

Analysis and Prediction Operations Bulletin No. 75

Operational Upgrade to the Sea State Forecast System

23 July 2008

Introduction

A version of the WAM wave model (WAMDI Group 1988) has been the operational sea state model run by the National Meteorological and Oceanographic Centre (NMOC) since June 1994. Output from this model is used as numerical forecast guidance for the Bureau's marine services. On 22 July 2008 the system was upgraded following research performed in CAWCR by Tom Durrant and Diana Greenslade evaluating the incorporation of two enhancements:

1. an increase in the resolution of the wave spectrum, and
2. expansion of the data assimilation system to include Envisat as well as Jason-1 significant wave height data

There will be no change to the post processed output products of wave height, direction and period forecasts currently produced. The output files of the full wave spectrum and the swell wave spectrum will reflect the increase in angular resolution.

System Changes

In the WAM model (and all spectral numerical wave models) the wave field is described by the energy density spectrum $E(f, \theta)$, where f is the frequency and θ the direction of propagation. Although the horizontal resolution of the model implemented in NMOC has changed over time to match improvements in the resolution of atmospheric forcing, the spectral resolution of 25 frequency bands and 12 directions has remained constant.

A directional resolution of 30° is relatively coarse and can lead to potentially negative impacts on the resulting wave forecasts. In particular, a coarse directional resolution constrains the wave energy to propagate in a limited number of directions. This can lead to undesirable features such as the so-called "sprinkler effect" when swell propagates over long distances and results in "clumping" of the energy. There are various techniques that can be used to minimize this effect but the simplest method is to increase the angular resolution of the spectrum. In this upgrade the angular resolution will be increased from 30° to 15° .

Since August 1999 the wave model has assimilated significant wave height (H_s) data from satellite altimetry measurements which are received in near real time via the GTS. Initially this data was sourced from the ERS satellites and more recently from Jason-1. The Bureau has for some time been receiving H_s data in near real-time from the Envisat satellite altimeter, so this upgrade is an opportunity to expand the Data Assimilation (DA) system by including this additional source of data.

The Fast-Delivery (FD) altimeter products included here are received at the Bureau within three hours of observation and typically contain systematic errors which can vary from mission to mission. Durrant et al., (accepted) compared Envisat and Jason-1 H_s to *in situ* buoy observations and showed that the Envisat data is overestimating low H_s and underestimating high H_s . They suggest a correction given by:

$$H_s^{adj} = 1.085H_s^{FD} - 0.213m$$

which is applied before passing the data to the DA. They found that no correction is needed for Jason-1 data.

Research Results

Durrant et al (in prep) performed several model runs over the month of January 2005. These were designed to test a) the impact of assimilating either one or two satellite data streams and b) the impact of increasing the angular resolution of the wave spectrum. All model runs were on the global domain (0-360°, 78°S – 78°N) at 1° spatial resolution. All runs used the same initial conditions, and the same wind forcing fields from the Bureau's global atmospheric model (GASP). 72-hour forecasts were made every 12 hours, after a 12-hour hindcast period, during which DA was performed (for the DA runs).

The different model runs were as follows:

- **Noaasim-12:** 12 directional bins, no DA
- **Noassim-24:** 24 directional bins, no DA
- **Jason-12:** 12 directional bins, DA with Jason-1 only
- **Jason-24:** 24 directional bins, DA with Jason-1 only
- **Both-12:** 12 directional bins, DA with Jason-1 and Envisat data
- **Both-24:** 24 directional bins, DA with Jason-1 and Envisat data

In situ buoy data (around the Australian coast) and the corrected altimeter data (over the entire globe) were used to make assessments of the effect of the changes to the wave forecasting system. A summary of the altimeter verification results is shown in Figure 1.

Assessment of the rms difference between the model H_s and the altimeter data shows that the best results are obtained from the case where both the directional resolution is increased *and* Envisat data is included in the DA as well as Jason-1.

The conclusions from the buoy verifications were that for short ranges, the best results would be obtained from assimilating both sets of altimeter data, while for longer range forecasts, the best results are obtained from the increased angular resolution. Further details can be found in Durrant et al (in prep).

