

# Advances in Swell Prediction for Australia's North West Shelf

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Greg Williams and Steve Buchan

RPS MetOcean Pty Ltd

38 Station Street, Subiaco, WA, Australia 6008

Phone +618 92111111

## Abstract

The Pilbara region in North West Australia is already the largest producer and shipper of iron ore in the world, and tonnages are projected to grow. Also, Australia's North West Shelf region is scheduled to surpass Qatar as the world's largest producer of LNG by the year 2020.

One of the constraints on iron ore exports from North West Shelf ports, is underkeel clearance for the long shipping channels associated with each port. Improved forecasts of swell will reduce the underkeel clearance allowance – directly increasing productivity.

The offshore Oil & Gas industry is also significantly affected by swell – both ambient conditions dominated by swell from the Southern, Indian and even Atlantic Ocean basins (affecting floating facility operability, LNG carrier underkeel clearance, side-by-side LNG product transfer and fatigue loadings) and tropical cyclone generated swell (affecting facility survival, riser disconnect/reconnect windows, LNG loading windows and requirements for post-storm inspections).

Both these industries, and the Port Authorities and Government instrumentalities which support and regulate them, would benefit from improved site-specific swell forecasting – both in terms of accuracy, and the extent of forewarning.

RPS MetOcean have developed a sophisticated swell prediction system comprised of automated cyclone track assimilation and advanced cyclone wind blending, the latest release of WaveWatch III supporting moveable grids and highly tuneable wind-forcings and physics, and a calibration system based on remote-sensing and near-realtime measurement networks.

In this paper we describe the key elements of the system, demonstrate the improvements and performance of the wind field blending and swell prediction components in a variety of tailored forecast and early-warning services, and discuss the applicability of the swell prediction system to similar regions worldwide.

## Background

In 1992, RPS MetOcean implemented a measurement-based near-shore tropical cyclone swell prediction system for Woodside Energy Limited, to assist them in safer management of their shipping channel from the Mermaid Sound LNG loading berth on the Dampier coast of Western Australia.

The system, known as the Remote Offshore Warning System (ROWS), is deployed every tropical cyclone season, and is recovered and refurbished during the winter. It comprises an array of meteorological and waves buoys which feed data into a reverse ray wave refraction model to forecast swell arrival times and heights in Mermaid Sound. The required forewarning time for completion of LNG carrier loading and exiting the shipping channel is 4 hours, making such a measurement-based system viable.

At the time of inception, this system was world-leading in providing accurate tropical cyclone swell forecasts in confined near-shore conditions. Modelling alone could not achieve the requisite accuracy – principally because of the difficulty in simulating tropical cyclone swell generation. HF radar was also trialled, but was range-limited, and could not achieve the necessary lead times.

## The Opportunity

The present ROWS is well-suited to its present site-specific application, and limited forecast lead time of only 4 hours.

However, consideration is now being given to new types of LNG carriers which would require longer lead-times for safe loading. This is not achievable with a measurement system coupled only to a wave refraction module.

In addition, there are emerging requirements for similar swell forecasting systems to improve the safety and efficiency of

- new LNG export facilities
- existing and planned floating production facilities
- increased iron ore shipping
- transshipment shuttle operations at nearshore loading zones
- general port operations

on Australia's North West Shelf.

Operating fleets of very-large crude carriers, larger LNG tankers, the premier of the world's largest FLNG facilities, and international Cape-size bulk-ore carriers are also sensitive to long-range swell – which arrives on the North West Shelf of Australia from remote ocean basins after 5-7 days in transit (Figure 1).

