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THE ACCURACY OF WIND AND WAVE FORECASTS

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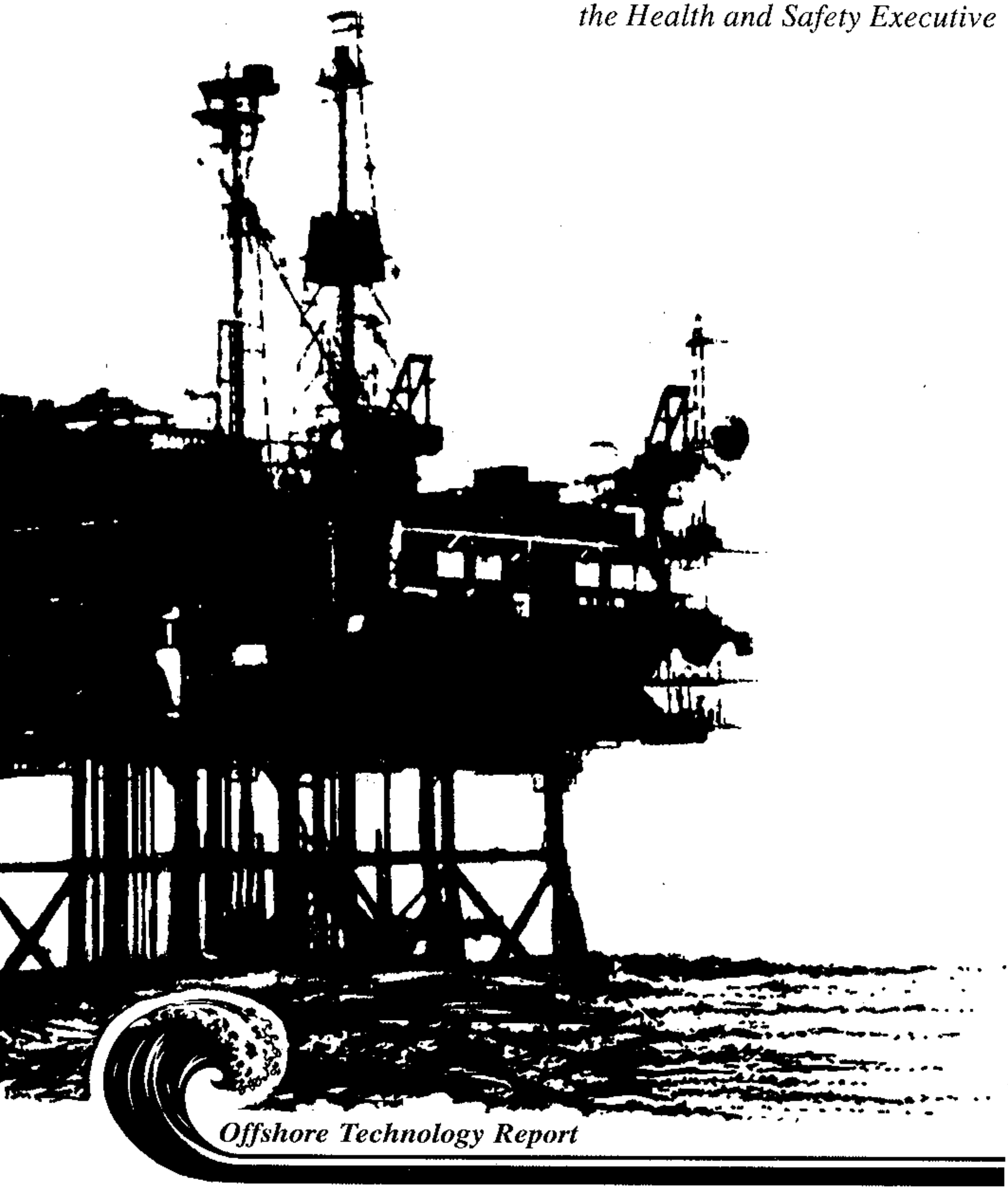

Offshore Technology Report

Health and Safety Executive

THE ACCURACY OF WIND AND WAVE FORECASTS

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SUMMARY

Statistics compiled by the UK Met Office for the verification of offshore wind and wave forecasts have been collated and presented to show the main seasonal and geographical variations in waters around the UK. For risk analysis purposes, it is useful to know the likelihood of a specified threshold being exceeded, when a forecast below that threshold has been made. Therefore, the raw verification statistics have been converted to probabilities of threshold exceedance, as a function of forecast period out to 120 hours.

The relative importance of RMS error and bias is discussed, and examples given. The contribution to forecast accuracy made by the additional input of the human forecaster to the guidance provided by the numerical forecast models is assessed and quantified.

CONTENTS

1. INTRODUCTION

When statistical analysis of risk in offshore operations is undertaken, some assessment is needed of the probability of a weather forecast being `incorrect'. More specifically, where some environmental threshold (e.g. wave height or wind speed) determines whether an operation is feasible or not, the risk analyst is concerned with the precision with which discrimination can be made in a forecast between exceedance and non-exceedance of this critical threshold. Clearly, this precision will decrease as the forecast period increases, and so the requirement is to quantify the probability of critical threshold exceedance as a function of forecast period, using data and experience gained in the routine provision of offshore forecasts.

The UK Met Office (UKMO) has global commitments for the routine production and dissemination of weather forecasts; in support of these activities, forecast accuracy is monitored on a routine basis, and forecast verification statistics have been compiled from analyses of differences between forecast and actual values, usually expressed as bias (difference in mean values) and root mean square (RMS) differences. These data are useful to demonstrate the overall improvements in accuracy over the years, and to investigate the short-term impact of specific changes introduced from time to time in the operational numerical forecasting suite of software. The available statistics can also be used to quantify the inherent uncertainties in offshore forecasts, and this report presents a selection of these data in forms which may be useful to the Offshore Industry.

2. THE FORECASTING PROCESS

2.1 BACKGROUND

The beginning of offshore exploration and production over the West European Continental Shelf in the 1970s provided a major incentive to the development of numerical wave modelling techniques. The industry had a clear requirement for accurate and site-specific forecasts of winds and waves to enable day-to-day operations to be planned with maximum efficiency and minimum risk. Therefore, several national meteorological services and independent forecasting companies began to offer services tailored specifically to meet the needs of the industry. Some of the national services developed numerical models to provide quantitative guidance to their forecasters who were responsible for the issue of advice to operators. As available computer power has increased, so the models have been made more complex, and methods for the assimilation of wind and wave reports have also been improved. At the present time, numerical forecasting models do not provide perfect guidance on all occasions, and so it is still the case that the human forecaster has an important role to play in the interpretation and fine-tuning of the model results.

2.2 THE ATMOSPHERIC MODEL

The first stage in the UKMO's routine production of offshore forecasts is the analysis of the wind field within the atmospheric numerical model. This model seeks to represent the important dynamic and thermodynamic processes governing atmospheric behaviour. All meteorological reports available within a few hours of the datum time (known as t+0) are assimilated by the model's analysis scheme to define conditions at the datum time over a regular grid of points. Using finite-difference techniques, the equations of motion appropriate for a compressible fluid in a rotating frame are integrated forward in time, using the t+0 analysis as the starting point, and hence wind fields are derived for 6, 12, 18, etc. hours ahead of the datum time. These fields are known as t+6, t+12, t+18, etc.

The atmospheric model operates on two resolutions; the Global model currently with a north-south horizontal grid resolution of about 93km provides boundary conditions to a Limited Area Model covering much of North America, the North Atlantic, the Mediterranean and Europe operating on a higher resolution of 50km. Each model assimilates wind and pressure reports from platforms, ships, buoys and land stations and uses optimum interpolation techniques to produce wind speeds and directions at each point of the grid, to be used as the initial state for the forecasting process.

2.3 THE WAVE MODEL

The analysed and forecast wind fields at the lowest level of the atmospheric model are then used to provide the energy input to the wave model. The UKMO model is a so-called 'Second generation' wave model, where the spectral shape is empirically defined, rather than being calculated at run time; this latter process is currently too expensive of computer time for an operational model of the high spatial resolution used. For each of the 16 directional and 13 frequency bands, the changes in wave energy are computed at each gridpoint using the local wind as energy input, allowing for propagation, dissipation and transfer between frequencies.

As with the atmospheric model, the wave model operates at two spatial resolutions; a Global model covers all oceans and provides boundary conditions for a European model (with spatial resolution of 25km) which covers the West European Continental Shelf to 14W between 30.5N and 66.7N, and also the Baltic and Mediterranean Seas. Further details of the model's formulation may be found in Golding (1983) and Francis (1985). Subsequent developments of the wave model are documented in UKMO internal memoranda by Holt (1992, 1993, 1994).

Initially, the wave fields were derived solely from the wind energy input, but from June 1993, wave measurements from the radar altimeter mounted on the polar-orbiting ERS-1 satellite have been assimilated into the Global wave fields. These additional data have been found to be especially valuable in improving the t+0 wave fields in the tropical and southern oceans where conventional observations are sparse. The wind fields in these data-sparse regions have also been improved since August 1993 by the use of wind data from the scatterometer on board ERS-1. (Foreman *et al*, 1994; Bell & Holt, 1993)

2.4 THE FORECASTER'S CONTRIBUTION

Since the operational forecaster is monitoring the weather as it occurs, he can often identify small discrepancies between the model analysis (or early forecast guidance) and his own analysis of the situation and recently-received data. Based on his understanding of atmospheric dynamics and his experience of the model's performance, he can decide whether this discrepancy is significant in the context of the current weather situation, and so make a judgement on whether he can improve the model's guidance. In general, an experienced forecaster can make some useful contribution during the first 24 hours or so of a forecast's evolution; thereafter, the complexities of the atmosphere's dynamics are generally better handled by the model. Also, if the model guidance indicates a close approach to some critical threshold for offshore operations, he can also apply his judgement and fine-tune his advice appropriately, bearing in mind the operator's requirements.

3. FORECAST ERRORS

3.1 GENERAL

At datum time (t+0), the forecaster sets out the expected evolution of the critical element over time. Based on the guidance of the numerical forecasting model, and incorporating his meteorological judgement based on all data available to him at the decision-making time, his estimate of the most likely magnitude of the element at time t_1 is $x(t_1)$. However, the value x has an associated error which means that there is a finite probability that the actual value at t_1 will exceed some critical threshold T (see Figure 1a).

The error band approximates to a normal distribution about the forecast value, with the 'width' of the band defined by the standard deviation available from verification statistics. Thus, knowing the difference between the threshold T and the forecast value x, we can use tables of the probability integral to determine the probability that T will be exceeded when a forecast of x has been made. (This probability can be represented as the shaded area in Figure 1a) The computed values of exceedance probability can then be presented as a function of forecast period and (T-x).

