DUPLICATE

Forecasting Research

Forecasting Research Division
Technical Report No. 100

United Kingdom contribution to the revision of the World Meteorological Organization Marine Meteorology and Related Oceanographic Activities Report No. 12

WMO Wave Programme: National reports for 1994 on wave measuring techniques, numerical wave models and intercomparisons.

By
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June 1994

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Introduction

This report was written at the request of the WMO wave programme. It is part of a biennial review of operational wave activities throughout the globe. The majority of the report is exactly as sent to WMO. However, this version contains two major additions to the WMO report. First, the names and addresses of contributors is included, and second each item has been associated with the institution that is performing the work. This should make the task of preparing the next report easier, and also help direct enquirers towards someone that can help them.

S J Foreman
17 June 1994

Annex II

NAMES AND ADDRESSES OF NATIONAL FOCAL POINTS FOR WAVES WHO RESPONDED TO SURVEYS

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Annex III

INDIVIDUAL NATIONAL REPORTS ON FORECAST DATA FORMATS, NEW TECHNIQUES FOR WAVE MEASUREMENTS AND NUMERICAL MODEL VERIFICATION PROJECTS.

United Kingdom

1 Introduction

The United Kingdom is continuing both its wave modelling and wave observing programmes. Specific developments during the period 1991 to 1993 were calibration and analysis of ERS-1 observations, assimilating them into numerical models, and using them to update wave climatologies. Several wave models transferred from being research tools into becoming useful tools for civil engineering. This report is divided into five subject areas: operational data formats, observational techniques, numerical modelling, interpretation of data and operational wave forecasting.

2 Operational data formats.

Operational wave model products are placed on the Global Telecommunications System in GRID and GRIB code. Charts are issued by facsimile.

3 Developments in techniques for measuring waves.

3.1 In situ measurements.

BD(OP)
BD(OM)
HR

Ship-board wave recorders continue to be used on Ocean Weather Ship Cumulus and some light vessels. Six meteorological buoys, that also measure wave height and period, have been deployed in the North East Atlantic, reporting in real time through a geostationary satellite as part of the UKON-4 network. In addition to these deep water buoys, there have been several deployments of buoys in shallow water designed to assist in developing models of waves inshore; three of these have been sited at where they can be used to validate the waves and currents used for the storm-tide warning service. It is planned to add wave measuring instruments to inshore operational meteorological buoys.

3.2 High frequency radar.

Sheffield
Marconi
Met O(RSI)

Two methods of high frequency (7 to 30 MHz) radio propagation are being investigated for wave measurements. Ground (surface) wave propagation has a range of 1-200 km. Data are being analyzed from two UK commercial radar systems. OSCR (primarily developed for measuring currents, 25-30 MHz) has a range of 1 to 30 km for currents with a resolution of 1km. A pair of radars yields a rectangular grid of current vectors up to an area of 500 km^2. PISCES (primarily developed for wave measurement, 7-15 MHz) has a range of 15 to 200 km for currents, 15 to 150 km for waves, with resolution of 7.5km. A pair of radars yields current vectors or directional wave spectra at beam intersection points within an area of about 10 000 km^2. Studies include assessing and developing the capabilities of the OSCR system for wave measurement and developing automatic algorithms for segmenting the spectra into swell and wind-sea. Comparison of ground wave measurements with *in situ* observations has been performed as part of the joint UK/Netherlands "NURWEC" project (Wyatt and Holden, 1992). Other research is aimed at real time derivation of bulk properties of the surface environment, including surface wind vectors, root mean square wave height and mean period. Research into skywave (ionospheric) propagation radar continues.

3.3 Ultra High Frequency (UHF) and Microwave Radar.

POL
DRA

Ships' radars use UHF or microwave radio waves. Systems have been developed to process the returns using PCs, improving on the earlier photographic techniques. These radars are being calibrated against buoys. Rig or ship mounted and land based versions of the radar are in use. Specialist side-looking glancing-angle radars have also been deployed from ships.

