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Forecasting Research

Forecasting Research Division
Technical Report No. 120

**An intercomparison of the
WAM and UKMO wave models
run at the UK Met Office.**

by

M.W. Holt

December 1994

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1 Introduction

Preliminary investigations of the WAM wave model (WAM group, 1988) run at the UK Met Office were reported by Holt (1994a). Since that study several teething problems with the WAM grid setup and wind specification have been identified and overcome, thanks in part to discussions with Peter Janssen, at ECMWF. The autotasking of WAM has been made more effective, and a longer advection timestep is used in the global model. Thus the timings reported earlier have been improved.

Following comparison with WAM at UKMO, the UK Met Office wave model has also been improved. The sea state is better represented for light winds, and swell dissipation has been reduced in line with current understanding of the balance of source terms. The changes are described in Technical Report 119 (Holt 1994b), and the revised model was implemented operationally in November 1994.

This report brings up to date details of the costs of running the WAM model, and compares the global WAM and UKMO wave models for both summer and winter hindcast studies. The costs of running on the UK Met Office European area wave model grid are examined, although further work is required with the implementation of WAM at the UK Met Office before a fully nested model may be run.

The next section of the report describes the revisions to the implementation of WAM at UKMO, Section 3 gives results of the model hindcasts, Section 4 briefly discusses model performance for low windspeeds and Section 5 gives the latest costs of running the model. Conclusions and a summary are presented in Sections 6 and 7.

2 Revisions to WAM at UKMO

In the preliminary runs of the WAM model, wind data from the UKMO NWP model were rescaled by 0.91 to give a 10m windspeed. Further investigation showed that whilst this factor was too small, nevertheless the unscaled windspeeds were too strong, and that a factor 0.94 was more appropriate (Figure 1). This corresponds to a nominal height of 19.5m rather than 25m for model level one in the UKMO NWP model. For the runs reported here, the UKMO windspeeds were multiplied by a factor 0.94 for use in the WAM model.

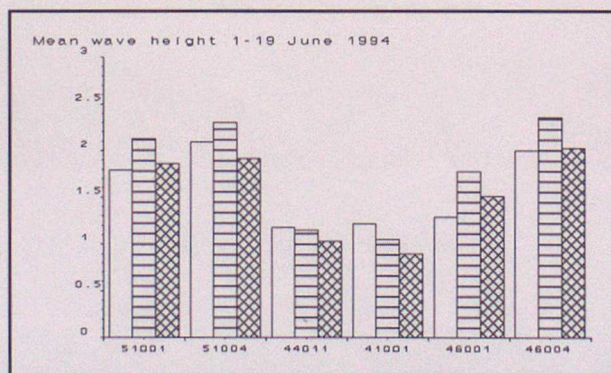


Figure 1: Mean wave heights observed and modelled for 1-19 June 1994. The observed value is shown blank, from the WAM model with unscaled UKMO winds with horizontal lines, and from WAM model with windspeeds scaled by 0.94 in crosshatching. All runs on the UKMO operational resolution global grid.

Tests of the global WAM model at constant windspeed revealed that the grid was not periodic in east-west. This was traced to an error in the WAM model preprocessing program whereby the grid join was checked against the latitude increment rather than the longitude increment. (Note this would not be a problem for a 'square' lat-long grid as at ECMWF). For the runs presented here this has been corrected, although in practice there was little difference at the buoy verification sites.

The efficiency of autotasking WAM has been investigated, mainly by using *atexpert* to analyse the speedup of individual loops. Some improvement in runtime has been achieved by selectively switching off autotasking for those loops with small potential for speedup. This is reported in more detail in Section 5.

The earlier runs of WAM on the global grid used a timestep of 600 seconds for both propagation and source term calculations. It has been found possible to use a timestep of 1200 seconds, which cuts the elapsed time by about half from the values reported in Technical Report 92. Tests have shown no impact on model performance from this change.

3 Hindcast studies: January 1992 and June 1994

The wave models were run using UKMO archived winds from December 1991 and January 1992. Both models were started from rest on 20th December 1991, and verified against buoy data from midnight on 31st December 1991 to midnight on 19th January 1992. This corresponded to previous studies carried out during recalibration of the UKMO wave model. A summer case was also run, from 1-19 June 1994, with the models starting from rest on 20th May 1994.

The UKMO wave model results presented are from the 1994 revised model (Holt, 1994b). The WAM model cycle 4 was run at the UKMO operational global resolution, of 0.833° latitude by 1.25° longitude, and also at the reduced resolution of 1.5° latitude by 1.875° longitude. Both wave models ran with their standard frequency resolution, and with 16 direction components.

Two buoys representative of the wave climate in each of the central Pacific, NE Pacific and west Atlantic were chosen for verification. The buoy positions are given in Table 1. These buoys are a subset of those used to verify the operational UKMO global wave model.

| Buoy | Lat | Long | location |
|-------|--------|--------|-----------------|
| 51001 | 23.39N | 162.3W | central Pacific |
| 51004 | 17.5N | 152.6W | central Pacific |
| 46001 | 56.3N | 148.3W | NE Pacific |
| 46004 | 50.9N | 135.6W | NE Pacific |
| 41001 | 34.9N | 73.0W | W Atlantic |
| 44011 | 41.1N | 66.6W | W Atlantic |

Table 1. locations of buoys used for model verification

3.1 Windspeed

Mean windspeeds at each of the buoy sites are shown in Figure 2. Observed and model values were close at all buoys, except at Buoy 46004 in January, and Buoy 44011 in June, where the model winds were appreciably stronger. However as the model winds are at a nominal height of 19.5m and the observations are at around 5m, this may indicate that model windspeeds were lower than in reality. The seasonal difference in mean windspeed is apparent.

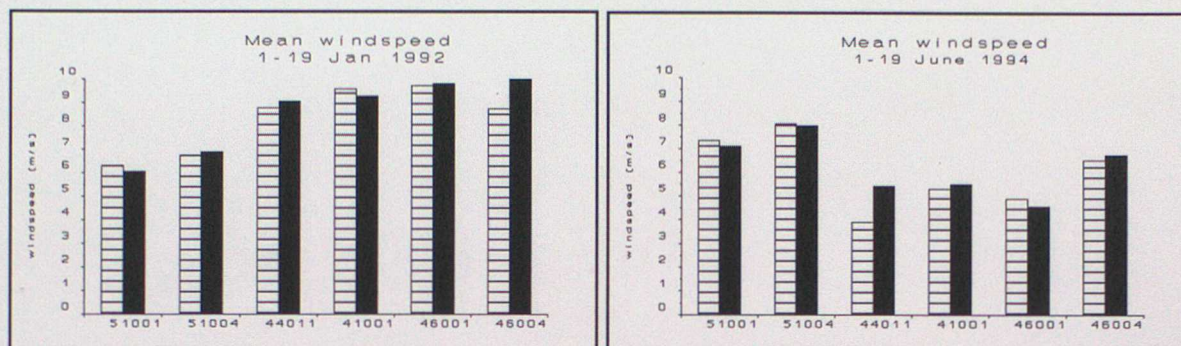


Figure 2 Mean windspeeds for 1-19 January 1992 (left) and 1-19 June 1994 (right). Observed shown lined, model values solid. The buoy anemometer height is close to 5m, the model value is uncorrected from the UKMO NWP model level 1 ($\sigma=0.997$) value.

3.2 Wave Height

The mean wave height bias for each model is shown in Figure 3. In the winter case the bias is similar in all three models at Buoys 51001 and 51004 in the central Pacific. At all the other buoys shown the UKMO wave model has the smallest bias. All models underestimated the wave height compared to observations.

In the summer case model biases were generally smaller than in winter, except at Buoy 51004 in the central Pacific. At Buoys 46001 and 46004 in the NE Pacific mean wave heights in the models were greater than observed. At Buoys 44011 and 41001 in the NW Atlantic the bias was smallest in the UKMO wave model.

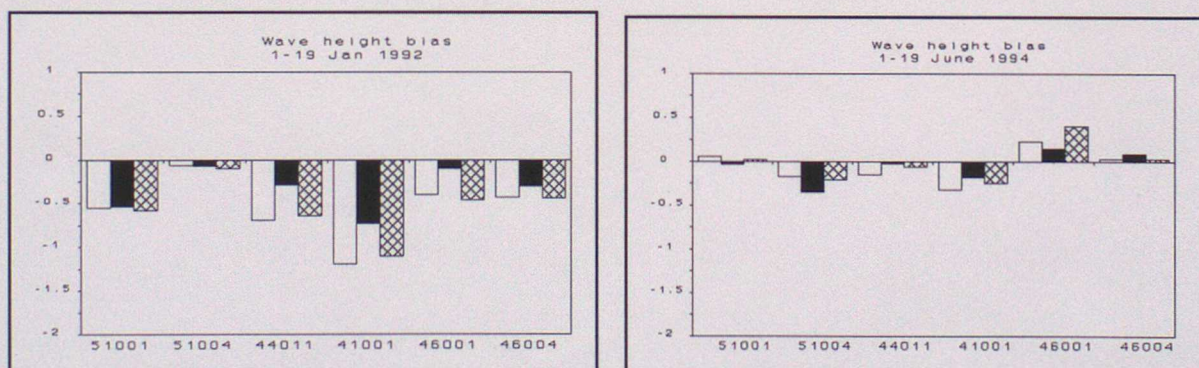


Figure 3 Wave height bias (model minus observed) at selected moored buoys. The WAM model on the operational grid is shown blank, the UKMO model on the operational grid shown solid, and the WAM model on the reduced grid with cross hatching. (left) the winter case (right) the summer case.

