TECHNIQUE FOR PREPARING GRIDDED WIND FIELDS TO ENHANCE AMBIENT AND TROPICAL CYCLONE WAVE HINDCASTING CAPABILITIES

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1. INTRODUCTION

This paper presents the results of our investigations into a method of blending ambient and tropical cyclone wind fields to negate the problems that arise in treating them separately, and to further enhance the hindcasting capacity of the directional spectral wave model that is forced by them.

Blending tropical cyclone vortices into synoptic wind fields is not a new technique. Kurihara et al (1993) investigated a scheme to improve the representation of the initial conditions of a high resolution hurricane prediction model by replacing the crudely resolved vortex in the large scale analysis with one that is properly specified for use in a prediction model. The present study aimed to develop a robust and elegant methodology for blending wind fields that could, to some extent, be automated and that would be applicable to the broad spectrum of tropical cyclones required for design criteria analysis.

Prior to 2007, at RPS MetOcean, ambient and cyclonic wind and wave modelling were treated separately. NCEP global gridded winds were calibrated against measured wind data in the regions of interest, and used to force the WAVEWATCH-III directional spectral wave model described by Tolman (2003). This approach accurately describes the ambient wave climate. However, spatial resolutions which optimally simulate the ambient wave climate, are unable to capture the finer structure of the smaller tropical storms. Consequently, tropical cyclone wind fields have routinely been modelled using a modified version of the Holland hurricane model (1980), at higher spatial and temporal resolution. On occasion, these simulations suffer from not accommodating the influence of synoptic wind fields within which the tropical cyclone is embedded.

A further problem associated with the modelling of tropical cyclone seastates in northern Australian waters, is the paucity of good calibration data. There are very few measurements of tropical cyclone seastates in this region (particularly in the Timor Sea), and of those, very few involve direct hits (or even close approaches). Accordingly, there is a real danger of applying inaccurate calibration to storm centres based on unreliable comparisons at the periphery of storms.

Implementation of an effective wind field blending technique allows much more accurate modelling of seastates at the periphery of storms, thereby considerably improving the reliability of model calibration.

Blending of tropical cyclone and synoptic wind fields also allows for much improved simulation of 'lead up swell' prior to the onset of a storm, and of the subsequent decay of the storm peak seastate. This has very important ramifications for the assessment of floating facility operability. It allows more accurate estimation of the lead-time for process shut-down and disconnection (should it be required). It also allows better simulation of reconnection conditions for facilities which may have been forced to vacate a riser mooring.

2. TRIAL #1 (Distance method)

Initially a rudimentary method of amalgamating ambient and cyclonic modelled wind fields was trialed – the ‘distance method’. This method specified a distance from the centre of the tropical cyclone within which the Holland vortex winds would be used. This distance had to be varied for each storm tested, to accommodate its unique radius to gales.

It was during the preparation of this method that it became apparent that tropical cyclones within the NCEP gridded winds were not always spatially coincident with the tropical cyclone 'best tracks' available from the Australian Bureau of Meteorology (BoM). The misplaced vortex in the gridded winds was addressed by limiting the wind speed outside the chosen distance to a specified value - for example 17.5 m s^{-1}.

A fundamental limitation of this technique was that it only addressed combining the wind speeds, and not the wind directions. This often resulted in major discontinuities in wind directions at the boundary between the vortex and gridded winds. Removal of the misplaced vortex by limiting the winds outside the modelled vortex was difficult to apply over a database of cyclones. If the upper wind speed limit was set too high, the false vortex was not removed. If the limit was set too low, the enhanced winds outside the vortex were erroneously reduced.

After trialing on tropical cyclones of varying sizes and strengths, this 'distance method' was deemed to lack the robustness required to partially automate the blending process, and was abandoned.

3. TRIAL #2 (Modified Kurihara et al. method)

The next trial involved removing poorly placed or represented tropical cyclone vortices from the NCEP global gridded winds using the method outlined in Kurihara et al. (1993). This essentially involved filtering the global gridded wind fields into a high frequency disturbance field and a low frequency environmental field. Using criteria specified in that paper, the vortex was identified and removed from the disturbance field, and the resultant disturbance field was then recombined with the environmental field.

The blending of the tropical cyclone vortex into the ambient wind field was done using the radius to maximum winds method. This method retains the tropical cyclone winds inside a specified multiple of the radius to maximum winds (R_{max}). Outside R_1 (a multiple of R_{max}), the method blends tropical cyclone and ambient winds as follows:

if $R < R_1$ then: $\text{speed}_{\text{blended}} = \text{speed}_{\text{TC}}$
if $R_1 < R < R_2$ then: $\text{speed}_{\text{blended}} = [(R_2 - R)\text{speed}_{\text{TC}} + (R - R_1)\text{speed}_{\text{ambient}}] / (R_2 - R_1)$
if $R > R_2$ then: $\text{speed}_{\text{blended}} = \text{speed}_{\text{ambient}}$

where R is the radial distance from the tropical cyclone centre;
R_{max} is the radial distance from the tropical cyclone centre to the maximum wind speed;
R_1 is a specified multiple of R_{max}; and
R_2 is a larger multiple of R_{max}.