3.4 Sonar.

SUDO
DRA

Upward looking side scan sonar is being used to measure the characteristics of breaking waves. Based on the technique of Thorpe and Hall (1983), further measurements have been made in Loch Ness. Measured quantities include the proportion of waves that break and the depth penetration of bubbles caused by wave breaking.

3.5 Lasers.

SUDO
DRA

Refraction of laser light at the ocean surface yields information on the high frequency waves. A sensor based on this technique is being developed.

QMC

3.6 Stereo photography.
As a tool for validating ERS-1, data research into measuring wave spectra from stereo photographs taken from a tower was performed.

3.7 ERS-1.

Met O
Rennell
IOSDL
DRA

ERS-1 carries three instruments of interest for wave studies. Two (Synthetic Aperture Radar and the altimeter) give information about the waves themselves. The scatterometer provides surface wind speeds. Validation of ERS-1 was through observational campaigns and model comparisons. Interpretation of ERS-1 scatterometer data is helped by comparisons with estimates of wind speed and direction from weather forecast models. Errors in the calibration of wave height were identified by comparison with wave models.

4 Numerical modelling.

4.1 Development of models.

POL
HR
Met O

"Second generation" models, in which the interactions between waves of differing frequency and direction are represented through a parametrization scheme, are being used and further developed for coastal defence and engineering (Southgate, 1987, Ewing and Hague, 1993, Hawkes, 1987). Modifications to the Met. Office wave model (Golding, 1983) were introduced to improve the handling of swell through refining the definition of wind sea and swell components of the spectrum; growth and dissipation in the model were also re-calibrated. A single point version of the Met. Office model has been developed to transfer the deep water waves from the global model into site specific shallow water forecasts that can take account of some shallow water effects and local wind variations. Interactions of waves, winds, and tide-surge models are being investigated using an international third generation wave model (WAM) in which the exchange of energy between different frequencies and directions is calculated using an approximation to the physical processes involved (Wu and Flather, 1992, and Wu, Flather and Wolf, 1993). The coupled models have been tested for UK storms of October 1987 and February 1990. Validation of the system consists of comparison of model results with significant wave height, wave period and water level measured by tide gauges, buoys and the GEOSAT altimeter. Plans are being made to implement the system operationally.

