Forecasting Research

Short Range Forecasting Division

Technical Report No. 8

WAM / UKMO
Wind Wave Model Intercomparison
Summary Report

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January 1992

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A four-way wind wave model intercomparison has been carried out using the wave and NWP models of ECMWF and the UK Met Office. The hindcasts were run for the month of November 1988, which was a period used previously in an assessment of an earlier version of the WAM model (Zambresky, 1989), and model results were compared against buoy observations. The WAM model (WAM group 1988) implemented at ECMWF is a 'third generation' model, using the discrete interaction approximation (Hasselmann et al 1985) to approximate the nonlinear transfer of wave energy by wave-wave interactions. The UKMO wave model (based on the description in Golding, 1983) is a second generation model, in which the nonlinear transfer is parametrized. A parametrization of directional relaxation of the spectrum in turning winds is included. The UKMO model has 13 frequency components, in the range 0.04Hz to 0.324 Hz, and the WAM model uses 26 frequencies, covering the range 0.042Hz to 0.41Hz.

Wind fields were taken from the archived data of the assimilation runs of the NWP models at ECMWF (Tiedtke, et al 1988) and the UK Met Office (Bell and Dickinson, 1982), so the wind fields come from the NWP models that were operational during November 1988. The wave models were both run on a global grid with 3º resolution in latitude/longitude and with 15º resolution in direction. This ensures that any differences in results arise from model formulation alone, not from the effects of resolution. Because the UKMO wave model uses winds from the lowest level of the NWP model (nominally 19.5m) the ECMWF windspeeds were scaled up from a height of 10m assuming neutral stability (a factor 1./0.91) before use in the UKMO wave model, and the reverse scaling was applied to reduce UKMO windspeeds to 10m height before use in the WAM model. Both models were 'cold-started' which leads to an expected small negative bias in wave heights over the first few days. The impact of this is evident from the timeseries.

For several buoys, output from the nearest model gridpoint is compared with observations. The buoy locations are shown in Figure 1. A summary of the verification statistics for windspeed is shown at Figure 2a, and for wave heights at Figure 2b, with the buoys grouped by geographic location. From Figure 2a it appears that the UKMO and ECMWF windspeeds were in fact close, so the rescaling of UKMO winds to 10m over-reduces the windspeed, and the corresponding rescaling of ECMWF winds for use in the UKMO wave model seems to have produced windspeeds slightly too strong, particularly in the N Atlantic. This is borne out by the wave height statistics (Fig 2b). Only in the central Pacific at Buoys 51001 and 51002 is the bias of ECMWF windspeeds closer to the bias of UKMO reduced windspeeds than to the bias of the unaltered UKMO windspeeds.

It is convenient to discuss the models' performance in each of the three geographical areas :

In the Central Pacific all model and wind combinations have a negative bias, Fig 2b, however the bias is greatest in the UKMO wave model with UKMO winds. The bias of the enhanced ECMWF windspeeds at the Hawaiian buoys is similar to the bias of the unaltered UKMO windspeeds, yet the UKMO model wave height bias is reduced when run with enhanced ECMWF winds. This suggests that the ECMWF winds are stronger than the UKMO winds in the Pacific mid-latitude storm tracks, leading to higher swell reaching Hawaii from mid-latitudes. This hypothesis is supported by the figures for the NE Pacific buoys, discussed in the next section. In the Central Pacific the UKMO wave model performed poorly both in absolute terms and relative to the WAM model. It has been suspected for some time that there is a deficiency in the representation of Pacific swell in the UKMO model; this is confirmed by these results. A comparison of 2-D spectra shows that the UKMO model has less swell coming from the NW Pacific than does the WAM model and also that for at least one occasion of several days duration the swell in the UKMO model is travelling in a more southerly direction than the swell in the WAM model (Fig 3a), by at least two direction bins. This is the case for both windfields and so the difference arises due to the model treatment of swell. However on a later occasion both models place the swell in a similar direction (Fig 3b), so the difference is not always present. From Figure 3 a) and b) it also appears that the northward moving swell on this occasion arrives later at Buoy 51002 in the UKMO model.

Comparison of model 1D spectra at Buoy 51002 for several swell episodes shows that, in general, the amplitudes of swell energy in the lowest swell frequencies (around 0.07 Hz) are similar in both models. It is in the range around 0.1 - 0.2 Hz that the UK wave model is systematically lower in wave energy than the WAM model and observations (Figures 3c, 3d). Both the models however have low wave heights in the Central Pacific, and this may in part be due to the formulation of the dissipation scheme, which is essentially the same in both models. The dissipation scheme was developed primarily to ensure an energy balance in fully developed windsea and it is known that swell energy may be over-reduced, particularly in the presence of light winds. Further loss of swell energy from the UKMO model may be associated with the swell/windsea separation which is inherent in a second generation model. It is probable that swell energy is removed from the UKMO model by the re-shaping of the windsea spectrum following windsea/swell separation, if any swell energy overlaps the definition of windsea. This is most likely to occur for swell around 0.1Hz and where the swell direction is distinct from, but within 90° of the wind direction. Such chopping of swell energy between the region of generation and the point of observation will also reduce the directional spread of swell in the UKMO model, as shown by comparing the southward moving swell in the WAM and UKMO models in Figure 3 a) or b). This middle-frequency 'energy gap' does not appear in the WAM model, which nearly always shows a single peak close to 0.12Hz in the 1D spectrum (eg WAM model, Figure 3d). The buoy data often shows a single peak in the 1D spectrum, close to 0.1Hz, slightly lower than the peak in the WAM model. However examination of WAM model 2D spectra shows the single model peak to contain contributions from more than just one of the separate swell systems present. There is little separation in frequency between the swell and windsea spectral peaks in the WAM model at Buoy 51002. It is also noticeable that energy levels at higher frequencies in the WAM model are often lower than in observations when developing new windsea in the presence of swell - eg Figure 3c. The UKMO model values are close to observed. This is in a range of frequency where all three source terms are important, and it is possible that the stronger nonlinear interaction between swell and windsea in the WAM model is affecting the energy balance at the higher frequencies.

Figure 5a shows a timeseries of wave height at Buoy 51002 in the Central Pacific, showing a systematic bias for the UKMO model with UKMO winds. The UKMO model value is persistently between ½m and 1m below the observed, and in addition the peak event of November 6th is missed. By comparison the WAM model with both ECMWF and UKMO winds was closer to the observed value for much of the time, but had lower variability in wave height, and missed the increase in height starting on November 22nd. We are unable to account for these differences as (Fig 3a, 3b) there are usually three distinct wave systems present, and lacking detailed 2D observations it is impossible to say in which of these systems the model differs from observations.

In the NE Pacific the unaltered UKMO and ECMWF windspeeds agree closely with observations at Buoys 46001 and 46002, and are marginally higher than observed at Buoy 46003 - a bias of +1.01m/s for ECMWF winds. Both models have a negative bias in wave height at Buoys 46001 and 46002, again the UKMO model being lower than WAM. The WAM model has a small positive bias in wave height at 46003. Although UKMO and ECMWF windspeeds agree closely at the buoy locations the wave height verification shows the UKMO model to have a greater negative bias than the WAM model, supporting the hypothesis that ECMWF winds are stronger than UKMO winds in mid-Pacific. Indeed the verification of wave heights in the NE Pacific is much improved for the UKMO model run with enhanced ECMWF winds. Examination of the timeseries (Fig 5b) shows that at Buoy 46002 both models missed completely two peaks in observed waveheight. Examination of charts for these times (Fig 6) shows that both models had centres with peak wave heights close to that observed at 46002, but placed one or two grid lengths to the north of the buoy. It appears that grid resolution of the wave grid, and possible small errors in position of the depression centre in the NWP model are contributing towards the mean negative bias. Buoy 46002 is always close to and downwind of depressions in the mid-latitude Pacific storm track, and it was noted by Zambresky (1989) that apparently swell radiating from close by depressions was not well modelled at 46002, whilst present in the observations. It seems that this remains a difficulty even in Cycle 3 of the WAM model, and also in the UKMO model. The mean values of observed windspeed and wave height, both observed and modelled, are shown in Figure 2c and 2d. It is clear that the mean windspeed observed at Buoy 46003 is greater than that observed at 46002, yet the observed mean wave height is higher at 46002. This may be explained by the presence of more swell in the observations at 46002 than is present at 46003, or it may be that, occupying a different position relative to the mean storm track, the conditions at 46003 are dominated more by rapidly turning winds as the depressions passing over 46003 continue to develop.