Thus inside R_1 tropical cyclone winds are used, outside R_2 ambient winds are used and between the two, linearly blended tropical cyclone and ambient winds are used. Wind directions are determined by applying the same blending algorithm and criteria to the wind vector components.

Although this vortex removal and blending technique did improve the automation of the wind field preparation process, it also had limitations. The Kurihara method of vortex removal typically resulted in a depression in the wind field where the NCEP vortex had been. This, combined with the fact that the Holland vortex is generally smaller than the NCEP vortex, left a depression or 'moat' in the blended wind field between the ambient and cyclonic signatures. Figure 1a shows the wind field for Tropical Cyclone Frank (1995) at an output time when the vortex was not removed. Figure 1b shows the wind field with vortex removed using the Kurihara method at a subsequent timestep. Note the resulting wind speed discontinuities in both space and time. The spatial plot shows a sharp 'front' between the Holland vortex and NCEP ambient wind field. The time history plot shows so-called 'moats' in the storm signature adjacent to the storm peak.

This trial, although improving on automation of the wind field preparation process, resulted in unrealistic wind signatures and also did not resolve the problem of vortex misalignment.

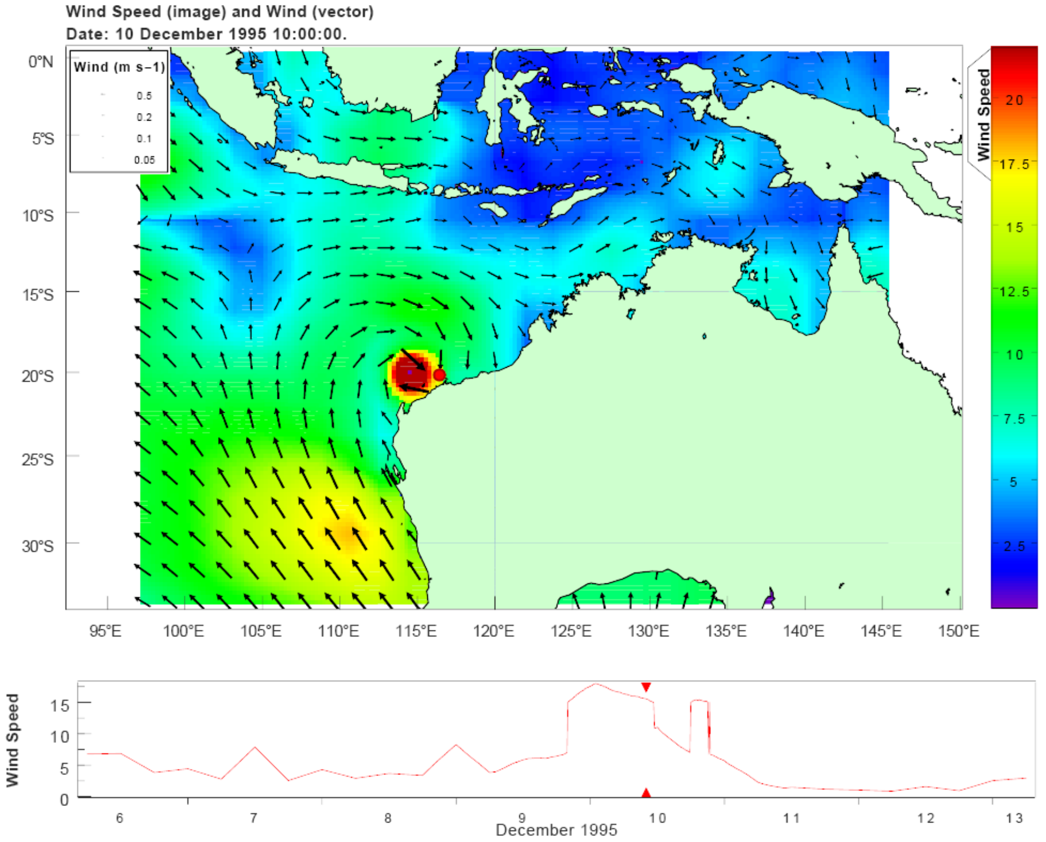

Figure 1a. Blended wind field for Tropical Cyclone Frank (1995) when the NCEP vortex was not removed.

