Operational implementation of the high resolution Ocean Wave model

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Introduction

On 5 December 1996 the Centre introduced a new, global Ocean Wave model with a spatial resolution of 55 km. Compared to the previous operational wave model (with a resolution of 1.5 degrees) this may be regarded as a major step forwards, which was made possible by the introduction of the new Fujitsu VPP700 computer in September 1996. In this article, some steps are briefly described that allowed high-resolution wave modelling, while also first verification results of the month of December 1996 are presented. Finally, near-future developments are given.

High-resolution wave modelling

The Centre has been doing operational wave forecasting since June 1992. The model was developed by the WAM group and solves the so-called energy balance equation for the wave spectrum, where the relevant processes such as generation of waves by wind, dissipation by white-capping and nonlinear transfer are modelled in an explicit way (Komen et al, 1994). Initially, a modest spatial resolution of the global wave model of 3 degrees was chosen, while the two dimensional wave spectrum had 25 frequencies and 12 directions. This first implementation performed satisfactorily in many respects except that extreme events were underpredicted. This changed to some extent with the introduction of the 1.5 degree version of the wave model, although the underprediction of extreme events still occurred occasionally. The reason for this improvement when going to higher resolution is that more details and variability of the driving wind fields are included. It is well-known that wave model results, in particular during extreme events, are sensitive to the variability of the wind because the wind-wave system acts as a rectifier. Therefore, additional improvements in predicting extreme events are expected with the introduction of the present operational wave model which runs on a spatial grid which (almost) matches the grid of the atmospheric model.

Another reason for going to higher resolution is that coasts such as the east coast of the United States and the North Sea are not well represented on the coarse, 1.5 degree grid. However, in order to describe wave system near coasts properly, shallow water effects are important as well. Therefore, the shallow water option in the WAM model was switched on.

Furthermore, even on the open oceans there are benefits from going to higher resolution, since for example frontal systems have more details than may be described on a 1.5 degree grid. An example of the presence of fronts in the wave height field for the North Atlantic area (including North Sea, Baltic and Mediterranean) is shown in Fig. 1. Here, contours of constant wave height are plotted together with the wave direction which is presented by arrows. In addition, it is seen that the present high-resolution wave model gives a fair representation of the wave field in coastal areas and even in the Baltic and Mediterranean.

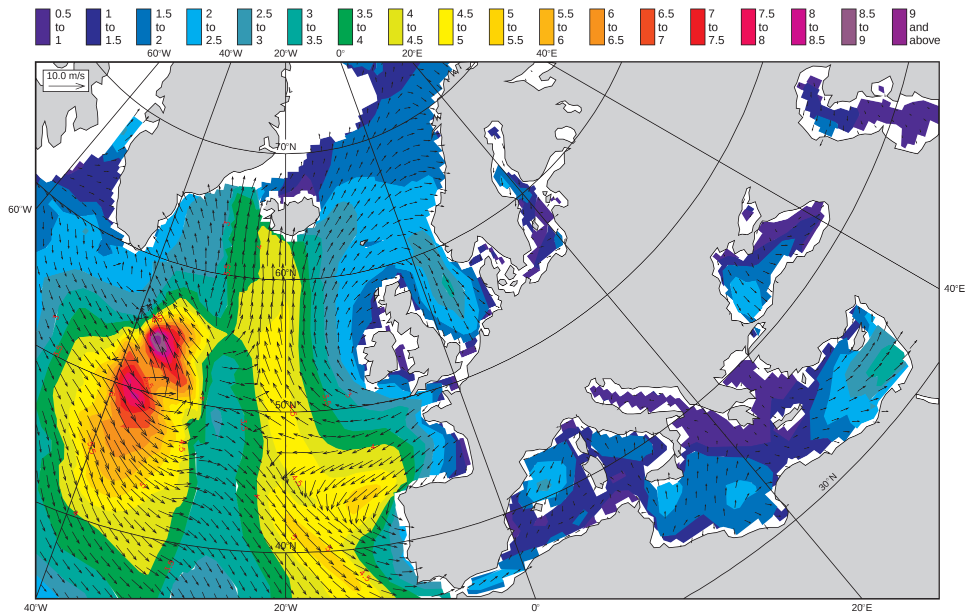

Fig. 1 Analysed wave height (in m) and wave direction for the North Atlantic and European waters. The bold numbers denote observations of wave height by the Synthetic Aperture Radar (SAR) on board the ERS-2 satellite.