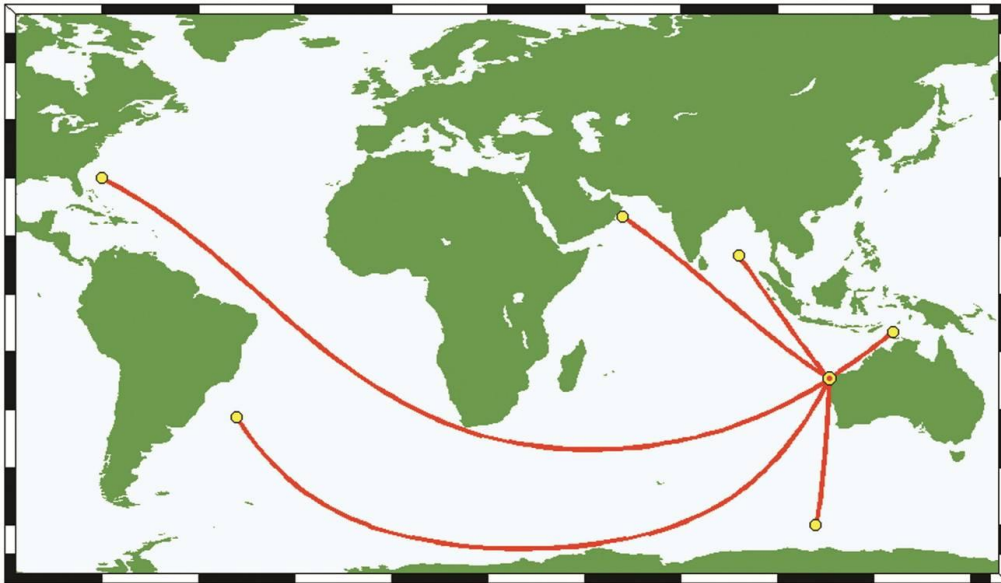


Figure 1 - Remote swell arrivals to the North West Shelf of Australia.

These increasingly demanding requirements, coupled with improvements in modelling capability, mean that it is timely to consider a new means of provision of accurate, long lead-time site-specific swell forecasting, for a range of applications.

## Concept

RPS MetOcean's vision is for a multi-client service providing accurate, reliable swell forecasts for at least 24 hours lead time, for a range of client-specified locations on the North West Shelf, with tailored products to facilitate a range of different applications.

We have established automated ingestion of

- NCEP global forecast products (winds, pressures, ice coverage etc)
- satellite altimeter and scatterometer data
- tropical cyclone track forecast data
- measured real-time meteorological and wave data

for use in swell forecasting.

Our model of choice is the mosaic grid version of NOAA's WaveWatch III, with a moving nested grid to accommodate tropical cyclone forcing, and nested coastal grids to support appropriate nearshore physics and bathymetry refinement.

The latest generation of data assimilation and forecast modelling systems exhibit varying degrees of skill in predicting cyclogenesis and storm intensity and movement, but rarely capture tropical storm position and structure (and therefore available energy) as well as specialist tropical meteorologists using consensus model guidance, radar and satellite remote-sensing, and subjective methods and experience. Whenever a cyclone exists as the dominant feature in the wind forcings, depicting its

size, shape, and true location is critical in correctly predicting the magnitude and directionality of resulting swell energy.

In our system, tropical cyclone wind fields are automatically generated from official WMO advisories via a heavily calibrated parametric single vortex model, which is melded with the synoptic NCEP winds (Figure 2) using a sophisticated blending process (Foster et al., 2009). The resulting wind forcings are high-resolution regional grids in which the position, structure, intensity, and influence of the storm has been restored to produce a coherent sea state (Figure 3).

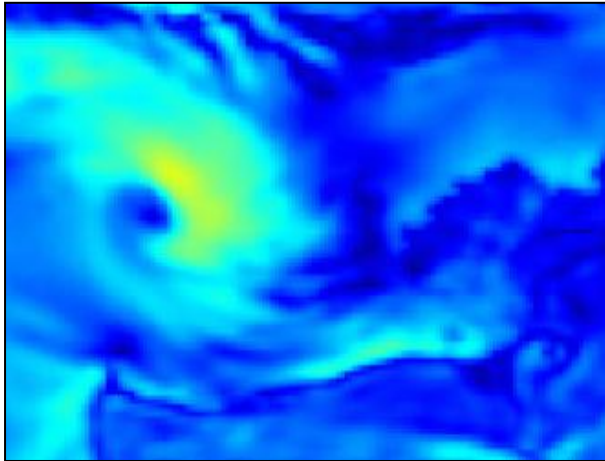


Figure 2 – Raw NCEP wind fields from synoptic scale model.