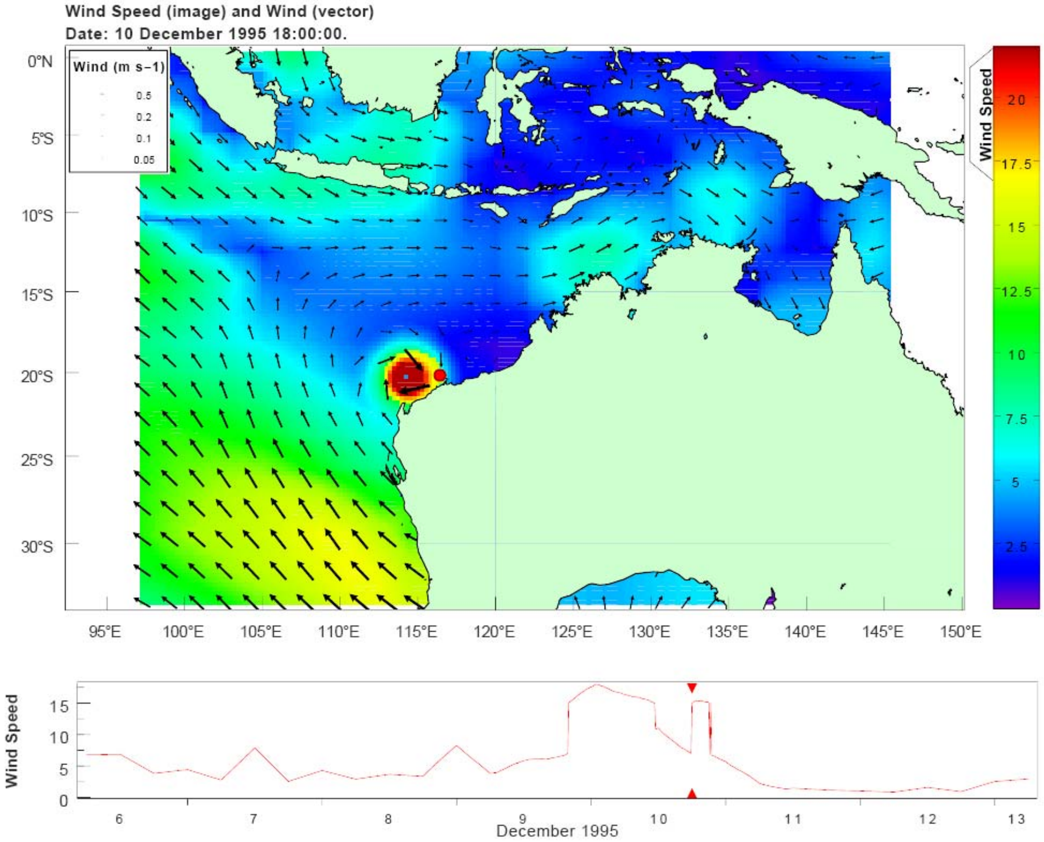

Figure 1b. Blended wind field for Tropical Cyclone Frank (1995) when the NCEP vortex was removed.

4. TRIAL #3 (Vortex Relocation method)

To overcome the introduction of ‘moats’ into the gridded wind fields while trying to remove the poorly placed NCEP vortices, a method of relocating the NCEP vortices, rather than removing them, was investigated.

The first part of the vortex relocation process is to identify the deviation of tropical cyclone vortices within the NCEP winds from the BoM ‘best tracks’. An interactive program was designed to allow visual identification of vortex deviation by overlaying the global ambient wind field with the corresponding storm track, and determining the difference in their locations at each global data timestep. Where the deviation was deemed too great, vortex relocation was required.

Vortex relocation moves the vortex within the NCEP winds from its original location to the more accurate BoM track location. This is achieved by applying a grid transformation within an elliptical area where the source and destination of the NCEP vortex coincides with the ellipse focii. The process creates a distorted grid from the original gridded data and then re-interpolates the data onto the original regular grid. An example of this is shown in Figure 2. Vortex relocation ensures a smooth transformation of data without introducing unrealistic discontinuities in the speed or direction of the wind field.