Figure 2 demonstrates, for two data sets, that the the assumption of normality for the distribution of forecast errors is a good one, thus allowing the analysis procedure to be implemented easily. However, some caution should be expressed regarding the extrapolation of the distribution to very low probabilities. For exceedance probabilities of less than (say) 5%, the results presented here should be considered indicative rather than prescriptive.

3.2 BIAS

Bias in the forecasts (defined as the mean difference between forecast and actual) may also affect the resulting probabilities. If the forecast has a positive bias over observations, and is not corrected at issue, then the distribution of actual conditions corresponding to the forecast will be shifted downwards (Figure 1b) and so the resulting probability of threshold exceedance will be reduced. Conversely, a negative bias not corrected at issue will produce an increased probability of threshold exceedance. Therefore, if the forecaster wishes to 'play safe' and reduce the probability that the threshold will be exceeded, he can certainly achieve this by incorporating a positive bias in his issued forecasts. However, in practice, a forecast may be used by the offshore operator for a variety of different purposes (e.g. there may be a set of critical thresholds, for different operations), and so there will probably be some adverse consequence of this over-forecasting. Also, a further result of a positive bias is that the number of 'false alarms' will increase, which will not be acceptable to the user of the forecasts. Therefore, forecasters generally aim to achieve zero bias in their issued site-specific forecasts.

4. DATA AVAILABLE

4.1 GENERAL

For some years, datasets have been accumulated containing forecast wind speeds and wave heights produced by the operational models for designated locations on and around the West European Continental Shelf, along with the corresponding reports of conditions received in real-time from these offshore locations. Statistics were generated primarily for the routine monitoring of the models' performance, and have not been subjected to detailed scrutiny with risk assessment in mind. The present study has examined the data seasonally and by location, with the locations being selected to represent, as fully as possible, the range of conditions experienced over the Continental Shelf.

Error statistics are available for t+0, t+6, t+12, t+18, t+24, t+36, t+48 from the operation of the European waters model, and then for t+48, t+72, t+96 and t+120 hours from the Global model. For brevity, data for t+6 and t+18 are not presented here; operationally, there is little requirement for a t+6 forecast, bearing in mind that a delay of a few hours is always necessary for observations at the datum time to be assimilated by the forecasting model and then for output to be scrutinised by forecasters before advice can be issued to users.

4.2 DATA LIMITATIONS

Since the UKMO introduced major changes (both computational and representational) to the operational atmospheric model in June 1991, the study has been restricted to material subsequent to this date.

Since the study is concerned with differences between forecast and actual conditions, it is worth emphasising that the reports from the offshore locations used to compute these differences will themselves be prone to error. Although the UKMO has a policy of visiting offshore locations within the British sector to advise on observing practices, the turnover of observing staff on installations is generally high, and inconsistencies (and gaps in the record) arise from time to time which take variable lengths of time to resolve.

Errors in observations will have impact on both bias and RMS errors. Any model bias is expected to be supplemented by observation bias, most likely arising from imperfect reduction of high-level winds to the 10m above mean sea level standard for meteorological reports. The RMS model errors will be increased due to `random' observing errors, largely arising from lack of consistency in observing practices due to day-to-day personnel changes.

5. SEASONAL VARIATIONS

5.1 REPRESENTATIVE LOCATION

For discussion on the seasonal variations of the bias and rms errors, a location in the Central/Northern North Sea has been chosen, as being broadly representative of conditions in waters around the UK. Beryl A (at 59.5N, 1.5E) has been selected as having provided reports of good quality in recent years, with few gaps in the record. The data are matched with forecast values from the nearest gridpoint of the European Wave model grid (59.5N, 1.54E)

5.2 RMS ERRORS

For each calendar month, RMS errors for each forecast time at 12-hour intervals to t+48 are shown in Figure 3. The values here are derived from all occasions when the observed wind speed fell in the range 10-15 m/s. It can be seen there is considerable month-to-month variability and an apparent difference in character between the two years shown, although with an underlying pattern of higher values in winter and lower in summer.

Figure 4 shows the same data smoothed both in the time domain and in the forecast period domain. (For example, the smoothed t+12 value for February is calculated from the weighted mean of the nine t+6, t+12 and t+18 values for Jan, Feb and Mar; all values are given single weighting except for the t+12 for Feb, which is given triple weighting. For clarity, t+6 and t+18 values are not shown in the figures.) This results in a more coherent presentation, showing the seasonal pattern with maximum in winter and the expected increase in RMS error with increasing forecast period.

The t+0 curve in Figure 4 represents the RMS difference between the observation and the analysis produced by the model's data assimilation scheme. This scheme must produce an analysis which is dynamically consistent (ie there must be consistency between the wind, pressure and temperature fields, not just at sea level, but at all other levels through the atmosphere), otherwise unacceptable instabilities will arise in the forecast computations. Since errors of measurement and transmission are a fairly common feature of real-time meteorological reports, some latitude must therefore be allowed between the reports and the final analysis. This explains the fact that the RMS values for t+0 are non-zero.

The differences between years will be a reflection both of the differing sample numbers falling in this range of wind speeds in different years, and also of the general character of the weather prevailing during each month. For example, a month dominated by stable anticyclonic conditions can be expected to give rise to smaller forecast errors than a month with very fast-moving westerly airflow, for which errors due to timing in the t+24 to t+48 period might be expected to be large.

Figure 5 shows the smoothed RMS errors at Beryl A for significant wave heights in the range 0-3m. Again, the increasing error with lengthening forecast period is evident, although the seasonal pattern is rather more variable than for the winds. One further notable feature is that the annual range of the t+0 curve is much greater than for the winds; for waves, the range is about 90% of the annual minimum, whereas for winds, the range is only about 45% of the minimum value. This difference reflects the fact that the analysed (t+0) wind field is derived directly from observations of winds in the vicinity of the platform, whereas the analysed wave field is derived from the input of the wind field to the wave model, rather than from wave observations directly.

5.3 BIAS

The monthly mean bias of model value with respect to observation is shown in Figure 6 for winds in the range 10-15m/s. As with the RMS errors, the month-to-month variability is large, and it is by no means clear that biases are (absolutely) larger for longer forecast periods. The smoothed data in Figure 7 show larger positive biases in winter more clearly, but still no obvious evidence of increasing bias with longer forecast times. This is reassuring, since it implies that, in the mean, the forecasting models are stable and do not display amplifying errors as they are run to longer forecast times. (Note that, in Figures 3, 4, 5, 6 and 7, there is a period when results for t+48 were not kept, and so there is a gap in the timeseries.)

6. GEOGRAPHICAL VARIATIONS

6.1 SELECTION OF LOCATIONS

An attempt has been made to select a good geographical spread of stations submitting good-quality reports. It has been possible to include in the study stations from the Northern, Central and Southern North Sea, the English Channel and the Irish Sea. There is a significant lack of data from areas to the west of the British Isles, although a UKMO programme for the deployment of several ocean buoys between 12W and 15W is currently under way. The quality of data from these buoys is presently under investigation, and so they have not been included in the present study. The stations for which forecast verification data have been studied are listed in Table 1.

Table 1
Stations used in the study

Ocean Weather Ship 'Mike'	66.0N	2.5E
North Cormorant	61.1N	1.1E
Beryl A	59.5N	1.5E
Ekofisk	56.5N	3.2E
Leman	53.1N	2.2E
Morecambe Bay	53.8N	3.6W
Channel Light Vessel	49.9N	2.9W

6.2 RMS ERRORS

Table 2 shows typical RMS errors for 48-hour forecasts of winds and waves, each variable being categorised in two ranges, as defined by the observed value. It can be seen that, for winds, there is an overall increase in the RMS errors with increasing latitude, albeit with some additional variability for some locations. This latitudinal variation is not unexpected, since mobility of weather systems is generally greater in the north, leading to somewhat larger errors due the difficulties which the models sometimes experience in specifying the intensity and rapidity of developments. For waves, the latitudinal correlation is less clear; although wave height errors arising from the timing and development of the wind field would be expected also to increase with latitude, the fetch as an additional controlling factor in the growth of wave energy will vary considerably depending on the wind direction. Thus, in some cases, large wind speed errors do not produce large wave height errors because the fetch limits the growth of the waves.

Table 2
RMS errors of 48-hour model forecasts against reports

	WIND SPEED				SIG WAVE HEIGHT			
	5-10m/s		10-15m/s		0-3m		3-6m	
	W	S	W	S	W	S	W	S
OWS Mike	4.5	2.5	4.3	3.2	1.1	0.5	1.3	0.8
N Cormorant	5.0	2.5	3.9	3.0	0.8	0.5	1.3	0.7
Beryl A	4.6	2.5	4.1	2.5	1.0	0.5	1.4	1.0
Ekofisk	5.0	2.8	3.8	2.5	1.1	0.7	1.3	0.7
Leman	3.5	2.5	3.3	2.5	1.0	0.5	0.7	0.5
Morecambe B	3.6	2.4	3.5	2.5	0.9	0.6	1.1	0.6
Channel LV	3.2	2.2	4.2	2.2	1.0	0.5	1.2	0.5

W=winter S=summer

6.3 BIAS

As discussed in Section 5.3, the change of bias with forecast period is less coherent than for RMS error, and so the presentation of 48-hour forecast bias is not necessarily a good indicator of bias at other forecast times. However, to illustrate the geographical variation in bias, Table 3 shows typical values at t+48 for each selected location. Overall, there is a tendency for larger positive biases in wind speed at the northern locations (although no similar indication for wave height) and also for the bias in both wind speed and wave height to decrease (in an absolute sense) from winter to summer.

Table 3
Bias of 48-hour model forecasts against reports

	WIND SPEED				SIG WAVE HEIGHT			
	5-10m/s		10-15m/s		0-3m		3-6m	
	W	S	W	S	W	S	W	S
OWS Mike	+1.0	-1.0	-1.0	-2.5	+0.3	-0.3	+0.2	-0.5
N Cormorant	+4.0	+1.5	+3.0	+1.5	+0.5	+0.2	+0.5	+0.2
Beryl A	+3.0	+0.5	+2.2	-0.5	-0.1	-0.1	+0.8	-1.0
Ekofisk	+3.0	+0.8	+2.5	+1.0	+0.7	+0.3	+0.7	-1.0
Leman	+1.6	-1.0	-0.5	-1.8	+0.6	+0.1	+1.0	-1.0
Morecambe B	+1.7	-0.5	-1.5	-2.0	+0.6	+0.3	-0.1	-0.5
Channel LV	+2.0	+0.5	+0.5	-1.0	+0.5	+0.2	+0.5	0.0

W=winter S=summer

7. FORECASTS BEYOND 48 HOURS

7.1 GENERAL

The concept of the UKMO nested-grid system (i.e. A Limited-Area model of finer resolution nested within and taking boundary conditions from a Global-scale model of coarse resolution) is linked logically to the forecast periods over which the models are run. The higher-resolution models are run to t+48 hours (i.e. covering the period for which generally more detail is required) and the coarser-resolution global models are run to t+120 hours (5 days) to provide a broader overview of developments on the global scale. This approach is also governed by the greater computational resources which are required by the higher-resolution models; at present it is too expensive of resources to extend the higher-resolution model either to a larger area or out to a longer forecast period.