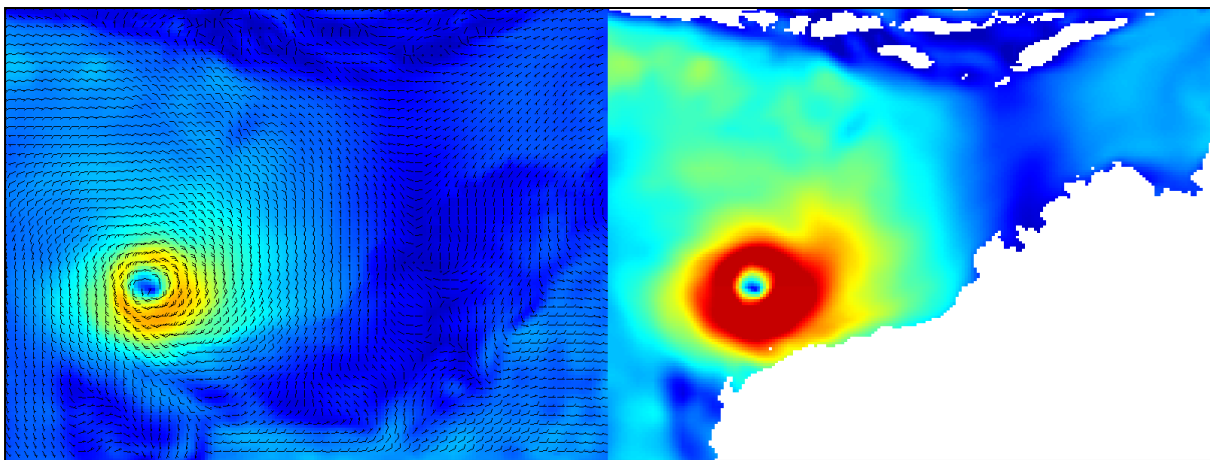
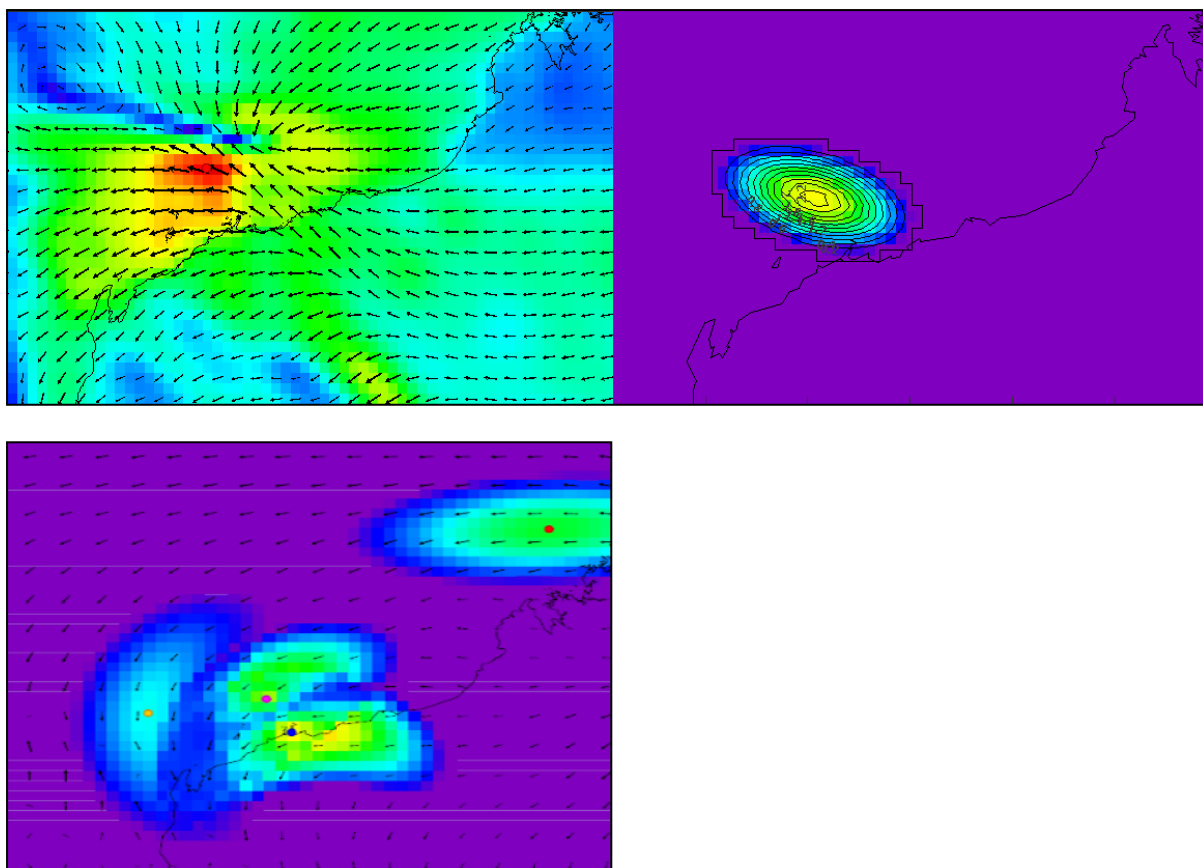
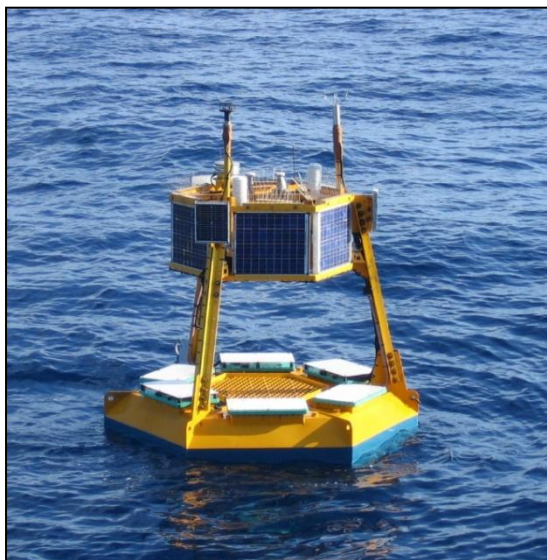


Figure 3 – High-resolution blended wind field (left) and resulting WaveWatchIII swell field (right).