In order to be able to do high-resolution wave modelling a number of developments were necessary (for more details see Bidlot et al, 1997). First of all, the numerics of the WAM model is limited by the well-known CFL criterion which imposes an upper bound on the size of the integration time step of the advection scheme, and the upper bound gets smaller for decreasing spatial step. In regular spherical coordinates the increments are constant in longitude and latitude, so that near the poles the zonal spatial step may become rather small. To circumvent this problem an irregular lat-lon grid was introduced. It still has a constant latitude increment but adjusts the size of the longitude increment in such a way that the actual distance between grid points is almost constant. In this way the CFL criterion becomes less restrictive near the poles. When compared to the regular grid, additional advantages of the irregular grid option are a reduction in the number of computations per time step and a reduction in memory because the latter option requires 25% fewer grid points to cover the globe.

The resulting version of the WAM model was nevertheless demanding in CPU usage, so that a message passing version of the model was required in order to make optimal use of the available computing power on the Fujitsu. The numerical code which is submitted to the parallel computer must be modified to contain instructions that will tell each processing element (PE) what to do. Moreover since the Fujitsu is a distributed memory computer, information contained on one PE is not automatically shared with the others and must be shared explicitly if there is a need for it. The information exchange is actually done in the message passing context, whereby one PE can send a message which is received by one or more other PE's. In its very basic implementation, the message is nothing more than a one-dimensional array of a given type containing values that are needed by the other PE('s) plus all the necessary information about the sender and the receiver. Each PE now has the task to solve the energy balance equation on a subdomain of the globe. The physics source terms, such as wind input, are local and require no exchange of information with other PE's. However, advection is nonlocal, and, therefore, before doing the advection the PE waits until it has received the necessary information from the others.

In this way an efficient code was obtained. On 6 processors a one day analysis and 10 day forecast with the present high resolution wave model is performed in 35 minutes elapse time. On a single processor such a task would take more then 3 hours so that a speed up is achieved of about 5.5.