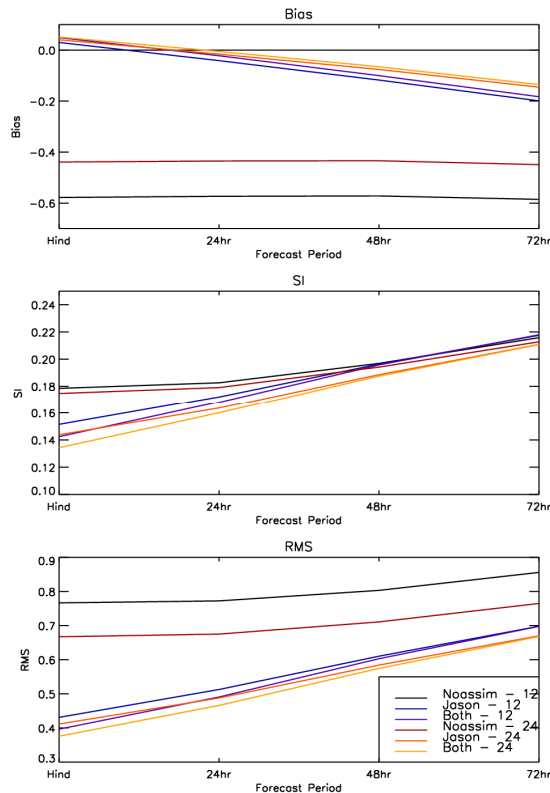


Figure 1: Bias, Scatter Index and RMS error of the wave model forecasts compared to global satellite altimeter data.

Operational Trial

The research results were sufficiently encouraging to justify the setting up of an operational trial of the system on NMOC. This was done during the first half of 2008 and exactly mirrors the operational system which incorporates a higher resolution regional model nested within the global model and a further higher resolution model nested within the regional model. Only the global model and the full Australian region system include DA. Trial forecasts were performed in real-time and the data cut-off for data used in the DA system was the same as that for the operational models. As is also done routinely for the operational models, co-located forecasts interpolated to the position of the wave buoys around the Australian coast and the wave observations are stored for later calculation of statistics.

Initially the trial system was run with the same spectral resolution as the operational system but including the (corrected) Envisat data in the DA step as well as the Jason-1 data. The systems were run for a period of about 6 weeks in January/February 2008. The results were inconclusive with very little change in the performance compared with the buoy measurements. However, as there is no degradation in performance it was decided that it is beneficial to include the Envisat data as well, since the CAWCR results show improvement in the open ocean. As the DA step does improve the wave model forecast this then will provide some redundancy in the observations used protecting against failure of either of the instruments or the communications which deliver the data.

The more intensive trial involving the increase in the angular resolution of the wave spectrum was commenced in March 2008. After some initial problems particularly with the very high resolution model, the system has been running robustly since 15 April. Results are presented here for the period 26 April – 25 June 2008.

Shown in Figure 2 is the comparison between the verification results for the current operational model and the test model with the upgrades.

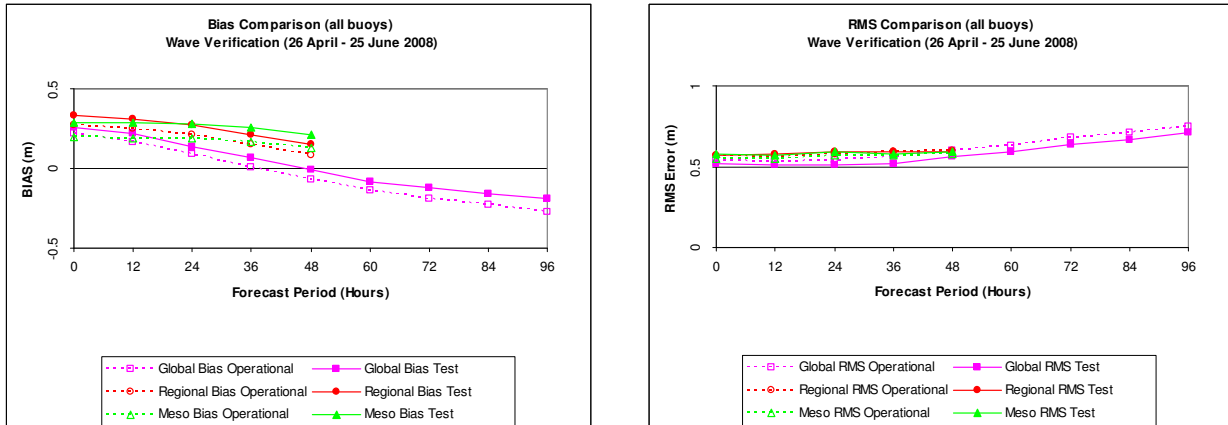


Figure 2: Bias (left) and RMS error (right) of the wave model forecasts compared to wave observations around the Australian coast.

Except for a slight increase in the (positive) bias for shorter forecast intervals, it is clear that the changes make a significant improvement to the global system. For the regional and mesoscale systems the picture is not so clear. While there is little change in the RMS error, the positive bias has been increased.