During wave model initialisation, spinup, and runtime data-assimilation, synoptic wind fields and associated wave fields are ‘nudged’ towards remote-sensed and measured real-time data over a prescribed ‘neighbourhood of influence’ (Figure 4). These data are derived from an array of meteorological and directional wave buoys that have been purpose-developed by RPS MetOcean (Figure 5) and deployed in long-running measurement programmes across the North West Shelf. Remote-sensing from space-borne altimeter and scatterometer missions improve the accuracy of long-period swell while marine wind observations improve the accuracy of short-fetch swell impacting nearby operators and sites within the network.



**Figure 4 - Observational nudging using objective analysis techniques.**  
The influence of a single offshore wind measurement (top panels) and multiple metbuoy observations (bottom left).



**Figure 5 – Purpose-built RPS directional wave and met buoy.**

Forecast products can be further refined (post-calibrated) via reference to any available measurement data. This includes the use of wave measurements to calibrate spectral wave predictions at coastal and offshore operational locations. The range of presently available marine real-time data ingestion sites is illustrated below (Figure 6). Additional terrestrial wind observations



are available via the WMO Global Telecommunications System (GTS) and can be used where necessary to improve coastal coverage.

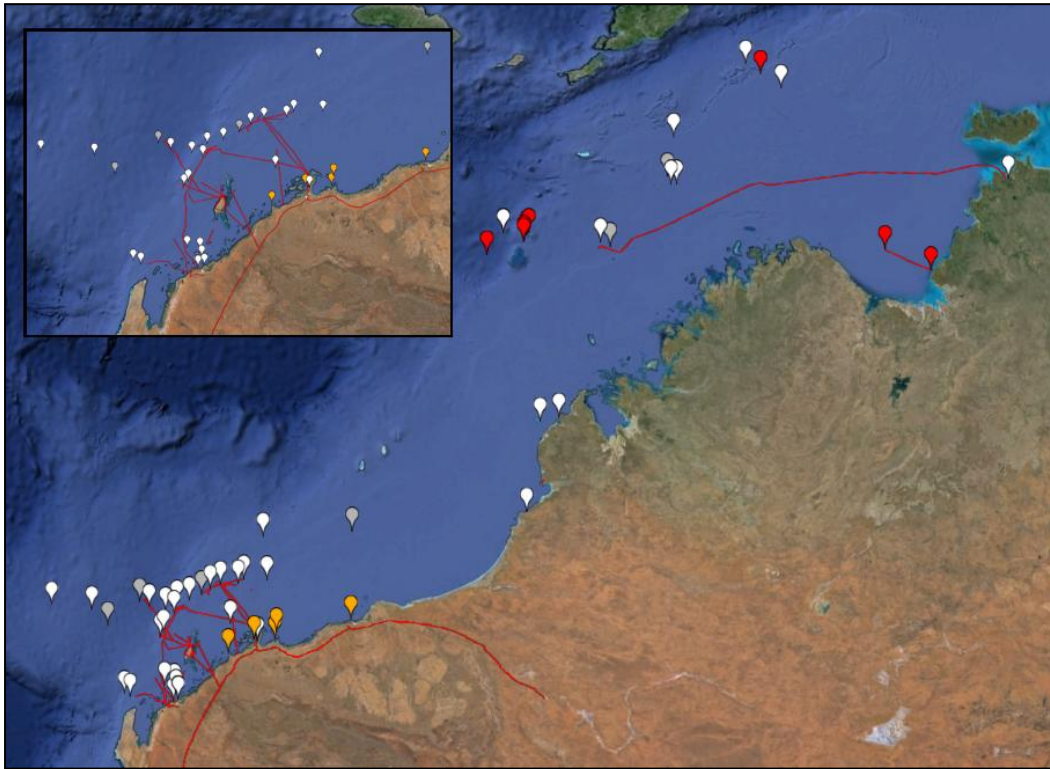


Figure 6 - RPS North West Shelf Measurement Network

All products are available for automated dissemination and visualisation via a web-based system, or by a range of other tailored data delivery systems.

## Products

The RPS swell prediction system is a flexible global infrastructure, with initial product lines providing 'swell-focused' services coupled with the refinement and confidence of realtime measurement networks. Existing services and applications include:

- Tropical cyclone swell alerts and notifications
- Swell inputs for Under Keel Clearance computations in ports and channels
- FPSO disconnect/reconnect forecasting
- FLNG side-by-side unloading operability forecasting
- Structural and operational limit-exceedence forecasts and alerts
- Management of berth occupancy and optimisation
- Vessel motion assessments, operational forecasts, and planning products
- Assessment of heave, pitch, roll motions of offshore drilling and installation facilities
- Loading response forecasts for ore carriers in mooring and loading zones
- Mooring line strain measurements and fatigue forecasts

## Performance

A demonstration of the improved performance of the locally tuned WaveWatch III model, is provided by the simulation of the swell which resulted in the well-documented failure of the reconnection of the Nghanhurra FPSO at Enfield location off the southern North West Shelf.