Thus, to assess the accuracy of model forecasts beyond t+48 requires that the coarser grid model output be compared with observations. Naturally, the coarser grid cannot represent the geographical detail present in the Limited-Area models, and this restriction is especially important for the wave model, with a relatively few sea points to represent small areas of ocean such as the North Sea.

7.2 ERRORS BEYOND (t+48)

Beryl A has again been selected to illustrate the progress of errors at longer forecast periods. Table 4 shows representative values of the RMS errors as a function of forecast period, the forecasts up to t+48 being derived from the European Model, and those beyond from the Global Model. (In general, Global Model RMS errors up to 48 hours are around 40% higher than those from the European Model.)

Table 4
Typical RMS errors in wind and wave forecasts
at Beryl A; model only

	Forecast period (hours)						
	12	24	36	48	72	96	120
WINDS							
Winter							
5-10m/s	3.2	4.0	4.3	4.6	5.5	6.0	6.5
10-15m/s	3.0	3.5	3.8	4.1	5.0	5.5	6.0
Summer							
5-10m/s	1.8	2.1	2.3	2.5	2.8	3.3	3.6
10-15m/s	1.9	2.1	2.3	2.5	4.0	4.3	4.6
WAVES							
Winter							
0-3 m	0.7	0.8	0.9	1.0	1.5	1.8	2.0
3-6 m	0.8	1.0	1.2	1.4	1.8	2.0	2.2
Summer							
0-3 m	0.4	0.45	0.5	0.55	0.6	0.7	0.8
3-6 m	0.7	0.8	0.9	1.0	1.3	1.6	1.8

The RMS values shown for both winds and waves approximately double as one moves from t+12 to t+120. The larger values in winter reflect the greater inherent mobility and intensity of weather systems in winter, since errors arise from lack of precision in timing and also from uncertainties in synoptic development. Differences between the two ranges of observed values (5-10 and 10-15m/s for winds, 0-3 and 3-6m for sig wave height are generally not great, with the exception of waves in summer. The higher summer waves seem as difficult to forecast as waves in winter, whereas the lower summer waves (no doubt representing the quieter anticyclonic periods) display quite low RMS values. Most of the rows in table 4 show a relatively large increase in error between t+48 and t+72, reflecting the transition from the European to the coarser-grid Global Model.

In common with the behaviour of the bias up to t+48, the bias beyond t+48 shows little coherence, with no tendency for larger biases at increasing forecast period.

8. PROBABILITY OF THRESHOLD EXCEEDANCE

8.1 USE OF RMS ERRORS

The technique described in Section 3.1 has been used to transform the available RMS errors into probabilities of threshold exceedance versus forecast period and (T-x). The results for Beryl A are shown in Figures 8,9,10 and 11. These curves demonstrate the effect on probability of threshold exceedance when different tolerances for forecast accuracy are applied. For example, Figure 8 shows that, at t+120, when the model forecasts wind speed to be 2.5m/s below some critical threshold, there is a 33% chance that the threshold will, in fact, be exceeded. However, if a tolerance of 5m/s is allowed, then the probability of the threshold being exceeded decreases to 20%.

The discontinuity in the curves between t+48 and t+72 is partly due to a change of scale on the x-axis, but mainly due to the use of the coarser global model for forecasts beyond t+48. It is fairly clear that, if computer resources were available to run the higher-resolution model beyond t+48, then somewhat smaller errors would result.

It is also worth emphasising that for (T-x) = zero, the probability of exceedance is 50% for all forecast durations. i.e. if a forecast equal to the threshold is made, there is a 1 in 2 chance that the threshold will be exceeded.

8.2 IMPACT OF BIAS

Because of the variation of bias with forecast period is less coherent than that of RMS errors, it is difficult to present a concise summary of the impact of bias on the exceedance probabilities. Although Table 3 showed that model biases can be larger, most biases fall within the range +1.5 to -1.5m/s wind speeds and between +0.5 and -0.5m for sig wave height. To illustrate the sensitivity to bias, probabilities of threshold exceedance for Beryl A have been recomputed with the addition of these biases.

Figures 12 and 13 show the range of probabilities which result from the addition of typical positive and negative biases. It can be seen that the impact of bias increases only slowly with increasing forecast period, but the impact on the exceedance probability of a given bias is much greater for smaller (T-x) values. (This arises since the bias is added to (T-x) before being expressed as a fraction of RMS value for conversion to probability.) In other words, where greater precision is required in a forecast, it is important to minimise not just the RMS error but also the bias.

8.3 GEOGRAPHICAL VARIATIONS

The RMS errors for 10-15m/s winds are summarised in Table 5, and the geographical coherence is quite good, with values generally increasing with increasing latitude in winter; in summer, the variation is much less. Thus, for both seasons, it seems possible to suggest RMS values typical for the Northern, Central and Southern North Sea, and to convert these to probabilities for selected thresholds.

Using these values as a guide, Figure 14 has been compiled showing representative values of probability exceedance for 3 subareas in winter; in summer the differences between the subareas are small and probably not significant, and therefore an overall North Sea value is given. Although the differences between the three areas in winter are not large, they confirm the subjective view that the likelihood of forecast precision decreases as one moves northwards in the North Sea.

Table 5
RMS forecast errors (m/s) for winds 10-15m/s

	WINTER				SUMMER			
	Forecast period (hours)							
	12	24	36	48	12	24	36	48
OWS Mike	3.4	3.8	4.0	4.3	2.5	2.7	2.9	3.2
N Cormorant	3.2	3.5	3.7	3.9	1.5	2.0	2.5	3.0
Beryl A	3.0	3.5	3.8	4.1	1.9	2.1	2.3	2.5
Ekofisk	2.6	3.1	3.5	3.8	2.0	2.1	2.3	2.5
Leman	2.3	2.7	3.0	3.3	2.0	2.1	2.3	2.5
Morecambe B	2.5	2.9	3.2	3.5	2.0	2.2	2.4	2.5
Channel LV	2.8	3.2	3.8	4.2	1.8	2.0	2.1	2.2

9. THE CONTRIBUTION OF THE FORECASTER

9.1 GENERAL

The `man+machine' philosophy for provision of forecasts has evolved over the last 30 years or so since numerical weather prediction models were recognised as being able to provide some useful input to the forecasting process. As models have increased in complexity, they have become increasingly valuable in providing guidance to the human forecaster. However, since the models do not yet represent every facet of the real atmosphere's behaviour, experience has shown that the forecaster must remain vigilant and apply his subjective judgement to the forecast scenarios which the models produce. There are several documented accounts of the success of the `model+forecaster' approach in severe weather situations (McCallum; 1990,1992,1993).

It might be argued that the benefit of the forecaster's input is only really significant on occasions of exceptional weather. In the offshore context, it is probably true that the cost to an operator of damage incurred due to a poor forecast of the `once per year' event can more than outweigh the cost savings from good quality forecasts for the rest of the year. Of course, it is difficult to build up a statistical summary of forecast performance for `exceptional' events, since by definition the sample sizes are small.

9.2 QUANTIFICATION OF FORECASTER INPUT

In principle, verification statistics for `model only' forecasts can be compiled for any location submitting reports routinely using the forecast for the nearest model gridpoint. However, an assessment of the added value provided by the forecaster can only be made for the subset of locations for which UKMO is contracted to supply `model+forecaster' forecasts. Also, since many forecasting contracts are relatively short-term, there are limited opportunities to build up long series of verification data.

For this study, `model+forecaster' verification data compiled for Ekofisk since mid-1994 for forecast periods to t+72 have been used for comparison with the `model only' results. Table 6 shows typical winter RMS errors for the `model only' and `model+forecaster' results.

Table 6
RMS forecast errors at Ekofisk - winter
`Model only' versus `Model+forecaster'

	Forecast period (hours)				
	12	24	36	48	72
WINDS (m/s)					
Model only	6.5	7.5	8.5	9.4	10.0
Model+forecaster	5.0	6.6	7.5	8.5	9.5
WAVES (m)					
Model only	0.8	1.0	1.2	1.4	1.8
Model+forecaster	0.55	0.8	1.1	1.3	1.7

Figure 15 shows the conversion of the RMS wave height errors to threshold exceedance probabilities, confirming the subjective view that the forecaster's impact is mainly evident for forecast periods less than 36 hours.

10. CONCLUSIONS

Statistics of offshore forecast errors derived from the UKMO operational use of numerical forecasting models have been examined. RMS errors in wind speed and wave height forecasts have been found to have a clear seasonal variation with maximum in winter. The mean error (bias) also shows some evidence for an annual cycle with higher (positive) values in winter and negative values in summer in places, although the geographical coherence is not great. Whereas RMS errors increase with increasing forecast period, there is no such consistent change of bias with forecast period.

Examination of data from different locations in waters around the UK has shown that RMS errors are larger at higher latitudes in winter, but the change with latitude is much smaller in summer. There is no clear relationship between bias and latitude.

A methodology has been devised to convert RMS errors into probability of threshold exceedance. This provides the risk analyst with guidance on the likelihood of a wind speed or wave height threshold being exceeded when a forecast at some margin below the threshold has been made. Such probabilities as a function of forecast period have been presented.

The impact of bias on these probabilities has been demonstrated, emphasising the importance of such biases being quantified and minimised.

Finally, the quantitative impact of the contribution of the human forecaster on forecast accuracy (in terms of the effect on exceedance probabilities) has been shown to be significant at low forecast periods, but to decrease at forecast periods beyond about 36 hours.

It should be borne in mind that any operational forecasting system is subject to continuous improvements, resulting either from new sources of data allowing better analysis of initial conditions, or from small- or large-scale improvements in the formulation of the numerical models. Therefore, the data presented here represent the state of the art in the period 1993/4, and further improvements can be expected over time.

It should also be emphasised that the above conclusions are derived from experience with the UKMO models and forecasting procedures. Since similar statistics from other bodies are not available (indeed, it is not known whether other forecasting organisations collect such data routinely), it has not been possible to carry out any comparisons. However, the findings are expected to apply in broad qualitative terms to other forecasting services operating with a similar 'model+forecaster' philosophy.