3.3 Wave Period

At each of the buoys the WAM model and UK model mean wave periods were close, and shorter than the observed period in the winter case. For the summer case model values were closer to observed. The difference in mean value between the two seasons is apparent, with longer period waves in the winter hemisphere.

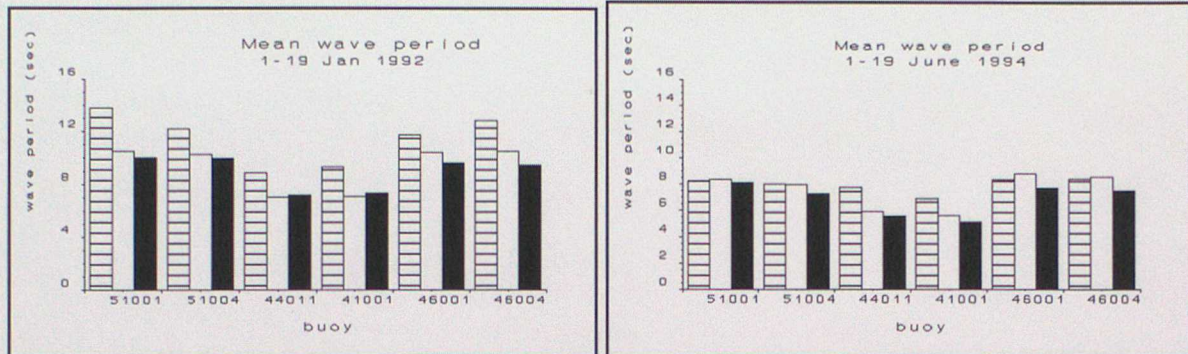


Figure 4 wave period, observed and model. Model values are calculated as the mean period of the spectrum. Observations shown lined, WAM model at operational resolution shown blank, and UKMO model shown solid. Both models at UKMO 'operational' resolution.

3.4 Wave height timeseries

3.4.1 Northern winter: 1st-19th January 1992

In general the timeseries of wave height show that there was little difference between the WAM model results on the global grid at operational and reduced resolution, using the same forcing winds. Occasionally wave heights were higher, and closer to observed, in the higher resolution model.

For much of the time the UKMO model wave heights were close to the WAM model values. However on some occasions, particularly associated with high winds, the UKMO wave height was greater than WAM, and much closer to observed.

3.4.1.1 Central Pacific

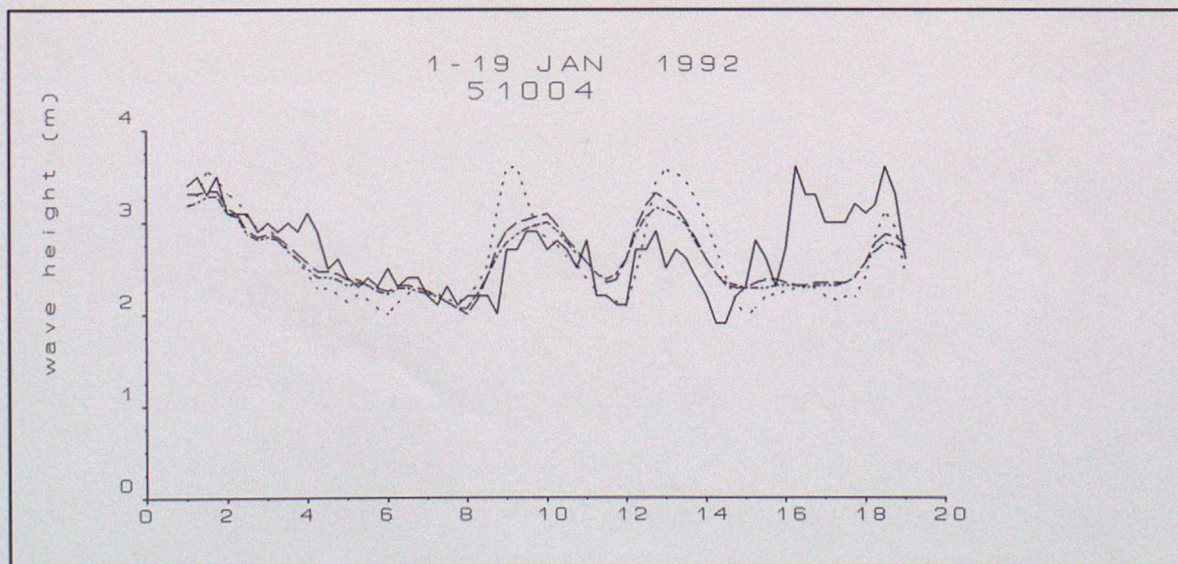


Figure 5 (a) Timeseries of wave height at Buoy 51004. Observed values are shown as a solid line, values from the UKMO model on the operational grid as a dotted line, from the WAM model on the operational grid as a dashed line and from the WAM model on the reduced grid as a dashed-dotted line.

At Buoy 51004 in the central Pacific, up to January 8th all models were close, and close to observed. On January 9th the UKMO was some 0.5m greater than observed, but reduced wave height fast enough to match the observed minimum on 12th. Although starting from a lower value the WAM model did not reduce wave height as much. Wave heights on 13th-14th were overestimated in all models. All models missed the observed peak wave heights from 16th onwards. The model winds at the buoy site were close to observed, and 5ms^{-1} or lower, so this was presumably due to a deficiency in the forcing winds in some remote storm causing a swell episode to be missed.

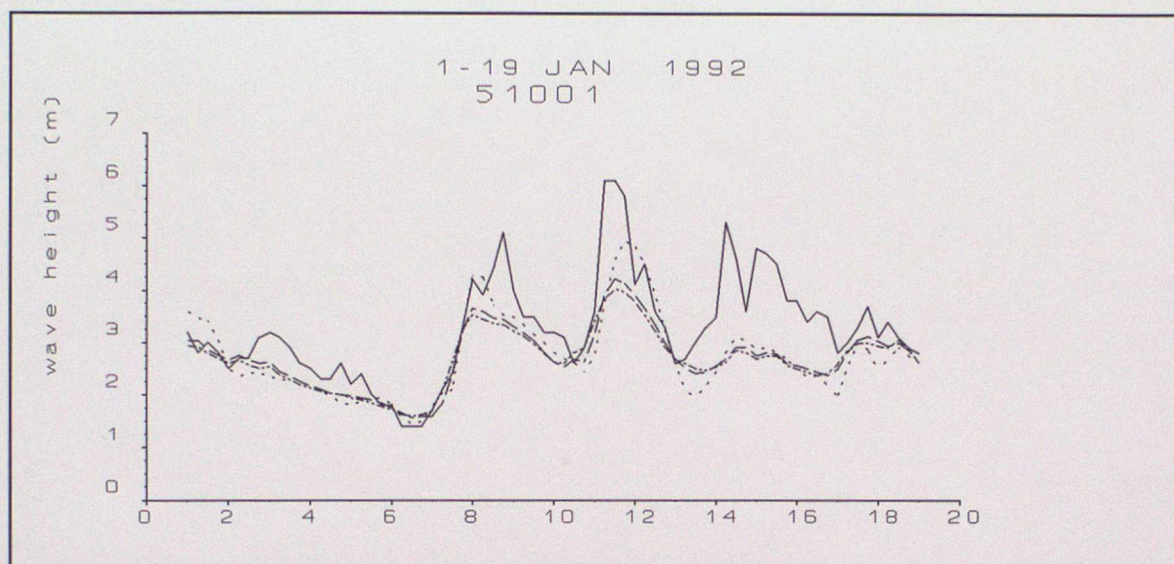


Figure 5(b) Timeseries of wave height at Buoy 51001 (as 5a)

At Buoy 51001 the same general comments apply. On January 8th UKMO wave height was close to observed, and greater than the WAM value. The peak on January 9th was missed by all models. The peak wave height on 11th was also missed by all models, but UKMO was some 0.7m greater than WAM and closer to observed. Both model and observed windspeeds at this time were at strongest 10ms^{-1} , so this peak wave height must have been a swell event. The falling wave heights on 12th were well modelled by UKMO; wave heights fell off more slowly in the WAM model. As at Buoy 51004 the swell episode 14th-16th was not captured by the models. The UKMO model reflected the observed variation of wave height on 17th-19th, but the mean value was too low. WAM lacked the variation but the mean was closer to observed. Windspeed increased uniformly from 1ms^{-1} at 6z 17th to 8.75ms^{-1} at 12z 18th, so the decrease in wave height between 18z 17th and 00z 18th was due to a reduction in swell.