In the Atlantic all buoys used in the verification are close to the coast of the USA, near the Gulf Stream, with depths close to 200m. Given the predominant mid-latitude westerlies the majority of cases will be fetch and duration limited development of windsea. Further, as the buoys are situated downstream of the data rich USA we may expect accurate surface analyses from the NWP models. This is indeed the case, as the verification results show that both wave models perform best in this region. The uncorrected model winds are closest to observations, and the wave models run with their own winds verify well, though with a small negative bias as may be expected from the cold start. Examination of a time series (Fig 5c) shows that all peak events were accurately modelled by both wave models and for both sets of winds. Thus the characteristics of growth of windsea are similar in both wave models, and NWP models provided accurate analyses. A comparison of 2-D spectra identified several cases with turning winds, and one of these is shown at Fig 4. The response of windsea to a turning wind is a result of the wave-wave interactions, which are calculated in third generation physics, but which are parametrized in second generation physics. This particular case shows that for the same wind field (Fig 4a,b) there is little difference in position of the peak of the spectrum as the wind turns, confirming the effectiveness of the UKMO model parametrisation. However it should be noted that the detailed rate of turning of waves is frequency dependent (and thus windspeed dependent) and the stronger winds in the WAM/ECMWF run (Fig 4c) result in a lower peak frequency. This leads to a difference in angle turned between 06z and 12z between the WAM/UKMO and WAM/ECMWF runs in this case, although by 00z 22nd all models have a similar direction for the sea. Because the UKMO model imposes a cosine squared distribution about the wind direction after reshaping, the directional spread of the wind-sea spectrum is less than in the WAM model as the turning takes place, however this does not affect the position of the spectral peak.

Summary

An exhaustive four-way wind wave model intercomparison has been carried out using modelled data for a one month period,thus allowing a comparison with observations. This is in contrast to previous model intercomparison studies which have used idealised wind fields on cartesian grids.

Various lessons were learnt during the intercomparison, and the important points to note for any future studies are :

- Both models should use the same grid and land-sea mask, and the same directional resolution. This ensures that any differences arise from model formulation alone.

- Care should be taken to ensure that the wind fields used are at the correct nominal height for use by each wave model, although our experience in this study showed that there was in fact little difference in nominal height of the wind fields output from the NWP models, when compared with observed "10m" windspeeds.

- For comparison output from both models should be plotted using a common chart plotting package - in practice the data from one centre must be transmitted to the other for processing. This allows a direct visual comparison and also the calculation of differences. It is also important to plot 2D and 1D spectra in the same way, as the visual impression of a spectrum is quite different when plotted normalised by maximum value using a linear contour interval, compared to a direct plot of Log (E).

- Useful conclusions were drawn from a study of both 2D and 1D spectra, as each presentation emphasised different aspects of model behaviour. The danger of using only normalised plots of 2D spectra was highlighted. Further conclusions were drawn from a comparison of modelled and observed 1D spectra. To gain a full understanding of the processes occuring in the model requires observations of the directional spectrum. Lacking such observations, all interpretation becomes speculative.

■ Future intercomparisons would benefit from the use of winds at a common height in both models, avoiding the need for arbitrary rescalings.

The study made use of timeseries of modelled and observed values at the various stations, calculated mean biases of wave height and windspeed for each station, global charts of wave height and direction, and 2D and 1D energy spectra for selected times and locations. The principal finding was that the UKMO model is deficient in swell, compared to observations and the WAM model. This is most noticeable in the Pacific and tropical regions. The results of this study suggest that the differences may in part be due to difficulties with the swell/windsea separation required in a second generation model, reducing swell energy as it travels between the point of generation and the point of observation. Both models have low wave heights in the Central Pacific, compared to observations at Hawaii. The dissipation term, which is of the same formulation in both models, may contribute to the loss of swell energy. It is known that the dissipation scheme used will over-reduce swell energy when any light wind is present. It is probable that both mechanisms described contributed to the loss of swell energy from the UKMO model, and there is scope for further development in these areas. The WAM model tended to have a single peak to the 1-D spectrum at Hawaii, at a frequency slightly higher than observed, and did not reproduce the double peaked spectra which were often observed. Contributions to the model peak came from both swell and windsea systems, which although distinct in direction, overlapped in frequency range. Growth of windsea in the WAM model at Hawaii appeared inhibited in light winds when any swell was present.

Both the wave models coped well with the fetch and duration limited windsea development at the buoys in the Western Atlantic.

Conclusions

■ Both wave models performed well in the NW Atlantic, with both sets of winds. This is mainly in situations involving fetch and duration limited growth of windsea. Verification shows both models wave heights slightly lower than observed, with the WAM model lower than UKMO.

■ The magnitudes of extreme events are forecast accurately by both systems, provided the synoptic development is correct in the NWP model.

■ A situation with turning winds showed good comparison between the two models. The UKMO model parametrization of this is effective.

■ Wave heights are systematically low in the Central and NE Pacific in both models. The UKMO model heights are lower than WAM, and the mean period of the UKMO spectrum is systematically shorter than observed. There is some evidence of a difference in the turning of swell after travelling large distances, and the directional spread of the UKMO model swell is less than in the WAM model.

■ The dissipation scheme, which is of the same formulation in both models, may contribute to the loss of swell energy.

■ The most significant difference between the two models is in the handling of swell. The UKMO model is deficient in swell energy particularly in the middle range of frequency, around 0.1 Hz. This may arise through difficulties associated with the separation of swell from windsea in a second generation model, as the swell travels between the point of generation and the point of observation.

■ In the presence of swell, development of windsea in the WAM model is slow, compared both to the UKMO model and observations. Windsea in the UKMO model in such cases is closer to observed. The stronger nonlinear interaction between windsea and swell in the WAM model may be affecting the energy balance at higher frequencies.

References

Bell, R S and Dickinson, A	1987	The Meteorological Office operational numerical weather prediction system. Sci Paper No 41, Meteorological Office, Bracknell (Pub HMSO)
Golding, B	1983	A wave prediction system for real-time sea state forecasting. QJ Roy Met Soc **109** pp 393-416
Hasselmann,S , Hasselmann , K , Allender, J H and Barnett, T P	1985	Computations and parametrisations of the nonlinear energy transfer in a gravity-wave spectrum, Part II: Parametrisations of the nonlinear energy transfer for application in wave models. J Phys O, **15** 1378-1391
Tiedtke,M, Heckley, W A and Slingo, J	1988	Tropical forecasting at ECMWF : The influence of physical parametrisation on the mean structure of forecasts and analyses. QJ Roy Met Soc **114** pp639-664
WAM group	1988	The WAM model - A Third Generation Ocean Wave Prediction model . J Phys O **18**, pp 1775-1810
Zambresky,L	1989	A verification study of the global WAM model December 1987 - November 1988. ECMWF Research Dept Technical Report No 63.

Figure Captions

Figure 1 Location of the buoys used in the study

Figure 2 a) Mean windspeed bias (m/s) at the buoy sites (all models).

b) Mean wave height bias (m) at the buoy sites (all models).

c) Observed and modelled mean values of windspeed at the buoy sites. (Unaltered model values)

d) Observed and modelled mean values of wave height at the buoy sites. (WAM model/ECMWF winds and UKMO model/UKMO winds).

Figure 3 Modelled 2D and 1D spectra at Buoy 51002, Hawaii, from the WAM model and the UKMO model, both with UKMO winds.

a) 2D spectra at 06z 20/11/1988

b) 2D spectra at 00z 26/11/1988

c) 1D spectra at 06z 20/11/1988

d) 1D spectra at 00z 26/11/1988

Figure 4 Modelled 2D Spectra at Buoy 41001, comparing the rate of turn of windsea in a turning wind, from 00z 21/11/1988 to 18z 21/11/1988. Time increases upwards in the figure.

a) WAM / UKMO

b) UKMO/UKMO

c) WAM / ECMWF

Figure 5 Timeseries of modelled and observed wave height (m):

a) At Buoy 51002, Central Pacific.

b) At Buoy 46002, NE Pacific.

c) At Buoy 44011, NW Atlantic.