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Figure 1a

Schematic representation of forecast variable and critical threshold

With no forecast bias

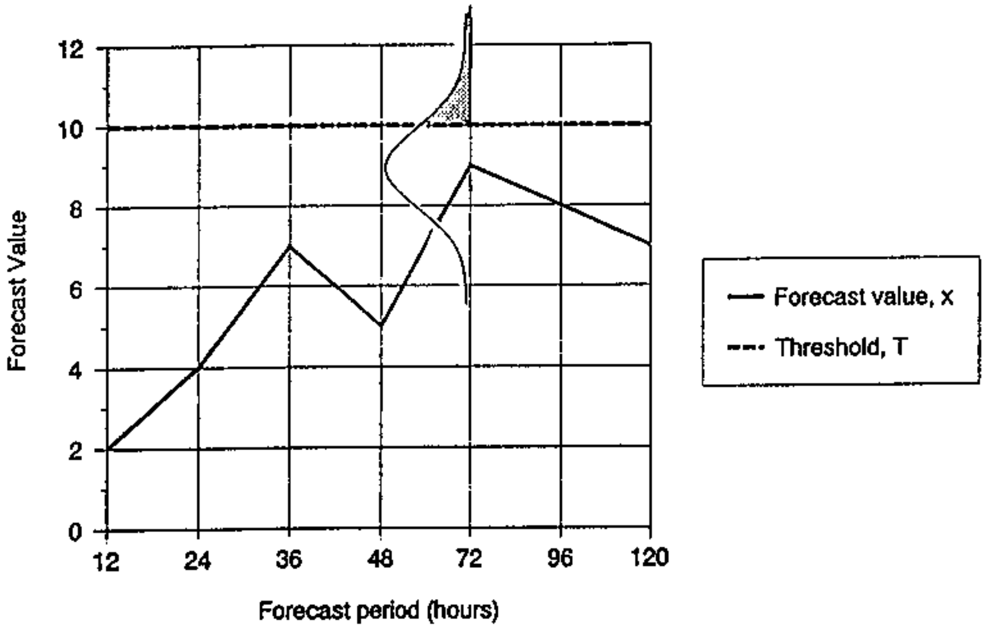
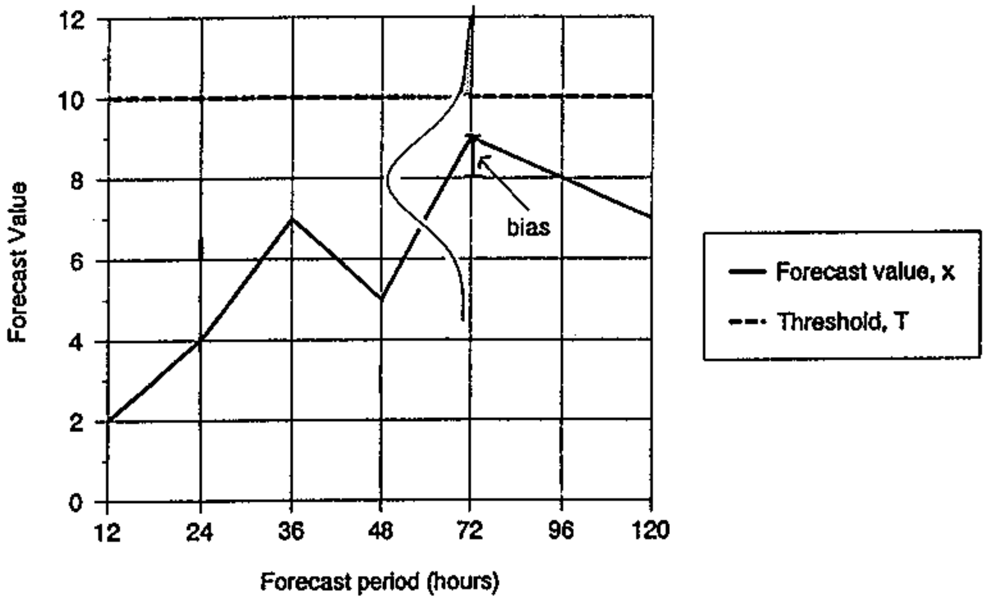


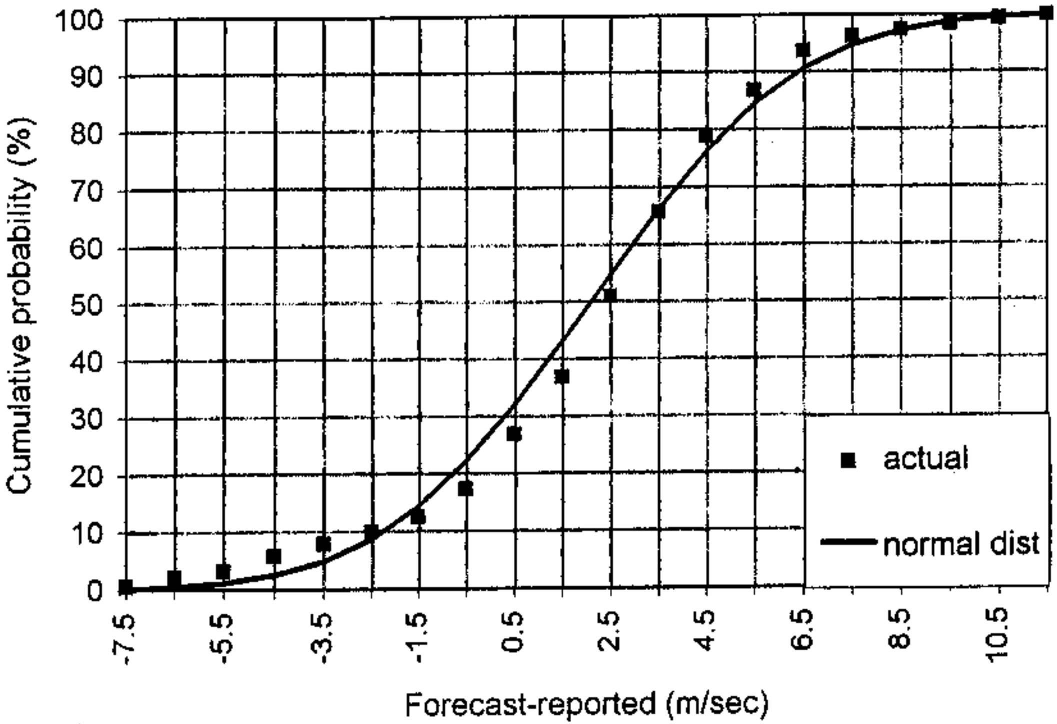
Figure 1b

Schematic representation of forecast variable and critical threshold

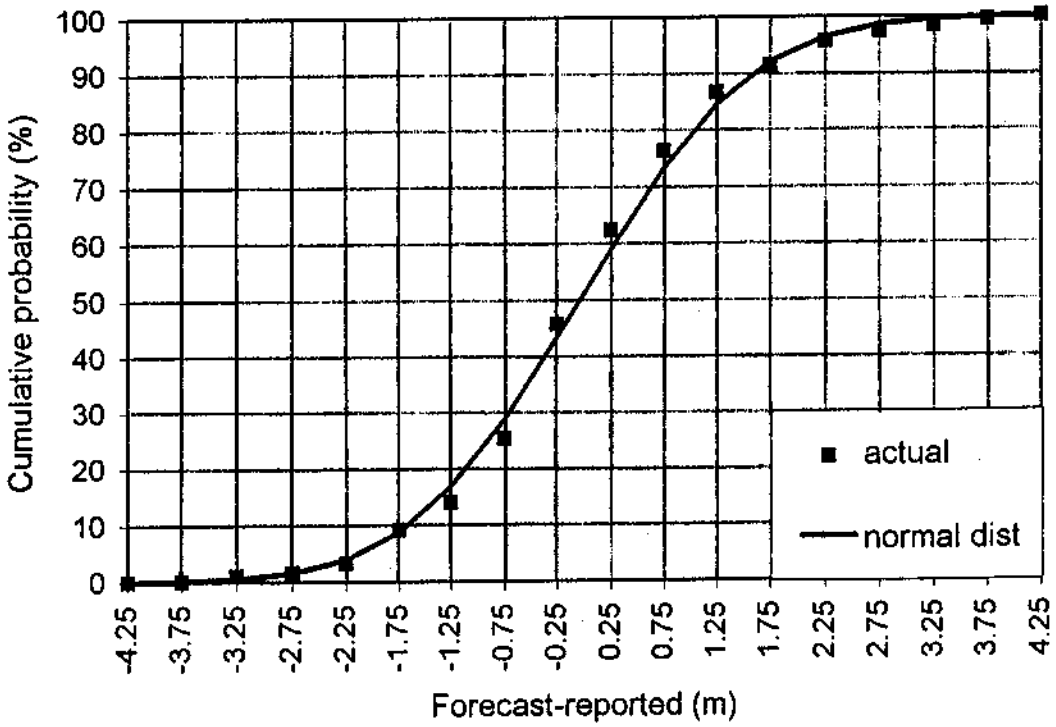
With forecast bias



Beryl A ; Wind speeds Figure 2a
24 hour forecast errors (model only)
January; 1992 to 1995