3.4.1.2 NE Pacific winter

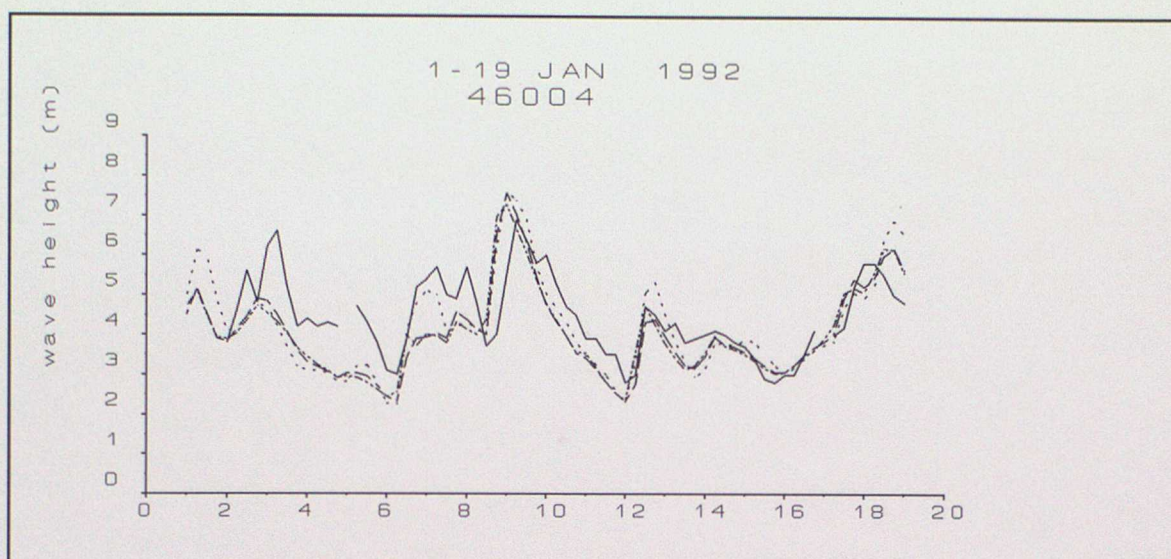


Figure 5(c) Timeseries of wave height at Buoy 46004 (as 5a)

At Buoy 46004 in the NE Pacific all the model wave heights were generally close, with UKMO wave heights greater at the maxima. The observed maximum on 3rd was missed by all models. On the 6-7th the observed maximum of 5m was matched in the UKMO model to within 0.5m, but missed by WAM which was 1.5m lower. On the 8-9th wave height grew at the same rate in all models, and matched the observed rate of increase. Model windspeeds for this storm were stronger than observed, peaking at 18ms^{-1} on 18z 8th compared to 13.9ms^{-1} observed, although the timing of the model wind increase matched the observed. The rate of reduction of wave heights on 11-12th was close to observed in all models, though model wave heights started to fall some 6 hours earlier than observed. For the growing waves on 12-13th the UKMO model overestimated the maximum by some 0.4m; WAM was close to observed.

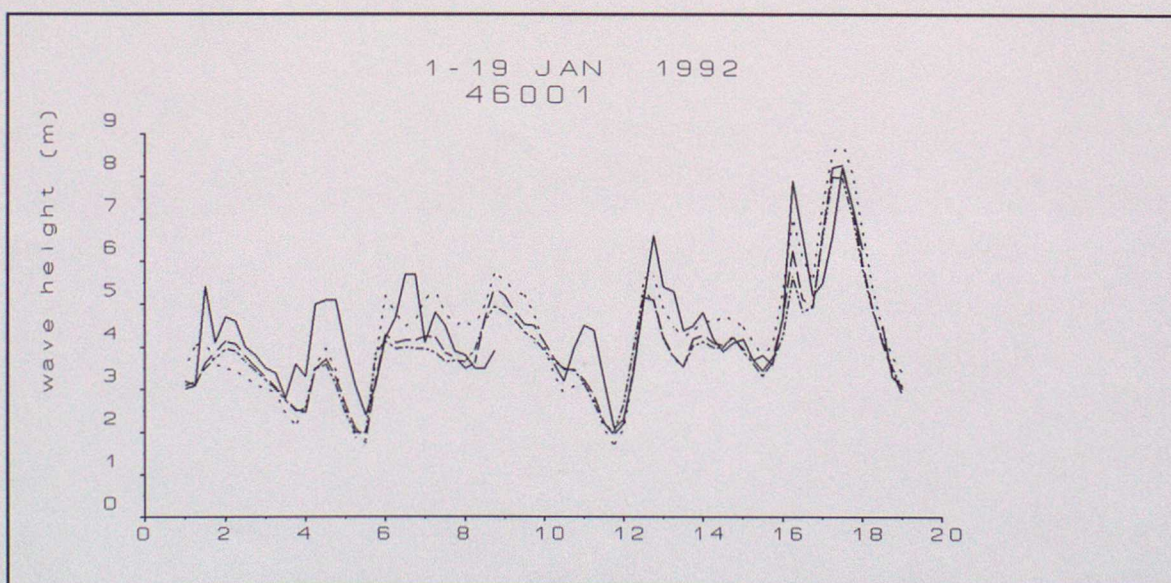


Figure 5(d) Timeseries of wave height at Buoy 46001 (as 5a)

At Buoy 46001 on the 4-5th a peak observed waveheight of 5m was missed by all models, which only reached just under 4m. On 6-7th the UKMO was closest to observed, but the variation of model wave height with time did not match the observed variation. The peak observed at 18z 6th was totally missed by WAM but attempted by UKMO. Model values were close on the 9th, but there were no observations. All models missed the peak on 11th, continuing to reduce wave heights. The minimum reached on 12th was

close to observed, and this was followed by a rate of growth on 12-13th close to the observed, but stopping short of the observed maximum wave height. The UKMO model peaked some 0.5m greater than WAM, and this affected the subsequent minimum in wave height on 13th-14th, where WAM was some 1m lower than observed. For the storm on 16th, the model timing was good but all models wave heights were lower than the observed maximum of 8m. The UKMO model managed 7m, WAM on the operational grid made 6m and WAM on the reduced grid around 5m. For the next peak on 18th at 18z all were close to observed, but again UKMO was greater by several tens of cm. The subsequent reduction in wave height 18th-19th was well modelled.

3.4.1.3 Western Atlantic winter

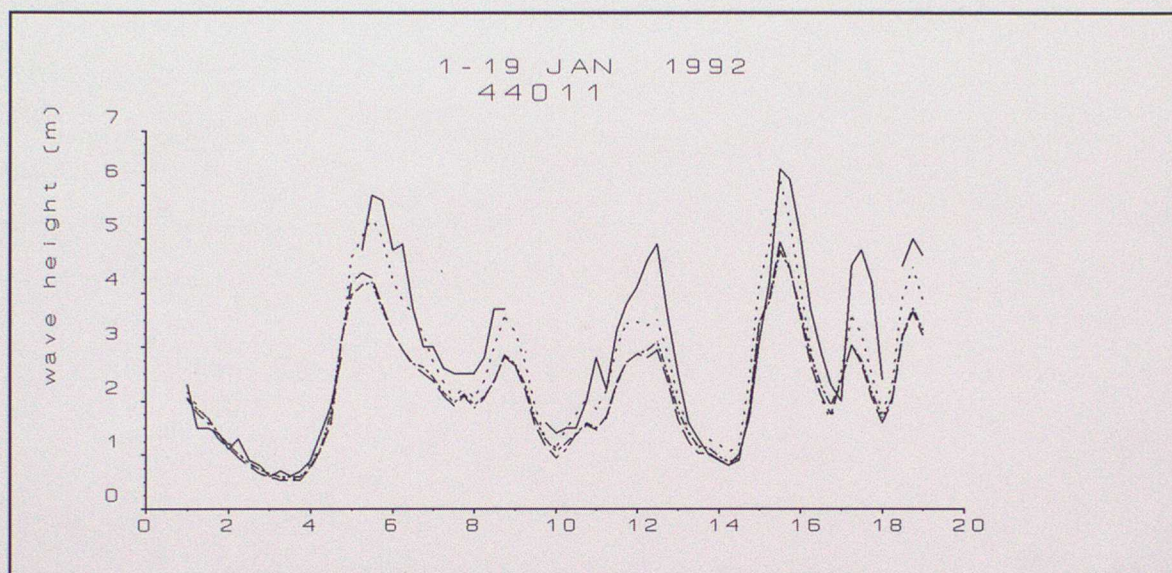


Figure 5(e) Timeseries of wave height at Buoy 44011 (as 5a)

At the buoys off the east coast of the USA, dominated mainly by windsea generated by storms moving out from the United States, we see the largest differences between the two wave models. At Buoy 44011 there was a very good timing of peak maximum and minimum wave heights. Up to 5th January all models were close, and agreed with observations. For the peak on 5th-6th, the UKMO model was close to observed (5.5m), within 0.5m. The WAM model missed by around 1.5m. Subsequent reduction in wave height in all models was too rapid, so that the minimum of 2.5m observed on 8th was underforecast by the models, at 2m. With a peak of 3.5m on the 9th, the UKMO model was close to observed. The WAM peak wave height was less than 3m. Growth in the UKMO model was more rapid than in WAM. Wave heights then decayed to just below the observed minimum on 10th. As the waves grew there was a minor peak on the 11th. All models missed this event. Timing appeared to be some 6 hours too early in the models, and wave growth in WAM was slower than in UKMO. For the storm on 12th the observed waves reached 5m. The UKMO model reached 3.5 and WAM 3m. The winds for this storm were well modelled however, both in timing and speed (Figure 5(f)). The following wave minimum on 14th was well modelled. The initial rate of growth to the peak on 15th-16th was good, but again UKMO model reached some 1.5m greater than WAM, and was closest to observed. Wave growth in WAM slowed down sooner than in observations. For the final two storms in the period all model wave heights were lower than observed. Wave height in the WAM model was some 0.5m below the UKMO value on 17th-18th, and some 1m below the UKMO value on 18th-19th.