Figure 6 Charts of Wave height and direction at 12z 23/11/1988

a) WAM model with ECMWF winds

b) UKMO model with UKMO winds.

Figure 1

BUOYS USED IN WAM/UK INTERCOMPARISON

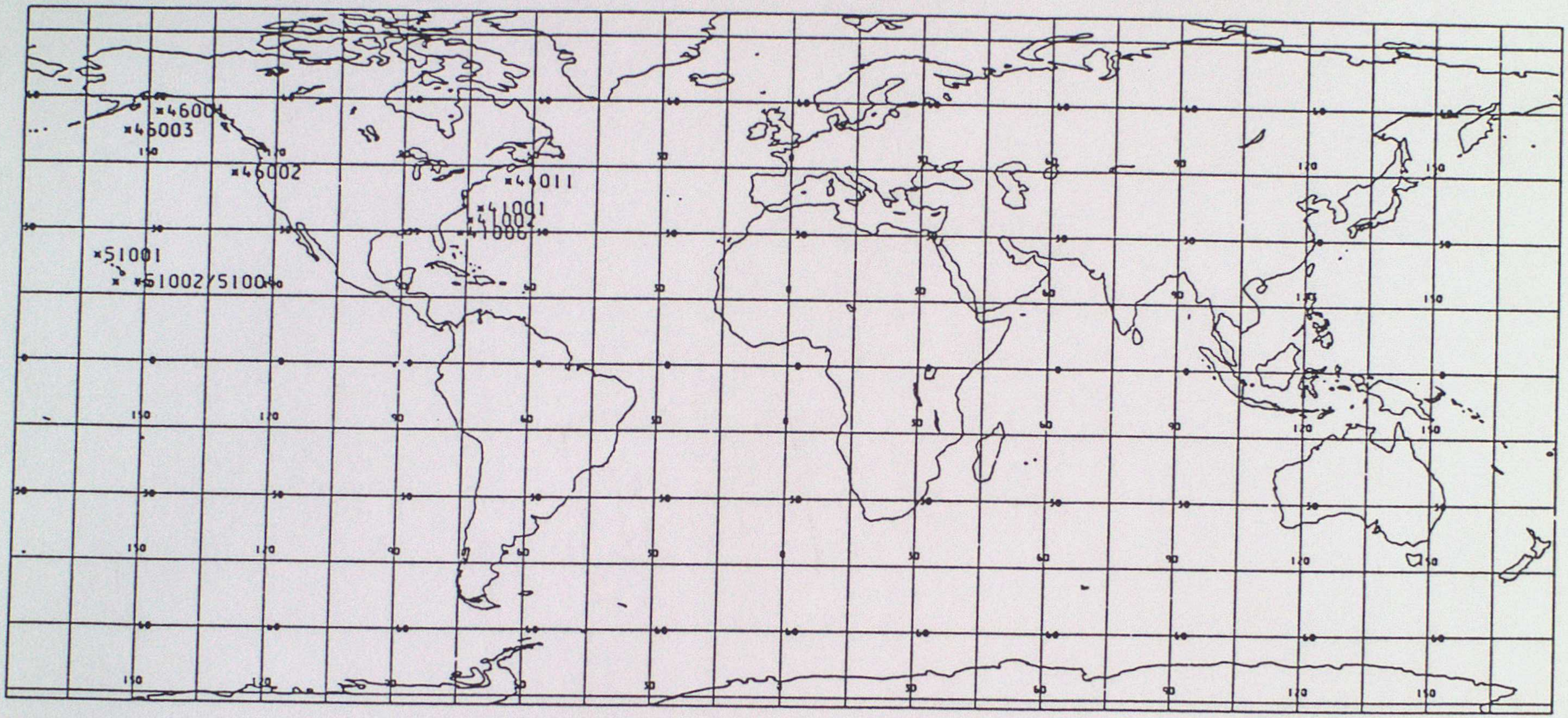
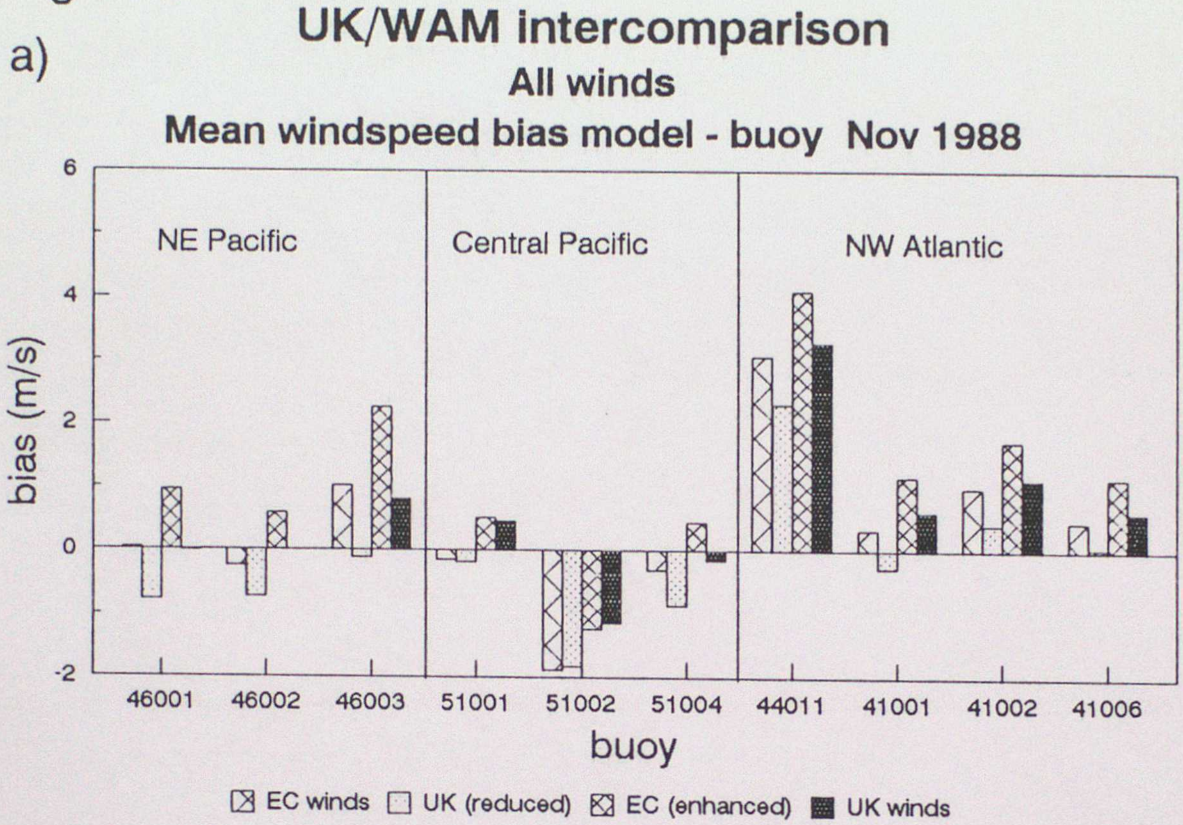


Figure 2

a)


UK/WAM intercomparison
All winds
Mean windspeed bias model - buoy Nov 1988
NE Pacific
Central Pacific
NW Atlantic
bias (m/s)
6
4
2
0
-2
46001 46002 46003 51001 51002 51004 44011 41001 41002 41006
buoy
EC winds
UK (reduced)
EC (enhanced)
UK winds

b)