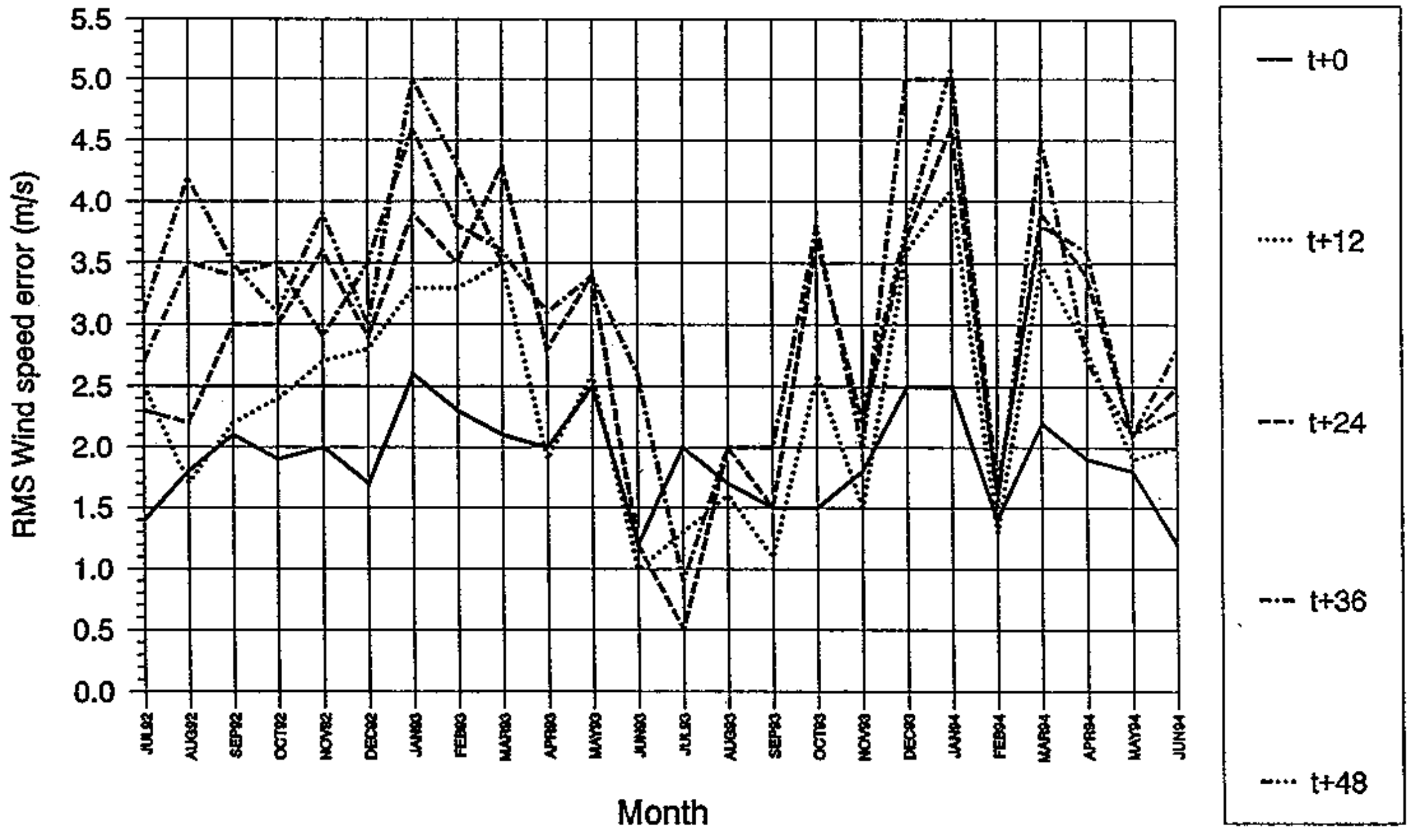


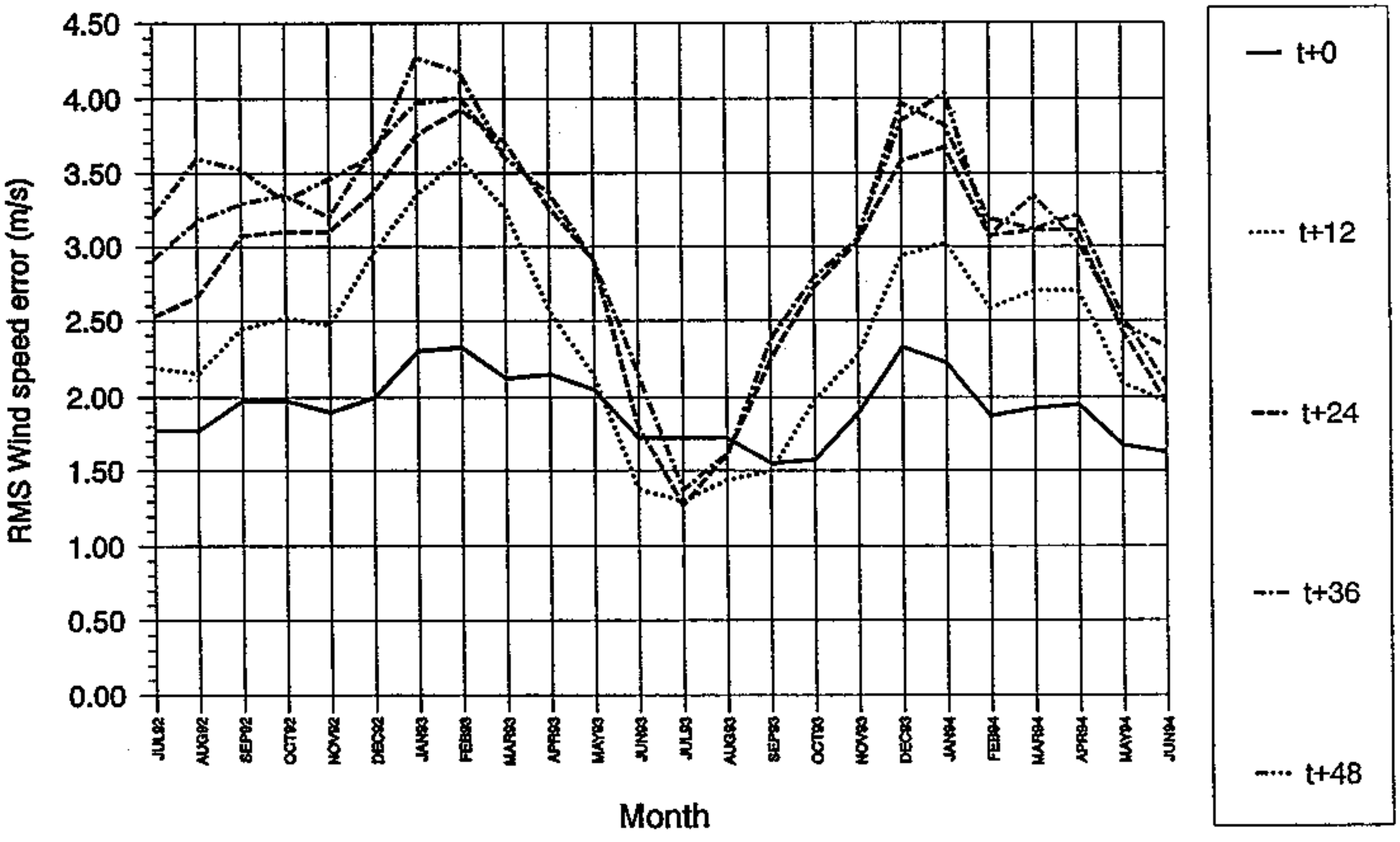
Beryl A; Significant Wave Height Figure 2b
48 hour forecast errors (model only)
January; 1992 to 1995



European Model: RMS Wind speed errors
BERYL A 63111 LAT: 59.5N LON: 1.5E
10-15M/S