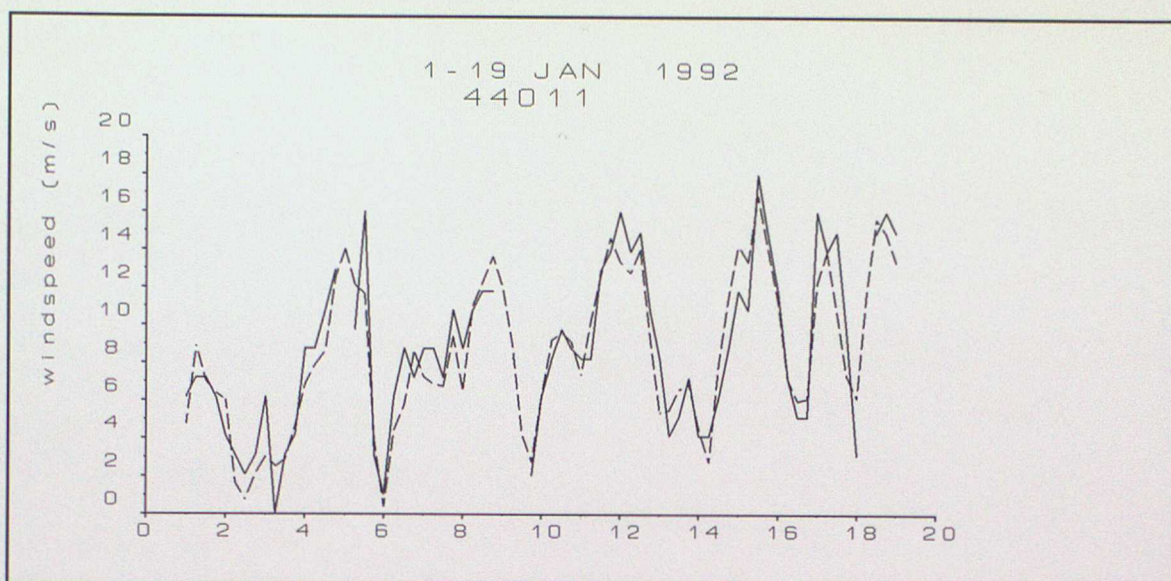


Figure 5(f) Timeseries of windspeed at Buoy 44011: Observed values solid, model values dashed.

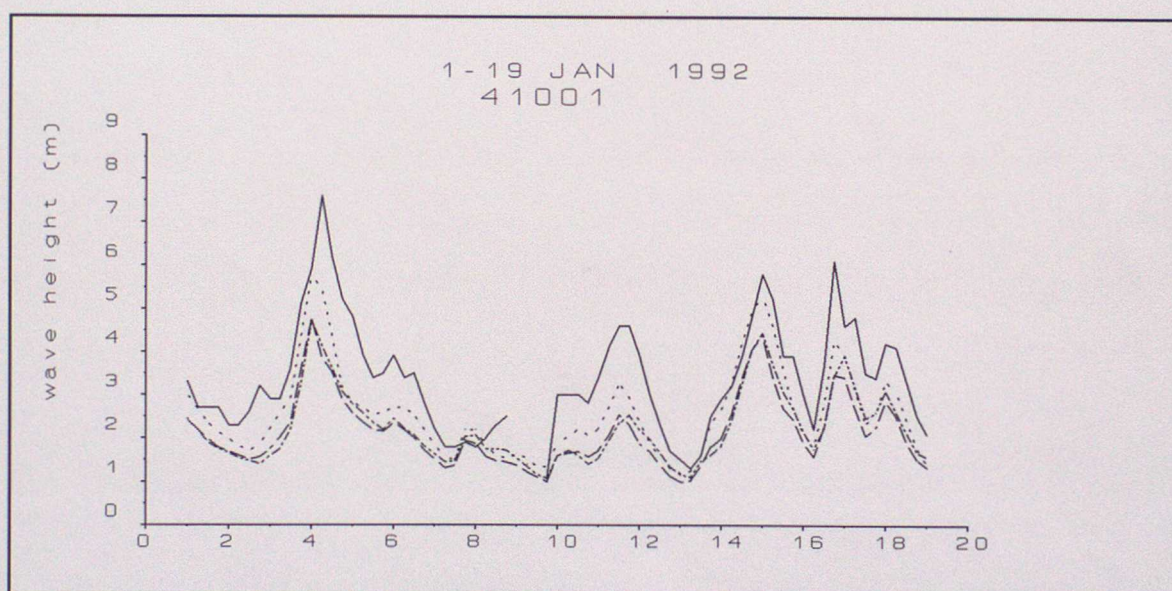


Figure 5(g) Timeseries of wave height at Buoy 41001 (as 5a)

At Buoy 41001 all models heights were close, and lower than observed for the first few days. Model winds were lower than observed on 2nd - 3rd. The timing of the storm on 4th was well modelled, but not the peak windspeed. Observed maximum windspeed was 18ms^{-1} at 00z 4th, compared to 16ms^{-1} in the model. All models failed to reach the observed maximum of 7.6m waves. The UKMO model reached 5.75m, WAM 4.75m. This affected the subsequent reduction in waves, so model waves were lower than observed until around 9th-10th. For the peak on 12th the model timing was good but wave heights were lower than observed, WAM was some 0.5m below UKMO. Model windspeeds were close to observed. The minimum wave height on 13th was well modelled. Growth rate for the next storm was good in UKMO, which reached a peak on 15th only 0.3m below observed. WAM was some 1.5m below observed. Initial growth in WAM was slower than in the UKMO model, and WAM stopped growing the waves earlier than was observed. The minimum on 16th was well modelled, but underestimated as models did not reach the preceding observed maximum height. Again, wave height was reduced faster in the UKMO model than in WAM. The sequence from 16th onwards was well modelled for timing of events, but peak maxima were low in the

models. Model windspeeds were close to observed, and all model wave heights were close during this period. In several of these storms, even though model (level one) windspeeds were close to observed, the wave models did not reach observed maximum wave heights. This supports the suggestion that model winds are light: model winds at a nominal height of 19.5m compare well with buoy windspeeds measured at 5m.

3.4.2 Northern Summer: 1-19 June 1994

The timeseries of wave height for the summer case study show that there was little difference between WAM model results on the operational and reduced resolution grids. In contrast to the winter case, on one occasion wave heights were higher and closer to observed on the coarser resolution grid.

3.4.2.1 Central Pacific

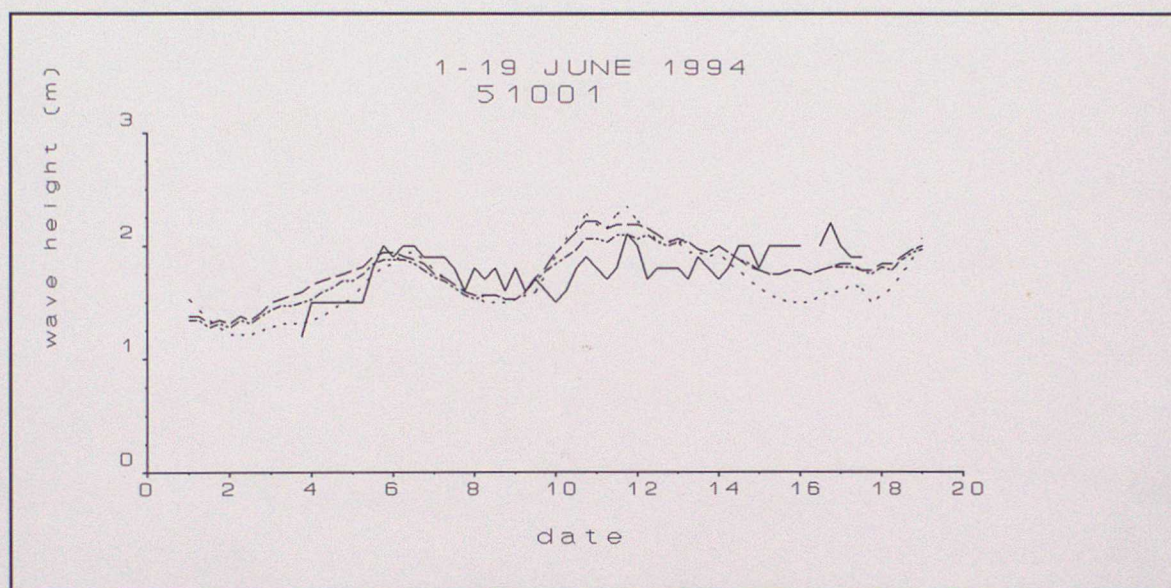


Figure 6(a) Timeseries of wave height at Buoy 51001: [As figure 5(a)]

At Buoy 51001 the wave heights in all models were close, and generally close to observations. The observations showed some variation on a timescale of one day - particularly noticeable from June 9th. This was not shown in the model wave heights, but the variation was only of about 0.3m. Windspeeds varied between 5 and 7.5ms⁻¹, and model values were close to observed. At the start and end of the period wave heights in UKMO model were slightly lower than in WAM.