The upgrade due to the increase in angular resolution should result in better propagation of the swell components in the model which are generally generated in the high latitude westerlies to the south of the Australian continent. The verification results were split into two bins:

1. Verification against data exposed to the westerlies (Jurien Bay, Rottnest Island, Cape Naturaliste, Cape du Couedic and Cape Sorell)
2. Verification against the rest of the data (NSW and south Queensland coast).

The results for the verification against stations exposed to the westerlies (Figure 3) show that the trial system performed significantly better for all three domains.

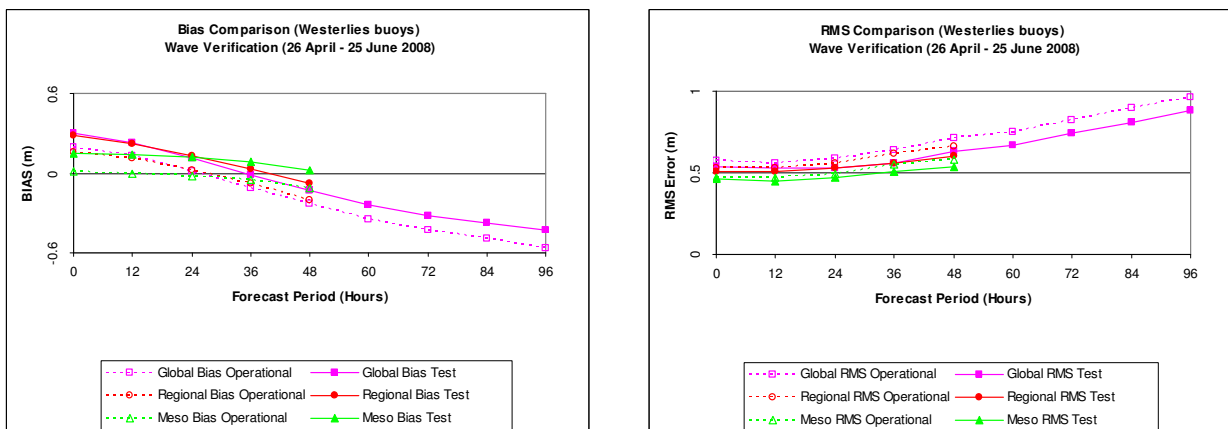


Figure 3: As for Figure 2 but for wave observations exposed to westerlies

Future Developments

This will be the final upgrade to the wave forecasting system prior to the replacement of the current Numerical Weather Prediction (NWP) systems that are run in the NMOC with NWP systems utilising the ACCESS (Australian Community Climate Earth System Simulator) Unified Model/Variational Assimilation (UM/VAR) system from the UK Met Office. The change to the UM/VAR system is expected to provide significant improvements in the surface wind field forecasts and therefore an immediate improvement in the wave forecasts. However, in parallel with the NWP upgrade an investigation will be made as to the suitability of the current wave model (it was been tuned to the characteristics of the NWP system at the time of implementation) and other models such as the NOAA/NCEP WAVEWATCH III.

The attraction of the latest version of WAVEWATCH III is the better treatment of shallow water waves and a more sophisticated algorithm to partition the various wind sea and swell components in the wave spectrum.

Other potential future developments include the incorporation of a system to verify the wave forecasts against altimeter data, as described and applied in Durrant et al (in prep).

Output Products

With this upgrade to the wave modelling system there will be no changes to the output provided from the model. A selection of wave forecast charts is available through the Bureau's Marine Services web pages (<http://www.bom.gov.au/marine/index.shtml>) and gridded files and products for specialized users are available for registered users from the Bureau's ftp server.

References

Durrant, T., D. J.M. Greenslade and I. Simmonds, Validation of Jason-1 and Envisat Remotely Sensed Wave Heights, *J.Atmos. Oc. Tech*, accepted July 18th, 2008.

Durrant, T., D. J.M. Greenslade and G.R.Warren, Assessing Upgrades to the Bureau of Meteorology's Wave Forecasting System using Satellite Altimeter Data, *CAWCR Research Report*, in prep.

WAMDI Group (1988): Hasselman, S., Hassleman, K., Bauer, E., Janssen, P.A.E.M., Komen. G.J., Bertotti, L., Lionello, P., Guillaume, A., Cardone, V.C., Greenwood, J.A., Reistad, M., Zambresky, L., and Ewing J.A., 'The WAM model - A third generation wave prediction model'. *J.Phys. Oceanogr.*, 18, 1775-1810.