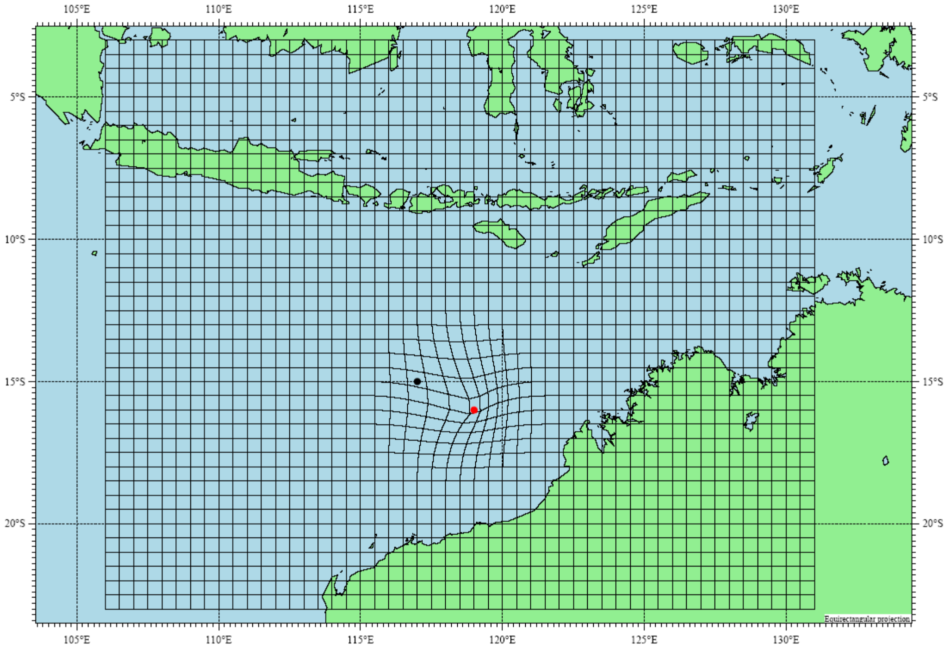

Figure 2. An example of a grid that has been distorted to relocate a tropical cyclone vortex from the position indicated by the black dot to the position indicated by the red dot.

In conjunction with the development of vortex relocation, several techniques for wind field blending were also trialed. The technique that was eventually chosen addressed the various issues (such as processing speed and wind field discontinuities) experienced with previous blending methods, via a simpler overall algorithm, based on R_{max} and on R_{OCI}, the radius to the Outer Closed Isobar.

This method entails the overlaying of the parametrically modelled ‘Holland’ vortex on the distorted synoptic wind field, without NCEP vortex removal. In essence, the Holland winds are used within R_{max} and where ever they exceed the synoptic winds outside of R_{max}. Further – to avoid direction discontinuities, directions within R_{OCI} are set to the Holland directions, and outside R_{OCI}, there is a controlled smoothing into the synoptic directions.

This approach offers the simplest blending algorithm and the qualitatively best looking blended wind field from all the methods trialed. It does not appear to introduce any artifacts such as wind speed ‘moats’ or direction discontinuities.

5. RESULTS

The vortex relocation method was used to hindcast wind and wave fields for a select database of tropical cyclones affecting the northwest of Australia. These cyclones were selected to represent a cross-section of intensities (weak, moderate and strong) and varying distances between the NCEP vortex and the BoM track. Examples of the effects of relocation for selected storm types are discussed below.

Weak NCEP Vortex and/or Short Relocation Distance

In many instances the effects of vortex relocation are subtle, due to the relative weakness of the NCEP vortex and/or the short relocation distance involved. Importantly, in such instances the process does not introduce significant distortions to the NCEP wind field. A spatial comparison of the blended wind field using vortex relocation against one using the Kurihara vortex removal method for Tropical Cyclone Frank in 1995 at a critical timestep, is presented in Figures 3 and 1b, respectively.