3.4.2.2 NE Pacific

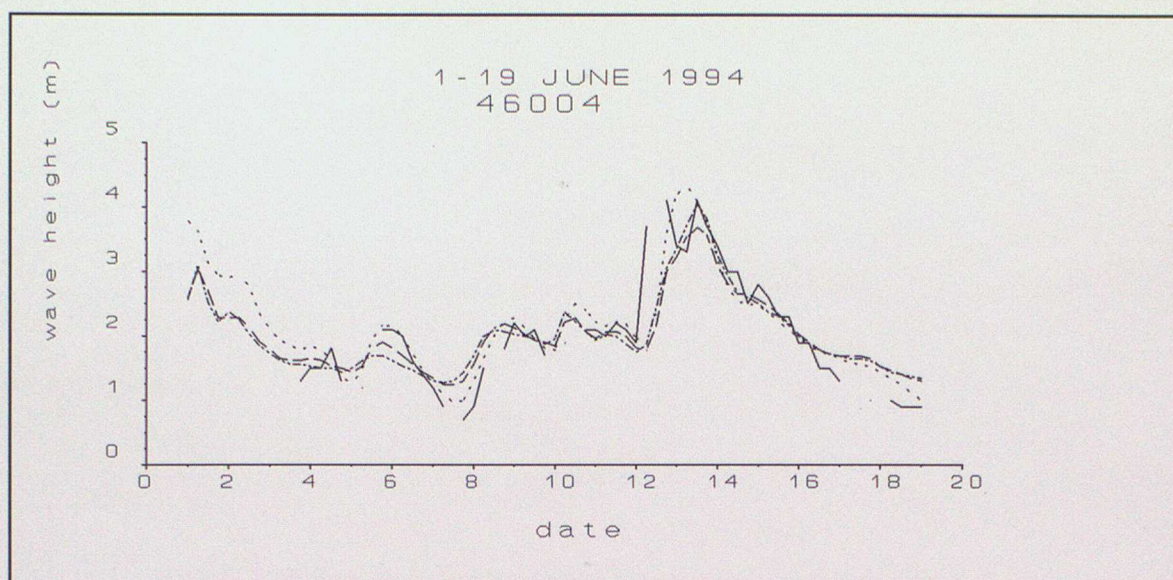


Figure 6(b) Timeseries of wave height at Buoy 46004

At Buoy 46004, the UKMO model started with waves slightly higher than WAM, but there were no observations to indicate which was better. The UKMO model closely followed observed values on the 6th, a peak that was missed by WAM by some 0.25m. None of the models matched the observed lowest wave height on 8th, but the UKMO model wave height decreased and subsequently grew faster than WAM during this period. All models missed the rapid growth observed on the 12th, starting 6 to 12 hours later than observed. The UKMO model reached the observed maximum of 4.5m, but again the timing was incorrect. The WAM model on the reduced grid had a higher wave height than on the operational grid on 14th, and was closer to observed. The decrease in wave height from 14th onwards was well captured in all models.

3.4.2.3 Western Atlantic

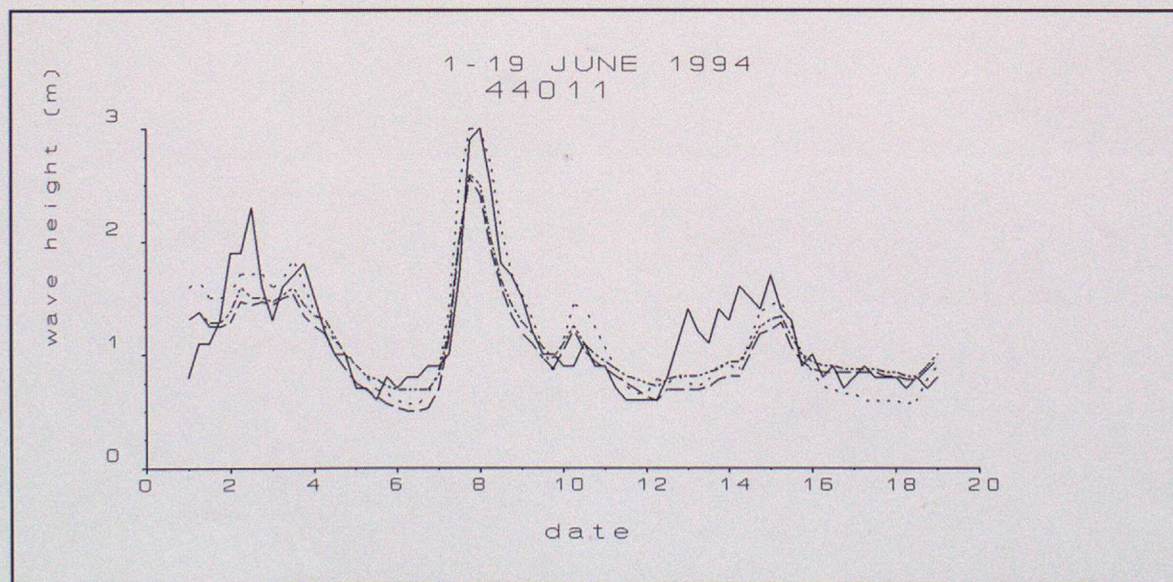


Figure 6(c) Timeseries of wave height at Buoy 44011

At Buoy 44011 the model wave heights were close, except for the storm of June 8th. Here the UKMO model matched well the observed maximum of 3m, with a good fit to the observed rate of growth and subsequent decrease in wave heights. The timing in WAM was good, but the WAM model only reached

2.5m, missing the observed value by 0.5m. Wave growth stopped too soon in the WAM model. However for this storm the maximum model windspeed was 12.3ms^{-1} , stronger than the observed 9.75ms^{-1} . From the 12th onwards observed winds were below 5ms^{-1} . Model winds were slightly stronger, increasing to 7ms^{-1} on the 15th. All models missed the wave height episode on 12th-14th June by some 0.5m. This was probably due to errors in the forcing winds, remote from the buoy site.

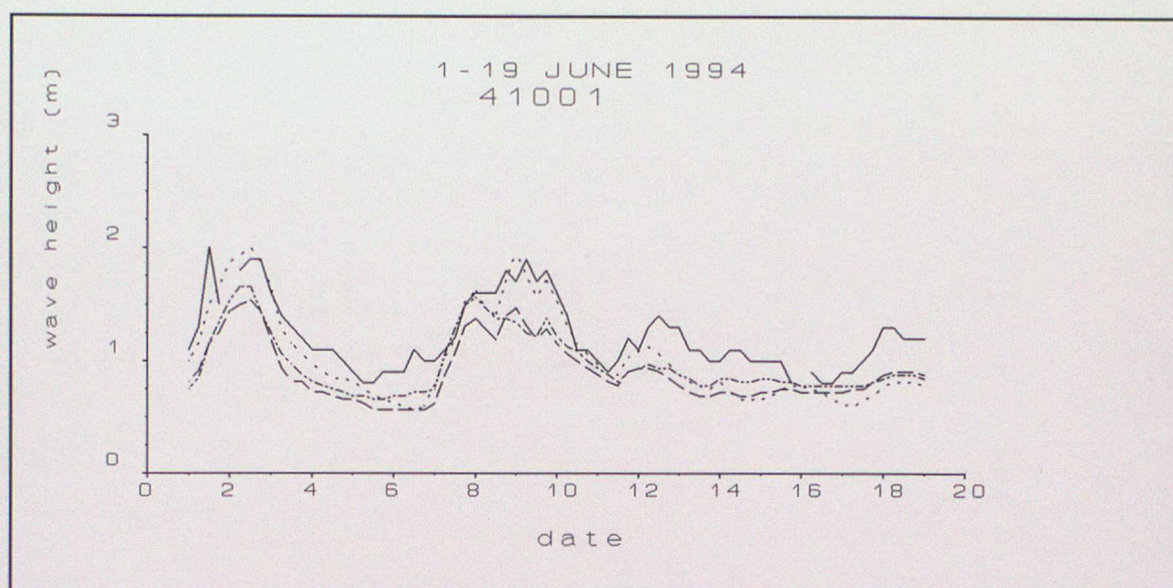


Figure 6(d) Timeseries of wave height at Buoy 41001

All models missed the observed peak of 2m at Buoy 41001 on 1st June, but matched the evolution of the maximum on 2nd-3rd June. The UK model maximum was close to observed, the WAM missed by some 0.3m, at both resolutions. All models were lower than observed on 6th June, but model wave heights increased rapidly so that the UK model matched the observed maximum between 9-10th June. The detailed time variation in wave height during this period was well modelled by all, but WAM wave heights were some 0.5m lower than observed. As at Buoy 44011, all model wave heights were lower than observed during 13-14th. Observed and model windspeeds were close, and lower than 5ms^{-1} from 13th to the 19th. All wave models finished the period with waves some 0.3m lower than the observed heights of just over 1m.

3.4.3 Overall impressions from the timeseries:

To summarise for both the summer and winter cases, wave heights from both models were generally close, reflecting the model response to the forcing winds. The most noticeable differences between the models arose when the WAM model did not reach the peak observed wave height, and the UKMO model was able to. This happened in every storm at both the Atlantic buoys in both summer and winter cases. Only on two occasions at the NE Pacific buoys in winter did WAM perform as well as the UKMO model in reaching observed maximum wave heights in storms. Conditions at the Atlantic buoys may be limited by fetch, as they are close to the eastern seaboard of the USA. Both models generally were close to observed wave heights in the minima, so this may further indicate that WAM did not reduce wave height sufficiently after reaching the maximum, for if the initial wave height in WAM were higher then wave height in the minimum might be too high. Apart from these instances, whenever the largest differences between model and observed values occurred, the models values usually were close. This suggests that either any deficiency is common to the formulation of both models, or that a wave generating event is missed by the wind field, perhaps locally for windsea, or remotely for swell.

On several occasions at the Atlantic buoys, the wave models did not reach the observed maximum wave height, even though the model winds were close to observed in both speed and timing. On one occasion the UKMO model reached the observed wave height, but the model windspeeds were stronger than observed. This reinforces the suggestion that level one windspeeds in the model may be light.

3.5 Wave energy Spectra

In this section selected 2D spectra at the moored buoy locations are compared, to highlight features of model performance. However no observations are available, so it is not possible to decide which spectrum is correct.

The plots are of the wave energy spectrum in frequency and direction, shown in polar representation. Frequency increases from zero at the centre to 0.4Hz at the box boundary. The direction, taken from the box centre outwards, gives the direction of travel of the wave energy. A small amount of noise may be generated at the low frequency contour by the interpolation used to produce the plot. Contours are of $\log(\text{energy})$, with contour interval 0.2, and lowest contour value -0.2.