Figure 7 illustrates the event, the prevailing modelled swell conditions, and a time history plot comparing the tuned model with the results of the global implementation of the NCEP WaveWatch III model. In this figure, the blue line is the NCEP forecast, while the red, purple and yellow lines represent the total, primary and secondary swell trains, respectively, from the tuned model. The tuned model accurately predicted the arrival time of the long period swell (which caused the winch wire breakage) 6 hours earlier than predicted by standard forecasting and the global modelling.

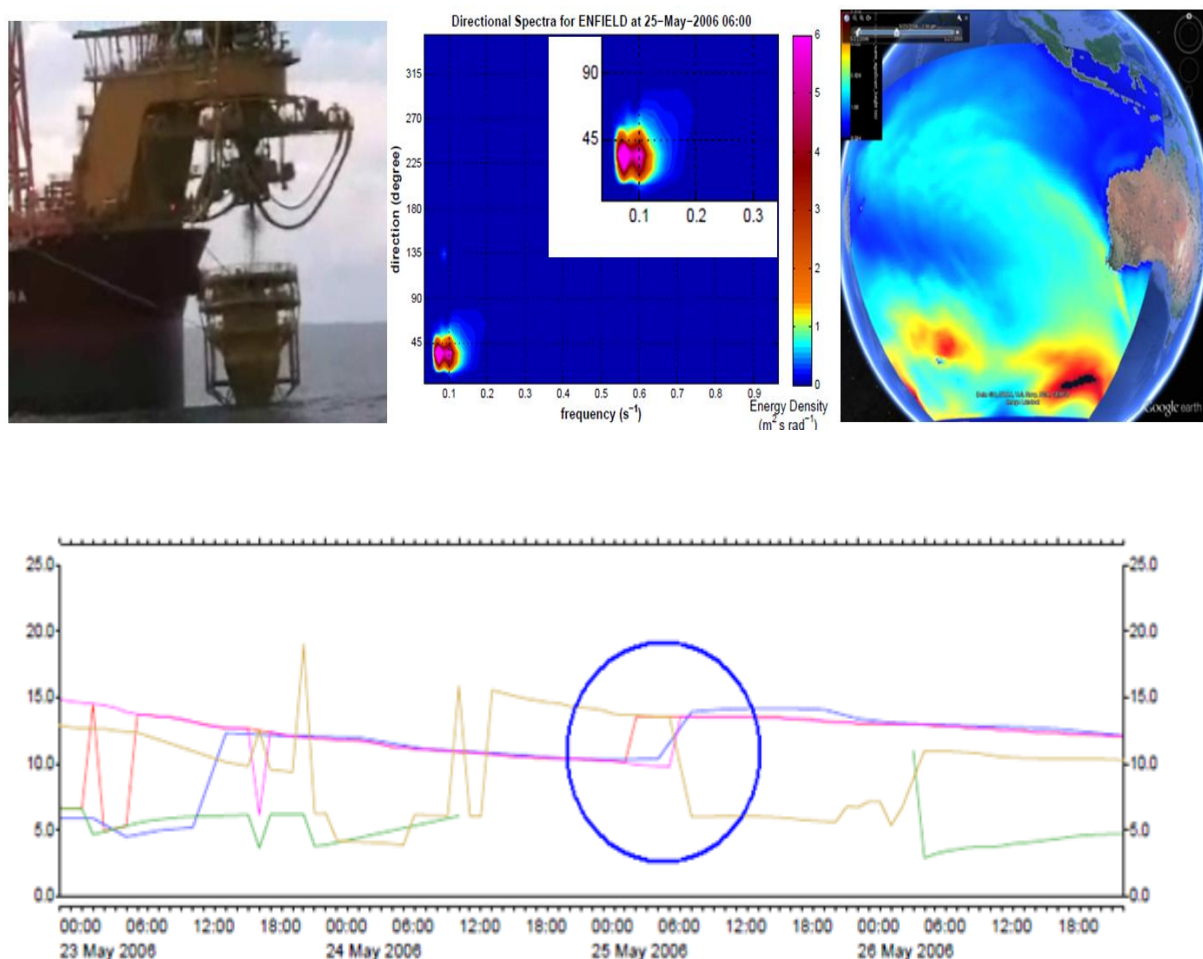


Figure 7 - Enfield location - NCEP operational wave model against RPS wave model. RPS configuration predicts arrival of long-period swell. Peak period switches to long-range swell.