Figure 3
Monthly values unsmoothed





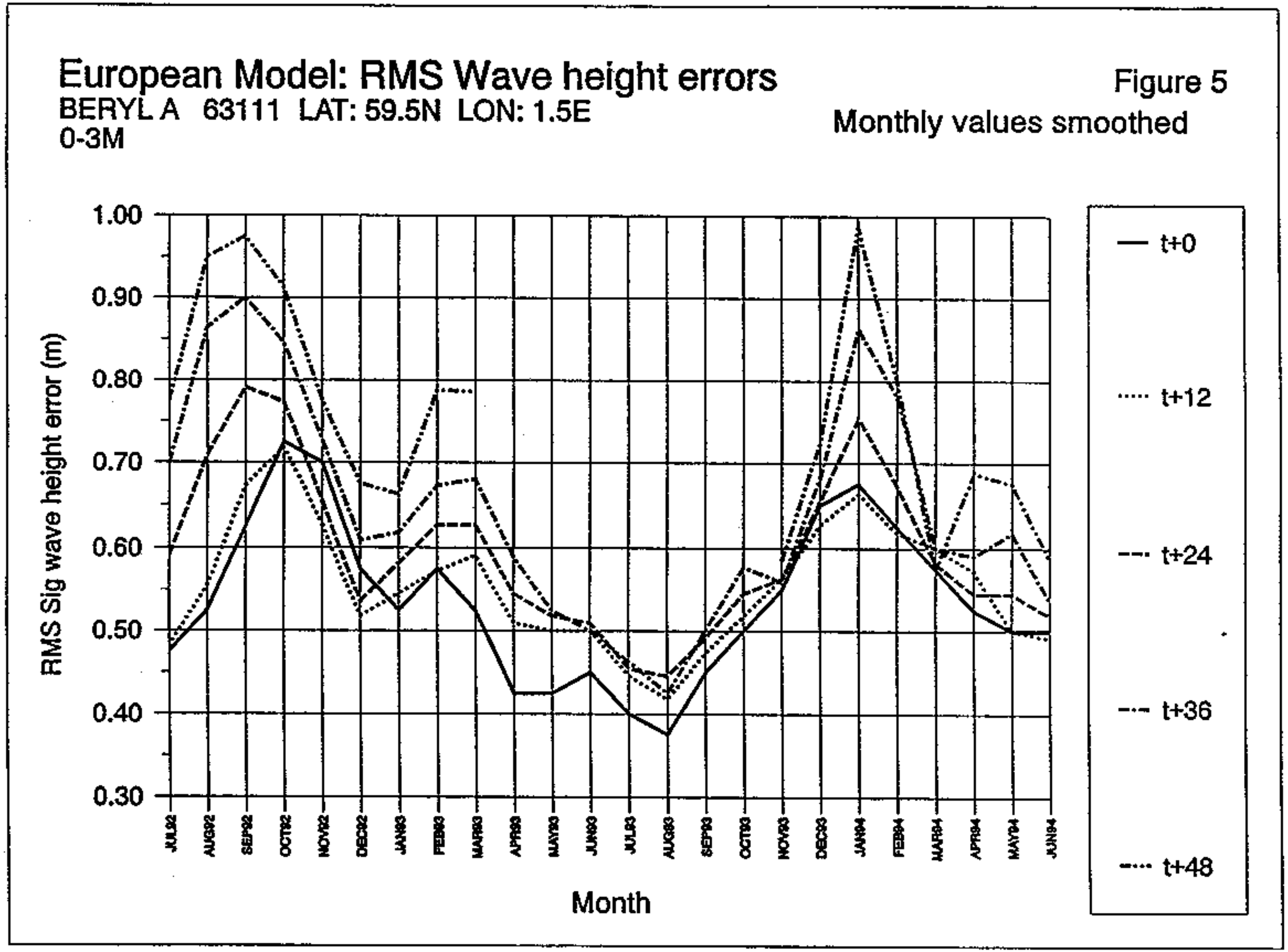
European Model: RMS Wind speed errors

BERYL A 63111 LAT: 59.5N LON: 1.5E

10-15M/S

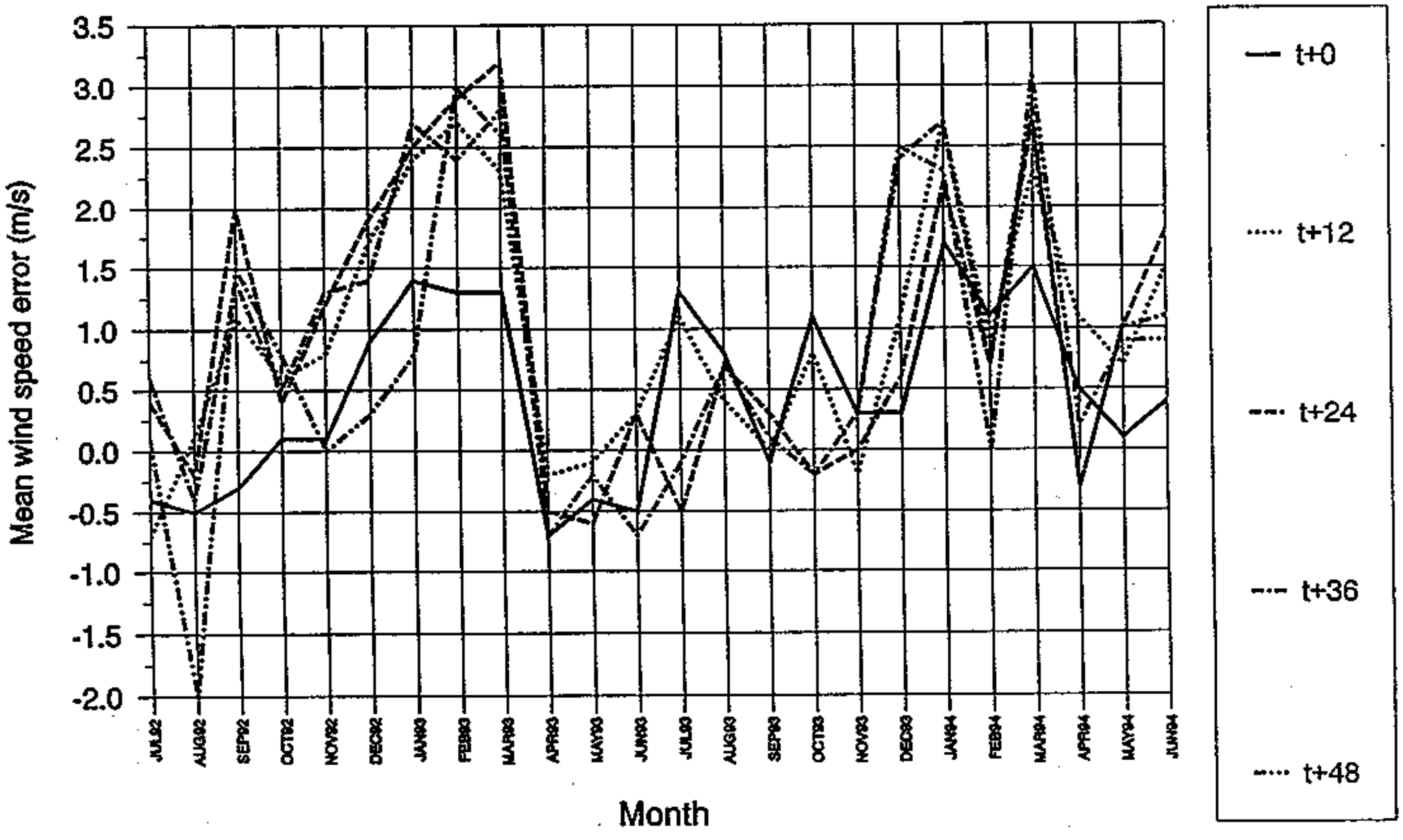
Figure 4

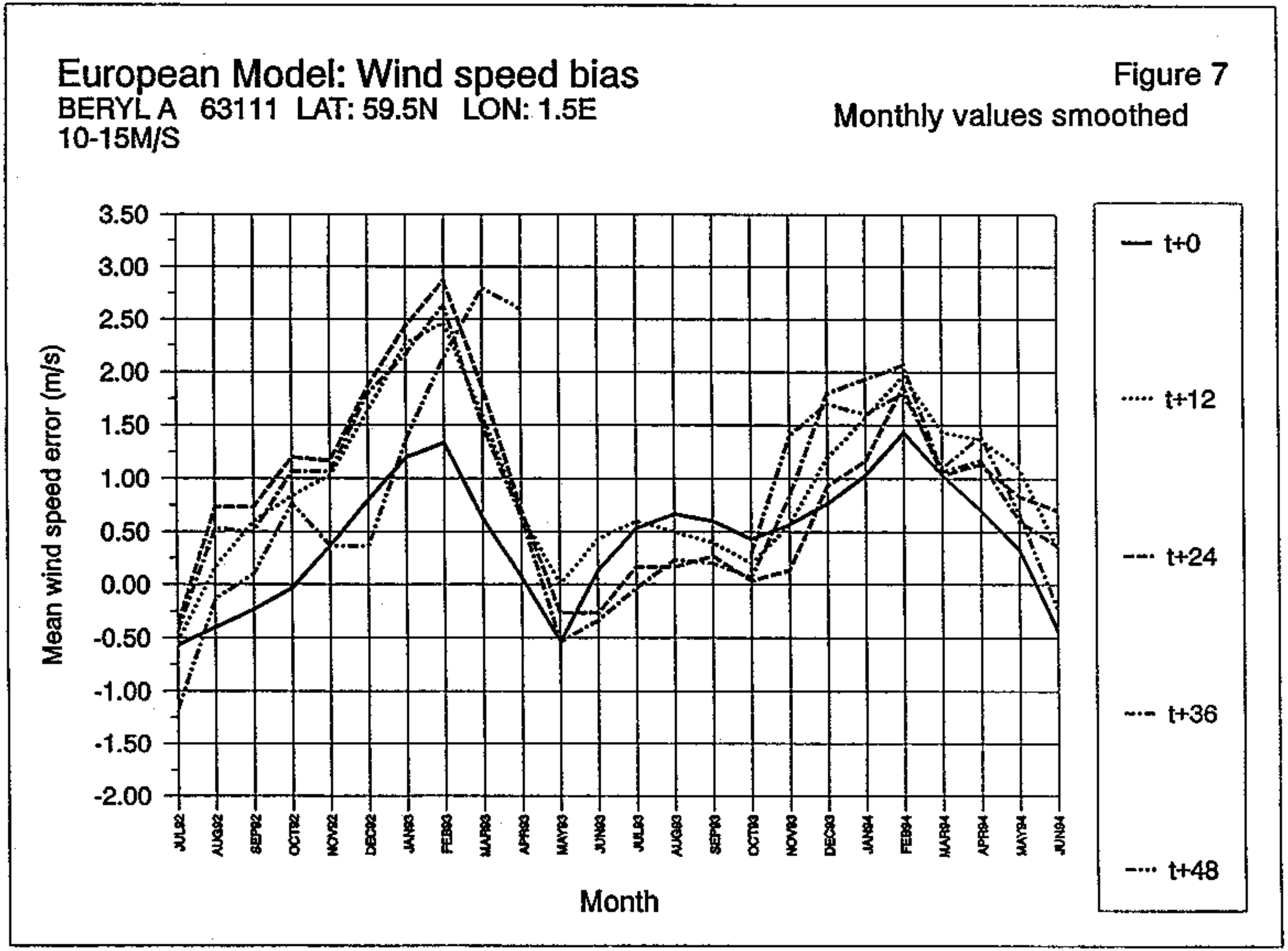
Monthly values smoothed


European Model: RMS Wave height errors
BERYL A 63111 LAT: 59.5N LON: 1.5E
0-3M
Figure 5
Monthly values smoothed
RMS Sig wave height error (m)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
JUL92
AUG92
SEP92
OCT92
NOV92
DEC92
JAN93
FEB93
MAR93
APR93
MAY93
JUN93
JUL93
AUG93
SEP93
OCT93
NOV93
DEC93
JAN94
FEB94
MAR94
APR94
MAY94
JUN94
Month
t+0
t+12
t+24
t+36
t+48