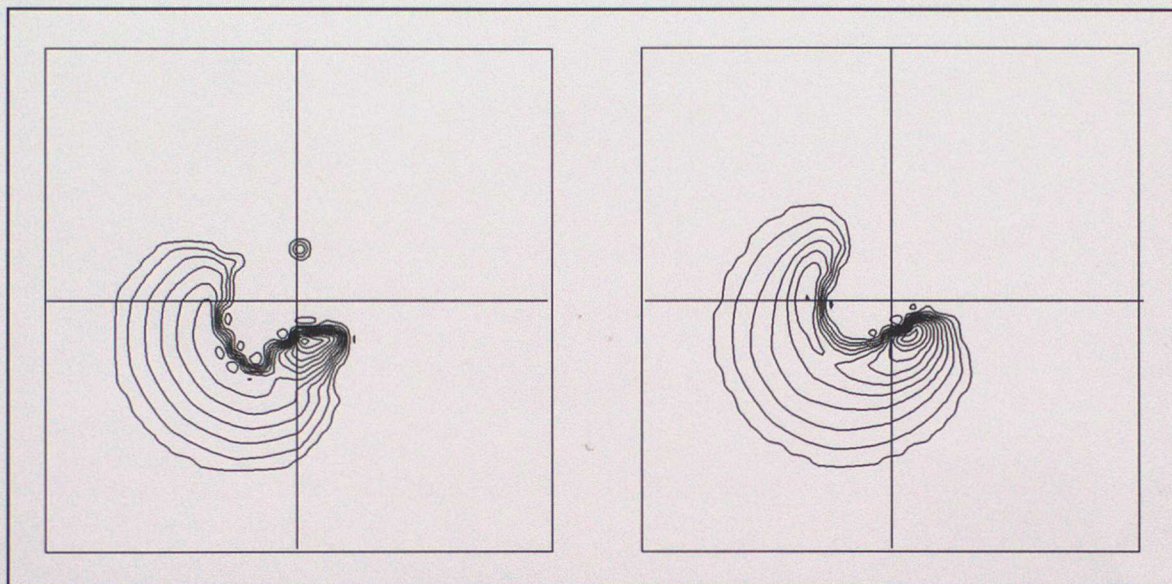


Figure 7 Wave energy spectrum at gridpoint (166,77) near Buoy 51004 in the central Pacific, at 06z 1/1/1992. (left) in the UKMO wave model, (right) in the WAM model.

The spectra in Figure 7 show several distinct wave systems: (1) the waves under the Trade winds, heading westwards or southwestwards; (2) swell travelling towards the southeast, and (3) in the UKMO model spectrum, swell travelling northwards. There are several differences between the spectra. In WAM the peak energy of (1) is travelling almost due west, in UKMO the peak direction is rather more south of west. The swell generated in the N Hemisphere (2) is similar in both, but at higher frequencies the energy is removed from the UKMO model spectrum. The swell from the southern hemisphere (3) is not present in the WAM model.

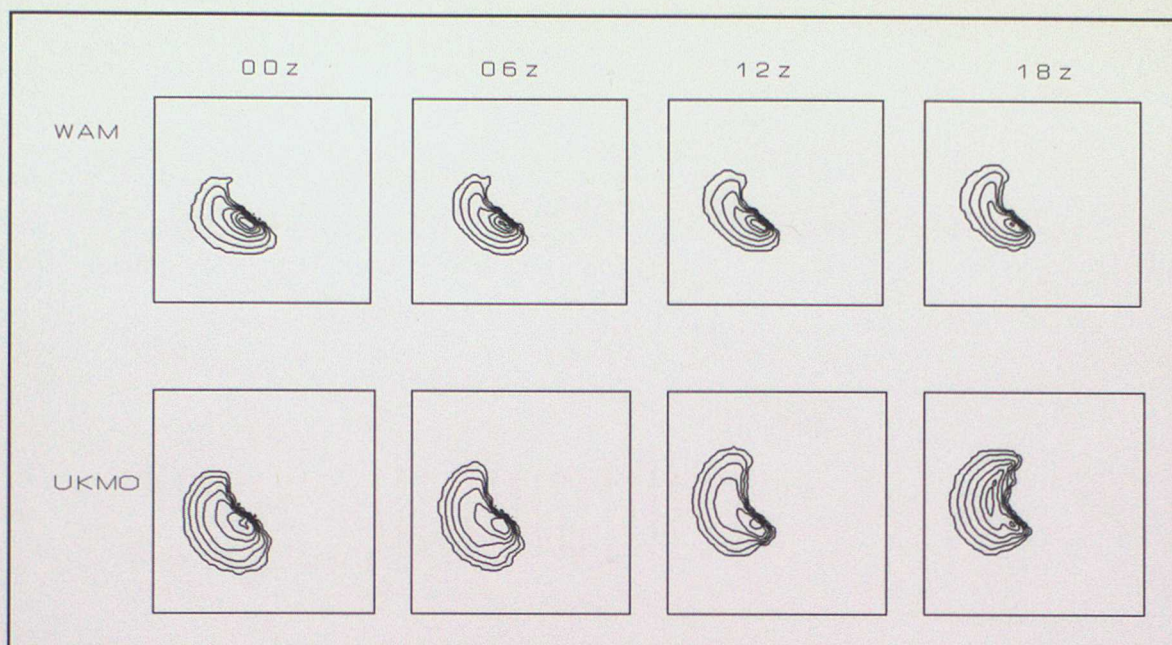


Figure 8 Model spectra at Buoy 41001 on 2/1/1992 (turning winds).

Figure 8 shows a sequence of spectra at intervals of 6 hours, during a period with turning wind direction near Buoy 41001. The model winds turned from SW towards slightly north of west. Wave spectra in both models are similar and the same main features are present in both. The peak of the spectrum is turned faster in the UKMO wave model. Wave height in the UKMO model is 2m, and in the WAM model around 1.8m. The observed wave height increases from 2.5m to 3m. [see Figure 5(g)]

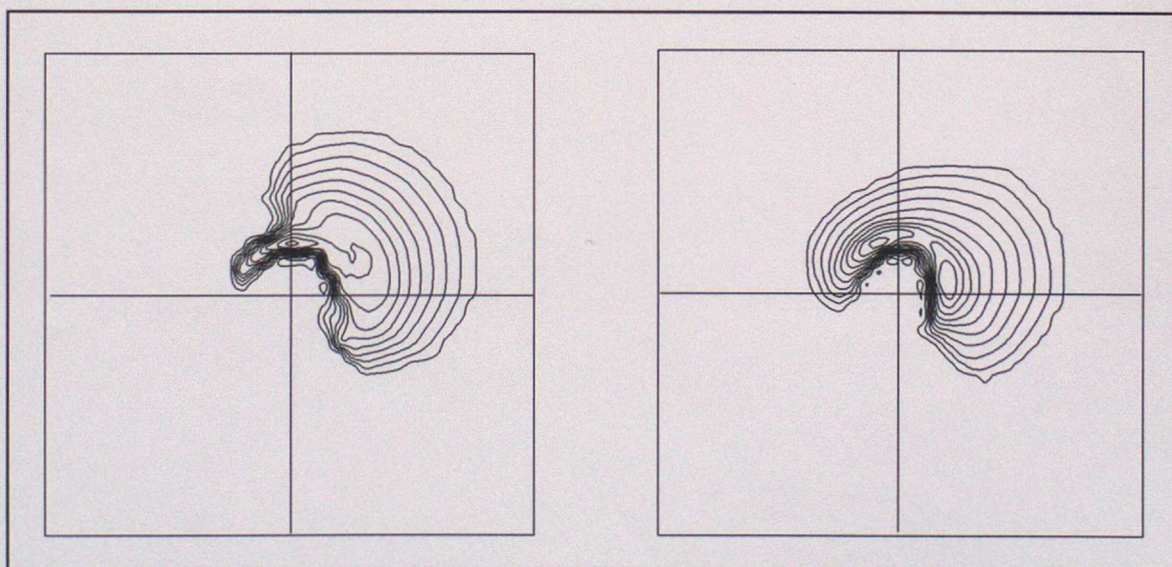


Figure 9 Model spectra at Buoy 46004 (point 180,36), 00z 2/1/1992. (left) UKMO and (right) WAM.

The spectra in Figure 9 show clearly the problem with 'poaching' of wave energy associated with the windsea-swell separation in the UKMO model. Both spectra show two distinct wave systems - swell heading towards the northwest, and growing and turning windsea heading northeast. For each spectrum the wave height is just over 4m. The peak energy of the swell in the UKMO model spectrum is travelling more northwards compared to the northwesterly swell in WAM. The UKMO model swell energy at low frequencies covers almost the same directional spread as in the WAM spectrum, but at higher frequencies the UKMO model has no energy in the swell system heading northwest - this energy has been counted as windsea in the model and placed with the windsea system heading northeast. This 'poaching' can take place

at any gridpoint following generation of swell energy - the lowest frequency that will be 'poached' depends on the model windspeed, as the lowest frequency for integration of windsea energy is taken to be 0.8 times the Pierson- Moskowitz frequency for that windspeed. This problem is most likely to affect swell passing through areas with strong winds, with a wind direction within 90° of the direction of swell propagation

4 Equilibrium wave heights at low windspeed

When a wind blows for long enough from a constant direction, and over sufficiently long fetch, an equilibrium sea state is established where the spectral energy source and transfer terms are in balance for each frequency and direction component. For high windspeeds it is unlikely that this equilibrium sea state will be attained in practice, as this requires the wind to blow for longer than a day, and over a fetch of several thousand kilometers. However for low windspeeds the conditions for an equilibrium sea state may readily be met.