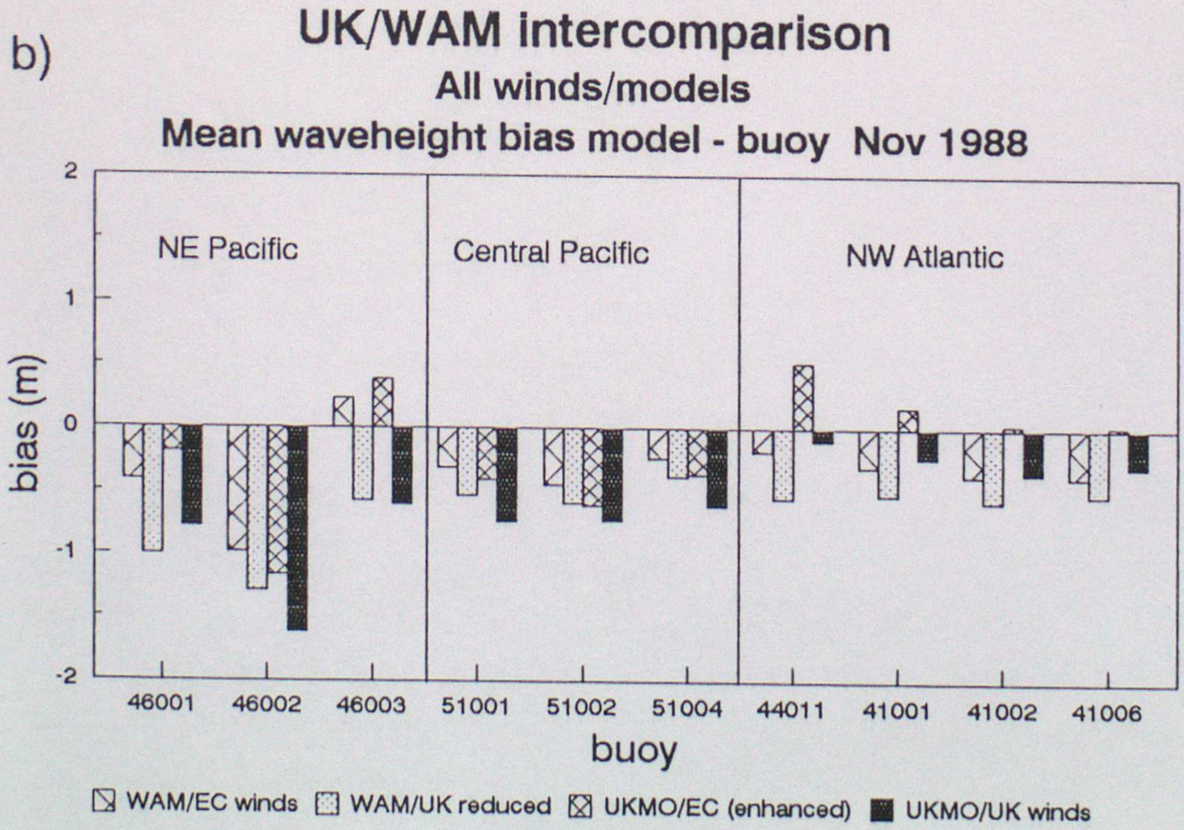

UK/WAM intercomparison
All winds/models
Mean waveheight bias model - buoy Nov 1988
NE Pacific
Central Pacific
NW Atlantic
bias (m)
2
1
0
-1
-2
46001 46002 46003 51001 51002 51004 44011 41001 41002 41006
buoy
WAM/EC winds
WAM/UK reduced
UKMO/EC (enhanced)
UKMO/UK winds