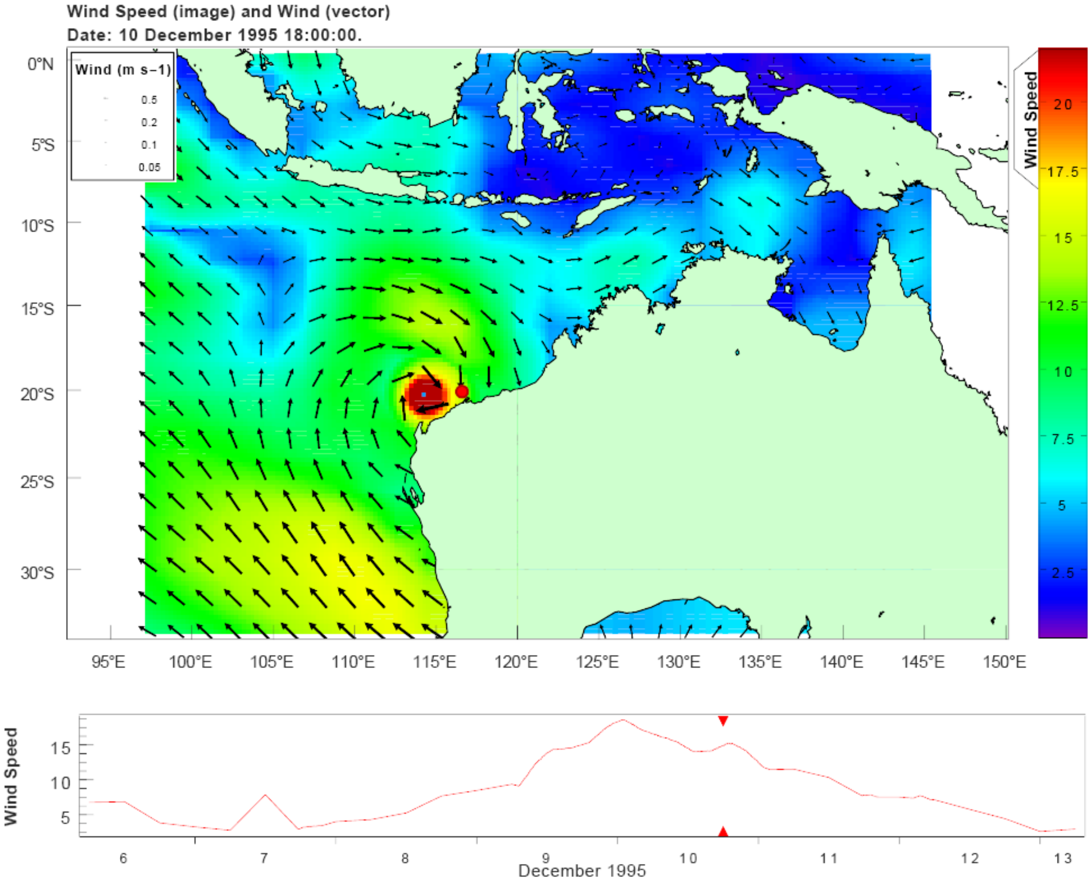

Figure 3. Blended wind field for Tropical Cyclone Frank (1995) when the NCEP vortex was relocated.

Strong NCEP Vortex

The effects of vortex relocation are most pronounced for storms that have a strong NCEP vortex signature that is not co-located with the BoM tropical cyclone track. An example of this is provided by Tropical Cyclone George in 2007. A spatial comparison of the blended wind field with and without vortex relocation at the same timestep is illustrated in Figures 4a and 4b.

Long Relocation Distance

Without vortex relocation, NCEP vortices that are separated from the BoM tropical cyclone track location by a long distance can cause significant distortions in the blended wind field. For instance, for Tropical Cyclone Neville (1992) a distinct NCEP vortex is visible in addition to the blended Holland vortex (Figure 5a). Vortex relocation addresses this issue by merging the two vortices, resulting in a more representative regional wind field (Figure 5b).

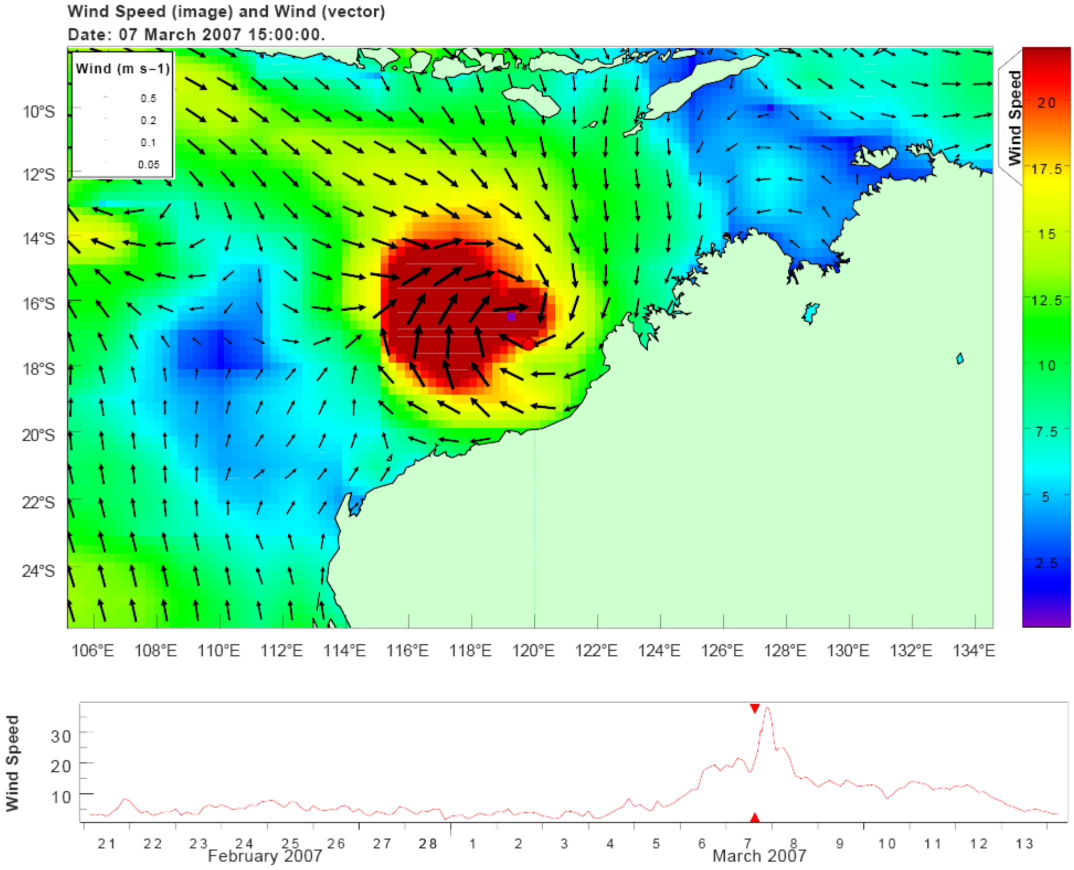

Figure 4a. Blended wind field for Tropical Cyclone George (2007) without NCEP vortex relocation.