European Model: Wind speed bias
BERYL A 63111 LAT: 59.5N LON: 1.5E
10-15M/S

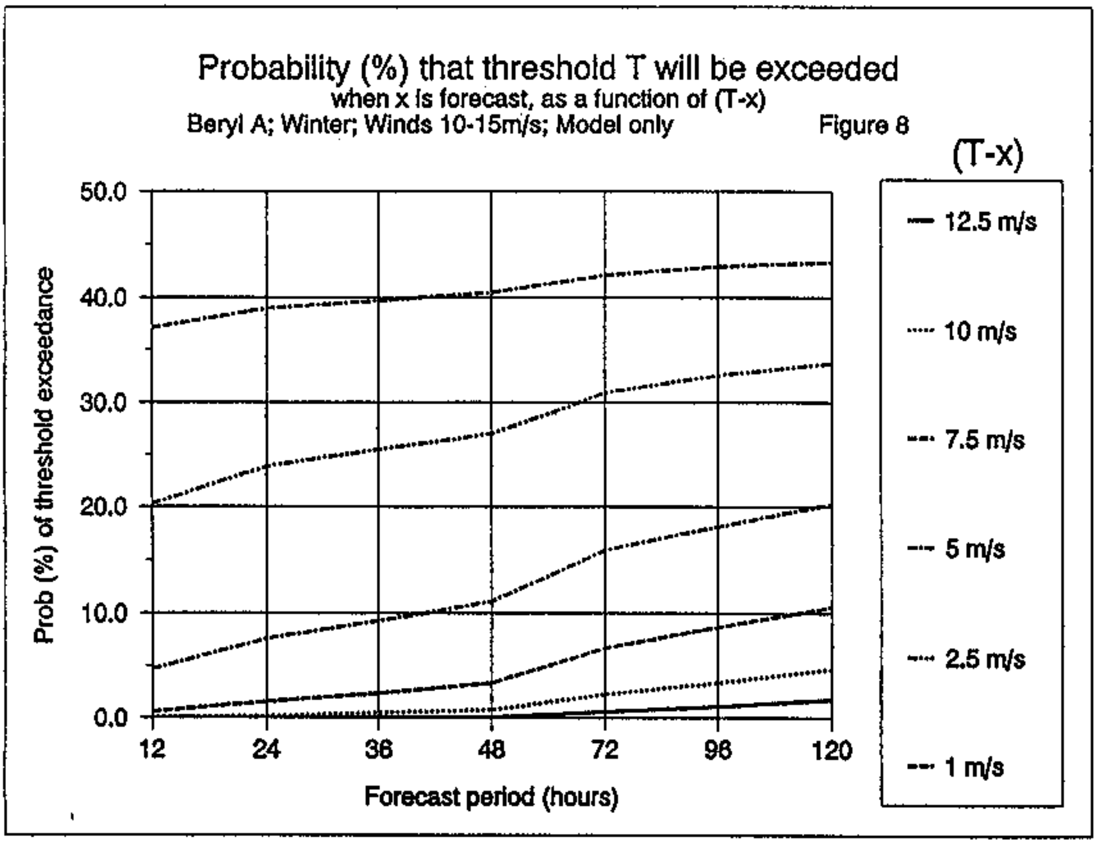
Figure 6
Monthly values unsmoothed



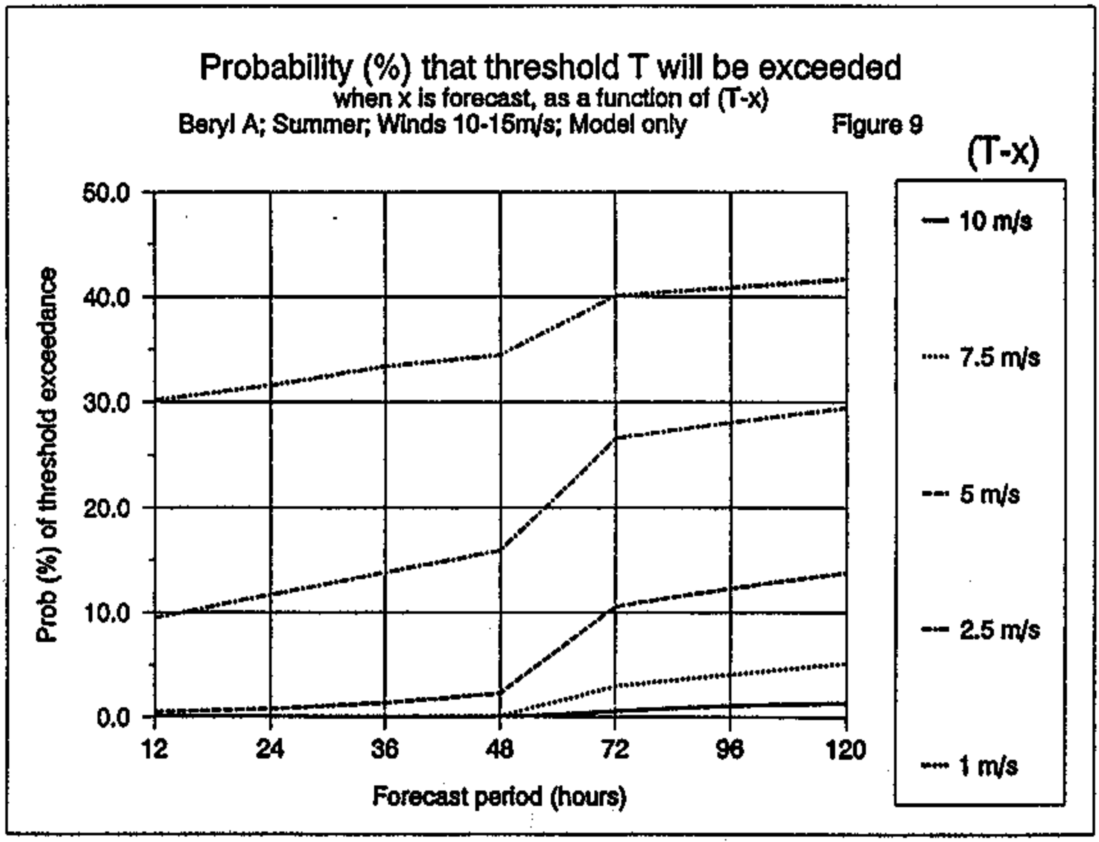


European Model: Wind speed bias
BERYL A 63111 LAT: 59.5N LON: 1.5E
10-15M/S

Figure 7
Monthly values smoothed



Probability (%) that threshold T will be exceeded
when x is forecast, as a function of (T-x)
Beryl A; Winter; Winds 10-15m/s; Model only Figure 8



Probability (%) that threshold T will be exceeded
when x is forecast, as a function of (T-x)
Beryl A; Summer; Winds 10-15m/s; Model only Figure 9

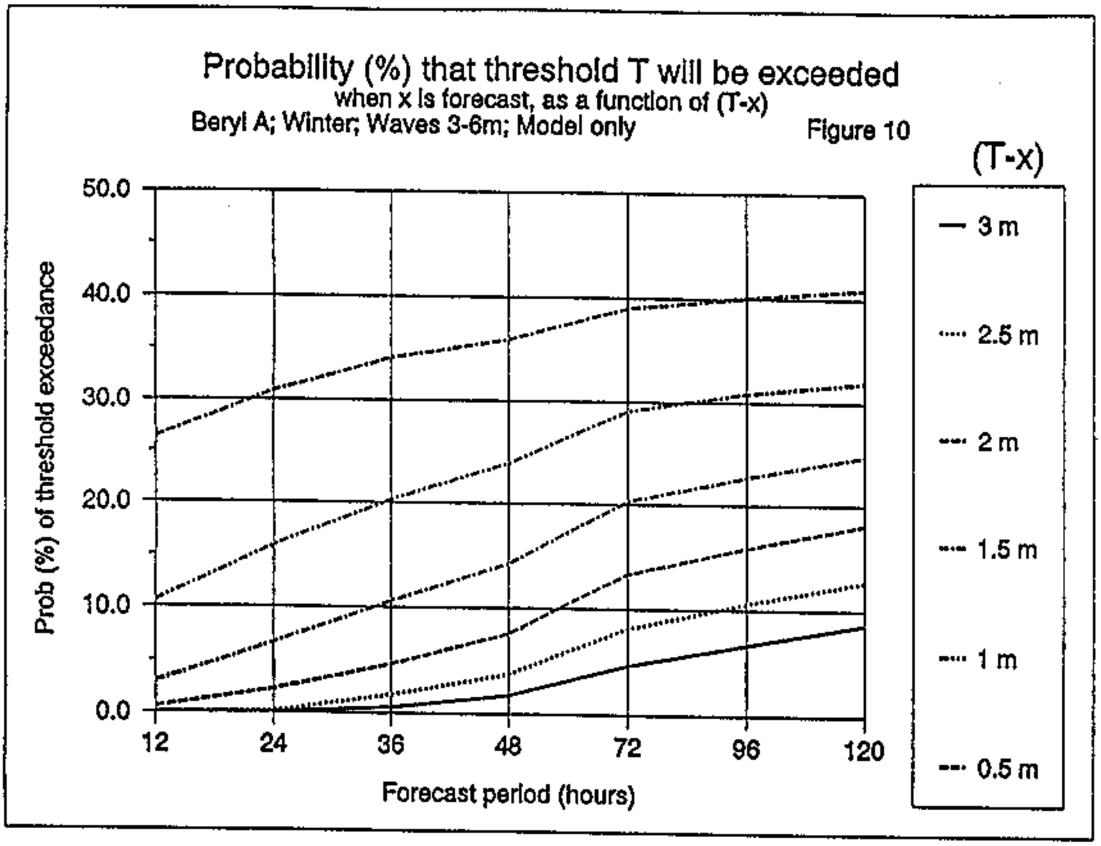

Probability (%) that threshold T will be exceeded
when x is forecast, as a function of (T-x)
Beryl A; Winter; Waves 3-6m; Model only