Figure 2c

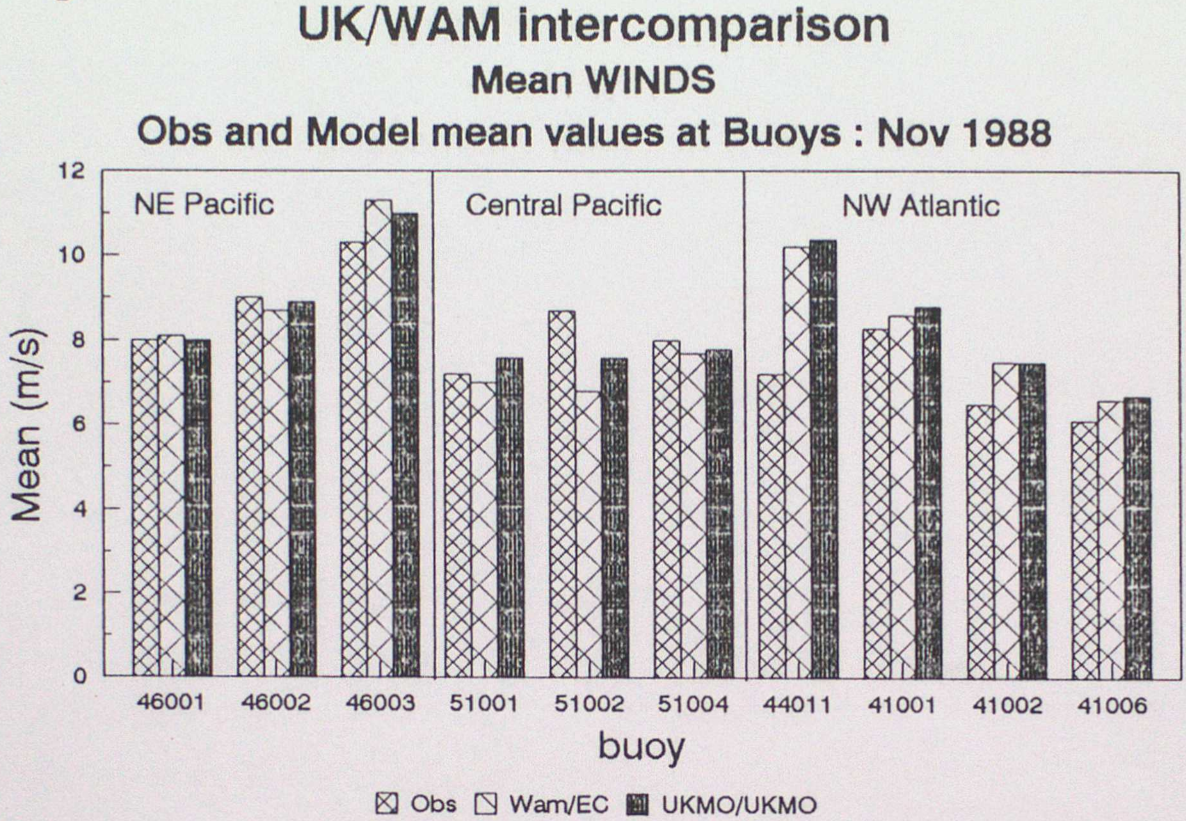


Figure 2d

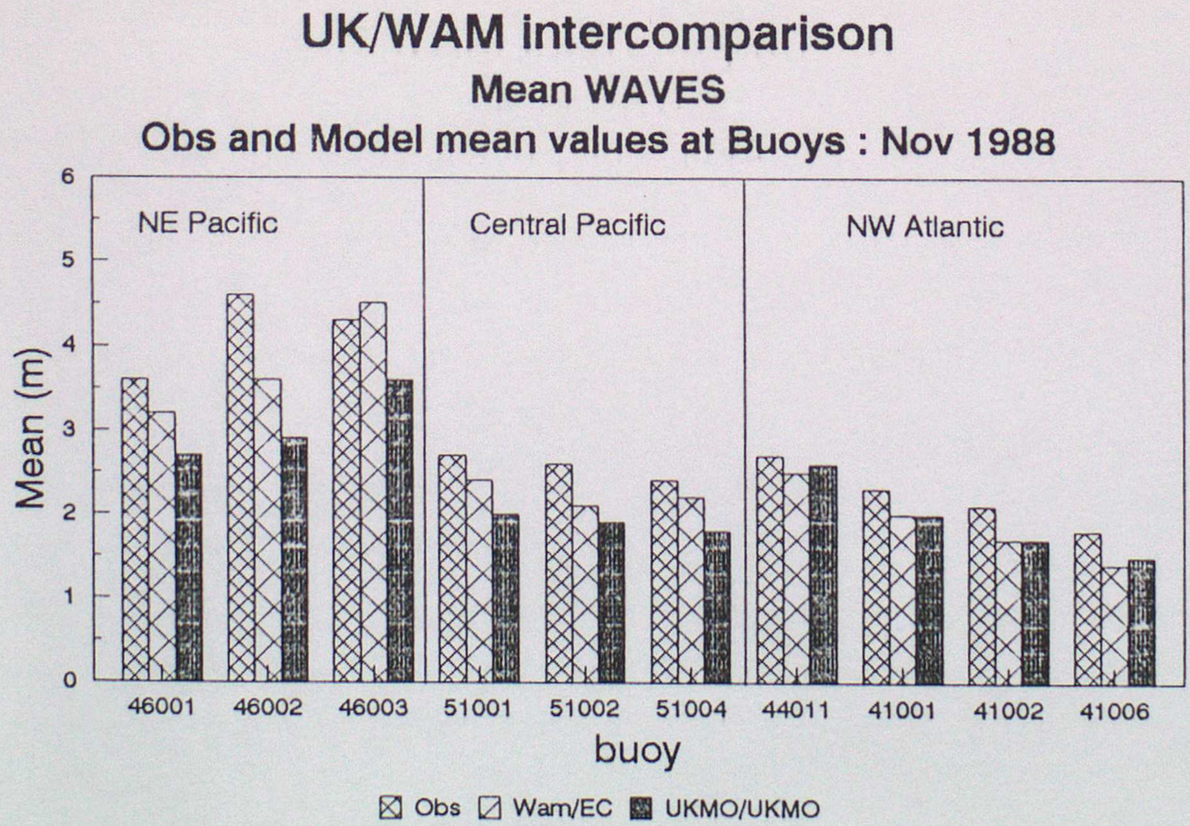
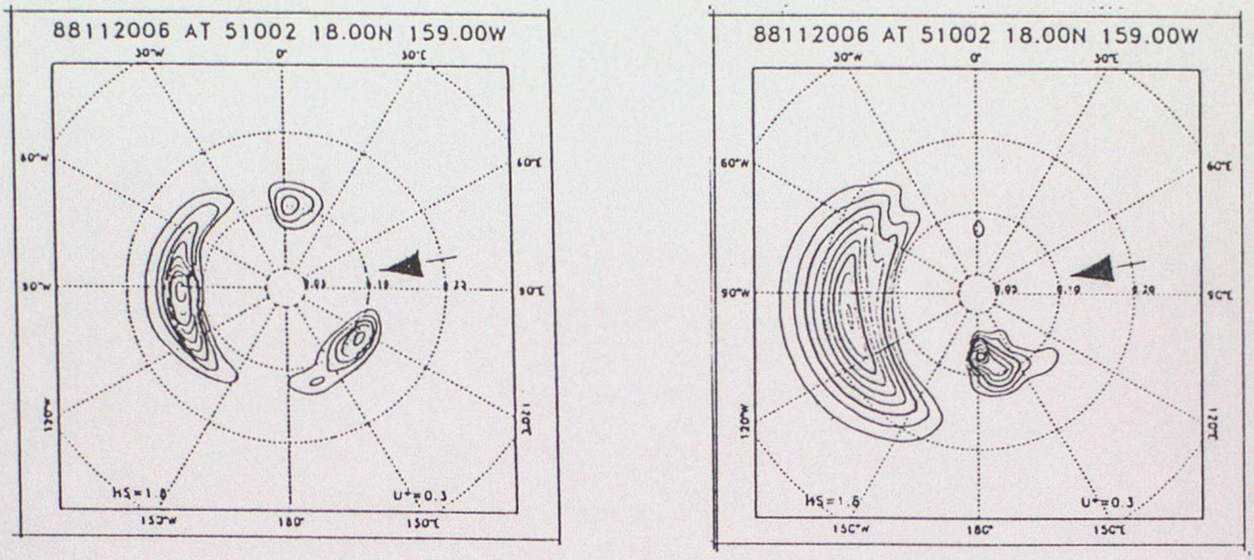


Figure 3a



WAM/UK

UK/UK

Figure 3b

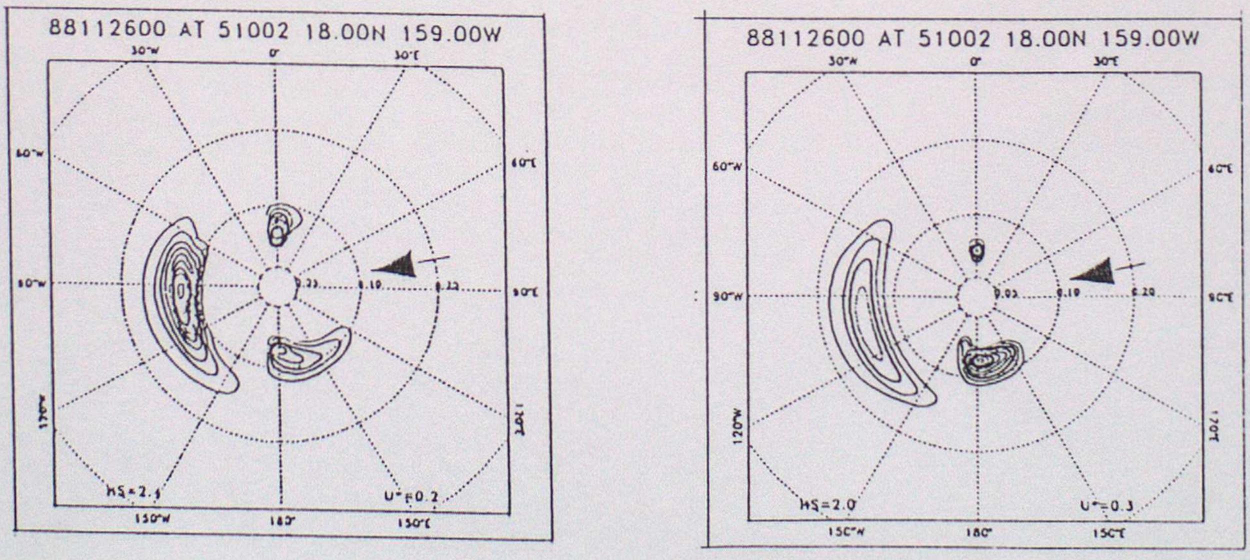
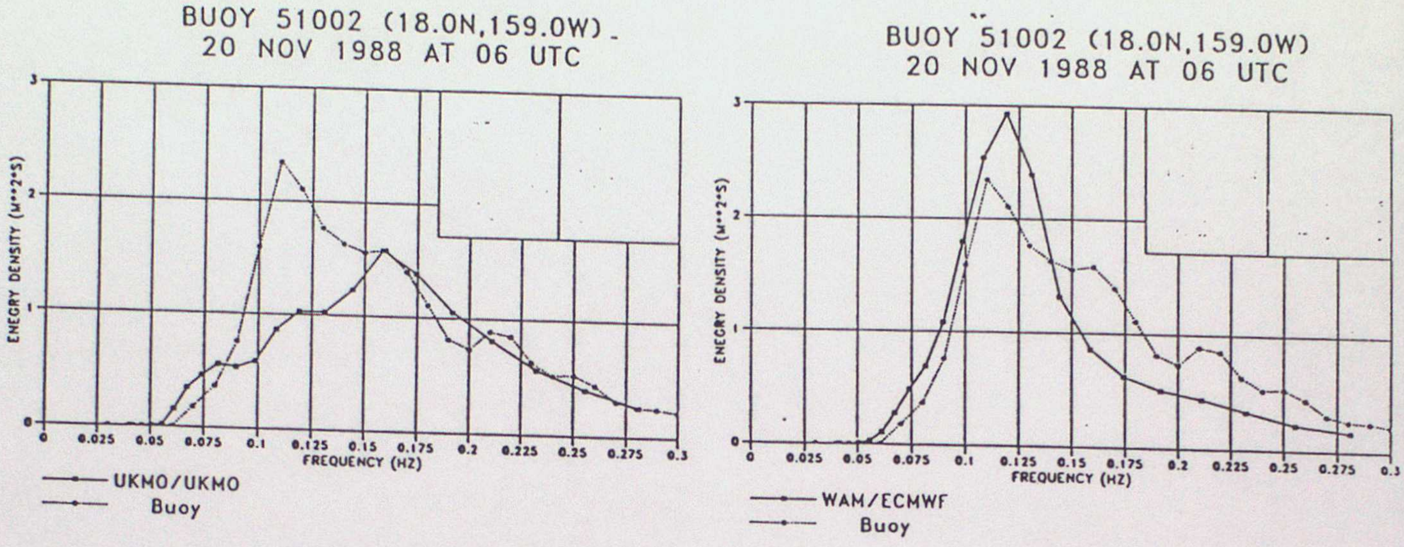