Figure 10 shows the equilibrium wave height reached at low windspeeds in the UKMO model, and in the WAM model at operational global resolution. The UKMO model reaches the Pierson Moskowitz (Pierson and Moskowitz, 1964) limiting value, but the WAM model for all windspeeds below 6ms⁻¹ reaches a constant limiting wave height of around 0.7m, which is greater than the Pierson Moskowitz limit. This must be because of the spectral form required to obtain a balance of source terms at equilibrium. Model and JONSWAP spectra for a 10m windspeed of 5m/s are shown in Figure 11. The WAM spectrum is more peaked, and has the peak at a lower frequency. There is less energy at higher frequencies.

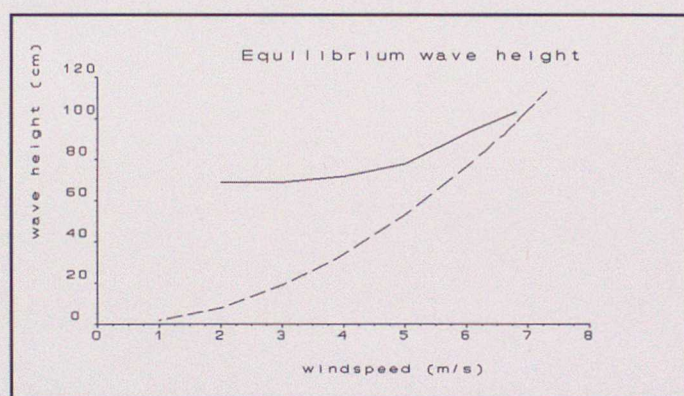


Figure 10 Equilibrium wave heights at low windspeeds, for duration limited wave growth. UKMO model shown dashed. WAM on 'operational' global resolution grid shown solid.

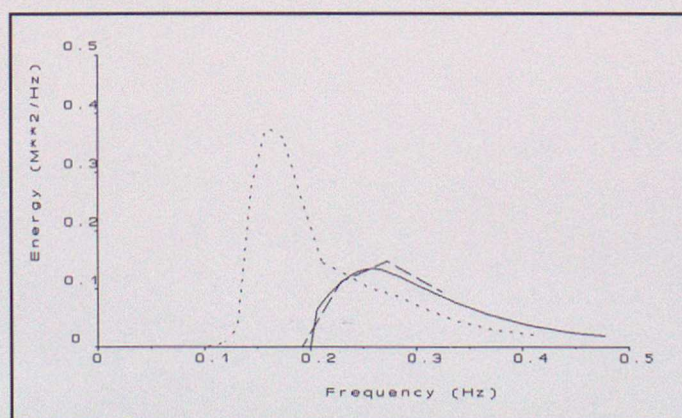


Figure 11 1D spectra for a 10m windspeed of 5ms⁻¹. WAM model shown dotted, UKMO model shown dashed, and JONSWAP shown solid. Windspeed used to calculate the UKMO model result was $U_{10}/0.94$

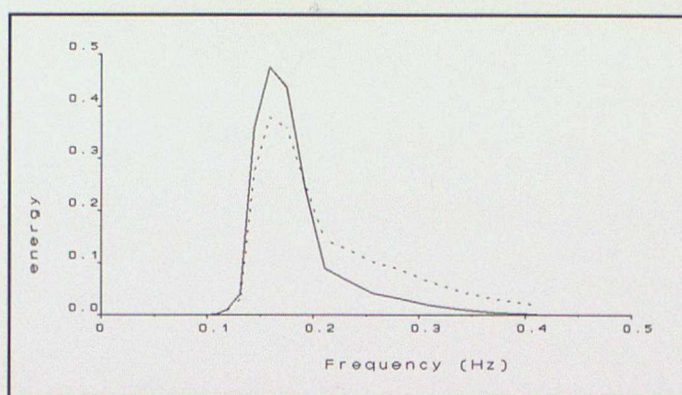


Figure 12 WAM model fully developed spectra for 10m windspeeds of 5ms^{-1} (dotted) and 3ms^{-1} (solid). The spectrum for a windspeed of 1ms^{-1} is identical to the spectrum for 3ms^{-1}

As windspeed increases from 3ms^{-1} to 5ms^{-1} the energy in the high frequency ($>0.2\text{Hz}$) part of the WAM spectrum increases, and the energy at the spectral peak decreases, although the wave height is barely altered. As shown in the schematic Figure 13, the wind input term at high frequencies is balanced by both nonlinear transfer and dissipation. Near the peak of the spectrum the balance is between nonlinear transfer and dissipation. For low windspeeds the nonlinear transfer calculated in WAM is forcing the energy at the peak of the spectrum to grow until balance is achieved with the dissipation calculated from the spectral form shown in Figure 12.

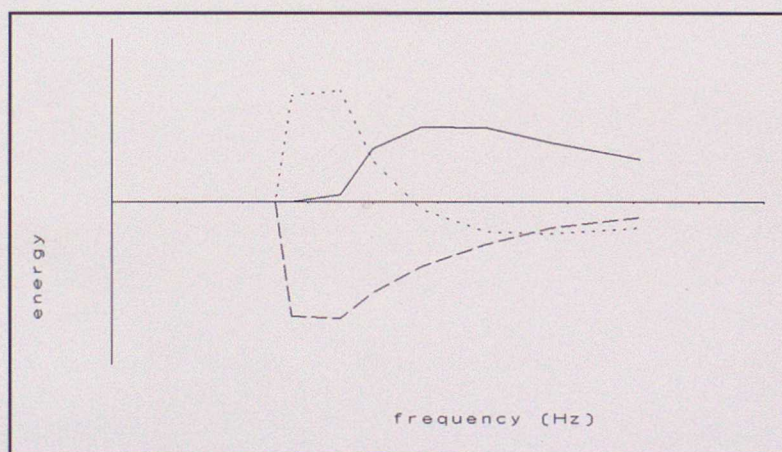


Figure 13 Schematic of the balance of energy source terms at equilibrium. Wind input (solid), dissipation (dashed) and nonlinear transfer (dotted)

5 Costs and timings

The elapsed time for a run of the WAM model depends critically upon the model configuration, and upon the number of blocks into which the grid is split. The calculation of nonlinear transfer in subroutine SNONLIN takes over half the CPU time, and timings are improved with this subroutine singletasked rather than multitasked.

At the operational global model resolution, using propagation and source timesteps each of 1200 seconds, and using approximately 6% of the available C90 in batch, a run in 14Mw of the 7 block WAM model took 596 seconds elapsed for a 24 hour forecast. For the three block version run in 32Mw the corresponding time was 425 seconds. Elapsed time for the UKMO model, with 10% of the C90 used, running in 14Mw, was 176 seconds (Figure 14). The best configuration of the WAM model cray resolution grid takes approximately two and a half times longer than the UKMO wave model. The elapsed time for the best

configuration of the WAM model using the reduced resolution global grid was 117 seconds, using 12.1% of the available C90 processors. For runs in batch, WAM on this grid costs about the same as the UKMO wave model on the operational grid.

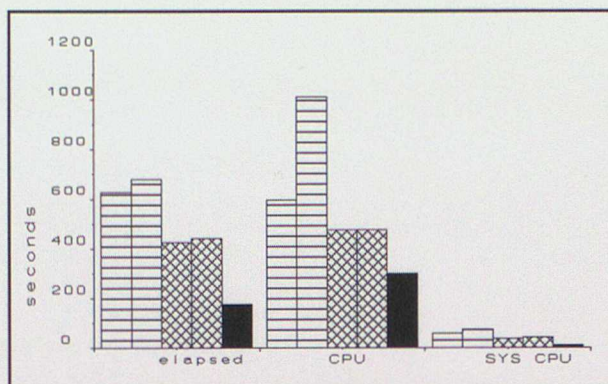


Figure 14 Elapsed, user CPU and system CPU times for a 24 hour run of the WAM model on the operational global grid. The first two bars (horizontal lines) are for the 7 block version run in 14Mw a) with SNONLIN singletasked and b) with SNONLIN multitasked, with no directives included. The third and fourth (crosshatched) bars are for the 3 block and 4 block versions run in 32Mw, both with SNONLIN singletasked. The solid bar is for the UKMO wave model.

On the shallow water European wave model grid, a 24 hour run of the WAM model including shallow water physics and depth refraction took 437 seconds elapsed, with 6.6% of available C90 processors. Corresponding time for the UKMO wave model was 144 seconds elapsed, with 7% of the available C90. These figures are for runs without boundary data. For the shallow water European model WAM takes three times longer than the UKMO wave model (Figure 15). Source timestep for the UKMO model was 1800 seconds, for WAM was 600 seconds, as required by the advection scheme for numerical stability.

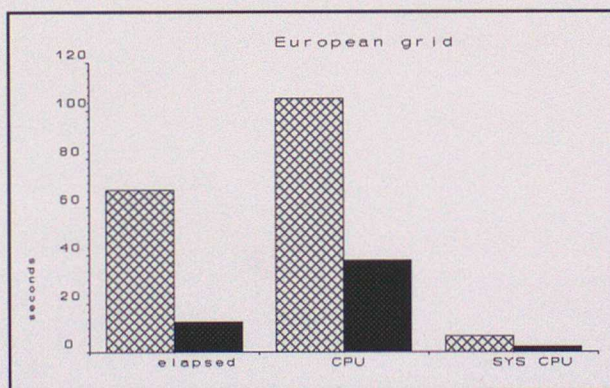


Figure 15 Timings for a 24 hour run on the resolution and area of the European waters grid, including shallow water physics. WAM model cross hatched, UKMO wave model solid.