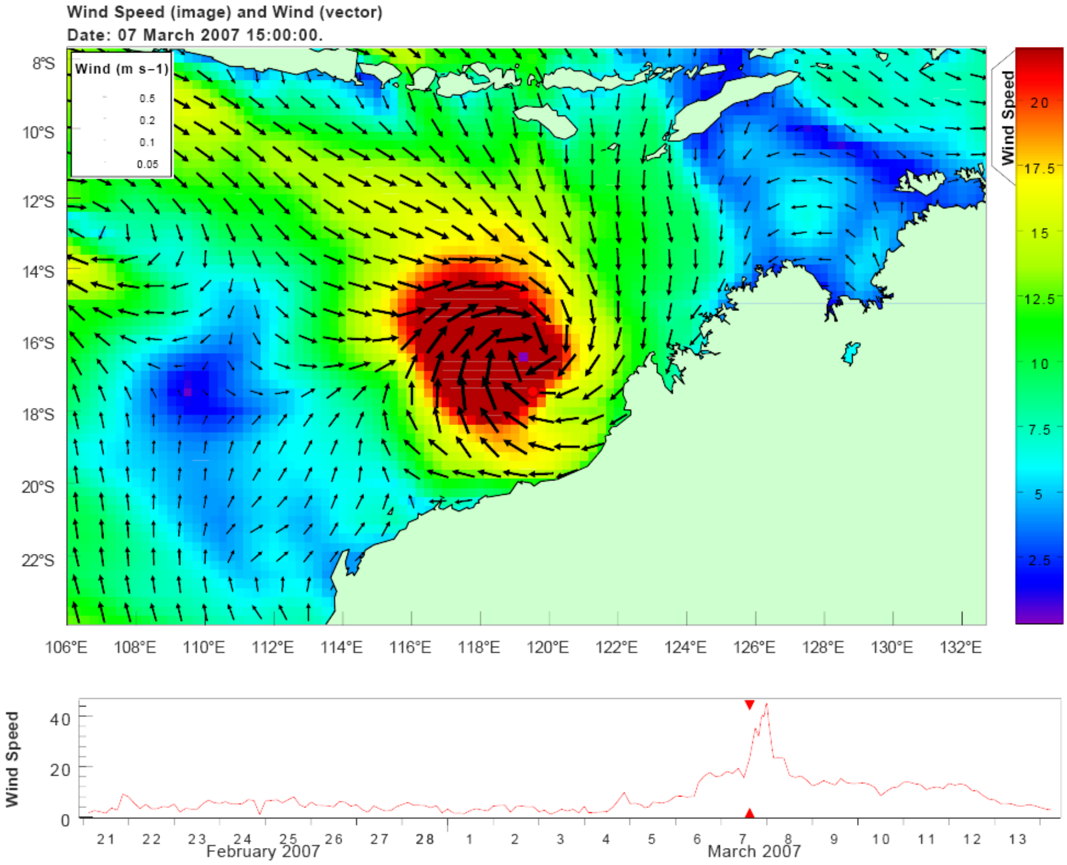

Figure 4b. Blended wind field for Tropical Cyclone George (2007) with NCEP vortex relocation.