The efficacy of the tropical cyclone wind field parameterization and subsequent blending, is illustrated in Figure 8, which shows a correlation of peak modelled versus measured wind speeds for all reliable marine measurements of tropical cyclones on the North West Shelf. The slope is effectively 1, and the correlation coefficient is high.

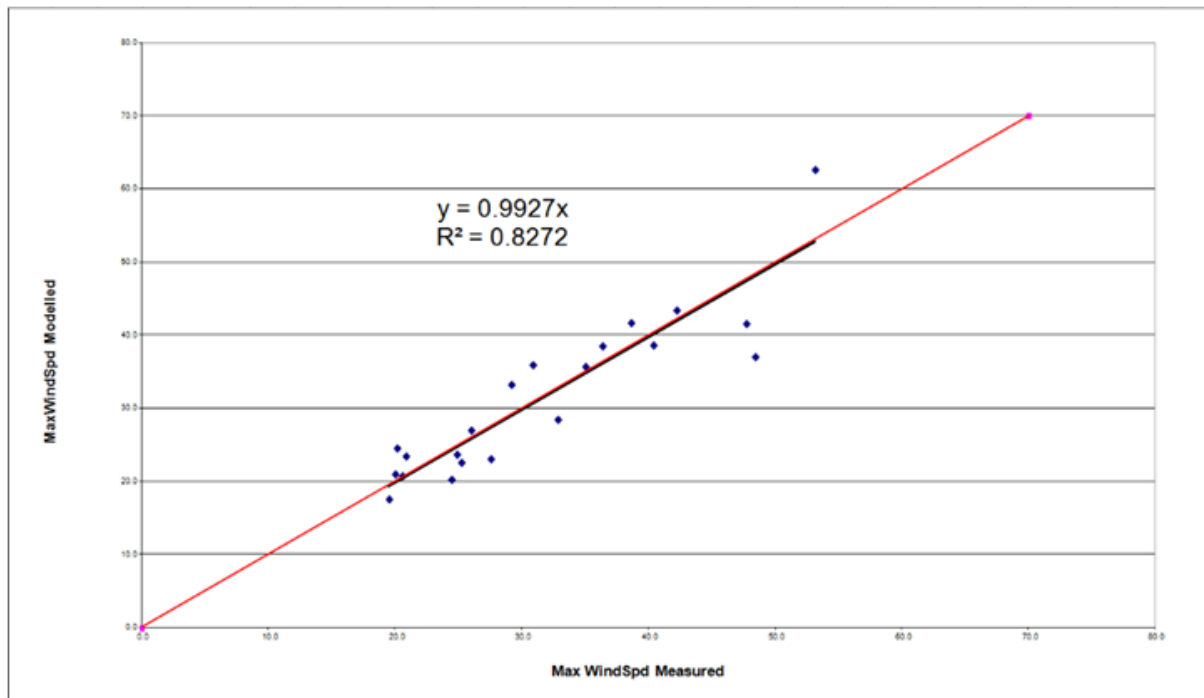


Figure 8 - RPS wind blending performance. Peak-to-peak comparisons against 30 years of Australian tropical cyclones.

The effectiveness of the wind field blending process is illustrated by the modelled versus measured overlay timehistory for tropical cyclone Olwyn winds at Learmonth, shown in Figure 9.

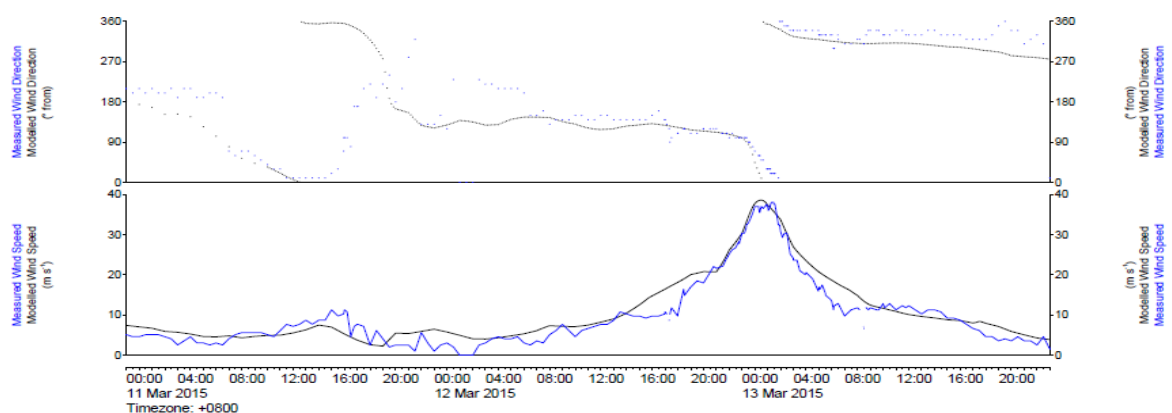


Figure 9 - TC-Olwyn blended winds compared against measurements at Learmonth.