5.1 Optimising the autotasking of WAM

To optimise the autotasked performance of WAM the following points should be noted.

- have as few blocks as possible for the given grid. (Note this will be constrained by available memory).
- One block is best, if the model will fit in memory. This is not possible on the UK Met Office C90 for the UKMO operational resolution global grid, which would require approximately 56Mw. (Two blocks will not fit in 32Mw)

- Multitasking without any other directives increases both CPU and elapsed time for a model run in the one block version of the coarser resolution global grid. In particular subroutine SNONLIN is not effectively autotasked. System CPU is increased by a factor of four over a singletasked model.

- Selectively adding directives `cfpp$ NOCONCUR L` to those loops identified by *atexpert* as having small speedups (less than 1.5) can increase performance to about as good as that of the corresponding model with subroutine SNONLIN single-tasked. Details of the loops selected are given in the appendix.

Typical values for a run of 24 hours under constant winds with the one block reduced resolution global grid WAM model are shown in Figure 16.

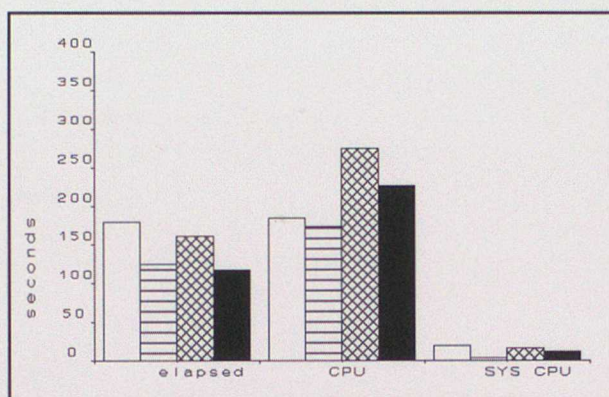


Figure 16 Improving the autotasking: Elapsed, user CPU and system CPU timings for a 24 hour run on the reduced global grid under constant windspeed. The blank bar is the three block configuration run in 14Mw, the horizontal lined bar is the one-block version run in 32Mw, both with SNONLIN singletasked. The crosshatched bar gives timings for the one-block version with SNONLIN multitasked, with no amendment. The solid bar gives the results following analysis with *atexpert*, with selected do loops specified for singletasking. (The results discussed here are for the WAM model autotasked using 'fpp' on a Cray C90 computer)

6 Discussion

Differences between wave height and wave period predicted by the revised UK Met Office wave model, and values predicted by the WAM model using the same forcing winds, are generally small. Both models are capable of simulating observed wave conditions for the wide range of wave conditions experienced globally. However the WAM model systematically underestimates the maximum wave height in storms, particularly at buoys in the western Atlantic near the coast of the USA. Wave growth in WAM in such cases can be slower than observed, and often stops earlier than the observed wave growth, so the observed maximum wave height is not reached.

There are differences between model predictions in the detail of the wave energy spectrum. However observations are not available to distinguish which model is 'best' in a given situation.

Running at the same resolution, the WAM model costs approximately two and a half times the elapsed and CPU time of the UK Met Office wave model. WAM model restart files are five times the size of the UKMO model restart files (details are given in Holt 1994a).

For both case studies the WAM model at the reduced resolution performed as well as on the higher resolution operational global grid, using winds at the resolution of the operational grid.

The tendency for the WAM model to grow windsea too slowly, and to not reach observed peak wave heights in storms has been noted also by other users, both in routine 'operational' running and in hindcast studies of extreme storms. There are several known shortcomings in the WAM model that may contribute to

this. The poor initial growth of windsea, and growth in light winds was addressed by Tolman (1991) who proposed extending the frequency range and resolution, and including a linear growth term to initiate wave growth from rest (similar to that used in the UKMO wave model). However these amendments were not included in the WAM model cycle 4. It would not be straightforward to include the linear growth term, as care must be taken regarding the interaction with the 'spectral tail' of wave energy used in the calculations of nonlinear transfer.

The standard WAM model does not take account of sea-ice, and the global hindcasts presented in this report did not include ice information. As the WAM model is being implemented quasi-operationally at several centres, this is starting to be addressed. However the inclusion of ice data in the model introduces the need to improve the representation in WAM of wave growth from rest, to cope with a receding ice edge.

The WAM model has a very simple first-order advection scheme - there is some concern that it is too simple. A third-order advection scheme has been tested (Bender and Leslie, 1994) for extended runs in the Southern Hemisphere, and shown to be an improvement. The same report discusses the relative merits of the WAM cycle 3 growth terms (Snyder, 1981) and the WAM cycle 4 terms (Janssen 1991), concluding that the cycle 3 growth terms give best results for the Australian waters and the Southern Hemisphere. Tolman (1991) has compared results from the WAM advection scheme with a flux-corrected scheme, showing how the first order scheme is dissipative, and cannot preserve the shape of a test pulse of energy.

There are also known shortcomings of the UK Met Office second generation wave model, mainly associated with the method for separating windsea from swell in the model spectrum. In certain circumstances this can remove swell energy from a wave system, and include this energy in the windsea, so altering the energy spectrum. This may be helped by developing an improved filter to distinguish between windsea and swell when reshaping the spectrum. Also, as pointed out during the 1994 revision of the wave model (Holt 1994b), the wave growth term should be based on current theories of wave growth, and the model 'physics' recalibrated, before developing a coupled wave-atmosphere model.

7 Conclusion

The revised UK Met Office wave model has been compared with the WAM model cycle 4, run at the resolution of the UK Met Office operational global wave model, using Met Office NWP winds. The WAM model was also run on a coarser resolution global grid.

Verification against measurements of wave height and wave period from representative buoys showed that the WAM model was only slightly affected by decreasing the resolution of the global grid.

In both summer and winter case studies the largest differences between observed and modelled values of significant wave height arose from deficiencies in the forcing winds - on such occasions both model values were close, but different from observed. The most frequent systematic difference between modelled values arose for the prediction of maximum waves in storms, measured at buoys in the western Atlantic or in the NE Pacific. Here the UK Met Office wave model was closer to the observed value, whereas the WAM model did not reach the observed maximum wave height.

Differences in detail were present in the wave energy spectra. This clearly identified the need for improvement in the process separating windsea from swell in the UK Met Office model.

Windsea growth in storms was perhaps the weakest feature in WAM. The observed extreme wave heights were not reached, and wave growth in the model slowed earlier than in the observations.

For low windspeeds the WAM model equilibrium wave spectrum varied only slightly with windspeed, and was quite different from the Pierson Moskowitz spectrum. Wave heights were higher than expected, and the spectral peak was at a lower frequency than expected.

Both models are capable of accurate predictions of wave height and period, given good quality wind data, but there is scope for improvement in the formulation of both wave models. However the UK Met Office wave model makes the best predictions of maximum wave height in mid-latitude storms, particularly in the western Atlantic.

The response of the wave models is sensitive to the quality of the forcing winds, and may be affected by errors in timing, position and amplitude of storms, both locally at the measurement sites, and also remote storms where swell is generated. Comparison with observations, and comparison of observed and modelled windsea wave heights, suggests that model level one windspeeds from the operational UKMO NWP model may be light.

References

- | | | |
|---|-------|--|
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Appendix - modset to improve autotasking of WAM model and routine SNONLIN.

```
*i SNONLIN.156
c ** disable autotasking for loop 2001
cfpp$ NOCONCUR L
*i SNONLIN.161
c ** disable autotasking for loop 2002
cfpp$ NOCONCUR L
*i SNONLIN.220
c ** disable autotasking for loop 2114
cfpp$ NOCONCUR L
*i READWND.2
c ** disable autotasking for readwnd
cfpp$ NOCONCUR R
*i WAMWND.100
c ** disable autotasking for loop 3101
cfpp$ NOCONCUR L
*i PROPAGS.569
c ** disable autotasking for loop 3131
cfpp$ NOCONCUR L
*i PROPAGS.573
c ** disable autotasking for loop 3132
cfpp$ NOCONCUR L
*i IMPLSCH.140
c ** disable autotasking for loop 1201
cfpp$ NOCONCUR L
*i IMPLSCH.326
c ** disable autotasking for loop 2544
cfpp$ NOCONCUR L
*i IMPLSCH.351
c ** disable autotasking for loop 2601
cfpp$ NOCONCUR L
*i IMPLSCH.357
c ** disable autotasking for loop 2602
cfpp$ NOCONCUR L
*i SEMEAN.56
c ** disable autotasking for loop 1001
cfpp$ NOCONCUR L
*i FEMEAN.70
c ** disable autotasking for loop 1001
cfpp$ NOCONCUR L
*i WAMWND.2
c ** disable autotasking for wamwnd
cfpp$ NOCONCUR R
*i STHQ.2
c ** disable autotasking for sthq
cfpp$ NOCONCUR R
*i SEMEAN.87
c ** disable autotasking for loop 3001
cfpp$ NOCONCUR L
*i STRESSO.90
c ** disable autotasking for loop 2100
cfpp$ NOCONCUR L
*i STRESSO.112
c ** disable autotasking for loop 2300
cfpp$ NOCONCUR L
```

```
*i SEPWISW.102
c ** disable autotasking for loop 2003
cfpp$ NOCONCUR L
*i PEAKFR.53
c ** disable autotasking for loop 1000
cfpp$ NOCONCUR L
```