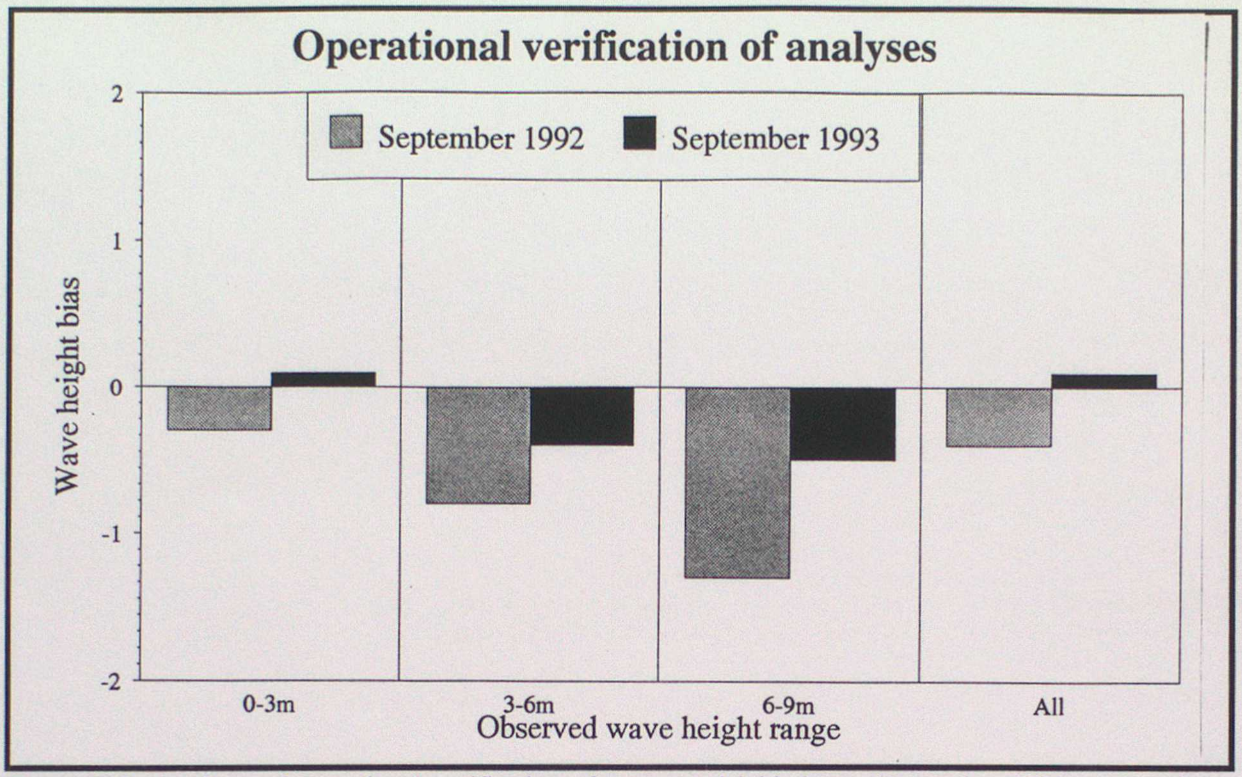

Figure 1 Comparison of operational verification of wave model hindcasts (September 1992) and analyses (September 1993) for the Met. Office global wave model.

4.2 Data assimilation.

Met O

The ERS-1 altimeter provides measurements of wave height and wind speed. A data assimilation scheme has been developed to introduce these into the operational global wave model. Figure 1 shows the impact of data assimilation by comparing operational verification of wave analyses for September 1992 (without data assimilation) with that for September 1993 (with assimilation of ERS-1 observations). Assessment of the accuracy of ship observations of waves is being performed as a precursor to assimilating *in situ* observations into the wave models.

4.3 Hindcast studies.

Met O

Comparisons of the Met. Office second generation model with the third generation WAM have continued. Handling of swell remains better in the WAM but, at the high horizontal resolution of the operational Met. Office model. The study is intended to determine whether the expense of running the WAM is justified by improved performance (five times the computing resource is needed as for the second generation model).

5 Interpretation of data.

5.1 Wave climatologies.

IOSDL

Earlier climatologies derived from GEOSAT data have been extended by comparisons with ERS-1 observations. Buoys have been used to cross-calibrate the two datasets (Carter, 1993).

5.2 Regional climatology.

POL

An atlas of the wave climatology for the North West European Shelf has been incorporated into a digital atlas (BODC, 1991).

5.3 Model archive.

Met O
HR

Wave heights, one dimensional spectra and low level winds from the Met. Office operational wave models has been archived since 1986. This archive has been used to supplement observations for applications in the offshore, coastal engineering, sea transport and wave power communities. A climatology is being prepared from the archive, for coastal engineering applications.

6 Operational wave modelling.

6.1 Model formulation.

Met O

Operational wave forecasts are based on a model developed from that of Golding (1983), the main enhancements being representations of great circle turning and directional relaxation of waves when the wind direction changes. Winds are derived from the numerical weather prediction models. ERS-1 data are assimilated into the global wave model; the regional model runs from a hindcast driven at its boundaries by the global model.

6.2 Model areas and resolution.

Met O

The global wave model resolution is 0.833° latitude by 1.25° longitude, with 13 frequency bins and directional resolution of 22.5°. The European wave model covers the eastern Atlantic east of 14°W between 30.5°N and 66.75°N, and the North, Mediterranean, Baltic and Black Seas with resolution 0.25° latitude by 0.4° longitude.