Figure 3c



UK/UK

WAM/EC

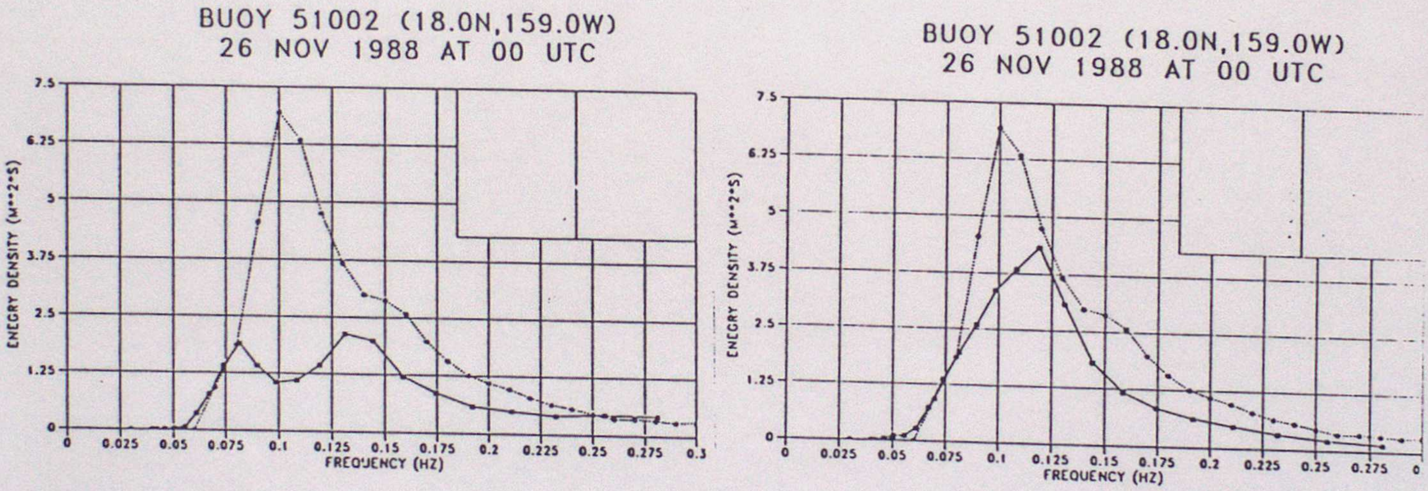
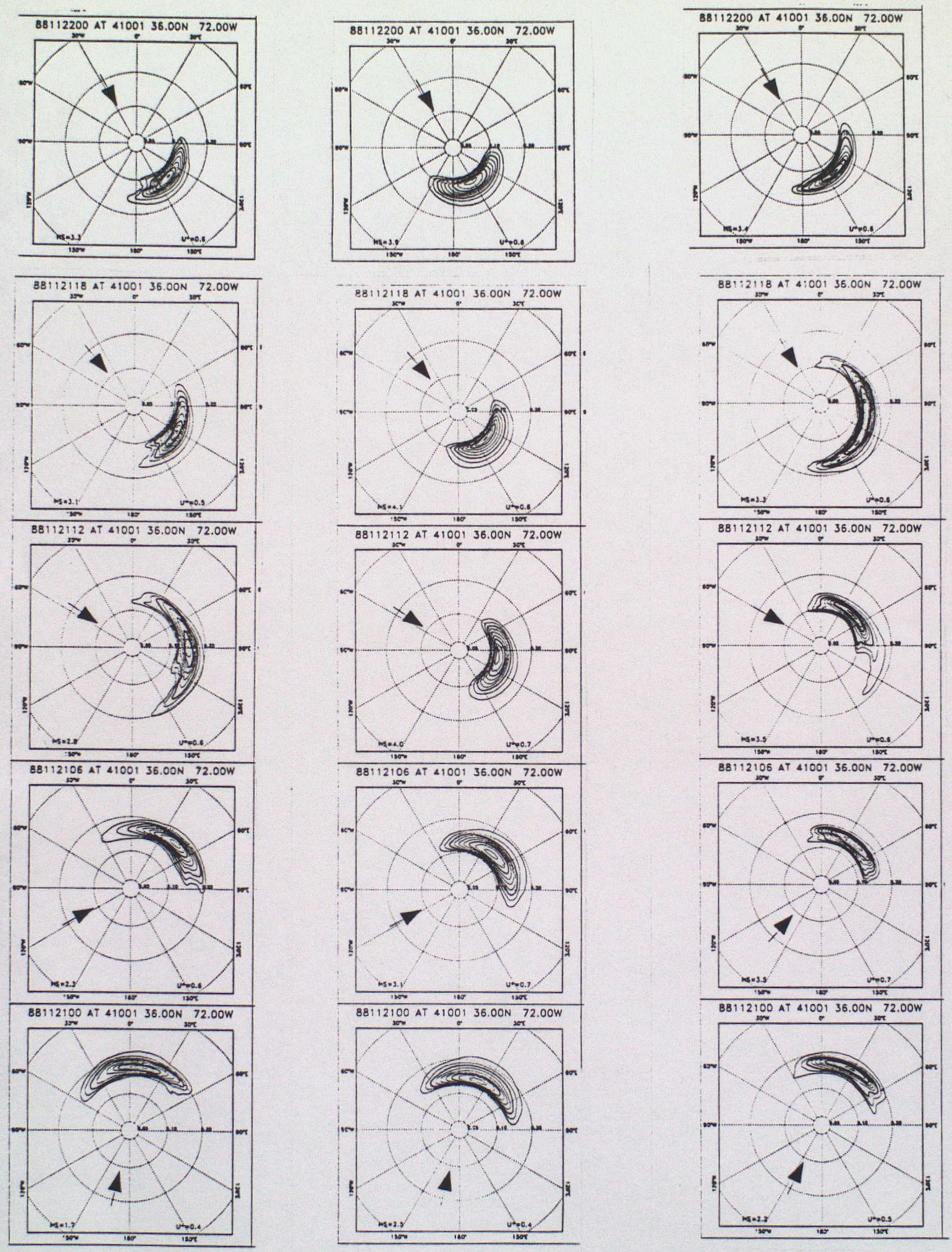