The improved accuracy of the tropical cyclone wind field representation carries over to the subsequent wave field simulation, as illustrated in Figure 10, which provides a correlation of peak modelled versus measured waves for all reliably measured severe tropical cyclone seastates on Australia's North West Shelf.

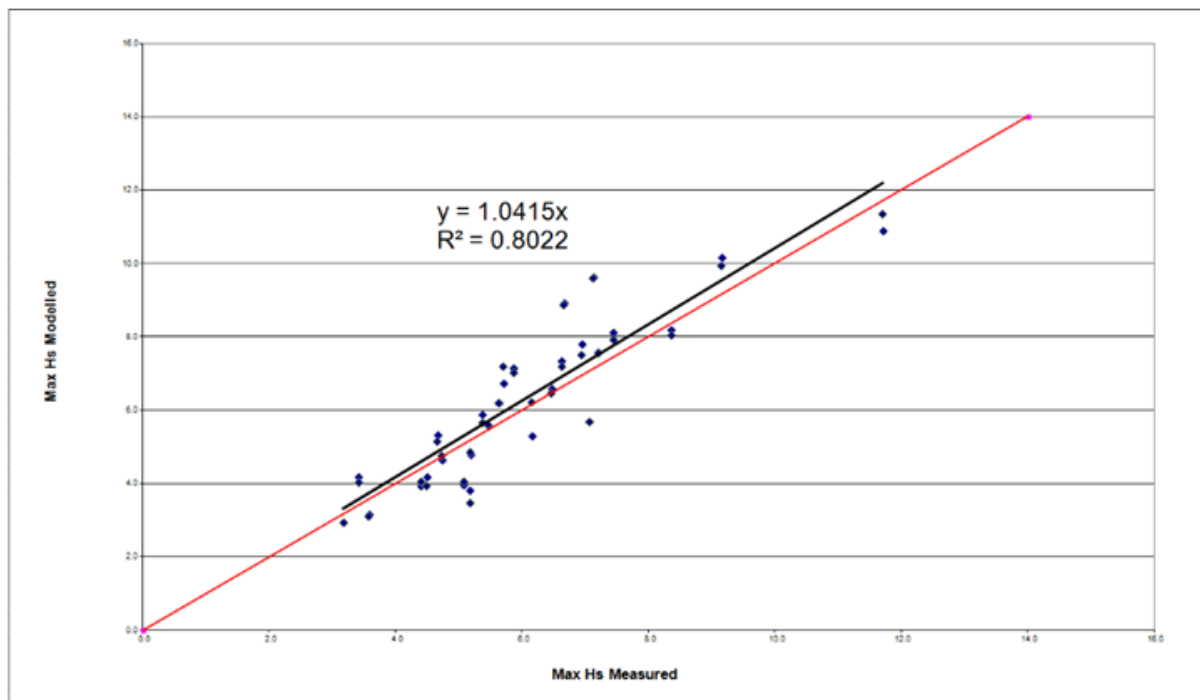


Figure 10 - RPS wave model performance. Wave height comparisons against 30 years of Australian North West Shelf tropical cyclones.

The slope of the correlation remains very near 1, and the correlation coefficient remains high – though there is (understandably) a little more scatter about the fitted line.

## Portability

The basic inputs for the Swell Forecasting System are available globally, so the service can be set up for any region (or project) in the world. What will vary is the scope of remote and in-situ real-time measurement systems, which can be used to improve the forecast system.

By accurate mapping of the source region of prevailing swell at any particular location of interest, we can access global databases of satellite measured winds, to effectively tune global modelled wind fields for any basin. An example of the back-tracing of dispersive swell paths for North West Cape is provided in Figure 11.

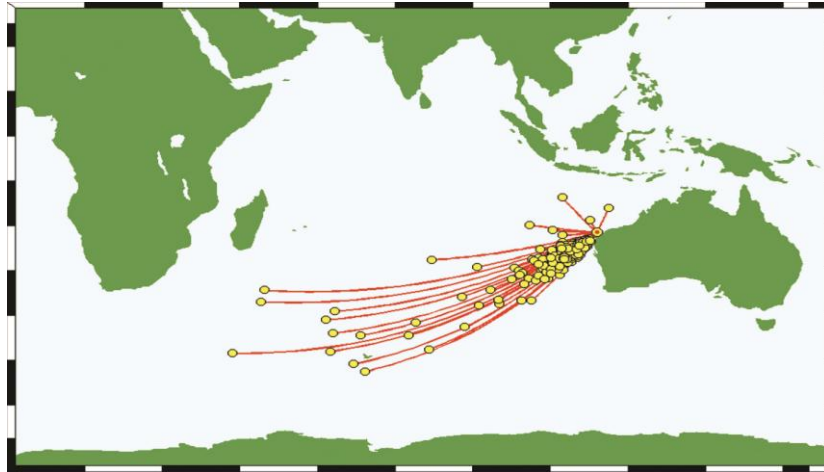


Figure 11. Back-tracing of dispersive swell arrivals at North West Cape, for 455 events identified from 2006 to 2008.