7 References

BODC (British Oceanographic Data Centre)	1991	United Kingdom Digital Marine Atlas. Proudman Oceanographic Laboratory, NERC. (On floppy disk)
Carter, DJT	1993	*Global wave height climatologies from ERS-1 altimeter data, and comparison with those from GEOSAT.* pp489-492 in Proceedings of First ERS-1 Symposium - Space at the Service of the Environment, Cannes, France, 4-6 November 1992, ESA SP-359 (March 1993).
Ewing, JA and RC Hague	1993	*A second generation wave model for coastal wave prediction.* Proc. Waves '93, New Orleans.
Golding, B	1983	*A wave prediction system for real time sea state forecasting.* Quart. J. Roy. Meteorol. Soc., **109**, 393-416.
Hawkes, PJ	1987	*A wave hindcasting model.* In: Advances in Underwater Technology, Ocean Sciences, and Offshore Engineering, **12**: Modelling the Offshore Environment. Society for Underwater Technology.
Southgate, HN	1987	*Wave prediction in deep water and at the coastline.* Hydraulics Research report SR 117.
Thorpe, SA and AJ Hall	1983	*The characteristics of breaking waves, bubble clouds, and near surface currents using side scan sonar.* Cont. Shelf Res., **1**, 353-384.
Wu, X and RA Flather	1992	*Hindcasting waves using a coupled wave-tide-surge model.* pp150-170 in preprint volume of: The Third International Workshop on Wave Hindcasting and Forecasting, Montreal, May 19-22 1992. Ontario: Environment Canada, 400pp.
Wu, X, RA Flather and J Wolf	1993	*A third generation wave model of European continental shelf seas with depth and current refraction due to tides and surges and its validation using GEOSAT and buoy measurements.* Proudman Oceanographic Laboratory, Report No. 33, 48pp.
Wyatt, LR and GJ Holden	1992	*Developments in ocean wave measurement by HF radar.* IEE Proc F, **139**, 170-174.

ANNEX IV

INDIVIDUAL NATIONAL REPORTS ON NUMERICAL WAVE MODELS

United Kingdom

1 Global wave model

Model type:	Coupled discrete (SWAMP,1985); deep water solution only.
Integration domain:	Global.
Grid:	Spherical latitude-longitude from 80.4°N to 77.0°S. Resolution: 0.833° latitude, 1.25° longitude.
Frequency resolution:	13 frequency components spaced logarithmically between 0.04Hz and 0.324Hz.
Direction resolution:	16 equally spaced direction components.
Data assimilation:	ERS-1 altimeter wave height and wind speed observations are assimilated into the global wave model. The assimilation scheme (Thomas, 1988, and Stratton et al, 1990) is a variant of the analysis-correction scheme of Lorenc *et al* (1991). After assimilation the model wave height matches the observed wave height, the model wind-sea matches the observed wind speed, and the pattern of the spectrum remains similar to that before assimilation.
Integration scheme:	Modified Lax-Wendroff. Source terms timestep = 3600s; advection timestep frequency dependent.
Boundary forcing:	Winds at lowest level of global atmospheric model (23m). Updated hourly.
Surface classification:	Sea ice analyses the same as global atmospheric model.
Physics parametrisations:	Linear growth (Phillips, 1958); exponential growth (Snyder, 1981); white-capping dissipation (Komen et al, 1984). Non-linear transfer of wave energy through directional relaxation in turning winds is included, and a term accounting for the great-circle turning of swell energy is applied.