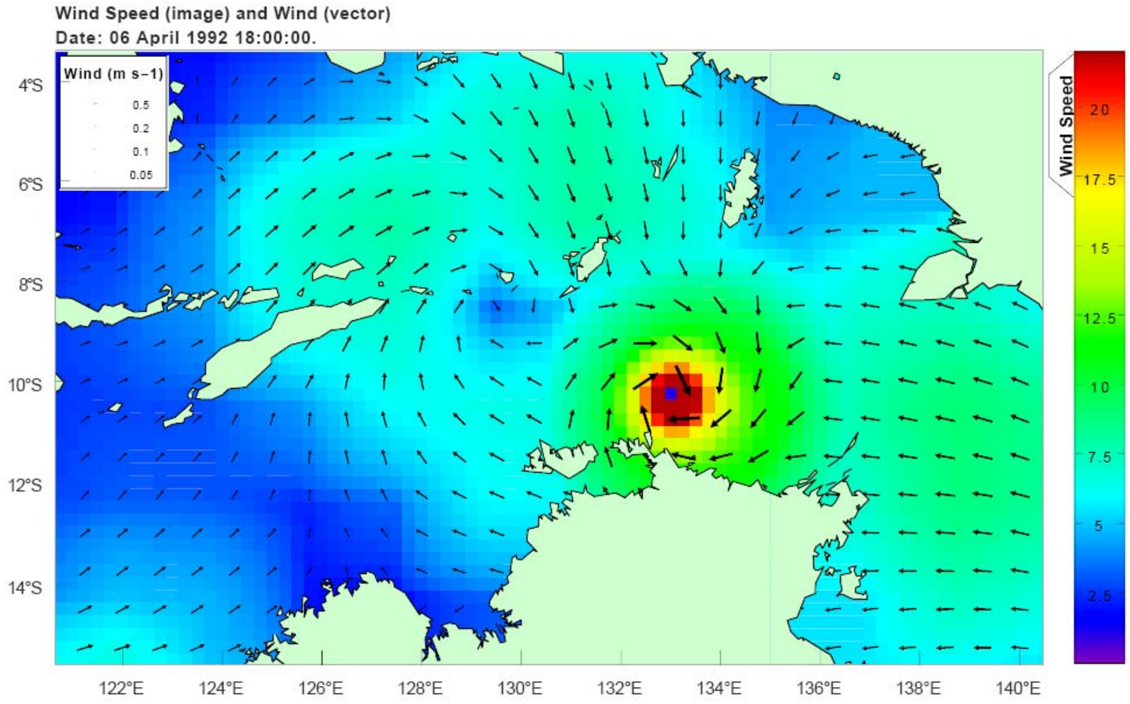

Figure 5a. Blended wind field for tropical cyclone Neville (1992) without NCEP vortex relocation.

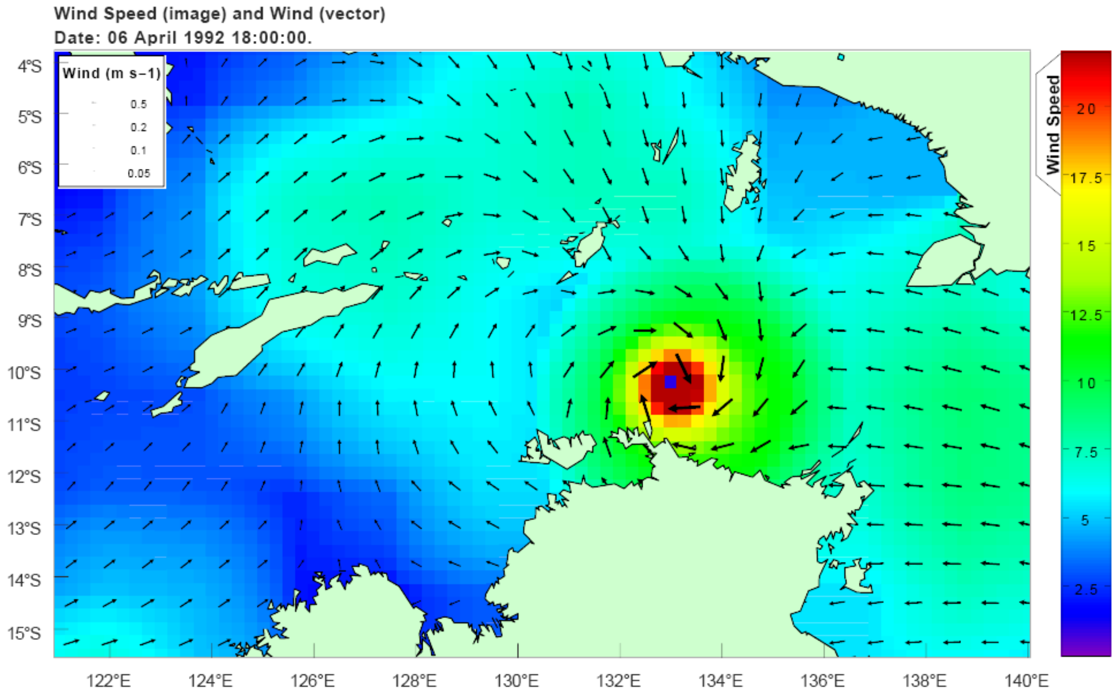

Figure 5b. Blended wind field for tropical cyclone Neville (1992) with NCEP vortex relocation.

Overall, the inclusion of vortex relocation into the wind preparation process, along with the simplified blending algorithm, has increased RPS MetOcean's ability to effectively represent realistic regional wind fields when influenced by tropical cyclones of many strengths and sizes.

This improvement is best illustrated by a time history comparison of modelled wind and wave data from both the second trial and the latest wind preparation process, against wind and wave data measured under Tropical Cyclone Frank in 1995 at North Rankin A (data supplied by Woodside Energy Limited). This plot is presented in Figure 6. Tropical Cyclone Frank is a good cyclone for purposes of comparison of measured and modelled data as it was a relatively uniform storm on an undeviating track with the eye passing within 130 km of the measurement location.