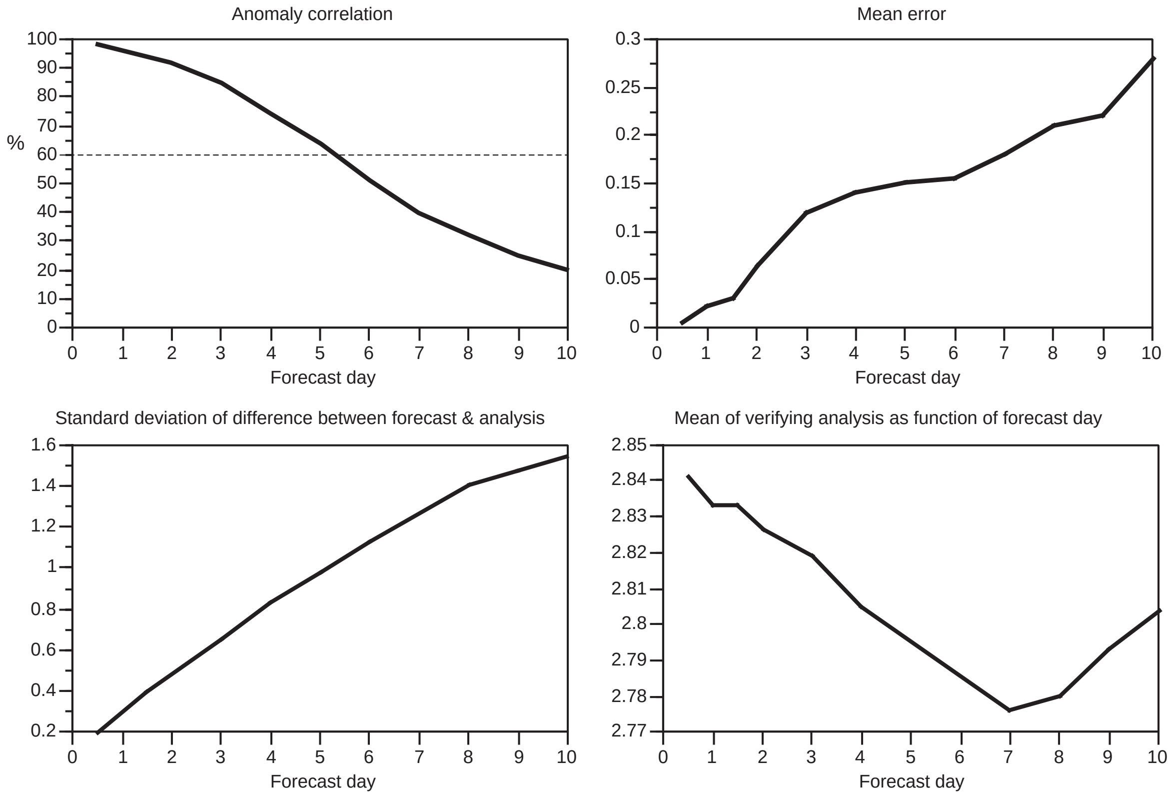

Fig. 2 Forecast verification against analysis for the Northern Hemisphere. Top left panel shows the anomaly correlation, the top right panel shows the mean error, the bottom left panel shows the standard deviation of the difference between forecast and analysis, while the bottom right panel shows the mean of the verifying analysis as function of forecast day.

First verification results

During a parallel run of about one month the performance of the high resolution wave model was extensively compared with the then operational 1.5 degree model. The forecast performance in areas such as the Northern and Southern Hemisphere was found to be very similar, while in coastal areas improvements were noted.

As an illustration the first wave height verification scores for the month of December are presented. Fig. 2 shows forecast scores for the Northern Hemisphere. From the plot of anomaly correlation the forecast skill is about 5 days which is a result that is typical for this area since the last two years. Also typical is the growth of the mean error during the forecast which may amount to more then 10% of the mean wave height.

In Fig.3 the first guess wave height is compared with Altimeter data from ERS-2. The verification statistics show a good performance of the new version of the wave model, since the scatter index (=normalised standard deviation of error) is only 14% while the is almost no bias. Finally, in order to show the good performance of the high resolution model in coastal areas, the verification of analysed wave height against buoy data for the North Sea is shown in Fig.4. Although there is a slight under estimation by the model of about 4% the scatter index is only 16% confirming the above claim.

Future prospects

The introduction of the high resolution version of the WAM model seems to be successful. In particular we have noted some improvements in coastal areas. Further gains are to be expected with the introduction of the T319 version of the atmospheric model, because this will result in higher variability of the surface wind.

Since the wave model is now running on almost the same grid as the atmospheric model, we are ready to implement a coupled atmosphere, ocean-wave model in the near future. The coupling of the two models allows a better representation of the air-sea momentum transfer, which in case of early cyclogenesis will give an extra slowing down of the air flow (Janssen, 1994). Since the wind decreases somewhat the result is a lower wave height during the forecast. Therefore the expectation is that this will reduce the error growth in wave height during the forecast as seen in Fig.2.