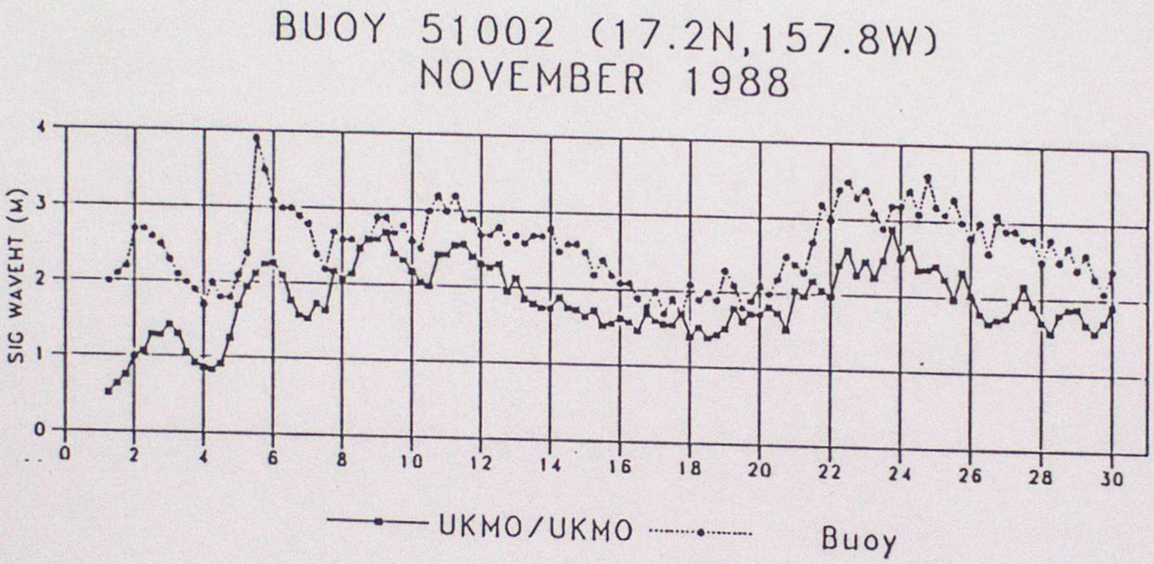
Figure 3d

Figure 4

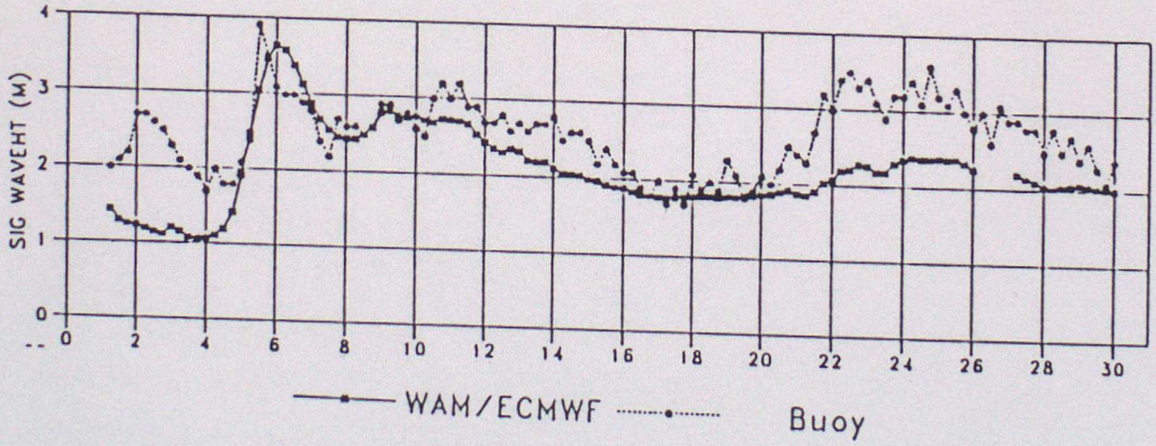


a) WAM/UK b) UK/UK c) WAM/EC

Figure 5a

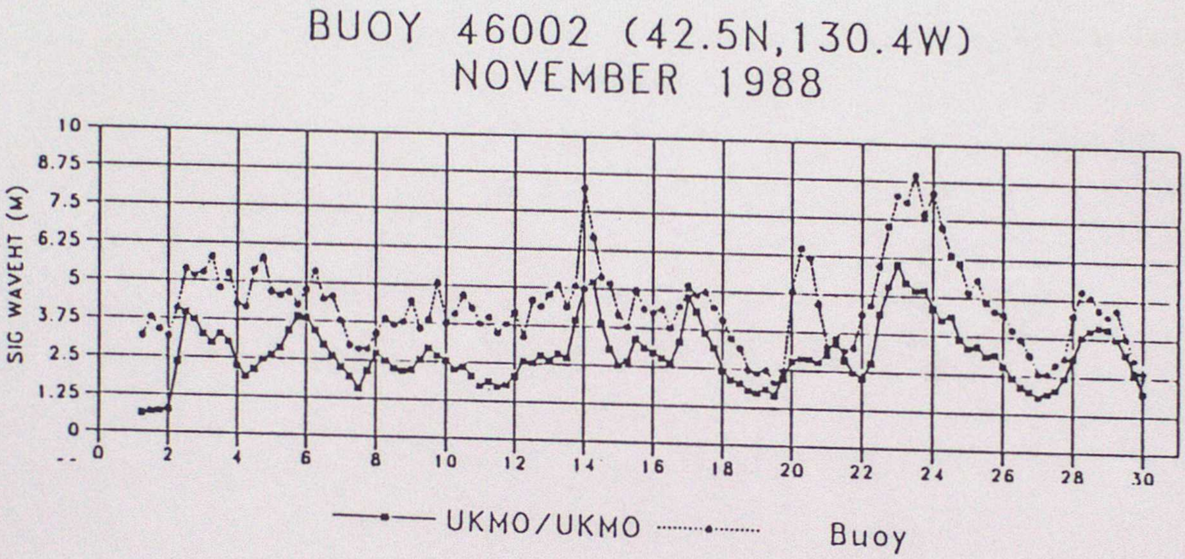


BUOY 51002 (17.2N,157.8W)
NOVEMBER 1988
SIG WAVEHT (M)
0
1
2
3
4
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
UKMO/UKMO
Buoy



SIG WAVEHT (M)
0
1
2
3
4
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
WAM/ECMWF
Buoy

Figure 5b


BUOY 46002 (42.5N,130.4W)
NOVEMBER 1988
SIG WAVEHT (M)
10
8.75
7.5
6.25
5
3.75
2.5
1.25
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
UKMO/UKMO
Buoy

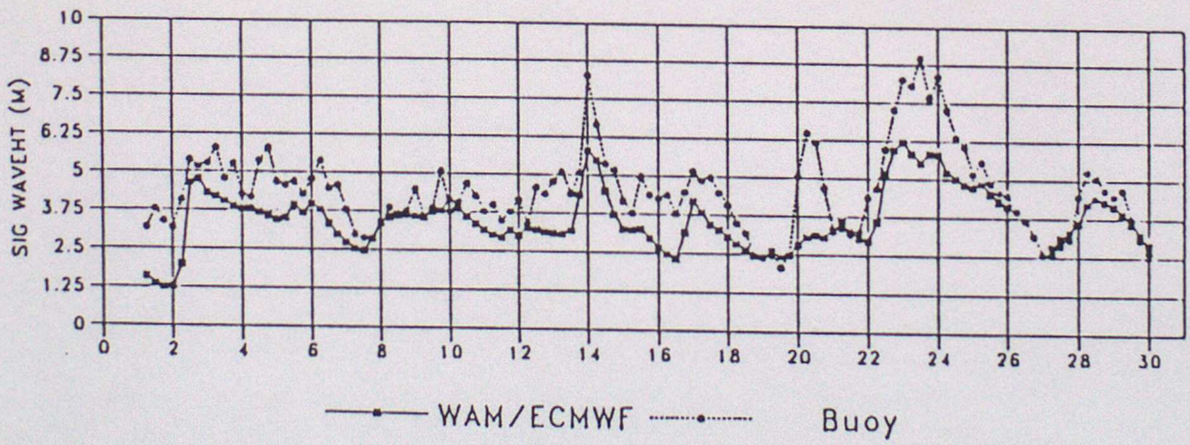

SIG WAVEHT (M)
10
8.75
7.5
6.25
5
3.75
2.5
1.25
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
WAM/ECMWF
Buoy