Products

Area	Format	Forecast times	Product	Applications
N Atlantic	Chart	T+00, 24, 48, 72	Sig. wave height and wind sea and swell directions	Radio facsimilie chart production
N Atlantic	Chart	T+00, 24, 48, 72	Swell height, period and direction	Radio facsimilie chart production
N Atlantic	Chart	T+00, 24, 48, 72	Swell height and direction	Radio facsimilie chart production
N Atlantic	Chart	T+24, 48, 72	Swell height, period and direction	Ship routeing
N Pacific	Chart	T+24, 48, 72	Sig. wave height and wave directions	Ship routeing
N Pacific	Chart	T+24, 48, 72	Swell height, period and direction	Ship routeing

2 Regional wave model

Apart from having no data assimilation, the formulation of the regional wave model is identical to the global wave model in all respects except the following:

Model type: Coupled discrete; depth dependency specified to 200m with 2m resolution.

Integration domain: European continental shelf and Mediterranean, Black and Baltic seas.

Grid: Spherical latitude-longitude from 67.7°N to 30.5°N, and east of 14.1°W. Resolution: 0.25° latitude, 0.4° longitude.

Source terms timestep: 1800s.

Boundary forcing: 1. Winds at lowest level of regional atmospheric model (23m). Updated hourly.

2. Spectral values at lateral boundaries from global wave model. Updated hourly.

Surface classification: No sea ice.

Physics parametrisations: Identical to global model, without great-circle turning of swell, but with refraction and bottom friction (Collins, 1972).

Products

Area	Format	Forecast times	Product	Applications
North Sea	Chart	T+00, 12, 2, 36	Sig. wave height and wave directions	Offshore industry, ship routeing
North Sea	Chart	T+00, 12, 24, 36	Swell height, period and direction	Offshore industry, ship routeing
North Sea	Grid code	T+00, 06, 12, 18, 24, 30, 36	Sig, wave height	Offshore industry
Coastal locations	Tables	T+03, 06, 09, 12...36	Winds, waves, wind sea, swell	Coastal flood warning
Mediterranean	Chart	T+00,12,24,36	Sig. wave height, wave directions	Offshore industry
Mediterranean	Grid code	T+00, 12, 24, 36	Swell height, period and direction	Offshore industry

References

Collins, J.I. 1972 *Prediction of shallow water wave spectra.* J. Geophys. Res., **77**, 2693-2707.

Komen, G., K. Hasselmann, and S. Hasselmann 1984 *On the existence of a fully developed windsea spectrum.* J. Phys. Oceanogr., **14**, 1272-1285.

Lorenc, A.C., R.S. Bell, and B. Macpherson 1991 *The Meteorological Office analysis correction data assimilation scheme.* Q. J. Roy. Meteorol. Soc., **117**, 59-90.

Phillips, O.M. 1958 *The equilibrium range in the spectrum of wind generated waves.* J. Fluid Mech., **4**, 426-434.

Snyder, R.L., F.W. Dobson, J.A. Elliot, and R.B. Long 1981 *Array measurements of atmospheric pressure fluctuations above surface gravity waves.* J. Fluid Mech., **102**, 1-60.

Stratton, R.A., D.L.Harrison, and R.A.Bromley 1990 *The assimilation of altimeter observations into a global wave model.* AMS 5th Conference on Satellite Meteorology and Oceanography, London, 1990, 108-109.

SWAMP (Sea Wave Modelling Project) 1985 *An intercomparison study of wind wave prediction models. Part I: Principal results and conclusions.* Ocean Wave Modelling. Plenum Press, 256pp.

Thomas, J.P. 1988 *Retrieval of energy spectra from measured data for assimilation into a wave model.* Q.J. Roy. Meteorol. Soc., **114**, 781-800.

Replacements for UK entries in tables.