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References

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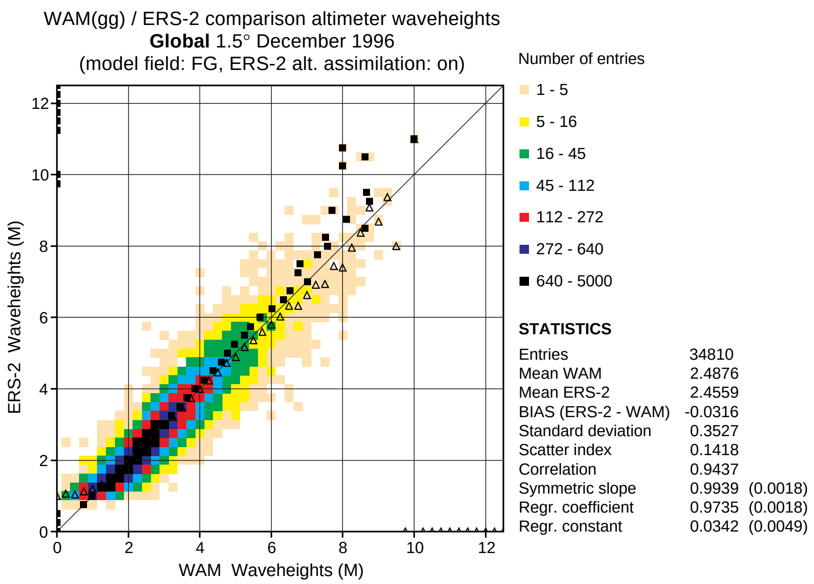
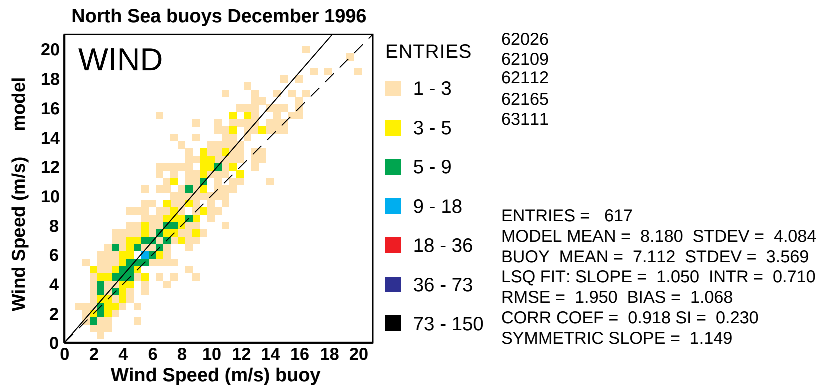
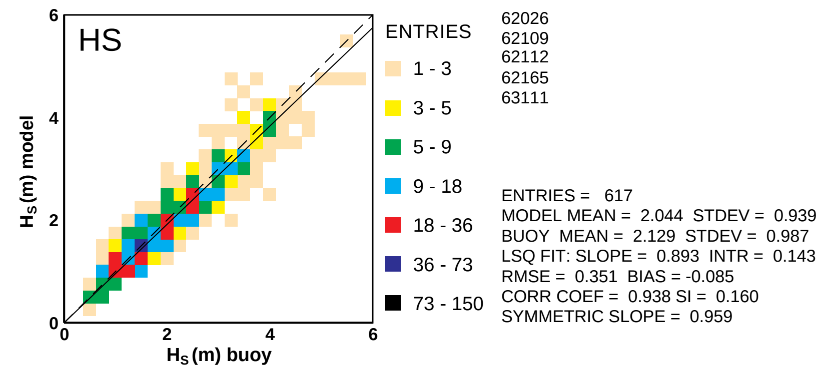


Fig. 3 Comparison of first-guess wave height and ERS-2 altimeter wave height for the globe.



Comparison of analysed ECMWF wind speeds with averaged buoy data.



Comparison of analysed ECMWF wave heights with averaged buoy data.

Fig. 4 Verification of analysed wave height against buoy wave height for a number of buoys in the North Sea.