In Figure 6, green represents the results of Trial #2 blending process, red represents the results of Trial #3 and the measured data are blue.

Trial #2 produced reasonable winds at the peak of the storm, but exhibited the problem of the wind speed 'moat' around the periphery of the storm. Also apparent is the direction divergence beyond the moat. The resulting wave field is under-predicted both at the storm peak, and through the lead-up and decay periods.

Trial #3 mimicked the wind speeds at the storm peak, but avoided the wind speed moat, providing excellent replication of the lead-up and decay. The resulting wave field provided a better match with measurements at the storm peak, as well as much improved lead-up and decay. The matching at the storm peak is attributable to the 'broadening influence' of the synoptic winds at the periphery of the storm.

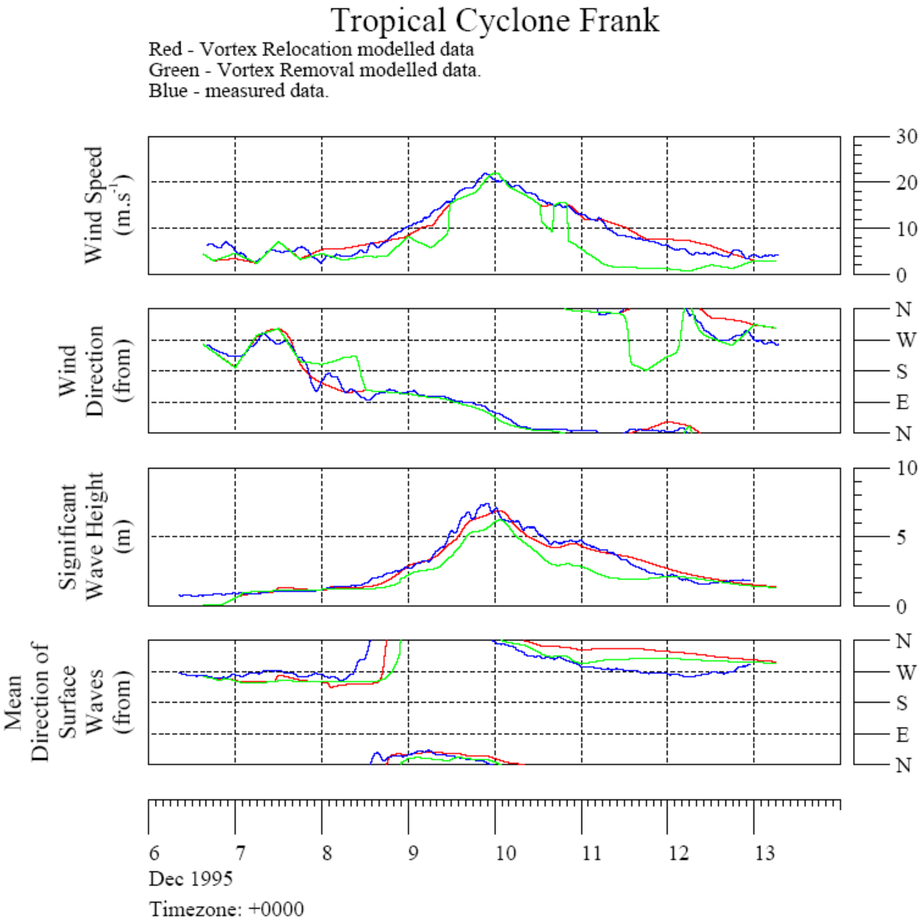

Figure 6. Time history comparison of wind and wave data measured during Tropical Cyclone Frank (1995) at North Rankin 'A' location (data supplied by Woodside Energy Limited) against modelled wind and wave data using the vortex removal and vortex relocation wind preparation techniques.

6. CONCLUSIONS

We have successfully developed a robust, flexible wind field blending process which provides for much-improved tropical cyclone wind field representation in data sparse regions. This in turn allows:

- much-improved wave model calibration;
- more accurate long term (decades) continuous wind and wave simulation;
- more accurate determination of storm peaks (and consequent estimates of extremes); and
- improved simulation of storm lead-up and decay, resulting in more reliable assessments of floating facility operability.

AKNOWLEDGMENTS

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REFERENCES

Holland, G., 1980: An Analytic Model of the Wind and Pressure Profiles in Hurricanes. Mon. Wea. Rev., **108**, 1212-1218.

Kurihara, Y., Bender, M.A. and Ross, R.J, 1992. An Inititalization Scheme of Hurricane Models by Vortex Specification. Mon. Wea. Rev., **121**, 2030-2045.

Tolman, H. L., 2003: User manual and system documentation of WAVEWATCH-III version 3.04.