Figure 10

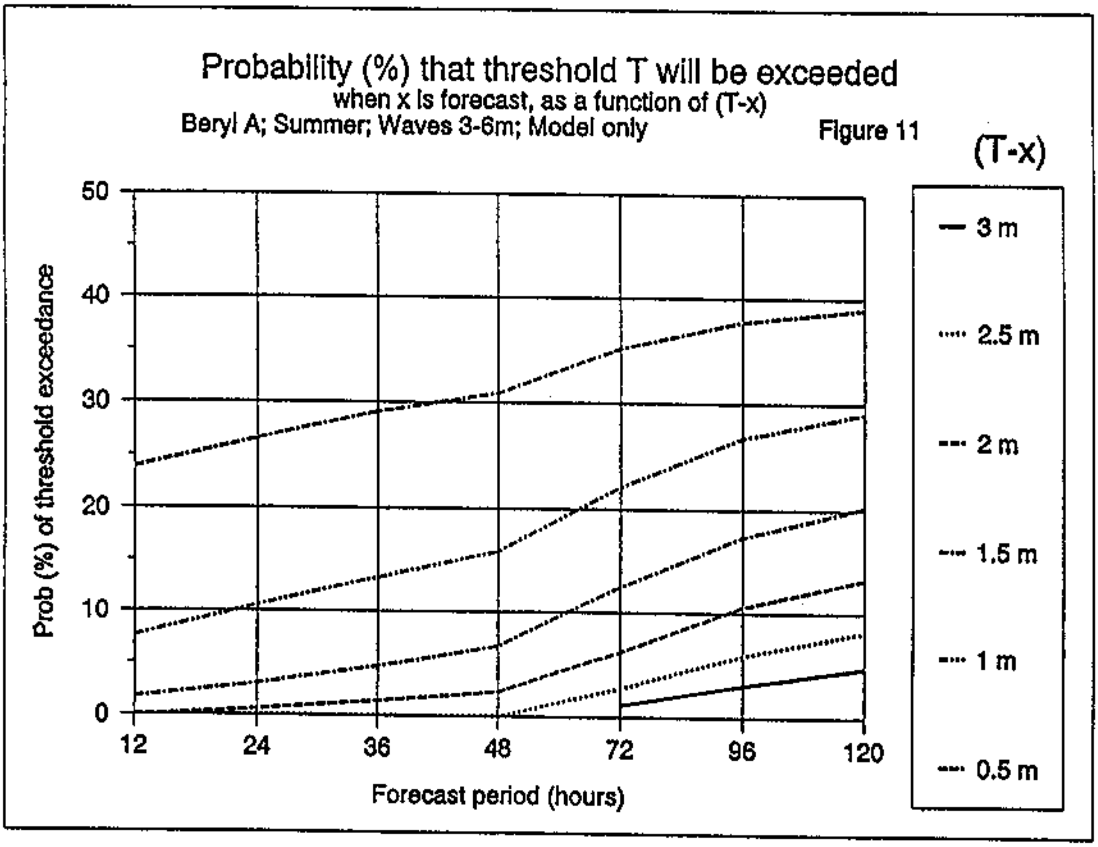
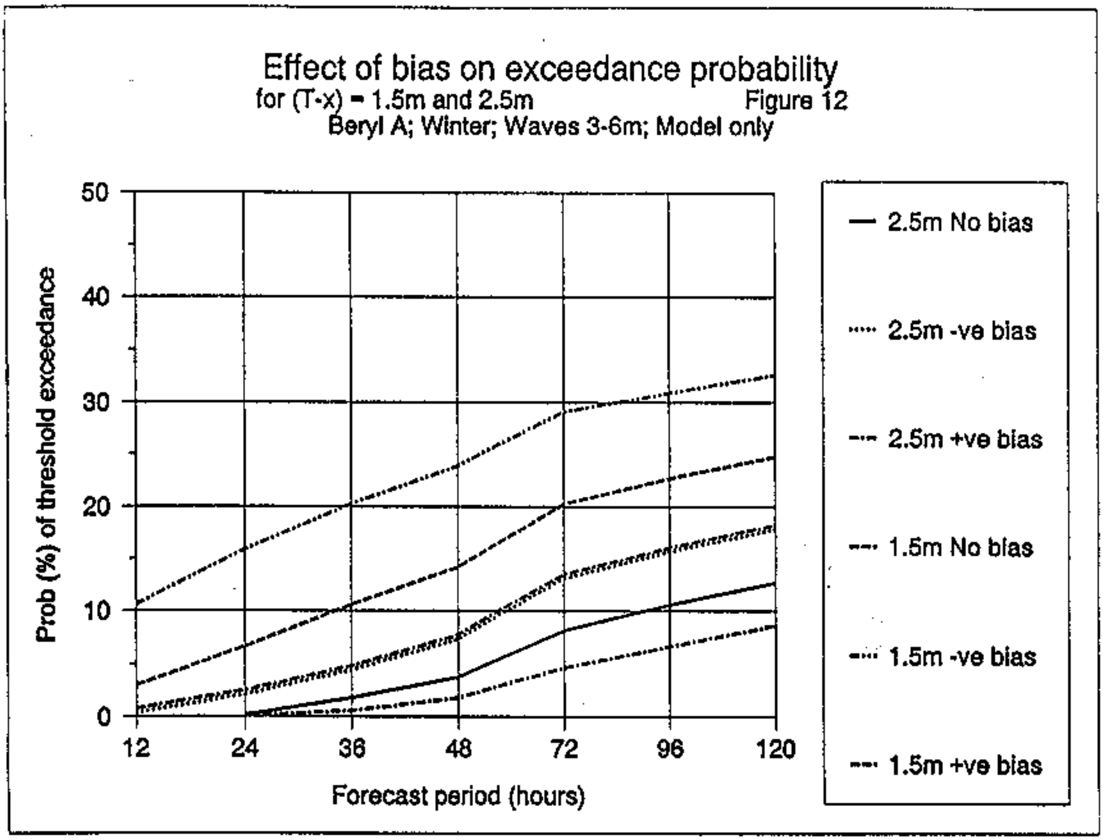
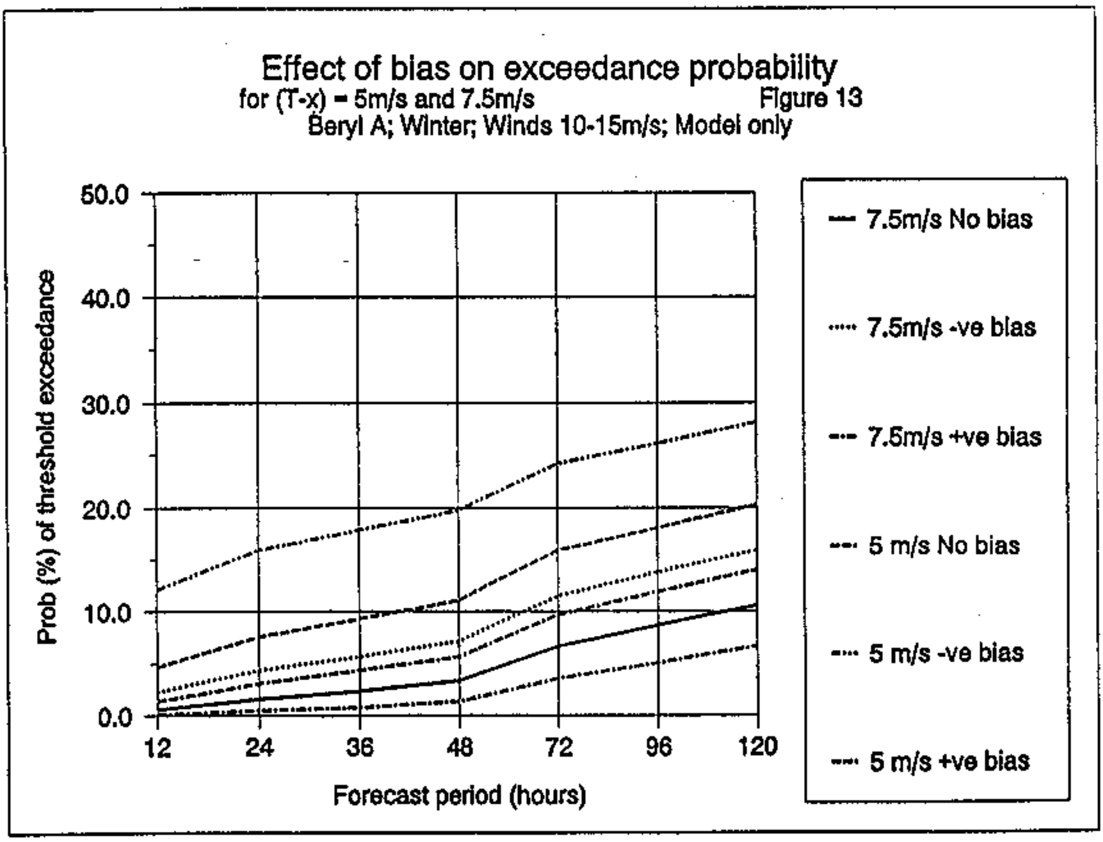

Probability (%) that threshold T will be exceeded
when x is forecast, as a function of (T-x)
Beryl A; Summer; Waves 3-6m; Model only

Figure 11



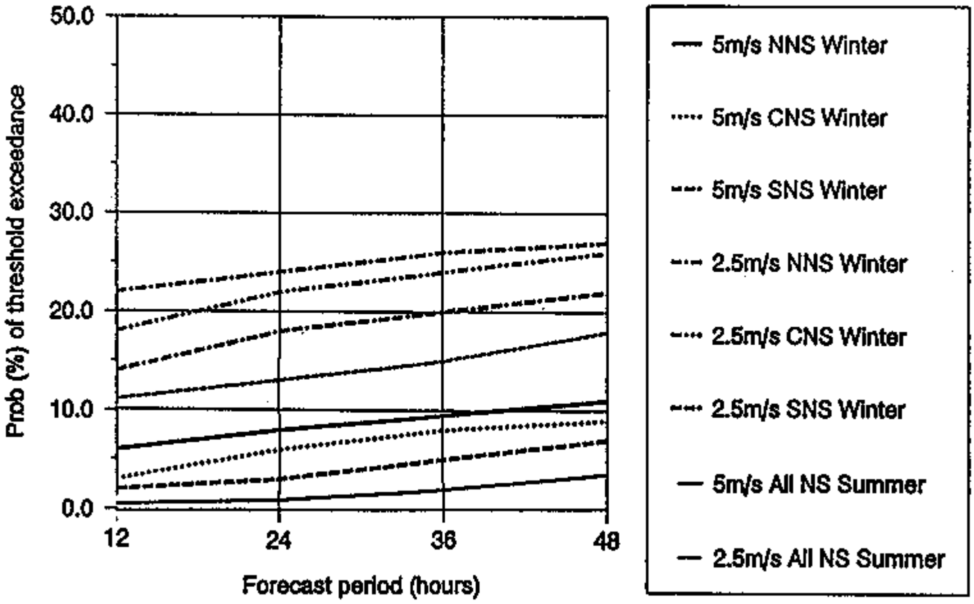
Effect of bias on exceedance probability
for (T-x) = 1.5m and 2.5m Figure 12
Beryl A; Winter; Waves 3-6m; Model only



Effect of bias on exceedance probability
for (T-x) = 5m/s and 7.5m/s Figure 13
Beryl A; Winter; Winds 10-15m/s; Model only

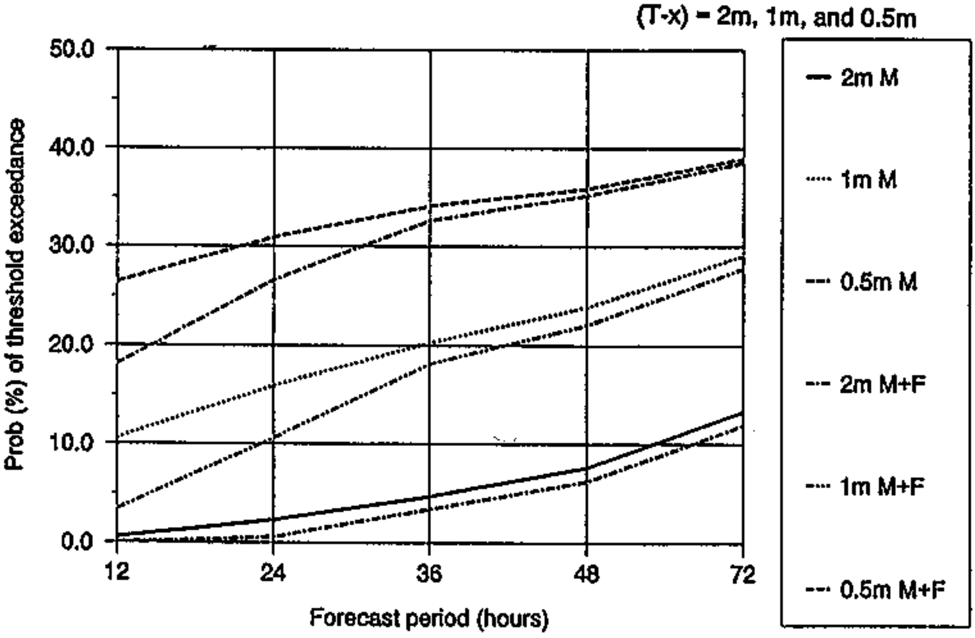
Representative probabilities for threshold exceedance Figure 14

Three North Sea areas (Northern, Central, Southern)
Winds 10-15m/s; Model only; (T-x)= 5 and 2.5m/s



Impact of forecaster input on wave height forecasts Figure 15

Comparison of 'model only' (M) and 'model+forecaster' (M+F)
Ekofisk; winter



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