Examples of simulations of recent wave events in various ocean basins, are provided in Figure 12.

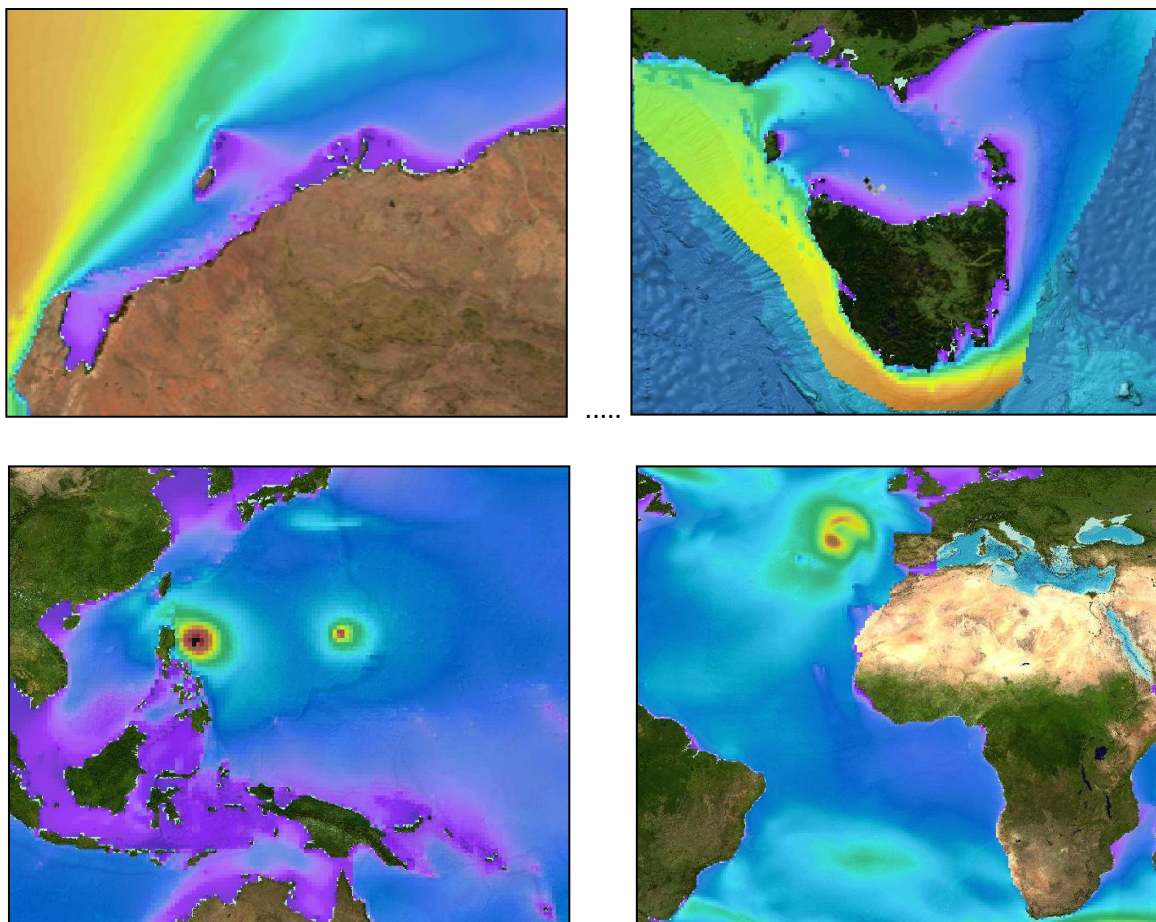


Figure 12 - Operational swell prediction for sensitive regions, continental shelves, and tropical zones. The global swell prediction system operates in all regions and is enhanced by coastal nesting and measurement programmes where available.

## Postscript

The continual accumulation of both modelled and measured meteorological and wave data also provides a valuable basis for further products and research – supporting design studies, cutting edge science, and research opportunities to validate and improve model physics.

## References

Foster, E.J. , M.A. Szyszka and A.J. Lemm, 2009. Technique for preparing gridded wind fields to enhance ambient and tropical cyclone wave hindcasting capabilities. Proceedings of the 11<sup>th</sup> International Workshop on Wave Hindcasting and Forecasting and Coastal Hazard Symposium, Halifax, Canada, October 2009.