and Young I R, "Hurricane Wind Waves - A Discrete Spectral Model", J Waterway Port Coastal and Ocean Engin, ASCE, Vol 112, 3, May 1986, pp 370-389.

6. Bode L and Mason L B, " Application of an Implicit Hydrodynamic Model Over a Range of Spatial Scales", Proc. CTAC93 Conf, Canberra, 1993.