Table 3 - Research into new techniques for wave measurements
3.1 In situ sensing

Who	Instrument type	Countries	How deployed	Products	Verification	Present and further uses
UKMO HR SUDO	Buoys	United Kingdom	Directional spectra, various deployments of wave rider and wave type	Directional spectra. Data return by satellite links or on-buoy storage.	Continuing	Research on buoy technology. Further deployments planned to assist developments of in-shore wave models.
UKMO HR	Wave recorder	United Kingdom	On board ships (third generation)	One-dimensional spectra	Continuing	Incorporating advances in sensor and computer technology and improved correction for ship heave/pressure sensor response.
SUDO	Inverted echo sounder	United Kingdom	Upward looking research tool	Frequency of wave breaking, duration of breaking events, phase speed of waves, number of waves breaking	Continuing	Studies of atmosphere - ocean exchanges.

Table 3 - Research into new techniques for wave measurements
3.2 Remote sensing - ground based

Who	Instrument type	How deployed	Products	Verification	Present and further uses
SUDO DRA	**LASERS** United Kingdom	Mounted downward-looking on exposed surfaces	Small scale surface roughness.	Continuing	Research into mechanisms of reflection and modification of high frequency radio waves by wind-roughened surfaces.
IOSDL	**STEREO PHOTOGRAPHY** United Kingdom	Mounted on tower over reservoir	Two dimensional height maps of the surface	Wave staff array	Research and calibration of ERS-1
SUDO POL	**MICROWAVE SOUNDERS** United Kingdom	Mounted on fixed platforms	Orbital velocity and wave direction.	Continuing (against buoys)	Wave sensing by radar, verification of wave models.
DRA	**RADAR**	Ship mounted, side-glancing	Directional wave spectra	Field trials against buoys	Real time wave measurement
POL	**X-BAND RADAR** United Kingdom	Ship-board. PC processing.	Automated capture of directional wave spectra.	Field trials against buoys.	North Sea observational programme.

Sheffield MARCONI	**HF SKY-WAVE RADAR** United Kingdom	Shore-based - range over 1000km	Wave and current data	Hindcasts of remote North Atlantic regions.	Long-term development
Sheffield MARCONI	**HF GROUND-WAVE RADAR** United Kingdom	(a) OSCR and (b) PISCES. Shore-based systems: (a) resolution 1km, range 1-30km; (b) resolution 7.5km, range 15-200km (currents) and 15-150km (waves).	Wave spectra and currents. Root mean square wave height and mean period; surface wind vectors.	Against directional wave buoys	Full directional wave spectra using radar frequencies 7 to 30MHz. Wave-current interaction studies. Real time data on waves in a region. High resolution shallow water studies.

Table 3 - Research into new techniques for wave measurements
3.3 Remote sensing - space based

Who	Instrument type	How deployed	Products	Verification	Present and further uses
IOSDL UKMO DRA	**ACTIVE RADAR** United Kingdom	Scatterometer, altimeter and synthetic aperture radar (SAR) on ERS-1. Aircraft deployments. GEOSAT altimeter.	Wave height and wind speed from altimeter. Wind vector from scatterometer. Wave spectra from SAR.	Ongoing, against buoys, other remote sensing, special observing campaigns, and models.	Calibration of sensors. Creation of global climatologies of waves. Assimilation of scatterometer winds into atmosphere model, wave heights into wave model. Plan to use ERS-2.
DRA		Space shuttle	Wave images	Against buoys	Wave analysis
SUDO DRA		Synthetic aperture radar on ERS-1	Influence of surface winds and waves of other features imaged by SAR.	Model analyses, in situ measurements.	Investigations of current shear regions and fronts

Table 4.1 - Numerical wave models operated by National Meteorological Services.