Figure 5c

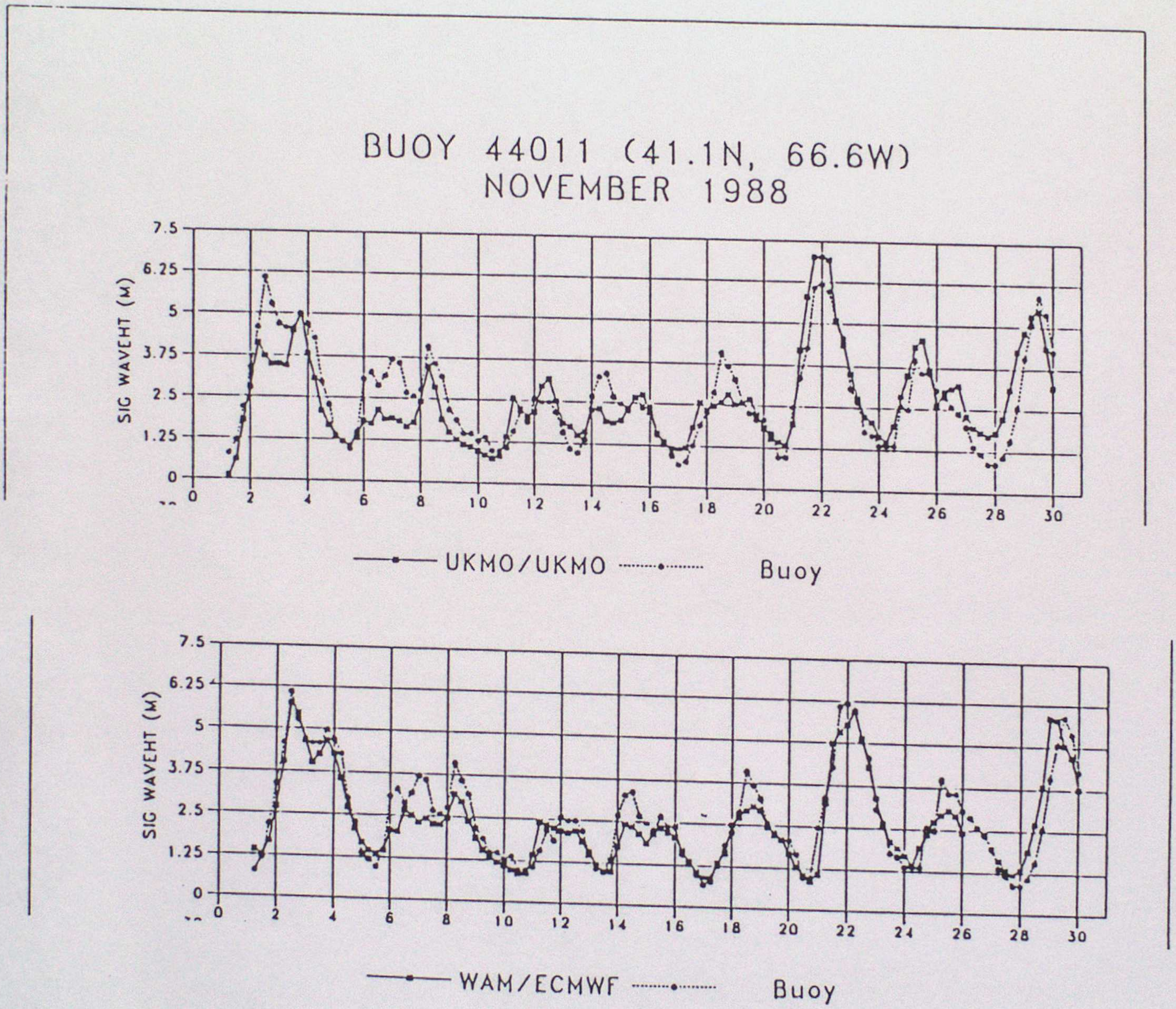

BUOY 44011 (41.1N, 66.6W)
NOVEMBER 1988
SIG WAVEHT (M)
7.5
6.25
5
3.75
2.5
1.25
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
UKMO/UKMO
Buoy
SIG WAVEHT (M)
WAM/ECMWF
Buoy

Figure 6a

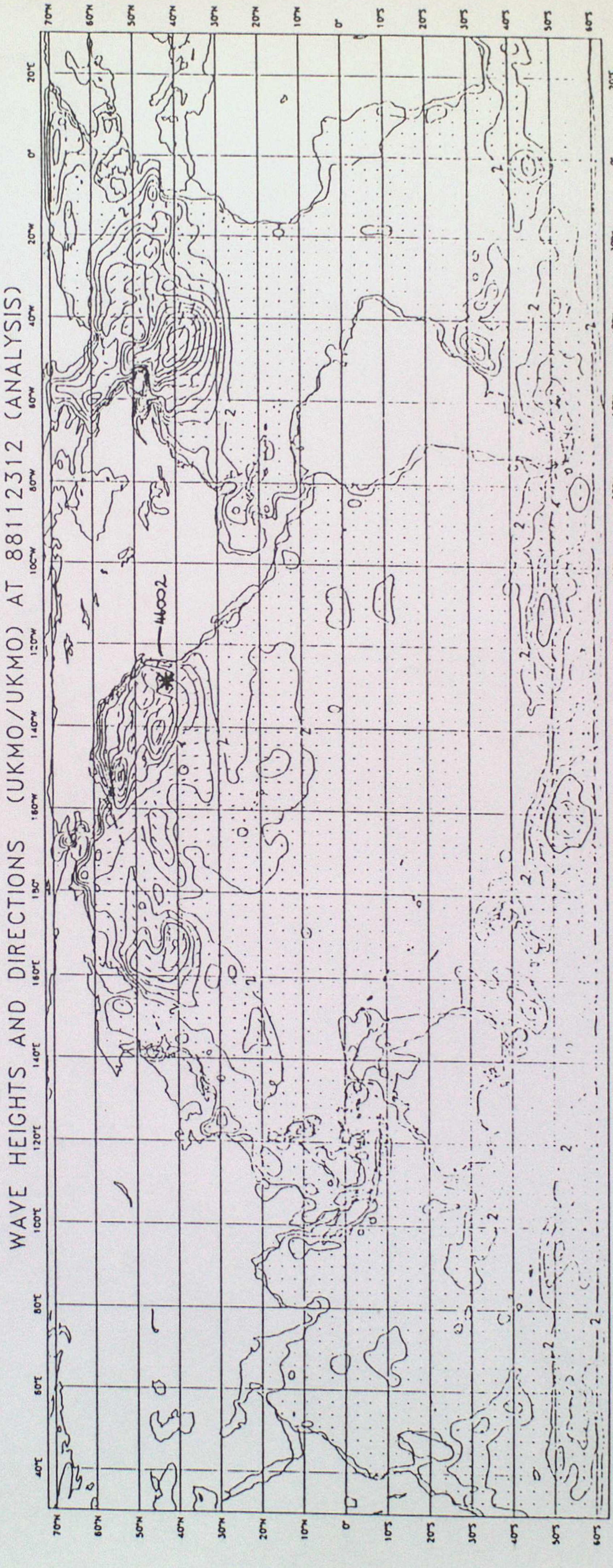
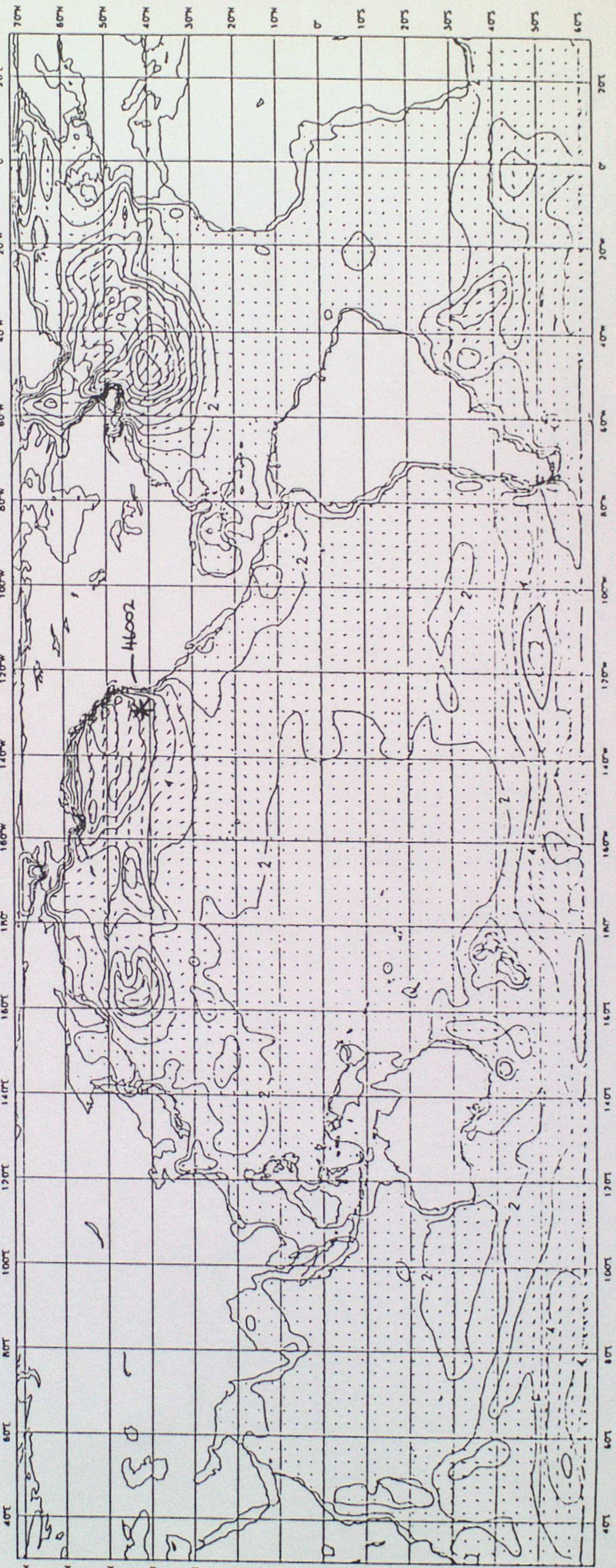

WAVE HEIGHTS AND DIRECTIONS (UKMO/UKMO) AT 88112312 (ANALYSIS)
46002

Figure 6b



WAM WAVE HEIGHTS AND DIRECTIONS (WAM/ECMWF) AT 88112312 (ANALYSIS)