Who	Name of model	Area	Grid	Type of model	Products	Source of wind information
UKMO	**UNITED KINGDOM** European model	North Atlantic east of 14°W from 30.75°N to 66.75°N, including the Mediterranean, Baltic, Black Sea, and North Sea.	0.25° latitude by 0.4° longitude.	Depth variations represented with 2m resolution (to 200m). Coupled discrete.	12h hindcasts and 48h forecasts of wind sea and swell (height, direction, and period). Significant wave height. Fields output as charts and as printouts or meteograms at selected points.	Analysis and forecast winds from the lowest level of the UK Met. Office fine resolution limited area numerical weather prediction model at half-hourly intervals.
UKMO	Global model	Global ocean.	0.833° latitude by 1.24° longitude.	Deep water. Coupled discrete. ERS-1 altimeter wave heights assimilated using successive correction since June 1993.	12h analyses and 120h forecasts of wind sea and swell (height, direction, and period). Significant wave height. Fields output as charts for local use and in digitally coded bulletins (GRIB) on the GTS.	Forecast winds from the lowest level of the UK Met. Office global numerical weather prediction model every hour.

Table 4.2 - Numerical wave models - operational (non National Meteorological Services or on request)[1]

Who	Name of model	Area	Grid	Type of model	Products	Source of wind information
Oceanroutes	**UNITED KINGDOM** Oceanroutes Atlantic	Atlantic	1° latitude and longitude. 22.5° direction.	Second generation, fetch and duration limits, water depth shoalling and refraction.	Forecast wave heights and spectra. From summer 1994	Oceanroutes surface pressure forecasts.
	Oceanroutes NW Europe	Offshore NW Europe	0.5° latitude and longitude. 22.5° direction.	Second generation, fetch and duration limits, water depth shoalling and refraction.	Forecast wave heights and spectra. From summer 1994.	Oceanroutes surface pressure forecasts.
HR	HINDWAVE	Coastal, site specific	Not applicable	Fetch and duration limited growth fitted to JONSWAP spectrum for deep water.	Hindcast waves for specific locations.	Meteorological Office analyses.
HR	WINDWAVE	Coastal	High resolution	Second generation (coupled discrete)	Directional spectra, wave height, wave period	Meteorological Office analyses
HR	OUTRAY, OUTURAY, INRAY, WENDIS	Coastal, site specific	20-200m	Ray tracking wave transformation models for shallow water	Wave heights and directions.	Not needed

[1]Note: these models reported as being available operationally for special projects, either through the National Meteorological Services or otherwise.

HR	PORTRAY	Site specific, harbours.	20-200m	Ray tracking; wave shoalling, refraction, diffraction, reflection.	Wave effects in harbours	Not needed
HR	SWALLOW	Site specific, sea walls	Not applicable	Model of sea wall overtopping.	Expected overtopping for sea wall designs.	Not needed

Table 4.3 - Numerical wave models - experimental

Who	Name of model	Area	Grid	Type of model	Products	Source of wind information
POL	**UNITED KINGDOM** Proudman Lab.	User defined; usually on European Shelf	Latitude/longitude. 1, 4, 12 and 35km.	Third generation (WAM) coupled to tide and surge model.	Hindcast waves, tide-surge levels, and tide-surge currents.	Meteorological Office limited area numerical weather prediction model.
UKMO	Met. Office	Global	Latitude/longitude. 0.833°to 3°.	Third generation (WAM).	Wave spectra, wave heights, wave-induced stress. Comparison with second generation model.	Meteorological Office global numerical weather prediction model.

Table 5 - Verification of numerical wave models.

Model	Period of verification	Parameters	Source and type of data	Type of verification	Use of results
UNITED KINGDOM Global and European wave models	October 1986 onwards	Surface wind speed, wave height and period	Fixed synoptic observations	Hindcasts and forecasts	Assessment of operational models
	Case studies (global model)	Surface wind speed, wave height	ERS-1 real time delivery altimeter observations	Statistics gathered routinely.	Assessment of observations and global wave model.
Coastal and second generation models (HR Wallingford)	1970 onwards	Wave height, period and direction	Wave buoys	Hindcasts and near shore transformations	Model validation and development.
Proudman Oceanographic Laboratory wave-tide-surge model	Case studies; Oct 1987, Feb 1990 and Jan 1993.	Surface wind speed, wave height and direction	GEOSAT altimeter and buoys	Hindcasts	Model development

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